AN ABSTRACT OF THE THESIS OF

Sharon L. Gutowsky for the degree of Master of Science in Geography presented on February 7, 2000. Title: Riparian Cover Changes Associated with Flow Regulation and Bank Stabilization along the Upper Willamette River in Oregon between 1939 and 1996.

Abstract approved: Signature redacted for privacy.

Julia A. Jones

This study investigates riparian cover change between 1939 and 1996 utilizing aerial photography, bank conditions and stream gauge data. Three sites under 1.0 km^2, along a 10-km reach north of Harrisburg, Oregon, were evaluated. The cover classification scheme included 18 classes composed of 3 canopy densities and 8 structural categories: water, bare gravel bars, herbaceous, shrub, small trees, medium trees, closed trees, and agricultural fields. Net cover changes and shifts between classes were analyzed for each site as a whole and as terrestrial vs. fluvial changes. Terrestrial changes (i.e. areas unaffected by channel movement) were discriminated from fluvial changes (i.e. areas where a channel migrated out, in or both) by inspection of 14 air photo coverages between 1939 and 1996.

Over 75% of each site experienced net cover change between categories of water, bare, cleared land, low vegetation, open-canopy trees, and closed-canopy trees. Water cover composed over half the area that remained the same. Net progressive structural change (i.e. an increase in cover maturity, e.g. bare changing to trees) exceeded or equaled net regressive structural change at each site. Progressive structural change was only slightly favored in fluvial areas, while terrestrial areas favored progression 4 to 1 at each site. Bare ground decreased by 35%, 65% and 90%, while forest cover increased by 10%, 50% and 150% at

the three study sites. The only areas of non-forest cover remaining in 1996 existed on land disturbed by the channel since 1939.

The maturation of structural cover was associated with decreases in channel dynamics and fluvial disturbance between 1939 and 1996. Channel migration affected 50% to 70% of each study area during this period, but most shifts occurred before 1956. Sixty-eight percent of the revetments present in 1996 were established by 1956. These revetments hardened portions of all outer bends along the study reach, limiting lateral channel migration. Upstream dams held 42% of the 1996 storage by 1956, which reduced peak flows.

Riparian Cover Changes
Associated with Flow Regulation and Bank Stabilization
along the Upper Willamette River in Oregon between 1939 and 1996

by

Sharon L. Gutowsky

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Dean of Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Sharon L. Gutowsky, Author

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1. INTRODUCTION

Throughout history cities have been built along large rivers. Rivers provided drinking water, transportation corridors and a means for waste removal. As technology progressed engineers became skilled at managing river systems in order to decrease flood hazards and threat of drought, increase the efficiency of urban drainage systems, prevent erosion of private property along river banks, and provide navigable water ways. While society benefited from structural solutions, physical processes that maintained the riverine ecosystem were altered. For instance, many large rivers lost the connection to their floodplains reducing the interplay between aquatic and terrestrial systems, which transformed the overall character of the remaining riparian corridor. Modification of a river's hydrograph and sediment regime directly influenced the composition and structure of the channel shape, instream aquatic communities and remaining riparian vegetation (Collier 1996).

Today's society is currently re-evaluating the way rivers are managed. Two actions by Congress reflect an increasing interest in preserving and restoring aquatic and riparian habitat: (1) During the 1990's Congress revised the United States Army Corps of Engineer's (USACE) mandate so that environmental restoration and flood control responsibilities have equal priority; (2) Congress funded the Conservation and Restoration Enhancement Program (presentation by Matt Rea USACE). The Willamette River is one of five pilot sites selected to begin this program.

The first major steps to restore and protect the Willamette River began in the 1930s. This movement was spurred by public health concerns and focused on pollution reduction. Led by Governor Tom McCall, Oregonians came together again in the 1970s to manage and plan for growth in the Willamette Valley and to establish a "greenway" along the river. More recently, the rising awareness of declining salmon runs in the Pacific Northwest revitalized and intensified an interest in restoring aquatic and riparian habitat along the Willamette River. In response to salmon concerns, Governor John Kitzhaber developed the Oregon Plan to guide salmon and trout habitat restoration efforts.

The Willamette River Basin Task Force (WRBTF) guides the Oregon Plan within the Willamette Basin. The WRTF places equal importance on human and ecosystem health. The task force recognizes that the "Willamette floodplain has been diked, drained, filled and confined to the point that it no longer functions as a healthy ecosystem with the capacity to support native fish and wildlife, absorb and reduce the impact of flooding, and filter contaminants" (WRBTF 1997). They recommend "a more balanced approach to flood management that allows the Willamette to act more like a river than a ditch" (WRBTF 1997). The task force also recognizes "87 percent of the basin's original wetlands and riparian plant communities have been converted to other uses and that an estimated 99 percent of the native prairies and 72 percent of bottom hardwood forests are gone" (WRBTF 1997). They recommend "a more systematic approach to protect and restore critical habitats by using–incentives, easements, land trades, riparian set backs and acquisitions to secure priority areas" (WRBTF 1997).

Contemporary approaches to restoration on large river systems focuses on the importance of natural processes (Gurnell 1997, Petts 1990, Pinay et al. 1990, Poff et al. 1997). Assessing the reversibility of hydrogeomorphic processes associated with riverine and riparian land forms and their biota provide a vital step toward sound management and restoration of large rivers (Amoros et al. 1987). Ecological restoration on large rivers therefore requires a historical awareness of the system (Landers et al. 1998). This study investigated riparian conditions along the Upper Willamette River before and after the installment of dams and revetments. Two riparian cover conditions were examined along with their associated hydrogeomorphic regimes: (1) The 1939 cover formed under a relatively "natural" regime; (2) The 1996 cover developed under a "managed" regime, following the installation of boulder revetments and dams. Alterations in the hydrogeomorphic regime may have directly influenced the character of the riparian corridor. This study tested the hypothesis that decreased channel movement and flood scour associated with revetments and dams reduced the disturbance of vegetation and land forms, resulting in reductions in immature vegetation and increases in mature vegetation.

2. METHODS

2.1. Site Description

The Willamette River originates in the southern end of the Willamette Valley and flows in a northerly direction over 475 km to the Columbia River (Figure 1). It is bounded by the Coast Range on the west, the Cascade Mountains on the east, the Calapooya Mountains on the south and drains an area of 29,138 km^2. This 9th order channel basin has the highest runoff per unit drainage area for large rivers and holds the 13th largest river in terms of discharge in the continental United States (Krammerer 1987). Natural peak runoff is primarily rain-driven. Annual precipitation averages 1.35 m, and 70% of this occurs between November and March (PNRBC 1971). Average monthly temperatures range from 4.1° C in January to 18.6 ° C in August. Attributable to its proximity to the Pacific Ocean, this area experiences an unusually mild climate for a latitude of 44°.

Today the Willamette River is an alluvial gravel-bedded river running in a single channel for most of its length. The northern downstream portion of the river is incised and has bedrock outcrops. Willamette Falls, a basaltic intrusion upstream of the Clackamas River tributary, acts as a base level control for the upper river. The upper river runs through lake deposits and gravel alluvium transported during the Missoula Floods that were reworked during the Pleistocene and more recent periods (Klingeman 1973).

Three sites along the upper Willamette River were selected for this study. These sites reside within a 10 km reach beginning 6 km north of Harrisburg, Oregon (Figure 2). The area of the northern site was 0.96 km^2; the middle site was 0.88 km^2; and the southern site was 0.97 km^2. The drainage area above Harrisburg is 8,860 km^2 (USDI 1998). The average

Figure 1. Willamette Basin

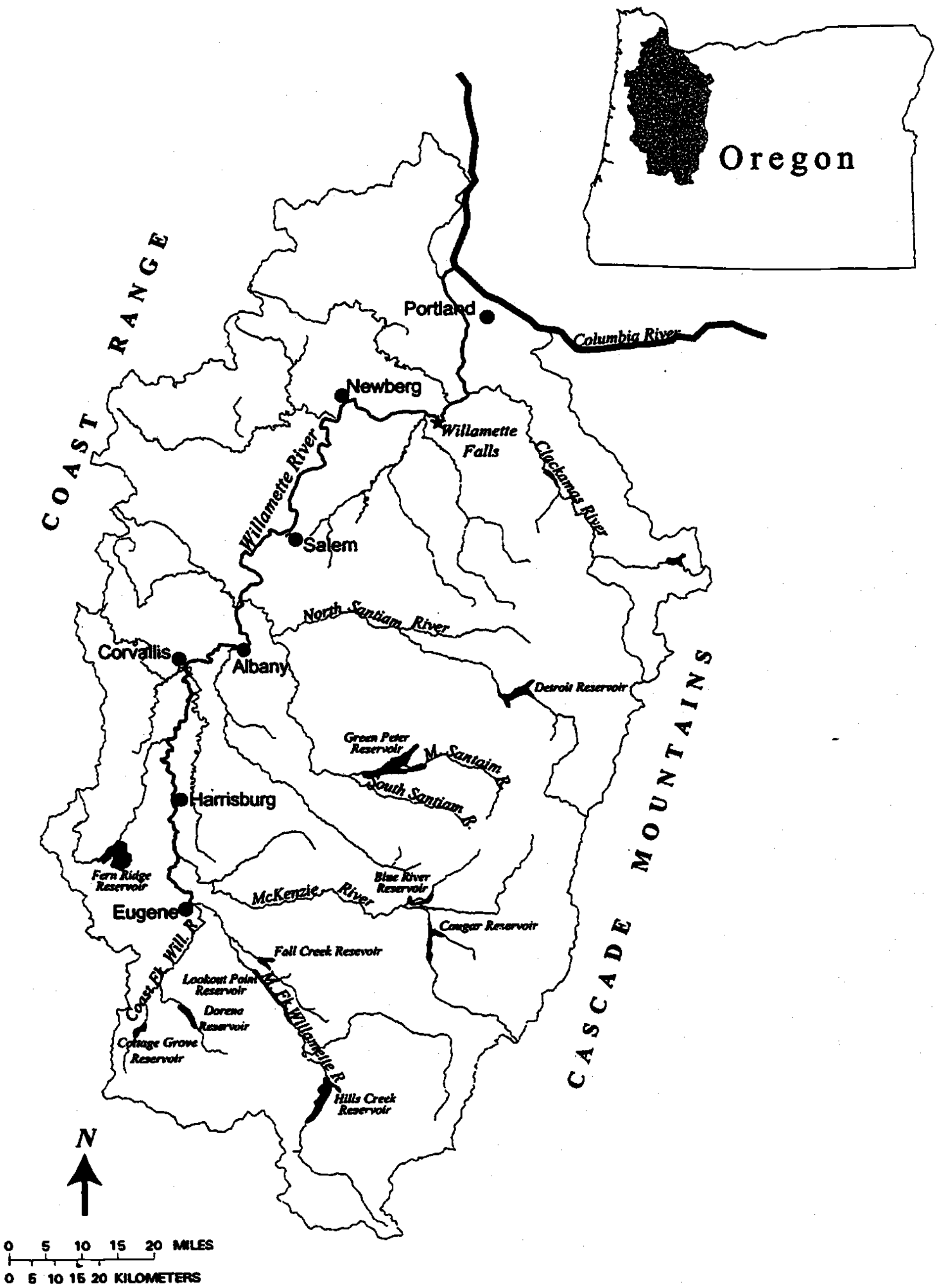
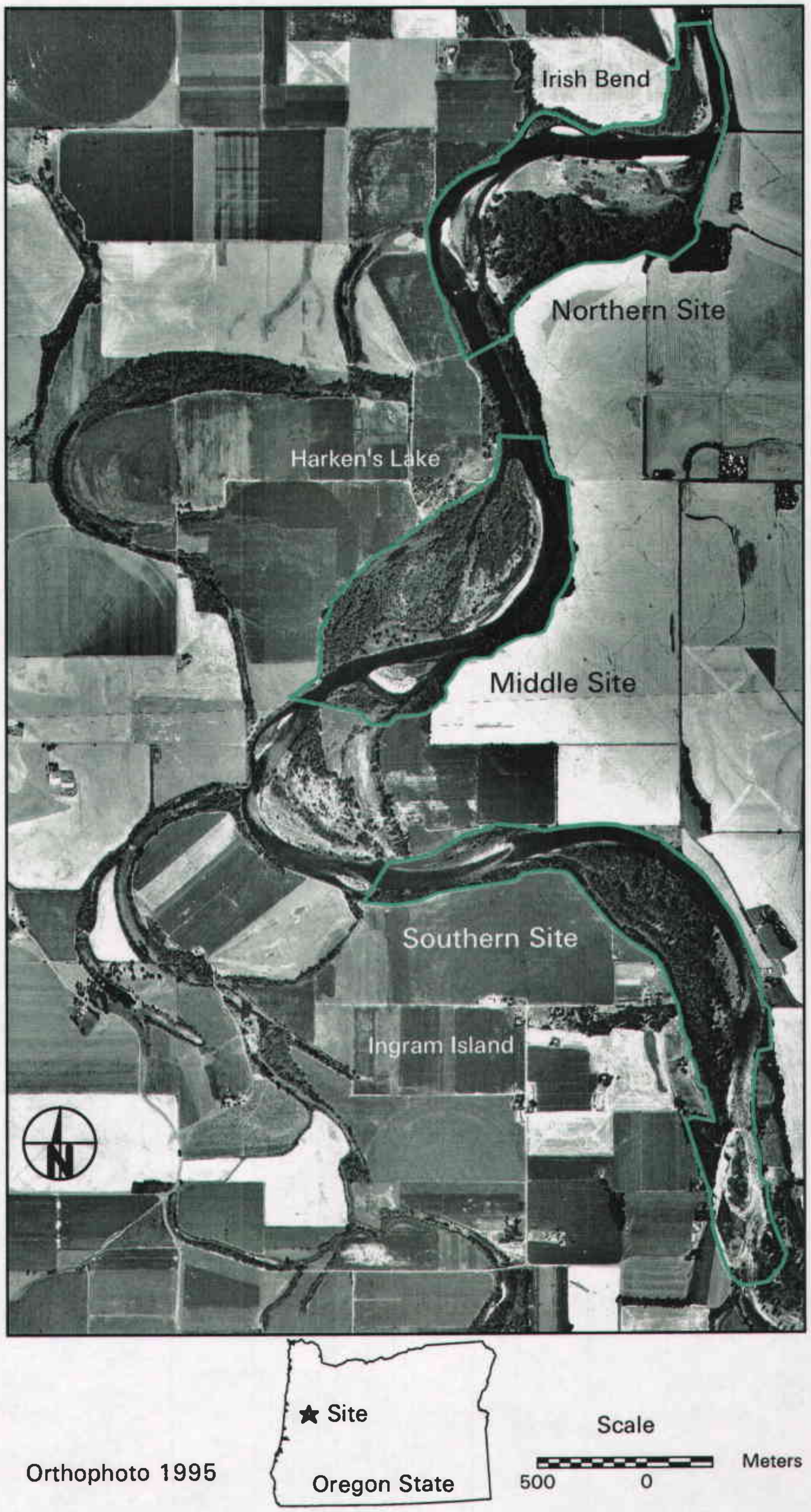


Figure 2. Study Reach Map



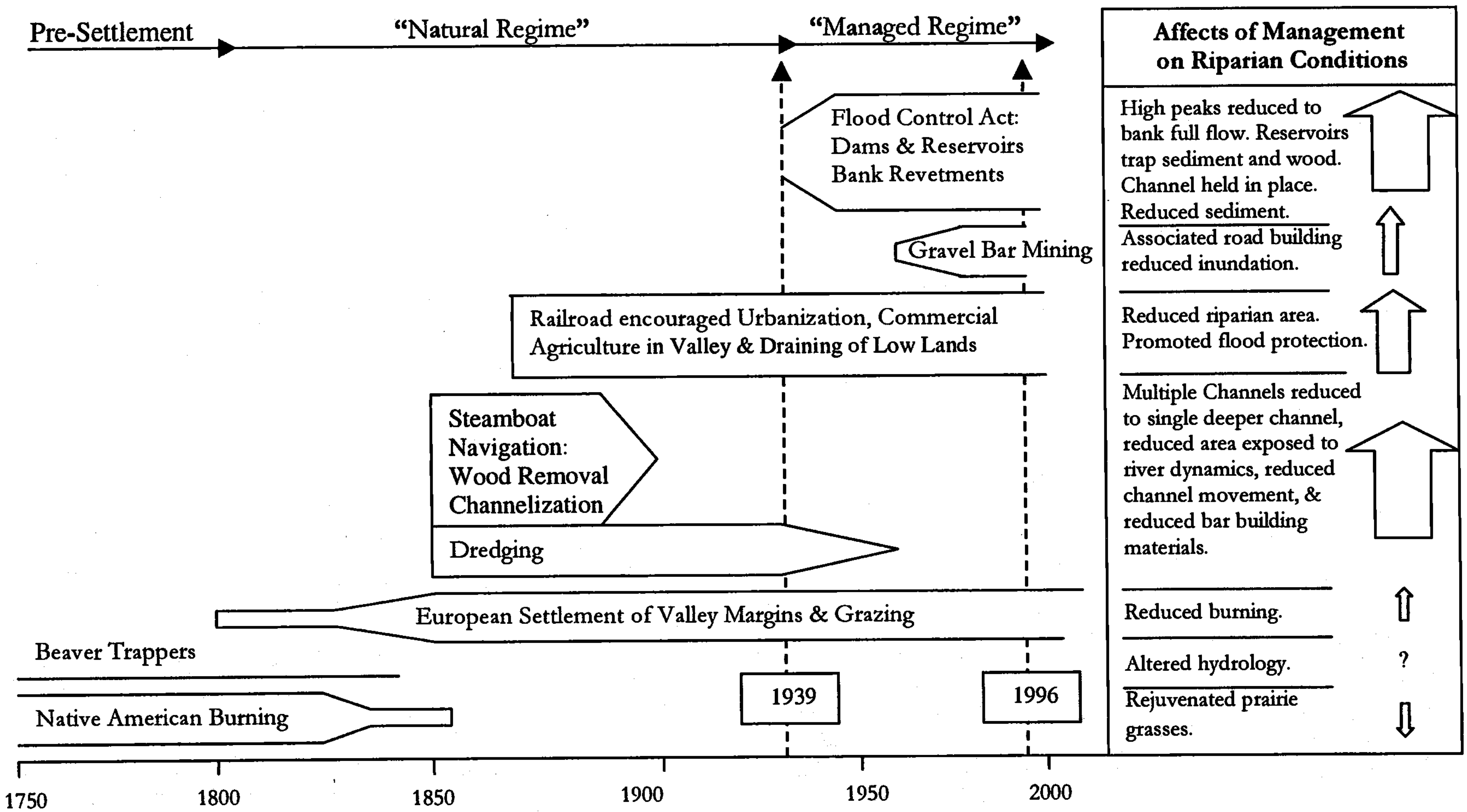
channel gradient was approximately 0.9 m/km over the study reach (Klingeman 1973). The surrounding floodplain banks were approximately 4 – 6 m above the low water line along this reach (field estimate).

2.2. Site History

Land and river management along the Willamette River corridor greatly altered the form and function of aquatic, riparian and floodplain habitat (Figure 3). In the mid-1800s near Harrisburg, the pre-settlement stream banks were only 1.5 to 2.6 m above the low water line (Sedell & Froggatt 1984). Dense woodland covered the floodplain from 1.5 to 3.5 km on either side of the river (Sedell & Froggatt 1984). The floodplain was dissected by sloughs and each year new channels were cut and old channels closed off by drifts of large woody debris (Sedell & Froggatt 1984). In the late 1800's over 550 large wood pieces per kilometer were removed from the river and its banks, with average sizes of 30-60 m in length and 0.5 – 2 m in diameter (Sedell & Froggatt 1984). Wood pieces contributed to the structural complexity of the river system by creating slack water and trapping sediment (Benner & Sedell 1997).

During this period the secondary channels and sloughs of the upper Willamette River were closed off by dikes, concentrating the river into primary channels (USACE 1979). Channelization of the Willamette River along with ditch draining of low lands allowed conversion of wetlands to arable land (Boag 1992). Flows were further concentrated within the channel, through the installation of wing dams and scraping of bars (USACE 1979). The River and Harbor Dredging Act of 1896 authorized dredging of the river, enabling paddle wheeler navigation between Portland and Eugene (USACE 1975). In 1912, dredging between Corvallis and Eugene maintained a channel depth of 0.61 - 0.75 m measured from

Figure 3. Human Interaction along the Willamette River



⇧ Upward arrows mark management which reduced disturbance of cover, encouraging the development of mature vegetation.
⇩ Downward arrows mark management which increased disturbance of cover, causing a regression of vegetation or maintenance of immature vegetation.
Arrow width indicates the relative severity of impact on riparian conditions. (Boag 1992, Boyd 1999, USACE 1999, 1979, 1975, Morris Brothers conversation)

the low water datum prior to dam augmentation (USACE 1975). A great loss of riparian habitat coincided with these management strategies.

Significant changes along the Willamette River corresponded with Euro-American settlement. Between 1850 and 1932 the river lost much of its complexity between Corvallis and Harrisburg experiencing declines in: the primary channel area by 19%, secondary channel area by 8.3%, tributaries and sloughs by 36.4%, and islands by 39.4% (PNERC 1998). Over the longer reach between Albany and Harrisburg, 40% of the total channel length was lost between 1850 and the late 1960s (Benner & Sedell 1996). The Upper Willamette River channel pattern converted from a complex anastomosed river, with multiple dynamic anabranches around semi-stable channel islands, to a simpler single meandering channel (terms defined in Church 1992). The remaining channel roughly doubled in width as a result of concentrating flow into a single channel (PNERC 1998). Between 1850 and 1932, community composition along the channel margin between Corvallis and Harrisburg changed significantly. Forest with conifer margins declined from 76.1 to 16.2%, while forest without conifer margins increased from 1 to 43.2% (PNERC 1998). Prairie margins declined from 22.9 to 0.0% and agriculture margins increased from 0.0 to 37.7%, as prairie became converted to agriculture (PNERC 1998).

The hydrogeomorphic regime changed dramatically between 1938 and 1968 by the addition of dams and revetments. Dam construction on the Willamette's tributaries occurred between 1942 and 1968. These dams reduced fall and winter peak flows to bank full flows, stored early spring runoff, and augmented summer low flows (Huff et al. 1976, Benner & Sedell1996). Dams also blocked the transport of sediment, bed load and large woody debris. The installation of revetments between 1938 and 1971 along the study reach also altered the geomorphic processes of scour, erosion and deposition. Installation of boulder revetments between the 1930s and 1980s resulted in the stabilization of 1/4 of the main channel between Eugene and Albany (Benner & Sedell 1997). Stream gauge analysis of four stations from 1945 to 1965 approximated the rate of bed degradation at 0.3 m per decade on the main stem of the Willamette River between Harrisburg and Wilsonville (Klingeman 1973).

2.3. Site Selection

Several factors contributed to the selection of the sites for this study. The reach north of Harrisburg, Oregon had some of the few remaining patches of natural vegetation adjacent to the Willamette River. Aerial photography of this reach spanned fifty-seven years, a relatively long time period. Various data sets collected along this reach were available from research underway at the Western Ecology Division of the Environmental Protection Agency (EPA). Two long-term United States Geological Survey (USGS) stream gauges, Harrisburg and Albany, bracketed this reach. Management of water runoff and riverbanks along this reach changed significantly over the period of the aerial photo record. Three riparian sites within this reach were selected because of their relatively large area of natural cover, minimal human intervention to cover, and proximity to each other, ensuring a similar hydrologic regime. These three sites will be referred to as the northern site (river mile 151 – 152 upstream of Irish Bend), the middle site (river mile 154-155 surrounding Harkens Landing) and the southern site (river mile 155-156 on Ingram Island) (Figure 2).

2.4. Data Sources

Two sets of aerial photo coverages were examined in detail for this study. The earliest coverage available was 1:10,500 black and white photography, flown in 1939 and funded by the USACE Portland Division. This study used frames 159 (flown May 1), 9984, 9986 and 9988 (flown July 17). The most recent coverage available was 1:24,000 natural color photography, flown in 1996 and funded by the EPA's Western Ecology Division. This study used frames 4-2, 4-3 and 4-4, flown on July 22nd. These photos captured the disturbance affects of the 1996 February flood, one of the highest since the completion of the dams which resulted in 18 counties being declared national disasters (USACE 1999). Fourteen aerial photo sets covering the study reach taken between 1939 and 1996 were reviewed in order to investigate channel dynamics associated with cover change. These intermediate black and white photo sets included: 1944 (1:10,000 University of Oregon (U of O)), 1948 (1:20,000 U of O), 1956 (1:20,000 U of O), 1960 (1:20,000 U of O), 1961 (1:10,000 USACE), 1963 (1:20,000 U of O), 1968 (1:20,000 U of O), 1970 (1:20,000 U of O), 1972 (1:10,000 USACE), 1976 (1:10,000 USACE), 1978 (1:20,00 U of O), 1981 (1:10,000 USACE), 1982 (1:31,640 U of O) and 1986 (1:10,000 USACE).

2.5. Pretreatment and Rectification

A cover change analysis was undertaken utilizing a geographic information system (GIS). First, the aerial photographs were scanned at 600 dots per inch (dpi) and saved in a Tiff format. The resulting pixel size on the ground equaled 0.5 m^2 for the 1939 photos and 1.0 m^2 for the 1996 photos. Second, the scanned images were geo-rectified using Imagine 8.3 software. In order to minimize photographic distortion of the 1996 images, the photo frame with the site nearest to the center was selected for each one. These 1996 digital images were then cropped to include only the area shown in the 1939 photo for each site. A 1995 orthophoto (created by Spencer Gross in Portland, Oregon) was used as the base map because it enabled a wider selection of viable ground control points than a map.

A zoom transfer scope was used to verify common ground control points between the photo coverages and the 1995 orthophoto. The zoom transfer scope allowed the photo image to be magnified and stretched until it matched the printed orthophoto image. Remnant floodplain fluvial features, road intersections, field intersections, and buildings were used to align the images. This process was especially important for selecting accurate control points for the 1939 photos because many features changed significantly by 1995.

Once images were aligned, numerous possible ground control points were noted on a print of the orthophoto and printed enlargements of the photo images. The area covered by the 1939 photos was printed at a scale of 1:5,250 (2 X the photo scale). The area covered by the 1996 images was enlarged to a scale of 1:8,000 (3 X the photo scale). The scale for printing the orthophoto images was selected to give the highest resolution possible while leaving sufficient alignment features in the zoom transfer scope frame of view. All possible ground control points were pin-pointed with a dot from a fine point felt tip marker on enlarged paper copies of the images. Written notes detailing the exact location of the points were helpful because the amount of detail seen through the zoom transfer scope and later at the computer terminal was higher than the accuracy of the marker. Specified parts of intersections, building corners and other micro features were utilized as control points (Figure 4). An evenly distributed coverage of >15 accurate points across each photo was sought for rectification (Figure 4).

Figure 4. Ground Control Point Example

Features considered for rectification ground control points at southern site on 1996 image.

⊕ mark ground control points.

All feasible ground control points were entered manually onto the digital photo images and the digital orthophoto using Imagine 8.3. The pairs with the highest root mean square error (rms) were eliminated. The images were then geo-rectified using the non-linear rubber-sheeting model (order 2 polynomial) in Imagine 8.3. The second order polynomial model required a minimum of 6 points for rectification; a minimum of 12 points were used to rectify each image in this study. The average error for each photo rectification was < 2 m on the ground (Appendix 1). This meant the average rms was < 4 pixels for each 1939 image (pixel length = 0.5 m) and < 2 pixels for the 1996 images (pixel length = 1.0 m). The images were rectified using nearest neighbor resampling. This method transferred the original values without averaging them, which was important for discriminating between vegetation types, and therefore best suited for use before classification. Once the images were rectified and geo-referenced, site boundaries were delineated. Boundary delineation maximized the natural land cover and minimized agricultural areas present in 1996. Site boundaries were then adjusted as needed to minimize agricultural areas present in 1939.

2.6. Classification and Mapping

Classification and mapping involved several steps: (1) creation of a classification system, (2) manual delineation of homogeneous polygons with a minimum mapping unit guideline, and (3) manual assignment of classes to polygons based on cover features distinguished on air photos. A structural cover classification system was created for this study. This classification system had eight structural cover types: water, bare, herbaceous, shrub, small trees, medium trees, large trees and cleared land. All vegetative cover was further subdivided into density classes: sparse, open and closed. These divisions resulted in a classification system with eighteen cover classes (Table 1). The classification system was based on features visible in the air photos, therefore in multistoried canopies the understory was ignored.

Table 1. Cover Classification System

Cover Code	Cover Class	Class Descriptor and Density of Cover
W	Water	100 % water
B	Bare	unconsolidated shore with < 5 % vegetation
HS	Herbaceous Sparse	between 5 % & 30% non-woody vegetation
HO	Herbaceous Open	between 30% & 70% non-woody vegetation
HC	Herbaceous Closed	>70% non-woody vegetation
SS	Shrub Sparse	between 5 % & 30% woody vegetation
SO	Shrub Open	between 30% & 70% woody vegetation
SC	Shrub Closed	>70% woody vegetation
TSS	Tree Small Sparse	between 5 % & 30% small trees
TSO	Tree Small Open	between 30% & 70% small trees
TSC	Tree Small Closed	>70% small trees
TMS	Tree Medium Sparse	between 5 % & 30% medium crown forest
TMO	Tree Medium Open	between 30% & 70% medium crown forest
TMC	Tree Medium Closed	>70% medium crown forest
TLS	Tree Large Sparse	between 5 % & 30% large crown forest
TLO	Tree Large Open	between 30% & 70% large crown forest
TLC	Tree Large Closed	>70% large crown forest
C	Cleared	agricultural land

Each structural class had common ground features associated with it. Observations were based on field visits in the Summer of 1999. Water cover included all water bodies: the river, inlets and inland ponds. Bare cover included unconsolidated shore areas with less than 5% vegetative cover, and generally consisted of cobble bars. Herbaceous cover represented non-woody vegetation consisting of forbs, sedges and grasses. Reed canarygrass and prairie were common examples of vegetation in this category in 1999, however discussions with landowners indicated that canary reed grass was not common in 1939. Shrubs were defined as having woody stems and intricate branching. Willow and blackberry were common in this category in 1999, however discussions with landowners indicated blackberry also was not common in 1939. Trees were defined as having a free stem. The most common trees at the sites in 1999 included black cottonwood (poplars), mature willows, Oregon ash and big leaf maple. Cleared land referred to property stripped of natural vegetation for agricultural use.

Cover types were identified and mapped as class polygons (Figures 5, 6, 7, & 8). Manual delineation of homogeneous areas consistent with the 18 cover classes were made on the computer screen in Imagine 8.3 while viewing rectified digital images displayed at a scale of 1:2,000. Classification was assisted by viewing stereo pairs of photos with a Lietz stereoscope (MS-27 Sokkisha Limited, 3X magnification) and an adjustable hand lens (Canon, 8X magnification). A minimum mapping unit of 30 m^2 (5.5 m/side) acted as a rough guideline to assist in decisions between lumping and splitting areas. Areas of cleared land and water bodies falling below the minimum mapping unit were delineated as separate polygons because of their distinct character. Each polygon was given an identification point. The cover class code (Table 1) was added to the attributes of the polygon after the coverage was built.

Each polygon was classified visually. Classes were discriminated based on cover structure and density (Table 1), which was a function of photo interpretation elements including texture, shape and tone (Table 2). Three density classes subdivided all vegetation cover classes (Table 1): sparse (< 30% cover), open (30% - 70% cover), and closed (>70% cover) with the aide of percent tree crown density scales created by the U. S. Forest Service (Payne 1981, 424). Relative canopy height aided in distinguishing among cover classes. Height was interpreted from shadow lengths on individual photos and 3D-stereoscope viewing of air photo stereo pairs. Three tree crown classes were distinguished by

Figure 5. Northern Site Classified Images

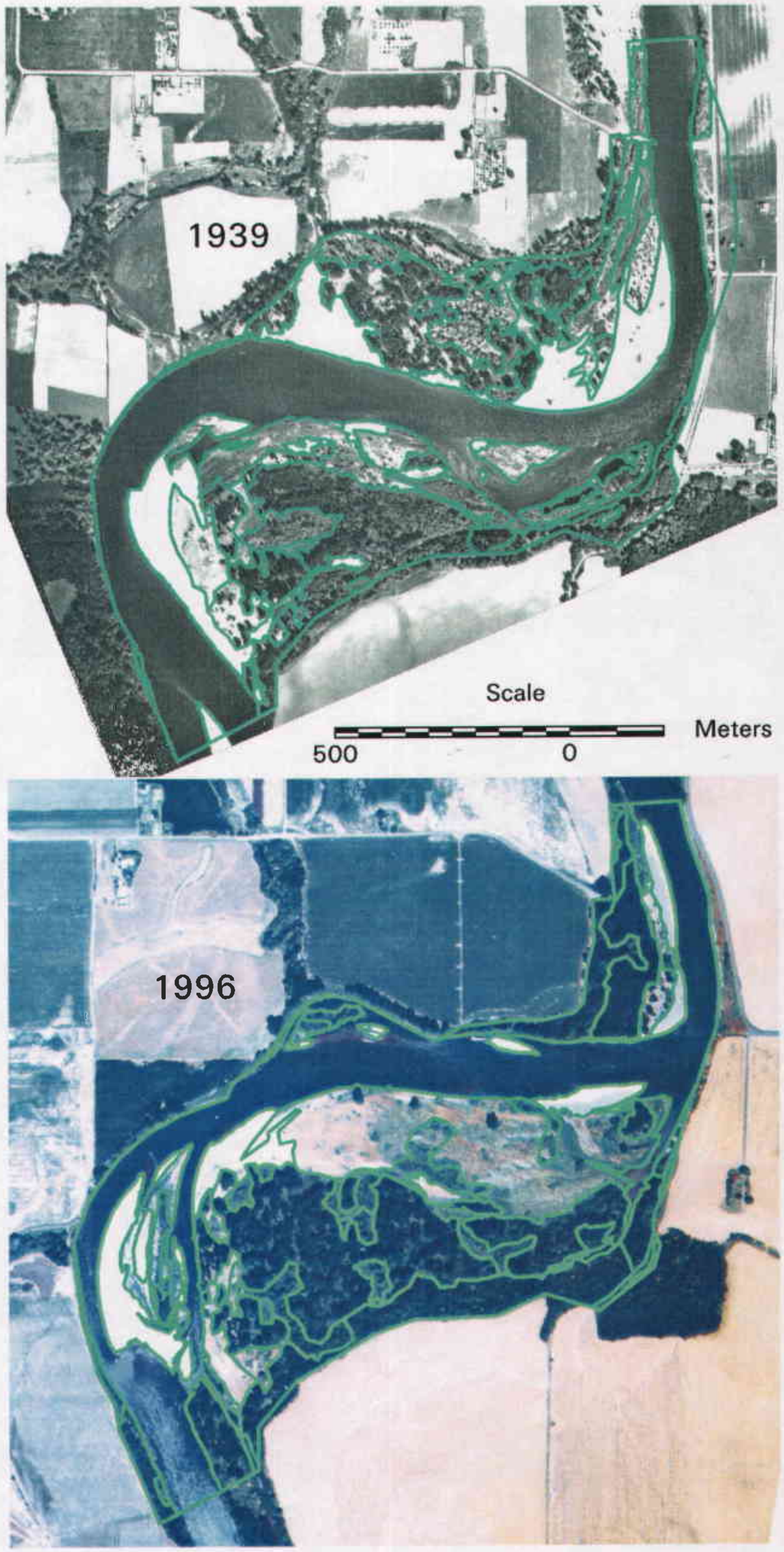


Figure 6. Middle Site Classified Images

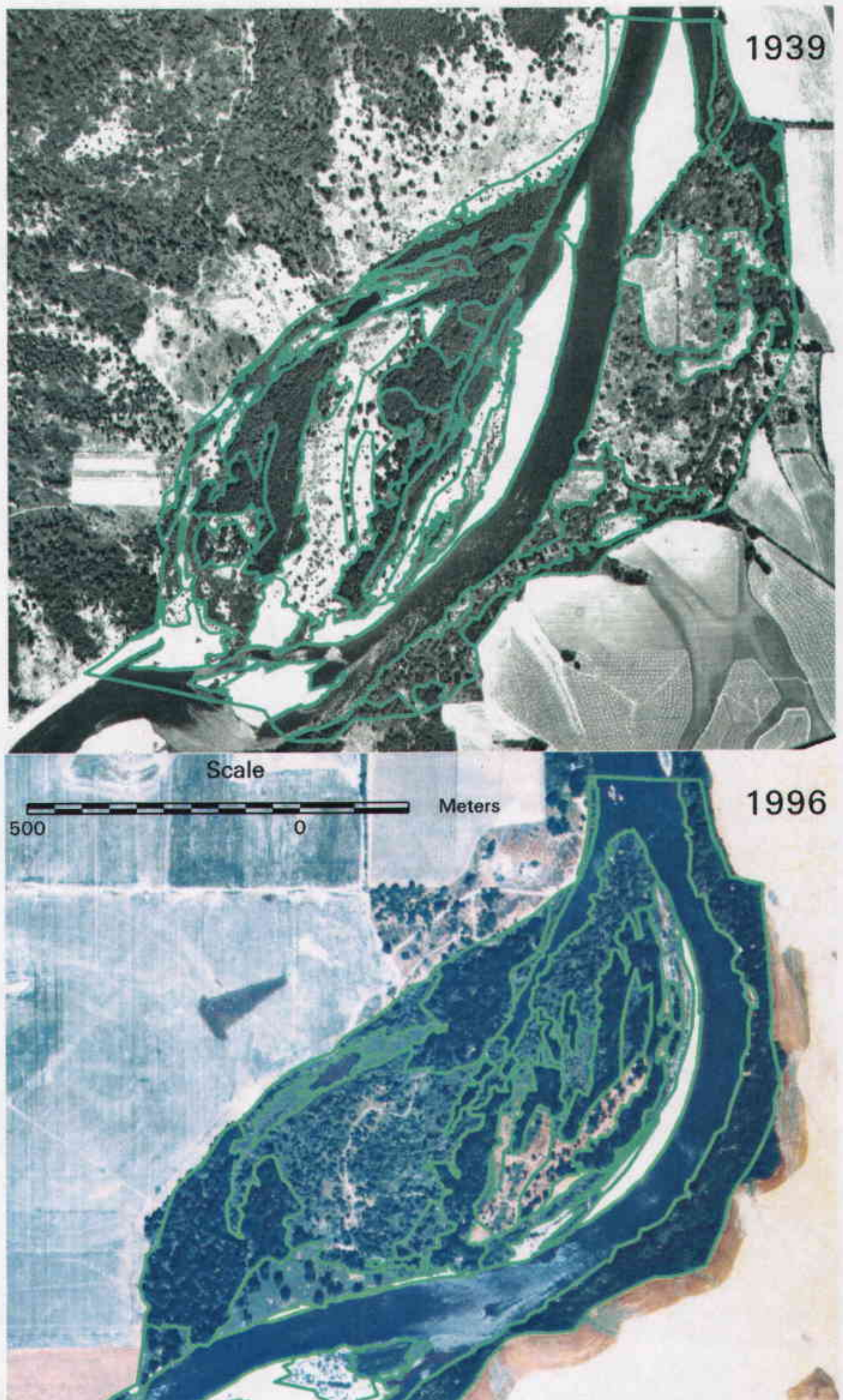


Figure 7. Southern Site Classified 1939 Image

Figure 8. Southern Site Classified 1996 Image

Scale

500 0 500 Meters

measurement of crown diameter on 1:2,000 digital images with a micrometer wedge scale created by the U. S. Forest Service: small (< 0.00015 m), medium (0.00015 – 0.0084 m) and large (>0.0084 m) (Payne, 1881, 421). The 1996 images were displayed in black and white adjacent to 1939 images, ensuring consistent interpretation by allowing direct comparison.

Table 2. Air Photo Interpretation Class Indicators

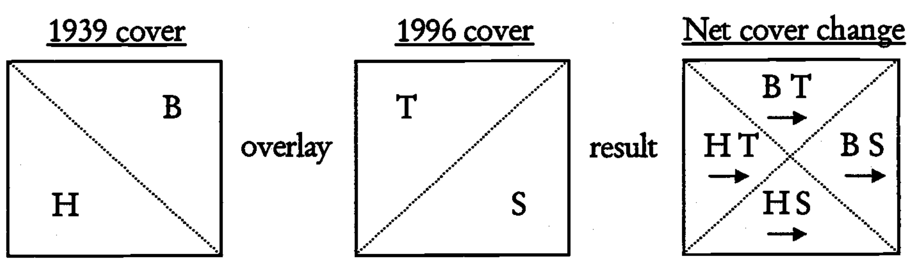
Cover Type	1939 Indicator	1996 Indicator
Water	texture: homogenous smooth tone: dark gray - gray with white reflections other: well defined edge	texture: homogenous smooth tone: dark blue –blue with white reflections other: well defined edge
Bare	texture: homogenous smooth tone: white other: generally proximal to water	texture: homogenous smooth tone: white - tan other: generally proximal to water
Herbaceous	texture: homogenous smooth tone: light gray	texture: homogenous smooth tone: gold & green
Shrub	texture: irregular rough tone: light gray	texture: irregular rough tone: light green
Tree Small	texture: bumpy tone: medium gray other: circular polygons < 0.0015 m diameter.*	texture: bumpy tone: green other: circular polygons < 0.0015 m diameter.*
Tree Medium	texture: rough rounded bumps tone: medium gray other: circular polygons 0.0015 – 0.0084 m diameter.*	texture: rough rounded bumps tone: green other: circular polygons 0.0015 – 0.0084 m diameter.*
Tree Large	texture: rough rounded bumps tone: dark gray other: irregular edged circular polygons >0.0084 m diameter. *	texture: rough rounded bumps tone: dark green other: irregular edged circular polygons >0.0084 m diameter.*
Cleared	texture: smooth with linear patterns tone: light gray other: straight edges, rectilinear polygons	texture: smooth with linear patterns tone: gold other: straight edges, rectilinear polygons

Measurements refer to tree crown diameter on digital images zoomed to a 1:2,000 scale.

2.7. Change Analysis

A change detection analysis was conducted to reveal changes in cover between 1939 and 1996. This process was carried out in Arc/Info using the Intersect command. This command meshed the 1939 and 1996 vector layers, creating a polygon for each different cover class combination (Figure 9). For example, an area that was bare in 1939 and became shrub in 1996, would represent one cover class combination in the change detection analysis. Hence 324 (18^2) class combinations were possible. The area for each class combination was then summarized in Microsoft Excel 97 pivot tables. Changes were expressed as a percent of total site area, where 1% approximately equaled 10 m^2.

Figure 9. Arc/Info Intersect Procedure Revealed Cover Change



1939 cover classes were replaced with 1996 cover classes, the net change between 1939 and 1996 were displayed by class combinations i.e. H (herbaceous) goes to T (trees) in the left portion of the site and B (bare) goes to S (shrub) in the right portion of the site.

Cover change table matrices utilized two classification schemes: (1) the original 18 classes, and (2) classes grouped into 6 categories: water (W), bare (B), low vegetation (HSTS); open trees (TO), closed trees (TC) and cleared land (C). Open herbaceous and open shrub cover did not exist in 1939 or 1996, therefore only 16 of the 18 classes were utilized. The categories of water, bare and cleared land were identical to the classes with the same title. The "low vegetation" category was composed of herbaceous (H), shrub (S) and small trees (TS). The "open tree" category was composed of medium and large tree covers of sparse and open canopy densities. The "closed tree" category was composed of closed canopy medium and large trees. The term "forest" referred to the sum of the open and closed tree categories, which included all medium and large tree classes.

Two sets of changes in cover categories over time were computed: (1) overall net site changes and (2) net site change subdivided into fluvial areas and terrestrial areas. "Fluvial area" defined areas that had been a part of the river channel or other water bodies between 1939 and 1996, i.e. areas where water became land or vice-versa, and areas occupied by the channel at some time between 1939 and 1996. "Terrestrial area" defined areas that had not been a part of the channel between 1939 and 1996, i.e. changes among bare ground and vegetation classes. Fluvial change areas examined gross channel migration, including the entire area of channel migration over the 56-year period. A subset of the fluvial area called net channel migration was also examined, which compared land cover gained by the abandoned 1939 channel area to land cover lost in the 1996 channel.

Cover changes were summarized to assess how much net progressive structural change (PSC) and net regressive structural change (RSC) occurred over time for the overall site, fluvial areas and terrestrial areas. Progressive structural change followed a general trend of an increase in biomass overtime, i.e. beginning with bare cover and developing toward a closed canopy forest. Regressive structural change defined areas that experienced a reversal of progression, i.e. a reduction in vegetative cover. Regressive structural change occurred when disturbance reset the progression of cover. Many development scenarios were possible. Four schemes investigated net structural cover change between 1939 and 1996:

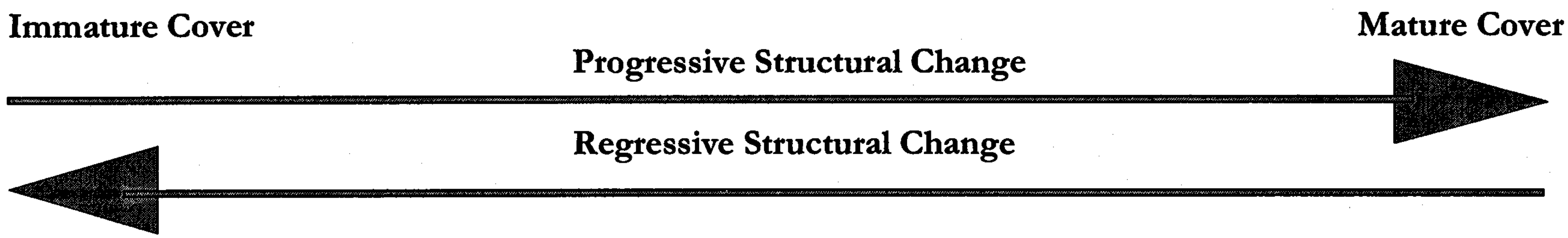
two table matrix configurations and two graphics. The table matrixes shared the same progression, while the graphics offered slight variations in progression (Figure 10).

All cover change computations used only 1939 and 1996 covers, therefore expressing net change. This underestimated the total change, especially for areas affected by channel migration. Some areas experienced both regressive and progressive structural change if they were eroded and deposited, or cleared and regrown between 1939 and 1996. For example, an area of trees with no net change between 1939 and 1996 in a channel area actually meant the 1939 stand was eroded by the channel and a new stand of trees with similar traits grew in the same location on newly deposited land by 1996. Whereas a terrestrial area with no net change probably had the same vegetation in 1939 and 1996. In most cases fluvial areas experienced more degrees of change than terrestrial areas.

2.8. Hydro-geomorphic Regime Characterization

Hydrologic conditions influencing the development of riparian cover for pre-dam and post-dam regimes were characterized by annual peak flow recurrence intervals and annual bank full flow frequency. Two 30-yr periods of peak flow records were utilized to compare annual peak flow recurrence: 1909 – 1939, and 1968 – 1998. A basic ranking technique was used to determine recurrence intervals. The Harrisburg stream gauge located approximately 6 km upstream of the study reach began recording stream flows in 1944. The Albany stream gauge located 68 river km downstream of the Harrisburg gauge began recording stream flows in 1894. A correlation was established between the Albany and Harrisburg annual peak flows between 1944 and 1998 (Appendix 2). This allowed annual peak flows prior to 1944 at Harrisburg to be estimated from Albany annual peak flows. The

Figure 10. Cover Change Scenarios



8 Structural Types used in Cover Change Diagrams (Table 2, Figures 11, 16 & 20)

water	bare	clear	herbaceous	shrubs	small trees	open forest	closed forest

18 Classes used for Polygon Delineation and Classification Changes (Tables 1, 3, 7 & 11)

W	B	C	HS	HO	HC	SS	SO	SC	TSS	TSO	TSC	TMS	TLS	TMO	TLO	TMC	TLC

6 Categories used for Category Changes (Tables 4, 5, 6, 8, 9, 10,12, 13 & 14)

water	bare	clear	low vegetation	open forest	closed forest

6 Groups used for Degree and Direction of Cover Change (Figures 15, 19 & 24)

W	B	HS HO HC C	SS TSS SO TSO SC TSC	TMS TLS TMO TLO	TMC TLC
water	bare	herbaceous & clear	shrub & small trees	open forest	closed forest

correlation equation was Y = 1.0273 X + 13198, producing a R^2 of 0.8809. Y represented Albany annual peak flows in cfs and X represented Harrisburg annual peak flows in cfs.

Annual frequency of bank full flow, as defined by USACE, was also analyzed for pre and post regulated conditions. Bank full at Harrisburg equaled a stage height of 10.7 feet, which translated to a 42,000 cfs flow. Each daily discharge above 42,000cfs was considered a bank full event. Harrisburg stream gauge data was divided into two periods to analyze pre and post dam bank full flow frequency: 1944 – 1967 and 1968-1998. All large dams present in 1996 were completed by 1968, providing a breaking point for this analysis. The analysis therefore provided a conservative estimate because the "pre"-dam representation occurred in a period when dams were installed incrementally. Furthermore bed degradation during this time, implied a higher discharge would have been needed to reach bankfull in the period after 1968. However the discharge of 42,000 cfs was used for both periods making the analysis even more conservative.

Bank stabilization along the study reach was investigated using a GIS coverage created by field GPS readings (Fernald at the EPA, Corvallis). This coverage also delineated banks along the floodplain boundary since these high banks were relatively resistant to erosion. Locations and installation dates of USACE revetments along the reach were identified using two USACE Portland documents: (1) 1986 photography with revetments outlined and named, and (2) a list of revetments by name, installation date and revetment length. This revealed the extent and timing of bank hardening along the study reach.

3. RESULTS

3.1. Northern Site

3.1.1. Comparison of cover for the overall site, 1939 and 1996

In 1939, cover at the northern site was dominated by water (36% of site area), bare ground (12%), large open-canopy trees (10%) and medium closed-canopy trees (14%) (Table 3). "Dominant" referred to a class which occupied > 10% of the site area. In 1996, cover at the northern site was also dominated by water (29% of site area), but vegetation was dominated by closed herbaceous (16%) and large open-canopy trees (22%) (Table 3). Dramatic increases occurred in closed herbaceous cover (1 to 16%) and large open-canopy trees (10 to 22%) (Table 3). Net changes in the six simplified categories reflected a net progressive structural change between 1939 and 1996: water areas decreased from 36 to 29% cover, bare areas decreased from 12 to 8% cover, low vegetation increased from 15 to 27% cover, and forest increased from 33 to 36% cover (Table 4). Mostly water and forest covers composed 26% of the site that experienced no net change between 1939 and 1996 (Table 4, gray cells). Progressive structural change occurred on 39% of the site (Table 4, green cells & blue cells in row), and regressive structural change occurred on 33% (Table 4, yellow cells & blue cells in column). A decline in forest dominated regressive structural change while progressive structural change occurred between several classes (Figure 11).

In 1939, bare, shrub, and herbaceous cover concentrated on point bars along the channel margin. All bare cover was adjacent to the channel, whereas shrub and herbaceous cover tended to be inland of bare cover (Figure 12, 1939). Trees generally occurred inland

Table 3. Northern Site Classification Changes between 1939 and 1996

		1996 Class Coverage (% of Site)																		1939
		W	B	C	HS	HO	HC	SS	SO	SC	TSS	TSO	TSC	TMS	TLS	TMO	TLO	TMC	TLC	Total
1939 Class Coverage (% of Site)	W	12	5				7		1	2					1	1	5		1	36
	B	3	2				4		1								1			12
	C	3																		3
	HS																			
	HO	1																		2
	HC																1			1
	SS																		1	1
	SO	2								1							4		1	8
	SC																1		1	2
	TSS																			
	TSO																			
	TSC																1			1
	TMS	1														1	1			3
	TLS																			1
	TMO	2					1										1			3
	TLO	4					2		1								2			10
	TMC	1								1						1	5		5	14
	TLC	1															1			3
1996	Total	29	8			1	16		4	5				1	1	3	22		9	100%

A forward move between classes represents a progressive structural change. →

W	B	C	HS	HO	HC	SS	SO	SC	TSS	TSO	TSC	TMS	TLS	TMO	TLO	TMC	TLC
water	bare	clear	herbaceous			shrubs			small trees			open forest				closed forest	
W	B	C	H			S			TS			TO				TC	

A backward move between classes represents a regressive structural change. ←

[gray cells] represent percent of site remaining in the same class in 1939 and 1996 coverages.

Cells below gray cells represent regressive structural change. Cells above gray cells represent progressive structural change.

Bold values represent class combination areas ≥ or equal to 5% of the site (approximately 50 square meters).

Rounding values to whole integers created apparent inaccuracy of row and column totals.

Table 4. Northern Site Category Changes
between 1939 and 1996

		1996 (% of Site)					1939
		W	B	HSTS	TO	TC	Total
1939 (% of Site)	W	12	5	11	7	1	36
	B	3	2	5	1		12
	C	3					3
	HSTS	3		2	7	2	15
	TO	7		6	5		17
	TC	2		2	7	5	16
1996	Total	29	8	27	27	9	100%

Table 5. Northern Site Category Changes
for Fluvial Areas
between 1939 and 1996

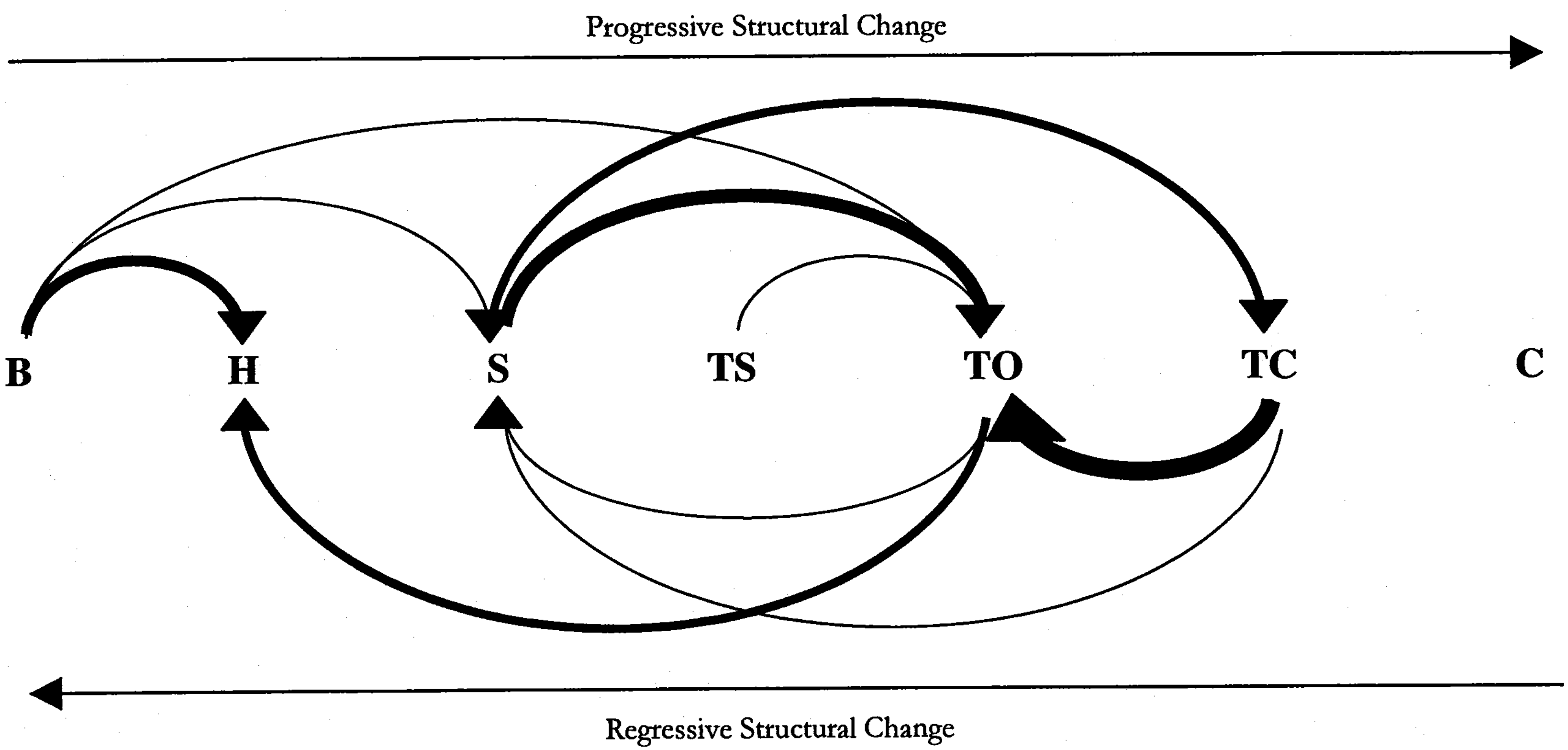
		1996 (% of Site)					1939
		W	B	HSTS	TO	TC	Total
1939 (% of Site)	W	12	5	11	7	1	36
	B	3	2	5			11
	C	3					3
	HSTS	3		1	1		5
	TO	7		4			11
	TC	2		1			3
1996	Total	29	8	22	8	1	68%

Table 6. Northern Site Category Changes
for Terrestrial Areas
between 1939 and 1996

		1996 (% of Site)			1939
		B	HSTS	TO	TC	Total
1939 (% of Site)	B			1		1
	C					
	HSTS		1	6	2	10
	TO		2	5		6
	TC		1	7	5	13
	Total		5	19	8	32%

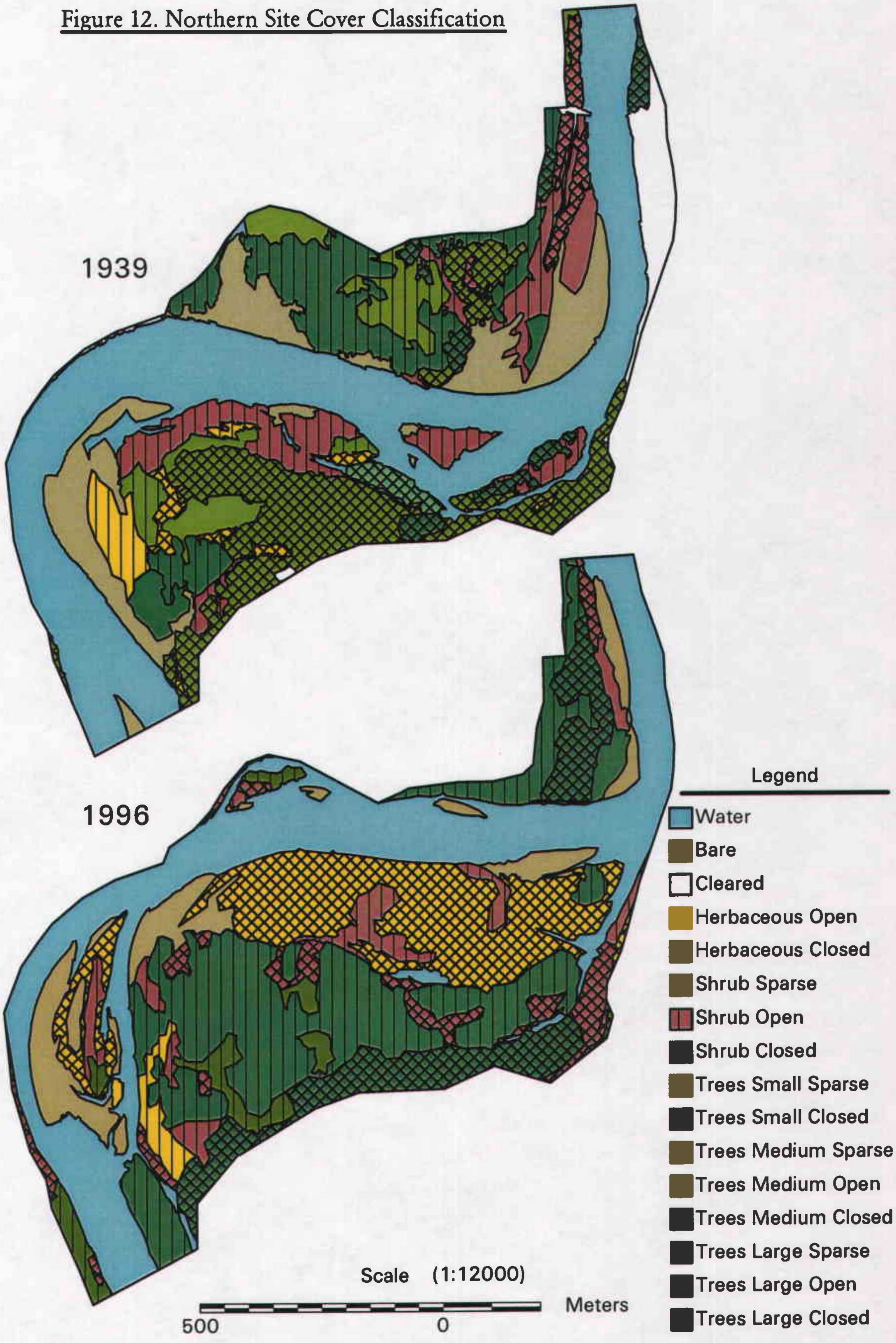
W = water
B = bare
HSTS = low vegetation (herbaceous, shrub & small trees)
TO = open-canopy forest (medium & large trees with sparse or open canopy)
TC = closed-canopy forest (medium & large trees with closed-canopy)
[green] represent progressive structural change between categories. →
water | bare | low vegetation | open forest | closed forest
[yellow] represent regressive structural change between categories. ←
[grey] represent areas of no change between categories in 1939 and 1996 coverages.
[blue] represent changes associated with 1939 and 1996 channel areas.
Rounding values to whole integers created apparent inaccuracy of totals.

Figure 11. Northern Site Cover Change Diagram (1939-1996)



B = bare, H = herbaceous, S = shrub, TS = small trees, TO = open-canopy trees, TC = closed-canopy trees, and C = cleared
The thickness of the arrow shaft represents the percent of site experiencing that particular change in cover between 1939 and 1996

Figure 12. Northern Site Cover Classification



of other covers and off the main channel (Figure 12, 1939). In 1996, bare and herbaceous covers also concentrated on point bars along the channel margin and upstream portions of mid-channel bars. In 1939, bare areas were wide and complex relative to the narrow linear strips present in 1996 (Figure 12). In 1996, tree cover expanded and bordered the main channel in more areas. The 1996 cover also had relatively large areas of contiguous large open trees and herbaceous cover, while the 1939 cover appeared to occur in smaller patches (Figure 12). The only exception was the mid-channel bar, whose land surface was not established in its 1996 form until 1994. Other 1996 surfaces were established by 1956.

3.1.2. Cover changes in the fluvial area, 1939 to 1996

Fluvial changes affected 68% of the northern site (Table 5). Only 12% of the area at the northern site remained covered by water in 1939 and 1996 (Table 5). Two thirds of the area that was covered by water in 1939 (or 24% of the site) became land by 1996, and about 2/3 of the area covered by water in 1996 (or 18% of the site) was land in 1939 (Table 4, blue cells). Net channel migration accounted for net increases in cover by bare ground (3% loss, 5% gain) and low vegetation (3% loss, 11% gain); a net decrease in agricultural fields (3% loss, 0% gain); and virtually no change in forest cover (9% loss, 8% gain) (Table 4, blue cells). Gross channel migration accounted for a net increase in low vegetation (4% loss, 21% gain); and net decreases in bare ground (8% loss, 5% gain), agricultural fields (3% loss, 0% gain), open-canopy trees (11% loss, 8% gain) and closed-canopy trees (3% loss, 1% gain) (Table 5). Areas created by channel dynamics since 1939 resulted in net progressive structural change on 30% of the site and net regressive structural change on 23% of the site (Table 5. green & yellow cells). Exchange between cover categories favored increased low vegetation: bare ground became low vegetation (RSC 0%, PSC 5%), forest tended toward low vegetation (RSC 5%, PSC 1%), and no exchange occurred between bare and forest (RSC 0%, PSC 0%) (Table 5). Gross channel change favored progressive change overall because dramatic channel shifting ended by the mid-1950s, allowing progression to dominate in the last 40 years.

Channel movement at the northern site between 1939 and 1996 included: an eastward shift in the north, a northward shift in the central portion of the site, and a westward shift in the south (Figure 13, blue polygons). By 1944 the bare point bar forming at the apex of the southern point bar in 1939 elongated, and widened into a mid-channel bar located downstream of the 1944 revetment (Figure 14, Lower Bend). Three events occurred by 1956: (1) The area between the mid-channel bar and the point bar to the south filled in with land; (2) The bank downstream of the revetment eroded, and (3) The southern and northern mid-channel bars present in 1996 formed. In 1961, overflow paths ran along the southern border of the abandoned 1939 channel and scour marks were present across the bar deposited since 1939 (Figure 12 & 13). By 1963, extension of the 1944 revetment halted channel widening and forest erosion downstream of the 1944 revetment (Figure 14). After the mid-1970s, the only landform changes were the formation of mid-channel bars.

Structural change in fluvial areas progressed further on the older deposits. The degree of progressive structural change was highest in the abandoned 1939 channel and gradually declined toward the 1996 channel (Figure 15, 1939 fluvial area, dark blue-purple polygons grades to lighter blue polygons). For example, in the northern portion of the site where the channel moved east, long linear patterns of cover were arrayed parallel to the river on land deposited since 1939 (Figure 12, 1996). The maturity of cover increased with distance from the river, i.e. bare cover near the channel and forest farthest away. Most of

Figure 13. Northern Site Fluvial and Terrestrial Areas

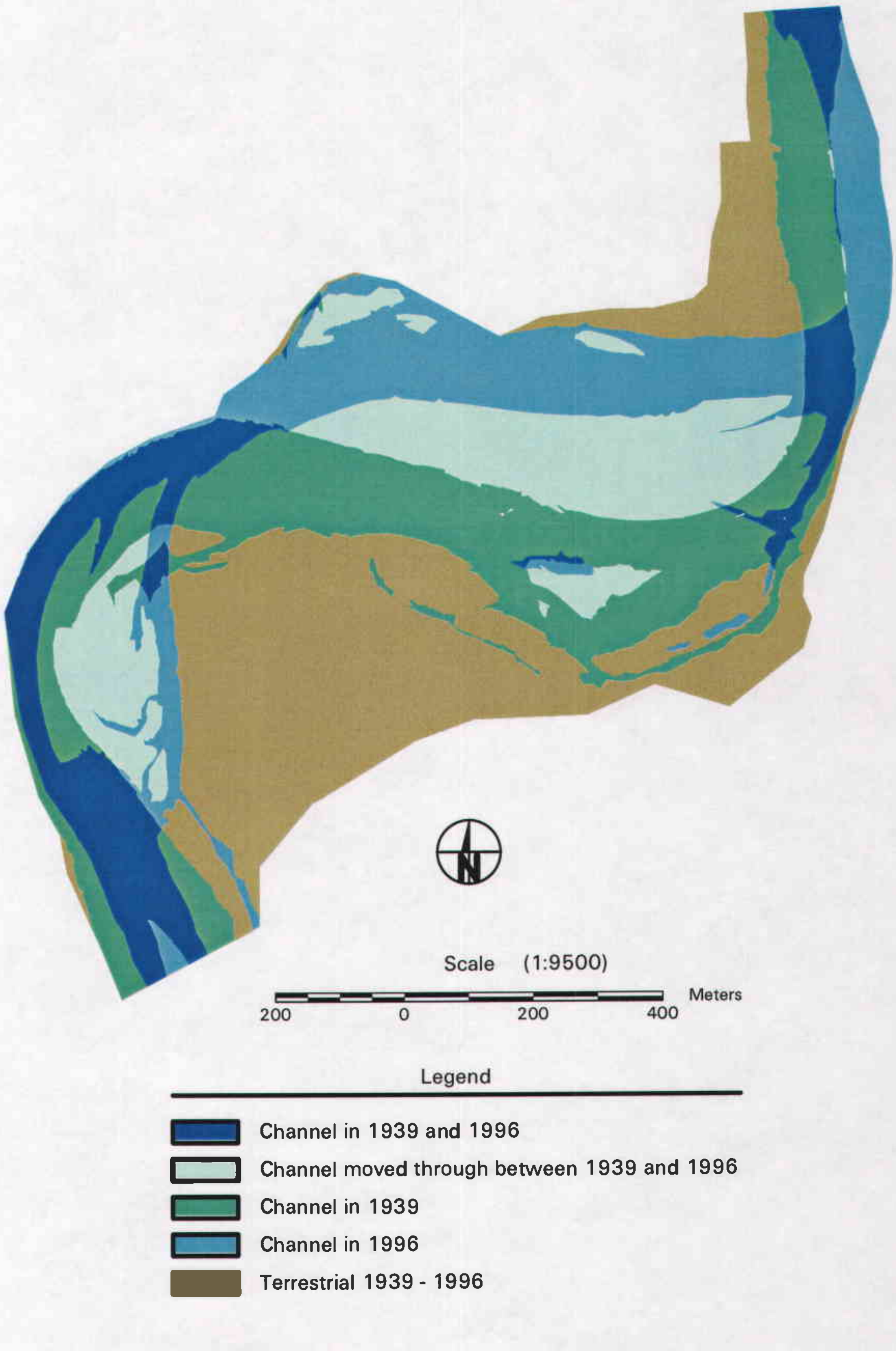
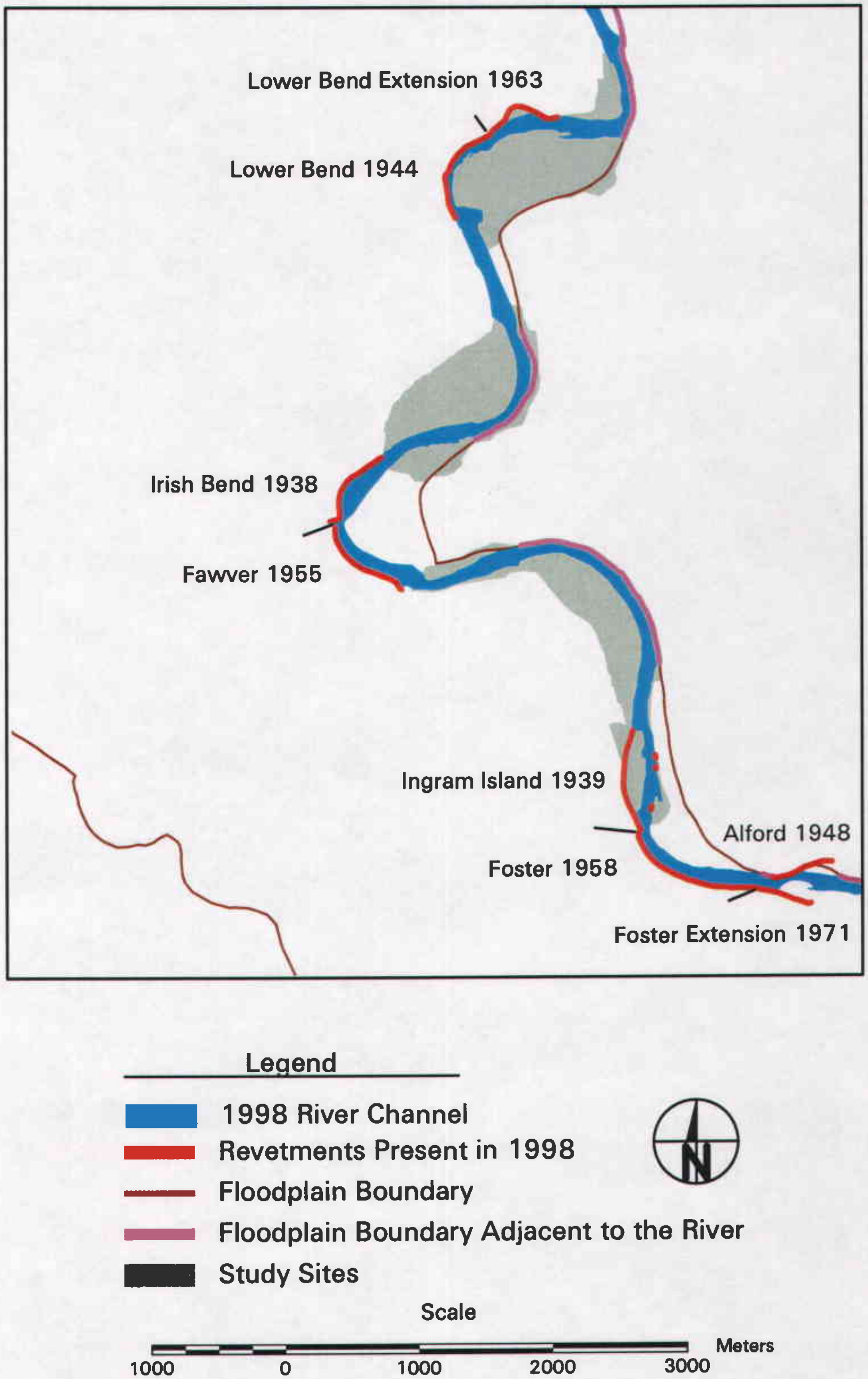
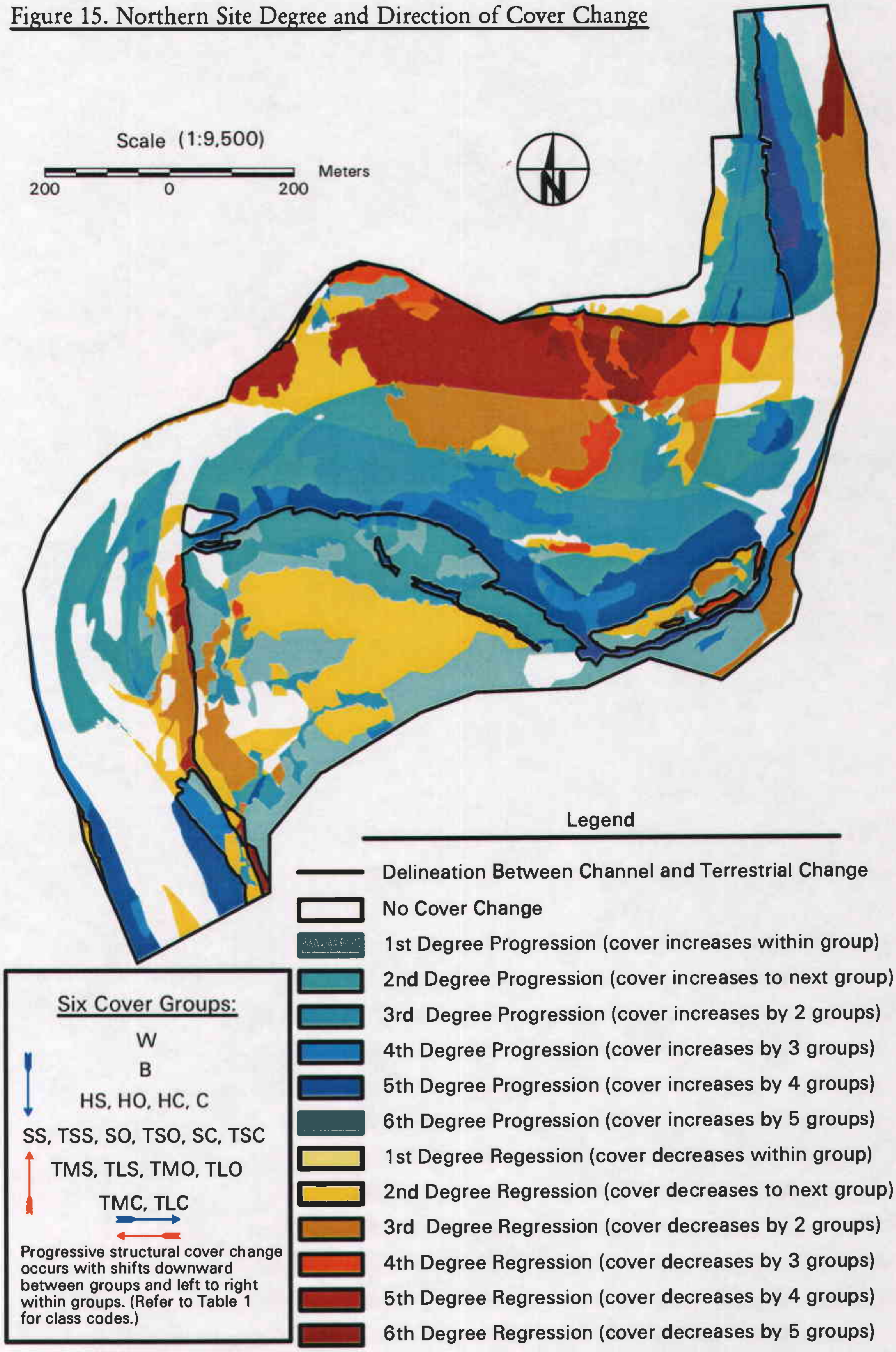


Figure 14. Bank Conditions along the Study Reach



Dates on map indicate when revetments were installed.

Figure 15. Northern Site Degree and Direction of Cover Change



the disturbed areas correlated with the 1996 channel, although south of the main channel herbaceous cover replaced the trees and shrubs of 1939 (Figure 15, fluvial area, yellow-orange polygons). The areas with no net change covered 1/5 of the site and tended to be the immature structural covers, i.e. water and bare ground (Figure 15, white polygons).

3.1.3. Cover changes in the terrestrial area, 1939 to 1996

Areas not reworked by channel migration between 1939 and 1996 comprised 32% of the northern site. One third of the terrestrial area experienced no net change from 1939 to 1996, 1/3 experienced progressive structural change, and 1/3 experienced regressive structural change (Table 6 & Figure 12, tan polygons). Forest cover, designated a mature cover, dominated these areas. Changes consisted of a net increase in open-canopy trees (2% loss, 14% gain); net decreases in low vegetation (8% loss, 3% gain) and closed-canopy trees (8% loss, 2% gain); and virtually no change in bare ground (1% loss, 0% gain) (Table 6). The exchange between categories associated with terrestrial changes favored forest: more low vegetation became forest than vice versa (RSC 3%, PSC 8%), bare became forest (RSC 0%, PSC 1%), and no exchange occurred between bare ground and low vegetation (RSC 0%, PSC 0%) (Table 6). A mature forest cover dominated terrestrial areas with no net change. Areas that remained the same were dominated by forest cover (Figure 15, terrestrial area, white polygons).

The area unaffected by channel migration between 1939 and 1996 was located on the inside of river bends (Figure 13, tan polygons). The terrestrial area that underwent progressive structural change experienced a lower degree relative to 1939 fluvial areas because most terrestrial areas already had vegetation (Figure 15, terrestrial area, blue polygons). Terrestrial areas experienced approximately equal amounts of progressive and regressive structural change. The areas of terrestrial regressive structural change were also less dramatic than the fluvial areas. All terrestrial regressive structural change occurred in 1939 forest categories (Table 6, yellow cells). The majority of the regressive structural change was a change from medium closed-canopy trees to large open-canopy trees (Table 6, yellow cells & Figure 15, terrestrial area, yellow-tan polygons). The change from medium to large trees was unusual in an open to closed canopy shift and could be considered a progressive structural change, contrary to the general scheme of analysis. This would mean the terrestrial area heavily favored progressive over regressive structural change (RSC 3%, PSC 16%).

Forest cover that went from medium closed-canopy to large open-canopy trees may be considered progressive structural change for the following reasons (Figure 15, terrestrial area, yellow-gold polygons). In 1999, the disturbed areas south of the fluvial area remained forest cover and were dominated by large cottonwoods with a dense under story of trees including willow, hazelnut and dogwood (Figure 15, terrestrial area, yellow polygons). Intermediate photos showed forest in this area prior to 1961. But by 1961, only shrub and herbaceous vegetation remained. This finding, combined with landowner's comments, indicated logging activity occurred in this disturbed area. Regressive areas north of the fluvial area also shifted from medium closed-canopy to large open-canopy trees. Two possible explanations support this change as a progressive structural change: (1) natural thinning and maturation as a result of competition or (2) a shift from an even canopy in 1939 to a two storied canopy due to continued cottonwood growth after interspersed shrub and tree species matured at shorter heights, causing them to become understory in 1996 images.

3.1.4. Northern site summary

Overall the site experienced net increases in low vegetation (15 to 27%) and open-canopy trees (17 to 27%); and net decreases in water (36 to 29%), bare (12 to 8%), closed-canopy trees (16 to 9%), and agricultural fields (3 to 0%). Only 26% of the northern site cover remained unchanged between 1939 and 1996. This consisted of water cover in the fluvial area and forest cover in the terrestrial area (Table 5 & 6, gray cells). Two thirds of the channel area shifted to a new location between 1939 and 1996. The majority of this channel movement occurred between 1939 and 1956. Fluvial changes accounted for an increase in low vegetation and decreases in all other categories. Terrestrial changes accounted for an increase in open-canopy trees and decreases in all other categories. Fluvial change favored progressive structural change slightly, while terrestrial change favored progressive structural change 5 to 1.

3.2. Middle Site

3.2.1. Comparison of cover for the overall site, 1939 and 1996

In 1939, cover at the middle site was dominated by water (19% of site area), bare (12%), open shrub (11%), medium closed-canopy trees (10%) and large sparse-canopy trees (16%) (Table 7). In 1996, water (23%), medium open-canopy trees (18%), and large closed-canopy trees (34%) dominated cover at the middle site (Table 7). Dramatic increases occurred in medium open-canopy trees (0 to 18%) and large closed-canopy trees (9 to 34%). Net changes in the six simplified categories demonstrated a shift toward increased forest cover: water areas increased from 19 to 23% cover, bare areas decreased from 12 to 4%

Table 7. Middle Site Classification Changes between 1939 and 1996

		1996 Class Coverage (% of Site)																		1939
		W	**B**	**C**	**HS**	**HO**	**HC**	**SS**	**SO**	**SC**	**TSS**	**TSO**	**TSC**	**TMS**	**TLS**	**TMO**	**TLO**	**TMC**	**TLC**	**Total**
1939 Class Coverage (% of Site)	**W**	**7**	1				1	1		1				1	1	3			2	**19**
	B	3	1				1		1					1		2			3	**12**
	C	2	1						1								1		2	**6**
	HS																			
	HO																			
	HC																			**1**
	SS	1																	1	**3**
	SO	2	1												1	3			3	**11**
	SC	1														1			1	**4**
	TSS																		1	**1**
	TSO																			
	TSC																			**1**
	TMS																			**1**
	TLS	**5**	1						1						1	2			**6**	**16**
	TMO																			
	TLO	2														1			4	**6**
	TMC														1	3		1	**5**	**10**
	TLC	1														2			**6**	**9**
1996	**Total**	**23**	**4**				**3**	**2**	**2**	**2**			**1**	**2**	**5**	**18**	**3**	**2**	**34**	**100%**

A forward move between classes represents a progressive structural change. →

W	B	C	HS HO HC	SS SO SC	TSS TSO TSC	TMS TLS TMO TLO	TMC TLC
water	bare	clear	herbaceous	shrubs	small trees	open forest	closed forest
W	B	C	H	S	TS	TO	TC

A backward move between classes represents a regressive structural change. ←

[gray cell] represent percent of site remaining in the same class in 1939 and 1996 coverages.
Cells below gray cells represent regressive structural change. Cells above gray cells represent progressive structural change.
Bold values represent class combination areas > or equal to 5% of the site (approximately 50 square meters).
Rounding values to whole integers created apparent inaccuracy of row and column totals.

cover, low vegetation decreased from 21 to 9% cover, and forest increased from 42 to 64% cover (Table 8). Twenty-four percent of the site experienced no net change between 1939 and 1996 (Table 8, gray cells). This area was composed primarily of closed-canopy trees and water. Progressive structural change occurred on 49% of the site (Table 8, green cells and blue cells in row) and regressive structural change occurred on 27% (Table 8, yellow cells and blue cells in column). Closed-canopy trees becoming open-canopy trees dominated regressive structural change, while progressive structural change occurred between several categories, with the most notable changes proceeding from bare and shrub to forest (Figure 16).

In 1939, bare cover was adjacent to the channel, concentrated along the inside bends of the channel, on bars between the channel and inlets, and on a mid-channel bar (Figure 17, 1939). In 1939, shrub cover was arranged in large linear patterns parallel to the flow, inland of bare areas (Figure 17, 1939). In 1939, tree cover consisted of small patches arranged in larger linear patterns parallel to flow on the east side of the main channel, while large trees covered the western riverbank located on the floodplain level. In 1996, only two small bare areas existed: a thin linear strip on a point bar and a swath between the primary channel and an alcove (Figure 17, 1996). Shrub areas generally formed a border along the bare areas in 1996. Tree cover was extensive by 1996 and occurred in a large swath on the east side of the channel and to the west of the alcove. The area between this alcove and the primary river channel was reworked by the channel by 1956, and by 1996 a mosaic of small patches developed parallel to the flow.

Table 8. Middle Site Category Changes
between 1939 and 1996

		1996 (% of Site)					1939
		W	B	HSTS	TO	TC	Total
1939 (% of Site)	W	7	1	3	6	2	19
	B	3	1	3	3	3	12
	C	2	1	1	1	2	6
	HSTS	4	1	1	7	7	21
	TO	7	1	1	4	10	23
	TC	1			6	11	19
1996	Total	23	4	9	28	36	100%

Table 9. Middle Site Category Changes
for Fluvial Areas
between 1939 and 1996

		1996 (% of Site)					1939
		W	B	HSTS	TO	TC	Total
1939 (% of Site)	W	7	1	3	6	2	19
	B	3	1	1	1	2	8
	C	2	1	1	1	1	5
	HSTS	4		1			6
	TO	7	1	1	1	2	12
	TC	1					1
1996	Total	23	4	7	9	7	50%

Table 10. Middle Site Category Changes
for Terrestrial Areas
between 1939 and 1996

		1996 (% of Site)				1939
		B	HSTS	TO	TC	Total
1939 (% of Site)	B		1	2	1	5
	C				1	1
	HSTS		1	7	6	13
	TO			3	9	13
	TC			6	11	18
	Total		2	18	29	50%

W = water
B = bare
HSTS = low vegetation (herbaceous, shrub & small trees)
TO = open-canopy forest (medium & large trees with sparse or open canopy)
TC = closed-canopy forest (medium & large trees with closed-canopy)

(green) represent progressive structural change between categories. →

water | bare | low vegetation | open forest | closed forest

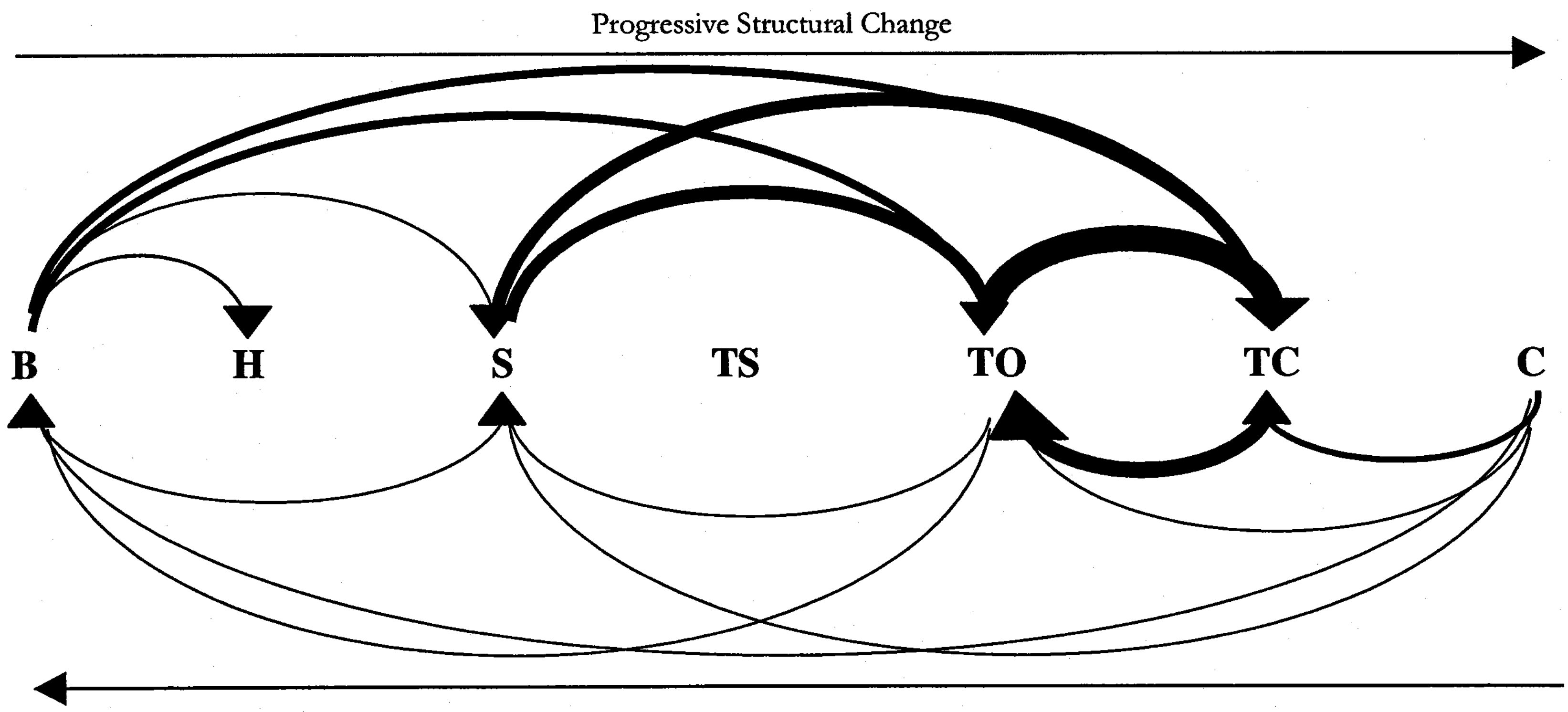
(yellow) represent regressive structural change between categories. ←

(grey) represent areas of no change between categories in 1939 and 1996 coverages.

(blue) represent changes associated with 1939 and 1996 channel areas.

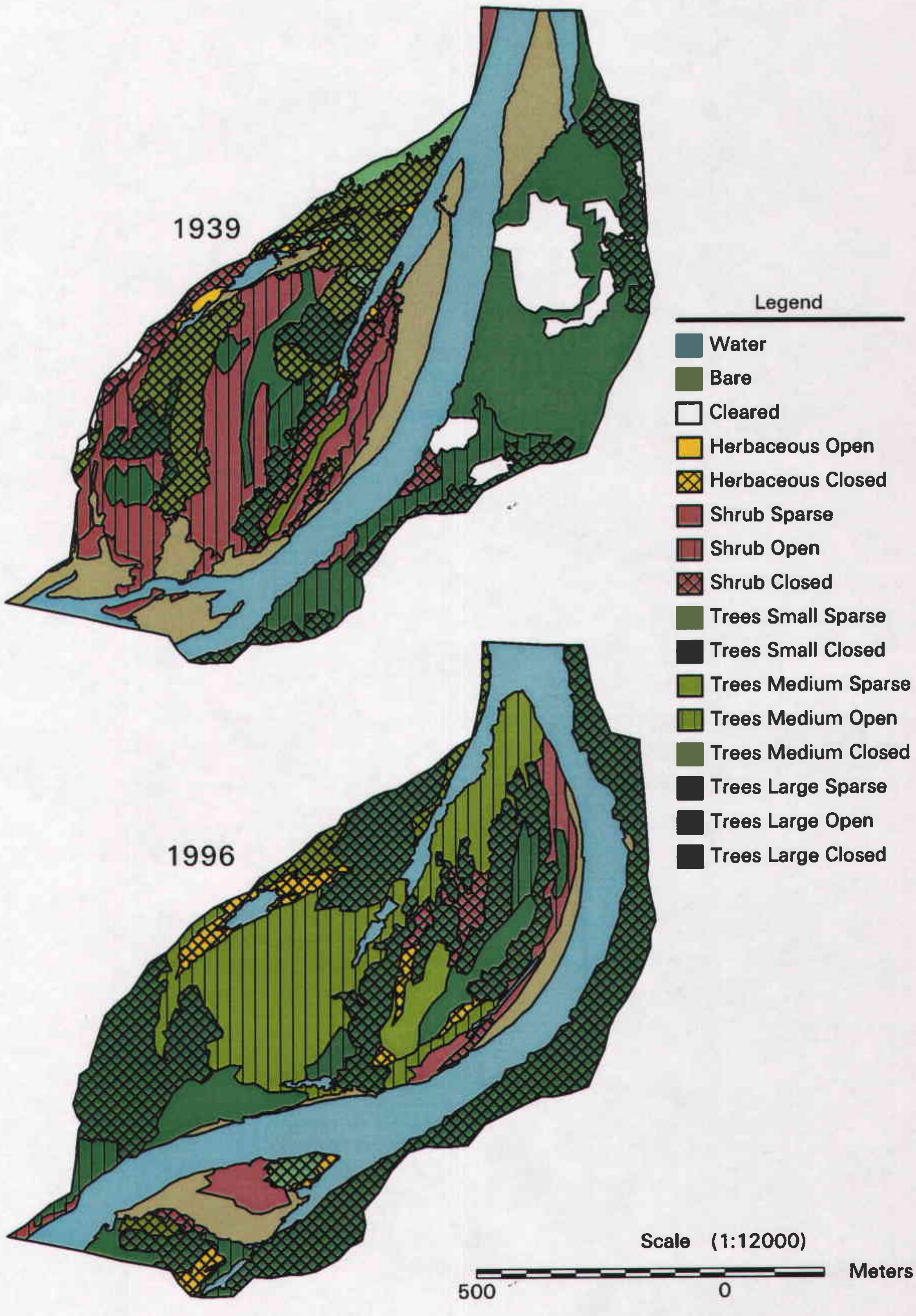
Rounding values to whole integers created apparent inaccuracy of totals.

Figure 16. Middle Site Cover Change Diagram (1939-1996)



B = bare, H = herbaceous, S = shrub, TS = small trees, TO = open-canopy trees, TC = closed-canopy trees, and C = cleared
The thickness of the arrow shaft represents the percent of site experiencing that particular change in cover between 1939 and 1996

Figure 17. Middle Site Cover Classification

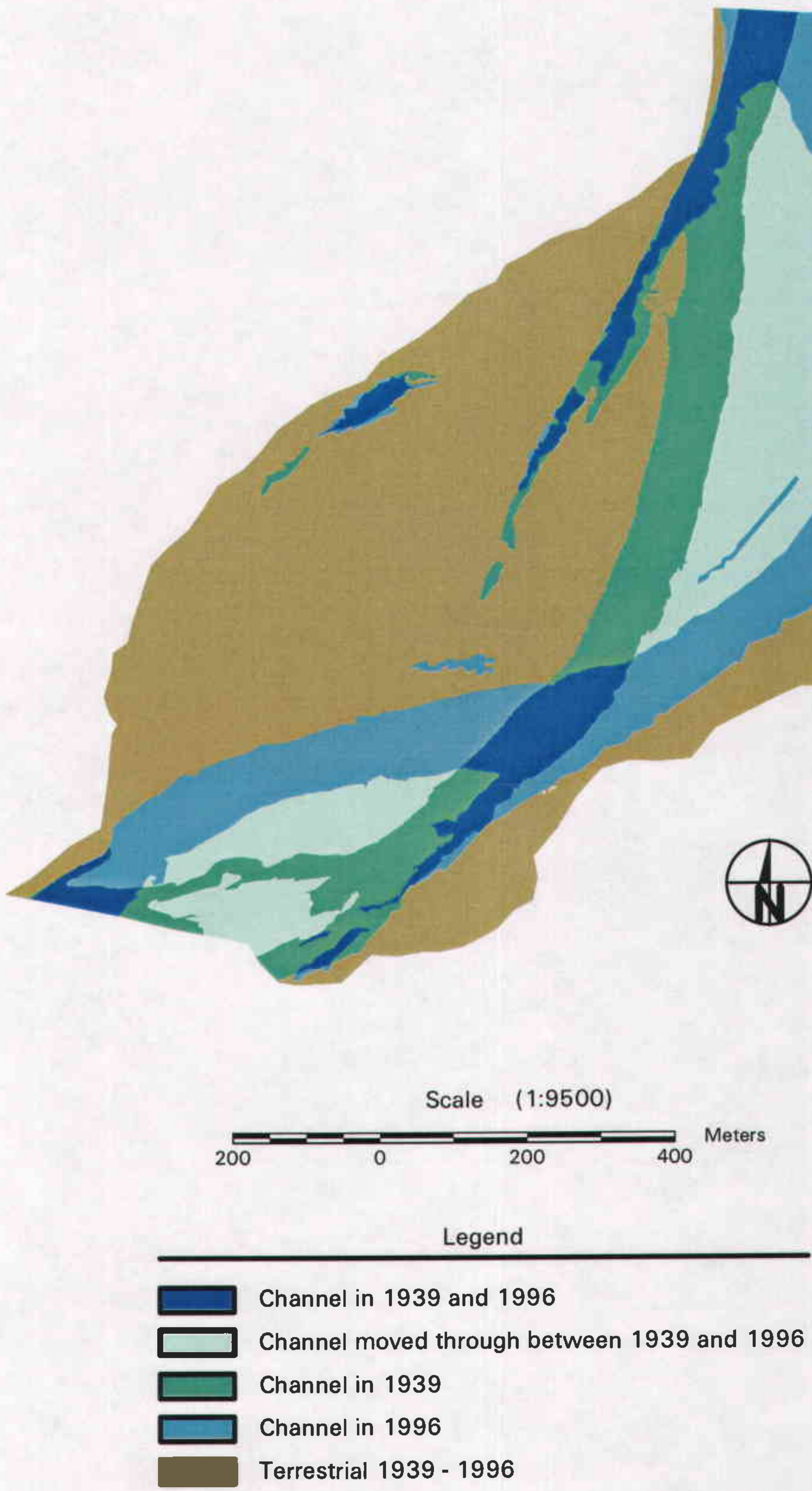


3.2.2. Cover changes in the fluvial area, 1939 to 1996

Fluvial changes affected 50% of the middle site (Table 9). Only 7% of the site area remained covered by water in 1939 and 1996 (Table 9). Two thirds of the area that was covered by water in 1939 (or 12% of the site) became land by 1996, and about 3/4 of the area covered by water in 1996 (or 17% of the site) was land in 1939 (Table 8, blue cells). Net channel migration accounted for net decreases in bare ground (3% loss, 1% gain) and low vegetation (4% loss, 3% gain); and no net change in forest (8% loss, 8% gain) (Table 8, blue cells). These changes generally maintained the proportions of cover in each category. The gross channel migration accounted for net increases in low vegetation (4% loss, 6% gain) and closed-canopy trees (1% loss, 7% gain); and net decreases in bare ground (7% loss, 3% gain), agricultural fields (6% loss, 0% gain), and open-canopy trees (11% loss, 8% gain) (Table 9). Exchanges between categories were minor and favored no particular category or type of change: low vegetation became bare ground (RSC 1%, PSC 0%), forest became low vegetation (RSC 1%, PSC 0%), and bare became forest (RSC 1%, PSC 3%) (Table 9). Areas created by channel dynamics resulted in progressive structural change on 21% of the site and regressive structural change on 20% (Table 9, green & yellow cells).

The downstream portion of the 1939 channel at the middle site gradually shifted east, while the upstream portion of the channel gradually shifted northwest, reworking the intervening area (Figure 18, blue areas). At the downstream end of the 1938 revetment on the southwestern bank, the water's force was released and directed at the southern end of the point bar (Figure 14, Irish Bend). Between 1939 and 1944, the upstream section of the channel shifted north, aligning its flow with the revetment. By 1948, many changes

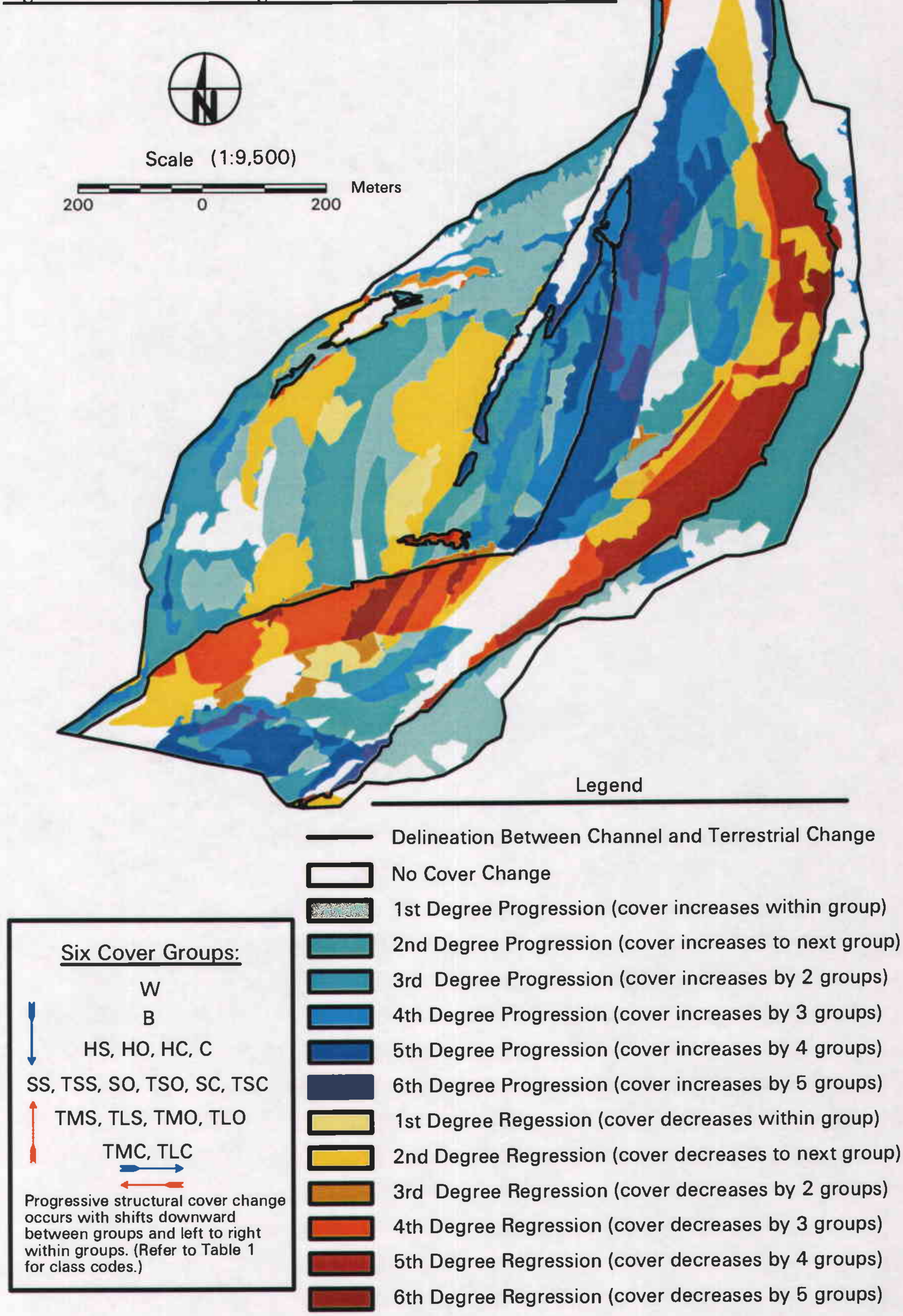
Figure 18. Middle Site Fluvial and Terrestrial Areas



occurred, including the scouring of all vegetation south of the inlet (after a large peak flow of 210,000 cfs in 1945). By 1956, the downstream portion of the channel shifted to the east and reached its 1996 position. The southern upstream section continued to change. By 1963, a mid-channel bar formed downstream of the revetment. A mid-channel bar present in 1939 was absent by 1972. Little change occurred after 1972, with the exception of a mid-channel bar becoming linked to the west bank by 1996, and the abandonment of the southern secondary channel.

As the northern channel section shifted east, sections of the floodplain covered by large trees were replaced with a mosaic of smaller linear patches of cover parallel to the flow (Figure 17). In the southern portion of the site, the channel shifted northwest into bare and shrub cover. By 1996, this reworked area regenerated immature cover including bare, shrub and small trees. Most of the areas experiencing regressive structural change were coincident with the 1996 channel and adjacent areas (Figure 19, fluvial area, yellow– maroon polygons). The highest degree of progressive structural change occurred in the abandoned 1939 channel and adjacent areas created by deposits (Figure 19, fluvial area, dark blue - purple polygons). Areas reworked by the channel since 1939 experienced a lesser degree of progressive structural change than abandoned 1939 channel areas, but still increased their net cover (Figure 19, fluvial area, blue polygons). The areas with no net change covered 1/5 of the site and were largely composed of water, with the exception of a bare and a large sparse-canopy tree area (Figure 19, fluvial area, white polygons). This tree area that experienced no net change actually experienced a lot of change. The channel wiped out the 1939 trees as it moved through, and then a new stand of trees grew on the deposited land after the channel shifted away.

Figure 19. Middle Site Degree and Direction of Cover Change



3.2.3. Cover changes in the terrestrial area, 1939 to 1996

Areas not reworked by channel migration between 1939 and 1996 comprised 50% of the area at the middle site. Over 1/2 of this area experienced net progressive structural change, 1/10 of this area experienced net regressive structural change, and 1/3 remained the same terrestrial category (Table 10). Changes consisted of net increases in open-canopy trees (9% loss, 15% gain) and closed-canopy trees (6% loss, 17% gain); net decreases in bare (4% loss and 0% gain) and low vegetation (13% loss, 1% gain); and virtually no change in agricultural fields (1% loss, 0% gain) (Table 10). The exchange between categories associated with terrestrial changes favored progressive structural change and increased forest: bare ground became low vegetation (RSC 0%, PSC 1%), low vegetation became forest (RSC 0%, PSC 13%), and bare ground became forest (RSC 0%, PSC 3%) (Table 10). All regressive structural change occurred in 1939 closed-canopy trees (Table 10, yellow cells). Closed-canopy trees dominated the areas of no change (Table 10, gray cells).

The areas unaffected by channel migration were east and west of the 1939 and 1996 channel extents (Figure 18, tan polygons). Terrestrial areas experienced a lower degree of regressive and progressive structural change relative to fluvial areas (Figure 19). Terrestrial areas with regressive structural change existed along two swathes parallel to the river's flow north of the river and in one small patch at the southeastern tip of the site (Figure 19, yellow-gold polygons). All three disturbance areas were aligned with remnant channel features from previous main channel paths, i.e. alcoves and ponds. These regressive areas may become overflow channels at higher flows. Most of the regressive structural change areas remained forest cover with the exception of areas surrounding the pond at the western edge of the site (Figure 19, yellow –gold polygons & Figure 17).

The area experiencing the highest degree of terrestrial progressive structural change resided between the main alcove and the 1939 channel (Figure 19, dark blue polygons). This area was probably reworked by channel shifting from the alcove position in an easterly direction prior to 1939. This area went from bare, herbaceous and shrub patches in 1939 to large closed-canopy cottonwoods in 1996. The other areas of lesser progressive structural change, west of the alcove, went from shrub to forest between 1939 and 1996. The progressive structural change areas west of the river remained forest cover, but they changed from open to closed-canopy trees. These areas surrounded 1939 agricultural fields located on the floodplain, therefore logging activity may have created the open-canopy structure present in 1939.

3.2.4. Middle site summary

Overall the site experienced net increases in water (19 to 23%), open-canopy trees (23 to 28%) and closed-canopy trees (19 to 36%); and net decreases in bare (12 to 4%), low vegetation (21 to 9%) and agricultural fields (6 to 0%). Mostly water cover in the fluvial area and forest cover in the terrestrial area composed 22% of the site that experienced no net change between 1939 and 1996 (Table 9 & 10, gray cells). Two thirds of the channel area shifted to a new location between 1939 and 1996. The majority of this channel movement occurred between 1939 and 1956. Fluvial area changes favored no particular category. Terrestrial changes favored increased forest cover. Fluvial change experienced nearly equal amounts of progressive and regressive structural change, while terrestrial change favored progressive structural change 3 to 1.

3.3. Southern Site

3.3.1. Comparison of cover for the overall site, 1939 and 1996

In 1939, cover at the southern site was dominated by water (38% of site area) and bare cover (17%) (Table 11). In 1996, cover at the southern site was dominated by water (37%), and vegetation was dominated by medium open-canopy trees (13%), large open-canopy trees (14%), and large closed-canopy trees (18%) (Table 11). Several forest categories increased dramatically: medium open-canopy trees (from 1 to 13%), large open-canopy trees (from 1 to 14%) and large closed-canopy trees (from 4 to 18%) (Table 11). Bare cover declined dramatically (from 17 to 2%) (Table 11). Net changes in the six simplified categories demonstrated a shift toward increased forest: water cover had virtually no net change (38 to 37%), bare areas decreased from 17 to 2% cover, low vegetation decreased from 20 to 10% cover, and forest increased from 18 to 51% cover (Table 12). Twenty-seven percent of the site had the same cover in 1939 and 1996 (Table 12, gray cells). Water composed most of this area. Progressive structural change occurred on 52% of the site (Table 12, green cells & blue cells in row) and regressive structural change occurred on 21% of the site (Table 12, yellow cells & blue cells in column). Regressive and progressive structural changes were spread across category exchanges, with the most notable proceeding from bare and shrub to forest (Figure 20).

In 1939, bare cover concentrated along the inside of river bends, and shrub cover was adjacent to the bare areas (Figure 21). In 1939, large tree cover bordered the outer edges of the site on inside bends, while small and medium trees were closer to the channel

Table 11. Southern Site Classification Change between 1939 and 1996

1939 Class Coverage (% of Site)	1996 Class Coverage (% of Site): W	B	C	HS	HO	HC	SS	SO	SC	TSS	TSO	TSC	TMS	TLS	TMO	TLO	TMC	TLC	1939 Total
W	**20**	1				1		1					1		**6**	2		**5**	**38**
B	**5**	1				1		2					1		1	3	1	2	**17**
C	4															1		1	**6**
HS																			
HO																			1
HC															1				1
SS															1	3		1	**6**
SO	1												1		1				4
SC																		1	2
TSS																			
TSO																			
TSC	1														1	2		2	**7**
TMS																			1
TLS																1		2	4
TMO																1			1
TLO																		1	1
TMC	4					1		1										1	**7**
TLC																1		1	4
1996 Total	37	2				2	1	6	1				3	1	13	14	2	18	100%

A forward move between classes represents a progressive structural change. →

W	B	C	HS	HO	HC	SS	SO	SC	TSS	TSO	TSC	TMS	TLS	TMO	TLO	TMC	TLC
water	bare	clear	herbaceous			shrubs			small trees			open forest				closed forest	
W	B	C	H			S			TS			TO				TC	

A backward move between classes represents a regressive structural change. ←

[gray cell] represent percent of site remaining in the same class in 1939 and 1996 coverages.

Cells below gray cells represent regressive structural change. Cells above gray cells represent progressive structural change.

Bold values represent class combination areas > or equal to 5% of the site (approximately 50 square meters).

Rounding values to whole integers created apparent inaccuracy of row and column totals.

Table 12. Southern Site Category Changes
between 1939 and 1996

		1996 (% of Site)					1939
		W	B	HSTS	TO	TC	Total
1939 (% of Site)	W	20	1	3	9	6	38
	B	5	1	4	5	3	17
	C	4			1	1	6
	HSTS	3		1	11	5	20
	TO				3	3	7
	TC	4		2	3	2	11
1996	Total	37	2	10	31	20	100%

Table 13. Southern Site Category Changes
for Fluvial Areas
between 1939 and 1996

		1996 (% of Site)					1939
		W	B	HSTS	TO	TC	Total
1939 (% of Site)	W	20	1	3	9	6	38
	B	5		3			8
	C	4					4
	HSTS	3		1			4
	TO						
	TC	4		1	1		6
1996	Total	37	2	7	10	6	62%

Table 14. Southern Site Category Changes
for Terrestrial Areas
between 1939 and 1996

		1996 (% of Site)				1939
		B	HSTS	TO	TC	Total
1939 (% of Site)	B		1	4	3	9
	C			1	1	2
	HSTS			11	5	16
	TO			3	3	6
	TC		1	2	2	5
	Total		3	21	15	38%

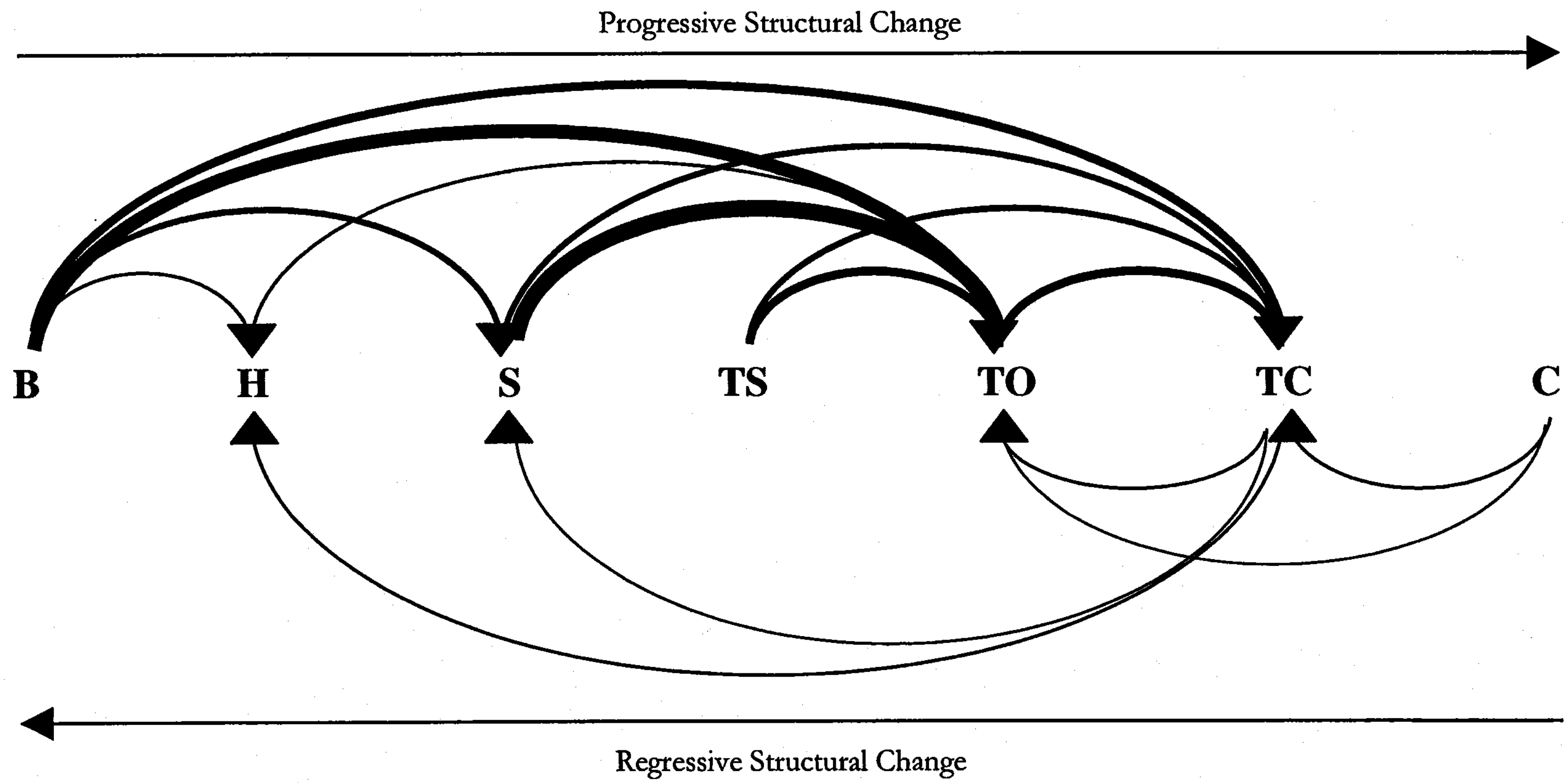
W = water
B = bare
HSTS = low vegetation (herbaceous, shrub & small trees)
TO = open-canopy forest (medium & large trees with sparse or open canopy)
TC = closed-canopy forest (medium & large trees with closed-canopy)

represent progressive structural change between categories. →

water	bare	low vegetation	open forest	closed forest

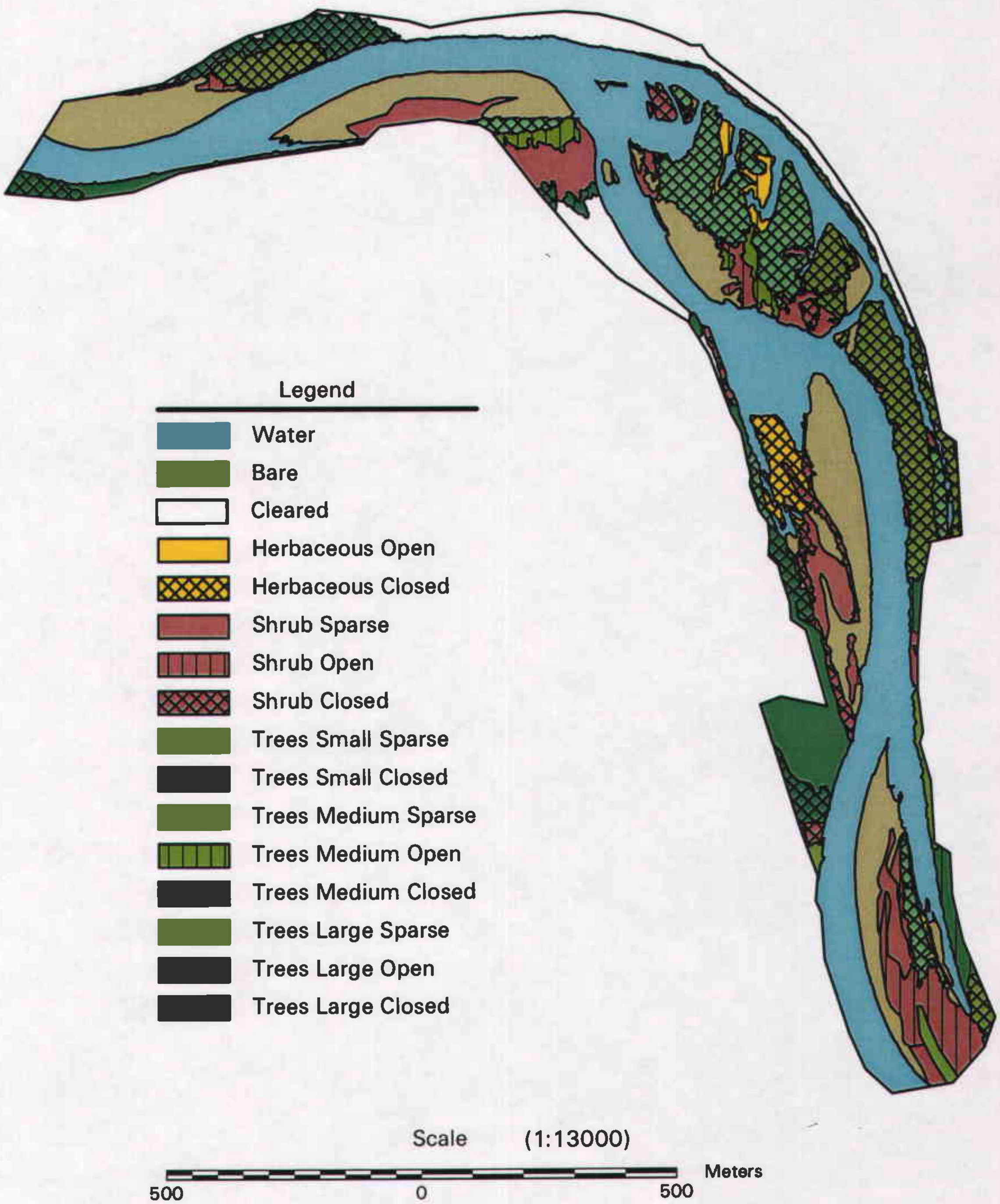
represent regressive structural change between categories. ←
represent areas of no change between categories in 1939 and 1996 coverages.
represent changes associated with 1939 and 1996 channel areas.
Rounding values to whole integers created apparent inaccuracy of totals.

Figure 20. Southern Site Cover Change Diagram (1939-1996)



B = bare, H = herbaceous, S = shrub, TS = small trees, TO = open-canopy trees, TC = closed-canopy trees, and C = cleared
The thickness of the arrow shaft represents the percent of site experiencing that particular change in cover between 1939 and 1996

Figure 21. Southern Site Cover Classification for 1939

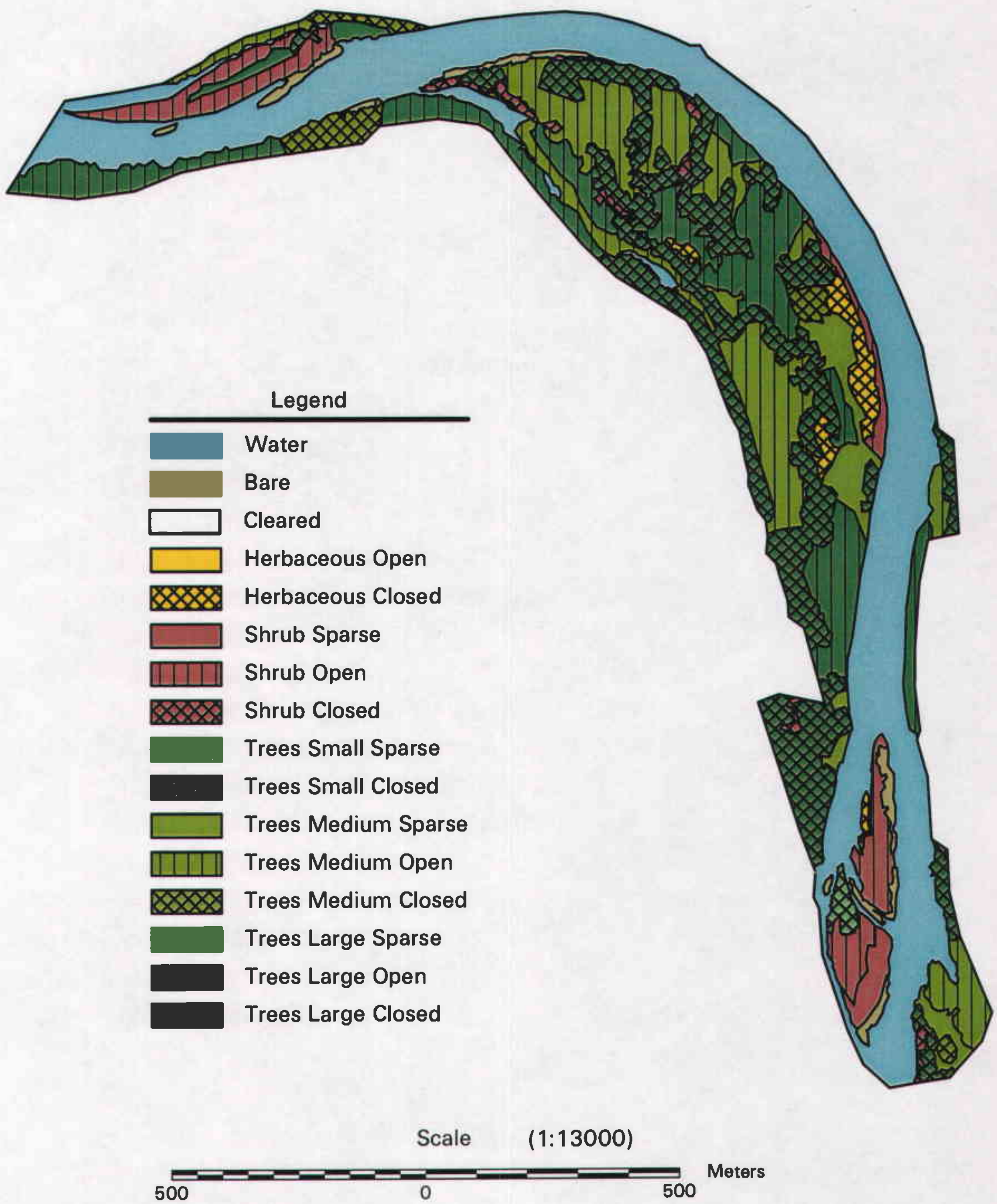


and alcoves adjacent to shrub cover (Figure 21). In 1996, trees dominated all areas of the site except for the mid-channel bars and the protruding point (Figure 22). Large closed tree cover tended to be in elongated patches along overflow paths and sloughs, winding through the surrounding open forest area (Figure 22). Non-forested areas only occurred in areas reworked by the channel since 1939. Bare areas were rare, only present in narrow linear strips on the upstream edges of mid-channel bars and protruding points near alcoves (Figure 22). Shrub cover was also adjacent to bare cover but was limited to the mid-channel bar and the points adjacent to alcoves (Figure 22). Small tree cover disappeared by 1996 (Figure 22).

3.3.2. Cover changes in the fluvial area, 1939 to 1996

Fluvial changes affected 62% of the southern site (Table 13). One-fifth of the site remained covered by water in 1939 and 1996. Half the area that was covered by water in 1939 (or 19% of the site) became land in 1996, and half the area covered by water in 1996 (or 16% of the site) was land in 1939 (Table 12, blue cells). Net channel migration accounted for a net increase in forest (4% loss, 15% gain), a net decrease in bare (5% loss, 1% gain), but no net change in low vegetation (3% loss, 3% gain) (Table 12, blue cells). Gross channel migration accounted for net increases in low vegetation (3% loss, 7% gain) and open-canopy trees (0% loss, 10% gain); net decreases in bare ground (8% loss, 1% gain) and agricultural fields (4% loss, 0% gain); but no net change in closed-canopy trees (6% loss, 6% gain) (Table 13). Exchange between categories favored low vegetation: bare ground became low vegetation (RSC 0%, PSC 3%), forest became low vegetation (RSC 1%, PSC 0%), and no exchange occurred between bare ground and forest (RSC 0%, PSC 0%)

Figure 22. Southern Site Cover Classification for 1996

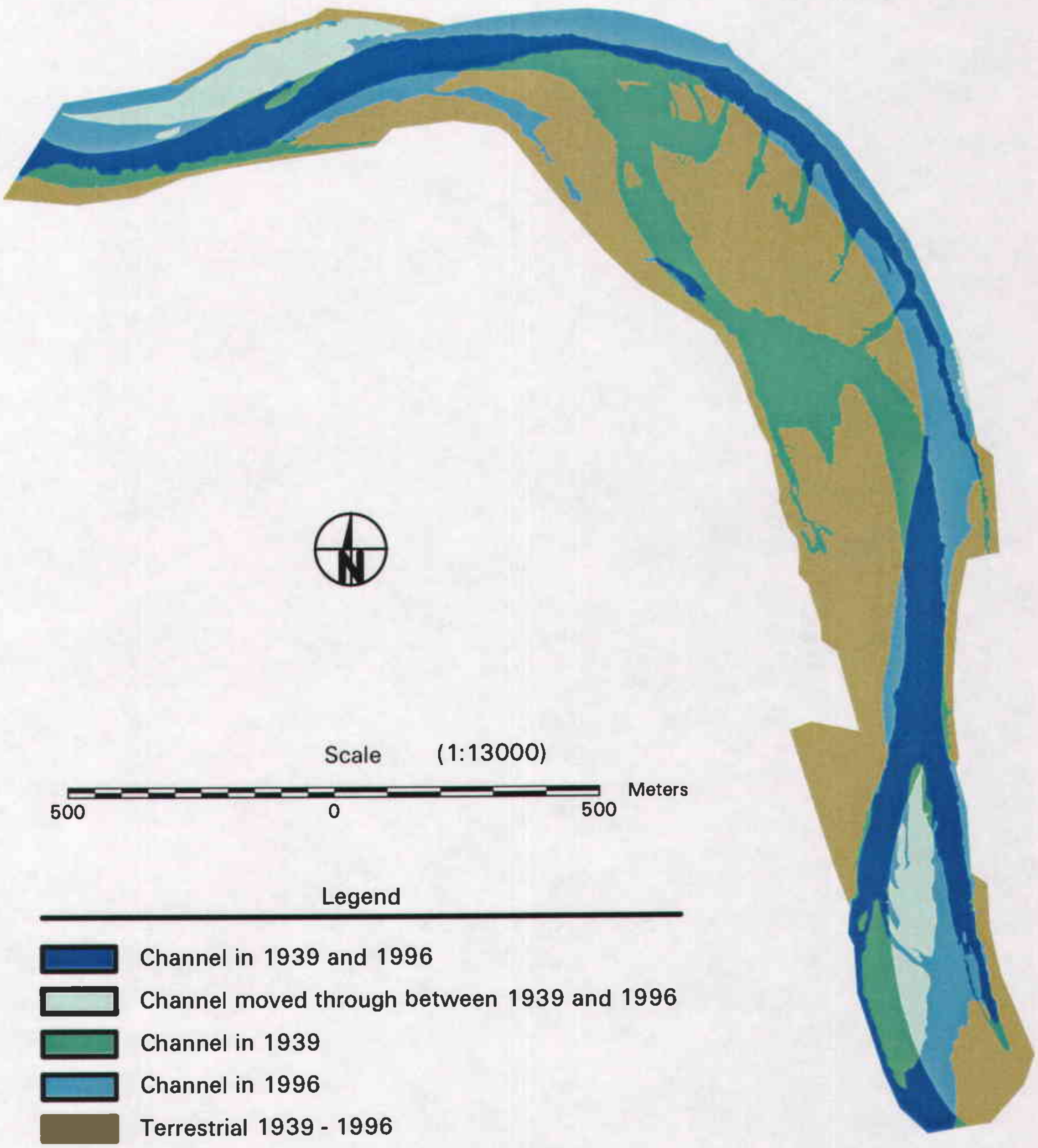


(Table 13). Areas reworked by the channel resulted in progressive structural change on 22% of the site and regressive structural change on 18% (Table 13, green & yellow cells).

Between 1939 and 1996, the northeastern portion of the channel shifted north then back to a central position (Figure 23). The central portion of the channel went from a 1939 primary channel on the west and secondary channel on the east, to a single eastern channel by 1996, as flow shifted between 1939 channels (Figure 23). The southern portion of the channel gradually shifted from a single channel on the west to a primary channel on the east, with a secondary channel on the west (Figure 23).

By 1944, the secondary western channel around the island in 1939 became the primary channel as flow shifted to the secondary channel (Figure 23). Channel movement did not disturb the land between the channels. By 1948, the northwest bank eroded northward almost to the site boundary. By 1956, the western portion of the split 1939 channel was filled with bare land at the upstream end, turning the 1939 channel into a slough. The central portion of the channel obtained its 1996 position by 1956, and the 1939 channel west of the 1939 mid-channel bar filled in. Significant erosion of the southern point bar opposite the 1939 revetment also occurred by 1956 (Figure 21 & 14). This was probably related to erosion upstream of the 1939 revetment, south of the site on the west bank, which forced the channel to make an abrupt turn at the beginning of the revetment (Figure 14, border of Foster and Ingram Island revetment). The 1939 revetment was extended upstream in 1958. By 1972, the channel at the site closely resembled its 1996 shape. By 1976, the point bar opposite the 1939 revetment eroded, creating a wide channel where the 1996 mid-channel bars formed by 1994 (Figure 14 & 23).

Figure 23. Southern Site Fluvial and Terrestrial Areas

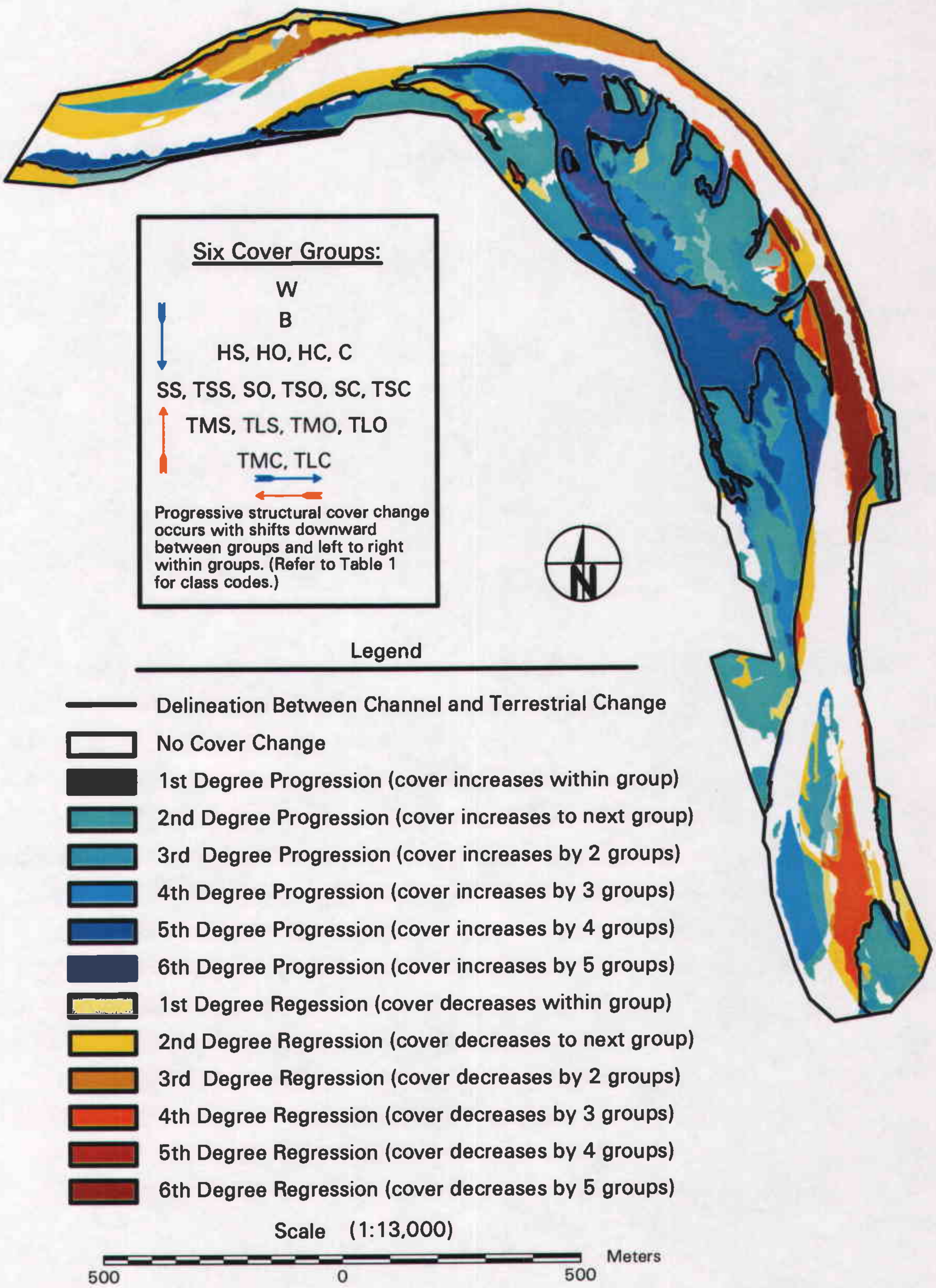


The majority of the regressive structural change areas were coincident with the 1996 channel and inlets, with the exception of the upstream end of the northern point bar, which deposited where 1939 forest eroded (Figures 24, fluvial area, yellow-maroon polygons). The majority of progressive structural change occurred where the 1939 channel was abandoned and became forest cover (Figure 24, fluvial area, dark blue-purple polygons). The western end of the northern point bar and the southern mid-channel bars which were deposited recently also showed progressive structural change, but to a lesser degree than the 1939 abandoned channel (Figure 24, fluvial area, blue polygons). The northern point bar was bare in 1939 and became mostly shrub by 1996. The mid-channel bars of 1996 had similar covers to the 1939 point bar, thus the less mature vegetative covers were maintained through erosion, deposition and regeneration in these recently disturbed areas. One third of the fluvial area experienced no net change and this consisted of water (Figure 23, dark blue polygons & Figure 24, fluvial area, white polygons).

3.3.3. Cover changes in the terrestrial area, 1939 to 1996

Areas not reworked by channel migration between 1939 and 1996 comprised 38% of the area at the southern site. Approximately 3/4 of this area experienced net progressive structural change, 1/10 of this area experienced net regressive structural change, and 1/10 of this area remained the same terrestrial category (Table 14). Forest cover coincided with areas of no net change (Table 14, gray cells). Changes consisted of a net increase in open-canopy trees (3% loss, 18% gain) and closed-canopy trees (3% loss, 12% gain); and net decreases in bare (8% loss, 0% gain), low vegetation (16% loss, 2% gain) and agricultural fields (2% loss,

Figure 24. Southern Site Degree and Direction of Cover Change



0% gain) (Table 14). The exchange between categories favored progressive structural change and increased forest: bare ground became low vegetation (RSC 0%, PSC 1%), low vegetation became forest (RSC 1%, PSC 16%), and bare ground became forest (RSC 0%, PSC 7%) (Table 14).

Three areas were unaffected by channel migration: (1) the inside bend of the 1939 channel, (2) the 1939 island, and (3) areas east of the 1996 channel (Figure 23). Most terrestrial areas experienced net progressive structural change, but to a lesser degree than fluvial area changes (Figure 24, terrestrial area, blue polygons). Terrestrial areas went from a diverse 1939 cover, to a 1996 cover dominated by forest, with the exception of a few small areas located along the abandoned 1939 channel (Figure 21 & 22). The areas adjacent to the 1939 abandoned channel, such as the western edge of the 1939 island and the 1939 bare bar to its south, experienced the highest terrestrial progressive structural change (Figure 24). The terrestrial area that experienced net regressive structural change along the eastern bank remained tree classes. The other areas of terrestrial regression were located along the 1996 channel (Figure 24, terrestrial area, yellow polygons). Terrestrial areas with no net change covered 1/7 of the site and consisted of forest cover (Figure 24, terrestrial area, white polygons).

3.3.4. Southern site summary

Overall the site experienced net increases in open-canopy trees (7 to 31%) and closed-canopy trees (11 to 20%); net decreases in bare (17 to 2%), low vegetation (20 to 10%) and agricultural fields (6 to 0%); but virtually no change in water (38 to 37%). Only 25% of the site experienced no net change between 1939 and 1996. This area consisted of water cover in the fluvial area and forest cover in the terrestrial area (Table13 & 14, gray cells). One half of the channel area shifted to a new location between 1939 and 1996. The majority of this channel movement occurred between 1939 and 1956. Fluvial changes increased low vegetation while terrestrial changes favored increased forest. Fluvial change experienced nearly equal amounts of progressive and regressive structural change, while terrestrial change favored progressive structural change 6 to 1.

3.4. Review of Land Cover Change

Less than 25% of each site remained in the same category from 1939 to 1996 and 1/2 to 4/5 of this was water. All three sites lost bare cover and gained forest cover between 1939 and 1996. All land cleared for agricultural purposes reverted back to natural cover by 1996. By 1996, only a portion of the total bare areas present in 1939 remained: 67% at the northern site, 33% at the middle site, and 12% at the southern site. The bare cover in 1996 was restricted to areas that had been reworked by the channel since 1939. By 1996, forest cover increased at all sites by the following percentage of its 1939 area: 1% at the northern site, 152% (1.5 times) at the middle site, and 283% at the southern site (3 times). By 1996, open-canopy forest cover increased by the following percentage of its 1939 areas: 158% at the northern site (1.5 times), 147% at middle site (1.5 times), and 443% (4.5 times) at the southern site. By 1996, closed-canopy forest nearly doubled at the southern and middle sites, and declined by half at the northern site.

Net vegetation increases (progressive structural change) exceeded or equaled net declines in vegetation (regressive structural change) at all sites, both in areas affected by channel reworking (fluvial change) and those that were unaffected (terrestrial changes). Progressive structural change and regressive structural change proportions in all categories were similar for the middle and southern sites. Progressive structural change only slightly outweighed regressive structural change at the northern site (PSC 39%, RSC 33), while the middle (PSC 49%, RSC 27%) and southern sites (PSC 52%, RSC 28%) favored progressive structural changes 2 to 1 over regressive structural changes.

Over half of each site was affected by channel shifting from 1939 to 1996, but even in disturbed areas there were slight increases in vegetation cover from 1939 to 1996. Fluvial areas favored regressive structural change at all three sites: 30% (PSC) vs. 23% (RSC) at the northern site, 21% (PSC) vs. 20% (RSC) at the middle site, and 22% (PSC) vs. 18% (RSC) at the southern site. Channel deposition created a gradual progression in cover maturity when deposited bare land became colonized by herbaceous cover, followed by shrub or small tree cover, and finally forest cover as the channel moved away. Net changes in fluvial areas at all sites resulted in decreased bare ground and cleared land, while herbaceous cover increased. Exchange between cover categories associated with fluvial areas favored herbaceous cover at the northern site and varied at the other sites.

Terrestrial areas favored increased vegetation 4 to1 over diminished vegetative cover at two of the sites: 27% (PSC) vs. 6% (RSC) at the middle site, and 29% (PSC) vs. 3% (RSC) at the southern site. The northern site experienced equal progressive and regressive structural change, 9% (PSC) vs. 10% (RSC). However, progressive structural change would be favored 5 to 1 over regressive structural change at the northern site, 16% (PSC) vs. 3% (RSC), if the shift from medium closed-canopy to large open-canopy trees were considered a progressive structural change. All terrestrial regressive structural change occurred in 1939 forest categories, and 80% of this disturbed area remained forest in 1996. Net terrestrial changes at all sites decreased bare ground, herbaceous cover, and cleared land, while open-canopy trees and overall forest increased. Exchange between categories associated with terrestrial change favored forest development. Terrestrial areas tended to be covered in trees by 1996.

Areas experiencing the highest degree of progressive structural change correlated with abandoned 1939 channels not located on the 1996 channel. A common sequence of immature cover adjacent to the channel and increasingly mature cover occurring away from the channel showed a correlation between maturity of cover, and the time since the river reworked the area. The degree of progressive structural change gradually declined starting at the edge of the 1939 channel moving toward the 1996 channel, because the degree of progressive structural change was correlated with the time since the land was deposited. Almost all these fresh deposits experienced a net progressive structural change since 1939. Areas of terrestrial change experienced a lesser degree of progressive structural change relative to the abandoned 1939 channel because vegetation already existed in 1939. Despite this head start most terrestrial areas experienced net progression since 1939.

Areas that experienced the highest degree of regressive structural change correlated with the 1996 channel and adjacent areas. The degree of regressive structural change in terrestrial areas was lower than fluvial areas. These areas generally remained forest cover and tended to be aligned with likely overflow paths or areas bordering the 1996 channel. Water in fluvial change areas and forest in terrestrial change areas dominated areas with no net change.

In 1996, the only areas with bare, herbaceous, shrub and small tree cover existed on land deposited since 1939. Almost all dramatic channel change and high flow scouring of vegetation occurred prior to the mid-1950s. By the mid-1950s the channel assumed the configuration it retained through 1996, with the exception of mid-channel bars. After the mid-1970s the only notable changes were widespread maturation of cover and the development and shifts of mid-channel bars. Therefore despite fluvial disturbance on over half the site areas by channel migration between 1939 and 1956, progressive structural change dominated because the last forty years provided stable conditions.

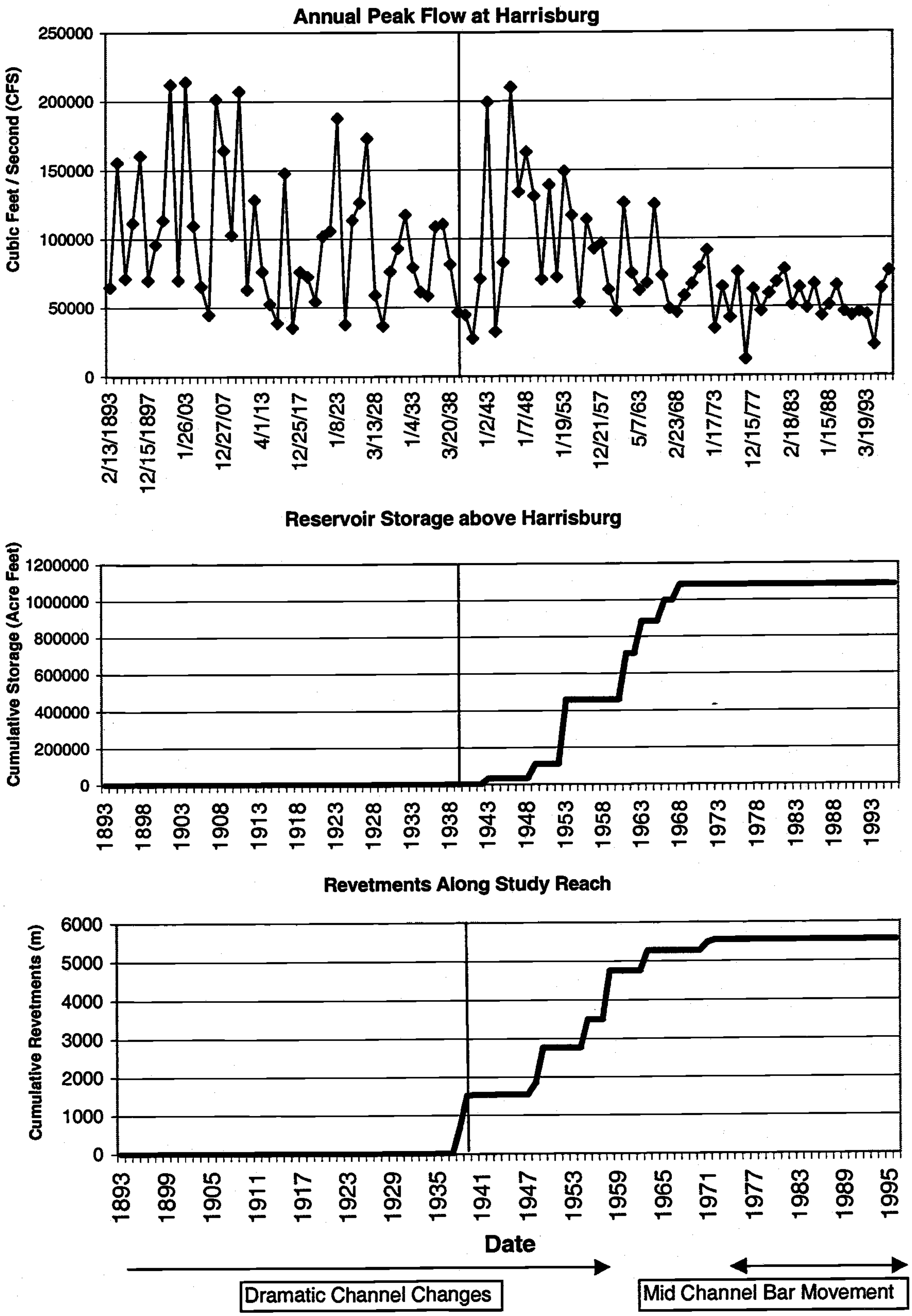
3.5. Changes in Flow and River Bank Conditions between 1939 and 1996

3.5.1. Dams

Nine large dams were constructed on the tributaries of the upper Willamette River between 1949 and 1968 (Appendix 3). The Willamette River at Harrisburg averaged an annual discharge of 11,860 cfs and runoff volume of 8,594,000 acre-ft/yr. (USDI 1998). By 1956, storage capacity reached 42% (Figure 25) of the 1996 level and was capable of capturing 5% of the annual runoff. By 1968, all current dams were in operation with usable storage capable of capturing 13% of the average annual discharge recorded at the Harrisburg stream gage (USDI 1998). Analysis of annual peak flows (Appendix 4) and annual frequency of bank full flows at Harrisburg allowed comparison of the hydrologic regime influencing the 1939 and 1996 riparian cover.

The regulation of dams operated for flood control correlated with a decline in the magnitude of peak flows and the frequency of over bank flows, reducing opportunities for cover disturbance. Prior to dam construction approximately half the annual peaks exceeded 90,000 cfs and 4 of these exceeded 200,000 cfs (Figure 25). Only one annual peak exceeded 90,000 cfs after the dams were completed in 1968. The Harrisburg mean annual peak flow for the 1968-1998 period was 60% of the 1909-1939 period. The 5-year recurrence annual

Figure 25. Timeline Graphic



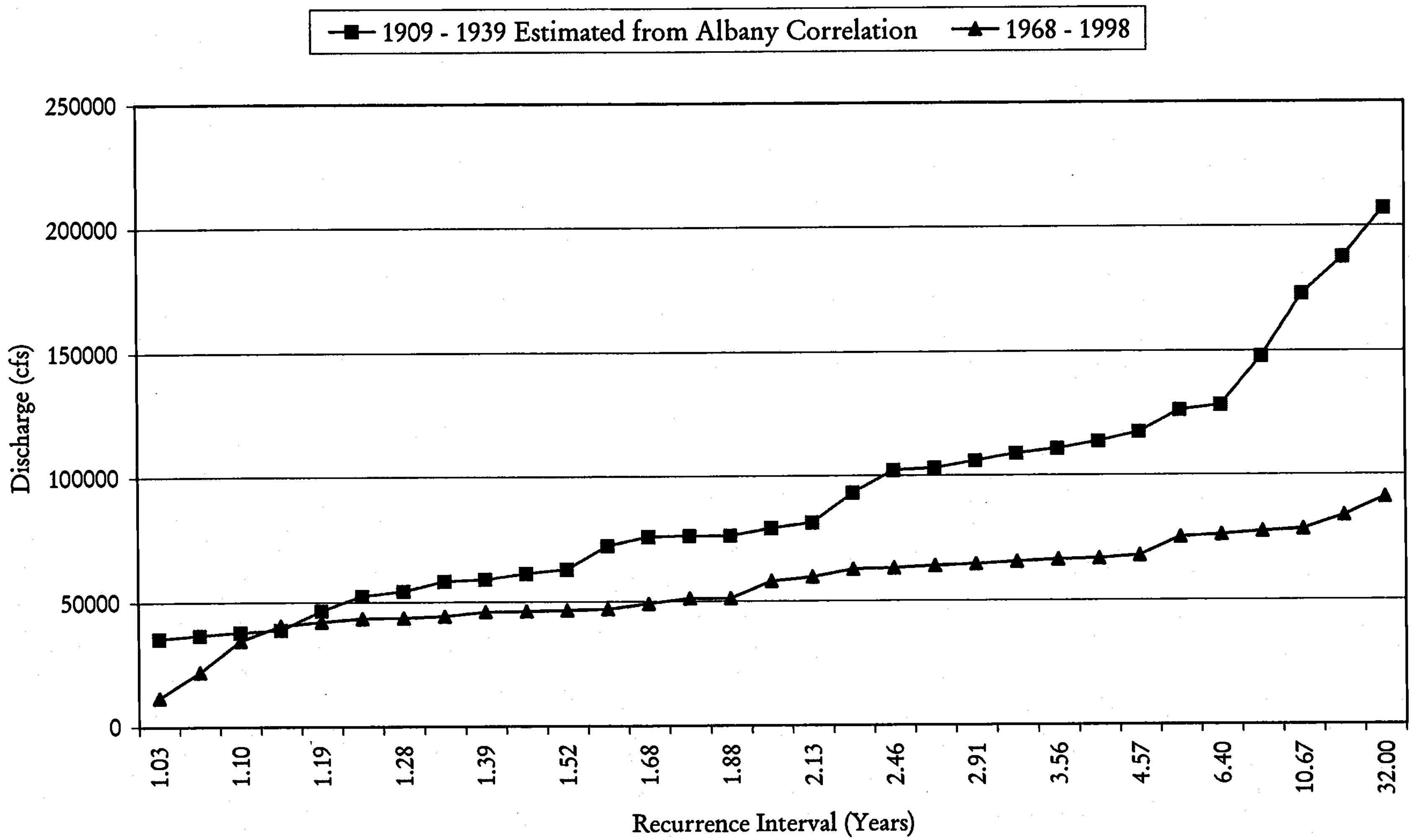
peak flow for 1968-1998 was 60% of the 1909-1939 5-year recurrence annual peak flow. None of the peak flows in the 1968-1998 period exceeded the pre-dam 5-year recurrence discharge of 126,353 cfs (Figure 26). The 1909-1939 2-year recurrence annual peak flow was only exceeded twice in the 1968-1998 period (Figure 26). Bank full flows at Harrisburg occurred an average of 12 days/year between 1944 and 1968, but declined to only 8 days/year after reservoir completion.

3.5.2. Revetments

The thalweg of the study reach was approximately 10,000 m long from the top of the northern site to the bottom of the southern site. However, a 12,000 m reach was utilized to analyze bank conditions relevant to the study reach, which included revetments slightly upstream of the southern site (Fernald unpublished data EPA). Along the west bank of the river, eight revetments were installed along this study reach between 1938 and 1971, covering 40% of the western bank (Figure 14 & Appendix 5). Portions of the eastern bank were composed of Pleistocene deposits, which corresponded to the floodplain boundary delineated by the USGS (O'Connor 1997). These high banks slowed channel migration, acting as a natural revetment. However, noticeable erosion occurred along these boundaries between 1939 and 1996. By 1996, 50% of the eastern bank was composed of this Pleistocene boundary and 5 minor revetments (Figure 14 & Appendix 5). By 1956, 68% of the 1996 revetments were in place. By 1971, essentially all outer banks of the study reach were constrained by revetments and high floodplain banks (Figure 25 & 14).

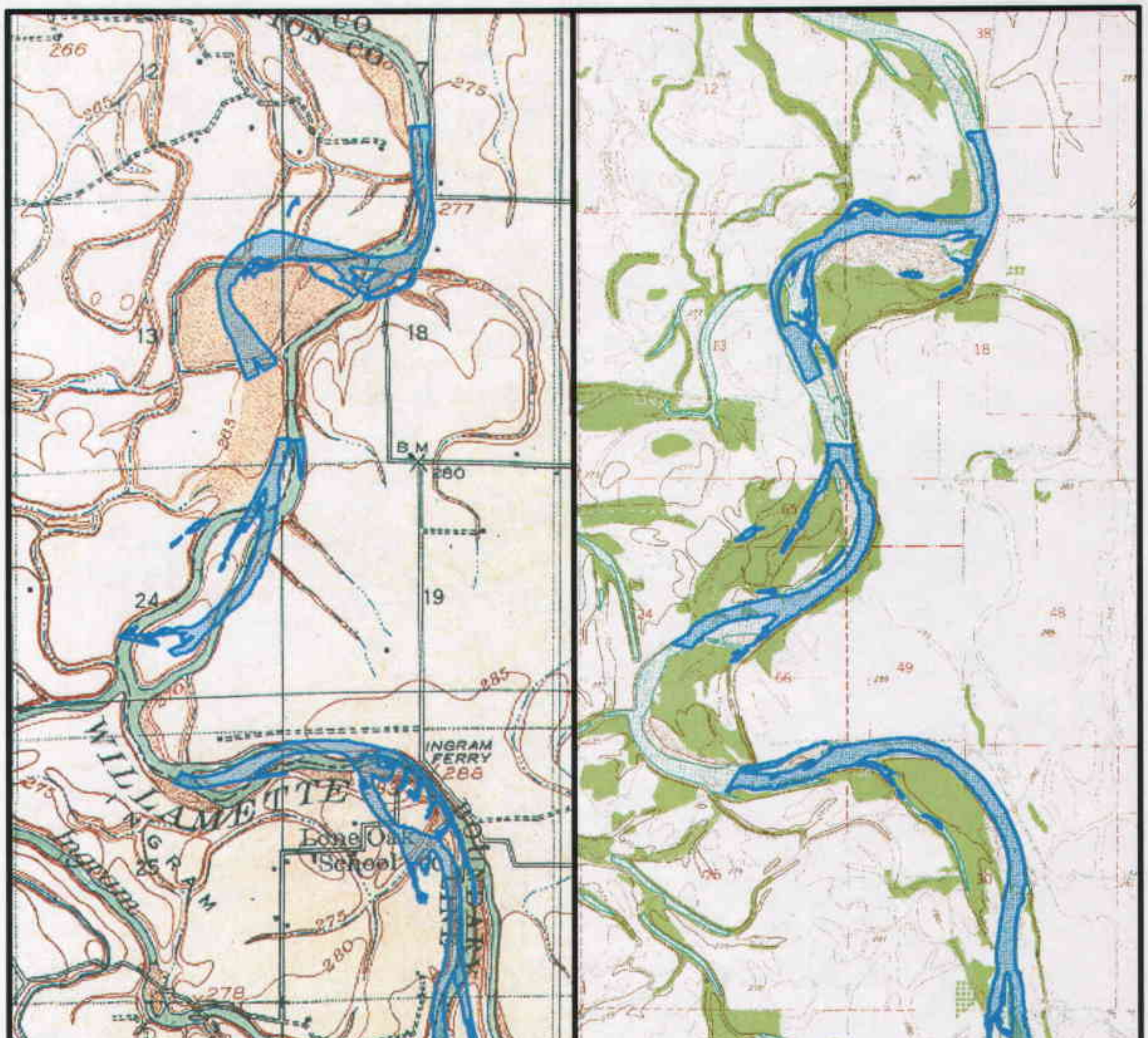
Topographic maps surveyed in 1909 and 1969 at 5-foot contour intervals allowed the degree of channel dynamics between 1909 and 1939 to be visually compared with the degree

Figure 26. Harrisburg Annual Peak Flow Recurrence



of channel dynamics between 1969 and 1996, when flows were regulated and outer bends hardened. The period bracketed by the coverages coincided with the hydrologic analysis of annual peak flows. The noticeable difference between the 1909 channel and the 1939 channel segments at the study sites, revealed a higher degree of thalweg shifts during the "natural" hydrogeomorphic period when compared to the similar position of the 1969 and 1996 channel segments during the "managed" hydrogeomorphic period (Figure 27). The dynamic channel contributed toward relatively diverse, patchy immature structural cover of 1939, while the stable channel contributed to the shift toward the relatively homogeneous mature cover of 1996.

Figure 27. Comparison of Channel Dynamics



1909 base map with
1939 site channel segments overlaid
representing 30 years of change
prior to dams and most revetments.

1969 base map with
1996 site channel segments overlaid
representing 27 years of change
after dams and most revetments.

Scale 1:45000

1000 0 1000 2000 Meters

4. DISCUSSION

4.1. Factors Influencing Riparian Cover

Two forces work simultaneously on riparian cover: (1) exogenous environmental change and (2) endogenous properties of species (White 1979). The development of a community driven by environmental change experiences allogenesis, while a community driven by species properties undergoes autogenesis. It is difficult to decipher the endogenous from the exogenous drivers because of interactions between plants and their environment. Examples of allogenic factors included hydrologic conditions and related geomorphic processes, while examples of autogenic factors included soil condition, sunlight availability and plant traits. The balance point between the influence of allogenic and autogenic forces affected the resultant riparian community.

The particular combinations of specific environmental and plant situations had different affects on the riparian community. The hydrogeomorphic regime dictated the duration and level of inundation by flood water and channel dynamism. Surface water inundation, and fine grain substrate fostered the growth of riparian vegetation (White 1979). Riparian species varied in colonization ability, tolerance to flooding and shade tolerance, resulting in a distribution of communities along elevation and disturbance gradients away from the active channel (White 1979). Once vegetation was established it could directly influence the impacts of high flows by increasing channel roughness and decreasing flow velocities, allowing sediment to be trapped rather than scoured (Collier 1996, Graf 1978). The higher the magnitude of the peak flows, the greater the ability of the flow to modify the channel and scour vegetation (Gupta 1983, Minear 1994).

The structure of the cover was related to changes in the disturbance regime. The primary allogenic factor influencing the resultant vegetation in this study was the frequency of fluvial disturbance. The autogenic process was limited to analysis of structural cover changes rather than species succession, or plant community diversity and composition because the 1939 information was limited to air photos. Two hydrogeomorphic regimes influencing riparian cover were compared in this study. A "natural" regime created a structurally diverse cover in 1939. A "managed" regime established a mature homogenous 1996 cover. The comparative analysis of fluvial and terrestrial areas provided another perspective for understanding how natural and managed regimes impact riparian cover. Terrestrial area changes generally represented the cover character associated with the managed regime. Fluvial area changes generally represented the cover character associated with the natural regime because the channel disturbed these areas. However the channel became stationary after 1956 allowing a stable environment to dominate for 40 years prior to 1996.

4.2. The Natural Regime Hypothesis

The natural regime offered a balance between allogenic processes which provide disturbance, and autogenic processes which encourage maturation of cover. The natural regime created an environment that ensured all stages and structures of riparian communities existed simultaneously over time. Disturbance was an integral, frequent part of a natural riparian ecosystem. Therefore, the natural succession of riparian communities may be considered cyclical or circular, being reset by exogenous factors like floods and channel reworking rather than continuing towards a "climax" (White 1979). Active channel dynamics ensured the constant renewal of various biotypes by resetting succession (Bravard et al. 1986, Amoros et al. 1987). As the river abandoned old arms and cuts into outer banks, it simultaneously destroyed former flood plain features and their vegetation features, while creating new areas ready for colonization by the earliest stages of ecological succession (White 1979, Bravard et al. 1986, Dykaar & Wigington 2000). Topographic instability associated with erosion and deposition processes maintained the diversity of riparian habitat by creating heterogeneous land surfaces that supported various succession stages (Gregory 1991, Bravard et al. 1986). Consequently fluvial dynamics reduced the life span of each resident community, while maintaining the reproducibility of all community types and the overall diversity of riparian cover. The patterns of vegetation shifted, but overall composition and diversity remained constant.

4.3. Findings Related to the Natural Regime Hypothesis

From 1939 to 1996, the structure of riparian cover changed on approximately 3/4 of each site, indicating that dynamic forces were at work. The 1939 cover that developed under the "natural" hydrogeomorphic regime had greater immature bare coverage and less mature forest cover relative to 1996 cover, which formed under the "managed" hydrogeomorphic regime. This shift appeared to be the result of the decrease in channel migration and over bank flooding between 1939 and 1996 (Figure 27). Examination of photos between 1939 and 1996 revealed that the vast majority of the channel shifting occurred prior to 1956, i.e. by 1996 autogenic forces dominated vegetative dynamics in the riparian zone for 40 years. Hence, net progressive structural change outweighed regressive structural change at all sites.

Channel migration and mid-channel bar development appeared to be the dominant processes generating new land surfaces. In 1996, the areas with immature cover, i.e. bare, herbaceous, and small tree cover, coincided with the channel change areas and active channel margins. The highest degree of regressive structural change was associated with the new 1996 channel while the highest degree of progressive structural change was affiliated with abandoned 1939 channels. Several areas illustrated shifting patterns of vegetation stages linked with the time since the channel disturbed the area. Immature cover was found on more recently deposited land closer to the channel, while increasingly mature cover was located away from the active channel and arranged in linear patterns parallel to the flow (for example the north west bank of the northern site in 1996, Figures 12 & 15). The most common sequence included bare areas adjacent to the channel, then shrub, and then tree cover.

Fluvial areas only slightly favored progressive structural change with the largest margin being 30 % PSC to 23% RSC, while terrestrial areas favored progressive structural change by a ratio of at least 4 to 1. Fluvial areas at all sites increased in herbaceous cover, which was a relatively immature cover. Areas of no <u>net</u> cover change in fluvial areas tended to be water and immature cover, implying maintenance of structural diversity through rejuvenation.

These findings supported the theory that newly deposited areas reset structural progression and that subsequent vegetative development relates to the time since channel reworking. These findings also supported previous observations (Bravard et al. 1986, Amoros et al. 1987) that channel movement combined with succession, maintains cover diversity while cover types shift their spatial pattern.

4.4. The Managed Regime Hypothesis

Revetments and dams affected fluvial dynamics by restricting processes of channel migration and reducing the frequency and magnitude of over bank flooding (Bravard et al.

1986). Dams reduced the recurrence frequency of high flows, lowering the mean magnitude of peak flows, reducing the competence of flows to move existing bed load, and decreasing sediment supply (Petts 1979, Shen & Lu 1983, Collier 1996, Williams & Wolman 1984). Revetments prevented lateral erosion and redirected erosive forces toward adjacent unprotected banks and riverbed. Decreased sediment sources, by revetments reducing lateral inputs and dams blocking sediment transport, reduced the opportunities for deposition while increasing the water's erosive potential. Bed degradation associated with dams and revetments further hindered the ability of the river to over flow its banks. This further reduced the depth and velocity of the remaining over bank flows, thus lessening the force exerted on terrestrial surfaces. Regulation of flow allowed vegetation to quickly stabilize bare bars below the mean high water level of the channel because the resultant reduced peak flows had less force, and augmented summer flows raised the water table (Schumm 1985). Once the channel margins were vegetated, the banks became more stable (Schumm 1985). Eventually the flow preferred one channel around a mid-channel bar, while the abandoned secondary channel filled, attaching the mid-channel bar to the point bar (Schumm 1985).

The absence of lateral channel migration prevented erosion of old biotypes and deposition of new land on bars, leading to the disappearance of immature cover (Bravard et al. 1986) and increased vegetation overall (Williams & Wolman 1984, Schumm 1985). Riparian communities in the absence of allogenic disturbance were driven by autogenic processes which led to the development of mature vegetation eventually becoming relict to the extent that they were subject to aging (Bravard et al. 1986). The managed hydrogeomorphic regime was a relatively stable environment allowing autogenesis to progress until a late structural stage had been reached and mature vegetation predominated (White 1979).

4.5. Findings Related to the Managed Regime Hypothesis

Immature bare cover areas decreased and mature open-canopy tree cover increased at all sites between 1939 and 1996. Overall net progressive structural change outweighed net regressive structural change 2 to 1 at all sites (if the shift from medium closed-canopy trees to large open-canopy trees at the northern site was considered succession). Exchange between categories favored forest development at all sites. Despite disturbances, terrestrial areas that experienced regressive structural change remained forest cover. All terrestrial areas experienced a decrease in bare, cleared and herbaceous covers, while open-canopy trees and forest cover increased, showing a shift toward later structural stages and increasingly mature vegetation. In fact, no bare areas remained in terrestrial areas by 1996. All channel change areas experienced a decrease in bare and cleared cover, while herbaceous cover increased, showing a shift toward later structural stages, but to a lesser degree than terrestrial areas.

Nearly all terrestrial areas experienced succession, but this progression was of a lower degree relative to 1939 fluvial change areas because terrestrial areas were further along in development in 1939. Fluvial change areas favored progressive structural changes because these areas were undisturbed for decades. Large tree cover comprised the majority of terrestrial areas without change, indicating that a late structural stage had been reached in these areas.

The periods of dramatic channel change and minimal channel change were related to the timing of flow regulation and revetment building (Figure 25, 26 and 27). By the early 1970s the channel remained nearly stationary, by time all the dams and revetments present in 1999 were in place. Mid-channel bars were the only new surfaces deposited after the 1970s and they generally became vegetated, which stabilized the land. Prior to 1956, bars apparently continued to shift. Once vegetated, the flow began to prefer one channel. Gradually the secondary channel filled in removing much of the bar from channel disturbance. This fostered further vegetative development. The bare swath of land between the main channel and an alcove at the middle site was an example of a mid-channel bar that recently became part of the point bar (Figure 12). Mid-channel bar development often correlated with the downstream ends of revetments because channel widening through erosion of downstream banks was common, and fostered deposition. For example, erosion and vegetative scour occurred in the area downstream of the 1963 revetment at the northern site. Once the river was released from revetment control, it expended its erosive energy on adjacent unprotected banks (Figure 14). The erosion area was made apparent by the shape of the 1963 revetment. Once the channel widened, a mid-channel bar formed that had shrub and tree cover by 1996 (Figure 17). However revetments were often lengthened to halt the river widening as evidenced by the revetment extension dates reducing mid-channel bar formation (Figure 14 & Appendix 5).

These findings support the observations of others (Amoros et al. 1987, Bravard 1986, Schumm 1985, White 1979, Williams & Wolman) and the theory that decreased fluvial disturbance hindered the destruction of old biotypes and the generation of new land surfaces, fostering a maturation of cover on existing surfaces.

5. CONCLUSION

The early stages of riparian vegetation development thrived in a high disturbance environment representing species with strong reproductive strategies (White 1979). Poplar, willow, and maple have fast growth rates, low density wood, short life spans, low shade tolerance and the ability to sprout when damaged (White, 1979). This study demonstrated that the riparian corridor changed significantly in the last 60 years along a short section of the Upper Willamette River. These changes coincided with increased structural management of the river, which altered the hydrogeomorphic regime, and in turn influenced the age structure of riparian cover. Given the current management strategies and riparian conditions, this study indicated that future riparian cover will continue to depart from diverse patchy habitat representing all successional and structural stages, toward more homogeneous cover dominated by terrestrial forest limited to terrestrial disturbances. If streambed degradation, sediment trapping and vertical accretion of vegetated areas continue, it is possible that strictly upland communities may eventually replace riparian communities.

Once riparian forests are established and revetments lock outer bends in place, it is likely that even large peak flows similar to the ones that maintained the pre-management ecosystem, will not be capable of rejuvenating the earlier stages of vegetative development. In order to restore the diversity and viability of the riparian cover, restoration of natural processes is suggested. It may be possible to provide the river with a larger meander belt by revetment removal and increases in peak flows, fostering increased channel dynamics capable of providing a more diverse and healthy, riparian community. However it is highly unlikely that conditions will be allowed to return to pre-settlement conditions given social tolerances.

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APPENDICES

Appendix 1. Ground Control Point Root Mean Square Error

Photo # 159 (1939 Northern Site)

Point ID	X residual	Y residual	RMS Error
GCP # 1	-2.574	1.851	3.171
GCP # 2	0.727	-6.579	6.619
GCP # 3	-0.463	-3.856	3.883
GCP # 4	2.882	1.375	3.194
GCP # 6	-1.513	3.64	3.942
GCP # 8	-1.762	1.037	2.044
GCP # 9	3.98	-0.737	4.047
GCP # 10	-6.012	-0.251	6.018
GCP # 11	3.437	2.233	4.098
GCP # 13	-0.706	0.983	1.211
GCP # 15	2.829	-0.111	2.831
GCP # 17	-0.824	0.415	0.923
Total	2.7995	2.6542	3.8577

Photo # 9984 (1939 Middle Site)

Point ID	X residual	Y residual	RMS Error
GCP # 1	-0.0358	-1.904	1.938
GCP # 4	-0.41	1.25	1.315
GCP # 5	-1.535	-5.334	5.551
GCP # 6	-1.937	0.315	1.962
GCP # 7	-1.199	0.401	1.264
GCP # 8	3.321	4.825	5.857
GCP # 10	2.204	-2.494	3.328
GCP # 11	-0.57	1.384	1.497
GCP # 12	-1.429	3.528	3.807
GCP # 13	1.597	-4.734	4.997
GCP # 15	-0.184	1.586	1.597
GCP # 16	0.501	1.179	1.281
Total	1.5527	2.9452	3.3294

Photo # 4-4 (1996 Northern Site)

Point ID	X residual	Y residual	RMS Error
GCP # 1	1.503	-0.318	1.536
GCP # 4	-2.818	0.933	2.968
GCP # 5	-1.387	0.155	1.396
GCP # 7	-1.171	1.205	1.68
GCP # 9	-0.518	-0.859	1.003
GCP # 8	2.376	-1.042	2.594
GCP # 10	2.57	0.733	2.673
GCP # 11	-0.811	-0.528	0.968
GCP # 12	-2.138	0.428	2.18
GCP # 13	-1.075	0.973	1.45
GCP # 14	1.238	0.229	1.259
GCP # 16	2.622	-0.878	2.766
GCP # 17	1.061	-1.794	2.084
GCP # 18	-2.211	0.544	2.277
GCP # 19	0.759	0.221	0.79
Total	1.7775	0.8408	1.9664

Photo # 4-3 (1996 Middle Site)

Point ID	X residual	Y residual	RMS Error
GCP # 1	0.279	0.327	0.429
GCP # 2	-1.319	-0.683	1.486
GCP # 3	0.746	-0.435	0.863
GCP # 4	-0.107	0.182	0.211
GCP # 5	0.708	-0.889	1.137
GCP # 6	0.111	-0.15	0.187
GCP # 7	-0.209	1.097	1.117
GCP # 8	-0.509	0.481	0.7
GCP # 9	0.733	0.432	0.851
GCP # 10	-1.337	-0.81	1.564
GCP # 11	-0.437	-0.041	0.439
GCP # 12	1.592	-0.03	1.593
GCP # 13	-0.354	-0.544	0.649
GCP # 14	1.216	-0.803	1.457
GCP # 15	-0.61	1.108	1.265
GCP # 16	0.116	0.435	0.45
GCP # 17	-0.832	-0.561	1.004
GCP # 18	-1.055	1.053	1.49
GCP # 19	0.916	0.886	1.275
GCP # 20	0.351	-1.052	1.108
Total	0.8066	0.6914	1.0624

Residuals and Errors are measured in pixels.
1939 pixel length = 0.5 m
1996 pixel length = 1.0 m

Photo # 9988 (1939 Southern Site)

Point ID	X residual	Y residual	RMS Error
GCP # 4	-1.6767	3.045	3.476
GCP # 5	1.021	-1.895	2.152
GCP # 9	0.672	-1.385	1.54
GCP # 12	-1.726	2.241	2.829
GCP # 14	2.407	0.191	2.415
GCP # 17	-3.366	-1.947	3.889
GCP # 20	-1.389	2.318	2.702
GCP # 19	-3.071	2.161	3.755
GCP # 21	2.173	-0.832	2.326
GCP # 8	0.54	-0.033	0.541
GCP #30	1.801	3.445	3.888
GCP #31	0.201	0.65	0.68
GCP #24	1.319	-3.675	3.905
GCP #28	2.591	-4.547	5.233
GCP #33	-1.496	0.264	1.519
Total	1.9105	2.3226	3.0074

Photo # 9986 (1939 Southern Site)

Point ID	X residual	Y residual	RMS Error
GCP # 1	-2.71	-3.017	4.055
GCP # 3	0.481	-2.103	2.157
GCP # 4	-1.874	-0.528	1.947
GCP # 5	0.621	1.834	1.936
GCP # 6	0.403	-1.132	1.202
GCP # 8	0.53	1.079	1.02
GCP # 9	-0.757	0.765	1.077
GCP # 10	5.913	-0.654	5.949
GCP # 11	2.702	1.989	3.355
GCP # 12	-0.421	-1.295	1.362
GCP # 13	1.287	2.858	3.135
GCP # 14	-2.59	-0.144	2.594
GCP # 17	-3.584	0.346	3.601
Total	2.42	1.6307	2.9182

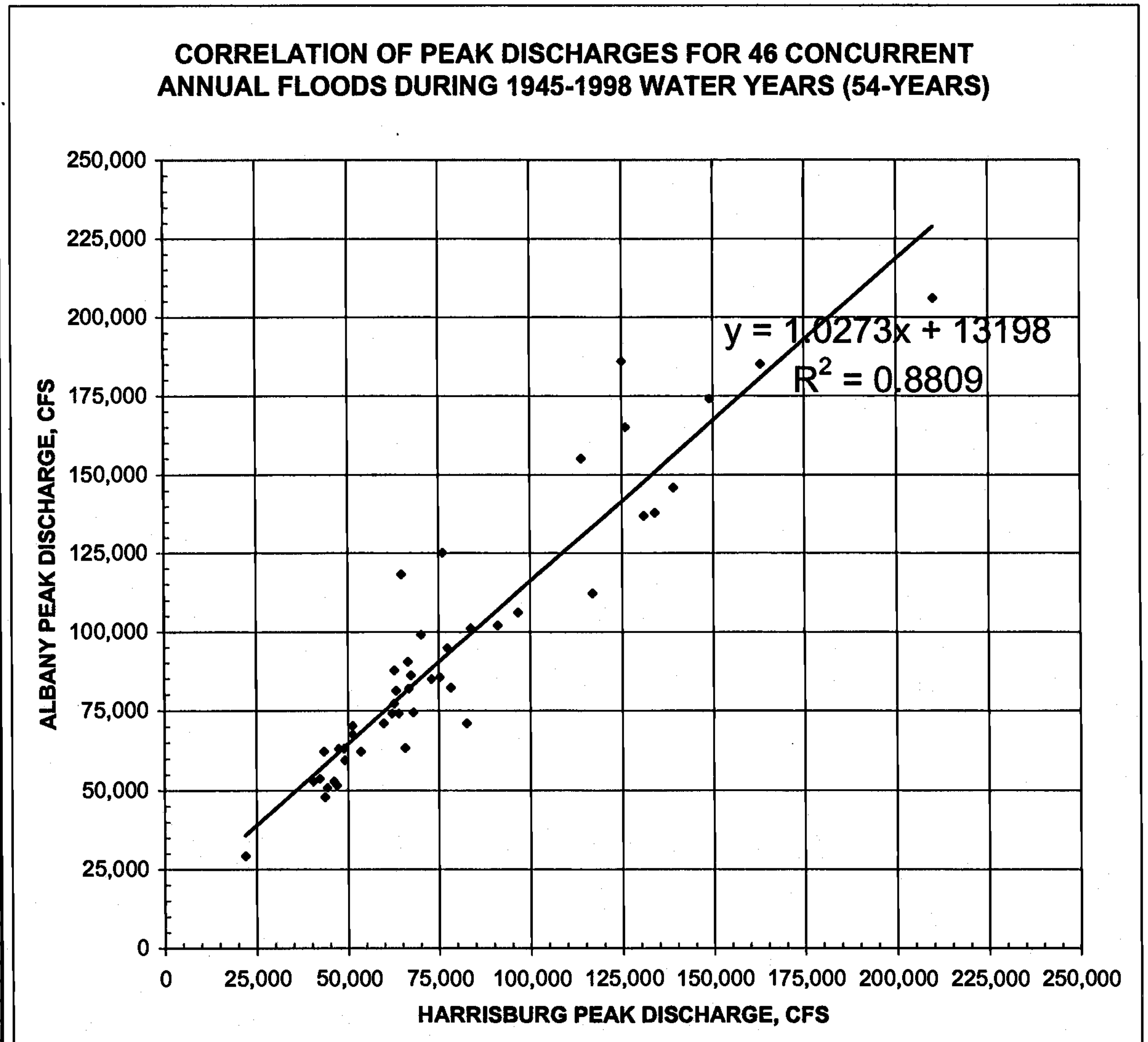
Photo # 4-2 (1996 Southern Site)

Point ID	X residual	Y residual	RMS Error
GCP # 1	-0.24	-0.988	1.017
GCP # 3	1.352	0.033	1.352
GCP # 4	0.089	-1.312	1.315
GCP # 6	1.147	-0.097	1.151
GCP # 8	-0.29	0.15	0.326
GCP # 9	0.487	-2.208	2.261
GCP # 11	-1.524	0.749	1.698
GCP # 12	-0.684	1.834	1.957
GCP # 13	0.407	0.386	0.561
GCP # 14	0.458	-0.766	0.893
GCP # 15	-0.542	-0.656	0.851
GCP # 16	1.05	0.515	1.169
GCP # 17	-0.542	-0.686	0.874
GCP # 18	0.931	0.349	0.994
GCP # 19	-0.538	-1.093	1.219
GCP # 20	-1.787	0.086	1.789
GCP # 21	2.108	-0.715	2.226
GCP # 22	-0.427	1.482	1.542
GCP # 23	-0.391	1.732	1.775
GCP # 24	-0.349	-0.526	0.632
GCP # 5	-0.714	1.731	1.872
Total	0.9293	1.0632	1.4121

Residuals and Errors are measured in pixels.
1939 pixel length = 0.5 m
1996 pixel length = 1.0 m

CORRELATION OF PEAK DISCHARGES FOR CONCURRENT ANNUAL FLOODS, HARRISBURG VERSUS ALBANY, FOR PERIOD OF HARRISBURG RECORD

HARRISBURG	ALBANY	W.Y.
82,600	71,100	1945
210,000	206,000	1946
134,000	138,000	1947
163,000	185,000	1948
131,000	137,000	1949
70,200	99,000	1950
139,000	146,000	1951
	Not concurrent in 1952 WY	
149,000	174,000	1953
117,000	112,000	1954
53,400	62,200	1955
114,000	155,000	1956
	Not concurrent in 1957 WY	
96,700	106,000	1958
62,700	77,200	1959
47,400	63,000	1960
126,000	165,000	1961
	Not concurrent in 1962 WY	
62,100	74,000	1963
67,400	86,100	1964
125,000	186,000	1965
73,000	84,800	1966
48,800	63,000	1967
46,000	52,800	1968
	Not concurrent in 1969 WY	
66,800	81,900	1970
78,300	82,200	1971
91,100	102,000	1972
	Not concurrent in 1973 WY	
64,700	118,000	1974
42,100	53,700	1975
75,300	85,400	1976
	Not concurrent in 1977 WY	
62,700	87,700	1978
46,900	51,600	1979
59,700	71,000	1980
68,000	74,400	1981
77,400	94,700	1982
51,200	70,200	1983
64,000	74,000	1984
49,100	59,500	1985
66,500	90,400	1986
43,400	62,300	1987
51,200	67,600	1988
65,600	63,300	1989
	Not concurrent in 1990 WY	
43,600	47,900	1991
	Not concurrent in 1992 WY	
44,200	50,900	1993
21,900	29,300	1994
63,200	81,300	1995
76,100	125,000	1996
83,800	101,000	1997
40,400	52,800	1998



Appendix 3. Timeline Data

Peak Flows | **Storage** | **Revetments**

Albany Peak (cfs)	Date	Harrisburg Peak (cfs)	Date	Reservior	Cumulative Storage (Acre Ft)	A.C.E. Revetment Name	Date	Cumulative Revetment (m)	New
79700	2/13/1893	64735	1893		0		1893	0	
173000	1/16/1894	155555	1894		0		1894	0	
86400	1/14/1895	71257	1895		0		1895	0	
128000	1/23/1896	111751	1896		0		1896	0	
178000	11/18/1896	160422	1897		0		1897	0	
85100	12/15/1897	69991	1898		0		1898	0	
112000	3/3/1899	96176	1899		0		1899	0	
130000	1/15/00	113698	1900		0		1900	0	
231000	1/15/01	212014	1901		0		1901	0	
85100	12/10/01	69991	1902		0		1902	0	
233000	1/26/03	213961	1903		0		1903	0	
126000	2/17/04	109804	1904		0		1904	0	
80400	12/31/04	65416	1905		0		1905	0	
59200	2/25/06	44780	1906		0		1906	0	
220000	2/6/07	201306	1907		0		1907	0	
182000	12/27/07	164316	1908		0		1908	0	
119000	1/22/09	102990	1909		0		1909	0	
226000	11/24/09	207147	1910		0		1910	0	
78000	1/20/11	63080	1911		0		1911	0	
145000	1/14/12	128299	1912		0		1912	0	
91500	4/1/13	76221	1913		0		1913	0	
67100	1/26/14	52470	1914		0		1914	0	
53000	1/15/15	38744	1915		0		1915	0	
165000	2/8/16	147768	1916		0		1916	0	
49500	4/9/17	35337	1917		0		1917	0	
91200	12/25/17	75929	1918		0		1918	0	
87500	1/24/19	72327	1919		0		1919	0	
69000	1/28/20	54319	1920		0		1920	0	

Albany Peak (cfs)	Date	Harrisburg Peak (cfs)	Date	Reservior	Cumulative Reservoir Storage (Acre Ft)	A.C.E. Revetment Name	Date	Cumulative Revetment (m)	New
118000	1/1/21	102017	1921		0		1921	0	
122000	11/23/21	105911	1922		0		1922	0	
206000	1/8/23	187678	1923		0		1923	0	
52000	2/3/24	37771	1924		0		1924	0	
130000	2/6/25	113698	1925		0		1925	0	
143000	2/8/26	126353	1926		0		1926	0	
191000	2/22/27	173077	1927		0		1927	0	
74000	3/13/28	59186	1928		0		1928	0	
50800	3/23/29	36603	1929		0		1929	0	
91500	12/21/29	76221	1930		0		1930	0	
109000	4/3/31	93256	1931		0		1931	0	
134000	3/21/32	117592	1932		0		1932	0	
94500	1/4/33	79141	1933		0		1933	0	
76300	1/25/34	61425	1934		0		1934	0	
73200	12/23/34	58407	1935		0		1935	0	
125000	1/13/36	108831	1936		0		1936	0	
127000	4/16/37	110778	1937		0		1937	0	
96800	3/20/38	81380	1938		0	Irish Bend	1938	682	682
61000	2/17/39	46532	1939		0	Ingram Island	1939	1514	832
59000	3/1/40	44585	1940		0		1940	1541	
41200	12/28/40	27258	1941		0		1941	1541	
86000	11/18/41	70867	1942		0		1942	1541	
218000	1/2/43	199359	1943	Cottage Grove	32930		1943	1541	
46300	11/6/43	32222	1944		32930		1944	1541	
Harrisburg	2/14/45	82600	1945		32930		1945	1541	
	12/29/45	210000	1946		32930		1946	1541	
	12/14/46	134000	1947		32930		1947	1541	
	1/7/48	163000	1948		32930	Alford	1948	1846	305
	12/13/48	131000	1949	Dorena	110492	Lower Bend	1949	2765	919
	1/22/50	70200	1950		110492		1950	2765	
	10/30/50	139000	1951		110492		1951	2765	
	2/4/52	71800	1952		110492		1952	2765	

Date	Harrisburg Peak (cfs)	Date	Reservior	Cumulative Reservoir Storage (Acre Ft)	A.C.E. Revetment Name	Date	Cumulative Revetment (m)	New
1/19/53	149000	1953	Lookout Pt.	459692		1953	2765	
11/23/53	117000	1954	& Dexter	459692		1954	2765	
12/31/54	53400	1955		459692	Fawver	1955	3500	735
12/22/55	114000	1956		459692		1956	3500	
12/12/56	92600	1957		459692		1957	3500	
12/21/57	96700	1958		459692	Foster	1958	4752	1252
1/28/59	62700	1959		459692		1959	4752	
2/10/60	47400	1960		459692		1960	4752	
2/11/61	126000	1961	Hills Creek	708592		1961	4752	
11/23/61	74600	1962		708592		1962	4752	
5/7/63	62100	1963	Cougar &	883292	Lower Bend Ext.	1963	5269	517
1/20/64	67400	1964	Carmen-Smith	883292		1964	5269	
12/23/64	125000	1965		883292		1965	5269	
1/6/66	73000	1966	Fall Creek	998792		1966	5269	
1/28/67	48800	1967		998792		1967	5269	
2/23/68	46000	1968	Blue River	1084342		1968	5269	
11/9/68	58100	1969		1084342		1969	5269	
1/27/70	66800	1970		1084342		1970	5269	
1/18/71	78300	1971		1084342	Foster Ext.	1971	5481	212
1/21/72	91100	1972		1084342	Unknown	1972	5547	66
1/17/73	34400	1973		1084342		1973	5547	
1/16/74	64700	1974		1084342		1974	5547	
1/9/75	42100	1975		1084342		1975	5547	
1/8/76	75300	1976		1084342		1976	5547	
5/17/77	11700	1977		1084342		1977	5547	
12/15/77	62700	1978		1084342		1978	5547	
2/8/79	46900	1979		1084342		1979	5547	
1/13/80	59700	1980		1084342		1980	5547	
12/4/80	68000	1981		1084342		1981	5547	
12/7/81	77400	1982		1084342		1982	5547	
2/18/83	51200	1983		1084342		1983	5547	
2/14/84	64000	1984		1084342		1984	5547	

Date	Harrisburg Peak (cfs)	Date	Reservior	Cumulative Reservoir Storage (Acre Ft)	A.C.E. Revetment Name	Date	Cumulative Revetment (m)	New
11/30/84	49100	1985		1084342		1985	5547	
2/23/86	66500	1986		1084342		1986	5547	
11/28/86	43400	1987		1084342		1987	5547	
1/15/88	51200	1988		1084342		1988	5547	
1/10/89	65600	1989		1084342		1989	5547	
4/28/90	46500	1990		1084342		1990	5547	
5/19/91	43600	1991		1084342		1991	5547	
11/27/91	46200	1992		1084342		1992	5547	
3/19/93	44200	1993		1084342		1993	5547	
1/6/94	21900	1994		1084342		1994	5547	
1/14/95	63200	1995		1084342		1995	5547	
2/8/96	76100	1996		1084342		1996	5547	

Gray cells within the annual peak discharge column denotes large peaks > or equal to 90,000 cfs.
Gray cells within the storage and revetment columns indicate new additions to the system.
Data Source: USGS Water Data for Oregon, USACE information & EPA research data of Sam Fernald.

Appendix 4. Annual Peak Discharge Recurrence Intervals

Harrisburg Annual Peak Discharge 1909-1939 Estimated from the Albany Peaks | **Harrisburg Annual Peak Discharge 1968-1998**

Water Year	Discharge (cfs)	Rank	Recurrence	Water Year	Discharge (cfs)	Rank	Recurrence
1909	207147	1	32.00	1/21/72	91100	1	32
1923	187678	2	16.00	11/19/96	83800	2	16.00
1927	173077	3	10.67	1/18/71	78300	3	10.67
1916	147768	4	8.00	12/7/81	77400	4	8.00
1912	128299	5	6.40	2/8/96	76100	5	6.40
1926	126353	6	5.33	1/8/76	75300	6	5.33
1932	117592	7	4.57	12/4/80	68000	7	4.57
1925	113698	8	4.00	1/27/70	66800	8	4.00
1937	110778	9	3.56	2/23/86	66500	9	3.56
1936	108831	10	3.20	1/10/89	65600	10	3.20
1921	105911	11	2.91	1/16/74	64700	11	2.91
1909	102990	12	2.67	2/14/84	64000	12	2.67
1921	102017	13	2.46	1/14/95	63200	13	2.46
1931	93256	14	2.29	12/15/77	62700	14	2.29
1938	81380	15	2.13	1/13/80	59700	15	2.13
1933	79141	16	2.00	11/9/68	58100	16	2.00
1913	76221	17	1.88	2/18/83	51200	17	1.88
1929	76221	18	1.78	1/15/88	51200	18	1.78
1917	75929	19	1.68	11/30/84	49100	19	1.68
1919	72327	20	1.60	2/8/79	46900	20	1.60
1911	63080	21	1.52	4/28/90	46500	21	1.52
1934	61425	22	1.45	11/27/91	46200	22	1.45
1928	59186	23	1.39	2/23/68	46000	23	1.39
1934	58407	24	1.33	3/19/93	44200	24	1.33
1920	54319	25	1.28	5/19/91	43600	25	1.28
1914	52470	26	1.23	11/28/86	43400	26	1.23
1939	46532	27	1.19	1/9/75	42100	27	1.19
1915	38744	28	1.14	1/15/98	40400	28	1.14
1924	37771	29	1.10	1/17/73	34400	29	1.10
1929	36603	30	1.07	1/6/94	21900	30	1.07
1917	35337	31	1.03	5/17/77	11700	31	1.03
mean cfs =	2830490			mean cfs =	1740100		
std dev cfs =	44445			std dev cfs =	17698		

Data Source: USGS Water Data for Oregon

Appendix 5. Study Reach Bank Conditions

	Revetments					Geologic Constraints		
	Length (m)	River Bank	On Channel	A.C.E. Name	Installation	Length (m)	River Bank	On Channel
	682	left	yes	Irish Bend	1938	801	right	yes
	832	left	yes	Ingram Island	1939	1050	right	yes
	305	right	no	Alford	1948	1566	right	yes
	919	left	yes	Lower Bend	1949	314	right	yes
	735	left	yes	Fawver	1955	1803	right	yes
	1252	left	yes	Foster	1958			
	212	left	no	Foster Ext.	1971			
	90	right	yes					
	29	right	yes					
	14	right	yes					
	22	right	yes					
Total	5092					5534		
Total Left Bank	4632					0		
Total Right Bank	460					5534		

Thalweg of Reach (m)	12,000
% Hardening Left Bank	38.60%
% Hardening Right Bank	49.95%