

# CHANNEL-DYNAMIC CONTROL ON THE ESTABLISHMENT OF RIPARIAN TREES AFTER LARGE FLOODS IN NORTHWESTERN CALIFORNIA<sup>1</sup>

Thomas E. Lisle<sup>2</sup>

*Abstract: Large floods in northwestern California in the past two decades have mobilized extensive areas of valley floors, removed streamside trees, and widened channels. Channel cross sections were surveyed to illustrate an hypothesis on the linkage between sediment transport, colonization of channel margins by trees, and streambank recovery. Riparian trees, e.g., white alder (Alnus rhombifolia), colonize the water's edge at low flow to receive adequate moisture during the dry season. Such stands can endure annual high flows only after the flood-enhanced sediment load declines and the width of the annually mobile bed contracts to the low-flow width. Streambank formation along the low-flow margin can then proceed by deposition of fine sediment and organic debris.*

---

A series of large floods from 1950 to 1975 (Harden and others 1978) greatly altered riparian ecosystems in north coastal California from the Eel River basin northward. Channel aggradation as much as several meters, channel widening as much as 100 percent, and extensive destruction of trees by flood waters widened the zone of active bed sediments at the expense of riparian corridors along many streams (Hickey 1969; Kelsey 1980; Lisle 1981). Although most aggraded channels have degraded to stable bed elevations as excess sediment has been transported downstream, many remain widened (Lisle 1981). If probability prevails and such large floods do not recur, how will riparian stands and associated streambanks recover over the next few decades?

This paper presents a hypothesis on a relation between colonization of streamside trees and channel dynamics that may govern the recovery of riparian stands and reconstruction of streambanks. During large floods, extensive areas of streambeds and floodplains can be mobilized by high shear stresses and new inputs of sediment. Riparian species of willow and alder that have low tolerance to moisture stress tend to colonize the water's edge during summer low-flow periods. Because these trees also require a stable substrate, they can establish only after the zone of annually mobilized bed material contracts to a small fraction of the width mobilized by the last large flood. Once established, the trees can trap fine sediment and organic debris, add root strength to

bed material, reduce local shear stress, and thereby induce formation of new streambanks. Widened channels thus may recover when new streambanks form inside flood-eroded banks at a spacing dictated by the zone of annually mobilized bed sediment.

---

## Trees Along Mobile Bed Margins

---

Channel cross sections showing substrate and vegetation of three creeks affected by recent floods (1964, 1972, and 1975) in north coastal California illustrate colonization and growth of riparian trees along mobile bed margins. All examples were surveyed across reaches where bed and banks were composed of alluvium. The first example (Prairie Creek) presents the hypothesis in detail and illustrates bank formation along a channel transporting abundant fine sediment. The second (Hurdygurdy Creek) shows contrasts with a channel transporting little fines. The third (Willow Creek) details plant species occupying micro-habitats within the channel.

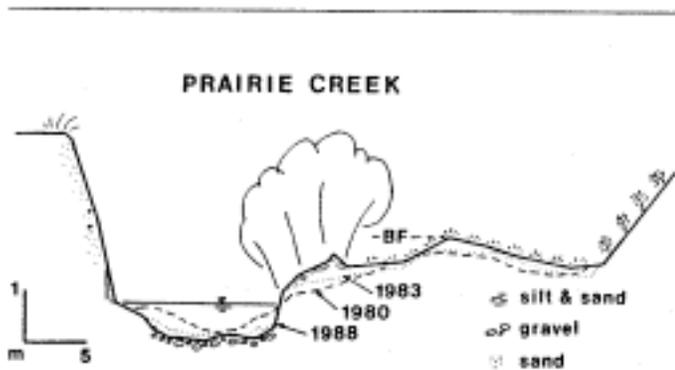
### Prairie Creek

Prairie Creek, a tributary of Redwood Creek, Humboldt County, with a drainage area (DA) of 34 km<sup>2</sup> at the study reach, has a moderate sediment yield with abundant fines (Lisle, in press). The basin is heavily forested mostly with old-growth redwood. Summers are relatively cool and moist because the basin is only a few kilometers from the coast. Tertiary sands and gravels of the Gold Bluffs Formation (Moore and Silver 1968) underlying much of the basin supply readily mobile bed material. Flood flows usually cause modest changes in channel morphology, however, because human disturbance has been relatively light, the channel gradient is low (0.0032 in the study reach), and streambanks are strengthened by dense riparian vegetation. The mobile portion of the streambed—that which is entrained annually—is composed of sand and gravel with median grain diameter (D<sub>50</sub>) of 9.0 mm and is armored with pebbles and cobbles (D<sub>50</sub>=25.5 mm) (Lisle, in press).

---

<sup>1</sup> Presented at the California Riparian Systems Conference; September 22-24, 1988; Davis, California.

<sup>2</sup> Research Hydrologist, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Arcata, Calif.



**Figure 1** - Cross section of Prairie Creek, showing bed elevation changes from 1980 to 1988 and the distribution of riparian vegetation and substrate. Approximate bankfull elevation is indicated by BF.

A natural levee approximately 0.7 m high had accreted progressively on the inner right bank immediately adjacent to the mobile bed from 1980 to 1988 (fig. 1). The levee, which was composed of fine sand, silt, and organic debris, supported a narrow dense stand of red alder (*Alnus oregona*). The levee was highly irregular, due to locally thick deposits of newly laid fine sediment and local scour around large woody debris caught among the alders. The alders were rooted at about one-half of bankfull stage, and thus were probably flooded several times on average each year. Bankfull elevation in this cross section was poorly defined but, by extrapolation from adjacent reaches, corresponds approximately with the top of the bar.

In contrast to the levee, the adjacent bar surface was smooth and covered with low herbaceous vegetation. The bar accreted less than 0.3 m from 1980 to 1988. The bar surface in 1980 was composed of sand and pebbles and scant herbaceous vegetation; by June 1988, a denser mat of vegetation and organic matter had accumulated. This mat was probably more efficient at trapping fine sediment than the sparsely vegetated surface of 1980.

Repeated surveys of this cross section since 1980 suggest the following sequence of processes in forming the levee on the inner right bank. A major flood occurred in the Redwood Creek basin in 1975 (Harden and others 1978). Tree-ring dating of the largest trees on the levee indicate that trees within the channel were stripped by the flood but reestablished within a few years. The entire streambed was extensively reworked by the flood, or in other words, the bed apparently became mobile over its entire width (39 m).

Afterward, the mobile zone of the bed contracted to approximately its width at the time of study (10m), and alder were able to colonize the low-water's edge along the left margin of the bar. At this time the bar surface merged smoothly with the mobile bed, as indicated by the 1980 survey. During even modest stormflows, high

friction generated by alders rooted low in the water created steep velocity gradients away from the main flow and promoted rapid deposition of fine sand, which is only intermittently suspended. Sand comprises as much as 55 percent of suspended sediment in Prairie Creek (Lisle in press). Sedimentation rates over the remainder of the bar were slower because of its smoothness and the depletion of coarse suspended fractions at the levee. As a result, the levee originated at a lower elevation but built faster than the bar, so that a level floodplain may be formed eventually. Channel incision since 1980 apparently helped to define a higher bank as the levee built (fig. 1). Root strength probably helped to stabilize these higher banks.

### Hurdygurdy Creek

Hurdygurdy Creek ( $DA = 70 \text{ km}^2$  at the study reach), a major tributary of the South Fork Smith River, Del Norte County, is coarser and steeper than Prairie Creek and carries little fine sediment. In the study reach, the bed surface is mainly cobbles and boulders ( $D_{50} = 155 \text{ mm}$ ), and channel slope is 0.02. Moisture stress on riparian vegetation is greater than along Prairie Creek, because Hurdygurdy Creek is farther from the coast (20 km) and summers are hotter and drier. Sediment is predominantly coarse bedload derived from metamorphic rocks of the Mesozoic Age. Unpublished data provided by Mike Furniss, Six Rivers National Forest, Eureka, California shows that the channel appears stable and cross sections surveyed since 1976 show little change.

White alders (*Alnus rhombifolia*) grew within the channel of Hurdygurdy Creek, but in contrast with trees in Prairie Creek, were not associated with bank formation (fig. 2). The alders were rooted near the low-flow water surface elevation, which was at less than one-half of bankfull stage. At this cross section, alders on the left portion of the channel ended abruptly at a certain point that was not related to elevation, but instead probably defined the left margin of the mobile bed. The bed to the right of the alders had an equal elevation and thus equal availability of moisture. This area was an active bar deposited against the larger, stabilized flood bar upon which the alders had established. The bed among the alders was clearly not mobile enough to cause removal of the trees. The alders grew among mossy boulders that had not moved apparently since the flood of 1964. Cores extracted from the largest trees indicated colonization of the bar was no later than 1966. The alders had trapped abundant large woody debris but little fine sediment.

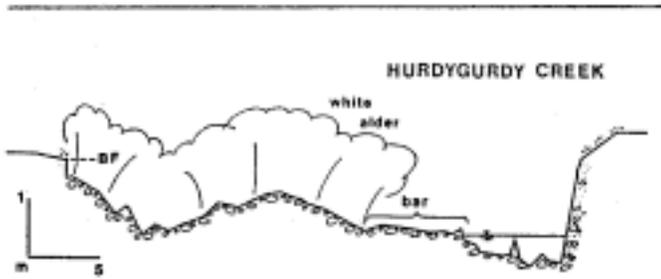


Figure 2 - Cross section of Hurdygurdy Creek surveyed in July 1986, showing growth pattern of riparian trees and substrate. BF indicates bankfull elevation.

### Willow Creek

Willow Creek (DA = 110 km<sup>2</sup> at the study reach) is similar to Hurdygurdy Creek in climate and geology. The study site is 0.5 km upstream of the Highway 96 bridge and 1 km upstream of the junction of Willow Creek with the Trinity River in Humboldt County. Cartographic channel slope in the study reach is 0.019. The 1964 flood destroyed the stream gauge, which was located in the study reach, and deposited sediment on the prominent terrace (T2, fig. 3) 4-5 m above the existing streambed. Unrecorded large floods occurred probably in 1972 and 1975, as well; high rainfall and runoff were recorded in Redwood Creek, the adjacent basin to the west (Harden and others 1978).

Wet-site trees and herbs, including white alder, willow (*Salix hindsiainai*; *S. lasiolepis*), black cottonwood (*Populus trichocarpa*), and sweet clover (*Melilotus albus*), grew in a narrow band (2-5 m wide) along the low-flow water's edge (Zones 1 and 2 in Section 1, Zone 1 in Section 2, fig. 3; table 1). Riparian alders and willows were established no higher than about 0.4 m above a stage typical of late summer, which is approximately 0.3 m below that during the survey. Bankfull was poorly defined, but corresponded roughly with the top of the bar in Section 1. Riparian trees were rooted at less than one-half of bankfull stage as defined. Cores extracted from the largest trees indicated colonization in 1973-1975. Herbaceous species growing on higher, drier sites (Zones 3 and 4) were typical of those that invade disturbed ground and have a wide range of moisture tolerances. The base of the drier zones was 0.2 m (Section 1) and 0.9 m (Section 2) above late summer stage.

As in Prairie Creek, riparian trees were rooted densely at the low-flow water's edge and appeared to stabilize alluvium sloping toward the channel thalweg. The trees thereby helped to define streambanks that were well below bankfull stage. As in Hurdygurdy Creek, however, little fine sediment deposited among the trees, which would lead to bank formation.

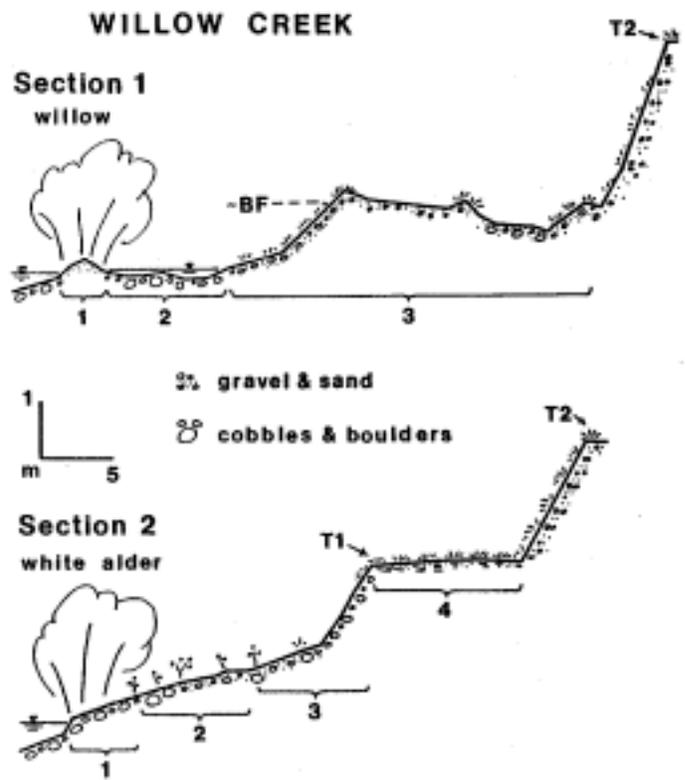


Figure 3 - Partial cross sections of Willow Creek surveyed in June, 1988, showing distribution of riparian vegetation and substrate. Numbered brackets show vegetation zones of table 1. BF indicates approximate bankfull elevation; T1 and T2 are alluvial terraces.

**Table 1** - Species, relative abundance, and indicated habitat conditions of vegetation along zones of Sections 1 and 2 (fig. 3), Willow Creek.

|            | Species <sup>1</sup> and abundance <sup>2</sup>   | Indicated habitat  |
|------------|---|--|
| Section 1: |   |  |
| Zone 1     | <i>Salix hindsiana</i> -A (sandbar willow), <i>Populus trichocarpa</i> -S (black cottonwood), <i>Mellilotus albus</i> -C (sweet clover)   | High year-round moisture                                       |
| Zone 2     | <i>Salix hindsiana</i> -S, <i>Mellilotus albus</i> -S   | High moisture  |
| Zone 3     | <i>Mellilotus albus</i> , <i>Silene gallica</i> (catchfiy), <i>Bromus sp.</i> , <i>Erodium cicularium</i> (filaree), <i>Aira Caryophylla</i> (hair grass), <i>Kohlraushia velulina</i> , <i>Medicago polymorpha</i> (bur-clover), <i>Torilis arvensis</i> , <i>Vicia americana</i> (vetch), <i>Trifolium sp.</i> <sup>3</sup> | Recent or frequent disturbance; variable moisture requirements |
| Section 2: |   |  |
| Zone 1     | <i>Alnus rhombifolia</i> -A (white alder), <i>Rumus crispus</i> -S (curly dock), <i>Mellilotus albus</i> -C unknown grass-C   | High moisture  |
| Zone 2     | <i>Mellilotus albus</i> -A, <i>Kohlrauschia velutina</i> -C, <i>Silene gallica</i> -S, <i>Lotus sp.</i> -S, <i>Lupinus sp.</i> -S   | Disturbance  |
| Zone 3     | <i>Silene gallica</i> , <i>Bromus sp.</i> , <i>Aira caryophyllea</i> , <i>Taraxacum officinale</i> (dandelion) <i>Cirsium sp.</i> , <i>Trifolium sp.</i> , <i>Lotus sp.</i> <sup>3</sup>  | Disturbance  |
| Zone 4     | <i>Bromus sp.</i> (and other grasses)-A, others: <sup>3</sup> <i>Lotus sp.</i> , <i>Trifolium sp.</i> , <i>Vicia americana</i> , <i>Cirsium sp.</i> , <i>Salix lasiolepis</i> (arroyo willow)   | Stabler substrate than Zone 3                                  |

<sup>1</sup> Scientific names follow Munz (1968).

<sup>2</sup> A-abundant, C-common, S-sparse

<sup>3</sup> All species approximately equal in abundance: sparse to common.

---

## Discussion and Conclusions

---

One might expect flood-widened channels to become narrower by accreting material against eroded stream-banks. Post-flood surveys of cross sections at gaging stations, however, have shown this not to be the case (Lisle 1981). Instead, observations of incipient bank formation and growth patterns of riparian trees suggest that recovered stream margins may become defined well within flood-eroded channels and below bankfull stage, and then accrete vertically.

The first step in this process is for sediment load to decrease to a level whereby the zone of annually mobile bed material contracts and becomes confined to a zone corresponding to summer flow margins. Riparian trees, especially white alder which require both a stable substrate and a shallow rooting depth to year-round moisture (Griffin and Critchfield 1976), can then establish along low-flow margins, even though they are frequently inundated during the wet season. With further growth, trees can significantly stabilize bank materials by adding root strength and reducing local shear stress through added roughness. In streams such as Prairie Creek that carry abundant fine sediment, trees may also promote deposition of suspended sediment, particularly sand and organic debris, and thereby cause banks to build vertically. In streams such as Hurdygurdy and Willow Creeks that are steeper and carry little fine sediment, banks may not readily form but instead become defined by channel incision between densely rooted riparian corridors.

This mechanism for the recovery of channels and riparian stands could apply to a variety of gravel-bed streams in Mediterranean climates. Observations of stages in colonization and growth of riparian trees and their substrate could indicate much about the condition and recent geomorphic history of the channel. The presence of narrowly spaced riparian corridors inside flood channels indicates that sediment load has waned considerably since the last flood, and that the channel has an extensive width to accommodate an increased load. The absence of trees within bankfull margins, on the other hand, may indicate that the entire width of the bed was mobilized recently and that an increased load may lead to further bank erosion or bed aggradation.

The hypothesis has not been tested. It suggests many opportunities, however, for fruitful collaborations between plant ecologists and fluvial geomorphologists seeking to understand channel recovery from floods.

---

## Acknowledgments

---

I thank Bruce Bingham for identifying species at Willow Creek, researching their habitat requirements, helping to survey the cross sections, and reviewing the manuscript; and Lori Dengler for reviewing the manuscript.

---

## References

---

- Griffin, James R.; Critchfield, William B. 1976. The distribution of forest trees in California. Research Pub. PSW 82/1972. Washington, DC; U.S. Department of Agriculture, Forest Service; [reprinted with supplement, 1976] 118 p.
- Harden, Deborah R.; Janda, Richard J.; Nolan, K. Michael. 1978. Mass movement and storms in the drainage basin of Redwood Creek, Humboldt County, California—a progress report. U.S. Geological Survey Open-File Rep. 78-486, 161 p.
- Hickey, John J. 1969. Variations in low-water streambed elevations at selected stream-gaging stations in Northwestern California. U.S. Geological Survey Water-Supply Paper 1879-E, 33 p.
- Kelsey, Harvey M. 1980. A sediment budget and an analysis of geomorphic process in the Van Duzen River basin, north coastal California, 1941-1975. Geological Society of America Bulletin 91(4): 1119-1216.
- Lisle, Thomas E. 1981. Recovery of aggraded stream channels at gauging stations in northern California and southern Oregon. In: Davies, Timothy R.H.; Pearce, Andrew J., editors. Proceedings, Erosion and Sediment Transport in Pacific Rim Steeplands. IAHS-AISH Pub. 132: 189-211.
- Lisle, Thomas E. Deposition of fine sediment in natural gravel streambeds. Water Resources Research [in press].
- Moore, George W.; Silver, Edward A. 1968. Geology of the Klamath River delta, California. U.S. Geological Survey Prof. Paper 600-C; C144-C148.
- Munz, Phillip A. 1968. A California Flora with Supplement. University of California Press, 1681 p.