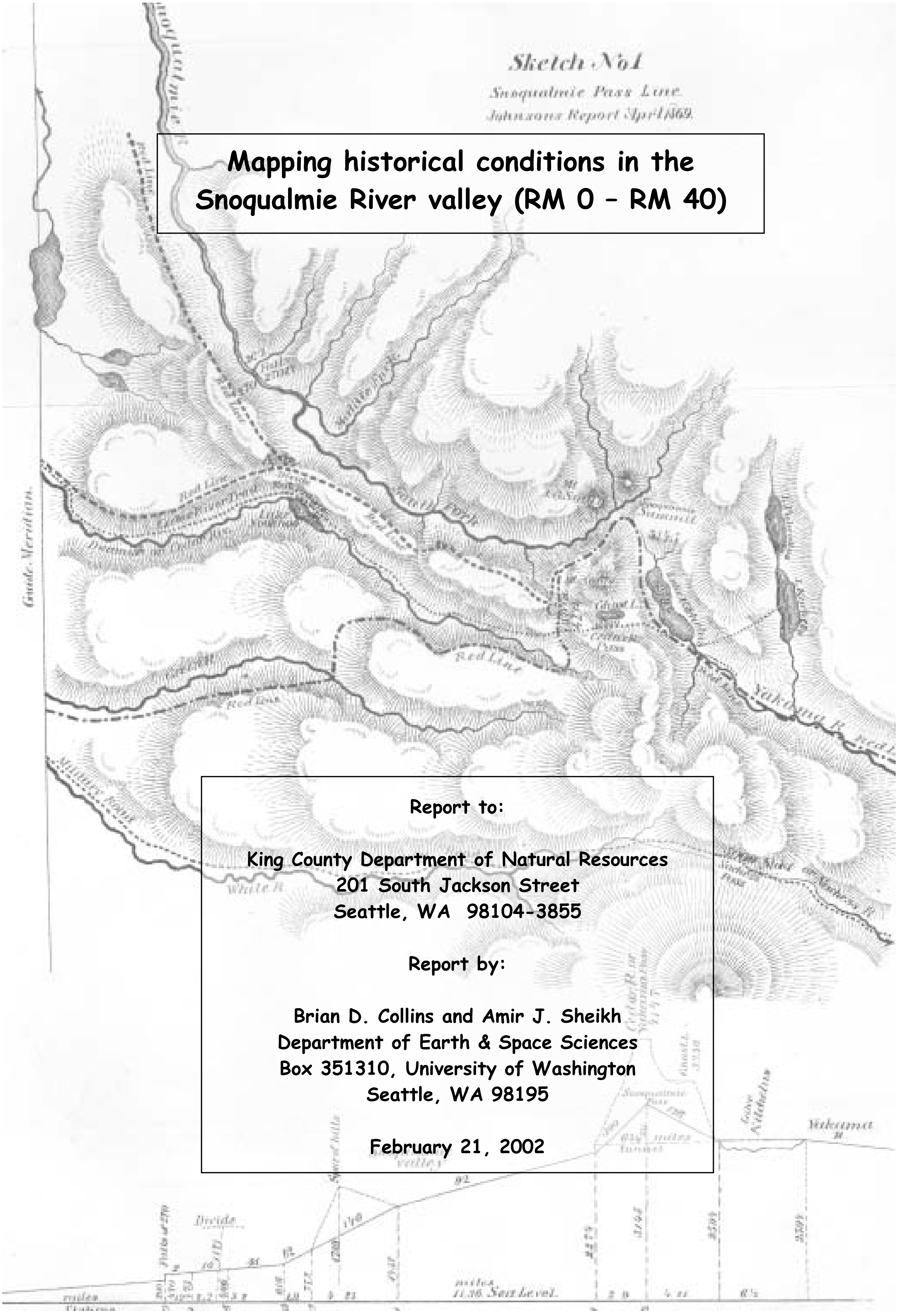
Mapping historical conditions in the Snoqualmie River valley (RM 0 – RM 40)



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SUMMARY

Archival materials, including maps and field notes from the General Land Office (GLO) cadastral survey from 1871-1873 and aerial photographs from 1936, were entered into a GIS (geographic information system). In combination with a DEM (digital elevation model) constructed from LIDAR (light detection and ranging) imagery, these materials were used to map the channel, wetland, forest, and oxbow ponds in the Snoqualmie River valley prior to Euro-American settlement, or about 1870. To evaluate subsequent change, conditions were also mapped from 1936 and 2000 aerial photos.

The river can be broken into several morphologically distinct reaches. Throughout most of the study area, Holocene (post-glacial) deposition by the Snoqualmie River has built up the river and its meander belt as much as 6 m above the valley bottom. Along the lower river (RM 2-12), the channel is relatively straight with little or no meander belt; nearly the entire valley is several meters lower in elevation than the riverbanks. Upstream, the meander belt is ~ 1 km wide, with valley-marginal low-lands narrower than in the downstream reach. Exceptions are where the Tolt River alluvial fan (RM 23-27), and the Raging River fan and a fan north of Tokul Creek (RM 35.5-39.5) narrow the meander belt.

Historically wetlands occupied low areas marginal to the meander belt. Seasonal flooding and tributaries replenished such “valley wetlands.” Historic records indicate that vegetation in a large wetland complex between about RM 4 and RM 11 was primarily shrubs and small trees with scattered small spruce trees. Ponds and wetlands also occupied many oxbows created by historical channel avulsions. The pre-Euro-American-settlement forest, reconstructed from GLO field notes, was dominated by hardwoods, including red alder, willow, vine maple, bigleaf maple, black cottonwood, and crabapple. Western redcedar and Sitka spruce, while less common, were the largest trees. Combining LIDAR and georeferenced GLO field data in a GIS shows that tree species grew in distinct elevation ranges relative to the riverbank, with spruce, willow, and alder being most tolerant of flooded conditions, growing 1-4 m lower than the riverbank. Forest composition varied with distance from the river, with alder and willow more dominant in immediate streamside areas.

Since ~1870, only a few additional oxbows have been created, because the river migration rate is generally low; most oxbows that now exist were created prior to the earliest mapping in ~1870. Valley wetlands, on the other hand, are substantially diminished in area, in 2000 being less than one-fifth (19%) the pre-settlement wetland area. Forest cover in 2000 is about one-sixth (16%) its mapped pre-settlement extent.

The historical data can be applied to various restoration opportunities, including: (1) hydraulically reconnecting the river to oxbow ponds and wetlands where that connection has been lost; (2) planting along the river and oxbow ponds and wetlands; (3) restoring ditched floodplain tributary creeks; and (4) restoring valley wetlands.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Scope

This report describes historical channels, wetlands, and riparian forests of the Snoqualmie River valley downstream of Snoqualmie Falls. The landscape descriptions in this report were developed to further a comprehensive description of salmonid physical habitat conditions in the river and valley floor prior to Euro-American settlement. The information was developed to help King County identify and prioritize protection and restoration actions.

Specific work products, and their potential applications, include:

(1) Geographic Information System (GIS) mapping of channels, water bodies, and wetlands in ~1870, 1936, and 2000. This mapping characterizes the historical riverine landscape morphology and processes, providing a broad context for habitat restoration planning and a foundation for more site-specific planning.

(2) Characterization of the pre-settlement forest, including the sizes, distributions, and factors influencing the locations of trees. This information provides a tool for forest restoration.

(3) Background data for evaluating the feasibility of restoring floodplain features. Detailed topography from LIDAR (Light Detection and Ranging) imagery, and historic map information on the ages and origins of features to help direct efforts to maintain, recreate, or create a connection with the river.

Methods

Collins et al. (in press) describe the methods used to characterize historical conditions. Briefly, in the Snoqualmie River valley, the pre-Euro-American settlement mapping (hereafter referred to as "~1870 conditions") relies primarily on information in 1871-1873 General Land Office (GLO) cadastral survey maps and field notes. The "~1870 conditions" map does not show the local land clearings from the Euro-American settlement that had occurred by that time. Clearings shown on the GLO map are infrequent and small by the early 1870s; the intent of the mapping is to focus on conditions immediately prior to widespread settlement and commercial forest clearing.

The GLO maps were geo-referenced and brought into a GIS by mapping corners and quarter corners to current Washington Department of Natural Resources (WDNR) data. Because the GLO maps are based on field data along section lines or along navigable rivers only, we also drew on detailed topography from a DEM made from LIDAR and on 1:9,600-scale 1936 and 1:10,000-scale 1938 georeferenced aerial photos. Bearing tree records in the GLO field notes (see Collins and Montgomery, in press, for detail) were also georeferenced to current WDNR data. We mapped the 1936 layer from aerial photos, and the 2000 layer from ortho-rectified 1:12,000 scale WDNR color aerial photos. There was no field checking.

Assumptions in Mapping ~1870 Conditions

It is important to understand that mapping in the ~1870 GIS layer reflects important assumptions, simplifications and extrapolations:

(1) *Forest cover.* The continuous extent of forest cover is assumed based on the continuous forest cover described in GLO notes along section lines. However, this simplification neglects the presence of any natural (non-wetland) meadow clearings in the valley forest, either within section interiors or along section lines but not noted in field notes.

(2) *Oxbow ponds and wetlands.* The ~1870 mapping includes several oxbow ponds and wetlands that were not shown on the GLO maps. This is presumed to be because the GLO survey lines did not cross the features, and thus were missed in the field. We mapped these features that were not included on the GLO maps, based on their presence on later mapping (e.g. 1921 USGS 1:125,000-scale topographic map "Sultan," 1936 or 1938 aerial photographs) and the absence of evidence for river migration or avulsion which could have created the features in the intervening time. For some of the oxbow ponds and wetlands that *were* shown on GLO maps, we modified the feature dimensions and shape, because the GLO mapping was based on the map drawers' extrapolations from incomplete section-line data, and we could use more complete (but more recent) aerial photo and topographic data.

(3) *Valley wetlands.* Wetlands not associated with, and larger in scale than river oxbows, and occurring in low-elevation areas generally marginal to the river meander belt, in this report are called "valley wetlands" to distinguish them from "oxbow wetlands." These wetlands are incompletely drawn on the GLO maps. This in part is because of inconsistencies within and between maps, and in part because, as with the oxbow features, the features were not crossed by section lines and were not field surveyed by the GLO. We used topographic information and 1930s aerial photographs to modify the boundaries of wetlands between section lines. A few wetlands not shown on GLO maps were added in cases where they were not crossed by section lines and thus would have been missed by the GLO survey. Similar to the logic described above used to add several oxbow features, we added these wetlands based on later evidence for their prior existence.

(4) *Wetland vegetation.* We mapped wetland vegetation type as emergent, scrub-shrub, or forested, based on the information available for a given wetland. This included description in the GLO notes, and appearance of wetland remnant areas on 1936 or 1938 photos. However, these descriptions have varying levels of certainty. This is due to incomplete information, or in some cases no information. For example, some of the oxbows mapped by the GLO as ponds may have been mapped by modern field workers as wetlands. In addition, oxbow wetlands by their nature change in state through time,

with a common natural history that includes transition through time from open water to wetland and eventually meadow (e.g. Strahler, 1960).

(5) *Floodplain creeks.* The GLO maps are weakest in showing the locations of floodplain tributary creeks, because these streams, unlike navigable rivers, were not "meandered," or followed out in the field, and mapped by measuring distances and taking bearings. Instead, there location is known when they are encountered along section lines; otherwise, their location is sketched in. In many cases, these locations are clearly wrong in context of modern topography. In drawing small streams on the ~1870 layer we made use of the stream locations along surveyed section lines, but then relied on relict stream topography shown on the 1936 and 1938 aerial photos and LIDAR DEM. In some cases, there was no basis for redrawing the streams, and they were left as shown on the GLO map. Thus, small streams shown on the ~1870 conditions map may be mislocated, or may have been missed altogether; it is also possible that some streams we mapped from relict features on the 1930s photos may have been relict already by ~1870.

Assumptions in Mapping 1936 and 2000 Conditions

Wetlands in the 1936 and 2000 layers were generally mapped if they were visible on aerial photographs, and if they were shown on published National Wetland Inventory and King County wetland mapping. We included on these layers only those wetlands having natural vegetation; in other words, we excluded areas that had been converted to agricultural or other uses that would in the modern regulatory framework be mapped as wetland based on their hydrology or soils.

Certainty Levels and Uses of Landscape-Scale Mapping

The various mapping situations described above are listed in Table 1, which we used to guide us in coding each channel, wetland, and pond in the completed ~1870 conditions GIS layer. Associated with each source code is a relative certainty level, coarsely categorized as "high," "medium," and "low." This information is important for users of the GIS layers, because it indicates the assumptions and interpretations, and associated uncertainties, associated with each.

The mapping is intended primarily to characterize historical landforms and hydrographic features, and how they varied along and across the valley bottom, and how the landscape has changed through time. Because of the limitations, uncertainties and assumptions associated with interpreted historical conditions, the historical conditions mapping should be considered as a starting point for more site-specific characterization, which could include more detailed historical and site investigations than was possible for this landscape-scale treatment.

Table 1. Mapping situations for features on ~1870 GIS coverage, and associated relative certainty levels.

Code	FEATURE	Certainty
	Large Channels (e.g. rivers, associated sloughs, large tidal channels)	
C1	(i) Meandered by GLO and (ii) consistent with topography.	H
C2A	(i) Meandered by GLO, but (ii) necessary to locally refine boundaries because location is inconsistent with topography (e.g. river goes uphill).	M
C2B	(i) Sketched (not meandered) by GLO; (ii) adjusted channel location and shape between GLO control points using topography and more recent aerial photographs.	M
	Small Channels (e.g. floodplain creeks and small tidal channels)	
CR1A	Shown on (i) GLO (near section line) maps and (ii) early maps or aerial photographs.	H
CR1B	Shown on (i) GLO (not near section line) or USC&GS maps and (ii) early maps or aerial photographs and (iii) only minor adjustments for consistency with photos.	H
CR2A	Shown on (i) GLO (not near section line) or USC&GS maps and (ii) on earliest topographic maps or early aerial photographs and (iii) channel is adjusted using photo or map location.	M
CR2B	Shown on (i) GLO (not near section line) maps and (ii) channel has been filled or abandoned, and visible as relict channel on earliest topographic maps or early aerial photographs and (iii) Channel is adjusted using relict channel location on photos or topographic information.	M
CR2C	Shown on (i) GLO (near section line) and (ii) not shown on early maps and photos.	M
CR3A	(i) Not shown on GLO but (ii) relict channel shown on earliest topographic maps or early aerial photographs and (iii) reasonable from topography & hydrography to infer a channel would have been present. Location may be locally adjusted using photographs or topographic map information.	L
CR3B	(i) Shown on GLO (not near section line) and (ii) necessary to adjust location, no information on early photographs or maps for informing the adjustment.	L
CR3C	(i) Shown on GLO (not near section line) and (ii) not adjusted, no information on early photographs or maps for adjusting location.	L
	Wetlands	
W1A	(i) Mapped by GLO, (ii) consistent with topography, and (iii) shown on earliest topographic maps or photos OR (iii) if created >GLO, shown on later photos.	H
W1B	(i) In field GLO field notes, (ii) consistent with topography, and (iii) shown on earliest topographic maps or aerial photos	H
W2B	(i) Not mapped by GLO, (ii) consistent with topography, and (iii) shown on earliest topographic maps or aerial photos.	M
W2A	(i) Wetland mapped on GLO adjacent to polygon; boundary extended because: (ii) consistent with topography, and (iii) shown on early topographic maps or aerial photos.	M
W3	(i) Not mapped by GLO; (ii) mention of wetland in GLO field notes, but ambiguous, and necessary to make substantial extrapolation based on topography OR (iii) wetland mapped or apparent on later topographic maps or aerial photographs.	L
	Ponds	
P1	(i) Mapped by GLO and (ii) shown on early maps or aerial photos, and (iii) consistent with topography. Boundary may have been locally adjusted using topographic map or aerial photo information. OR (iv) if created >GLO, shown on later photos.	H
P2A	(i) Mapped by GLO, but (ii) necessary to substantially alter shape and size, based on topography and aerial photo and topographic map information.	M
P2B	(i) Not mapped by GLO, but (ii) present on early aerial photos or maps, and (iii) no evidence feature was artificially created prior to early maps or photos.	M

GEOLOGIC and TOPOGRAPHIC SETTING

Influence of Pleistocene History

The Pleistocene history of the Snoqualmie River valley profoundly affects the current topography, the historic channel behavior, and associated valley-bottom landforms. The broad, low-gradient valley was created by sub-glacial fluvial erosion (Booth, 1994). The LIDAR DEM shows that the river elevation and associated meander belt is higher in elevation than the surrounding valley floor (Figure 1). This is presumed to have resulted as the Snoqualmie River has deposited sediment throughout the post-glacial (Holocene) period. As a consequence, extensive areas along the valley margins are lower than the riverbank by typically 2-3 m and as much as 6 m.

Analysis Reaches

We divided the river into the following reaches for analysis and reference (Figure 1):

(1) Lower River (RM 0-RM 2). The river is relatively straight. The valley bottom is dominated by large oxbow lakes and marshes created by the Skykomish or Snoqualmie rivers.

(2) Duvall Reach (RM 2-RM 12). The valley bottom is mostly lower in elevation than the streambanks, and historically included extensive wetlands. The meander belt is narrow or absent, and the river relatively straight (Figures 1 and 2).

(3) Lower Meandering Reach (RM 12-RM 23). The meander belt is well developed and includes numerous oxbow lakes and wetlands. Low-elevation areas marginal to the meander belt are present but narrower than in the Duvall Reach (Figure 1 and 2).

(4) Tolt Fan Reach (RM 23-RM 27). The Tolt River has built an extensive Holocene fan into the Snoqualmie River valley, forcing the river toward the west valley wall. The river pattern is straight (Figure 1).

(5) Upper Meandering Reach (RM 27-RM 36). Similar to the lower meandering reach.

(6) Upper Fan Reach (RM 36-RM 39.5). River migration is limited by the alluvial fans of the Raging River and immediately upstream of the Raging River on the north valley wall (downstream of Tokul Creek).

(7) Falls Reach (RM 39.5-RM 40.3). Upstream from Tokul Creek to Snoqualmie Falls, the river becomes progressively more confined by bedrock valley walls.

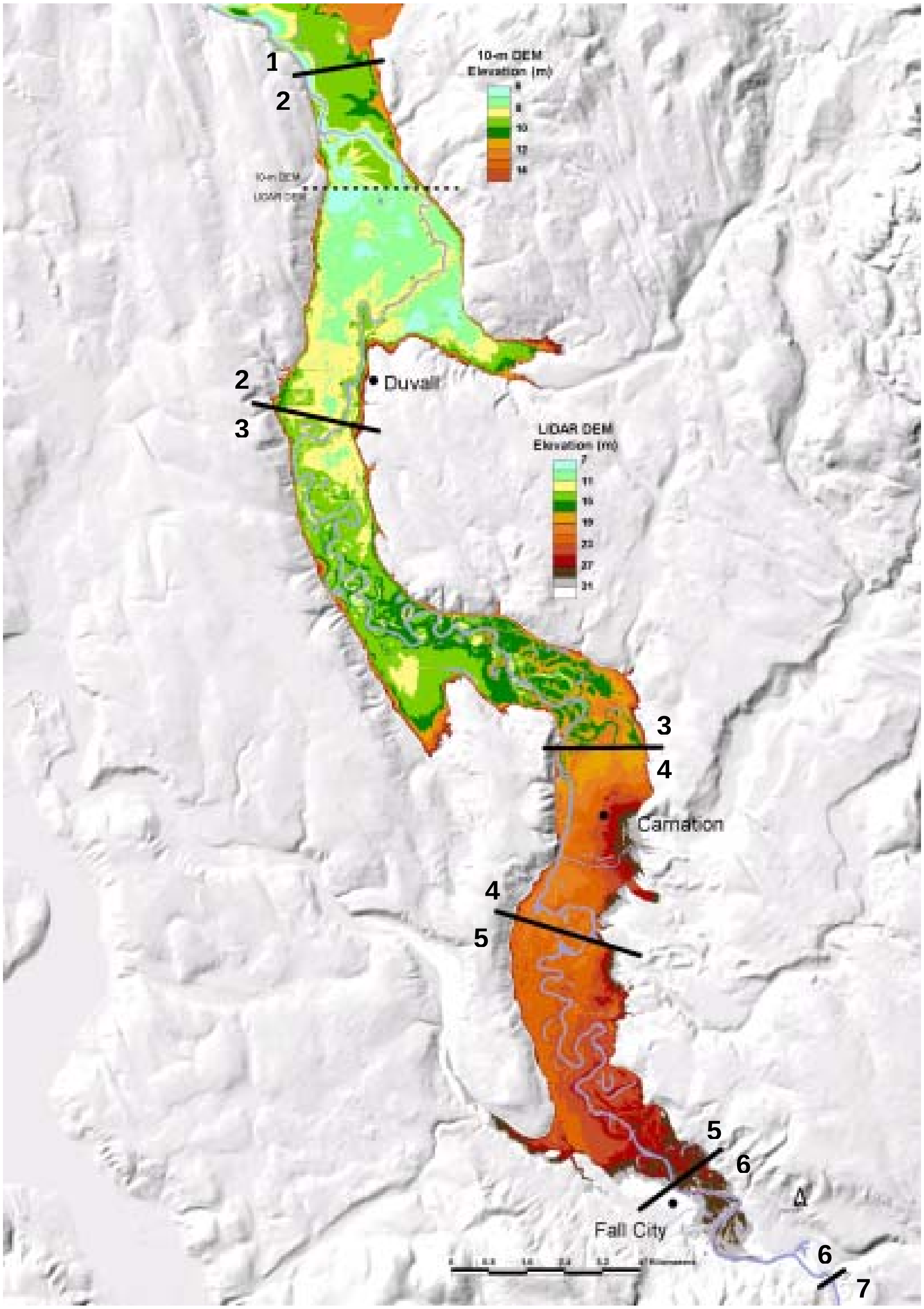

Figure 1. Analysis reaches used in this study, and locations of towns in the Snoqualmie River valley.

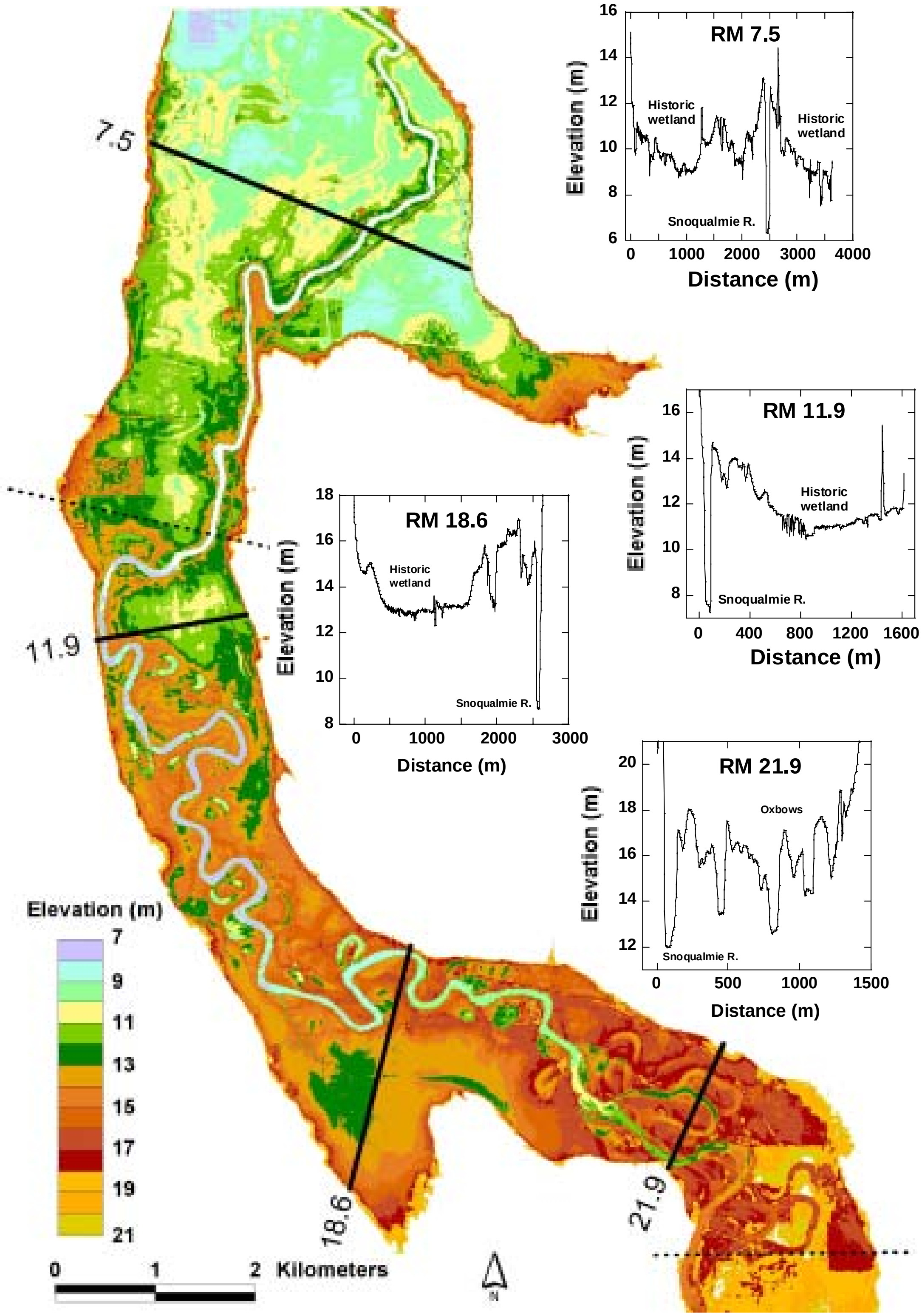

Figure 2. Topography and representative valley cross-sections in study reaches 2 and 3.

PRE-SETTLEMENT (~1870) CONDITIONS

Reach Descriptions

(1) *Lower River (RM 0-RM 2).* The lower two river miles are dominated by large oxbow depressions, relict from the Snoqualmie or Skykomish rivers, now filled by ponds or wetlands. These features appear to have been created prior to the GLO mapping, and one is shown by the GLO.

(2) *Duvall Reach (RM 2-RM 12).* The most notable wetland feature in the Snoqualmie valley and the dominant characteristic of the Duvall reach was an extensive system of marshes that occupied nearly the entire valley from RM 2 to RM 12 (Figure 3). The GLO field notes indicate that the area was primarily a thick growth ("…almost unpassable…") of shrubs and small trees. The shrubs were described as hardhack, crabapple, willow, alder, and tule. A few areas are described as "cranberry marsh." The tree cover was described as "…a few scattering scrubby spruce and cedar" or "…a few scattering scrubby spruce, entirely worthless." From this information the area appears to have been primarily a scrub-shrub (rather than forested or emergent) freshwater wetland. This interpretation is supported by images of a 3-km^2 remnant of the marsh shown on 1938 aerial photographs, which suggest a brushy marsh with scattered conifers (Figure 4). Bearing tree data (see later, "Forest Conditions") also support the description of marsh tree cover as spruce having a small diameter, and small-diameter alder, maple, and vine maple.

The marsh system was characterized in the GLO notes as seasonally "subject to overflow to the depth of 8 feet," which is consistent with the modern elevation of the lowland area being several meters below the riverbank (see cross sections in Figure 2). It is likely that the valley has subsided somewhat since these soils were drained and ditched. However, field observations of flooding depths made in 1873 prior to any draining indicate that the area was naturally lower than the riverbed. At the time of the survey on April 4, 1873, the water was described as "… 6 to 18 inches deep." In addition, marshes elsewhere in the study area that have not been ditched are also topographically lower than the riverbanks.

The DEM shows a considerable amount of subdued, sinuous topography within this marsh, presumably created by ancient river meanders, and the water depth would have varied locally and seasonally. It appears likely water was present in summer, with perennial ponds present locally in the 1936 images and mapped on the 1873 cadastral survey maps. However, other than these mapped features, the amount and location of perennial water is not clear from the available information.

(3) *Lower (RM 12-RM 23) and* (4) *Upper (RM 27-RM 36) Meandering Reaches.* The 20-river-mile length of these two reaches includes nearly all of the oxbow wetlands and ponds in the Snoqualmie River valley. More than 40 oxbow features were mapped as existing within the two reaches (as indicated above, two additional oxbows are between RM 0 and RM 2). A number of wetlands also formed within the lower-elevation valley margins, marginal to the elevated meander belt ("valley wetlands"). Within the meander

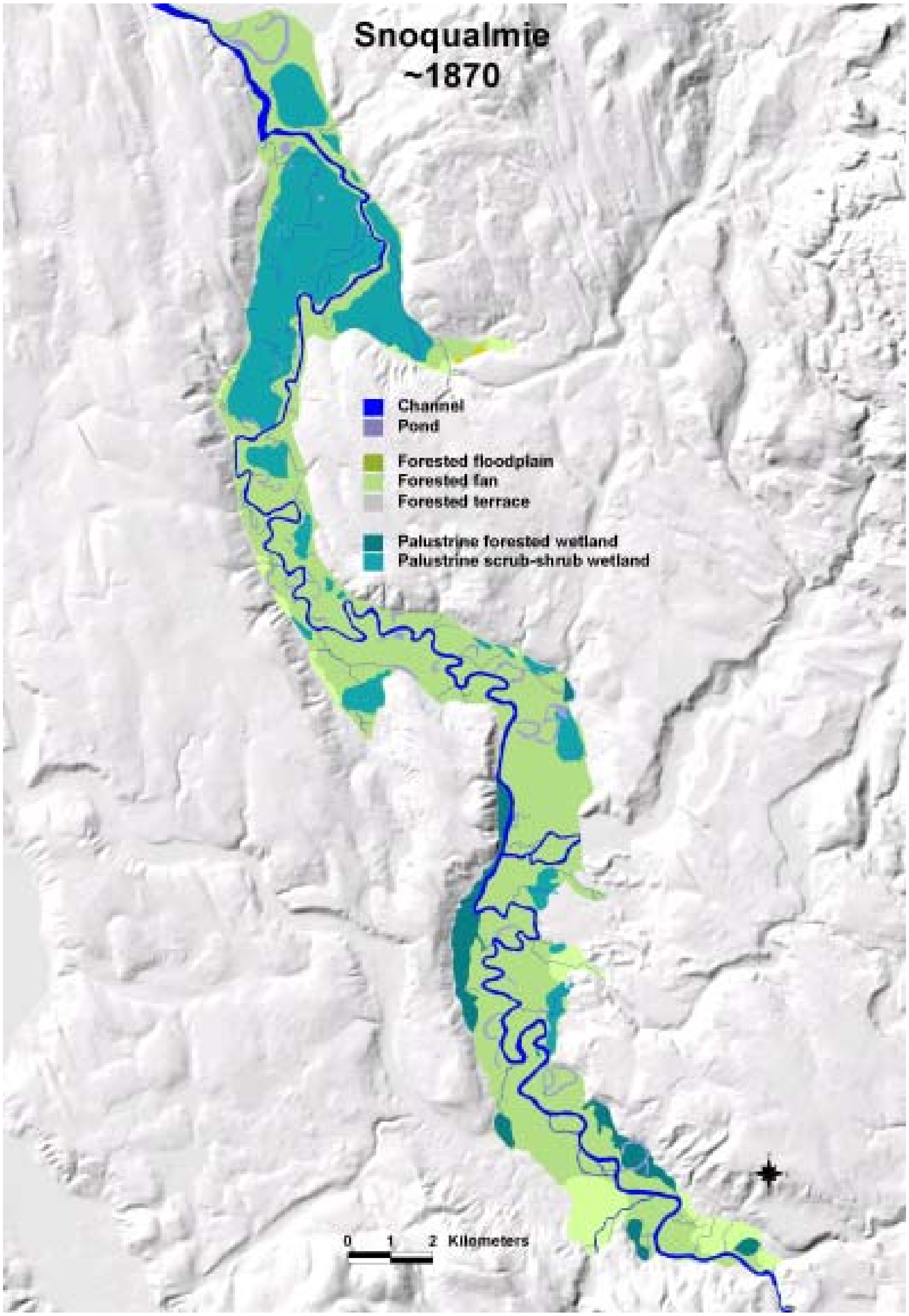

Figure 3. Environmental conditions interpreted to exist in the Snoqualmie River valley ~1870.

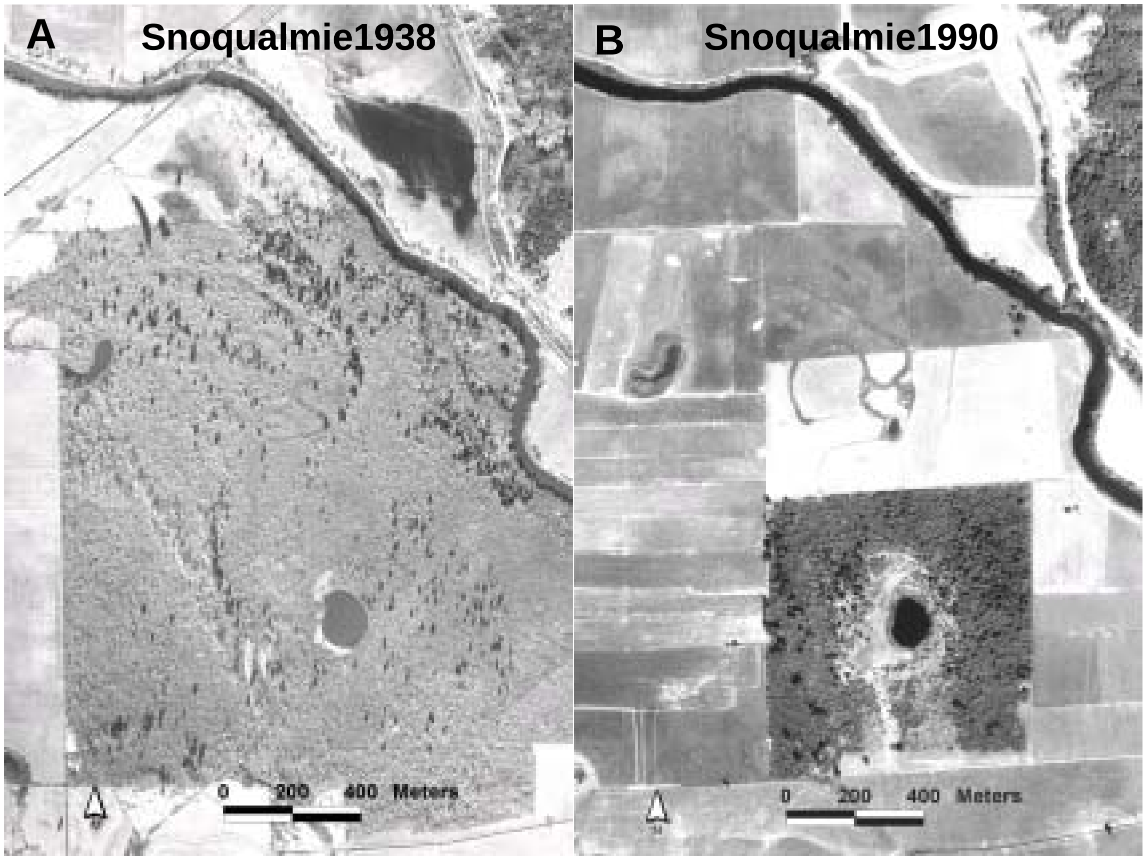

Figure 4. Remnant patch of historical wetland-pond complex at approximately RM 6 along the Snoqualmie River (see Figure 3) in 1938 and 1990. Photo also shows wetland on the north side of the river in 1938.

belt, topography was highly irregular in a cross-valley direction, with depressions corresponding to oxbows that were formed recently enough to persist as ponds or wetlands, or swales that are presumably much earlier oxbows that have largely filled in (e.g, cross section RM 21.9 in Figure 2).

One of the prominent valley wetlands in Figure 3 is on the south valley wall about midway between Duvall and Carnation. The extent of this wetland was mapped using the GLO survey notes; the survey was discontinued along section lines because of the "impassable swamp." The wetland is partially coincident with the area mapped as the "Ames Lake Creek peat area" by Rigg (1958), which is significantly larger than the area we mapped, which might suggest the wetland may have been larger than we have mapped. While this marsh has been drained, portions of several of the larger valley-marginal wetland areas remain in the current landscape.

(4) *Tolt Fan Reach (RM 23-RM 27).* The Tolt River created an alluvial fan in the Holocene, which has pushed the Snoqualmie River to the west valley wall (Figure 1). The

river pattern is straight. The lack of oxbow lakes or relict channels suggests little historic river migration; while the slope of the Tolt River fan is low, it effectively acts to topographically confine the Snoqualmie River.

(6) *Upper Fan Reach (RM 36-RM 38.5).* In this reach the Snoqualmie River is, similar to within the Tolt River reach, again relatively confined by the alluvial fans of the Raging River on the south and the fan complex downstream of Tokul Creek on the north valley side, which limits channel migration.

(7) *Falls Reach (RM 36-39.7-RM 40.3).* Above Tokul Creek the Snoqualmie River is confined between sheer valley walls.

In-Channel Wood

The Army Engineers made early investigations of Puget Sound rivers, and also submitted annual reports on their activities, which in the last decades of the 19th century and the first decades of the 20th century emphasized removing snags to improve navigation (see Collins et al., 2002, for background). The Snoqualmie River does not appear to have been a primary concern of the engineers, with few exceptions concentrating their attention in the Snohomish River only as far upstream as the town of Snohomish.

The Army Engineers' first reported description of the Snoqualmie River, and thus likely their first examination of the river, was in 1880. Unlike most other rivers (e.g. the Skagit, Snohomish, and Stillaguamish) the Snoqualmie's description did not include wood. This may or may not suggest that wood was not abundant enough to create problems for navigation; it may instead reflect earlier, undocumented clearing of in-channel wood that may have been carried out by settlers. Assistant Engineer Robert Habersham's report on navigation conditions from a field investigation in August 1880, indicates that

> *"From [Snohomish City] within 3 miles of Fall City, on the Snoqualmie, the highest settlement on the river, a distance of 40 miles, boats can carry 3.5 feet during high stages, and 18 inches at all times. This portion of the Snoqualmie runs between banks from 10 to 30 feet high, with an average width of 250 feet…. The obstructions are: Kelsay's Riffle, 6 miles above the Forks; Little Island Bar, 11 miles above the forks; Toalt Riffle, 30 miles above the Forks; and Sanawa Riffle, at the head of navigation…"* (U. S. War Department, 1881).

The river was thereafter irregularly snagged, which may imply that snag accumulation was not rapid. The first reported operation was in 1887, when a total of 708 snags were taken from the Snohomish and Snoqualmie rivers combined (snags removed from both rivers are grouped together in the Army report) from August 22 to October 26 (U. S. War Department, 1888). The next reported snagging operation was in 1893

> *"…as far as Tolt River, the practical head of navigation, where there had never been any snagging done before"* (U. S. War Department, 1883).

The crew removed 400 snags from the Snoqualmie and cut down 28 trees leaning over the river. The snagging was resumed the next year, on October 25 when 125 snags were removed from the two rivers:

> *"Work was prosecuted on [the Snohomish] and its tributary, the Snoqualmie, to a point called Tolt River, about 40 miles up from salt water, till November 7, when the fall rains and consequent freshets caused too high water to do profitable snagging"* (U. S. War Department, 1895)

Snagging continued on an irregular basis into the first decade of the 20th century; 75 snags were removed in 1901, 2 snags in 1903, 199 snags in 1905, and 1,494 snags in 1908. There is not complete information in these years on the locations where snagging took place.

Table 2. Snags removed from four north Puget Sound rivers, 1880-1910 (from Annual Reports of the Chief of Engineers).

RIVER	Drainage Area (km^2)	1881-1890	1891-1900	1901-1910	TOTAL 1881-1910
Skagit	7,800	776	21,553	14,369	36,698
Snohomish (including Snoqualmie and Skykomish)	4,645	920	2,898	6,527	10,345
Nooksack	2,072	1,462	758	1,850	4,070
Stillaguamish	1,770	87	956	1,021	2,064

It is difficult to interpret from these data whether snags were more or less abundant than in other north Puget Sound rivers (Table 2). One problem in comparing between rivers is that available records only sometimes indicate the specific locations that were snagged. Another is that the extent of navigation, and thus the length of channel regularly snagged, varied considerably between rivers. The three-decade totals in Table 2 do show a correspondence between river basin size and the number of snags removed.

Forest Conditions

While the Army field investigations and snagging records provide little insight into wood loading, the GLO field notes indicate the common names (Table 3) and diameters of trees that grew immediately streamside, which would over time contribute dead wood to the channel. Surveyors were instructed to establish survey points with witness trees at "meander" points where section lines intersected the banks of navigable rivers (White, 1991). We call witness trees at these meander points "streamside" in this analysis, to distinguish them from trees more distant from the river ("valley bottom").

Tree frequencies in Figure 5 are biased against smaller-diameter species such as vine maple, since bearing trees were greater than 7.5 cm in diameter (see Collins and

Montgomery, in press, for detail). However, field investigation using early 1870s instructions to GLO surveyors show that using the GLO bearing tree data to characterize basal area estimates is reasonably accurate (Collins and Montgomery, in press).

Most streamside trees were hardwoods: alder, willow, vine maple, maple, cottonwood, and crabapple (Figure 5; we use the names used by surveyors; see Table 3 for likely species). Conifers accounted for only 7% of streamside trees. Because bearing trees underestimate the frequency of small-diameter species such as vine maple and alder, conifers probably accounted for even less than 7% of trees. However, the few conifers accounted for 43% of streamside basal area (Figure 5), indicating that conifers were the largest trees and would have provided nearly half the dead wood biomass to rivers from immediate streamside forests. Cedar alone, which accounted for 4% of stems, comprised 27% of streamside basal area, and averaged 97 cm (38 inches) in diameter (Figure 6A); spruce, which averaged 91 cm (36 inches) in diameter, accounted for only 2% of stem number, but 14% of basal area. Maple (average diameter 54 cm or 21 inches, range of 10-132 cm or 4-52 inches) and cottonwood (average diameter 54 cm or 21 inches, range of 8-152 cm or 3-60 inches) were the dominant hardwoods by basal area, both accounting for 18% and 15% of the total, respectively. Alder was the third hardwood having an average diameter substantially greater than 15 cm, averaging 35 cm (14 inches).

Table 3. Trees and shrubs recorded as witness trees in GLO field notes, and probable common and scientific names. Trees are listed in decreasing frequency of occurrence.

NAME USED IN GLO FIELD NOTES	PROBABLE SPECIES
Alder	Red alder *(Alnus rubra)*
Vine maple	Vine maple *(Acer circinatum)*
Maple	Bigleaf maple *(Acer macrophyllum)*
Willow	Willow spp. *(Salix spp.)*
Crabapple	Pacific crabapple *(Pyrus fusca)*
Cottonwood	Black cottonwood *(Populus trichocarpa)*
Spruce	Sitka spruce *(Picea stchensis)*
Cedar	Western redcedar *(Thuja plicata)*
Hemlock	Western hemlock *(Tsuga heterophylla)*
Barberry, Bearberry	Oregon grape (?) (*Berberis nervosa)*
Hazel	California hazel *(Corylus cornuta californica)*
Fir	Douglas-fir *(Pseudotsuga menziesii)* Grand fir *(Abies grandis)*
Cherry	Bitter cherry *(Prunus emarginata)*
Dogwood	Western flowering dogwood *(Cornus nutallii)*
Elder	Elderberry spp. *(Sambucus spp.)*

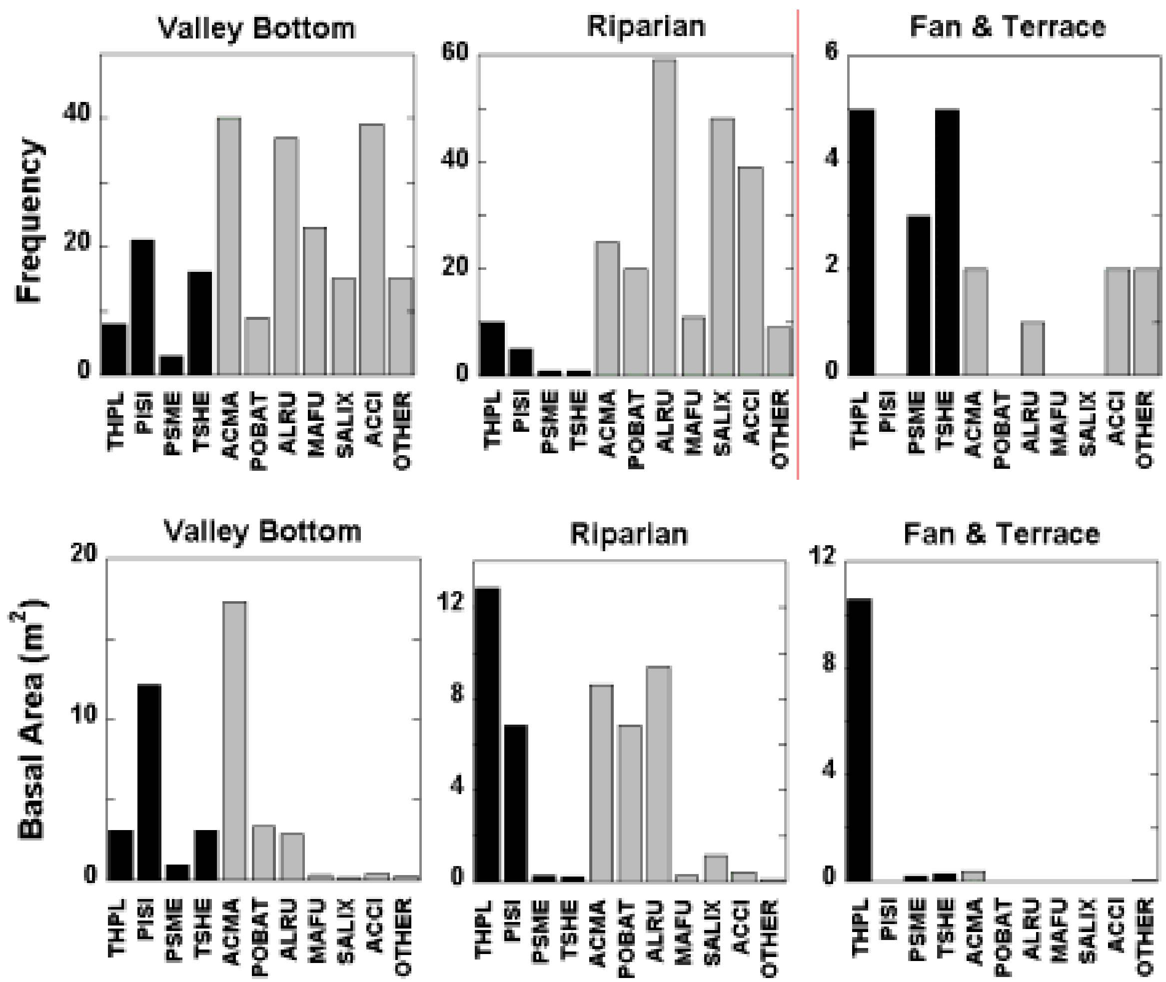

Figure 5. Bearing trees from GLO field notes in the Snoqualmie River valley. Top tier, from left to right: frequency of trees in (valley bottom forest, stream-adjacent forest, and alluvial fans and river terraces. Bottom tier, left to right: cumulative basal area in valley bottom forest, stream-adjacent forest, and fans and terraces. Coniferous species have dark-shaded bar. THPL: western redcedar (*Thuja plicata)*; PISI: Sitka spruce (*Picea sitchensis)*; PSME: Douglas fir (*Pseudotsuga menziesii)* may also include some Grand fir *(Abies grandis)*; TSHE: western hemlock (*Tsuga heterophylla)*; ACMA: bigleaf maple (*Acer macrophyllum)*; POBAT: black cottonwood (*Populus trichocarpa)*; ALRU: Red alder (*Alnus rubra)*; MAFU: Pacific crabapple (*Malus fusca)*; SALIX: Willow (*Salix spp.);* ACCI: vine maple (*Acer circinatum)*. "Other" species include: dogwood *(*western flowering dogwood*, Cornus nuttallii)*, hazel (beaked hazelnut, *Corylus cornuta var. californica*); bearberry or barberry (uncertain, possibly Oregon grape, *Mahonia aquifolium*); chittemwood (cascara, *Rhamnus purshiana*), cherry (bitter cherry, *Prunus emarginata);* elder (red elderberry*, Sambucus racemosa*).

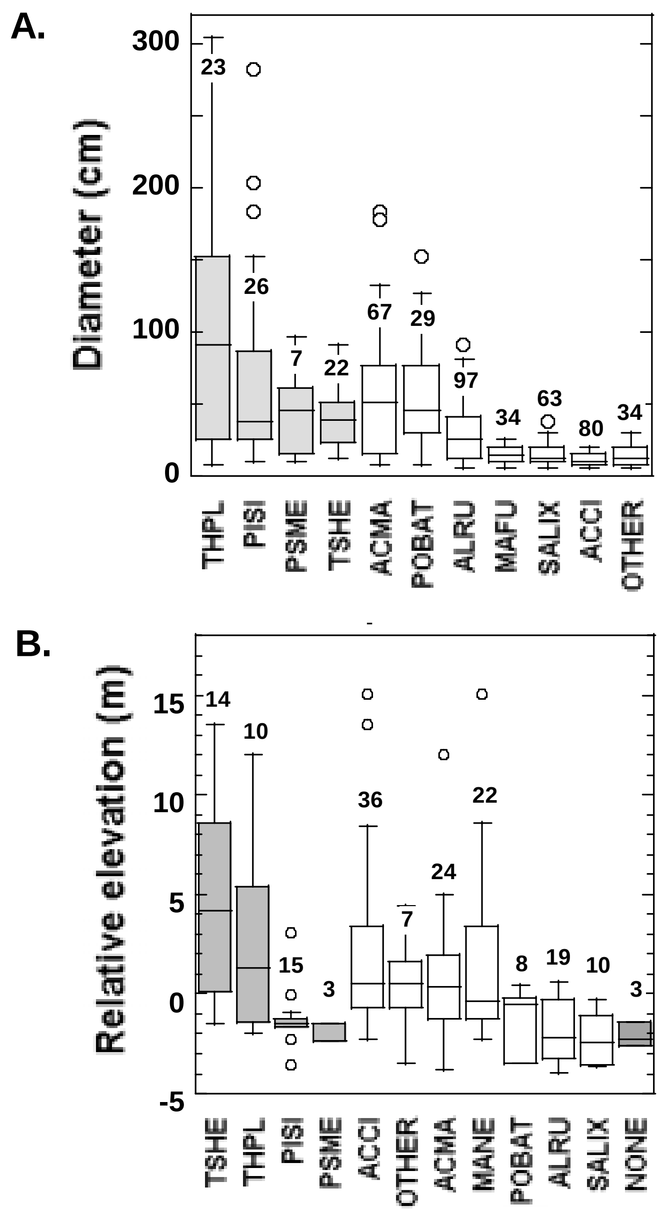

Figure 6. A. Distribution of diameters of GLO bearing trees in the Snoqualmie River valley. B. Elevation of GLO bearing trees relative to the Snoqualmie River's bank. Conifers have shaded bars. In both plots, numbers are sample size for each species. Species abbreviations are as in Figure 7. Conifers have shaded boxes. Each box encloses 50% of the data with the median value displayed as a line. The lines extending from the top and bottom of each box indicate the minimum and maximum values, excepting outliers (circles), or points with values greater than the inner quartile plus 1.5 times the inner two quartiles. Numbers are sample size.

Conifers were somewhat more abundant in the forest more distant from the river ("valley bottom" in Figure 5), although still accounting for only 21% of the stem number (compared to 7% in streamside areas), they accounted for 46% of basal area (Figure 5). Cedar was the largest tree, averaging 91 cm (36 inches) and ranging from 8 to 305 cm (3-120 inches) in diameter (Figure 6A). Similar to the streamside forest, maple and cottonwood were the largest hardwoods (mean = 58 cm or 23 inches and 58 cm or 23 inches, respectively). However, because of the slow rate of channel migration in the Snoqualmie River, bearing trees from the immediately streamside area are most representative of the dead wood that would enter the river.

Trees were distributed predictably relative to the riverbank elevation (Figure 6B). The data in Figure 6B were developed by comparing present-day elevation shown on LIDAR DEM for locations of GLO notes to the present-day riverbank elevation nearest to the point. The elevation distribution of spruce shows a tolerance for seasonally-inundated sites, generally occurring 1-2 m below the river bank elevation, and alder and willow occurred as much as 4 m below the riverbank elevation.

In summary, the immediately streamside forest was dominated by a variety of hard-woods. Of these, only maple, cottonwood, and alder were typically of a large enough size as to be expected to create stable in-channel wood. The few conifers immediately streamside, primarily cedar and spruce, could be quite large [diameter ranges of 15-244 cm (6-96 inches) and 13-203 cm (5-80 inches), respectively]. Cedar, spruce, maple, and cottonwood would be expected to have been the most common key pieces in jams. Observations in the Snohomish River (Collins et al., 2002) indicate that hardwoods with a broadly shaped crown, such as maple, are likely to form snags within the main channel.

Table 4. Summary of forest tree conditions suggested by GLO bearing tree records from 1873.

SUMMARY OF FOREST TREE CHARACTERISTICS
• Hardwoods more common than conifers, especially in streamside areas.
• Common hardwoods include alder, willow, vine maple, maple, cottonwood, and crabapple.
• Conifers were the largest trees, especially cedar and spruce.
• Species had distinct elevational ranges relative to the streambank, with spruce, willow, alder being most tolerant of flooded conditions.
• Spruce were the dominant tree in valley-marginal shrub-scrub marshes.
• Alder and willow had a greater dominance in streamside areas than farther from the river.

HISTORICAL CHANGES

1936 Conditions

Much of the forest present prior to Euro-American settlement had been cleared, and much of the wetland cleared and drained by 1936 (Figure 7). Riparian vegetation remained along river channels and oxbows in some areas in 1936 (Figure 8).

In contrast to the change in forest and "valley wetland" area, there was little change in the Snoqualmie River and its associated oxbows (Figure 9). By 1936 the river had cut off (avulsed) only eight meander bends.

Notable on the 1936 photographs are numerous large gravel bars in the Tolt River and downstream in the Snoqualmie River (Figure 7), which presumably reflects high sediment yields in the Tolt River watershed due to upstream forest clearing.

2000 Conditions

Diminishment of forest and valley-marginal wetland area continued through the 20th century (Figures 10 and 11). Similar to the previous map period there was little change in the channel or associated oxbow water bodies; in the 64-year period between 1936 and 2000 one meander bends avulsed (Figure 9). Also notable is the increase in urbanized area between 1936 and 2000 (Figure 11). Most of the development was concentrated on the Raging River fan and the fan on the north valley side, downstream of Tokul Creek in the upper watershed, and on the Tolt River fan in the Carnation area (Figure 10).

Meander avulsion continued to be uncommon (Figure 9), although the few river changes in the 1936 to 2000 period may in part reflect the establishment of bank revetments in the 1960s and 1970s (King County GIS mapping). However, there was little revetment present prior to 1936, when relatively little change occurred to the channel. This relatively slow rate of meander avulsion means that most about three quarters 35 of 48) of oxbow ponds and wetlands mapped from 2000 photographs were created prior to 1873.

The small rate of change to the river contrasts with the extensive historical changes to wetlands and forests, which have been greatly diminished (Figure 11). The forest cover in 2000 was 16% that mapped for ~1870. The area of "valley" wetlands in 2000 was 19% that in ~1870.

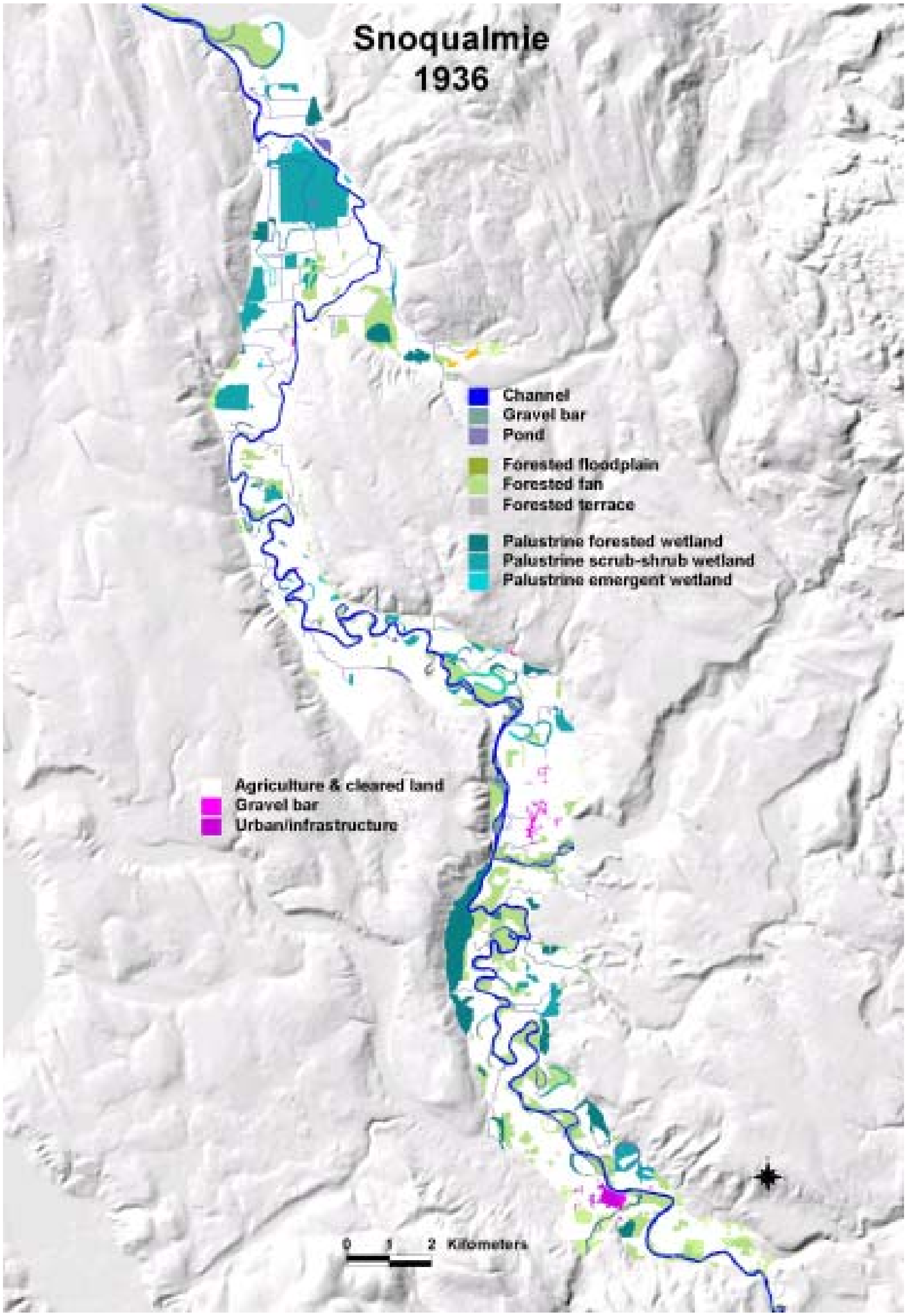

Figure 7. Environmental conditions interpreted to exist in the Snoqualmie River valley in 1936. Portions of the northern study area were mapped from 1938 photographs, and in the southernmost from 1941 photographs.

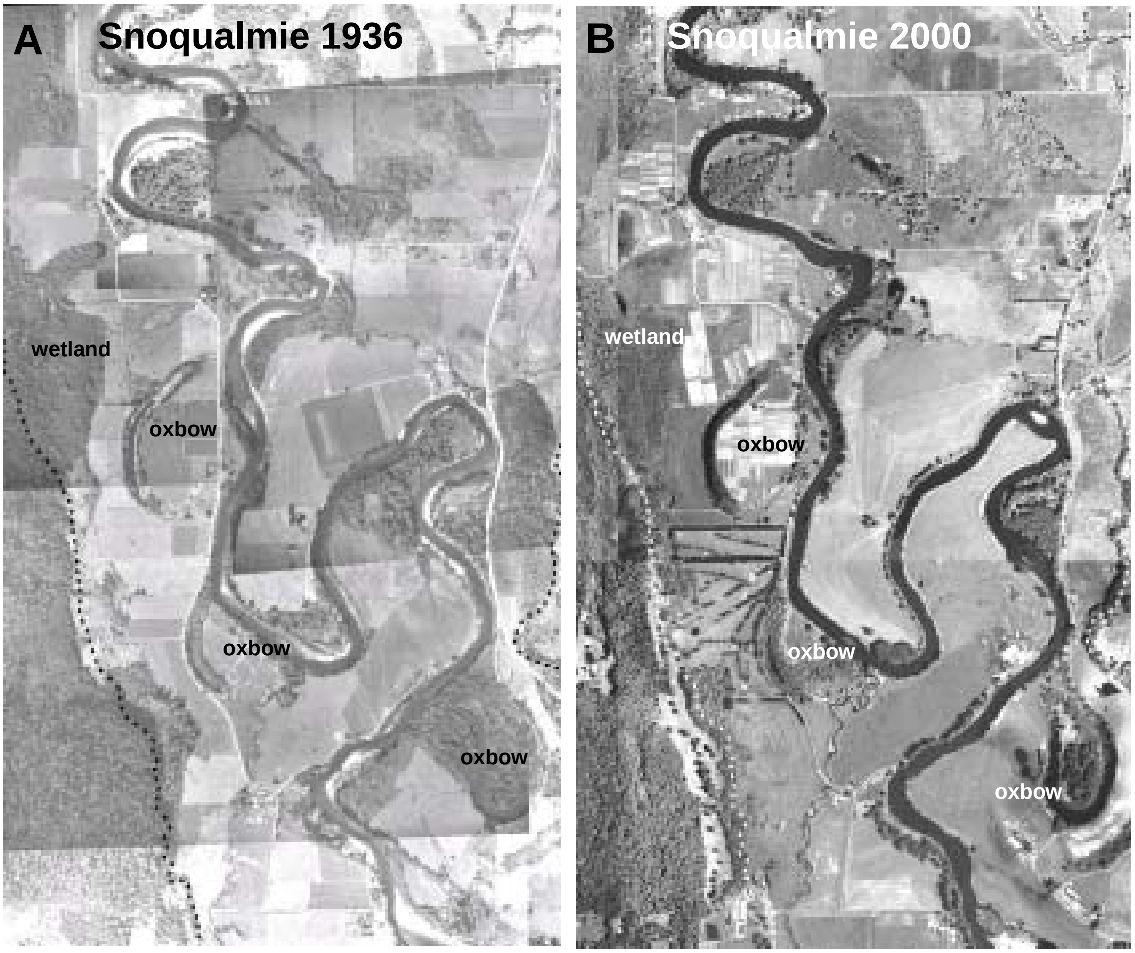

Figure 8. Aerial photographs from A. 1936 and B. 2000 showing change to forest cover in the Snoqualmie River valley, RM 29 to RM 34. Relatively little change has occurred to the channel or oxbow lakes in this time period.

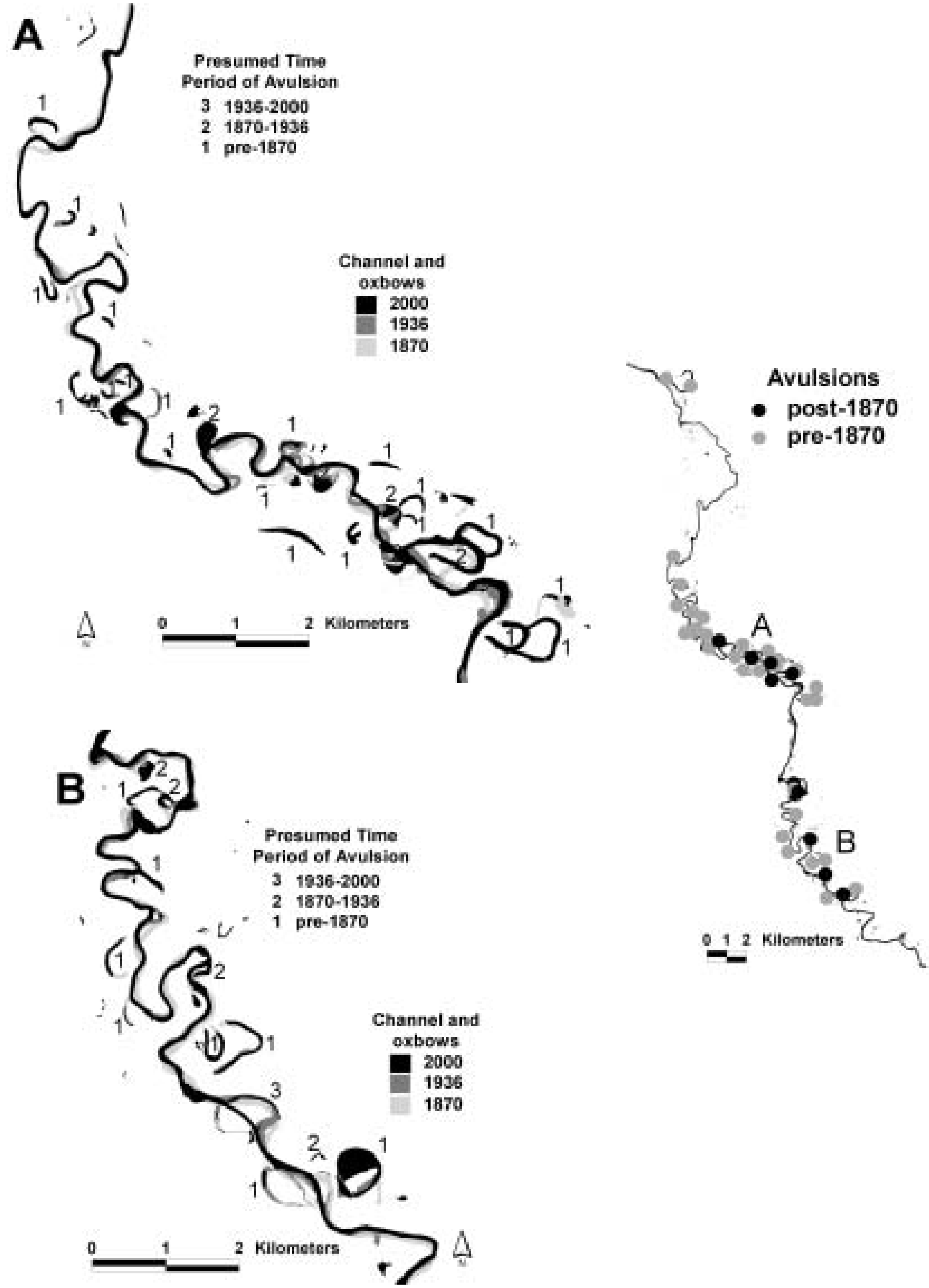

Figure 9. Historical channel positions and time periods of oxbow creation.

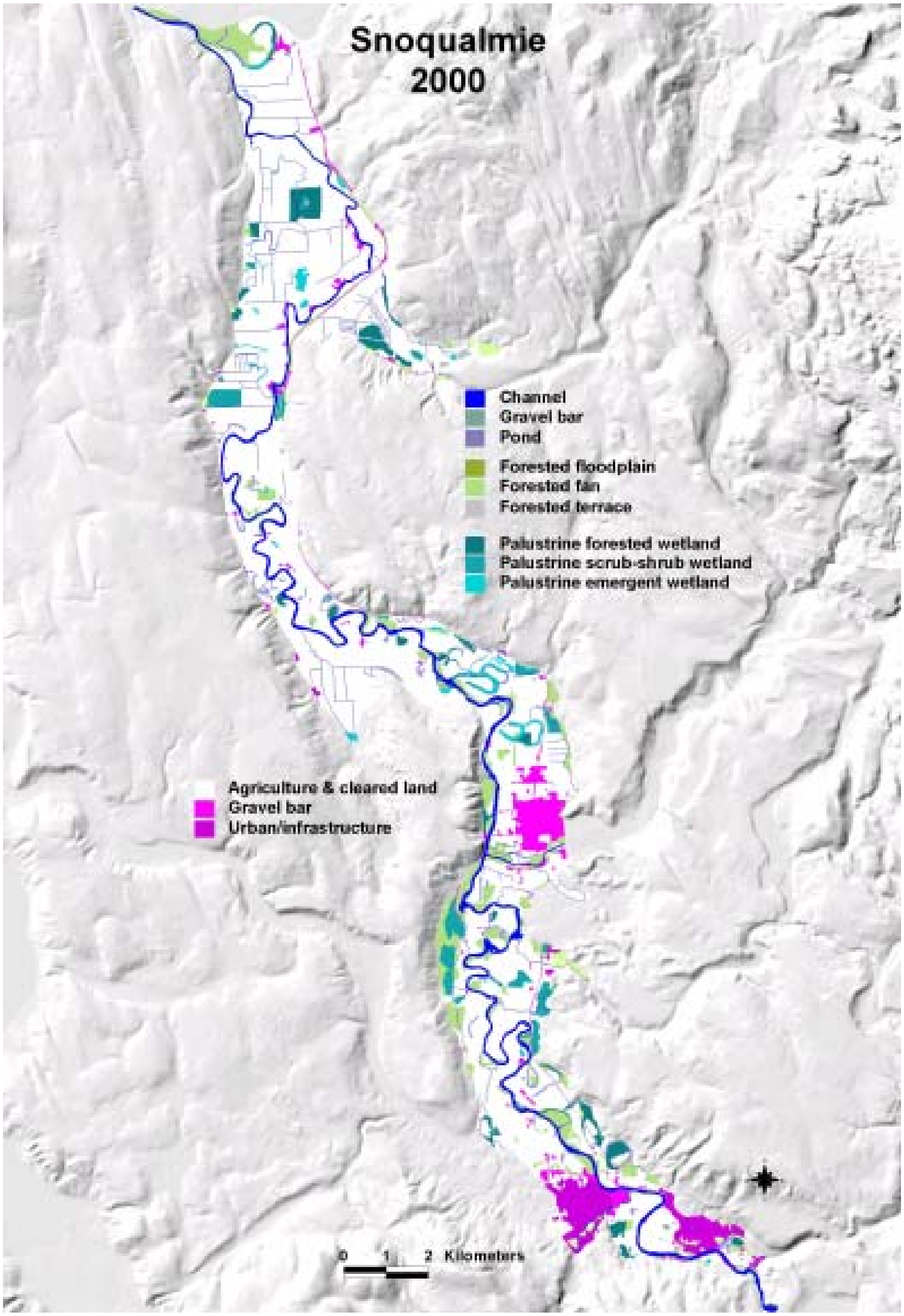

Figure 10. Environmental conditions interpreted to exist in the Snoqualmie River valley in 2000. Portions of the northern study area were mapped from 1990 photographs.

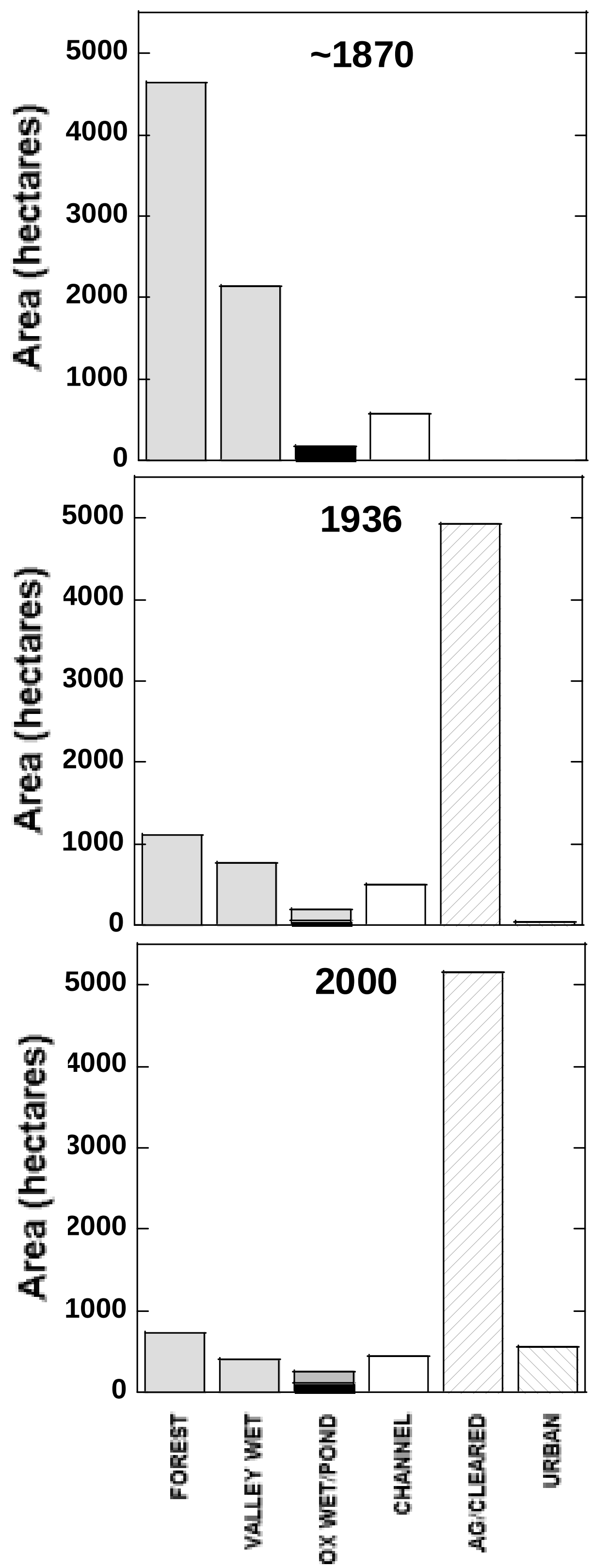

Figure 11. Areal extent of forest, valley wetlands, oxbow ponds (black bar) and oxbow wetlands, agricultural or cleared land, and urbanized land, measured from mapping for ~1870, 1936, and 2000. In the ~1870 mapping, oxbow wetlands were not distinguished from oxbow ponds as they were in the later years.

APPLICATION TO RESTORATION PLANNING

Historical data can be applied to several types of restoration activities:

(1) *Reforestation.* Data from GLO field notes provide information about tree species that grew in historical forests and their locations with respect to riverine and topographic variables.

(2) *Connecting the river with oxbow ponds and wetlands.* Oxbows are formed by the avulsion of river bends. Through time, oxbows become isolated from the river as sedimentation plugs the river-proximal ends of the oxbow. Most oxbows then exist for some period of time as ponds or wetlands with a tie creek between them and the river channel, until eventually they are filled by sediment. The longevity of oxbow features is largely a function of the sedimentation rate, and spatial patterns of sedimentation, which vary from river to river.

On the Snoqualmie, tie creeks connected many oxbows to the river prior to land use changes by settlers. Field investigations of topography, and detailed site-specific historical investigations can reveal the historical hydrologic connection between the oxbow and channel, as part of evaluating the feasibility of reestablishing the hydrologic connection. Table 5 and Figure 12, which include an inventory of historical and current oxbow features, is a starting point for such evaluations.

(3) *Restoring Valley-Marginal Wetlands.* Historical information provides a starting point for assessing the feasibility of restoring wetlands that exist or formerly existed in low-elevation areas outside the meander belt.

(4) *Restoring Tributary Creeks.* Numerous floodplain creeks have been straightened and channelized. Site-specific studies using field surveys, soils and hydrologic information, the 1936 aerial photos, and local knowledge can improve knowledge of the historic location and pattern of these streams for programs to reestablish historical creek morphology.

Characteristics of the Snoqualmie River valley suggest several general conclusions regarding restoration planning (Table 6). The relatively slow rate of river migration and avulsion has implications for programs to reestablish streamside forest buffers. Abundant oxbow lakes are relatively static, and there is potential for improving or establishing their use as off-channel habitat by connecting them to the river and riparian planting. The low elevation of formerly extensive valley-marginal wetlands would facilitate their "passive" restoration.

Table 5. Inventory of historical off-channel water bodies and wetlands. Numbers in "ID" refer to the analysis reaches in Figure 1; each site is referenced to Figure 12. "First map information" is the earliest map source that shows the feature. The "historical area" is the area on the interpreted ~1870 map, except for features that were created more recently than that date (e.g. oxbow ponds and wetlands created by later avulsions). "Historical map source" and map certainty refer to Table 1.

ID	Type	Time Period Created	First Map Source	Historic Area (ha)	2000 Area (ha)	Historical Map Source	Historical Map Certainty
1A	Oxbow pond-wetland complex	<1870	1936	4	5	P2B	M
1B	Oxbow pond-wetland complex	<1870	1870	32	21	P1	H
2A	Valley wetland	<1870	1870	142	0	W1A	H
2B	Valley wetland	<1870	1870	11	0	W1A (36%) W2A (64%)	H (36%) M (64%)
2C	Valley wetland	<1870	1936	2	3	W3	L
2D	Valley wetland-pond complex	<1870	1870	1029	148	W1A (95%) W2A (5%)	H (95%) M (5%)
2E	Valley wetland	<1870	1870	289	50	W1A (53%) W2A (47%)	H (53%) M 47%)
3A	Oxbow wetland	<1870	1870	4	3	P1	H
3B	Valley wetland	<1870	DEM	59	0	W3	L
3C	Oxbow pond	<1870	1870	2	2	P2B	M
3D	Oxbow pond-wetland complex	<1870	1870	1	1	P2B	M
3E	Oxbow pond	<1870	1870	1	1	P2A	M
3F	Oxbow pond	<1870	1870	1	1	P2A	M
3G	Oxbow pond	<1870	1870	3	3	P2B	M
3H	Oxbow pond-wetland complex	<1870	1870	1	1	P2A	M
3I	Valley wetland	<1870	NWI/DEM	30	0	W3	L
3J	Oxbow pond	<1870	1870	4	7	P2A	M
3K	Oxbow pond	<1870	1870	2	1	P1	H
3L	Oxbow pond	<1870	1936	1	1	P2B	M
3M	Oxbow pond-wetland complex	<1870	1936	1	5	P2B	M
3N	Oxbow pond	<1870	1870	2	1	P2B	M
3O	Valley wetland-pond complex	<1870	1936	5	0	P2B	M
3P	Oxbow pond	<1870	1870	1	1	P2B	M
3Q	Valley wetland-pond complex	<1870	1936	3	2	W2B	M
3R	Oxbow pond	1936-2000	2000	NA	3	P1	H
3S	Valley wetland	<1870	NWI	9	0	W3	L
3T	Oxbow pond-wetland complex	<1870	1870	4	3	P2B	M
3U	Oxbow pond	<1870	1936	1	<0.5	P2B	M
3V	Oxbow pond	<1870	1936	2	2	P2B	M
3X	Valley wetland	<1870	1870	67	0	W1A (73%) W2A (27%)	H (73%) M (27%)
3W	Oxbow pond-wetland complex	1870-1936	1936	6	5	P1	H
3Y	Oxbow pond	<1870	1870	6	6	P2B	M
3Z	Oxbow pond	<1870	1870	3	3	P1	H
3AA	Oxbow pond-wetland complex	<1870	1870	1	2	P2B	M
3AB	Oxbow wetland	1870-1936	1936	3	4	W1A	H
3AC	Oxbow wetland	1870-1936	1936	6	4	W1A	H

Table 5 (continued).

ID	Type	Time Period Created	First Map Source	Historic Area (ha)	2000 Area (ha)	Historical Map Source	Historical Map Certainty
3AD	Oxbow pond-wetland complex	<1870	1870	1	1	P2B	M
3AE	Oxbow pond-wetland complex	<1870	1870	3	3	P2A	L
3AF	Valley wetland-pond complex	<1870	1936	23	26	W3	L
3AG	Oxbow pond-wetland complex	1870-1936	1936	14	20	P1	H
3AH	Oxbow pond-wetland complex	<1870	1870	8	8	P2A	M
3AI	Oxbow pond	<1870	1870	9	2	P2A	M
3AJ	Valley wetland-pond complex	<1870	1870	58	11	W1A (71%) W2A (29%)	H (71%) M (29%)
3AK	Oxbow wetland	<1870	1870	9	10	P1	H
3AL	Valley wetland	<1870	1870	11	0	W3	L
3AM	Oxbow wetland	<1870	1870	9	10	P1	H
4A	Valley wetland	<1870	2000	31	8	W3	L
4B	Valley wetland	<1870	1936	41	0	W3	L
4C	Oxbow pond-wetland complex	1870-1936	1936	3	4	P1	H
5A	Valley wetland-pond complex	<1870	1870	140	59	W1A (6%) W2A (94%)	H (6%) M (94%)
5B	Oxbow pond	<1870	1870	3	2	P1	H
5C	Oxbow pond	1936-2000	2000	NA	3	P1	H
5D	Valley wetland	<1870	1936	7	3	W3	L
5E	Oxbow pond-wetland complex	<1870	1870	2	3	P2B	M
5F	Oxbow pond	1936-2000	2000	NA	<0.5	P1	H
5G	Oxbow pond	<1870	1870	6		P2B	M
5H	Valley wetland-pond complex	<1870	1870	48	32	W1A (35%) W2A (19%) W3 (42%)	H (35%) M (19%) L (42%)
5I	Oxbow pond	<1870	1870	3	1	P2B	M
5J	Oxbow wetland	1870-1936	2000	NA	2	W3	L
5K	Oxbow pond-wetland complex	<1870	2000	2	2	W3	L
5L	Oxbow pond	<1870	1870	6	6	P2B	M
5M	Oxbow pond	<1870	1870	9	7	P1	H
5N	Valley wetland	<1870	1870	24	9	W3	L
5O	Oxbow pond	1870-1936	2000	NA	1	P2B	M
5P	Oxbow pond	1936-2000	2000	NA	3	P2B	M
5Q	Oxbow pond	1870-1936	1936	1	1	P1	H
5R	Valley wetland-pond complex	<1870	1936	64	22	W3	L
5S	Oxbow pond-wetland complex	1870-1936	1936	5	1	P1	H
5T	Oxbow pond-wetland complex	<1870	1936	11	25	P2A	M
6A	Valley wetland-pond complex	<1870	1870	25	17	W1A (4%) W2A (96%)	H (4%) M (96%)
6B	Valley wetland-pond complex	<1870	2000	17	11	W3	L

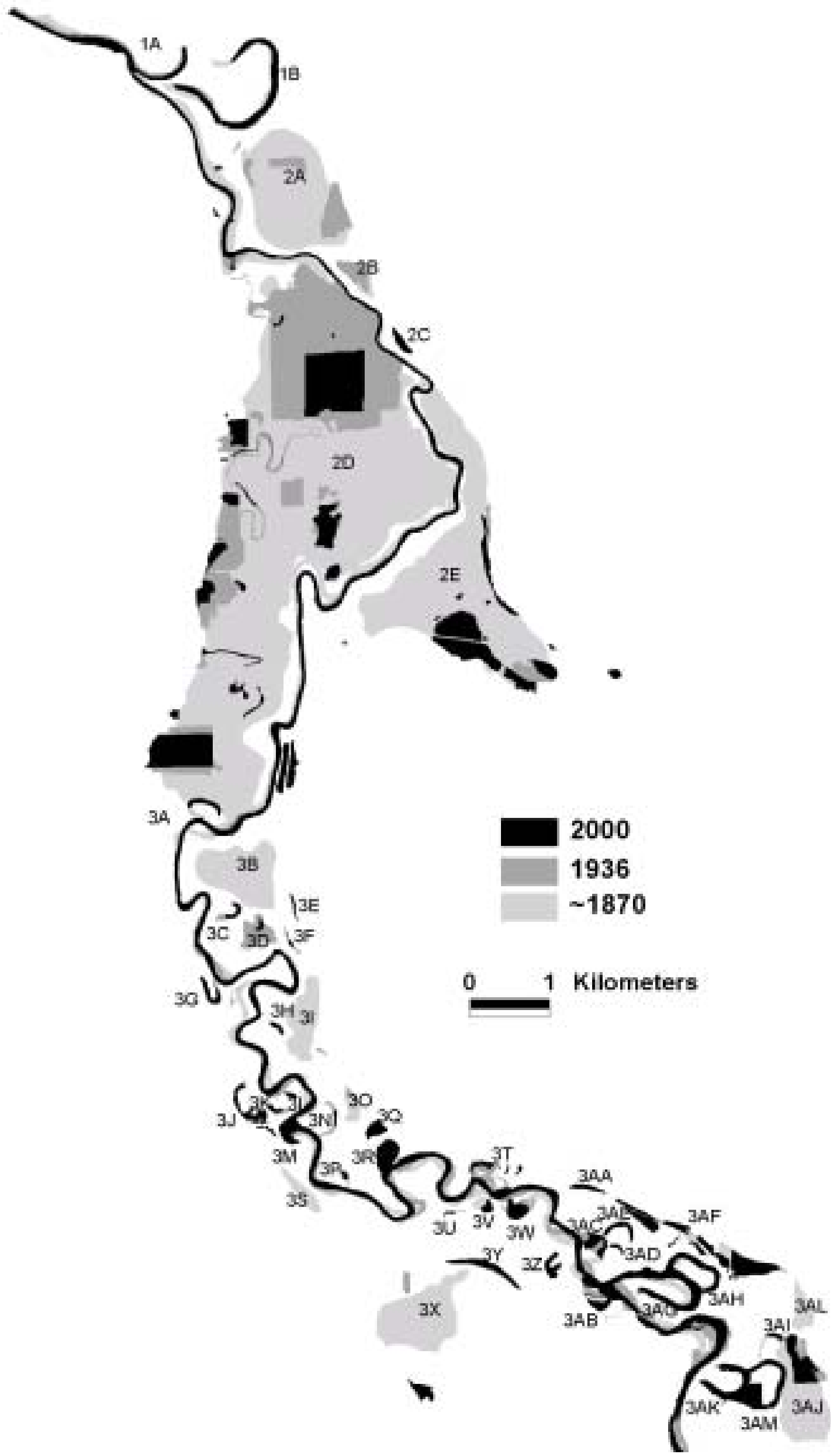

Figure 12. Index map for inventory of floodplain wetlands and ponds in Figure 5.

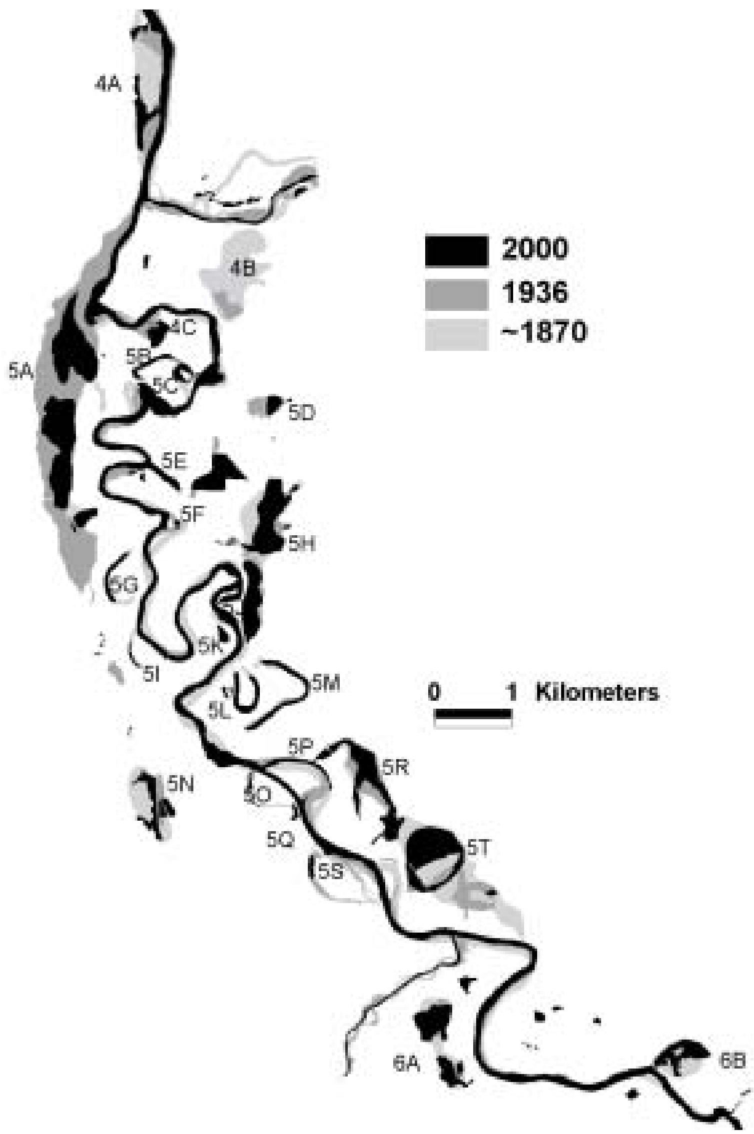

Figure 12 (continued). Index map for inventory of floodplain wetlands and ponds in Figure 5.

Table 6. Summary of restoration opportunities and considerations.

CONCLUSIONS RELEVANT FOR RESTORATION
River Channel
• Very slow rate of migration and avulsion
Oxbow Lakes & Wetlands
• Oxbow lakes and wetlands were and are abundant
• Oxbows are relatively static, most having been created earlier than the first map in 1873
• Potential for hydrological reconnection to the river and for riparian planting
Floodplain Tributary Creeks and Sloughs
• Potential to restore natural morphology to channelized and straightened creeks.
Valley-Marginal Wetlands
• Historically extensive, especially in lower part of river
• Topography favors “passive” restoration

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