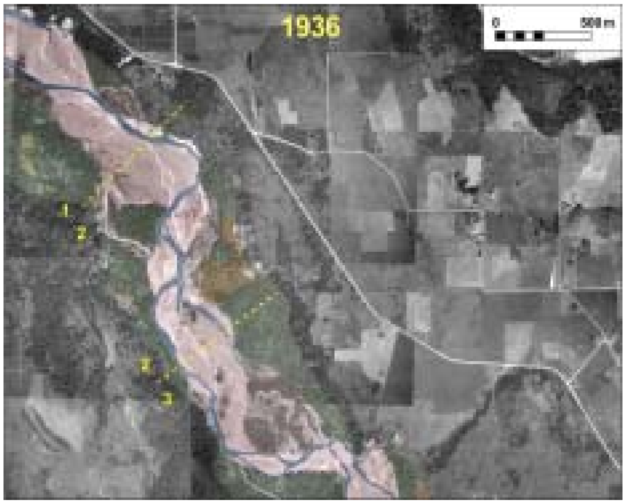
Historical Aquatic Habitats in the White River Valley, RM 5 – RM 28, King County, Washington



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SUMMARY

We reconstructed riverine environments of the White River in King County, Washington, from RM 5 to RM 28, for the time of early Euro-American settlement (~1870) in a Geographic Information System (GIS) using maps and field notes of the General Land Office (GLO) survey from 1867-1874, early maps from the US Geological Survey, orthorectified 1936 and 1940 aerial photos, other historical sources, and a high resolution lidar digital elevation model (DEM) provided by King County. We also mapped conditions from 1936 and 2000 aerial photographs. A companion study concentrates on historical channel locations of the White River in the same study area (Collins and Sheikh 2004a).

The White River from about RM 8 to RM 28 flows in a canyon the river has cut within the late Holocene (last ~5,000 years) into Quaternary glacial and volcanic lahar sediments. Downstream of the canyon the river flows on a large late-Holocene alluvial fan built into the Duwamish-Puyallup trough. At the transition between the canyon and the fan, historically the river split into a branch to the north—continuing as the White River (herein referred to as the “historical lower White River”) to its confluence with the Black River to form the Duwamish River—and to the south—as the Stuck River to the Puyallup River, roughly in the modern location of the White River. Most of the water flowed northward in the historical lower White River, and considerably less flowed south into the numerous, shallow and shifting channels that comprised the Stuck River. The entire flow was diverted to the south in 1907.

Inset between late Holocene river terraces, the floodplain in the canyon had a complex network of sloughs, ponds, wetlands, and tributary streams. Hardwoods dominated riparian forests, as reconstructed from GLO field notes. Western redcedar (*Thuja plicata),* while less common than five other tree species and comprising only 5% of immediately streamside trees and 16% of trees on the floodplain not immediately streamside, were the only species that commonly attained a large size (average diameter 56 cm streamside, and 90 cm not streamside) and so would most commonly have been large enough to

function as key pieces in wood jams. Other common species with moderate average diameters (ranging from 22 to 32 cm) were red alder *(Alnus rubra),* black cottonwood *(Populus trichocarpa),* Douglas fir (*Pseudotsuga menziesi),* and bigleaf maple (*Acer macrophyllum*). That large trees were not common may reflect effects of earlier fires, shown on 1897 and 1902 land classification maps, and may also reflect the White River's rapid channel shifting.

The amount of floodplain habitat (e.g. sloughs, wetlands, and ponds) varied with time, in part in response to flood history. A series of large floods in the first decades of the 20th century widened the river substantially so that the active channel accounted for 34% of the floodplain area. Gradually in the decades since the mid 1930s the channel has narrowed, and floodplain sloughs, wetlands, and ponds have formed in the reforested former mainstem channel; the active channel in 2000 accounted for 15% of the floodplain. No floods have approached the magnitude of the early 20th century floods since the closing of Mud Mountain Dam in 1948. On the White River Fan and the lower part of the canyon (the King County line on the White River Fan at RM 5 to ~RM 12.5 in the canyon), levees and revetments have isolated the river from the floodplain, and stopped the river's episodic creation and modification of floodplain habitats.

Our mapping of floodplain habitats (sloughs, wetlands, and ponds) for the ~1870 period is incomplete and fragmentary, because of the coarseness of the GLO survey and because subsequent river channel shifting obscured or eliminated much indirect evidence that would have been visible on the 1930s aerials or other sources. As a result, we have not made quantitative estimates of historical floodplain habitats. Additionally, the year 2000 mapping has not been field checked. The GIS mapping of floodplain habitats is most useful for describing the types and distributions of riverine habitats and their change through time. Quantitative estimates of floodplain habitats would require field surveys to confirm recent (year 2000) conditions; historical floodplain habitats cannot be completely reconstructed for the purpose of quantitative comparison.

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INTRODUCTION

Scope

This report describes aquatic habitats reconstructed for the time of early Euro-American settlement (primarily from mapping in 1867-1874, and referred to in this report as approximately 1870), and accompanies Geographic Information System (GIS) data for the White River from the King County line (RM 5) to below Mud Mountain Dam (closed in 1948; see Galster 1989 for detail) at about RM 28 in King County, Washington (Figure 1). This study and report accompany a study of historical channel locations in the same study area (Collins and Sheikh 2004a). The GIS data and associated metadata include: (1) a coverage showing hydrologic features and land cover in ~1870, interpreted from General Land Office (GLO) plat maps and field notes, early USGS topographic maps, 1931, 1936 and 1940 aerial photographs and other sources (Table 1); (2) GIS coverages of "bearing tree" data from GLO field notes (see Collins et al. 2003a, for detail), including the common name, diameter, and relative spacing of trees in the study area's historical forest; (3) coverages showing channels, ponds and wetlands and land use/land cover in 1936 and 2000; (4) supporting geospatial data, including orthorectified 1931, 1936 and 1940 photomosaics, georeferenced GLO plat maps and early USGS topographic maps.

Study Area

For a more detailed description of the study area, see Collins and Sheikh (2004a). Geologic field evidence indicates Mt. Rainier's Osceola Mudflow (~5,700 years ago; see Dragovich et al. 1994) blocked the early-Holocene outlet of the White River, which was then through the present-day South Prairie Creek valley, and diverted the White River to its present location (Crandell 1963). The White River subsequently eroded its present canyon, roughly from Mud Mountain Dam at the upper end of the study area to the city of Auburn (see Figure 1). The canyon contains a series of river terraces[1] of different elevations, which imply the river has subsequently incised. High-volume lahars and lahar-runout floods that traveled to the Duwamish estuary continued to inundate the White River canyon in the late Holocene, including at least three times in the last 2,200 ybp (Zehfuss et al. 2003).

Sediment generated from incision of the White River canyon augmented sediments from the Osceola and later lahars to build a large alluvial fan, herein termed the “White River Fan” (for detail, see Dragovich et al. 1994). This fan has been built into the broad, low gradient trough sculpted by Pleistocene glaciation (Booth 1994) in which the modern day Green River flows to the north, and the White River flows to the south (Figure 1). For the current analysis, the Fan reach is considered separately from the canyon reach at RM 7.6, in the vicinity of the Auburn Wall; see Collins and Sheikh 2004a for detail. Until 1907, the White River, upon leaving the downstream end of its canyon, split into two rivers, the White and the Stuck. The majority of the river flowed northward in the White River, which joined the Green River, retaining its name as the White River until it merged with the Black River to form the Duwamish River. The much smaller Stuck River flowed southward to the Puyallup River. Since 1907, the White River has been maintained in the former course of the Stuck River. In this report the valley in which the White River historically flowed northward will be referred to as the “historical lower White River valley.” The study area extends to the south to the King County line, but we have limited the extent of our mapping of the White River Fan to the extent of coverage by 1936 aerial photos.

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[1] We use “terrace” in this report to refer to any continuous surface in the valley bottom that is several meters higher in elevation than the floodplain. We use “floodplain” to refer to the geomorphic floodplain, or the surface currently flooded by the river and inclusive of all floodplain sloughs. We use “slough” to refer to floodplain channels connected to the river typically at both ends, or in some cases at the downstream end and fed by floodwater, springs or wetlands at the other end. We use “floodplain channels” to include sloughs and tributary creeks.

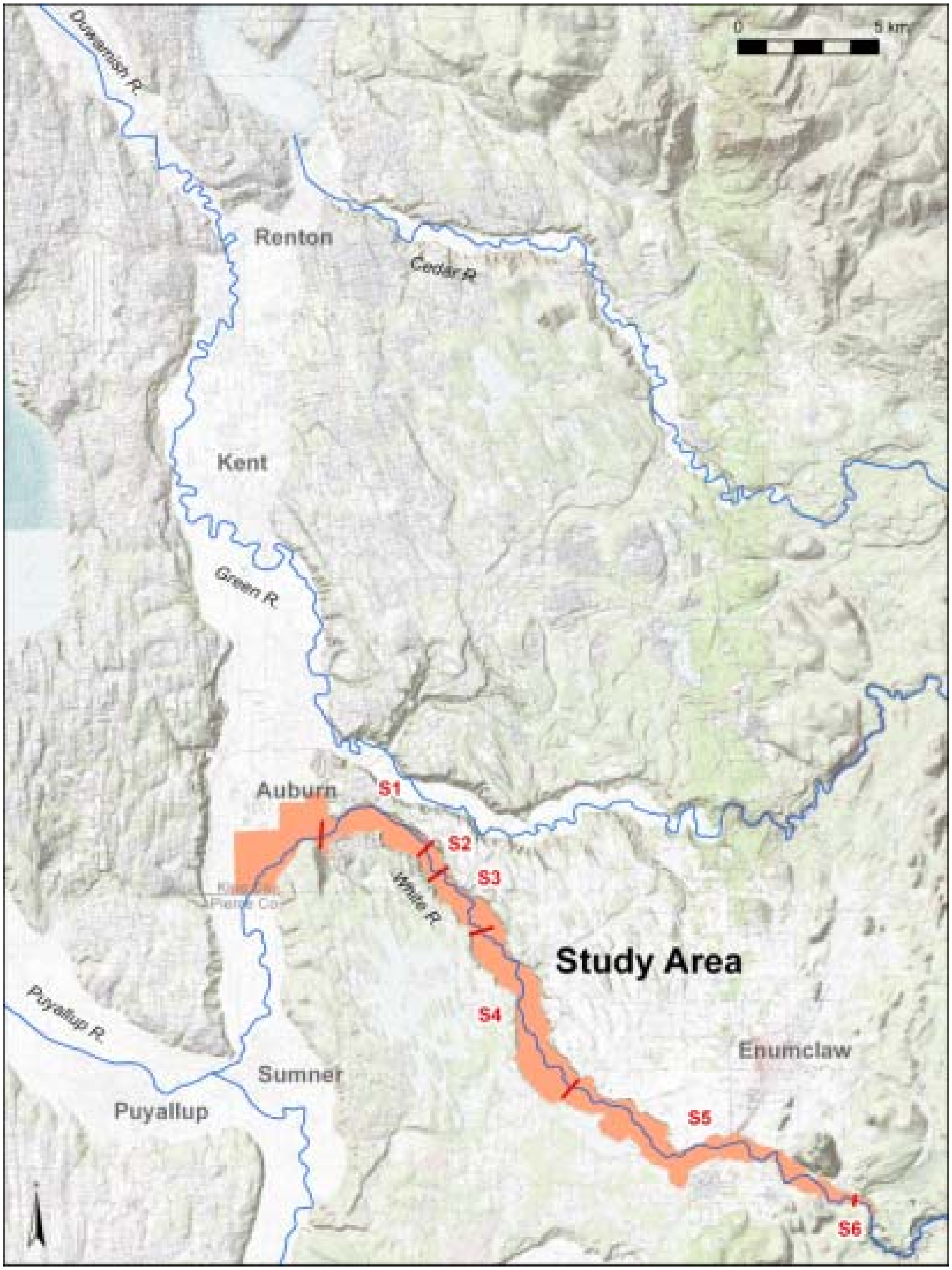

Figure 1. Location of the study area. Map shows modern river locations. Segment boundaries and numbers (“S1” etc.) refer to segments mentioned in text. See Collins and Sheikh (2004a) for detail on segments.

METHODS

Methods Used in Mapping 19th Century Conditions

Plat maps and field notes from the General Land Office survey are the primary source for land cover, channels, and wetlands at the time of early Euro-American settlement (Table 1). In mapping wetlands and creeks on the White River Fan, the earliest US Geological Survey (USGS) topographic maps (Table 1), at a scale of 1:125,000, supplemented the public land survey. We also used recent USGS topographic maps, soils surveys, and the digital National Wetlands Inventory (NWI) as supplemental information for mapping and characterizing wetlands (Table 1). We georeferenced (maps) or orthorectified (aerial photos) all of these images and brought them into a GIS. We also made use of a high-resolution digital elevation model (DEM) from lidar imagery for most of the area, excepting some of the left-bank (south) side of the White River valley where lidar was not available. For more information on these sources and their use in interpreting historical environments, see Collins et al. (2003) and Collins and Sheikh (2003).

The GLO surveyors generally "meandered" (field surveyed, using bearings and distances along the channel edge) channels shown as polygons on the plat maps (see White, 1991 for detail). Because the White River was field meandered, we consider its depiction on plat maps generally reliable. There are inaccuracies, however, as indicated where the channel location is inconsistent with topography (e.g. where a channel is mapped on a valley wall). In these areas, we have modified the channel position to be consistent with topography. The channel as drawn on the GLO plat maps reflects the meandering method and so is sometimes drawn with an angular appearance, an artifact that results from the GLO cartographers' literal rendering of the meander data.

The GLO field notes are a unique source of small channel widths, field measured and recorded to the nearest half link (1/2 link = 10 cm). We used these field-measured channel widths to estimate widths of small channels—those shown on the plat maps as lines, and in a few cases such as the Stuck River, smaller channels represented by polygons—in our GIS mapping. The GLO's mapping of smaller channels is typically reliable only near section lines, because the surveyors did not meander these streams, only noting and measuring them where intersected by section lines. Between section lines, the channel location can be reconstructed (with varying levels of confidence) using evidence such as relict channels visible on early aerial photos for location, or channels on early topographic maps (which are less precise than the early aerial photos) to confirm the channel's existence and its general location. In general using relict channels on aerial photos to locate historical channels creates the potential for interpretation error, as well as the potential for mapping channels that are older (or younger) than the time for which we are interpreting conditions.

Early aerial photos were useful for this purpose in this study only on the White River Fan. In the canyon reach, the early USGS topographic map did not show smaller channels, and for the most part the detailed topography shown by the lidar DEM was not useful because the river has migrated and avulsed extensively (and frequently) over its floodplain, generally (with some exceptions) erasing topographic clues to channel locations in the early-settlement time period. For this reason, in only a few cases we attempted to reconstruct the probable location of small channels in the floodplain of the White River canyon. Therefore the GIS coverage and map in this report do not show all of the floodplain channels that would have been present.

The Stuck River was not meandered in the GLO survey. The river's location on the plat maps can only be considered accurate where it was crossed by field surveys along section lines. Between these fixed points, we made use of topographic indicators, where the land surface has not been regraded or developed in the uppermost part of the river, near where it branched off from the White River. The location and plan view pattern of the river otherwise between section lines is not well constrained.

The GLO plat maps are the primary source for mapping wetlands and ponds. The GLO survey generally noted and mapped wetlands only where encountered along a section line. In a few cases on the

White River Fan we could use the earliest USGS topographic maps to extend wetland boundaries between section lines, or to map wetlands entirely within section interiors. However, the topographic maps are limited in usefulness because they were surveyed after many wetlands were drained, and because they were drawn at a coarse scale. We supplemented these map sources using wetlands identified from 1931, 1936 and 1940 aerial photographs, and by using NWI wetland mapping, and the extent of organic soils shown on soils maps (Table 1). We did not find useful historical sources for mapping the small wetlands that would have existed in the White River canyon. Therefore the GIS coverage and map in this report do not show the small wetlands that would have existed on the floodplain in the White River canyon. In general, historical floodplain habitats (sloughs, ponds, and wetlands) are incompletely mapped in the canyon reach. Additionally, for the most part we are not able to map small ponds or wetlands, for the same reasons—the GLO survey was confined to section lines and would have missed most of these features, and subsequent channel migration has erased visual and topographic evidence of there presence.

We have not distinguished differences in forest communities other than by geomorphic location (i.e., on floodplains, terraces, or fans, and whether immediately streamside or not). For the present purpose, we concentrated on characterizing the nature of wood that would have been recruitable to rivers. We used bearing trees from the GLO field notes to characterize the diameter, species frequency, and basal area of forest trees; see Collins et al. (2003) and Collins and Sheikh (2003) for explanation. We also gathered information on fluvial wood from Annual Reports of the Army Engineers (e.g. Ober 1898) and other engineering assessments (e.g. Chittenden 1907).

Methods Used in Mapping 1936 and 2000 Conditions

For 1936 conditions, we mapped land use/land cover, wetlands, and channels from the 1936 aerial photographs without supplemental information, except for lidar imagery in a few places where it was appropriate (e.g. for confirming the presence of floodplain sloughs in floodplain areas where the main channel had not been present since 1936). We did the same for 2000 conditions, except that we made extensive use of lidar imagery in mapping small floodplain channels and in a few cases channel locations on recent topographic maps. Because the mapping was from aerial photographs and lidar exclusively with no field checking, we distinguished “channels” from “lidar lineaments.” Channels were visible on the aerial photographs or mapped on recent topographic maps. “Lidar lineaments” are linear topographic depressions visible on lidar imagery, which may or may not correspond to channels or relict channels. Lineaments were divided into two categories: “1” for stronger lineaments (deep and continuous for a significant distance), and “2” for weaker ones. It is likely that many of the “1” lineaments are active channels, because they are similar to those lineaments that correspond to channels that were evident on the photos or topographic maps, but this cannot be confirmed without field checking. No aspect of our 2000 mapping, including floodplain features (sloughs, wetlands or ponds), has been field checked.

Table 1. Maps used in study, 1867-2000. Source: 1 = University of Washington libraries; 2 = US Army Corps of Engineers Seattle District; 3 = Bureau of Land Management; 4 = Intercounty River Improvement District; 5 = King County.

YEAR & SOURCE	TYPE & SCALE	TITLE	AREA
1867-1891[3]	General Land Office plat maps and field notes (1:31,680)	(1) T21N R4E (1867) (2) T21N R5E (1867) (3) T20N R5E (1872) (4) T20N R6E (1872) (5) T19N R6E (1873) (6) Parts of T20N & T21N, R5E (Muckleshoot Indian Reservation) (1874) (7) T19N R7E (1891)	(1) RM 5-6 (2) RM 6-13 (3) RM 13-18 (4) RM 18-25 (5) RM 24-26 (6) RM 6-16 (7) RM 26-28
1895[1]	USGS topographic (1:125,000)	Tacoma Quadrangle (Gannett et al.)	RM 5-24
1909[1]	US Soils Bureau Soils Survey (1:125,000)	Reconnaissance Soil Survey of the Eastern Part of Puget Sound (A.W. Mangum)	RM 5-28
1931[4]	B/W aerial (1:20,000)		RM 5-18
1936[2]	B/W aerial (1:10,500)		RM 5-26
1940[2]	B/W aerial (1:12,000)		RM 5-28
1972[1]	USDA SCS Soil Survey (1:24,000)	Soil Survey King County Area, Washington	RM 5-28
1993-1994[1]	USGS topographic (1:24,000)		RM 5-28
	National Wetland Inventory (Digital)		RM 5-28
2000[5]	Color aerial (Digital; 2 ft cell)		RM 5-28
2003[5]	Lidar Digital Elevation Model (Digital 2 m cell)		RM 5-28, exclusive of parts of south side of river valley bottom.

HISTORICAL CONDITIONS

Channels and Wetlands

The White River in the canyon reach branched in several areas, creating forested islands as large as 3 km in length (Figure 2). Sloughs exited and rejoined the river. The GLO surveyors crossed a number of these floodplain sloughs, but for the most part we could not reconstruct these sloughs in detail, because the river has migrated across much of the area where sloughs would have been, erasing visual indicators on aerial photos and topographic evidence visible on the lidar DEM. As indicated previously, it was not possible to completely map sloughs or small wetlands and ponds. Figure 2 shows only a small proportion of floodplain habitats that would have existed.

On exiting the canyon, historically floodwaters diverged and flowed down the White River Fan, in a number of shifting and ephemeral flood channels to the southwest and south to the Stuck River drainage (Figure 2). Other channels drained to the northwest and west to Mill Creek, which drained the marsh-filled lower elevation western part of the historical lower White River valley at the western margin of the Auburn fan. The channels drawn on the White River Fan in Figure 2 reflect a combination of streams shown on the GLO maps and flood channels evident on 1940 aerial photographs. Some of the channels mapped from the photographs may have been created more recently than the second half of the 19th century. Many of the channels were mapped as discontinuous because it was not possible to trace them on the photographs; in the GIS layers they are coded as “ephemeral” and are not included in channel area estimates.

The ~1870 Stuck River’s location is not well constrained because it was not meandered by the 1867 GLO field survey. The ~1870 location is only known precisely at section boundaries. In the upper part of the historical Stuck River course, it was possible to use topography indicated by lidar imagery to approximate the historical location and channel pattern. Elsewhere, the channel would have had multiple channels, as described below, but this is not reflected on the map in areas where we had no data for reconstructing these channels.

Major Hiram Chittenden was charged in 1906 with evaluating the evidence that would indicate whether the Stuck or the White had been the larger channel previous to Euro-American settlement era. He concluded that the river had primarily flowed northward for at least a few hundred years:

> "…in the geological formation of the valleys, and in the record of the first surveys [referring to the General Land Office surveys], is conclusive that the White River for an indefinite period in the past—running back certainly for hundreds of years—has mainly flowed north into the Duwamish until within the past few years" (Chittenden 1907).

In reaching his conclusion, Chittenden (1907) drew on the fact that the lower Stuck valley is a "low, swampy basin, with a surface soil of peat" thick enough to suggest a lower-energy depositional environment (unlike that of the historical lower White River) for a considerable period of time. He also pointed out that the GLO surveys indicated there were "no natural channels through this basin of any greater consequence than small creeks, and these wound about in irregular courses, affording outlets for local drainage."

Chittenden (1907) also pointed out that in the southern end of the Stuck River basin the valley floor rises "about eighteen feet" above the lowest part of the valley, when it encounters the deposits of the Puyallup River; the town of Sumner is built on this topography. He reasons from this that had the White been "flowing in that direction at the same time, it would certainly have filled the Stuck basin as fast as the Puyallup, being a larger stream." His argument does not take into account the depositional effects of the Electron Mudflow into the Puyallup valley about 500 ybp (Crandell 1963), which could account for the higher elevation in the Puyallup valley, or the possible effects of the Tacoma Fault Zone (see Sherrod et al. 2004 for recent review), but neither possibility contradicts Chittenden's interpretation of the dominance of the White channel for several centuries. In the longer view of several thousand years (post-Osceola Mudflow, or ~5,700 ybp) because the shape of the greater White River fan is broadly symmetrical from north to south, it seems likely sedimentation to the north and south was broadly equal.

From talking with settlers and Indians, an Army Engineers surveyor reached the same conclusion regarding the historical dominance of the White River:

> "From settlers who have lived near by for the last fifteen years and from the Indians on the Muckleshoot Indian Reservation at the head of the river, I learned that Stuck River was formerly little more than a brook which one could step across at low water. It pursued the same general course as it does now, forming a succession of sloughs with slight depth…." (Ober, 1898).

This account pieced together second hand by a government surveyor is consistent with descriptions in GLO field notes from an 1867 survey. Ober's description of the Stuck River in the last years of the 19th century indicates that by that time a considerable amount of the White River discharged to the Stuck:

> "…This is a stream of small cross section at low water, but with considerable fall and consequent great velocity of current…The width of the river between the high-water lines is about 400 feet. In places it reaches a width of 600 feet. The width of the stream at low water averages about 80 feet. The river for the first 3 miles is choked with log jams, and flows through a heavily-wooded country which is thickly settled. The discharge at the average low-water stage is about 40,000 cubic feet per minute [666 cfs]. From one-fourth to one-third of the total volume of White River, at low water, passes down Stuck River. At high water probably one half goes down Stuck River." (Ober 1898).

He goes on to indicate that the Stuck River had excavated this channel only recently:

> "… Since then it has excavated for itself the present channel, the bottom of which is from 8 to 16 feet below the level of the valley. It is constantly jamming up with logs and drift, which back up the water and force it to cut a new channel around the obstruction." (Ober 1898)

Our mapping of the Stuck River (Figure 2) makes use of the 1867 GLO field notes and plat maps, and therefore reflects the conditions that the Army Surveyor reconstructed from talking with settlers and Indians, and that Chittenden surmised, not the condition noted in Ober's 1898 visit, by which time the Stuck River had acquired more flow and a larger channel.

Riparian Forests

This description of historical forest composition draws primarily on bearing tree data from the GLO field notes (see section on methods, earlier in this report) because this data is the most systematic, quantitative, and consistently available. In the study area, the overwhelmingly most common immediately-streamside bearing trees were red alder (*Alnus rubra*), which accounted for more than half (55%) of bearing trees (Figure 3). Black cottonwood (*Populus trichocarpa*), was the second most common streamside bearing tree (17%); conifers together accounted for 17% of streamside bearing trees (Douglas fir, *Pseudotsuga menziesii*, 10%, western redcedar (*Thuja plicata*) 5%,, Sitka spruce, *Picea sitchensis*, 2%) . The valley bottom bearing trees (trees not immediately streamside) were more diverse, and included more conifers—40% of the total—with Douglas fir (22%), bigleaf maple (*Acer macrophyllum*; 21%), red alder (17%), and western redcedar (16%) being common, and black cottonwood less common (8%).

The largest diameter immediately-streamside bearing trees were western redcedar although the sample size is small (2 trees of 42 total) which averaged 55.9 cm. Douglas fir (4 trees averaging 32.4 cm), bigleaf maple (3 trees averaging 27.1 cm) and black cottonwood (7 trees averaging 26.8 cm) were moderate-diameter trees. None were very large on average compared to elsewhere in the White-Green-

Duwamish river valley system (see Collins and Sheikh 2004b) or relative to the size necessary to function as key pieces in wood jams. This could reflect the White River’s relatively dynamic lateral migration (Collins and Sheikh 2004a). It may also reflect the effects of recent fire; land classification mapping (Plummer et al. 1902; Gannet et al. 1897) show most of the forest in the canyon reach as having been burned. The largest diameter valley bottom (not immediately streamside) bearing trees were also western redcedar (14 trees averaging 88.9 cm). Species commonly having a moderate diameter were red alder (15 trees averaging 29.6 cm), black cottonwood (7 trees averaging 25.4 cm), Douglas fir (19 trees averaging 25.3 cm), and bigleaf maple (18 trees averaging 22.6 cm).

A diversity of tree sizes is ideal for making wood jams, including a sufficient number of large ones to initiate a jam, and numerous trees of various sizes to build the jam. The bearing tree data indicates that western redcedar would have contributed the largest functional wood to the White River likely to function as key pieces in jams. Although western redcedar was not common immediately streamside (5%), it was more common (16%) in the valley bottom where river migration could recruit trees over time. Other species were more common streamside than western redcedar and were on average moderately large in diameter, with means ranging between 27 cm and 32 cm; the same was true of trees not immediately streamside.

In-Channel Wood

We found few descriptions of in-channel wood in the study area. The Army Engineers snagging operations, whose records elsewhere provide an indication of the sizes and amounts of wood, extended up the historical lower White River (present-day Green River) no farther than Kent, which was then the upstream limit of navigation. All other descriptions of in-channel wood that we have found are of the Stuck River and the White River at the mouth of the canyon.

In his 1898 field survey for the Army Engineers, Ober (1898) noted about the Stuck River “the river for the first 3 miles is choked with log jams” and that it was “constantly jamming up with logs and drift, which back up the water and force it to cut a new channel around the obstruction.” Chittenden (1907) added to Ober’s observation that the lower river transported “an enormous load of driftwood.” He described the White River watershed as “everywhere timbered and the trees along the banks are constantly being undermined and dropped into the channel.” He went on to write “the channels are strewn with immense trunks, often two hundred feet long, with roots, tops and all” (Chittenden 1907).

Chittenden indicated that drift in the first years of the 20th century had been “increased immensely” by saw logs and by wood from the clearing of old jams, and that in the lower river: “…the drift consists mainly of saw logs and smaller debris, though occasionally large trees find their way so far down,” and that larger drift would function as key pieces to nucleate jams:

> “Wherever these floating obstructions catch in the bottom or on the banks or against bridge piers they become nuclei for other drift and develop into “jams,” which frequently block the channel altogether.” (Chittenden 1907)

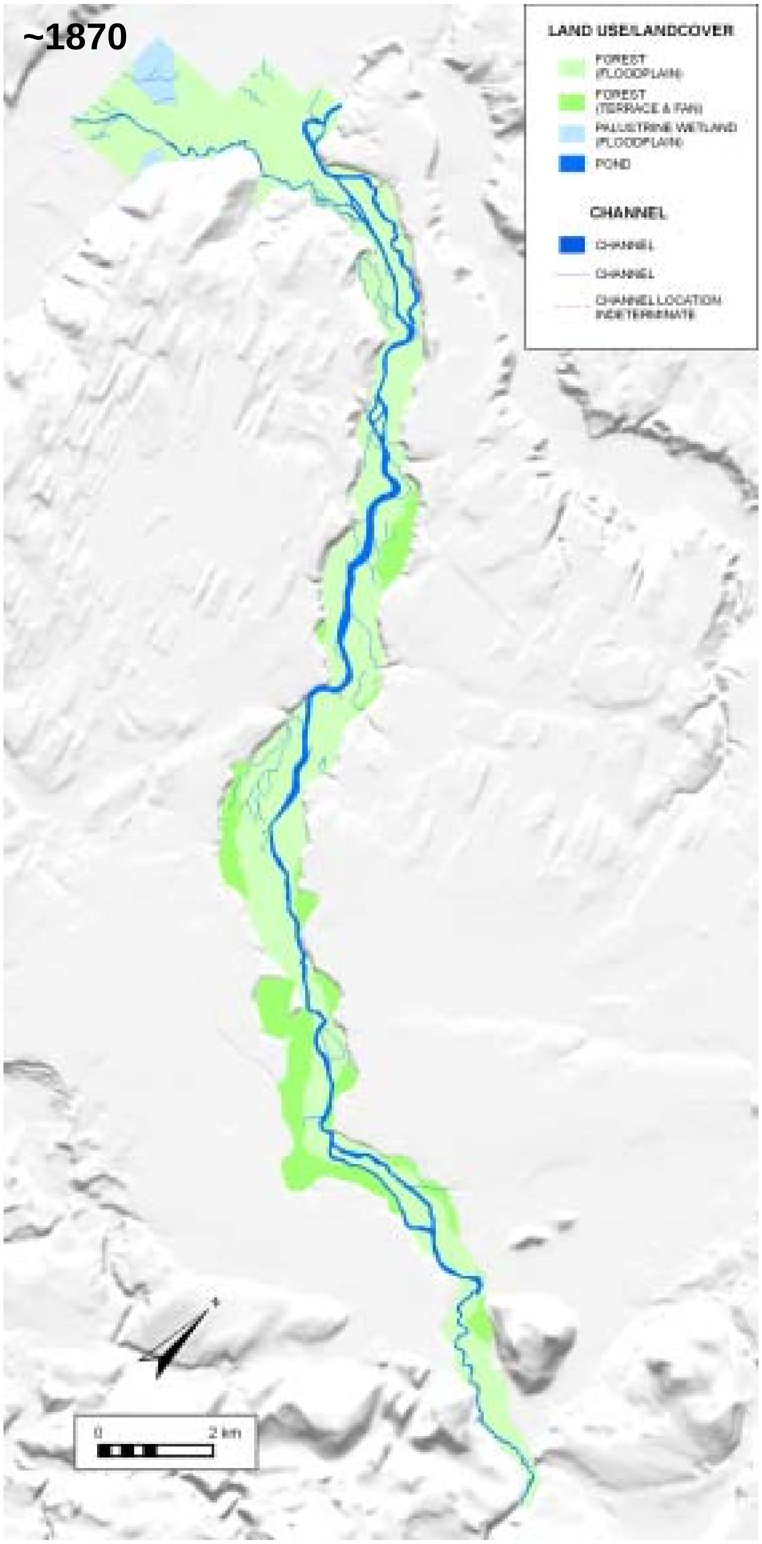

Figure 2. Historical land use/land cover, channels, and wetlands in the study area, approximately 1870.

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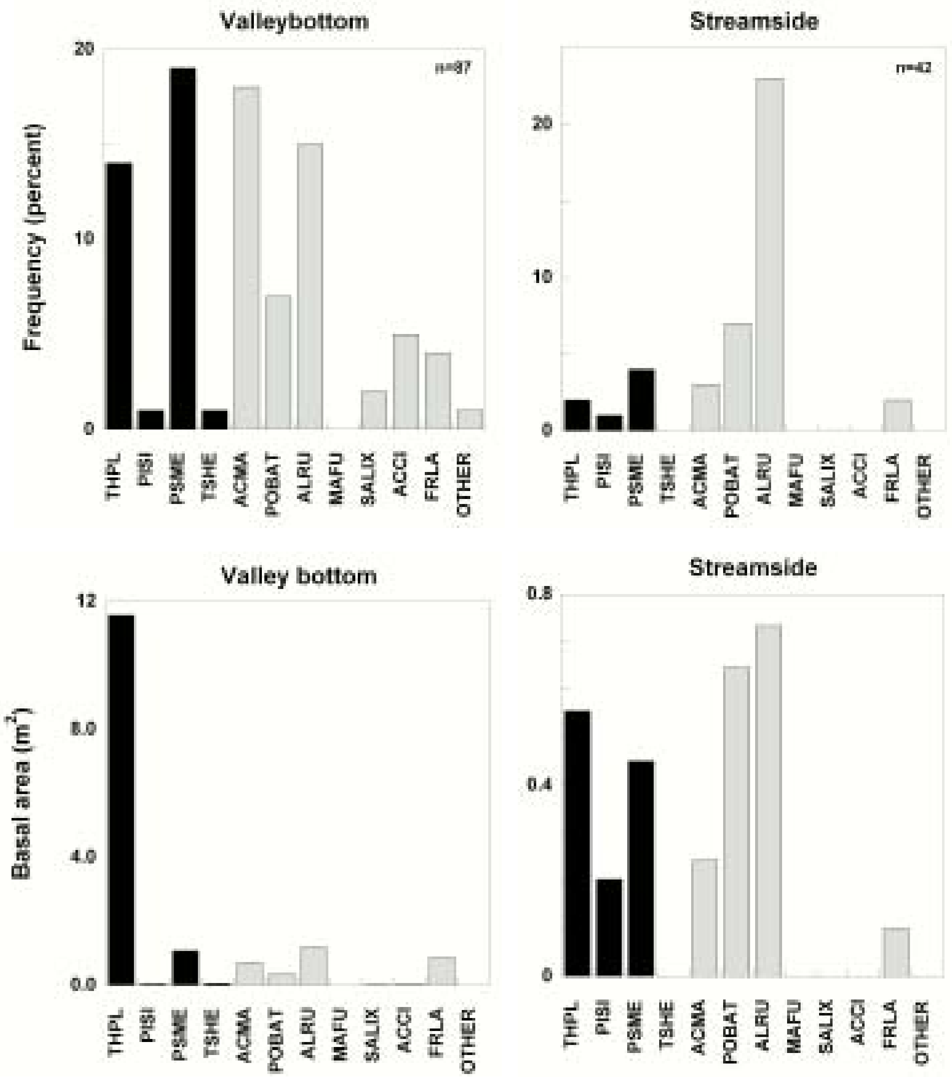


Figure 3. Frequency and cumulative basal area of bearing trees in General Land Office field notes for the study area. Black bars are coniferous species and gray bars are deciduous species. THPL: *Thuja plicata* (western redcedar); PISI: *Picea sitchensis* (Sitka spruce); PSME: *Pseudotsuga menziesii* (Douglas fir); TSHE: *Tsuga heterophylla* (western hemlock); ACMA: *Acer macrophyllum* (bigleaf maple); POBAT: *Populus trichocarpa* (black cottonwood); ALRU: *Alnus rubra* (red alder); MAFU: *Malus fusca* (Pacific crabapple); SALIX: *Salix spp*. (Willow species); ACCI: *Acer circinatum* (vine maple); FRLA: *Fraxinus latifolia* (Oregon ash); “Other” includes: PREM: *Prunus emarginata* (bitter cherry). *Note that scale of y-axis varies between panels in plots of basal area.*

CHANGE, ~1870-2000

Primary land use changes on the White River fan include levees and revetments built along the lower river (see Collins and Sheikh 2004a for detail) and the transformation of the White River Fan to agriculture, which dominated in 1936, to urban, which dominated in 2000. The canyon reach saw logging by 1936; "cleared" areas in Figure 4A reflect areas that had been logged relatively recently before that year. By 2000 (Figure 4B), there was limited urban development, primarily on terraces, and agriculture within the study reach. These latter land uses locally have eliminated sloughs or isolated them from the river. Changes to the river and its sloughs also reflect the flood history.

Mainstem

The active channel area and channel width increased substantially in the period between the GLO mapping and the 1931 and 1936 aerial photographs (Figures 5A-5K). The active channel decreased in all segments from 1936 to 2000, as illustrated in Figure 5 and quantified in Figure 6. Channel areas in the 1930s are between two and four times greater than the GLO-era channels (Figure 6). As described earlier in the "methods" section of this report, GLO plat maps generally depict the channel as wider than measured in the field, and the discrepancy varied locally, but it is likely that the GLO maps overestimate the actual channel area, which would cause the magnitude of pre-1930s channel widening in Figure 6 to be an underestimate. On the other hand, while we believe there is strong evidence supporting our interpretation that GLO channels represent the active channel (i.e., including low-flow channel, bare gravel bars, and gravel bars with colonizing vegetation), we do not know how consistently this convention was observed. However, it is likely that the channel drawn on GLO plat maps is a reasonably accurate representation of the active channel.

The active channel area then diminished substantially from the 1931-1940 period, in all segments, in the subsequent two decades. The channel area in all cases diminished to the 1955-1959 period, in most cases returning to channel areas similar to those first mapped by the GLO in the 19th century, with the exception of segment 6, which is a relatively confined reach. The channel area in some segments increased in segments 2, 3, and 4 after the 1955-1959 period, and decreased slightly in segments 1 and 5.

Several large floods between 1918 and 1934 correspond in time with the channel widening in the 1931-1944 period. Records of flood peaks are incomplete prior to 1929. Records from the USGS "White River near Buckley" gage (12098500) in the study reach at RM 27.9 (drainage area 401 mi^2) include flood peaks from WY 1929-1934 and WY 1939-current (Figure 7). The nearby (RM 23.3, drainage area 427 mi^2) USGS "White River at Buckley" gage (12100000), also in the study reach, include flood peaks from WY 1900-1902, WY 1911-1912, WY 1914-1919, WY 1921-1923, WY 1935-1938, and WY 1978-current. For the purpose of identifying the years of largest floods on record and their relative magnitude, a regression of flood peaks from the two sites shows that data from the sites are interchangeable for the present purpose, with larger floods (>15,000 cfs) at the two gages agreeing within 1 to 3%. In the 103-yr period of record, 15 years are missing, and all of the missing years are prior to 1929. The available record shows that the six largest floods on record were in the period between 1918 and 1934 (data is missing from six of these seventeen years). The largest flood was in 1934 (28,000 cfs at the "Near Buckley" station), the second largest was in 1918 (23,100 cfs at the "At Buckley" station), the third was in 1919 (19,000 cfs at the "At Buckley" gage), the fourth in 1932 (17,000 cfs at the "Near Buckley gage), the fifth 16,600 cfs in 1922 (at the "At Buckley" gage), and the sixth largest in 1933 (16,600 cfs at the "Near Buckley" gage).

This series of large floods could explain the increase over GLO-era areas, as well as an increasing channel area between 1931 and 1936. Riparian logging could have caused some channel widening, but the 1936 photos do not suggest there had been widespread riparian logging in the first decades of the 21st century. Channel narrowing that followed would then have resulted from the absence of large floods, which in turn could have been influenced by the closing of Mud Mountain Dam in 1948. Quantifying the effects of the dam would require hydrological analysis not undertaken for this project.

Levees built in segments 1 and 2 may have had some influence on channel area (see Figure 5B and 5C). The channel area remained constant in segment 1 after levees were built (“L1” in Figure 6). However, segment 5, which lacks levees, showed a similar response (Figure 6; Figures 5G-K). In segment 2, where a levee was breached in the late 1970s (“L2” in Figure 6), the channel widened. However, the timing of this widening is similar to that in segment 4, and slightly different than that in segment 3.

Floodplain Sloughs

The length, number, or area of floodplain sloughs cannot meaningfully be compared between earlier periods and currently, for several reasons. First, to accurately map *current* sloughs would require field checking, because few sloughs can be seen on forested floodplains such as the White River from aerial photographs alone. The same is true for earlier aerial photographs. The problem is even greater for characterizing conditions prior to the aerial photographic record (i.e. before 1931), which relies on map sources. Early USGS topographic maps are drawn at a very small scale and show little detail. The GLO plat maps are based on field mapping that did not involve meandering floodplain sloughs.

Channel Area

The active channel area of the White River, measured from the GIS mapping, is given in Table 2. Area increased from 265 hectares in ~1870 to 630 in 1936, and decreased again to 287 hectares in 2000. The active channel accounted for 14%, 34%, and 15% of the floodplain, respectively. This fluctuation in channel size was due to changes in the high flow channel area; the low flow channel was only 3% greater in 2000 than 1936, an amount that is within the error caused by difference in river stage between the two photo years. (As indicated previously, the ~1870 low-flow channel could not be measured because the GLO plat maps showed only the active channel.) While low flow habitat area was effectively unchanged between 1936 and 2000, changes in the high flow channel area have direct effects on the amount of floodplain habitat, as described below.

We did not estimate the area of floodplain sloughs. This is because we could not fully map sloughs from the ~1870 period, nor could we reliably map sloughs in 2000 without field checking. Similarly, the area of ponds and wetlands could not reliably be mapped in the ~1870 time period, and would also require field checking to reliably indicate areas for the year 2000. Querying the 2000 GIS coverages can give an initial estimate of pond and wetland area, which can then be refined in the field, and similarly the 2000 GIS mapping of floodplain channels can be refined in the field.

Qualitative statements can be made about how the total length and area of floodplain sloughs has changed through time. First, temporal change in mainstem channel area has been substantial, and indirectly this influences the amount of slough habitat. When more of the floodplain is occupied by active channel, less of the floodplain area is occupied by sloughs, and so there is a net loss of slough habitat, and at the same time no gain in low flow mainstem channel habitat. When the mainstem active channel narrows, as it did between 1936 and 2000, there is no loss in low flow mainstem channel habitat (and a possible increase in quality), and a significant gain in floodplain habitats, because sloughs, wetlands, and ponds form in the areas formerly occupied by the main channel. In summary, it is likely that from 1870 to 1936 there was a decline in floodplain habitats (e.g., sloughs, wetlands, and ponds) with no compensating gain in mainstem low flow channel area, and from 1936 to 2000 there was a gain in floodplain habitats, with no loss in low flow mainstem channel habitat area.

Second, parts of the floodplain have been isolated from the river. On the White River Fan, the channel was leveed prior to 1936. There was also a net loss in channel area when the White River was blocked from its former course and diverted to the former course of the Stuck River, which was then straightened. In the canyon, diking in the 1950s isolated the floodplain from the river to about RM 12.5, so that by this time the river was isolated from its floodplain in the approximately 7.5 river miles upstream from the King County line.

In general, this reconstruction is most reliable as a qualitative description of how the landscape was structured and the processes and elements that structured it; quantitative estimates of habitat areas (especially in the dynamic environment of the White River valley) are incomplete or imprecise and best used to indicate the relative importance of different habitats. When using these data for the purpose of quantitative habitat assessments, it is important to keep in mind the nature of the source data, and the assumptions with which we used those data to make these quantitative estimates of historical habitats. In particular, floodplain habitats (sloughs, ponds, and wetlands) are incompletely mapped in the 1870 period, and many of the features that were mapped have a lower level of evidence than other features. In particular: (1) Floodplain habitats mapped from the 2000 photos were not field-checked. Mapping also made use of lidar imagery that was not available for the entire valley bottom. (2) Large channels taken from GLO maps for the 1870 coverage incorporate errors in those maps. We have found in north Puget Sound valleys that the river widths shown on the plat maps may vary from the field-measured width, from surveyor to surveyor, and from township to township and that on average the map widths were a few percent greater than field measured widths. Platting of GLO channels was also pictorially crude, as evident by the jagged, geometric shape to many of the channels in the GIS mapping (e.g. in Figure 2). However, where it has been possible to independently corroborate large channels shown on GLO maps, their positional accuracy is relatively good.

Habitat Restoration Implications

One factor involved in restoring lost habitats in the study reach is the isolation by levees of the river from the floodplain in the lower part of the canyon reach, and in the entire fan reach. Restoring existing, relict floodplain habitats in these areas involves restoring hydrologic connectivity to the floodplain that levees now isolate from the river. Restoring dynamic floodplain habitats, created and modified through time by channel migration and avulsion, involves removing or setting back levees.

A second factor involved in habitat restoration is restoring very large flood events lost by the construction of Mud Mountain Dam. The relationship between loss of very large floods and habitat loss involves a hypothesis requiring more study. Based on the evaluation of historical photos and maps for this study, and comparison to rivers elsewhere in the eastern Puget Sound area, it appears that rivers such as the White River under a natural flow regime experience cycles of channel widening associated with very large floods, followed by narrowing. This occurred, for example, in the Nooksack River, with the timing of channel widening roughly similar to that in the White River study area (Figure 8A); segments "UN1" and "UN2" in Figure 8A historically most closely resembled the White River study area in channel pattern and are in a similar topographic setting. In the Nooksack River, after the channel widening in the 1930s, the active channel area declined through time, but remain greater than in their mid-19th century condition; other segments of the river have undergone significant area increases in the last few decades. In the White River, channel areas declined precipitously following their peak in the 1930s, and this decline is associated in time with the closing of Mud Mountain Dam (Figure 8B). (The Nooksack River is not dammed.) This suggests the hypothesis that natural fluctuations in channel area associated in time with very large floods is eliminated by dams that eliminate these floods, and that this in turn causes progressive channel narrowing. The history of the Cedar River supports this hypothesis. The Cedar River's channel pattern historically was similar to that of the White River in the study area. Water diversion in 1904, followed by impoundment of water in a water storage dam in 1914 (shown as "MD" for Masonry Dam, in Figure 8C), in combination with bank protection and levee construction, has progressively narrowed the active channel of the Cedar River, so that the 2000 area was 37% that of the area shown on GLO plat maps in 1864-1865 (Figure 8C).

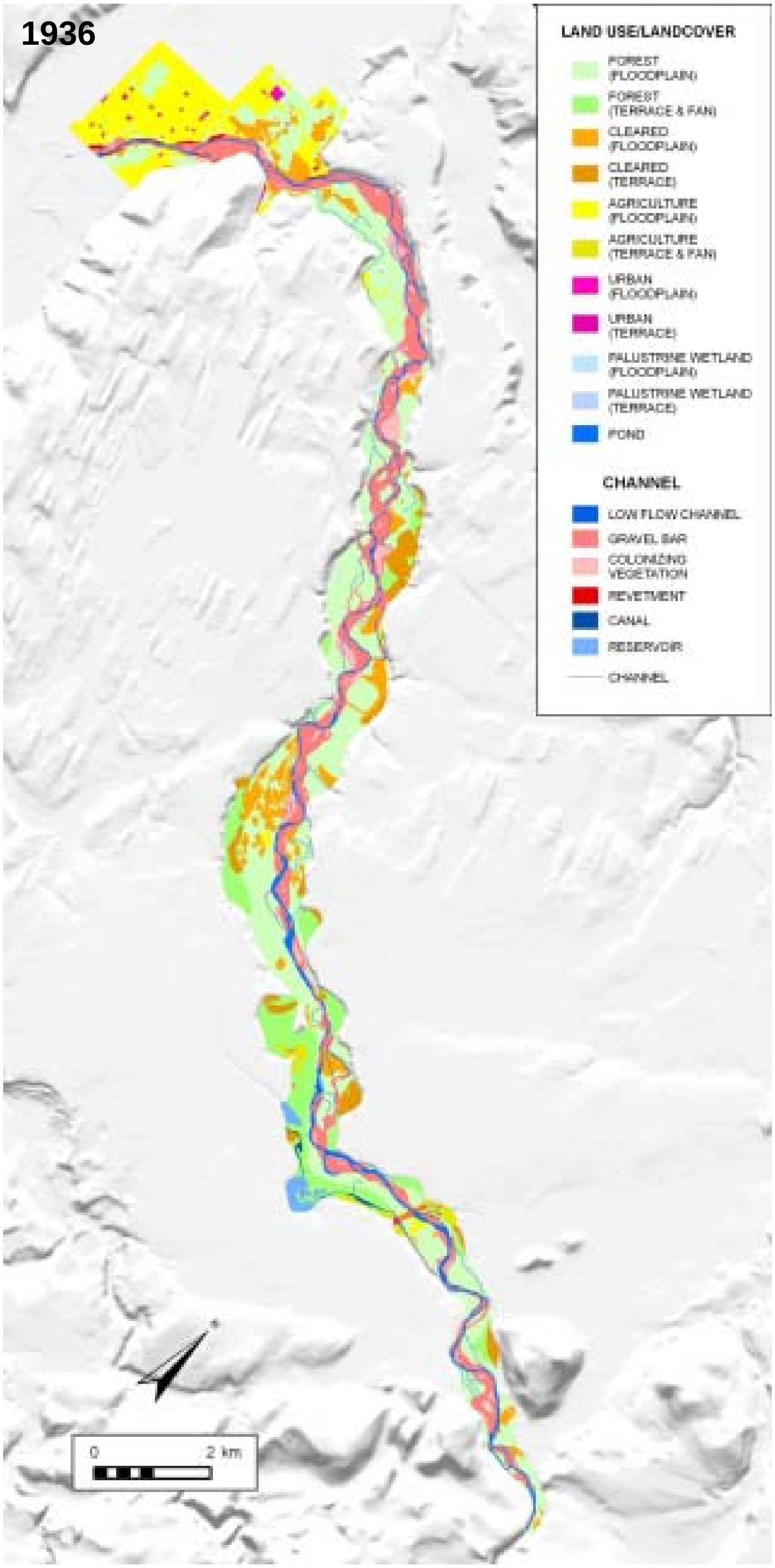
An extension of this hypothesis having implications for riverine habitat is that the loss of very large floods, and the loss of natural fluctuations in active channel area, causes the progressive loss of floodplain habitats. Dramatic channel widening could reduce the amount of floodplain habitat compared to conditions prior to the widening, but only for a few decades while forests colonize much of the widened channel. Associated with this narrowing, or following channel avulsion, floodplain sloughs, ponds and wetlands form in the reforested relict topography from the former main channel. In the absence of a flood disturbance, presumably these habitats gradually fill in or become blocked, so that in the absence of a future large flood event, floodplain habitats would decline over time; if this hypothesis is correct, floodplain habitats in the White River floodplain should have decreased since the closure of Mud Mountain Dam. Proving or disproving this hypothesis would require further study. Additional hypotheses to explore include the possibility that maintaining frequent channel avulsion could largely maintain floodplain habitats in the absence of very large floods. The maintenance of frequent channel avulsion, in turn, is associated with a supply of very large fluvial wood, necessary to initiate stable jams, and with bank erosion that can recruit large numbers of trees to contribute to these jams (Collins and Montgomery 2002).

Table 2. Estimated mainstem channel areas in the study area, measured from GIS coverages. The active channel encompasses the low flow channel and the high flow channel (bare gravel bars and gravel bars with colonizing vegetation). The low flow and high flow channel were not differentiated in the GLO plat maps.

MAINSTEM CHANNEL	AREA (HECTARES)					
	~1870	PERCENT OF FLOODPLAIN AREA	1936	PERCENT OF FLOODPLAIN AREA	2000	PERCENT OF FLOODPLAIN AREA
Active Channel	264.7	14%	630.0	34%	286.6	15%
Low flow	-		*135.7*		*140.5*	
High flow	-		*494.3*		*146.1*	

Figure 4 (following two pages). Land use/land cover, wetlands, ponds and channels in the study area, mapped from aerial photographs for (A) 1936 and (B) 2000.

A


1936
LAND USE/LANDCOVER
FOREST (FLOODPLAIN)
FOREST (TERRACE & FAN)
CLEARED (FLOODPLAIN)
CLEARED (TERRACE)
AGRICULTURE (FLOODPLAIN)
AGRICULTURE (TERRACE & FAN)
URBAN (FLOODPLAIN)
URBAN (TERRACE)
PALUSTRINE WETLAND (FLOODPLAIN)
PALUSTRINE WETLAND (TERRACE)
POND
CHANNEL
LOW FLOW CHANNEL
GRAVEL BAR
COLONIZING VEGETATION
REVETMENT
CANAL
RESERVOIR
CHANNEL
0
2 km

B

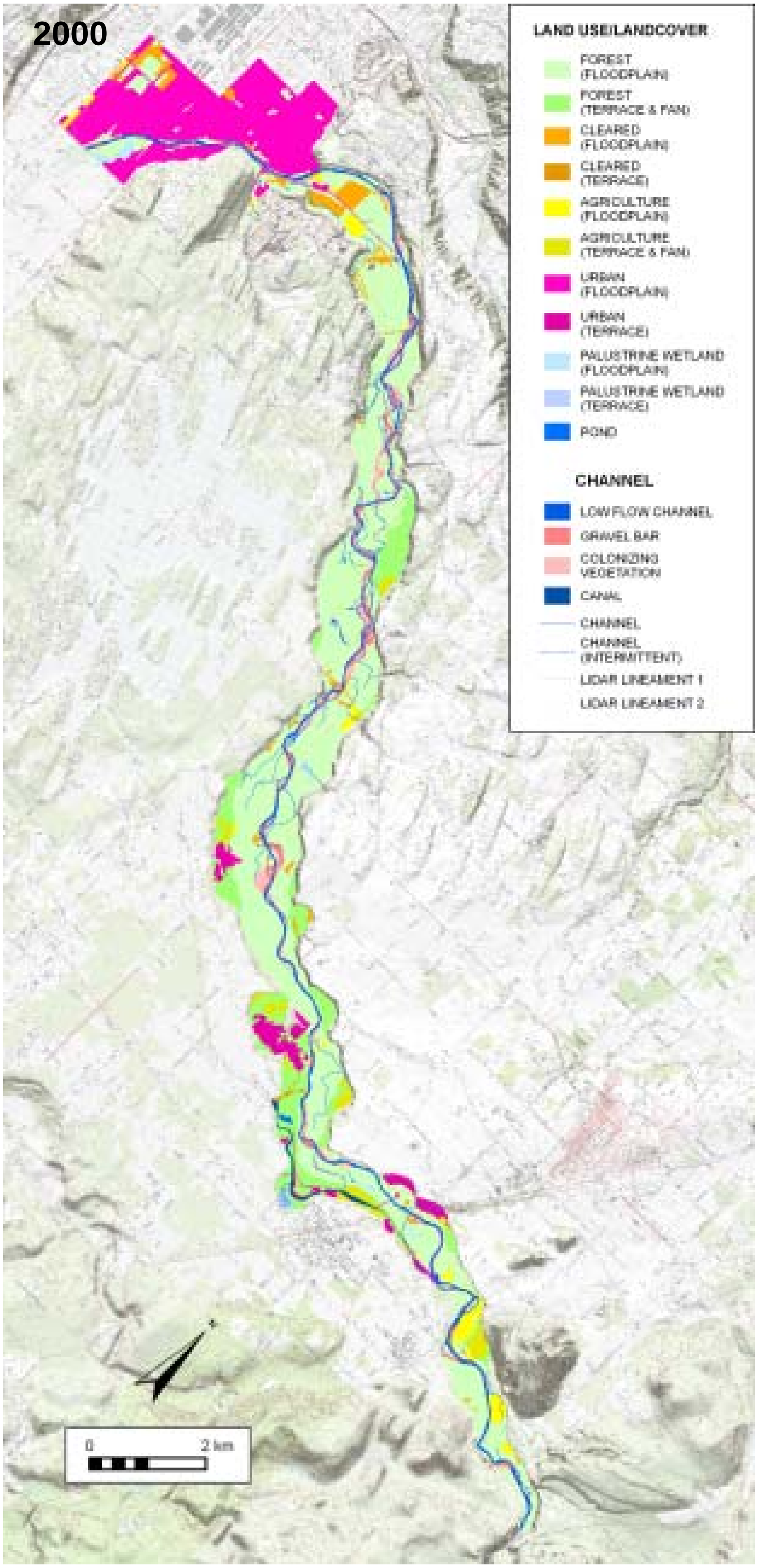
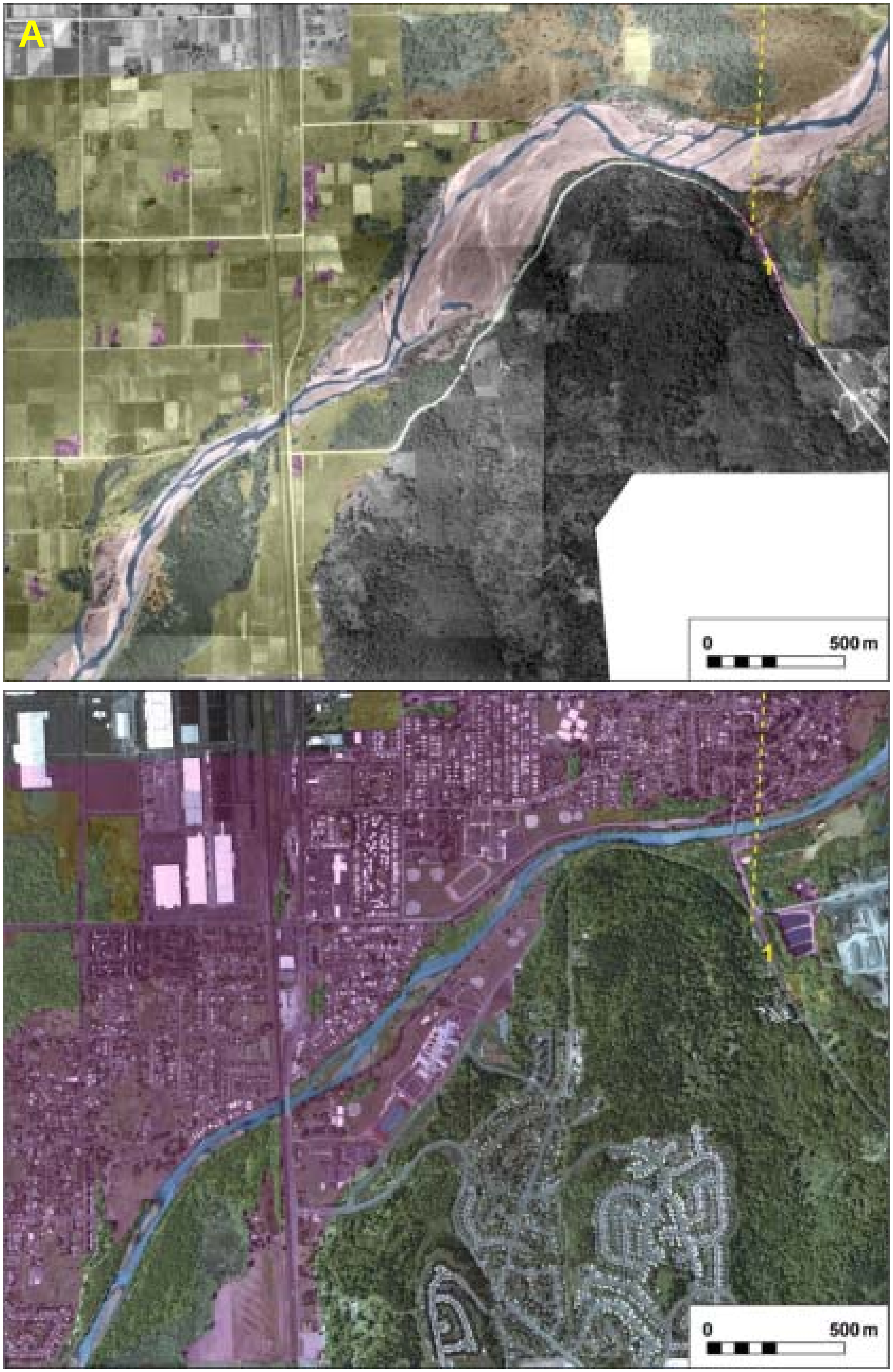

2000
LAND USE/LANDCOVER
FOREST (FLOODPLAIN)
FOREST (TERRACE & FAN)
CLEARED (FLOODPLAIN)
CLEARED (TERRACE)
AGRICULTURE (FLOODPLAIN)
AGRICULTURE (TERRACE & FAN)
URBAN (FLOODPLAIN)
URBAN (TERRACE)
PALUSTRINE WETLAND (FLOODPLAIN)
PALUSTRINE WETLAND (TERRACE)
POND
CHANNEL
LOW FLOW CHANNEL
GRAVEL BAR
COLONIZING VEGETATION
CANAL
CHANNEL
CHANNEL (INTERMITTENT)
LIDAR LINEAMENT 1
LIDAR LINEAMENT 2
0
2 km

Figure 5 (following 11 pages). Paired sets of aerial photographs from 1936 (upper panel on each page) and 2000 (lower panel on each page), sequenced from downstream to upstream. Yellow dashed lines and yellow numbers indicate segment boundaries and segment numbers, as described in text. Photographs are overlain by GIS coverages. All photographs are oriented with north at top of page. Colors and channels are as in Figure 4, except that “revetment” is shown with a crosshatch pattern.


A
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1
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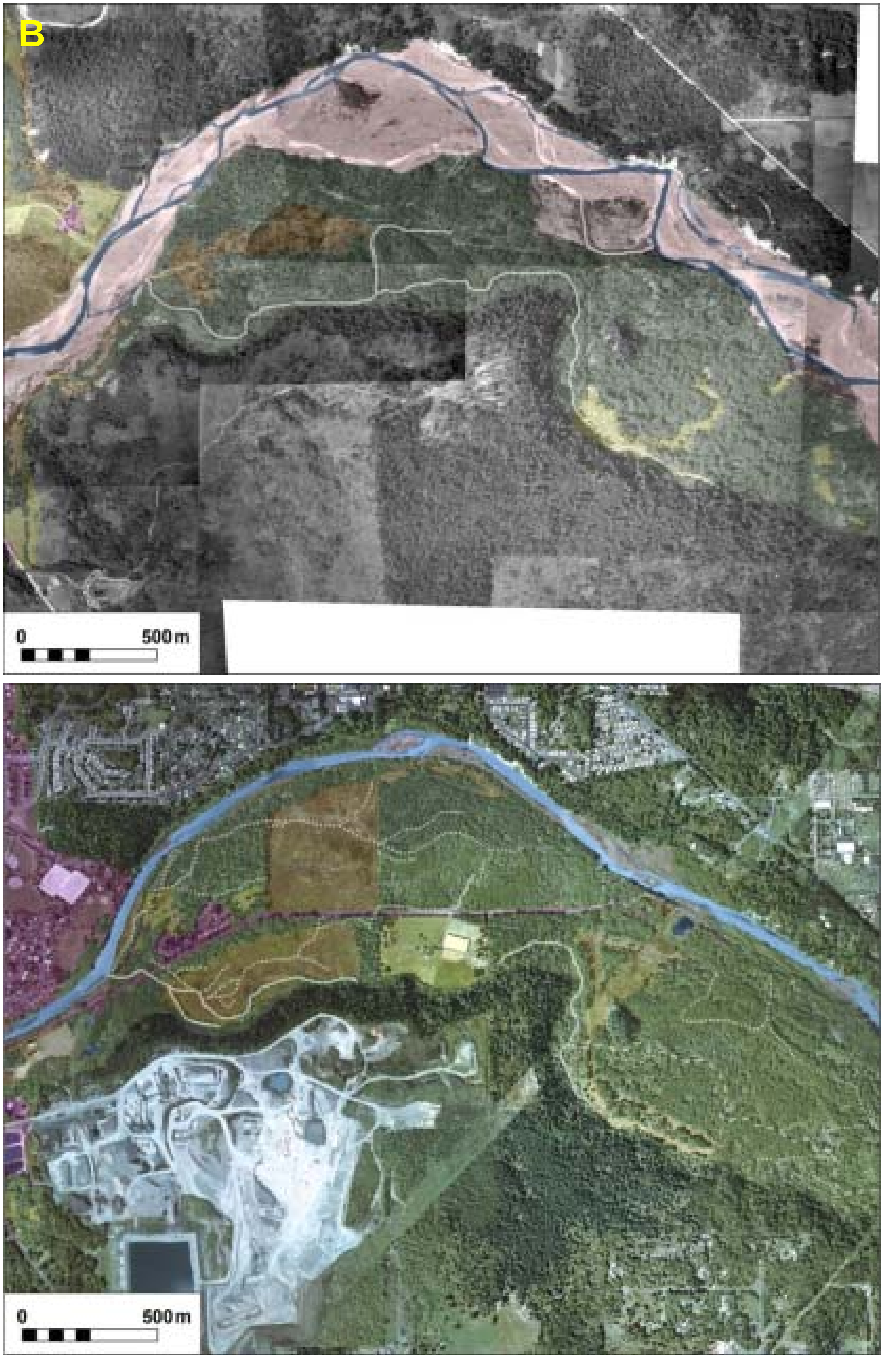
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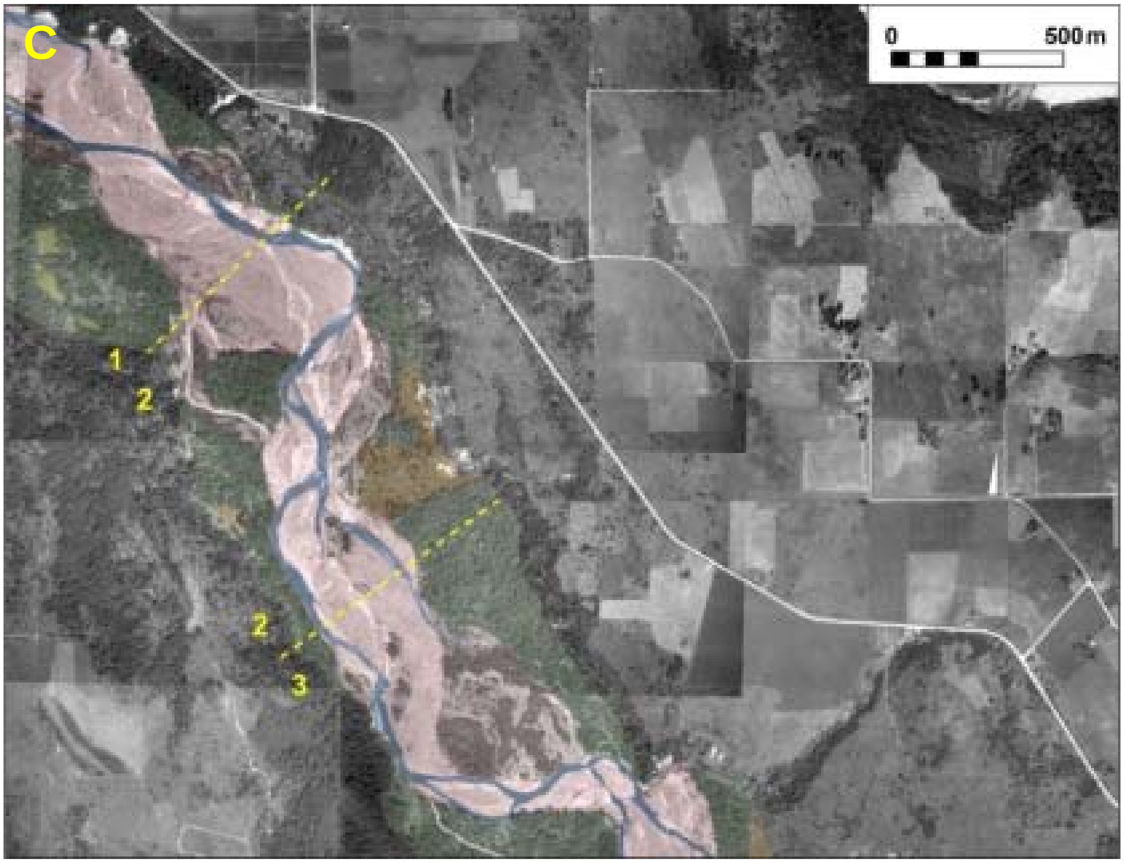
C
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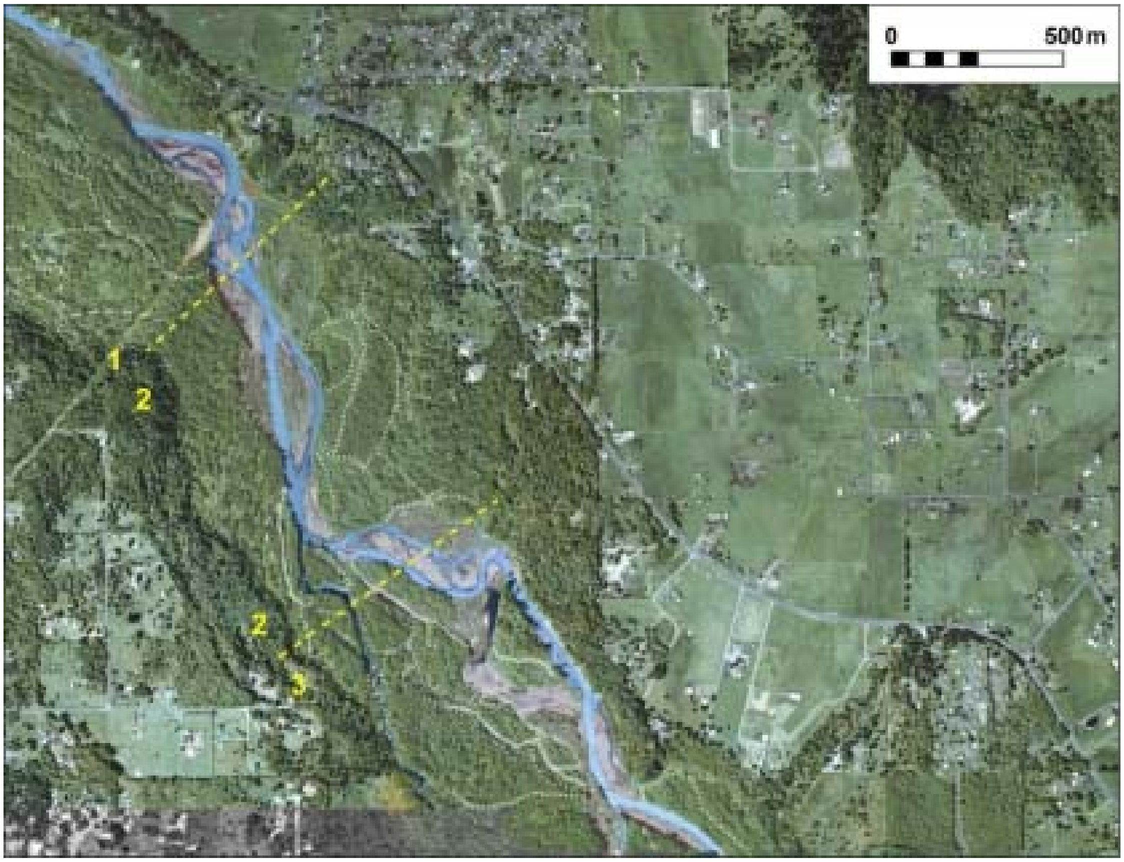
500 m
1
2
2
3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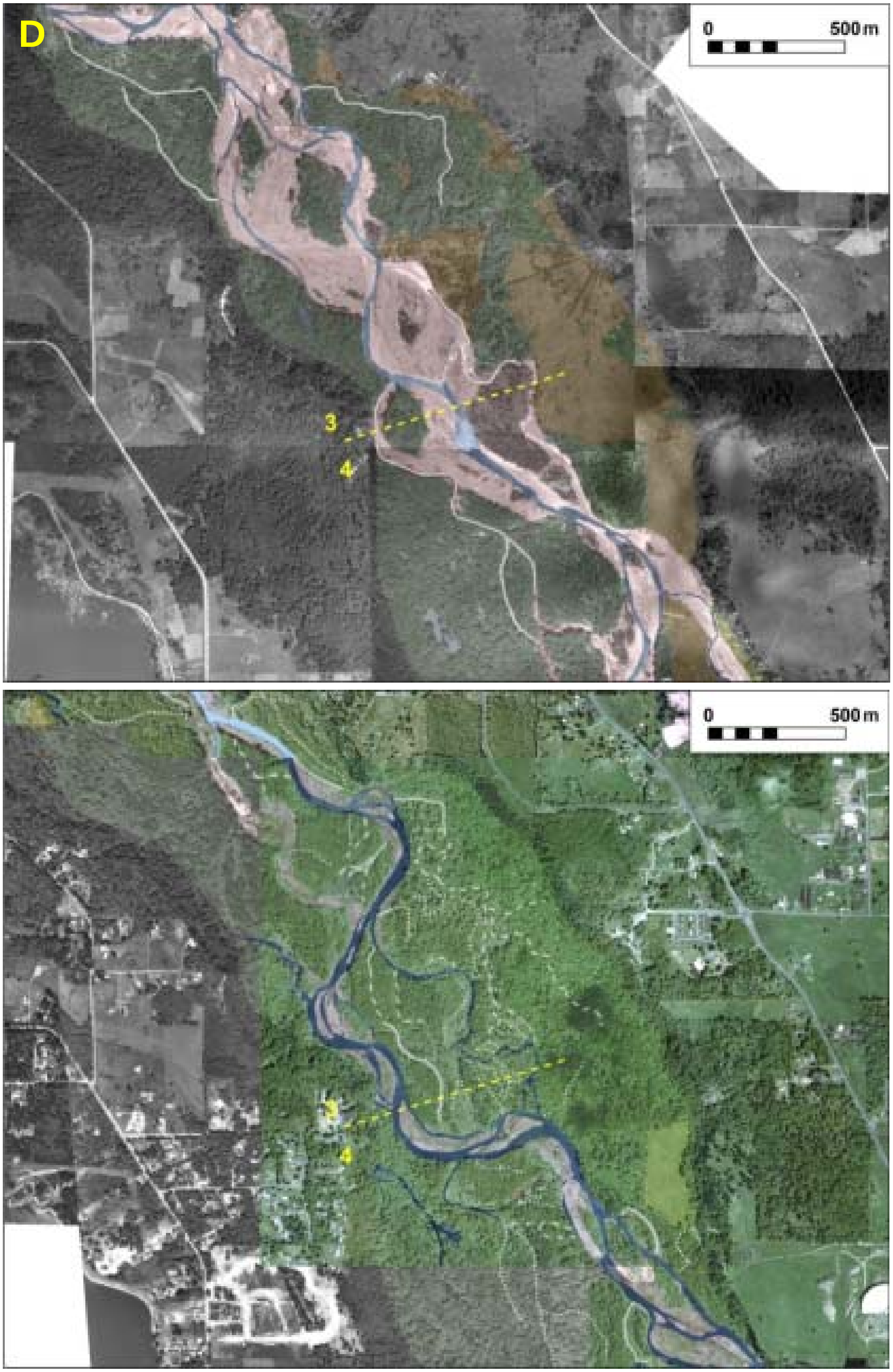
500 m
1
2
2
3


D
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4
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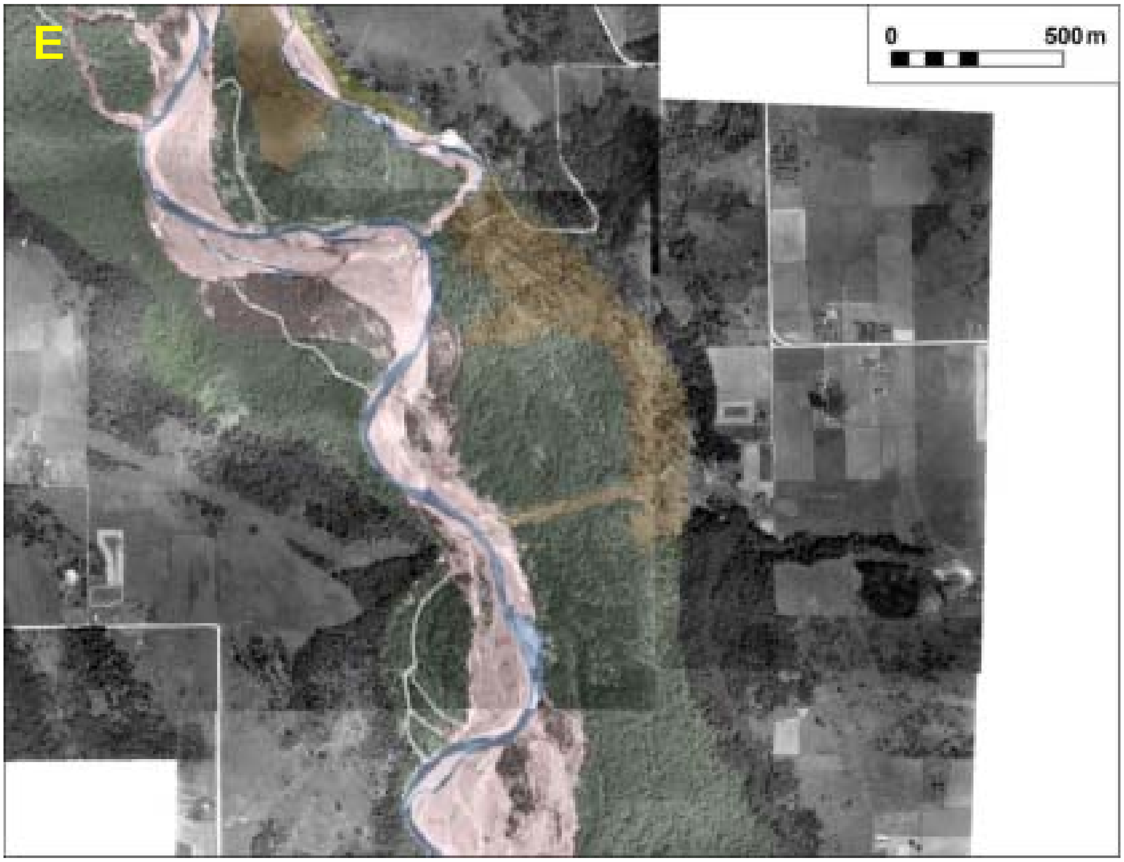
500 m
3
4


E
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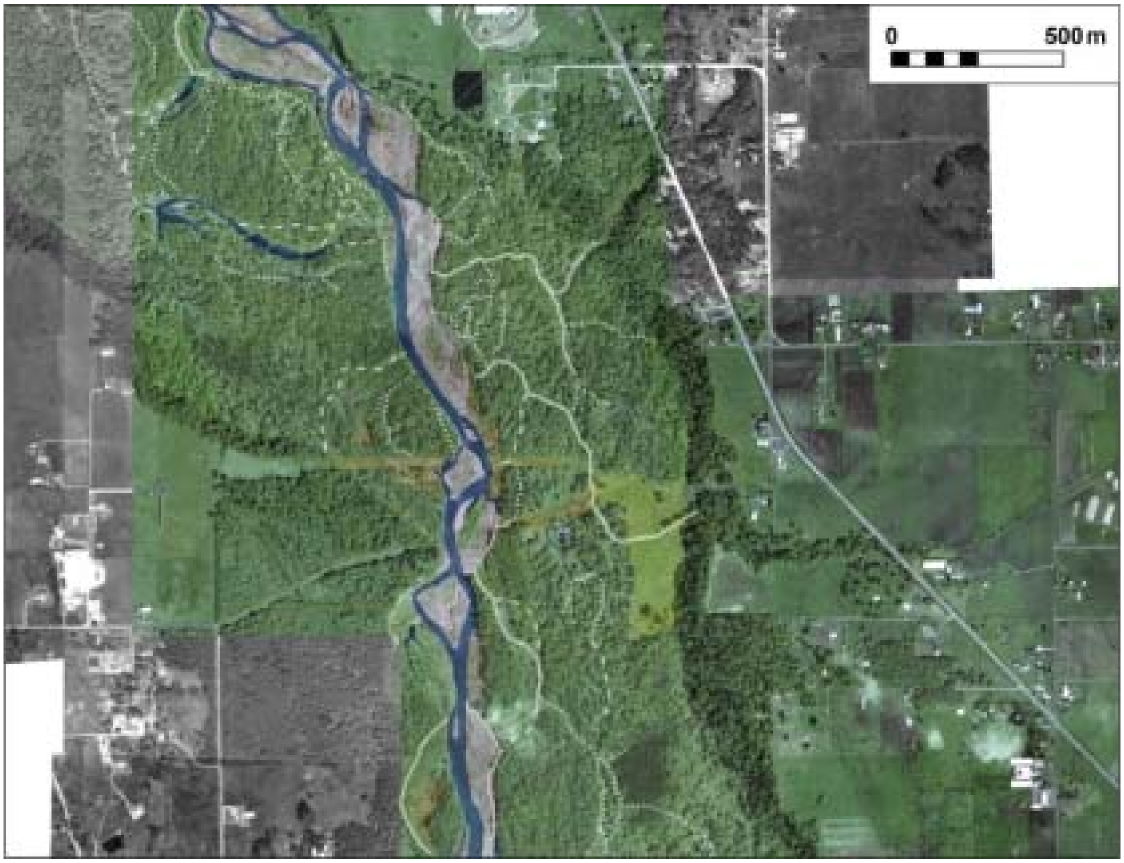
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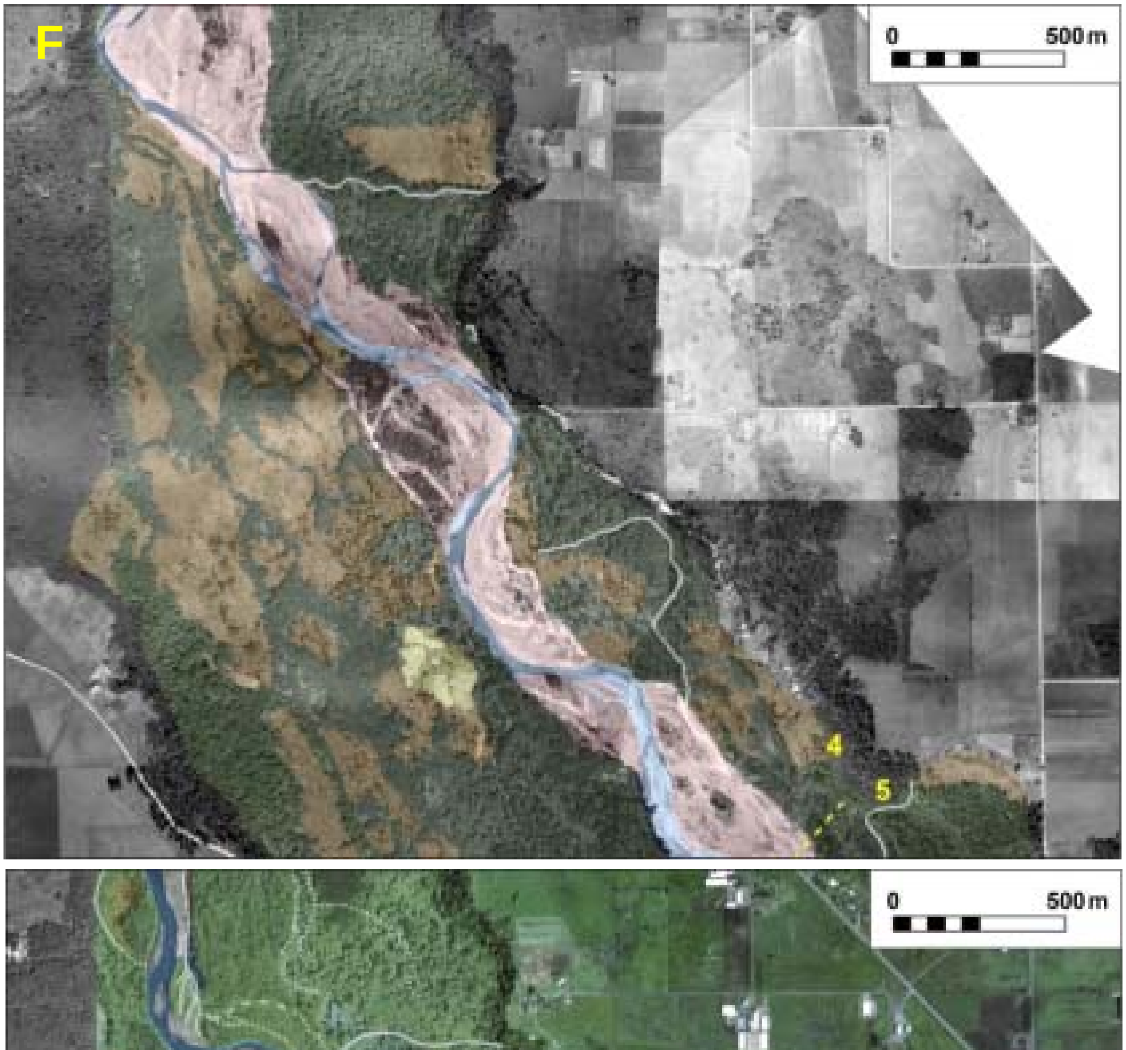
F
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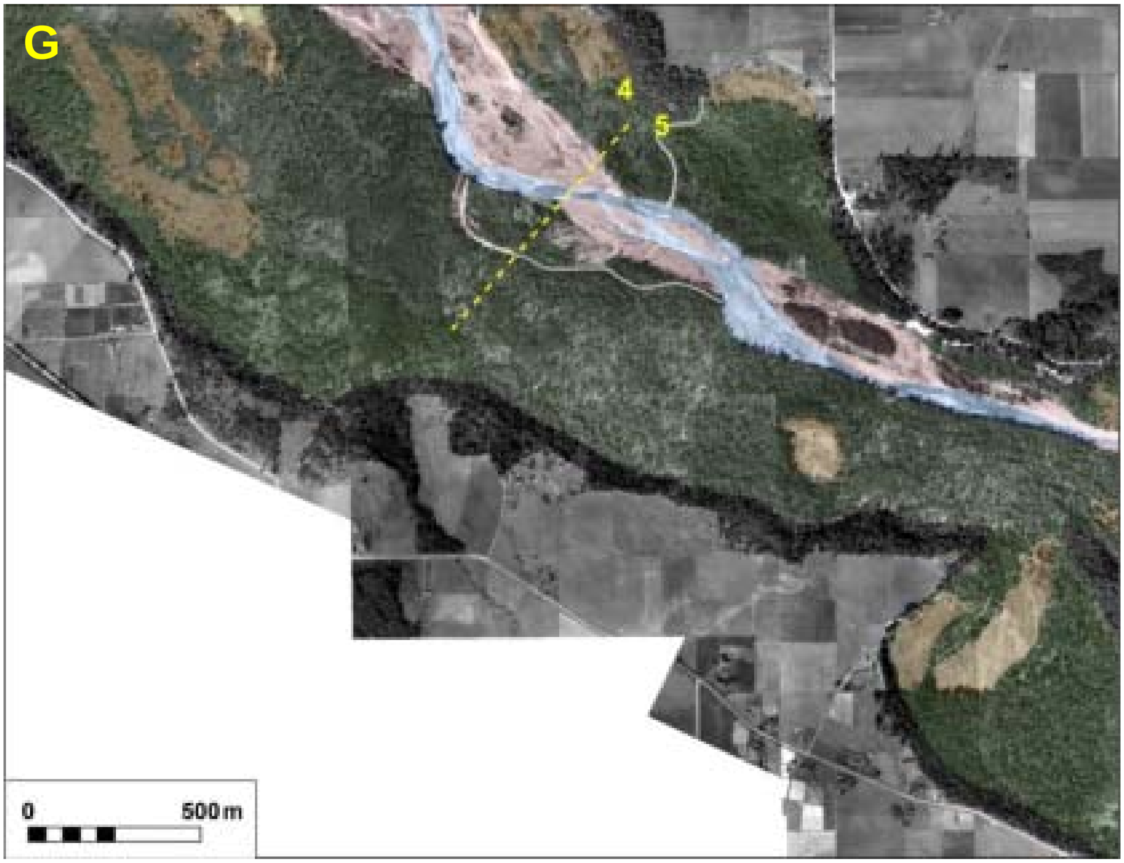
4
5


G
4
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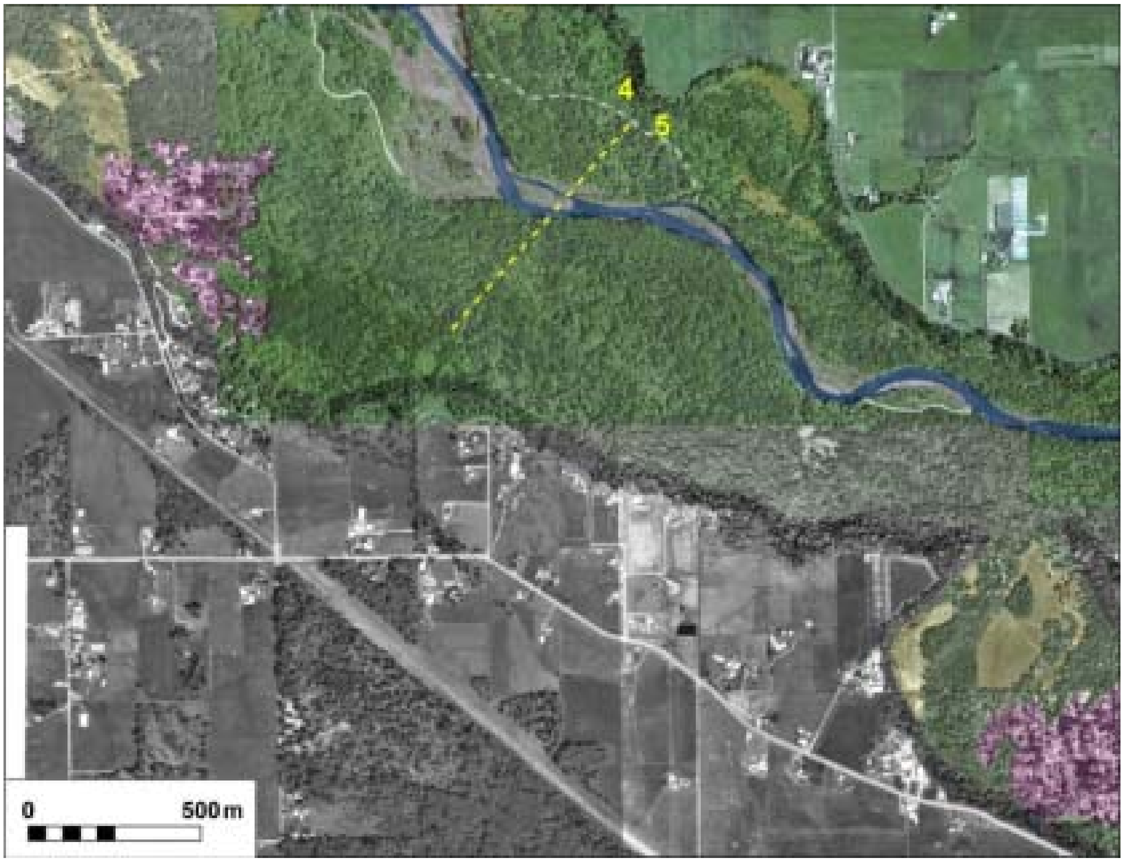
4
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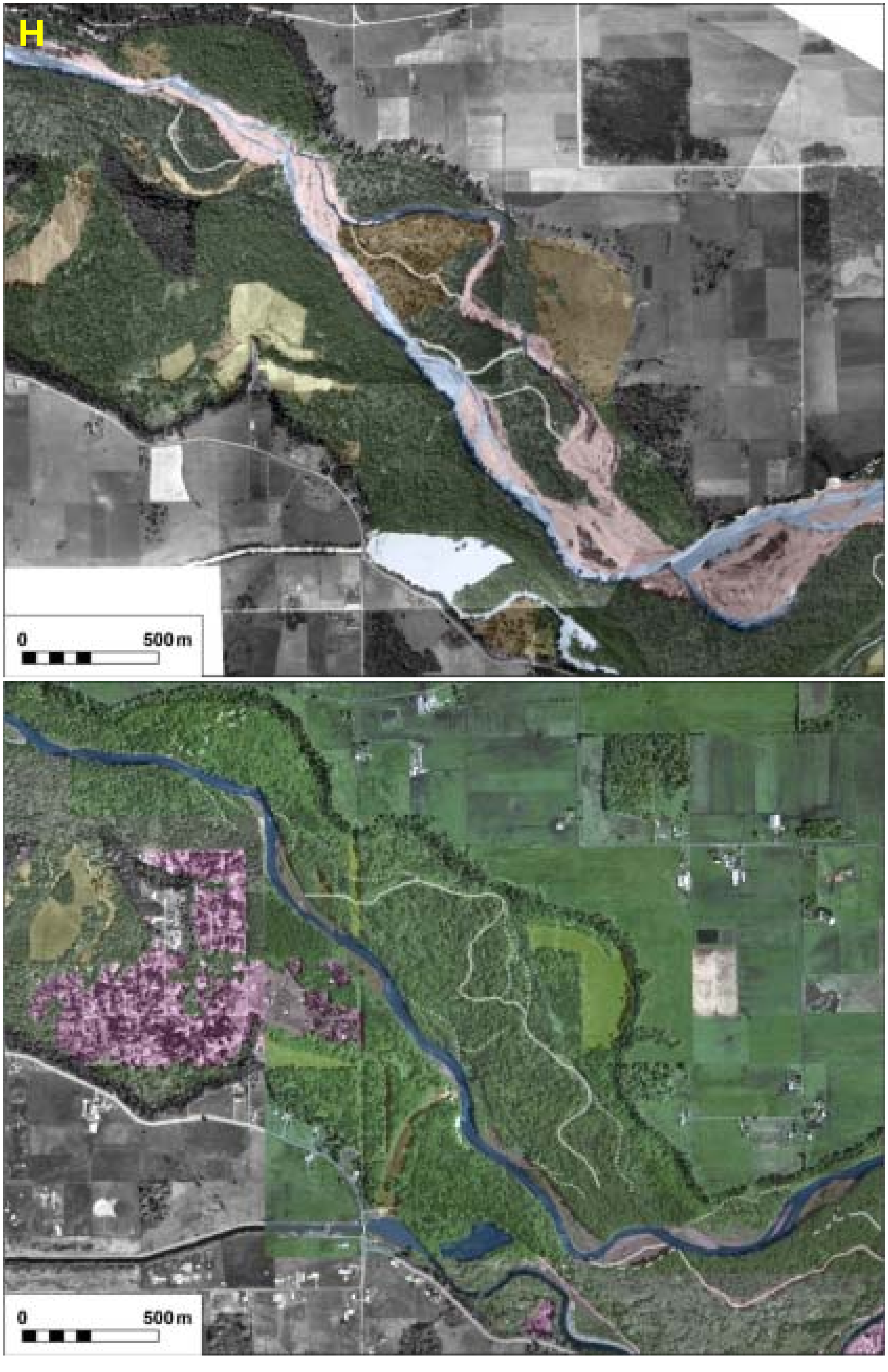
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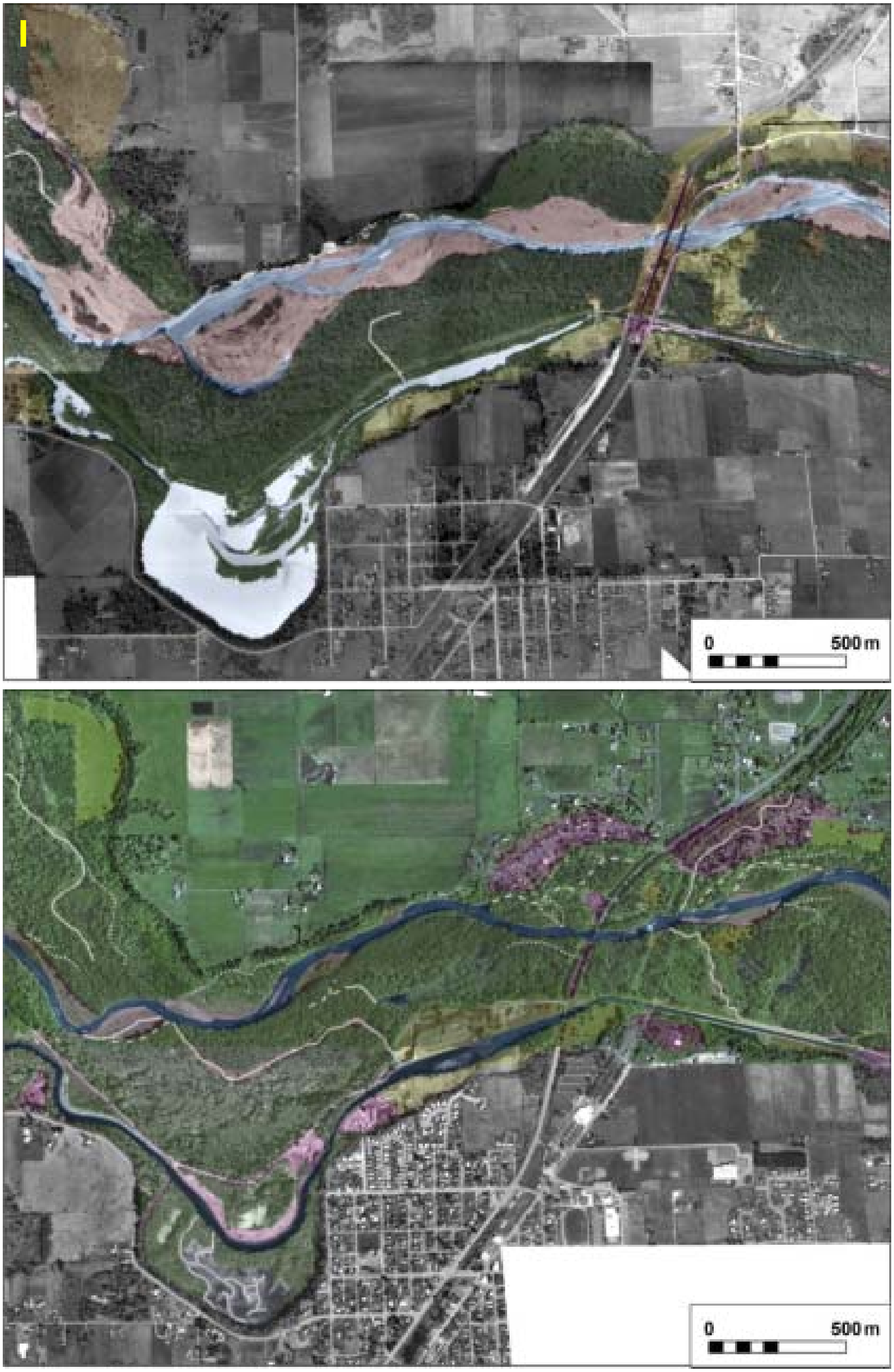
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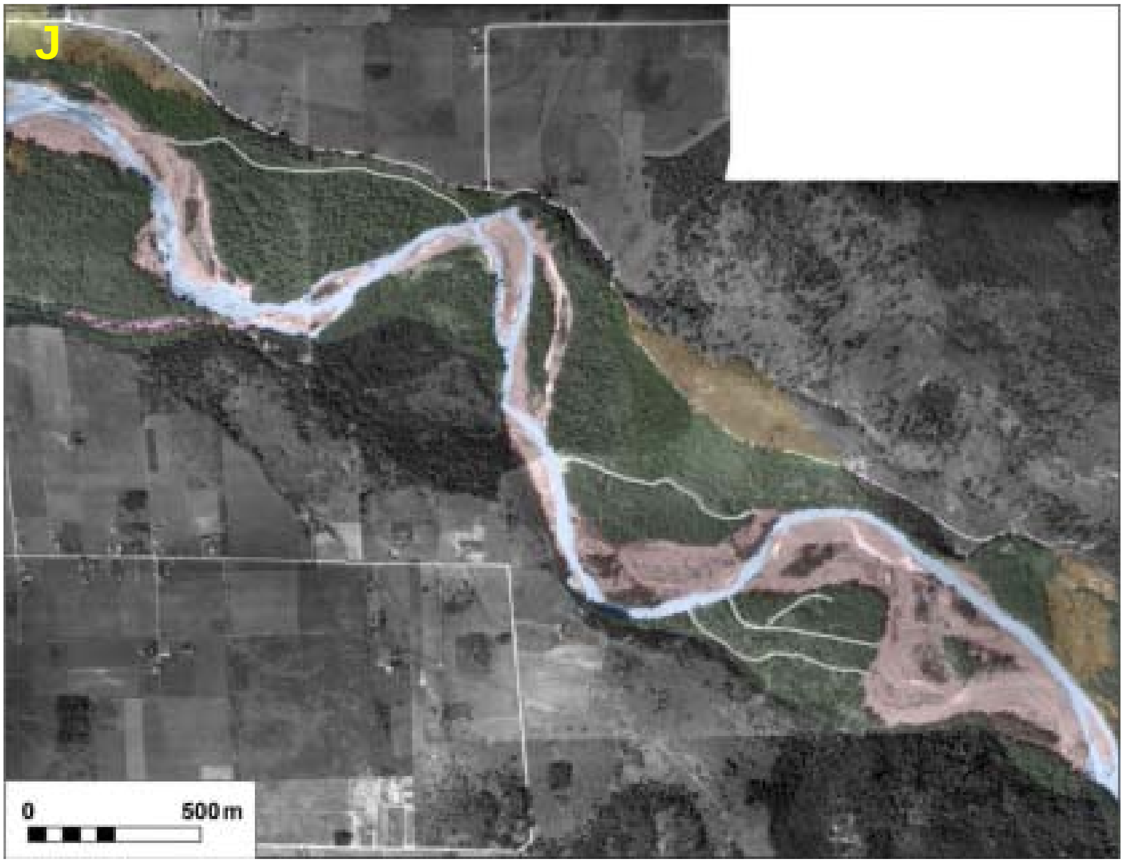
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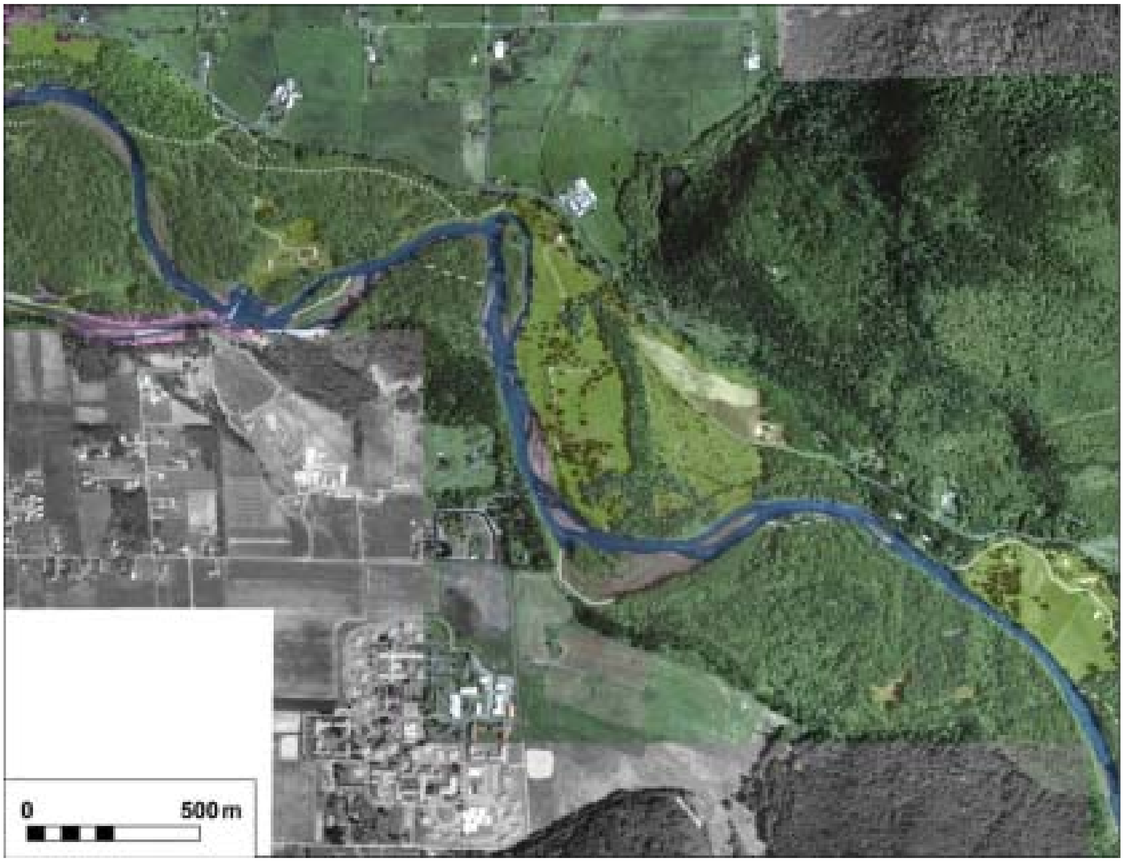
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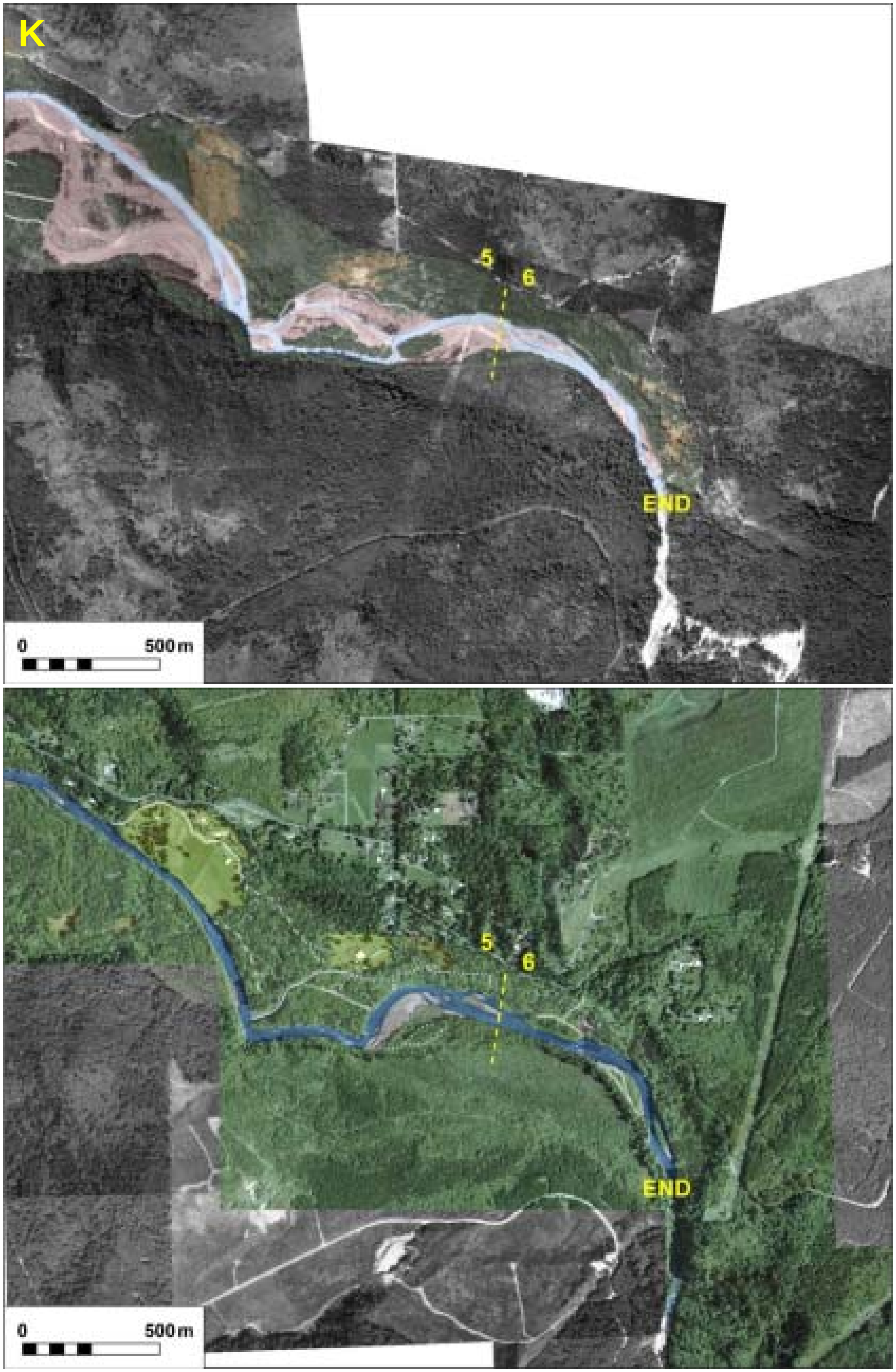
K
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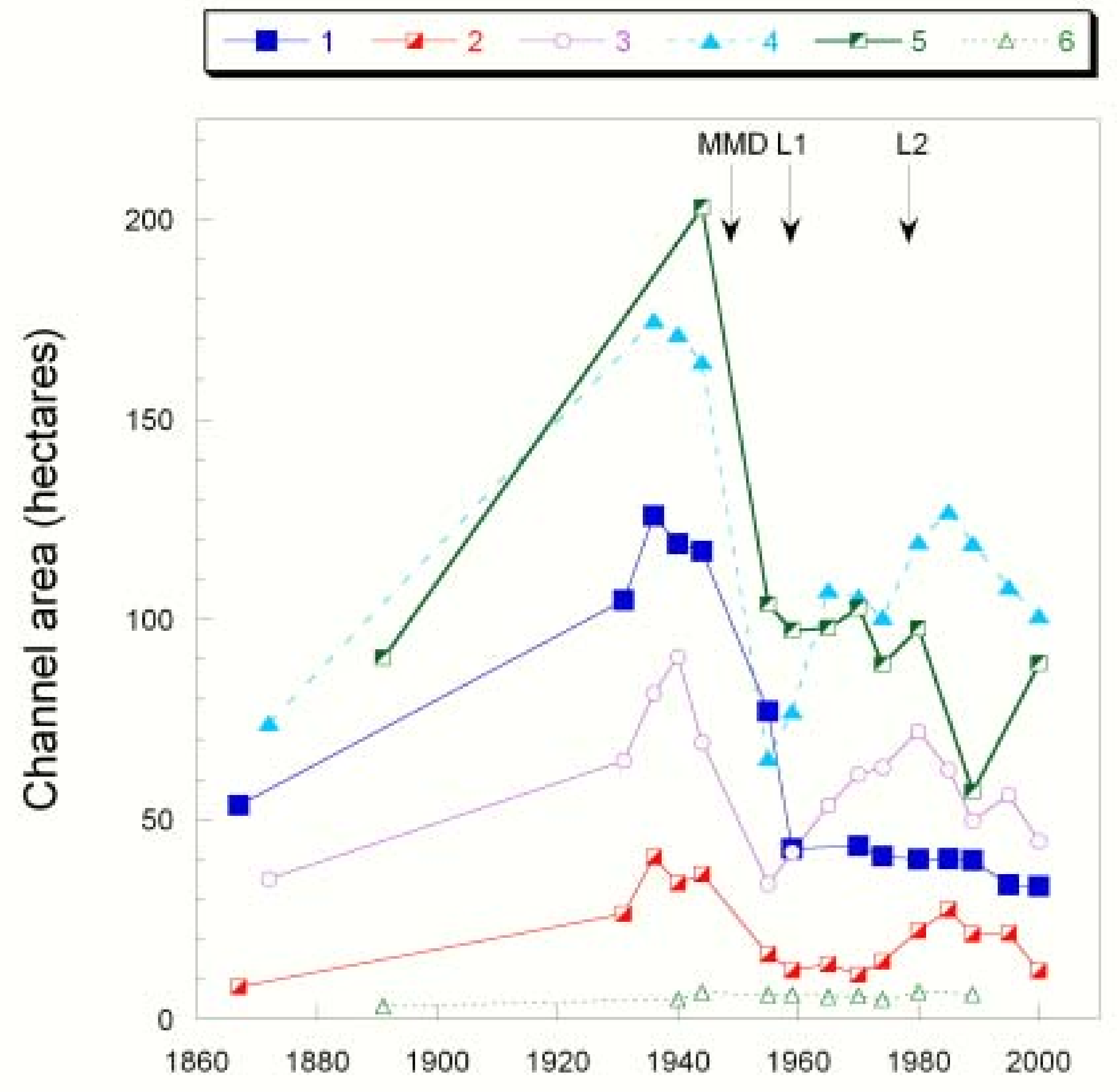


Figure 6. Area, in hectares, of active channel (low-flow channel, gravel bars, and colonizing vegetation on bars) versus time for six segments of the White River study area. Segment locations are shown in Figures 1 and 5. Area was measured from digitized aerial photographs except for earliest (19th century) data, which is from GLO plat maps. Years of map and aerial photograph coverage varies between segments. MMD = Mud Mountain Dam; L1 = levees built in segments 1 and 2; L2 = levee breached in segment 2.

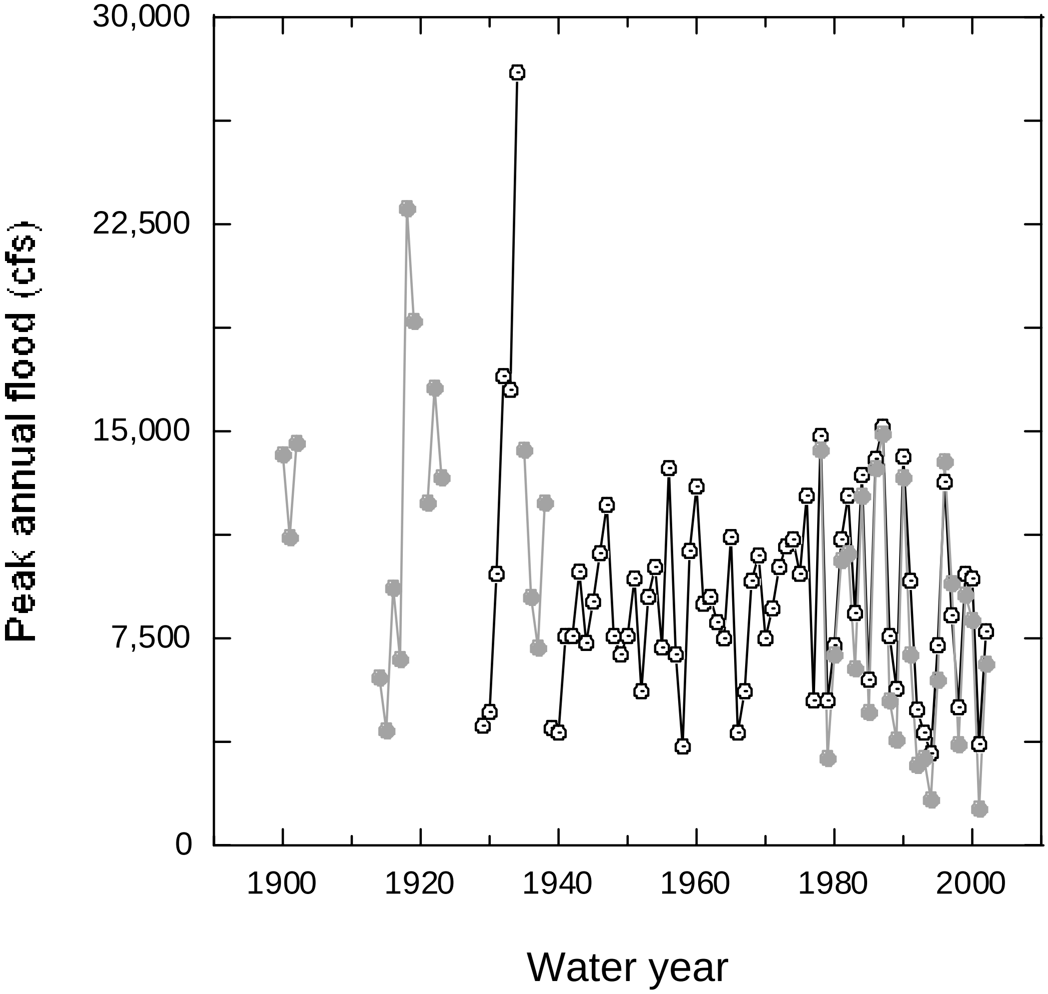
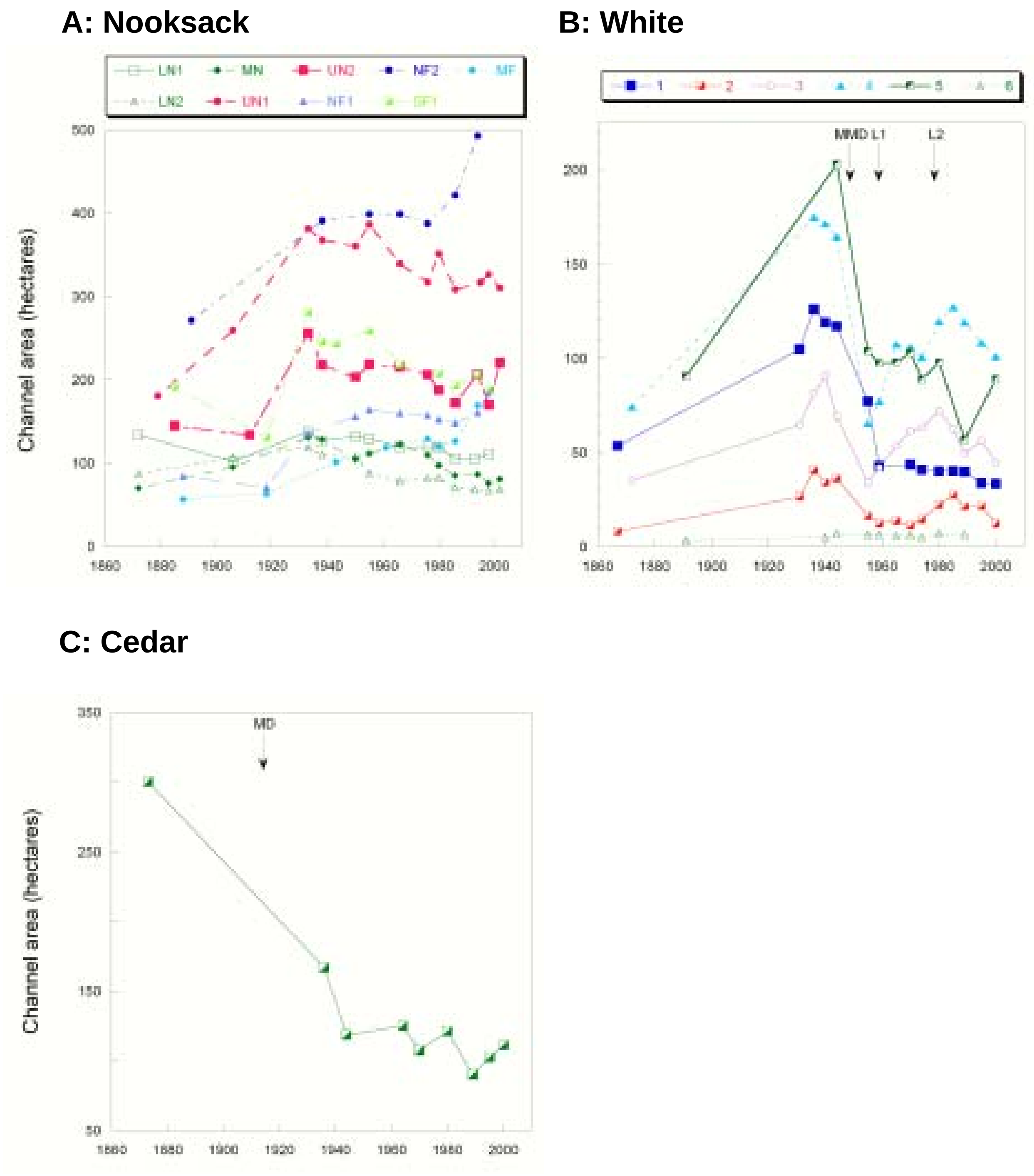


Figure 7. Peak annual floods from the USGS "White River near Buckley" gage 12100000 (black line and open circle), and USGS "White River at Buckley" gage 12098500 (gray line and solid gray circles).


A: Nooksack

B: White

C: Cedar

Figure 8. Active channel area change through time in (A) reaches of the Nooksack River, (B) White River (from Figure 6), and (C) Cedar River. “MD” in panel C marks the closing of Masonry Dam on the Cedar River, upstream of reach for shown in panel C. Data for panel A is from Collins and Sheikh (2004c); data for panel C is from Collins et al. (2003b).

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