# A NEW APPROACH TO FLOOD PROTECTION DESIGN AND RIPARIAN MANAGEMENT[1]

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*Abstract: Conventional engineering methods of flood control design focus narrowly on the efficient conveyance of water, with little regard for environmental resource planning and natural geomorphic processes. Consequently, flood control projects are often environmentally disastrous, expensive to maintain, and even inadequate to control floods. In addition, maintenance programs to improve flood conveyance and enhance levee stability, such as clearing riparian vegetation in channels and on levees, undergo little – if any – technical scrutiny. Such programs are often prescriptive in nature, rather than based on actual performance standards. A new approach to planning channel modifications for flood damage reduction is presented that is multi-objective and incorporates proper consideration of hydrologic, geomorphic, and biologic factors that influence stream hydraulics.*

Extensive channelization of natural streams has occurred in the last 40 years in urbanizing areas. The purpose of these channelization projects, termed "channel improvements" by hydraulic engineers, was generally to maximize the area and value of developable land by reducing flood hazards. The conventional design methods used for flood control channels were developed mainly based on research carried out in the first half of this century (Brater and King, 1976; Chow 1959). The design methods were based on the application of hydraulics research on sediment-free fluid flow in relatively simple artificial pipe, flume, and weir configurations to modified natural streams. Parallel research in fluvial geomorphology on the behavior of natural streams in flood was not typically incorporated into design methods used by public works engineers.

The design methods used today are little different from those used forty years ago. However, with the advent of the computer and hydraulic programs such as HEC-2 (U.S. Army Corps of Engineers, 1982), the analysis of flood elevations and hydraulics is considerably quicker and easier.

The usual design standard for flood control projects is to protect surrounding areas against inundation in a 100-year flood or the Standard Project Flood (equivalent to about the once in 200- to 500-year flood). Most channelization projects have only been in existence for 2 or 3 decades, and so very few projects have actually experienced floods the size of the design flood. Nevertheless, there is now sufficient "operating" experience with artificial flood control channels in smaller floods to now be able to assess the adequacy of some of the conventional hydraulic engineering design criteria, and to propose a new approach to flood control design and riparian management.

## Problems with Conventional Flood Control Design

### Underestimation of Roughness of Lined Channels

Conventional flood control design methodology seeks to minimize the right-of-way required for flood control channels by increasing flow velocities, thereby allowing a narrower channel to be built that reduces flood elevations. This is done typically by lining the channel with smooth reinforced concrete. With a suitable slope in a uniform channel, the low roughness of the concrete can allow "super-critical flow" to develop very fast-moving shallow flow. When super-critical flow occurs, the channel cross-section and right-of-way can be significantly reduced. This has led to many channels of this type being built in California in the last two or three decades.

Coastal Northern California has experienced two large floods in the last three decades, in January 1982 and February 1986. The experience of the channelized Branciforte Creek (completed 1959) in Santa Cruz County in 1982, and Corte Madera Creek (completed 1970) in Marin County in 1982 and 1986, shows that these supercritical flow channels do not perform as designed and can overtop their banks at flows considerably smaller than their design flood.

Figure 1 shows the channelized Corte Madera Creek overtopping in the 1982 flood when in-channel flows were approximately 4,500 cfs, equivalent to about the 15-year flood. The design flood at this location was 7,800 cfs, with 2 feet of freeboard, equivalent to about the 200-year flood.

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**Figure 1**— Corte Madera Creek during the January 4, 1982 flood overtopping its banks just upstream of a bridge near the College of Marin. Turbulence in foreground is water hitting the bridge face. The rectangular concrete channel is about 2 feet below water surface during a 15-year recurrence flood of 4,500 cfs. The channel was designed to contain a 200-year flood of 7,800 cfs with 2 feet of freeboard. Similar flooding occurred in February of 1986. (Photo: Philip Williams)

On Branciforte Creek during the 1982 flood, the channel filled to the top of its capacity at a peak discharge of 6,650 cfs. This channel was designed to contain a Standard Project Flood of 8,500 cfs with 2 feet of freeboard.

The primary reason for the failure of these channels in medium-sized floods was that the actual effective roughness of the channel during the flood was considerably larger than that calculated by conventional design methods.

Immediately after the 1982 flood, it was possible to identify the flood profile on Corte Madera Creek by flood marks in the chain-like fence along the channel shown in Figure 1.

The best fit analysis using HEC-2 indicates that the actual Manning's roughness at the time of the flood peak was approximately 0.030 instead of the 0.014 assumed in the design for smooth concrete channel (Vandivere and Williams 1983). The higher roughness meant that flow was "sub-critical" rather than super-critical as designed, and consequently flood elevations were approximately 6 feet higher than predicted for the design flood, even though flows were considerably lower.

The primary reason for the increased roughness was the bed load sediment conveyed through the channel. After the flood, boulders up to 12 inches in diameter were observed in a sediment delta formed at the downstream end of the channel. Without considering the effect upon roughness of bed forms, gravel and boulders of this magnitude would be sufficient to cause the increase in roughness that was observed by increasing energy losses at the bed of the channel. A number of researchers in fluvial geomorphology (e.g., Limerinos 1970) have demonstrated the relation between bed load size and channel roughness in natural streams. For a Manning's roughness of 0.030, the d84 value would be 2.6 inches (d84 = 84 percent of particles in the sample are smaller than 2.6 inches).

In retrospect, the increase in roughness observed in the concrete channel is not surprising. Wherever flood flows are large, large amounts of sediment are mobilized and are conveyed downstream by natural watercourses. This bed material cannot be prevented from entering the concrete channel section, and all of it is conveyed throughout the channel length without the opportunity for deposition in any section. Nevertheless, concrete channels of this type continue to be designed and constructed based on "clear water" analysis, ignoring the direct effects of sediment on the hydraulics.

In natural streams, super-critical flow rarely occurs in long reaches due to the size of bed material mobilized (Jarrett 1984).

### Failure to Account for Channel Bed Erosion and Deposition

Clear-water analysis design procedures currently in use do not take into account the significant changes in channel morphology that occur during the course of a flood. Reassertion of meandering in an artificially straightened channel can cause levee failure. However, the most significant effects on flood levels are changes in the channel bed.

Hydrologic design criteria for artificial channels assume high antecedent rainfall prior to the design flood event. In California and in many other locations, this creates the conditions for large numbers of debris avalanches and mudflows (National Research Council and U.S. Geological Survey 1984). Large amounts of sediment and debris are introduced into tributary streams and can cause significant aggradation (filling with sediment) of the bed, particularly where the floodplain has been developed, eliminating the natural sediment storage area. This can raise flood elevations and cause flood paths to be substantially different than those predicted.

Further downstream, the channel bed can degrade during the course of a flood, lowering flood elevations below those predicted by clear water analysis. An example of the failure to consider the erosion and deposition of sediment in a river channel is the case of the San Lorenzo River Channelization Project in Santa Cruz completed in 1958. The defect in the original hydraulic design, which assumed that the river channel could be maintained at down to about 8 feet below sea level at its mouth, has been documented by Griggs (1984). By 1982, the channel bed had typically silted up about 6 feet. According to clear-water analysis, the flood control project could only protect against the 30-year flood. In January 1982, the flood flow of 30,000 cfs was approximately the 30-year flood, but the flood was contained within the levees. Approximately 4-6 feet of scour had occurred at the downstream end during the time of the flood peak, greatly increasing the capacity of the channel.

Current design criteria do not recognize the benefit of keeping a natural sand bed in a channel in reducing flood levels. This leads to construction of flood control projects such as the Los Angeles River flood control channel which have concreted the channel bed, preventing scour in a large flood.

### Failure to Account for Debris

Clear-water design of channels generally ignores or underestimates the role of floating debris in increasing flood elevations. In California and in many other areas, large floods can carry large amounts of debris such as uprooted vegetation and trees, fences, and parts of structures. On smaller streams, this, combined with sediment, invariably impedes or completely blocks the hydraulic efficiency of small- to medium-sized culverts. Further downstream on the main channels, bridges and culverts can be partially obstructed, causing significant increases in flood elevations upstream. On some creeks during large floods, the water surface profile is actually a staircase of obstructed culverts and backwater ponds.

The rise in water surface elevation due to backwater from an obstructed bridge can greatly exceed the reduction in water surface elevation due to stream channelization. Figure 2 shows an extreme case – a bridge across Soquel Creek in Santa Cruz County obstructed by debris during the 1982 flood (9,700 cfs, or about a 16-year flood event) (Thompson 1982). Flood elevations were increased at least 10 feet upstream and directed the main flood flow out of the channel.

### Underestimation of Maintenance Requirements

The engineering perception that the design of flood control projects is mainly a question of selecting the appropriate channel geometry, has led to an emphasis on initial construction of a flood control project. This in turn has led to neglect of consideration of how flows, sediment, and vegetation interact in determining flood-elevations in modified streams. Very little analysis has been carried out of realistic maintenance requirements. Instead, assumptions are made concerning stream geometry and channel roughness, and these are imposed as maintenance requirements on the channel, whether or not they are cost-effective.

Typically, in trapezoidal earth-lined flood control channels, a design Manning's roughness of about 0.03 to 0.04 is used. According to a somewhat subjective interpretation of roughness values for low-gradient natural streams, the design engineer may determine that no woody vegetation can be allowed in the channel bed and banks, and any that grows there must be regularly removed as part of a prescriptive maintenance procedure. Wide trapezoidal channel beds exposed to the sun are ideal nurseries for riparian vegetation such as willows and cattails, and costs of removal can be high. Frequently, local flood control districts have insufficient money for maintenance and economize by carrying out prescriptive maintenance every few years instead of every year. This can result in the vegetation being managed at a state at which it offers greatest resistance to flows – short dense brushy vegetation in the channel bed. Figure 3 illustrates how roughness changes with the age of riparian vegetation.

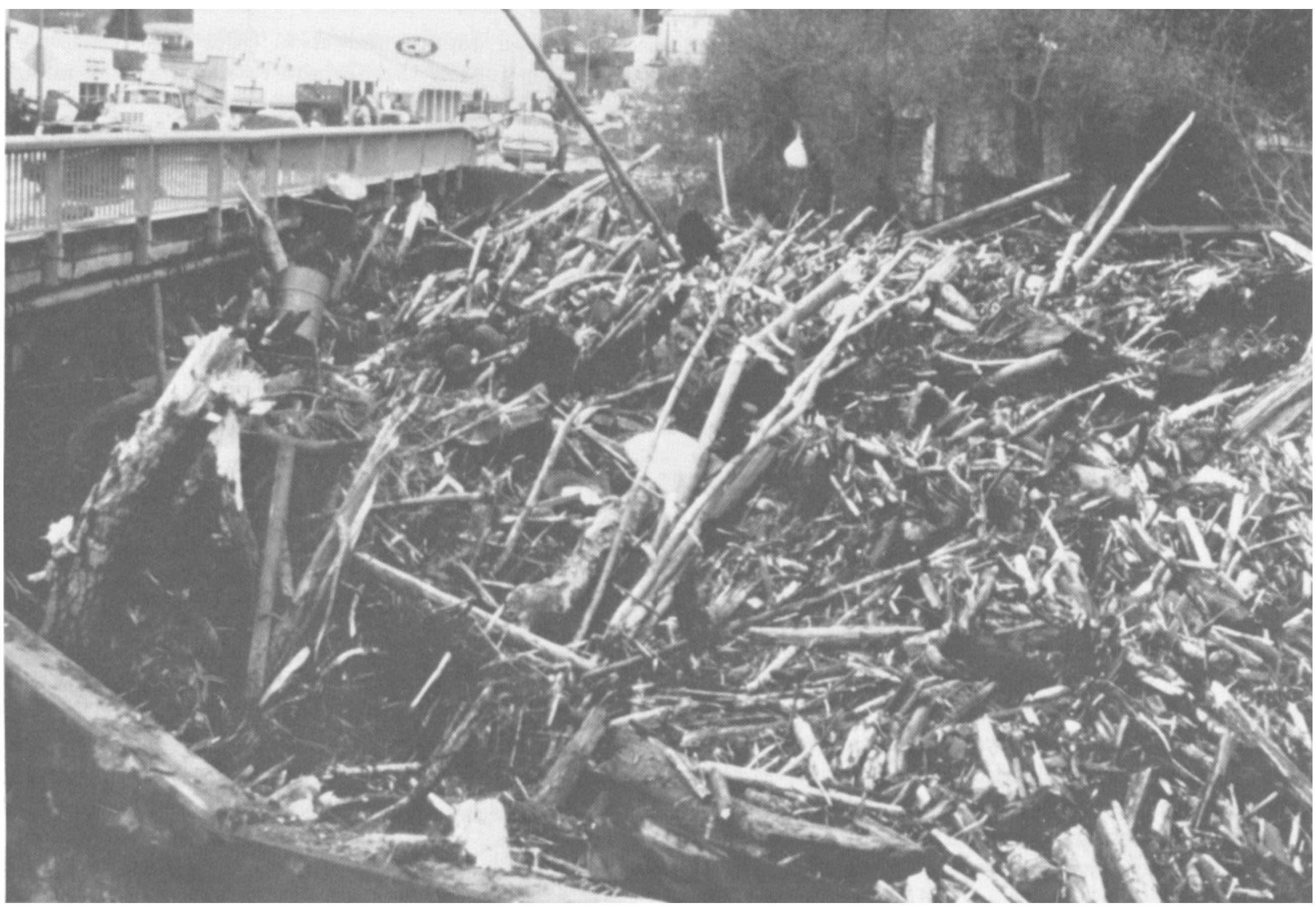

**Figure 2**—A debris jam of Soquel Creek at the upstream side of the Soquel Drive Bridge after the January 4-5, 1982 flood. This jam (27,000 yd') diverted most of the flood discharge (estimated at 9,700 cfs and about 15-year recurrence) through town (visible in upper left background). Flow depths of up to 6 feet exceeded predicted 100-year elevations. (Photo: Gary B. Griggs)

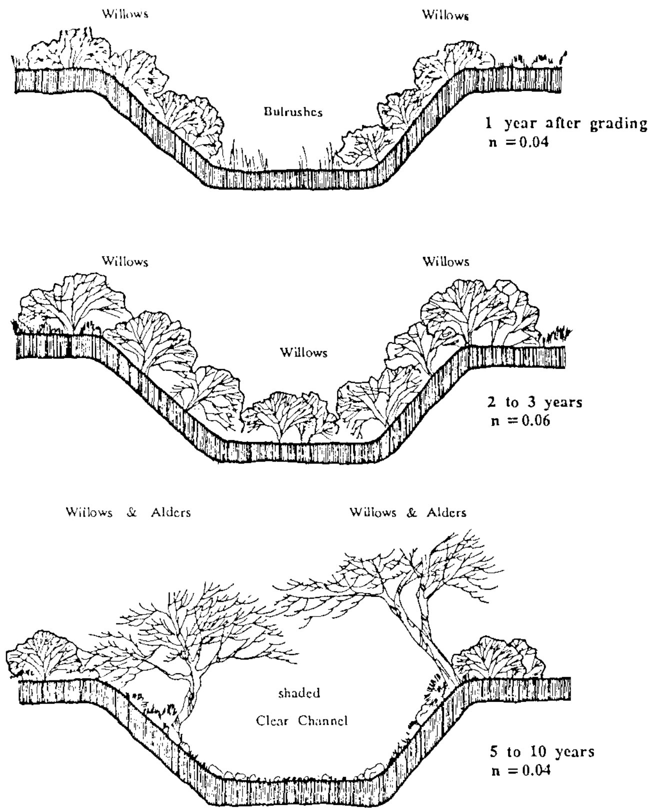


**Figure 3** — Conceptual diagram of change in channel roughness with age of riparian vegetation.

Other maintenance costs that are frequently underestimated are sediment, debris, and garbage removal and repair of channel bank erosion.

The lack of effective maintenance can often negate the reductions in flood elevation initially achieved by channelizing the stream.

### Current Design Methods Overestimate Channelization Benefits

Failure to recognize the design problems described earlier tends to result in an exaggerated expectation of benefits of stream channelization over alternatives that preserve a more natural creek corridor. Recognition of realistic roughnesses and the role of sediment and debris would tend to reduce the supposed benefits of lined channels in favor of preserving flood plains and providing adequate bridge crossings. Recognition of natural scouring during floods would call into question the rationale for lined channel beds. Adequate consideration of maintenance requirements would recognize the hydraulic benefits of more natural riparian vegetation and channel morphology over geometric cross-sections.

## A New Approach to Flood Control Design

With an experience of the last few decades, we suggest a design process that will lead to greater long-term reduction in flood damages while allowing the enhancement of riparian corridors. The following are the key elements of this process:

1. Utilize an integrated planning process: This requires an understanding that stream modification will affect more than flood levels. All the significant hydrologic, geomorphic, ecologic, and economic factors have to be considered, rather than approach the design as a plumbing problem. This generally requires involvement of a range of skills beyond traditional hydraulics engineering.
2. Clearly Identify Design Objectives: Stream modifications are rarely single-purpose projects. They typically can include the following:
   - Flood damage reduction (it is important to state this goal in this fashion rather than the nebulous and impossible "control" of floods);
   - Protecting or restoring riparian ecosystems;
   - Providing recreational access;
   - Enhance property values along creek corridor.
3. Understand the physical system: This means developing an understanding of the natural hydrology and geomorphology of the particular watershed and then identifying past, and possible future, human-caused influences on these physical processes. Such an understanding provides the setting in which to establish specific design criteria for a particular reach.
4. Carry out an integrated design: An integrated design would consider not only the direct effects of stream modification on flood elevation but also all the significant processes that affect flood elevations and are affected by the channel modification. Typically, these would include:
   - Downstream effects on hydrology and stream morphology;
   - Effect of future changes in watershed on hydrology and sediment delivery;
   - Relationship between riparian vegetation management and channel hydraulics;
   - Effect on seasonal streamflows;
   - Effect on groundwater levels and recharge;
   - Effect on fisheries;
   - Effect of changes in flow velocities on bank erosion, downcutting, and upstream drainage system;

- Planning for the consequences of failure of any part of the flood management system, e.g., levee failure or culvert obstruction;

- Designing to minimize long-term maintenance requirements, taking into account the evolution of the stream corridor.

5. Develop maintenance program based on performance standards: The methods used presently for flood control channel maintenance are generally prescriptive in nature. Typically, there is a maintenance program at a set time interval to strip vegetation and regrade channels whether or not it is actually required. Such maintenance practices are not only environmentally destructive but can be expensive and not particularly effective.

A performance standard-based maintenance program would establish maximum design floodwater surface elevations. Periodic monitoring of the stream channel, including cross-section surveys and inspection of potential obstructions and channel roughnesses would be required. The results of this monitoring would be used in standard hydraulic programs such as HEC-2 to determine in what portions of the channel sediment removal or vegetation thinning may be required. This approach could significantly reduce the frequency, extent, and environmental disruption of channel maintenance. It would tend to allow riparian vegetation to reach maturity, thereby shading the channel and reducing roughness (see Figure 3). It would also allow the channel the opportunity to flush out some of its accumulated sediments in small-sized floods.

## An Example of Integrated Design — Wildcat Creek

The Wildcat Creek flood control project in North Richmond, California, is an example of the application of many of the aspects of the integrated design approach described above. This project was originally proposed more than 20 years ago as a concrete channel, then as a single-purpose trapezoidal earth channel. Concern by local citizens and environmentalists led to the adoption of a multi-purpose design by the Army Corps of Engineers and Contra Costa County Flood Control District. The key elements of this adopted design, referred to as the "consensus plan," are shown in Figure 4 and are contrasted with the earlier trapezoidal plan. This project, which is intended to reduce flood damages in the adjacent community, restore the riparian corridor, and provide public recreational access, is now under construction.

## References


Brater, Ernest F.; King, Horace W. 1976. Handbook of hydraulics. 6th ed. New York: McGraw-Hill.

Chow, Ven Te. 1959. Open-channel hydraulics. Tokyo: McGraw- Hill Kogakusha Ltd. 680 p.

Griggs, Gary B. 1981. Flood control and riparian system destruction: Lower San Lorenzo River, Santa Cruz County, California. In: Warner, Richard E. and Hendrix, Kathleen M., editor, California riparian systems: ecology, conservation, and productive management. Berkeley, University of California Press, p. 142-149.

Jarrett, Robert D. 1984. Hydraulics of high-gradient streams. In: Journal of Hydraulic Engineering, 110(11).

Limerinos, J.T. 1970. Determination of the Manning coefficient from measured bed roughness in natural channels. USGS Water Supply Paper 1898-B. 47 p.

National Research Council and U.S. Geological Survey. 1984. Debris flows, landslides, and floods in the San Francisco Bay Region, January 1982. 1982 Overview and summary of a conference held at Stanford University, August 23-26, 1982. Washington, D.C.: National Academy Press. 83 p.

Thompson, W.R. 1982. A flood hazard assessment of the town of Soquel. Unpublished thesis. University of California at Santa Cruz.

U.S. Army Corps of Engineers. 1982. HEC-2 water surface profiles: programmers manual.

Vandivere, William B; Williams, Philip B. 1983. Flood analysis of the January 4, 1982 storm: Corte Madera Creek, Marin County, California. Unpublished report supplied by author. 21 p. + tables.

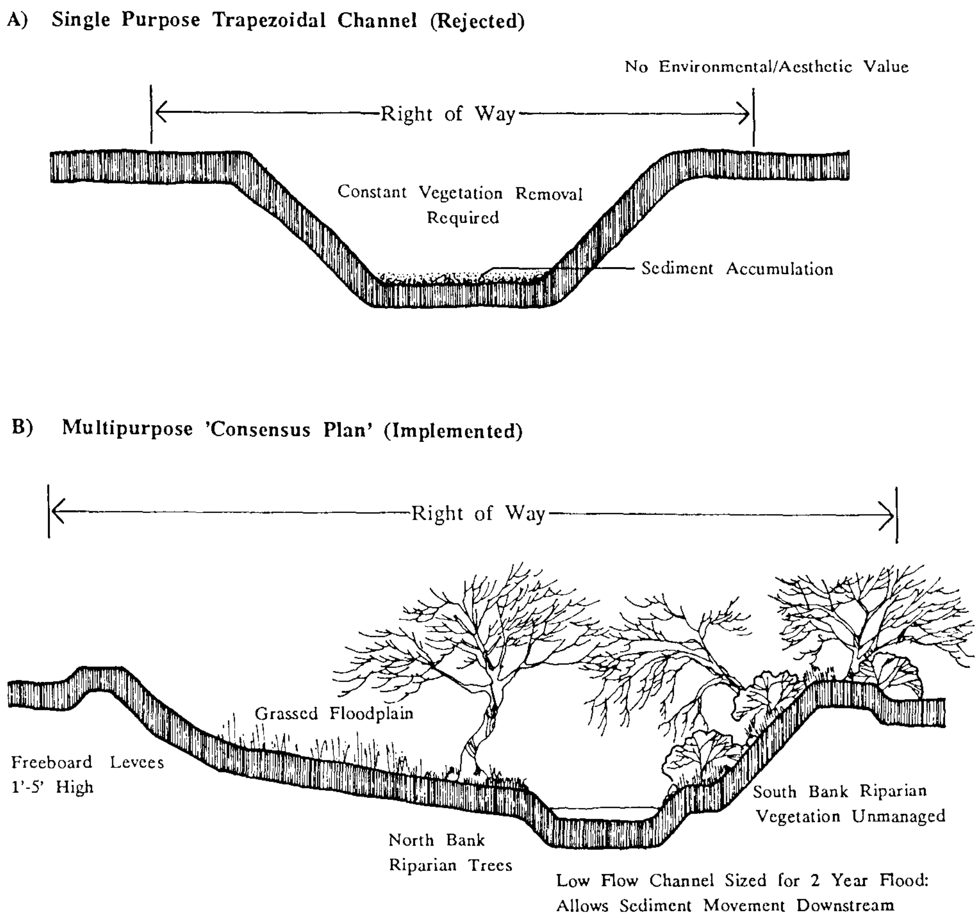


**Figure 4**— Conceptual designs for Wildcat Creek Flood Control Project.