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CONTROL WORKS TO STABILIZE AND CHANNELIZE RIVERS IN THE WESTERN UNITED STATES

by

Philip H. Burgi

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Throughout history man's attempts to alter the natural river regime for human purposes has created a variety of problems resulting from our inability and unwillingness to look at the effect on the total watershed. In some cases the problems have been solved and man coexisted with the river. However, in most cases the problems persist. The purpose of this presentation is to summarize river channelization and stabilization projects developed in the Western United States over the past 80 years. Following are a few examples of small and large river systems where channelization and river stabilization were effectively used: Muddy Creek, Fivemile Creek, Upper Snake River, Middle Rio Grande River, Lower Colorado River, and the Columbia River.

Most rivers, if left undisturbed, will establish a regime that is in a state of equilibrium. The river's capacity for transport of suspended and bed materials will remain relatively unchanged. Stabilization and channelization are attempts by man to control a river by guiding it along an alignment designed to accommodate water and sediment regimes in a natural and sustainable manner. Sustainable river control works require maintenance of the balance between the water and sediment regimes of the river in time and space.

Channelization is accomplished through "hard" engineering solutions using riprap, concrete mats, roller-compacted concrete and drop structures and/or "soft" engineering solutions such as jacks, grade controls, and bioengineering concepts. In the United States there is increasing emphasis on "soft" engineering as a holistic means to alter the riverine environment from the perspective of a controlled aquatic ecosystem. There are many considerations that should be included in river control work planning and design, including fish and wildlife, recreation, riparian habitat, and instream needs. Topics in this presentation are limited to various engineering methods of river stabilization and channelization.

MUDDY CREEK

Muddy Creek is a tributary of the Sun River that in turn drains into the Missouri River at Great Falls, Montana. The watershed drains 300 mi^2 including some 50,000 acres of irrigated lands. The creek meanders through highly erodible sandy soil. Return flows from irrigation in the late 1950's increased the annual runoff from 10,000 acre-ft/yr before irrigation to 80,000 acre-ft/yr. These increased flows have produced severe incision of the creek with resultant large scale bank slumping. Muddy Creek annually transports roughly 200,000 tons of sediment into the Sun and Missouri Rivers, figure 1. Sediment degrades water quality, recreational activities, fishing and general aesthetics in the downstream rivers.

Figure 1. - Sediment laden Muddy Creek as it flows into the Sun River in the State of Montana.

Several activities are underway to bring the continued degradation of Muddy Creek under control. These include operational changes and delivery system modifications for the irrigation district and methods to stabilize, restore, and rehabilitate the riparian corridor of Muddy Creek. A yearly reduction of 20,000 acre-ft of irrigation return flow was recently achieved by using "best management practices" on the irrigated lands. A stream restoration demonstration project began in 1994 in a 4.1-mile reach of the creek to place 9 chevron weir rock ramp grade control structures and 33 barbs to control the 15 feet of stream gradient (S=0.0015) in the reach. The purpose of the grade control is to halt the incision of the creek. The purpose of the barbs is to halt the lateral migration of the creek. Barbs, or bendway weirs, are upstream angled jetties. Barbs displace the thalweg from the base of the banks. The low flow areas between the barbs fill with sediment creating vegetation areas and building banks. The plan will demonstrate the performance of the structures in the test section and the response of the creek to the gradient control. The desire is to create a stable, meandering channel similar to figure 2.

Fivemile Creek

This creek is found in west-central Wyoming on a small watershed of 1,000 mi^2. It is typical of many western watersheds where agricultural development and the return flows associated with irrigation have changed the river regime. In the period from 1925 to 1950 the Bureau of Reclamation developed a 52,000-acre irrigation project and used the creek (S=0.0045) as a conveyance channel for return drainage to Boysen Reservoir some 35 miles away. Average annual precipitation in the area is approximately 10 inches. The ephemeral creek had an annual runoff of 5,000 acre-ft before the irrigation project. The project increased the annual flow in the creek to 92,000 acre-ft. Fivemile Creek changed from a small meandering stream to a deeply incised channel over a 2-year period. The sediment yield increased from approximately 650,000 tons to 4.5 million tons annually. The change in river regime resulted in several serious impacts to the land, including loss of irrigated lands, loss of pasture lands, damage to bridges, and large sediment runoff into Boysen Reservoir. A comprehensive plan was developed to gather data and develop a stabilization plan for Fivemile Creek.

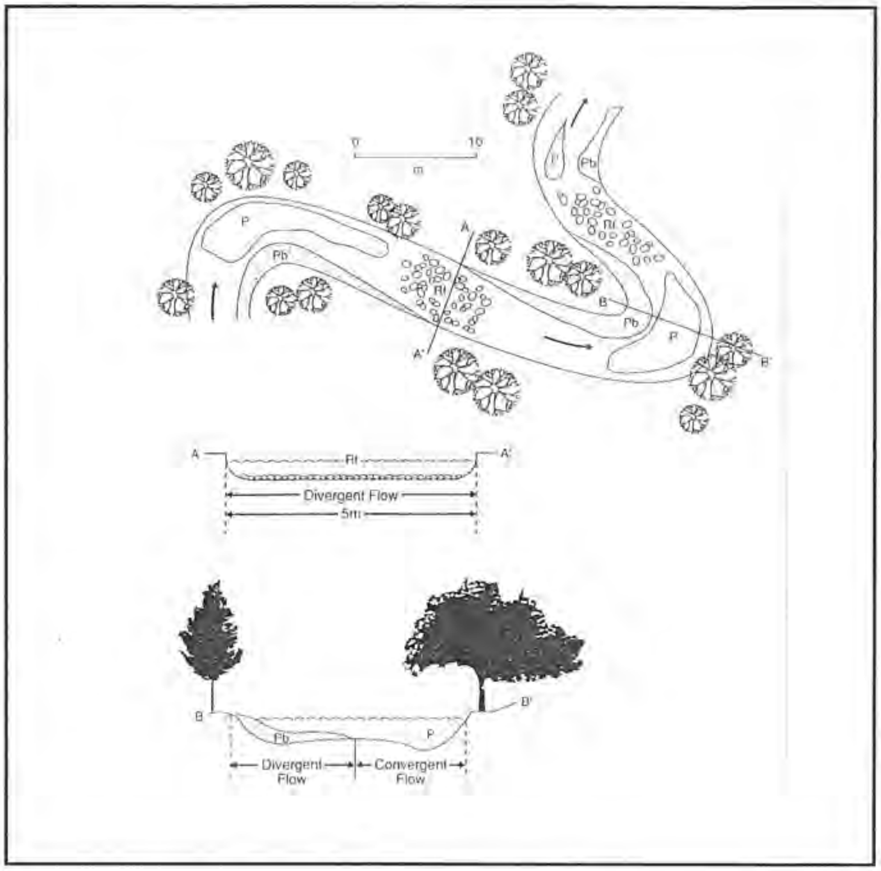

Figure 2. - Idealized natural channel.

By 1952 the deterioration of Fivemile Creek had reached major proportion. Several control methods were proposed, including rock riprap in the channel, paving the channel with concrete, and developing a separate collection channel to convey the irrigation return flow 35 miles to Boysen Reservoir.

The final design was based on keeping the high velocity flow away from the highly erodible banks. Channel training by artificial barriers using jacks was proposed. Wood jacks were used in those channel reaches where there was no erosion resistant bedrock. The jacks were aligned to guide the flow through the bends as shown in figure 3. Over 450,000 willows and Russian olive seedlings were planted in the jack fields. The work was completed by

Figure 3. - Photograph of Jacks along Fivemile Creek in State of Wyoming.

the end of 1954 at a cost of $24,000/mile of control work. Figure 4 shows the significant success of the control works by decreasing sediment yield to one-tenth. This is a significant improvement in light of the continued increase in watershed runoff over the same period.

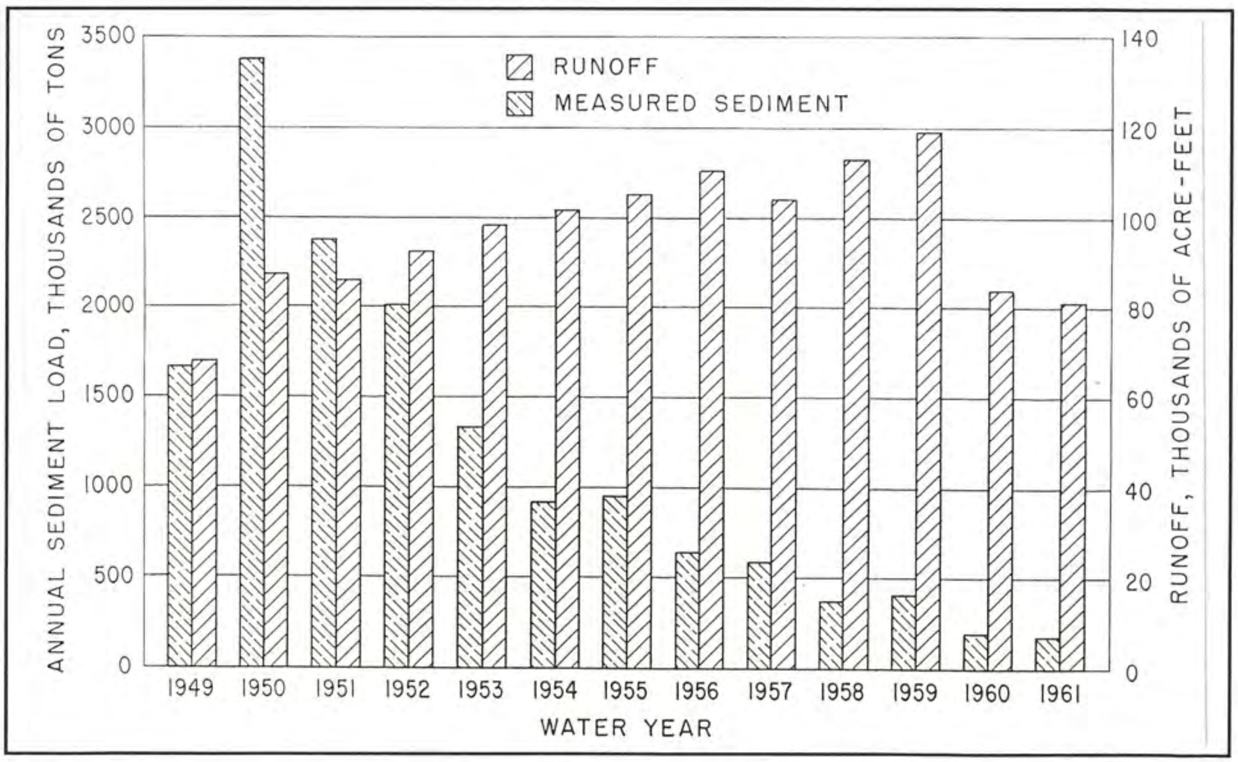

Figure 4. - Comparison of annual sediment load to runoff - Fivemile Creek.

UPPER SNAKE RIVER

Many of the rivers in the Pacific Northwest that need channel stabilization carry high flows, have steep gradients, and the streambeds are composed of sands and gravels. The Upper Snake River has been one of the most difficult rivers to stabilize in this region. To stabilize the riverbanks, dumped stone revetments and gravel levees are used. The drainage area in the Upper Snake River is 9,000 mi^2. Peak flows are of the order of 30,000 ft^3/s and the average slope is 0.0036. Figure 5 shows the design for placement of 0.5- to 1.5-ft^3 riprap in an 18-inch thick blanket. Due to the fact the original riprap toe did not extend below the river invert, there was failure of the riprap slope caused by undermining at the toe. It was found that, with a flow depth of 15-20 ft and a velocity range of 10-12 ft/s, a toe trench was needed which extended 5 feet below the river invert, figure 6. The riprap design should include:

- Adequate toe depth
- Eliminate small stones that prevent interlocking
- Provide uniform stone size
- Side slope should be 1 on 2 or flatter
- Riprap layer should be 1-1/2 times thicker than average size material

Along rivers such as the Snake, the single most important design feature of channel protection is the riprap toe.

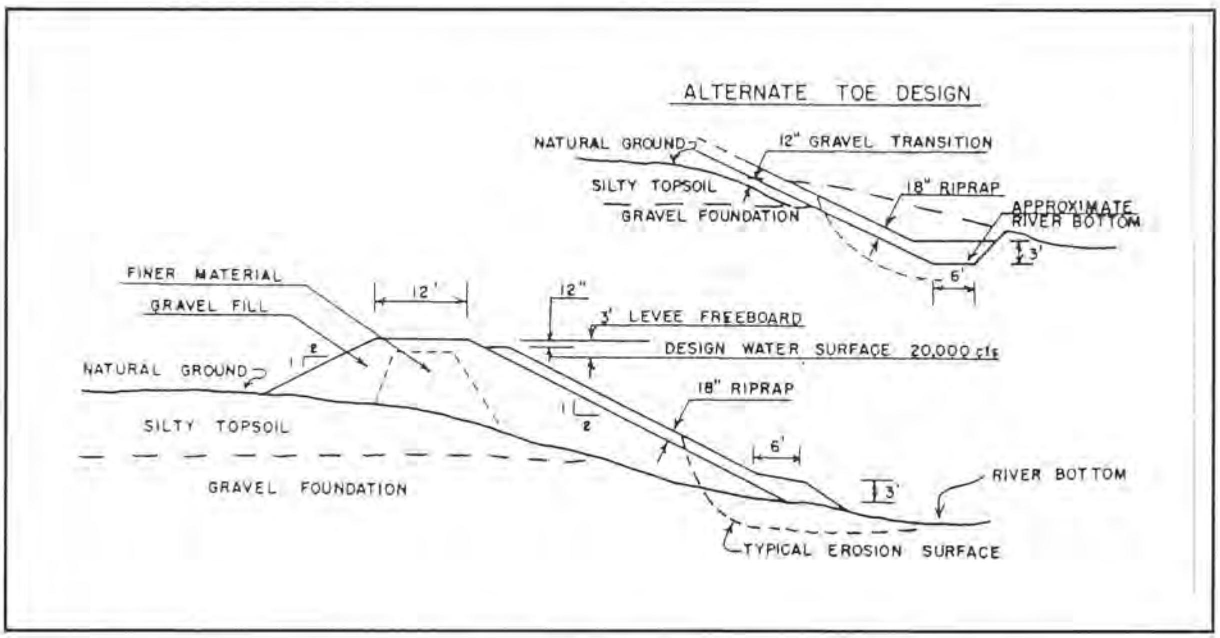

Figure 5. - Upper Snake River - Typical levee section before 1951.

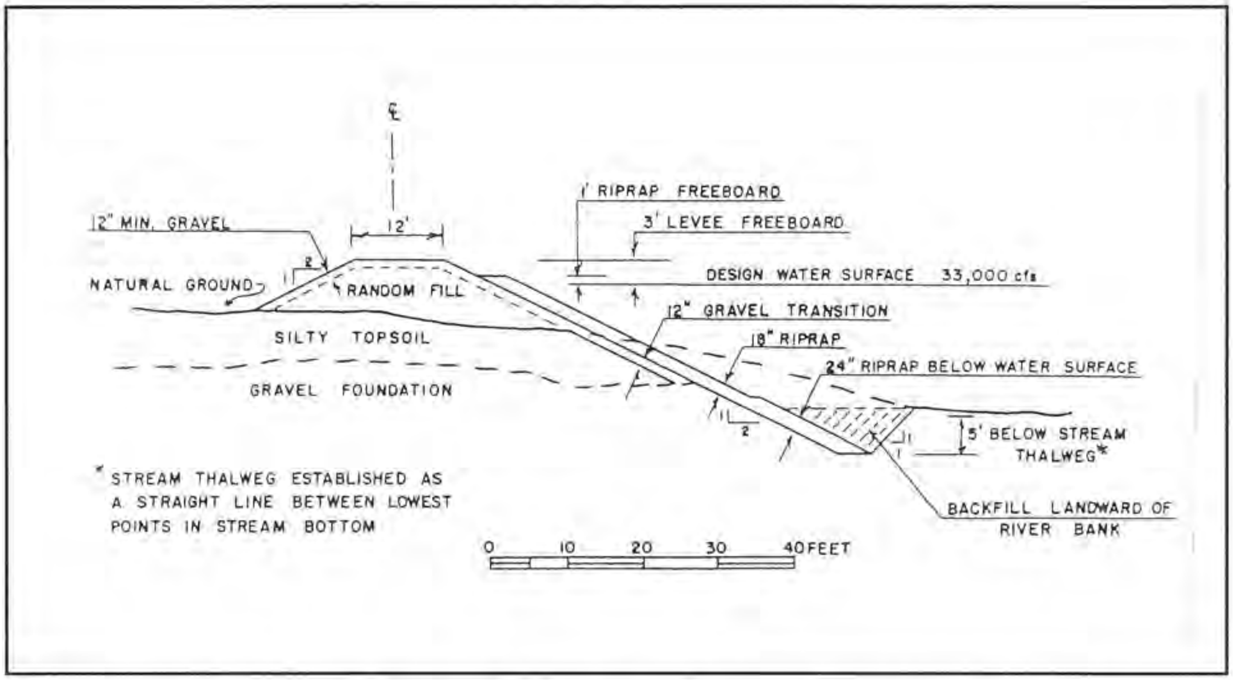

Figure 6. - Upper Snake River - Typical levee section after 1951.

MIDDLE RIO GRANDE RIVER

The Middle Rio Grande River in central New Mexico is confined by a floodway for approximately 183 miles. The channel has no banks and since there is more sediment entering the floodway than leaving, the average channel bottom elevation is at or above the areas behind the levees. The channel slope is roughly 0.00085 and the river is considered in flood stage for flows over 5,000 ft^3/s. The floodway was constructed in the mid-1930's to provide flood protection to the adjacent irrigated lands and urban developments. Channel stabilization was needed to protect the levees. The Kellner Jetty System was utilized to stabilize the channel.

The jacks consist of three angle irons (4 in by 4 in by 1/4 in) 16-ft long and joined at the center as shown in figure 7. The jacks are spaced on 12.5-ft centers and joined by 3/4-in cables to form a jetty field. The jacks are well suited for sand or silt laden channels which are subject to considerable channel scour during periods of high riverflows. The system is permeable, extremely flexible, and readily conforms to channel scour. It reduces flow velocity, resulting in deposition in the jetty field and allows vegetation to grow in the built-up areas. There is normally a 2- to 3-ft/year deposition rate in the jetty field. In a short time a secondary bank is developed, figure 8, which protects the levee and riverbanks and results in higher velocities in the thalweg to scour a deeper, more defined channel. The system costs were approximately $57,000 per mile of protection in 1960. This system has proven very effective on the wide shallow rivers of the Southwest, such as the Rio Grande, where sediment content is high, the channel slope is flat, and the riverbed is subject to considerable scour during floods.

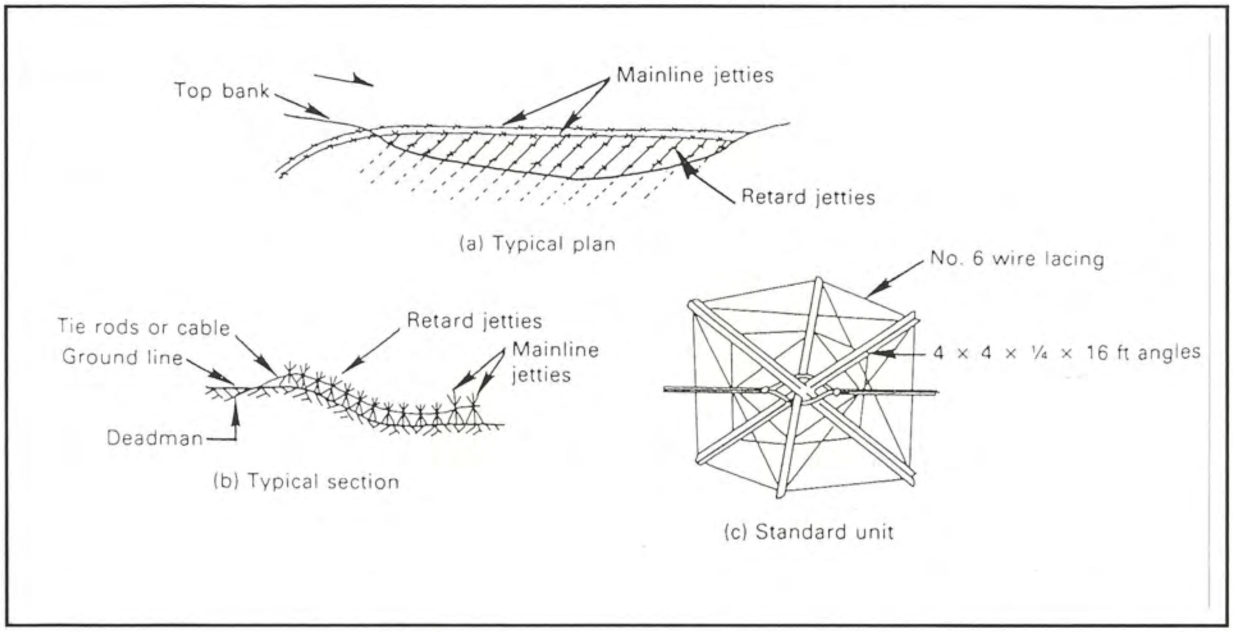

Figure 7. -Typical steel jacks.

Figure 8. - View of the Middle Rio Grande River near Albuquerque, New Mexico.

LOWER COLORADO RIVER

Channelization on the Lower Colorado River dates back to 1905 when a flood breached a small levee and the entire Colorado River flowed into the Salton

Sea until 1907. In the period from 1909-1912 a levee was built on the Lower Colorado River using riprap. It was maintained until 1935 when construction started on Hoover Dam. Hoover Dam caused two significant changes on the 400 miles of river below the dam: a change in the seasonal pattern of flow and a change in the sediment load. Before Hoover Dam, flood peaks reached 100,000 ft^3/s and low flows would fall below 1,000 ft^3/s. After the dam was built, the peak flows have normally been below 25,000 ft^3/s and the low flows are at least 6,000 ft^3/s. At Yuma, Arizona, annual sediment loads before Hoover Dam were 160,000,000 tons. After Hoover Dam was built, the sediment loads average one-tenth of that amount. This has resulted in channel degradation of up to 12 ft. The river's average slope is 0.00025.

On the Lower Colorado River, the clear water releases cause degradation downstream of the dams and resultant aggradation in the backwater reaches of the next dam downstream. In intermediate reaches an unstable, braided-type channel attacks the vulnerable banks. If the attack on the riverbed and banks can be controlled, then a sustainable river channel can be achieved. Various methods of bank stabilization have been tried. Permeable structures designed to cause deposition of river sediments in designated areas were first used. Both railroad rails placed vertically in the river on 4-ft centers and Kellner-type jacks were used. In both cases, the river velocities were too high and sediment concentrations too low. Erosion rather than depositionresulted. Sediment concentrations of 700 parts per million were needed for deposition to occur and the river carried only 300 parts per million.

The solution for this river with low concentrations of sediment and steep slopes was the use of riprap levees to control the vulnerable reaches. The river is now considered to be fully controlled from Hoover Dam to the international border.

COLUMBIA RIVER

Work on the Columbia River ship channel between Portland, Oregon, and the Pacific Ocean began as early as 1878. Early work consisted of channel dredging and use of a few dikes near the mouth of the river. These works were needed not so much to stabilize the channel as to deepen the channel for navigation purposes. It was desired to maintain a 25-ft deep and 300-ft wide channel. The average discharge in this section of the river is 245,000 ft^3/s. In the period from 1912 to 1916 dredging was found to be too expensive and ineffective because it required continual maintenance. On the lower Columbia River a second method, section control works, was found to be more effective, using dredging only as needed. For the section control works, the cross-sectional flow area was reduced using contraction dikes to produce the high velocity needed to scour a prescribed depth and prevent deposits in the improved channel. Figure 9 shows the concept and improvement in channel depth and control at Henrici Bar in the period from 1909 to 1959 as a result of strategically placed dikes. The overall general effect of channel control dikes has lowered the bed of the river over the bars and shoals. In 1930 the navigation channel project was enlarged to a 35-ft deep, 500-ft wide navigation channel. There are 150 contraction dikes along this 80-mile length of river. The project is now considered to be in a maintenance mode.

CONCLUSIONS

In the United States, river control works have developed over the years through trial and error, supported by theoretical and laboratory studies. The traditional approaches have resulted in "hard" engineering solutions that have been single-purpose in scope, often resulting in degradation of the aquatic ecosystem. Historically the traditional solutions have not considered the multi-purpose needs of a watershed system but have focused on the immediate problems along individual reaches of the river. This has resulted in somewhat of a patchwork approach to channelization on many river systems.

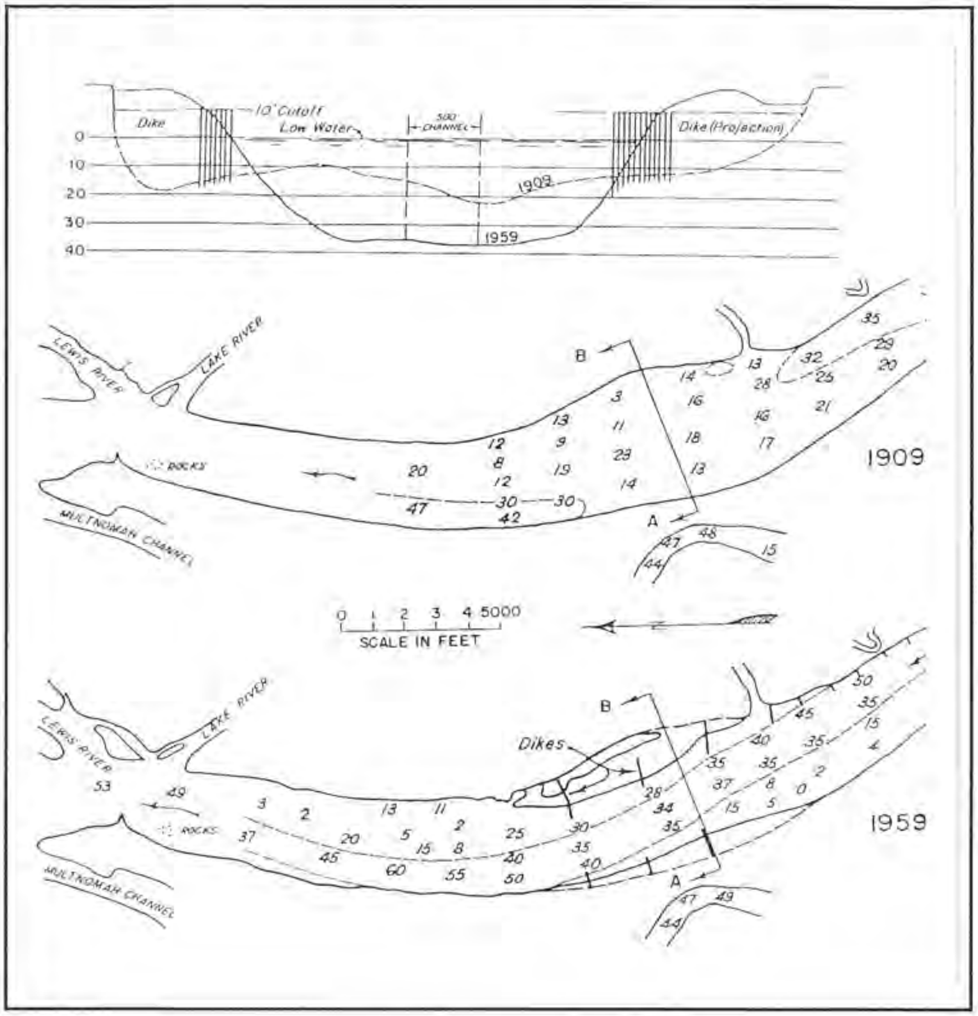

Figure 9. - Henrici Bar - 1909-1959.

The case studies presented in this paper summarize various engineering methods used to stabilize and channelize rivers in the Western United States. The following engineering conclusions can be summarized based on the knowledge gained through these experiences on river systems.

- Jetty fields are most effective in straight reaches or in river curves with radii greater than 14 channel widths.
- Jetty fields are successful in stabilizing rivers that carry appreciable quantities of suspended sediments and have rather flat slopes.
- Extensive planting of seedlings behind jack lines results in long-term stabilization of riverbanks.

- Annual deposition in jetty fields will range from 1 to 3 ft.
- Riprap bank protection should be uniform in size and normally have a blanket thickness 1-1/2 times the average size material.
- The riprap toe should be properly designed to prevent undercutting.
- Contraction dikes can be used to achieve velocities needed to provide equilibrium depths desired in navigation channels of rivers.
- Soft engineering practices using bioengineering concepts should be used when possible to protect the riverine environment and natural aesthetics of the river system.

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