# CARMEL RIVER MANAGEMENT PLAN

MONTEREY PENINSULA WATER MANAGEMENT DISTRICT

April 1984

CARMEL RIVER MANAGEMENT PLAN

## CONTENTS



## FIGURES

# CARMEL RIVER WATERSHED MANAGEMENT PLAN

## I. INTRODUCTION

### A. History of the Planning Process

The Carmel River Management planning process was set in motion because the people of the watershed, particularly those who own property along the river and their local government, mostly in the form of the Monterey Peninsula Water Management District, perceived the need to protect the natural, social, and economic values of the Carmel River.

To meet this goal, a citizens advisory committee was formed to study the problems and recommend a solution. The committee's final recommendation was the formation of a Carmel River Management Program. This program was approved by a vote of the property owners along the river on July 18, 1983. Of the 455 ballots cast, 367 or 80.7% supported the formation of the program. The program is funded by a collection of $45,000 annually based on the linear footage of each property owner's riverbank and $105,000 annually in water distribution system user fees. The scope of the program is embodied in Ordinance No. 10 of the Board of Directors of the Monterey Peninsula Water Management District. As stated in the preamble to the Ordinance, the program will "protect the water course, the watershed, public ways, life and property in the zone; promote the restoration of river banks and scenic resources; reduce environmental degradation; and enhance the fish and wildlife habitat".

This plan also provides for the actual implementation of the necessary measures to protect and restore the river.

### B. River Management/Watershed Management

While it is readily apparent that the successful protection and restoration of the Carmel River and its diverse resources must include management not only of the narrow river corridor but also of the rest of the watershed to which the river is directly connected, this plan addresses in detail only that portion of the watershed that involves the mainstem of the Carmel River in its alluvial reach - approximately the lowermost fifteen river miles. A watershed management plan for the entire basin is nearing completion. The largest problem that the river currently faces is channel instability in this alluvial reach. The upper areas of this basin have not yet experienced heavy suburban or residential development and the upper watershed, except for Tularcitos Creek, is not contributing substantial problems to the lower reaches, a factor which is mostly due to the presence of two water supply dams on the upper river effectively trap the majority of the rivers' sediment load at this point. Only when the riverbanks in the alluvial reach are stabilized will the management of the rest of the watershed become very important.

This plan proposes flexible and comprehensive river management. Not only will the property owner's needs along the river change, but also the river's itself. This plan cannot predict these changes but its goals and policies do form the basis for dealing with these problems.

Effective river and watershed management must be dynamic, requiring ongoing monitoring of public needs and resource conditions, testing and refining of techniques, and responsive adjustment of management actions. The most effective management of the river requires the residents along the river to exercise not only their right to participate in policy formulation, but also their responsibility for the implementation of the plan and program.

## C. Problems and Findings

The problems on the mainstem of the Carmel may be relatively straightforward, but their solution is somewhat more complicated. As seems to be the case whereever man has decided to live, his activities have altered and disrupted the natural processes of the ecosystem in the area. The immediate problem, which can be solved, lies in the relative instability of the river channel even at relatively low flows (those above 2500 cfs). The more long-range problem is the fact that the human encroachment on the active 100-year floodplain has put many houses, businesses, roads, bridges, and probably even lives in hazard for the flood event which will eventually occur. This river management plan cannot really cope with the problems which face the Carmel River during and after a 100-year flood, or even floods of somewhat lesser magnitude.

The instability afflicting the river is best correlated to the loss of riverbank cohesion through a decrease in the amount of native vegetative cover. Without a protective system of vegetative roots and cover, these unconsolidated riverbanks are highly susceptible to erosion. The loss of riparian vegetation and the resulting erosion of the underlying alluvial banks has greatly effected the river system. Wildlife and fish habitat have both been greatly impacted. There has been extensive loss of riverbank properties, and several homes and bridges are currently threatened. The instability of the river has also led to a progressive decrease in aesthetic values.

## D. Goals and Policies

This plan presents both a comprehensive set of general goals and specific policies and designs, which provide the basis for specific management actions relative to the river's problems. These goals are those developed by the Citizens Advisory Committee and embodied in Ordinance No. 10 of the Monterey Peninsula Water Management District. The policies identify the general approaches that should be utilized to achieve specific goals, given the particular problems of the Carmel River.

E. Recommendations

The recommendations which form the basis of this plan were developed from the overall goals and policies and are based upon a detailed knowledge of the river's problems and a consideration of the means (legal and financial) by which the program can be implemented. The plan identifies the river's problems in detail, possible and preferred solutions to these problems and their respective costs. The detailed recommendations are presented as a comprehensive management program. Yet this ideal solution cannot be constructed all at once, it must be progressively implemented. For example, erosion control work of the preferred solution design must be accomplished working progressively downstream from the source of the bank instability. Recommendations also have different priorities depending upon the severity of the problems they address and their implementation costs.

F. Implementation

The adoption of this plan will signal only the beginning of a long-term process of implementation. The program is currently set-up to last ten years. Within the framework of the plan, property owners and the Water Management District must develop further sources of funding for the proposed restoration program. Part IV addresses the tasks defined for implementing the plan more fully.

G. Need for the Plan

This plan gives riverbank property owners and other concerned Carmel River Watershed residents a detailed plan and program to successfully accomplish the goal of restoring and protecting the Carmel River. With the guidelines set forth in this plan, property owners and the Water Management District will be able to work together to achieve their common goals. Without such a plan and program there can be no comprehensive river management. Stopgap, piecemeal action would continue with the probable results of continued or even accelerated environmental degradation and property damage.

## II. BACKGROUND INFORMATION

### A. Setting

The Carmel River drains about 255 $mi^2$ while flowing northwest out of the valley between the Santa Lucia mountains on the south and the Sierra del Salinas to the north and east. The river empties into the Pacific Ocean near Carmel. Figures 1 and 2 show the Carmel basin and locate important place names. The river is 36 miles long, though this plan is primarily concerned with only the lower fifteen miles where the river flows through an extensive alluvial valley. Following Kondolf (1982), this plan separates the river into three distinct reaches: the lower river, from the mouth to the narrows, about nine miles upstream; the middle river, from the narrows to Camp Stephani, which is located just downstream from the confluence of Tularcitos Creek or just upstream from Robles del Rio; and the upper river, where it flows through rugged canyons. (Much of the following background information is only slightly modified from its presentation in Curry and Kondolf, 1983).

The upper watershed is sparsely settled and the Tularcitos basin is used for grazing, as is a portion of the upper Carmel Basin, but a large part of the latter lies within the Ventana Wilderness of Los Padres National Forest. Most of the population is in the vicinity of Carmel Valley Village and Robles del Rio, and dispersed through the flats and flanking hills of the middle and lower Carmel Valley. Extensive residential development has occurred from the narrows to the mouth in the last three decades, and in the last two decades extensive commercial development has taken place near the mouth of the river. Much of this development is located within the 100-year floodplain and is clearly vulnerable to erosion and flooding.

Climate: As is typical for Central California, over 90% of the annual precipitation falls from November through March, almost all of it as rain. Orographic effects are pronounced. Rainfall decreases from an annual average of over 36 inches in the headwaters, to 16.9 inches at Carmel Valley Village, to 14.2 inches near the valley mouth (Renard, 1980).

Geology: Bedrock in the basin is mainly Sur Series crystalline rock (granite, gneiss, schists) or Monterey Shale with significant outcrops of sandstone and volcanics. The area is extensively faulted, although most of the faults are still poorly mapped, especially in the rugged upper basin. The dominant northwest/southwest trend of the faults is reflected in the drainage network (Williams, 1983).

Historic Floods: There have been two and possibly three major floods by the Carmel River in historic times. The largest, which has been estimated by the Corps of Engineers to approximate the Standard Project Flood (a 500 year event) (U.S. Army Corps of Engineers, 1967), was in 1862. The next great flood occurred in 1911. The Monterey Cypress of March 11, 1911 reports that more

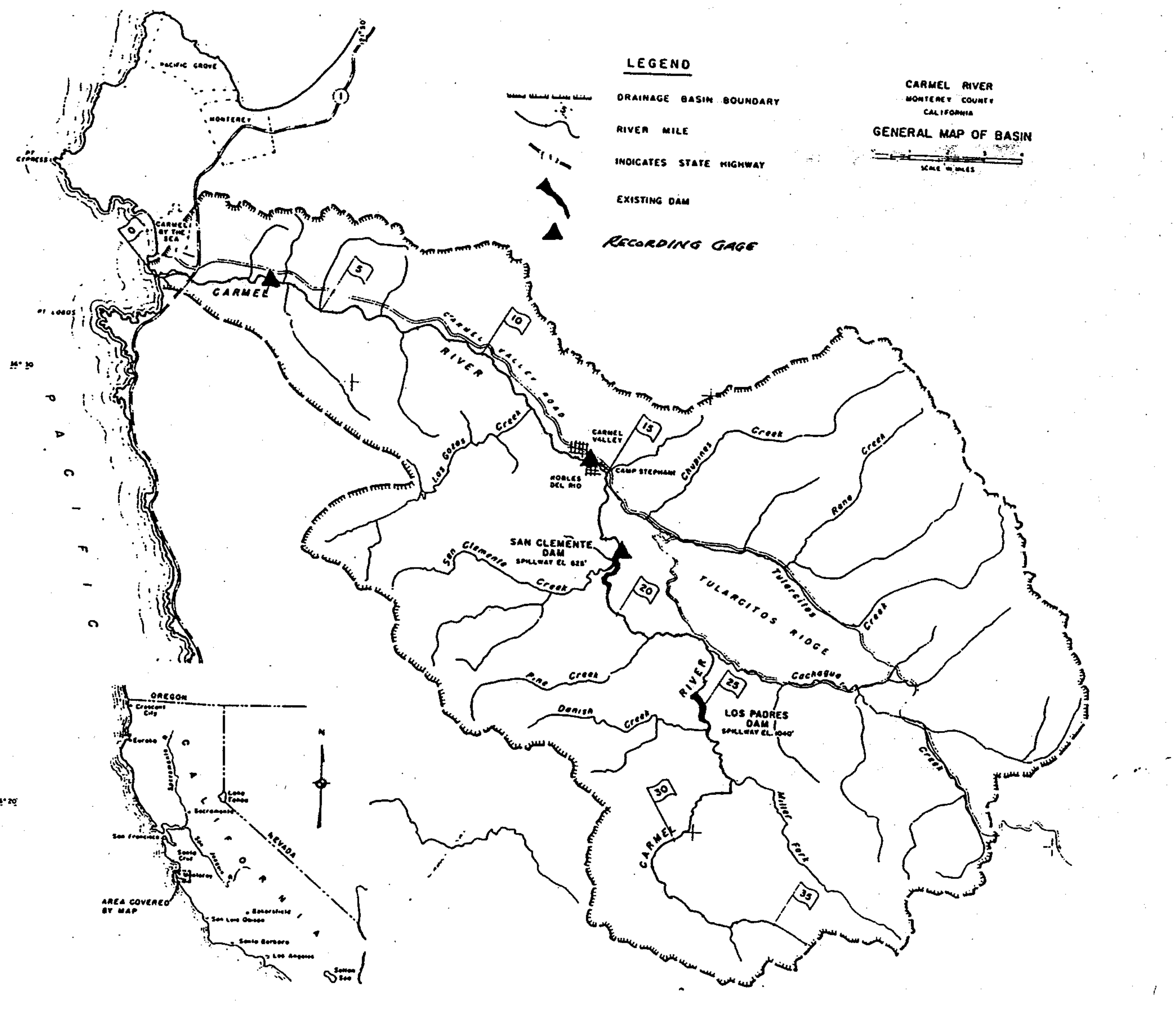



FIGURE 1. Basin and Location Map for Carmel River Basin, from U.S. Army Corps of Engineers.

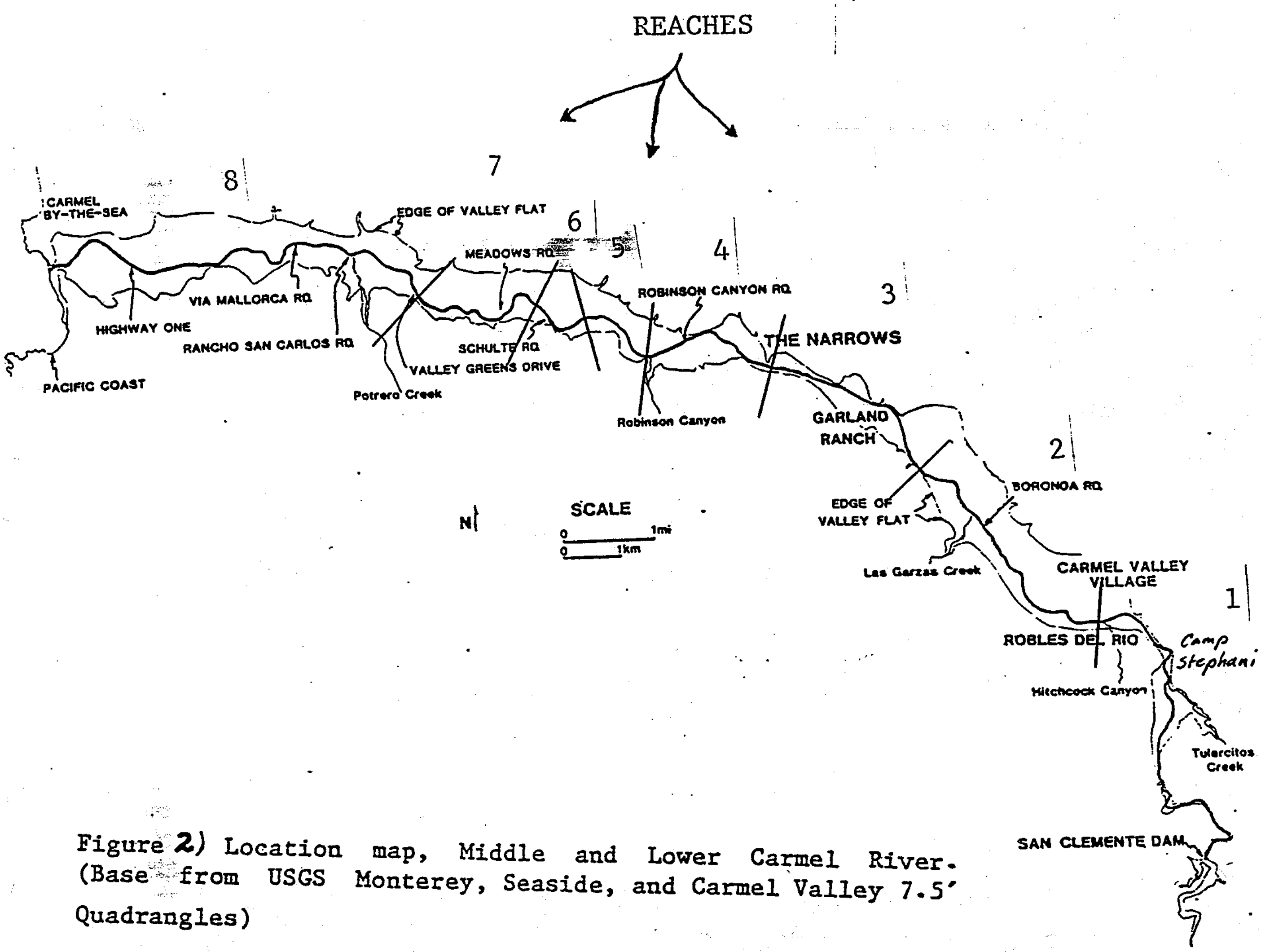



Figure 2) Location map, Middle and Lower Carmel River. (Base from USGS Monterey, Seaside, and Carmel Valley 7.5' Quadrangles)

than 25 acres of orchard were destroyed by lateral migration of the river (Kondolf, 1982). Figure 3 shows the historic channel changes of the river as documented by Kondolf (1982). The peak discharge has been estimated at over 20,000 cfs at San Clemente Dam, or about that of a 100 year flood (U.S. Army Corps of Engineers, 1967). The third flood, that of 1914, is less well documented, and it is not certain whether it was smaller in magnitude than the 1911 flood, or simply occupied the 1911 channel and caused less disruption (Kondolf, 1982).

Dam Construction: There are currently two dams on the Carmel, both designed for water supply rather than flood control. The San Clemente Dam was built in 1921 replacing an older diversion structure and is approximately 18 miles upstream from the mouth. In 1946, Los Padres Dam was constructed seven miles farther upstream. Both reservoirs are small (2,150 and 3,200 acre-feet respectively when built), with little effect on flood flows, but do affect low summer flows. The Carmel River was perennial before 1918 and only intermittent since, being dry in late summer in all but very wet years (Williams, 1983).

Channel Response: The historical response of the river to the dam construction and concurrent fire supression has been documented in detail by Kondolf (1982) and Curry and Kondolf (1983). An additional factor in the river channels response has been a lack of major floods after 1914. While the river can be said to have basically narrowed, incised and increased in sinuosity, the lower Carmel and the middle Carmel responded differently to these changes in the system.

The lower Carmel narrowed, incised, and developed a dense riparian corridor by 1939, the year of the areas first comprehensive aerial photography. The lower Carmel then remained virtually unchanged until the recent instability began.

In contrast, above the narrows, the middle Carmel has continued to change up to the present day. The channel became less braided from 1939-1965 and has incised and begun to migrate laterally in addition, particularly in recent years. Much of this change may be due to the inherent instability of this section of the river, which, with a gradient of .005 compared to the lower Carmel's .003, is significantly steeper (Kondolf, 1982).

Bank Devegetation: To complicate the situation, extensive groundwater pumping by the local private water supplier, California-American Water Company (Cal-Am), began in the early 1960's. This pumping, coupled with a severe drought in 1976-1977, deprived some of the riparian vegetation in the affected reaches of water for virtually two years. As a result, much of this vegetation died, providing the starting point for bank erosion.

Without the vegetation to hold the (non-cohesive) unconsolidated river banks together, the river found it easier to

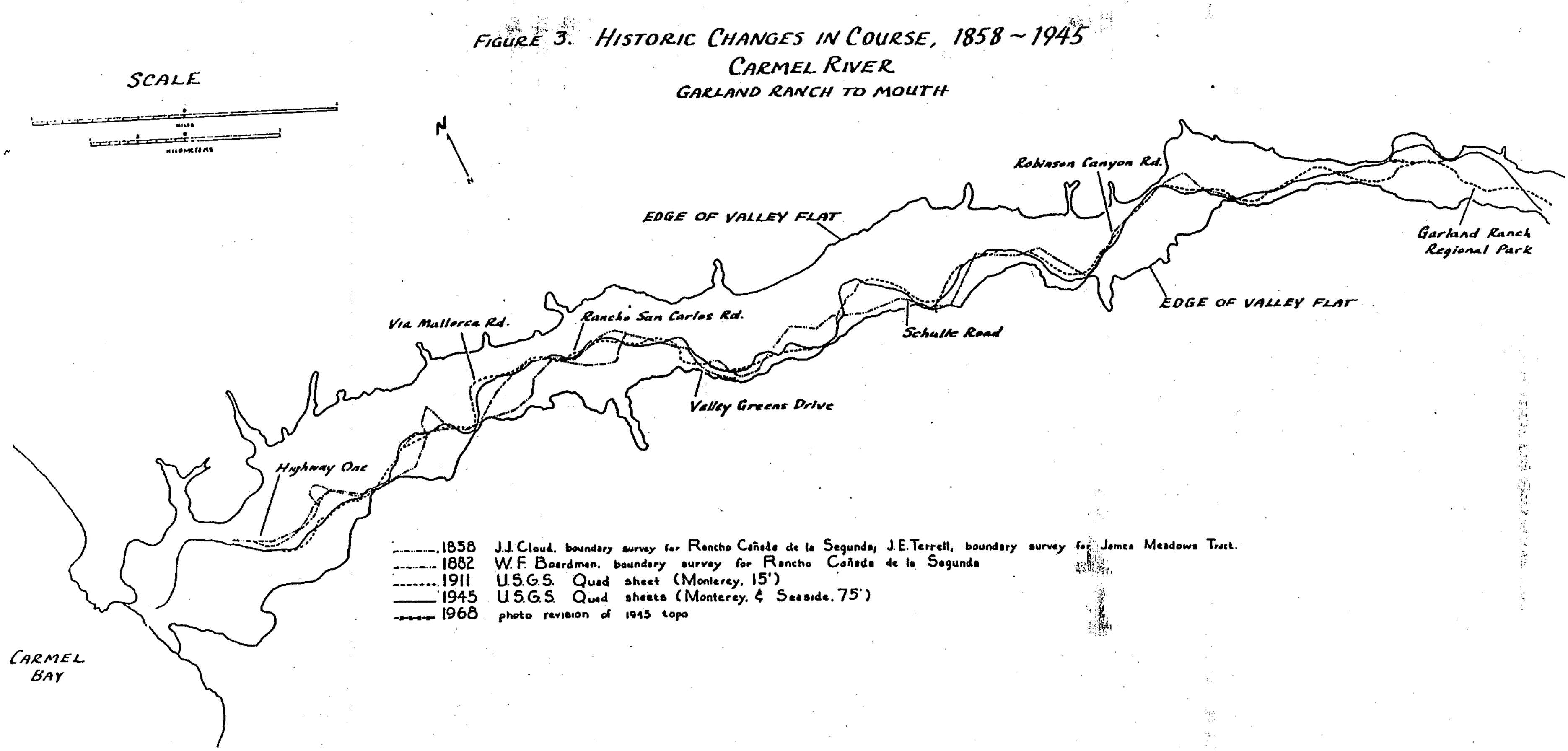



Figure 3. Historic changes in course, Carmel River, Garland Ranch to mouth. Data from boundary surveys for Spanish land grants and USGS topographic maps.

migrate laterally than to disturb its armored bed.

Bank Erosion: While the base cause of the fundamental channel changes since 1911 lies in the decrease in sediment supply due to dam construction and fire suppression, the bank erosion which has occurred in the last 15 years is largely associated with the loss of bank stability at specific sites. Major bank erosion in 1968-69, 1972-73, 1977-78, 1979-80, 1981-82, 1982-83 has occurred primarily in the Scarlett Road - Valley Greens Drive reach, except for in 1982 and 1983 when substantial erosion took place in the middle Carmel from Equiline Bridge to the narrows. Virtually no significant erosion has occurred west of Valley Greens Drive since 1970.

B. Problems and Solutions

Erosion and Sedimentation Problems: The primary problem on the Carmel River is bank erosion, which has been occurring in large amounts at relatively low flows, generally due to the presence of non-cohesive, unprotected banks. Once the erosion has taken place it presents another problem: the erosion introduces large amounts of sediment into the channel which then moves downstream and can cause further erosion or instability. This describes a positive feedback loop or a potentially self-perpetuating system. In this way property downstream, which would have otherwise remained stable, can suffer bank erosion. Once the sediment is in the river channel it will move downstream as long as the transport capability of the riverflow exceeds the amount of material. If flow decreases below a given value which is dependent upon the amount of sediment being trandported, material will be deposited. This may cause the development of sand bars and localized channel aggradation. This, in turn, elevates water levels and can cause the flow to impinge on areas that are not protected. It can also cause an increase in the forces directed against a given bank which may then exceed the binding forces. Aggradation can thus redirect the river's course and the impact of its flows. The field of fluvial geomorphology does not currently have the ability to predict where and what consequences particular sediment inputs will have downstream.

Curry and Kondolf (1983) have shown that bank erosion contributed over 90% of the basins sediment yield in 1982 and over 80% in 1983. The solution, then, is to control bank erosion, by whatever means necessary, which would thereby reduce or eliminate this source of substantial sediment. If the banks were stable, the sediment load would be limited to tributary sediment contributions and localized changes in channel storage. Curry and Kondolf (1983) addresses this issue in detail. Their conclusion runs as follows: given the stability of the river's banks, and "normal" tributary contributions, a "normal" range of river flows will flush most of the excess sediment out of the channel within a ten year period. This will tend to reestablish a more stable cross section and longitudinal profile. Structural features and vegetation planting can then reduce the excessive width of the current channel and promote bank stability.

The effects of bank erosion and the corresponding downstream sedimentation problems can vary from minor to severe. The most severe comes about when erosion creates additional locations of instability. There is also the effect on flood hazard, which is increased by substantial channel aggradation. The excess material, particularly sand sized material (the most easily moved) can severely impact downstream fish habitat. A sand bed river discourages spawning and also causes problems for the rearing of young fish. Bank erosion causes general degradation of the resource, loss of riparian vegetation, decrease in aesthetic values, along with other secondary impacts.

A question that needs to be addressed is how the lower reaches of the river from Valley Greens Drive to the ocean have remained stable despite the passage of large amounts of sediment over the past five years. Very little bank erosion has occurred in this stretch of the river. The channel is narrow, deep, and well vegetated. The banks are extremely cohesive, so that increases in discharge are taken up primarily by increases in depth and velocity. As documented by Kondolf (1982), there is considerable scour in this part of the river at high flows (greater than 2000 cfs). To quote from the Curry/Kondolf sediment report (1983), "the Carmel is a potentially unstable system. On the Lower Carmel, the presence of bank vegetation can make the difference between a narrow, stable channel and a wide, shifting channel." Repeated surveys show that the bed elevation has not changed significantly , at least in the reaches surveyed, despite the high sediment load. This reach of the river has an extremely high bedload transport capacity, which tends to flush large amounts of sediment (mostly sand and gravel size) through without causing erosion problems.

The erosion problems on the river can be discussed in detail more easily when the river is divided up into reasonable segments. For the purposes of the Carmel River Management Program, the river has been subdivided into eight reaches. This division tends to locate areas of erosion separated by stretches of relative stability, while at the same time trying to keep the reaches approximately equal in length, except for the furthest upstream and furthest downstream which have remained stable in recent years. Working from upstream to downstream the reaches are:

1) Upstream of Esquiline Bridge
2) Paso Hondo - Los Laureles
3) Garland Park - Narrows
4) Carmel Valley Ranch - Robinson Canyon Creek
5) Begonia - Manor Well
6) Schulte Bridge
7) All Saints - Valley Greens Bridge
8) Carmel Valley Golf & Country Club - Lagoon

The delineation of these reaches is somewhat arbitrary though it makes discussion of specific sites of erosion much more manageable. Various parts have suffered at different times and it is not the purpose here to detail and discuss every instance of erosion along the river. Major problem areas will be identified, and the current (1-1-84) situation defined, and the magnitude of the job facing the river management program described.

Reach 1: This stretch from San Clemente Dam to Robles del Rio has not seen many erosion related problems over the years. The channel is generally well vegetated and steep with coarse bank material. The largest problem facing the property in this reach is the fact that too many structures are too close to the river. In anything over a 10-year event, structures begin to get wet.

Reach 2: This reach, which includes Boronda Road Bridge, has suffered significant bank erosion since 1978. The current situation is not good. Below the Little League field coarse material has formed several large point bars causing the river to actively erode at the outside of bends, as the river finds it easier to erode unprotected banks than to mobilize its armored bed. The sinuosity is increasing and this situation is self-perpetuating and is causing downstream sedimentation problems of the type discussed at the beginning of this section. No work has yet been done to address these problem areas which effect the entire river downstream. This problem directly lead to the erosion of the Palmer property at the foot of Panetta Road which resulted in the loss of a swimming pool. The erosion from this location moved sediment downstream and formed a large gravel bar at the Boronda Road Bridge. This bar diverted flow to the south bank and threatened the southern abutments of the bridge as well as causing loss of land on the properties immediately upstream. The problem has progressed further downstream increasing the threat to property owners on the south bank downstream of the confluence of Garzas Creek. A gravel bar is enlarging and diverting flow against the south bank. The bank is reasonably well-protected by concrete blocks and concrete riprap placed in 1982 and 1983, but the area is unstable. The instability continued downstream, eroding banks and began to cut behind the protective works at the Mills property. Erosion also occurred just downstream and at what is known as the O'Neal bridge, which caused the southernmost abutment to collapse in 1983 and resulted in some bank failure on the northside of the river.

Reach 3: This reach suffered extensive erosion during the winter of 1983. The history of previous erosion included the winter of 1969 when Carmel Valley Road was washed out, and then relocated from the bluff down onto the floodplain. The river was straightened through Garland Park as part of the relocation. Downstream of Rancho Don Juan Bridge the south bank failed in 1978 near the obvious eucalyptus grove. This bend was rebuilt by the U.S. Soil Conservation Service using gabions and willows though this work failed in 1983. The 1983 erosion began where the channel leaves the bedrock at the upstream limit of Garland Park. Extensive erosion occurred as the high velocity flows channel bounced from bank to bank, including the undermining of part of a house at 600 W. Carmel Valley Road. The north bank at Garland Park parking lot failed, though the rest of the channel down to Don Juan Bridge remained stable. Below the bridge, a mid channel bar diverted flow which then threatened Carmel Valley Road. Continuing downstream, Randazzo and Koontz both lost substantial property. Below the private bridge, the channel remained reasonably stable through the narrows, though the sinuosity appears to be increasing. Much of this damage has been repaired through various means, though the piecemeal approach to the problems does not address their root, which is primarily sedimentation from upstream erosion.

Reach 4: This reach has shown considerable instability, particularly in recent years. In 1969 Robinson Canyon Road Bridge was washed out. It was rebuilt to withstand much higher flows and is one of the best designed bridges on the river. Conditions upstream, however, are causing the river to attack the southern abutment, and this could cause problems at higher storm flows. When comparing aerial photographs from 1965 to the present for this reach, there are two features that stand out. The most obvious is the loss of riparian vegetation, particularly the virtual elimination of the riparian corridor on the south bank of the river at Carmel Valley Ranch. Second is the increased width of the river and the associated growth of extensive gravel bars. There has even been significant change from 1980 to 1983. Sinuosity appears to be increasing in this reach as the river migrates laterally. Carmel Valley Ranch has spent large sums of money on structural bank works which have not been entirely effective. The golf course has lost parts of several greens, tees, and a long stretch of sand trap upstream of Robinson Bridge. The river has become increasingly angular as it negotiates the sharp bend below the Carmel Valley Road overlook. The shale bedrock outcrop diverts water towards the south bank and a growing gravel bar tends to keep it along the south bank. A relatively resistant point, due to a cement wall and vegetation which define the upstream end of a post and wire revetment, at the downstream end of the sand traps is currently diverting flow towards the north bank, and land at the former sand and gravel plant is being eroded. From here the main current is directed towards the south abutment of the bridge. After a short straight reach the excess sediment load has caused formation of a mid channel bar which diverts water against the north bank, and erosion during 1983 exposed the casing of a Cal-Am well, which has since had to be abandoned.

The structural works built by Carmel Valley Ranch show some of the problems facing that particular type of work and the inability of the piecemeal approach to protect against upstream instability. Aggradation from upstream erosion caused local erosion behind the post and wire revetment when large floating debris caught on the top of the structure and diverted flows. Unfortunately, the design of the works also seems to be causing problems. By protecting the land on the south bank with the revetment, the angularity of the river was accentuated from a temporary instability in 1980 to a permanent condition. This structure has caused the erosion of property downstream, and will continue to promote instability in the reach. A much better design would have been to redirect flow to imitate the 1965 channel, by making the river go through a gentle arc on the outside of the bend.

Reach 5: From the Begonia well to the Manor well, the river has increased its width, formed large gravel bars and caused localized to severe erosion, particularly on the north bank from the Stevens property through the Berwick Ranch and the Egg Ranch. Again, the most obvious change since 1965 is the loss of riparian vegetation. How this primarily came about, whether by landowner removal, disease, groundwater pumping or erosion is a matter of debate. Much of the north bank is protected by riprap and concrete. Erosion at the Egg Ranch and Hacienda Hay and Feed took place in 1980, erosion on the south bank near the Stevens property occurred in 1983. The project design for this reach would primarily consist of channel narrowing vegetative and structural works to assist in flushing excess sediment downstream, and localized terrace revegetation.

Reach 6: The Schulte Bridge reach has seen the most extensive erosion along the Carmel River. Significant erosion occurred in 1978, 1980, 1982, 1983. Altogether about 15 acres of land have been lost to erosion in the last five years. The enormity of the channel change has initiated lawsuits and numerous reports. The current situation is interesting because the present low flow channel has a similar configuration to the 1965 channel, similar to what it was before the 1978 erosion. The river is attempting to return to a stable configuration by itself. If this low flow channel can be stabilized through vegetative and structural works, this reach will make substantial progress towards stability. However, without stable banks, the channel may change drastically in even one storm, as was seen in 1983. With the channel narrowed and the banks stable, downcutting will continue to occur with the final result of a stable, single thread channel with overbank terraces to accommodate high flows. Downstream of the bridge, widening has occurred due to the excess sediment load and has encouraged the development of extensive gravel bars which tend to divert flow against one bank or the other.

In 1979, the SCS constructed a gabion mattress on the north bank just downstream of the bridge and planted willows there. This has been one of the most successful projects on the river. This bank has remained stable through many high flows and a healthy growth of willows has been established.

Reach 7: This reach from All Saints School to Valley Greens Bridge suffered substantial erosion in 1978, which was then extensively rebuilt by the SCS. The banks from All Saints to Meadows Road were riprapped and some willows were planted. In 1983 a section of the riprap failed and the Drummonds on Fawn Court lost substantial property including their swimming pool, and almost their house. Downstream, large sand bars have formed, though the river banks have remained stable. Localized erosion has occurred on the outside of bends, particularly near where the Wolter Brothers had mined sand and gravel in the past. Vegetation, except at Fawn Court, Prado del Sol, and the Wolter's property, is in good condition. From the Wolters to Valley Greens Bridge, the river has been stable since 1978 despite the passage of very large quantities sediment. There are several reasons for this. Primarily it is the Carmel Valley Golf and Country Club efforts to encourage vegetation growth over extensive well-placed riprap and regular golf course watering.

Reach 8: From the Golf and Country Club to the Lagoon, the river channel has remained stable in all flows except those during major floods. Even the flood of 1958 caused only local erosion. The more hazardous problem in this reach is overbank flooding, particularly when upstream erosion is introducing large amounts of sediment into this section of the river. The river below the Rancho Canada Golf Course is protected to some degree by a series of levees.

Overall: The overall condition of the Carmel River in 1983-84 is not especially good. There are substantial stretches of the river which are lacking in vegetation. The channel is overly wide almost its entire length from Boronda to Valley Greens Drive. The inability of the river to move its excess sediment load is contributing to the problem through the positive feedback loop discussed at the beginning of this section. In addition, the sediment increases flood hazard and damages fish habitat. Much of the work done along the river has either not been designed or emplaced properly and will most likely not withstand high flows. The piecemeal approach to bank protection can and has caused extensive problems along the river. This situation can most easily occur when gaps were left upstream, in the middle, or downstream of bank protection works, as frequently happens when some properties have works done but others do not. Bank protection works also tend to give property owners a false sense of security, particularly when they were employed improperly. The comprehensive management scheme, which this plan proposes, does provide the framework for the progressive restoration of the river.

## C. Requirements of a Given Solution

Any solution to the problems of the Carmel River must be able to address a wide range of concerns. The preferred solution which this plan proposes and defines is considered the optimal solution, effectively balancing the opposing forces of the river's different needs as described below.

Maintenance of Sediment Transport: The primary problem facing the river is the long stretches of unstable banks.

Unstable banks have been, and will continue to be, eroded, thereby introducing excess sediment into the channel. This sediment has formed bars and diverted flow to cause further erosion. As discussed by Curry and Kondolf (1983), any solution must effectively address this excess of sediment within the active channel. Unless a central stable channel can be created, the mid-channel and point bars will remain, redirecting flow against the banks, which will prevent the reestablishment of vegetation and continue the supply of excess sediment through bank erosion. A narrow, stable channel, with its higher sediment transport rates, is necessary to "flush out" the excess sediment. A comprehensive solution must attempt to increase the sediment transport rates which can most easily be done by constricting the active channel width. Curry and Kondolf (1983) recommend that the central channel be designed to contain approximately the 5-year storm or about 5000 cfs. The methods for constructing such a channel depend upon the funding available. The more money spent effectively shortens the number of years until reasonable stability is reached. Curry and Kondolf (1983) have presented extensive data on bedload transport rates and grain size and have developed a model which can accurately predict the transport rates at a given flow, providing the situation is similar to 1981-1983 when they collected their data. Sediment transport is the critical issue that any solution must address and is considered the primary requirement. Without both a decrease in the supply of sediment and an increase in sediment transport rates, stability cannot hope to be achieved.

Revegetation of Riverbanks: At the same time that the channel is constrained, the terrace banks must have additional protection, otherwise flows that overtop the central channel could cause further bank erosion. The stabilizing influence of riparian vegetation, particularly willows, is well documented in the literature as Curry and Kondolf (1983) have found. Planting of vegetation is one of the cheapest and is at the same time a reasonably effective means of protecting land from erosive forces. Vegetation also provides a number of benefits which most other types of protective works do not (in themselves) provide. These benefits cover a wide range of factors, including fish and wildlife habitat improvement and aesthetic value improvement.

Improvement of Fish Habitat: The improvement of the anadromous fisheries resource present in the Carmel River watershed has long been considered a primary goal of any river restoration program. The Carmel River supports probably the largest self-sustained steelhead resource south of San Francisco. This resource is in danger as essential habitat has been or is being degraded or destroyed by water development, bank erosion, and flood plain encroachment. Snider (1983) estimates that the production of sea-run adults has declined 50-75% in the past 60 years, and that natural production will cease in the next decade if the present rate of habitat destruction continues. Any program which stabilizes the river banks and encourages the reestablishment of the riparian corridor will improve the fisheries habitat. This revegetation, however, must be compatible with channel bank protection goals. A further means of habitat enhancement lies in the restoration of a natural pool and riffle sequence as discussed by Curry and Kondolf (1983). As they note, the disturbed reaches of the river are mostly lacking in natural low-flow pools. Yet their research indicates that a good pool/riffle sequence did exist in the lower river in 1965. They suggest the placing of pool-locating features at appropriate intervals (150-175m) in the disturbed reaches. These features need to be carefully designed and emplaced in such a manner as to encourage the development of a pool sequence which makes the best use of existing natural features.

Recreation: The issue of public access and use of the riparian corridor and the Carmel River channel itself has long provoked heated debate. The clash is between proponents of private property and those who feel that the Carmel River is a unique resource which the local community should be able to enjoy in a variety of ways. Currently the only official public access to the river exists at Garland Regional Park and at Carmel River Beach State Park. Despite this lack of access, the river and its associated riparian corridor are enjoyed by many people. Children play in the river, people float down the river in all types of rafts and canoes, fisherman use it extensively during the steelhead season, and horseback riders frequent many sections of the river mostly at lower flows. Motor vehicles are currently prohibited from the river channel.

This plan is primarily concerned with the progressive restoration of the Carmel River from the point of view of bank erosion control through a stable channel design, and the effective management of the riparian corridor once this goal is achieved. The primary mechanism for this restoration will be the reestablishment of natural river bank vegetation and, therefore, the riparian corridor. Any activity that is directly contrary to this process of restoration and would have a serious impact on the vegetation or the design channel, cannot be supported by this program. Certain uses, and the majority of the current ones on the river, are compatible at various levels with this program, providing certain standards are created or precautions taken. The river management program must attempt to educate the public about the consequences of activities which are deleterious to the health of the riparian system.

Particular recreation activities are discussed below in relation to the river management program. There are three categories which need to be considered: (1) children/rafters; (2) fishermen; and (3) horseback riding/hiking.

(1) Children/rafters: This type of activity will continue regardless of attempts to control it, and for the most part is relatively harmless. It is possible for people who raft the river to break down the banks or trample young vegetation as they try to get down to or leave the river channel. The river management program has the responsibility to design and construct its works to minimize any hazard to either playing children or

rafters. In addition, the program should discourage the use of bank protection materials (specifically concrete riprap with reinforcing bar protrusions) that may be hazardous to these activities. Children must be educated that willow stems are not to be pulled out despite the fact that they look like keen toys.

(2) Fishermen: Fishermen have long been considered a virtually intractable force, which tends to invade the river channel below Esquiline Bridge during the steelhead season. This type of concentrated use can damage riverbanks and vegetation in rather localized areas, particularly near the good fishing pools. The program must attempt to inform and educate the fishermen, through the Department of Fish and Game and the Carmel River Steelhead Association, that particular care needs to be taken around young willow plantings, and the river in general. January and February are a particularly important time as willows planted in the fall (November) will be just beginning to sprout.

(3) Horseback riding/hiking: Horses have often been blamed, frequently with just cause, for destroying riparian vegetation and thus initiating bank erosion. Horse traffic can rapidly crush young vegetation and breakdown river banks. However, the Monterey County General Plan and the Carmel Valley Master Plan have included the creation of a system of horse/hiking trails along the river with language such as "Equestrian and hiking trail easements along the river shall exist in a continuous unbroken system usable year round, subject to controls necessary to mitigate erosion and protect riparian vegetation" (Draft Carmel Valley Master Plan, 1983). The Carmel River Management Program must address the issue of trail location and construction where it is consistent with the land use plans. These trails must be located away from fragile vegetation and unstable banks. It may even be wise to curtail horse traffic for one or two seasons to give the vegetation a chance to get established. At Garland Park, the equestrian trail is located on the upper terrace, out of the channel and outside of, or on the fringe of, the riparian corridor. Proposed trails as located in the Carmel Valley Master Plan exist along the full length of the river, from the mouth to the village.

Aesthetics: Aesthetic requirements for channel restoration works is another rather slippery topic, and of particular importance in the time frame considered. While the end result of this program's channel restoration and bank stabilization works, a narrow channel fringed with a dense riparian corridor similar to the conditions which existed in 1965 or earlier, is clearly acceptable from an aesthetic viewpoint, there may be concern with the initial construction and maintenance of the works until the vegetative growth has developed and covered them. Works of a temporary nature are also contemplated which would allow the establishment of vegetation, and then would be removed. Any solution to the existing erosion problems along the river must be formulated to provide direct and immediate enhancement of the river's aesthetic values or it will not be considered acceptable. The maintenance and improvement of the aesthetic nature of

Carmel Valley, which is undoubtedly one of its most important resources is of primary importance.

## III. POSSIBLE SOLUTIONS

There are five possible lines of attack on the problems of the Carmel River. These are: 1) no action; 2) management solutions; 3) structural solutions; 4) vegetation solutions; and 5) structural/vegetative solutions. The details of each of these possible solutions is discussed below.

### A. No Action

This would allow the current piecemeal approach to bank protection to continue which will allow stream banks to erode from Robles del Rio to Valley Greens Drive and possibly further until a very wide, constantly shifting, channel develops.

### B. Management

Land use and ground water guidelines could be developed such that the river would tend to slowly return to its stable pattern and eventually reestablish the riparian corridor. This assumes no large storm flows or droughts and the active cooperation of the land owners.

Neither of these "solutions" is a possible approach for the Carmel River Management Program.

### C. Structural Solutions

There are numerous possible structural solutions to bank erosion in general and most of these could be applied to the problems of the Carmel River. Generally, the most limiting factor is cost, followed by environmental considerations. Most of the options discussed below have been used at one time or another along the alluvial reach of the river. Study of these works helps provide information on the effectiveness of the various types of structural works, and their relative advantages and disadvantages.

Channelize River: A possible solution would be the direct channelization of the river from Robles del Rio to the ocean or perhaps only Valley Greens Drive, which would still involve at least 20 miles of continuous riverbank protection. This solution is obviously not compatible with the goals of the Carmel River Management Program not to mention its prohibitive costs, environmental damage and aesthetic impact, etc.

RipRap: This type of riverbank protection is currently the most popular with the residents along the river. Riprap can vary from concrete rubble, or concrete blocks to dolomite or granite boulders. The size used in the past has varied from fist-sized to 5-ton boulders. Generally speaking, the larger the material, the greater the protection that is obtained, provided that the material is properly emplaced to prevent the finer materials behind the riprap from being drawn out by the vacume created from the force of the passing flow (i.e., the use of a filter fabric or other material). The riprap must also be placed deep enough to negate the effects of scour and subsequent undercutting. The advantages and disadvantages of each type of riprap is discussed below.

(1) Concrete Rubble: Concrete rubble which generally comes from the demolition of large buildings around the Peninsula (i.e. the San Carlos Hotel and Cannery Row), has been used extensively by residents generally as a stop-gap emergency form of bank protection. It is reasonably cheap, though not always available, and can be dumped off trucks at high flows for emergency work. Problems with this rubble include the reinforcing rod (rebar) which extrudes from much of the rubble, other materials (trash, wood, etc.) which are included in the rubble, problems caused by improper placement (proper placement is impossible at high flow), asthetics, and problems with the establishment of vegetative cover and willows. The cost of such bank protection material varies tremendously depending primarily on supply, distance involved in transporting it, and what is done with it once the truck dumps it. If a large demolition contract is taking place (like the San Carlos Hotel), homeowners may only have to pay transportation charges. At other times costs may be much higher. The effectiveness of concrete rubble as bank protection depends primarily on how effectively the material was placed. The effectiveness is low when the material is dumped into the flowing river, yet increases substantially if a filter material is provided and the rubble is placed and compacted by heavy equipment, and even further if placed properly and then riparian vegetation is established over it. Effectiveness also depends on the size of the individual pieces, the velocities present in the river and what is taking place upstream of it. Virtually any work can be compromised if sufficient erosion occurs upstream to substantially alter the hydrologic system.

(2) Concrete Blocks: This type of protection consists of concrete cubes, usually 3 feet on a side which have a hook on the top so that the block can be cabled to a more secure location. Generally, these blocks are placed in rows and cabled together, and may be placed to form walls. Occasionally, the blocks are merely dumped down the bank, then perhaps cabled to a deadman or a similar secure structure. The problems with these blocks are about the same as those with concrete rubble: 1) placement so that scour is not a problem; 2) aesthetics are affected more as rows of blocks effectively look like concrete walls and channelization structures; and 3) it becomes even harder to establish riparian vegetation, as fewer gaps exist between and around the blocks. Advantages are the size and weight of the cubes which mean that they will remain in place through a wide range of flows unless undercut, and the fact that individual cubes can be cabled together to provide more extensive protection. The concrete blocks are fairly expensive to construct considering form construction time and materials, cost of concrete and cost of placement. Costs should be around $100/block. In terms of effectiveness, this again depends on placement though it would generally be much higher than concrete

rubble due to size, weight, and the presence of blocks which are cabled together.

(3) Dolomite Riprap: The use of dolomite boulders apparently began in 1980 when the U.S. Army Corps of engineers used the rock to protect bridge abutments at Boronda and Schulte Roads. The use has increased dramatically in the past 2 years as other local sources of riprap have disappeared. The dolomite comes from the Kaiser quarry which lies northeast of Salinas. There are few advantages to the dolomite except that it seems to be all that is available in large quantities at the present time. The dolomite is exotic to the Carmel River basin and its vibrant white color creates aesthetic problems. Also, much of the dolomite that has been used in recent years is not quite large enough to do the job effectively. The cost of this dolomite riprap is high, around $30-40/ton. The effectiveness of the dolomite is again dependent on how it is placed, and the size used. The dolomite placed at both the Boronda and Schulte Bridges by Monterey County has progressively washed downstream during the last three storm seasons (see Curry and Kondolf, 1983), providing information on the transport rates of coarse material. Natural boulder riprap must be placed more carefully than concrete riprap because of its greater roundness which makes it easier to move if its original placement is disturbed.

(5) Granite & Other Riprap: This type of riprap has been used in limited quantities along the river. The granite has primarily been of the Santa Lucia Diorite group which is not very common in the basin either, so that it appears somewhat out of place, yet its speckled brown color blends well with natural colors found along the banks of the river. The cost of granite riprap varies depending on the distance transported, but commonly costs more than its dolomite equivalent. The effectiveness depends on size and placement. Natural riprap seems to provide better conditions for the establishment of riparian vegetation than does its concrete counterpart. If properly placed, this type of rip-rap should be able to withstand a 10- to 20-year event, or more if high velocity flow is not directed against it.

The critical factor for the use of riprap as a bank protection is placement. Riprap, if improperly placed, may not withstand a five-year event regardless of its size. However, large riprap properly placed may withstand extremely high velocities and should be considered as a possible solution at locations of high risk, i.e., bridges, homes, businesses, or production wells.

Tetrapod Jacks: These three-dimensional structures are built by bolting three large timbers, generally railroad ties, together at right angles and then connecting the outer limbs with barbed wire which acts to collect debris and break up and divert high velocities. Jacks can be assembled on the spot by the property owner and emplaced with minimal effort. The wooden jacks can float and therefore provide protection only near the surface and do not prevent scour and undercutting. Jacks can also be made from railroad rails which are more costly, harder to build and emplace, but are heavier and tend to remain in place. Overall, jacks should be considered emergency protection and not a long-term solution to bank erosion problems. A row of jacks cabled to a secure deadman can provide a certain level of protection in some cases. They do not work as well on a river like the Carmel which is generally deep with high velocities. Jacks work best with shallow flooding and moderate velocities. Jacks should be considered a temporary solution at best, something used in an emergency, and then replaced with improved bank protection works. Jacks do not provide any environmental enhancement, they only prevent major erosion. They are not aesthetically attractive and pose potentially hazardous conditions for recreational users of the river channel.

Post & Wire Revetments: This category of bank protection works contains a number of different types which are all based on a strong, permeable fence-like structure, built in place out of wood, rail, or pipe, the front face of which is covered with wire and usually back-filled with river cobbles. These structures tend to divert flow and break up high velocities while allowing water through to help recharge the aquifer and provide water and nutrients for vegetation. These revetments can become very effective if they are coupled with an intensive revegetation program along the bank they are protecting. This approach has only been used on a limited basis on the Carmel River. Carmel Valley Ranch has constructed extensive works of this type in the last few years with somewhat mixed results. The works constructed on the south bank at Carmel Valley Ranch consisted of a double row of pile-driven telephone poles with 8" x 8" cross-ties bolted to the poles. Fencing was attached along the faces of the structure and was filled with river cobbles. Problems occurred with this design due to two reasons: (1) limited bank erosion and bank sloughing will occur if the banks behind the structure are completely unstable, as the structure is designed to be highly permeable; and (2) the tops of the poles were above the level of the cross ties so that debris could easily become lodged there if flow was high enough. This occurred where a large tree caught on top of the structure and diverted moderate velocity water at the unprotected banks behind. Other structures can be designed using pipe and rails welded or bolted together, either as complex as that at CVR or much simpler, depending on the level of protection desired and the funding available. This type of work does pose some problems. It presents aesthetic impacts and may effect fish and wildlife habitats by acting as a barrier or trap in certain cases. This system can be designed to be a temporary protective work, which may then be removed once the vegetation behind it has become sufficiently established. This type of bank works shows promise for some of the River Management Program's activities on the river. The costs of construction for post and wire revetments depends on the materials used, and the level of protection desired. For less protection, a single row rather than a double row could be used. Effectiveness will depend on design and construction technique. If the structure is over-topped and the banks behind are not sufficiently protected, serious erosion could result, though this would probably only happen in greater than 10-year floods.

Gabions: Gabions are wire baskets which are filled with river cobble. The individual baskets come in various sizes which can then wired together to form a larger unit. After the basket is filled, the top is wired to the ends and sides. The simplest gabion structure is one row of gabions usually three feet high. A second row may be added and stepped back 18 inches if one is protecting a bank. For more than two row walls, additional basal courses must be added. There are numerous advantages to gabion walls and revetments including: (1) ease of handling and transportation; (2) speed of erection; (3) flexibility (avoiding damage by debris or differential bank movement, and also avoids the necessity of extensive foundation preparation); (4) permeability; (5) the upper section of a gabion structure can easily support vegetation; and (6) the use of existing excess river cobble to provide protection. Disadvantages are chiefly related to aesthetic impacts, as many consider the gabions unsightly, the amount of labor involved in construction (though it is unskilled labor), and problems with the lifespan of the wire basket material. The cost of gabions is relatively high at about $10/ft$^2$. However, since labor is 40% of the cost of construction, much can be saved if unskilled conservation corps workers can be used. Properly placed gabions can probably withstand all but the most infrequent events. Foundations must be started below the depth to which scour is expected to occur and the ends of these structures must be securely anchored. Gabions should be considered for use along the Carmel River where high levels of protection are desired, particularly as the natural riparian vegetation may be readily reestablished over the in-place gabion revetments. If the structure is properly designed and planted with vegetation, it will not be very many years until the original work is obscured by vegetative growth.

Articulated Concrete Blocks: This type of bank protection is a fairly recent development. The idea is based on a series of interlocking structures which then form a mat or continuous line of protection. This system provides flexibility, rapid installation, and the ability for vegetation to grow between the individual blocks. There are currently several patented systems available. The main disadvantage of these systems is their edges, which must be effectively protected against scour and undermining, something that the blocks themselves do not provide. Also, the blocks must be laid on a relatively smooth slope, and should be placed on a filter cloth. The cost of this type of protection is relatively high; though somewhat lower than gabion revetment construction. There is currently only one example of these articulated, precast concrete blocks on the Carmel River. Carmel Valley Ranch installed them to protect the terrace bank behind their post and wire revetment in one location. They have not yet seen a high enough flow to test their effectiveness. This system is not very aesthetically attractive yet may become quickly covered with vegetation, if planting takes place concurrently with installation. The system provides some immediate bank protection, while providing a suitably protected location for riparian vegetation establishment. Gabions would seem to provide a higher level of protection than do the concrete blocks, for only a slightly higher cost.

Rubber Tire Networks: Rubber tires provide a low-cost means of limited bank protection. The tires are cabled or banded together into a large mat (similar to the precast concrete block technique) which is laid on the sloped bank and anchored. Advantages of this method of bank protection lie in cost, including time and ease of installation, flexibility (debris tends to bounce off), and the ease of establishing vegetation between the tires. Disadvantages are chiefly aesthetic impacts, difficulties in properly binding the tires together, inability to cope with scour, and the fact that the large gaps in the center of tires allows substantial material to be eroded, even if the system is in place. Cost of tire mattresses can be very low if junk tires are donated by businesses, or bought in bulk. Tires have been used sporadically along the Carmel River with limited success. Problems developed with the bands connecting the tires, which tended to break under stress or through time, so that groups of tires were occasionally seen floating down the river during storm flows. The potential liability from these tires when they break loose must be considered. At a location just upstream of Schulte Bridge, tires have worked more successfully, as willows were planted between them which have grown up and added to the bank protection.

Car Bodies, Etc.: Other types of bank protection which have been used along the Carmel and in other locations have been lumped into this category because they were considered unacceptable and incompatible with the environmental considerations upon which this program is based. Such methods include crushed car bodies, sand-cement sacks, reinforced earth walls, timber and concrete crib walls, etc. Despite the fact that numerous (hundreds?) car bodies exist (mostly buried) along the banks of the river, they do pose severe aesthetic and environmental problems. Environmental degradation of this sort is not allowed by the California Department of Fish and Game in any case. Sand-cement sacks are being used in several places along the river, noticeably at Via Mallorca Bridge. The sacks provide substantial protection for the bridge abutments, however, they do not allow any vegetative growth unless covered by top soil which would be scoured away at high flows. The sacks may be considered as a means of protection for critical locations like bridge abutments.

## D. Vegetative Solutions

The important role of vegetation in slope or channel stability has long been known. Engineers, particularly in New Zealand, have recognized the ability of certain plants, especially willows, to provide substantial bank stabilization (Curry and Kondolf, 1983), and have used vegetation to control erosion and re-train river channels. Acheson (1968) states, "it would not be too much to say that willows and poplars when properly controlled have been the mainstay of our river protection work in New Zealand to date." In fact, most areas in New Zealand have willow and poplar nurseries or even plantations to provide stock to meet all of the local requirements.

Willows or other suitable vegetation may often be the simplest and cheapest way of establishing bank protection, though damage and mortality are often high and a number of years is required before continuous protection will be available. Severely eroding bends or other critical areas may have to be protected by other means, though vegetation can be used to supplement these structural works.

Curry and Kondolf (1983) define the Carmel River as a potentially unstable system. The presence of riparian bank vegetation can make the difference between a narrow, stable channel and a wide, braided, and shifting one. Aerial photographs from 1965 and earlier show a stable channel flanked by a well-developed riparian corridor. The stable reaches on the present river, from Valley Greens Drive to the lagoon, show similar conditions to those that must have been present along much of the rest of the river. Here the channel is fringed by a dense band of trees, shrubs and vines which provide a thick mat of fine surface roots along the toes of the riverbanks. This root mass protects the unconsolidated sands, gravels, and silts which form the alluvial flats of the valley, which, without their protection would offer very little resistance to erosion.

The use of vegetation for bank stabilization along the Carmel River would be a very cost-effective method of erosion control. The major problem with only a vegetative approach is the difficulty with getting the vegetation established so that it can provide the protection discussed above. Willows need several seasons of undisturbed growth to develop the extensive root systems with which they can protect the river banks. During these first few seasons, the willows will be quite vulnerable to high storm flows, possible drought, animal browsing and animal and/or human trampling. While these factors may be taken into account and the vegetation protected against them as far as possible, the chance will remain that a storm flow will occur the first winter which will damage or destroy a large amount of the vegetative works. The damaged areas will have to be replanted and this process could continue for many years until a series of winters provided more favorable conditions for growth.

The advantages of using vegetation to protect the river banks, and retrain the river to a stable channel pattern, are many: (1) it would enable the reestablishment of the natural riparian corridor with all of its benefits; stable channel, enhanced fish and wildlife habitat, improved aesthetic values; (2) it is a relatively low cost solution compared with entirely structural solutions; (3) it would improve water quality; and (4) it would reduce erosion related costs for the county and private landowners. The only disadvantage of a vegetative approach to the problems of the Carmel River is the lack of immediate protection. There is also no guarantee that the vegetation will become established with sufficient vigor to withstand the first few winter's storm flows.

Costs for revegetation can initially be quite low, in the range of several thousand dollars per mile of riverbank, though the costs may increase substantially if the first year's storms severely damage the young plants.

E. Structural & Vegetative Solutions

These solutions bring together the best of both the structural and vegetative solutions discussed previously. The result is an attractive, environmentally compatible and cost-effective means of providing satisfactory bank protection works along the reaches of the Carmel River currently experiencing severe erosion. These methods can begin the work of retraining the river to a stable configuration.

The advantages of a biotechnical approach are (1) Structural and vegetative components provide natural reinforcing, adding to the strength and integrity of the entire system; (2) Actual field studies (Gray and Leiser, 1982) have shown that in many instances this combined approach is more cost effective than the use of either vegetation or structures alone; (3) Biotechnical protection systems are environmentally compatible, and in most cases enhance the existing environmental situation; (4) This approach emphasizes the use of local, natural materials, which are generally more aesthetically attractive; and (5) Biotechnical systems tend to be more labor-skill-intensive rather than energy-capital-intensive, such that well-supervised skilled labor can be substituted for high-cost, energy-intensive materials.

The disadvantages of this type of approach lie mainly in the tradeoffs between cost and effectiveness. Costs will be decreased if the ratio of structural to vegetative works is reduced, although the effectiveness of the works might also be reduced, at least until the vegetation was securely established.

The biotechnical method has a wide range of possible designs. Virtually all of the structural works discussed in the previous section can be adapted to the biotechnical approach. Certain design changes need to be made in each case to allow for the efficient propagation of vegetation. The options available range from a design that is mostly vegetative with limited structural works where necessary to substantially increase the survival quotient of the vegetation to a design that is mostly structural with the vegetation relegated to a secondary role. The relative cost and effectiveness for each solution varies tremendously from one end of the above range to the other.

Few landowners along the Carmel River have tried a biotechnical approach to their riverbank erosion problems. While some landowners have actively encouraged the growth of riparian vegetation along their riverbank property, the majority have not. Those attempts which have been made mostly lie downstream of Meadows Road and encompass the so-called "stable" reaches of the river. Carmel Valley Golf and Country Club has done an excellent job over the years of encouraging their willows and cottonwoods. This reach and downstream have not had to cope with the same magnitude of water table drawdown as the Robinson Canyon to Schulte reach suffered during the 1976-77 drought, and so it has been much easier to encourage the vegetation. However, few of the riverbank works upstream of Schulte, particularly since 1980, have managed to establish any substantial growth of vegetation. Whether this is the result of a lack of knowledge and understanding on the part of the landowners or their contractors, or a desire to avoid the necessity for ongoing maintenance, or finally, a belief that the works which they put in, generally riprap, will be sufficient to protect them, and the aesthetics of the rubble or rock did not bother them sufficiently to do anything about it. The extent of this problem is highlighted by the fact that Fish and Game has been requiring vegetation of riverbank protection works for many years, as a condition of their permit approval, yet the majority of the landowners affected have not made significant attempts to follow these conditions, and Fish and Game does not have sufficient staff and time to enforce the revegetation and maintenance portions of their permits.

Costs using biotechnical methods vary as widely as the options available. Generally, the fewer structural works the lower the cost, though this would again depend on the type of structural works planned. Costs might range from $1/ft to $250/ft. Cost is also somewhat related to effectiveness for at least the first few years.

When discussing the effectiveness of a given solution, not only must the return interval for a given event be considered but also when in the life of the project this event occurs. This last distinction is the most important one in regard to the various levels of protection given by the biotechnical works. If the vegetation is given sufficient time to properly develop its root system, a biotechnical approach relying mostly on vegetation with structural features, could be as effective in protecting a given stretch of property as a higher cost design which has more emphasis on structural works. The high risk would only be in the first few years, while on the other hand, a structural approach is effective from the time when it is emplaced. This risk is probably worth taking to lower costs, because in most cases, the landowner is not able to control problems from developing upstream. Even were an extensive structural solution designed and built, upstream erosion could change channel characteristics at that location such that the structure might fail at a level far below that which it was designed to withstand. For this reason and others, it seems most reasonable to use limited structural works along with extensive vegetative planting (except where more extensive structural works are needed to protect particularly critical areas) to provide the riverbank erosion protection proposed by the Carmel River Management Program.

## IV. PREFERRED SOLUTION

In previous sections the problems of the Carmel River and possible methods to begin the restoration have been discussed, while this section will detail the Carmel River Management Program's preferred solution to the river's problems.

The river is currently, from Robles del Rio to Valley Greens Drive, in a highly unstable condition. This instability is the result of a loss of bank stabilizing riparian vegetation, subsequent bank erosion, channel widening and downstream deposition of eroded materials in the form of point and mid-channel gravel bars. The goal of the River Management Program is the progressive restoration of the river to the conditions which characterized the river prior to these recent erosional problems. Consultants to the Water Management District, Dr. Robert Curry and G. Mathias Kondolf, have provided a detailed historical analysis of the river along with a thorough understanding of sediment transport and the development of a "response model" based upon both theoretical and empirical information and data which enables the effects of proposed changes in the water sediment balance to be estimated. Based upon their analysis, they concluded that the goal of a restoration program should be the condition of the river as it existed in 1965 with certain minor modifications to accommodate changes in land-use within the watershed since that time. They feel, and the River Management Program's preferred solution is based on this premise, that restoration techniques should attempt to emulate the natural channel geometry of the 1965 channel, because this channel closely approximates, by their calculations, the theoretical best design which could transport the amounts of sediment and water that characterized the period of 1930-1965. Indeed, reaches of the Carmel River that are similar to their 1965 conditions (i.e. Valley Greens Drive to the Lagoon) are currently stable and well-vegetated, and have been reasonably able to handle the increased sediment load caused by upstream erosion.

The recommendations of this Plan, including the preferred solution, have been formulated with the goal of maximizing public benefits and minimizing public costs, yet still providing for comprehensive river management and natural resource protection. This cost-effectiveness is considered an important component of the requirements for a given solution. As a result, the preferred solution proposed by this Plan has incorporated a high degree of flexibility with regards to the level of funding available. Generally, the more funding available initially, the faster the goal of river restoration and bank stabilization may be reached. On the other hand, lower levels of funding, while providing nearly the same level of protection as a more expensive solution at the end of 10 years, would entail higher risks initially, though certainly not as high as currently exist, and increased annual maintenance costs. This low level of funding should be able to be met almost entirely by the $45,000 annual benefit assessment portion of this programs funding. Federal funding or further landowner contributions through the sub-zone process would decrease the time required for restoration and lessen the risks for the first few years.

The preferred solution proposed by this program is based on a biotechnical approach as developed by the District staff and its consultants. The basic premise of this solution is the need to narrow the currently "over-wide" channel. Limited structural works would be constructed out from existing riverbanks to a design width. Existing terrace banks will be protected (when necessary) with structural works of a permeable, environmentally compatible nature. The area between the design low-flow channel and the existing terrace banks, known as the channel margin area, will be systematically revegetated, along with the terrace banks. Irrigation of suitable design will be coordinated with landowners or provided by the Carmel River Management Plan. (For further details and construction standards see Preferred Solution section on Appendix A). The implementation of the preferred solution requires an approach that works its way progressively downstream from the upstream extent of erosion problems. This solution will not be as successful unless upstream reaches are stable and not introducing large amounts of sediment into the channel.

The discussion below details the preferred solution and how it fulfills the requirements of a given solution as considered in Section II C of this Plan.

REQUIREMENT #1: MAINTAIN SEDIMENT TRANSPORT:

The design low-flow channel is based upon a slight modification of the 1965 natural channel geometry. This narrowing of the current channel is required to improve sediment transport and begin the process of "flushing" out the excess sediment currently stored in gravel bars. By encouraging the formation of a central low-flow channel, designed to accommodate the 5-year event or about 5000 cfs, the basis of a stable configuration of the river will be introduced. In addition, the central channel will help eliminate any braiding of the river at flows less than 10,000 cfs, or the flows at which major erosion has occurred in the last five years. By emphasizing the use of native vegetation and local materials, a reasonable start will be made in eliminating the excess of sediment within the channel. River cobbles will be used to fill gabion baskets at those sites which are currently contributing substantial sediment, a means of using this excess sediment to protect the eroding terrace banks. This channel will be created by one of three methods: (1) by stabilizing the existing low-flow channel if the geometry is close to that of the design channel and the channel lies approximately in the position desired; (2) by delineating the limits of the design channel with suitable structural and vegetative works and allowing the natural activity of the river to move the sediment necessary to create the channel (this approach will be used the majority of the time); and, (3) where absolutely necessary to enable any restoration to begin in the worst reaches, by using heavy equipment to construct a pilot channel. Generally, this channel will be encouraged to exist in the center of the currently overwide reaches, so that two levels of protection will be created. The low-flow river channel, bordered by the channel margin and finally the existing terrace banks, which will also be stabilized.

REQUIREMENT #2: ENHANCE FISH HABITAT:

Protection and restoration of the steelhead habitat is a primary requirement of any solution to the river's problems. Fortunately, almost any restoration scenario will help the fish habitat. The critical factors relate to upstream and downstream migration and spawning conditions. This preferred solution will enhance both of these issues in several ways. By confining the river to a central stable low-flow channel, the currently existing "critical" riffles will be eliminated for the most part, greatly improving migration at low flows. Critical riffles occur as excess sediment is deposited on the falling limbs of storm hydrographs effectively aggrading the channel and forcing the stream flow to assume a shallower and wider condition. As has been seen this year, migration problems can occur over these riffles even when flow is in the neighborhood of 100 cfs. By reducing or eliminating bank erosion on the mainstem and the larger tributaries, much of the fine sediment which currently clogs spawning gravels will be removed by subsequent storm flows. The reestablishment of a vigorous growth of riparian vegetation, will improve fish habitat in a number of ways. Vegetation provides shade, which is very effective in reducing average water temperatures particularly in the spring and summer. This vegetation will encourage the reestablishment of animal and insect habitat which will lead to a better food supply for the fish. Riparian vegetation beside the low-flow channel provides cover and better protection from predators. This plan also proposes, based on Curry and Kondolf's analysis, the reestablishment of a natural pool and riffle sequence which will greatly improve habitat and migration conditions. Pools provide cool water for fish to rest in during upstream migration at low flows and when the other parts of the river become too warm for the fish. This Plan's preferred solution calls for the construction or placement of natural or man-made pool locating features at appropriate intervals (about 150m). Additionally, the natural pool-riffle sequence provides both better sediment transport characteristics and an initial basis for the development of a stable low-flow channel.

If the conditions described above of the preferred solution are implemented, a realistic goal would be a 50% increase in the quality of fish habitat at the end of five years.

REQUIREMENT #3: ENHANCE RIPARIAN VEGETATION & WILDLIFE HABITAT

The preferred solution has, as its basis, the revegetation of the riverbanks and, in effect, the restoration of the riparian corridor and its associated habitat. Beyond the immediate control of bank erosion which this solution addresses, this plan will provide for comprehensive management of the riparian corridor as discussed in the implementation section. The vegetation, consisting of willows, alders, and cottonwoods, will be planted and irrigated by a variety of methods depending upon the specific requirements of a given site. In general, willows will be planted in and along any structural works constructed in the active channel and its banks. In addition, vegetation will be planted between these structural works within the channel margin area. The existing river banks will also be planted, at the bottom, midline and top. Irrigation will be accomplished either by individual property owners, or by a portable or permanent system installed and operated by the District as part of the Management Program.

REQUIREMENT #4: RECREATION NEEDS:

The preferred solution takes into account the current level of recreational usage and future usage based upon the construction of hiking/horse trails along the river as proposed by the Carmel Valley Master Plan. No additional recreation needs are anticipated or desired within the river management zone, except at existing public use facilities such as Garland Regional Park. The use of permeable structural works such as gabion baskets does not present appreciable hazards for those who enjoy the river whether children, rafters, or fishermen. The program, through the permit process, will encourage the use of alternate materials in the place of hazardous concrete rubble. By removing snags throughout the year, the program will make the river safer for use by rafters. The designs proposed under this program will take existing hiking/horse trails into account, and the program will work with concerned groups, such as the Monterey Peninsula Regional Park District, to construct these and future trails in such a way as to minimize the environmental impacts.

REQUIREMENT #5: IMPROVE AESTHETIC VALUES:

Physical modifications of a river without proper environmental safeguards can seriously disrupt wildlife habit, and aesthetic values. A meandering, shaded stretch of river with alternating deep pools and rocky riffles has much more value for animals and people than a straight, bare, silted-in stretch with uniform depth of water and/or mechanically shaped riprapped banks. For those who have seen both, the contrast of the river's conditions in 1965 and today makes this statement painfully evident. Scenic beauty and aesthetic values are difficult to quantify, and are frequently overlooked because they are seldom directly associated with economic benefit. Aesthetic values may stem from either natural or man-made features, though in the context of Carmel Valley, natural features should be the principle component. This preferred solution proposes the extensive revegetation of the riverbanks in an effort to restore much of the former scenic beauty of the Carmel River before countless tons of concrete and other unnatural bank stabliizing measures were placed along the river. A stable, well-vegetated river channel will be a large step towards recovering much of this damaged beauty.

Beyond the specific requirements listed and discussed in 1-5 above, the proposed solution must address a number of other issues. Some will be presented below, and others will be included in the implementation section.

This solution is fully compatible with virtually all existing and future private landowner bank protection works. Generally speaking, landowners have been limited to protecting their terrace banks, not because they might not have wanted to do more, but because they had no control of what was happening upstream of them. This program will address both terrace bank protection and channel narrowing to reestablish a stable configuration, along the entire river working from upstream to downstream. This solution takes into account the existing terrace banks whether protected or not. Where protection exists, channel narrowing structures can be integrated to form two levels of defense. The program will encourage the covering and revegetating of those banks currently protected by concrete or natural riprap.

Since the program must progress down the river starting at the upstream extent of erosion problems near Esquiline Bridge, this solution also proposes works for property owners further downstream where this progressive restoration may not reach for several years, depending primarily upon levels of funding. Bank protection methods will be designed upon request which will be entirely compatible with the overall scheme, once restoration reaches that specific location.

The solution recommends only limited structural works in these areas, unless there is danger to a critical location, such as bridge, house, road, etc., and extensive revegetation using willows and cottonwoods. Property owners may wish to construct more extensive bank protection works and these will be allowed as long as the proposed works conform to the standards set forth by the River Management Program in this document in Appendix A. These works should be limited to terrace bank protection, and must be capable of being revegetated.

## V. ALTERNATIVE ACCEPTABLE SOLUTIONS

Beyond the preferred solution described above, there are a number of alternative solutions which may be applied to the river's problems. Generally, all of the structural methods discussed in Section III will be acceptable, provided that they may be covered and vegetated, and provided they are in conformance with the appropriate standards in Appendix A. A distinction must also be made between emergency and non-emergency situations. Ordinance 10 makes the further distinction between situations where a high probability of damage exists or is imminent, and situations where immediate action is required to mitigate clear and present danger to life and property.

In an emergency situation, any clean riprap, concrete rubble or other type of work described in the possible solution section may be used, except tires or loose fill. The District reserves the right to require removal or modification of these emergency works once the emergency condition is no longer in effect in order to bring the works into compliance with structural standards defined in this management plan.

Alternative acceptable solutions include: (a) concrete cubes and rubble; (b) dolomite, granite, or other riprap; (c) gabions; (d) variations of pipe and wire or post and wire revetments; and (e) articulated concrete blocks, providing the structural and revegetation requirements of the Appendix A are met. The most basic requirement covers revegetation. All structural works must be capable of being extensively revegetated with native riparian vegetation consisting of willows, alders, and cottonwoods. This vegetation must be established not only on the top of the work at the terrace level but also on the face and at the toe of the bank.

## VI. COMPREHENSIVE RIVER MANAGEMENT

The comprehensive management of the Carmel River includes a wide range of activities. Priorities for individual activities are determined by the Carmel River Advisory Committee (CRAC), and will undoubtedly be modified to reflect the changing needs of the program, the people, and the river as the management plan is implemented.

This outline presents the types of activities which the Management Program will undertake. Specific actions will be discussed in detail in the implementation section. The program attempts to begin the restoration of the river through two means; (1) direct construction of a limited nature to define the central low-flow channel progressing from upstream to downstream and (2) creating a trained staff which is directly responsible for Carmel River Management to provide technical advice, designs, funding (when possible), and a responsive and simplified permit process which will allow property owners to protect their land within a comprehensive framework of compatible works.

Erosion Control and Prevention: The program will provide a River Management plan which analyzes the problems of the river, evaluates possible solutions, and proposes a preferred solution (this document). An erosion control guidebook will be provided which details the advantages and disadvantages of the various acceptable types of bank protection which a landowner may choose from. The guidebook will detail design and construction standards, list sources of materials, contractors, relative costs and levels of protection. Staff will assume the permit process from the County and work to simplify the process for landowners. Staff will provide actual designs for specific projects when requested to by landowners, and continue the process through the construction phase. Staff will conduct an annual review of the river to determine current conditions and hazards. Property owners will be notified of hazardous conditions, especially trees. The program will coordinate the removal of snags during the summer and fall and provide emergency snag removal when feasible.

The program will actively seek outside funding for the construction of erosion control works. The $45,000 works portion of the program's budget will be spent constructing the works of the preferred solution as described in the introduction to this section.

Maintenance of Vegetation: One of the basic premises of this program is the reestablishment of the riparian corridor at least within the Zone #3 boundaries (that land within 25 feet of the river level during a 10-year storm). The program will continuously monitor the health of vegetation, and will encourage the revegetation, both through the permit process and its own construction, of areas which need to be planted as prioritized by CRAC. The District will provide limited numbers of willows to individual property owners free of charge along with a planting and irrigation guide. The program will provide for irrigation at those locations where the District performs construction. For individual landowners, the program will provide detailed irrigation system design and funding at the discretion of CRAC and the District Board of Directors.

Education: The program will work to educate landowners and the general public regarding river management and erosion prevention.

Research: Staff will continue to conduct research into the dynamics of the Carmel River systems particularly regarding fluvial geomorphology, fishery and vegetation resources, and erosion potential.

Other Related Activities: The program will work with the Water Management District and Monterey County to implement the Watershed Management Plan. This will include the detection and control of excessive sedimentation problems from the tributaries of the Carmel River. Staff will work with the Regional Park District to develop and implement trail standards for existing and future trails along the river.

# VII. IMPLEMENTATION

## A. Introduction

This river management plan presents a review of the Carmel River's problems with a brief analysis of their causes, and a series of solutions which address both the problems and their probable causes. This plan indicates that responsible, comprehensive management of the riparian corridor must be coupled with watershed management to effectively begin the restoration of the Carmel River. Reliance on one source of water supply (the Carmel River and its aquifer) may, during unusual circumstances (i.e. a drought) bring about serious environmental damage. An understanding of the limits of this system allows progress to be made towards a way of life which balances human needs with those of the environment. To be most effective, man must learn to live within the constraints placed by the environment, and not try to mold it to his wishes.

The findings presented within this plan indicate that reasonable development and resource use does not need to conflict with river restoration and management if done with care and in a way compatible with natural river functioning. This plan will help guide management actions by providing a framework for any actions taken along the river. River management cannot take place through one-time, immediate actions, but is a dynamic, ongoing process. The program must continually monitor its effectiveness, keeping those techniques that work and eliminating those activities that are not effective. Adoption of this plan will provide common objectives and a general/specific framework for such dynamic, flexible management.

It is not possible to attempt implementation of all plan recommendations immediately. Limited staff and funding prevent it. This plan is instead based on the <u>progressive</u> restoration of the river and its riparian corridor, and the proper management of this resource once this restoration has succeeded. Therefore, recommendations that are of higher priority, as determined by CRAC, should be implemented first, followed by other recommendations as program capabilities allow.

The plan recommends a priority for each of its possible lines of action. This priority is based on the severity of the problem, its position as it relates to the progressive restoration approach as well as the cost of implementation. As a result, each recommended action has been assigned to one of four implementation categories: (1) support (includes expansion) of an ongoing effort which should continue; (2) high priority and/or immediate implementation (within one year); (3) secondary priority and/or delayed implementation (as funding becomes available); and (4) lower priority and/or potential future implementation.

The recommendations of this plan have been formulated with an effort towards maximizing public benefits while minimizing the costs as well as providing natural resource protection and restoration. The plan emphasizes the cost-effectiveness of: (a) biotechnical approach to erosion control; (2) coordinating existing and future management into a single agency when possible; and (3) increasing the responsibility of the public and other resource users for the proper management of their own activities. Plan implementation will, of course, cost money, and this was the primary reason for the formation of the Carmel River Management Program with its $150,000 annual budget. While this budget covers administrative costs and provides about $45,000 annually for actual construction, this amount will not meet the costs of complete restoration. The works portion of the budget will probably cover the costs of constructing the low-flow channel locating structures and revegetation as the program progresses downstream from Esquiline Bridge over the course of the program's ten year life. While this level of funding could eventually provide considerable bank protection if the vegetation is allowed several years of growth without a large storm-flow, it will not be able to provide any structural terrace bank protection works. The funding for this activity must come from the landowners, or outside agencies at the county, state or federal level.

It seems reasonable to assume given the current state of affairs that additional funding will not be readily bavailable from these outside sources. Outside funding will only accelerate the restoration process and this may not be worth the strings that most agencies attach to their funds. However, the program will actively seek outside funding for river management and restoration purposes. The program will gladly accept any outside help providing the requirements for such funding remain feasible within the context of this river management plan.

The following sections detail the activities of the program and the relative priority of each. After that, the role of the public and the affected property owners in the implementation of the river management program is addressed.

## B. MPWMD Zone No. 3/Carmel River Management Program Activities and Obligations

The role of the river management program is defined in outline form by Ordinance No. 10 of the MPWMD. Beyond this, the Advisory Committee has further detailed the program's activities and priorities.

Staff: The program staff consists of three persons: (1) District Engineer (2) Resource Analyst (3) Secretary. The Engineer and resource Analyst are full-time positions, and the Secretary is half-time. Staff has two vehicles, both trucks: a two-wheel drive and a four-wheel drive. This staff has no obligations to the MPWMD other than the Carmel River Management Program.

Permits: The simplification of the permit process, which will ease the burden on property owners who desire to undertake bank protection works, is one of the most important facets of the River Management Program. The permit process will allow staff to implement the provisions of this Plan. Staff will coordinate between the CRMP permit requirements and those of the California Department of Fish and Game, by using consistent standards when possible. It is important that staff work to educate the public regarding the river's needs and the reasons for requiring those activities which might affect the river's health and stability to fall under permit regulation.

The boundaries of Zone No. 3, or the area where the permit process will be in effect, is defined as that land within 25 lineal feet of the riverbank assessment line which is the waterline of the Carmel River during a flow with a recurrence interval of ten (10) years. Therefore, the permit process will only affect a narrow strip of land alongside the channel, not even the entire riparian corridor. This directly limits the program, as was the intent, to erosion control work along with sufficient land to enable the re-establishment of riparian vegetation with appropriate irrigation facilities.

Zone activities have been segregated into three categories: (1) Those activities specifically exempt from the permit process; (2) Those which have been defined as "Minor Works" and will go through that branch of the permit process; and (3) "Regular Works" which shall follow the permit process set down in Ordinance No. 10 (see Appendix 1).

Those works which fall into the regular permit category must undergo the review process set forth in Ordinance No. 10 which requires a public hearing and review by outside agencies when appropriate. For specific details and requirements of the permit process, see Rules 124, 125, and 126 in Ordinance No. 10, and Permit Requirements, (Appendix B). The ordinance also reviews the process for emergency permits. A sample permit procedure will be included in the Erosion Control Guidebook which Staff plans to complete by late spring.

Enforcement of permit conditions has long been the weak link in the entire process. The bottom line of all permit regulation is that people will only follow those conditions they feel will directly benefit them. It is up to this program to educate property owners in this respect and make them believe that these conditions are necessary to insure the structural integrity of their projects. Staff will also attempt to educate contractors about the proper way to accomplish specific projects. Staff hopes that enforcement will also take place through the passive neighborhood or community involvement of adjacent property owners. Active enforcement, to the extent possible with the limited staff, will take the form of frequent site inspections to insure compliance. The program has the legal authority to seek civil and criminal penalties, either through the District Attorney or its own counsel, though this action is contemplated only in extraordinary circumstances.

Technical Assistance:

(a) Designs: Staff will provide complete engineering design for proposed works upon request by the concerned landowners on a first come, first serve basis as staff time allows. The program will provide lists of contractors, sources of materials, and other information which will help the landowner(s) to more easily complete a project which has been approved by staff. One advantage of staff designs beyond the cost factor, is the fact that these designs will obviously conform to all CRMP permit requirements. (Priority 2)

(b) Construction/Inspection: Landowners may request CRMP staff to help procure a suitable contractor and there is the possibility that CRMP funds may be available to help landowners with the actual construction costs. CRMP staff will provide frequent site inspections to insure that the construction is being done properly and that all permit requirements are being met. (Priority 3)

(c) Maintenance: The majority of projects undertaken along the river in the future under CRMP permit requirements will be required not only to plant and maintain willows, but also to maintain the structural works in an appropriate manner. Permit conditions will detail the extent of the maintenance requirements and CRMP staff will provide designs for various types of irrigation systems that may be used. Proper maintenance is directly in the best interest of the property owner and the neighbors downstream, as improperly maintained banks works could result in failure at much lower flows than was designed to withstand. (Priority 2)

(d) Coordinate Property Owners: Staff will work with and encourage multiple property owners' participation in an effort to extend the scope of projects, so that upstream problems are also treated when possible. Large numbers of participants will tend to reduce the costs for each owner and provide much improved protection. The progam is concerned with ending the excessively piece-meal approach to protection, whereby a property owner may spend large sums of money only to see this work compromised by either upstream failure or an upstream project which changes the reach's hydraulic geometry. Coordination can take several forms, from projects involving several owners to those involving many. The larger projects should take the route of sub-zone formation. This involves the same process that was used to form the Carmel River Management Zone. It includes a protest hearing and then an election which requires a majority of the involved property owners to approve it. In this way, entire stretches may be improved at once without any gaps which would later cause problems. (Priority 2, ongoing)

Construction: Each year the benefit assessment funds will be used to construct works and plant vegetation as directed by CRAC and the MPWMD Board of Directors, though generally this work will follow the scenario described in this management plan. It will involve the construction of channel narrowing structures in a progressively downsteam fashion from Esquiline Bridge. Those projects which CRMP funds pay for will be maintained by staff. If outside funding is obtained, this yearly project scope may be enlarged, or made more comprehensive.

Snag Removal: Staff will remove or provide for removal of snags and other debris from the channel upon notification and the reception of access permission by a property owner, once appropriate guidelines have been set by CRAC and the District Board. Alternatively, snags may be cabled or otherwise properly secured to the bank when appropriate. Staff will work to minimize the presence of motorized vehicles in the channel for this purpose. Staff will coordinate with the County and private bridge owners to secure emergency response to snag accumulation on bridges during storms. Staff will also identify hazardous trees, those which appear likely to fall into the river, and notify the appropriate landowners. Staff will attemp to secure removal of these trees where their removal does not conflict with shade or wildlife requirements. (Priority 2)

Annual Review: CRMP staff will conduct an extensive annual review of river conditions through aerial photo interpretation and a comprehensive walk of the entire alluvial reach of the river. Staff will locate areas that are in danger of erosion during the coming winter. Staff will notify these residents and work with them to develop projects to rectify this hazard if the property owners so desire. (Priority 2, ongoing)

Riparian Vegetation: Since the enhancement and re-establishment of riparian vegetation is a primary goal of the river mangement program, much of the staff's time will be taken up monitoring the health of the vegetation and designing irrigation systems to protect it during times of drought. Staff shall review aerial photographs and make extensive inspections of the riparian corridor to determine changes in the health of the riparian vegetation. Staff may retain the services of a vegetation expert to provide further informtion on plant requirements, possible treatments for disease, etc.

High priority will be given to replanting vegetation in those areas that currently lack it. As is discussed in earlier sections of the plan, vegetation without structural protection may suffer high losses until it becomes sufficiently established in two or three years. Despite this, staff will encourage property owners to plant willows even in downstram areas that do not have the stable channel design constructed. Staff hopes to provide willows in limited numbers free of charge to residents. Even with a low success rate, much vegetation could be re-established in a few years particularly if downstream diversion is implemented by the MPWMD and the California American Water

Company during the summer months. CRMP may also bear the costs of this replanting as determined by CRAC and the MPWMD Board. Staff will attempt to prioritize those areas which need planting (though there currently are several miles of unvegetated banks) so that the most needy areas are taken care of first.

Staff will provide information on proper species, planting techniques, irrigation requirements, and general maintenance to residents. To further encourage vegetation planting, CRMP staff will provide design and engineering for irrigation systems intended to water riparian vegetation along the riparian corridor. Funding may be available to partially support the initial costs of these systems. Staff will design systems for those areas where irrigation is necessary to maintain health of the vegetation, and if irrigation easements are provided by property owners, the CRMP may, at CRAC and the Board's discretion, construct entire systems. (Priority 2)

Community Education: Staff will actively attempt to educate property owners and the general public regarding river management and erosion prevention. This will take the form of a guidebook, which will provide information on the cost, effectiveness, and liabilities of bank modification, along with permit conditions. Staff will initiate workshops and forums to present this and other information to landowners. Staff will appear at local meetings of concerned organizations to give talks describing the activities of the program and what the public should know about the erosion control process. Staff will try to initiate awareness programs at public schools, as children of all ages are frequent users of the river and its riparian corridor. (Priority 2)

Research: Despite the fact that several years of intensive research have taken place recently in a wide range of areas, including fluvial geomorphology, fishery, wildlife, vegetation resources, and sediment transport, there still remains much that is unknown or improperly documented. Staff will continue research in several areas notably sediment transport and the dynamic response of the river to the CRMP restoration scheme. Additionally, research will be conducted in coordination with other MPWMD staff on riparian vegetation, focusing on the water requirements of the vegetation and techniques for most successful propagation. Staff will actively encourage outside researchers (particularly graduate students) to conduct studies which will benefit the MPWMD data base relating to the Carmel River Watershed. Equipment for most of this research is already available through the MPWMD and will not increase the costs of the program. (Priority 1)

Emergencies: CRMP staff will provide emergency response during storm flows in regards to technical assistance to property owners, possible sources for emergency protection materials and contractors, snag removal (when feasible), and the declaration of emergency status as defined by the permit process in Ordinance 10 (see Appendix A). Some funding may be available to property owners for emergency work, though this will be decided on a case-by-case basis by CRAC and the MPWMD Board of Directors. Staff will coordinate with Monterey County Flood Control, Monterey County Public Works, and the Corps of Engineers when bridges or other public property is threatened. The program is currently setting up an erosion potential warning system which will provide a hotline phone number to receive the MPWMD's latest erosion potential rating and other appropriate information. This rating will be constantly updated so that property owners and residents can keep informed more easily. (Priority 2)

C. <u>Property Owner Obligations</u>

In a very real sense, the effective implementation of this program rests in the hands of the property owners and residents along the river. Virtually all of the land along the river is privately owned. Landowners bear the ultimate responsibility for the health of the river. Most of the river's problems can only be solved at their source, where the erosion has occurred or is occurring. Solving these problems at their source is impossible without informed public cooperation. The public shall be expected to take an active role in erosion control and vegetation maintenance. Program staff will be available to educate and assist the public in assuming their responsibilities, but in no way can the program undertake the entire task of implementation alone.

<u>Easements</u>: One of the principle features of the preferred solution of this Management Plan is the confinement of the existing overwide channel in a narrow low-flow channel of stable design. This specific task is beyond the ability of landowners to accomplish, and would not be worthwhile unless entire reaches of the river can be done at one time. The benefit assessment portion of the program's funding was set up primarily to accomplish these comprehensive channel works. For the program to accomplish this task, property owners must provide an easement for program staff and their contractors.

Other types of easements are also needed. Staff has already requested surveying permission from all of the landowners in order to complete the County's and FEMA's requirements for assuming the permit process and constructing the proposed works. Easements or permission are also needed for inspection of already constructed works so that credits may be granted. Access is required for permit approval so that staff can insure that conditions are met prior to, during, and after construction. Access will be needed for snag removal in addition to the construction easement described above.

<u>Funding of Projects</u>: While the Management Program provides $45,000 of its funding annually for the construction of bank and channel works, any property owner who has constructed works knows how far this amount will go. Of course, since the funding is primarily for channel works which are of a limited nature, the funds will go further. However, structural bank protection will

have to be funded by residents or groups of residents unless large amounts of outside funding suddenly become available. As described earlier, the program will provide as much help as possible in the form of engineering, design, inspection, and funding. The most cost-effective means of providing this funding is through the sub-zone process as described in the previous implementation section under "coordination of property owners." Neighbors must be able to cooperate with each other and the Carmel River Management Program.

Vegetation Reestablishment: Landowners should realize that the goal of this program, a stable, well-vegetated channel, is in their best interest, and, therefore, encourage the program to the extent possible. One of the easiest ways will be the planting and irrigation of riparian vegetation. If all property owners planted a reasonable amount of willows for the size of their riverbank frontage, the health of the river would improve dramatically within several years. The reestablishment of riparian vegetation will provide the river with a much more beautiful appearance, greatly enhancing aesthetic values as well as protecting property. Landowners should be willing to spend a small amount of their time and money irrigating and encouraging this vegetation.

Permit Compliance and Education: The landowner will hopefully understand the necessity for a permit system which controls activities along the river. They will acquire better protection, which in the long run will be cheaper when done right the first time, when they follow the standards this plan has formulated. In addition, their projects will not subject them to excessive liability from downstream property owners, since the permit process will allow only those works which fall within the design framework, which has been formulated expressly with the downstream effects of various works in mind.

Property owners must work to educate themselves and their neighbors in the proper methods of erosion control and vegetation irrigation and maintenance. With an informed public, progress will be made much quicker towards solving the river's problems.

## VIII. CONCLUSION

The Carmel Valley is and has been a beautiful place to live, work, and enjoy. Environmental degradation of one of Carmel Valley's most important features, the Carmel River and its riparian corridor, has greatly accelerated in recent years. Increasing population has and is changing the rural and formerly agricultural nature of the Valley. The increasing population has led to and increased demand for water. This demand has had unforeseen environmental consequences, which are only now being taken into account. The massive bank erosion which has characterized the Carmel River since the drought OF 1976-79 can be effectively halted through a program such as the Carmel River Management Program. The CRMP provides an excellent tool to private individuals through which they can work to reestablish the natural balance between man and the river that was formerly enjoyed in Carmel Valley. If property owners and the public cooperate with the program and utilize its features to the extent intended, the river's condition, at the end of the 10-year life of the program, should be approaching that which existed in 1965.

REFERENCES

Acheson, A.R., 1968, River Control and Drainage in New Zealand, New Zealand Ministry of Works, Govt. Printers, Wellington, New Zealand. 296 p.

Curry, R.R., and Kondolf, G.M., 1983, Sediment Transport and Channel Stability, Carmel River California, unpublished draft report to MPWMD.

Gray, D.H., and Leiser, A.T., 1982, Biotechnical Slope Protection and Erosion Control, Van Nostrand Reinhold Company Limited, New York, N.Y. 271 p.

Kondolf, G.M., 1982, Recent Channel Instability and Historic Channel Changes of the Carmel River, Monterey County, California, unpublished MS thesis, University of California, Santa Cruz.

Monterey County, 1983, Draft Carmel Valley Master Plan.

Santa Cruz County, 1979, San Lorenzo River Watershed Management Plan, Watershed Management Section, Planning Dept., County of Santa Cruz. 277 p.

Snider, W.M., 1983, Reconnaissance of the Steelhead Resource of the Carmel River Drainage, Monterey County, California Department of Fish and Game, Environmental Services Branch, report 83-3.

U.S. Army Corps of Engineers, 1967, Flood Plain Information, Carmel River, Monterey County California, San Francisco District, San Francisco, CA.

Williams, J. and Kondolf, G.M., 1983, eds, Guidebook for Conference on Channel Stability and Fish Habitat, Carmel River, California, June 16-18, 1983.

Williams, J., 1984, Carmel River Watershed Management Plan, unpublished draft report to California Department of Fish & Game.

# APPENDIX A

## STANDARDS FOR DESIGN, CONSTRUCTION, AND OPERATION

APPENDIX A

TABLE OF CONTENTS

APPENDIX A

STANDARDS

In order to promote consistency of design and implementation of river bed and river bank protective works, it is necessary to establish STANDARDS for the practices which are to be allowed. This STANDARDS chapter is organized into three distinct, but not separate, sections. The first section will cover river bed and river bank works combined. The section which follows will cover bank protection works only. One will note that there is a distinct difference between the two sections concerning river bank protective works. This difference is arrived at due to the fact that in the second circumstance, the protective work must be capable of standing alone in performing its task. The third section will cover STANDARDS which are not unique to either of the two previous section's protective schemes. This section will cover general standards that should be adhered to in any construction project.

Figures referred to in this Appendix can be found at the end of this particular Appendix.

A. RIVER BED AND BANK PROTECTIVE WORKS (PREFERRED SOLUTION)

The preferred solution consists of a structural-vegetative intertwining approach. Two basic types of structural works are favored in this solution. These would consist of gabions and pipe (post) and wire revetments. Gabions offer a more durable type of protective work, and would be installed where a permanent structure is deemed necessary. The pipe (post) and wire revetment offers a type work that can provide good structural benefits, with an added benefit of fairly easy removal (if desired) upon maturation of the associated vegetation which was planted at the time of installation of the revetment. Both types of structural works are of the permeable variety.

The vegetative works favored in this solution consist of willow revetments. These revetments would consist of rows of willows which incorporate an intensive planting of willow stems. These willow stems would be planted to a depth that would provide for adequate anchoring of the revetment to prevent the risk of losing the benefits of the revetment.

The basic scheme of the preferred solution lies in the establishment of a herringbone arrangement of structural and vegetative revetments being placed along the river. Figure 1 is a drawing of a typical reach of the river which exhibits the herringbone arrangement. These revetments would originate at each of the terrace banks, and would migrate toward the center of the river channel in a rate equal to their rate of migration in a downstream direction. This herringbone arrangement will induce the water in the river to follow a path toward the center of the river channel, and to subsequently create a central low flow channel at that location. This low flow channel should approximate a width of seventy-five (75) feet. (It should be noted that actual low flow channel width will be dependent on specifics of the reach being considered, and upon actual flow through that reach. The river will decide its own depth as it seeks to establish equilibrium within the new constraints encountered.

The exact arrangement of structural and vegetative measures will be dependent on the specific site the works are to be installed on. In general, areas of sharp meander bends will require gabion walls placed in an arrangement such that individual walls are placed 25 to 50 feet apart. Straight sections of the river channel may require that gabion walls be placed on 150 to 250 foot centers. Pipe (post) and wire revetments may be placed inbetween the gabion walls to provide for more protection. Vegetative revetments should be placed on 25 to 50 foot centers between the gabion revetments. Willows shall also be planted in the individual gabion walls, and along the pipe (post) and wire revetments.

If desired, a double row type of pipe (post) and wire revetment may be utilized in lieu of the gabion walls.

The following is a listing of STANDARDS to be utilized in the performance of the preferred solution, combined river bed and river bank protective works. The STANDARDS listed below are for some facets of work which will be encountered in the construction of protective works.

It may be desired by certain property owners to provide for more protection along the terrace bank than would be directly provided by the preferred solution. In this case, additional works as provided in Section B should be considered and utilized.

## 1. CONSTRUCTION STANDARDS-RIVER BED AND BANK PROTECTION WORKS

### a) CLEARING

Prior to any grading or excavation, any vegetation located in areas scheduled for structural modification shall be removed. During this removal process, willow plantings shall be salvaged and preserved for future use in the works to be performed. Extreme caution shall be exercised in performing this work so as to disturb as little of the adjoining vegetation as is possible.

All vegetation not marked for preservation shall be removed by cutting off at the surface of the ground. Only roots and stumps that interfere with the placement of structural works shall be removed.

All materials removed in this item (unless otherwise preserved for future use) shall be disposed of off site in a location approved by the Water Management District.

### b) PREPARATION OF FOUNDATIONS

Areas requiring placement of structural measures shall be prepared in a manner prescribed under the individual standards relating to the specific materials being used.

c) CONSTRUCTION OF WORKS - GABIONS

A keyway shall be excavated along the line of placement of each particular gabion wall that is to be installed. This excavation should begin in the terrace bank allowing for placement of the gabion wall so it will tie into the bank by ten (10) feet. The keyway shall be deep enough to allow for the placement of at least one course of gabions below the grade of the bed of the river. The gabion wall should be placed at least six (6) feet deep at a distance of 25 to 50 feet from the edge of the low flow channel, and at least nine (9) feet deep at a distance approximating 25 feet from the edge of the low flow channel. The keyway shall be excavated at least three (3) feet wide, and shall allow for safety considerations involved in the placement of gabions in the deeper excavations. Figure 2 illustrates the placement requirements discussed in this section.

Gabions shall consist of a uniform hexagonal wire mesh woven in a triple twist pattern with openings 8 x 10 type (3.25" x 4.5" approx.) fabricated in such a manner as to be non-ravelling and designed to provide the required flexibility and strength. The perimeter edges of the twisted wire mesh shall be woven around a reinforcing wire in a manner designed to prevent slippage and the edges of the mesh shall be securely selvedged. All corners shall be reinforced by heavier wire. Gabions shall be as manufactured by Terra Aqua Inc. (Maccaferri Gabions International), or equivalent. The gabion baskets shall have a minimum cross-sectional dimension of 3 feet by 3 feet.

Gabions shall be so fabricated that the sides, ends, lid, base, and diaphragms can be readily assembled at the construction site into rectangular baskets of the specified sizes. Where the length of the gabion exceeds one and one-half times its horizontal width the gabion shall be divided by diaphragms of the same mesh and gauge as the body of the gabion, into equal cells whose length does not exceed the horizontal width. Diaphragms shall be secured in the proper position on the base section such that no additional tying will be required at this juncture.

Gabions shall be placed along the limits of the keyway which had been excavated previously. The first layer of baskets shall be placed in the keyway and adjoining baskets wired together as recommended by the manufacturer. The baskets shall be filled with 4" to 6" uniformly graded stone (cobble) which is to be obtained from gravel bars in the vicinity of the work area. When the first layer of baskets has been completely filled, the lid shall be fastened down as recommended by the manufacturer. The next layer shall be placed directly on top of the first layer, and shall be fastened to the first layer by wire. The second layer shall then be filled with acceptable stone, and the lid subsequently fastened down. If a third layer is required, the previous process shall be followed.

When the keyway has received its required gabions, the gabion wall shall be backfilled with river gravel. Additional rows of gabions shall be placed upon the completed layers so as to meet grade requirements as listed on the drawings. Normally, one row of gabions will be protruding above the bed of the river at the intersection with the low flow channel, and the grade will increase going in a direction toward the terrace bank such that the grade provided at the terrace bank equals the elevation of the river in the 10 year storm. The same installation pattern should be followed in the installation of these additional rows.

Additional support should be provided for the first twenty-five (25) feet from the intersection with the low flow channel bank. Steel railroad rails, three (3) inch nominal diameter steel pipe, drill rod, or other material acceptable to the District shall be placed on five (5) foot centers such that the supports will be founded at a depth of eight (8) feet below the elevation of the bottom grade of the gabion wall at that location. It may be necessary to provide additional support at other locations along the revetment. This may be provided by performing the above installation of steel rails (etc.).

Willow stems shall be placed in the gabion wall during construction. The stems shall be placed on two (2) foot centers, and shall be placed so as to extend at least three feet below the bed of the river. Refer to the STANDARD entitled "Vegetative Treatment" for specific information relating to the planting of the willow stems.

d) CONSTRUCTION OF WORKS - PIPE (POST) AND WIRE REVETMENTS

Pipe to be used in the construction of pipe (post) and wire revetments shall measure a minimum of three (3) inches nominal diameter. The pipe selected must be strong enough to withstand the forces exerted on it during the driving operation. If desired, steel piles may be utilized in lieu of the steel pipe. A W4x13 should be satisfactory for this type of construction. (Use of steel railroad rails would also be allowable.)

Wooden posts may also be utilized in this type of work. These posts should have a diameter of at least eight (8) inches, and should not be treated with a preservative unless it can be exhibited that the preservative will not be detrimental to the habitat of the river.

Wire to be used in the construction of pipe and wire revetments shall consist of a uniform hexagonal wire mesh woven in a triple twist pattern with openings of approximately 2.5" x 3.25". This mesh shall be fabricated in such a manner as to be non-ravelling and designed to provide flexibility and strength. Number eight (8) wire should be utilized in the manufacture of the mesh. Cable to be utilized in this type revetment shall measure no less than one-half inch in diameter.

Prior to placement of the revetments, a keyway shall be excavated along the line of placement of each particular revetment that is to be installed. This excavation shall begin in the terrace bank allowing for placement of the pipe (post) and wire revetment so it will tie into the bank by ten (10) feet. The keyway shall be excavated three (3) feet deep along its entire length.

Upon completion of keyway preparation, the pipes (etc.) that are to be utilized in the construction of the revetment shall be driven to a depth of eight (8) feet below the bottom elevation of the excavated keyway. The pipes (etc.) shall be placed on eight (8) foot centers along the line of placement.

The pipes (etc.) shall be provided in lengths that will provide for the following installed grades: the top grade at the intersection of the revetment with the low flow channel shall be approximately three (3) feet above the river bed (this should allow for the passage of the 5 year storm without river bed terrace overflow occuring, and the top grade at the intersection of the revetment with the terrace bank shall equal the elevation of the 10 year storm.

The previously specified wire mesh shall be placed along the line of the revetment. The wire mesh should be placed on the water side (or upstream side) of the line of the revetment. The mesh shall be installed so that it fills the entire depth of the excavated keyway. This mesh shall be securely fastened to the pipes (etc.) by tying with a strong wire. The wire mesh shall be installed so as to extend to the very top of the previously installed posts. If one course of mesh is not sufficient to extend to the top of the revetment, then additional courses shall be installed. Courses of mesh shall be installed so as to provide for an overlapping of at least two (2) feet. A one-half inch diameter steel cable shall be placed at the top, bottom and mid point of the wire mesh and shall be attached to the pipes (posts) in a manner which will insure that the cables will remain securely fastened to the pipes. The cable shall be woven through the wire mesh such that the completed product will be free from any sags. The cable shall be tightened and fastened off at the ends of the revetment. Figures 3 and 4 illustrate the requirements for installation of this type of protection measure.

After installation of the mesh and cables is complete, the keyway shall be backfilled with river gravel.

It may be desireable to install a double row of this type revetment rather than a single row. If this is the case, the same procedure would be followed, except that bracing would have to be placed between the two rows. This bracing may be provided by using six (6) inch beams for wooden post revetments, or steel cables for steel pipes and beams. The two rows shall be installed three (3) feet apart. Adequate cross bracing must be provided. A double layer of mesh would need to be installed on each row of revetments, one layer on each face of the revetment. Upon completion of the mesh installation, the double row would then be filled with 3" to 6" uniformly graded stone (cobble) which is obtained from gravel bars in the vicinity of the work area.

e) CONSTRUCTION OF WORKS - VEGETATIVE REVETMENTS

A trench of a width of at least two (2) feet shall be excavated from the edge of the proposed low flow channel to the terrace bank. The trench shall extend into the terrace bank by three (3) feet. The trench shall normally be excavated to a depth of 3 to 4 feet. Actual depth of excavation shall be determined at the time of placement by the Water Management District.

Two (2) rows of willow stems shall be placed in the trench, one on each side of the excavation. The willow stems shall be planted on one foot centers, and the willows planted in the two rows shall provide for a staggered arrangement upon completion.

Details on the preparation of and planting of willow stems may be seen in the STANDARD entitled "Vegetative Treatment".

Figure 5 illustrates the desired placement requirements of the vegetative revetments.

B. BANK PROTECTION WORKS (ALTERNATIVE ACCEPTABLE SOLUTIONS)

The following is a listing of STANDARDS to be utilized in the performance of bank protection works. These STANDARDS are for areas where river bed works are not needed, or where river bed works will be installed at a later date.

The STANDARDS listed below are for some facets of work which will be encountered in the construction of various bank protection schemes. It will be apparent that the use of STANDARDS will be dependent on the type of protective material utilized in the specific works being contemplated.

STANDARDS contained in Section C should be added to the Construction of Works STANDARDS concerning the protective material being utilized, and to the STANDARDS entitled "Clearing", and "Preparation of River Bank".

1. CONSTRUCTION STANDARDS-BANK PROTECTION WORKS

a) CLEARING

Prior to any grading or excavation, any vegetation located on the river banks located in the work area to receive protective materials shall be removed, unless site conditions will allow for placement of works without their removal. This determination shall be made by the Water Management District. During this removal process, willow plantings shall be salvaged and preserved for future use in the works to be performed.

All vegetation not marked for preservation shall be removed by cutting at the surface of the ground. Only roots and stumps that interfere with the placement of structural works shall be removed.

All materials removed in this item (unless otherwise preserved for future use) shall be disposed of off site in a location approved by the Water Management District.

b) PREPARATION OF RIVERBANK

The riverbank shall be prepared for the installation of the protective works in a manner prescribed under the individual STANDARDS relating to the specific materials being used.

c) CONSTRUCTION OF WORKS - ROCK RIPRAP

River banks shall be graded to a slope of 1.5:1 to 2:1 (horizontal:vertical) in preparation for placement of rock riprap, unless the slope has been approved for placement of works without alteration by the Water Management District. In areas requiring the placement of additional fill material, all newly introduced fill material shall be compacted to a density of 90% of the Standard Proctor Density as determined by ASTM D-698.

A keyway shall be excavated at the base of the slope to a depth that will be secure from bed scour incurred in the 10 year storm. This keyway shall follow the same slope as was provided on the river banks. A filter cloth shall be placed upon the completed slope, and shall extend to the bottom of the excavated keyway. This filter cloth shall be such as to prevent the passage of fines through the cloth from the soil behind it.

Rock riprap shall be provided that is natural to the Carmel Valley, unless it can be proven to be unfeasible. Individual rock fragments shall be dense, sound, and resistant to abrasion, and shall be free from cracks, seams, and other defects that would tend to increase their destruction by water action. Riprap shall be reasonably well-graded approximating the following limits:

| | |
|---|---|
| Nominal thickness of riprap | 24 inches |
| Maximum size of riprap | 3000 pounds |
| 40-50% greater than | 1250 pounds |
| 55-60% from - to | 100 pounds - 1250 pounds |
| 5% less than | 100 pounds |

The rock riprap shall be placed to grade in a manner to insure that the larger rock fragments are uniformly distributed and the smaller rock fragments serve to fill the spaces between the larger rock fragments (chinking) in such a manner as will result in a well-keyed, densely placed uniform layer of the specified thickness. Hand placing will be required only to the extent necessary to achieve the above results. During placement of the riprap, willow stems shall be placed in at least three (3) rows along the length of placement, with stems in each row being placed on two (2) foot centers. Individual rows shall be placed at the top, toe, and at the midpoint of the rock faced slope. Additional willow plantings shall be placed on unprotected slopes which extend above the limits of the riprap. Any willows salvaged during bank clearing shall be utilized at this point in the work. Refer to the STANDARD entitled "Vegetative Treatment" for specific information relating to the planting of the willow stems.

Figure 6 illustrates the desired result to be obtained in the installation of rock riprap bank protection.

Each individual rock riprap project must be tied into the river terrace at both the upstream and downstream ends of the project area, unless another protective measure exists at either end that the project may be tied into. This may be accomplished by extending the protected slope into the terrace at a 45 degree angle to the stream flow axis. These ties should extend at least thirty (30) feet into the river terrace. Figure 7 illustrates the intent of this paragraph.

d) CONSTRUCTION OF WORKS - CONCRETE RUBBLE

River banks shall be graded to a slope of 1.5:1 to 2:1 (horizontal:vertical) in preparation for placement of concrete rubble, unless the slope has been approved for placement of works without alteration by the Water Management District. In areas requiring the placement of additional fill material, all newly introduced fill material shall be compacted to a density of 90% of the Standard Proctor Density as determined by ASTM D-698. A keyway shall be excavated at the base of the slope to a depth that will be secure from bed scour incurred in the 10 year storm. This keyway shall follow the same slope as was provided on the banks. A filter cloth shall be placed upon the completed slope, and shall extend to the bottom of the keyway. This filter cloth shall be such as to prevent the passage of fines through the cloth from the soil behind it.

Concrete rubble that is to be utilized in bank protective works shall be void of all deleterious materials, and shall be composed of concrete portions which are reasonably well-graded from a size of approximately 100 pounds to a size of 3000 pounds.

Concrete rubble shall be placed to grade in a manner to insure that the larger concrete portions are uniformly distributed and the smaller concrete portions serve to fill the spaces between the larger concrete portions (chinking) in such a manner as will result in a well-keyed, densely placed uniform layer of a thickness of thirty (30) inches. Upon completion of placement activities, all protruding steel reinforcement rods shall be cut off flush with the surface of the slope with bolt cutters or similar equipment. During placement of the rubble, willow stems shall be placed in at least three (3) rows along the length of placement, with stems in each row being placed on two (2) foot centers. Individual rows shall be placed at the top, toe, and at the midpoint of the rubble faced slope. Additional willow plantings shall be placed on unprotected slopes which extend above the limits of the concrete rubble. Any willows salvaged during bank clearing shall be utilized at this point in the work. Refer to the STANDARD entitled "Vegetative Treatment" for specific information relating to the planting of the willow stems. Figure 8 illustates the desired result to be obtained in providing this type of bank protective work.

Each individual concrete rubble project must be tied into the river terrace at both the upstream and downstream ends of the project area, unless another protective measure exists at either end that the project may be tied into. This may be accomplished by extending the protected slope into the terrace at a 45 degree angle to the stream flow axis. These ties should extend at least thirty (30) feet into the river terrace.

e) CONSTRUCTION OF WORKS - CONCRETE CUBES

Concrete cubes which are utilized in bank protective works shall have dimensions approximating 3′ x 3′ x 3′, and shall be equipped with "grab hooks" to facilitate in their placement. The "grab hooks" shall be stong enough to allow for the lifting and maneuvering of the concrete cube. The concrete utilized in the construction of such cubes shall have a minimum 28 day compressive strength of 3000 psi. This strength will help insure the durability of the concrete cubes.

Prior to the actual placement of the concrete cubes, the riverbank will have to be shaped to allow for such placement. This STANDARD provides information with respect to this item.

A keyway shall be excavated to a depth of at least three (3) feet below the lowest elevation of the river bed in the work area. This keyway shall be excavated to a width that will allow for the placement of concrete cubes in a row of double thickness. Prior to placement of concrete cubes, filter cloth shall be placed over the surface of the keyway excavation. This filter cloth shall be such as to prevent the passage of fines through the cloth from the soil behind it. The concrete cubes shall be installed allowing for a two (2) inch separation between individual blocks in each row, and in subsequent row placements. Upon completion of each row of concrete cubes, the cubes shall be connected together by means of utilizing a one-half inch diameter steel cable, and tying the cubes together by using the "grab hooks".

Another row shall be placed upon the completed double row. The outside face of this row shall be placed 1.5 feet from the outside face of the bottom row, and the concrete cubes shall be placed such that the vertical spacings between blocks to not line up in a row. The placement of filter cloth installed underneath the bottom cubes shall continue along the inside face of the second row of cubes. Earth fill shall be placed in six (6) inch layers between the cut earth slope, and the inside face of the concrete cube construction. Each layer of fill shall be compacted by means of a vibratory plate compactor until the soil is in a dense configuration. When the compacted fill is level with the top of the last installed row, subsequent rows shall be installed as detailed in the placement of the second row. Upon completion of installation of the last row of concrete cubes, the river bank extending above that row shall be graded to a slope of 2:1 (horizontal:vertical).

During placement of the concrete cubes, willow stems shall be placed in at least three (3) rows along the length of placement, with stems in each row being placed on two foot centers. Individual rows shall be placed at the top, toe, and at the midpoint of the faced slope. Additional willow plantings shall be placed on unprotected slopes which extend above the limits of the concrete cube construction. The willow stems shall be installed in between the concrete cubes in the separations provided for during construction. Any willows salvaged during bank clearing shall be utilized at this point in the work. Refer to the STANDARD entitled "Vegetative Treatment" for specific information relating to the planting of the willow stems. Figures 9 and 10 illustrate the desired results from the installation of this protective work.

Each individual concrete cube project must be tied into the river terrace at both the upstream and downstream ends of the project area, unless another protective measure exists at either end that the project may be tied into. This may be accomplished by extending the protected slope into the terrace at a 45 degree angle to the stream flow axis. These ties should extend at least thirty (30) feet into the river terrace.

f) CONSTRUCTION OF WORKS - ARTICULATED CONCRETE BLOCKS

Riverbanks shall be graded to a slope of 1.5:1 to 2:1 (horizontal:vertical) in preparation for placement of articulated concrete blocks. In areas requiring the placement of additional fill material, all newly introduced fill material shall be compacted to a density of 90% of the Standard Proctor Density as determined by ASTM D-698. A keyway shall be excavated at the base of the slope to a depth that will be secure from bed scour incurred in the 10 year storm. This keyway shall follow the same slope as was provided on the river banks. A filter cloth shall be placed upon the completed slope, and shall extend to the bottom of the excavated keyway. This filter cloth shall be such as to prevent the passage of fines through the cloth from the soil behind it.

Articulated concrete blocks will be allowed that possess features which include flexibility, rapid installation, and provisions for establishment of vegetation within the revetment. Some manufactured systems come equipped with a filter cloth. If this is the case with the selected system, the above requirement concerning filter cloth will be waived. Manufacturer's information with respect to the proposed system shall be submitted to the Water Management District for review and approval.

The particular articulated concrete block scheme which has previously been approved by the Water Management District shall be installed in accord with manufacturer's instructions. Emphasis shall be placed on providing adequate protection to the edges of the particular system being installed. This protection may be provided by the installation of rock riprap, gabions, concrete blocks, or other suitable measures. These additional measures shall be installed in accord with the particular STANDARD, where applicable.

Protection of the top and toe edges shall be such as to prevent scouring activity from undermining the articulated system. Edge protection measures shall be "keyed" into the slope at least three (3) feet along the top edge. Along the bottom edge, the particular protection measure shall be installed directly adjacent to the articulated system which has been previously installed, and shall completely fill the entire depth of the toe keyway.

Figures 11 and 12 illustrate in detail the requirements of this section.

Edge protection measures at the upstream and downstream ends of the river bank works shall be installed such as to tie the articulated system into the river terrace, unless another protective measure exists at either end that the project may be tied into. This may be accomplished by extending the protected slope into the terrace at a 45 degree angle to the stream flow axis. These ties should extend at least thirty (30) feet into the river terrace.

Willow stems shall be placed in at least three (3) rows along the length of placement, with stems in each row being placed in each opening provided in the articulated system. Individual rows shall be placed at the top, toe, and at the midpoint of the faced slope. Additional willow plantings shall be placed on unprotected slopes which extend above the limits of the articulated system. Any willows salvaged during bank clearing shall be utilized at this point in the work. It is highly recommended that additional willow stems be incorporated into the openings provided in the articulated concrete block system. Refer to the STANDARD entitled "Vegetative Treatment" for specific information relating to the planting of the willow stems.

g) CONSTRUCTION OF WORKS - GABIONS AND REVET MATTRESSES

River banks shall be graded to a slope of 1.5:1 to 2:1 (horizontal:vertical) in preparation for placement of gabions or revet matresses. In areas requiring the placement of additional fill material, all newly introduced fill material shall be compacted to a density of 90% of the Standard Proctor Density as determined by ASTM D-698.

A keyway shall be excavated at the base of the slope to a depth that will be secure from bed scour incurred in the 10 year storm. This keyway shall be vertical, and shall be wide enough to allow for placement of standard sized gabion baskets which measure 3′ in width. A filter cloth shall be placed upon the completed slope, and shall extend to the bottom of the excavated keyway.

Gabions shall consist of a uniform hexagonal wire mesh woven in a triple twist pattern with openings 8 x 10 type (3.25" x 4.5" approx.) fabricated in such a manner as to be non-ravelling and designed to provide the required flexibility and strength. Revet mattresses shall consist of a uniform hexagonal wire mesh woven in a triple twist pattern with openings 6 x 8 type (2.5" x 3.25" approx.) fabricated in such a manner as to be non-ravelling and designed to provide the required flexibility and strength. The perimeter edges of the twisted wire mesh shall be woven around a reinforcing wire in a manner designed to prevent slippage and the edges of the mesh shall be securely selvedged. All corners shall be reinforced by heavier wire. Gabions and revet mattresses shall be as manufactured by Terra Aqua Inc. (Maccaferri Gabions International), or equivalent. The gabion baskets shall have minimum cross-sectional dimensions of 3′ x 3′ and the revet mattresses shall provide for a thickness of 18 inches.

Gabions shall be so fabricated that the sides, ends, lid, base, and diaphragms can be readily assembled at the construction site into rectangular baskets of the specified sizes. Where the length of the gabion exceeds one and one-half times its horizontal width, the gabion shall be divided by diaphragms of the same mesh and gauge as the body of the gabion, into equal cells whose length does not exceed the horizontal width. Diaphragms shall be secured in the proper position on the base section such that no additional tying will be required at this juncture.

Gabions shall be placed along the toe of the slope in the keyway which has been excavated previously. It is most likely that two (2) courses of gabions will be required to fill the keyway. The first layer of baskets shall be placed in the keyway, and adjoining baskets wired together as recommended by the manufacturer. The baskets shall be filled with 4" to 6" uniformly graded stone (cobbles) which is to be obtained from gravel bars in the vicinity of the work area. When the first layer of baskets has been completely filled with stone, the lid shall be fastened down as recommended by the manufacturer. The next layer shall be placed directly on top of the first layer, and shall be fastened to the first layer by wire. The second layer shall then be filled with acceptable stone, and the lid subsequently fastened down. If a third layer is required, the previous process shall be followed.

When the keyway has received its required gabions, the gabion wall shall be backfilled with river gravel. Care should be taken to leave 18 inches of space on the back side of the gabion wall to facilitate installation of the revet mattress.

Revet mattress shall be so fabricated that the sides, ends, lid, base and diaphragms can be readily assembled at the construction site into rectangular baskets of the specified sizes. The base, sides, and two ends of the revet mattress are usually made of a single sheet of wire mesh (main sheet). Partition panels, made of the same type of wire mesh, are attached to the base of the main sheet to form two (2) foot long pockets into which the revet mattress is divided. The lid is formed by a single separate sheet.

Revet mattress cells shall be placed on the prepared river bank, with the short dimension of the compartments running up and down the slope, and the long dimension along it. The first (bottom) row of revet mattress shall be placed such that the top grade of the mattress will be equal to the top grade of the gabion wall at their intersection. The mattress compartments shall be wired to the gabion wall, and to the adjoining mattresses. The remainder of the mattresses shall then be placed, being careful to wire adjoining compartments together. The installed revet mattress baskets shall then be filled with 3" to 6" uniformly graded stone (cobbles). When the baskets are completely filled, their lids shall be securely fastened down.

During the operation of placing the stone, willow stems shall be placed in at least three (3) rows along the length of placement, with stems in each row being placed on two (2) foot centers. Individual rows shall be placed at the top, toe, and at the midpoint of the rock faced slope. Additional willow plantings shall be placed on unprotected slopes which extend above the limits of the revet mattresses. Any willows salvaged during bank clearing shall be utilized at this point in the work. Refer to the STANDARD entitled "Vegetative Treatment" for specific information relating to the planting of the willow stems.

Figure 13 presents a cross-sectional view of this type of protective work.

Each individual gabion-revet mattress project must be tied into the river terrace at both the upstream and downstream ends of the project area, unless another protective measure exists at eith end that the project may be tied into. This may be accomplished by extending the protected slope into the terrace at a 45 degree angle to the stream flow axis. These ties should extend at least thirty (30) feet into the river terrace.

h) CONSTRUCTION OF WORKS - PIPE (POST) AND WIRE REVETMENTS

Pipe to be used in the construction of pipe and wire revetments shall measure s minimum of three (3) inches nominal diameter. The pipe selected must be stong enough to withstand the forces exerted on it during the driving operation. If desired, steel piles may be utilized in lieu of the pipe. A W4x13 beam should be satisfactory for this type of construction.

Wooden posts may also be utilized in this type of work. These posts shall have a diameter of at least eight (8) inches, and should not be treated with a preservative unless it can be exhibited that the preservative will not be detrimental to the habitat of the river.

Wire to be used in the construction of pipe and wire revetments shall consist of a uniform hexagonal wire mesh in a triple twist pattern with openings of approximately 2.5" x 3.25". This mesh shall be fabricated in such a manner as to be non-ravelling and designed to provide flexibility and strength. Number eight (8) wire should be utilized in the manufacture of the mesh. Steel cable to be utilized shall have a diameter of at least one-half inch.

Prior to placement of the revetment, a keyway shall be excavated along the proposed location of the revetment. This location should be approximate to the location of the toe of the slope that is to be protected by the works. A depth of three (3) feet should provide for adequate embedment of the mesh to be installed.

Upon completion of keyway preparation, the pipes (etc.) that are to be utilized in the construction of the revetment shall be driven to a depth of eight (8) feet below the bottom elevation of the excavated keyway. The pipes (etc.) shall be placed on eight (8) foot centers along the line of placement. The pipes shall be provided in lengths that will provide for a final grade that will equal the height of the five (5) year storm at the low flow channel end, and will equal the height of the ten (10) year storm at the terrace bank end.

The wire mesh shall be placed along the line of the revetment. The wire mesh should be placed on the water side of the revetment, and should be installed so that it fills the depth of the excavation. The mesh shall be secured tightly to the pipes by tying with a strong wire. The mesh shall be installed so as to extend to the very top of the pipes. Additional courses of mesh may be needed to complete the installation. If more than one course is required, they shall be overlapped by at least two (2) feet. Upon completion of this installation the keyway shall be backfilled with river gravel. A one-half inch diameter steel cable shall be placed at the top, bottom and mid point of the wire mesh and shall be attached to the pipes (posts) in a manner which will insure that the cables will remain securely fastened to the pipes. The cables shall be woven through the wire mesh such that the completed product will be free from any sags. The cable shall be pulled tight before securing at the end of the revetment.

Figures 14 and 15 illustrate the requirements for installation of this type of bank protection work.

Protection measures for the ends of the revetment shall be provide by the use of either riprap, concrete rubble, or gabions. These additional measures shall be installed in conformance will the STANDARDS contained in this section. End protection measures shall be installed such as to tie the revetment into the river terrace, unless another protective measure exists at either end that the project may be tied into. This may be accomplished by tying off the revetment into the terrace bank at a 45 degree angle to the stream flow axis. These ties should extend at least thirty (30) feet into the river terrace.

Willow stems shall be placed along the revetment during construction. The stems shall be placed on two (2) foot centers, and shall be placed so as to extend at least three (3) feet below the bed of the river. Additional willow stems and plantings shall be placed on the slopes behind the revetment. These plantings should be placed in at least four (4) rows (or as recommended by the Water Management District), with each plant being placed on two (2) foot centers in each row. Any willows salvaged during clearing should be utilized at this juncture. Refer to the STANDARD entitled "Vegetative Treatment" for specific information relating to the planting of the willow stems.

i) CONSTRUCTION OF WORKS - JACKS

Jacks shall be constructed of 6" x 6" x 8′ creosoted or pressure treated timbers, and shall be fastened together in a fashion that will result in a three-dimensional finished product known as a tetrapod. The timbers shall be fastened together by means of one-half inch diameter bolts with nuts and washers which are passed through drilled holes in the approximate center of each beam.

Each dimension of the completed tetrapod shall be threaded on three rows upon that plane with two strands of 12 gauge barbed wire which are placed on 1′-2" centers. A one-half inch diameter steel cable shall be attached in a crossing fashion to one of the planes of the tetrapod. The cable shall be fastened to the beams by means of passing it through holes which have been drilled through the beams approximately three (3) inches from the end of the beams. After the cable has been passed through the holes, a clamp shall be attached to the end of the cable to make it secure.

Jacks shall be placed along the banks of the river in a manner that will provide continuous coverage of the top of the bank during high flows. Jacks should be assembled in groups such that when tied one after the other on a steel cable, the assemblage will reach from the top of the bank to the toe of the bank. The jack assembly shall be tied together by means of an one-half inch steel cable. The completed assembly shall be anchored to a deadman, and the deadman buried at a distance of 15 feet from the top edge of the bank. The deadman should measure 3′ x 3′ x 3′ in dimension, and should be made of concrete. A hook shall be provided for connecting the cable.

The deadman should be buried such that it is covered by at least three (3) feet of soil. It is recommended that jack assemblies be placed along the top of the bank on 10′ to 15′ spacings. The jacks should be placed along the entire length of bank that requires protection.

Figure 16 is an illustration of this type of protective work.

The protection provided by jacks should be considered as an emergency stop-gap measure only.

C. GENERAL CONSTRUCTION ITEMS

This section will cover STANDARDS that are to be followed in all construction practices. These STANDARDS should be added to applicable STANDARDS taken from the previous two sections.

1. CONSTRUCTION STANDARDS - GENERAL ITEMS

a) ACCESS TO WORKS

Access roads to the work area shall be placed in a manner such as to protect from injury all vegetation other than grasses (unless deemed impossible). These access roads shall provide for safe passage of construction equipment and supply vehicles. Access roads shall not cross live streams unless a suitable stream crossing is installed. A stream crossing consists of culverts with enough capacity to pass the base flow of the stream that is likely to occur throughout the duration of the need for such a crossing. The culverts shall be backfilled with coarse, clean gravel and cobbles which are obtained from the dry portions of the river bed.

During dry periods, access roads shall be sprinkled with water to help abate dust pollution to the surrounding area. Upon completion of construction operations, all constructed access roads and stream crossings shall be removed. All disturbed areas shall be treated as covered under the STANDARD entitled "Vegetative Treatment".

b) DIVERSION OF BASE FLOW

Prior to the onset of construction operations, the base flow of the river shall be diverted around the work area, if in fact the base flow of the stream will be interfered with during the execution of construction activities. The diversion shall be constructed from its downstream confluence with the base flow in an upstream direction. The diversion shall be sized to carry the expected base flow of the stream that can be expected to occur throughout the duration of of the need of such a diversion. A freeboard of 1.5 feet shall be included in the sizing of such a diversion.

At the upstream intersection of the diversion with the base flow, a cofferdam shall be constructed in the original base flow channel. This cofferdam shall be constructed of clean stream gravels and cobbles, and shall be sized so as to be stable under all flow conditions expected to occur throughout the duration of the need for such a diversion.

The cofferdam shall be constructed in a manner such that its height will equal that of the surrounding abutments it is tied into.

Upon completion of work requiring the need of such a diversion, all diversion and cofferdam works shall be removed. The base flow shall be returned to its original location (as is reasonably possible), and the cofferdam materials shall be returned to their place of origination.

c) REMOVAL OF WATER

All excavations shall be dewatered and kept free of standing water or excessively muddy conditions as needed for the proper execution of the construction work. Care should be exercised to prevent the removal of fines from the areas being dewatered. The party performing the construction work shall furnish, install, operate and maintain all drains, sumps, casings, well points, and other equipment needed to perform the dewatering as specified.

Water removed during dewatering operations shall pass through a settling basin before it may be introduced into the base flow of the river. This settling basin shall be sized to allow for the settling out of the fine particles contained in the water. Schemes utilizing filter fabric may also be utilized to perform this task.

A detailed dewatering plan shall accompany any permit request submitted to the Water Management District for review and approval.

d) POLLUTION CONTROL

All work shall comply with applicable Federal, State and local laws, orders, and regulations concerning the control and abatement of water pollution. Work shall be performed by methods that will prevent entrance of accidental spillage of solid matter, contaminants, debris, and other objectionable pollutants and wastes into the watercourse, and into underground water supplies.

No clearing, stripping, or grading shall take place on the project until the stream has been diverted (if required), and the dewatering settling basin has been installed and approved by the District.

e) VEGETATIVE TREATMENT

It is necessary to prepare and plant willow stems properly to insure growth and stability of the stem. The following requirements shall be followed in the preparation of the stems for planting:

1. The willow stems shall be long enough to allow for an embedment of three (3) feet into the subsoil, the thickness of the protective work being installed, the depth of topsoil to be placed, and a protrusion of the stem not to exceed 12 inches.

2. The willow stems shall be selected from healthy wood of reasonable straightness from plant species that root easily and are native to the Carmel Valley.

3. The willow stems shall be clear cut with unsplit ends. The butt end of stems should be cut on an angle to provide a point to facilitate driving.

4. Branches and leaves on the stems shall be trimmed as close as possible to the main stem.

5. Stems greater than one inch in diameter are required. The larger the diameter, the better the results will be.

6. Stems put out their greatest concentration of and strongest shoots just below an annual ring which is formed from a terminal bud scar. Stems should be cut so that a terminal bud scar is within 1 to 4 inches of the top of the stem.

7. Stems must not be allowed to dry out. The stems must be kept covered and moist during transport, storage, and during the planting operation. Stems may be kept submerged in water if desired. At no time should stems be left exposed to air which will allow them to dry out prior to planting.

The following guidelines shall be followed in the planting of the willow stems:

1. The stems should be planted right side up. (butt ends in the ground - a good idea would be to point all butt ends of the stems when they are cut, then the pointed end shall be placed in the ground)

2. Avoid stripping the bark or bruising the stems when setting them in the ground. In soft soils, the stems may be driven in with a wooden maul or mallet. In firm soils, a pilot hole should be provided to planting. The pilot hole may be provided by using a hand auger, iron bar, or by other acceptable methods.

3. Tamp the soil around the cutting. The cutting must be firm in the ground so that it cannot be readily removed by the force exerted by water, or manually pulled out by vandals.

The following bank protection works require the placement of topsoil over the completed structural works to a location approximating the middle of the slope: Rock riprap, Concrete rubble, Gabions and revet mattresses. Topsoil shall be provided that contains fertile loam and is free from excessive quantities of roots, grass, weeds, sticks, stones, or other objectionable materials. Approved topsoil shall be spread over the slopes containing the above mentioned works to a depth of at least 4 inches above the highest protruding rock or chunk of concrete contained in the work being covered. Care shall be taken during the placement of topsoil not to harm the willow stems which have previously been planted.

Upon completion of all activities at the project site, all disturbed areas shall be treated in such a manner so as to eliminate the possibility of sediment reaching the water course. The area may be seeded and mulched, mulched only, covered by netting or jute mesh, or any other acceptable method of protection as approved by the Water Management District.

D. OPERATION AND MAINTENANCE

A necessary requirement to the performance of any protective work along the Carmel River will be the execution of an Operatrion and Maintenance Agreement between the property owner(s) and the Monterey Peninsula Water Management District. This agreement shall cover the performance of items such as the operation of irrigation systems and the maintenance requirements involved in the repair of works and the removal of debris. The Operation and Maintenance Agreement shall provide a breakdown of responsibilities between the parties involved. Yearly inspections of works approved by the District shall be made to ascertain that required maintenance is being performed by the owner(s).

A fully executed Operation and Maintenance Agreement shall be mandatory before a river work permit is granted by the District.

E. GENERAL NOTE REGARDING STANDARDS

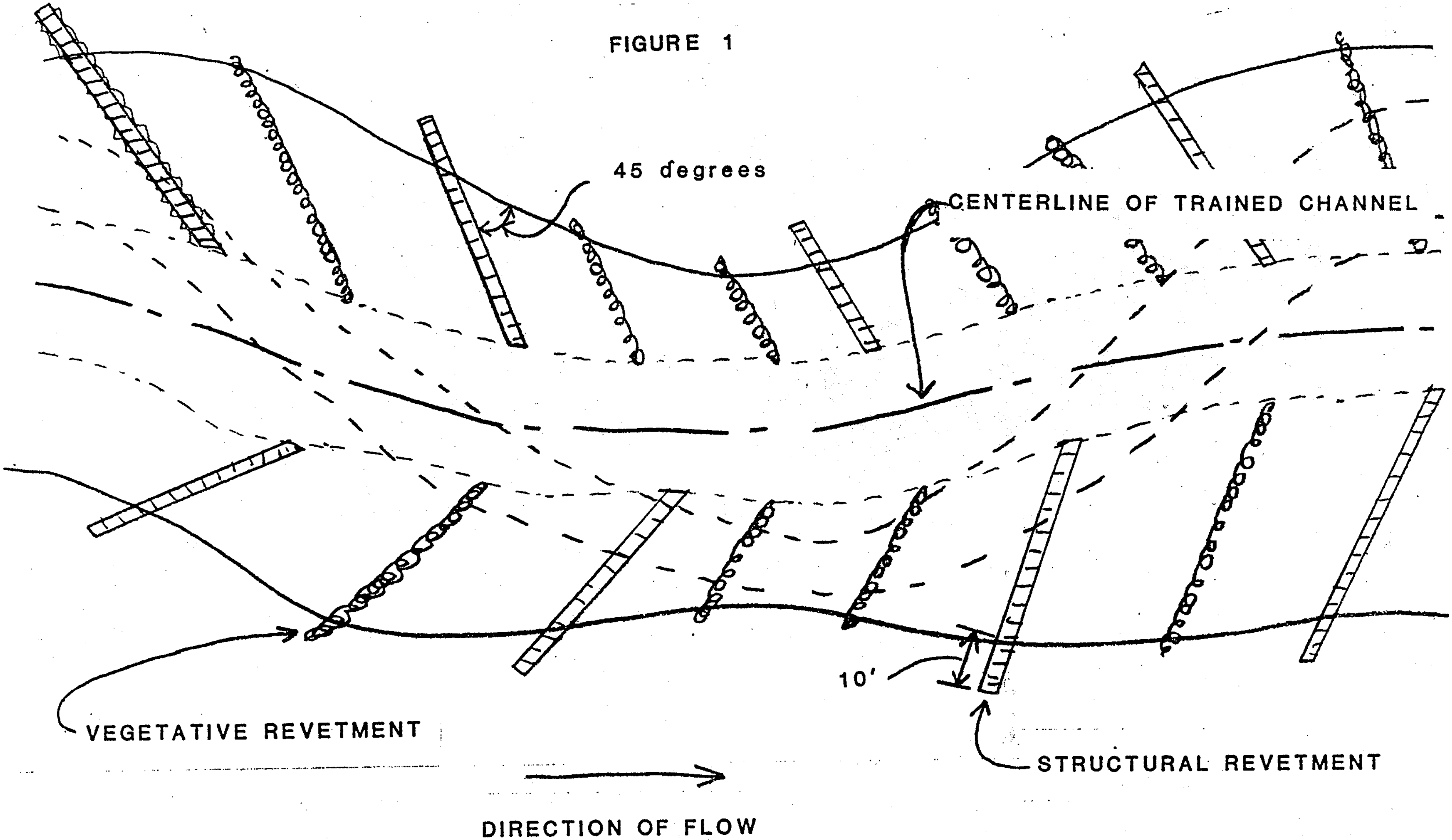
This listing of STANDARDS is not intended to be all inclusive. It will be apparent that in certain situations, special STANDARDS will be required based upon those particular circumstances.

## FIGURES - APPENDIX A

# PREFERRED SOLUTION

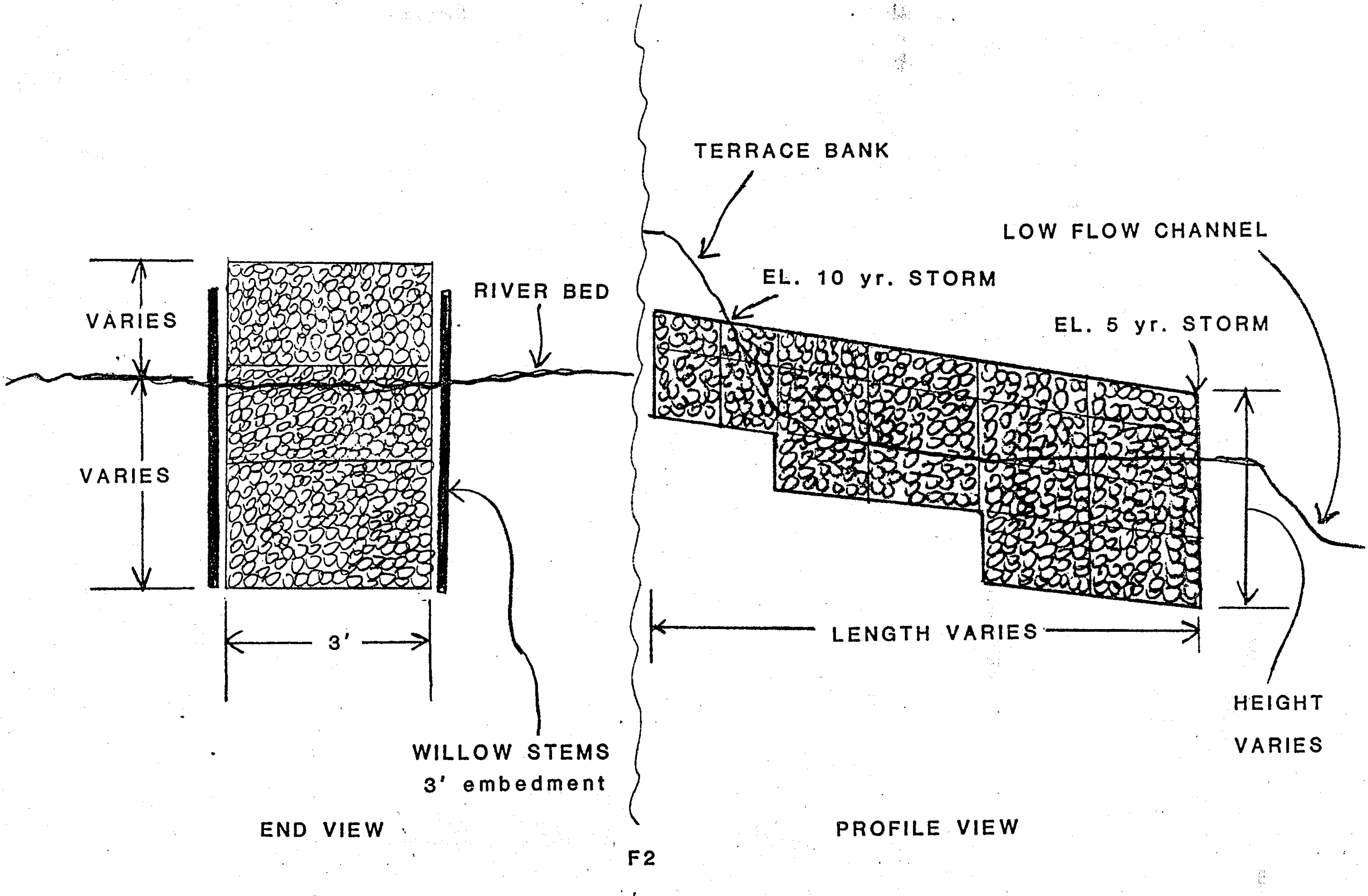
plan view

FIGURE 1



# PREFERRED SOLUTION — GABION REVETMENT

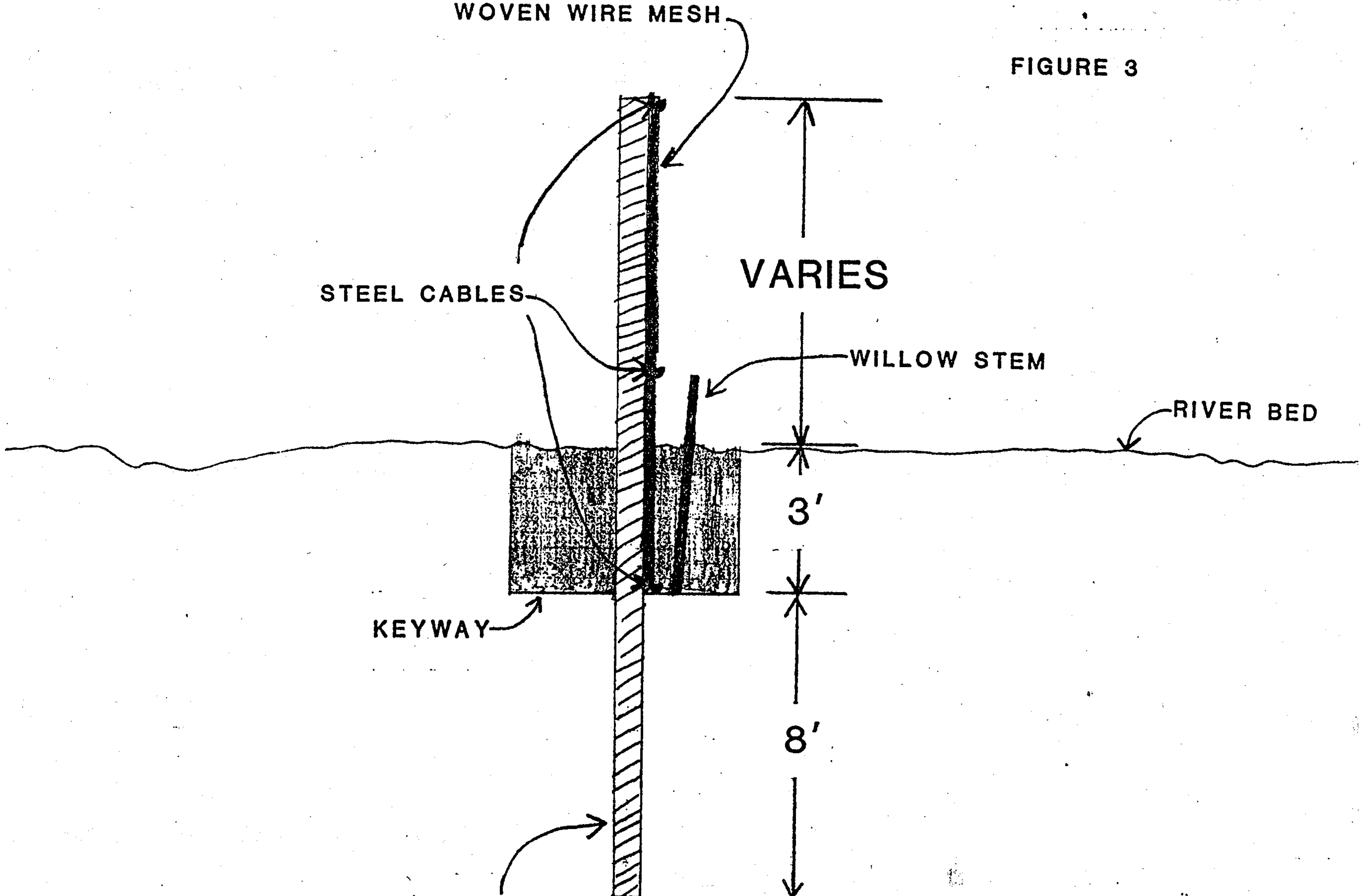
FIGURE 2



# PREFERRED SOLUTION
# PIPE (POST) & WIRE REVETMENT

CROSS-SECTIONAL VIEW

FIGURE 3

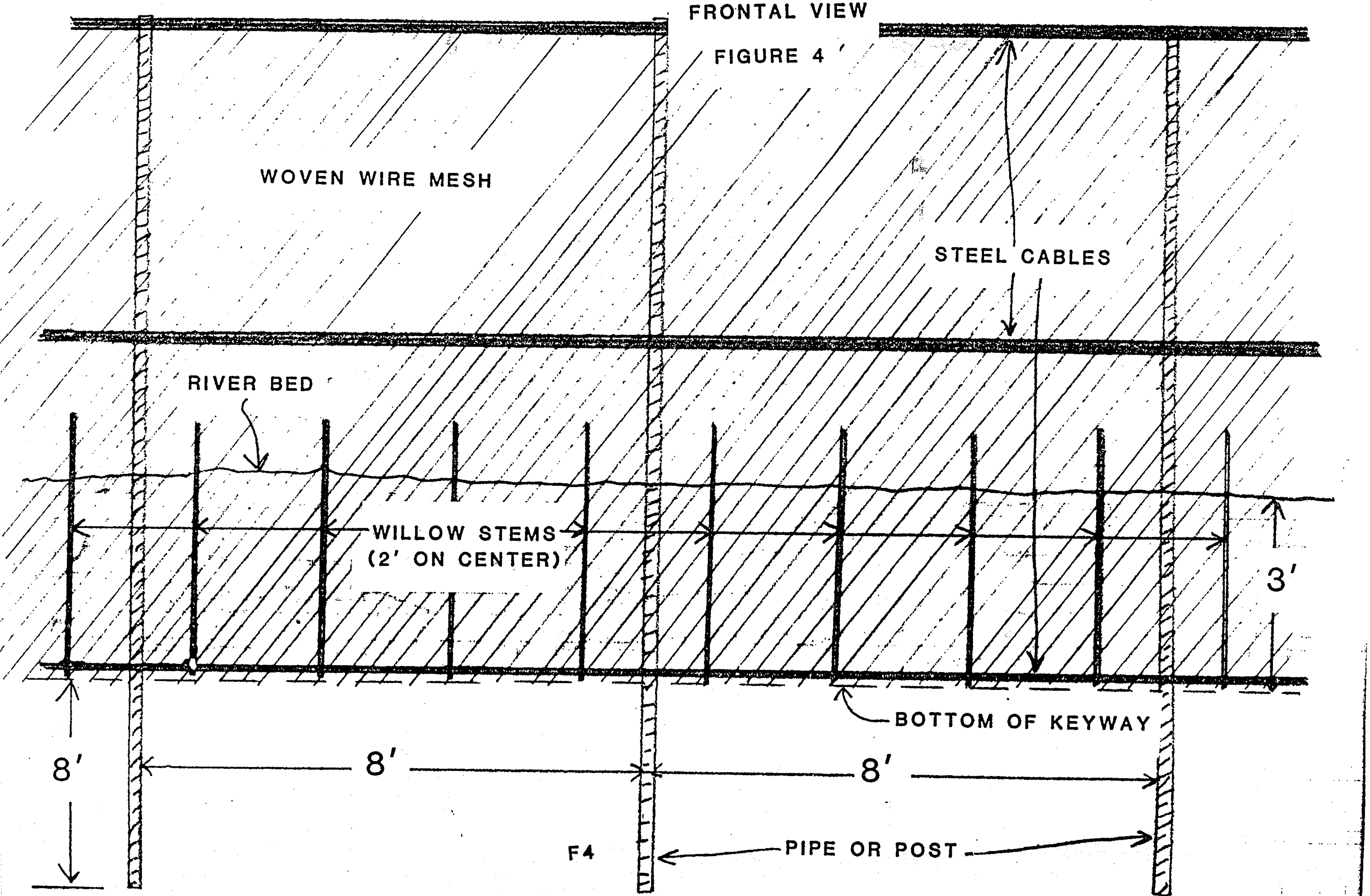



F3

# PREFERRED SOLUTION – PIPE (POST) & WIRE REVETMENT

FRONTAL VIEW

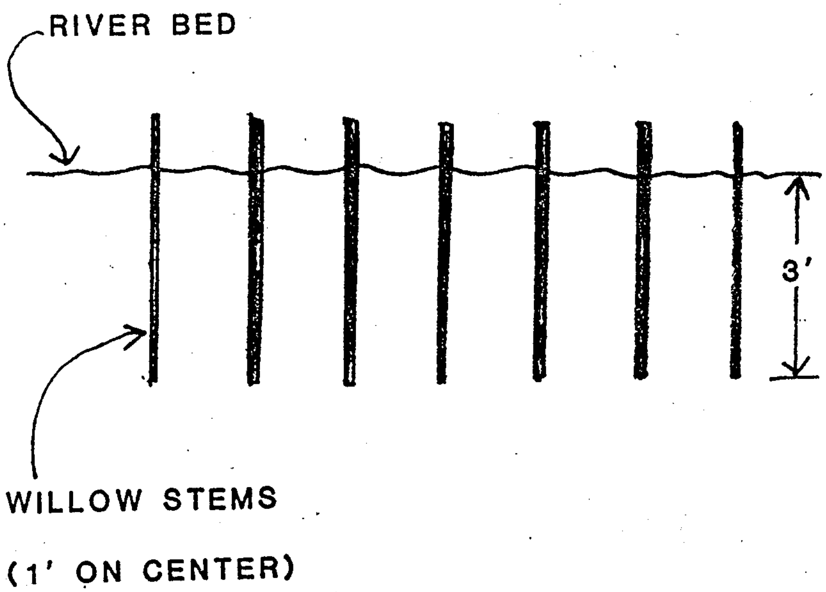
FIGURE 4



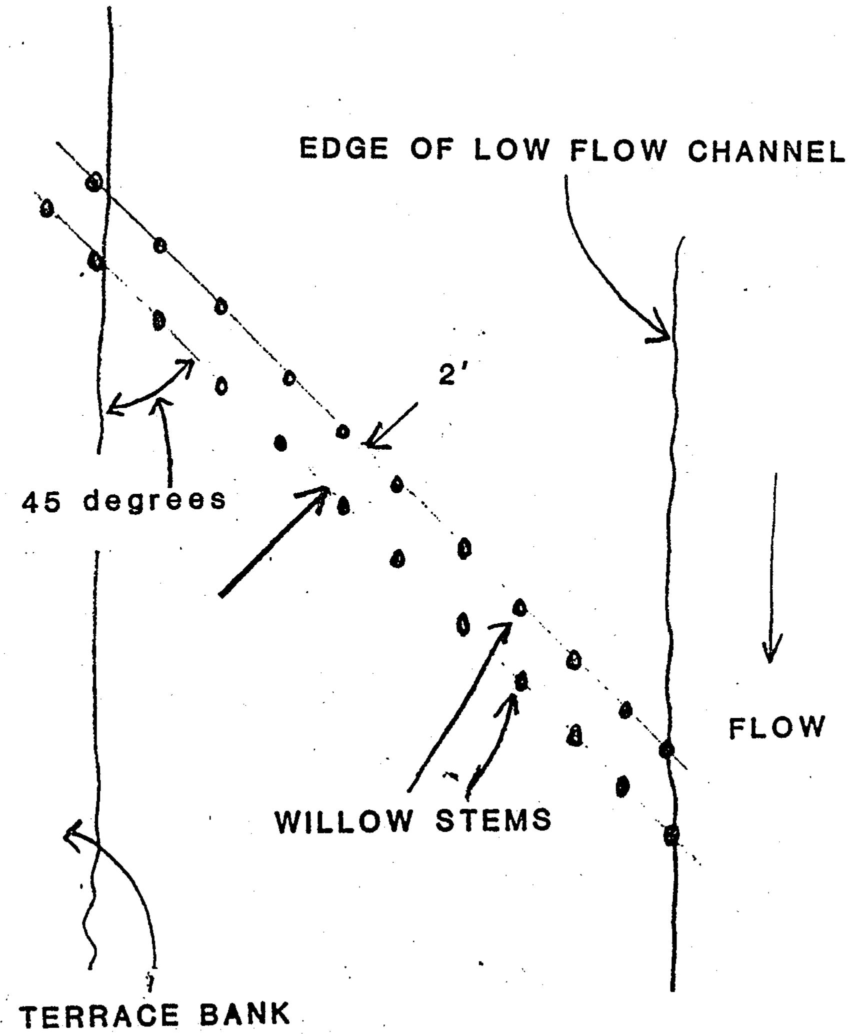

F4

# PREFERRED SOLUTION – VEGETATIVE REVETMENT

FIGURE 5




PROFILE VIEW

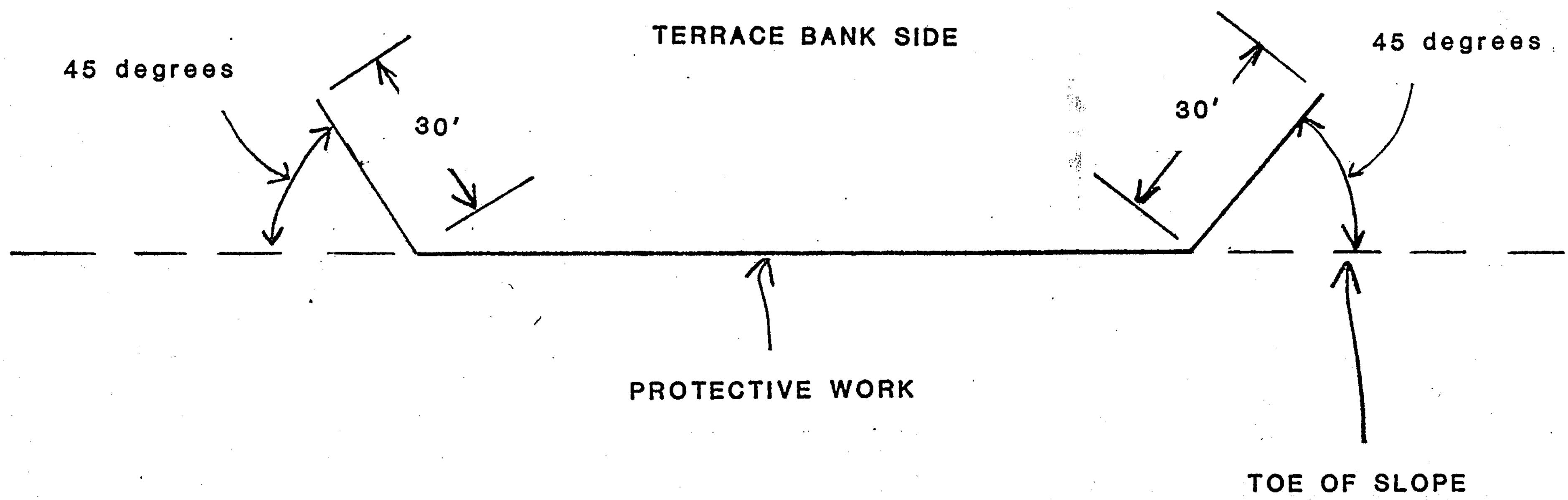



PLAN VIEW

# TYING IN OF WORKS DIAGRAM

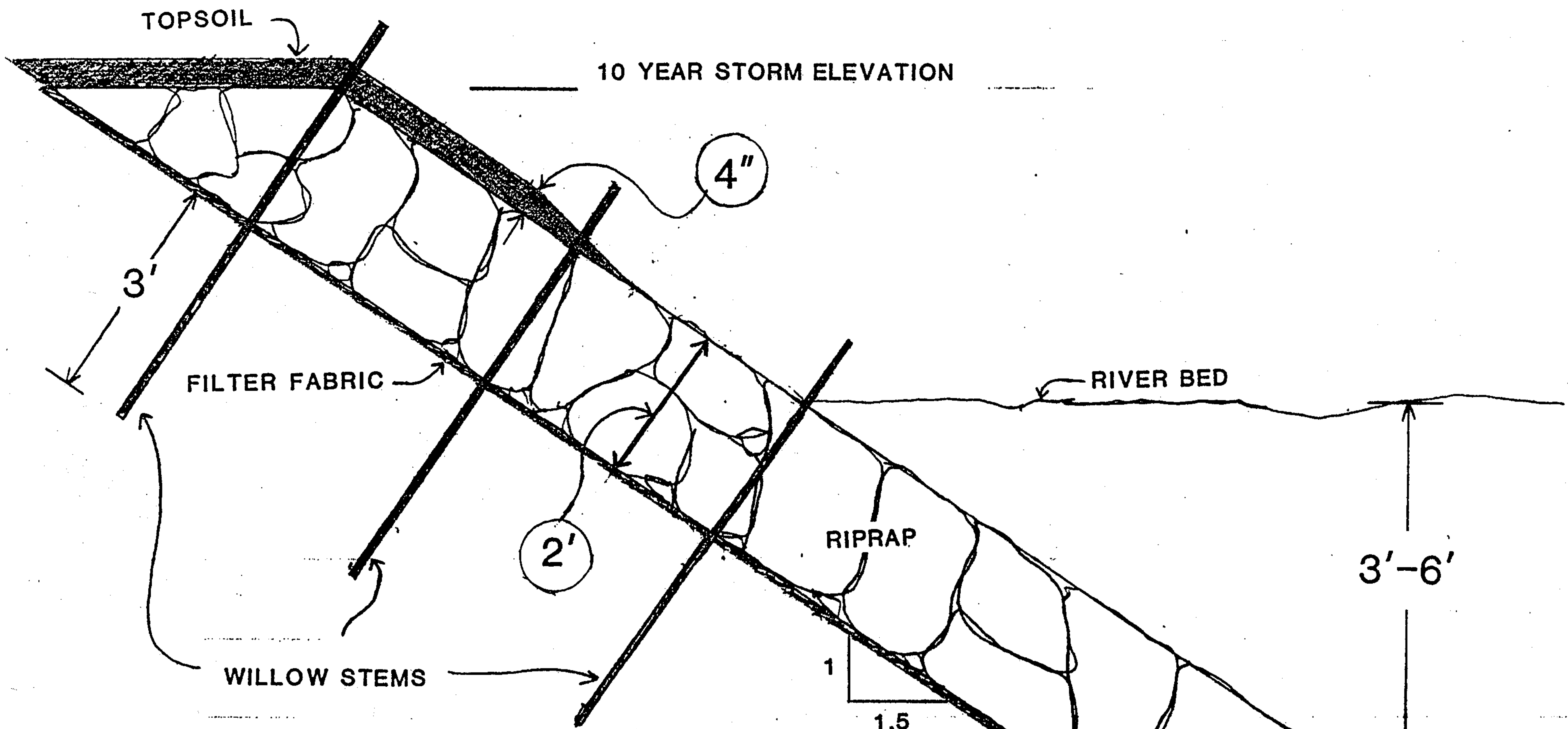
PLAN VIEW

FIGURE 6



# RIPRAP BANK PROTECTION

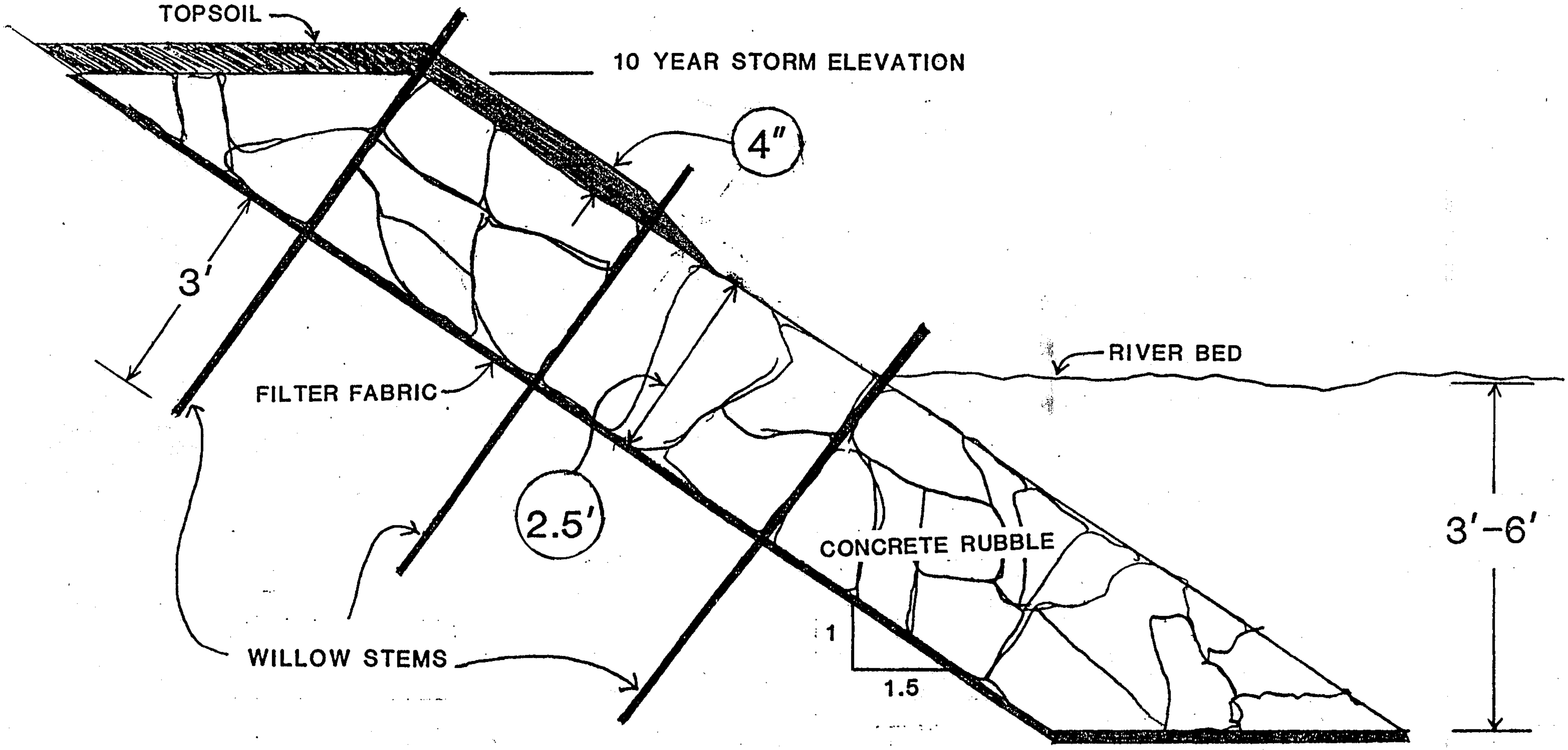
FIGURE 7




F7

# CONCRETE RUBBLE BANK PROTECTION

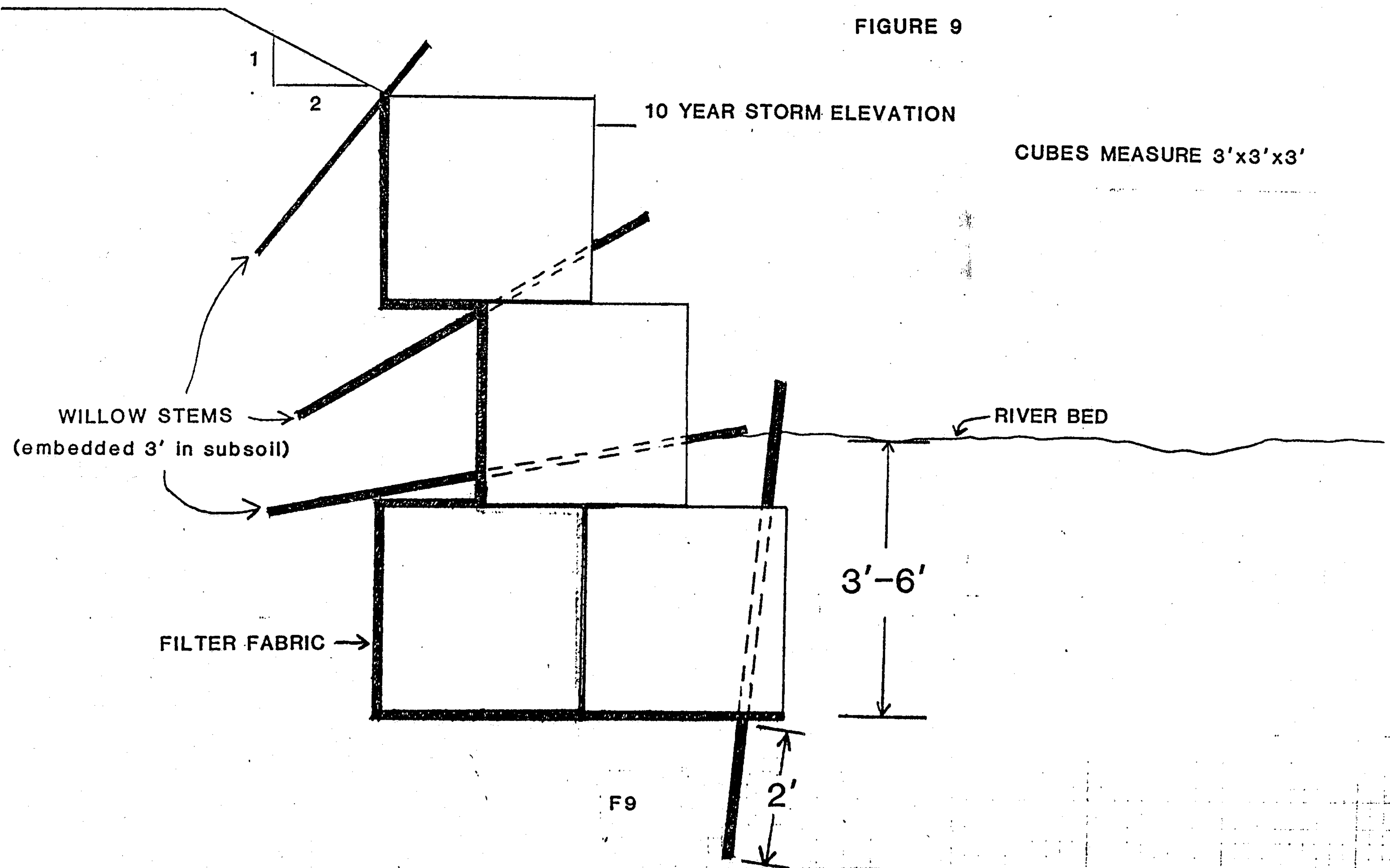
FIGURE 8



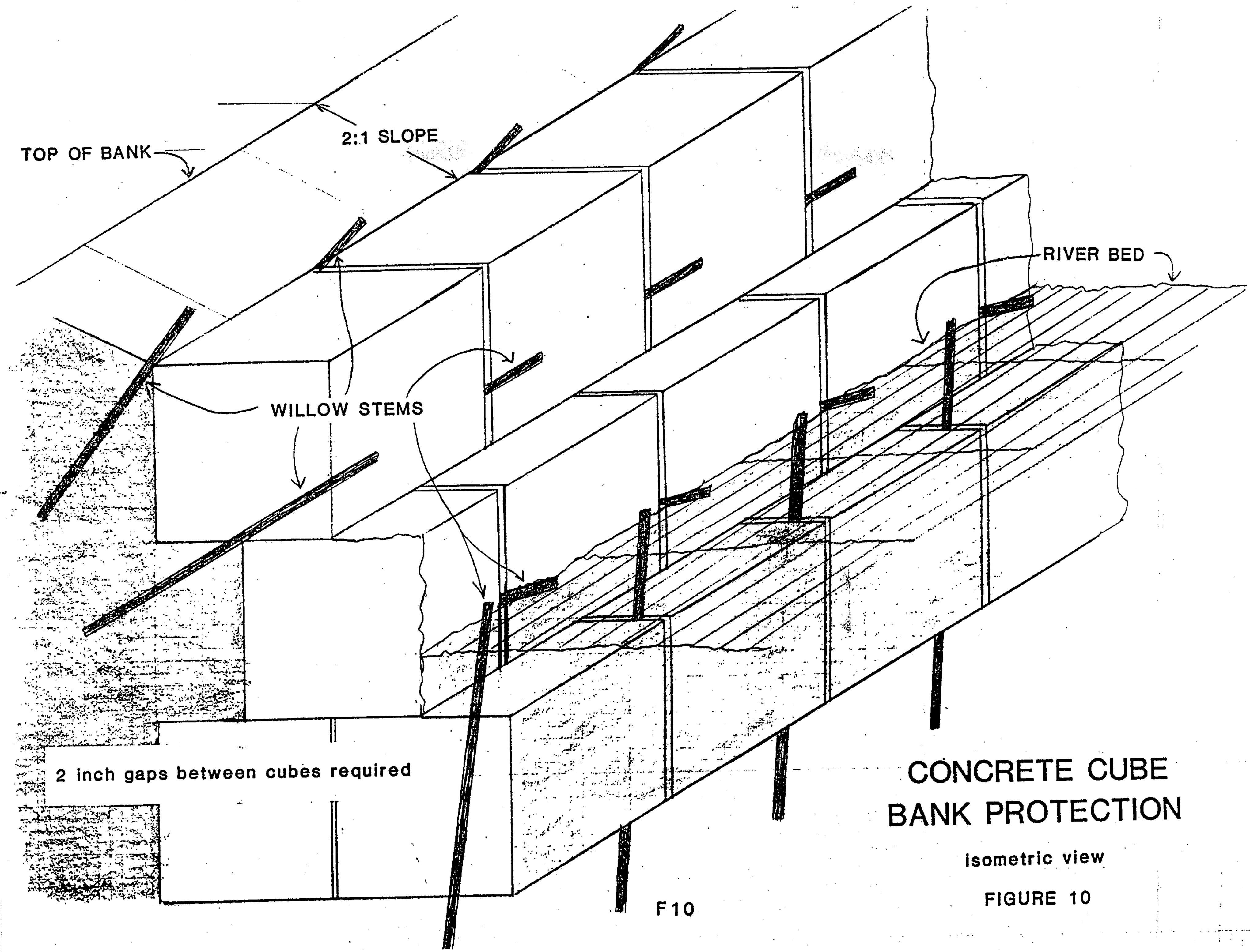
## CONCRETE CUBE BANK PROTECTION

cross-sectional view

FIGURE 9




F9




CONCRETE CUBE
BANK PROTECTION

isometric view

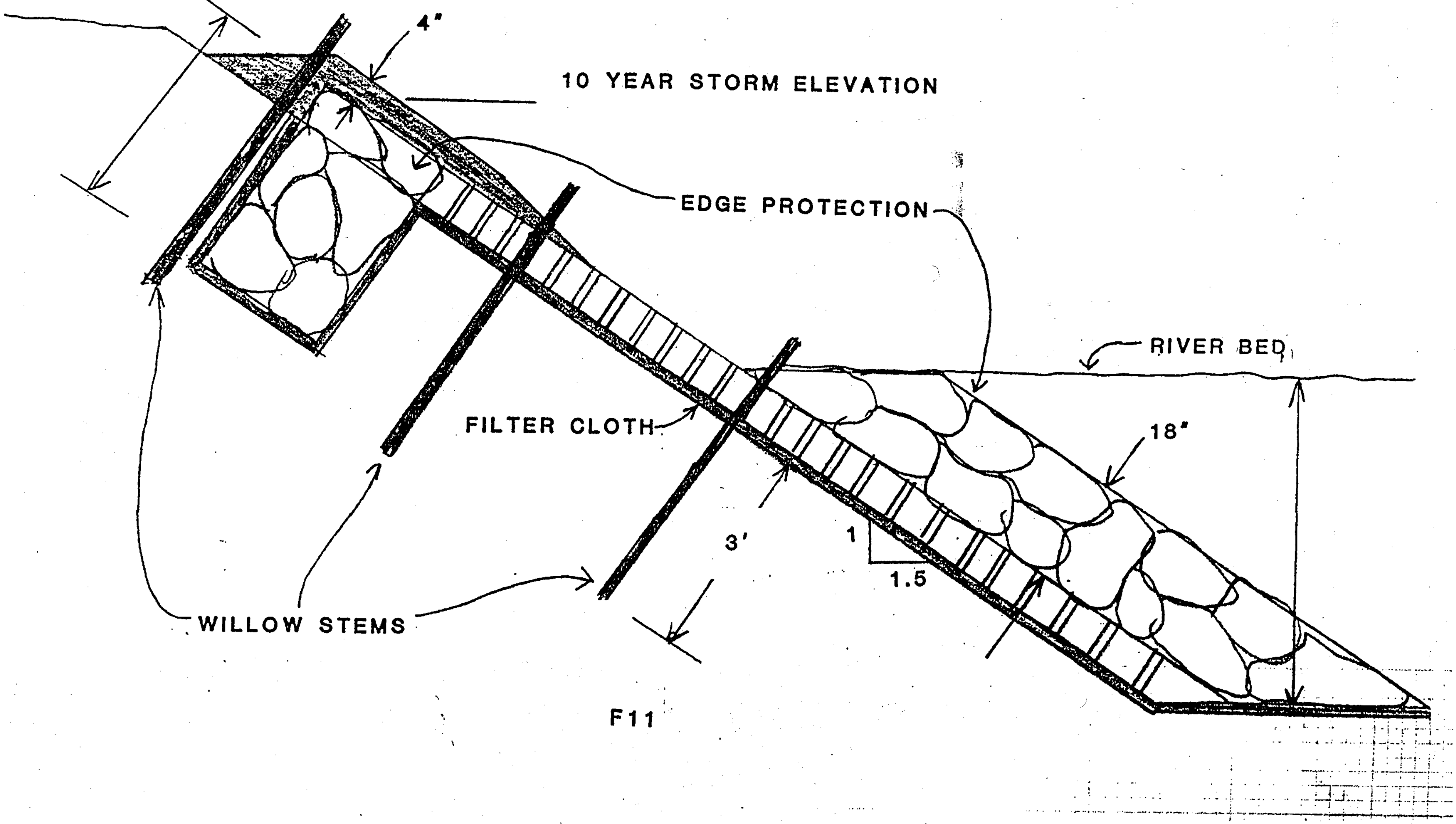
FIGURE 10

F10

# ARTICULATED CONCRETE BLOCKS BANK PROTECTION

CROSS-SECTIONAL VIEW

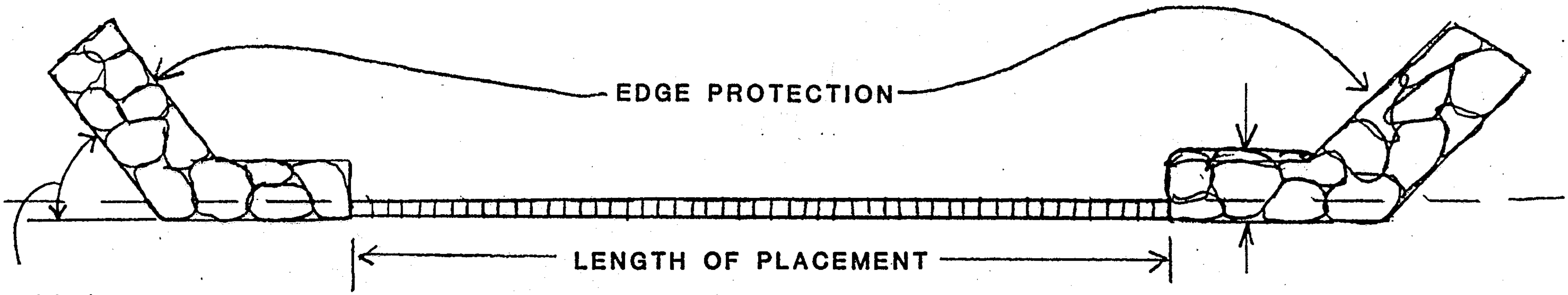
FIGURE 11




F11

# ARTICULATED CONCRETE BLOCKS BANK PROTECTION

FIGURE 12



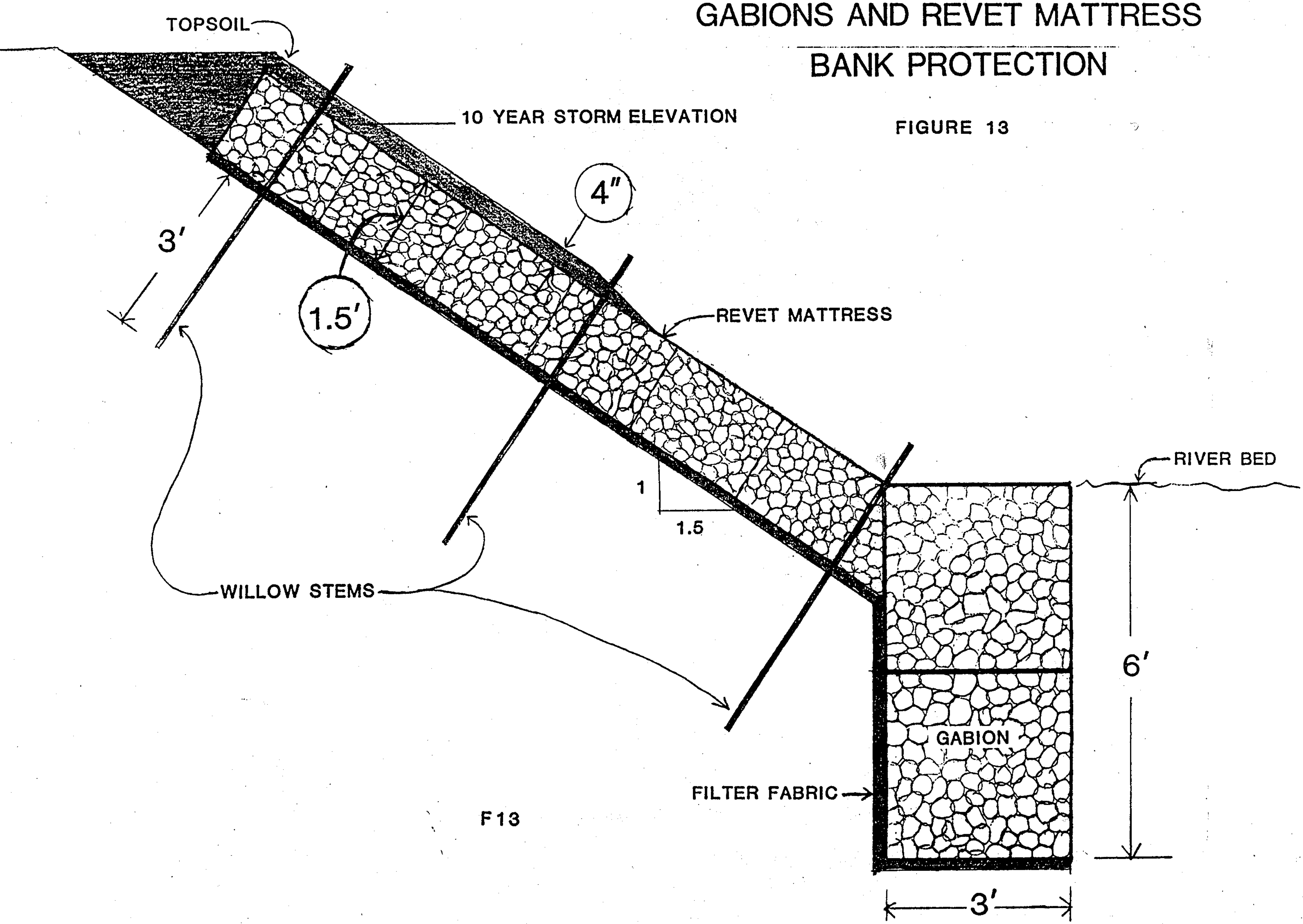

PLAN VIEW OF

SLICE CUT AT TOE OF SLOPE

# GABIONS AND REVET MATTRESS

## BANK PROTECTION

FIGURE 13



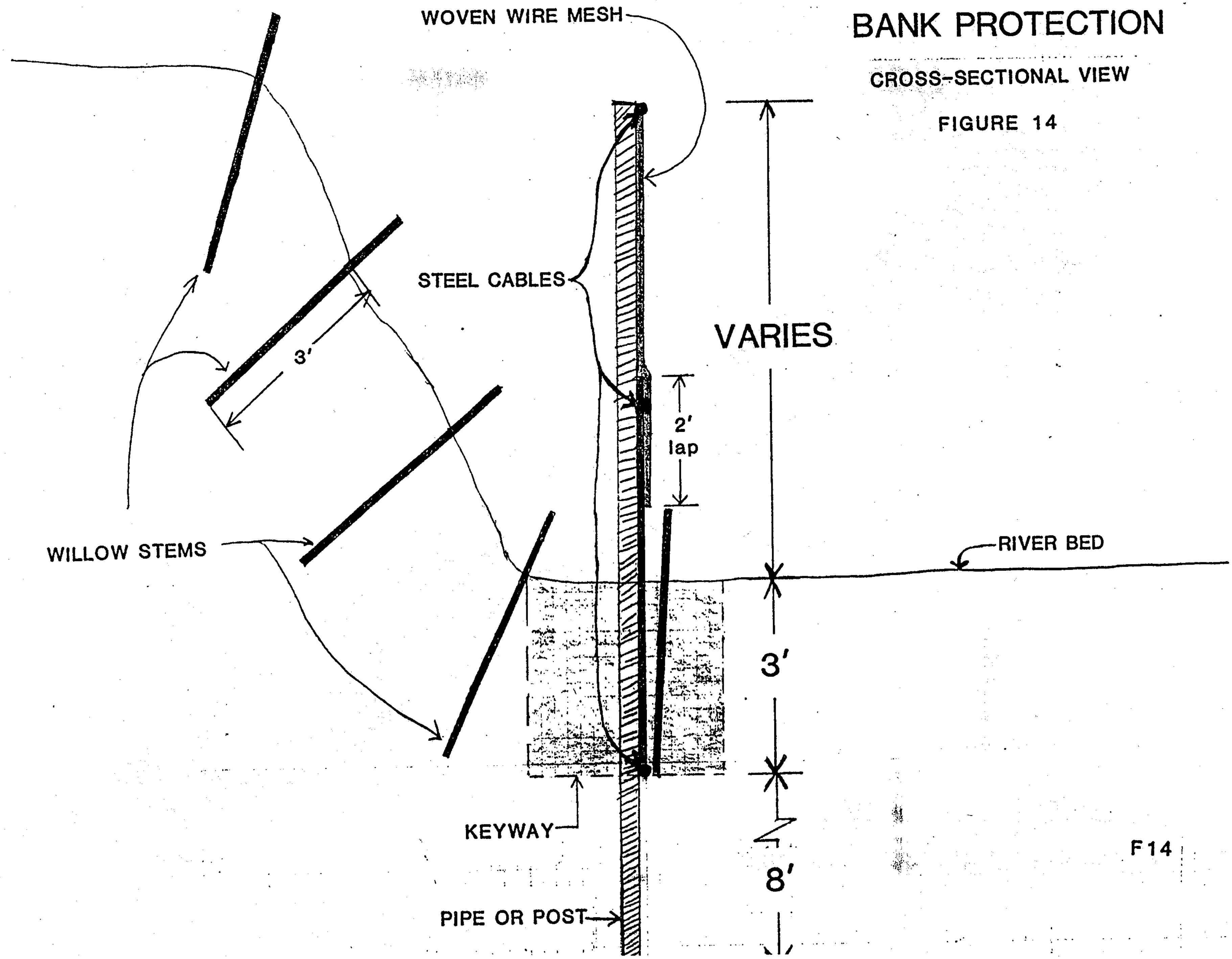

F13

# PIPE (POST) & WIRE REVETMENT

## BANK PROTECTION

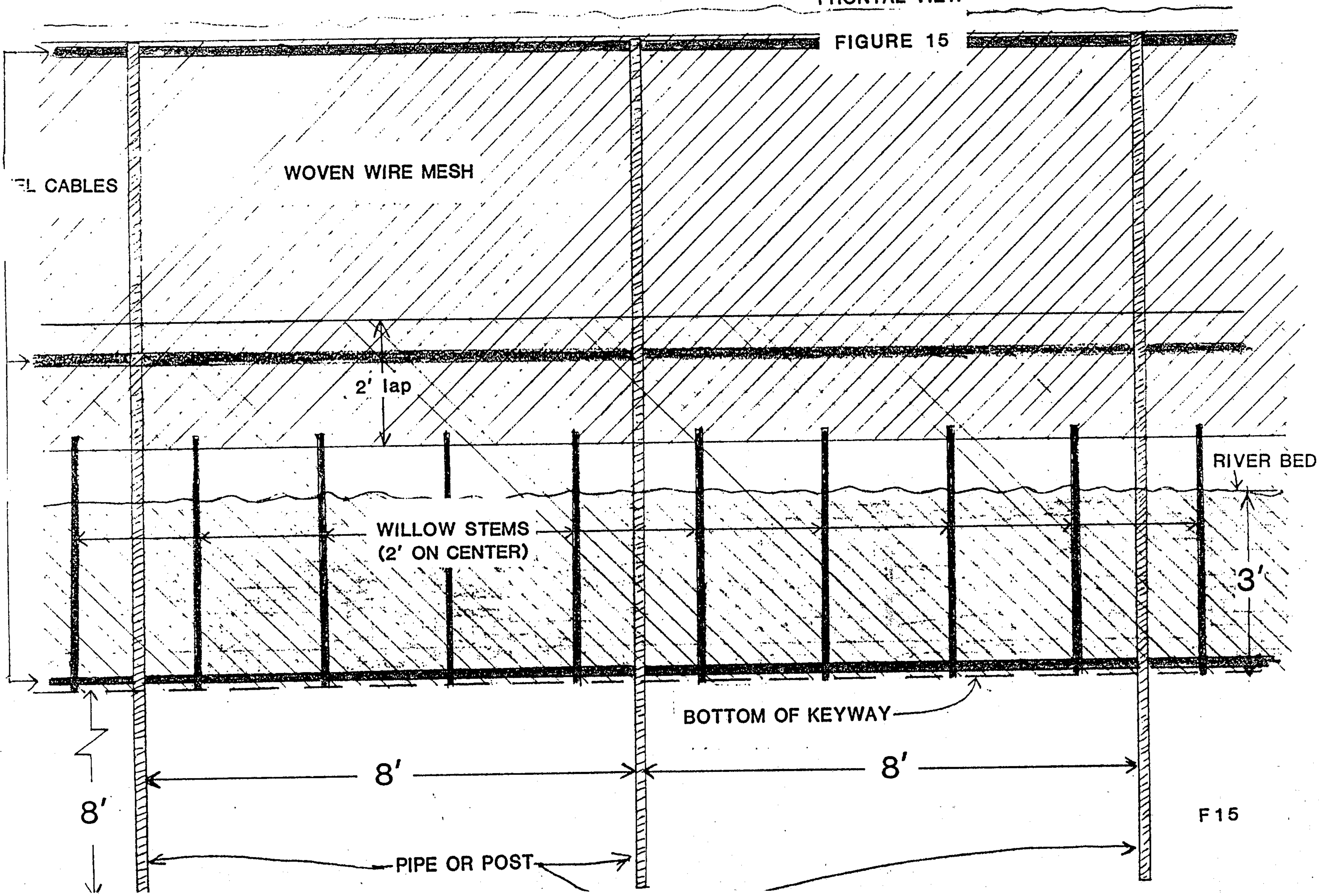
CROSS-SECTIONAL VIEW

FIGURE 14




F14

# PIPE (POST) & WIRE REVETMENT
## BANK PROTECTION
FRONTAL VIEW



# WOODEN JACKS

FIGURE 16