Flood Trends in the Applegate Basin

Large, frequent floods are a common and natural occurrence in the Applegate basin. Large Applegate floods, in fact, have devastated private property and valuable agricultural land throughout settlement history, and bridge collapse, soil loss, access problems, residential flooding, and large-scale channel relocation are just a few of the difficulties associated with Applegate floods.

Flood engineering solutions have long been proposed and implemented in this valley, yet the success of these projects has been limited. Levee construction projects, in particular, have been used in an effort to safeguard floodplain lands from floodwaters. Such efforts, however, have failed, and disjointed sections of a once grand levee system now dot the floodplain in places far removed from the active river channel.

Applegate Dam represents another flood management strategy. Yet, even this massive engineering approach lacks the flood buffering capacities to alleviate catastrophic flooding along the lower river. The dam effectively controls moderate floods but does little to reduce the impacts of large 15-20 year events.

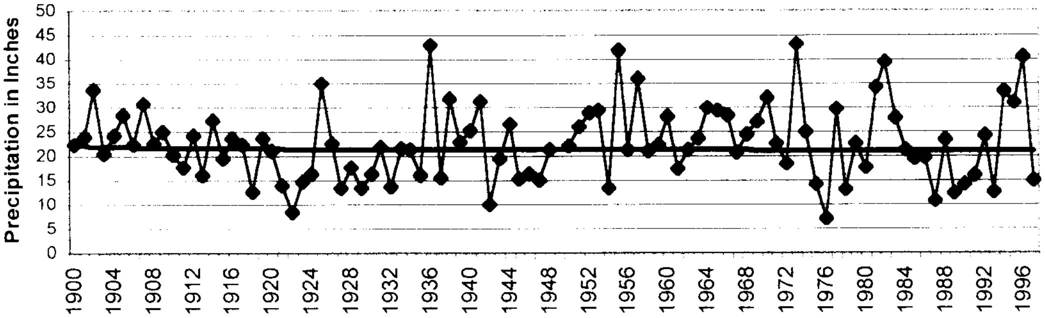
The flood history of the Applegate basin highlights the frequency and size of expected flood events. Understanding this history is crucial for planning appropriate floodplain land use strategies. Streamside lands provide productive farming and grazing areas throughout the Applegate Valley, and these lands also comprise some of the most scenic and valuable land in this basin. As a result, we need to be aware of the natural flood processes which continuously affect and re-shape our lands.

The following information provides insight into the flood history and flood probability of the Applegate River.

Precipitation

The precipitation record for Medford, as well as more recent records for both Grant's Pass and Buncom, reflects a large variation in yearly amounts of precipitation in addition to significant decadal trends. A plot of winter precipitation at Grant's Pass, for example, (figure 1) illustrates the potential variability in winter precipitation in the Applegate Valley. Despite a relatively uniform long-term average, winter precipitation totals for Grant's Pass differ by as much as 36 inches. Furthermore, drought periods appear frequently in the climate record of Southern Oregon, and numerous dry and wet cycles typify the precipitation record of this region.

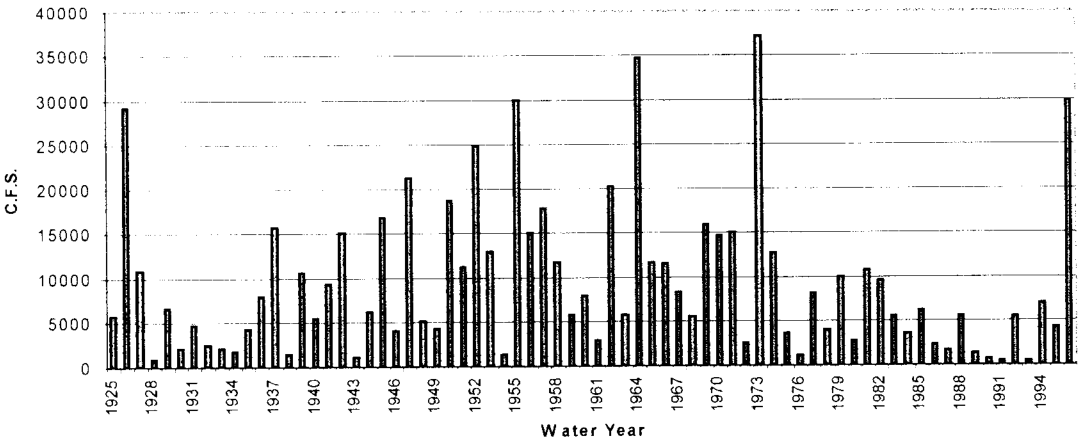
Figure 1
Winter Precipitation Totals at Grant's Pass (November-March)



Streamflow

United States Geological Survey (U.S.G.S.) stream-flow gauges on the mainstem Applegate River provide an historical record of flood magnitude and frequency. Both the Ruch and Applegate gauges recorded historical peak flows, and their combined data sets create a long-term flood record from 1926 to the present. (Figure 2).

Figure 2
Annual Peak Discharge at Applegate (1926-1997)

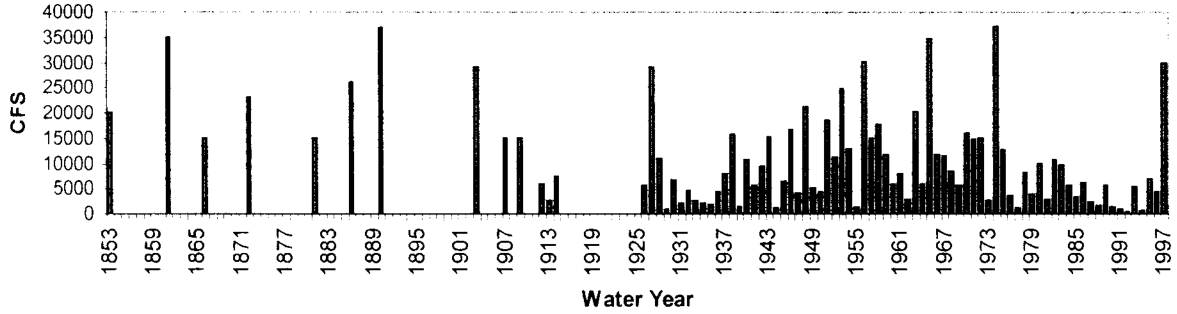


The flow history of the Applegate River mirrors the variability displayed by the precipitation record, and peak flows for the Applegate, both preceding and following dam construction, vary dramatically. The largest recorded flow, for example, occurred in 1974 and produced a discharge of 37,200 CFS at Applegate. In contrast, the lowest recorded pre-dam peak flow stands at 850 CFS and occurred in 1929 (Figure 2). This substantial variation between peak flows attests to extreme climatic variability and the unpredictable nature of this system.

Flooding

One of the few predictable features present in the hydrologic record of the Applegate is the frequent occurrence of large flood events. United States Geological Survey gauge data combine with anecdotal accounts, old newspaper articles, damage estimates, Army Corp of Engineer studies, and climate records to document the existence and magnitude of large floods from the mid 1800's to the present. As a result, we can graph and estimate the recurrence interval of large floods in the Applegate Valley from 1853 to the present (figure 3).

Figure 3
Historic Flood Estimates of the Applegate Valley
Pre 1912 data estimated by property damage, climate records, Army Corps study, and historical newspaper accounts



From 1927-1997, flood events roughly equal to or greater than the 1997 (~30,000 CFS) flood occurred on average every 14.4 years (Figure 2). Additional insight stems from the historical estimates of flood magnitude prior to U.S.G.S gauge installation (figure 3). This information, while less precise than the U.S.G.S. data, indicates that between seven and nine large magnitude flood events (~30,000 CFS) occurred from 1853 to 1998. This indicates that a flow equal to or greater than the 1997 flood occurred on average every 16-20 years.

Flood Recurrence intervals:

Flood recurrence intervals display the average length of time (in years) between events of a given magnitude, and flood recurrence intervals for the Applegate gauge provide further evidence of frequent, large floods (figure 4).

FLOOD RECURRENCE INTERVALS

Source & Year	2 Year	5 Year	10 Year	20 Year	25 Year	50 Year	100Year
ARWC 1999	10,600	17,000	24,000	33,500	-	-	-
U.S.G.S. 1970	9,800	19,000	27,700	34,800	37,000	47,000	57,000
U.S.G.S. 1987	9,110	18,700	26,700	-	38,900	49,200	60,500

Recurrence intervals for Applegate Gauge. All values in cubic feet per second (CFS).
Figure 4

Data from figure 4, for example, indicate that the 20-year flood event at Applegate has a magnitude of roughly 33,000-35,000 CFS. This suggests that in any given year there is a 5% chance of a 33,000-35,000 CFS flood, and that such a flood occurs, on average, every 20 years. Consequently, a smaller flood, similar in magnitude to the 1997 event, has a recurrence interval of approximately 15 years.

Timing:

Large floods in the Applegate basin generally occur between December and the end of February. The largest floods on record take place after a period of heavy snowfall at moderate to low elevations--this snowfall is commonly followed by a warming trend with heavy precipitation. Warm temperatures and precipitation liquefy the snowpack and produce extensive runoff and flooding. This rapid climatic transition from snow to warm rain appears to trigger most major flood events within the Applegate basin. Climate records, for example, display that the 1858, 1880, 1890, 1927, 1964, 1974, and 1997 floods followed this model.

Summary:

Destructive floods occur roughly every 15-20 years in the Applegate Valley. Extreme floods, however, can occur in successive years, and historical evidence points to several very large floods which occurred less than 10 years apart. Moreover, the historical record shows that the Applegate Valley will continue to experience large floods. Consequently, appropriate flood coping strategies, which protect valuable floodplain lands, private property, and ecological balances, need to be developed. Engineering solutions, including levee and dam construction, have not eliminated flooding and will not do so in the future, and increased flood planning and awareness of floodplain processes may provide the only viable path to flood damage reduction within the Applegate Valley.

Historical Conditions in the Applegate Valley

Land use in the Applegate basin has dramatically altered river conditions throughout the Applegate-Murphy reach. From the earliest placer mining operations in the 1850's to the grazing, road building, and logging booms of the twentieth century and the eventual construction of Applegate dam, the Applegate river continues to respond to and evolve with human land use activities.

Highly erosive floods and historical land use activities have altered or removed many river channel features. And while the size and frequency of large floods appear unchanged between 1850 and the present, flood energy has increased while bank resistance to erosion has declined. Historically, beaver dams were common, floodplain vegetation was extensive and mature, large woody debris filled many of the channels, and multiple-channel island complexes were plentiful and stable along the mainstem Applegate and its tributaries. The many natural structures and diversions present throughout the watershed dispersed and slowed potentially erosive floodwaters. Moreover, these same natural features stabilized streambanks and protected floodplain areas from erosion.

The present situation, however, differs dramatically from the past, and today land use practices straighten channels and increase stream velocities. Vegetative clearing reduces stream bank resistance to erosion, and levees intensify flood energy and isolate the river from floodplain processes. Roads and bare soil increase overland runoff and can increase local flood heights. Furthermore, increased flood energy, reduced stream bank cohesion, and increased sediment deposition along the lower river produce widespread channel instability and erosion.

Many stable channel features, which helped reduce flood damage and improve habitat complexity historically, are not compatible with the present land use and hydrological regime. As a result, channel instability and erosion characterize much of the Applegate-Murphy reach today.

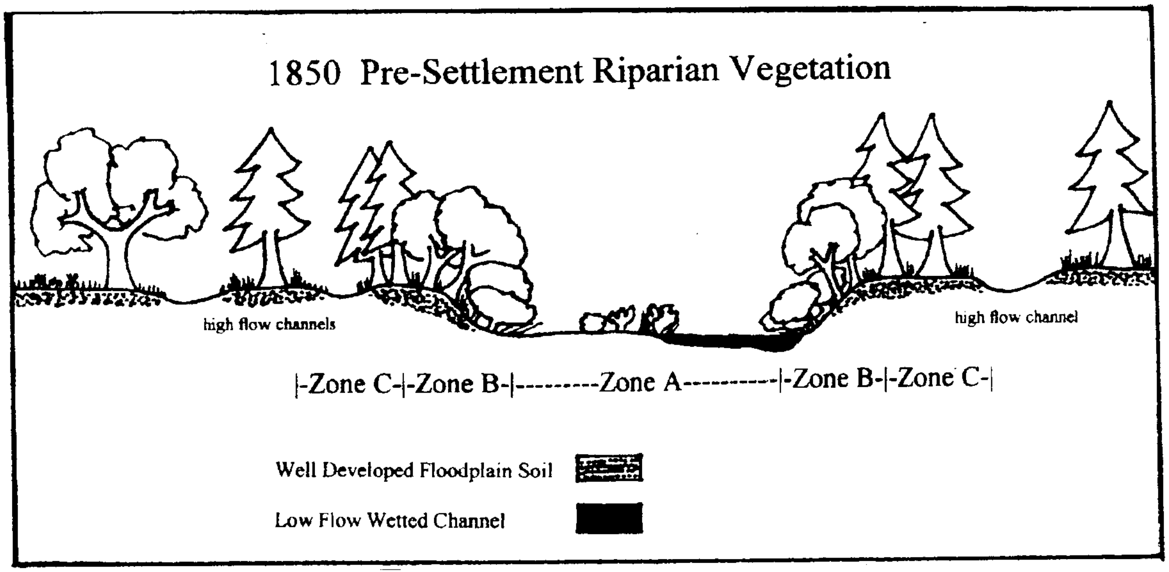
Recommendations

In an effort to reduce flood damage to private property and improve aquatic habitat, it is imperative that we allow the river ample space to flood. High flow channels that were created by the 1997 flood display the area needed to convey 10-20 year flood events. If we reclaim these areas, we will guarantee destructive flooding every 10-20 years as floodwaters seek overflow channels.

Furthermore, streamside vegetation is imperative to channel stability. Mature trees hold the channel in place during high flows and prevent large-scale channel relocation and erosion. Moreover, mature streamside vegetation traps passing woody debris and confines it to the river channel. Without mature trees along stream banks, river channels erode, widen, and scour large areas of floodplain land. And in the absence of stabilizing vegetation floodwaters are free to open up new channels and restrict landowner access to private lands.

Importantly riprap and levee projects increase the erosive energy of floodwaters. Such projects can increase downstream flooding and often increase flood erosion on adjacent lands. Whenever possible, we should avoid confining or focusing the river's flow.

Applegate River Pre-Settlement Vegetation Conditions



1850 Pre-Settlement Riparian Vegetation

Extensive and diverse riparian vegetation typified stream margins along the majority of the Applegate River historically, and three distinct zones of vegetation existed along the lower river prior to white settlement and mining:

A) In zone A, numerous Applegate reaches exhibited vegetation growing within the active river channel. During low summer flows or long term drought sequences, riparian vegetation colonized parts of the river channel bottom. Shrubs within the active channel provided shade, cover, and velocity refuge for juvenile fish throughout the lower river. Furthermore, in-stream vegetation trapped sediment and likely led to the formation of relatively stable, vegetated islands. Islands then worked to slow floodwaters, and trap sediment.

B) Zone (B) represents the riparian area along the wetted margin of the Applegate. This zone was densely vegetated by hardwood and shrub species, including alder, willow, and cottonwood. Nearly all historical photos, in fact, display thick, overhanging vegetation, and in many examples limbs or stems of streamside vegetation are in the flowing water. This band of vegetation stabilized stream banks, trapped passing woody debris, and reduced the tendency for the Applegate channel to relocate and scour out floodplain areas.

C) Adjacent to the zone (B) hardwoods, a narrow band of mature conifers (zone C) appears in most historical photographs. These conifers paralleled the river channel and appeared just above the zone of seasonal inundation. These trees were some of the largest in the basin prior to floodplain settlement, and they were responsible for stabilizing upper stream banks and overflow channels during exceptionally high flows. Today, reduced riparian vegetation facilitates bank erosion and increases the tendency of the Applegate River channel to relocate during large floods.

Applegate River Flood History

Year	Damage and comments	Precipitation record
1853	Area unsettled, no record of damage	17 days and nights of snow, followed by three days of rain
1861	Bunkum completely inundated River swept away flumes of sterling creek, mill ruined Floods scoured topsoil from some farms, deposited soil over other farms Water three feet deep in houses Bridges, boats, fences, all swept away Communities completely wiped out	Flood believed larger than 1964
1864	Smaller magnitude floods	
1866	Smaller magnitude floods	
1867	Smaller magnitude floods	
1872	Jacksonville-Illinois valley stage coach delayed due to high water Water higher than it had been for six years	
1880	Streambed erosion severe in the Ashland area	One foot of snow followed by five days of rain
1881	Repeat of 1880	January downpour melts mountain snows
1886	Floods devastated sterling creek Floods buried saltmarsh mining claims	
1890	Floods stripped cropland and undercut streambanks Extensive removal of topsoil Four farms lost between fifteen and twenty acres of bottomland soil each New channel cut though farms Numerous farms were "washed away or debris covered" (Humbug area) Bridges, barns, haycrops, fences, livestock disappeared This flood reportedly smaller than 1861	40" of snow in Jacksonville followed by warm rains which liquefy the snowpack Flood believed larger than 1964
1894		
1903	Considerable areas of ground were "swept away" Locals estimate: five years to recover 1903 flood approximated the storm intensity of 1890	11.69" of precip. for the month*
1907	Rogue River Courier: "It is the history of this valley for the past fifty years abnormally high water occurs on average every ten years"	9.33" of precip. for the month*
1927	Washed out the approach to Mckee bridge Lost fences and topsoil; furniture, house, and car carried away Elliot Ck., Middle Fk., and Carberry Ck. bridges lost Ed Taylor lost bridge for second or third time Wilderville hatchery demolished Quality alfalfa field turned to gravel deposits Practically all bridges on Thompson and Williams Creek out Ranches "sliced out", roads gone, irrigation ditches destroyed Remains of huge logs on high points of rock-(wood was up on these same high points when pioneers first entered this valley)	8.91" of precipitation for month* Several days of rain with snowmelt and high temperatures
1948	Less severe than 1927	
1953	Bridges taken out	10" precipitation for month*

1955	Bridges washed away Access to ranchland removed $4,000,000 damage in Southwest Oregon Heavy road reconstruction in 1955 indicates extensive road damage Meadows, farm fields, and hay land became littered with "rocks and trash" Heavy soil loss	12.58" precipitation for month*
1964	Earth washed off fields 16' high bridge washed out Severe channel erosion, mass wasting--channel cuts through pasture Greatest property damage on record for Southwestern Oregon Wood pieces found twelve feet up a tree on lower river Sand and silt on roads, trailers washed away Three new houses became a "part of the river" Family of skunks move into flooded house Families stranded with washed out bridges	16" precipitation for month* Freezing level jumps up to 11,000' after snow at lower elevation-temperature at sun-rise 55 degrees
1966	In aftermath of 1964 flood, landowner surrounds house with 13' high wall to protect against future flooding	
1974	Severe channel erosion, mass wasting, and road damage Bridges washed out River was 6.5 feet above flood stage Similar destruction to the 1964 flood 2900 acres of farm land inundated	10.6" precipitation for month Frozen ground throughout the area did not allow water to infiltrate-extreme runoff results
1980	Applegate Dam completed	Storm hung over Applegate and Bear Creek drainages
1997	Extensive Damage throughout basin	20.23" precipitation for month Snow level rises above 7000' for 5 days --3" rain in 24 hours

*Precipitation measurements form Grant's Pass gauge

There are 31 official floods recorded between 1890-1960
Subsequent floods: 1962, 1964, 1974, 1997

1978, May 23-Mailtribune reports that Lost Creek Dam did not alter the level of the 80 year flood event

"Flood damages run high in this [Applegate] Valley; more than 10% of the total damages in the Rogue basin from the 1955 flood occurred in the Applegate Valley, most of which was direct agricultural damage."------- from Rogue River Basin-State Water Resources Board, 1959

"It is the history of this valley for the past fifty years, abnormally high water occurs on average every ten years"--------- 1907, rogue river courier

Applegate River Systems Analysis

Completed by:
The Applegate River Watershed Council
1999

Historical and Current Floodplain Function along the Lower Applegate River (River Mile 14-25)

1850-1999

Table of Contents

Introduction

The Applegate River is part of a dynamic system that evolves over geologic time as climate, tectonic activity, and disturbances influence sediment loads, vegetation patterns, and runoff. Over shorter, historical intervals of time, however, the potential for stability or equilibrium exists within the Applegate valley, and the overall effect of a fluctuating climatic regime can generate a channel geometry which is adjusted to long term trends in vegetation, sediment, and runoff (Wolman and Gerson, 1977).

This study attempts to evaluate historical conditions of the Applegate River between Applegate and Murphy. Our evaluation focuses on river conditions prior to and immediately following European settlement of the Applegate Valley. Importantly, we recognize that this period simply represents a snapshot in time. Study results highlight an arbitrarily chosen period, and this period reflects the human and natural disturbance regime and climatic trend of the time.

The study reach is located between River Mile 13 and 25 along the lower Applegate River, in both Jackson and Josephine counties, Oregon. This stretch of river drains approximately 650 square miles of the Applegate Basin and maintains a broad floodplain (.5 mile wide) with a moderate channel slope(.02-.04). Cobble, gravel, sand, and silt characterize stream deposits, and floodplain vegetation has been largely cleared for agricultural practices. The composition, maturity, and density of riparian communities vary considerably throughout this reach.

Ample descriptions of Rogue Basin historical conditions exist, but specific historical information for the Applegate River is scarce, and historical resources for the Applegate-Murphy reach are limited. Nonetheless, this report utilizes personal accounts, historical photographs, government surveys, journal entries, and other available sources to build a picture of the Applegate-Murphy reach prior to white settlement and mining.

Earliest evidence:

Geologic evidence along the lower Applegate River displays the magnitude of geomorphic change that has occurred throughout the Applegate-Murphy reach. Bench gravels, for example, at one time formed the floodplain surface of the Applegate Valley and now exist as terraces along the lower river floodplain. Applegate terraces rise more than 50' above the present river channel and demonstrate the dramatic effect of climate change on river morphology and valley form (U.S.A.C.E 1965). During the Pleistocene period in this instance, Bowen (1969) suggests that heavier precipitation increased upland erosion and stream deposition sufficiently to aggrade the entire lower valley floor more than 50' above the present channel elevation. Increased glaciation, decreased stream competency, or a lack of upland vegetation may have also contributed to increased sediment deposition.

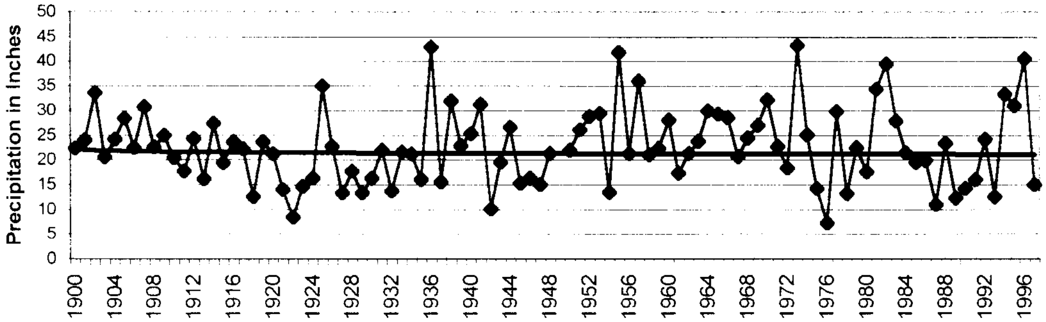
River channel characteristics throughout the Pleistocene differed greatly from today, and an aggrading, braided channel network probably characterized much of the Applegate Murphy reach. Furthermore, aggrading Pleistocene channel characteristics suggest a period of instability and frequent channel relocation, and stable floodplain vegetation may have been sparse throughout this period (Ligon, Dietrich, and Trush 1995). As climate patterns evolved, however, sediment loads in the Applegate eventually decreased, and the river's relative competency to remove sediment increased. The river removed excess alluvium from the lower valley floor, and over time the current floodplain surface emerged as the valley bottom. As river channel characteristics began to resemble those of today, stable vegetative communities began to occupy the Applegate floodplain.

Hydrologic History:

Precipitation

The precipitation record for Medford, as well as more recent records for both Grant's Pass and Buncom reflect a large variation in yearly amounts of precipitation in addition to significant decadal trends (Oregon climate service, 1999). A plot of winter precipitation at Grant's Pass, for example, (Figure 1) illustrates the potential variability in winter precipitation in the Applegate Valley. Despite a relatively uniform long-term average, winter precipitation totals for Grant's Pass differ by as much as 36 inches. Furthermore, drought periods appear frequently in the climate record of Southern Oregon, and numerous dry and wet cycles typify the precipitation record of this region (LaLande1995).

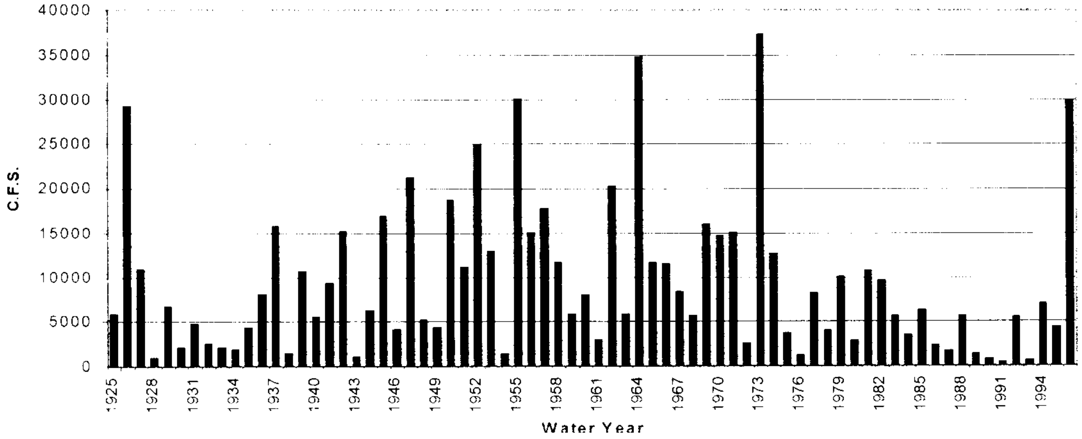
Figure 1
Winter Precipitation Totals at Grant's Pass (November-March)



Streamflow

U.S.G.S. stream gauges on the main stem Applegate River provide an historical record of flood magnitude and frequency. Both the Ruch and Applegate gauges recorded historical

Figure 2
Annual Peak Discharge at Applegate (1926-1997)



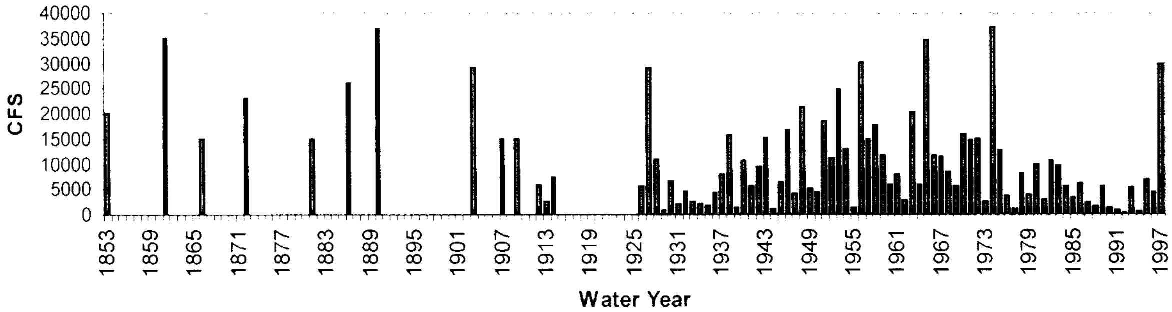
peak flows, and their combined data sets create a long-term flood record from 1926 to the present.[1] (Figure 2).

The flow history of the Applegate River mirrors the variability displayed by the precipitation record, and peak flows for the Applegate, both preceding and following dam construction, vary dramatically. The largest recorded flow, for example, occurred in 1974 and produced a discharge of 37,200 CFS at Applegate. In contrast, the lowest recorded pre-dam peak flow stands at 850 CFS and occurred in 1929 (Figure 2). This substantial variation between peak flows attests to extreme climatic variability and the unpredictable nature of this system.

Flooding

One of the few predictable features present in the hydrologic record of the Applegate is the frequent occurrence of large flood events. United States Geological Survey gauge data combine with anecdotal accounts, old newspaper articles, damage estimates, Army Corp of Engineer studies, and climate records to document the existence and magnitude of large floods from the mid 1800's to the present. Using this information, we can graph and estimate the recurrence interval of large floods in the Applegate Valley from 1853 to the present.

Figure 3
Historic Flood Estimates of the Applegate Valley
Pre 1912 data estimated by property damage, climate records, Army Corps study, and historical newspaper accounts



From 1927-1997, flood events roughly equal to or greater than the 1997 (~30,000 CFS) flood occurred on average every 14.4 years (Figure 2). Furthermore, estimates of historical flooding, prior to U.S.G.S. gauge installation, provide additional flood history information for the Applegate (Figure 3). These estimates, although less precise than the U.S.G.S. data, indicate that between seven and nine large magnitude flood events

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[1] The relationship between peak flows at both Ruch and Applegate is sufficient (R^2=.9804) to extend the data series at Applegate, using corrected values from the earlier Ruch gauge (see appendix 1). Consequently, a continuous record of peak flows from 1926 to the present exists for the Applegate gauge (Figure 2).

(~30,000 CFS) occurred from 1853 to 1998. This suggests that a flow equal to or greater than the 1997 flood occurred on average every 16-20 years.

Flood recurrence intervals display the average length of time (in years) between events of a given magnitude, and flood recurrence intervals for the Applegate gauge provide further evidence of frequent, large magnitude floods (Figure 4).

Source & Year	2 Year	5 Year	10 Year	20 Year	25 Year	50 Year	100Year
ARWC 1999	10,600	17,000	24,000	33,500	-	-	-
U.S.G.S. 1970	9,800	19,000	27,700	34,800	37,000	47,000	57,000
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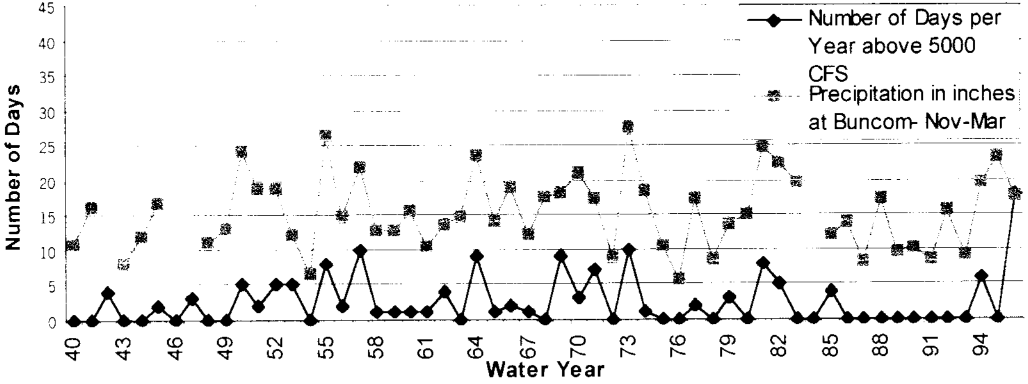
Recurrence intervals for Applegate Gauge. All values in cubic feet per second (CFS).
Figure 4

Data from Figure 4, for example, indicate that the 20-year flood event at Applegate has a magnitude of roughly 33,000-35,000 CFS. This suggests that in any given year, there is a 5% chance of a 33,000-35,000 CFS flood, and that such a flood occurs, on average, every 20 years. Consequently, a smaller flood, similar in magnitude to the 1997 event, has a recurrence interval of approximately 15 years.

The flood frequency patterns listed above, however, only represent a snapshot in time, and variations in climate, vegetation, land use, and water impoundment alter the hydrologic response to precipitation and can change recurrence intervals along with flood frequency and magnitude. Land use within the Applegate Valley, for example, has altered the hydrograph of the Applegate River (Applegate River Assessment 1995). Stream channelization, timber harvest, vegetative clearing, road building, grazing, and removal of beaver and large woody debris from Applegate streams has modified natural stream conditions and likely increases flood frequency and magnitude (Dunne and Leopold 1978).

Climate change also affects the magnitude and frequency of flood events. In Southern Oregon, for instance, climatic fluctuations directly influence stream flow as wet and dry cycles elicit high or low flow stream response (Figure 5). The flow record of the Applegate reflects this climatic variability as several drought periods exist within settlement history. A thirty-year dry period, for example, lasted from roughly 1920 to

Figure 5
Number of Days per Water Year With Stream Discharge Above Base Flow of 5000 CFS at Applegate Gauge; and Winter Precipitation Totals at Buncom Rain Gauge (in inches)



1940; a cooler, wetter period with increased flooding and high flows followed this cycle and lasted from roughly 1940 to the mid 1970's (Broecker 1975). And most recently, the mid 1980's saw another dry period. Applegate dam controlled flows on the mainstem Applegate throughout this final period of record, but tributary records show reduced stream flow throughout this interval.

Large dams further alter the relationship between precipitation and stream flow, and the Applegate reservoir reduces stream flows during storm events and augments low flows during dry periods. In extreme cases, reservoir operations completely alter the natural relationships between precipitation, runoff, and stream flow.

Historical stream flow records for the Applegate display hydrologic change on several levels, and climate change, land use, and water impoundment function together to create the peak discharge values in Figure 2. Three distinct trends emerge on the historical record which evidence stream response to land use, climate change, and water impoundment: (1) The Ruch gauge records peak flows from 1912-1953 and represents a dry climate trend combined with heavy mining and grazing in upland areas. (2) The Applegate gauge extends from 1939-1980 and represents a wetter and cooler period with extensive land use changes, including road building and major logging operations. And finally (3) the gauging record from 1980 to the present records peak flows following the closure of Applegate dam. Figure 6 (on the following page) documents the three hydrologic trends listed above.

Differences in the 1.5 year recurrence interval manifest the hydrologic changes represented by these three distinct periods of record (Figure 7).

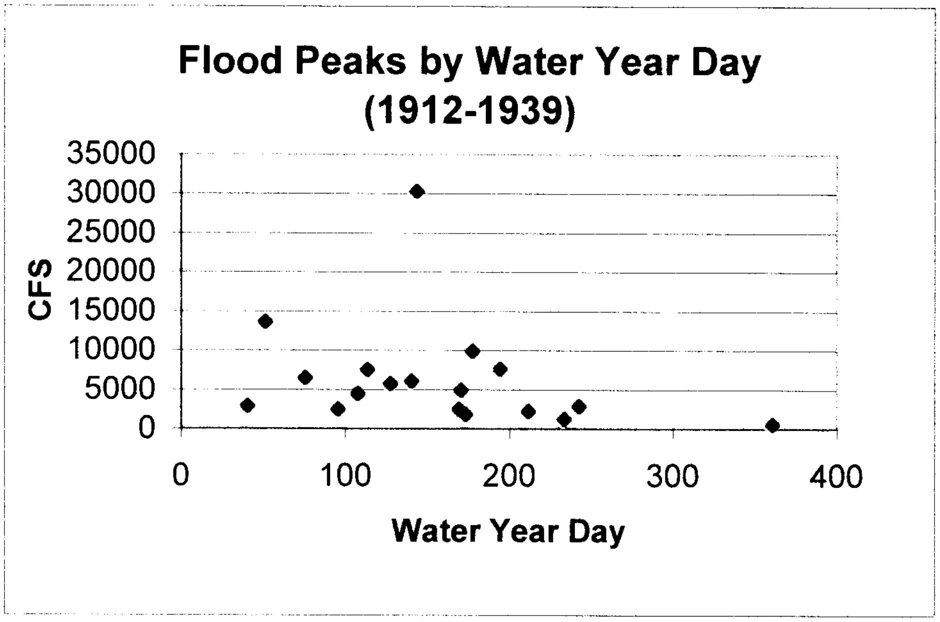
Figure 7

	1912-1953	1939-1980	1980-1997
Volume of 1.5 Year Recurrence Interval Event	4534 CFS	5750 CFS	2260 CFS

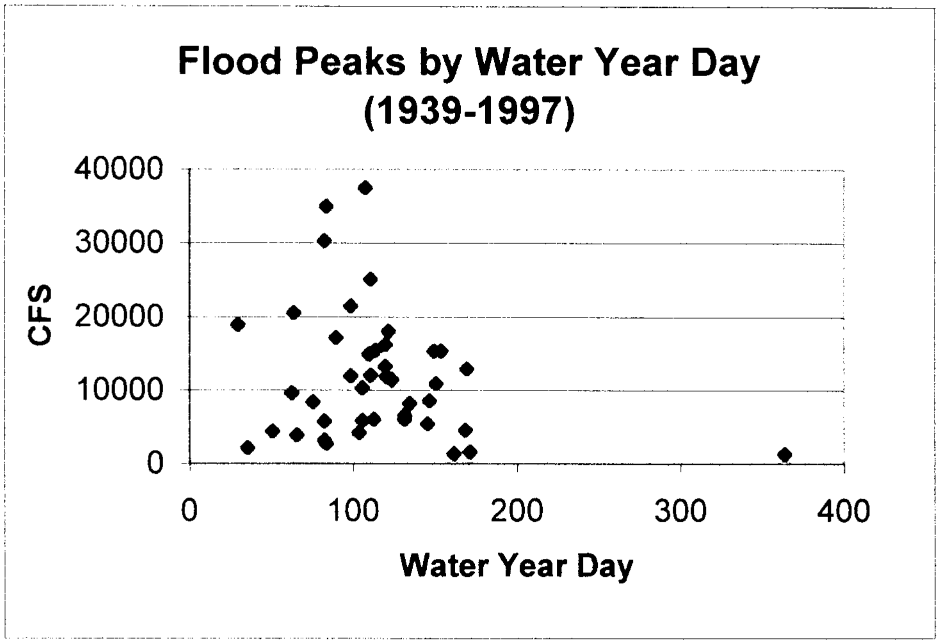
Figure 7 displays discharge changes for the 1.5 year event at Applegate. 1912-1953 represents a dry climatic trend, 1939-1980 represents a wetter cycle, and 1980-1997 shows the effects of Applegate Dam.

The 1.5 year flood event is thought to be the channel forming discharge that both shapes and maintains river channel geometry (Johnson and Heil 1996, Leopold 1994, Williams 1978). Changes in the frequency and magnitude of flood events, therefore, alter river channel morphology, as stream channels adjust to accommodate bank full discharges. Subtle changes in a flood regime, however, are common, and such changes frequently reflect climate or land use change. Furthermore, drastic alterations to a natural hydrologic regime can result from large-scale dam schemes. The Applegate River is no exception, and Applegate dam reduces the magnitude of channel forming flows by more than 50%.

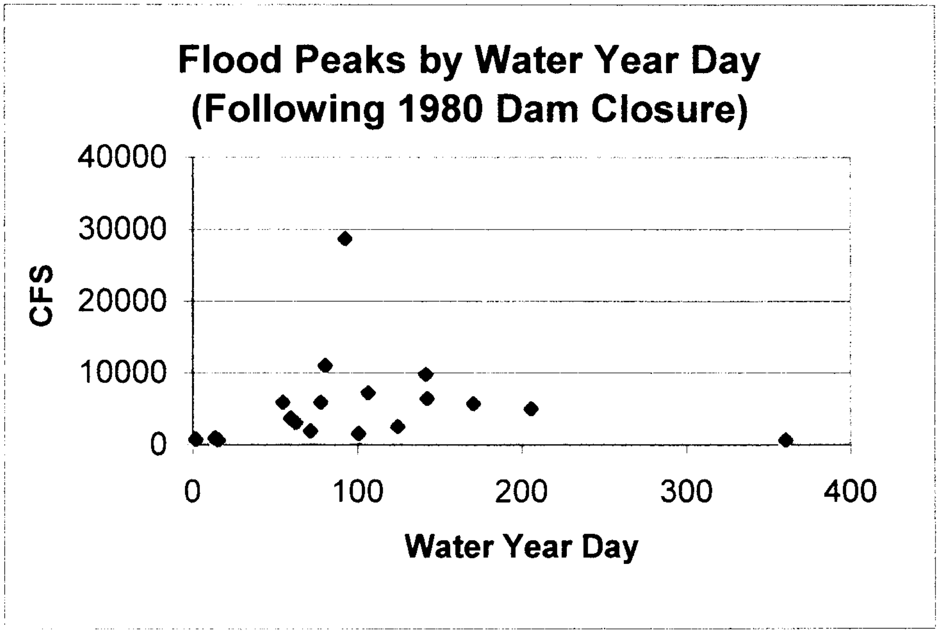
Figure 6



A) Note very few flood peaks above 10,000 CFS.
This graph represents relatively dry climatic conditions.



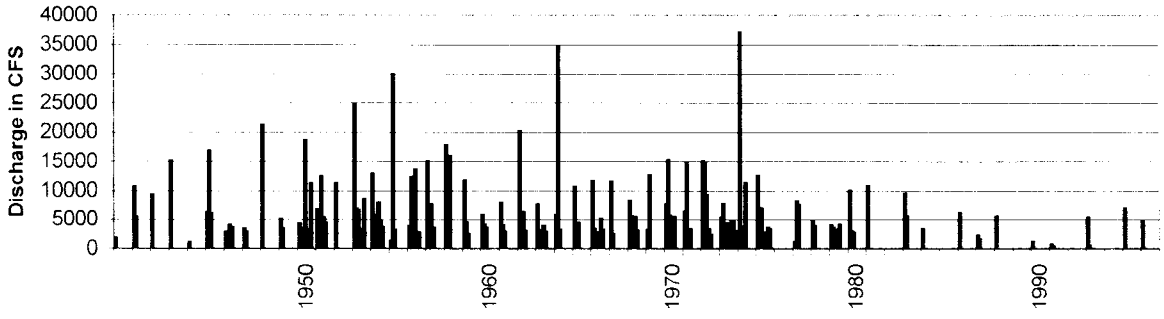
B) Note large number of flood peaks above 10,000 CFS.
This graph represents a wet climatic interval.



C) Note few peaks above 10,000 CFS.
This graph manifests the low flows created by Applegate Dam operations.

Significant alterations to the 1.5 year flood event evoke channel changes which can affect channel shape, off-channel habitat units, and flood trends. In the Applegate, reductions in the 1.5 year event are likely to reduce aquatic habitat complexity and river channel capacity (Williams and Wolman 1974). Figure 8 illustrates this dramatic reduction in peak flow frequency and magnitude following the closure of Applegate Dam in 1980.

Figure 8
Peak Flows Above Baseflow by Year (Applegate Gauge)



Flood Timing:

Large floods in the Applegate basin generally occur between December and March. The largest floods on record take place after a period of heavy snowfall at moderate to low elevations--this snowfall is commonly followed by a warming trend with heavy precipitation. Warm temperatures and precipitation, in turn, liquefy the snowpack and produce extensive runoff and flooding. This rapid climatic transition from snow to warm rain, in fact, appears to trigger most major flood events within the Applegate basin. Climate records suggest that the 1858, 1880, 1890, 1927, 1964, 1974, and 1997 floods followed this model.

Historical Conditions

Change:

Land use in the Applegate basin has dramatically altered river conditions throughout the Applegate-Murphy reach. From the earliest placer mining operations in the 1850's to the grazing, road building, and logging booms of the twentieth century and the eventual construction of Applegate dam, the Applegate river continues to respond to and evolve with human land use activities.

Erosive floods and human occupation have altered or removed many historical river channel features. And while the magnitude and frequency of large floods appear unchanged between 1850 and the present, flood energy has increased while bank resistance to erosion has declined. Historically, hydraulic roughness was much higher than at present; beaver dams were common, floodplain vegetation was extensive, large woody debris filled many of the channels, and multiple channel-island complexes were plentiful and stable along the mainstem Applegate and its tributaries. As a result, the myriad natural structures and diversions present throughout the watershed dissipated and slowed potentially erosive floodwaters. Moreover, historical land use activities leading to the construction of roads, use of heavy equipment, exposure of bare soil, and removal of mature woody vegetation from steep upland slopes served to increase both overland runoff rates and stream peak flows. The net effect of these activities may have increased peak flows within the main stem Applegate.

Historically, floodwaters were dispersed across the valley floor, and erosion rates were minor. Meandering channels, mature vegetation, islands, beaver dams, high flow channels, and log jams slowed flood pulses and directed water far out on to the floodplain where stream velocities could be further reduced and sediment deposited.

The current situation differs dramatically from the past, and today, land use practices straighten river channels and increase stream velocities. Vegetative clearing reduces stream bank resistance to erosion, and levees intensify flood energy and isolate the river from floodplain processes. Roads and bare soil increase overland runoff, reduce lag times, and increase local flood peaks. Consequently, increased flood energy and sediment loads and reduced stream bank cohesion produce widespread channel instability and erosion on the lower Applegate River.

Many stable channel features, which helped reduce flood damage and improve habitat complexity and stability historically, are not compatible with the present, dam controlled, hydrological regime. High flow channels, for example, which convey flood waters and provide important aquatic habitat, become clogged with debris and sediment in the absence of frequent moderate floods. As a result, a loss of complex off-channel habitat and a reduction in flood conveyance capacity characterize much of the lower river today.

Channel Characteristics

Old maps (1904-1905), historical accounts, and photos display a sinnuous historical channel pattern with a relatively wide and shallow, uniform cross section. Local historical accounts attest that "one could cross just about anywhere," (Johnson, 1978) and early explorers as well as land surveyors found no difficulty in crossing the uniform channel during moderate flow. Historical journal entries from 1879 provide additional evidence of shallow, uniform cross sections and suggest that 100' wide stream reaches in the Applegate area were often no more than 18" deep during summer months (Pullen 1995).

Channel Type

The historical lower Applegate river channel appears to have evolved from a moderately entrenched, moderate gradient, riffle dominated channel, with stable banks (Rosgen C channel) to a wider, shallower braided stream (Rosgen D channel) in many places (Applegate River Assessment 1995, Aerial photos 1939-1997). In fact, Leopold's (1964) channel slope vs. discharge graph places the lower Applegate near the threshold separating braided and meandering streams, and as a result even minor changes in bank stability and sediment input appear to encourage channel changes which result in stream braiding, widening, and channel avulsion. Several reaches along the lower river clearly display such change as unstable braided channels exist where narrower, well vegetated channels formerly dominated.

Many of the morphological changes along the lower Applegate are attributable to increased sediment loads of fine gravel and sand (Dunne *et al.* 1978). Increases in this material commonly induce channel widening and instability, and where gravel and sand deposits remain unvegetated, channel instability in the lower Applegate is likely to persist (Dunne *et al.* 1978).

Sinnuosity

Sinnuosity values (channel length divided by valley length) for the lower Applegate River vary over time and reflect both land use and flood trends (Figure 9).

Sinnuosity on the Applegate (Applegate-Murphy Reach)

Year	Sinnuosity
1855*	1.23
1939	1.2
1957	1.25
1974	1.3
1996	1.17
1997	1.21

*Retracing of 1850's DLC and GLO survey stream position.

Figure 9

A tracing of river locations during the 1855-1857 Donation Land Claim and Government Land Office Surveys yields an approximate sinnuosity of 1.23, and further analysis of subsequent aerial photos suggests continuous overall change as sinnuosity values drift from 1.3 in 1974 (largest peak flow of record) to a low of 1.17 in 1996 (22 years after a major flood).

Channelization and riparian encroachment have significantly altered sinnuosity throughout Applegate settlement history. Aerial photographs document this alteration through channel straightening, levee building, floodplain encroachment, and corresponding decreases in sinnuosity values. Frequent large floods and levee failures, however, allow the mainstem Applegate to cut new channels and increase channel sinnuosity. Aerial photographs taken following large floods (1957, 1974, 1997), for example, display higher sinnuosity values than photos following longer stable intervals without floods (1939, 1996). In this example, landowner intervention following large floods appears to reduce stream sinnuosity, while recurring floods reestablish natural meander trends through channel avulsion, levee washout, and erosion. In contrast to this pattern, however, levees and channel straightening projects along small tributary streams exhibit greater success, and floods along many tributary streams have been unable to restructure channelization projects. As a result, numerous lower river tributary streams, that meandered historically, are now straight ditches.

Interestingly, air photo evidence suggests that floodplain encroachment and vegetative removal typically reduce arable acreage over the long-term. For example, even today, landowners regularly expand agricultural land near high flow channels or along stream courses. This vegetative clearing creates unstable streambanks and floodplain surfaces that are commonly scoured or removed by large floods. The final result often finds less arable land available after expansion and flooding than prior to vegetative clearing and agricultural extension. Figure 10 (following page) provides a time sequence example of channel widening and streambank erosion throughout settlement history.

Aerial photos, in fact, show that even as late as 1974 large areas of forested land were cleared along the lower river floodplain. Air photo sequences reveal landowners filling and cultivating previous high-flow channels and document increasing flood damage to newly devegetated sites. This type of land use increases flood energy and guarantees future property damage when floodwaters reoccupy overflow channel areas.

Width-Depth Ratios

Channel widening and increases in channel width/depth ratios are exceptionally common in Western North America (Kondolf 1996), and channel widths along the lower Applegate have increased since 1850 (personal measurements, Applegate River Assessment 1995, G.L.O. 1855).

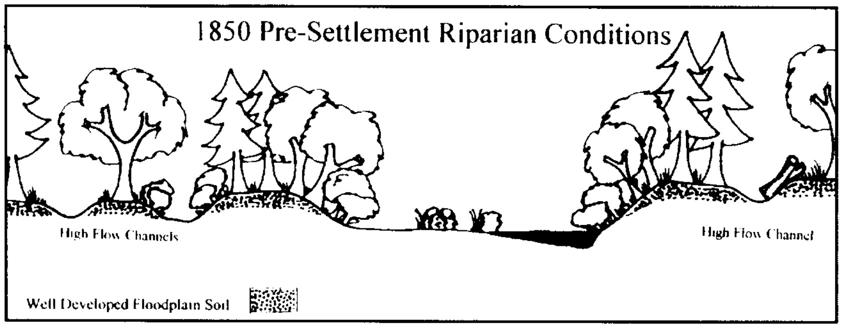
Land use practices within the Applegate basin increase sediment loads while vegetative clearing undermines bank stability. As a result, increased flood energy scours riparian environments, and bank erosion leads to channel widening and increased sediment yields. Under such conditions, low gradient reaches commonly aggrade with upland or stream bank sediment, and increased bedload initiates stream braiding and channel widening (Kondolf and Curry 1986). Changes in channel width, however, vary drastically between Applegate and Murphy, and select sites maintain widths similar to historical values, while several low gradient reaches have widened by over 100%.

Substrate

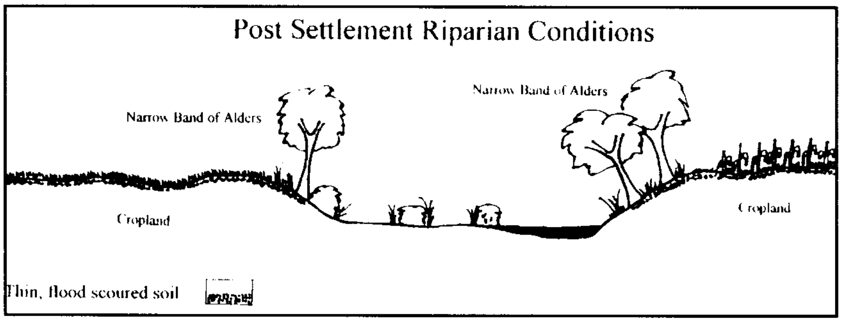
Historical photos and early explorers' diaries attest to large quantities of unconsolidated cobble and gravel within the active channel of the lower Applegate (S.O.H.S. photos 1998, LaLande 1987). Photos display stratified deposits of gravel throughout the upper and lower reaches of the river. A variety of substrate size classes, from cobble to small gravel, appear along stream margins and in depositional areas. Substrate looks clean and mobile, and in contrast to today, large deposits of silt and sand are not represented in the historical record.

Large gravel deposits appear more abundant in the river channel above Ruch today than in historical photographs, and reworked mine tailings, unstable tributaries, and in-stream aggregate operations appear to overload the mainstem river with large substrate today. Streams such as Palmer Creek, the Little Applegate, and Beaver Creek aggraded with mining sediment historically, and today unstable terraces and perched stream confluences suggest that mining substrate is still entering the mainstem river. A great deal of this

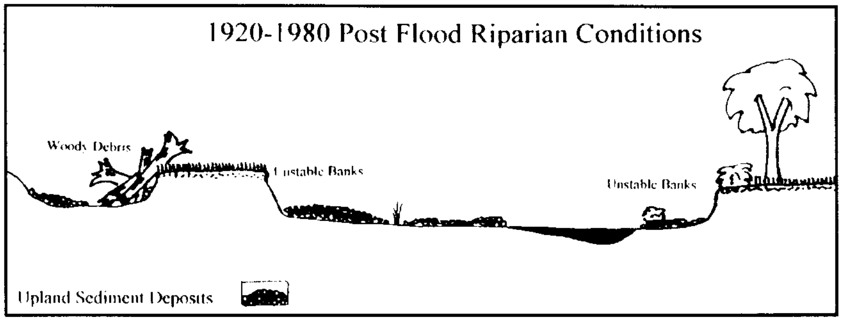
Figure 10


1850 Pre-Settlement Riparian Conditions

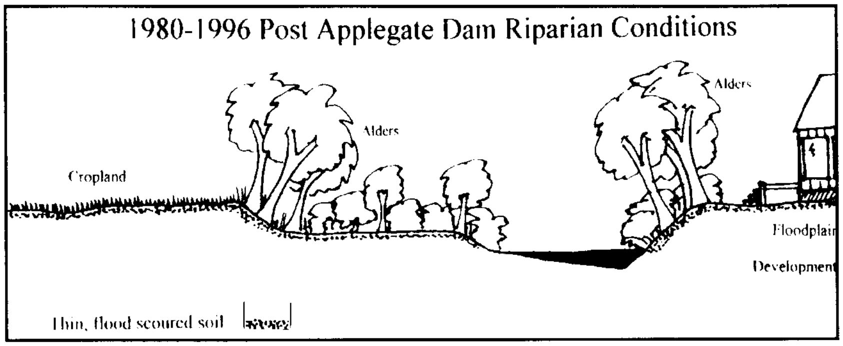
Thick riparian vegetation stabilizes banks. Mature trees stabilize the floodplain environment, and numerous high-flow channels exist to convey floodwaters. Floodplain soil is stable and fertile. High flows spread out over the floodplain, while vegetation and flood channels dissipate flood energy.


Post Settlement Riparian Conditions

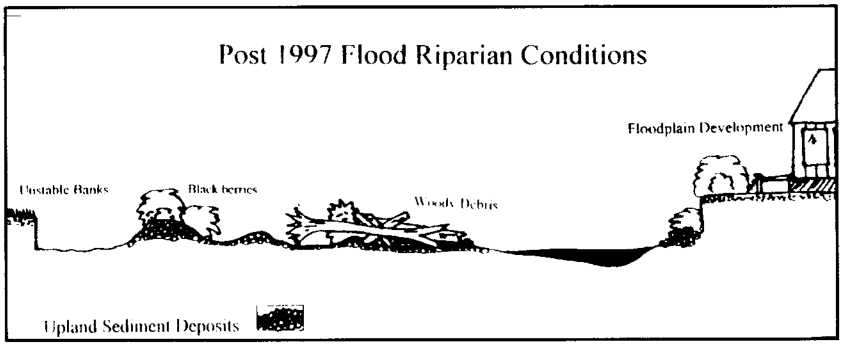
Mature floodplain vegetation has been cleared to establish crops and pasture land. High-flow channels are filled in or cultivated, and natural stream processes reduce riparian vegetation to a thin strip. Moderate floods erode floodplain soils and increase channel width.


1920-1980 Post Flood Riparian Conditions

Without high-flow channels, floodwater storage areas, and mature vegetation, flood energy is no longer dissipated. As a result, stream banks erode and widen, and floods remove soil and vegetation from the floodplain. Private lands are devastated.

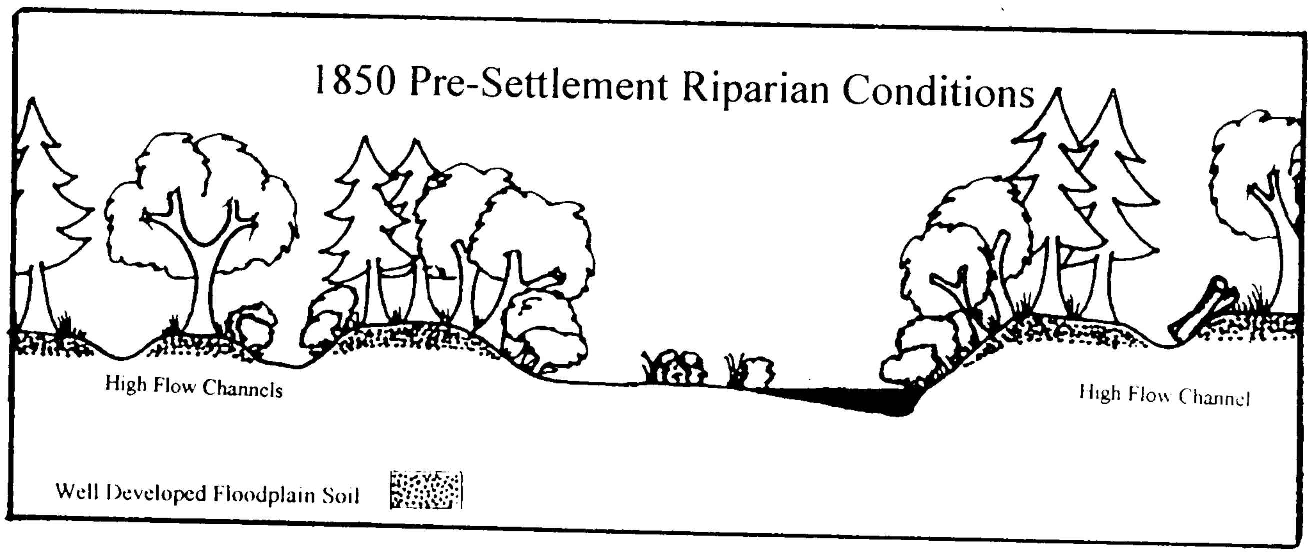

1980-1996 Post Applegate Dam Riparian Conditions

Applegate Dam reduces high flows. Vegetation and humans colonize floodway areas, and increasing amounts of vegetation and sediment occupy the active channel, reducing channel capacity. Human floodplain encroachment further reduces floodwater storage areas.

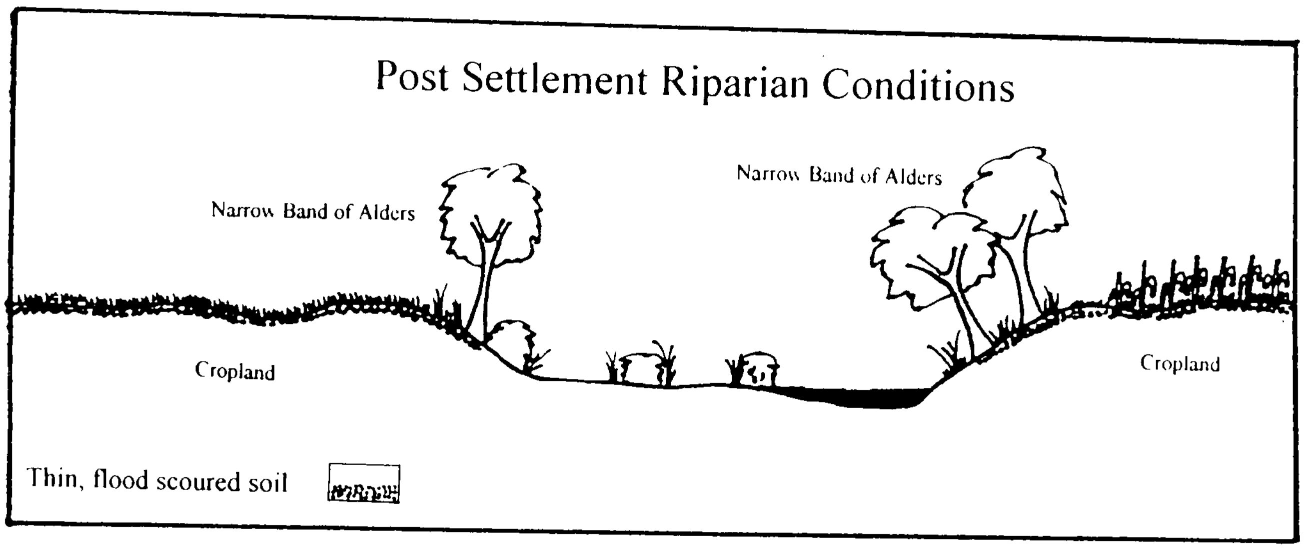

Post 1997 Flood Riparian Conditions

15-20 year floods devastate the lower river floodplain and stream channel. Floods seek out relict channels and floodwater storage sites. These features no longer function, and floods now scour away valuable agricultural land. Little vegetation remains to stabilize floodplain soils. A dynamic unstable channel results.

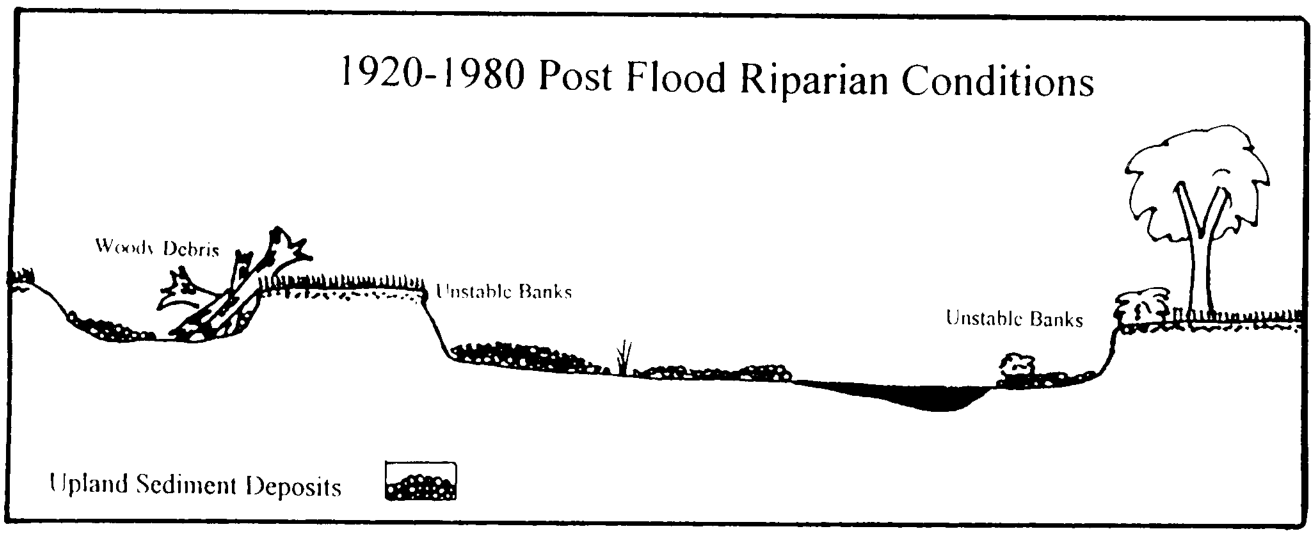
Applegate River Channel Evolution 1850-1997



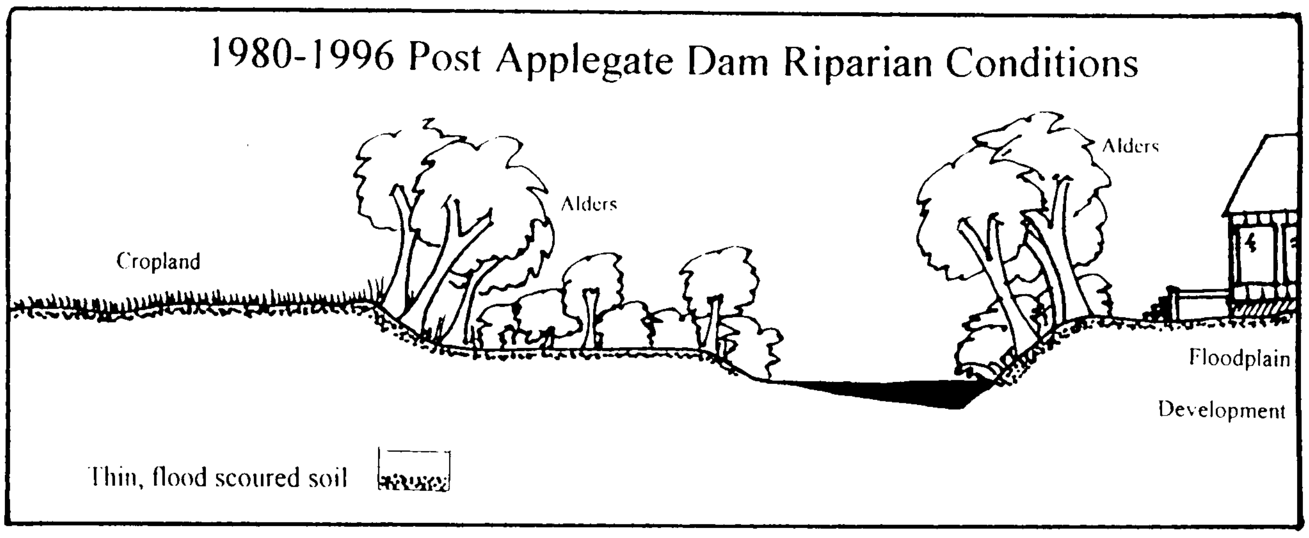
1.) Thick riparian vegetation stabilizes banks along channel margins. Mature trees stabilize the floodplain environment, and numerous high-flow, flood relief channels exist to convey floodwaters. Floodplain soil is fertile and stable. High flows spread out over the floodplain, while vegetation and flood channels dissipate flood energy.



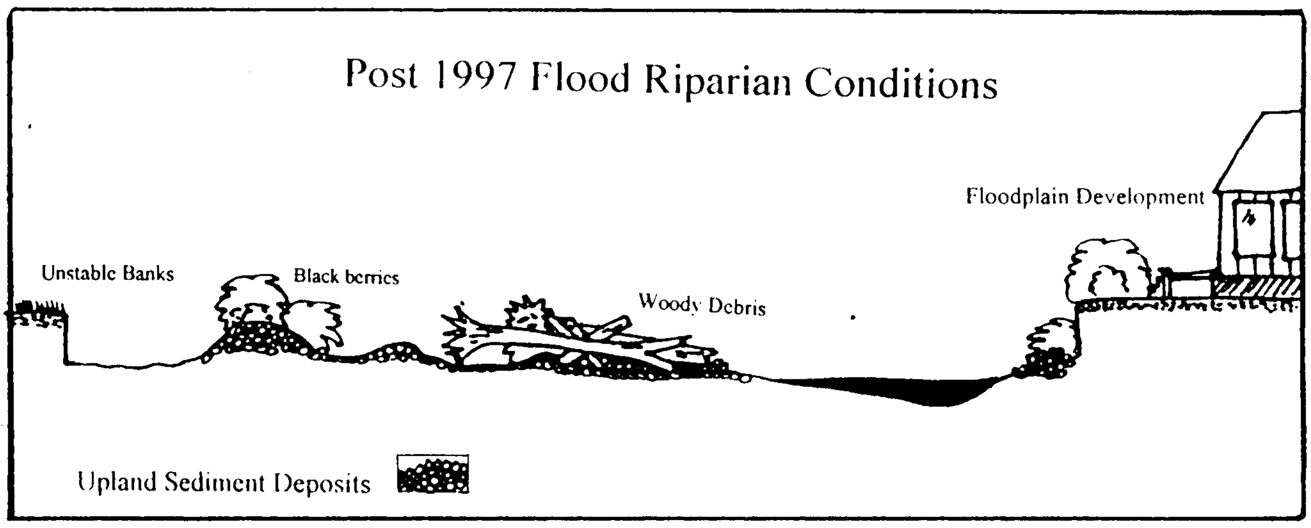
2.) Mature floodplain vegetation has been cleared to establish crops and pasture land. High-flow flood relief channels are filled in or cultivated, and natural stream processes begin to reduce the remaining riparian vegetation to a thin strip. Moderate floods erode floodplain soils and increase channel width.



3.) High flow channels no longer convey excess floodwater, floodwater storage areas are absent, levee systems and channel straightening concentrate flood energy, and vegetation no longer dissipates floodwater energy. As a result, stream banks erode and widen, and floods remove streamside vegetation from stream margins. Valuable agricultural land is scoured and washed away, and in places, river channels isolate private lands and impede landowner access. Additionally, active sediment sources increase sediment loads and fill in low gradient areas--this leads to further channel instability and widening.



4.) Applegate Dam reduces high flows. Vegetation and humans begin to colonize historically inundated floodplain and stream channel areas. Vegetation traps sediment and remains in place throughout dam-reduced peak flows. Increasing amounts of vegetation and sediment in the main channel reduce channel capacity, while floodplain encroachment further reduces available floodwater storage sites.



5.) 15-20 year floods devastate the lower river floodplain and stream channel. Increases in floodplain land use reduce the area available for floodwater storage and transport. 1997 floodwaters encounter reduced channel capacity and seek out relict flood relief channels and floodwater storage sites. These features no longer exist, and as a result floodwaters scour valuable agricultural land. Little vegetation remains in place to stabilize floodplain soil, and upland sediment fills in lower river areas with silt and sand. A dynamic, unstable channel results.

substrate and sediment was absent prior to 1850, and it is likely that much of the fine sediment originally contained within mining deposits has been flushed out and deposited along the lower river

Off-Channel Features

While a stable main channel characterized much of the lower Applegate historically, well-established off-channel sloughs, alcoves, and side channels were also common between Applegate and Murphy throughout early settlement history (Diller 1914). A 1904 U.S.G.S. survey, for example, points to several stable multiple channel complexes near river mile 15, and 1855 Donation Land Claim (D.L.C.) surveys document stable, well-vegetated side-channel units both near Murphy and Applegate. Furthermore, historical photos show additional, well-vegetated off-channel reaches near Murphy (Josephine Historical Archives, 1998). In all, Diller (1914) and (D.L.C.) records document 8-9 stable multiple channel areas between River Mile 0 and 25 on the Applegate River.

D.L.C. surveyors recorded mature vegetation, including trees measuring from 10-18" in diameter, both along side-channels and on river islands, and extrapolation from the D.L.C. surveys indicates that, on average, 1.25 multiple channel sections per river mile were present on D.L.C. lands in the mid 1800's. Furthermore, county tax lot maps from the 1950's document 7 historically stable alcoves or large sloughs within the Applegate-Murphy reach.

1855 Surveyors followed a large (20-30,000 CFS) 1853 flood by only 2 years, yet they found mature trees both on islands and along the active river channel. These trees stabilized historical off-channel alcoves, sloughs, and side channels. Today, however, only two years after the 1997 flood, nearly all islands along the lower Applegate are void of large woody vegetation, and many areas along stream banks are void of both soil and mature vegetation. Off-channel areas today lack stabilizing vegetation and are often unstable, transient features.

Alcove and slough off-channel units linked the mainstem river with former channels in many locations throughout the past. Subsequent large floods, river flow regulation, levee construction, and land use encroachment, however, appear to have disconnected or removed many of these stream features. Today, for example, few relict channels or meander scars remain a part of the Applegate River system. Dammed flow regulation, in particular, reduces seasonal high flows, which created and maintained many of these off-channel features historically. Additionally, increased sediment budgets and loss of floodplain and riparian vegetation may have destabilized many off-channel features and allowed floodwaters to restructure off-channel units. And finally, riverside landowners continue to fill and cultivate high-flow channels even today.

Following large 1955, 1964, and 1974 floods, government sponsored levee projects proliferated along the lower Applegate River. These projects isolated the lower river from natural floodplain processes, and 1950s county tax lot maps document stable off-channel features that no longer exist today.

Wetlands

While little empirical evidence of wetlands exists for the lower Applegate River, anecdotal and historical sources attest to numerous surface depressions (former channels), which maintained water throughout all or part of the year. Furthermore, beaver populations between Applegate and Murphy were reportedly large, and such populations would have maintained wetlands which are absent today (Pullen 1995). Extensive beaver populations and wetland areas were also located near the mouth of the Applegate, and documented swampland areas below the mouth suggest that wetland sites may have been common throughout the lower Applegate as well (Harrington, in Pullen 1995).

1939 air photographs show scant evidence of remaining wetland areas, yet the high water table along the lower river floodplain and the abundance of relict channels suggest that floodplain areas may have remained inundated throughout pre-settlement winter months. Interestingly, anecdotal sources indicate that irrigation practices raised the summer water table along parts of the Applegate floodplain, and as a result several seasonal wetland areas began to fill with water year-round in the wake of improved irrigation techiques. Photographic comparisons may support this observation as 12 wetland meander scars are present in 1997, compared with only 3 in 1938 photos.

Islands

Further evidence of channel destabilization and complexity loss is offered by the reduction of stable islands within the lower Applegate River. 1939 air photos, for example, show 22 islands with stable woody vegetation between Applegate and Murphy. Subsequent aerial photos, however, from 1959-1974 display between only two and three such islands.

Intra-channel Islands with stable Woody Vegetation Applegate-Murphy				
1939	1957	1965	1974	1996
22	2	2	3	6-10

Data collected from 1939-1996 aerial photographs

Figure 11

In place of islands, later photos show increased channelization, levee construction, gravel extraction, and floodplain encroachment. 1996 aerial photos depict between six and ten stable island complexes and suggest that dam operations reduced flooding and allowed vegetation to colonize and stabilize several new islands prior to the 1997 flood (Figure 11).

Indeed, the loss of stable islands further illustrates the lack of stability along the lower river. Personal accounts attest to numerous well vegetated islands within the river throughout the early 1900's, yet channelization, high sediment loads, increased flood energy, and reduced bank stability throughout the 1900's appear to have eliminated island vegetation and destabilized island complexes.

Natural episodic change within a river system is common, and natural processes often produce changes in downstream river geomorphology. On the Applegate, however, shifting, unvegetated islands and bars have replaced many of the stable, well vegetated islands present in early historical photos--historical records suggest that these features are the result of human land use practices rather than natural causes (personal accounts, photos, Dunne *et al.* 1978, U.S.D.A. 1970).

Stable islands within the Applegate played several significant roles along the lower river. Importantly, islands slowed and diffused floodwater energy. They also accumulated sediment, and in many cases hydraulic conditions along island shoals may have contributed to spawning gravel deposition (Ligon *et al.* 1995). Moreover, islands collected large wood which further contributed to aquatic habitat complexity and flood energy dissipation.

Although the 1939-1996 aerial photo sequence shows a 55% reduction in stable islands, the period following the closure of Applegate dam (1980-1996) clearly displays vegetative stabilization of shifting bars and islands within the lower river. Thus, with the flood reduction downstream of Applegate dam, shifting, unvegetated islands appear to stabilize with vegetation (Williams and Wolman 1984). Large floods, however, which occur even with dam operations, bring pulses of sediment and erode unvegetated portions of the lower river. These large events continue to mobilize island sediment and restructure the lower Applegate channel. The 1996-1997 aerial photo series clearly illustrates this process--Applegate dam initiated vegetative colonization of islands and bars throughout the lower river by reducing seasonal high flows, and the 1997 flood reversed this trend, as floodwaters stripped vegetation, remobilizing large bodies of sediment.

Flood Relief Channels

High-flow flood relief channels have been systematically removed from the lower Applegate River. Historical aerial photos and personal accounts show numerous high flow channels within the Applegate valley, and 1939 photos clearly display inactive channels alongside the main stem Applegate during low-flow periods. 34 sites, in fact, between Applegate and Murphy maintained high-flow channels in 1939. By 1996, however, only roughly 13 such high water complexes remained. 1939 photographs show well-established vegetation along many such flood relief channels, and D.L.C. and G.L.O. reports document well-developed soils and mature trees along river margins prior to mining and settlement. Consequently, well vegetated, off-channel and high-flow stream channel features must have been relatively stable prior to European settlement.

High-flow channels allowed large floods to spread out across the floodplain and provided stable channels through which floodwaters passed without instigating widespread erosion. Mature riparian vegetation maintained channel stability and dissipated floodwater energy during high flow events. Importantly, flood relief channels provided complex winter habitat and high flow velocity refuge for lower river fish.

Throughout this century, available floodwater storage sites and the number of high flow channels has been drastically reduced. In places where the lower river floodplain was undeveloped in 1939, aerial photographs display at least an 70% reduction in stable floodplain sites capable of conveying and dissipating floodwater without widespread soil loss (Figure 12, following page). Where mature vegetation is lacking today, soil loss and erosion typify the floodplain environment.

Low Gradient Reaches

Sites near Moore Bar (RM 15) contain the lowest gradient sections of the study reach, and low gradient areas of the Applegate appear to have maintained perennial multiple channel complexes historically (U.S.G.S. 1908, B.L.M. aerial photographs 1939, Diller 1914). Furthermore, multiple channel, low gradient reaches such as Moore Bar promote stream meandering and large woody debris retention, and low gradient reaches in the Applegate probably provided some of the most complex and valuable stream habitat on the mainstem river. Wood aggregates stabilized island and multiple channel complexes along the lower river historically, and debris jams likely diverted stream flow into side channel areas and stabilized islands and banks from erosion (Reeves, Hall, Roelofs, Hickman, and Baker 1991; Krouse 1998). Moreover, unconsolidated gravel deposits, common in low gradient areas, probably facilitated stream scouring near meander bends and woody debris aggregates. As a result, low gradient depositional areas in the Applegate historically maintained multiple channel sections (U.S.G.S. 1954) and large wood aggregates (Pullen 1995). These stream characteristics, in turn, contributed to complex riffle/pool habitat maintenance (Reeves *et al.* 1991).

Multiple-channel low gradient areas are prime sites for gravel deposition, and aggregate extraction occurs among many formerly complex low-gradient stream environments within the Applegate today. Unfortunately, most aggregate mining areas in the Applegate currently exhibit braided stream characteristics and lack stream complexity. Furthermore, stabilizing vegetation is frequently absent from gravel extraction sites, and the lack of vegetation combines with instream excavation to induce channel instability. Moreover, the locally focused gravel mining, common on the Applegate today, will likely result in continued, long term channel adjustment both above and below present mining sites (Kondolf and Larson 1995).

Floodplain tributaries:

Tributary streams that flow across the Applegate floodplain contribute sediment, water, and valuable aquatic habitat to the lower river environment. Unfortunately, floodplain tributary courses have been reconfigured throughout history, and tributary functions today are impaired by land use activities. 1857 government land office surveys and more recent historical air photos, for example, suggest that Slagle Creek once flowed parallel to the mainstem Applegate for roughly one kilometer. Cheney Creek also followed this trend, and 1940's aerial photographs display lower Cheney Creek flowing parallel to the

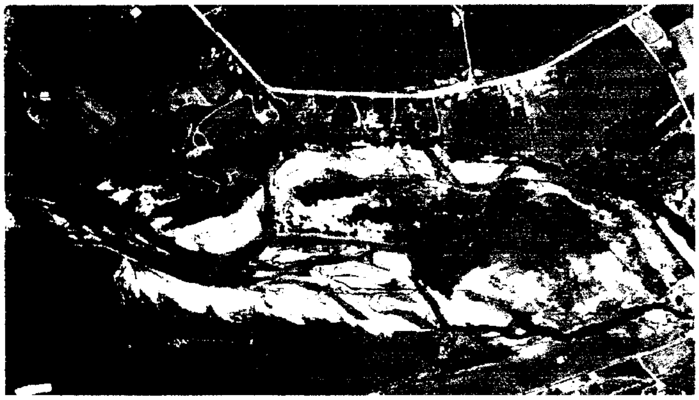
Figure 12
Applegate River Channel Evolution 1939-1997

Historical 1939 Photograph

A wide, well-vegetated floodplain area with numerous high-flow channels existed at this site in 1939. Riparian vegetation stabilized stream banks and mature trees stabilized the floodplain environment. When high flows occur, vegetation and high-flow channels will dissipate flood energy and distribute flows across the floodplain surface. Moreover, mature vegetation stabilizes channel positions and reduces widespread channel relocation during floods.
Sinnuosity=1.16

Pre-flood 1996 Aerial Photograph

Floodplain encroachment and development have reduced the river's ability to both store and transport floodwater in this photograph. Most mature vegetation has been removed at this point, and mature floodplain vegetation has been replaced by cropland. In addition, channelization and encroachment have straightened the river channel.
Sinnuosity=1.01



Post-Flood 1997 Aerial Photograph

A 15-20 year flood has devastated the floodplain environment, and only areas with mature trees remain intact. During floods, the river occupies an area equal to the forested area in the 1939 photograph. Where trees were cleared to increase arable acreage, floodwaters strip away valuable land. In addition, the lack of stable floodplain vegetation has allowed the river to carve a new channel, creating an island. This denies landowner access to agricultural land.
Sinnuosity=1.17

Applegate for roughly one kilometer as well. Historically, both Cheney and Slagle Creek meandered along the Applegate floodplain, and these low gradient reaches provided an ideal gradient for fish spawning and rearing. Importantly, the low gradient, meandering channel system present along the lower reaches of many Applegate tributaries offered an ideal setting for beaver activity and large wood deposition (Pullen 1995). As a result, these sites may have maintained complex aquatic habitat, including beaver ponds, side-channels, and large woody debris aggregates.

Unfortunately, human land use activities have shortened and straightened the lower reaches of many tributaries, including both Slagle and Cheney Creek. Cheney Creek and Slagle Creek, for example, have lost approximately 80% of their original floodplain channel length, and they now flow directly to the Applegate. This shortening and straightening of Applegate floodplain tributaries has destabilized stream reaches and reduced available fish habitat. Furthermore, crucial low velocity juvenile rearing and adult spawning habitat, once present in tributary streams along the lower Applegate River, has been lost. In addition, many lower river tributaries contain fish passage barriers and no longer facilitate salmonid success.

Vegetation

The Riparian Zone

Extensive and diverse riparian vegetation typified stream margins along the majority of the Applegate river historically, and historical photographs display several important zones of riparian vegetation (Figure 13): In zone (A), numerous river reaches exhibited vegetation growing within the active river channel. During low summer flows or long term drought sequences, riparian vegetation appears to have colonized parts of the river channel bottom. Shrubs within the active channel provided shade, cover, and velocity refuge for juvenile fish throughout the lower river. Furthermore, in-stream vegetation traps sediment and can eventually lead to the formation of relatively stable, vegetated islands. Such islands or bars, then trap woody debris and can develop into well treed, complex habitat

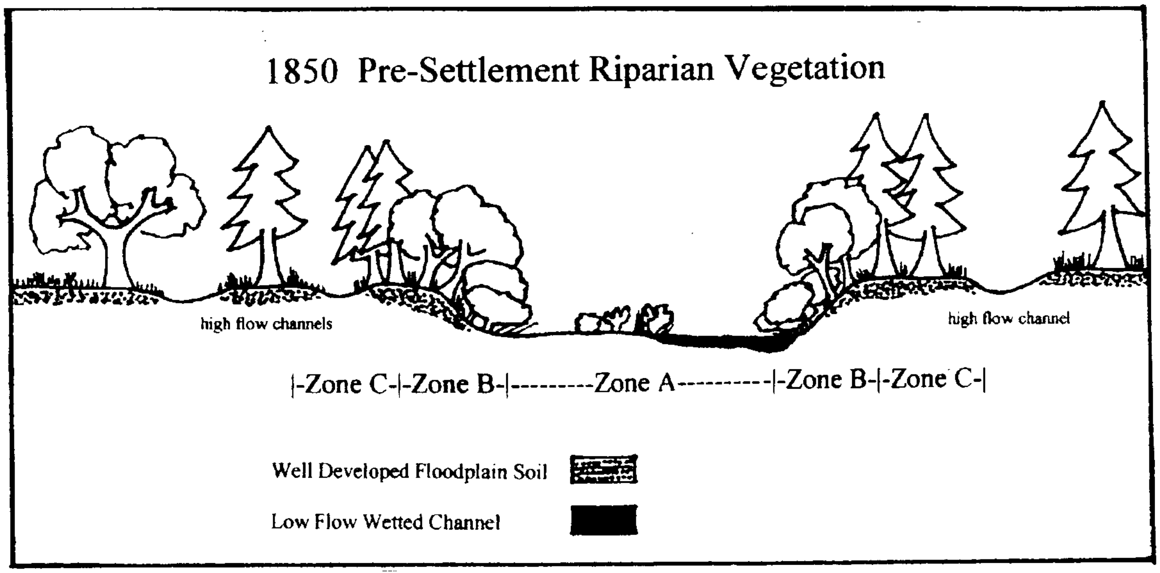


Figure 13

units. The development of instream vegetation, however, relies upon low stream flows or drought periods; Applegate dam increases summer low flows and likely inhibits this natural process today. Zone (B) represents the riparian area along the wetted margin of the Applegate. This zone was densely vegetated by hardwood and shrub species, including alder, willows, and cottonwoods (Pullen 1995, GLO 1855, DLC 1855). Nearly all historical photos, in fact, display thick, overhanging vegetation, and in many examples limbs or stems of streamside vegetation are under water. This band of very dense streamside vegetation extended for approximately 20' on both sides of the river, along most lower river reaches. Pullen (1995) suggests that the drier, south facing, north bank maintained less dense riparian vegetation than the opposing bank, but historical photographs indicate that both banks were densely vegetated. Adjacent to the zone (B) hardwoods, a band of mature conifers (zone C) appears in nearly all historical photographs. These conifers parallel the river channel and appear just above the zone of seasonal inundation (see Figure 13).

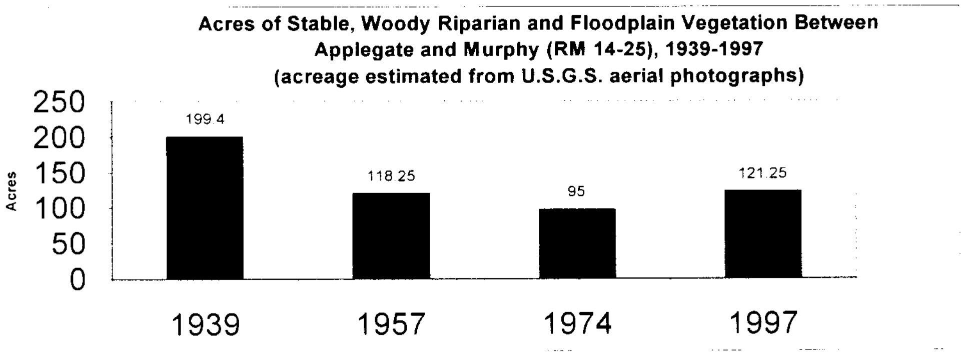
The three zones of vegetation listed above provided shade, cover for fish, a sediment and woody debris trap, and they dissipated and slowed flood waters. Additionally, pre-settlement riparian vegetation also offered substantial protection against bank erosion (Benner 1996). Mathews (1990), for example, suggests that dense riparian vegetation consolidates bank materials, armors banks from abrasive stream flow, and both reduces stream velocities and induces sediment deposition. In fact, bank sediment with 16-18% root reinforcement is up to 600 times more resistant to erosion than unvegetated material lacking root reinforcement (Gray and Leiser 1982). Interestingly, Rogue valley residents recognized this as early as 1890-- when The Ashland Tidings (1890) reported that streams in the Bear Creek Valley suffered significantly more bank erosion during 1890 floods than during previous floods, when bank vegetation remained intact.

Riparian vegetation on the Applegate is important for both fish and wildlife ecosystems and hydrologic stability. On rivers such as the Applegate, which appear to fluctuate between braided and single channel systems, maintenance of stream side vegetation is imperative to stream channel stability (Kondolf and Curry 1986).

Floodplain Vegetation

Early residents of the Applegate valley cleared large portions of land along the lower river floodplain. Settlers removed both hardwoods and conifers as they established open tracts of farm and ranch land. Initially, settlers maintained mature vegetation within the agricultural lands of the floodplain, yet by the early 1900's the majority of natural floodplain vegetation had been cleared from the lower Applegate Valley.

Figure 13.5



Acres of Stable, Woody Riparian and Floodplain Vegetation Between Applegate and Murphy (RM 14-25), 1939-1997 (acreage estimated from U.S.G.S. aerial photographs)

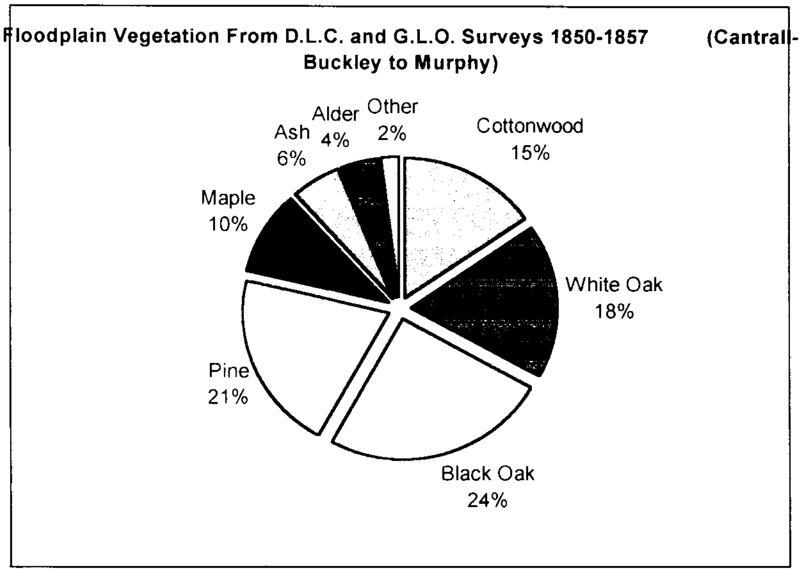
Between 1939 and 1957, roughly 80 acres of natural floodplain vegetation were cleared from floodplain areas. By 1960 large-scale agricultural clearing appears complete, and changes in the amount of undisturbed riparian and floodplain vegetation at this point are likely linked to aggregate operations and flood disturbances (Figure 13.5).

Historical Characteristics

Government surveyors recorded valley bottom vegetation characteristics in the 1850's and utilized existing natural vegetation to establish section boundary corners. As a result, historical survey records offer insight to the natural vegetation of the lower river floodplain environment.

Qualitative descriptions from government surveyors describe the Applegate-Murphy floodplain as a scattering of Pine and Oak, with Cottonwoods and other hardwoods along the river corridor. Detailed examination of survey records reveals that Cottonwood, Pine, Black Oak, and White Oak comprised over 75% of the floodplain tree species utilized for bearing trees (Figure 14).

Figure 14



Surveyors selected healthy, representative trees, which were close to survey corners, for bearing trees, and as a result, G.L.O. and D.L.C. vegetation information provides a valuable random sample of species and size information on the lower river floodplain (McKinley and Frank 1996).

Historical surveys also provide information on tree size and forest density. Surveyors measured, marked and identified four trees at every boundary corner and two additional trees at each quarter section increment. Consequently, surveyors cataloged over 73 trees along the river between Applegate-Murphy, and the diameter of these "bearing trees" averaged over 22". Because surveyors avoided young or very old trees (McKinley *et al.*

1996), 22" may be a relatively accurate evaluation of average tree diameter. In any case, survey data suggest that floodplain vegetation was stable and mature.

Sites near river mile 15, which today exhibit mainly exposed cobble bars and herbaceous vegetation, supported 48" diameter pines and mature Maples and Oaks in the 1850's. Additional sites near Provolt near River Mile 20 also exhibit unvegetated cobble environments today, yet this same area supported 18" diameter Cottonwoods historically (G.L.O. and D.L.C. surveys 1855-57).

Survey records, in fact, document a mature, stable open forest along most of the lower Applegate River floodplain. Surveyors found suitable bearing trees, on average, 87' from surveyed boundary corners, and this suggests that large floodplain trees were spaced, on average, no more than 120' apart. Floodplain and forest density varied with soils, microclimate, fire history, topography, and Native American land use, yet survey data document an open forest of mature pine and oak throughout the majority of the Applegate-Murphy reach.

Historical journal entries offer additional insight into floodplain vegetation characteristics. Ogden's 1827 journals, for example, evidence areas of "dry grass and stones," while other journal entries suggest open prairie like conditions (Pullen 1995). Dense thickets and areas of brush (Pullen 1995), however, also appear to have typified small portions of the lower Applegate floodplain historically, and densely wooded or brushy sites may have corresponded with wet areas that offered summer water resources and fire protection. Such sites could have been located among high-flow channels where moist conditions dominated throughout the year.

Nevertheless, little mention of understory vegetation exists in the historical record of the Applegate floodplain, and forest density and species composition suggest very frequent, low intensity fires within the floodplain environment (Agee 1993). Evidence, in fact, implies that the 1850's landscape lacked underbrush, and that native American burning maintained far more open grasslands than at present (Ashland Tidings 3/4/1892). Indeed, Native Americans may have burned the lower Applegate floodplain for a variety of reasons, and historical accounts of human caused fires in southern Oregon are substantial (LaLande 1995, Agee 1993). Regardless of the source, however, fire appears to have played a major role in reducing undergrowth on the lower river floodplain and promoting an open forest of fire resistant species.

Interestingly, McKinley *et al.* (1996) find that floodplain and riparian ponderosa pines were the largest trees in the Applegate basin historically. Shallow groundwater reserves may have alleviated drought stress, and the frequent, low intensity fires of the floodplain reduced fuel loads and insured the success of mature, fire resistant trees. Post settlement agricultural clearing altered this pattern, however, and presently the largest trees in the Applegate Basin are located at uppermost elevations (McKinley *et al.* 1996).

Frequent, low intensity fires and a stable channel network prevented large-scale disturbance on the lower river floodplain historically, and large trees dominated the floodplain environment. Today, however, erosion and channel relocation typify the lower Applegate, and large diameter trees are rare along the river banks. Flood magnitude and frequency have not changed, but floodplain and stream channel stability has declined while floodplain and streambank erosion has increased.

Surveyors also documented cottonwoods and other hardwoods along the lower Applegate River, and wet areas adjacent to the stream channel dampened fire activity among cottonwood/alder environments. Consequently, frequent low intensity fires appear to have maintained the scattered forest of Pine and Oak on the floodplain, while the damp riparian corridor allowed the dense growth of other, less fire tolerant species.

The onset of European settlement in the Applegate valley changed this floodplain vegetation pattern. Both passive and active fire suppression reduced fire frequency along the lower river, and as floodplain vegetation responded to fire regime changes, shrubby species and non-fire resistant trees invaded unsettled portions of the valley. Personal accounts relate that understory vegetation was common in the early 1900's, and settlers cleared undergrowth from the lower valley throughout this period (Foerst 1999, Young 1999).

Historically, much of the lower river floodplain maintained a mature, stable, open forest community. Furthermore, well-developed soils along meander bends were both common and productive (Lalande 1991, interviews 1999, McKinley et. al. 1996). All evidence, in fact, points toward floodplain and channel stability. Large floods were common prior to white settlement, yet early flood events do not appear to have devastated the lower river environment. Subsequent floods, however, have stripped soil and exposed bare cobble and gravel deposits. And as land use and settlement increased within the Applegate valley, flood damage became better documented, but damage also became more widespread. Currently floods devegetate islands and riparian areas which appear to have withstood the impact of large historical flood events.

Mature riparian and floodplain vegetation stabilized the lower river environment historically. Flood relief channels, alcoves, and side channels were more stable than at present, and floodwaters as well as channel shifts probably inundated ecologically complex, stable off-channel floodplain areas. Importantly, vegetation slowed floodwaters and stored excess sediment. Presently, high velocity floodwaters traverse across open farm and ranch land and create unstable channels, resulting in widespread erosion and long term instability.

The Role of Large Wood

Historical documents provide little information on large woody debris in the lower Applegate River. Several sources, however, offer insight into the presence, quantity, and function of large wood in the historical river channel. Pullen (1995), for example, states that large wood was very common in the Applegate riparian zone, and when pioneers first entered the Applegate area, large wood accumulations were documented among numerous high points of rock along the river (Mail Tribune, 1927).

Examples of historical woody deposits provide evidence of large flood events prior to European settlement, and the Mail Tribune reports that the 1927 flood removed and replaced wood aggregates that were present when early pioneers first entered the Applegate basin. Additional evidence of large wood within the lower river stems from early 1900's flood accounts which document large pieces of wood passing downstream and destroying early bridges (McKinley et. al. 1996). Post flood photographs from 1965 and 1975 also point to large amounts of wood within the Applegate system. Photos display upper tributary streams with at least one large diameter (> 1' diameter) log for every 10 meters of stream (Mail Tribune 1965). Additional post flood photos exhibit massive large (>6' height) wood jams in the upper river which contain more than 250 pieces of wood each (U.S.D.A. 1999), and personal accounts document large wood jams along the lower river as well (Krouse 1999).

Clearly, large quantities of wood moved through the Applegate system historically. 1997 photos of Applegate dam, in fact, show immense quantities of woody debris trapped behind the dam. This wood, which moved downstream with a large flood pulse, no longer contributes to the natural hydrologic system of the lower river. Importantly, low water bridges along the middle Applegate also trap large amounts of woody debris and further reduce the flow of large wood throughout the system. Also, current riparian conditions do not contribute large diameter trees to the Applegate because small diameter alders line the river in place of mature cottonwoods and pines. Moreover, the present riparian forest is less efficient at trapping and retaining passing woody debris than the pre-settlement riparian vegetation.

Within the Applegate-Murphy reach, stable riparian and floodplain vegetation likely trapped significant amounts of large wood during flood events (Benner 1988). Also, low gradient multiple channel reaches accumulated large wood deposits, while islands and multiple channel sections throughout the lower Applegate trapped and held large wood aggregates as well. Historical photos suggest that small, singular pieces of wood did not play a significant role along the lower Applegate River. Large flows probably flushed small wood pieces into aggregates or out of the basin, and evidence suggests that as stream size increases, only larger pieces and stable aggregates typically remain within the stream channel (Likens and Bilby 1982, Bilby and Ward, 1989).

Channelization, removal of riparian vegetation, loss of off-channel units, the closure of Applegate dam, and active large wood removal all serve to reduce the amount of large wood in the lower river today.

Historically, wood influenced channel morphology, sediment loads, organic matter retention, and ecological productivity (Bilby et. al. 1989). Wood conglomerates trapped sediment in the upper and lower river and helped form islands and shoals (Benner 1988). In fact, studies show that woody debris in forested Oregon streams can store as much as

1.92m^2 of sediment per meter of stream (Swanson and Lienkaemper 1978). Wood jams also likely diverted water into side-channels and helped dissipate floodwater energy (Reeves et al.1991). In addition, large wood groups in the upper river channels probably served to slow and store flood waters and may have worked to decrease peak flows down stream (Benner 1988). Moreover, pool scours around large wood groups offer cover, velocity refuge, and complex habitat for both adult and juvenile fish.

Sediment Changes Within the Lower River

Human land use activities create river sediment loads in excess of historical levels, and increased sediment loads in the Applegate stem from several major upland sources. Historical mining practices, upland grazing, vegetative clearing, and road building combine to introduce massive amounts of sediment to the main stem river channel. Much of this sediment is then deposited wherever stream energy decreases. The Applegate-Murphy reach maintains several low-gradient (<.03 slope) depositional areas where large amounts of upland sediment are stored.

Sediment loads in the Applegate basin naturally run high (Applegate River Assessment 1995). Yet, historical sediment loads appear to have been minute compared with post settlement sediment inputs (U.S.D.A 1970). Evidence of the pre-1850's sediment load, however, is minimal, and any attempt to quantify pre-settlement sediment levels will require geologic field studies. Nonetheless, several vague historical references may suggest that fine sediment was less abundant historically than it is today. Peter Ogden Skene, for example, traversed the banks of the Applegate in 1827 and repeatedly noted the stones which lined both sides of the river from Murphy to the upper Applegate (LaLande 1987). Ogden, however, fails to mention the sand deposits that characterize much of the lower river today in his diaries. Furthermore, turn of the century photographs do not show the massive deposits of sand that characterize much of the lower river today. Additionally, government surveyors evaluated agricultural potential along the lower Applegate and do not mention sandy soils, and anecdotal accounts recount fewer sand or small gravel bars and shoals historically (Weatherby 1999).

Today, in contrast, U.S.G.S. quad maps for the lower river display extensive sand deposits throughout the Applegate-Murphy reach. Reconnaissance reveals sand deposits both within the river channel and on the floodplain surface of the mainstem river and smaller tributary streams. Sand deposits along low gradient reaches are up to four feet deep, and extend for hundreds of meters in select low-gradient areas (ARWC 1998). Moreover, gravels between river mile 12-20 rest on sand deposits, and interstitial spaces are filled with sand. Photographs from upper Applegate tributaries in the 1960's provide significant evidence of an increased sediment budget and document massive amounts of sand mobilized by mining and logging practices (U.S.D.A. 1970).

Hydraulic mining sediment aggraded the river channel historically, and large volumes remain in the system today and affect river channel morphology. Recently constructed (~ last 100 years) gravel terraces and aggraded sediment deposits along the mouths of the Little Applegate, Palmer Creek, and Beaver Creek for example, indicate that sediment mobilized during 1800's mining operations remains in the basin today. This sediment continues to augment mainstem sediment loads.

Sheep and cattle grazing also instigated erosion and sedimentation, which continues to affect basin sediment loads. Between 1870 and 1920, for example, approximately 103,000 sheep and 7500 cattle grazed upland pastures in the Ashland resource area annually (Atzet and Wheeler 1982). Livestock devegetated grazing lands and compacted soils, and overgrazing often centered on stream corridors and mesic meadow environments. In extreme cases, unvegetated gullies 500' long, 15' across, and 8' deep display the legacy of historical grazing even today (Whitall 1994). Livestock mobilized large amounts of sediment, facilitated overland runoff, and instigated sediment sources which are still active. Importantly, grazing and devegetation of stream corridors and meadows served to further reduce upland floodwater storage potential.

Logging practices contribute large quantities of sediment to the mainstem Applegate as well. Tree clearing, road building, and skid trail and heavy equipment use mobilized sediment historically and continue to do so today. Although clear-cut areas revegetate, roads remain in place and both reduce infiltration rates and disrupt subsurface and surface water flows. Local increases in flood peaks, increased sediment loads, and reduced lag times reflect logging operations in the watershed today. Importantly, devegetation whether by humans or livestock can also reduce evapotranspiration and can increase slope susceptibility to mass movement (Dunne *et al.* 1978). Long-term slope instability, in turn, creates supplementary sediment sources.

In addition, Channel straightening combines with the activities listed above to increase floodwater energy and stream channel erosion. As a result, many of the tributaries in the Applegate have down-cut and created steep unstable slopes which contribute sediment to the main stem river. These incised creeks can remain unstable long after upslope sediment sources stabilize.

The low gradient alluvial valley reaches of the Applegate serve as a storage site for upland sediment. Low gradient reaches attracted human settlement because of the alluvial deposition which occurred here naturally, yet human induced sediment loads alter the lower river environment and elicit channel changes and instability today (Kondolf 1996). In fact, where sand and gravel sediment loads increase, rivers typically widen and take on braided characteristics with unstable, rapidly shifting channels and bars (Dunne *et al.* 1978). The addition of numerous mid channel bars, then, focuses stream energy to channel margins and initiates lateral scour even at moderate flows (Newton 1998). Furthermore, increased sediment loads and flood peaks between Applegate and Murphy will likely increase channel shifting, bank erosion, and the instability of bars throughout the future (Dunne *et al.* 1978).

Channel Relocation

Channel relocation and meander genesis are common features on all alluvial streams. The lower Applegate River provides no exception, and floods initiate large-scale channel relocation with associated soil loss and property damage. Meander scars between Applegate and Murphy suggest that the main Applegate channel has occupied many different positions across the floodplain, and post-settlement channel shifts of up to 1500 feet are well documented. 1850's government surveys, for example, document channel locations which evidence active channel relocation throughout settlement history. Nevertheless, survey evidence also suggests that the location of some reaches along the lower Applegate has not changed in over 150 years. Sites that maintain healthy floodplain vegetation, for instance, exhibit fewer channel shifts throughout the 1939-1997 air photo series. Sites lacking mature vegetation or maintaining active aggregate operations, in contrast, display major channel relocation during large floods.

Geologic evidence maintains that the margins of the Applegate floodplain have been stable for an extended period (Bowen 1969). Stable, older alluvial deposits (Qoa) exist along floodplain margins, while frequently reworked Quaternary alluvium (Qal) resides along the stream corridor. In fact, limited sediment core research documents 2300+ year old wood fragments in the stable floodplain margins. Indeed, this limited evidence may suggest that the current floodplain surface has remained relatively static for over 1,000 years. In any event, older alluvial deposits along floodplain margins remain undisturbed today, and recent channel relocations are limited to the alluvial zone (Qal) near the current active channel (Bowen 1969).

Nonetheless, avulsions within this Quaternary alluvial (Qal) zone have scoured topsoil, destroyed homes, and damaged valuable property throughout settlement history. Recent channel relocations, however, appear more frequent and destructive than pre-settlement shifts. Historically, numerous high flow channels were well vegetated, stable, and available to convey high flows. Large floods inundated the floodplain, yet as floodwaters receded, stable complex channel systems remained in place, and the river course returned to pre-existing channels. Settlers, however, cleared land and utilized high flow areas for agriculture and development, and as a result large areas which originally conveyed floodwaters are no longer stable. At present, events such as the 1997 flood traverse across an unstable floodplain and scour out new channels. When floodwaters recede, the few remaining stable, long-term channels may fill with sediment and destabilize. The frequency and extent of channel relocation may not have changed since the 1850's, but stable secondary channels no longer remain to convey high flows or accommodate channel shifts. The result, of course, leads to widespread erosion and chronic instability. The river simply has less room to flood today than it did prior to European settlement.

Effects of Applegate Dam

Applegate dam has numerous effects on the lower river environment, and dam induced changes in the flow regime indirectly and directly affect the Applegate-Murphy reach.

Flood Control

Applegate dam reduces the magnitude and frequency of small, frequent floods. Yet, its ability to reduce large (30,000+ CFS) floods appears minimal. A comparative review of flood flows at Copper and Applegate, for example, suggests that Applegate dam would not have reduced the 1955, 1964, or 1974 flood significantly (Figure 15).

Historical High Flows at Applegate and Copper

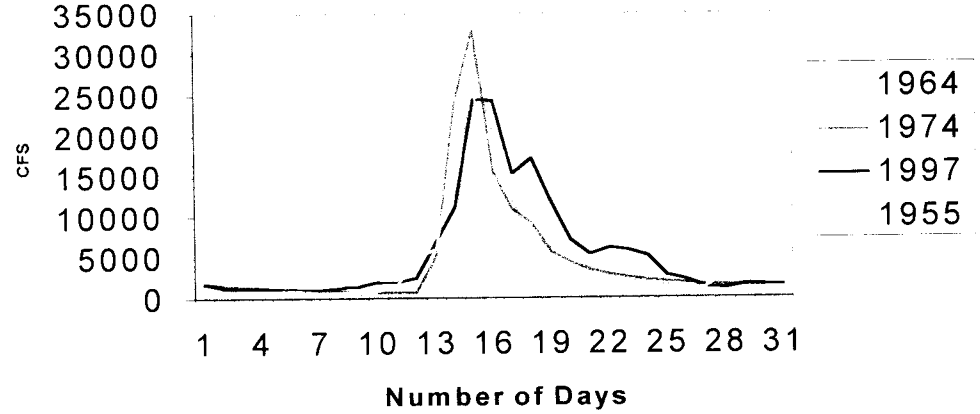
Gauging Station	1955	1964	1974	1997
CFS @ Copper	20,300	29,000	29,800	18,800
CFS @ Applegate	30,000	34,700	37,200	29,700

Figure 15

During large (34,000+ CFS) floods, U.S.G.S. Figures (1970) indicate that a dam induced flow reduction of 22-24% will decrease the innundated floodplain area by as little as 1-8%. Furthermore, calculations from over 20 cross section surveys between Provolt and Applegate suggest that Applegate dam would have reduced the 1964 flooded area by an average of only 6%. And while Applegate dam may reduce floodwater depth, 92-99% of the lands that were flooded historically should continue to flood (U.S.G.S. 1970).

Figure 16

Flood Hydrographs for Major Floods at Applegate



Note the receding limb of the 1997 flood; river levels remained above 5000 CFS for 8 days longer than any previous flood (see figure 17).

Moreover, Applegate dam's ability to buffer floods declines each year as sediment fills reservoir space. Presently, approximately 166 acre-feet of sediment reduces reservoir storage annually (Davidson 1999). As a result, even with Applegate dam in operation, flood damage in the Applegate valley will continue (Rogue Basin 1985).

Dam control alters the duration of high downstream flows, and applegate dam lowers peak flows but often maintains relatively high flows on the lower river for extended periods (Figure 16). A comparison of historic floods displays that Applegate dam maintained 1997 river levels above 5000 CFS for approximately 8 days longer than any other historical flood (Figure 17). Furthermore, during years of above average winter precipitation, Applegate dam appears to maintain discharges above 2500 CFS for 5-15 days longer than historical pre-dam conditions (Figure 18). By increasing the number of high flow days on the Applegate, streambanks may become saturated. This wetting of soil, in turn, can reduce the cohesion betweeen soil particles and induce streambank erosion (Wolman and Miller 1960). This process could then exacerbate lower river erosion, instability, and channel widening.

While the number of days during which high flows saturate stream banks is only slightly above normal, however, (Figures 16-18) this process by itself is unlikely to play a large role in lower river erosion. Nonetheless, increased bank saturation could accelerate bank failure and instability significantly where streambank vegetation is lacking.

Figure 17

Number of Days per Water Year With Stream Discharge Above Base Flow of 5000 CFS at Applegate Gauge; and Winter Precipitation Totals at Buncom Rain Gauge (in inches)

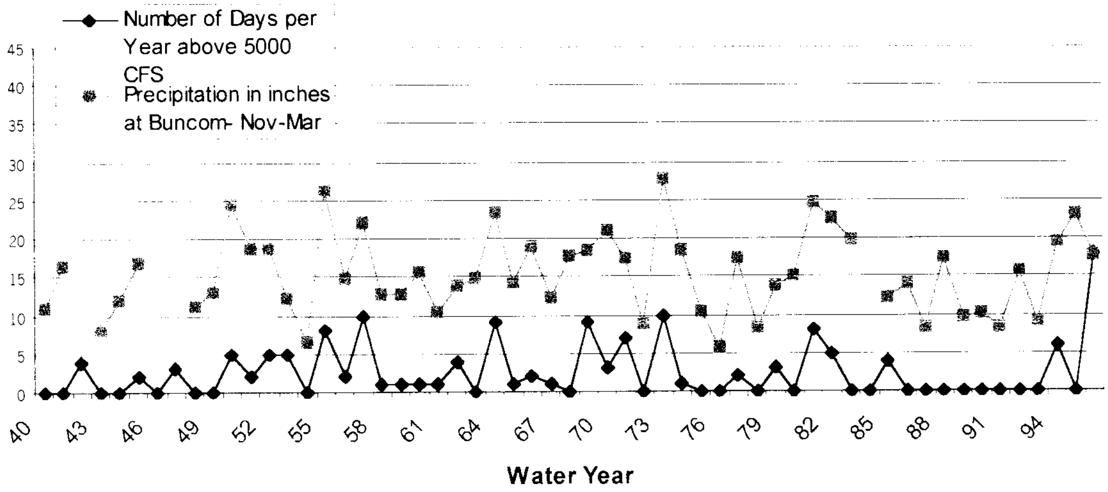
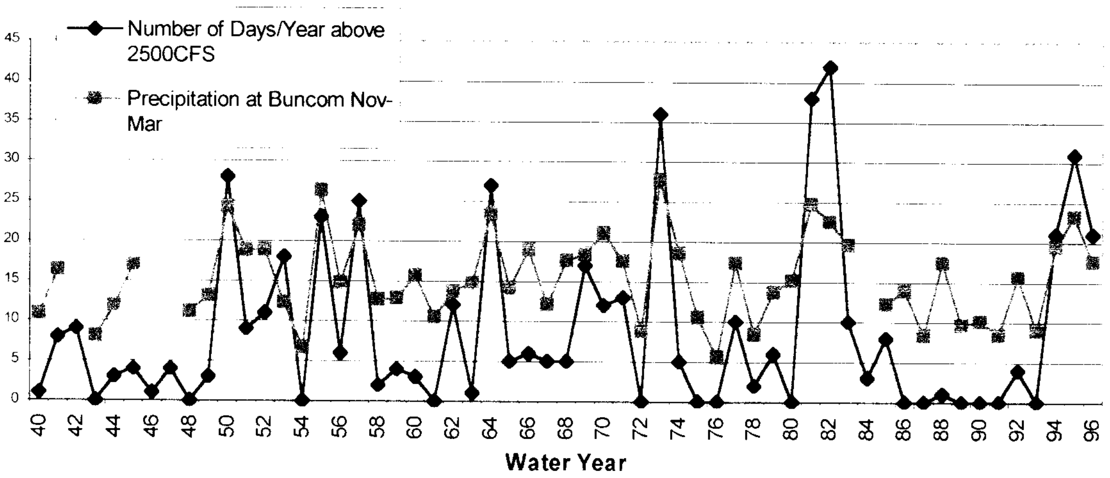


Figure 18
Number of Days/Water Year With Stream Discharge Above Base Flow of 2500 CFS at Applegate Gauge; and Winter Precipitation Totals at Buncom Rain Gauge (in inches)



Downstream channel change

While Applegate dam's abilities to reduce large floods prove minimal, its effects on the downstream environment are not. Applegate dam clearly reduces yearly flood peaks and increases summer flows. But, Applegate dam also disrupts the flow of sediment and wood throughout the river system. More than 93% of the sediment from the upper tributaries, in fact, settles out in the reservoir, and almost all above dam large woody debris is trapped behind the dam (Davidson 1998).

Dams initiate numerous long term changes in downstream environments, and a downstream reduction in channel capacity is the most common result of a large upstream dam scheme (Kondolf and Mathews 1990). A reduction in moderate magnitude floods on the Applegate, for instance, encourages vegetation to colonize bars, islands, and stream banks. In-stream vegetation, in turn, traps sediment and actively fills in channel margins--where additional vegetation can lead to significant channel narrowing. Increased channel roughness and a reduction in floodwater conveyance also commonly result throughout this process as thick riparian vegetation slows floodwaters. In addition, the desynchronization of tributary and mainstem sediment conveyance may also occur below large dams and can further reduce channel capacity (Kondolf et. al. 1990).

Additional change involves the loss of off-channel habitat units. With a reduction in high flows, the stream channel/floodplain connection is frequently lost. Without this floodplain connection, alcoves, sloughs, and side channels are unlikely to remain active along the lower river floodplain (Ligon *et al.* 1995). Indeed, off-channel features fill with debris, sediment, and vegetation, and dam released flows do not maintain overflow channels. This situation leads to a loss of complex riparian and aquatic habitat and further reduces flood conveyance capacity (Kondolf & Larson 1995; Johnson 1992).

Water released from dams possesses erosive energy in excess of normal stream water. This "hungry water," carries little sediment and commonly flushes sand and small gravel from downstream sites. Consequently, downstream environments can lose valuable spawning gravel to dam released water. This phenomenon greatly alters aquatic environments, as stream tractive forces remove smaller sand and gravel leaving only larger, immobile substrate. This process, however, remains undocumented on the Applegate.

Large dams reduce sediment loads and can help stabilize dynamic riparian environments (Kondolf *et al.* 1990, Williams *et al.* 1984). Over a short term, such stabilizing effects, produced by Applegate dam, could prove beneficial for the unstable lower Applegate floodplain, where high sediment loads and bank instability threaten private property. In the event of a 15-20 year flood, however, the stabilizing effects of Applegate dam may prove more harmful than beneficial to the lower Applegate Valley. Through channel narrowing, reduced cross sectional area, and increased hydraulic roughness, the river channel's ability to effectively convey floodwaters will decrease. This can then lead to increased flooding and erosion during large events. In fact, current land use trends combine with channel capacity reduction, the loss of seasonal high flow channels, floodplain de-vegetation, and a drastic reduction in available area for floodwater storage to insure that flood damage and erosion will continue with each large flood.

A reduction in channel capacity and floodwater conveyance followed the completion of Applegate dam, and the 1980-1997 time series aerial photographs, provide ample evidence of this process. From 1980-1996 photographs clearly show channel narrowing and vegetative colonization of stream margins. After 17 years of reduced flows, 1997 floodwaters encountered reduced channel capacity and were forced on to the unvegetated floodplain. Agricultural fields and residential property provided the overflow channel network as floods removed much of the newly established vegetation and scoured out both old and new flood relief channels. In the absence of another large flood, dam operations will again reduce channel capacity as vegetation recolonizes active channel margins. Landowners may also reduce stream channel capacity by diverting and filling channel scours from the1997 event. The next large flood will begin this entire process anew.

During the 1997 flood many Applegate Valley residents witnessed floodwaters that decimated 23 year old riparian vegetation. The consensus among numerous residents, in fact, was that no riparian vegetation could resist the force of a 15-20 year flood. Residents, however, were witnessing the removal of vegetation that had adapted to stream flows one half the size of normal yearly Applegate flows. Consequently, when Applegate dam was unable to reduce high flows in 1997, the river reoccupied its normal channel and removed any obstructing vegetation.

Levee Construction

The Applegate river has a long history of levee construction and use. Levees were present along the lower river in 1951 and were likely established in the wake of the 1927 flood (U.S.G.S. 1954). Subsequent levee construction efforts from the Army Corps of Engineers and private citizens established numerous additional levee systems following both the 1964 and 1974 floods. Several associated problems, however, accompanied levee construction on the Applegate. Large floods, for example, eroded levees and frequently inundated levee protected agricultural lands. Levees, in some cases, then acted as barriers, trapping flood waters on the floodplain or redirecting erosive stream flows across productive agricultural land. Furthermore, levee construction isolated flood water storage areas, and as a result water, which historically spread out across the floodplain, was forced to remain within the confined channel and increase downstream flooding. In fact, increased channel instability, downstream bank erosion, stream bed level change, and loss of habitat complexity are all common side effects of levee construction and channelization (Dunne *et al.* 1978).

The floods of 1964, 1974, and 1997 damaged Applegate levee systems extensively. Remaining levees now divert stream flows and impede natural floodplain processes. Furthermore, some remaining Applegate levees, in their current state of disrepair, serve little flood control purpose. Rather, they occupy floodplain area and can contribute to increased flood heights.

Episodic Change in the Applegate

Current conditions within the Applegate basin facilitate episodic channel change along the lower river. Mature vegetation is lacking from riparian corridors and floodplain areas, and while Applegate dam reduces moderate floods, it does little to reduce 20-year events. Additionally, the Applegate River now has active sediment sources as well as stored sediment loads far in excess of historical amounts. As a result, 10 to 20 year intervals of time will likely see the Applegate River in a readjustment phase. Sediment pulses will be stored, and vegetation will stabilize stream banks, bars, and islands against the moderate yearly event allowed by dam operations. With each large flood event, however, the episodic character of the Applegate River will reemerge. Temporarily stable sediment sources will remobilize, streamside vegetation will be cleared, and new channels will carve through floodplain areas. It remains unlikely that the lower Applegate river channel can permanently adjust to this combination of increased sediment loads, Applegate dam flow regulation, and large 15-20 year floods. Should conditions remain unchanged, the lower Applegate will not achieve equilibrium, and episodic channel change will continue to characterize the lower river.

If the historical flood record of the Applegate provides any evidence of future trends, large floods will continue to occur on a 15-20 year interval. Unfortunately, yearly Applegate dam flood reductions will only prepare the river channel for floods a fraction the size of the expected 15-20 year flood. The result, in many reaches, will see the Applegate's channel bounce from a narrow, single thread, stabilizing channel to a bedload dominated braided channel type.

Implications

While riparian conditions and floodplain land use certainly play important roles in shaping river function today, larger basin wide issues need to be addressed before lower river recovery is implemented. As sediment loads have been anthropically increased in the Applegate, attempts to restore pre-settlement channel conditions are unlikely to succeed unless upstream sediment sources are reduced (Kondolf and Larson 1995). Ultimately, increased sediment loads will continue to alter channel morphology and reduce channel stability (Sullivan *et al.* 1987). Applegate dam leads the effort to reduce upland sediment input, yet the effects of road building, grazing, mining, and logging among undammed tributaries will continue to elevate main stem sediment loads and will shape downstream channel morphology for years to come.

Applegate dam, by reducing moderate winter flows, will continue to encourage vegetative and human colonization of floodway areas, and the resulting channel capacity reduction will exacerbate future flooding. The establishment of vegetation along channel margins and likely flood overflow sites will stabilize sediment loads and channel location, and vegetative colonization of exposed braided sites should occur naturally when a sufficient interval between floods exists. Because flood energy has increased, however, any such revegetation process will require a substantial interval between large floods and a river wide attempt to restore floodwater storage paths and floodplain stability. Such an effort may require longer than average interval between floods and a basin-wide land use approach.

The 1997 flood created channels and flood storage areas large enough to contain a 30,000 CFS flood. If we attempt to reclaim 1997 flood channels or scoured lands, we will insure heavy flood damages again in the future. Furthermore, if Applegate Dam continues to reduce seasonal high flows, newly created flood channels will not be maintained, and future floods will prove destructive. Containing future floodwaters within levees will promote additional flood damage and channel instability along the lower river.

Summary

Flooding:

Many historical alterations to upland and riparian areas have led to increased flood damage and large-scale morphological channel changes within the study reach. Increased flood damage, for example, appears to stem largely from the loss of stable floodplain and riparian vegetation. Mature vegetation stabilized the main channel as well as important high-flow channels and floodwater storage sites historically, and the current lack of vegetation promotes channel widening, increased sediment loads, and stream channel instability. Importantly, floodplain encroachment has removed much of the area available for floodwater storage, and encroachment and vegetative clearing work together to remove high-flow channels and other stable off-channel units. Without these historical conveyors of floodwater, erosion and flood damage are likely to continue.

Increased sediment loads from historical land use practices, including grazing, road building, vegetative clearing, and mining continue to aggrade low gradient river reaches. In numerous cases, bedload deposition works to fill in active channels and promote lateral stream scour and channel instability. This process pushes channel morphology toward a braided stream character.

Levees and revetment projects also work to increase flood damage and reduce channel stability. Levees restrict natural floodplain processes and eliminate floodwater storage sites. Over time, this serves to increase downstream flooding and promote channel instability. Furthermore, levee systems in disrepair deflect floodwaters and can increase flooding and erosion.

The loss of large wood also affects river stability along the lower river. Wood is no longer available to trap sediment loads, diffuse flood energy, armor stream banks, or maintain off-channel areas. As a result sediment loads are very mobile, and channel stability is compromised.

Applegate dam reduces frequent high flows and encourages vegetative colonization of active channel areas. This process decreases channel capacity and can lead to increased flooding during large events. Moreover, the reduction in seasonal bankful discharge fails to maintain high-flow channels and backwater areas, and these sites are then no longer available to convey or store floodwaters. Additionally, dam flow regulation encourages floodplain encroachment as landowners seek to increase usable land among flood prone areas. Riparian and floodplain clearing then lead to increased erosion and soil loss, and in many instances, examples show vegetative clearing and increased agricultural land in the short term followed by an eventual net loss of land due to flood erosion.

Aggregate extraction induces channel instability as well. Instability commonly occurs both upstream and downstream from local excavations, and long-term channel adjustments often result. Particularly where large floods capture aggregate pits, the influx of bed load material promotes an unstable braided channel geometry.

Habitat Degradation:

Land use changes and dam operations also produce negative effects on aquatic species and stream habitat throughout the study reach.

Sedimentation, for example, drastically alters stream channel morphology and deposition of fine material reduces spawning success. Throughout this process, width: depth ratios increase, and channel exposure to solar heating increases. The resulting warm stream temperatures inhibit cold water fisheries.

The loss of mature riparian vegetation also appears to negatively affect fisheries success along the lower Applegate. Historically, dense streamside vegetation worked to reduce stream temperatures, provide in-stream cover, and maintain stream channel stability.

Many riparian areas, which lack mature vegetation today, promote high stream temperatures and fail to contribute wood or cover for habitat complexity.

The relative scarcity of woody debris in the river channel today directly reduces cover, habitat complexity, and off- channel habitat maintenance in low-gradient areas. Large wood in the stream system is necessary to provide habitat for fish and aquatic invertebrates, and without large wood, unstable sediment loads, channel instability, and simplified aquatic habitat characterize much of the lower river.

The systematic removal of off-channel rearing habitat and high velocity refuge sites has dramatically reduced the habitat complexity of the lower Applegate. Settlement pressures and land use activities have worked to remove alcoves, side channels, beaver dams, and other off-channel areas from the margins of the Applegate. The corresponding loss in habitat complexity likely plays a significant role in the reduction of salmonid rearing success.

Levee construction increases stream velocities and removes complex habitat. Channelized reaches become featureless river sections, and cover and velocity refuge do not exist within such reaches. Increased flood velocities denude riparian areas and erode channel banks, further degrading existing aquatic habitat.

Applegate Dam operations fail to maintain off-channel habitats along the lower river. As a result, winter and summer rearing habitat and high-flow refuge areas are no longer maintained for main stem rearing juvenile fish.

Moreover, aggregate extraction degrades complex low gradient environments along the lower river. Stable multiple channel sections are denuded, large wood is relocated, spawning gravel is excavated, and channel instability commonly results. As aggregate extraction typically focuses on low-gradient multiple channel sites, tremendous degradation to historically complex river reaches has resulted. Areas, which may have provided significant salmonid rearing habitat historically, maintain simplified, aquatic habitat today

Recommendations

Applegate Dam must pass seasonal flows of approximately 5000 CFS to retain a channel geometry capable of handling larger 15-20 year events. This process will also function to maintain complex aquatic habitat features and flood channels.

Overflow channels should not be filled in or cultivated in the aftermath of a flood. These channels should be allowed to function naturally, and they require mature riparian vegetation to maintain integrity during flood events.

Upland sediment loads must be reduced in order to reduce channel aggradation, avulsion and floodplain scour.

The lower river environment requires more mature vegetation to stabilize floodplain lands in the event of a flood. In places, riparian buffers need to be established or widened. Existing floodplain areas with mature woody vegetation should be preserved and expanded where possible.

In-stream aggregate operations affect floodplain stability and can degrade aquatic habitat. Aggregate extraction options that maintain channel stability during floods and improve habitat complexity need to be explored and implemented.

Disjointed and defunct levees do little to reduce flood damage, and they may actually increase flooding. Additionally, levee systems severely restrict natural flood processes and reduce flood conveyance capacity and habitat complexity. Wherever possible, levee removal options should be considered.

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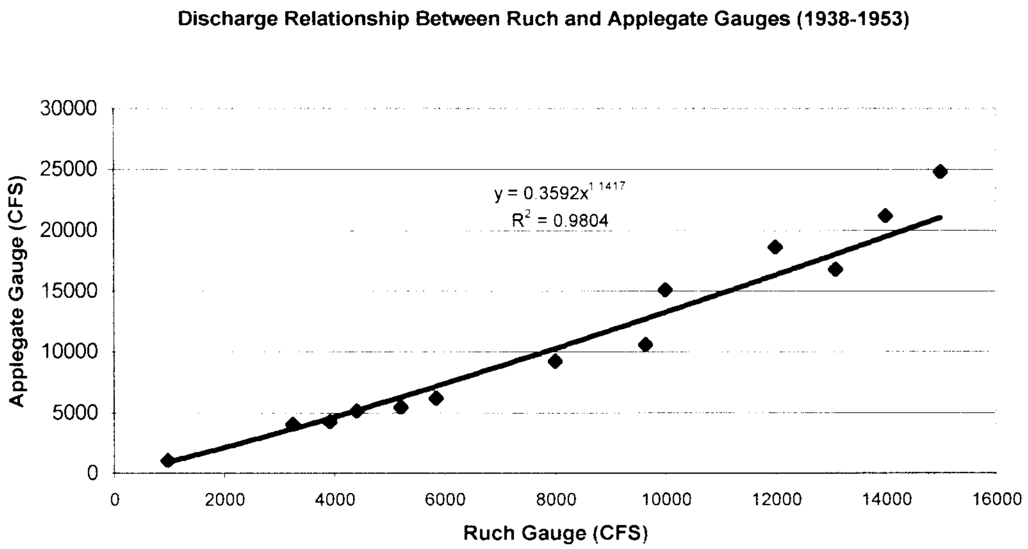
Appendix

1.



Discharge Relationship Between Ruch and Applegate Gauges (1938-1953)

Applegate River Channel Evolution 1939-1997

1939 Aerial Photograph

[illegible] well vegetated floodplain area and numerous high flow channels exist to convey and store excess floodwater. Thick riparian vegetation stabilizes banks along channel margins, and mature trees stabilize the floodplain environment. When high flows occur, vegetation and high flow channels dissipate flood energy and distribute flows across the floodplain surface. Moreover, mature vegetation stabilizes current channel positions and reduces widespread channel relocation. Erosion is minimal at this stage, and floodplain soils are stable and fertile.

Sinuosity = 1.16

1996 Aerial Photograph

Floodplain encroachment and development have reduced the river's capacity to both store and transport floodwater. Most mature vegetation has been removed, and native floodplain vegetation has been replaced by cropland. Channelization and encroachment have straightened the river channel.

Sinuosity = 1.01

1997 photograph

The 1997 flood devastated the lower river floodplain environment, and only floodplain areas with mature trees remained intact. During floods, the river occupies an area equal to the forested area in the 1939 photograph. Where trees are cleared to increase arable acreage, erosive floodwaters strip away valuable agricultural land. In many locations, a net loss of arable land follows tree clearing and floodplain encroachment efforts. In addition, the lack of stable floodplain vegetation has allowed the river to carve a new channel, creating an island. This denies landowner access to valuable agricultural land. Note that the river regained much of the sinuosity present in the 1939 photograph.

Sinuosity = 1.17