DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the
DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

Miscellaneous Field Studies
Map MF-515 (Sheet 1 of 3)

ARTIFICIAL RESERVOIRS AND THE SEDIMENT SYSTEM
[Parts of text modified from Gottschalk, 1964]

The damming of a stream to create an artificial reservoir is a major change in the drainage basin of the stream that has several effects on the sediment system in the basin. Such reservoir is an irregularity in the stream profile to which the stream responds with adjustments that alter its sediment-transport processes. As the stream flows into the reservoir, its velocity and turbulence are substantially diminished, and it deposits most or all of its sediment load in patterns similar to that illustrated in the schematic cross section below. Sand and gravel are deposited at the upstream end of the reservoir, and progressively finer materials are deposited in relation to the extent to which flow velocity and turbulence are reduced. The depositions at the upstream end of the reservoir change the base level of the stream, and the stream channel attempts to adjust to the new base level by filling in or aggrading upstream from the reservoir. The water flowing out of the reservoir has an increased capacity for sediment transport (having deposited its sediment load in the reservoir), and a deepening or degradation of the channel system downstream from the reservoir may occur.

The degree of aggradation depends upon the stream gradient, the size gradation of the sediment, the hydrologic regime, and the degree of fluctuation of the reservoir surface. Aggradation is smallest on steep-gradient streams transporting primarily fine-grained sediment (silt and clay), such as those streams draining the upland provinces in the study area.

Where the outflow from the reservoir has sufficient tractive force to initiate movement of materials in the channel downstream from the dam, channel degradation takes place immediately, and may result in a correlative degradation of tributary channels as their base levels are lowered. The rate of degradation depends upon the type of material in the channel, and the velocity, turbulence, and other hydraulic characteristics of the outflow. Where materials in channel beds are more resistant to erosion than those in channel banks, bank erosion may proceed at a greater rate than channel deepening in order to satisfy natural conditions of balance between flow and sediment load. Degradation proceeds until the channel downstream from the reservoir comes into equilibrium in gradient and materials with the flow conditions imposed by reservoir releases.

The sediment-related problems associated with a given reservoir are unique, but several general problem categories persist in the design and operation of most reservoirs. A major problem associated with sediment deposition in a reservoir is the loss of usable space available for the storage of water. This loss directly affects the services dependent upon water storage, such as water supply, flood control, and recreation. Other problems include diminution of water clarity (turbidity) induced by sediment carried in suspension, the concentration of sediment-carried pollutants in depositional areas, the areal distribution of deltaic deposits (affecting reservoir form and function in shoreline and shallow-water areas), and shore erosion (bank caving and sliding) caused by wave action or water-level fluctuation.

Channel aggradation and degradation, and other sediment-related problems in a reservoir system evolve over long periods of time and involve in some manner nearly the entire drainage basin within which the reservoir is situated. Accordingly, these problems must be considered on the basis of long-term, basin-wide planning.

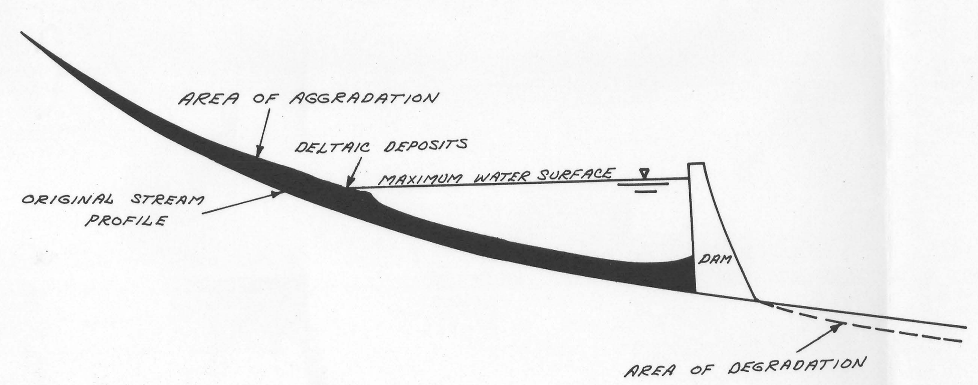


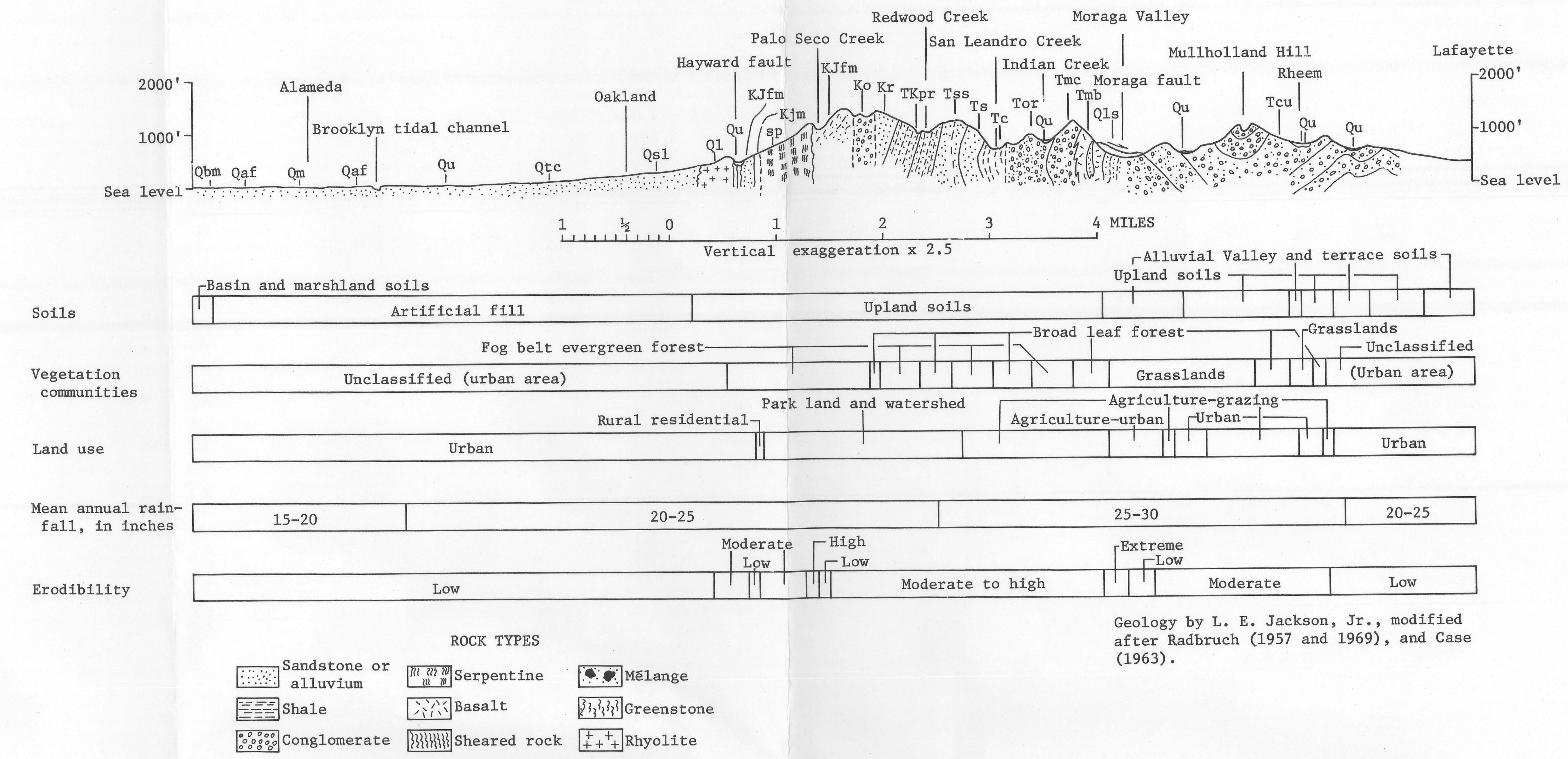
FIGURE 3.--SCHEMATIC REPRESENTATION OF SEDIMENTATION PROCESSES ASSOCIATED WITH RESERVOIR CONSTRUCTION.

SEDIMENT YIELDS IN THE BAY HILLS EROSIONAL PROVINCE BASED ON RESERVOIR SEDIMENTATION SURVEYS DURING THE PERIOD 1875-1965

San Pablo Reservoir[1] (drainage basin area = 30.63 sq mi)					Upper San Leandro Reservoir (drainage basin area = 29.16 sq mi)					Chabot Reservoir[2] (drainage basin area = 41.71 sq mi[3])				
Date	Period years	Total years	Sediment yield in tons/sq mi/yr[4] Period	Sediment yield in tons/sq mi/yr[4] Total	Date	Period years	Total years	Sediment yield in tons/sq mi/yr[4] Period	Sediment yield in tons/sq mi/yr[4] Total	Date	Period years	Total years	Sediment yield in tons/sq mi/yr[4] Period	Sediment yield in tons/sq mi/yr[4] Total
										1875	0	0	-	-
										1900	25	25	2,432	2,432
										1910	10	35	5,266	3,237
1917	0	0	-	-										
										1923	13	48	1,506	2,767
					1924	0	0	-	-					
					1935	11	11	885	885					
1936	19	19	1,083	1,083										
1938	2	21	20,796	2,952										
					1941	6	17	7,731	3,304					
										1942	19	67	694	2,180
1943	5	26	6,071	3,555										
1965	22	48	1,695	2,702										

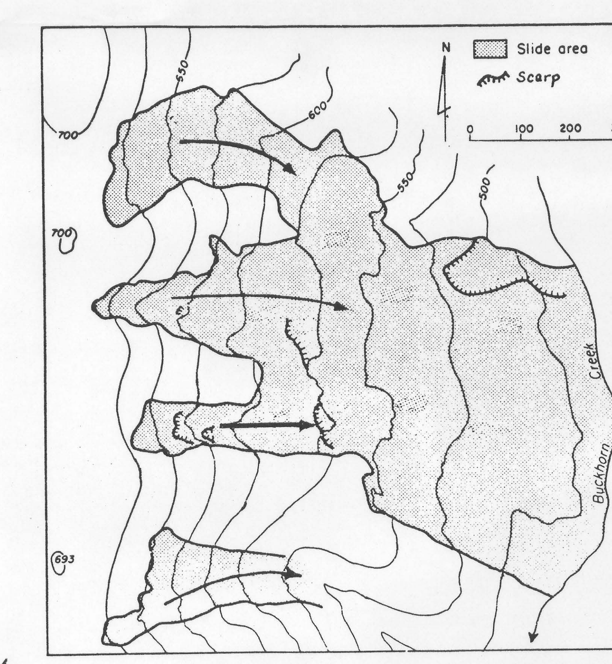
[1]Briones Reservoir was installed just upstream from San Pablo Reservoir in 1967.
[2]Sediment deposition in Chabot Reservoir altered after 1924 owing to installation of upper San Leandro Reservoir upstream in the same basin.
[3]Reduced to 11.46 square miles in 1924.
[4]Additional sediment, principally fine material, may be carried downstream from reservoirs by release flows and overflows at the spillways during storm periods, and thus is unmeasured.

Sediment yields, in tons per square mile per year, were determined for a total area of 72.4 square miles of lands draining into four major reservoirs operated by the East Bay Municipal Utility District (EBMUD). These yields for various periods since 1875 were determined from data on reservoir sedimentation surveys provided by the EBMUD (Blanchard, 1947 and written commun., 1971). The data show considerable period variability in sediment yield which includes a significant anomaly at San Pablo Reservoir probably related to excessive runoff in 1937-38. The long-term rates, however, are consistent throughout the drainage system at about 2,700 to 3,300 tons per square mile per year during the 90-year period of measurements.



Geology by L. E. Jackson, Jr., modified after Radbruch (1957 and 1969), and Case (1963).

SCHEMATIC CROSS SECTION FROM ALAMEDA TO LAFAYETTE SHOWING INTERRELATIONS AMONG GEOLOGY AND TOPOGRAPHY, SOILS, VEGETATION COMMUNITIES, LAND USE, RAINFALL, AND ERODIBILITY. THE VARIOUS FACTORS ARE DISCUSSED IN THE EXPLANATORY PAMPHLET, PAGES 3-14, AND THE GEOLOGIC SYMBOLS ARE EXPLAINED IN TABLE 2, PAGE 6.



General map of the Moraga test site showing dimensions and location of the complex landslide with respect to Buckhorn Creek. Arrows indicate general direction of downslope movement. Buckhorn Creek flows into an arm of Upper San Leandro Reservoir about 2,500 feet southeast of the slide area [modified from Kojan, 1968].

GRAVITATIONAL MASS MOVEMENT AS A SOURCE OF STREAM-BORNE SEDIMENT

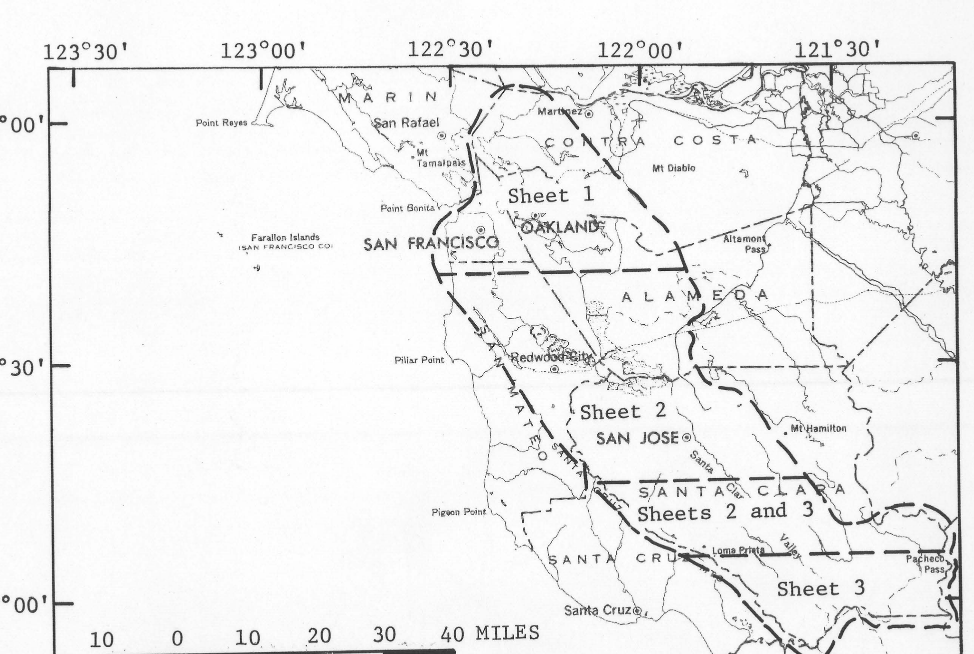
Throughout the bay hills erosional province (and in many other areas of the San Francisco Bay region), the location of landslides and other expressions of gravitational mass movement with respect to stream channels suggests that mass wasting may be a significant source of fluvial sediment. The extent and rate of the downslope transfer of soil and rock are related to a variety of geomorphic factors, but some principal mechanisms which initiate and graduate downslope movement are related to stream actions. Streambank scour at the bases of loosely consolidated slopes is followed initially by underwater slope failure. As supportive lower bank sediments are removed at higher stages of flow, the stress along the potential failure surface of the slope exceeds the resistance to shear along that surface causing a failure of the upper bank. Stream scour continues to erode the bases of slides, and acts as an important agent in maintaining slide activity. Scour continuing after a slide or slump has occurred, however, is often ineffective in completely removing displaced sediment, and the locus of scour may translate to the opposite side of the channel and initiate bank erosion and(or) slumping there.

This general process in conjunction with additional mass-wasting processes[1] contributes sediment to streams in highly variable quantities at unspecific times, and is largely unmeasured in the San Francisco Bay region. However, an index site near Moraga in the bay hills erosional province has been studied by the U.S. Forest Service (Kojan, 1968), and Kojan's methods and findings serve to illustrate both the complexity and significance of mass erosion.

Using inclinometers at 76 locations on and adjacent to the Moraga test site (see below), Kojan measured rates of downslope creep of surface materials ranging from 0 to 1 inch per month during 1965-66, and recorded measurable downslope displacements to depths of about 28 feet. A simple calculation shows that a creep rate of one-fourth inch per year involving an 8-foot thick section of soil will annually supply 1 ton of sediment per 50 feet of stream length (Kojan, 1968, p. 128). This figure, which is a minimum figure for the Moraga test site, indicates a sediment contribution at the site of about 14 tons annually to Buckhorn Creek and Upper San Leandro Reservoir.

Further studies are necessary to evaluate the activity of areas of mass wasting so that major sediment source areas may be defined in conjunction with existing surficial deposit mapping (Nilsen and Brabb, 1971). Thus, the data from this microcosmic description do not suffice for general extrapolation to other areas of landslide activity, but serve to illustrate the magnitude of effects of a routine geomorphic occurrence infrequently accounted for in planning studies related to sedimentation.

[1]Many aspects of mass wasting in the San Francisco Bay region are currently being described and mapped. A suitable reference associated with this topic is Nilsen and Brabb (1971).



INDEX MAP

Base from U.S. Geological Survey San Francisco Bay Region 1:125,000, 1970, sheets 2 and 3

SCALE 1:125 000

1 ½ 0 1 2 3 4 5 6 7 8 9 10 MILES
5000 0 5000 10000 15000 20000 25000 30000 35000 40000 45000 FEET
1 ½ 0 1 2 3 4 5 6 7 8 9 10 KILOMETERS

CONTOUR INTERVAL 200 FEET
DOTTED LINES REPRESENT 40-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL
DEPTH CURVES AND SOUNDINGS IN FEET—DATUM IS MEAN LOWER LOW WATER
SHORELINE SHOWN REPRESENTS THE LINE OF MEAN HIGH WATER
THE MEAN RANGE OF TIDE IS APPROXIMATELY 2 TO 5 FEET

MAP EXPLANATION

Erosional and depositional provinces

1. Santa Cruz Mountains uplands (see sheets 2 and 3)
2. Diablo Range uplands (see sheets 2 and 3)
3. Bay hills
4. Upland valleys and ridgetop terrain
5. Foothills
6. Bay plain and alluvial valley

Gaging station (see sheets 2 and 3)

Reservoir survey site

PRELIMINARY MAP OF EROSIONAL AND DEPOSITIONAL PROVINCES AND DESCRIPTIONS OF SEDIMENT-TRANSPORT PROCESSES IN THE SOUTH AND CENTRAL SAN FRANCISCO BAY REGION, CALIFORNIA

BY
WILLIAM M. BROWN III AND LIONEL E. JACKSON, JR.

1973

Explanatory pamphlet accompanies map sheet