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Riparian Cottonwood Ecosystems and Regulated Flows in Kootenai and Yakima Subbasins

Impacts of Flow Regulation on Riparian Cottonwood Forests of the Yakima River

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RIPARIAN COTTONWOOD

ECOSYSTEMS & REGULATED FLOWS

IN KOOTENAI & YAKIMA SUB-BASINS

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and

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Contract No. 00000005
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AN OVERVIEW OF THE KOOTENAI AND YAKIMA RIPARIAN COTTONWOOD PROJECTS.

1.0 INTRODUCTION

Riparian vegetation and especially cottonwood and willow plant communities are dependent on normative flows and especially, spring freshette, to provide conditions for recruitment. These plant communities therefore share much in common with a range of fish species that require natural flow conditions to stimulate reproduction. We applied tools and techniques developed in other areas to assess riparian vegetation in two very different sub-basins within the Columbia Basin. Our objectives were to:

- Document the historic impact of human activity on alluvial floodplain areas in both sub-basins.
- Provide an analysis of the impacts of flow regulation on riparian vegetation in two systems with very different flow regulation systems.
- Demonstrate that altered spring flows will, in fact, result in recruitment to cottonwood stands, given other land uses impacts on each river and the limitations imposed by other flow requirements.
- Assess the applicability of remote sensing tools for documenting the distribution and health of cottonwood stands and riparian vegetation that can be used in other sub-basins.

An overview of this work is presented here, more detailed information is provided in three separate reports as below.

1. The impact of flow regulation on riparian cottonwood forests along the Kootenai River in Idaho, Montana and British Columbia.
2. The impact of flow regulation on riparian cottonwood forests along the Yakima River.
3. A comparison of remote sensing tools for assessing the distribution of riparian cottonwood forests in the Columbia Basin.

Each is presented as a stand alone report and is available at the BPA website as separate document. Appendices to the major reports are included as separate files to minimize file size.

This work was funded under the innovative projects program of the NWPPC and BPA.

2.0 STUDY AREAS

Maps of the study areas are provided in the separate reports. A description of some of the essential differences between the sub-basins is provided below.

Kootenai River: The Kootenai River is an international sub-basin with one major reservoir (Libby) mid-way on the portion of the river we looked at. There are few dams, none of which have significant storage, in the headwaters of this river. Irrigation removals are minor but diking for agricultural has had major impacts on the lower portion of the river. The hydrograph below Libby dam is highly regulated. Over the last decade, flows on the downstream reaches of this river have been manipulated to create a series of artificial spring freshettes aimed at stimulating spawning in white sturgeon. This gave us the opportunity to observe the response of native cottonwoods and willows to these experimental flow releases.

Yakima River: The Yakima River has several storage reservoirs in the upper reaches of the system. The major alluvial floodplains lower on the system support extensive areas of intensive agriculture. A significant proportion of the annual flow is removed from the river for irrigation. Agriculture, settlement and regulated flows have had a significant impact in the floodplain portions of the system. Flows vary substantially over the season in a manner that is referred to locally as “flip-flop”. In this sub-basin our project benefited substantially from collaborative research activities on the alluvial floodplains of this system. A Bureau of Reclamation project, the **Yakima Reaches Project** under the direction of Dr. Jack A. Stanford of the University of Montana Flathead Biological Station has completed extensive work on the basic ecology of these alluvial floodplain areas.

3.0 METHODS

We applied six major tools is assessing riparian vegetation in these sub-basins.

1. A regional overview using Landsat and other data sources.
2. A historic assessment, using air photo interpretation comparing photos over a 50 to 80 year period, of riparian vegetation and land uses in three study reaches (5-12 km in length) along portions of the main stem rivers in each sub-basin.
3. An assessment of the present distribution of cottonwood, using a range of remote sensing tools, in these study reaches.
4. An assessment of the health of riparian vegetation and cottonwood stands, based on vegetation transect data collected at 30 to 60 sites in each sub-basin on point bars both within and outside the major study reaches.
5. An assessment of annual and seasonal flow data for each study reach.

The methods used are described in detail in the separate reports.

4.0 RESULTS

Kootenai River: We found that human impacts on the floodplain were much more extensive in the reaches below the Libby dam than in our study reaches upstream of the reservoir. Much of the lower river is diked and most of the floodplain is now farmland. Cottonwood stands do occur in the three downstream reaches however and we found recent cottonwood recruitment at three transect sites that has occurred as a result of spring flow releases for white sturgeon in the 1991 to 2000 period. The shape of these experimental releases varied widely between years and we were able to identify the years in which recruitment likely occurred.

Yakima River: We found extensive human impacts in all the alluvial reaches we studied. Unlike the Kootenai River however, there is still an active floodplain, between dikes and other constrictions, along most of the mainstem Yakima and its major tributaries. Gravel mining has had a major impact in many areas. Very little recruitment to cottonwood stands is occurring as a result of the highly modified flow regime in this sub-basin.
This work provides a good basis for more detailed future studies that will be co-ordinated with other research and restoration activities in this sub-basin, especially the Yakima Reaches Project and riparian restoration projects being carried out by the Yakima Indian Nations.

Tools Assessment: We found that Landsat data was ineffective in providing a regional overview of cottonwood distribution, due to problems in differentiating between deciduous hardwood species. Forest cover available in Canada did provide a good overview of cottonwood distribution in the Canadian portion of the Kootenai sub-basin. It appears that new hyper-spectral satellite data may allow the separation of deciduous species and could play a role in future work.

At a study reach scale we found that traditional visual typing of vegetation types from air photos, ADAR and IKONOS all could be used to document the distribution of cottonwood stands and other riparian vegetation types. Each approach had positive attributes, some limitations and varied in cost. Hymap, a new hyper-spectral data source (flown at low elevation) has been used to separate deciduous species in the Yellowstone area. This tool will be of major value in future studies of riparian vegetation.

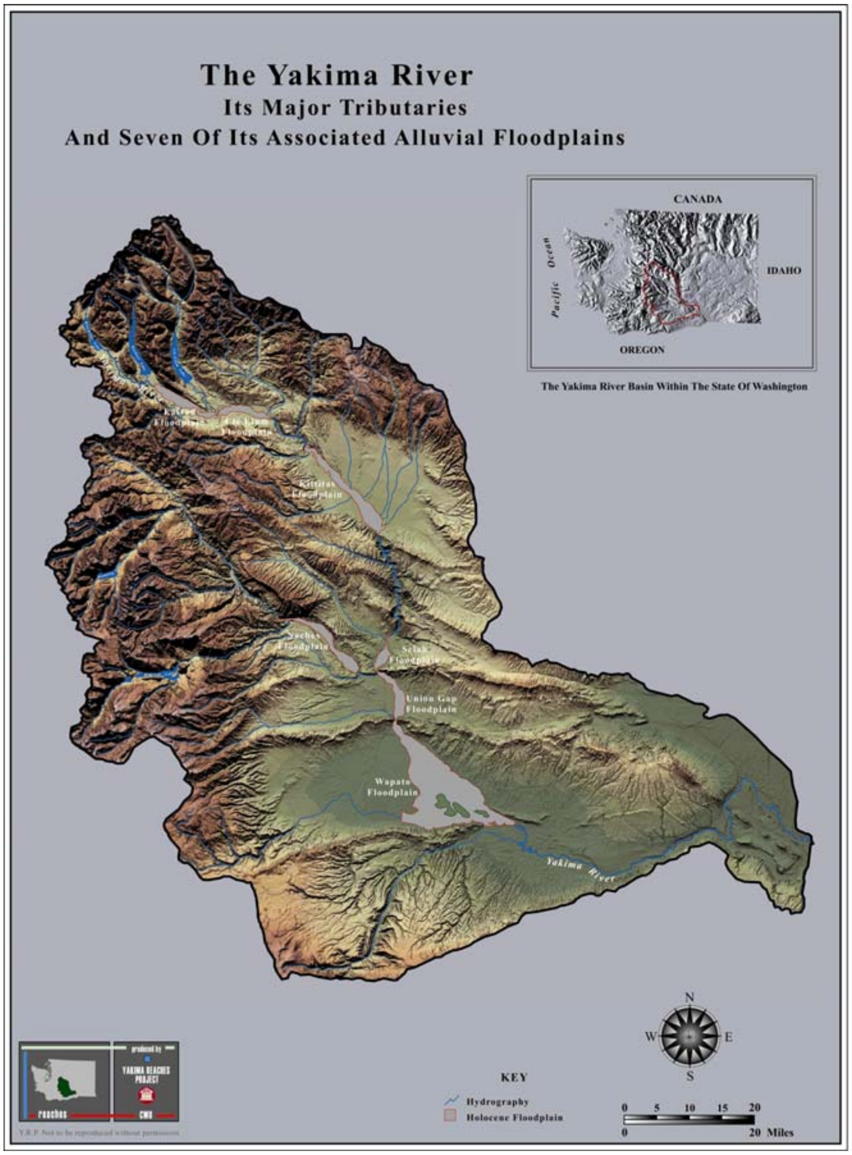
5.0 CONCLUSIONS

Our most important conclusions are that:

- Major losses to riparian vegetation and ecological function have occurred in response to regulated flows in both river systems.
- There are major differences in the seasonal hydrograph and the impact of other land uses in each sub-basin. As a result, separate strategies for managing regulated flows to maintain riparian vegetation are required in each sub-basin.
- On the Kootenai, we found clear evidence that spring releases do in fact result in the establishment of cottonwood recruitment, as has been documented in other basins.
- This work provides the science and the conceptual tools for managers to integrate the requirements of cottonwood and riparian vegetation into the complex mix of flow demands found in each sub-basin.
- This work has also allowed us to develop tools that can be used effectively and efficiently to document the status of riparian vegetation along rivers in other parts of the Columbia Basin.

The recent report by the Independent Scientific Advisory Board on salmon recovery strategies provides an analysis of the various planning strategies in the Basin and good advice on future direction for restoration work. They note that natural disturbance events, such as flood events, have not been given sufficient consideration in past planning. They also indicate that management is moving from more artificial management strategies toward the restoration of ecological function. A move toward more normative flows on regulated rivers is a critical element of this strategy and should be an important feature of future restoration efforts. We see our work as an important element in this move toward more normative conditions that will generate important benefits in re-establishing ecological function and providing important habitat improvements for both fish and wildlife species.

THE IMPACTS OF FLOW REGULATION ON RIPARIAN COTTONWOOD FORESTS OF THE YAKIMA RIVER



FOR: **BONNEVILLE POWER ADMINISTRATION**
PORTLAND, OREGON

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November 8, 2001.

THE IMPACTS OF FLOW REGULATION ON RIPARIAN COTTONWOOD FORESTS OF THE YAKIMA RIVER

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THE IMPACTS OF FLOW REGULATION ON RIPARIAN COTTONWOOD FORESTS OF THE YAKIMA RIVER

1.0 INTRODUCTION

Riparian Forests are critical to the structure and function of rivers and the fish and wildlife dependent on riparian and aquatic ecosystems (Rood and Mahoney 1990, Braatne et al. 1996, Braatne, Lorang and Jamieson 2001). In this report, we describe the nature and extent of riparian cottonwood forests on the Yakima River; an important watershed in the Columbia Plateau Province. Under pre-settlement conditions, alluvial floodplains with multiple channels, complex aquifers and extensive cottonwood forests were a major feature of this river basin. The construction and operation of headwater dams in both the upper Yakima and Naches Rivers to enhance the supply of irrigable waters has had a major impact on the structure and function of riparian forests in the basin. Altered flow regimes and the effects of other land uses have lead to severe reductions in alluvial floodplains, channel simplification and impaired ecosystem function (Ring and Watson 1999, Eitemiller et al. 2000). Several authors have described the dependence of native fish and wildlife on native riparian vegetation and natural river dynamics (Rood and Mahoney 1990, Stanford et al. 1993, 1996, Ward and Stanford 1995a,b, Williams et al. 1996). Correspondingly, fish and wildlife habitat values have been dramatically reduced as a result of various changes in land use and flow regulation along this river corridor (Fast et al. 2001). Our studies in the Yakima Basin follow the work of these and other researchers who have explored the relationships between regulated flows, riparian forest communities and native fish and wildlife.

1.1 BASIC CONCEPTS

The recruitment of cottonwood seedlings along rivers is dependent on dynamic fluvial processes (Bradley and Smith 1984, Rood and Mahoney 1990, Rood and Mahoney 1995, Braatne et al. 1996, Mahoney 1996, Scott et al. 1996). (See Figure 1). Dynamic seasonal flow patterns, combined with periodic spring flooding, produce moist, barren substrates that are necessary for seedling recruitment (Bradley and Smith 1986, Rood and Mahoney1990, Rood and Mahoney 2000, Scott et al. 1996). After germination on these nursery sites, the roots of young seedlings must keep pace with declining river levels (root growth averages 2.5 cm per day); Mahoney and Rood 1991, 1992, 1998, Selgelquist et al. 1993, Johnson 1994, Rood et al. 1995). If river levels decline too rapidly, young seedlings rapidly succumb to drought stress. Older cottonwood stands are also dependent on periodic flooding and recharging of the alluvial water table (Johnson and Jones 1977; Rood and Heinze-Milne 1989; Rood and Mahoney 1990; Snyder and Miller 1991; Stromberg and Patten 1992). Dams that attenuate spring peakflows and reduce summer baseflows induce significant levels of drought stress among all age-classes, and thereby promote a decadent age- structure among local populations (Fenner et al. 1985, Bradley and Smith 1986, Rood and Mahoney 1990, Stomberg and Patten 1991, Scott et al. 1996). Such modified flows commonly lead to the loss of ecologically important riparian forests.

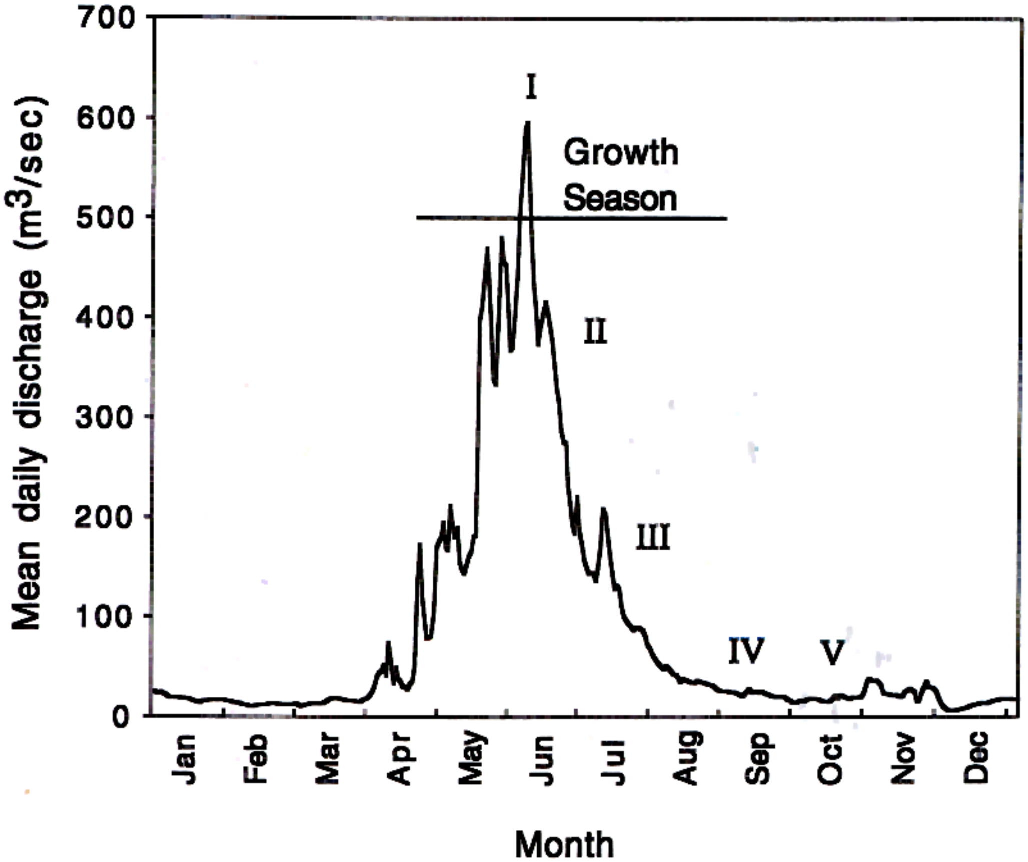


Figure 1. A representative daily hydrograph for large alluvial rivers in western North America prior to the construction of major dams upstream. Roman numerals represent important components relevant to the recruitment of poplar seedlings: (I) high flows drive geomorphic processes that create suitable moist and barren nursery sites, (II) falling flows expose the nursery sites, (III) gradual flow decline after germination permits the growing roots to maintain contact with the receding moisture zone, (IV) sufficient flows through the hot and dry period of mid- to late summer, and (V) sufficient flows in late summer and autumn provide seedlings with a favorable water balance to withstand the winter months (modified from Mahoney and Rood 1998).

Research on many rivers in western North America has demonstrated that flow regulation has severe impacts on downstream cottonwood forests. Several studies have found a steady decline in the extent and health of riparian cottonwood ecosystems (Rood and Mahoney 1990; Bradley et al. 1991, Braatne et al. 1996, Mahoney 1996). The primary causes of these declines have been woodland clearing and impacts due to water diversions and damming (Braatne et al. 1996). Most of the studies on dam-induced declines have occurred along rivers on the Great Plains that support prairie and Fremont cottonwoods (Johnson et al. 1976, Bradley and Smith 1986, Rood and Heinze-Milne 1989, Rood and Mahoney 1990, Rood and Bradley 1993, Snyder and Miller 1991, Stromberg and Patten 1992 and Johnson 1992. More recently, work has been initiated on Black Cottonwood along the Columbia River in Canada (Rood et al. 1995) and on the

Kootenai River (Polzin and Rood 2000). This research has shown that declines in riparian cottonwoods are primarily related to regulated flow regimes that suppress the recruitment of cottonwood seedlings. Since cottonwoods are a relatively short-lived tree (100-200 years), declines in seedling recruitment over the past century have lead to the widespread loss of riparian cottonwood forests.

In recent years, some researchers have successfully applied their knowledge of the life history and ecology of cottonwoods to promote natural patterns of recruitment below dams on several western rivers (Rood and Gourley 1996, Rood and Kalischuk 1998). In these cases, high water volumes available during "wet years" were released in a manner that was compatible with seed dispersal and establishment criteria of cottonwood seedlings. These practices are now widely accepted as a tool for promoting the recovery of riparian cottonwood forests.

This report is intended to provide a better understanding of the impact of flow regulation on riparian cottonwood forests along selected reaches (Cle Elum, Union Gap and Upper Wapato) of the Yakima River and developing options for mitigating those impacts. These study reaches were specifically selected due to their distinctive seasonal flow regimes as regulated by the BOR Yakima Irrigation Project. Similar work has been completed on the Kootenai River as part of the same project (Figure 2). The following tasks are addressed in this report:

Historic analysis of riparian forests derived from air photos of different eras
Analysis of river edge vegetation analysis based on field belt-transect data
Analysis of historic and contemporary regulated flows, based on gaging data
Preliminary review of options to mitigate declines in riparian cottonwood forests.

This work was funded under innovative projects program of the Northwest Power Planning Council (NWPPC), Columbia Fish and Wildlife Authority (CBFWA) and Bonneville Power Authority (BPA); Project No. 20034. This is part 2 of 3 reports that were generated to meet the objectives established under this project. All aspects of this research activity were completed between June 30, 2000 and October 31, 2001.

2.0 STUDY AREA

The Yakima River Basin is located in south central Washington (Figure 3), encompassing an area of approximately 15,900 square km (6,155 square miles). The Yakima River originates near the crest of the Cascade Range and flows 344 km (214 miles) southeastward to its confluence with the Columbia River (Fast et al. 2001). Major tributaries include the Kachess, Cle Elum and Teanaway rivers in the northern part of the basin and the Naches River in the West. Six major reservoirs located in the headwaters of the Yakima and Naches basins form the primary storage for the Yakima Irrigation Project, managed by the US Bureau of Reclamation.

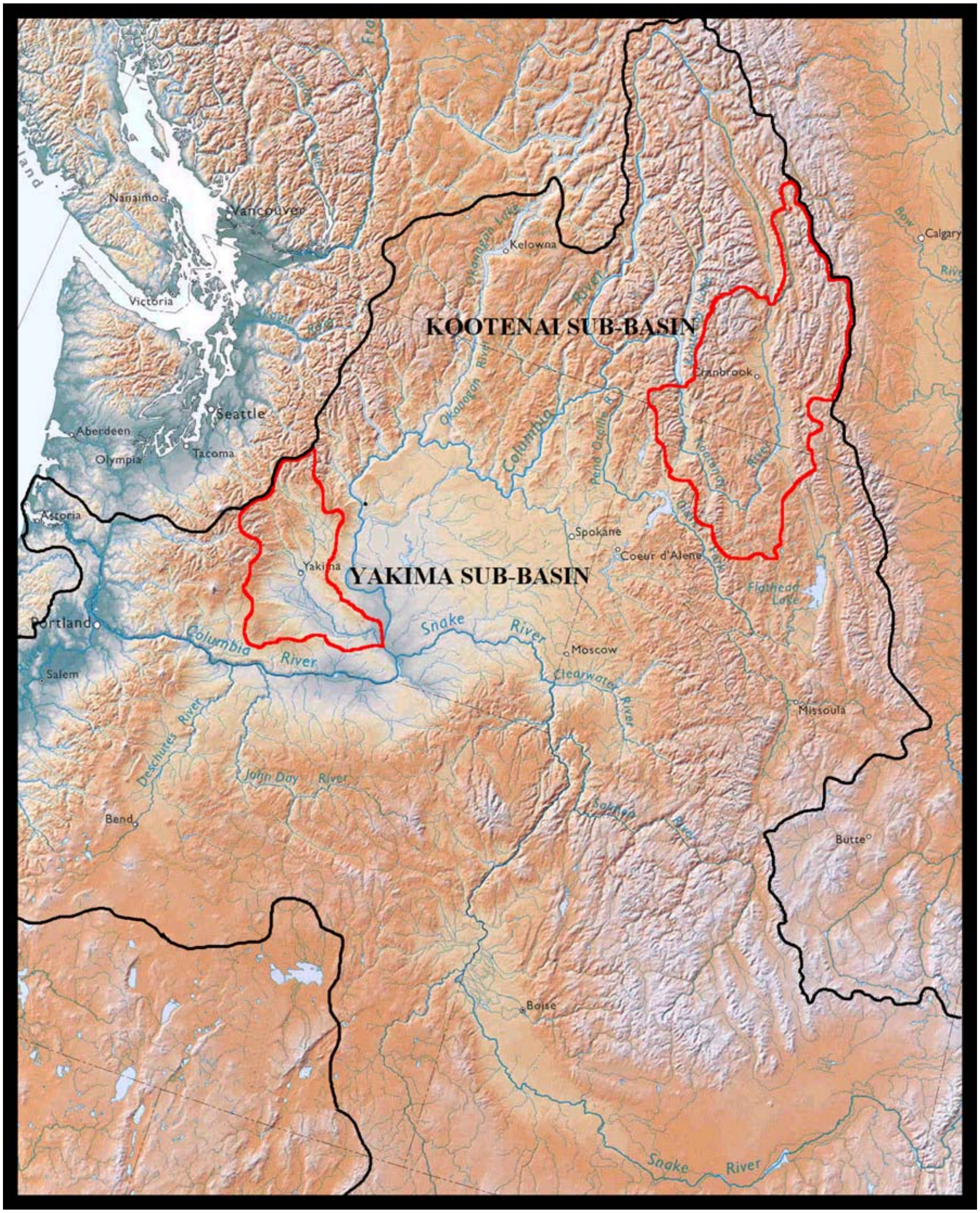


Figure 2. The location of the study basins within the Columbia Basin.

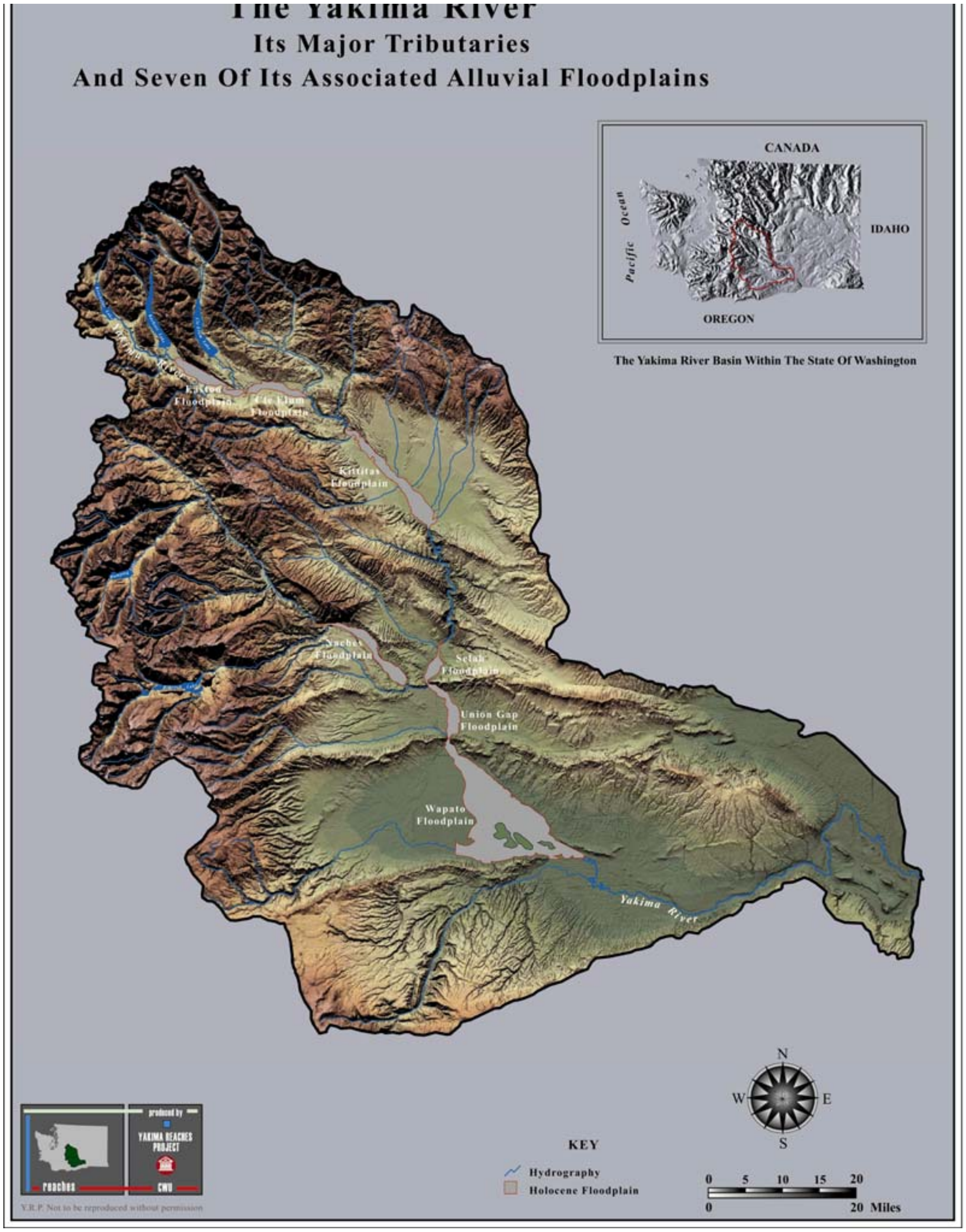


Figure 3. The Yakima River Basin and its Major Tributaries.

The topography of the Yakima Basin is characterized by a series of long ridges extending eastward from the Cascades and encircling several alluvial floodplains (Figure 3). The areal extent of these alluvial floodplain reaches was extensive prior to European settlement: Easton (2679 ha), Cle Elum (1750 ha), Kittitas (5,420 ha), Selah (1182 ha), Naches (3310 ha), Union Gap (2325 ha), and Wapato (24,854 ha) (Eitemiller 2000). Historically, cottonwood galley forests dominated these floodplain habitats. Today, despite extensive clearing and agricultural activity, riparian cottonwoods still occupy significant portions of these alluvial reaches. Our field studies focused on the Cle Elum, Union Gap and Upper Wapato reaches in order to capture longitudinal variation in vegetation patterns along the riparian corridor of the Yakima River and the highly variable regulated flows between these study reaches.

3.1 Assessment of the historic conditions of riparian cottonwood stands: Technical staff with the Central Washington University Department of Geography and Land Studies were sub-contracted to document temporal changes in the extent of riparian cottonwood forests in three selected study reaches (Cle Elum, Union Gap and Upper Wapato). Previous work had been completed by CWU in these reaches as part of their BOR funded Yakima Critical River Reaches Project. Dr. Braatne worked closely with their staff in the basic approaches to the mapping of riparian cottonwoods from aerial photographic images. Aerial photographs of the study reaches, from the 1920's and 1940's were collected and scanned at 400 dpi (the maximum resolution possible with the available scanning software). Digital ortho-photographs based on photos from the mid 1990's were purchased from the Washington State Department of Natural Resources (DNR) and used as the mapping base. The older photos were rectified and geo-referenced using ERDAS Imagine software. The photographs were then exported to ArcInfo where they were appended into a single image. Each image was used as a backdrop on which the forest overstory (mature cottonwood canopy) and mesostory (mixed mosaic of herbaceous and woody species) components of riparian floodplain communities were digitized. These vegetation components were classified from the hardcopy aerial photographs by drawing on mylar overlays using a stereoscope. These overlays were then used as reference polygons for digitizing. The digital information was exported to Adobe Photoshop and Adobe Illustrator where graphics processing was finalized.

3.2 Assessment of seasonal discharge and river stage: Databases on seasonal discharge and river stage as maintained by the US Geological Survey (USGS) and US Bureau of Reclamation (BOR) were used in our analyses of seasonal flow patterns for the Yakima River from 1991 to 2001. Primary recording stations were located at Cle Elum for the Cle Elum reach and Parker, WA for the Upper Wapato Reach. We combined flow data from gages below Roza Dam and the lower Naches River to estimate discharge and river stage for the Union Gap Reach. Data obtained from these gages was used to develop hydrographs for three time intervals: a) 1908-1915, to represent natural flows prior to construction and operation of headwater dams in the Upper Yakima and Naches Rivers), b) 1973-80, to represent the standard seasonal pattern of flow manipulations from the 1950's through the 1970's, and c) 1991-1998 to represent seasonal flow regimes in relation to the unique patterns of "flip-flop" flow manipulations that were initiated in 1981 along the Yakima and Naches Rivers.

3.3 River edge vegetation analysis: Riparian vegetation patterns along riverbanks and scroll bars were systematically sampled using belt-transects in each of the study reaches. Scroll and/or point bars were systematically sampled within each reach as these geomorphic surfaces typically show the highest probability for the recruitment of cottonwood and willow seedlings. Twelve belt-transects were established and sampled within each study reach. Each belt-transect was established perpendicular to the river edge and extended several meters upslope to mature cottonwood stands. Given differences among floodplain features, belt-transects ranged from about 50 m to 150 m in length. Areas along the riverbank dominated by herbaceous plants (both native and exotic species) were sampled using 1m x 1m quadrats placed at 1 m intervals along the transect (quadrats were positioned on the upstream side of the transect line). Larger quadrats were used to sample areas dominated by shrubs (2m x 4m quadrats) and trees (5m x 20 m quadrats). Estimates of percent plant cover were obtained for all species. Stem counts, diameters at 0.5 m and age-class determinations (cores collected at 0.5 m) were obtained for dominant trees and shrubs. A permanent metal stake was placed at the top of each transect and the location of the top and bottom of each transect were recorded using a Trimble GPS Pathfinder ProXRS (sub-meter resolution, Trimble Navigation Inc., USA). These methods follow general sampling protocols of Mueller-Dubois and Ellenburg (1974), Goldsmith et al. (1986), Johnson et al. (1987, 1992, 1995), Scott et al. (1993), and Auble et al. (1994), Rood and Kalischuk (1998).

A transit level was used to determine the relative elevation (+/- 0.1 cm) of each quadrat. The bottom elevation for each transect was tied to the current water surface, with the date and specific time recorded for each measurement. GPS coordinates (Trimble ProXRS) of this benchmark were then linked with river stage data as derived from the nearest river gage (USGS/BOR river gage data) and/or survey benchmark data from the groundwater well networks of the Yakima Critical Reaches Project. This elevation data allowed us to correlate riparian plant distribution with the distinct flow regimes of each study reach.

Surface substrates were classified into one of four categories: 1) fines -- fine sediment (sand, silt, or clay, 2) fine-cobble -- coarse surface (gravel, cobbles) with a subsurface of fines, 3) cobble -- coarse surface (gravel, cobbles, small boulders) without fines below the surface layer of rock, and 4) large boulders and bedrock. A visual classification of these substrate classes was recorded for each quadrat.

Estimates of plant cover were converted to an octave scale for all subsequent analyses. This minimized sampling error, while preserving fine-scale differences at low values. Octave classes used in this study were: 0 (0% cover), 1 (1%), 2 (2-4%), 3 (5-9%), 4 (10-18%), 5 (19-35%), 6 (36-72%), 7 (73-100%); with mid-points of each coverage class used in subsequent data analyses. A detailed list of species for each study reach was developed with the most common species summarized in Appendix A. Species nomenclature will follows Hitchcock and Cronquist (1991) and Whitson et al. (1996).

This sampling regime allowed us to closely document the composition and structure of mature riparian cottonwood forest communities (trees, shrubs, forbs, both native and exotic species) and patterns of cottonwood seedling recruitment in relation to current and historic flow conditions for each study reach.

4.0 RESULTS

The funding constraints inherent to the BPA Innovative Projects Program would allow only a limited analysis of field data collected within the riparian forests of the Yakima Basin. The following results and discussion sections thus outline only the major aspects of our observations for each study reach.

4.1 Cle Elum Reach

4.1.1 Riparian Floodplain Forests (1942 to 2000)

Changes in the riparian forest communities and overall loss of floodplain habitat in the Cle Elum reach were documented through a comparative analysis of aerial photos taken in 1942 and 2001 (Figures 4 and 5). The 1,750 ha of Holocene floodplain habitat in this reach (Eitemiller et al. 2000) declined to 625 ha by 1942 and only 576 ha by 2001. The active riparian forest overstory increased slightly from 283 ha in 1942 to 318 ha in 2001. This slight increase in forest cover is primarily related to the abandonment of gravel mining operations and riparian pastures within the floodplain from 1942 to 2001. Several additional changes in critical floodplain features can also be observed in Figures 4 and 5.

4.1.2 Seasonal Discharge Patterns (1911 to 2000)

Seasonal patterns of daily discharge and river stage are critical to understanding relationships between flow dynamics and the composition and structure of riparian plant communities. Historic patterns of seasonal discharge for the Cle Elum Reach are shown in upper graph of Figure 6. Natural flow patterns, prior to the construction and operation of headwater dams, are shown in the upper graph. In the early 1900's, natural peakflows associated with snowmelt were followed by progressive declines in discharge and stage over the summer months with periodic rain-driven stormflows during the winter months (Figures 6 & 7). These historic flow regimes, notably gradual stage declines during the seed dispersal periods, would have favored the widespread establishment of native willows and cottonwoods in this study reach. In contrast, seasonal flow patterns were highly modified following construction of headwater dams and regulated flows to support the irrigation of agricultural crops within the Basin (lower graph, Figure 6). Recent flow management practices decrease springtime flows and maintain exceptionally high levels of discharge (flows >> spring discharge values) throughout the summer months. These regulated flows limit natural declines in river stage during the growing season (Figure 7), thus inundating nursery sites suitable for willow and cottonwood seedlings. Such high levels of discharge during their seed dispersal phase limits the germination and establishment of native willows and cottonwoods throughout this study reach.

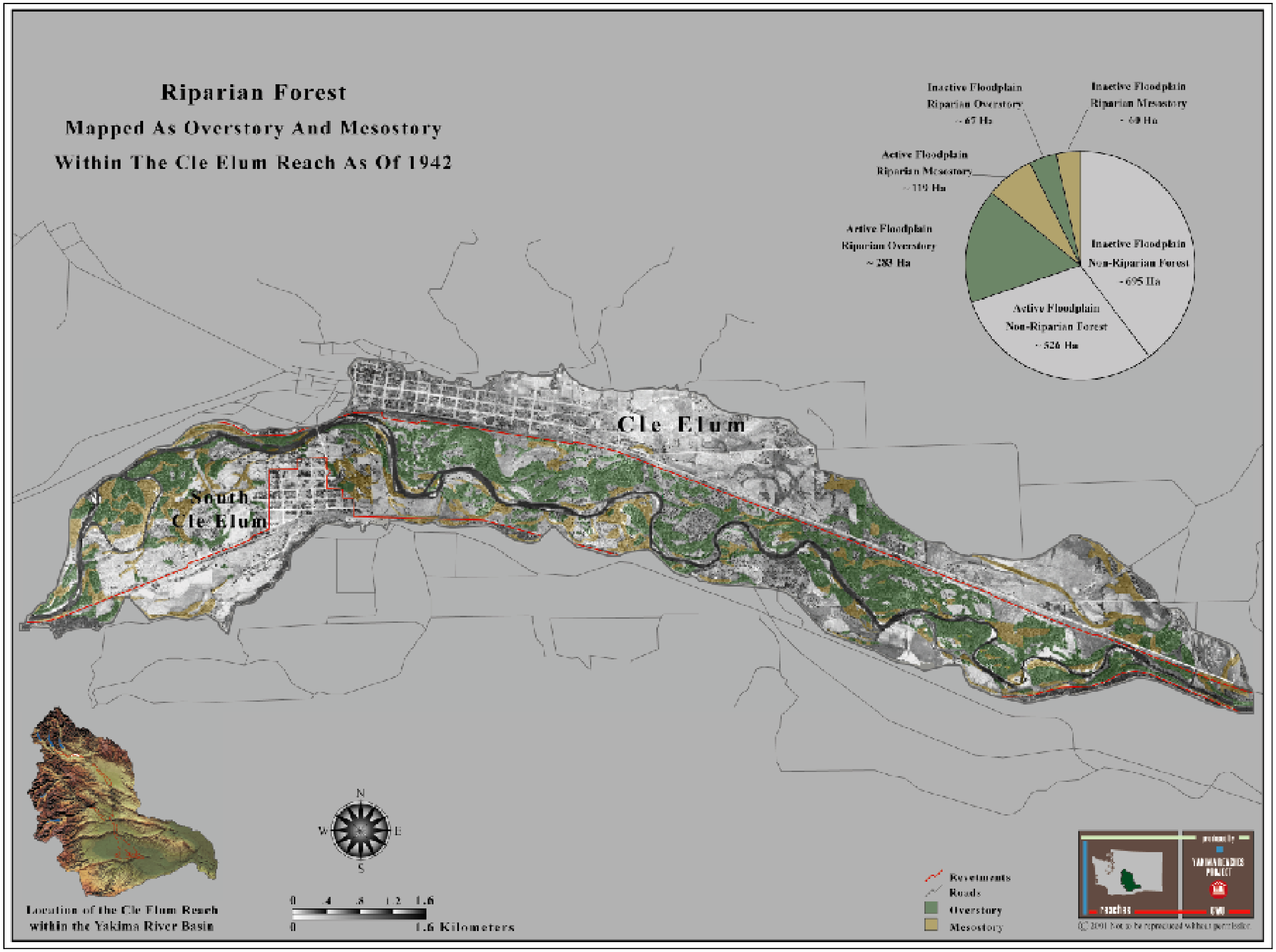


Figure 4. The areal extent of riparian forest on the Cle Elum reach of the Yakima River, WA (1942).

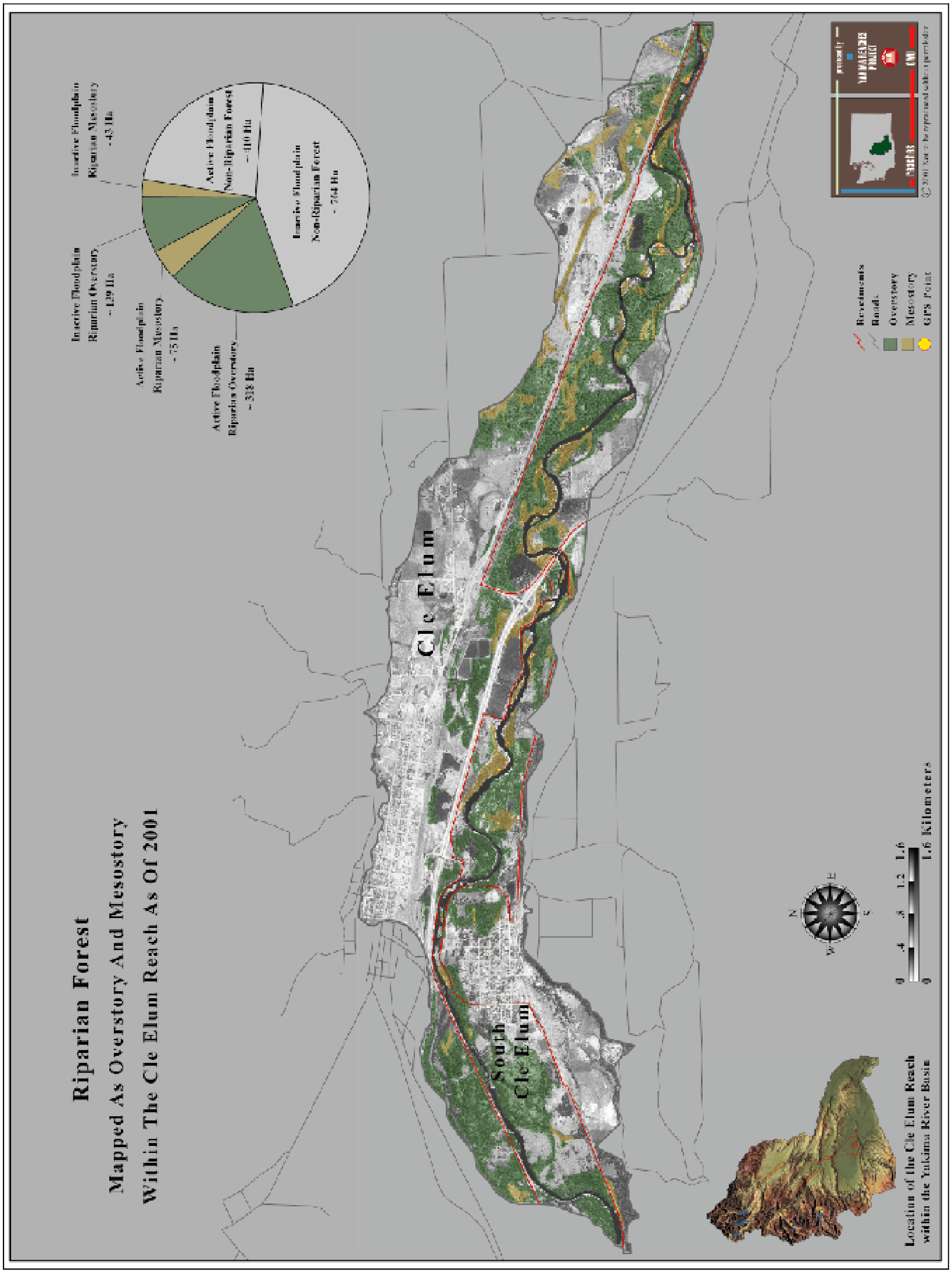
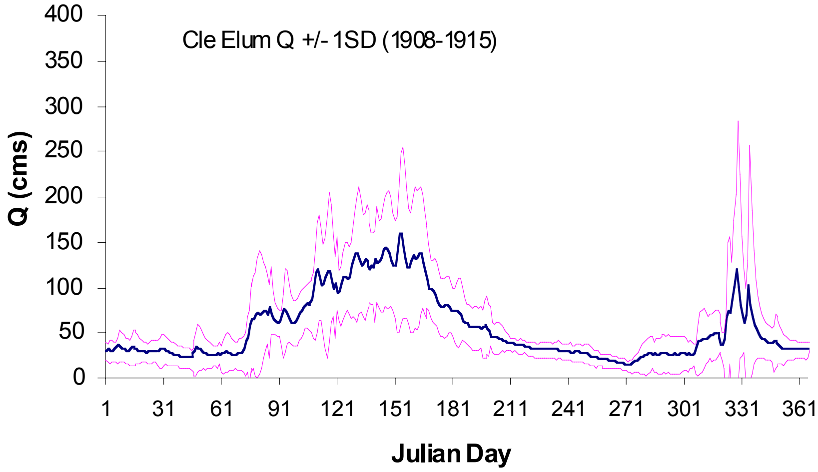


Figure 5. The areal extent of riparian forest on the Cle Elum reach of the Yakima River, WA (2001).



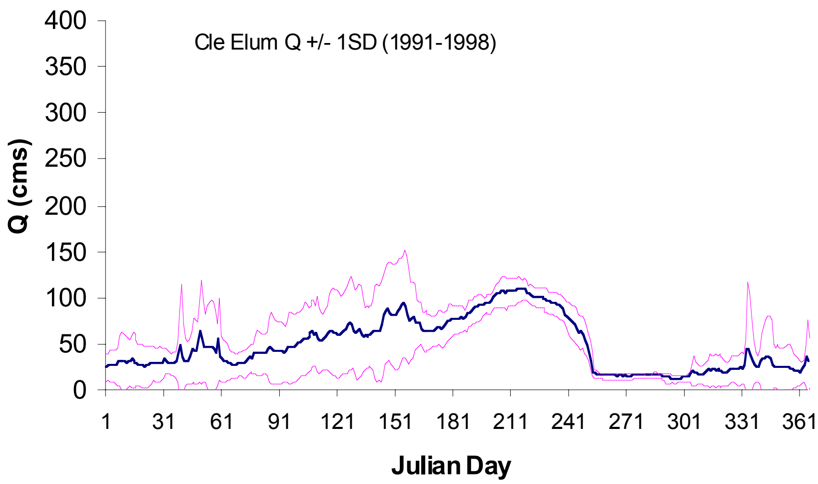


Figure 6. Historic patterns of seasonal discharge for the Cle Elum Reach of the Yakima River, WA. Values are daily means +/- 1 SD (Cle Elum gaging station)

4.1.3 Composition and Structure of Riparian Plant Communities

Along the Cle Elum reach, riparian populations of willows, cottonwoods and other native plants were largely composed of healthy and vigorous individuals (Figure 8). However there was a widespread lack of younger willow and cottonwoods throughout the reach. Willows and cottonwoods were more abundant at elevations of one meter or more above baseflow conditions (see Figures 7 & 9). This pattern of distribution corresponded to those areas of the floodplain located above the elevated discharge and stage associated

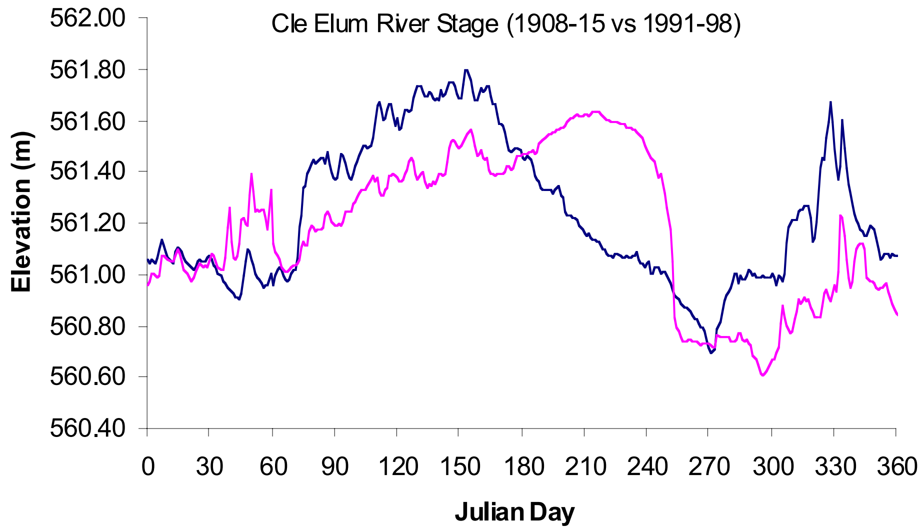
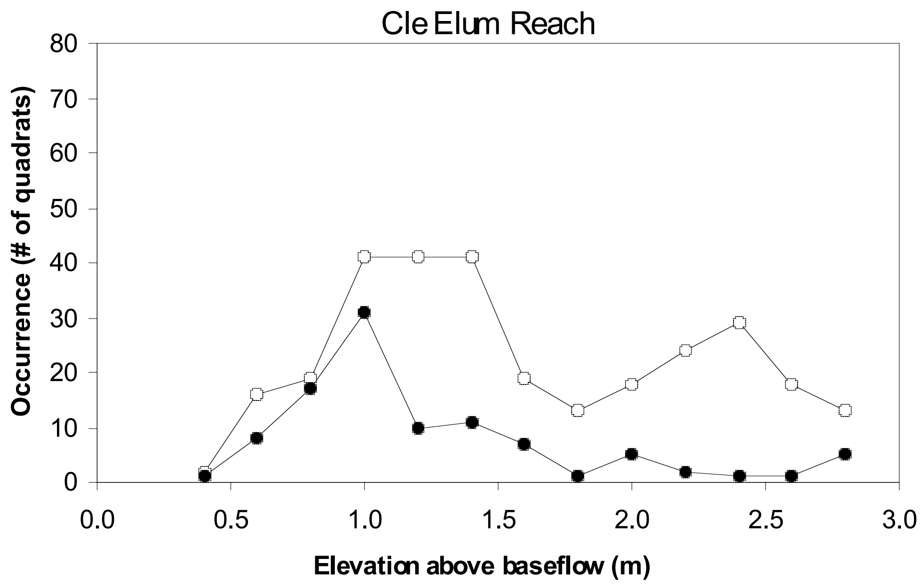


Figure 7. Seasonal patterns of river stage for the Cle Elum Reach of the Yakima River, WA. Blue line = 1908 to 1915, Pink line = 1991-1998.

Figure 8. Representative photo of riparian cottonwood forest communities in the Cle Elum Reach. Note the absence of younger willows and cottonwoods and relative absence of exotic weeds on this broad barren scroll bar.

with the regulated flows in this alluvial reach (see Figures 6 & 7). Similarly, grasses and forbs were more abundant at these higher floodplain elevations (Figure 10). Herbaceous life forms were dominated by perennial species, thus native grasses and forbs were more common than annual exotic weeds. However, invasive stands of reed canarygrass



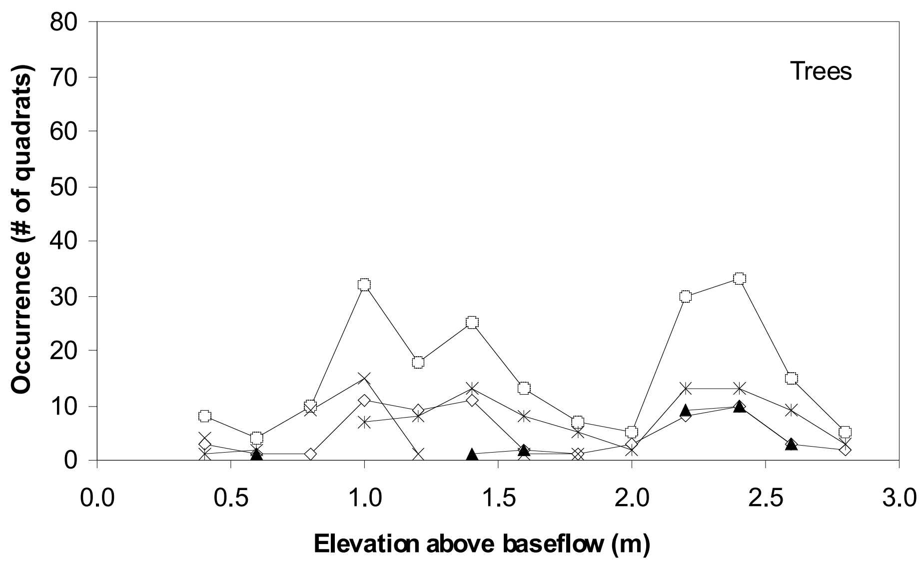
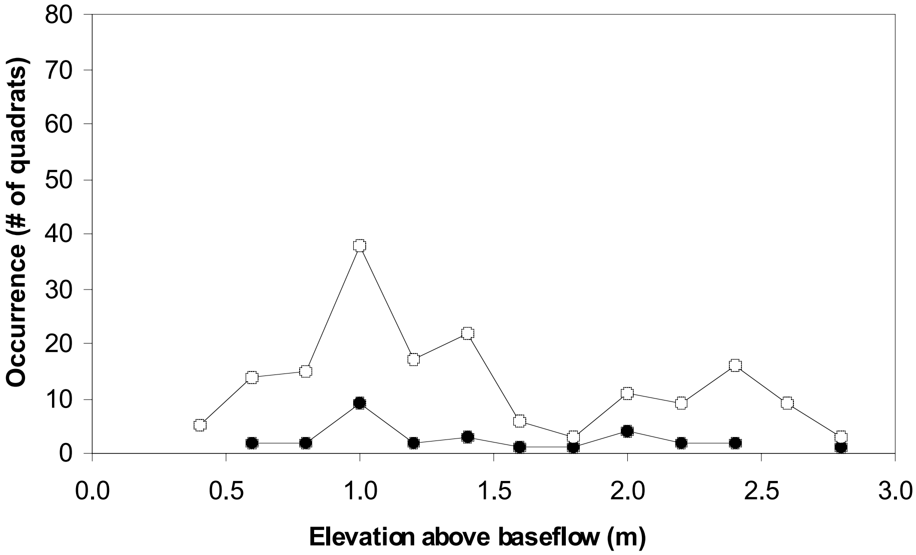


Figure 9. The distribution of shrubs and trees relative to seasonal baseflow conditions in the Cle Elum study reach (Shrubs: open circles = all shrub species, closed circles = native willows; Trees: open circles = all tree species, closed circles = mature cottonwoods, closed triangles = other deciduous species, open diamonds = conifer species, x = 2000 cottonwood seedlings).

dominated riverbanks throughout this study reach. The relative abundance of reed canarygrass was indicative of the persistent elevated flows that favor its expansion via vegetative propagules during the summer months (a fairly common observation in many flow-regulated rivers of western North America).



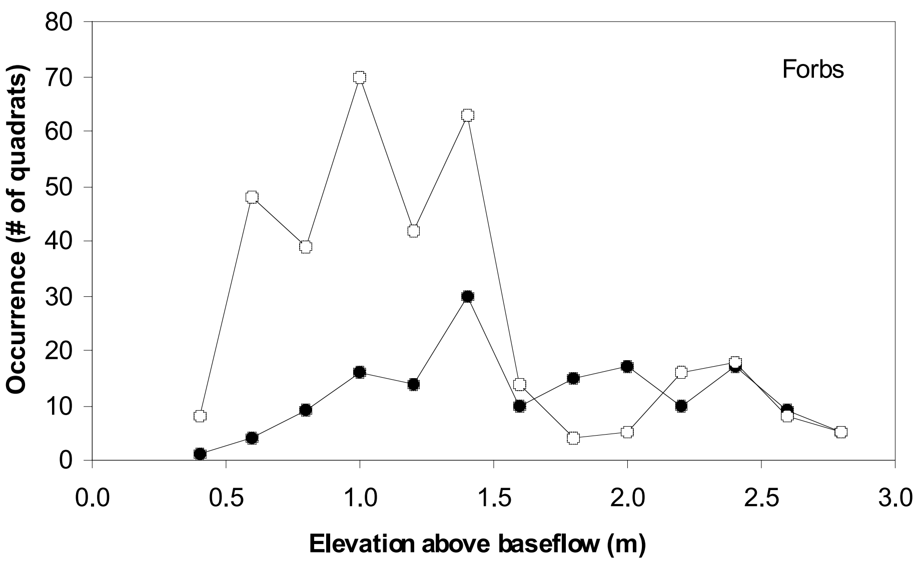


Figure 10. The distribution of grasses and forbs relative to seasonal baseflow conditions in the Cle Elum study reach (open symbols = perennial species, close symbols = annual species).

4.2 Union Gap Reach

4.2.1 Riparian Floodplain Forests (1942 to 2000)

Changes in the riparian forest communities and overall loss of floodplain habitat in the Union Gap reach were documented through a comparative analysis of aerial photos taken in 1927 and 2001 (Figures 11 and 12). The 2,325 ha of Holocene floodplain habitat in this reach (Eitemiller et al. 2000) declined to 454 ha by 1927 and 421 ha by 2001. The active riparian forest overstory increased slightly from 264 ha in 1927 to 273 ha in 2001. This slight increase in riparian forest cover is primarily related to the abandonment of gravel mining operations and agricultural activities within the floodplain. Several additional changes in critical floodplain features can also be observed in Figures 11 and 12.

4.2.2 Seasonal Discharge Patterns (1980 to 2000)

Under recent regulated flows (1987-1996), there were very low levels of seasonal variation in discharge and river stage along the Union Gap reach (Figure 13). The total range of variation in seasonal discharge was only about 75 cms, and the river stage decline during periods of willow and cottonwood seed dispersal was less than 15 cm. This lack of stage decline represents a highly unusual flow pattern, even among other flow-regulated rivers in western North America. In effect, the lack of seasonal declines in river stage severely limits the opportunity for seedling recruitment by willows, cottonwoods and other native riparian plants within this study reach.

4.2.3 Composition and Structure of Riparian Plant Communities

Along the Union Gap reach, scattered stands of riparian cottonwood were largely composed of healthy and vigorous trees (Figure 14). However, European willows (*Salix alba* and *Salix x. rubens*) comprise a fairly significant component of the riparian forest community along with other exotic woody and herbaceous species. Similar to other study reaches, younger ages classes of native willow and cottonwood were largely absent. Given the relative stability of regulated flows and lack of a significant stage declines (Figure 13), vegetation was commonly found growing closer to the river channel than observed in other reaches. While native willows and cottonwoods were primarily located at elevations of one meter or more above baseflow conditions, they were also commonly found as low as one-half meter above seasonal baseflows (see Figures 13 & 15). Grasses and forbs were found at comparable elevations (Figure 16). Perennial grasses, such as reed canarygrass, were more common than annual grasses. Invasive annual and perennial forbs were also common members of these riparian communities. The close proximity of this riparian corridor to the City of Yakima, fruit orchards, agricultural fields and major highway networks were all important factors along with regulated flows in driving the relative abundance of exotic species within this study reach.

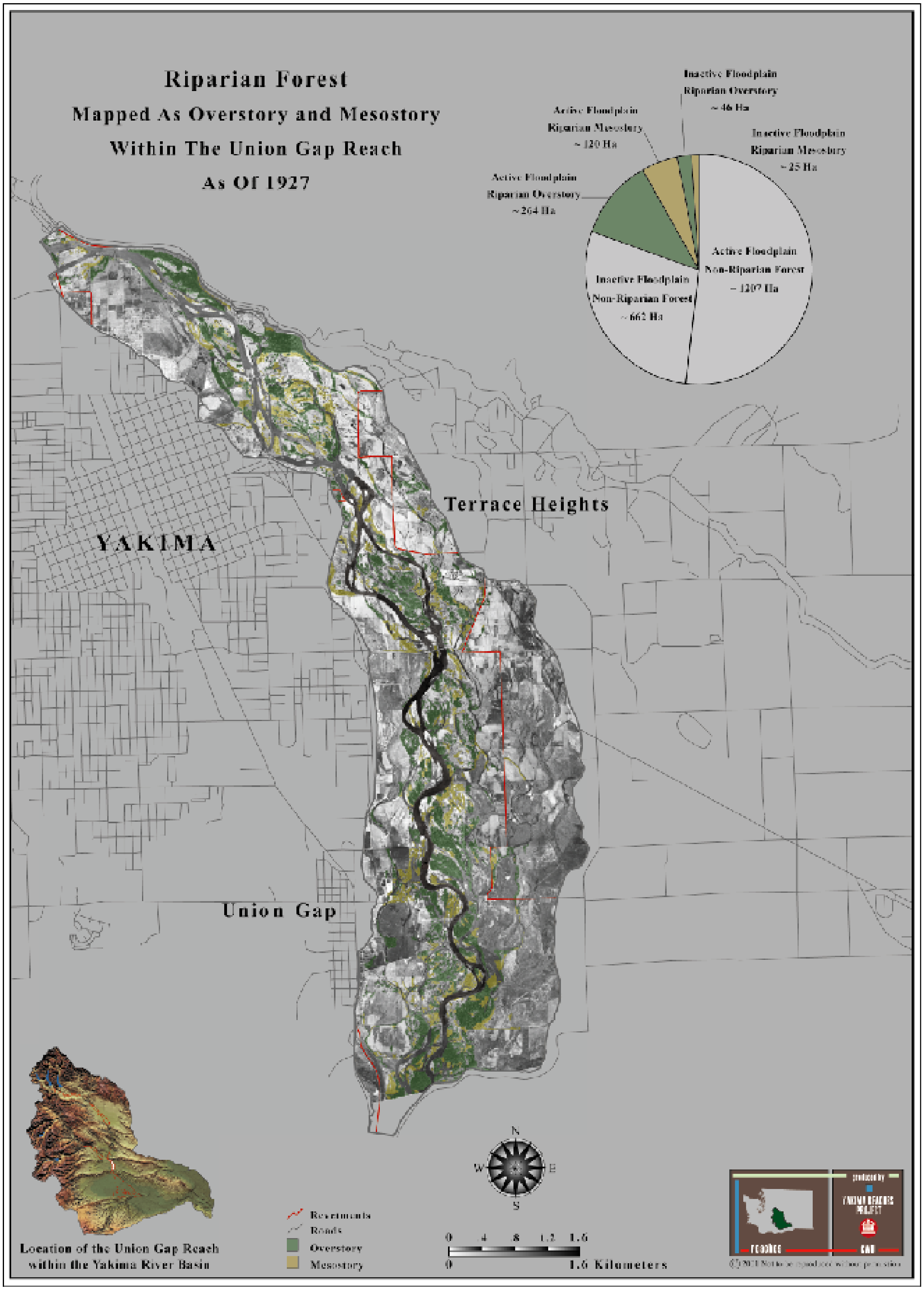


Figure 11. The areal extent of riparian forest on the Union Gap reach of the Yakima River, WA (1927).

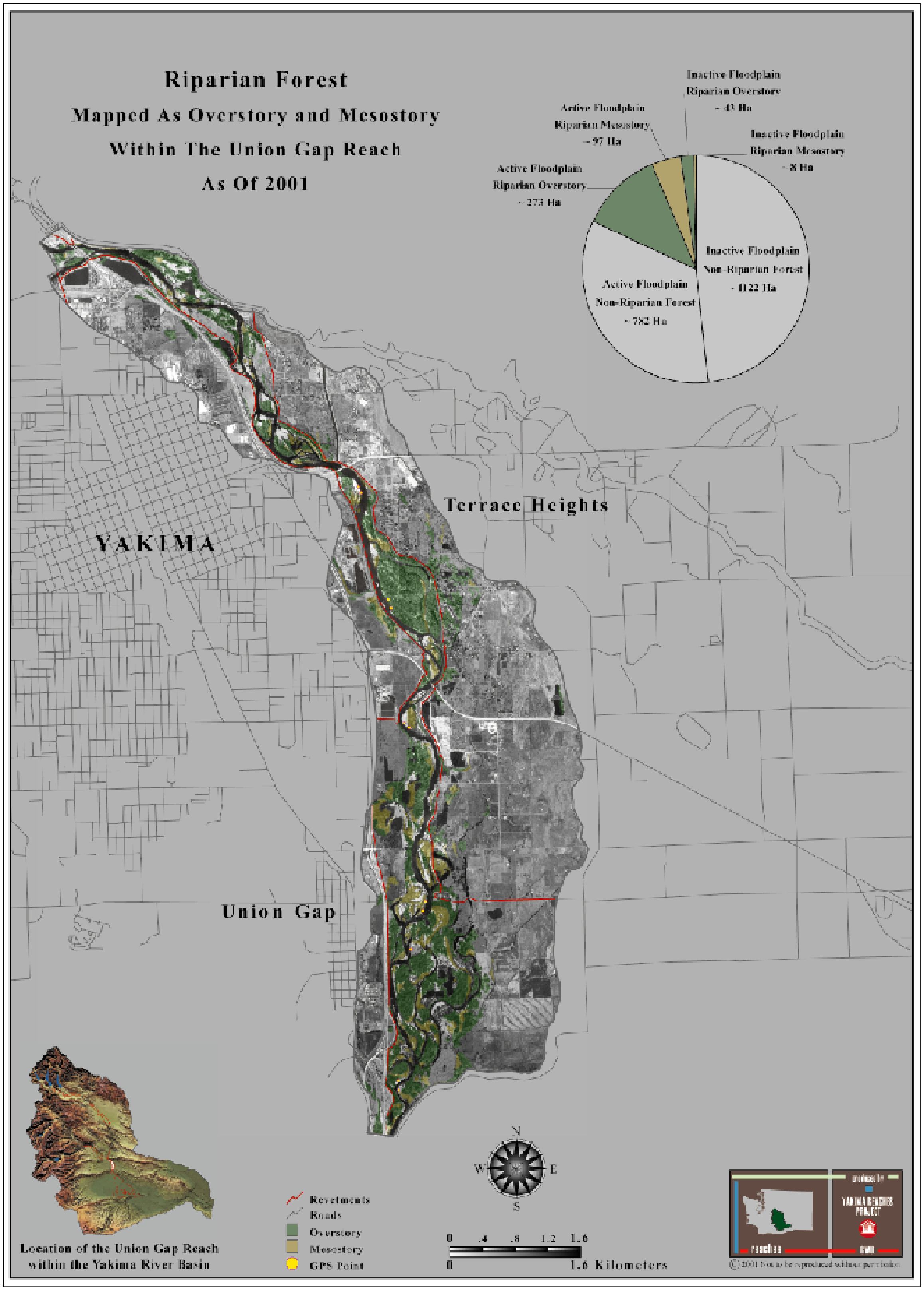
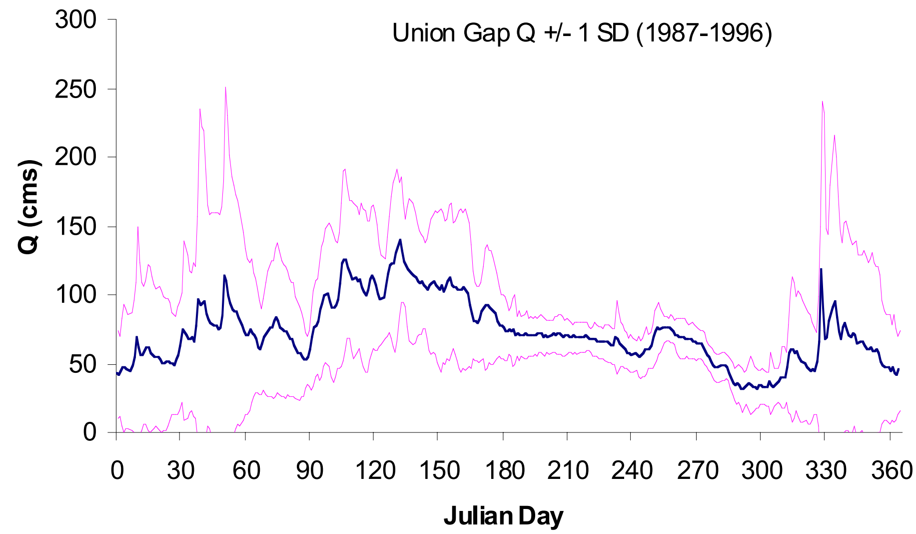


Figure 12. The areal extent of riparian forest on the Union Gap reach of the Yakima River, WA (2001).



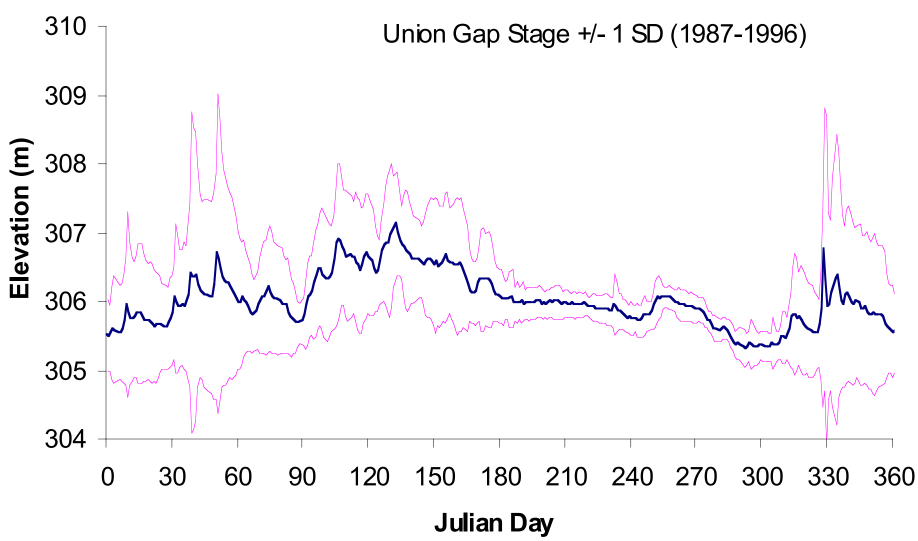


Figure 13. Seasonal patterns of discharge and river stage for the Union Gap Reach of the Yakima River. Values are daily means +/- 1 SD (Roza & Lower Naches gaging stations)

Figure 14. Representative photo of riparian vegetation patterns in the Union Gap Reach. Riparian Cottonwoods are in the background to the right of the photo w/ European willow along with the high density of exotic weeds in the foreground.

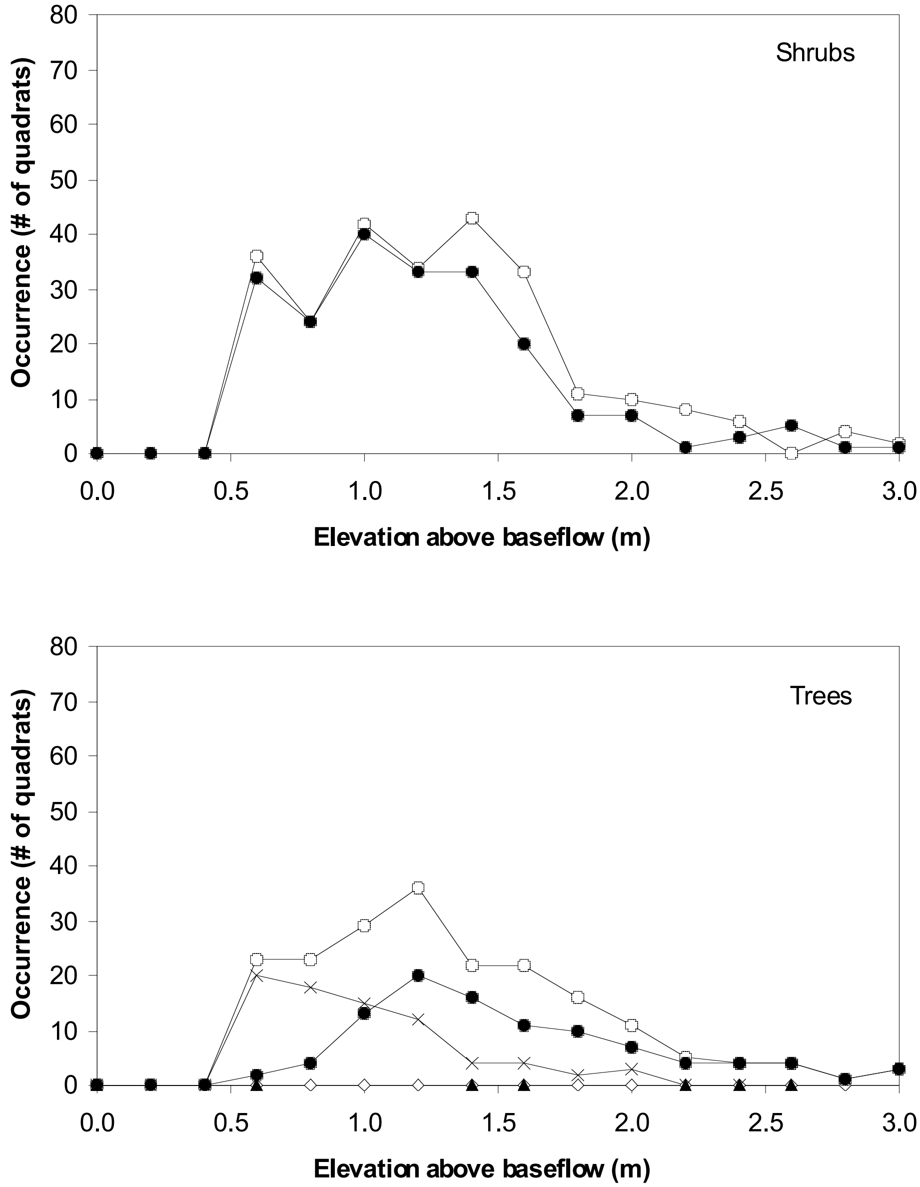
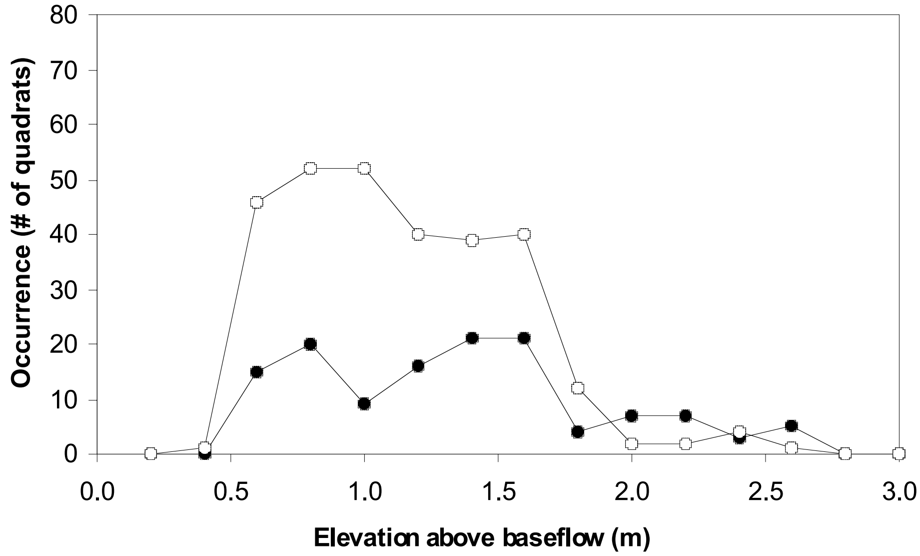


Figure 15. The distribution of shrubs and trees relative to seasonal baseflow conditions in the Union Gap study reach (Shrubs: open circles = all shrub species, closed circles = native willows; Trees: open circles = all tree species, closed circles = mature cottonwoods, closed triangles = other deciduous species, open diamonds = conifer species, x = 2000 cottonwood seedlings).



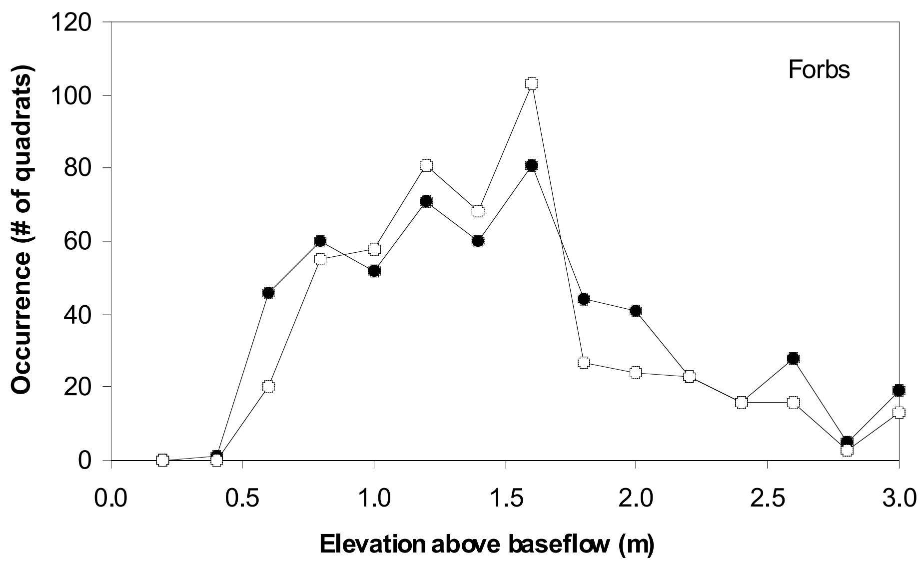


Figure 16. The distribution of grasses and forbs relative to seasonal baseflow conditions in the Union Gap study reach (open symbols = perennial species, close symbols = annual species).

4.3 Upper Wapato Reach

4.3.1 Riparian Floodplain Forests (1942 to 2000)

Changes in the riparian forest communities and overall loss of floodplain habitat in the upper Wapato reach were documented through a comparative analysis of aerial photos taken in 1947 and 2001 (Figures 17 and 18). The 24,854 ha of Holocene floodplain habitat in this reach (Eitemiller et al. 2000) had declined to only 1,415 ha by 1947 and 1,168 ha by 2001. Furthermore, the active riparian forest overstory declined from 610 ha in 1947 to 498 ha in 2001. This decline in riparian forest cover is primarily related to the expansion of agricultural activities and active dewatering of this floodplain by irrigation withdrawals. Several additional changes in critical floodplain features in the upper Wapato can also be observed in Figures 17 and 18.

4.3.2 Seasonal Discharge Patterns (1911 to 2000)

Natural seasonal flow patterns, prior to the construction and operation of headwater dams on the Yakima and Naches Rivers, are shown in the Figure 19 (upper graph). In the early 1900's, natural peakflows associated with snowmelt were followed by progressive declines in discharge over the summer months with periodic rain-driven winter stormflows (Figure 19). The low flows observed during the summer months seem lower than expected for such a large river basin, and may thus be indicative of significant irrigation withdrawals from this reach as early 1908. More recent seasonal flows have been further modified by more extensive irrigation withdrawals during the early summer months (Figures 19 and 20). Thus current flow management practices not only lower springtime flows, but also maintain exceptionally low levels of discharge and river stage throughout the summer (lower graph in Figure 19 and Figure 20). During drought periods of the late 1980's, many channels in the Wapato reach were commonly dry during significant portions of the growing season (Braatne, pers. obs.). These highly regulated flows lead to a severely altered river stage (Figure 20), limiting the recruitment of native willows and cottonwoods to such low elevations that all germinating seedlings are readily scoured as discharge levels rise during the winter months. The lack of spring peakflows to recharge shallow groundwater acquifers combined with low summertime flows further induce significant levels of water stress in mature cottonwoods (Braatne, Hinckley and Stetter 1992, Braatne et al. 1996). This regulated flow regime thus has very serious consequences for the long-term health and vitality of riparian cottonwood forests along the Wapato reach.

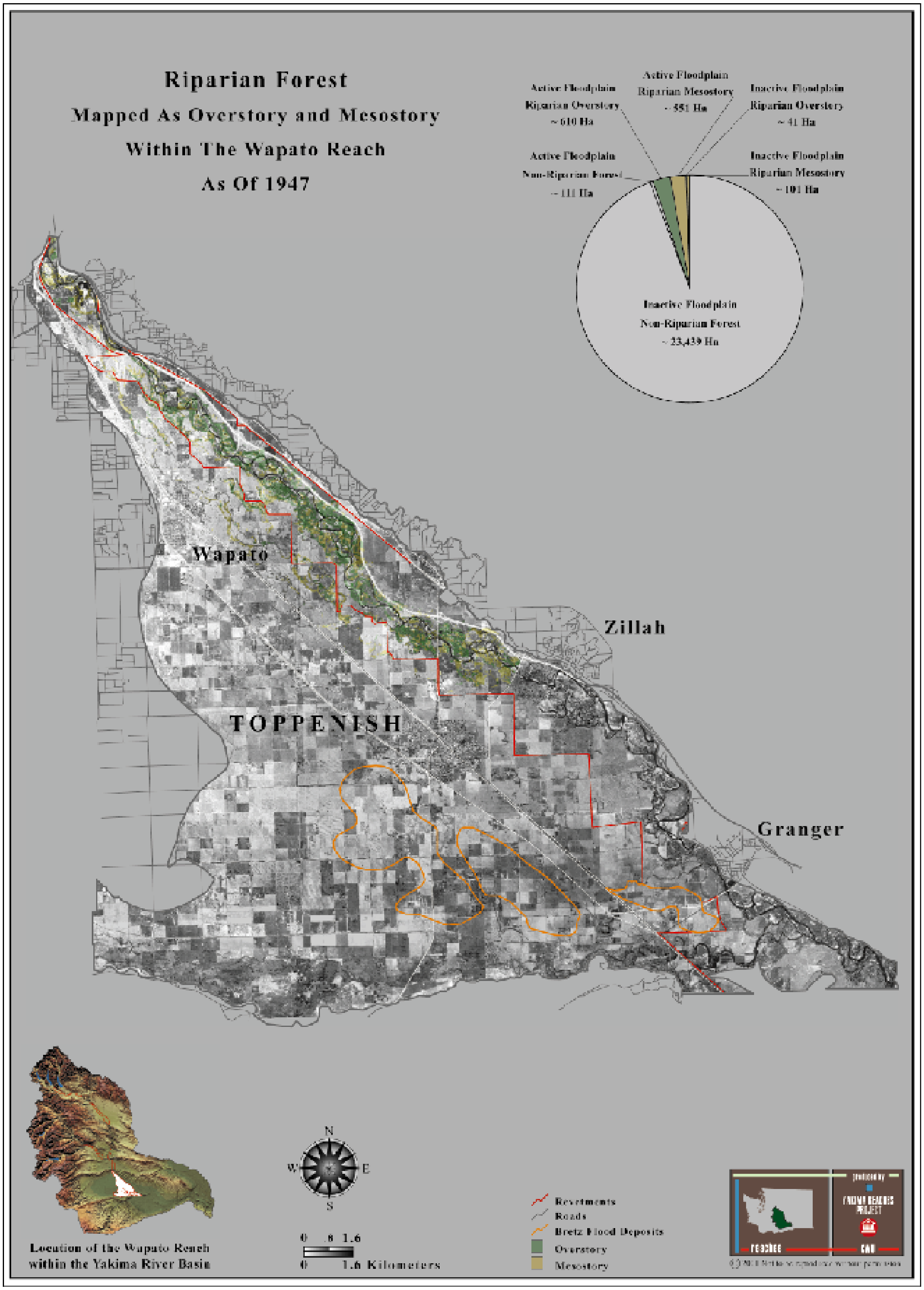


Figure 17. The areal extent of riparian forest on the upper Wapato reach of the Yakima River, WA (1947).

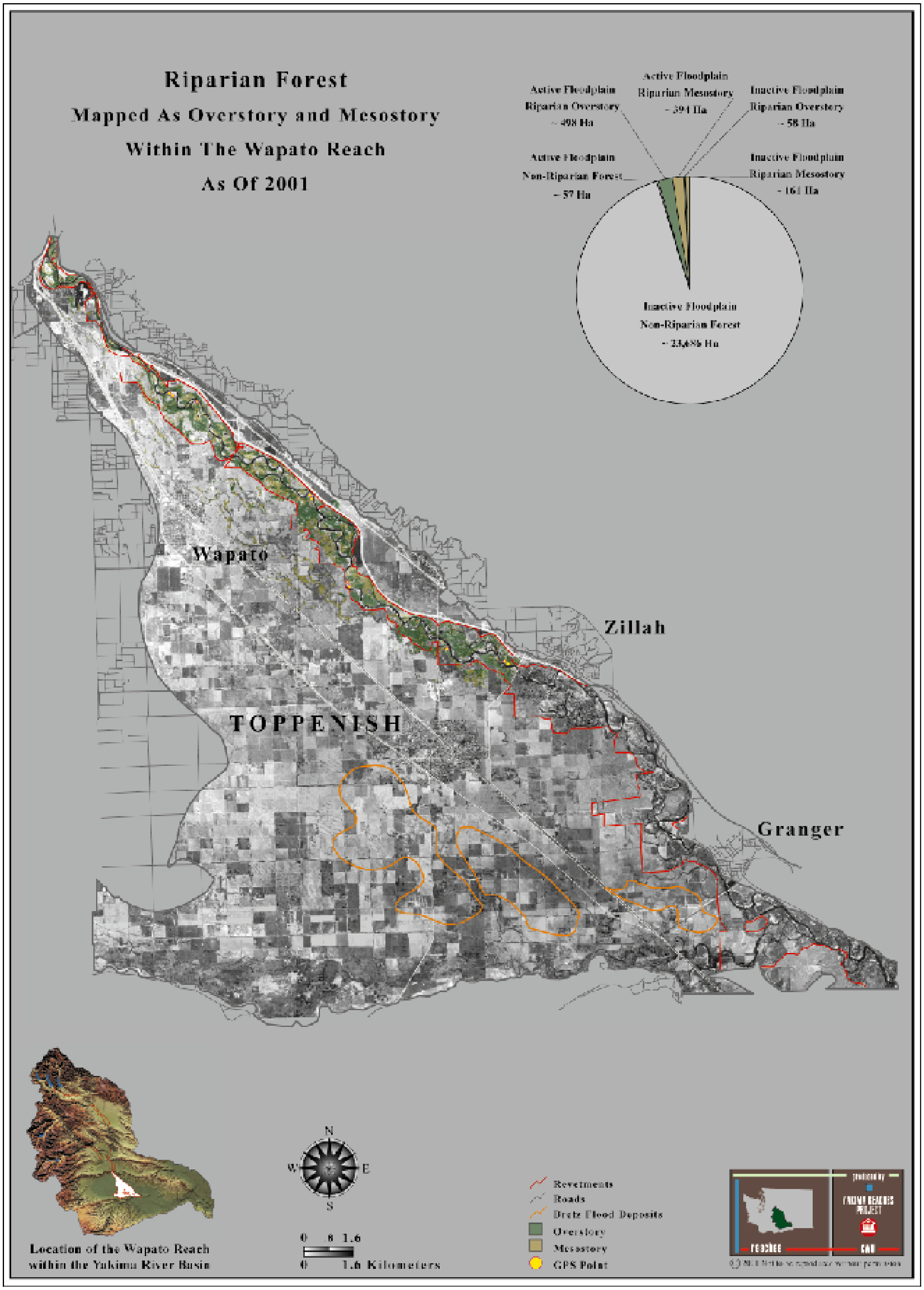
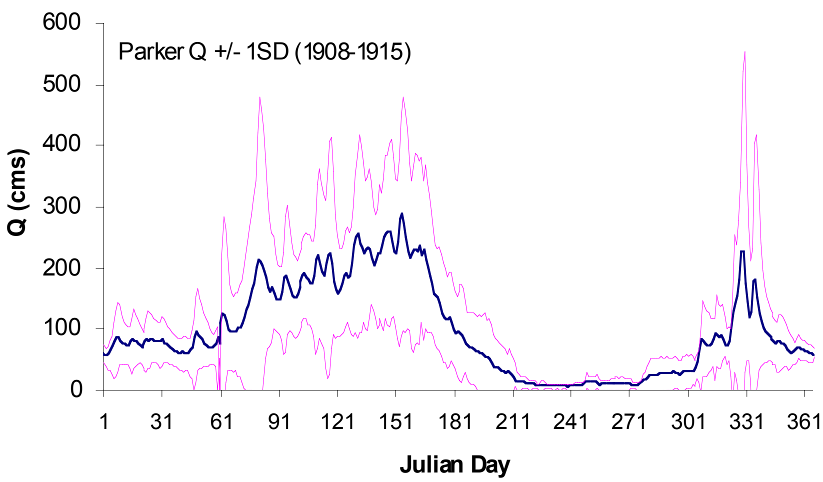


Figure 18. The areal extent of riparian forest on the upper Wapato reach of the Yakima River, WA (2001).



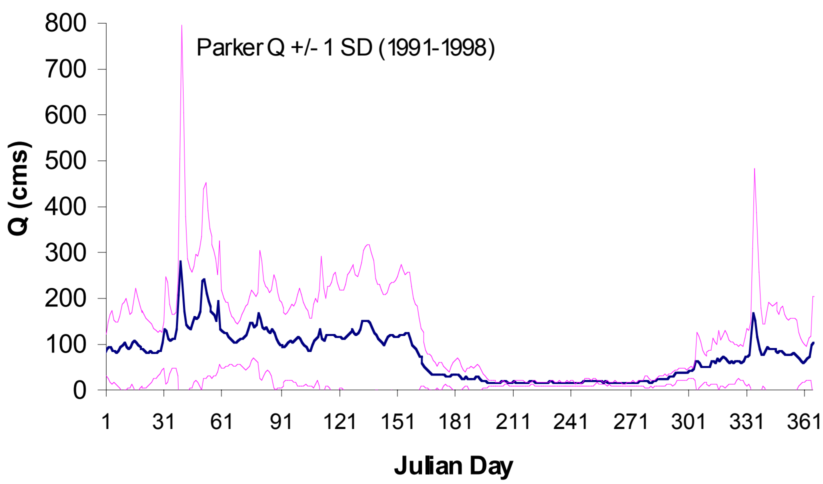


Figure 19. Historic patterns of seasonal discharge for the upper Wapato Reach of the Yakima River, WA. Values are daily means +/- 1 SD (Parker gaging station)

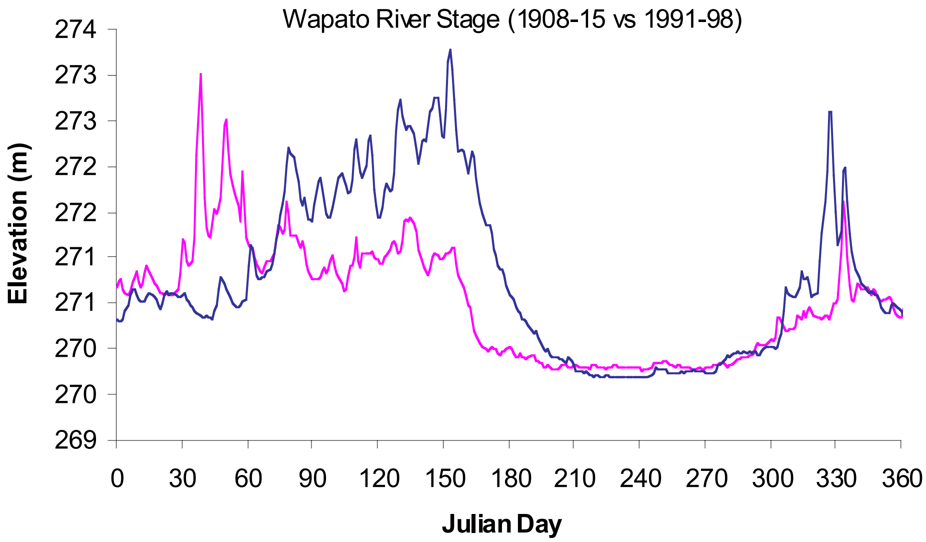
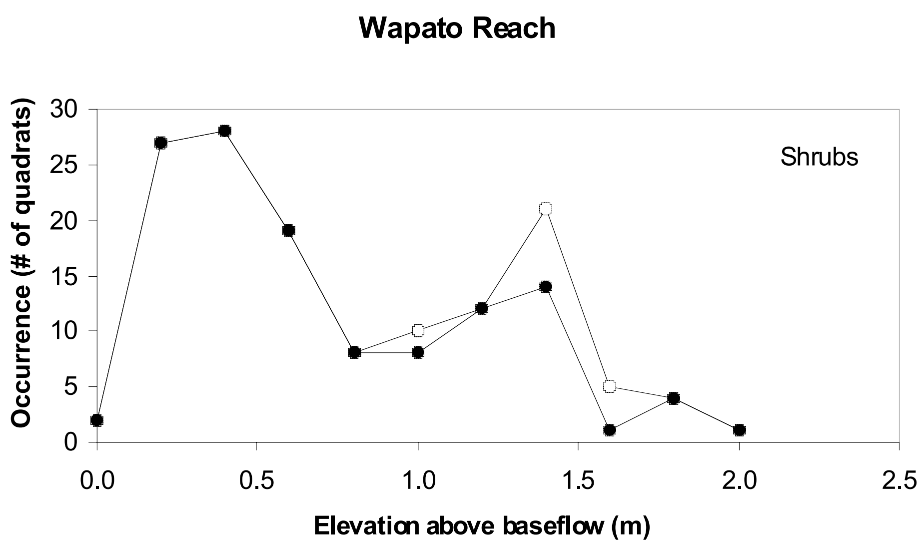


Figure 20. Seasonal patterns of river stage for the upper Wapato Reach of the Yakima River, WA. Blue line = 1908 to 1915, Pink line = 1991-1998.

4.3.3 Composition and Structure of Riparian Plant Communities

Along the upper Wapato reach, remnant and fragmented stands of riparian cottonwood were composed of a mosaic of healthy and low vigor trees (Figure 21). European willow (*Salix alba* and *Salix x. rubens*) and Silver Maple (*Acer saccharinum*) were variable components in these riparian forests along with other exotic woody and herbaceous species. With the exception of 2000 seedlings, younger ages classes of native willow and cottonwood were largely absent from this reach. In response to low and relatively stable summer baseflows (Figure 20), riparian vegetation was commonly found growing very close to the water's edge (Figures 22 & 23). Mature willows and cottonwoods were located at elevations over one meter above baseflow conditions, yet young seedlings were commonly found at less than one-half meter above seasonal baseflows (see Figures 20 & 22). Germination at such low elevations was the primary cause for their widespread mortality as flows later increase during the late fall and winter. Grasses and forbs were found at comparable elevations (Figure 24), with exotic and invasive species comprising a large component within these riparian communities. Annual grasses and forbs were only slightly more abundant than perennial species. Reed canarygrass was widespread, yet less dominant relative to other study reaches. The exceptionally low summer baseflows appear to be an important factor leading to the increased occurrence of exotic species, though the proximity of this corridor to fruit orchards, vineyards, agricultural fields and major highways were also important variables influencing the abundance of exotic plants in this study reach.

Figure 21. Representative photo of riparian cottonwood forests and associated riparian vegetation patterns in the upper Wapato Reach. Note the absence of younger cohorts of willow and cottonwood and the abundance of exotic weeds on this scroll bar.



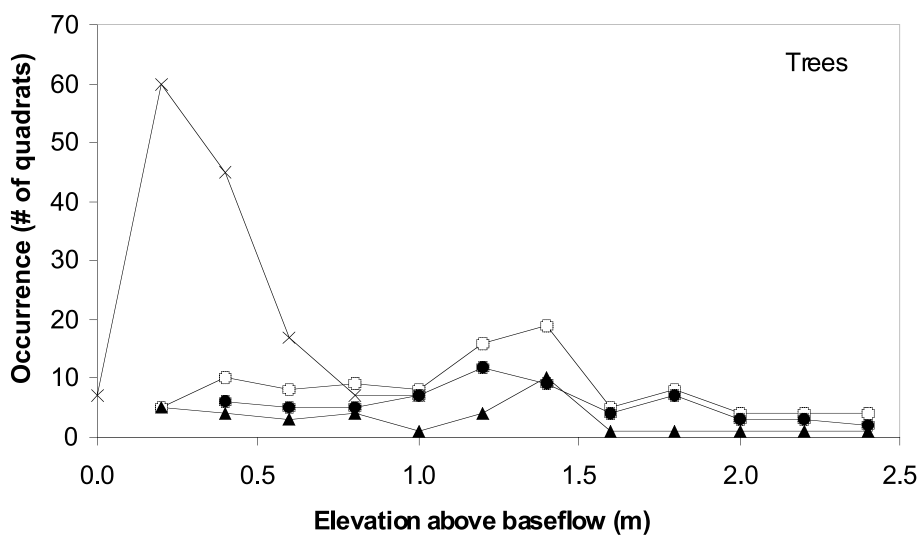


Figure 22. The distribution of shrubs and trees relative to seasonal baseflow conditions in the upper Wapato study reach (Shrubs: open circles = all shrub species, closed circles = native willows; Trees: open circles = all trees, closed circles = mature cottonwoods, closed triangles = other deciduous species, x = 2000 cottonwood seedlings).

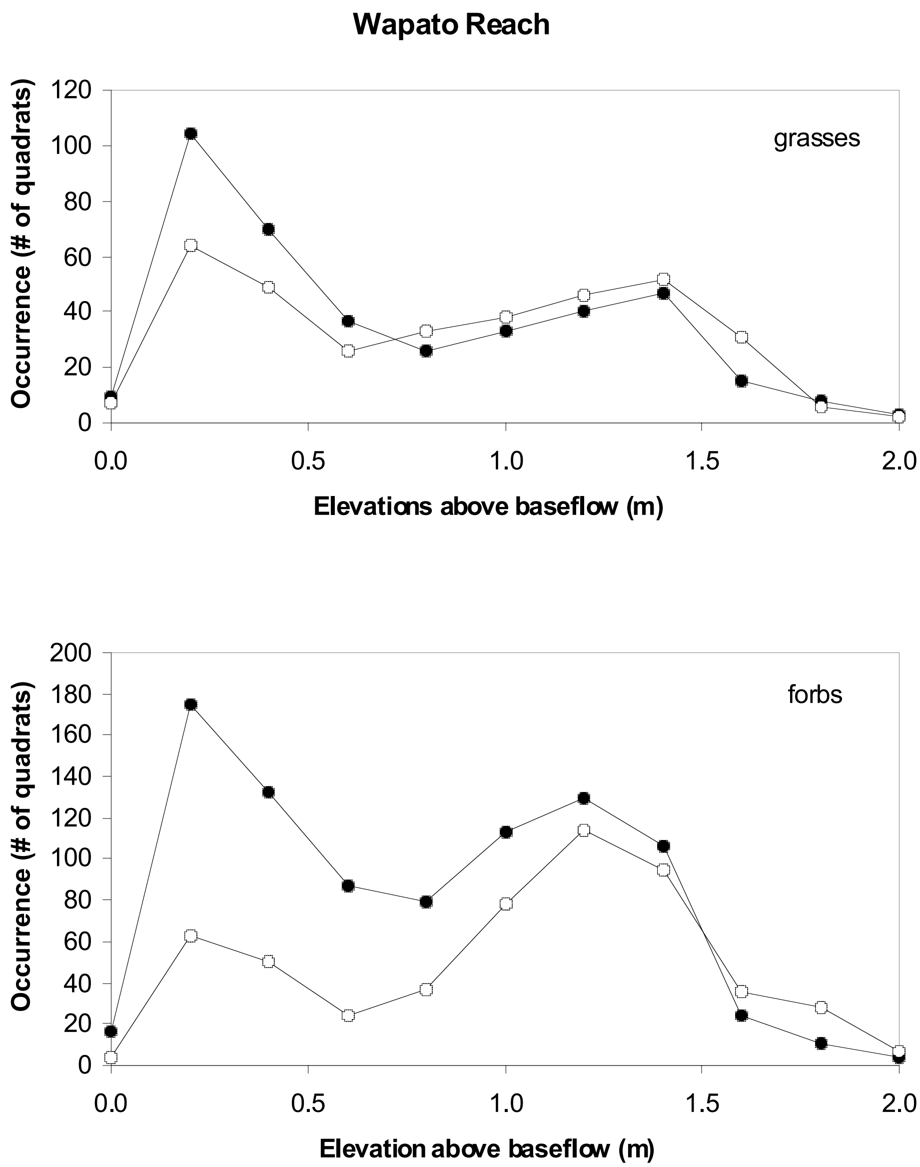


Figure 23. The distribution of grasses and forbs relative to seasonal baseflow conditions in the upper Wapato study reach (open symbols = perennial species, close symbols = annual species).

4.4 Age structure of riparian cottonwood forests across study reaches

In all study reaches, mature (and occasional juvenile) trees were cored to determine the age structure of local cottonwood populations. Since cottonwood establishment is generally correlated to peak flood events, this limited dataset was graphed in relation to peak annual discharge from 1900 to 2000 (Figure 24). Additional sampling is needed to complete this analysis, however, the following patterns should be reviewed; a) the lack of correlation between peak flows and historical patterns of cottonwood recruitment, b) the relative abundance of 40 to 50 year old cohorts, c) the lack of cottonwood recruitment over the last 20 years, and d) absence of willow and cottonwood recruitment following the major flood events of 1996. (In all our sample transects, we observed only one small cohort of 1996 seedlings in the Union Gap reach.) These preliminary results suggest a highly skewed age class structure, and the absence of cottonwood recruitment under current regulated flows warrants concern among local resource managers and floodplain ecologists. Although additional sampling will be needed to specifically elucidate recruitment patterns in relation distinct flow events over the last century, these results demonstrate the importance developing options for managing flows to promote the recovery of riparian cottonwood forests along the Yakima River.

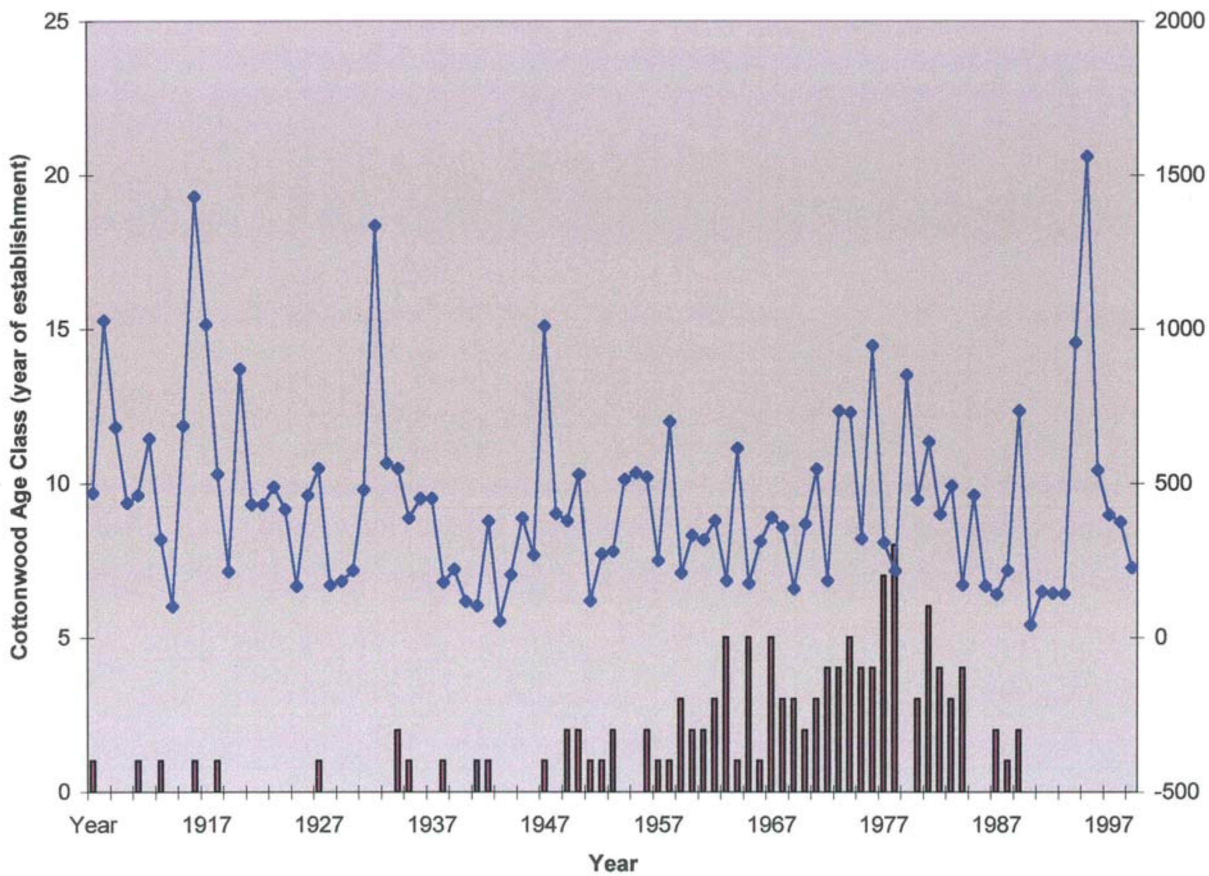
5.0 DISCUSSION

The results of our study clearly show how the natural flow regimes of selected alluvial reaches have been significantly altered by the construction and operation of headwater dams, municipal and irrigation withdrawals and agriculture activities in Yakima Basin. As a result, the general health and extent of riparian cottonwood forests in selected reaches have been severely compromised by the cumulative impact of these activities.

Although confined by man-made structures (highways, levees, railway tracks, etc.), remnants of active alluvial floodplains persist in all study reaches. Based on a comparison of aerial photos from 1927, 1942 and 1998, the extent of mature cottonwood stands have moderately increased in some reaches while declining in others. The limited expansion of cottonwood forests in some reaches appears to be largely the result of the maturation of younger trees found on abandoned gravel mining and agricultural sites. Declines in the Wapato reach appear related to the expansion of agricultural activities and excessive irrigation withdrawals. Other reaches in the Basin, such as the Naches, Kittitas and lower Wapato, should be assessed to confirm these general trends in riparian forest cover. However, these findings actually mask the subtle and persistent problems associated with the lack of seedling recruitment identified in field studies of these alluvial floodplains.

The Cle Elum, Union Gap and upper Wapato reaches were specifically selected for study on the basis of their distinctive patterns of flow regulation (locally referred to as “flip-flop”). High flow regimes along the Cle Elum reach are maintained near bankfull elevations throughout the summer months. In early September, these regulated flows are diminished to provide conditions for spawning by fall chinook. A different regime occurs in the Union Gap reach where high flow regimes are maintained throughout the irrigation season (May – September). In contrast, flow regimes on the Wapato reach are very low throughout the summer and early fall. These regulated flow regimes contrast sharply with the historic patterns of seasonal flow that occurred prior to the construction of headwater dams and diversions to irrigate crops and pastures within the Yakima Basin.

Figure 24. Age Structure of Riparian Cottonwood Populations in relation to Annual Peakflows on Selected Alluvial Reaches of the Yakima River



Prior to dam construction and irrigation withdrawals, seasonal flows along the Yakima River were similar to the generalized flow regime shown in Figure 1 (See also historic flow conditions in Figures 6 and 16). Collectively, these figures reveal important components of a natural hydrograph to the recruitment of cottonwood seedlings: a) high spring flows to drive geomorphic processes that create suitable moist and barren nursery sites, b) falling flows to expose these nursery sites, c) gradual flow declines after germination to permit the roots of seedlings to maintain contact with the receding moisture zone, d) sufficient flows through the hot and dry period of mid- to late summer to promote seedling survival, and e) sufficient flows in later summer and autumn to provide seedlings with a favorable water balance to withstand the winter months.

Detailed field transects along the Cle Elum, Union Gap and Wapato reaches show that the current patterns of flow regulation in the Yakima Basin have had a significant negative effect on the recruitment of cottonwood seedlings. These findings closely correspond to our understanding of the life history and ecology of cottonwoods (Braatne et al. 1996) relative to the observed flow regimes of these study reaches. High flows during the periods of seed dispersal (May – July) along the Cle Elum and Union Gap reaches completely inundate potential nursery sites. During the same time period, low flows along the Wapato reach result in the germination of seedlings at low elevations near the base of riverbanks. After the irrigation season is over, higher flows along the Wapato reach readily scour and remove these young seedlings. As a result, there was no significant level of seedling recruitment observed in any of these study reaches. The extent of younger stands (< 25-35 yrs old) was also extremely limited in all three reaches. Riparian vegetation is thus dominated by older age class stands that were established prior to the initiation of the "flip-flop" flow regimes in the early 1980's. If current flow patterns persist, native willows and cottonwood forests will be largely composed of decadent and fragmented populations with progressively lower levels of stand vigor and genetic diversity.

Previous studies conducted by the Dr. Braatne and researchers with the UW/WSU Black Cottonwood Research Program have identified another issue critical to cottonwood establishment. Surveys of riparian cottonwood forests along the Yakima River revealed that the sex ratios of local populations shift from a balanced ratio of 1 male:1 female near the confluence of the Yakima and Teanaway Rivers (Cle Elum Reach) to a highly skewed ratio of 7 males:1 female along the upper Wapato Reach near Zillah (J.H. Braatne, unpub. data). This strong shift in sex ratios and lack of reproductively mature females in local populations will significantly lower the reproductive fitness of cottonwood populations in this lower reach. These observations, combined with the absence of cottonwood seedlings in recent field studies, clearly show that regulated flows have altered the reproductive potential of cottonwoods in the mid to lower sections of the Wapato reach. This loss of reproductive potential significantly lowers the capacity for these populations to respond favorably to normative flow conditions and increases the risk for extinction of locally adapted genotypes.

Our studies further reveal that regulated flows have promoted the invasion of alluvial floodplain habitats by exotic weeds and woody species such as St. John's wort, several species of knapweed, pepperweed and thistle, silver and Norway maple, green ash, American and Chinese elm and European willow. These altered flow regimes also favor the vegetative propagation of reed canarygrass, a highly invasive perennial grass. All of these invasive and exotic species have a life history strategy that allows them to more readily adapt to the current (flip-flop) flow regimes of the Yakima Basin. As a result, exotic species have a distinct competitive advantage over native willows and black cottonwood. These exotic species are also more abundant at rather low elevations (less than one meter above seasonal baseflows), suggesting that prescribed flow regimes could be a very cost- efficient mechanism for limiting the expansion of exotic weeds on local floodplain habitats (Additional funding to support further analyses of field data would yield critical insights into the specific nature of these distribution patterns and competitive hierarchies with native species.) It also appears that basic fluvial geomorphic processes, such as cut and fill alluviation, have been significantly altered by these regulated flow patterns. Although additional studies are needed, our findings still suggest that there is a significant risk to the long-term viability of riparian cottonwood forests along the Yakima River.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Although the results of our study show that there is a significant risk to the viability of cottonwood forests along the Yakima River, there has been extensive documentation of the recovery of cottonwoods in response to modified flow regimes along many regulated rivers in western North America (Mahoney and Rood 1998). Spring flow releases below dams to mimic spring flood events on regulated rivers have been tested and proven effective to promote native willow and cottonwood recruitment on the Old Man River in Alberta and the Truckee River in Nevada (Rood and Gourley 1996, Rood and Kalischuk 1998). In these cases, higher water volumes available in "high snowpack years" were released from reservoirs in a manner that was compatible with the timing of seed dispersal and germination by cottonwood seedlings. These flow management practices are now widely accepted by resource managers in Alberta (Mahoney 1997), Idaho (Mike Merigiliano, pers. comm.) and Nevada (Rood and Gourley 1996) and are commonly integrated with regional programs to restore native fish populations. In our work on the Kootenai River, as part of this innovative project (see Jamieson and Braatne 2001), we found that spring flow releases to stimulate spawning in white sturgeon, resulted in the recruitment of cottonwood at sites below Libby Dam. These studies combined with our research results demonstrate the potential efficacy of similar flow management strategies for promoting the recovery of riparian cottonwood forests in the Yakima River Basin.

On the basis of our research and management experience in the Yakima and several other river basins, we are now in a unique position to develop options for modifying flow regimes to promote the recovery of native cottonwood and related riparian habitat types. These modified flow regimes (during periods of higher water availability, i.e.high snowpack years) would mimic natural spring freshet conditions, thus enhancing native willow and cottonwood establishment, assisting in the management of exotic plants and providing long-term benefits for riparian-dependent wildlife, salmon and other native fisheries. However, additional studies linking fluvial geomorphic processes with the recruitment of cottonwood seedlings are needed before specific flow prescriptions can be proposed in the Yakima Basin; due to the complex flow management regimes and variable levels of channel confinement and sediment supply among alluvial reaches. Our recent proposal to the Columbia Plateau Province for further studies within the Yakima River Basin is specifically designed to address these research needs and identify promising flow management options for aquatic and riparian ecosystems (Braatne, Lorang and Jamieson 2001).

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APPENDIX 1: Common Plants of the Riparian Corridors of the Cle Elum, Union Gap and Upper Wapato Alluvial Reaches of the Yakima River Basin.

Code	Genus/species	Family	Common Name	Stratum	Life Form	Native/ Exotic	Wet I
ABGR	Abies grandis	Pinaceae	Grand fir	Tree	WT	Native	NL
ACCI	Acer circinatum	Aceraceae	Vine maple	Shrub	WS	Native	FAC
ACSA	Acer saccharinum	Aceraceae	Silver maple	Tree	WT	Exotic	NI
ACMI	Achillea millifolium	Asteraceae	Yarrow	Herb	PH	Native	FACL
AGRE	Agropyron repens	Poaceae	Quackgrass	Herb	PG	Exotic	FAC-
AGRU	Agrostis Alba	Poaceae	Redtop	Herb	PG	Exotic	FACV
AGSP	Agropyron spicatum	Poaceae	Blue-bunch wheatgrass	Herb	PG	Native	UPL
ALIN	Alnus incana	Betulaceae	Mountain alder	Shrub	WT	Native	FACV
ALOP	Alopecurus sp.	Poaceae	Foxtail	Herb			NL
ALRU	Alnus rubra	Betulaceae	Red alder	Tree	WT	Native	FAC
AMAL	Amelanchier alnifolia	Rosaceae	Western serviceberry	Shrub	WT	Native	FACL
AMAR	Ambrosia artemisiifolia	Asteraceae	Annual ragweed	Herb	AH	Exotic	FACL
AMPO	Amaranthus powellii	Amaranthaceae	Powell's amaranthus	Herb	AH	Exotic	NL
AMRE	Amaranthus retroflexus	Amaranthaceae	Rough pigweed	Herb	AH	Exotic	FACL
ANSP	Anthemis cotula	Asteraceae	Chamomile	Herb	AH	Exotic	FACL
APAN	Apocynum androsaemifolium	Apocynaceae	Spreading dogbane	Herb	PH	Native	NI
APCA	Apocynum cannabinum	Apocynaceae	Hemp dogbane	Herb	PH	Native	FAC
ARLU	Artemisia ludoviciana	Asteraceae	Prairie sage	Herb	PH	Native	FACL
ARTR	Artemisia tridentata	Asteraceae	Big sage	Shrub	WS	Native	NL
ASAG	Astragalus agrestis	Fabaceae	Purple milk-vetch	Herb	PH	Native	FACV
ASCA	Aster campestris	Asteraceae	Western meadow aster	Herb	PH	Native	NL
ASCO	Aster conspicuus	Asteraceae	Showy aster	Herb	PH	Native	NL
ASFO	Aster foliaceus	Asteraceae	Leafy aster	Herb	PH	Native	FACV
ASMO	Aster modestus	Asteraceae	Few-flowered aster	Herb	PH	Native	FAC
ASTER	Aster sp.	Asteraceae	Aster	Herb			NL
BEGL	Betula glandulosa	Betulaceae	Scrub birch	Tree	WT	Native	OBL
BEAQ	Berberis aquifolium	Berberidaceae	Tall Oregongrape	Shrub	WS	Native	NL
BICE	Bidens cernua	Asteraceae	Nodding beggars-tick	Herb	AH	Native	FACV
BRASS	Brassica sp.	Brassicaceae	Mustard	Herb			NL
BRCI	Bromus ciliatus	Poaceae	Fringed brome	Herb	PG	Native	FAC
BRIN	Bromus inermis	Poaceae	Smooth brome	Herb	PG	Exotic	FAC
BRTE	Bromus tectorum	Poaceae	Cheatgrass	Herb	AG	Exotic	NL
CACO	Carex concinnoides	Cyperaceae	Northwest sedge	Herb	PG	Native	NL
CADI	Carex disperma	Cyperaceae	Crawford's sedge	Herb	PG	Native	FAC
CAER	Cyperus erythrorhizos	Cyperaceae	Red-rooted cyperus	Herb	AG	Invasive	OBL
CAES	Cyperus esculentus	Cyperaceae	Yellow-nut grass	Herb	PG	Exotic	FACV
CAEU	Carex eleusinoides	Cyperaceae	Goose-grass sedge	Herb	PG	Exotic	FACV
CARO	Carex rostrata	Cyperaceae	Beaked sedge	Herb	PG	Native	OBL
CARU	Carex rupestris	Cyperaceae	Curly sedge	Herb	PG	Native	FACV
CASP	Carex sp.	Cyperaceae	Sedge	Herb			NL
CEDI	Centaurea diffusa	Asteraceae	Diffuse knapweed	Herb	AH	Exotic	NL
CERE	Centaurea repens	Asteraceae	Russian knapweed	Herb	PH	Exotic	NL
CEMA	Centaurea maculosa	Asteraceae	Spotted knapweed	Herb	PH	Exotic	NL

CESA	Ceonothus sanguineus	Rhamnaceae	Redstem ceonothus	Shrub	WS	Native	NL
CESP	Cerastium sp.	Caryophyllaceae	Chickweed	Herb			NL
CHAL	Chenopodium album	Chenopodiaceae	Lambsquarter	Herb	AH	Exotic	FAC
CHIN	Cichorium intybus	Asteraceae	Chicory	Herb	PH	Exotic	NL
CHVI	Chrysopsis villosa	Asteraceae	Hairy goldaster	Herb	PH	Native	NL
CIAR	Cirsium arvense	Asteraceae	Canada thistle	Herb	PH	Exotic	FAC-
CIED	Cirsium edule	Asteraceae	India thistle	Herb	PH	Native	FACV
CIVU	Cirsium vulgare	Asteraceae	Bull thistle	Herb	PH	Exotic	FACU
CLOC	Clematis occidentalis	Ranunculaceae	Purple Clematis	Herb	PH	Native	FACU
COAR	Convolvulus arvensis	Convolvulaceae	Field morning-glory	Herb	PH	Exotic	NL
COCA	Cornus canadensis	Cornaceae	Bunchberry	Herb	PH	Native	FAC
COCO	Corylus cornuta	Betulaceae	Hazelnut	Shrub	WS	Native	NI
CONU	Cornus nuttallii	Cornaceae	Pacific dogwood	Shrub	WS	Native	NI
COST	Cornus stolonifera	Cornaceae	Red-osier dogwood	Shrub	WS	Native	FACV
CRDO	Crataegus douglasii	Rosaceae	Black hawthorn	Tree	WT	Native	FAC
CYDO	Cynodon dactylon	Poaceae	Bermuda grass	Herb	PG	Exotic	FAC
CYOF	Cynoglossum officinale	Boraginaceae	Common hound's-tongue	Herb	PH	Exotic	NL
DAGL	Dactylis glomerata	Poaceae	Orchard-grass	Herb	PG	Exotic	FACU
DIFU	Dipsicus sylvestris	Dipsacaeae	Teasel	Herb	PH	Exotic	NI
DISA	Digitaria sanguinalis	Poaceae	Hairy crabgrass	Herb	AG	Exotic	FACU
ECCR	Echinochloa crusgalii	Poaceae	Large barnyard-grass	Herb	AG	Exotic	FACV
ELGL	Elymus glaucus	Poaceae	Blue wildrye	Herb	PG	Native	FACU
ELEO	Eleocharis sp.	Cyperaceae	Spike-rush	Herb	PG	Native	NI
ELPA	Eleocharis palustris	Cyperaceae	Common spike-rush	Herb	PG	Native	OBL
EPAN	Epilobium angustifolium	Onagraceae	Fireweed	Herb	PH	Native	FACU
EPCI	Epilobium ciliatum	Onagraceae	marsh willow-herb	Herb	PH	Native	FACV
EPMI	Epilobium minutum	Onagraceae	Small-flowered willow-herb	Herb	AH	Native	NL
EPPA	Epilobium paniculatum	Onagraceae	annual willow-herb	Herb	AH	Native	UPL
EPSP	Epilobium sp.	Onagraceae	Willow-herb	Herb			NL
EQAR	Equisetum arvense	Equisetaceae	Field horsetail	Herb	PH	Invasive	FAC
EQHY	Equisetum hyamale	Equisetaceae	Common scouring-rush	Herb	PH	Native	FACV
EQPR	Equisetum pratense	Equisetaceae	Shady horsetail	Herb	AH	Native	FACV
ERHY	Eragrostis hypnoides	Poaceae	Creeping eragrostis	Herb	AG	Exotic	OBL
EUGL	Euphorbia glyptosperma	Euphorbiaceae	Corrugate-seeded spurge	Herb	AH	Invasive	NL
FAVI	Fragaria virginiana	Rosaceae	Blueleaf strawberry	Herb	PH	Native	UPL
FEID	Festuca idahoensis	Poaceae	Idaho fescue	Herb	PG	Native	FACU
FESP	Festuca spp	Poaceae	Fescue	Herb			NL
GADI	Gayophytum diffusum	Onagraceae	Spreading gayophytum	Herb	AH	Native	NL
GAAP	Galium aparine	Rubiaceae	Cleavers	Herb	AH	Native	FACU
GATR	Galium triflorum	Rubiaceae	Sweet-scented bedstraw	Herb	PH	Native	FACU
GEBI	Geranium bicknellii	Geraniaceae	Bicknell's geranium	Herb	AH	Invasive	NL
GERO	Geranium robertianum	Geraniaceae	Robert's geranium	Herb	AH	Invasive	NL
GIAG	Gilia aggregata	Polemoniaceae	Scarlet gilia	Herb	PH	Native	NL
GNCH	Gnaphalium chilensis	Asteraceae	Cotton-batting plant	Herb	AH	Native	FAC
GEMA	Geum macrophyllum	Rosaceae	Bigleaf avens	Herb	PH	Native	FAC+
HASU	Haplopappus suffruticosus	Asteraceae	Shrubby goldenweed	Shrub	WS	Native	NL
HELA	Heracleum lanatum	Apiaceae	Cow parsnip	Herb	PH	Native	FAC+
HEAU	Helenium autumnale	Asteraceae	Sneezeweed	Herb	PH	Native	FACV
HOJU	Hordeum jubatum	Poaceae	Foxtail barley	Herb	PG	Invasive	FAC-
HYPE	Hypericum perforatum	Elatinaceae	Common St. John's-wort	Herb	PH	Exotic	NL

IRPE	Iris pseudacorus	Iridaceae	Yellow fleur-de-lis	Herb	PH	Exotic	OBL
IRSP	Iris sp.	Iridaceae	Iris	Herb			NL
JUBU	Juncus bufonius	Juncaceae	Toad rush	Herb	AG	Native	FACV
JUEF	Juncus effusus	Juncaceae	Common rush	Herb	PG	Invasive	FACV
JUME	Juncus mertensianus	Juncaceae	Merten's rush	Herb	PG	Native	OBL
JUNC	Juncus sp.	Juncaceae	Rush	Herb			NL
JUVI	Juniperus virginiana	Pinaceae	Juniper	Tree	WT	Invasive	NI
LAOCH	Lathyrus ochroleucus	Fabaceae	Creamflowered peavine	Herb	PH	Native	NL
LAOCC	Lappula occidentalis	Boraginaceae	Western stickseed	Herb	AH	Native	NL
LAPA	Luzula parviflora	Juncaceae	Smallflowered woodrush	Herb	PG	Native	FAC
LASE	Lactuca serriola	Asteraceae	Prickly lettuce	Herb	AH	Exotic	NI
LEDE	Lepidium densiflorum	Brassicaceae	Common pepperweed	Herb	AH	Exotic	FAC-
LELA	Lepidium latifolium	Brassicaceae	Perennial pepperweed	Herb	PH	Exotic	FAC
LESP	Lepiduim sp	Brassicaceae	pepperweed	Herb			NL
LEVU	Leucanthemum vulgare	Asteraceae	Ox-eye daisy	Herb	PH	Exotic	NL
LIDA	Linaria gentisifolia/dalmatica	Scrophulariaceae	Dalmation toadflax	Herb	PH	Exotic	NL
LIVU	Linaria vulgaris	Scrophulariaceae	Butter and eggs	Herb	PH	Exotic	NL
LOCO	Lotus corniculatus	Fabaceae	Birdsfoot-trefoil	Herb	PH	Exotic	FAC
LOCR	Lotus crassifolius	Fabaceae	Big deervetch	Herb	PH	Native	NL
LODE	Lotus denticulatus	Fabaceae	Meadow lotus	Herb	AH	Invasive	NL
LOHI	Lonicera hispidula	Caprifoliaceae	Hairy honeysuckle	Shrub	WS	Native	NI
LOIN	Lonicera involucrata	Caprifoliaceae	Black twin-berry	Shrub	WS	Native	NI
LOMI	Lotus micranthus	Fabaceae	Small-flowered deer-vetch	Herb	AH	Invasive	NL
LOUT	Lonicera utahensis	Caprifoliaceae	Utah honeysuckle	Shrub	WS	Native	NI
LUSE	Lupinus sericeus	Fabaceae	Silky lupine	Herb	PH	Native	NL
LYSA	Lythrum salicaria	Lythraceae	Purple loosestrife	Herb	PH	Exotic	OBL
MEAL	Melilotus alba	Fabaceae	White sweet-clover	Herb	AH	Exotic	FACL
MEAR	Mentha arvensense	Lamiaceae	field mint	Herb	PH	Native	FACV
MELU	Medicago lupulina	Fabaceae	Black medic	Herb	AH	Exotic	FAC
MEOF	Melilotus officinalis	Fabaceae	Yellow sweet-clover	Herb	AH	Exotic	FACL
MESA	Medicago sativa	Fabeaceae	Alfalfa	Herb	PH	Exotic	NI
MICR	Microseris sp.	Asteraceae	Microseris	Herb			NL
MIGR	Microsteris gracalis	Polemoniaceae	Pink microsteris	Herb	AH	Native	FACL
MOLI	Montia linearis	Portulacaceae	Narrowleaved montia	Herb	AH	Native	NL
MONA	Monarda Fistulosa	Lamiaceae	Wild begamint	Herb	PH	Native	FACL
MOSS	Moss	Bryophyte	Moss	Herb			NL
MYAL	Myosotis sylvatica v. alpestris	Boraginaceae	Wood forget-me-not	Herb	PH	Native	FAC
NECA	Nepeta cataria	Lamiaceae	Catnip	Herb	PH	Exotic	FAC
OSCH	Osmorhiza chilensis	Apiaceae	Mountain sweet-cicely	Herb	PH	Native	NL
PACA	Panicum capillare	Poaceae	Common witchgrass	Herb	AG	Invasive	FACL
PANC	Panicum sp.	Poaceae	Witchgrass	Herb			NL
PASP	Paspalum distichum	Poaceae	knotgrass	Herb	PG	Exotic	FACV
PERI	Penstemon richardsonii	Scrophulariaceae	Richardson's penstemon	Herb	PH	Native	NL
PHAR	Phalaris arundinacea	Poaceae	Reed canarygrass	Herb	PG	Invasive	FACV
PHHA	Phacelia hastata	Hydrophllaceae	Silverleaf phacelia	Herb	PH	Native	NL
PHLO	Physallis longifolia	Solanaceae	Ground cherry	Herb	AH	Invasive	NL
PHLOX	Phlox sp.	Polemoniaceae	Phlox	Herb			NL
PHPR	Phleum pratense	Poaceae	Timothy	Herb	PG	Exotic	FAC-
PHSE	Phacelia sericea	Hydrophyllaceae	Silky phacelia	Herb	PH	Native	NL

PICO	Pinus contorta	Pinaceae	Lodgepole pine	Tree	WT	Native	FAC
PIPO	Pinus ponderosa	Pinaceae	Ponderosa pine	Tree	WT	Native	FACU
PIEN	Picea engelmannii	Pinaceae	Engleman spruce	Tree	WT	Native	FAC
PLMA	Plantago major	Plantaginaceae	Common plantain	Herb	PH	Exotic	FAC
POAV	Polygonum aviculare	Polygonaceae	Smartweed	Herb	AH	Exotic	FACW
POCO	Poa compressa	Poaceae	Canada bluegrass	Herb	PG	Exotic	FACU
PODO	Polygonum douglasia	Polygonaceae	douglas smartweed	Herb	AH	Invasive	FAC
PODE	Populus deltoides	Pinaceae	Prairie cottonwood	Tree	WT	Invasive	FAC
POFR	Potentilla fruticosa	Rosaceae	Shrubby cinquefoil	Herb	PH	Native	FAC-
POPA	Poa palustris	Poaceae	Fowl bluegrass	Herb	PG	Exotic	FAC
POPE	Polygonum persicaria	Polygonaceae	Heartweed	Herb	AH	Exotic	FACW
POPR	Poa pratensis	Poaceae	Kentucky bluegrass	Herb	PG	Invasive	FAC
POSP	Poa sp.	Poaceae	Bluegrass	Herb			NL
POTR	Populus trichocarpa	Salicaceae	Black cottonwood	Tree	WT	Native	FAC
POTRS	Populus trchocarpa saplings	Salicaceae	Black cottonwood	Shrub	WS	Native	FAC
POTR5	Populus trichocarpa seedlings	Salicaceae	Black cottonwood	Shrub	WS	Native	FAC
PRVI	Prunus virginiana	Rosaceae	Common chokecherry	Shrub	WS	Native	FACU
PRVU	Prunella vulgaris	Fabaceae	Self-heal	Herb	PH	Exotic	FACU
PSME	Pseudotsuga menziesii	Pinaceae	Douglas fir	Tree	WT	Native	NL
PUNU	Puccinellia nuttalliana	Poaceae	Nuttall's alkaligrass	Herb	PG	Native	OBL
PUTR	Purshia tridentata	Rosaceae	Bitter-brush	Shrub	WS	Native	NL
RAAC	Ranunculus acris	Ranunculaceae	Meadow buttercup	Herb	PH	Exotic	FACW
RANU	Ranunculus sp.	Ranunculaceae	Buttercup	Herb			NL
RILA	Ribes lacustre	Grossulariaceae	Pricky currant	Shrub	WS	Native	FAC
ROAC	Rosa acicularis	Rosaceae	Prickly rose	Shrub	WS	Native	FACU
RONU	Rosa nutkana	Rosaceae	Nootka rose	Shrub	WS	Native	NI
ROPA	Rorippa islandica	Brassicaceae	Marsh yellowcress	Herb	PH	Invasive	NL
ROPS	Robinia pseudo-acacia	Fabaceae	Black locust	Tree	WT	Exotic	FACU
ROWO	Rosa woodsii	Rosaceae	Wood's rose	Shrub	WS	Native	FAC+
RUAC	Rumex acetosella	Polygonaceae	Sheep sorrel	Herb	PH	Exotic	FACU
RUCR	Rumex crispus	Polygonaceae	Curly dock	Herb	PH	Exotic	FAC+
RUPA	Rubus parviflorus	Rosaceae	Thimbleberry	Herb	PH	Native	NL
SAAL	Salix alba	Salicaceae	European white willow	Tree	WT	Exotic	NL
SABE	Salix bebbiana	Salicaceae	Bebb's willow	Shrub	WS	Native	FACW
SABR	Salix brachycarpa	Salicaceae	Short-fruited willow	Shrub	WS	Native	FACW
SAEX	Salix exigua	Salicaceae	Coyote willow	Shrub	WS	Native	OBL
SALA	Salix lasiandra	Salicaceae	Pacific willow	Shrub	WS	Native	FACW
SAMO	Salix monticola	Salicaceae	Mountain willow	Shrub	WS	Native	OBL
SALIX	Salix sp.	Salicaceae	Willow	Shrub			NL
SARU	Salix ex. Rubra	Salicaceae	European willow	Tree	WT	Exotic	FACW
SASI	Salix sitchensis	Salicaceae	Sitka willow	Shrub	WS	Native	FACW
SECE	Secale cereale	Poaceae	Cereal rye	Herb	AG	Exotic	NL
SCLA	Scirpus acutus	Cyperaceae	Great bulrush	Herb	PG	Native	OBL
SCMI	Scirpus microcarpus	Cyperaceae	Small-fruit bulrush	Herb	PG	Native	OBL
SELA	Setaria lutescens	Poaceae	Yellow foxtail	Herb	AG	Exotic	NL
SEVU	Senecio vulgaris	Asteraceae	common groundsel	Herb	AH	Invasive	FACU
SEVI	Setaria viridis	Poaceae	Green foxtail	Herb	AG	Exotic	NL
SIHY	Sitanion hysterix	Poaceae	Squirreltail	Herb	PH	Native	FACU
SIID	Sisymbrium altissimum	Brassicaceae	Tumblemustard	Herb	AH	Exotic	FACU

SILO	Sisymbrium loeselii	Brassicaceae	Loesel tumblemustard	Herb	AH	Exotic	FACU
SIME	Silene menziesii	Caryophyllaceae	Menzies' silene	Herb	PH	Native	FAC
SINO	Silene noctiflora	Caryophyllaceae	Nightflowering silene	Herb	AH	Exotic	NL
SMRA	Smilacina racemosa	Liliaceae	False spikenard	Herb	PH	Native	FAC
SMST	Smilacina stellata	Liliaceae	Solomons seal	Herb	PH	Native	FAC-
SOAR	Sonchus arvense	Asteraceae	Perennial sow thistle	Herb	PH	Exotic	FACU
SOCA	Solidago canadensis	Asteraceae	Canada goldenrod	Herb	PH	Native	FACU
SODU	Solanum dulcamara	Solanaceae	Climbing nightshade	Shrub	PH	Exotic	FAC+
SOLI	Solidago sp.	Asteraceae	Goldenrod	Herb			NL
SOOC	Solidago occidentalis	Asteraceae	Western goldenrod	Herb	PH	Native	FACW
SPBE	Spiraea betulifolia	Rosaceae	Shiny-leaf spiraea	Shrub	WS	Native	FACU
STAM	Streptopus amplexifolius	Liliaceae	Clasping-leaved twisted-stalk	Herb	PH	Native	FAC
STCO	Stipa comata	Poaceae	Needle & thread	Herb	PG	Native	NL
STCR	Stellaria crispa	Caryophyllaceae	Crisped starwort	Herb	PH	Native	FAC+
STOC	Stipa occidentalis	Poaceae	Western needlegrass	Herb	PG	Native	UPL
STRI	Stipa richardsonii	Poaceae	Richardson's needlegrass	Herb	PG	Native	NI
SYAL	Symphoricarpos albus	Caprifoliaceae	Common snowberry	Shrub	WS	Native	FACU
SYOF	Sisymbrium officinale	Brassicaceae	Tumblemustard	Herb	AH	Exotic	FACU
TAOF	Taraxacum officinale	Asteraceae	Common dandelion	Herb	AH	Exotic	FACU
TAVU	Tanacetum vulgare	Asteraceae	Common tansy	Herb	PH	Exotic	NI
THPL	Thuja plicata	Pinaceae	Western red cedar	Tree	WT	Native	FAC
TITR	Tiarella trifoliata	Saxifragaceae	Foamflower	Herb	PH	Native	FAC
TODI	Toxicodendron diversifolia	Anacardiaceae	Poison-ivy	Herb	PH	Invasive	FACU
TRDU	Tragopogon dubius	Asteraceae	Yellow salsify	Herb	PH	Exotic	NL
TRHY	Trifolium hybridum	Fabaceae	Alsike clover	Herb	PH	Exotic	FACU
TRPR	Trifolium pratense	Fabaceae	Red clover	Herb	PH	Exotic	FACU
TRRE	Trifolium repens	Fabaceae	White clover	Herb	PH	Exotic	FAC-
TYLA	Typha latifolia	Typhaceae	Common cattail	Herb	PG	Exotic	OBL
ULPU	Ulmus pumila	Ulmaceae	Chinese elm	Tree	WT	Exotic	NL
URDI	Urtica dioica	Urticaceae	Stinging nettle	Herb	PH	Exotic	FAC
VEAM	Veronica americana	Scrophulariaceae	American brooklime	Herb	PH	Native	OBL
VEBL	Verbascum blatteria	Scrophulariaceae	Moth mullin	Herb	PH	Exotic	UPL
VEHA	Verbena hastata	Verbenaceae	Blue verbena	Herb	PH	Native	FAC
VESO	Verbena sp.	Verbenaceae	Vervain				NL
VETH	Verbascum thapsus	Scrophulariaceae	Common mullein	Herb	PH	Exotic	NI
VEVI	Veratrum viride	Liliaceae	Green false hellebore	Herb	PH	Native	OBL
VIAM	Vicia americana	Fabaceae	American vetch	Herb	PH	Native	FAC
VISA	Vicia sativa	Fabaceae	Common vetch	Herb	AH	Exotic	UPL
VICSP	Vicia sp.	Fabaceae	Vetch	Herb			NL
VIOSP	Viola sp.	Violaceae	Violet	Herb			NL
XAST	Xanthium stumarium	Asteraceae	Common cocklebur	Herb	AH	Invasive	FAC