Rethinking Flood Control Channel Design

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Designing an effective flood control scheme requires a multiobjective approach.

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RETHINKING FLOOD-CONTROL CHANNEL DESIGN

On Jan. 4, 1982, the 10-year-old Corte Madera Creek flood-control channel in Marin County, Calif. faced its first significant test. As the rains fell, record flood flows occurred upstream from the channel. Most of the over-bank floodwater was diverted from the project, leaving only about 5,000 cfs—equivalent to the 20-year flood—to enter the channel. But the waters overtopped the channel's banks, even though the flow was well below design capacity.

The Corte Madera incident illustrates the problems of traditional flood-control channel design. Until the last decade, the standard method of flood control was channelization—converting a natural stream to a uniform channel cross section. But this single-purpose approach is under increasing scrutiny from both engineers and the public. Engineers are becoming concerned that traditional designs may not work as intended and fail during floods. The public, meanwhile, is becoming dissatisfied with the environmental destruction normally caused by single-purpose design.

Combined with reduced federal funding for flood-control projects, this reassessment is pushing flood-control engineers to explore new design options that reflect multiobjective stream corridor planning.

Traditional hydraulic engineering methods remain largely unchanged from 30 to 40 years ago. Used by every civil engineer, they are largely based on data from flume experiments and measurements of the hydraulics of straight, uniform canals. These methods are then applied in the modification of natural stream systems.

But streams aren't flumes. They aren't straight. They have varying and interacting flows, changing channel configurations and sediment loads, and differing bed and bank characteristics. Flood-control engineers try to achieve safe designs by simplifying a stream to replicate the hydraulics of the laboratory flume, but this may lead to a false sense of security.

COMMON PROBLEMS

The growth of suburbia over the last 30 years has meant a corresponding growth in the construction of traditionally designed flood-control channels. Although few channels have yet had to convey floods approaching design flows, common problems are emerging that can in some circumstances reduce their effectiveness, leading to flooding of areas considered safe.

These problems arise from the notion that channel construction is a technical "fix," rather than part of a damage-reduction strategy that can encompass an entire watershed and stream corridor. This narrow focus means that important factors could be misjudged or overlooked:

- The effect of sediment. Traditional design methods usually assume clear-water hydraulics that discount the way in which sediment can affect the performance of a channel. Sedimentation was ignored in the 1959 construction of the San Lorenzo River project in Santa Cruz, Calif. The design grade was 5 ft lower than the natural channel and below sea level at the mouth of the river, creating a sediment trap. During the first few years of operation, even small flows caused the channel to silt in, reducing the capacity to about the 30-year flood. Instead of the few thousand dollars a year in maintenance costs estimated by the designers, the city was faced with prohibitive sediment-removal costs of more than $1 million a year.
- Flow resistance. Flow resistance is often underestimated because the selection of the Manning n hydraulic roughness is, at best, a matter of engineering judgment. The lack of monitoring and analysis of the actual performance of flood-control channels makes it difficult to assess how accurate these values are for large floods. There are many factors affecting flow resistance, and Manning's n is a black box combining them all. Most engineers focus almost exclusively on bank vegetation as the

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With supercritical flow, the Corte Madera Creek does not overtop its banks. But in subcritical flow during the 1982 flood, it did.

major factor in Manning's *n* simply because it is most visible and controllable, ignoring other processes that may be dominant. The emphasis may then be on clearing vegetation, even though certain factors, such as sediment transport and bed forms, may have more of an effect on flow resistance.

- Supercritical flow. Supercritical flow may not occur. Assuming traditional design methods, the minimum right-of-way width and maximum bank-erosion protection can be achieved by putting the stream in a concrete box and inducing high-velocity shallow supercritical flow. Achieving supercritical flow requires low bed and bank roughness. For clear water in straight concrete channels, Manning's roughness is about 0.015. But every large flood carries appreciable amounts of bed load, and this can significantly increase the composite channel roughness, causing the flow to shift back to deeper, slower-moving subcritical flows, sometimes leading to over-bank flooding. This is what occurred at Corte Madera Creek.
- Debris obstruction. Large floods can generate debris, which can catch on bridge pilings or culverts and substantially increase flood elevations. Actual 100-year flood profiles through urban areas can resemble a staircase of backwater pools behind obstructed bridges rather than a uniformly sloping water surface.

In traditional flood-control design, debris blocking effects are frequently underestimated. This focuses too much attention on achieving a desired uniform flow-channel conveyance, when the most cost-effective approach may be the replacement of bridges or improved emergency maintenance procedures to remove debris.

- Channel boundaries. The hydraulics of many flood-control channels are calculated with the assumption that beds and banks do not erode or fill with sediment during big floods. But where streams flow in alluvium and are unlined, erosion and sediment accumulation can affect flood risk. The 1982 flood on the San Lorenzo River, for example, should have overtopped the levees, according to standard HEC-2 rigid boundary analysis. But by the time of the flood peak, water surface elevations were several feet lower than predicted because the bed was considerably scoured.

Unfortunately, predicting the amount of scour and deposition is complex, but discounting the beneficial effects of scour during flood flows can lead to unnecessary, costly measures.

- Maintenance requirements. Textbook hydraulic design tends to impose rigid requirements for maintaining the channel cross section and allowable vegetation. Maintenance crews are then forced to clear the channel, using costly methods harmful to the environment, to make the channel conform to old design office estimates.

In some instances, maintenance procedures may actually increase flood risks. According to design requirements, the bed and banks of a trapezoidal earth channel, for example, must be continuously cleared of vegetation to minimize roughness. But little research has been carried out on the actual roughness effects of vegetation on flood flows. There is typically no differentiation made between the relative effects of in-channel, bank and floodplain vegetation.

Maintenance is usually underfunded and unglamorous—and channels are not cleared every year. The flat exposed bed of a trapezoidal channel is the perfect growing medium for certain aquatic plants, which could choke the channel within two years, substantially reducing its capacity. But sometimes, if the channel is left completely unmaintained for a longer period, riparian vegetation on the banks will eventually shade out the channel, increasing its flow capacity again. Some channels are cleared indiscriminately only every few years and are thereby managed at their minimum conveyance rather than maximum.

THE NEW APPROACH

Most importantly, the new approach to flood-control channel design considers flood-hazard reduction as just one component of a multiobjective riparian corridor management strategy. This strategy also includes and may give equal weight to the protection and enhancement of the riparian environment and the improvement of its esthetics.

The new emphasis is on continual long-term management of a creek corridor. Management entails a continuum of periodic interventions in the natural system that ranges from modification to maintenance, rather than the traditional two-step sequence of construction followed by maintenance. It requires the establishment of a monitoring and feedback mechanism that allows for the prioritization of damage reduction—some of which may be nonstructural—and the identification of failure mechanisms. Within this context, the need for channel

ROUGH TIMES

Many residents of California's wealthy Marin County were willing to live with flooding of the Corte Madera Creek if it meant that the natural stream corridor could be left intact. So when a concrete-channel flood-control project was proposed, they rallied against it. But in spite of local opposition, Unit 3 of the U.S. Army Corps of Engineers' Corte Madera Creek flood-control project was completed in 1972. Its design was based on the mistaken assumption that the standard project flood could be safely conveyed with a low Manning's roughness (0.014) that would allow supercritical flow to occur. What later occurred illustrates the problems of a single-purpose approach to designing a flood-control channel.

During the record flood of Jan. 4, 1982, the concrete channel overtopped its banks and flooded adjacent properties, even though the flow was well below design capacity. Measurements of peak flood elevations and of flow made it possible to reproduce the hydraulics of the flow by using HEC-2. Instead of Manning's roughness of 0.014, the actual roughness was at least 0.03.

After another failure during a smaller flood in 1986, the Corps estimated that much of the increase in roughness was due to the resistance effect of sediment bed forms moving down the channel. This caused the channel to flow subcritically instead of supercritically, causing flood elevations about 6 ft higher than predicted. During the flood, large amounts of gravel and boulders were conveyed through the channel and deposited in the delta at the channel mouth.

Fluvial geomorphologists had previously recognized the effect of increasing bed-load sediment size on increasing Manning's roughness values in natural channels, as well as the increase in the size of the bed load moved by larger flood flows. But the Corte Madera Creek project was designed with the flawed assumption that clear-water flow without sediment occurs during large floods. Unfortunately, this mistaken idea is still used in the design of many flood-control projects.

modification to reduce flood damage in the riparian corridor can be clearly established.

The corridor—a wider area that includes trees, wetlands and public-access paths—becomes the design focus. The successful development of a multiobjective design requires an understanding of the complex physical behavior of natural streams and how the stream interacts with its ecosystem.

Although fluvial geomorphologists are getting a better idea of how streams behave, the results of their research are not routinely used in flood-control design. What is needed is a synthesis of hydraulics engineering and fluvial geomorphology, which would encourage designers to work with natural processes rather than combat them. This synthesis could lead to substantial savings, because the resulting design would anticipate sediment movement, stream meandering and bank erosion. Concepts, such as the equilibrium stream profile, regime equations relating channel geometry to flow parameters and the formation of floodplain terraces, can be used in developing new designs for modified channels.

Incorporating fluvial geomorphology in a multiobjective scheme allows the different goals to complement each other. This aided the completion of a "two-stage" flow-channel design concept developed in Europe and the U.S., a design that is now being used in the construction of the Wildcat Creek project in Contra Costa County, Calif. The design called for the construction of an artificial floodplain terrace and the excavation of a low-flow channel (sized to the equilibrium bank full flood). The terrace provides space for a walking trail, and the low-flow channel allows fish and sediment to move downstream. Planting riparian trees on the bank shades out the channel, which prevents vegetation encroachment, minimizes maintenance, improves water quality and creates a continuous corridor for wildlife. Riparian vegetation can also slow bank erosion.

Anticipating the natural behavior of the stream can also permit a shift to less-destructive methods of maintenance, methods that are based on performance rather than on prescriptive criteria determined by the engineer at the time of design. Meanwhile, a program for monitoring actual flood flows and elevations can assist in deciding where and whether channel capacity needs to be increased, bridges replaced or floodwalls constructed. Such attention to detail would help avoid the need to embark on a costly, large-scale channelization project.

Increasing public interest in creek protection is now accompanied by a demand for restoring the environmental characteristics of previously channeled streams. Environmental and esthetic improvements can usually be made, but the options are limited by available rights of way. For new projects, right-of-way width requirements are often cited as the major impediment to selecting a multiobjective design over a traditional flood-control channel. However, taking a more realistic assessment of actual flow resistance, the role of sediment and long-term maintenance of traditional design approaches may mean that there is little difference between the two alternatives.

I hope this means that hydraulics engineers will no longer be seen by local residents as advocates of environmental destruction, turning natural streams into storm sewers. Instead, they could be seen as guardians of urban creeks—helping to preserve them and protect them against flood damage.

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