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BULLETIN NO. 167

PILOT LEVEE MAINTENANCE STUDY

Sacramento-San Joaquin Delta

JUNE 1967

RONALD REAGAN
Governor
State of California

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FOREWORD

Historically, flood-control projects have been designed, constructed, and maintained for the single purpose of flood control. In 1961, a controversy arose over the single-purpose flood-control maintenance practices that resulted in denuding the levees of vegetation in the Sacramento-San Joaquin Delta, particularly along the Sacramento River. Protesting groups maintained that recreational, esthetic, and wildlife values of the Delta waterways should be considered along with the flood-control function of the levees.

The Pilot Levee Maintenance Study was conducted in response to a recommendation by the Sacramento River and Delta Recreation Study Committee, the formation and work of which were authorized by the California State Legislature under provisions of Assembly Bill 139, Chapter 324, Statutes of 1961.

This Bulletin briefly covers the material presented in two annual progress reports prepared in 1963 and 1964 and the preview to Bulletin No. 167, prepared in 1965. Findings during the last year of study and the conclusions and final recommendations of the Pilot Levee Maintenance Study are described in detail.

The Pilot Levee Maintenance Study has developed data and information which concludes that native vegetation as well as other species of vegetation can be maintained and propagated compatibly with the flood-control function. Also, experiments indicate that timely preventive measures in many cases can be employed to avert total reconstruction of levees involving the removal of existing vegetation. Before such multiple-use maintenance procedures are adopted for project levees, however, such problems as cost-sharing among beneficiaries, source of additional funding, authorization, and public access to levees, should be given further consideration by the Legislature.

William R. Gianelli

William R. Gianelli, Director
Department of Water Resources
State of California
June 30, 1967

State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES

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ABSTRACT

The Pilot Levee Maintenance Study was conducted as a result of the levee stripping controversy in 1961 to test alternative methods of levee maintenance that could provide for multiple uses of levees, especially in the Sacramento-San Joaquin Delta. It is concluded that with proper vegetative management programs, certain Delta levees can be adapted and maintained to serve the needs of esthetics, recreation, and wildlife, as well as the primary purpose of flood control. Such vegetative management will require new techniques and additional authorization and monies.

The common practice of rock revetting certain Delta levee slopes above normal water levels may not be necessary with appropriate vegetative management for erosion control. The protection of levee slopes against erosion at and below normal water levels must be accomplished by the use of some form of revetment. The portions of newly constructed levees not faced with revetment should be planted to ground cover after construction. Ground cover species showing the best adaptability to the Delta are Tifway and Tifgreen bermuda, coastal bermuda, and creeping wildrye.

Existing ground cover can be preserved and managed to meet the needs of flood control, recreation, and wildlife. Planting programs can be undertaken where native vegetation cannot meet multiple-purpose requirements.

Vegetation need not be controlled on berms where channel capacity is not critical to flood-control needs. Trees and shrubs may be allowed on the levee slope in open patterns where berms do not exist on the waterside of the levee.

Preventive maintenance in the form of berm protection and timely repair of toe erosion of levees and berms can head off major reconstruction work which involves removal of vegetation.

Present-day annual levee maintenance costs in state maintenance areas range from $800 to $2,500 per mile, depending on the location, type of section, and condition of the levee. The additional cost of maintaining a structurally sound, revetted levee that is free of major encroachments, if trees and shrubs were retained on the waterward slope, is estimated to be $600 per mile per year, using specialized equipment. Such additional cost to make the levee suitable for other purposes should be borne by interests other than flood control.

Before multiple-purpose levee maintenance techniques are adopted for project levees, a number of problems including cost-sharing among beneficiaries, source of additional funding, authorization, and public access to levees, should receive further consideration by the Legislature.

CHAPTER I: INTRODUCTION

During 1961, a flood of protests against the denuding of levees in the Sacramento - San Joaquin Delta was launched by sportsmen's organizations, wildlife conservation groups, and the public in general. Levee maintenance regulations dictated that virtually all shrubs and trees be cleared from levees to insure that the flood control protection provided by the levees would not be impaired.

The California State Legislature, recognizing the desirability of preserving scenic and recreational values as well as the wildlife resources, adopted several measures recommending federal and state action toward greater consideration of esthetics and recreation in levee maintenance practices.

The Pilot Levee Maintenance Study was begun to conceive and test alternative methods of levee maintenance that would provide for multiple use of levees. A number of tests was conducted to determine if vegetative growth could be allowed on levees and berms to preserve and enhance esthetic, recreational, and wildlife habitat values without impairing the flood control capability of the levees.

Any proposal for vegetation on levees must include a demonstration that vegetation can be managed so that the degree of flood protection is not diminished from what would be provided under current standards. Levees must be maintained adequately to allow proper inspection for rodent holes, sloughs, erosion, or other damage. Uncontrolled vegetation prevents effective inspection and impedes floodfighting.

The recreational uses of multiple-purpose levees involve both esthetics and the physical use of the levees and berms. The scenic values of the levees are not restricted to recreationists and boaters, but extend to the motorists who drive the levee roads, including State Highway 160. Standards defining specific patterns of vegetation cannot be recommended for esthetics, since the beauty of the waterways is determined by individual tastes. However, most vegetative management programs designed to meet flood control and wildlife objectives will go a long way toward enhancing esthetic appeal.

Levees and berms to be used by bank fishermen, picnickers, and campers ideally should provide shade, low growing ground cover, and generally pleasant surroundings. Problems associated with access to these areas are discussed in the Resources Agency report, "Delta Master Recreation Plan", released in June 1966, and are not treated in this bulletin.

Multiple use of levees also involves development of the wildlife habitat. Levee vegetation, particularly trees, provides an important habitat for significant populations of over 100 wildlife species. Continued removal of this vegetation could mean the eventual elimination of these species from the Delta. Thick, bushy evergreen trees and

Barge placing rip-rap on newly reconstructed levee for flood control shrubs, affording frequent small sanctuaries along levees and berms, are necessary for the protection and perpetuation of wildlife.

Present Levee Maintenance Practices

A trip down the river road into the Delta area reveals the variations in the appearance of levees bordering the waterways. With a turn of the road or bend in the river, the levee may change abruptly from a rock-revetted, sterile hulk to a ragged slope overgrown with weeds, shrubs, and trees. This inconsistency in levee appearance presents an almost insoluble puzzle to anyone trying to understand how the principles of levee maintenance are applied.

To begin to understand the lack of uniformity of levees in the Delta, it is necessary to recognize that there are different types of levees with different agencies or groups responsible for their maintenance.

These different types of levees fall under the three broad categories of project levees, direct-agreement levees, and nonproject levees. Project levees comprise approximately 15 percent of the levees in the Delta area, direct agreement levees about 10 percent, and nonproject levees the remaining 75 percent.

Project levees are those included in the Sacramento River Flood Control Project and the Lower San Joaquin River and Tributaries Project. These levees were constructed or rebuilt by the U. S. Corps of Engineers and are maintained to federal standards by or under the supervision of the State of California.

Direct agreement levees include some of the levees along the Stockton Deep Water Channel and also levees that were repaired by the U. S. Corps of Engineers following major breaks or inundations. However, these levees are maintained to federal standards by the local interests in direct agreement with and under the supervision of the Corps. The State has no jurisdiction or responsibility for the maintenance of these levees.

Examples of the wide variation in levee appearance

Nonproject levees are those privately constructed and maintained by landowners or local districts and are not required by law to conform to any standards of maintenance. These levees are usually maintained for the sole purpose of flood protection to the landowner with no consideration for esthetic or recreation values.

This variation in levee maintenance responsibility accounts for part of the nonuniformity in the appearance of levees. There is, however, a lack of uniformity even among project levees.

Many project levees are maintained by local districts under the supervision of the State. Even though the districts are subject to federal standards, the attitudes, available equipment, methods, and financial resources differ between districts, and these factors also contribute to the nonuniformity of levee appearance.

The federal maintenance regulations are excellent guidelines to be followed for preserving the overall integrity of the project levee system. In the past, these regulations have been interpreted many ways, depending upon the objectives of the user at the time. There are many areas within the project system where mature trees have been tolerated on levee slopes until they posed a threat to the integrity of the levee or until the levee was in need of major repair. It is not logical, however, to accept an interpretation of the regulations that would forever prevent all trees and shrubs on levee slopes under all circumstances.

Multiple - purpose levee maintenance practices, which would allow vegetation on levees and still maintain the flood control function, are more costly than the present-day methods of levee maintenance. Currently, monies are not available to preserve and enhance levee vegetation -- only to maintain the levees for flood control. Consequently, vegetation, especially trees, is generally unattended until it must fall to the more pressing demands of flood control.

CHAPTER II: EXPERIMENTATION

All field experiments in the Pilot Levee Maintenance Study were conducted to develop alternative levee maintenance techniques which would allow vegetative growth on levees and berms without endangering the flood-control function.

Much of the work done at the test sites was conducted by other governmental agencies under contract to the Department of Water Resources. The work on adaptability of ground cover species to the upper Delta environment and maintenance of the vegetation itself to achieve specified results was performed by the State Division of Soil Conservation and the U.S.D.A. Soil Conservation Service. The Department of Fish and Game assisted by recommending species of trees and shrubs with good wildlife habitat values for use on Delta levees.

Other experiments pertaining to repair and maintenance of levees and berms, with consideration for retaining native vegetation, were performed by the Department of Water Resources and the Corps of Engineers. Coordination among the various agencies participating in the study was excellent.

Area of Investigation

Field testing for the Pilot Levee Maintenance Study was conducted within the Sacramento-San Joaquin Delta area and primarily on levees bordering the Sacramento River. All test sites are within the Sacramento River Flood Control Project. Levees in the central Delta area, composed primarily of peat soils, were not considered for testing. These peat levees are unique, posing special problems of subsidence and instability, which will require a different approach to achieve multiple uses.

Five sites were selected for conducting the various tests. The locations of these sites are shown in Figure 1.

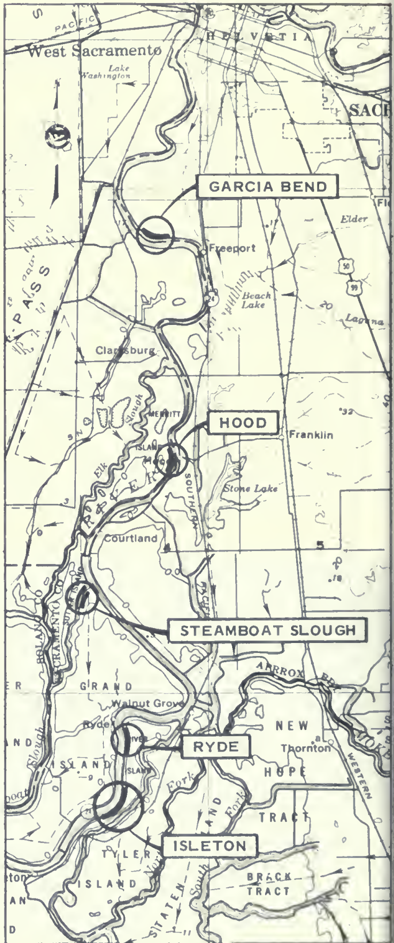

Figure 1. Location map

The nomenclature used to describe the various portions of the levee section are shown in Figure 2.

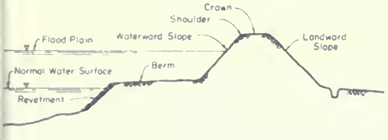

Figure 2. Nomenclature of a levee

Garcia Bend Test Site

Located on the left bank of the Sacramento River about two miles upstream from the town of Freeport, this site is under private ownership but presently maintained by the Department of Water Resources. Testing was conducted on a 3,000 - foot section of the levee and berm.

The site is covered with large trees and a dense undergrowth of brush and weeds on the waterside berm. Two natural beaches, the largest 300 feet long, are also located at the site. This part of the river is noted for good striped bass fishing and is also used by water skiers during the summer.

Garcia Bend test site

Ryde Test Site

This site, near the town of Ryde on the left bank of the Sacramento River, is owned and maintained by local interests. The levee and berm in this area were recently reconstructed and have little undergrowth and no large trees. A 3,000-foot section of levee and berm was used to conduct the various tests.

Ryde test site

Steamboat Slough Test Site

This test site lies along both banks of Steamboat Slough, from its junction with the Sacramento River to a point approximately 3,000 feet downstream. There are no berms on either bank; however, dense undergrowth and a large number of trees cover the levee slopes.

The area is accessible by water and road and is used extensively for recreation. There are two small sandy beaches on the left bank and one on the right bank. This section of the slough is extremely popular with cruiser boaters, who tie up for extended periods of time.

Steamboat Slough test site

Hood Test Site

The Hood test site is on the right bank of the Sacramento River opposite the town of Hood. A 400-foot section of levee, recently reconstructed and covered with quarry rock, was used as the test area.

Hood test site

Isleton Test Site

The Isleton test site is on the left bank of the Sacramento River about 2 miles upstream from the town of Isleton. A section of levee and berm approximately 1 mile long was used to conduct the various tests. This site exhibited a varying range of hydraulic, levee, and vegetative conditions and was selected for the final phase of field testing.

Isleton test site

Conduct of Experiments

The types of experiments conducted were classified under three basic categories, with a number of specific tests in each category. The experiments conducted at each test site are summarized in Table 1.

TABLE 1
Summary of Experiments

Experiment	Garcia Bend	Ryde	Steamboat Slough	Hood	Isleton
Plant Performance and Maintenance					
Ground Cover Adaptation	■	■			
Erosion Control	■				
Tree Adaptation		■			
Controlled Growth			■		■
Levee Protection and Repair					
Berm Construction			■		
Berm Repair					■
Berm Reconstruction					■
Revetment With Vegetation					
Plantings Over Rip-rap	■			■	
Revetment Around Trees	■				
Concrete Block Revetment		■			

The experiments at the five test sites were oriented toward the development of alternative levee maintenance techniques designed to allow for the multiple use of levees and berms. These experiments provided considerable information on plant characteristics, costs, problems associated with levee maintenance, and other data. The evaluation of this information led to the conclusions reached in this report.

Plant Performance and Maintenance

The four tests conducted under this category of experiment were Ground Cover Adaptation, Erosion Control, Tree Adaptation, and Controlled Growth.

Ground Cover Adaptation. Tests to determine the adaptability of newly introduced species of plants to the upper Delta environment, their growth characteristics, and the maintenance techniques necessary for their propagation were conducted at the Garcia Bend and Ryde test sites. Much of the work was done by the State Division of Soil Conservation and the U.S.D.A. Soil Conservation Service. A detailed report describing the tests has been prepared by these agencies, and copies are on file in their offices as well as with the Department of Water Resources.

Table 2 below summarizes the results of the Ground Cover Adaptation tests.

TABLE 2
Summary of Results, Ground Cover Adaptation Tests

Species	Garcia Bend Test Site			Ryde Test Site		
	Spring 1964	Fall 1964	Adaptability	Fall 1964	Spring 1965	Adaptability
Forbs						
Alkali bulrush	■		poor		■	poor
Aarons beard					■	poor
Broadfruited bur reed					■	poor
Matgrass					■	good
Periwinkle	■		poor		■	poor
Spikerush					■	poor
Grasses						
Alkar wheatgrass				■		poor
Coastal bermuda	■		very good		■	very good
Creeping wildrye	■		very good		■	very good
Goars fescue		■	poor	■		poor
Greenar wheatgrass				■		poor
Kikuyu grass	■		good		■	good
Perla grass		■	fair	■		fair
Pygmy bamboo					■	poor
Reed canary grass		■	poor	■		poor
Saltgrass					■	fair
Tifgreen bermuda (sod)					■	very good
Tifgreen bermuda (stolons)					■	very good
Tifway bermuda (sod)					■	very good
Tifway bermuda (stolons)					■	very good
Topar wheatgrass		■	poor	■		poor
Western wheatgrass		■	poor	■		poor
Legumes						
Los Banos trefoil		■	poor	■		poor
Salina clover		■	poor	■		fair

Plantings at the test sites were accomplished in the spring and fall of 1964 and in the spring of 1965. Of the 15 species planted under irrigation during the spring seasons, six became well established and grew vigorously. These six were: coastal bermuda, creeping wildrye, Tifway bermuda sod and stolons, and Tifgreen bermuda sod and stolons. Other species which showed promise for berm and levee slope stabilization were kikuyu grass and matgrass. The remaining species ranged from partial stands to complete failures.

The nine species of fall plantings, which generally grow well in cooler weather, developed good initial stands; however, without water the following year, they failed to develop.


Ground cover adaptation plots at the Ryde test site

None of the plants in the ground cover adaptation tests was watered after the initial year of establishment to test their ability to survive without irrigation.

At the Ryde test site, a temporary cover crop of Wimmera 62, an annual, was seeded early in the fall, fertilized, and irrigated. This cover crop provided adequate, protective cover throughout the winter.

It was difficult to establish and maintain selected species where native vegetation had to be removed. Many applications of herbicides were only partially successful in ridding the test area of native vegetation. Once the test plots were planted and irrigated, the native species began to crowd the test plants. The indigenous plants had such a foothold that selective herbicide control was ineffective and handweeding was finally used to keep the plots free of competition. These problems could be of considerable importance in any major levee revegetation program of this type.

The successful establishment of those plants which showed an ability to adapt well to the new environment required the elimination of existing vegetation, complete seedbed preparation, fertilization, irrigation, and early spring planting. Existing vegetation was removed by cultivation and herbicides, and the seedbed was prepared as soon as the land was capable of supporting heavy machinery.

Erosion Control. Two locations on the Garcia Bend test site, each approximately 50 feet by 250 feet, were used to conduct specific tests on vegetative erosion control capability. The plots were cleared and planted with kikuyu grass in July 1963 and irrigated by hand until November 1963.

The purpose of this test was to determine: 1) the effectiveness of the kikuyu grass plantings against erosion, and 2) the ability of the kikuyu grass to establish itself, not only on the berm and slope area, but also in the tidal fluctuation zone. The kikuyu grass and the other plants in the ground cover adaptation test plots also were tested for their ability to withstand inundation and silt deposition.


Kikuyu grass test plot at Garcia Bend

Test results showed that the kikuyu grass was not able to establish itself in the tidal zone sufficiently to control erosion. However, new ground covers, as well as native grasses, established above the tidal zone did effectively control erosion. It is evident that the protection of levee slopes against erosion at normal water levels must be accomplished by the use of some form of revetment.

Above the normal tidal zone, the flood of December 1964 put the kikuyu grass and other species in the ground cover test plots to the extreme test of their ability to survive erosion, inundation, and silt deposition. Erosion did not occur to any degree in the test plot areas where the plantings had established themselves, even though the areas were continuously subjected to erosive forces of the flood for as long as 40 days. Further observations all along the Sacramento River revealed that good stands of indigenous ground cover such as creeping wildrye, horsetail, and bermuda grass were equally effective in controlling erosion.

Plant species showing the ability to survive the inundation and emerge through 6 inches of deposited silt were creeping wildrye, coastal bermuda, and kikuyu grass. Creeping wildrye was the only species tested that emerged through 12 inches of deposited silt.

<u>Tree Adaptation</u>. In June 1964, a tree adaptation test was started at the Ryde test site. Based on recommendations made by the U.S.D.A. Soil Conservation Service, the following 10 species of 5-year stock trees were selected for

Tree adaptation test at the Ryde test site

testing on the basis of growth characteristics most favorable from the standpoint of levee flood-control integrity and maintenance:

Red ironbark	Athel
Water wattle	Trident maple
Beefwood	Arizona ash
Common olive	Black mulberry
Hollyleaf cherry	Purple plum

These species all had the following characteristics: 1) tap-root system as opposed to a spreading-root system, 2) nonsusceptibility to common tree diseases, 3) small canopy as opposed to trees that commonly topple from windthrow, 4) maximum height of 30 to 35 feet, and 5) sturdy trunks and limbs.

The trees were planted in 10 rows of 4 trees each, on 20-foot centers from the shoulder of the levee to the berm. This was done to test the adaptability of the trees at varying elevations on the levee slope and berm.

The trees were watered only during the initial year of establishment to test their ability to survive without constant irrigation. In general, the trees on the waterward slope of the levee failed to survive, while those planted on the berm closer to the water adapted very well to the new environment.

On the waterward slope of the levee, the red ironbark and the purple plum demonstrated the greatest ability to survive. The Arizona ash, trident maple, and the beefwood indicated only partial adaptation; all the other trees tested failed to survive.

Controlled Growth. Experiments on controlled growth were carried out at the Steamboat Slough and Isleton test sites to develop alternative maintenance techniques and to determine the costs involved in this type of levee maintenance.

At the Steamboat Slough test site, a 2,000-foot section of levee and berm had not been cleared for some time and was completely overgrown. The area was selectively cleared; that is, dead, diseased, and root-exposed trees, as well as dense undergrowth, such as grape and blackberry vines, were removed. The area was then regularly maintained.

At the Isleton test site, a similar controlled-growth test was conducted. All dead and diseased trees were removed, and the good ones were trimmed and topped. Ground cover was cut to a height of about 6 inches, and the brush along the water's edge was trimmed to a height of 5 to 6 feet.

Five plots of existing indigenous ground cover were selected at this site on which to test the effectiveness of herbicides in growth control. Four types of herbicides (Paraquat, Ansar 526, Enide 50W, and Casaron 50W) were tested for their ability to control the growth rather than kill it. These herbicides were sprayed during the spring, after the ground cover had been cut, in an attempt to stunt the growth and thereby reduce maintenance costs. If the test had proved successful, the maintenance costs for mowing ground cover could have been reduced considerably.

Test results, however, indicated that these herbicides, when applied once a year, failed to stunt the growth of the indigenous grasses. The grasses grew back strong the following season.

Levee Protection and Repair

Three types of tests conducted under this category of experiment were Berm Construction, Berm Repair, and Berm Reconstruction.

Berm Construction. In August 1965, the Corps of Engineers let a contract for the construction of a test berm on the west bank of the Steamboat Slough test site. Instead of removing all trees and growth on the waterside of the levee, as is normally required to carry out bank protection work, vegetation above the normal water level was left relatively undisturbed, and the levee was reinforced by the construction of the berm. This test was of extreme interest to the Pilot Levee Maintenance Study as another possible alternative levee maintenance practice; consequently, the Department of Water Resources followed the project closely.

The shoreline on a 400-foot section of levee was cleared of all stumps, roots, buried logs, and other objectionable material. Quarry rock was placed under the water to anchor and form the toe of the berm. Sandy fill material from the slough channel was then placed between the rock toe and the shore to form the berm.

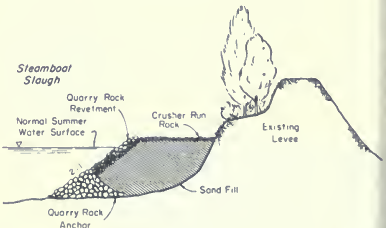

Figure 3. Berm construction test at the Steamboat Slough test site

The berm was constructed to a height about 3 feet above the normal summer water level and covered with a layer of crusher-run rock. The 2:1 slope on the waterside of the berm was revetted with quarry rock to prevent erosion during normal flows and to protect the bank against wave action from the numerous boats which use the area.

This experiment was highly successful in preventing erosion while at the same time preserving the esthetic beauty of the existing vegetation. The cost of this job competed favorably with the cost of present-day levee rehabilitation methods. It is estimated that the cost for reshaping levees and placing rock at a similar area today would average about $45 per lineal foot, compared with the actual cost of this job of approximately $48 per lineal foot.

Berm Repair. At the Isleton test site, a 300-foot section of the waterside berm had begun to erode. Although this section had not eroded to a point where the flood-control function of the levee was in immediate danger, continued erosion would have soon jeopardized the levee section. The objective of this test was to develop an estimate of cost for repairing a partially eroded berm before the integrity of the levee was threatened to a point where complete rehabilitation would be necessary.

The berm was repaired by adding channel sand to the eroded section and then placing quarry rock revetment to prevent any further erosion. The cost of this job amounted to approximately $9 per lineal foot.

Berm Reconstruction. Another section of waterside berm at the Isleton test site, approximately 100 feet long, was in considerably worse condition than the previously mentioned section. Erosion had cut into the berm about 15 to 20 feet, and, at one point, the levee itself was beginning to erode.

The berm was reconstructed to prevent the necessity of complete rehabilitation of the levee, to develop berm reconstruction techniques, and to develop an estimate of cost for such a practice. A 4-foot-high quarry rock toe, having a 1:1 slope on the waterside and a 2:1 slope on the landside, was constructed at the normal summer waterline. Sand fill from the channel was then placed in the eroded area on an approximate slope of 6:1 behind this rock toe. The cost for reconstructing this berm amounted to approximately $23 per lineal foot.

Revetment with Vegetation

Four separate tests were conducted to determine if vegetative growth would be compatible with revetment. Two of the tests were carried out at the Garcia Bend test site, one at the Hood test site, and one at the Ryde test site. The objective of these tests was to improve the esthetic value of revetment by allowing vegetation either to remain or be planted with the revetment.

Plantings Over Rip-Rap. At the Garcia Bend test site, a 300-foot section of berm was cleared of all vegetation, resloped to 2:1, and covered with cobblerock revetment in June 1963. One year later, 250 tons of fill material were spread to a depth of 6 inches over the cobblerock. Three separate plots of kikuyu grass, coastal bermuda, and creeping wildrye were planted on the fill material to stabilize the soil.

Experiment on the esthetic treatment of revetment at the Garcia Bend test site

Cobblerock revetment hand-placed around existing trees

The plants, irrigated periodically throughout the remainder of the summer, survived in the area above the normal summer water level and prevented the soil from being washed away the following winter. The following spring, native vegetation began to creep into the test plots. Such vegetation, when maintained in the normal course of flood-control maintenance, would add considerably to the esthetic value of the levee.

At the Hood test site, a 400-foot section of levee already revetted with quarry rock was covered to a depth of 12 inches with fill material dredged from the river. Four different mixtures of grasses were seeded in separate plots during the fall of 1964, fertilized, and then irrigated until the first rains began a month later in November.

In December, the floodwaters coming down the Sacramento River completely destroyed the test site. The ground cover never had a chance to establish itself, and, as a result, the fill material was completely washed away. It is evident that ground cover plantings over revetment should be done during the spring to minimize the possibility of being destroyed by floodwaters.

Revetment Around Trees. A test involving the placement of cobblerock around existing trees was conducted on a 200-foot section of berm at the Garcia Bend test site. The area was selectively cleared, resloped to 1-1/2:1, and revetted with 660 tons of 4-inch-minimum cobblerock. Most of the sloping and rocking was done by hand, as the remaining trees prevented the use of equipment normally used for such work.

As expected, this technique improved the appearance of this section considerably. The cost of this job was $1.51 per square foot, compare with $0.37 per square foot for a normal rock job. The increase in cost for this type of treatment will definitely limit its use.

Installation of specially built concrete block revetmen

Concrete Block Revetment. The final test in the series was conducted at the Ryde test site. This involved the installation of a specially fabricated concrete block revetment. The blocks were 18"x24"x4" and had 3"x6" voids built in. The idea was to install the blocks in a continuous mat and allow the vegetation to propagate through the voids.

In the test, the berm was resloped to approximately 3:1. The blocks were then placed in a continuous mat, extending from the top of the berm to a point below the low summer water level. Different plants were extended into the voids to determine if they would grow in this tidal fluctuation zone.

Shortly after the blocks were installed, the continuity of the mat was broken by undermining at certain locations. The blocks were not fully effective in controlling erosion in the tidal fluctuation zone. Also, the majority of the plantings failed to propagate through the voids in the tidal zone.

Field Costs of Experiments

One of the objectives of the Pilot Levee Maintenance Study was to determine, if possible, the costs involved in maintaining levees for multiple uses. To this end, all field costs were carefully documented.

However, the actual costs incurred in the field tests of this study are relatively high and consequently are not directly applicable to the determination of costs of similar maintenance practices on a larger scale. Many of the field costs were incurred under experimental situations on a very small scale. For example, the ground cover adaptation tests were conducted in areas where a great amount of site preparation work was required to provide as consistent conditions as possible for the testing. The high quality of site preparation needed for the pilot studies would not be expected for operational programs which would use ground cover plantings.

The documentation of the field costs, nevertheless, does indicate the relative magnitude of alternative maintenance costs and was used to develop the more representative cost estimates for a large-scale operation presented later in this report.

Table 3 is a summary of the costs incurred for the major field tests conducted in this study.

TABLE 3
Field Costs of Experiments

Experiment	Test Site	Test Area	Cost
Plant Performance and Maintenance			
Ground Cover Adaptation	Garcia Bend	24,500 sq ft	$ 7,580
Ground Cover Adaptation	Ryde	39,800 sq ft	7,752
Erosion Control	Garcia Bend	21,200 sq ft	3,385
Tree Adaptation	Ryde	36 trees	572
Controlled Growth	Steamboat Slough	88,000 sq ft	13,198
Controlled Growth	Isleton	525,000 sq ft	9,488
Levee Protection and Repair			
Berm Construction	Steamboat Slough	400 feet	19,500
Berm Repair	Isleton	300 feet	2,772
Berm Reconstruction	Isleton	100 feet	2,300
Revetment With Vegetation			
Plantings Over Rip-rap	Garcia Bend	12,500 sq ft	9,388
Plantings Over Rip-rap	Hood	8,600 sq ft	2,510
Revetment Around Trees	Garcia Bend	6,200 sq ft	9,537
Concrete Block Revetment	Ryde	1,500 sq ft	2,300

Experiment Conclusions

The experiments conducted in this study have led to the general conclusion that alternative levee maintenance practices can be used to allow vegetation on levees. This vegetation can be maintained for the multiple use of levees without jeopardizing the primary function of flood control.

Plant Performance and Maintenance

Ground Cover Adaptation. New species of ground cover introduced on the Sacramento River Flood Control Project levees adapted well to the new environment. The bermuda grass hybrids and creeping wildrye were the most suitable for stabilization of the berm and levee slope. The kikuyu grass and matgrass also indicated promise for soil stabilization.

Tests showed that, where vegetation is already established, it would be extremely expensive to attempt to reestablish and maintain selected species. Even on new levee projects after initial ground cover establishment, indigenous species would do the job if allowed to come in naturally. It does not seem important to maintain selected groundcover species on levees unless a particular use is required of the levee.

Erosion Control. Ground cover could not be established for erosion control in the tidal fluctuation zone. All attempts to propagate vegetation in this zone were unsuccessful. It is apparent that some form of revetment must be used for erosion control at normal water levels.

It does appear, however, that native and new ground covers can effectively control erosion if established above the normal summer water level. Precise criteria guiding the use of vegetation for this purpose cannot be defined on the basis of this study. Such criteria must be developed by testing the plants under the full range of the varying hydraulic and soil conditions common to the Delta.

Substitution of ground cover plantings for revetment seems to be competitive in cost. Rip-rap can be placed on the reshaped levee slope for about $0.37 per square foot. The cost of establishing ground cover would be approximately $0.07 per square foot. Subsequent annual maintenance and replacement costs for the ground cover would likely run higher than those for revetment. These costs cannot be determined until a trial is performed over an extended period of years.

Tree Adaptation. Certain species of trees already established above the flood plain on the waterward slope of the levee can be allowed to remain provided they are spaced in open patterns, trimmed and topped, and maintained on a regular basis. The trees must be maintained so that they do not become root-exposed, pose a threat to the integrity of the levee, or impede floodfighting.

Native trees on berms may be allowed to remain without any restrictions as to location or spacing unless clearing is required to provide adequate capacity to pass floods. The trees need be maintained only if some use other than wildlife is required of the berm.

On levees where there are no berms and new trees are desired on the waterward slope, they should be planted above the flood plain, no closer than 30 feet together, and such that when fully grown, the edge of their crown spread will be at least 5 feet from the shoulder of the levee. Care should be taken to irrigate the trees sufficiently for establishment. The tree adaptation test indicated that irrigation for only one summer following planting was insufficient to prevent the trees from dying.

Figure 4 illustrates the recommended location and spacing of trees perpendicular to a section of levee, with and without a berm. Spacing parallel with the levee should not be closer than 30'.

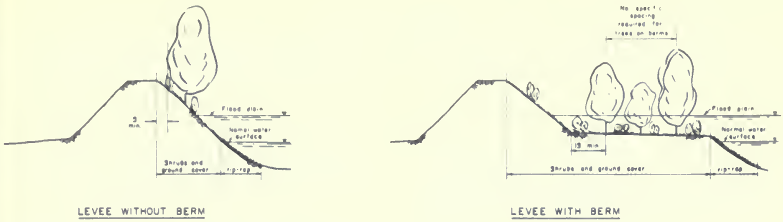

Figure 4. Recommended location and spacing of trees on levees

Controlled Growth. A controlled-growth maintenance program, using selective clearing techniques, can be accomplished without endangering the flood-control function of the levee. Existing trees and shrubs can be saved and developed for multiple use. However, the cost of this type of maintenance would be greater than the normal costs of levee maintenance for flood control alone.

Levee Protection and Repair

Levees today are normally not repaired until there is a definite threat to the flood-control function of the levee. Such deferred maintenance requires major rehabilitation. This can be averted by preventive maintenance consisting of reconstruction or repair of existing berms, or construction of completely new berms. A preventive maintenance program could lead to the development of multiple-use levees by preserving existing vegetation and providing berms suitable for recreation and wildlife use.

The costs for levee rehabilitation under present-day methods, depending on the location and condition of the particular section of levee, range from \$20 to \$70 per lineal foot on levees in the Sacramento River Flood Control Project. This includes the cost of stripping off existing vegetation, reshaping the levee, and placing rock revetment. The actual field costs incurred in the pilot studies for levee protection and repair work ranged from \$9 to \$48 per lineal foot. If the common practice of deferred maintenance followed by expensive levee rehabilitation were to be more economical than preventive maintenance, the deferred maintenance would have to be delayed at least 12 years, assuming 4% interest on the capital investment. Since such a delay cannot be guaranteed, it appears that costs for preventive maintenance are competitive with present-day methods of deferred maintenance and costly levee rehabilitation.

Revetment with Vegetation

Experiments conducted with the esthetic treatment of revetment indicate that such treatment is expensive. Construction problems associated with this type of treatment, the relatively high costs of installation, and the added maintenance costs will limit the use of this practice.

There is no doubt that the esthetic value of mechanical revetment can be improved considerably by allowing vegetation to exist. Rather than an expensive planting program, however, establishment of native vegetation should be encouraged. If maintained on a regular basis, this native vegetation can not only improve the appearance of the levee, but also provide additional cover for wildlife.

CHAPTER III: PROPOSED ALTERNATIVE LEVEE MAINTENANCE PRACTICES

The proper encouragement and maintenance of native and newly introduced grasses, shrubs, and trees on levees is the first step toward achieving the goal of multiple use.

Vegetation on Levees and Berms

The Pilot Levee Maintenance Study has concluded that grasses, shrubs, and trees can be allowed on levees and berms if they are maintained properly. Existing vegetation should be preserved where possible and new species planted where desirable.

On levees overgrown with native vegetation where the flood-control function of the levee is jeopardized, a selective clearing and controlled-growth program should be initiated. The area should be cleared of dead, diseased, and dangerous trees, as well as thick, undesirable undergrowth. Once this is accomplished, the vegetative growth can then be controlled by trimming, mowing, and the proper application of herbicides on a regular basis.

On berms, vegetation need not be controlled where channel capacity for design floodflow is not a critical factor. If some specific active recreational use is to be provided, then vegetation control must be provided accordingly.

On newly reconstructed levees and at places where native ground cover has not been able to establish naturally, a planting program should be initiated. The following species of perennial grasses are considered very good ground cover from the standpoint of climate and soil adaptability, soil stabilization, and maintenance characteristics:

Tifway bermuda	Coastal bermuda
Tifgreen bermuda	Creeping wildrye

The hybrid bermuda grasses are commercially available and should be planted during the spring by the stolonization process and irrigated for establishment. In the following years, 200 pounds per acre of 16-20-0 fertilizer should be applied in the early fall and again in the spring to maintain an effective vegetative cover and to keep down the invasion of undesirable weeds. The hybrid bermudas, which are seedless, should pose no problem to surrounding farmlands.

The creeping wildrye is not commercially available. It is native to much of the levee system on the Sacramento River, and its propagation should be encouraged.

If an area cannot be planted early in the spring, a fall seeding of Wimmera 62, an annual, should be sown, fertilized, and irrigated for establishment, to provide cover on the area through the winter. This should be done no later than September 15, to assure that the plant material is rooted before possible flooding. The cover crop can be removed the following spring and the area planted to the perennials previously described.

For areas where new shrubs and trees are desired, the species listed in Tables 4 and 5 are recommended for planting.

Some of the plants tested in this study for their adaptability were recommended by the U.S.D.A. Soil Conservation Service. Other shrubs and trees not tested in this study are native to the Delta and therefore were considered adaptable. All species listed are compatible with flood-control, recreation, and wildlife interests.

When planting shrubs and trees on levees, care should be taken to keep them in open patterns with one exception. For wildlife purposes, the Department of Fish and Game recommends that dense clusters be placed at strategic locations approximately one-quarter mile apart when other vegetation is nonexistent on the berms or adjacent to the levees. Such clusters should comprise an area of 2,000 to 3,000 square feet. Only in extreme situations, where long stretches of levee have no berm or where there is no existing vegetation, should these clusters be planted on the waterward slope of the levee. This is to avoid increasing the amount of work involved in flood-control inspection. Under these extreme situations, such clusters could be tolerated without endangering the flood-control function of the levee.

A regular maintenance program should be used for any vegetative management practice. In many cases, this maintenance could best be performed with specialized waterborne equipment. This is especially true where shrubs and trees grow adjacent to the water and are difficult to reach with conventional mobile equipment.

TABLE 4

Shrubs Recommended for Planting

Species*	Growth Rate	Height	Growth Habit	Remarks
Evergreen				
Quail bush	fast	3'-10'	open	excellent for wildlife
Darwin barberry	slow	4'-10'	dense	excellent for wildlife
Parney's red clusterberry	fast	6'	open	excellent for wildlife
Canarybird crotalaria	med	6'-12'	open	scenic
Mule fat	slow	over 10'	open	excellent for wildlife
Toyon	med	5'-15'	dense	excellent for wildlife
Chinese photinia	fast	over 10'	dense	excellent for wildlife
Deciduous				
Crape myrtle	slow	over 10'	dense	scenic, hardy in full sun
Jacquemont cherry	fast	under 10'	open	scenic, wildlife food
Rose acacia locust	fast	7'	open	excellent for wildlife
Red elderberry	fast	8'	open	excellent for wildlife
Blue elderberry	fast	4'-10'	open	excellent for wildlife

*Common name. See glossary for botanical name.

TABLE 5
Trees Recommended for Planting

Species*	Growth Rate	Height	Growth Habit	Remarks
Evergreen				
Bailey acacia	fast	20'-30'	dense	excellent for wildlife
Black acacia	fast	40'	dense	excellent for wildlife
Camphor tree	slow	50'	open	very large crown spread
Dwarf blue gum	fast	30'	dense	excellent for wildlife
Aleppo pine	med	30'-60'	dense	thrives in arid conditions
Jelecote pine	fast	40'-80'	dense	scenic
Hollyleaf cherry	slow	10'-35'	open	excellent for wildlife
Coast live oak	med	20'-70'	dense	very strong root system
Holly oak	med	40'	dense	very strong root system
Cork oak	med	50'	open	very strong root system
Interior live oak	slow	75'	open	very strong root system
Red ironbark	fast	40'	dense	scenic, wind tolerant
Coast beefwood	fast	10'-30'	dense	scenic, hardy
Deciduous				
English hawthorn	med	30'	open	scenic, suitable for berms
Paul's double scarlet hawthorn	med	18'-25'	open	scenic, suitable for berms
Stribling mulberry	fast	35'	dense	thrives in any soil
Flowering plum	med	10'-15'	open	thrives in any soil
Pissardi flowering plum	fast	10'-15'	open	thrives in any soil
Thundercloud flowering plum	med	10'-15'	open	thrives in any soil
Black locust	fast	40'-50'	dense	excellent for wildlife
Arizona ash	med	40'	dense	excellent for wildlife
Trident maple	fast	25'	open	scenic

*Common name. See glossary for botanical name.

Preventive Maintenance

A program of berm construction and spot-repair of levee and berm toe erosion should be initiated to eliminate the necessity of total reconstruction at many vegetated areas along the levees. This work could be best performed with waterborne equipment capable of constructing the berm, rebuilding eroded sections, and placing revetment.

New berms should be constructed to an elevation somewhat above normal summer water levels. Both berms and rebuilt sections should be faced with revetment up to the aforementioned elevation. The precise elevation will depend upon the hydraulic regimen at the specific location in question. The zone above the revetment must have a well - established ground cover to protect against the erosive forces of floodwaters.

Estimated Costs

Present-day annual levee repair and maintenance costs for flood control in state maintenance areas range from $800 to $2,500 per mile. This wide range of costs results from problems with encroachments in certain areas, different physical conditions of levees, special problems with vegetation control, and the frequency of certain activities.

Annual repair and maintenance costs for multiple-use levees will also vary for such conditions. For estimating purposes, the costs presented here are discussed under the general categories of establishment, repair, and maintenance.

The cost to establish ground cover by stolonization, on a one-mile stretch of newly reconstructed levee 20 feet wide, is estimated to be $8,100. This covers the cost of planting and irrigating the stolons for establishment. Most of the seedbed preparation would normally evolve as part of the reconstruction work.

On levees where new trees are desired, results of the tree adaptation test indicate that it may be more economical to have the work done by private contractor. A tree planting program is currently underway by the Corps of Engineers at Monument Bend on the Sacramento River where the cost for planting and establishing 1,044 trees by private contract is approximately $8.50 per tree. The trees to be planted consist of 2 and 5-gallon can and bare-root stocks.

The cost to selectively clear native vegetation from the waterward slope of levees can be as high as $0.15 per square foot. This cost, of course, will depend on the density of the vegetation, the extent to which it would be cleared, and the type of labor used.

Costs for levee protection and repair will vary depending upon the location and specific nature of the job. For example, on tests conducted in this study, levee protection and repair costs ranged from $9 to $48 per lineal foot. A berm on a section of levee at the Isleton test site on the Sacramento River was spot-repaired and rip-rapped for approximately $9 per lineal foot. The berm on another section of levee near the same location had eroded more severely and required complete reconstruction. The cost of this berm reconstruction was $23 per lineal foot.

In another test conducted at the Steamboat Slough site, a section of levee in need of reconstruction was rehabilitated by constructing a toe berm rather than rebuilding the levee itself. The actual cost of constructing this new berm by private contractor amounted to $48 per lineal foot.

Annual maintenance costs were estimated for a levee assumed to be structurally sound, protected against erosion at normal water levels, and free of encroachments other than normal pumping and drainage facilities. It was also assumed that specialized land and waterborne equipment would be used and that Department of Water Resources personnel would operate the equipment.

The annual maintenance cost for the assumed levee without shrubs and trees is estimated to be $1,300 per mile of levee. This includes; $800 for levee inspection, rodent control, roadway maintenance, and repair of revetment works; $250 for ground cover maintenance on the landward slope of the levee; and $250 for ground cover maintenance on the waterward slope of the levee.

If shrubs and trees are retained or added to the waterward slope of the levee, the annual maintenance costs will increase by approximately $600 per mile. Thus, the total cost to maintain the assumed levee (with shrubs and trees) for multiple-use would be $1,900 per mile per year.

In the case where a berm affronts the levee, trees and shrubs may be allowed on the berm rather than the levee slope. The additional cost for maintenance of shrubs and trees on berms where channel capacity for flood control is not a factor, will depend upon the use to be made of the berm and the size of the berm. If wildlife habitat is the only use to be made of the berm, the additional annual maintenance costs for multiple-use would be minimal. If active recreation areas are provided on the berm, an intensive shrub and tree maintenance program would be required with correspondingly increased maintenance costs perhaps even higher than the $1,900 per mile per year estimated for the assumed levee without a berm.

The costs presented in this chapter were estimated on the basis of the experimental costs. More accurate estimates of costs can be developed only through the actual use of the specialized land and waterborne equipment.

Table 6 presents the estimated costs to establish and maintain multiple-purpose levees using the specialized land and waterborne levee maintenance equipment.

TABLE 6

Estimated Costs to Establish and Maintain Multiple-Purpose Levees

Description	Cost
Establishment	
Install and establish stolons on waterward slope of newly reconstructed levee	$ 8,100 per mile
Plant and establish new trees	$ 8.50 per tree*
Selectively clear native grasses, shrubs, and trees on waterward slope of levee	$ 0.07 to $0.15 per sq ft
Spot-repair berms and add rip-rap	$ 9 per lineal foot
Reconstruct berm and add rip-rap	$ 23 per lineal foot
Construct new berm and add rip-rap	$ 48 per lineal foot
Maintenance	
Perform flood-control maintenance (excluding ground cover maintenance)	$ 800 per mile per year
Maintain ground cover on landward slope of levee	$ 250 per mile per year
Maintain ground cover on waterward slope of levee	$ 250 per mile per year
Maintain shrubs and trees on waterward slope of levee	$ 600 per mile per year

*Actual contract cost at Monument Bend

Other Considerations

The achievement of multiple-purpose flood-control projects will depend on flood control, recreational and wildlife interests working together toward mutually acceptable objectives.

Aside from the physical aspect and additional costs of maintaining levees for multiple purposes, other factors must be considered before multiple-purpose levee projects can be achieved. Among these are: sharing of maintenance costs, public access to levees, and formulation of administrative procedures for multiple-purpose flood-control projects.

At the present time, all levee maintenance costs are borne by flood-control beneficiaries. The introduction of uses other than flood control will require sharing of levee maintenance costs among flood control and the added uses in some manner proportional to the value received from multiple-purpose maintenance.

Access to existing single-purpose flood-control levees is now required only by flood-control maintenance agencies. If specific reaches of levees are developed and maintained for active recreational uaes, some provisions would have to be made for allowing and controlling public access in a manner compatible with adjacent land uses as well as the primary purpose of flood control. Public access, however, would not be required to levees and berms developed and maintained for esthetic and wildlife purposes.

There is a division of flood-control responsibilities and duties between The Reclamation Board and Department of Water Resources. In addition, certain responsibilities are passed on to local districts. The interjection of new interests and agencies into the present picture would require very careful planning and possibly additional authorization for some of those agencies.

There is no single agency that now has the authority and responsibility to implement a program of multiple-purpose levee use.

CHAPTER IV: SUMMARY

The Pilot Levee Maintenance Study has developed data and information which show that native and other vegetation can be maintained compatibly with flood-control functions, and that preventive maintenance can avert periodic total reconstruction of levees. The costs of such maintenance practices were estimated on the basis of costs of experiments conducted during the study. These estimates represent the relative difference between maintaining a generalized levee condition with and without vegetative management.

To more precisely identify representative costs for the wide range of conditions that would be encountered, it would be necessary to practice multiple-purpose levee maintenance on a large-scale basis, using specialized equipment to achieve an efficient operation.

In addition to identifying more precise costs, a number of other problems should be resolved before adoption of multiple-purpose levee maintenance techniques. Among them are:

- Development of a well-defined cost-sharing formula.
- Access to privately owned levees.
- Determination of responsibility for conducting multiple-purpose maintenance.
- Formulation of proper administrative procedures.

Steps that should be taken toward developing multiple-purpose flood-control projects include:

- Determination of the large-scale operation costs of the multiple-purpose maintenance techniques developed by the Pilot Levee Maintenance Study, using specially developed land and waterborne levee maintenance equipment.
- Definition of a cost-sharing formula and means of financing.
- Development of specific proposals for incorporating perpetual multiple-purpose levee maintenance techniques into existing projects.
- Development of mutually acceptable objectives among flood control, recreation, and wildlife interests.
- Development of the framework for the administration of multiple-purpose levee maintenance projects.

The Legislature should give consideration to the extent to which existing levees under state jurisdiction should be converted to multiple-purpose uses and to providing the means by which the foregoing activities can be undertaken.

GLOSSARY OF BOTANICAL NAMES OF PLANTS

Common Name	Botanical Name
Forbs	
Alkali bulrush	Scirpus robustus
Aarons beard	Hypericum calycinum
Broadfruited bur reed	Sparganium eurycarpum
Matgrass	Lippia nodiflora
Periwinkle	Vinca major
Spikerush	Heleocharis palustris
Grasses	
Alkar wheatgrass	Agropyron elongatum
Coastal bermuda	Cynodon dactylon
Creeping wildrye	Elymus triticoides
Goars fescue	Festuca arundinacea aspera
Greenar wheatgrass	Agropyron intermedium
Kikuyu grass	Pennisetum clandestinum
Perla grass	Phalaris tuberosa hirtiglumis
Pygmy bamboo	Bambusa pygmaea
Reed canary grass	Phalaris arundinacea
Saltgrass	Distichlis spicata
Tifgreen hybrid bermuda	Cynodon dactylon
Tifway hybrid bermuda	Cynodon dactylon
Topar wheatgrass	Agropyron trichophorum
Western wheatgrass	Agropyron smithii
Legumes	
Los Banos trefoil	Lotus tenuis
Salina clover	Trifolium fragiferum
Shrubs	
Quail bush	Atriplex lentiformis
Darwin barberry	Berberis darwin
Parney's red clusterberry	Cotoneaster lactea
Canarybird crotalaria	Crotalaria agatiflora
Mule fat	Baccharis viminea
Toyon	Photinia arbutifolia
Chinese photinia	Photinia serrulata
Crape myrtle	Lagerstroemia indica
Jacquemont cherry	Prunus jacquemonti
Rose acacia locust	Robinia hispida
Red elderberry	Sambucus racemosa
Blue elderberry	Sambucus glauca

Common Name	Botanical Name
Trees	
Bailey acacia	Acacia baileyana
Black acacia	Acacia melanoxylon
Camphor tree	Cinnamomum camphora
Dwarf blue gum	Eucalyptus glubulus compactus
Aleppo pine	Pinus halepensis
Jelecote pine	Pinus patula
Hollyleaf cherry	Prunus ilicifolia
Coast live oak	Quercus agrifolia
Holly oak	Quercus iles
Cork oak	Quercus suber
Interior live oak	Quercus wislizenii
Red ironbark	Eucalyptus sideroxylon rosea
Coast beefwood	Casuarina stricta
English hawthorn	Crataegus oxyacantha
Paul's double scarlet hawthorn	Crataegus oxyacantha 'Pauli'
Stribling mulberry	Morus alba 'Stribling'
Flowering plum	Prunus cerasifera blireiana
Pissardi flowering plum	Prunus cerasifera 'Pissardi'
Thundercloud flowering plum	Prunus cerasifera 'Thundercloud'
Black locust	Robinia pseudoacacia
Arizona ash	Fraxinus velutina
Trident maple	Acer buergerianum