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EROSIONAL AND DEPOSITIONAL PROVINCES AND SEDIMENT TRANSPORT IN THE SOUTH AND CENTRAL PART OF THE SAN FRANCISCO BAY REGION, CALIFORNIA

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INTRODUCTION

Erosion, transportation, and deposition of sediment constitute a complex system that can pose numerous problems in man's interactions with the landscape. Erosion generally refers to the wearing away of the land surface, and in the study area is expressed on a variety of exposed soil and bedrock surfaces such as landslide scarps, roadcuts, and the banks and beds of stream channels and gullies. Eroded material may be transported by several agents, of which running water is usually considered the most important. Gravity, wind, and ground water also share in the transport process and vary in activity throughout the study area. Transported sediment eventually comes to rest in depositional sites exemplified by such features as sand and gravel bars in river channels, artificial debris basins, and mudflats. Obviously, erosion, transportation, and deposition are three interrelated parts of a single dynamic process. Even on the smallest scale, erosion cannot take place in the absence of a transportation mechanism, and transported materials eventually must be deposited, if even for a short period of time until they are moved again. For convenience, the dynamic process just described will be referred to hereafter in this report as the *sediment system*.

This report is intended to present both quantitative and conceptual information on the multifaceted sediment system and its relation to man's activities in the south and central parts of the San Francisco Bay region (fig. 1). Because data on the sediment system are lacking for many parts of the study area, general descriptions only of the sediment system throughout the study area have been made to alert the reader to conditions that might require detailed site investigations.

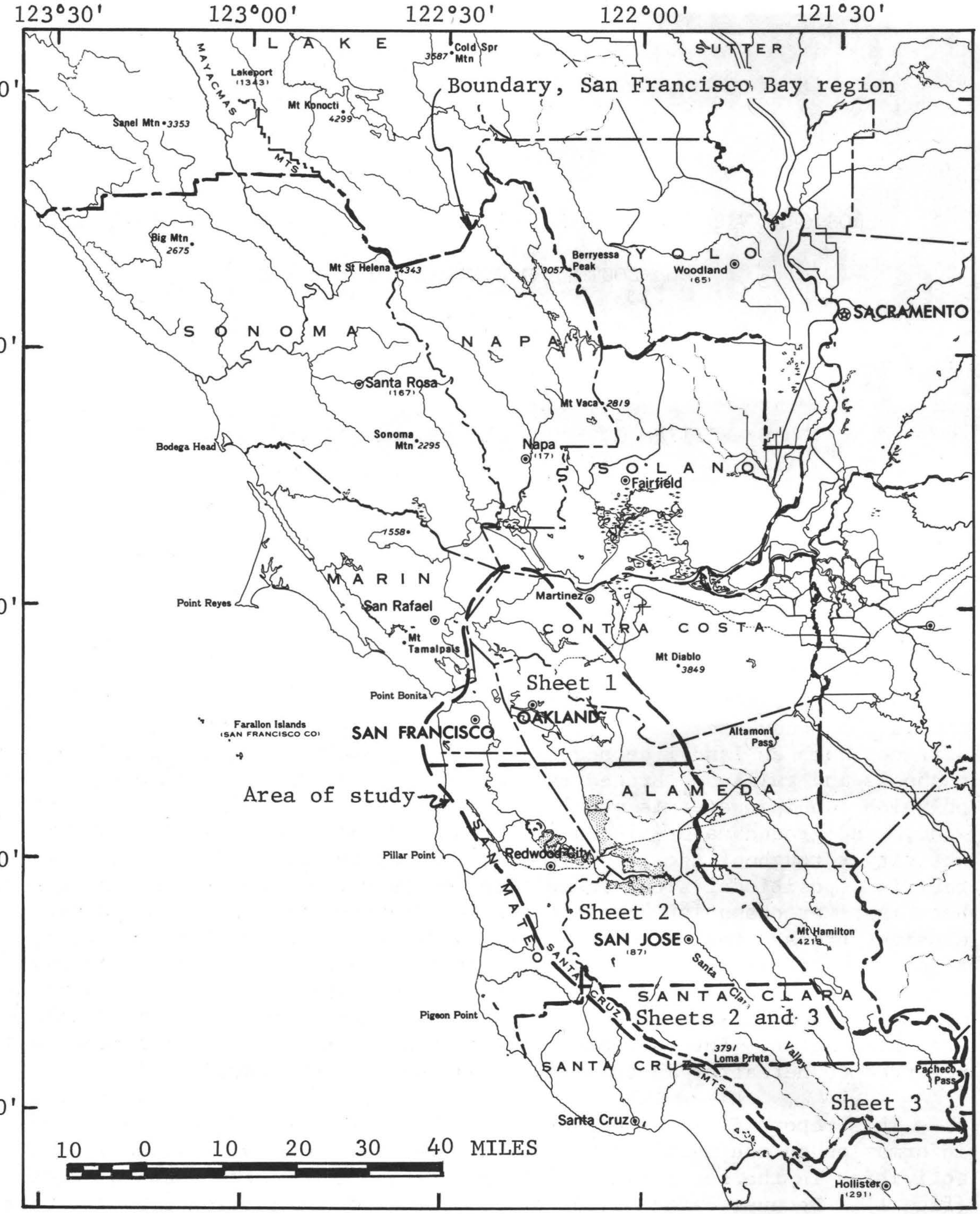


FIGURE 1.--Map of San Francisco Bay region showing area of study (base from State of California and U.S. Geological Survey, 1:1,000,000, 1971).

This report was written as an experiment in format and style. It is a preliminary report and is not intended to be an exhaustive treatment of the sediment system. The data presented in the report, and the data used for mapping the erosional and depositional provinces are complete through September 1970 only, and may not accurately reflect existing conditions.

The study area of this report is divided into six general erosional and deposition provinces (sheets 1, 2, and 3). The following text describes the major factors--geology and topography, soils, vegetation communities, land use, rainfall and runoff, and erodibility--affecting the sediment system and how these factors interact within each province with respect to the sediment system. Quantitative information is provided on the three map sheets accompanying individual case studies of typical processes of the sediment system in the study area.

FACTORS AFFECTING THE SEDIMENT SYSTEM

The sediment system in the study area encompasses a variety of complex and interacting processes, and varies in meaning with the temporal and spatial contexts to which it is applied. For example, a reservoir design might require concern with a 100-year operation period and a drainage area of 75 square miles. A debris basin for trapping eroded material during construction activities may be designed for a single rainfall season and an area of a few acres. Man-induced vegetation changes and other alterations of the landscape may affect the sediment system throughout thousands of square miles and correspond to millenia of geologic change. Thus, the concern here is to provide summary information that can be viewed in several contexts, depending upon the needs of the user of this report. In this section, general information on geology and topography, soils, vegetation communities, land use, rainfall and runoff, and erodibility, is provided for use with both the subsequent descriptions of the erosional and depositional provinces, and the cross sections shown on sheets 1 and 2.

Factors Affecting Erosion and Transportation of Sediment

A short summary of the combination of factors affecting the erosion and transportation of sediment in any area is given in table 1. The individual factors are discussed in more detail in subsequent sections of the report. Obviously, the full effects of interactions among the listed factors are exceedingly difficult to assess. Table 1, then, serves as a reminder of the multiplicity of processes involved in the erosion and transportation of sediment.

TABLE 1.--*Factors affecting erosion and transportation of sediment on the land surface*

[Modified from Johnson (1961) and Guy (1970)]

Primary factors	Elements of primary factors most important in the sediment system	Influence of elements on erosion and transportation of sediment
Climate--------	Rainfall and subsequent runoff---	Raindrop splash erosion: The impact of raindrops on the land surface breaks down aggregates of soil, dislodges and disperses soil particles, and tends to consolidate the soil surface. Precipitation excess, or the difference between rainfall that infiltrates into the soil and rainfall that becomes surface runoff, is thereby increased. The impact of raindrops on very shallow surface runoff (sheet flow) imparts turbulence to the runoff thereby increasing its capability to to move larger particles.
		Flow erosion: Physical force due to pressure difference and impact of flowing water dislodges, disperses, and transports soil particles. Intensity and duration of rainfall affect rate of runoff after infiltration capacity of soil is reached.
	Temperature---------------------	Alternate freezing and thawing (perhaps of minimal importance in the San Francisco Bay region): Expands soil, increases its moisture content, and decreases cohesion. Thus dislodgment, dispersion, and transport of soil particles are facilitated.
	Wind----------------------------	Wind erosion: Dislodges soil particles by force due to pressure difference and (or) impact. Dislodged particles transported by upward currents of turbulent air flow.
Gravity--------	Mass wasting---------------------	Gravitative transfer of material downslope: Soil creep, landslides, and other forms of downslope mass movement introduce rock and soil particles into stream channels.
Geology--------	Properties of soil masses--------	Grain size and sorting: Affects ease of dislodgment and transport of sediment particles.
		Stratification (layering): Stratum of lowest permeability may control infiltration rate through overlying layers.
		Porosity: Determines water-holding capacity.
		Permeability: Determines percolation rate.
		Volume change and dispersion properties (swell potential): Soil swelling loosens and disperses soil and thereby reduces cohesion and facilitates dislodgment and transport.
		Moisture content: Moisture may reduce cohesion and lengthen erosion period by increasing the period of precipitation excess.
	Properties of the soil constituents-------------------	Grain size, shape, and specific gravity: Determines force needed for dislogment and transport, against force of gravity and cohesion.
Topography-----	Slope----------------------------	Orientation: Determines effectiveness of climatic forces.
		Steepness: Affects energy of flow as determined by gravity.
		Slope length: Affects quantity or depth of flowing water. Depth and velocity affect turbulence. Both velocity and turbulence markedly affect erosion and transportation of sediments.
Soil covering--	Vegetation and land usage--------	Vegetative cover: All vegetative cover, whether alive or dead, protects the land surface from erosion in proportion to its interception of raindrops and its retardation of flow erosion. Vegetative canopy diminishes force of raindrops, and leaf litter, roots, and other parts of the vegetal community decrease velocity of runoff and increase soil porosity.
		Nonvegetative cover:
		Bare ground: A minimum of surface protection results in maximum raindrop splash erosion, reduced infiltration, increased runoff, and maximum erosion.
		Artificial cover: Paved surfaces, rooftops, lined channels, and other artificial surfaces afford maximum protection of underlying soil and rock, but cause highly efficient runoff and transport characteristics.

Geology and Topography

Commonly, the land surface of an area reflects the erosional properties of the underlying geologic formations. The erosional properties depend on the lithology of the formations and on the degree to which the formations have been fractured or sheared by tectonic activity. The general erosional properties and topographic expression of several important geologic units in the study area are summarized in table 2 and on schematic cross sections shown on sheets 1 and 2).

Soils

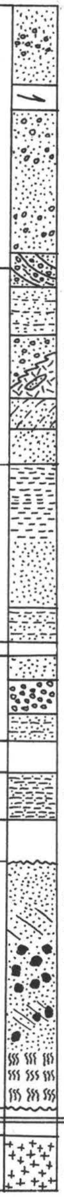
The soil covering of the landscape is the primary source of the varied materials transported by running water. These materials include not only pure rock fragments, but also organic solids and complex chemical solutions--all the products of the interactions among climate, geologic parent material, landform, biological activity, and time. The soils of the study area are as varied as the local combinations of these active and passive agents, and the resistance to erosion of the soils is similarly variable, depending upon both the physical size of the fragmental rock particles and the nature of the inorganic and organic materials that bind the particles together (Guy, 1970, p. 2).

Detailed descriptions of soils in the study area are beyond the scope of this report, but are provided in reports by the U.S. Department of Agriculture (1939, 1961, 1966, 1968). For the purpose of this study, the soils are divided into three general groups: (1) Upland soils that form in an erosional environment; (2) alluvial soils that form in a depositional environment; and (3) artificial fills such as landfill, that are formed or altered by man.

Upland Soils

The upland soils are divided into two parts principally on the basis of climate. In the fog-influenced mountains west of San Francisco Bay and in the Berkeley Hills, soil formation is more active than in the drier areas of the Diablo Range. In a natural system, the soils of the Diablo Range would be less stable, lacking the vegetal covering and moisture necessary for development of a stable profile. However, land-use practices that remove the protective vegetal covering from the deeper, more highly-developed soils of the Santa Cruz Mountains and the Berkeley Hills expose these soils to high rainfall and runoff. Therefore, the amount of soil material available for transport as fluvial sediment becomes the distinguishing characteristic related to erosion processes in the two areas.

TABLE 2.--*General erosional properties and topographic expression of geologic units in the south and central San Francisco Bay region, California*



Period	Symbol	[2]Names and symbols for the geologic units traversed by schematic cross sections shown on sheet 1 and sheet 2		General erosional properties and topographic expression of geologic units [Modified from Radbruch (1969) and Cotton (1972)]
QUATERNARY	Qaf	Artificial fill		
	Qu	Alluvium, undifferentiated		This sequence includes sediments of varying character generally underlying areas of flat to gently sloping topography. Most are poorly consolidated, and have little or no slope stability where units are geologically deformed or artificially altered. Clayey soils developed on these units swell when wet and shrink when dry. Erosion is greatest along stream channels and on slopes, although several units exist in a primarily depositional environment and do not erode.
	Qbm	Bay mud		
	Qls	Landslide deposit		
	Qt	Terrace deposit		
	Qtc	Temescal Formation		
	Qm	Merritt sand		
	Qsl	San Antonio Formation		These units occur in moderately sloping to steep, dissected hilly areas. They are deeply weathered, thus making available considerable amounts of easily erodible material. Large landslides have formed in the San Antonio Formation. Seasonal shrink-swell of soils formed on these units contribute to downslope creep.
	Qoal	Older alluvium		
TERTIARY, Upper	QTs	Santa Clara Formation		
	Tsi	Siesta Formation (not shown on section)	Tcu, Contra Costa Group, undivided	The upper Tertiary rocks are poorly consolidated, highly fractured, commonly have steep dips, and contain swelling clays. These units form many types of topography from flat valley bottoms to very steep-sided ridges. Stability of steeper slopes is generally poor; many landslides form in both rock and soil on both natural and cut slopes. Sediment yields from areas underlain by upper Tertiary rocks are among the highest in the study area.
	Tmc Tmb	Moraga Formation Tmc, clastic member Tmb, basalt	Tcu, Contra Costa Group, undivided	
	Tor	Orinda Formation	Tcu, Contra Costa Group, undivided	
	Tbr	Briones sandstone		
TERTIARY, Lower	Tt	Tice Shale (not shown on section)	Tm, Monterey Group	
	Tc	Claremont Shale	Tm, Monterey Group	The lower Tertiary rocks are generally well-consolidated compared with upper Tertiary rocks. These units underlie steep to very steep ridges and hillsides. Slope stability is generally good. Firm rocks disintegrate slowly, providing only a shallow soil covering; thus, the quantity of material available for transport as fluvial sediment is small.
	Ts	Sobrante Sandstone	Tm, Monterey Group	
	Tss	Eocene sandstone and shale		
	TKpr	Pinehurst Shale		
CRETACEOUS	Kr	Redwood Canyon Formation		Redwood Canyon and Joaquin Miller Formations form steep-sided ridges and canyons. Oakland Conglomerate is generally a ridge former. These rocks are generally firm and provide only a shallow soil covering. Shale beds in Redwood Canyon Formation are prone to landsliding, but slope stability is generally good.
	Kb	Berryessa Formation of Crittenden (1951)		
	Ko	Oakland Conglomerate		
	Kjm	Joaquin Miller Formation		
JURASSIC	Jk	Knoxville Formation (not shown on section)		Contains easily eroded soft shales, and generally forms valleys. Slope stability is generally fair. Irregular weathering produces shallow to moderately deep soils.
JURASSIC AND CRETACEOUS	KJfm	Massive to thick-bedded	KJf, [3]Franciscan Formation	The topography of the Franciscan Formation grades from moderately steep hillsides and ridges underlain by the thin-bedded unit to regions of high relief underlain by the massive unit. The mélange unit is generally expressed as topographically anomalous terrain. Slope stability ranges from very low in intensely sheared areas to high in places where bedrock is less disrupted by shearing. Soil covering of the Franciscan Formation in the Santa Cruz Mountains is considerably deeper than that in the Diablo Range. The mélange unit is highly susceptible to severe erosion in its natural state, and has among the highest potentials for yielding sediments of units throughout western California.
	KJfss	thin-bedded	KJf, [3]Franciscan Formation	
	KJfs	Mélange	KJf, [3]Franciscan Formation	
	sp	Serpentine	KJf, [3]Franciscan Formation	Serpentine is a generally soft and intensely sheared unit underlying moderately steep dissected hills and valleys. Soil covering is thin or absent. Slope stability, however, is poor, and serpentine masses are subject to sliding on both natural and artificial slopes.
TERTIARY	Tl	Igneous rock Leona Rhyolite		This unit forms steep, knobby, dissected hills. Rock may be exessively fractured and deeply weathered; however, soil development is lacking or minor. Thus, easily transported materials are not abundant.

[1]Rock types shown on schematic cross sections, sheet 1 and sheet 2.
[2]Does not include all geologic units present in study area.
[3]A more detailed description of the units of the Franciscan Formation is available in Cotton (1972).

West bay and Berkeley hills: These soils consist generally of moderately deep to deep (25 to 50 inches), silty and sandy loams protected on the surface by leaf litter, roots, and other organic products of perennial forest.

Diablo Range: These soils consist generally of shallow to moderately deep (<30 inches) clay loams on gentler slopes, and rocky soils on steeper slopes which are influenced more by physical decomposition and disintegration of bedrock than biological activity. Vegetal protection is seasonally diminished, and soil covering is easily removed during early fall and winter rains, hence keeping the soil profile thin.

Alluvial Soils

Alluvial soils, developed on recent and older depositional areas, are divided into three subgroups on the bases of landform and time as follows: Alluvial valleys and terraces, alluvial fans and flood plains, and basin and marshlands.

Alluvial valleys and terraces: These soils occur in areas of undulating or hilly relief where older deposits have been tectonically deformed and eroded. Natural protection from erosion is due to moderate slopes (<35 percent) and(or) moderate rainfall (<30 inches), but infrequent, intense rainfall may initiate gullies and slumps.

Alluvial fans and flood plains: These soils occur in areas of slight to gentle relief that currently are mostly urbanized. They rarely erode except along stream channels.

Basin and marshlands: These soils are currently forming in areas of little relief where finer particles settle from suspension in the bay margins at the interfaces between stream outflow and tidal action.

Artificial Fills

Artificial fills are placed and altered (such as, by compaction) on the land surface by man, and are composed of highly variable quantities of rock fragments and assorted organic and inorganic debris. These fills erode on their oversteepened and(or) unprotected margins that occur in several types of urban development, and erode along the periphery of the bay due to tidal currents and wave action.

Vegetation Communities

Vegetal biomes, or ecological formations identified in terms of characteristic vegetation forms, coexist in a somewhat systematic fashion with the several other factors affecting sedimentation processes. The detailed definitions of biomes with respect to erodibility would include such parameters as plant size and stratification, degree of ground coverage, response of foliage to climatic fluctuations and the shape, size, and texture of the foliage (Strahler, 1969, p. 328-329). Several vegetal biomes exist throughout the San Francisco Bay region, and are described by Williams and Monroe (1970). Four major vegetal biomes that affect erosion processes in the study area are described on the following pages.

Fog belt evergreen forest.--This biome occurs throughout the Santa Cruz Mountains and along the extreme western ridges and canyons of the Oakland-Berkeley hills. Drip from spring and summer fogs supplement winter rains and allow this moisture-demanding biome to sustain itself through the summer drought. Where fog-borne moisture is less frequent, the fog belt evergreen forest seeks the minimal insolation of the northeast facing slopes. The forest is a complex mixture of coastal redwood, hardwoods, Douglas-fir, and in some areas introduced exotics, such as eucalyptus. Soils beneath these forests are moderately deep with a thick surficial layer of leaf litter. The shallow, dense, redwood root mat and the thick forest floor organic layer make the fog belt evergreen forest the most effective biome for retarding surficial erosion in the study area.

Chaparral.--Chaparral usually occurs locally and regionally in the drier parts of the study area, such as in the rain shadows along the eastern sides of the mountain ranges. Common plants include scrub oak, manzanita, buckbrush, chamise, toyon and coyote bush. The chaparral community produces comparatively little leaf litter or humus, and is usually associated with shallow and rocky soil. It is also adapted to semiregular burning that greatly enhances the erosion potential of the underlying land surface in early fall just preceding the winter rains.

Broadleaf forest.--This biome includes a wide spectrum of plant assemblages which vary in composition and density with precipitation and exposure. Common trees are bay laurel, several oak species, bigleaf maple, boxelder, and in more arid areas digger pines. Broadleaf forest occurs where fogs are too infrequent and insolation is too severe to support fog belt evergreen forest, but sufficient moisture is present to support the less moisture-demanding broadleaf forest varieties. The broadleaf forest biome commonly occurs on the well-insolated southwest facing slopes where fog belt evergreen forest climatic conditions are marginal. Under less moist climatic conditions beyond the fog belt evergreen forest limit, broadleaf forest may cover all slopes. In more arid areas, the biome seeks the less insolated northeast facing slopes. The broadleaf forest may locally thin out and grade into savannah and chaparral. Riparian woodlands of such varieties as willows and buckeye may occur along stream courses throughout the area of study. Soil depth and leaf litter cover varies with tree density, rainfall, and slope. The broadleaf forest is comparable to the fog belt evergreen forest in its natural propensity to retard erosion.

Grasslands.--The grasslands or grassland savannahs are commonly located on the westward-facing (windward) slopes which receive slightly more precipitation than the chaparral-covered, leeward rain-shadow slopes. Common species of grasses composing the largest part of the grassland biome include red brome, soft chess, wild oats, and farmers foxtail. Scattered trees found in the grassland savannah include live oak, bay laurel, and buckeye. Soils are normally shallow and rocky, and the fibrous roots of the grasses act as a principal binding agent to retard soil erosion. The grassland terrain may be expected to have an erosion potential lower than that of the chaparral-covered areas but greater than that of the forested areas. Burning, overgrazing, and tilling are the principal factors contributing to decreased erosion resistance in the grasslands.

Land Use

Man acts as a geomorphic agent by modifying the constituent elements of the sediment system in many ways. Aspects of his land-use activities, then, are important parameters in the evaluation of the sediment system. Six general land-use categories were selected to illustrate the ways man alters the sediment system on a regional scale.

Urban.--The landscape is intensively utilized for industrial activities, transportation systems, and medium- to high-density residential development. The urban landscape appears in the sediment system as a complex of temporal and spatial discontinuities resulting from such diverse actions as channelization of streams, reshaping of the land surface with cuts and fills, the building of reservoirs, roadbuilding and paving, and alterations of vegetal patterns. The land surface is variably exposed during building activities, and later is made partially impervious to rainfall as construction is completed. The variability of water discharge is increased, and the natural grading and adjustments of stream channels are interrupted. Erosion, transportation, and deposition rates fluctuate and differ widely throughout the urban system, and tend to be unpredictable due to the transitional nature of urbanization.

Rural residential.--The land surface retains its natural dynamic equilibrium, and is only slightly modified by low-density housing and limited agricultural practices. Sedimentation problems are localized and are related predominantly to roadbuilding. Erosion, transportation, and deposition rates vary within the constraints of the background geomorphic system, and are predictable to the degree that system is studied and defined.

Parkland and watershed.--The land surface is preserved in a particular state for its scenic and recreational value, and for its value as a drainage basin for water supplies (usually domestic and industrial). Alteration of land surface is generally greatly restricted. Erosion, transportation, and deposition rates are usually well monitored, and many precautionary measures are taken to reduce sedimentation problems.

Multiuse forest.--The land surface is forested, and is utilized for timber products and(or) for recreational purposes and low-density housing. Various amounts of the land surface are subjected to severe alterations by logging operations, roadbuilding, and fires. Erosion, transportation, and deposition rates are highly variable depending upon the extent and intensity of different land uses and are difficult to monitor or predict except by detailed study.

Agriculture-grazing.--The land surface is either under cultivation or is used for grazing. Erosion, transportation, and deposition rates vary with the type and intensity of use. The importance of soil retention to agriculture often dictates careful erosion-control practices; however, many practices remain inconsistent with the nature of the land surface and excessive grazing is a historical and continuing influence on land-surface degradation.

Agriculture-urban.--The land surface is in transition from agricultural to urban use. Subdivision development predominates during which the land is cleared and leveled, and commonly is left open for many months before actual construction and planting takes place. Erosion-control practices on agricultural and grazing lands commonly are relaxed during lengthy periods of the negotiations of property transfer. The complexity and variability of the sediment system begin to approach that of the urban system.

Rainfall and Runoff

> "Of the several active and passive environmental forces that affect erosion and transportation of sediment, rainfall is considered to be the most dynamic and hence at times by far the most important" - (Guy, 1970, p. 10).

The impact of raindrops on the land surface both loosens and redistributes soil particles in relation to the size of the raindrops, rainfall intensity, and the properties of the soil mass. The loosening of the particles makes them more readily available for transportation, and redistribution of the particles tends to consolidate the soil surface, thus reducing the ease of infiltration of water into the soil. The accumulating water then is concentrated into channels and rivulets, and has a potential to initiate particle motion in turbulent flow.

The rapidity with which this process proceeds is related to the variety of factors explained in table 1; however, the variations in rainfall intensity and duration often predominate where excessive erosion is concerned. For example, rainfall of low intensity which is continuous or spaced at intervals would augment the growth of vegetation which in turn would diminish rapid runoff. However, the prevailing climate of the San Francisco Bay region includes a distinctly seasonal pattern of precipitation in which intense and irregularly spaced storms dominate the erosional regime.[1] Thus vegetal growth (except in fog-belt areas) may not respond to rainfall with sufficient rapidity and variability to maintain a natural protection of land surface, especially against the early fall and winter storms. In other words, in the natural system there is an optimum rainfall for a given terrain in terms of sediment production.

In the climatic environment of the San Francisco Bay region, the regimen of precipitation is such that the amount of rainfall, the duration of the storm during which it falls, and the frequency of occurrence of storms for a site are closely related to the mean annual rainfall for that site (Rantz, 1971, p. C237). On a regional basis, therefore, mean annual rainfall is used as a parameter in evaluating erodibility.

Runoff-induced erosion in the bay region, however, tends to be episodic rather than continuous. Most of the measured fluvial-sediment discharge at stations in the study area has occurred during only a few storms in the past 35 years, notably in the 1938, 1941, 1952, 1956, 1958, 1967, and 1969 water years. The tables and graphs on the accompanying map sheets show the relation between water discharge and sediment discharge, and the amount of sediment eroded from the land surface during the periods of sediment measurement at individual stations.

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[1]Guy (1970, p. 7) states the following: "Maximum erosion occurs at combinations of precipitation and temperature that result in a combination of rapid weathering, maximum runoff, and relatively sparse vegetation. These factors imply also that for a given location and mean precipitation and temperature, a highly variable climate will cause more erosion than would a nonseasonal climate."

Erodibility

Erodibility of the landscape involves a complex combination of the several previously mentioned factors, and temporal and spatial variations in any one of those factors may have profound effects on erodibility. For example, much of the Diablo Range would seem to be highly erodible because of sparse vegetation, steep slopes, highly-fractured and sheared bedrock, and poorly-developed soils. However, rainfall in the Diablo Range is sparse, major erosion occurs only during infrequent storm periods, and the average rate of sediment movement on the land surface is comparatively low. In foothill areas west of San Francisco Bay, dense vegetation, gentle slopes, well-developed soil profiles, semiconsolidated bedrock, and moderate rainfall combine in a natural system of low erodibility. Yet the impact of land usage on that system has resulted in some of the highest erosion rates in the study area during the past several years. Four general examples of erodibility are given in the following text and are associated with the schematic cross sections shown on sheets 1 and 2.

Low.--Areas of low erodibility generally coincide with the bay plain and alluvial valley erosion province. Slopes range from 0 to 5 percent in these areas. Flooding and deposition of stream-borne sediment are the chief widespread erosion-related problems. Alluvial fans which have been built up by deposition from sediment-laden streams on the bay plain, and flood plains of inland streams are the most active depositional locations.

Local gullying and rapid bank retreat along streams which are actively downcutting and shifting their channels through recent flood-deposited alluvium constitute the only areas of high erodibility on the alluvial plains. Vegetation, where the areas are not urbanized, consists predominantly of grasses and agricultural types.

Moderate.--Areas of moderate erodibility are typified by slopes ranging from 5 to 30 percent. Average annual rainfall ranges from 20 to 30 inches. Natural vegetation may be grass, scrub, or forest depending upon exposure to spring and summer fog. Erosion types include sheet erosion, gullying, streambank failure, and scattered slumping. Landsliding may occur on artificially oversteepended slopes, especially in areas underlain by deeply weathered or highly fractured bedrock. As in most cases, erodibility becomes locally high where the ability of natural vegetation to retain soil has been impaired by such means as overgrazing, fire, and construction-related activities.

High.--Terrain is generally or locally steep. Rainfall is about 25 inches or greater, and is augmented by the additional moisture of fog drip. Bedrock is deeply weathered, fractured, or steeply dipping. Soil creep and landsliding are the chief natural erosive processes. Significant gullying and sheet erosion may occur where the natural vegetal covering has been removed.

Extreme.--Areas directly underlain by active landslides and gullies. Rainfall is usually moderate to high, but small amounts of rainfall may be sufficient to cause severe local erosion. Vegetation is sparse due to land usage or the inability of vegetal communities to stabilize on a moving soil mass. Bedrock is deeply weathered, highly fractured, or steeply dipping. Landsliding, gullying, soil creep, and sheet erosion exist in a variety of combinations.

DESCRIPTIONS OF EROSIONAL AND DEPOSITIONAL PROVINCES

The study area of this report (sheets 1, 2, and 3) was subdivided into six general geomorphic regions intended to reflect similarity in both landscape evolution and current processes of the sediment system. These regions, called erosional and depositional provinces, reflect broad conditions of adjustment between tectonic and erosional forces. These conditions portend the sequence of immediate and long-term adjustments in the sediment system that may be of importance in various types of land-use planning. For example, accelerated erosion resulting from grazing practices and the replacement of natural vegetation with new species will continue until a different landform evolves that is in equilibrium with the processes imposed on it. Long-term planning, therefore, must take into account the desirability of that landform for future uses. The following descriptions will help to define the mechanics of the sediment system, and imply methods by which the interaction of man and the landscape can be understood.

Bay Plain and Alluvial Valley

The bay plain and alluvial valley provinces are primarily regions of sediment deposition, although areas of erosion exist along unprotected banks of laterally-cutting streams. Sediments transported by streams from the adjacent mountains form alluvial fans, sand and gravel bars on stream flood plains and in artificial channels, and deltaic deposits in sloughs and in the bay.

The bay plain subprovince lies intermediate between the base of the foothills and the shoreline of the San Francisco Bay. It is composed of extensive areas of manmade fill, and a broad alluvial apron of fan, flood-plain, and deltaic deposits derived from the adjacent mountain ranges. The alluvial apron sediments interfinger with the mud and peaty organic deposits of San Francisco Bay. Slopes range from flat to slightly greater than 5 percent. Slopes as much as 25 percent and greater may occur where present streams have cut down through older fan deposits near the foothills. Rainfall ranges between 14 and 20 inches. Vegetation types include marshland, grassland, and chaparral.

The alluvial valley subprovince consists of flat- to nearly flat-bottomed valleys underlain by thick alluvial deposits. Valley margins are composed of solitary or coalesced alluvial fans. Rainfall is highly variable, having a range of 14 to 30 inches. Vegetation is predominantly grassland, occassionally intermixed with areas of scrub or forest.

Bay Hills

The bay hills erosional province generally contacts the bay plain and alluvial valley provinces around the periphery of the San Francisco Bay, and grades into various upland areas along the San Francisco peninsula and in the Berkeley Hills. The geology of the province is extremely complex, varying greatly in the eastern and western parts; however, the different geologic units erode similarly. The topography of the province consists of subparallel, northwest-trending ridges and valleys, and rolling hills. Slope gradients range from less than 5 percent to more than 75 percent, and elevations range from about 200 to 2,000 feet. Annual rainfall ranges from 20 inches at lower elevations and in the interior valleys to 30 inches at higher elevations and favorably exposed valleys. Spring and summer fogs, driven through the Golden Gate by prevailing westerly winds, are intercepted by vegetation on westward-facing slopes, causing fog drip which contributes up to 10 additional inches per year to the local precipitation.[1] The additional moisture sustains stands of coastal redwoods in the province; however, the predominant vegetation type is a woodland characterized by scattered oak trees and extensive coverings of grassland and chaparral.

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[1] Southward along the San Francisco peninsula and along the east bay hills, the influence of fog wanes and the bay hills province grades into climatically different provinces. Arbitrary boundaries are drawn, but considerable gradation is assumed.

Deep soils are characteristic of this province, and erosive processes reflect complex downslope movement of colluvial masses. Creep is extensive, but exists in combination with coalescent landslides and slumps (Radbruch and Weiler, 1963, p. 13-15). Sheet erosion and gullying are both common and severe where vegetal covering has been removed by overgrazing, fire, or construction activities. Rates of sediment yield measured for sites within this province are currently the highest in the study area.

Foothills

Gradational between the upland provinces and the alluvial plains adjacent to the bay, areas having gentle to moderately steep slopes, occur generally between elevations of 100 and 1,000 feet. These foothill areas are the southern extensions of the bay hills province, and are differentiated from that province primarily by climatic influences. The relief in these areas is considerably more subdued than in the mountainous areas, and the terrain is characterized by rolling hills. Slope steepness only locally exceeds 20 percent. Rainfall averages about 20 inches per year, fog moisture is minimal, and the characteristic vegetal covering is a savannah composed of annual grasses and scattered oaks and chaparral.

This province is underlain principally by older dissected and deformed Quaternary alluvium having strongly developed soil profiles (Helley and Brabb, 1971). Dominant erosion processes in this province include gullying, streambank failure, and scattered hillslope failures that often take the form of rotational slumps. Slopes that are artificially oversteepened during construction fail readily.

Upland Valley and Ridgetop Terrain

This province consists of the larger upland valleys and isolated, grassy ridgetops which occur within the hilly or mountainous provinces. Slope steepness generally ranges from nearly level to about 20 percent. Rainfall ranges from 15 to 30 inches per year depending upon geographic location and exposure. Vegetal covering is characteristically grassland, but grades into forest at the valley and ridgetop margins. Alluvial soils in the valleys are subject to moderate erosion by streambank failure and gullying, and the ridgetops are generally stable but subject to minor erosion along roadways. The valleys are also areas of sediment deposition, especially where streambed aggradation takes place upstream from reservoirs.

Diablo Range Uplands

The Diablo Range uplands erosional province grades southeastward from the bay hills erosional province, and is differentiated from other upland provinces in the study area primarily by its climate and intensity of land use by man. The Diablo Range uplands province, like the Santa Cruz Mountains province, is topographically defined by narrow ridges and deep valleys having little or no flood-plain area. However, because of the lower average rainfall and limited exposure to fog moisture, the Diablo Range province sustains a less productive and less protective vegetal covering. Consequently, the formation of deep soils similar to those of the Santa Cruz uplands is limited despite a similarity in the parent bedrock of the two provinces. Thus, areas of active erosion in the Diablo Range province are more frequently characterized by processes involving principally the downslope movement of fractured bedrock masses, such as debris slides and rockfalls, rather than processes involving principally colluvial masses, such as slumps, creep, and earthflows.[1]

The present erosion cycle in this province consists of canyon cutting and the headward growth of stream valleys. These processes are uniform neither in time nor space, and vary due to differences in the stratigraphy and structure of geologic units and episodic rainfall events (Crittenden, 1951, p. 11). Distinctions among the bedrock units underlying much of the province imply a variation in erosion regime not accounted for here by a subdivision of the province. However, from the perspective of sediment yield and active erosion--measures of the composite of forces described in table 2--the province suffices as a regional unit. The more detailed mapping and interpretation of bedrock units and surficial geology are provided in other current reports (Cotton, 1972, and Nilsen and Brabb, 1972, which may be used in conjunction with this report for specific studies.

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[1]Descriptions of various types of downslope mass movements and the distinctions among them are discussed for the San Francisco Bay region by Nilsen and Brabb (1972).

Santa Cruz Mountains Uplands

This province occurs along the western boundary of the study area, and includes rugged terrain characterized by steeply-sloping, V-shaped canyons having few areas of summit or valley flat. Elevations range from about 500 to 3,000 feet above mean sea level, and slope steepness ranges from about 15 to 75 percent. Average rainfall in this province is the highest in the study area, ranging from 30 to 50 inches per year. Vegetal covering is predominantly forest, but includes some chaparral and grasses. The underlying geology is typically complex, and the geologic structure is dominated by the San Andreas fault zone which approximates the western boundary of the study area.

Within this province, the principal geologic activity of streams consists of the deepening of canyons, as the capacity of streams to transport sediments on the average exceeds the quantity of sediment made available for transport. The streams have little or no flood-plain area within the province, and accommodate increasing runoff with an increase in velocity and depth of flow. This lends to the natural instability of the steep slopes which form the channel boundaries, and the downslope movement of rock and soil masses is a common occurrence.

The primary resistance to erosion in this province is offered by a protective vegetal covering that diminishes rainfall impact and retards rapid runoff. Thus, slopes tend to erode rapidly where soil and bedrock are exposed to the heavy rainfall by the removal of natural vegetation.

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