Geomorphologic Factors Affecting Sediment Generation and Transport Under Pre- and Post-Urbanization Conditions at Rancho Mission Viejo and in the San Juan and San Mateo Watersheds, Orange County, California

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1. INTRODUCTION

Erosion, transport, and deposition of sediment in watersheds of coastal Southern California occur within a cascading system of upland hillslopes, swales, channels, estuaries, and beaches and littoral zones. These different geomorphic zones within this interconnected system variably shed, move, or store sediment, sometimes in response to episodic events such as major storm events and wildfires. Functionally, there are important connections between the sediment cycle and key geomorphic and habitat values that include channel-floodplain connectivity, channel and bank stability, as well as estuary and floodplain management.

Sediment-source and -transport dynamics can change considerably during, and following, urbanization. Typically, upland sediment availability (and transport) increases during the construction period, due to the additional exposure of bare soil during the grading and construction process, and before landscaping vegetation has stabilized the soil. The extent of change depends on the type of sediment exposed, position of the development within the landscape, and the types of storms that occur during the construction period, as well as the type and extent of sediment control measures implemented during construction.

Following the construction period, upland sediment availability typically decreases to below pre-urban levels, as less sediment is available in the areas that have been paved or stabilized by landscape vegetation, and sediment pulses associated with fires are reduced with fire management practices. Implementing, maintaining and refining best management practices (BMPs) after urbanization, however, is necessary to maintain the sediment transport processes which prevailed beforehand. In the absence of BMPs, impervious surfaces can cause higher and more fluctuating flows, which in turn may erode the streambed, resulting in an incised channel, an isolated floodplain, decreased bank stability, and higher rates of sediment transport.

1.1 Report objectives

The degree to which urbanization affects sediment transport processes and rates can vary considerably depending on the type of urbanization and its location within the watershed, as well as the physical characteristics of the watershed such as geology, soils, relief, vegetation, fire frequency, rainfall patterns/amounts, and many other factors.

This report describes the primary processes involved in sediment transport within the San Juan and San Mateo watersheds, and how these processes are expected to change following the planned urban expansion within the watersheds (proposed B4 alternative or 'Ranch Plan'). Several key conditions and principles were considered in the planning process to reduce the impacts to sediment transport and maintain the natural sediment transport processes that support habitat value. These conditions and considerations are discussed throughout the report, and summarized in Chapter 6.

1.2 Context and background

This document is being prepared as part of a set of technical documents to support the environmental impact review for the General Plan Amendment and Zone Change application, B4 alternative (or 'Ranch Plan'), a comprehensive development and habitat-management plan submitted by the Rancho Mission Viejo (RMV) to the County of Orange. The planned project area is located in southern Orange County, and includes RMV and portions of the surrounding area. Within this project area, urbanization is planned in several distinct and concentrated areas ('planning areas'), leaving the remaining area as designated open space and habitat.

In addition to the foundations laid out in the General Plan, this project also incorporates goals developed during several years of coordinated planning by cooperating teams drawn from RMV staff, senior consultants, and resource-agency and environmental-hazard professionals. These efforts have led to new understandings and development of two key documents which describe the bed and channel conditions sought to protect essential habitat and sensitive species:

- The Southern Subregion Natural Community Conservation Plan/Habitat Conservation Plan (Southern NCCP/HCP) Planning Guidelines, jointly prepared by the County of Orange, the California Department of Fish and Game, the U.S. Fish and Wildlife Service, consultants, and RMV staff;

- Watershed and Sub-Basin Planning Principles, San Juan/Western San Mateo Watersheds, Orange County, California, prepared by the NCCP/SAMP working group which included professionals from the U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, California Department of Fish and Game, Orange County, RMV and a coordinating consultant.

These collaborative efforts establish salient bed- and channel-management policies or guidelines supported by RMV and other project proponents and each of the participating agencies. These efforts drew upon substantial field research conducted in the area by the cooperators, and are listed in the two documents, among others. Goals and standards for bed and channel conditions and sediment transport are described in the plans to conserve and protect habitat (PCR and Dudek, 2002) and in the Habitat Management Plan (Appendix H4). The role of sediment transport (or, more appropriately, changes in sediment transport) in habitat conservation planning is also discussed below (see sections 4.2, 4.3 and 4.4), and its role in supplying coarse sediment needed to 'nourish' the beaches is considered in sec.4.3.1.

Incorporating bed- and channel- management guidelines as well as habitat needs into the context of flood protection is one of the goals of the planning effort. This combination is perhaps groundbreaking in that it can serve as a model for future projects in the region. Previous hydraulic analyses were evaluated to determine if the project's hydrologic impacts exceed the thresholds of significance from a CEQA perspective. Although unmitigated impacts will not exceed the thresholds, mitigation measures will be implemented to meet County standards.

1.3 Approach

Sediment delivery, transport, and export – and the associated bed and bank conditions providing essential habitat – are primary influences in the planning and design of a large project. To date, these factors have been discussed primarily in conjunction with wetland and stream-corridor planning/permitting and biological resource conservation plans. Orange County seeks to evaluate sediment and bed conditions as part of its general plan review.

As one indication of likely effects, Orange County has requested that the modified universal soil loss equation (MUSLE) be applied to describe the differences in pre- and post-construction rates of sediment production. In response to this request, Phillip Williams and Associates (PWA) staff used this methodology to quantitatively estimate changes in sediment production in response to the B4 alternative on the Rancho Mission Viejo (Stewart and others, 2004). While the PWA study is useful as a rapid and timely response to a request made by Orange County to provide a comparison of potential pre- and post-project erosion and sediment production, other considerations are needed to evaluate the role of sediment in flood protection, habitat conservation, and the ability to sustain viable populations of sensitive species. In addition, at a more fundamental level, an integrated flood- and habitat-protection program is a key mandate of the Natural Communities Conservation Planning process and several years of planning to minimize effects on channels, wetlands, and other aquatic resources.

In this document, we complement and supplement work recently done by PWA by considering erosion, sedimentation, and bed conditions in a broader sense, including other aspects of the cycle of erosion and sedimentation. We further discuss sources of sediment (such as in-channel erosion or incision), response to episodic events, and specific implications of the overall design of the planning areas on the amount and particle-size of sediment transported. This report discusses how these factors will affect channel conditions, habitat needs, coarse sediment (and 'beach sand') supply, and other issues often not considered in evaluating sediment and sedimentation because they have not been evaluated prior to the CEQA process. It also summarizes how planning areas have been sited to reduce the negative effects of changes in sediment transport associated with urbanization, consistent with the Basin and Sub-Basin Watershed Planning Principles.

2. GEOMORPHIC SETTING

2.1 Physiography and setting

The project area largely coincides with the boundaries of Rancho Mission Viejo, located in southern Orange County, just north of San Diego County and west of Riverside County. The ranch covers portions of two major watersheds, San Juan and San Mateo Creeks. The physiography and basic surface hydrologic conditions are described in the Baseline Geomorphic and Hydrologic Conditions report (PCR and others, 2001); ground-water conditions as they affect channels are discussed in the baseline ground-water report (Hecht, 2001).

2.1.1 San Juan Creek Watershed

The San Juan Creek watershed is located in southern Orange County, California. The watershed encompasses a drainage area of approximately 176 square miles, and extends from the Cleveland National Forest in the Santa Ana Mountains to the Pacific Ocean at Doheny State Beach near Dana Point Harbor. The major tributaries to San Juan Creek include (from west to east): Oso, Creek, Trabuco Creek, Horno Creek, Chiquita Creek, Gobernadora Creek, Trampas Canyon, Bell Canyon, Verdugo Canyon, and Lucas Canyon, amongst other tributaries which originate in the National Forest. Most tributaries flow from steep canyons. As the streams flow, they coalesce and widen out into several alluvial floodplains. Elevations in the watershed range from over 5800 feet at Santiago Peak to sea level at the mouth of San Juan Creek.

The San Juan Creek watershed is bounded on the north by the San Diego Creek, Aliso Creek and Salt Creek watersheds to the west, and on the south by the San Mateo Creek watershed. The Lake Elsinore basin, which is a tributary of the Santa Ana River watershed, adjoins the eastern edge of the San Juan Creek watershed.

2.1.2 San Mateo Creek Watershed

The San Mateo Creek watershed is located in the southern portion of Orange County, the northern portion of San Diego County, and the southwestern corner of Riverside County. San Mateo Creek flows 22 miles from its headwaters in the Cleveland National Forest to the ocean just south of the City of San Clemente. The total watershed is approximately 139 square miles, and lies mostly in currently undeveloped areas of the Cleveland National Forest, the northern portion of Marine Corps Base Camp Pendleton (MCBCP), and ranch lands in southern Orange County (Lang, 1998). Major (named) tributaries in the watershed include Cristianitos Creek, Gabino Creek, La Paz Creek, Talega Creek, Cold Spring Creek and Devil Canyon Creek. Elevations range from approximately 3340 feet above sea level in the mountains of the Cleveland National Forest to sea level at the mouth of San Mateo Creek.

The proposed project area includes the portion of the San Mateo Creek drainage basin within Orange County, including the La Paz, Gabino and most of the Cristianitos Creek watersheds, plus a sliver of Talega Creek. Approximately 17 percent of the total runoff in the San Mateo Creek basin emanates from these four tributaries (Larry Carlson, MCB Camp Pendleton, personal comm.).

The San Mateo Creek watershed is bounded on the north and west by the San Juan Creek watershed, to the south by the San Onofre Creek watershed, and to the northeast by the Lake Elsinore watershed.

2.2 Regional geology

The San Juan and San Mateo Creek watersheds are located on the western slopes of the Santa Ana Mountains, which are part of the Peninsular Ranges that extend from the tip of Baja California northward to the Palos Verdes Peninsula and Santa Catalina Island. The geology of the region is complex, and has been dominated by alternating periods of tectonic downwarping and uplift, and mass wasting and alluviation. Within the watersheds, the Santa Ana Mountains are composed of igneous and metasedimentary rocks of Jurassic age and younger. The exposed rocks in the mountainous areas are slightly metamorphosed volcanics, which have been intruded by granitic rocks of Cretaceous age, principally granodiorites, gabbros, and tonalites.

Overlying these rocks are several thousand stratigraphic feet of younger sandstones, siltstones, and conglomerates of upper Cretaceous age, composed largely of material eroded from the older igneous and metasedimentary rocks now underlying the Santa Ana Mountains.

Younger sedimentary rocks comprise the bedrock between the Santa Ana Mountains, their foothills, and the Pacific Ocean. Most of the project area is underlain by these marine and non-marine sandstones, limestones, siltstones, mudstones, shales, and conglomerates, many of which weather, erode, and/or hold ground water in characteristic ways. Overlying them are Quaternary stream and marine terraces, and Holocene stream channel deposits.

During the past two million years or so, the two watersheds have been affected by at least three processes which fundamentally affect sediment yields[1]:

- Continuing tectonic uplift, typically 400 feet or more, which has left at least four major stream terrace levels along the major streams;
- Downcutting of the main canyons to sea levels which have fluctuated widely during the global glaciations. As recently as 18,000 years ago, worldwide sea level was about 410 feet lower, and the shoreline was several miles further west than at present. San Juan, Chiquita, Gobernadora, San Mateo, and Cristianitos Creeks (among others) flowed in valleys graded to the depressed sea level, at elevations often 60 to 120 feet lower than at present. The flat valley floors now found along these streams were deposited as sea level rose, leaving often-sharp slope breaks at the base of the existing hillsides and tributary valleys which also have been filling during the recent geologic past.[2] These fill materials are geologically young, soft, and prone to incision under certain conditions.
- Development of hardpans in soils which formed under climates both warmer/colder and drier/wetter than present, which convey runoff to headwater streams at relatively rapid rates, much as if some of the ridge tops were paved.

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[1] Soil types, ground-water recharge and water quality are also affected by these processes but are beyond the scope of this report.

[2] Large landslides in the Monterey shale and related formations in the lower reaches of these streams (and on Radio Tower Hill) probably occurred during low stands of sea level, when the major streams cut deeper and further into the bedrock hills; these slides are relict features which do not add to present-day sediment yields, except where parts of the slide masses may be actively moving or incising.

3. PRIOR WORK AND SOURCES

Numerous erosion- and sediment-related studies have been conducted for the San Juan and San Mateo Creek watersheds and vicinity. These studies range from watershed-scale resource studies to more narrow technical investigations of slope stability or hydrology. The following is a description of the studies most pertinent to this report; a more complete list of references cited is found in Chapter 7.

- PWA (Stewart and others, 2004) used the MUSLE to quantify changes in upland sediment production in response to the B4 alternative on the RMV.
- GeoSyntec Consultants (2004) prepared a Water Quality Management Plan for the Rancho Mission Viejo, describing potential water quality, water balance, and hydromodification impacts due to urbanization, and plans for reducing these impacts.
- KEA Environmental, Inc. compiled a summary of baseline conditions in the San Juan Creek watershed for the U.S. Army Corps of Engineers Los Angeles District in 1998.
- Simons & Li Associates, Inc., prepared hydrology and sediment transport studies for the U.S. Army Corps of Engineers' San Juan Creek Watershed Management Study in 1999.
- R. Daniel Smith and his colleagues at the Army Corps of Engineers Waterways Experiment Station recently completed assessments of riparian ecosystem integrity in the San Juan and San Mateo Creek watersheds (Smith, 2001; Smith and Klimas, 2003).
- Soils mapping for Orange County and the western part of Riverside County was published by the U.S. Department of Agriculture Soil Conservation Service (now the Natural Resources Conservation Service) in 1978. Soil mapping was published for San Diego County in 1973.
- Prof. Stanley Trimble (UCLA) has carried out a long-term study of channel erosion and sediment yields in the San Diego Creek watershed, adjacent to San Juan Creek.
- During the early 1980's, the U.S. Forest Service Glendora Research Station, the Environmental Quality Laboratory and the California Institute of Technology published a series of studies focusing on the factors that influence sediment yield, transport, and sediment management in Southern California's mountains, coastal plains, and shorelines, and identified that episodic sedimentation is fundamental to foothill channels in this region (c.f., Wells and Brown, 1982; Wells, 1981; Taylor, 1981; Dunn, 1988; DeBano, 1988).

- Vito Vanoni, Robert Born, and Hassan Nouri (1980) conducted a detailed study of channel response to the January-March 1978 floods, including discussion of a sand and gravel mining operation along San Juan Creek.

- Slopes, slope deposits, and their stability have been assessed by Goffman, McCormick, and Urban (1999) as part of field investigations leading to the project plan.

- Geologic mapping and engineering geologic assessments by California Division of Mines and Geology staff (Morton, 1970, 1974; Morton and Miller, 1981) have proven essential to understanding (a) response of various soil-geologic types to episodic events, (b) the distribution of sources of fine and coarse materials, and (c) the bedrock and hydrogeologic conditions that serve to stabilize channels.

A range of additional studies describing and defining bed conditions and geomorphic processes required or sought for sustaining suitable habitat or protecting sensitive wildlife species are considered in the NCCP Guidelines, the Watershed Principles, and in PCR and Dudek (2002), among others.

3.1 Field-based studies conducted

To supplement these keystone efforts, Balance Hydrologics has undertaken several different types of field studies on and around the project area specific to sediment transport, including:

- Reconnaissance of bank and bed conditions on selected drainages within RMV;

- Concentrated studies on channel stability within the Gobernadora and Chiquita watersheds (in prep);

- Estimates of peak flow and baseflow measurements at established cross sections on drainages within RMV (initially presented as Appendix A of Hecht, 2000, and subsequently updated);

- Wildermuth Environmental and Balance have been operating stream gages at several locations within the project area at which baseline peak flows and hydrographs are being developed.

This field work is supported and augmented by knowledge gained through the study of aerial photographs, soil surveys, geologic maps, and other previous studies performed in southern Orange County.

Through these field studies and supporting background research, we have compiled an extensive dataset of the characteristics within RMV that drive, maintain, and otherwise affect, sediment transport. In this report, this field knowledge will be used to substantiate, support, and/or supplement the estimates of changes in sediment availability using the MUSLE method.

3.2 Terrains

Terrain designations are largely based on soils, geology, and topography, as these provide many of the fundamental factors that influence the hydrology and geomorphology characteristic of each terrain type. Bedrock is the raw material from which soils are weathered, and, as such, it determines the size and types of particles that will comprise the soil. The resistance of different kinds of bedrock to weathering and erosion also controls the topography of the landscape within a given terrain and, therefore, influences the hydrology of the watersheds and morphology of the drainage networks. Watershed hydrology is also strongly influenced by the annual and multi-year climatic patterns typical of Southern California.

Three major geomorphic terrains have been identified by Balance staff within the San Juan Creek and western San Mateo Creek watersheds: **(1)** sandy and silty-sandy; **(2)** clayey; and **(3)** crystalline (PCR and others, 2002). These terrains are manifested primarily as roughly north-south oriented bands of different geologic and soil types. The soils and bedrock that comprise the western portions of the San Juan Creek watershed (*i.e.,* Oso Creek, Arroyo Trabuco, and the lower third of San Juan Creek) contain a high percentage of clay. The soils typical of the clayey terrain include the Alo and Bosanko clays on upland slopes and the Sorrento and Mocho loams in floodplain areas. In contrast, the middle portion of the San Juan basin, (*i.e.,* Cañada Chiquita, Gobernadora Canyon, and the middle reaches of San Juan Creek) is a region characterized by silty-sandy substrate that features the Cieneba, Anaheim, and Soper loams on the hillslopes and the Metz and San Emigdio loams on the floodplains. Within these sandy and silty areas are erosional remnants locally overlain by between 2 and 6 feet of exhumed claypan or hardpan. The upstream portions the San Juan Creek watershed, comprising the headwaters of San Juan Creek, Lucas Canyon Creek, Bell Canyon, and Trabuco Creek, may be characterized as a "crystalline" terrain because the bedrock underlying this mountainous region is composed of igneous and metamorphic rocks. Here, slopes are covered by the relatively coarse-grained Friant, Exchequer, and Cieneba soils, among others, while stream valleys contain deposits of rock and cobbly sand.

4. FINDINGS

This chapter describes the types of analysis undertaken to support and supplement the MUSLE sediment transport work by PWA (Stewart and others, 2004), which discusses the process and results of the sediment supply rate comparison of pre- and post-development conditions. The following sections put these results in a broader context, addressing other sources of sediment as well as distinguishing types of sediment transport. They also address how geomorphic principles applied at the landscape and project scale have been implemented to reduce the negative effects of urbanization on sediment and bed conditions.

4.1 The Modified Universal Soil Loss Equation (MUSLE)

The universal soil loss equation (Wischmeier and Smith, 1965) was originally developed to quantify soil loss from cultivated fields, but is also commonly used to assess changes in erosion rates on a watershed scale in response to changes in land cover or land use. Orange County recommended the use of the modified universal soil loss equation (MUSLE; Williams, 1981) as an index quantifying the change in sediment production within the proposed project area in response to planned urbanization. The results of this study are summarized in a separate document (Stewart and others, 2004).

The results of the MUSLE analysis reflect an important portion of the sediment production within the watershed. The factors used in the MUSLE method, by definition, consider mainly sediment production under 'normal' conditions, and explicitly do not consider erosion or sediment transport associated with episodic events such as landslides or mudflows, and other watershed disturbances such as wildfire. In the predominately intermittent streams of Southern California, much of the sediment transport occurs in response to these episodic events and, increasingly, watershed disturbance (see also section 4.3).

The numbers derived using the MUSLE method quantify (to some extent) the amount of upland soil lost from sheet and rill erosion, but do not directly correlate to sediment yield (Wischmeier, 1976). A portion of the soil eroded from the slope segments is deposited downslope, accumulating in alluvial storage areas without reaching the main stream channel. Additionally, some sediment may reach the channel system but is stored in the channel or riparian corridor. Conversely, bank erosion or incision of channels can release much additional sediment into the stream system, sometimes several times the MUSLE background rate if the hydrology changes substantially. Releases from or storage in the channel corridor may also account for differences between MUSLE-derived numbers and actual measurements of sediment transport or of reservoir sedimentation.

The MUSLE method also does not normally include an analysis of the cyclic sediment production associated with urbanization. Upland sediment erosion is typically reduced following the construction phase, as much of land surface is covered with pavement or stabilized by landscape vegetation. However, urbanization sometimes increases sediment yield further downstream within the watershed, as channels adjust to new hydrologic conditions, causing incision and bank erosion. Channel adjustment is occurring in Gobernadora Canyon, Trampas Canyon and elsewhere related to existing upstream land uses. The incision associated with these 'hydromodification effects' must be considered separately from the MUSLE analysis (see sections 4.5 and 4.6; and GeoSyntec, 2003; 2004).

Because of the timescale and variability of the sediment transport processes outside the coverage of MUSLE, it is difficult to provide quantitative estimates of sediment transported by these processes. It is possible, however, to qualitatively describe how these processes relate to upland sediment production (as estimated by MUSLE), and estimate the likely percentage of sediment transport that is covered by the MUSLE method. These relationships are discussed in the sediment transport process sections below.

In summary, the MUSLE method provides a useful comparison of the potential change in base erosion rates of uplands in response to land-use change following urbanization, but consideration should be made for sources of sediment, and processes of sedimentation and erosion, not covered by MUSLE analysis. Further, as noted below, other metrics may prove more significant than volumes in assessing sediment status and bed conditions.

4.2 Sediment transport needs of aquatic species

In conjunction with the 'coordinated process' involving the NCCP/HCP, SAMP/MSAA and the GPA/ZC, leading local biologists prepared a report addressing geomorphic and hydrologic processes that must be considered in long-term habitat conservation planning (PCR and Dudek, 2003). An excerpt from this report addressing key physical processes is attached to this report as Appendix B for reference purposes. Although the Geomorphic and Hydrologic Needs report addresses the habitat needs of listed aquatic/riparian dependent species only, these species are effectively surrogate planning species for the general range of aquatic/riparian habitat systems in the study area because the listed species habitat needs reflect a broad spectrum of habitat considerations.

The following is a short summary of most pertinent habitat needs of sensitive species as they relate to sediment transport processes. For a thorough discussion of the habitat needs for the four sensitive species, see the PCR/Dudek report (2003).

- Arroyo Toad:
    - use sandy sediment produced in upland catchments and delivered to the streams for breeding and foraging habitat.
    - depend on periodic scouring flows and mass movements/debris flows are important for maintaining breeding habitat.
- Least Bell's Vireo:
    - occupy unobstructed, flood-prone areas that are periodically scoured by episodic flow events.
- Southwestern Willow Flycatcher:
    - utilize broad, stable terraces for habitat.
- Tidewater Goby:
    - can not tolerate excessively high levels of fine sediments, as this could result in mortality of eggs or juveniles by burying spawning areas, or by constraining access of spawners.
- Southern Steelhead:
    - spawn in gravelly substrate streams having pool-riffle morphology; these gravels must be relatively free of fine sediment, with adequate interstitial space for egg incubation.
    - use pools and cover created by logs and other organic debris before they out-migrate to the ocean; riparian corridors must be sufficiently wide to grow the large trunks and logjams needed to regularly provide these raw materials, which often last only for 5 or 10 years before decaying.

Many of the processes listed above are further detailed in the sections below. Planning principles have been implemented to limit negative effects to critical habitat of these sensitive species (see sections below for specific planning measures).

4.3 Sediment-size considerations

Early assessments of bed conditions and water quality in the proposed project area identified four key goals related to sediment size:

(a) While limiting erosion and additional sediment transport are sound goals, maintaining a supply of sand and fine gravel is important both to nourishing beaches and sustaining the habitat of arroyo toads and other sensitive species.

(b) A reduction in fine sediment transport or on the bed of the stream is seen as a benefit to channel, riparian, habitat functions and values in general, and will be consistent with conservation goals for the arroyo toad, tidewater goby, least Bell's vireo and other listed or sensitive species.

(c) A reduction in fine sediment will reduce concentrations of use- and habitat-impairing biostimulatory nutrients and trace metals, particularly in winter baseflows (Orange County database; Ballman and others, 2001).

(d) Turbidity is directly correlated with erosion and transport of fine sediment. Reductions in the supply of fine sediment entering the stream system will directly reduce ambient turbidity during all storm runoff conditions, both winter and summer.

The proposed project has been planned with minimizing fine-sediment delivery in mind while also maintaining the transport of sand and fine gravel to sustain sensitive-species habitat and nourish the beaches. The basis for these dual goals and the approaches to be used to attain them are described in the following sections.[3] These sections qualitatively describe the anticipated effects that urbanization and other proposed land-use changes may have on coarse- and fine-sediment supply, and the relative benefits and/or detriments of each.

4.3.1 Coarse sediment

Medium-grained sand and fine gravel are of particular interest in the San Juan and San Mateo watersheds, as these are the types of sediment that are most important for beach supply, as well as in-stream habitat value. Beaches along the Orange and San Diego County coast are very important ecologically, as an element of shoreline protection, and as a central amenity and icon of place.

Both San Juan and San Mateo creeks contribute sand to the Oceanside littoral cell, which extends 65 miles from Dana Point to Point La Jolla (USACOE, 1990). Since 1958 at least eleven different sediment budget analyses have been developed to model beach sand processes within

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[3] The MUSLE methods requested by Orange County to evaluate sediment and sediment transport for flood-protection considerations unfortunately do not address the sizes of the sediment eroded or transported; the analyses in this report can help supplement other submittals.

the Oceanside littoral cell (USACOE, 1991).[4] These studies have identified streams as responsible for contributing between 16 to 61 percent of total beach material inputs, with 33 percent being the estimate in the 1990 and 1991 Corps of Engineers studies. The remainder of the beach material is contributed by erosion of seacliffs and coastal terraces. The wide range of estimates is probably the result of the different assumptions underlying the various sediment budget studies as well as actual fluctuations in storm and wave conditions which entrain the material.

The materials that contribute to beaches along the Oceanside littoral cell are small enough to be moved laterally along the shore by wave action, but large enough not to be washed away by ocean swells. The beach area to which the San Juan and San Mateo Creeks discharge is characterized by a bimodal grain size distribution. Approximately 15% (by weight) of the sediments have a diameter of 8mm, and 30% are 0.3mm in size (USACOE, 1990). This distribution illustrates the importance of fine gravel (classified as sediments 4 to 64 mm in size) and medium sand (0.25 to 0.5 mm) on beaches in the study area**.** Cobbles also have a substantial role in beach morphology and stability, but are relatively scarce by volume. The largest material tends to reside the longest on the beaches before being transported offshore.

As discussed above, coarse sediment is also an important component of the riparian habitat used by arroyo toad and other sensitive species.

4.3.1.1 Identification of coarse sediment supply

To identify the areas within the two watersheds likely to have the highest potential to yield these coarse sediments, Balance has applied a spatially distributed modeling environment within a geographic information system (GIS). The analysis recognizes that coarse sediment (important for habitat needs and for beach material supply) originate by two linked sets of processes:

- Year-to-year, **chronic coarse-material delivery** suitable for beach supply and valuable habitat, originates from easily erodible sandy and gravelly substrate.
- **Episodic coarse-material delivery**, such as following fires, floods, or landslides, contributes pulses of coarse sediment to the channel (and beaches), but also to floodplain storage sites, from which the materials can subsequently be metered out as part of the year-to-year contributions (Hecht, 1993; Inman and Jenkins, 1999).

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[4] One of the most recent and comprehensive analyses, this 1991 analysis also identified that San Juan Creek contributes to a distinguishable and northernmost subcell, bounded by Dana and San Mateo Points.

While both sources are volumetrically important in terms of coarse-material supply (c.f., Wells, 1988; Taylor, 1981), the processes by which they deliver sediments differ. To estimate chronic coarse-material sources, we considered four factors associated with soil type and geology. Each factor was used as a filter through which to screen out areas that are not expected to yield beach sands. These factors include:

- The inherent erodibility, '*K*' factor, of the soil is given the most importance in the methodology. Soil erodibility is affected by the infiltration capacity and structural stability of the soil. Soils with a high infiltration capacity and low structural stability are more likely to erode. Sandy soils with a high *K* factor are considered an important source of sand while clay soils with low erodibility are less likely to yield medium- to coarse-grained sediment.

- Slope is the second filter through which we identified beach sand supply areas. Areas with steep slopes have higher runoff velocity, more erosive power and therefore a greater capacity to transport coarse sediment to the stream.

- The third factor, runoff potential, identifies the infiltration rate of a soil and can be used to estimate runoff from rainfall. Soils with low infiltration rates (group D) have high runoff and are therefore considered to create rills, gullies or incised reaches, which may transport more sediment (both coarse and fine) to the local master streams, and thence to the beach. Group A soils presently have a high infiltration rate with lower runoff.

- The lithology of the soil parent material also influences whether an area is a beach sand source. Alluvium, volcanic, sandstone and crystalline bedrock types are more likely to produce coarse sediment as they weather or erode, whereas shales and mudstones are much less likely to produce the medium grained sands and pebbles important to aquatic species and beach sediment supply.

The analytical approach is presented diagrammatically in Appendix A.

The results of this analysis for the San Juan and San Mateo watersheds are shown in Figures 1 and 2, highlighting areas of primary and moderate potential sources of coarse-sediment supply (shaded red and yellow respectively). The primary sources highlighted by this method are the alluvial deposits found in streambeds and stored on floodplains and in eroding or erodible terraces. These deposits contain considerable amounts of unconsolidated sand and fine gravel that are available for transport by the stream, and supply coarse sediment on a chronic basis (during 'typical' flow events).

Based on recent studies of post-fire sediment management along the San Gabriel Mountains front (c.f., Wells, 1988; Taylor 1981; also, Table 2), field work, aerial photograph analysis conducted by Balance Hydrologics within the project area, and reported observations following the December 1958 fire (Fife, 1979); we recognized that the upland areas underlain by granitic and metavolcanic rocks supply a significant amount of coarse sediment to the streams and floodplains. This source of sand is predominately mobilized only during extremely intense and/or long duration storm events, like those that occurred in 1916, 1938, 1969, and 1995, or after watershed-scale fire removes stabilizing vegetation (see also section 4.3). Much of this sand is transported to the stream mainstems and stored on the floodplains, where it replenishes the chronic, alluvial beach sand sources. Hence, the ultimate sources of much of the coarse sediment in the San Juan and San Mateo watersheds are the coarse-grained soils formed on granitic and metavolcanic rocks exposed in the upper portions of the watersheds.

In order to highlight these areas of episodically-delivered coarse sediment contributing material to the channels and beaches, Figure 1 shows areas underlain by granitic and metavolcanic rocks (stippled pattern). These units include the Santiago Peak volcanics, the San Marcos gabbro, as well as undifferentiated granodiorite and tonalite. This analysis also included the Trabuco formation (a conglomerate) because it includes much granitic and metavolcanic sand, gravel, and cobbles, and is a source of coarse stream sediment (Fife, 1979).

Additionally, there are several sandy/silty sedimentary units in the central portion of the San Juan and San Mateo watersheds (predominately the Santiago and Sespe formations). Erosion of these formations also contributes to the sand supply stored in the side canyons (specifically Chiquita, Gobernadora, upper Gabino, and to some extent Cristianitos), and in the mainstem alluvial deposits. However, sediment generated from these units also contains significant amounts of silt-sized particles, smaller than the size of sediment important to aquatic habitat and the material forming the Oceanside Littoral Cell beaches. Where the soils are suitable, these areas contribute light to moderate volumes of sand and silt, typically during episodic conditions (Morton, 1970, 1974; G. Aguirre, pers. comm.), but also on a more regular basis. These areas, identified through the GIS analysis described above, are included in the 'moderate' classification (Figures 1 and 2).

4.3.1.2 Protection of coarse sediment supply and sediment transport

Planned urbanization has been concentrated, to the extent practicable, to areas that are not primary sources of coarse sediment supply (Figure 2). Much of the primarily ridge-top residential development has been planned for areas that are underlain by finer-grained bedrock, or bedrock that is capped by fine-grained and relatively erosion-resistant hardpan soils. The Chiquita, Gobernadora and Cristianitos/Gabino development bubbles are examples of these practices. In Trampas Canyon, the development bubble is sited primarily in the area upstream of the existing glass sand plant, which already traps the majority of the sediment produced within that portion of the watershed (and essentially all of the coarse sediment).

Urbanization within the alluvial valley floor areas has been severely restricted, such that the stream corridors' natural values remain as intact as possible. One such value is that the main chronic supply of coarse sediment will remain intact. Additionally, the protection of the wide stream corridors will maintain current sediment storage within the valleys, and allow for transport of sediment from the upper portions of the watershed, the ultimate source of much of the coarse material. Finally, the proposed project limits the number of in-stream structures (to several road crossings), allowing continuity of sediment transport in general, and avoiding interrupting the movement of coarse sediment material to the coast.

4.3.2 Fine sediment

The introduction of excess fine sediment (finer than coarse sand) to a stream channel is of particular concern due to its potential impacts both on habitat and on sensitive species (c.f., PCR and Dudek, 2002). Several factors affect the current (pre-project) supply of fine sediment to the creeks. Much of the area within RMV is currently used for nurseries, truck crops, and orchards, and stock grazing. In the past, these practices have significantly increased the amount of fine sediment introduced to stream channels by exposing bare soil to erosion by rainfall, reducing the amount of soil-stabilizing vegetative cover, and increasing runoff due to compaction of the soil. Currently, however, the Ranch operates under a grazing management plan that has reduced the impact of grazing and agriculture to fine sediment generation[5].

Perhaps the greatest influence on fine sediment generation, over time, has been the displacement of native grasses and sage scrub by Mediterranean grasses. These non-native plants lack the root systems and stormwater infiltration capabilities of native plant species that help reduce the generation of fine sediment.

Additionally, there is a high concentration of fine sediment currently emanating from the exposed former clay pits in the Gabino and Cristianitos watersheds, and a significant sediment influx in upper Gabino, at the base of several major debris slides.

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[5] see RMV Grazing Management Plan, Appendix J to the GPA/ZC application.

Further, there is a large supply of sediment that is being transported within Gobernadora Creek from channel erosion in the urbanized upper portion of the Gobernadora watershed. While this sediment is primarily fine sand, it has caused significant aggradation within the stream channel, and caused the stream to jump its banks and carve a new channel eroding through deposits of sand, silt, and clay, introducing additional fine material into the stream.

4.3.2.1 Limiting generation of fine sediment

The 'Ranch Plan' for urbanization follows several of the Baseline Conditions Watershed Planning Principles (NCCP/SAMP, 2003) intended to reduce the amount of fine sediment to the stream channels:

1. Urbanization footprints for the project area are sited on areas of the watersheds that are currently generating significant yields of fine sediment. Covering these areas with impervious surface and landscaping vegetation will reduce the amount of fine sediment eroded from these areas. Specifically, the clay hardpans on the ridges east of Chiquita and Gobernadora Canyons, as well as the clay pits area of the Cristianitos/lower Gabino watersheds are planned for urban development. The fine sediment eroding from the slides in upper Gabino will be managed by the golf course planned for development in that area.

2. Adaptive management of grazing practices will continue to reduce the impact of grazing to sediment inputs (see RMV Grazing management plan).

3. Native upland vegetation restoration in some areas of the watersheds characterized by clay soils will reduce fine sediment generation.

4. Riparian vegetation restoration will increase bank stability of the streams and increase the buffering capacity of the channels for both flow and sediment.

4.3.3 Sediment size and the MUSLE method

The MUSLE method does not distinguish between coarse- and fine-sediment generation. This is a significant limitation in that the benefit or detriment of the addition or loss of sediment availability depends on the size of the sediment. For example, a reduction in fine sediment (< 0.25 millimeters) is often seen as a benefit, especially in areas that have an unnaturally high pre-urban rate of fine sediment. A reduction in coarse sediment, however, could have a significant negative impact on habitat value or beach sediment supply. Ideally, urbanization would be planned to reduce the generation of fine sediment, and maintain the production of course sediment within the watersheds (see sections 4.3.1.2 and 4.3.2.1 above).

4.4 Episodicity

The MUSLE method of assessing changes to sediment transport only considers changes under 'normal' conditions. However, sediment transport in semi-arid and arid climates is heavily dependent on episodic events, such as wildfires and debris flows. Many of the streams within the study area are intermittent, and all are episodic. Concepts of "normal" or "average" sediment-supply conditions have a limited value in this flashy environment. Many of these channels are usually dry, or are actively adjusting to lower flows than the last major event, which may have occurred many years before[6]. In the semi-arid, Mediterranean-type climate of southern California, large sediment movement events can occur in a matter of hours or days. In many of these channels most sediment is moved—and most bed changes occur—during the large storms which may be expected every 5 to 15 years (c.f., Kroll, 1969; Hecht, 1993; Inman and Jenkins, 1999).

Figure 3 highlights the episodicity of sediment transport in San Juan Creek at San Juan Capistrano. In any given year, over half of the sediment is transported during highest one percent of flow in the year. In addition, year-to-year trends in sediment transport vary by orders of magnitude, with the majority of the sediment transported in three years (1978, 1980, and 1983) over the eighteen-year record.

According to accounts of unpublished U.S. Forest Service data on the fire history of the upper San Juan watershed, the greatest historic fire experienced prior to 1978 was the Steward Ranch fire, which occurred in December 1958 and burned roughly 76 percent of the upper San Juan watershed above the confluence with Bell Canyon (Fife, 1979; see also fire maps within the Southern Sub Regional Wildland Fire Management Plan, Appendix K of the GPA/ZC application). After the 1958 fire the chaparral did not fully re-grow until 1968, and had the 1969 floods occurred in 1959, runoff and sediment yield during that event would probably have been even higher that the levels experienced. This illustrates not only the importance of episodic events but the connection and interaction between different types of extreme events.

A reasonable estimate of the recurrence interval for remote wildland fires in Southern California chaparral is about 25 to 35 years (Fife, 1979; Calcarone and Stephenson, 1999). Following further development of the watershed, the frequency with which fires occur in National Forest land is unlikely to change. An aggressive fire prevention and suppression program is, however,

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[6] Actively adjusting channels may be aggrading, incising, or otherwise changing channel dimensions, depending on the magnitude, type, and various effects of the episodic event.

planned for the development bubbles (Appendix K of the GPA/ZC). Wildfire in adjacent areas will be controlled through the application of the Prescribed Fire Program (Appendix K of the GPA/ZC). Following an initial 'restoration' phase, native grasslands will be burned every 10 years. Wildfire in oak woodland sites will be controlled through the use of fire every 6 years to reduce the amount of shrub-like vegetation and chaparral/shrub sites will be burned on 10, 15, and 20-year return intervals.

4.4.1 Planning considerations for episodicity

Episodic sedimentation is usually important to maintain streambed conditions and of particular importance in sustaining habitat values and the bed mosaic required by least Bell's vireo, arroyo toad, and other species of concern. Episodic events are also vital in maintaining the mix of open channel and vegetated banks most likely to convey high flows with minimum bank erosion or channel disturbance. With appropriate planning, these events also have a basic role in channel restoration (Hecht, 1993). Anticipating episodic events and their effects is a significant available vehicle for integrating the 'flood protection' and 'habitat protection' aspects of channel management, as outlined in the project goals.

The proposed project allows this episodic role to persist by leaving at least one whole side of the Chiquita, Gobernadora, Narrow, Verdugo, Cristianitos, Gabino, and La Paz watersheds with intact natural slopes draining directly into these channels, fundamentally free of urbanization or infrastructure. Not only will sediment continue to naturally enter these channels during (and following) episodic events, but the lack of infrastructure makes it easy to manage these areas as open space with continuing episodic contributions of sediment.

4.4.2 Episodicity and the MUSLE method

Simons & Li Associates (SLA, 1999) estimated sediment production for the upper San Juan and Arroyo Trabuco watersheds using both the MUSLE and Los Angeles Debris (LAD) method. The LAD method was designed for use in the steep San Gabriel Mountains, and applies a fire factor intended to incorporate (at least partially) episodic events. The SLA comparison showed that LAD estimates of sediment production are 137 to 190 percent higher than estimates derived from the MUSLE method, and gives a broad estimate of additional sediment production in response to episodic events (Table 2).

4.5 Regional sediment transport

Studies in which suspended (and sometimes bedload) sediment are sampled typically lead to the development of a rating curve, such as the ones shown in Figure 4. In these studies, hydrologists and geomorphologists sample to measure the amount of sediment and water moving in a given flow past a point. After a range of flow conditions have been monitored, sampling results are then plotted on a rating curve that can be used to predict the amount of sediment moving under a variety of streamflow conditions. One of the limitations of this method of analysis is the scarcity and difficulty of making measurements during the high flows at which the majority of sediment is transported. While fine sediments can be transported at low and moderate flows, coarse sediments require moderate to high flows to become suspended in the water column or to move as bedload.

The U.S. Geological Survey (USGS) operates six suspended sediment stations in the vicinity of the RMV for which daily streamflow, daily mean concentration of suspended sediment, and daily suspended sediment discharge values for the stations are published in the online USGS Sediment Database (webserver.cr.usgs.gov/sediment). We used this data to generate sediment rating curves for the six stations based on the relationship between daily streamflow (cfs) and daily suspended sediment discharge (ton/day). For some stations, the data set is large enough to discern a change in the slope of the rating curve at higher flows. This change in slope indicates that suspended sediment discharge in these streams is limited by transport capacity (i.e., streamflow) at low flows and sediment availability at higher flows. It should be noted that the USGS data does not distinguish between fine and coarse sediments.

In comparing yield figures or sediment rating curves for different basins, it is important to keep in mind differences between the basins that will affect sediment yields and transport. These factors include precipitation regime, geology and soils, relief, bank and bed stability, drainage area, type of stream (i.e., alluvial or bedrock), tectonic setting, and fire and land use history of the basin.

The rating curves from the six local stations can be compared to the other stations in the region with similar underlying geology and mean annual rainfall (Figure 4). Table 1 lists several characteristics for each subwatershed considered in the sediment rating curve analysis. In general, drainages with similar physical characteristics function in a similar manner and have similar rating curve slopes. Of particular interest are subwatersheds underlain by Monterey shale which have steeply sloping sediment rating curves. This diatomaceous, chalky rock weathers quickly and yields high quantities of sediments at all flows. Very little sand is produced from this geologic type. In contrast, the crystalline bedrock sediment yield is highly episodic. At most flows crystalline watersheds will produce few sediments; however, at extremely high flows and/or after fires it yields high quantities of sediments.

Sediment-rating curves for San Juan and San Mateo Creeks fall within the lower half of the range for suspended-sediment transport rates from watersheds with similar climate, geology and land use, but are not drastically different than other watersheds in the area (Figure 4). They yield distinctly less sediment than Arroyo Trabuco; for example, during 1984[7] -- a moderately wet year – Arroyo Trabuco transported 17,200 tons of sediment, while San Juan Creek was report to yield about 3232 tons. Table 1 compares these two streams with other systems we consider to be of the same general types within the central and southern coastal mountains of within California.

Suspended sediment discharge in San Mateo Creek is less than both San Juan and Arroyo Trabuco for all measured flows. Sediment data for this station is only available for water year 1984. This was a dry year after several relatively wet years, notably 1978, 1980 and 1983. It is likely that a majority of the available sediment was removed from storage and transported down San Mateo Creek during the prior wet period leaving less available sediment in 1984. Another factor that may contribute to the lower suspended sediment discharge in San Mateo Creek is the absence of Monterey (or Monterey-type) shale and other sedimentary rocks in the drainage geology. This diatomaceous rock that underlies 10 percent of the drainage area in both Arroyo Trabuco and San Juan is known to yield high quantities of sediment as it weathers, possibly causing an upward shift in sediment rating curves in these watersheds. A third factor contributing to low levels of suspended sediment in San Mateo is the drainage area size, since sediment concentrations generally decrease with the scale of the basin. The San Mateo Creek at San Onofre station has the largest drainage area of all stations considered in this analysis.

The above discussion covers transport rates of suspended sediment, composed primarily of fine particles (medium-fine sand and smaller). Coarser grained sediments are transported primarily as bedload. Suspended sediment transport is related to bedload transport, but not necessarily linearly or predictably. The ratio of suspended sediment to bedload is primarily dependant on the type of sediment supplied to the stream. In clayey watersheds, a higher percentage of total

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[7] The most recent year during which both gages were operated by the US Geological Survey. WY1984 was a relatively dry year, with runoff about 40 percent of the long-term average on San Juan Creek.

sediment load is transported as suspended sediment than in watersheds that produce sand and gravel-sized particles.

Because of the difficulties in measuring bedload, there are fewer studies that include bedload transport rates than suspended sediment rates. Knudsen and others (1992) summarized several studies of bedload as a percent of total load for 12 major streams in central and southern coastal California. These studies suggest that bedload may constitute as little as 2 percent and as great as 60 percent of the total sediment load of the stream. Kroll and Porterfield (1969) estimated that 59 percent of the sediment transported by San Juan Creek is bedload. This is most likely an upper-bound estimate of current (2004) conditions, as gravel mining had not yet begun in the basin by that time. In 1979 and 1984, the USGS measured both suspended sediment and bedload at the San Juan gage. Percent bedload in 1979 was 49 percent, and was 31 percent in 1984. These are both lower values than for the San Mateo watershed, where USGS measurements of suspended sediment and bedload suggest that San Mateo Creek carried 50 percent of its load as bedload in 1984. Despite the variation in studies, they all suggest that the percent bedload of San Juan and San Mateo Creeks is on the high end of the range for coastal streams in central and southern California. The long-term average percent bedload for both creeks is most likely somewhere in the range of 35 to 45 percent. Within each watershed, however, percent bedload may vary significantly, with higher percentages coming from the areas producing more coarse sediment (areas of granitic and meta-volcanic rocks), and lower percentages coming from the silty-clayey terrains (underlain by the Monterey and Capistrano formations).

Kroll and Porterfield (1969) estimated long-term sediment transport for the San Juan drainage basin between 1931 and 1968, using measurements of streamflow and suspended sediment discharge, and estimates of bedload discharge. Their estimate of 1,230 tons per square mile per year is believed to underestimate the total sediment yield from the watershed because: (a) it is an estimate of the sediment that is actually transported by the streams rather than the total amount of sediment provided to them; and (b) the sediment data from which long term yields were extrapolated were collected during 1967 and 1968, two years that did not experience significant floods; and (c) throughout the Peninsular Ranges, sediment yields during this period were well below normal (c.f., Lang and others, 1998; Hecht and others, 1999; GeoSyntec, 2004). Because most sediment is moved during extreme events, such as relatively large floods, theseis last two points are is key.

4.5.1 Planning considerations for sediment transport

Urbanization within the proposed project area has been planned to anticipate and reduce the increase in sediment load typically associated with channel incision downstream from other areas of the county. Excess impervious area flow will be infiltrated and/or retained and re-used to limit increases in flow duration after development, especially at low recurrence intervals (GeoSyntec, 2004). This will reduce erosion affects typically associated with development and minimize the response of stream channels that are susceptible to incision. Also, residential areas and infrastructural corridors are generally concentrated away from the valley floors, maintaining the current sediment storage and buffering effects of the floodplain.

4.6 Bed sediment characterization

The size distribution of sediment on the bed of a channel can have a significant impact on the potential channel response following urbanization. Large, wide channels composed predominately of gravel- and cobble-sized sediment are less likely to incise than sand-bedded streams without significant gravel or cobble content. Additionally, channels that are transport limited (have a higher sediment supply than can be transported under normal conditions) have a moderate buffering effect that makes these channels less susceptible to channel response to urbanization.

Streams within the San Juan and San Mateo watersheds can be roughly divided into four different categories, based on bed sediment type affecting sediment transport, bank stability, habitat value and sensitive species use, among other considerations (Table 3, Figure 5). These categories are based on interpretation of observations made during various field studies within RMV. The categories are based on our field observations, generalized to reach-scale descriptions of bed conditions, and interpreted using regional geology and soils information. These generalizations were developed to provide a basis for the hydrology and sediment-transport modeling, as well as evaluate restoration potential and to highlight channels that are most likely to be susceptible to incision or other impacts caused by hydromodification.

The Chiquita, Gobernadora, Trampas, upper Cristianitos, and upper Gabino channels (along with several smaller tributaries of the central San Juan sub-basin) are predominantly ***sand-bedded***, with little or no gravel or cobble content in the bed material. Because of the small sediment size and corresponding lack of armoring, significant amounts of sediment are transported even at relatively low flows. Additional peak flows added to these creeks, unless mitigated through such measures as flow duration control (see GeoSyntec, 2004), could induce significant channel erosion.

Lower Gabino, La Paz, Bell, and the upper portions of San Juan, Verdugo, and Lucas creeks within or adjacent to Rancho Mission Viejo are predominately ***gravel-cobble bedded streams with coarse sand***. The coarser sediment within these streams is a direct reflection of the geologic terrain within the upper portions of the watershed, predominately composed of granitic and other crystalline metavolcanic rocks. Because of the larger bed-sediment size and bed structure within these creeks, the bed is mobilized much less frequently than in sand-bedded streams. The coarser bed allows the drainage to accept some additional flow and coarse sediment without significant channel response. In addition, the gravel/cobble-bedded streams are generally more dynamic systems than the sand-bedded channels, showing a greater morphological response to episodic events.[8] Because gravel-cobble beds tend to be stable at the size of storms most affected by urbanization[9], the effects of urbanization will be least evident and least significant in gravel-cobble bedded channels.

The portion of the San Juan Creek channel downstream from the Gobernadora Canyon confluence, and Cristianitos Creek downstream of the Gabino confluence, is generally composed of ***sand with significant gravel and cobble content.*** The bed in these reaches is finer than it is further upstream, for many and complex reasons. This sandier bed will mobilize more often than the bed sediment upstream, and will be more rapidly refilled or replenished. Lower Verdugo and lower Lucas Canyons also have a higher percentage of sand on the bed, probably due to local contributions from the sandy bedrock in the lower portions of those watersheds, and decreases in channel slope. While these reaches are likely to show a slightly greater channel response to urbanization than the cobble/gravel bedded streams, due to the sandier bed, they are dominated by dynamic transport processes typical of cobble/gravel streams, and maintain significant buffering capacity.

The San Juan creek channel upstream of Gobernadora Canyon has a ***compound bed,*** with moderately-resistant bedrock exposed in several places along San Juan Creek between the mouths of Verdugo and Gobernadora Canyons. Some of the larger outcrops are shown on the state geologic maps (Morton, 1974); others are distributed throughout this reach. The bedrock

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[8] While Southern California streams with cobble-gravel beds vary in the frequency of channel-changing episodic events, an average of 6 to 10 such events per century (or about an average interval of 10 to 15 years) may be typical. As one example, a careful examination of 200 years of records at the San Buenaventura mission showed 're-sets' of the Ventura River streambed to occur at average intervals of 11 years (Capelli and Keller, 1992). We suspect that similar frequencies may occur in the project area.

[9] While the maximum effects of urbanization vary with catchment size and drainage density, the current literature indicates that proportionate and absolute effects of urbanization are associated with lower-recurrence events – perhaps on the order of 0.25 to 2.5 years – and decrease rapidly with events of 5 to 10 years, to being difficult to discern at recurrences exceeding 25 to 50 years (c.f., GeoSyntec, 2003).

outcrops, together with the larger cobbles introduced from Verdugo and Bell Canyons, significantly limit potential downcutting in this portion of San Juan Creek such that this reach merits its own designation. Additionally, it has a complex history of aggregate mining during the 1970s and 1980s (c.f., Vanoni and others, 1980).

4.7 Comparing post-project with existing sediment yields

Sediment delivery to and movement within the main channels can be compared using information developed for the Baseline Conditions Report (PCR and others, 2001), the analyses and aerial photographs presented in the Watershed and Sub-Basin Planning Principles investigation, prior data and observations considered in this report, and the sediment-production discussion in the recent PWA report (Stewart and others, 2004). The comparisons are made on the basis of (a) sediment transported during the 2-year and 100-year events, as simulated by Huitt-Zollars (2004) and PWA (2003), (b) the coarse sediment fraction transported during such events, and (c) the capability of the watersheds to sustain the episodic sediment delivery considered key for several species, as well as channel stability and coarse-material supply to the beaches. Results are presented in Table 4.

Using data from the Baseline Report, the table identifies the basins where transport is presently limiting, where changes in peak flows or volumes are most likely to result in increased sediment yields. Other basins are limited by supply, and are most likely to exhibit significant change when yields (especially coarse-sediment yields) increase or decrease. Estimated long-term average sediment yields developed in the Baseline Report are cited for reference. Sediment-delivery ratios were estimated for this report based on our interpretation of aerial photographs available for different years. Emphasis was placed on 1938 because of the high-recurrence event (probably 30 to 40 years) which occurred during that year. Since the channels were rarely obscured by woody vegetation, it was possible to identify in the aerial photographs those portions of each drainage that were contributing coarse sediment to the main streams.[10] The proportion of coarse sediment in each channel was taken as the bedload percentage (sediment coarser than 0.25 mm) from the Baseline Report.

To estimate the contribution of coarse and fine sediment produced under the normal conditions, we used:

- the MUSLE modeling developed by PWA staff (Stewart and others, 2004),

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[10] We used original aerial photographs from various years under stereoscopic magnification. Several of the key 1938 photographs are reproduced in the Watershed and Sub-Basin report.

- the sediment delivery ratios from Table 4, and
- the bedload proportion of sediment yield from the Baseline Report.

We computed the coarse and fine sediment changes resulting from the project for both the 2- and 100-year events, based on estimated potential sediment production rates modeled by PWA. Coarse sediment yields change by relatively minor amounts when comparing existing and post-construction conditions, commonly less than 15 tons per 2-year event, and less than 250 tons per 100-year event. Larger changes are expected in San Juan Creek upstream of Gobernadora (to Verdugo), and in Talega Creek. Anticipated construction-period increases in sediment yields (without mitigation) are more substantial. Potential construction-period increases in lower Chiquita, central San Juan, Lower Gabino/Blind, and possibly Talega creek watersheds call for greater care and attention for both the 2- and 100-year event, and upper Cristianitos and lower Gabino/Blind creeks seem to warrant special care for the 100-year event. In all cases, the changes are of a magnitude amenable to mitigation and adaptive management.

In many hilly or mountainous areas in Southern California, episodic delivery of sediment to the channel is essential for maintaining the supply of the coarsest materials which often anchor or armor the bed, as well as sustaining beach-material supplies and conditions essential to the long-term viability of several species of concern. The finding that the LAD sediment model yields results 137 to 200 percent higher than the MUSLE formula in Orange County (see section4.4.2) implies that episodic events can account for perhaps 30 to 50 percent of the long-term sediment yield, and perhaps a slightly larger proportion of the largest material making up the bed of the streams. Table 4 shows the likely contribution from episodic events to the sediment yields of each basin,[11] and finds that nearly all watersheds and sub-basins will retain most or nearly all of their episodic sediment inputs because the key slopes yielding the coarse sediment will be left largely undisturbed. For example, the 1938 photographs show that the majority of the coarse sediment reaching the Gobernadora Creek came from the western side of the canyon (the sediment from the east side was deposited on the side-canyon floors or on the floodplain). The western portion of the canyon will remain as designated open space, maintaining coarse-sediment continuity to the creek.

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[11] Based on aerial photographs taken shortly after the 1938 storm (one of the three largest floods of the 20th century); observations made after the 2002 fire in upper Chiquita and the reports of Fife (1959); and substantial field work, including characterizing and tracing the sources of coarse clasts in exposed bank material along channels throughout the project area.

4.8 Sustaining grade and base level

As part of the project plan, detention basins have been proposed as a mitigation measure for, attenuating peak flows, reducing sediment transport, and treatment of runoff for water quality. Sound watershed-management practice when implementing sediment/detention basin management practices calls for addressing the 'hungry water' effect downstream of the basin. In many situations, sediment-depleted water is discharged from the detention basin into a high energy environment, allowing the clean water to erode the channel directly below the discharge point. In the proposed project, both (a) energy dissipation and (b) measures to sustain channel base level will be incorporated downstream from sediment detention basins and other hydraulic controls to sustain grade and to provide a stable base level.

The project design greatly simplifies sustaining grade downstream from controls because, with very minor exceptions, ponds and detention basins or other controls are being proposed only for minor streams and unchanneled drainages. Since the:

- control structures are small (conforming with RWQCB guidance to 'start at the source' to alleviate conditions of concern), small and site-appropriate measures can be used to maintain the existing channel pattern and grade,
- storm runoff is to be regulated to emulate the existing hydrographs and runoff-duration frequencies, the tributary and stream system is not being used to absorb the increased peak runoff during frequent storms, and the processes causing 'hydromodification' impacts in other Southern California channels are not expected to necessarily induce incision or widening,
- buffers from channels are generally quite wide, minimizing the number of structures in the channels and maximizing the drainage system's tolerance for changes in channels, and,
- infrastructure (such as sewage mains) are not located in or near the channels, minimizing the need for protective structures,

we conclude that effects of hungry water will be limited in magnitude and potential impact. Additionally, the volume and magnitude of peak runoff in most protected canyon or valley-floor areas will be equal to or less than that at present, because some flows are being directed to the relatively resilient San Juan Creek and lower Gabino channels. The intrinsic resilience of these larger channels – which have a very similar channel form as that reflected in 1938 aerial photographs or 1947 topographic maps (PCR and others, 2001) – is coupled with the proportionately smaller project-related discharges to minimize hungry-water effects on these two channels. In addition, these larger watersheds are inherently more dynamic systems than the side canyons, and better able to modulate the effects of any slight downstream erosion that may occur.

Most of the limited 'hungry-water' effects are amenable to being addressed with non-structural biotechnical and geomorphic approaches. These approaches vary by terrain (see section 3.1 for discussion of terrains) and the character of the channels:

1. *Sandy and Silty-sandy terrain*: Water quality and infiltration basins and ponds will be constructed along unnamed tributary channels and channel-less valleys. Appropriate energy dissipation will be installed downstream of each structure or control point. In addition to the curve-matching regulation of runoff described in the Water Quality Management Plan (GeoSyntec, 2004), 'hungry water' or potential downcutting will be controlled by a progressive sequence of:

    a. establishment of hydrophytic vegetation, either turf-forming (such as salt grass or sedges) or with interpenetrating roots (such as willows); then

    b. placement of turf-reinforced mats (TRMs) or other flexible and biodegradable membrane to abet vegetative growth to stabilize the small drainages downstream of controls; then,

    c. installation of conventional erosion-control fabrics and structures using standard techniques developed over the years to control gully- or small-channel incision.

    In through-flowing named stream corridors, the potential scale of incision is larger, and is most reasonably addressed by a progressive sequence to include:

    a. attempting to reduce runoff volumes and peaks from the watershed, by a combination of additional retarding of flow and use of (reconnecting, where needed) floodplains for flows of moderate to high recurrence.

    b. reducing sediment yields from a disturbed watershed upstream, such that avulsion (sudden channel changes, such as recently seen in Gobernadora Creek) can be minimized.

    c. widening the riparian corridor where the bed remains within the root zone of riparian vegetation, and managing its vegetation to promote dense interpenetrating roots, such as naturally occurs along many reaches of these streams, perhaps in combination with

d. reconfiguring the channel pattern to increase sinuosity to a stable thalweg length-to-channel slope value (c.f., Riley, 2003, for one approach supported by the Regional Boards).

e. emplacing well-keyed structural grade control, with a wide variety of potential designs; the sheet-pile structures along lower Wagon Wheel Creek are one example.

2. *Clayey terrain:* Differences between existing and future conditions will be the least in this terrain. Silty and clayey terrains are also most resistant to incision, in most cases. Hence, biotechnical stabilization is most favored in this setting, especially for the smaller unnamed channels downstream from the small retarding and infiltration basins proposed at many locations. A progressive sequence of:

   a. establishing hydrophytic or woody riparian vegetation, especially along the bases and crests of banks;

   b. installating turf-reinforcing mats and other shear-resistant soft structures;

   c. slight widening of channels where feasible without diminishing bank strength imparted by riparian vegetation, if significant;

   d. engineering slopes using fabrics, or placing thoroughly-keyed structural controls, usually in combination with a., b., and c., above.

3. *Crystalline terrain:* No new impoundments or runoff control structures are planned for crystalline terrain. The County of Orange design manuals are perhaps most effective in this terrain type, and can serve as a backup guidance, should impoundments be planned for areas within the crystalline terrain.

The stream reaches below the detention basins will be included in the adaptive management plan, to monitor channel stability and change the protocol if necessary. The various controls listed above will be used as necessary based on monitoring of downstream channel stability.

5. ADAPTIVE MANAGEMENT

The uncertainties inherent in sediment transport and bed sedimentation make regular and routine monitoring of potential project effects an integral portion of the project's adaptive management plan (AMP). To provide a flexible, iterative approach to long-term management of bed and channel conditions, nine questions should be addressed, and responsive measures recommended based on standard, conventional and understandable methods:

1. Are low flows being maintained at appropriate levels, sufficient to sustain the woody vegetation critical to maintaining root strength for channel stability?
2. Are peak flows being adequately controlled by the project?
3. Are the channels incising or otherwise changing their morphology or slope in response to urbanization?
4. Are new natural or induced sources of sediment forming in upland areas?
5. Are ponds and sediment basins functioning, and do they need to be maintained?
6. Is incision or channel distress observed downstream of ponds and basins?
7. Are there indications that sand movement to the beaches has been impaired?
8. Are other watershed events or processes contributing substantively to changes, if any?
9. Are bed conditions in the channels consistent with (a) aquatic and riparian habitat needs, (b) maintaining sufficient conveyance capacity to convey design flows, and (c) reasonable bank protection?

Methods to be used in assessing these questions and situations in a manner intended to promote design solutions are described in the following sections.

5.1 Stream walks

A geomorphologist or engineer familiar with both (a) flood conveyance estimation and (b) the bed conditions required to meet habitat needs and conditions for species of concern will walk critical reaches of named channels within the project each year in late April. The stream-walker will note bed conditions, measure high-water marks, note new sources of sediment or bank distress along the channels, estimate Manning's 'n' (roughness) at key locations, and assess whether bed and bank vegetation is suitable to meet conveyance and habitat objectives. Stream walks will occur during years 1,2,3,4,5 and 10 following substantial grading in a named-stream basin, and during any year within the first 10 seasons when 6-hour rainfall intensities exceed the 5-year recurrence at a nearby pre-selected recording rainfall gauge. The stream-walker will also similarly canvass the lower 2 miles of Bell Canyon and the upper Chiquita watershed north of Oso Parkway, two stream segments with largely-intact and formally-preserved watersheds, which can serve as control. Photographs showing key sites or problems will be taken. The individual conducting the walks shall be sufficiently senior and knowledgeable as to be registered as a geologist or engineer with the state. This individual will prepare an annual report by June 20, and submitted to Rancho Mission Viejo for distribution to appropriate agencies, specifying maintenance or repair measures needed to maintain suitable sediment transport and bed conditions. (Directed at questions 1, 2, 3, 6, 7, 8, 9)

5.2 Major stream cross sections

Monumented cross sections will be established and surveyed on:

a) lower Narrow Creek
b) Chiquita Creek (4 locations)
c) Gobernadora Creek (4 locations)
d) Bell Creek (2 locations)
e) Upper Cristianitos Canyon (3 locations)
f) Lower Gabino Creek (3 locations)
g) Gabino Creek within 0.5 miles of La Paz Creek
h) La Paz Creek within 0.6 miles of Gabino Creek

The cross sections will be spaced approximately 0.6 to 1.2 miles apart. They will be surveyed to the nearest 0.05 feet vertical, and include notations of bed material encountered and qualitative descriptions of vegetation, and other observations conforming to geomorphic conventions, such as the International Hydrologic Vigil Network standards. The initial surveys will be conducted prior to grading, with resurveys during years 1, 3, 5 and 10 following initial grading. Re-surveys will also be conducted during years when 6-hour rainfall intensities exceed the 5-year recurrence at a nearby pre-selected recording rainfall gauge. Results will be analyzed by the stream-walker, and included in the related report, recommending maintenance and restorative measures. The report will be submitted by May 20 of each year, to allow design and implementation (where needed) prior to the next winter. (Directed at questions 3, 6, 8 and 9)

5.3 Periodic aerial photography

Aerial photographs of the entire project area will be taken during May or June following project approval, and during each subsequent May or June of years ending in a '5' or '0', until the project has been completed. Resolution of the photographs will be sufficient to prepare 200-foot scale maps with 2-foot (or 0.5-meter) contours. Contour maps will be prepared for the San Juan Creek channel corridor from the Verdugo Canyon confluence to 0.5 miles downstream of Antonio Parkway showing the topography of the bed and of the banks to elevations 15 feet above the adjoining bed. Lidar or other technologies can be substituted for now-conventional photogrammetric methods. A qualified geomorphologist shall review the aerial photographs of the entire project area, identifying new upland sources of sediment, event-related or land-use disturbance, or evidence of channel change and instability. The geomorphologist will also assess discontinuities in sand transport throughout the project area, and will present an assessment of changes, if any, in the San Juan Creek corridor. Results will be presented in a report to be prepared by July 15 of each year to Rancho Mission Viejo for distribution to appropriate parties, including recommendations for maintenance, repair, or other actions. (Directed at questions 1, 3, 4, 5, 6, 7 and 9, plus 8 for San Juan Creek)

5.4 Evaluation of changes downstream of ponds and basins

Longitudinal profiles and channel or drainage-way cross sections will be established downstream of basins or ponds with capacities exceeding 1 acre foot, or which create a 4-foot elevation change in the energy grade line. Resurveys will occur whenever the stream-walker and/or the geomorphologist reviewing the aerial photos identify actual or incipient incision or erosion. Resurveys will be completed prior to July 1 when and where the need is identified in the May 20 report discussed above.

5.5 Supplemental assessments

Adaptive management of channels means changing with the flow of time. Nothing in the program above precludes problem- or condition-related investigations. Additional assessments may be conducted as deemed needed by the applicant to achieve the bed and bank conditions sought. Examples of circumstances in which supplemental investigations might be needed might include:

- A large landslide affecting one of the main channels.
- A large fire disturbing major portions of the contributing watershed

- Loss of riparian vegetation over long reaches due to tree blight or other cause.
- Bank and channel changes due to a major seismic event.
- Identification of new needs of species of concern.

While interdisciplinary expertise is warranted throughout the adaptive management program, it is likely to be especially warranted in such supplemental assessments.

6. CONCLUSIONS

This report describes potential changes in sediment supply, transport, and bed conditions associated with forthcoming urbanization of the San Juan and San Mateo watersheds. Consistent with its origin in work developed for the Special Area Management Plan (SAMP) and for the NCCP, it is the first sediment and sedimentation report submitted to Orange County which incorporates and balances sedimentation goals associated with (a) flood control and channel stability, (b) endangered species habitat stewardship, and (c) wetlands and stream channel permitting for habitat preservation and protection. All such goals must be weighted, consistent with the General Plan review, the NCCP guidelines, and the SAMP process. It is not possible to properly evaluate sediment conditions or movement without weighing all three sets of considerations.

The following conclusions tie together some of the most important aspects of the project planning goals as they relate to sediment transport:

1. A MUSLE analysis by PWA, responding to a request from Orange County, is a useful index for estimating potential changes in sediment production during, and following, development of the watershed. However, several other factors, such as particle size, episodicity, and habitat needs, must be considered to provide a more complete and balanced view of how sediment production and transport processes may be affected by the proposed development.

2. Maintaining the supply of coarse sediment to the stream corridors and downstream areas is important for habitat value and beach sediment supply. There are two primary sources of coarse sediment within the San Juan and San Mateo. The first is a chronic or regular sand source, sand that is supplied to the beach by stream transport on a yearly basis. Between storms, this sand is stored in channel and floodplain alluvial deposits and is mobilized during the largest events of the year. The ultimate source of much of the coarse sediment in the San Juan and San Mateo watersheds is the coarse-grained soils formed on granitic and metavolcanic rocks exposed in the upper portions of the watersheds. These areas contribute coarse sediment primarily on an episodic basis, in response to large storms and/or after watershed-scale wildfires.

3. Reducing upland sources of fine-sediment supports habitat needs of several sensitive species. The most significant sources of fine sediment are currently areas of non-native vegetation, the Gabino/Cristianitos clay pits, the debris slides in upper Gabino, and sediment derived from channel incision in the upper Gobernadora watershed.

4. Episodic sedimentation is usually important to maintaining streambed conditions, of particular importance in sustaining habitat values and the bed mosaic required by least Bell's vireo, arroyo toad, and other species of concern. Episodes are also vital to maintaining a mix of open channel and vegetated banks most likely to convey high flows with minimum bank erosion or channel disturbance.

5. Measured sediment transport in San Juan Creek is similar to or somewhat less than transport measured in other coastal California watersheds with similar underlying rock types and geologic histories. Observed rates at both high and low and low flows are neither remarkably high nor low. Transport rates in San Mateo Creek are at the lower end of the range for such streams. Sediment yields per unit area of watershed in the San Juan Creek catchment are higher than those in the San Mateo watershed, principally because the underlying geologic units in the San Mateo basin are intrinsically less erosive. Similarly, sediment yields from the clay-rich watershed of Arroyo Trabuco are substantially higher than in San Juan Creek, and dominate the sediment regime downstream of their confluence. Estimates of the bedload portion of the total sediment transport indicate that both San Juan and San Mateo Creeks have a relatively high portion of bedload compared to other coastal streams in southern California.

6. This report reflects important decisions made *prior to project design* which minimize and modulate sediment delivery of fine sediments under normal conditions, but also makes allowances to promote transport of beach sands and to maintain the episodic renewal of stream substrate intrinsic to maintaining healthy populations of several sensitive specials.

   The following is a summary of how the approach to siting urban areas within the proposed project has been planned to maintain and/or improve existing sediment supply:

   - Development areas were planned such that much of the urban areas will be concentrated on clayey terrain to minimize the effect of adding impervious area to the watershed, and reduce fine sediment generated from these areas. Adaptive management of tilling and grazing practices, along with native vegetation restoration in some areas, will also reduce the introduction of fine sediment to the stream channels, which would have beneficial impacts to in-stream and riparian habitat.

- Sandy valley bottoms will remain relatively free of urban impacts, allowing the supply of coarse sediment to the stream channels to be maintained.

- Mainstem stream corridors will remain intact, retaining current floodplain sediment storage and buffering effects (and associated habitat value), as well as maintaining a significant source of beach sand supply and allowing transport of sediment from the upper watershed areas.

- The urban planning areas are placed so that they minimize covering the main sources of coarse sand and gravel, which are important for year-to-year beach sediment supply. The ultimate source of much of this coarse sediment is in the granitic/crystalline terrain in the upper portions of the San Juan and San Mateo watersheds, east of the areas slated for urbanization. The continuity of these upland episodic coarse sediment sources to the beaches that they supply will be maintained by limiting urbanization within the mainstem alluvial valley bottoms, maintaining current transport capacity and sediment storage areas for chronic supply.

- The B4 alternative allows for some episodic sedimentation to persist by leaving at least one whole side of the Chiquita, Gobernadora, Verdugo, Cristianitos, Gabino, and La Paz watersheds with slopes fundamentally free of urbanization or infrastructure. Not only will sediment continue to naturally enter these channels during (and following) episodic events, but the lack of infrastructure makes it easy to managing these areas as open areas with continuing episodic contributions of sediment.

- Managed restoration of native riparian vegetation will increase bank stability of the streams and increase the buffering capacity of the channels for both flow and sediment. This restoration will be especially important downstream of water quality, detention, sediment, and flow duration basins, as these reaches may particularly susceptible to channel erosion due to sediment starving. These reaches will be adaptively managed so that additional channel stabilization measures can be implemented, if needed.

7. We computed the coarse and fine sediment changes resulting from the project for both the 2- and 100-year events, based on estimated potential sediment production rates modeled by PWA. Coarse sediment yields change by relatively minor amounts when comparing existing and post-construction conditions, commonly less than 15 tons per 2-year event, and less than 250 tons per 100-year event. Somewhat larger changes are expected in San Juan Creek upstream of Gobernadora (to Verdugo), and in Talega Creek. Anticipated construction-period increases in sediment yields (without mitigation) are more substantial. Potential construction-period increases in lower Chiquita, central San Juan, Lower Gabino/Blind, and possibly Talega creek watersheds call for greater care and attention for both the 2- and 100-year event, and upper Cristianitos and lower Gabino/Blind creeks seem to warrant special care for the 100-year event. In all cases, the changes are of a magnitude amenable to both mitigation and adaptive management.

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TABLES

Table 1. Watershed characteristics and periods of record for suspended sediment rating curves of selected streams in Orange County and comparison areas

USGS Gaging Station ID#	Station Name	Drainage Area (sq. mi.)	Period of Record (water years)	Equation of Rating Curve[6]	Geology[2]	SLA Station[1]	10 yr Peak (cfs)	Annual Rainfall (inches)	Comments
11046370	San Mateo Creek at San Onofre	132	1984	$y=0.0022*Q^{2.2133}$	50% Ku&T SS, 50% CR	--	--	19(3)	dry year after wet period
11046500	San Juan Creek nr San Juan Capistrano	106	1967-71	$y=0.0031*Q^{2.6391}$ & $y=0.2209*Q^{1.6346}$	10% Monterey SH, 50% Ku&T SS, 40% CR	CSJ4	6700	20(3)	WY1966 & 1968 very wet
11046530	San Juan Creek at La Novia Bridge	109	1987-88	$y=0.026*Q^{2.5628}$	10% Monterey SH, 50% Ku&T SS, 40% CR	CSJ5	6800	20(3)	WY 1987 & 1988 very dry
11046550	San Juan Creek at San Juan Capistrano	117	1971-86	$y=0.0139*Q^{2.038}$ & $y=0.04*Q^{1.8472}$	10% Monterey SH, 50% Ku&T SS, 40% CR	CSJ6	7100	20(3)	
11047000	Arroyo Trabuco at Camino Capistrano	36	1967-68	$y=0.0685*Q^{2.0065}$ & $y=0.1799*Q^{1.7093}$	10% Monterey SH, 50% Ku&T SS, 40% CR	CTB5	2500	19(3)	WY 1968 very wet
11047300	Arroyo Trabuco at San Juan Capistrano	54	1971-84	$y=0.0406*Q^{2.331}$	10% Monterey SH, 50% Ku&T SS, 40% CR	CTB6	5200	19(3)	
11138500	Sisquoc River near Sisquoc	281	1962-81	$y=0.01*Q^{2.04}$ & $y=0.14*Q^{1.75}$	100% Ku&T SS	--	--	16(4)	
11139350	Foxen Creek near Sisquoc	16.8	1968-73	$y=0.21691*Q^{2.66}$	100% Ku&T SS	--	--	16(4)	incising
11139500	Tepusquet Creek near Sisquoc	28.7	1968-72	$y=0.00075*Q^{2.75}$	99% Monterey SH	--	--	16(4)	
	Potrero Creek[5]	5	1991-93	$y=0.0458*Q^{2.0846}$	50% Monterey SH, 50% CR	--	--	20(3)	

Notes:

1. 10 year peak discharges were measured or estimated for several stations in the San Juan watershed (Simons, Li & Associates, 1999).
2. Percentages are visual estimates from surficial geologic maps. Ku&T: Cretaceous and Tertiary, SS: sandstone, SH: diatomaceous shale of the Monterey formation, CR: crystalline bedrock.
3. Mean annual rainfall for the drainage area estimated from isohyetal maps.
4. Mean annual rainfall record from 1948-1997 at Los Alamos NCDC station.
5. Data from Hecht and Napolitano (1995); Kondolf (1983).
6. y = suspended sediment.

Table 2. Comparison of sediment yield estimates for select watersheds in Orange County and surrounding areas.

Watershed	County	Author	Dominant Substrate Type	Method	Time Period	Sediment Yield (tons/yr/square mile)	Comments
San Juan	Orange	Kroll and Porterfield	crystalline and sedimentary	rating curve applied to gaging record	1931-1968	1230	based on measurements taken during 1967-1968
San Juan	Orange	Taylor	crystalline and sedimentary	calculated denudation rate	--	2500-6000	highest in mountainous areas, lower in foothills
San Juan	Orange	SLA	crystalline and sedimentary	LADB	--	4350-6850	indicated range is Q25-Q50 with no burn
San Juan	Orange	SLA	crystalline and sedimentary	MUSLE	--	3000-5000	indicated range is Q25-Q50
Arroyo Trabuco	Orange	SLA	crystalline and sedimentary	LADB	--	5700-9950	indicated range is Q25-Q50 with no burn
Arroyo Trabuco	Orange	SLA	crystalline and sedimentary	MUSLE	--	3000-5500	indicated range is Q25-Q50
San Diego	Orange	OCPFRD	crystalline and sedimentary	sampled sediment transport	1983-1998	1800	suspended sediment only
San Diego	Orange	OCPFRD	crystalline and sedimentary	debris basin sediment removal	1983-1998	395	low trap efficiency
Santa Ana	Orange	Kroll	crystalline and sedimentary	rating curve applied to gaging record	1941-1971	322	based on measurements taken during 1968-1971
Santa Maria	Santa Barbara	Kroll	sedimentary	rating curve applied to gaging record	1941-1971	356	based on measurements taken during 1968-1971
Los Penasquitos	San Diego	Prestegaard	sedimentary	debris basin sediment removal	NA	967-1194	author cites low trap efficiency and short time interval
Santiago Creek	Orange	Irvine Ranch Water District	crystalline and sedimentary	long term accumulation in Santiago Reservoir	1938-2000	6800-10800	may underestimate yields due to sand and gravel operations upstream

Table 3. Generalized bed conditions of major drainages in the San Juan and San Mateo watersheds, Orange County, California.

Subbasin		Reach name (or location)	Bed type	Habitat attributes[1]	Stability factors	Sediment modeling reaches[2]
San Juan Watershed						
	Central San Juan	below Gobernadora	sand/gravel/cobble	rapidly shifting bars; suited for arroyo toad; locally problematic arundo growth	channel is reported to be transport limited (USACOE, 1990); base level has lowered during past 50 years	SJ1, SJ2, SJ3
		above Gobernadora	cobble/gravel and coarse sand over bedrock	high gravel environment; arroyo toad present where water is available	exposed bedrock establishes baselevel; prior gravel mining in some portions of the channel	SJ4
	Chiquita	Chiquita Canyon	medium-fine sand, gravel rare or absent	gravel absent; no arroyo toad; suitable for least Bell's vireo.	riparian vegetation; locally, cohesive bed	CH1, CH2, CH3, CH4, CH5, CH6
	Gobernadora	Gobernadora Canyon	medium-fine sand, gravel rare or absent	gravel absent; no arroyo toad; suitable for least Bell's vireo and SW willow flycatcher	baselevel established by interpenetrating riparian roots	G01, GO2, GO3, GO4, GO5, GO6, GO7, GO8, GO9
	Unnamed; informally, Chiquadora Creek	Between Chiquita and Gobernadora Canyons	medium-fine sand, gravel rare or absent	sand; cobble in lower 400 m; no summer water, and very narrow; no arroyo toad	riparian vegetation; intermittent bedrock outcrops; incising in lower reaches to lower San Juan Cr level	NW1, NW2
	Unnamed tributary west of Trampas		medium-fine sand, gravel rare or absent	sand with minor gravel	incising to meet lower San Juan Creek level	SW1, SW2
	Trampas	Trampas Canyon	medium-fine sand, gravel rare or absent	sand with little or no gravel	incising below root zone of riparian vegetation downstream of glass-sand sediment pond	TR1, TR2, TR3
	Unnamed tributary near citrus orchard	West of Gobernadora Canyon	medium-fine sand, gravel rare or absent	sand over narrow cobble-gravel bed; very narrow (no arroyo toad)	cobbles, riparian vegetation	NE1, NE2
	Bell	Bell Canyon	cobble/gravel	shifting bars; widely suitable for sensitive species	abundant cobbles; lower reaches steepening to meet lower San Juan Creek level	BE1, BE2, BE3, BE4, BE5, BE6
	Verdugo	lower Verdugo	sand/gravel/cobble	widely suitable for sensitive species	woody riparian vegetation, cobble bars	VD1, VD2, VD3
		upper Verdugo	cobble/gravel/coarse sand	widely suitable for sensitive species	woody riparian vegetation, debris jams, cobble bars	VD4
	Lucas	lower Lucas	sand/gravel/cobble	disturbed bed in places	substantial road and other disturbance	LU1, LU2
		upper Lucas	cobble/gravel/coarse sand	gravel and cobble bars and relatively sparse riparian vegetation	woody riparian vegetation, cobble bars	LU3
San Mateo Watershed						
	Gabino	Lower Gabino, below La Paz	cobble/gravel/coarse sand	high gravel environment; arroyo toad present	large bedload; bed mobilized only occasionally	GA1, GA2
		Upper Gabino	medium-fine sand, gravel rare or absent	gravel absent; arroyo toad not reported	mainly riparian vegetation; cobble bars locally critical; local bedrock	GA3, GA4, GA5
	Cristianitos	Upper Cristianitos	medium-fine sand, some gravel and cobble	shifting bed; arroyo toad not reported; narrow and incised	incised below root zone; gravel bars, some cobble bars, with some near-channel woody riparian veg	CR1, CR2, CR3
		Lower Cristianitos	sand/gravel/cobble	sand, gravel, and cobble bed	dominant cobble/gravel bed structures	
	La Paz	La Paz Canyon	cobble/gravel/coarse sand with boulder bars	high gravel environment; arroyo toad present	largest bed material; bed mobilized only occasionally	LP1, LP2, LP3

Sources:

[1] PCR Services Corporation, 2002; Dr. Pete Bloom, unpublished

[2] PWA Ltd, 2004

Table 4. Comparison of existing, construction period, and post-construction sediment yields, Rancho Mission Viejo, southern Orange County, California. Sediment yields have been adjusted to local conditions and processes based on the Baseline Report, aerial photograph analysis, and field observations.

			San Juan Watershed								San Mateo Watershed			
		Source of Data	**Chiquita**			**Gobernadora**[6]	**Verdugo**	**Central San Juan**			**Upper Cristianitos**	**Upper Gabino**	**Lower Gabino/ Blind**	**Talega**
			Upper	Lower[5]	**Total**			**(lower)**	**(upper)**[7]					
	Basin Parameters													
	Drainage Area (sq. mi.)	*Baseline Rept*[1]	*4.57*	*4.64*	9.21	3.39	4.79	4.59	7.41		3.66	5.02	3.28	8.37
	Sub-basin number	*PWA,2004*	*31*	*8*	--	63	9	21	13		45	49	48	47
	Transport Limited By	*Baseline Rept*[1]	*supply*	*supply*	supply	supply	transport	supply	supply		supply	supply	transport	transport
	Estimated Average Annual Sediment Yield (t/sq mi)	*Baseline Rept*[1]	*3060*	*3060*	**3060**	**2918**	**3131**	**2500**	**3000**		**3416**	**2989**	**2989**	**2775**
	Estimated Sed. Delivery Ratio from 1938	*photointerpretation*[2]	*0.15*	*0.20*	**0.17**	**0.10**	**0.45**	**0.15**	**0.25**		**0.25**	**0.35**	**0.30**	**0.45**
	Estimated Bedload Proportion of Sed Yield	*Baseline Rept*[1]	*0.10*	*0.05*	**0.08**	**0.05**	**0.50**	**0.25**	**0.25**		**0.10**	**0.15**	**0.55**	**0.30**
2-Year Event	**Total sediment production (tons), MUSLE Model**	*PWA, 2004*												
	Existing Conditions		*1978*	*1033*	3011	2099	1317	380	1056		297	1053	271	2327
	Construction Period		*2757*	*3320*	6077	6268	1666	772	6820		1435	1276	1991	5858
	Post-Construction Period		*1403*	*511*	1914	1418	1305	383	587		245	1042	192	2031
	Estimated coarse sediment yield (tons)[3]													
	Existing Conditions		*30*	*10*	41	10	296	14	66		7	55	45	314
	Construction Period		*41*	*33*	83	31	375	29	426		36	67	329	791
	Post-Construction Period		*21*	*5*	26	7	294	14	37		6	55	32	274
	Change in coarse sediment yield (post-constr.)		*-9*	*-5*	**-15**	**-3**	**-3**	**0**	**-29**		**-1**	**-1**	**-13**	**-40**
	Estimated fine sediment yield (tons)[4]													
	Existing Conditions		*267*	*196*	471	199	296	43	198		67	313	37	733
	Construction Period		*372*	*631*	950	595	375	87	1279		323	380	269	1845
	Post-Construction Period		*189*	*97*	299	135	294	43	110		55	310	26	640
	Change in fine sediment yield (post-constr.)		*-78*	*-99*	**-172**	**-65**	**-3**	**0**	**-88**		**-12**	**-3**	**-11**	**-93**
100-year event	**Total sediment production (tons), MUSLE Model**	*PWA, 2004*												
	Existing Conditions		*25830*	*18975*	44805	29441	28453	4105	25440		4970	16221	3931	34654
	Construction Period		*36000*	*60997*	96997	87922	35999	8327	164239		24033	19648	28905	87263
	Post-Construction Period		*20901*	*7849*	28750	15587	28368	3948	7744		3766	15375	2575	28501
	Estimated coarse sediment yield (tons)[3]													
	Existing Conditions		*387*	*190*	609	147	6402	154	1590		124	852	649	4678
	Construction Period		*540*	*610*	1319	440	8100	312	10265		601	1032	4769	11781
	Post-Construction Period		*314*	*78*	391	78	6383	148	484		94	807	425	3848
	Change in coarse sediment yield (post-constr.)		*-74*	*-111*	**-218**	**-69**	**-19**	**-6**	**-1106**		**-30**	**-44**	**-224**	**-831**
	Estimated fine sediment yield (tons)[4]													
	Existing Conditions		*3487*	*3605*	7008	2797	6402	462	4770		1118	4826	531	10916
	Construction Period		*4860*	*11589*	15170	8353	8100	937	30795		5407	5845	3902	27488
	Post-Construction Period		*2822*	*1491*	4497	1481	6383	444	1452		847	4574	348	8978
	Change in fine sediment yield (post-constr.)		*-665*	*-2114*	**-2511**	**-1316**	**-19**	**-18**	**-3318**		**-271**	**-252**	**-183**	**-1938**
	Proportion of episodic coarse sed yield[8]	*this report*	*>40%*	*40%*	>40%	>40%	>40%	20	30		40	30	40	30
	Episodic component retained after construction[9]	*this report*	*Most*	*Most*	most	most	nearly all	most	some		most	nearly all	nearly all	nearly all

Notes

[1] See Baseline Report, Sec. 3.5 ff (PCR, PWA, and Balance Hydrologics, 2001)

[2] Based on photointerpretation of May and June 1938 aerial photographs by Balance Hydrologics staff.

[3] Equals the total sediment yield * sediment delivery ratio * bedload proportion of sediment yield

[4] Equals the total sediment yield * sediment delivery ratio * (1 - bedload proportion of sediment yield)

[5] Includes portions of several small watersheds draining directly to San Juan Creek

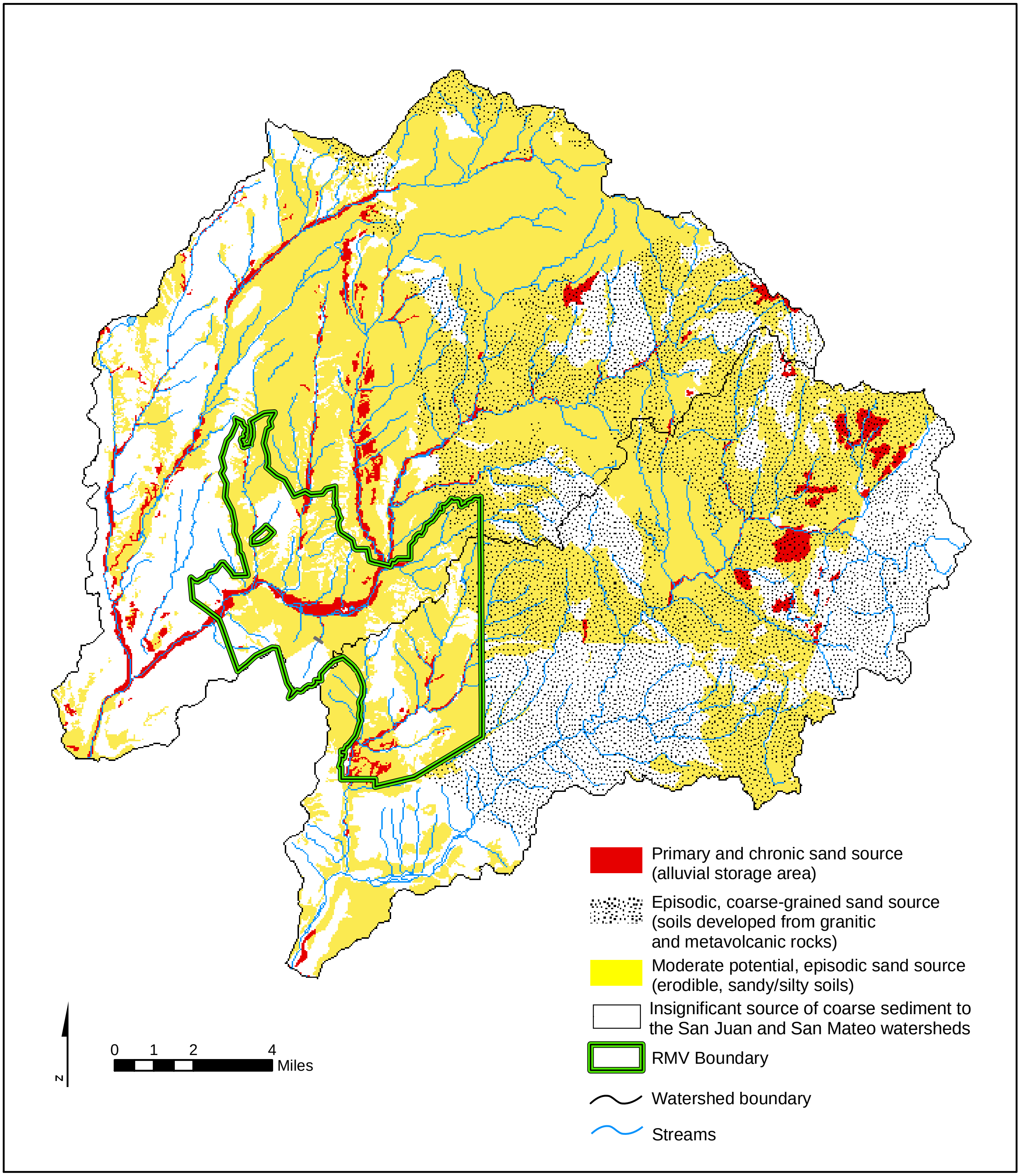
[6] Includes 'Chiquidora Canyon'

[7] Includes Trampas Canyon; values for both central San Juan basins are estimated for this report

[8] Percentage of long-term sediment yield delivered by episodic events

[9] Planning areas were designed to maintain episodic yield to the creeks; see section 4.4.1 of text

FIGURES



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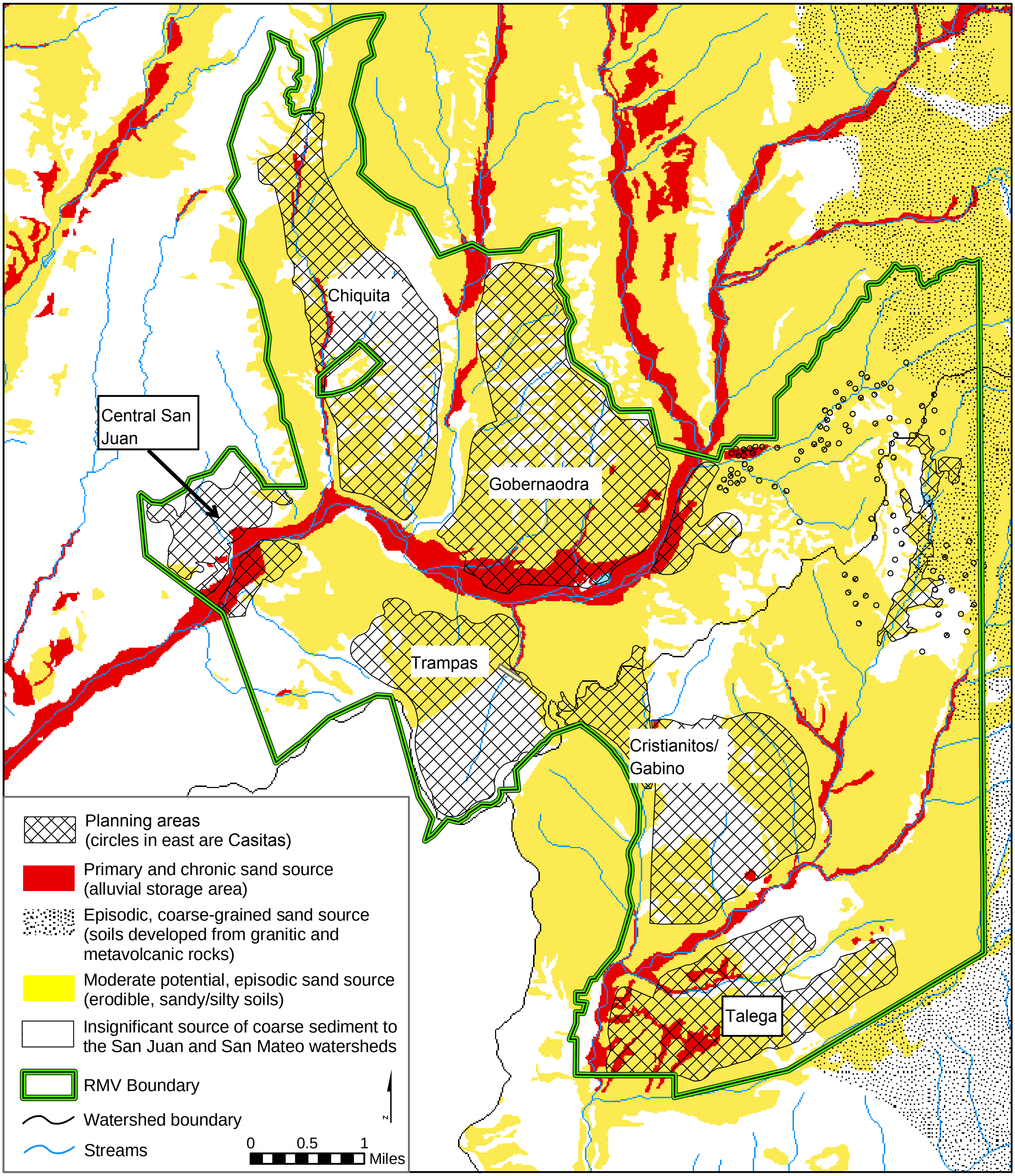
Balance Hydrologics, Inc.

Figure 1. Existing coarse sediment and beach material sources in the San Juan and San Mateo watersheds, Southern California

Most of the coarse-grained sand, particularly important to beach sand supply, originates upstream of the project area.

This map depicts both chronic (alluvial sediment storage areas) and episodic (upland areas) sand sources.

See Figure 2 for detail of project area.



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Balance Hydrologics, Inc.

Figure 2. Proposed planning areas, showing relations to primary coarse sediment areas, Rancho Mission Viejo, Orange County, California

Note: No obstructions to continuity of coarse sediment conveyance to the ocean are proposed as part of this project.

See Figure 1 for sediment sources in the greater San Juan and San Mateo watersheds.

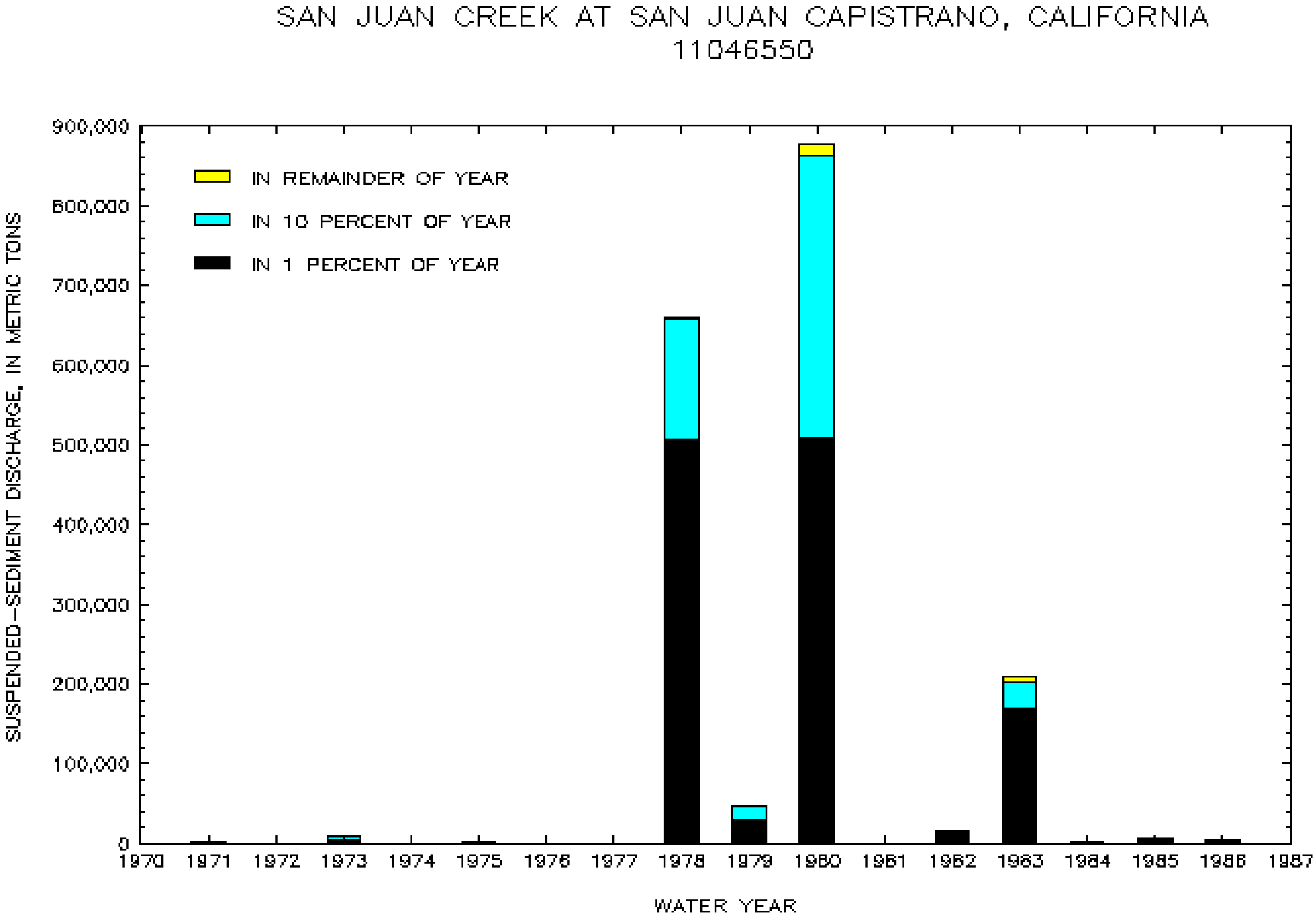

image source: http://co.water.usgs.gov/sediment/images/nm36.gif

Figure 3. **Suspended sediment histogram for San Juan Creek at San Juan Capistrano, Orange County, California.** This graph shows the highly episodic nature of sediment transport in San Juan Creek. The black portion of the bar represents the amount of sediment transported in the highest 1% (3.65 days) of the year, grey represents the highest 10% (36.5 days), and light grey (at top) represents the sediment transported during the rest of the year.

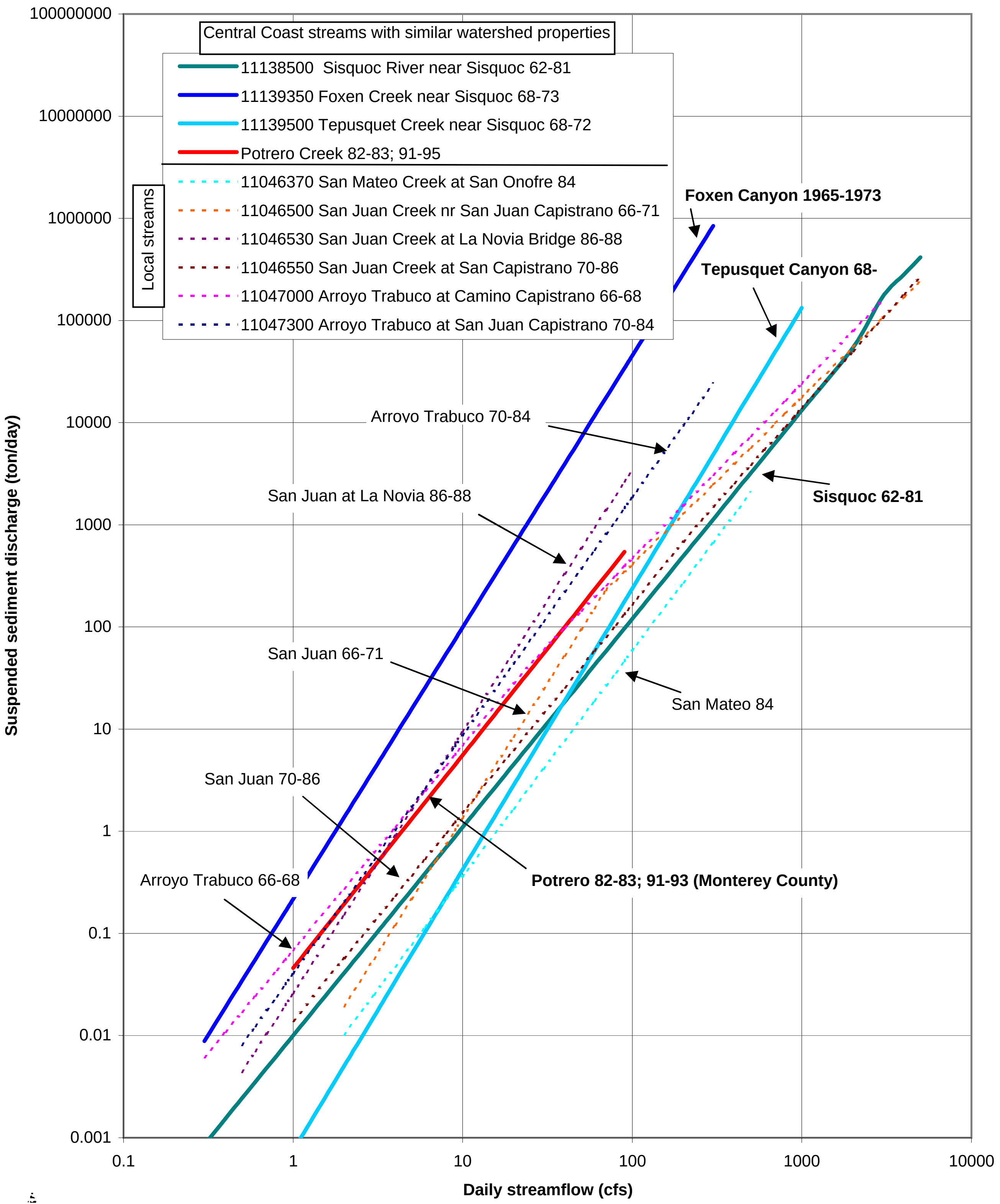

Figure 4. **Suspended-sediment rating curves for** streams of the San Juan and San Mateo Creek watersheds, southern California. Rating curves from several Central Coast streams draining watersheds with similar geology, size and existing landuse are also included. Note that most transport occurs at the high-flow end of these relations.

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Figure 4-- Regional sed rate curves3.xls, Central Coast

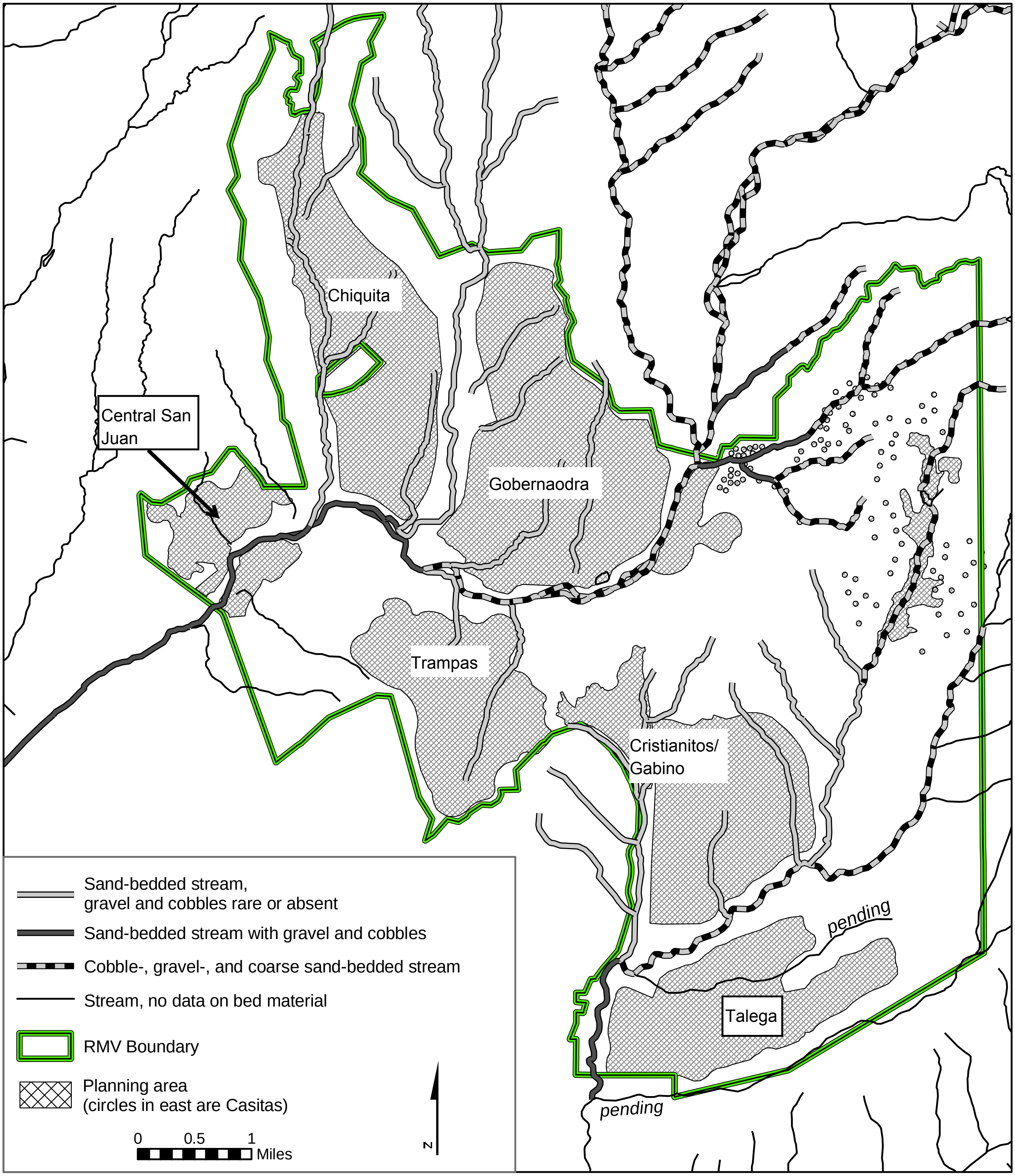

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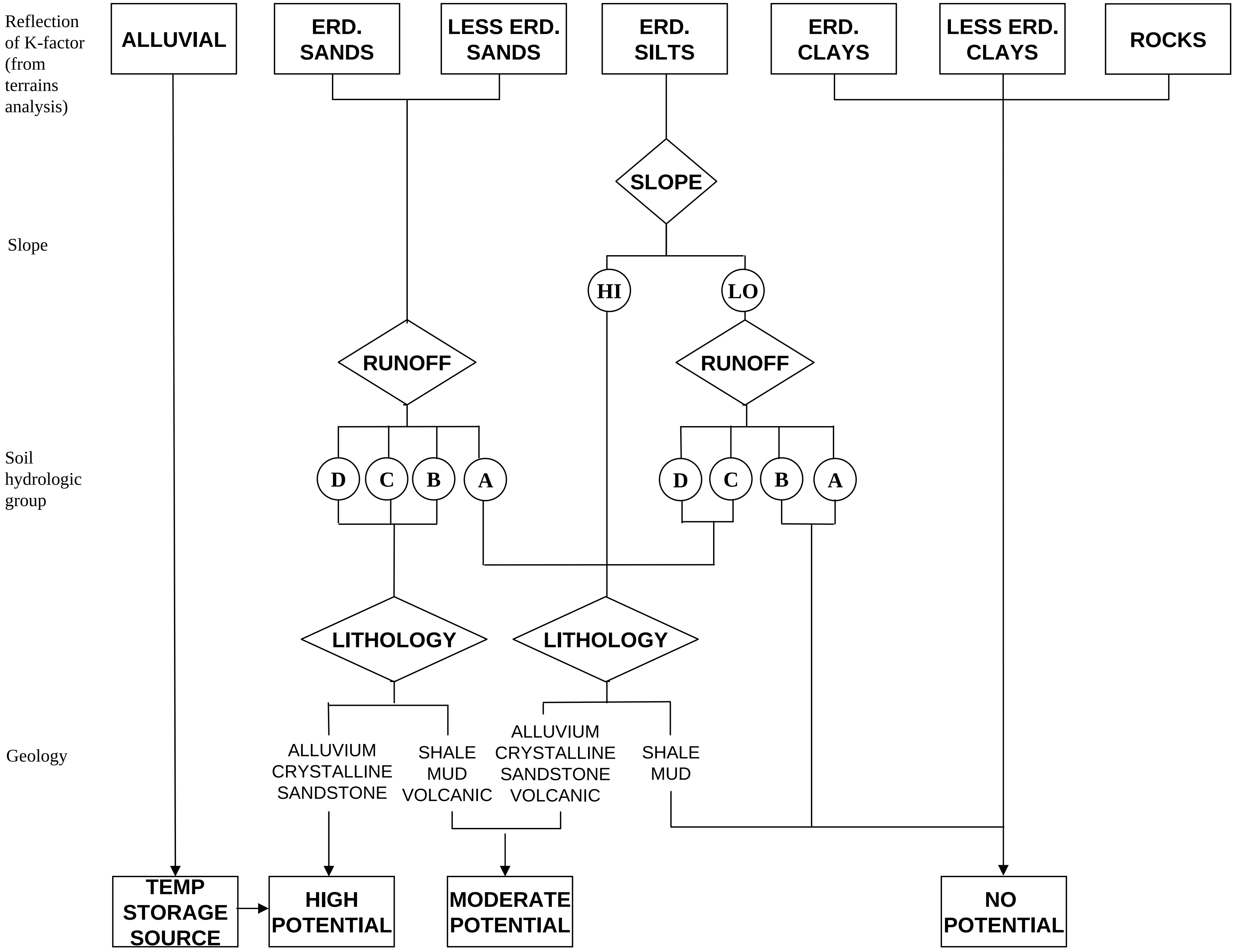
Figure 5. Generalized reach characterization of bed conditions on major drainages, San Juan and San Mateo watersheds, Rancho Mission Viejo, Orange County, California.

Note: The northern portions of the Chiquita planning area is planned as a golf course and open space and wil not significantly alter the existing channel.

APPENDICES

Appendix A. Schematic of method used to identify potential sources of sand within the San Juan and San Mateo watersheds.



A report prepared for:

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Geomorphologic Factors Affecting Sediment Generation and Transport Under Pre- and Post-Urbanization Conditions at Rancho Mission Viejo and in the San Juan and San Mateo Watersheds, Orange County, California.

Balance Project Assignment 99058.57

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