FEASIBILITY ASSESSMENT

CHELAN RIVER RIPARIAN REVEGETATION FEASIBILITY INVESTIGATION (CHELAN COUNTY, WASHINGTON)

Prepared for
Chelan County Public Utility District
327 North Wenatchee Avenue
P.O. Box 1231
Wenatchee, Washington 98807

Prepared by
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HERRERA

Note:
Some pages in this document have been purposely skipped or blank pages inserted so that this document will copy correctly when duplexed.

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Introduction

One of the requirements that stemmed from the relicensing process for the Lake Chelan Hydroelectric Project Dam was that a riparian feasibility study be conducted to better characterize the opportunities for the establishment of riparian vegetation on the banks of the Chelan River. Until recently, all flow was diverted out of the Chelan River for most of the year, with the exception of spill flows that occurred during June through August to control Lake Chelan elevation. Spill flows averaged between 3,000 cubic feet per second (cfs) and 4,000 cfs, but there were maximum flows in excess of 15,000 cfs on occasions. As a condition of the new license, the Chelan River must have a minimum flow of 80 cfs throughout the year. However, spring spill flows may still attain 6,000 cfs or higher. When the river was dry much of the year there was little chance for vegetation establishment, but the return of perennial flow presents an opportunity to plant riparian species that can tolerate the new flow regime. Due to the significant physical constraints associated with Reaches 2 and 3 of the Chelan River, this Feasibility Assessment is focused on Reach 1.

Reach 1 of the Chelan River begins immediately below the dam in Chelan, Washington, and extends downstream for approximately 2.29 miles. The bed of this relatively low gradient (1 percent) reach is primarily composed of large cobbles and small boulders, with a few areas where finer materials have accumulated. This reach of the Chelan River is moderately confined by hill slopes composed of glacial moraine deposits. These deposits, where they are not armored with rip rap, are easily erodible, and during high flows could represent a substantial source of sand and gravel to the river channel. However, under current conditions most of the fine bed materials are flushed out of the river during annual spill events.

Streamside vegetation is scarce along Reach 1, and is mainly present as patches of cottonwoods and alders and isolated conifer stands. The upper sections of this reach are relatively wide, with average channel widths between 100 and 140 feet. The channel becomes narrower in the middle of Reach 1 then considerably wider in the lowermost reach, spreading into multiple channels. This braided section harbors the most significant stands of riparian vegetation, with a fairly well developed riparian corridor along portions of the center- and right-channel braids.

The assessment addresses the following questions related to the potential for establishing riparian vegetation in Reach 1 of the Chelan River, as listed in the "Chelan River Fishery Forum (CRFF) Riparian Feasibility Investigation RFP":

1. Based on existing conditions, what native riparian species are capable of growing in Reach 1 without irrigation?
2. How many linear feet of river bank and at what density would the river bank need to be planted in order to initiate riparian corridor development?
3. What are site potential heights for each of the riparian species that could be established in Reach 1? What densities could be expected?
4. A desired goal is to have a native plant species mix, including tall trees, to provide shade, leaf litter, high flow velocity refugia, and, for trees, some eventually falling

into the river to provide instream large wood habitat. What species are recommended to achieve this goal?

5. Are there certain areas within Reach 1 that would not be suitable for establishment of a riparian corridor by planting?

To address these questions, a 2-day field survey followed by collection and review of existing data and modeling was used to develop a Limiting Factors Analysis for the Reach. (This is included as Appendix A.) The Limiting Factors Analysis provided the framework for this Feasibility Assessment.

Project Goals and Constraints

The goal of revegetation in Reach 1 of the Chelan River is to establish the beginnings of a sustainable riparian community, a community that would eventually provide shade, fish and wildlife habitat, and a future source of large woody debris to the reach. There are some significant constraints for achieving this goal. These constraints include: a relatively wide and shallow channel, extremes in flows, very rocky substrate, lack of soil nutrients (due to very little organic matter and no upstream sources of nutrients), few reliable sources of fine sediment recruitment, and the lack of woody debris.

The wide channel makes it difficult for vegetation to provide any substantial shade on the water. The only way to provide any shade is to plant tall growing vegetation right at the river's low water edge. In addition, some portions of the reach are oriented where shade would not be provided by bank plantings.

At low flows, there is a relatively narrow band along the channel where groundwater is close enough to the surface to support riparian vegetation. However, this also means that at high flows, riparian vegetation along the channel will be flooded for long periods of time. This limits the species that can successfully be introduced to the reach to those species that are resistant to high flows and are able to handle long term inundation.

The substrate of the river banks is consistently very rocky with only a few areas where enough finer textured material has accumulated at the surface to support riparian vegetation. Some areas were identified where finer textured materials exist below the top rocky mantle (The Limiting Factors Analysis [Appendix A: Figure A-5] depicts these locations). The rocky nature of the banks is also a constraint to typical planting techniques. Any planting will require use of specific planting methods that will place the plants deep enough into the substrate to reach finer sediments and a consistent groundwater supply.

Due to the lack of recruitment of fine sediments and woody debris, there are few "safe places" for seedling establishment throughout most of the reach. The exception is the furthest downstream portion of the reach (Sub-reach C), where woody debris has been deposited. This debris has become anchored in the rock and is now collecting smaller wood and fine textured sand and soil. This modified substrate has resulted in natural colonization of willows (*Salix* sp.) and black cottonwood (*Populus balsamifera* ssp. *trichocarpa*), and this portion of the reach now has an expanding and healthy riparian plant community.

Analysis Methods

A limiting factors analysis (Appendix A) was prepared and used as the basis of this feasibility assessment. The first step was to conduct a field survey of the site. Observations from that survey provided a clear idea of where to separate the reach into Sub-reaches A, B and C, with each sub-reach providing different degrees of opportunity for successful revegetation. Using data collected during the site survey, as well as data provided by Chelan County Public Utility District (Chelan PUD), maps were prepared of limiting factors to establishment of riparian vegetation on the site. These factors included depth to groundwater, duration of inundation, velocity, and substrate type. Vegetation data were also collected during the field survey. The collected data, along with consultation with local vegetation experts and reference materials, was used to produce a list of riparian plant species to be considered for planting on the site. A matrix was then developed of those species with an assessment of each species tolerances to the limiting factors identified. The reach maps and plant matrix are included in the Limiting Factors Analysis attached to this report as Appendix A.

Challenges and Opportunities

Sub-Reach A

The substrate in Sub-reach A consists almost entirely of large (3- to 6-inch-diameter) rocks, making it extremely difficult to install plant material by hand in this sub-reach (Appendix A: Figure A-5). There is also limited access for equipment. Because it is immediately below the dam, this sub-reach has no source for fine sediments at regular flows and sediments suspended during high flows are immediately washed downstream. In addition, its location below the dam means that there are no consistent sources of native plant propagules coming from upstream to colonize the sites.

Sub-reach A has several meanders where point bars have formed and where some fine substrate material has collected under the rocky surface substrate. Areas with appropriate planting substrate were identified during the field survey and by using aerial photos (Appendix A: Figure A-5). Riparian plants of several species could be planted in these areas and would be able to withstand the predicted high flows, periods of inundation, and periods of low flow.

Dense willow and cottonwood planting of selected banks could also provide some shade on the water. These banks would be selected by considering where plantings could provide shade to the water surface. During the field survey, a patch of willows was observed that almost looked like it had been planted and appeared to be expanding (see photo below). Subsequent investigation by PUD staff led to the conclusion that the source of the willows was likely one old willow that is completely inundated at 80 cfs. These willows are growing through a boulder bank that is high above the water's edge at 80 cfs, demonstrating that it is possible to establish willows on the banks; and that if even a few willows and cottonwoods get started from initial planting, they should expand both laterally and inland in even the toughest rocky shoreline.

Willow patch along bank in Sub-reach A

Sub-Reach B

Sub-reach B has larger rock substrate than Sub-reach A, i.e., in the size range of 4 to 8 inches. Furthermore, the alignment of this reach is very straight and it has no substantial point bars where fine substrate material has accumulated that is suitable for riparian plants. There is shallow groundwater along this sub-reach, thus the banks of this reach could be planted with willows and cottonwoods where they could provide some shade and habitat.

Sub-Reach C

Sub-reach C is a braided section of the project area with a developed and developing substrate of finer sediments. It has a healthy community of willow, black cottonwood, and gray alder (*Alnus incana*). If no active revegetation occurred in this sub-reach, it would still be expected to expand in terms of the aerial coverage of riparian plants. The species mix in this sub-reach consists primarily of three species—cottonwood, willow, and alder—with very few individuals of other species. It would be possible to conduct some planting to improve the diversity of this sub-reach; however, because of the relatively good substrate and other growing conditions, a more diverse mix of riparian plants is likely to establish naturally in the future, especially if these plants are introduced into Sub-reach A. Therefore, no supplemental planting has been recommended for this sub-reach, and it will continue to revegetate naturally.

Planting Concepts for Sub-Reach A and Sub-Reach B

Two revegetation treatments were developed to establish vegetation on sites with appropriate growing conditions on Sub-reach A and Sub-reach B. These are termed the

"Willow and Cottonwood Band" and the "Riparian Planting" treatments. The Willow and Cottonwood Band treatment consists of planting a 3- to 6-foot band of willows and cottonwoods immediately along the stream banks of both sub-reaches where shade can be provided by the plantings (Figure 1). The Riparian Planting treatment was developed for suitable planting areas in Sub-reach A that were identified in the site visit and through analysis of the limiting factors maps of that sub-reach (Figure 2). This treatment would include a band of willow and cottonwood along the stream but would also include a diverse mix of plant species extending to the landward limits of the suitable planting area. The Willow and Cottonwood Band treatment is not necessarily consistent with the desired goal of establishing a native plant species mix, but it is a feasible option that would provide many of the other desired benefits of revegetation.

By utilizing the plant matrix prepared during the Limiting Factors Analysis and evaluating each species' adaptation to the limiting factors and characteristics, a list was prepared of species capable of growing on the site given the existing conditions and without irrigation (because of available groundwater). This list (Table 1) includes potential heights, suggested planting densities, revegetation treatment, and plant placement. Tree and tall shrub species on this list, and to a lesser extent the small shrubs and herbaceous plants, could be expected to provide future shade, leaf litter, and high flow velocity refugia. Trees on the list could also eventually provide in-stream large wood habitat, thus meeting the "desired goal" of the project as identified by the CRFF. Figure 3 shows a conceptual cross section of a typical Riparian Planting area.

Table 1. Native Riparian Plants Appropriate for Chelan River Revegetation Efforts.					
Common Name	**Botanical Name**	**Expected Height**	**Plant Spacing**	**Treatment**	**Plant Placement**
Trees					
Black cottonwood	*Populus balsamifera* ssp. *trichocarpa*	50 to 80 feet	10 feet	Riparian	Scattered plantings of 1 to 3 among plantings immediately above willow band
Gray alder	*Alnus incana*	12 to 15 feet	5 feet	Riparian	Random clumps of 3 to 5 immediately above willow band
Water birch	*Betula occidentalis*	15 to 20 feet	5 feet	Riparian	Random clumps of 3 to 5 immediately above willow band
Tall Shrubs					
Red osier dogwood	*Cornus sericea*	5 to 7 feet	*3 feet*	Riparian	Random clumps of 3 to 5 immediately above willow band
Douglas hawthorn	*Crataegus douglasii*	8 to 12 feet	*5 feet*	Riparian	Random clumps of 3 to 5 above cottonwood and other riparian plantings
Streambank willow	*Salix exigua*	8 feet	3 feet	Willow Band and Riparian	3- to 6-foot band adjacent to stream edge
Scouler's willow	*Salix scouleriana*	20 to 30 feet	5 feet	Riparian	Random clumps of 3 to 5 above cottonwood and other riparian plantings
Pacific willow	*Salix lucida* ssp. *lasiandra*	30 to 40 feet	8 feet	Willow Band and Riparian	3- to 6-foot band adjacent to stream edge
Blue elderberry	*Sambucus nigra* ssp. *cerulea*	10 to 15 feet	3 feet	Riparian	Random clumps of 3 to 5 above cottonwood and other riparian plantings
Short Shrubs					
Woods rose	*Rosa woodsia*	3 feet	3 feet	Riparian	Random clumps of 5 to 7 above cottonwood and other riparian plantings
Herbaceous Wetland Plants					
Douglas' sedge	*Carex douglasii*	1 foot	18 inches	Riparian	Clumps in random placement in willow band
Field sedge	*Carex praegracilis*	1 foot	18 inches	Riparian	Clumps in random placement in willow band
Common spike-rush	*Eleocharis palustris*	1 to 2 feet	18 inches	Riparian	Clumps in random placement in willow band
Baltic rush	*Juncus balticus*	1 foot	18 inches	Riparian	Clumps in random placement in willow band

Figure 1.
Chelan River
Willow and Cottowood Band Plantings

Legend

- Sub-Reach Boundary
- Willow and Cottowood Band

N

0 200 400 800 ft

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NAD 1983 HARN
Washington State Plane North FIPS 4601 Feet
Aerial Photograph Date: 7/3/2013
Project: K:\Projects\Y2014\14-05911-000\Project\Figure 1. Willow Band Plantings.mxd (6/17/2015)

Figure 2.
Chelan River
Riparian Planting Map

Legend

- Sub-Reach Boundary
- Riparian Planting Areas

N

0 200 400 800
ft

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NAD 1983 HARN
Washington State Plane North FIPS 4601 Feet

Aerial Photograph Date: 7/3/2013

Project: K:\Projects\Y2014\14-05911-000\Project\Figure 2. Riparian Planting Map.mxd (6/17/2015)

Willow Planting:
6' Band of *Salix exigua* (Streambank willow) and *Salix lucida ssp. lasiandra* (Pacific willow) and *Populus balsamifera spp. trichocarpa* (black cottonwood)

Rush and Sedge Plug Planting

Cornus sericea (Red twig dogwood), *Alnus incana* (Gray alder), and *Betula occidentalis* (Water birch) Planting

Populus balsamifera ssp. trichocarpa (Black cottonwood), *Sambucus nigra ssp. cerulea* (Blue elderberry), *Rosa woodsii* (Woods rose) Planting

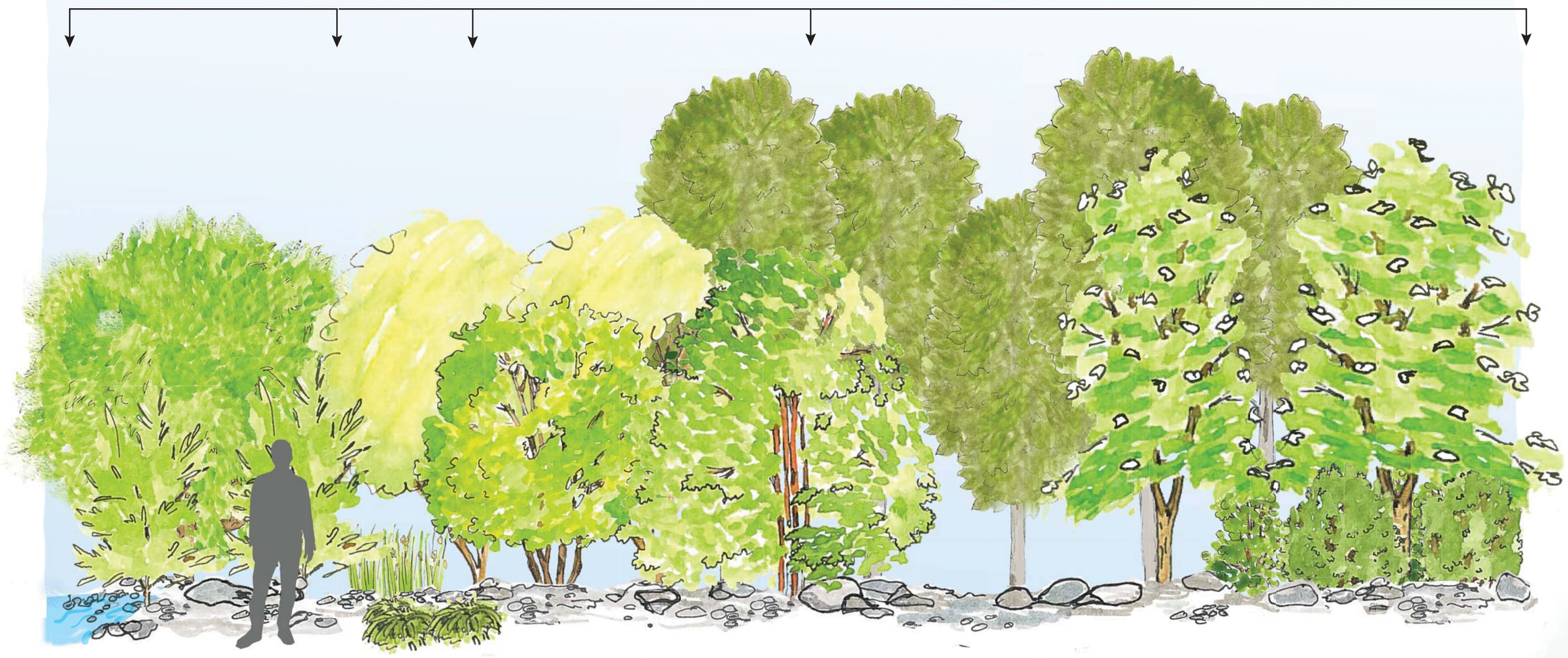

Figure 3: Conceptual Illustration of a Typical "Riparian Planting" Area.

Considerations for Successful Planting

As described previously and in the Limiting Factors Analysis (Appendix A), the key design constraints for the entire reach include: rocky substrate with little accumulation of fine materials suitable for plant growth, variable depths to groundwater and consistent moisture, periodic high flow velocities, and periods of extended inundation. These physical constraints must be considered in any plan for revegetation. To obtain successful establishment of plants and/or cuttings, it would be critical to install plants with deep roots and long cuttings and to place them deep enough in the substrate to reach the zone of consistent moisture.

The installation method must result in excavation of the planting hole through the surface cobble and into the finer textured substrate. Cuttings or small container plants could be installed by hand, but hand planting of riparian plants in larger containers (with more likelihood of survival) would be extremely difficult; the surface is compact, the substrate is large and difficult to move, and it is difficult to keep a planting hole open because of the continual caving in of loose rocky material. In order to properly install the plants given these conditions, it is likely that heavy equipment would need to be used. In addition to the difficult planting, there is limited access to some of the sites in Sub-reach A and Sub-reach B, and some of the sites would be accessible only by crossing the stream channel. Standard tracked equipment would also have problems moving around on the round cobble substrate, therefore rubber tracked equipment may be required.

If access by heavy equipment can be provided, container grown plants could be installed with an expandable stinger mounted on an excavator arm (see photo below). This method could be used to establish willow and cottonwood bands from 3 to 6 feet wide in strategic placements on the banks.

Expandable stinger

Willows and cottonwoods grown in 10-cubic-inch tubes, similar to those used in reforestation projects, could be hand-installed on the stream banks. This would be done by removing rocks to a depth where there is consistent moisture and then laying the cuttings on their sides with the foliage up and using rocks, gravel or sand to anchor them until they root into the substrate. This method of planting could also be used to establish sedges and rushes at the water's edge.

Alternatively, it is possible to use a caterpillar tractor with a ripper attachment to deep rip through the heavy rock layer on the selected planting areas in lines parallel to the water's edge. This would expose the underlying finer sediments and allow for hand planting. This equipment could rip a trench along the stream edge to allow the planting of willow and cottonwood cuttings in the willow and cottonwood band. It could also be used to allow hand planting of other trees and shrubs in the riparian planting areas.

Evaluation of Planting Impacts on Shade

Shadow modeling in GIS was used to assess the degree to which riparian revegetation could be used to increase shading of the Chelan River during the period when water temperatures are high. A date representative of the period of highest water temperatures was chosen by consulting a Chelan PUD annual temperature report for the upper Chelan River. The middle of the period of highest temperatures recorded in 2011 was approximately August 21.

Hourly solar elevation and azimuth were calculated for August 21, 2015, using the Washington Department of Ecology's SolRAd solar radiation model. These were entered into the ArcGIS Hillshade tool, along with 2009 top surface lidar elevation data from Puget Sound Lidar Consortium. The hillshade tool was then used to calculate shadows at 2-hour increments between the hours of 6:00 a.m. and 6:00 p.m. Figures 4a and 4b depict the resulting existing conditions shade map for 2:00 p.m.

The shading effect of riparian revegetation at 20 years' growth was estimated for both treatment types, i.e., willow and cottonwood bands, and mixed riparian plantings. The height of expected growth was added to the lidar bare-earth elevation in the areas where each treatment is feasible, and those expected-growth top-surfaces were merged with the existing conditions top-surface to create proposed conditions top surfaces. These were entered into the ArcGIS Hillshade tool using the same solar azimuth and elevation data used for the existing conditions shadow calculations. The difference between existing and proposed conditions shadows was calculated (Figure 5), and the water surface area in shadow at typical late August low-flow conditions was estimated by intersecting the shadow area with the HEC-RAS modeled inundation surface at 80 cfs (Table 2). If a 50-year timespan was modeled, there may be significant changes to the predicted shade since the cottonwoods would have reached their site potential height of 50 to 80 feet.

Figure 4a.
Chelan River
Existing Conditions Shade Map,
Sub-Reaches A & B
(August 21, 2:00 pm)

Legend

Sub-Reach Boundary

N

0 200 400 800 ft

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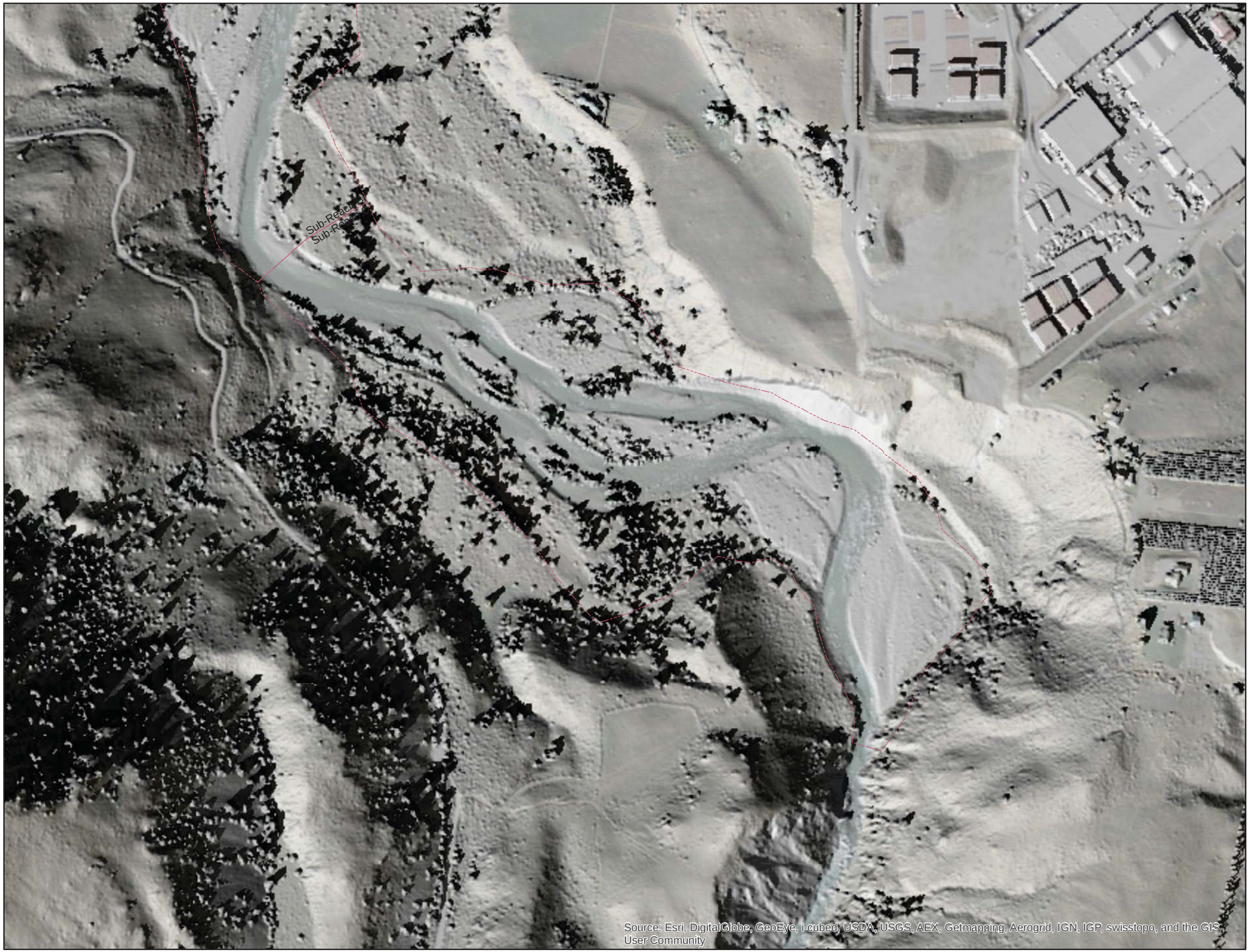
Washington State Plane North FIPS 4601 Feet
Aerial Photograph Date: 7/3/2013
Project: K:\Projects\Y2014\14-05911-000\Project\Figure 4. Existing Conditions Shade Map.mxd (6/17/2015)



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 4b.
Chelan River
Existing Conditions Shade Map,
Sub-Reach C
(August 21, 2:00 pm)

Legend

Sub-Reach Boundary

N

0 200 400 800 ft

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NAD 1983 HARN
Washington State Plane North FIPS 4601 Feet
Aerial Photograph Date: 7/3/2013
Project: K:\Projects\Y2014\14-05911-000\Project\Figure 4b. Subreach C.mxd (6/17/2015)

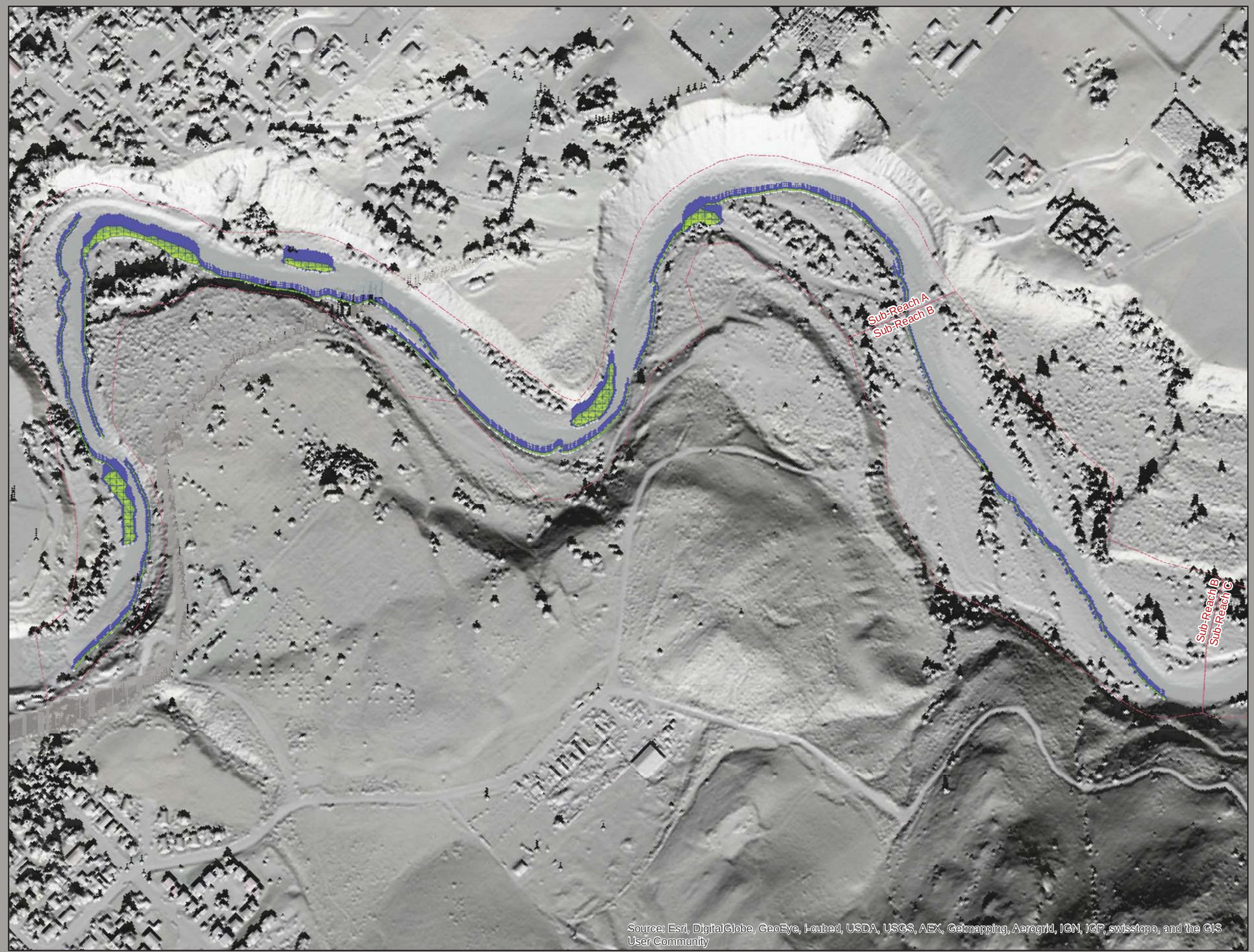

Figure 5.
Chelan River
Proposed Conditions Shade Map
Sub-Reaches A & B
(August 21, 2:00 pm)

Legend

- Sub-Reach Boundary
- Willow Band
- Riparian Planting Areas
- Combined Planting Additional Shade at 2:00 pm

N

0 200 400 800
ft

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NAD 1983 HARN
Washington State Plane North FIPS 4601 Feet
Aerial Photograph Date: 7/3/2013
Project: K:\Projects\Y2014\14-05911-000\Project\Figure 5. Proposed Conditions Shade Map.mxd (6/17/2015)

Table 2. Area of Additional Shade on 80 cfs Water Surface, August 21.			
Time	**Willow Bands (square feet)**	**Riparian Planting (square feet)**	**Willow Bands + Riparian Planting (square feet)**
12:00 noon	43,668	26,820	70,200
2:00 p.m.	67,932	39,744	106,776
Additional Shade Area as Percentage of 80 cfs Water Surface Area[a]			
Time	**Willow Bands**	**Riparian Planting**	**Willow Bands + Riparian Planting**
12:00 noon	5%	3%	8%
2:00 p.m.	8%	4%	12%

[a] Total 80 cfs water surface area in sub-reaches A, B, and C is approximately 900,000 square feet.

The additional shaded water surface area at 80 cfs (at 2:00 p.m. on August 21) that would result from planting the entire proposed length of willow and cottonwood bands would be approximately 70,000 square feet, or 8 percent of the approximately 900,000 square feet total water surface area in sub-reaches A, B, and C. The riparian planting areas by themselves would add approximately 40,000 square feet of shadow, 4 percent of the total water surface area. Therefore the estimated total for the combination of willow and cottonwood bands and riparian planting areas would result in an additional 107,000 square feet of shadow, 12 percent of the total water surface area. It should be noted that vegetation does not necessarily provide 100 percent shade, as is assumed in the shadow model. The actual shading effect of riparian vegetation, both existing and proposed, depends on canopy density in addition to the area covered and height of the vegetation. Immediately after planting, the canopy density in revegetated areas would be approximately 5 percent; this is expected to increase to approximately 100 percent in the willow and cottonwood bands and approximately 75 percent in the riparian planting areas after 20 years of vegetation growth. Canopy density is a major factor controlling the shading effectiveness of vegetation, but canopy structure also can have effects that may vary through the day with changes in solar azimuth and elevation. Estimates of the shading effect of existing and proposed vegetation could be improved by field measurements of the actual shade provided by existing vegetation throughout a typical late summer day.

Potential Riparian Conditions With and Without Planting

With planting, Sub-reach A could develop substantial plant coverage on point bars with suitable substrate (Figure 2). Species that could withstand the conditions on each site would be selected from the plant matrix. With appropriate species selection, plant material sizes and condition, and with the application of slow release fertilizer and mycorrhizal inoculum, successful plant establishment could be attained. Better growing conditions would result in plants having the ability to grow to larger size, spread vegetatively, and to eventually supply downstream sites with organic material and nutrients, woody debris and plant propagules.

Depending upon the location of these planting areas, the vegetation established could also provide some shade, as predicted by the shade modeling described above (Figure 5). Successful plantings could result in future vegetation establishment in the form of volunteer plants. Because of the rocky substrate it would take many years for enough fine materials to

accumulate for a grass and forb community to become established. However, planting of wetland sedge and rush plugs is suggested to provide some accumulation of fine sediments and to provide aquatic habitat. These species were selected because they have expansive root systems and tops that are flexible, and thus they are able to withstand high flows and velocities.

Sub-reach A has scattered willow and cottonwood seedlings establishing on point bars on sites that have some finer substrates between the surface rocks. The area immediately adjacent to the water's edge is devoid of willow seedlings. The substrates on the bars have very poor water holding capacity and little or no available plant nutrients. The existing seedlings on the bars are small, limited to only the best sites, and are sparse. They may continue to grow, but very slowly; and it may be many years before they mature enough to produce any seeds or rhizomes to increase the plant density. Because there is little supply of plant nutrients or propagules from upstream, the sites will remain very sparse without active revegetation.

Conceptual drawings have been developed for a typical Riparian Planting site such as those sites identified in Figure 2. Figure 6 depicts current conditions. Figure 7 depicts conditions that could be expected in 20 years, if unplanted; and Figure 8 depicts the projected appearance of that same site in 20 years, if planted. The current condition drawing was based upon a typical riparian planting area. The depiction of the 20-year future appearance with no planting takes into account the slow growth and minimal colonization that would be expected without supplemental planting. Figure 7 depicts the increased plant cover that proper planting techniques and planting treatments could attain 20 years after planting. These conceptual drawings are predictions of conditions that may occur in planting areas identified in Figure 2. However, it is not expected that all of Sub-reach A could achieve the same level of vegetation due to the many limiting factors along this reach that were described previously and in the Limiting Factors Analysis (Appendix A). Developing a "lush riparian forest in the Chelan River" is an unrealistic expectation.

Only willow and cottonwood band planting is recommended in Sub-reach B. Even with this supplemental planting, this reach will continue to have very little vegetation well into the future. Sub-reach C is currently the best vegetated sub-reach of the project site. It has cottonwood saplings as tall as 20 feet and healthy patches of willow. It also has a few other species such as alder and woods rose. If left unplanted it will continue to develop into a more mature community of mostly cottonwood, willow, and alder.

Because minimum stream flows will now be maintained in the Chelan River, it can be expected that some minimal riparian vegetation will naturally become established over the next 20 years, without any further actions. However, active revegetation efforts would dramatically accelerate the natural processes and result in quicker establishment of a more robust plant community.

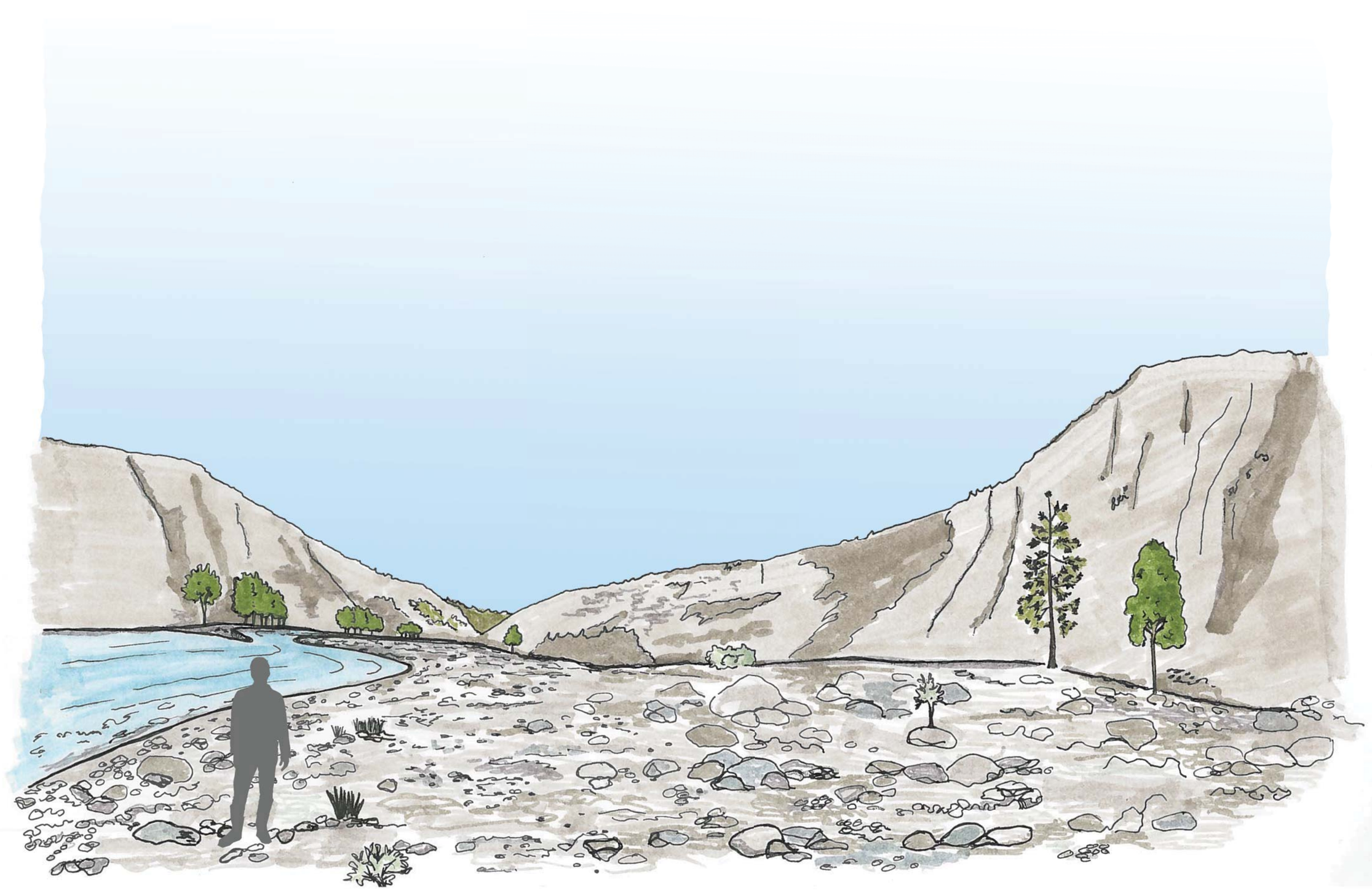

Figure 6: Current Condition of Typical Riparian Planting Area.

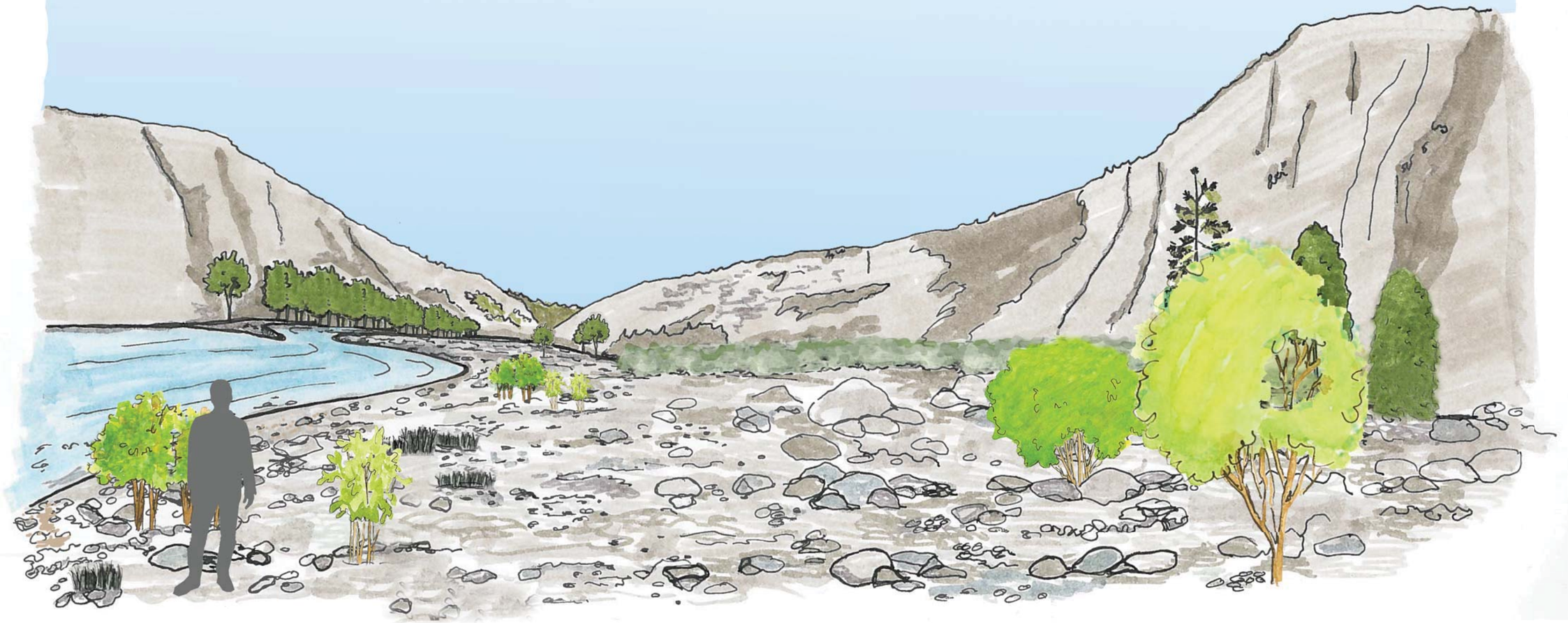

Figure 7: 20-Year Site Conditions With No Planting.

Figure 8: 20-Year Site Condition With Riparian Planting.

Recommendations and Conclusions

The greatest opportunity for establishing vegetation in Reach 1 of the Chelan River occurs in Sub-reach A. In this sub-reach there are a few places that provide the opportunity to establish a diverse riparian community that could even include large trees that would contribute to shading of the river. These are places where point bars have already begun to form and some finer material is accumulating. Establishing diverse vegetation in these areas would provide shade refuge for both aquatic and terrestrial species, as well as provide leaf litter and ultimately enhance the opportunity for development of additional zones of sediment accumulation. Over the long term it could initiate natural vegetation development in other areas in the reach. Establishment of willow and cottonwood bands in this sub-reach would provide a substantial increase in shading and would also be beneficial for aesthetics and for providing the many benefits of shoreline habitat features.

Planting efforts could also be considered in Sub-reach B. Sub-reach B, while perhaps the least suitable area for revegetation, still could benefit from planting willow and cottonwood bands in various places to improve habitat value and provide shade.

In Sub-reach C, which is naturally developing into a nicely vegetated area, the only purpose for active planting would be to supplement the existing vegetation with other species to kick-start development of a more diverse riparian area. However, since this diversity should develop naturally over time, active revegetation in this sub-reach has not been recommended.

In summary, the Limiting Factors Analysis and this Feasibility Assessment have addressed the five questions identified by the CRFF for assessing the potential for establishing riparian vegetation in Reach 1 of the Chelan River as listed below.

1. Based upon existing conditions, there are plants of various types (trees, shrub, sedges, etc.) that can be expected to survive in the harsh conditions of Reach 1 of the Chelan River, even without supplemental water. The existing vegetation conditions in Sub-reach C and the results of the "Limiting Factors Analysis" provide evidence of that. Table 1 in this Feasibility Assessment lists those species.

2. There are about 10,000 linear feet of river bank that could be planted with willows and cottonwoods at a recommended density of approximately 70 plants per 100 feet of bank. Of that, there are several locations totaling 1,500 linear feet of riverbank in the upper part of the reach (Sub-reach A) that have been identified as good locations for initiating establishment of a diverse riparian community that would extend further up the banks with a density of 300 to 500 plants per 100 linear feet of bank.

3. Table 1 in this report provides potential heights for each of the riparian species that could be established and approximate planting densities for the selected "Riparian Planting" sites. The site potential heights for the largest species are 50 to 80 feet for Black Cottonwood and 30 to 40 feet for Pacific Willow.

4. Table 1 also summarizes the recommended species for achieving the desired goals of the native species mix.

5. The planting maps included in this report show the areas that are suitable for establishment of a riparian corridor by planting; the remaining area is considered unsuitable due primarily to depth to moisture and substrate conditions.

It can be expected that over the very long term (50 years and beyond) the combination of strategic planting and natural colonization could result in establishment of patches of riparian vegetation interspersed throughout the river corridor.

The process of conducting a site visit and utilizing a flow model to map limiting factors provided the information to identify potential planting sites. The development of a matrix of potential plants and their abilities to withstand the limiting factors to establishment that exist in Reach 1 resulted in the selection of a plant species mix. Finally, the use of shade modeling provided a tool to select the potential planting areas that would most effectively provide cooling shade on the river. The recommendations for revegetation actions have been utilized on many similar sites throughout the west and can be expected to be very successful. However, that success is bounded by the natural limitations of the site and climate; and it is not expected that a "lush riparian community" will result.

This Riparian Feasibility Assessment and supporting Limiting Factors Analysis addresses the requirement that Chelan PUD comply with terms and conditions of the 401 water quality certification to conduct a Riparian Feasibility Investigation to better characterize the opportunities for the establishment of riparian vegetation on the banks of the Chelan River.

APPENDIX A

Limiting Factors Analysis

LIMITING FACTORS ANALYSIS

CHELAN RIVER RIPARIAN REVEGETATION FEASIBILITY INVESTIGATION (CHELAN COUNTY, WASHINGTON)

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June 18, 2015

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Introduction

This Limiting Factors Analysis has been developed as a tool to assess the feasibility of establishing native riparian vegetation on portions of Reach 1 of the Chelan River (Figure 1). The goal of the potential revegetation effort would be to establish the beginnings of a sustainable riparian community that would eventually provide shade, fish and wildlife habitat, and a future source of large woody debris to the reach.

This analysis includes an assessment of existing physical conditions within the reach that constitute the primary limiting factors for plant establishment. The selection and refinement of these limiting factors was based on a brief field survey, review of existing maps and images, and analysis of flow and hydraulic modeling data being developed for other Chelan River project work. This analysis also includes development of a list of potential riparian plants that might be considered for a revegetation effort, based on their growth characteristics and relationships to the physical conditions/limiting factors of the reach.

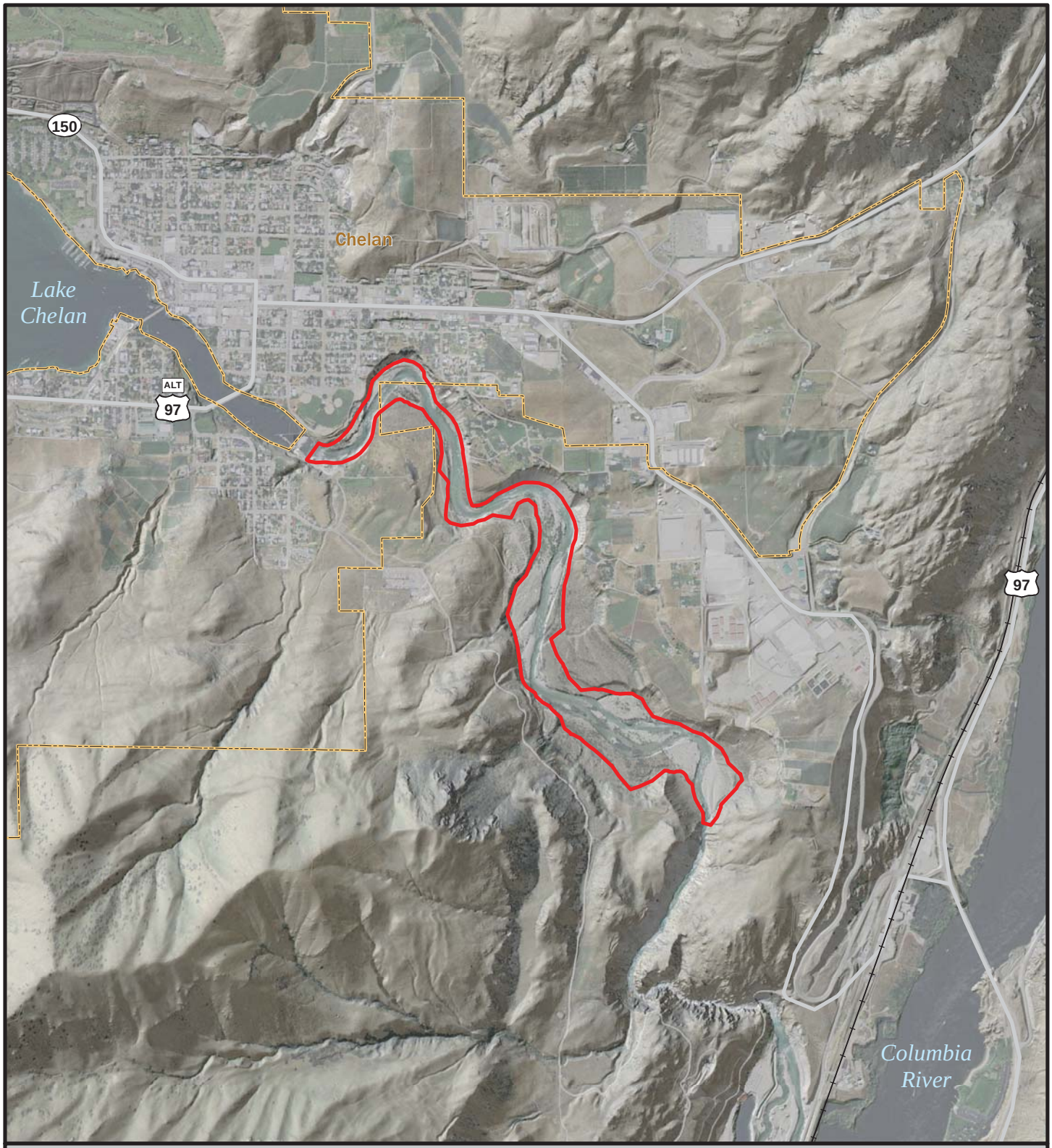
The major limiting factors to revegetation on this reach include: 1) a rocky substrate with little accumulation of fine materials suitable for plant growth; 2) variable depths to groundwater and consistent moisture; 3) periodic high flow velocities; and 4) periods of extended inundation.

One outcome of the assessment of physical conditions was that Reach 1 was divided into three sub-reaches based on differences in physical conditions. Therefore, the maps developed to support this analysis include maps for each sub-reach that depict the identified limiting factors. The maps are provided as Appendix A. A matrix of plant species suitable for revegetation with each species' corresponding abilities to withstand the physical conditions of the site is provided as Appendix B.

Methods

Field Survey

A field survey was conducted on December 17 and 18, 2014. During the survey, the entire length of Reach 1 was walked to get an overall impression of conditions on this reach of the river. Then, starting at the dam apron and proceeding downstream, data was collected on substrate characteristics and depth-to-groundwater at points along the reach where substrate was deemed suitable for planting. Pits were excavated at 20 feet from the water's edge at various points along the stream, and the depth to standing water was recorded. In addition, photos for use in substrate characterization were taken of the material in each test pit and along a 20-foot-long surface transect at right angles to the stream edge. During this survey, areas that seemed suitable for planting were identified and located by handheld GPS to place on project maps. Sub-reach breaks were also identified.



Legend

- Reach Area
- Railroad

Figure 1.
Vicinity Map of Chelan River Riparian Feasibility Area, Chelan County, Washington.

0 1,000 2,000 4,000
Feet

NAD 1983 HARN
Washington State Plane North FIPS 4601 Feet
K:\Projects\Y2014\14-05911-000\Projectlvicinity_map.mxd (2/23/2015)

Limiting Factor Maps Development

Limiting-factor maps were developed that depict depth-to-groundwater at low river flows, inundation periods, velocity zones and substrate suitability. Substrate and depth to groundwater data collected during the field survey were used in conjunction with aerial photographs and hydraulic model output to map the limiting factors of substrate composition and depth to consistent moisture. Information on flow velocities and inundation periods was developed from flow data provided by County Public Utility District (Chelan PUD) and a HEC-RAS hydraulic model provided by West Consultants. This information was used to map inundation-period and peak-flow velocity limiting factors.

Inundation-duration/flow relationships (Table 1) were defined based on flow data provided by Chelan PUD for water years 2011 through 2014. Water surface elevations for various flow levels were estimated using HEC-RAS model geometry developed by WEST Consultants, with roughness values modified by Herrera to match as closely as possible the surveyed river widths provided by Chelan PUD. This was done for flows of 85, 200, and 350 cfs. Water surface elevations were interpolated between cross sections and the lidar ground surface elevation was subtracted from the interpolated water surface elevation to generate interpolated flow depths. The resulting flow depths were reclassified as inundated (greater than zero) or dry (less than or equal to zero) and inundated areas were mapped for each modeled flow. Inundation maps are presented in Appendix A, Figures A-1 and A-2.

Table 1. Inundation-Duration/Flow Categories.

Flow (cfs)	Typical Duration
> 80	Perennially inundated
> 400	30 or fewer days
> 2000	10 or fewer days
> 4000	5 or fewer days
5000	Annual peak flow

Test pits dug during the site visit revealed that groundwater elevation near the river is approximately equal to adjacent river surface elevation, except in one location where hyporheic losses were likely. For feasibility mapping, therefore, we approximated dry-season groundwater elevation as equal to modeled river surface elevation at 80 cfs. Depth to groundwater was classified as suitable for plant establishment when the interpolated 80 cfs water surface elevation was less than 1.5 feet below the lidar ground surface, unsuitable due to lack of groundwater availability when it was greater than 1.5 feet below the surface, and unsuitable due to continuous inundation when it was at or above the surface. Areas with suitable groundwater depth are shown as an overlay on the inundation maps (Figures A-1 and A-2).

Velocity in the main channel and on each bank was also estimated for the typical annual peak flow using the HEC-RAS model geometry provided by WEST Consultants. Velocities were interpolated between cross sections and reclassified to correspond to the low, medium, and high velocity as defined by the tolerance ranges identified for the different plants listed in Appendix B. This relationship is summarized in Table 2.

Table 2. Flow Velocity Tolerance Classes.	
Velocity (fps[a])	**Velocity-Tolerance**
0 to 2	Low (gravel substrate)
2 to 4	Low (cobble substrate)
4 to 6	Medium
6 to 8	High
> 8	Unsuitable for planting

[a] fps = feet per second.

Substrate composition was classified based on 1-foot–resolution 2009 aerial imagery of the dry riverbed and 3-foot resolution lidar topography, with reference to photographs and information obtained from the site visit. Where the largest clasts were of sufficient size to show up individually on the aerial image the substrate was classified as boulder-dominant and therefore unsuitable for planting. Where individual clasts could not be distinguished the substrate was classified as cobble-dominant or finer, and potentially suitable for planting. Substrate classification was limited by the extents of the 2009 aerial image to the sub-reach closest to the dam. Lidar topography was used to refine the classification based on sediment size by reclassifying as unsuitable those areas with slope greater than 2:1 (27 degrees). Areas determined to have potentially suitable substrate using this methodology are shown in Appendix A, Figure A-5.

Plant Characteristics Matrix

During the field survey, an initial list of species existing at the site was developed by examining stems, fruits and fallen leaves, where available, to make positive species identifications. Since the survey by necessity occurred in late December, when deciduous plants were dormant and leafless, and herbaceous plants were dormant with little or no identifiable foliage, this was not a complete listing of plants that occur at the site. The list was expanded by reviewing documents listing species expected in the Chelan and Methow River areas to make additions to the list (Baesecke 2005; Wooten and Morrison 2008). The entire list was then reviewed by local experts (Bridgette Ranne, USFS Botanist for Chelan and Methow Ranger Districts, personal communication, December 2014; Katy Beck, Beck Botanical Services, personal communication, December 2014).

The complete list was then developed in a matrix that summarizes plant growth and habitat characteristics as well as the limiting factors on-site and each species tolerances to those factors. Characteristics such as preferred substrate, self-colonization potential, growth rates and expected height were obtained from various references and web sites (USDA 2015; Monsen et al. 2004; Gray and Sotir 1996). Ease of establishment by species was determined from observations during the site visit and professional experience. Planting techniques were determined based on past experience of species needs and the limiting factors of the site.

The number of days that each species would tolerate flooding were derived from various reference sources (Gray and Sotir 1996; Lair and Grabowski 2011). These tolerances will be used to determine which species are appropriate for planting in an area based on its mapped "Inundation Suitability Class."

Estimated tolerance to high flow velocities were based upon professional experience and various references (Fischenich 2001; River Partners 2015; Coppin and Richards 1997). Plant species in the "High" velocity category have root systems that are deep, fibrous, or rhizomatous and are, therefore, able to withstand the scouring of high flows. These species also have stems that are either flexible enough to bend during high flows without damage or are woody enough to withstand actual breakage. Species in the "Medium" category have brittle stems that can be damaged by high flows and/or root systems that may be washed out by high flows. The species in the "Low" category have easily damaged stems and weak root systems and are unable to withstand high flows. Flow velocity tolerance categories in the matrix are: Low (10 to 4 feet per second); Medium (4 to 6 feet per second); and High (6 to 8 feet per second). These tolerances can be used in conjunction with Table 2 to determine which species are appropriate for planting in an area based upon its mapped flow velocity and substrate type.

Results

After review of field notes, we determined the location of three sub-reaches and placed them on the project base maps in Appendix A. Sub-reach A is from the dam downstream a distance of 6,675 feet. This reach has some sinuosity and the development of a number of point bars with a rocky surface substrate underlain by some finer sandy materials suitable for planting. There are a number of cottonwood and willow seedlings started on these bars. This sub-reach has a variety of channel aspects and select stream banks could be planted to provide shade on the river. Sub-reach B is a relatively straight section of river that is about 2,000 feet long below Sub-reach A. This section does not have point bars and the substrate is primarily large cobble with very little fine material. There are few volunteer riparian seedlings in this reach and because of the rocky substrate, it is not well suited for active revegetation. This sub-reach runs directly north and south and would not be suitable for bank planting to provide shade. Sub-reach C is a braided section immediately below Sub-reach B and extends to the end of the project. It has a healthy, expanding cottonwood and willow community. The substrate is still very rocky but with good patches of fine sediments collecting in areas behind buried woody material. These patches may provide planting areas for other species to provide additional diversity and habitat. Because of the braided nature of this sub-reach, there may be opportunities to supplement bank vegetation for stream shading.

Based upon data collected during the field survey and interpretation of stream measurements and flow records, we developed graphical depictions on-site maps of the limiting factors of substrate composition, depths to consistent moisture, high flow velocities and inundation periods. These maps are included in Appendix A.

The matrix of native plants under consideration for revegetation efforts in Table B-1 in Appendix B shows preferred substrate texture, maximum flooding tolerance in days, estimated tolerance to high flow velocities, potential for self-colonization on this site without active planting, ease of establishment on the site, Planting Techniques, Growth Rates, and Expected Height of each species on the site.

Conclusion

There are significant limiting factors to plant establishment along Reach 1 of the Chelan River. Probably the most significant factors in terms of the area affected are the large substrate type and depth to groundwater at low flows. However, areas were identified that provide conditions suitable for establishment of a select assortment of plants. There is also evidence that, as demonstrated by Sub-reach C, with time and appropriate conditions, plants can become established in Reach 1. The next step will be to conduct a feasibility assessment that identifies the area(s) most suitable for planting and to provide general guidance on the revegetation strategy most appropriate for each.

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APPENDIX A

Maps of Project Sub-Reaches and Limiting Factors

Figure A-1.
Chelan River
Modeled Groundwater and Inundation Limiting Factor Zones
Sub-Reach A

Legend

- Sub-Reach Boundary

Groundwater Depth

- < 1.5 feet at 80 cfs

Inundation Duration

- 5 - 10 days
- 10 - 30 days
- > 30 days
- Perennial*

*Note:
Perennial inundation is continuous.
Gaps are artifacts of the 2-D representation of a 1-D hydraulic model.

N

0 200 400 800 ft

HERRERA

NAD 1983 HARN
Washington State Plane North FIPS 4601 Feet
Aerial Photograph Date: 7/3/2013

K:\Projects\Y2014\14-0591.000\Project\Figure A-1.mxd (6/17/2015)

Figure A-2.
Chelan River
Modeled Groundwater and Inundation Limiting Factor Zones
Sub-Reaches B & C

Legend

Sub-Reach Boundary

Groundwater Depth

< 1.5 feet at 80 cfs

Inundation Duration

5 - 10 days

10 - 30 days

> 30 days

Perennial*

*Note:
Perennial inundation is continuous.
Gaps are artifacts of the 2-D representation of a 1-D hydraulic model.

N

0 200 400 800 ft

HERRERA

NAD 1983 HARN
Washington State Plane North FIPS 4601 Feet
Aerial Photograph Date: 7/3/2013

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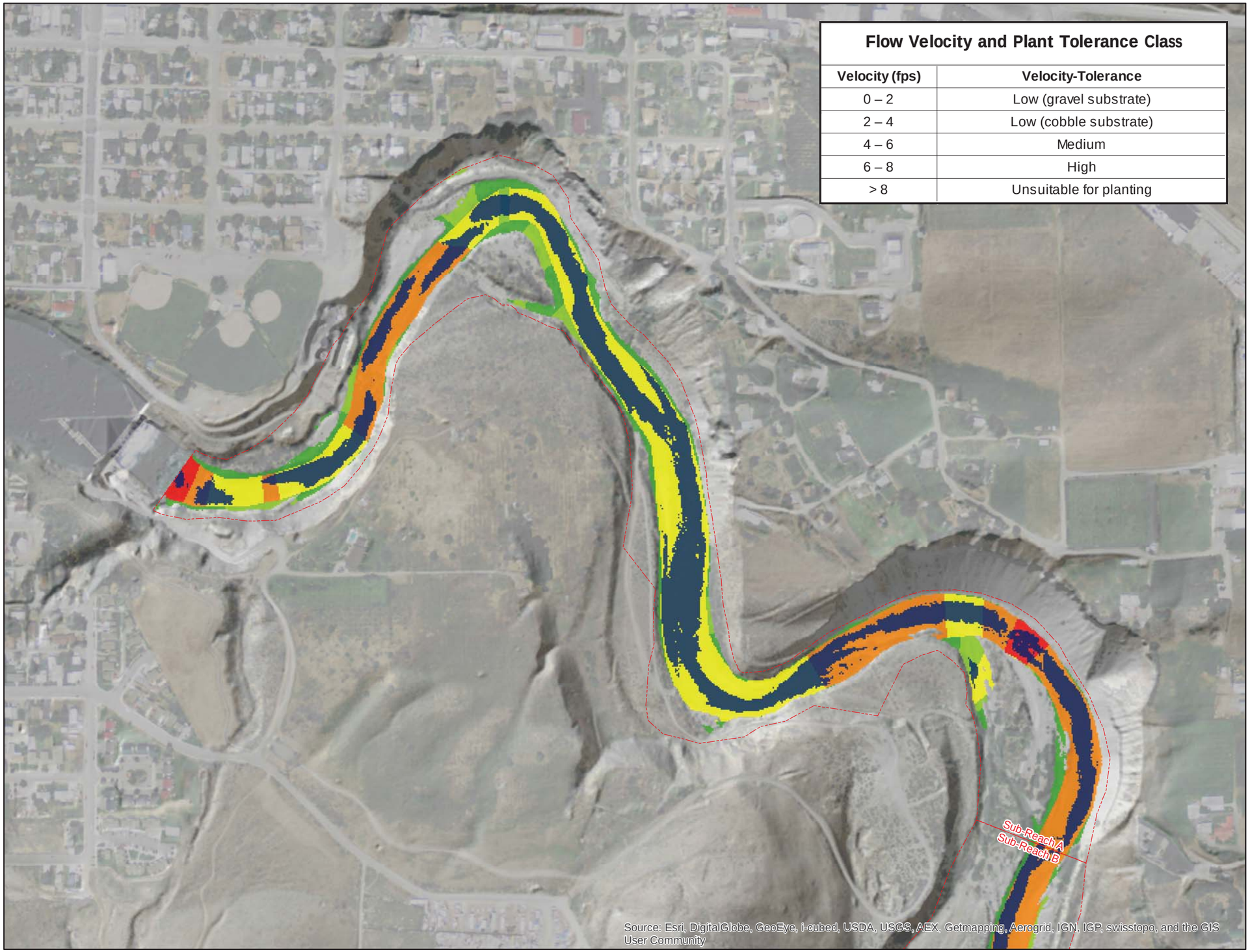

Flow Velocity and Plant Tolerance Class

Velocity (fps)	Velocity-Tolerance
0 – 2	Low (gravel substrate)
2 – 4	Low (cobble substrate)
4 – 6	Medium
6 – 8	High
> 8	Unsuitable for planting

Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure A-3.
Chelan River
Modeled Velocity Limiting Factor Zones
Sub-Reach A

Legend

- Sub-Reach Boundary
- Perennial Inundation*

Modeled Velocity at 5,000 cfs

- 1 - 2 feet/second
- 2 - 4 feet/second
- 4 - 6 feet/second
- 6 - 8 feet/second
- > 8 feet/second

*Note:
Perennial inundation is continuous.
Gaps are artifacts of the 2-D representation of a 1-D hydraulic model.

N

0 200 400 800 ft

HERRERA

NAD 1983 HARN
Washington State Plane North FIPS 4601 Feet
Aerial Photograph Date: 7/3/2013

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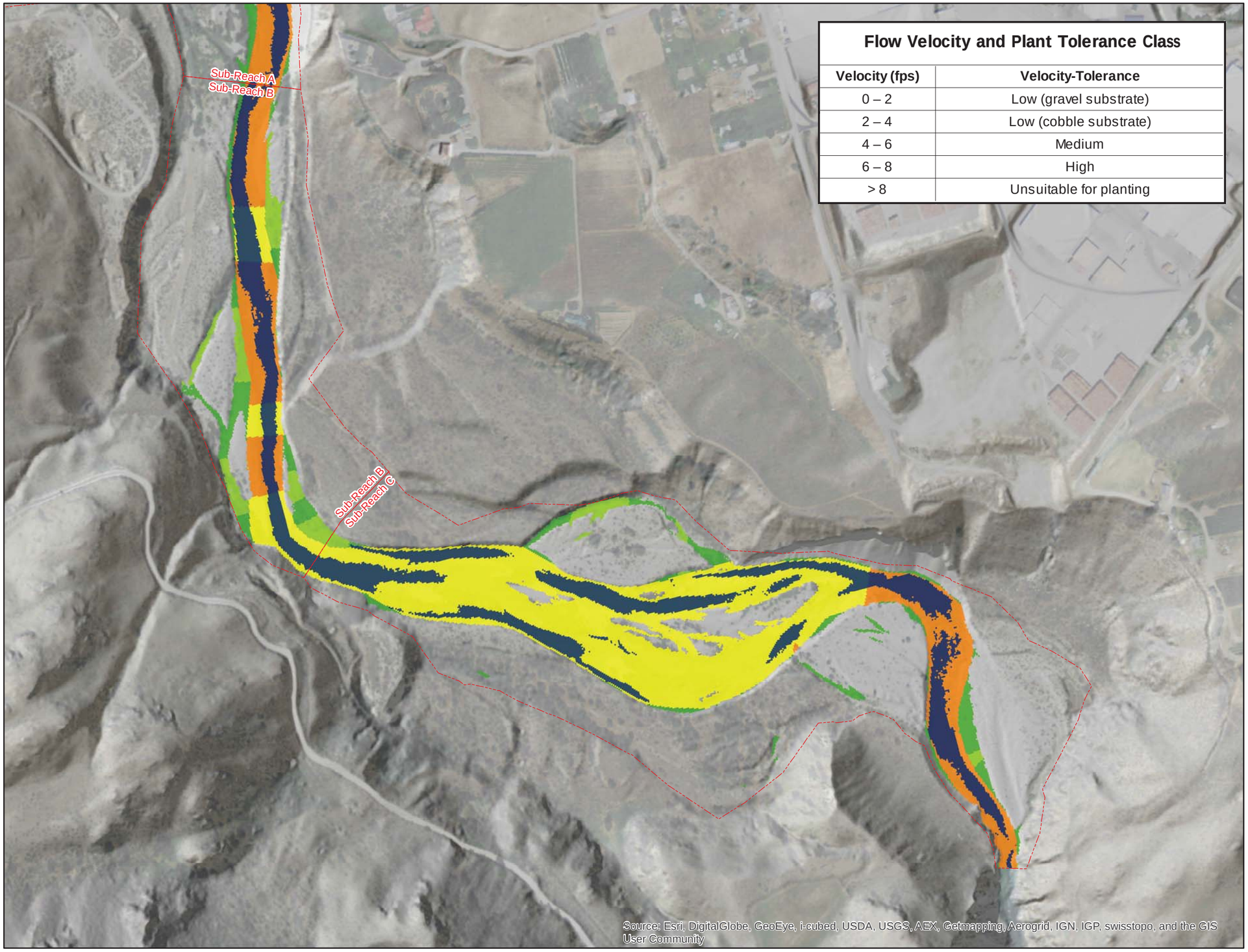

Flow Velocity and Plant Tolerance Class

Velocity (fps)	Velocity-Tolerance
0 – 2	Low (gravel substrate)
2 – 4	Low (cobble substrate)
4 – 6	Medium
6 – 8	High
> 8	Unsuitable for planting

Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure A-4.
Chelan River
Modeled Velocity Limiting Factor Zones
Sub-Reaches B & C

Legend

- Sub-Reach Boundary
- Perennial Inundation*

Modeled Velocity at 5,000 cfs

- 1 - 2 feet/second
- 2 - 4 feet/second
- 4 - 6 feet/second
- 6 - 8 feet/second
- > 8 feet/second

***Note:**
Perennial inundation is continuous. Gaps are artifacts of the 2-D representation of a 1-D hydraulic model.

N

0 200 400 800 ft

HERRERA

NAD 1983 HARN
Washington State Plane North FIPS 4601 Feet
Aerial Photograph Date: 7/3/2013

K:\Projects\Y2014\14-05911-000\Project\Figure A-4.mxd (6/17/2015)

Figure A-5.
Chelan River
Modeled Substrate Suitability
Limiting Factor Zones
Sub-Reach A

Legend

- Sub-Reach Boundary
- Perennial Inundation*
- Suitable Substrate, 2009 Aerial
- Field-Mapped Suitable Substrate

*Note:
Perennial inundation is continuous.
Gaps are artifacts of the 2-D representation of a 1-D hydraulic model.

N

0 200 400 800 ft

HERRERA

NAD 1983 HARN
Washington State Plane North FIPS 4601 Feet
Aerial Photograph Date: 7/3/2013

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APPENDIX B

Native Riparian Plants Under Consideration for Chelan River Revegetation Efforts

Table B-1. Native Riparian Plants Under Consideration for Chelan River Revegetation Efforts.

Common Name	Botanical Name	Preferred Substrate Texture	Maximum Flooding Tolerance in Days	Estimated Tolerance to High Flow Velocities[a]	Potential for Self-Colonization on This Site Without Active Planting	Ease of Establishment on This Site	Planting Techniques	Growth Rates	Expected Height On-Site
Trees									
Black cottonwood[b]	*Populus balsamifera* ssp. *trichocarpa*	Medium to Coarse Soils	120	High	High	High	Container or Cutting	High	50 to 80 feet
Quaking aspen[b]	*Populus tremuloides*	Fine to Coarse Soils	30	High	Low	Medium	Container	Medium	30 feet
Tall Shrubs									
Gray alder[b]	*Alnus incana*	Fine to Coarse Soils	120	High	High	High	Container	High	12 to 15 feet
Service to berry[b]	*Amelanchier alnifolia*	Fine to Coarse Soils	5	Low	Low	Medium	Container	Medium	8 to 12 feet
Water birch[b]	*Betula occidentalis*	Fine to Coarse Soils	120	High	Medium	High	Container	High	15 to 20 feet
Red osier dogwood[b]	*Cornus sericea*	Fine to Coarse Soils	120	High	Medium	High	Container or Cutting	High	5 to 7 feet
Douglas hawthorn	*Crataegus douglasii*	Fine to Coarse Soils	10	Medium	Low	Medium	Container	Medium	8 to 12 feet
Bitter cherry	*Prunus emarginata*	Coarse Soils	5	Medium	Low	Medium	Container	Low	20 feet

Table B-1 (continued). Native Riparian Plants Under Consideration for Chelan River Revegetation Efforts.									
Common Name	**Botanical Name**	**Preferred Substrate Texture**	**Maximum Flooding Tolerance in Days**	**Estimated Tolerance to High Flow Velocities[a]**	**Potential for Self-Colonization on This Site Without Active Planting**	**Ease of Establishment on This Site**	**Planting Techniques**	**Growth Rates**	**Expected Height On-Site**
Tall Shrubs (continued)									
Chokecherry[b]	*Prunus virginiana*	Fine to Coarse Soils	10	Medium	Low	Medium	Container	Low	15 feet
Streambank willow[b]	*Salix exigua*	Medium to Coarse Soils	120	High	High	High	Container or Cutting	High	8 feet
Scouler's willow	*Salix scouleriana*	Fine to Coarse Soils	30	High	High	High	Container	High	20 to 30 feet
Pacific willow	*Salix lucida ssp. lasiandra*	Medium to Coarse Soils	120	High	High	High	Container or Cutting	High	30 to 40 feet
Blue elderberry[b]	*Sambucus nigra* ssp. *cerulea*	Medium to Coarse Soils	30	High	Medium	Low	Container	High	10 to 15 feet
Short Shrubs									
Woods rose[b]	*Rosa woodsii*	Medium Soils	30	High	Medium	High	Container	High	3 feet
Forbs									
Dog bane	*Apocynum cannabinum*	Fine to Coarse Soils	10	Medium	Low	Medium	Seeding	Medium	2 feet
Milkweed	*Asclepias speciosa*	Fine to Coarse Soils	5	Low	Low	Low	Seeding	Medium	4 feet

Table B-1 (continued). Native Riparian Plants Under Consideration for Chelan River Revegetation Efforts.

Common Name	Botanical Name	Preferred Substrate Texture	Maximum Flooding Tolerance in Days	Estimated Tolerance to High Flow Velocities[a]	Potential for Self-Colonization on This Site Without Active Planting	Ease of Establishment on This Site	Planting Techniques	Growth Rates	Expected Height On-Site
Forbs (continued)									
Star flowered false Solomon's seal	*Maianthemum stellatum*	Fine to Coarse Soils	30	Medium	Low	Low	Container	High	2 feet
Sand dropseed	*Sporobolus cryptandrus*	Medium to Coarse Soils	5	Low	Low	Low	Seeding	Medium	2 to 3 feet
Canada Goldenrod	*Solidago canadensis*	Fine to Coarse Soils	10	Low	Low	Low	Seeding	Medium	2 to 3 feet
Sedges and Rushes									
Douglas' sedge	*Carex douglasii*	Fine to Medium Soils	60	High	Low	High	Container	Medium	1 foot
Field sedge	*Carex praegracilis*	Fine to Medium Soils	60	High	Low	High	Container	Medium	1 foot
Common spike to rush	*Eleocharis palustris*	Fine to Medium Soils	60	High	Low	High	Container	Medium	1 to 2 feet
Baltic rush	*Juncus balticus*	Fine to Medium Soils	60	High	Low	High	Container	Medium	1 foot

[a] Velocity Tolerance Categories: Low (gravel substrate), 0 to 2 fps; Low (cobble substrate), 2 to 4 fps; Medium, 4 to 6 fps; High, 6 to 8 fps.

[b] Species that were observed on-site during the December 18–19, 2014, site visit.