Appendix B

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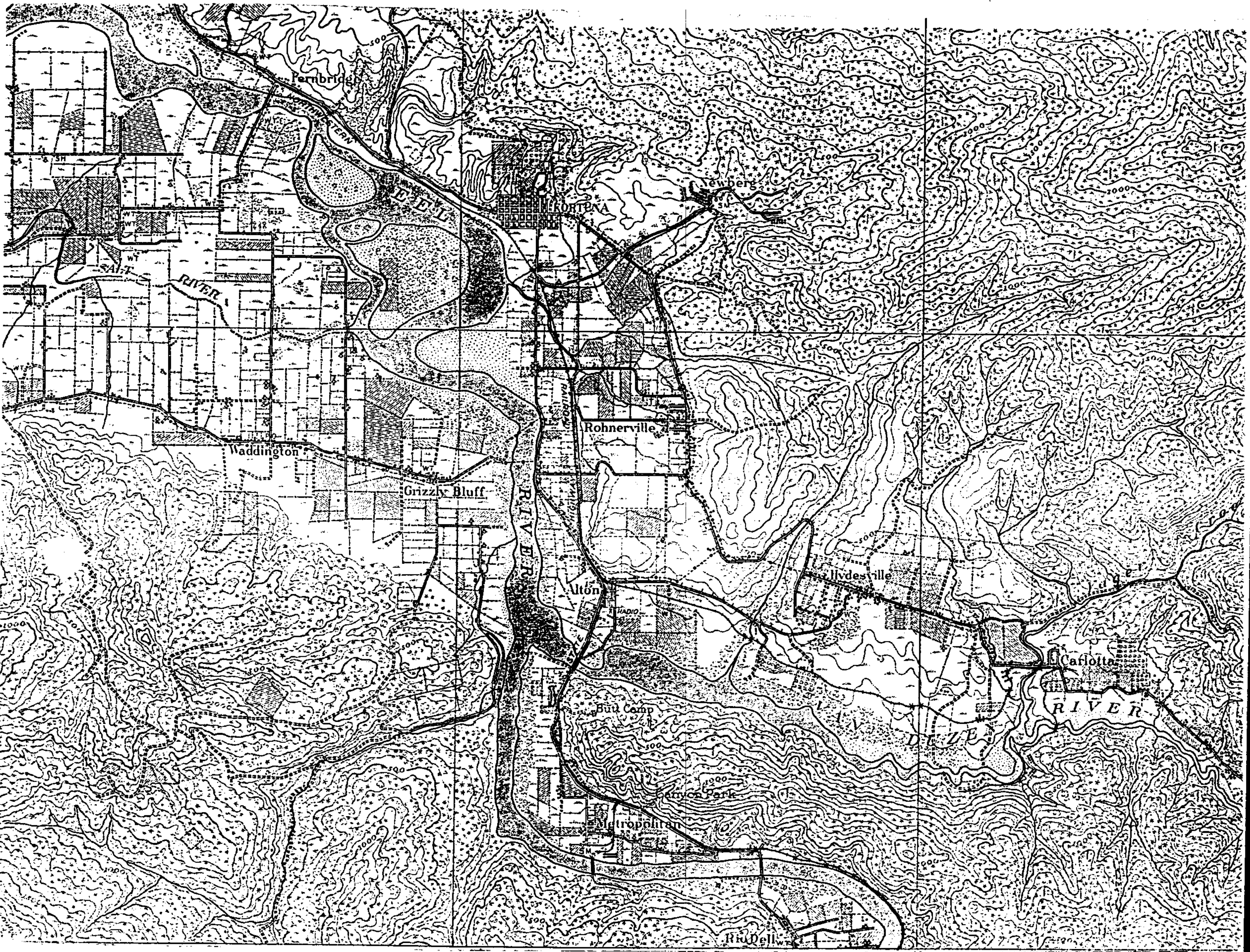
Consultants Report

AGGREGATE EXTRACTION FROM THE EEL AND MAD RIVERS, HUMBOLDT COUNTY:

GEOMORPHIC AND ENVIRONMENTAL PLANNING CONSIDERATIONS



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CONCLUSIONS AND RECOMMENDATIONS

1) By interrupting the continuity of sediment transport through the river system, instream gravel extraction can induce incision and other morphological changes, which can propagate miles upstream and downstream of gravel pits. Incision can occur both downstream and upstream of the gravel pit: downstream due to deprivation of sediment load, upstream from knickpoint migration.

2) The complexity of sediment transport and channel change in natural rivers is such that prediction of river behavior is plagued with a significant degree of uncertainty.

3) Computer models of sediment transport are simplifications of complex natural processes. The National Research Council (1983) concluded that the performance of all such models was so poor that their use could not be justified in flood insurance studies.

4) A thorough historical study of channel change and a sediment budget analysis should be undertaken on the Mad and Eel Rivers as a basis for understanding and predicting impacts in these channels.

5) Changes in river channel form and bed elevation should be monitored using cross sections surveyed to a common datum using standard procedures. Cross sections should be surveyed not only in extraction areas but in intervening reaches as well to provide longitudinal continuity.

6) The County should consider establishment of minimum thalweg elevations (redline) to protect bridge crossings and other resources. Incision of the thalweg below the redline would trigger a restriction or halt in extraction and any other activities that could be inducing incision under further studies indicate that extraction can be safely resumed.

7) Upland sources of aggregate (quarry and terrace gravels) should be inventoried and evaluated throughout the region.

8) Based on historical information, sediment budget analysis, and inventory of alternative sources, the County should develop a comprehensive aggregate resource management plan. A key component of the plan should be matching aggregate quality with end use requirements.

9) Although an excellent start has been made with historical and sediment budget studies completed for the EIR, the information base necessary to prepare a comprehensive aggregate resource management plan cannot be developed by June 1, so a preliminary EIR should be prepared to satisfy regulatory requirements this year. The preliminary EIR should describe the studies underway and the process by which a regional aggregate management plan will be developed and an EIR done on it in 1994.

10) The problems related to aggregate management in Humboldt County cannot be solved piecemeal. Comprehensive environmental planning is needed to examine all alternative sources and their environmental impacts, and to develop a coherent strategy to supply the county's aggregate needs while minimizing environmental impacts of extraction.

PURPOSE AND SCOPE

The purpose of this report is to provide guidance concerning geomorphic issues related to extraction of sand and gravel from the active channel beds of the Mad and Eel Rivers. Recommendations include consideration of regional approaches to management of all types of aggregate resources and methods of comparing the environmental impacts associated with extraction of each type. This guidance is presented from the perspective of an outside expert familiar with the geomorphic impacts of instream gravel mining and regulation of the activity in the State of California, the gravel requirements of spawning salmonids, and the geomorphic character of rivers of northern California in general, although not previously knowledgeable about particulars of the Mad and Eel Rivers.

This report is a written version (with citations and technical support) of the presentation made in Eureka on 17 December 1992 to a group composed of staff of the Humboldt County Planning and Public Works Departments, members of the Fish and Game Advisory Commission, staff of California Department of Fish and Game, gravel extractors, the local operators association, members of the Technical Committee, a member of the Board of Supervisors, and representatives of environmental organizations. This report applies principles of geomorphology and environmental planning, along with the author's experience with impacts of instream gravel mining elsewhere, to the situation in Humboldt County. However, specific recommendations of quantities extractable, extraction methods, location, and timing, and detailed protocols for monitoring and assessment of environmental factors in Humboldt County is beyond the scope of this report.

Since the site visit and writing of the draft version of this report, considerable historical and sediment budget analysis have been completed and reported by Andre Lehre, Randy Klein, and others as technical input to the EIR. Although I have not had an opportunity to review this material, it appears that these researchers have already completed some of the studies recommended here, although there are outstanding issues remaining that require further study (Randy Klein, personal communication 1993).

This report is organized as follows. An overview of the problem is followed by a review of river processes relevant to understanding the geomorphic issues related to instream aggregate extraction. The concept of sediment budget construction and the limitations of the existing science are reviewed, followed by a discussion of monitoring and management strategies for in-channel projects. The need for a broader, regional approach to management of aggregate demand and sources is considered, along with recommendations for the near-term strategy for Humboldt County in preparation of an EIR for extraction on the Mad River in 1993.

OVERVIEW OF THE PROBLEM

Sand and gravel are used for a large variety of construction activities including roads and highways (base material and asphalt), pipelines (bedding), septic systems (drain rock in leach fields), and concrete (aggregate mix) for highways and buildings. With the rapid population growth and consequent construction boom in California, the demand for aggregate has been strong. In 1986, the production of sand and gravel in California, primarily derived from river channels and their floodplains was estimated at 128,500,000 tons with an estimated value of nearly $500,000,000 (Sandecki 1989), nearly double the estimated production of 65,000,000 tons in 1955.

In Humboldt County, as in many other counties in the state, most aggregate has been derived from river deposits, both active channel and floodplain. This situation developed over time, with many major existing extractions having grown gradually, without, until recently, being subjected to any environmental analysis, and without a thorough planning process or analysis of cumulative effects. Although sediment budget and historical channel change studies have yet to define linkages between specific management activities and specific impacts, instream gravel extraction is implicated in degradation (downcutting) of the Mad River and consequent undermining of the Highway 299 bridge and impacts to other structures. As a result of these concerns, the County is now taking a serious look at the environmental impacts of instream aggregate extraction, in an attempt to balance the goals of aggregate supply for economic development and environmental quality in the Mad and Eel Rivers.

In California, instream gravel extraction is ineffectively regulated. Under the Surface Mine and Reclamation Act (1976, and amended), all mining operations (upland or in-channel) are required to prepare <u>reclamation plans</u>. The notion of reclamation is suitable for upland quarries, but, as I argue here, it is unsuitable for instream mining. Counties or cities are designated as lead agencies for approving reclamation plans and issuing special use permits or vested rights determinations. In Humboldt County, use permits are required of all mines except those operating before 15 May 1965, which may have vested rights (Sidnie Olson, Planning Department, Humboldt County, personal communication 1993). Instream mining operations must also obtain a Streambed Alteration Agreement from the Department of Fish and Game. In addition, permits for filling of waters of the United States may be required from the US Army Corps of Engineers under Section 404 of the Federal Water Pollution Control Act Amendments of 1972 and/or Section 10 of the Rivers and Harbors Act of 1899.

Despite all these requirements, the cumulative impacts of instream aggregate extraction are rarely thoroughly analyzed in any meaningful way, and an analysis of alternatives (required by the National Environmental Policy Act (NEPA), Section 404 of the Clean Water Act, and the California Environmental Quality Act (CEQA) is rarely performed.

In general, as lead agencies, county planning departments rarely have the resources or staff with expertise needed to properly address the technical issues related to instream extraction. In many counties, little monitoring has been conducted by lead agencies to assess compliance with permit conditions, and even less to document channel conditions as a means of assessing impacts. A survey of 56 county-level lead agencies in California in 1990 showed that only nine had established limits tied to hydrology or channel conditions, and only eleven required channel cross sections or aerial photography to monitor impacts (Kondolf and Matthews, in press). Moreover, county officials may be subject to political pressure or may be influenced by the needs of the county itself to extract aggregate for its operations. In many counties, illegal (unpermitted, non-vested) mines continue to operate.

The existing situation is unlikely to persist because of impacts to structures and aquatic resources. Caltrans is both a consumer of 15 percent of the state's aggregate and victim of bridge undermining by channel incision that may be related to instream mining. Mining (and other activities throughout the watershed) can produce incision that may propagate for miles, affecting distant bridges. About 150 of the state's bridges are critically threatened by scour (Cathy Crossett, Caltrans Structures Div., pers. comm. 1991). With the repair and replacement costs potentially reaching hundreds of millions of dollars, pressure is increasing for control of activities potentially responsible. Likewise, as a result of dramatic declines in anadromous salmon runs over recent decades, recent legislation requiring action to restore salmon runs, and recognition that lack of suitable spawning gravel in sites such as the Sacramento River below Keswick Dam is a major obstacle to restoration of salmon runs, pressure from fishery and environmental groups is increasing for stronger regulation of instream aggregate extraction.

This report reviews principles of river processes relevant to evaluation of impacts of instream aggregate extraction, considers the limitations in the science of sediment transport, and presents arguments for comprehensive environmental planning, in which preservation of natural resources and economic needs are balanced through intelligent, businesslike allocation of resources. This environmental planning should involve an inventory of all potential aggregate sources, evaluation of the relative quality of aggregate, and allocation to various end uses as appropriate, with environmental impacts factored into the cost of instream-produced aggregate.

REVIEW OF RIVER PROCESSES

Role of Rivers in the Landscape

As waters flow from high elevation to sea level, they sculpt the landscape, developing complex channel networks and a variety of stream channel forms. Of the rain that falls on the land surface, over half usually goes back into the atmosphere through evaporation or transpiration by plants. The remainder (a variable fraction, typically about one-third) can run off into the stream network, either running off directly into channels or infiltrating into the groundwater and draining more slowly. Obviously the atmosphere cannot provide more water than it receives indefinitely, and this imbalance is settled by evaporation from the sea. More water evaporates from the ocean surface than falls on it as precipitation. We have already observed that more water falls on the land than evaporates from it, so there is a net transfer of moisture from the sea to land. This is due primarily to the greater availability of water for evaporation on the ocean surface and the greater tendency for precipitation over land from orographic effects.

The land area drained by a given river is termed its <u>drainage basin</u> or <u>watershed</u>, and is separated from adjacent watersheds by topographic high points termed <u>drainage divides</u>. Above any point in a river system, the area over which surface runoff is collected to flow past that point is the <u>drainage area</u>. Drainage basins can be defined at many scales, from large river basins such as the Sacramento River at Sacramento (drainage 23,500 square miles), to its tributary basins such as the Pit River (4,700 square miles) and the North Fork of Battle Creek near Manzanita Lake (6 square miles).

Drainage basins can be viewed as the fundamental landscape units because so many processes occurring upstream in the drainage basin affect downstream reaches, and some processes in downstream reaches may affect upstream reaches. For example, construction of roads in the upper drainage basin may increase rates of erosion and sediment delivery to stream channels, filling downstream channels with sediment, causing the channel to <u>aggrade</u> (build up its bed with sediment), as illustrated along Redwood Creek (Kelsey et al., 1981). If the level of the sea or a lake drops, the channel of a tributary stream immediately upstream may <u>incise</u> or degrade (erode its bed downward), and this incision may propagate upstream for miles or tens of miles, as illustrated along Rush Creek, a tributary to Mono Lake (Stine 1987).

Energy Dissipation and Sediment Transport

Energy is dissipated by rivers in a variety of ways: by transport of sediment, by turbulence from rough, irregular bed and banks, and by energy losses at bends (Figure 1). As water flows from the upper reaches of the watershed downward through the drainage network, some of the potential energy inherent in its elevation at the point of origin goes into energy of motion, with the remaining energy expended upon transport of sediment and dissipated in turbulence. The steeper the channel, the more rapid the rate of energy dissipation (conversion of energy from potential to other forms). Steep channels typically have large rocks on the bed (with greater flow resistance and stability), with most energy losses concentrated in localized drops. These drops may be bedrock or boulder steps in step-pool reaches, or gravel-cobble riffles in pool-riffle reaches.

That rivers possess energy in excess of that required to move water to sea level is reflected in the potential for hydroelectric power generation in steep reaches of Sierra Nevada rivers. Many of these hydroelectric power projects are run-of-the-river, involving no large storage reservoirs, but simply diversion of flow from the channel into smooth canals or tunnels that convey the water at a gentle grade along the mountainside above the river. The river falls more steeply (dissipating energy in turbulence over boulders and bedrock) until the canal is 100-200 feet above river level, whence the water drops abruptly through reinforced pipes (penstocks) driving turbines in the power plant.

Much of a river's excess energy is used to move sediment. The sediment load of a river can be broken into three components: dissolved load, suspended load, and bedload. Dissolved load consists of the products of rock weathering, such as Calcium, Magnesium, and Carbonate (CO_3), carried in solution. Where chemical weathering is the dominant denudation process on the landscape, such as in humid tropical regions or landscapes underlain by soluble limestones, dissolved load can constitute most of the sediment load. Elsewhere, dissolved load is usually a minor component of total load. Suspended load, the largest component of the sediment load of most rivers, consists of mud, silt, and sand maintained in suspension by turbulence in the water column. In general, the concentration of suspended sediment decreases with height above the bed. Bedload consists of sand and gravel moved along the bed of the river by rolling, sliding, and bouncing (saltating) (Figure 2). Although gravel may move in suspension during large floods, gravel is primarily transported as bedload, so to understand processes relevant to instream gravel extraction, we are particularly interested in bedload transport.

Bedload usually constitutes a small fraction of a river's total sediment load. In low-gradient rivers, bedload might constitute 2 percent or less of total load, while in mountainous terrain, bedload may constitute 20 percent of total load (Collins and Dunne 1987).

Sediment transport is one way in which rivers dissipate excess energy. If the sediment load of a river is artificially reduced without reducing the magnitude of the flows, the flows will still possess the excess energy capable of moving sediment, and the river will tend to erode its bed and banks.

The size of sediment grains movable depends on the water velocity (a function of water depth and channel gradient) of the flow, as illustrated by Figure 3. Flow velocity determines not only the size, but also the amount of sediment that can be moved in a river. The rate of sediment transport typically increases geometrically with flow, that is, a doubling of flow typically produces more than a doubling in sediment transport. This is illustrated by graphs relating transport of sediment in tons per day to the flow rate in the Carmel River (Figure 4). Because the rate of sediment transport is so much greater in higher flows, most sediment transport occurs during floods.

The sediment transported by rivers consists of the soil and rock fragments eroded from the watershed. The amount of sediment transported from a basin (the basin's <u>sediment yield</u>) can be used to compute the rate at which the landscape is lowered by erosion (the <u>denudation rate</u>). These processes are generally slow, with denudation rates ranging from under one-half inch per thousand years in the Appalachian Mountains to 40 inches per thousand years in the Himalayas (Leopold et al. 1964, p. 28). In general, the highest, steepest mountains are being most rapidly uplifted and are also being most rapidly eroded. For example, the Cropp River basin in the Southern Alps of New Zealand is being uplifted at approximately 0.4 inches per year and is being lowered by erosion at approximately the same rate (Griffiths and McSaveney 1983). Viewed over a longer perspective, runoff erodes the land surface and the river network carries the erosional products from each basin. The watershed can be divided into the zone of sediment production (steep, rapidly eroding headwaters), the zone of transport (through which sediment is moved more-or-less in equilibrium) and the zone of deposition (Schumm 1977)(Figure 5). The watershed can also be viewed as a sediment "factory", and the river channel as a "conveyor belt", which transports the products downstream to the ultimate depositional sites below sea level (Figure 5). Along the length of the river system, the size of sediment changes, from coarse gravel-boulder in steep upper reaches to sands and silts in low gradient reaches.

Along this "conveyor belt", sediment in the river bed may appear stable in the short term and may be replaced by new transient sediment every year or two. Gravel bars in the Eel and Mad Rivers may look much the same from year to year, but the majority of gravel particles in them may be replaced annually or biannually, as sediment moved downstream from this site is replaced by sediment carried in from upstream. The dynamic nature of river channel features may not be apparent, but is of enormous importance in understanding the effects of human activities on river channel morphology.

Just as the sediments in the channel bed are mobile on a time scale of years, so the sediments that make up the river <u>floodplain</u> (the valley flat adjacent to the channel) are mobile on a time scale of decades or centuries. The floodplain acts as a storage reservoir for sediments transported in the channel, alternately storing sediments (by deposition) and releasing sediment to the channel (by bank erosion). Figure 6 depicts migrations of the channel of the Carmel River since the first surveys in 1857. The river channel migrated over a quarter of a mile in places, with most channel shifts occurring during two large floods in 1862 and 1911. The 1911 flood deposited a wide channel of sand and gravel. By 1940, the Carmel River had cut a narrow channel 12 ft deep, leaving the flood-widened bed as a terrace of alluvium flanking the new active channel. By 1960, the terrace had been subdivided for low density housing, despite the recent origin of the land.

The floodplain is a dynamic feature closely related to the channel. In fact, the channel and the floodplain are best viewed as a single unit hydrologically and geomorphically, just as the watershed is a single landscape unit. Unfortunately, the natural functions of the floodplain have frequently been ignored, with often disastrous effects.

Flood Frequency and Channel Form

Except in unusual cases below large springs (such as Fall River near Burney), flow in California rivers is exceedingly variable. This is due to the highly seasonal precipitation and variable intensity of the winter cyclonic storms. Within the year, flows range from seasonal lows (in late summer in the Coast Ranges, in winter in higher elevation Sierran snowmelt streams) to high flows (during winter storms along the coast, during spring snowmelt at higher elevations). Flows also vary from year-to-year, depending on the abundance and intensity of precipitation for the year. The typical pattern of high flows is of particular importance in shaping a stream channel, especially for rivers flowing through sediments, less so for rivers flowing through bedrock canyons. One way to statistically summarize the flood regime of a river to compute the arithmetic average of the annual peak floods, the mean annual flood or Q_{maf}. However, because year-to-year variation in flood magnitude is so great in regions with semi-arid or Mediterranean climates (such as California), this statistic is very sensitive to the sequence of years that chance to fall within the period analyzed. For example, an average over the period 1955-1986 (encompassing wet years 1955, 1965, 1982, 1983, and 1986) would be higher than an average over 1956-1991 (excluding 1955 but including the dry years of 1987-1991). Distortion of estimating frequent events can be avoided by calculation of return periods of floods based on assumed distributions, as discussed below.

The history of floods on a given river can be analyzed to develop probabilistic estimates of the likelihood of a certain sized flood occurring in a year. The flood that occurs as the annual peak flow, on an average of every two years is the "two-year flood" or "Q_2"; the flood that occurs every ten years is the "Q_{10}". The probability that these flood levels will be reached or exceeded in any given year is 50 percent and 10 percent, respectively. It is a common misconception that if a river experiences a 100-year flood one year, the probability of a comparable flood the following year will be less. In fact, the probability of another 100-year flood the next year remains the unchanged at 1 percent.

It is intuitive that rivers with larger flows possess larger channels to convey the larger quantities of water. But how much larger must the channels be? More to the point, is there a flow to which the channel adjusts its geometry? During summer low-flows most rivers do not fill their banks, but occupy a small low-flow channel, exposing gravel bars and other such features. At extreme floods, the river flows out of its banks and spreads across its floodplain. The flow that just begins to exceed the capacity of the banks is designated as <u>bankfull flow</u>; in many rivers, this occurs at about the $Q_{1.5}$ to Q_2, (Leopold et al. 1964). This implies that many channels are adjusted to these frequent floods rather than to larger, but less frequent floods. However, the relative importance of less frequent floods is greater in semiarid and arid environments (Wolman and Gerson 1978).

<u>Effects of Reservoirs</u>

Dams and diversions have profoundly altered the character and functioning of rivers in California. To understand the nature of these changes, it is helpful to view them in terms of the independent variables that control alluvial channel geometry: flow regime and sediment load. Changes in these variables will produce adjustments in alluvial channels. The nature of these channel adjustments will depend upon the characteristics of the original and altered flow regime and sediment load. However, some general trends can be expected, as outlined in Table 1 and discussed below.

Dams disrupt the longitudinal continuity of the river system, interrupting the action of the "conveyor belt" of sediment transport. Upstream of the dam, all bedload sediment and most suspended load is deposited in the quiet water of the reservoir, while downstream, water released from the dam possesses the energy to move sediment, but no sediment load. Clearwater released from the dam is known as "hungry water", because the excess energy is typically expended on erosion of the channel bed and banks for some years following dam construction. For example, on Stony Creek (a tributary to the Sacramento River), since the closure of Black Butte Dam in 1963, the channel downstream has undercut and migrated laterally, eroding enough bedload sediment to compensate for about 20 percent of the bedload now trapped by Black Butte Dam on an annual average basis(Kondolf and Swanson 1993).

The channel erosion below dams is frequently accompanied by a change in particle size on the bed, as gravels are transported downstream, leaving a coarse <u>lag</u> deposit of cobbles or boulders, known as an <u>armor layer</u>. Development of the cobble-bed is an adjustment by the river to changed conditions because the larger