DECOMMISSIONING MATILIJA DAM

AGENDA
May 3, 1999
1:00 – 4:45 PM

Multi-Purpose Meeting Room, 3rd Floor
Hall of Administration
Ventura County Government Center

1:00 – 1:10: **Introduction**
Supervisor John K. Flynn, County of Ventura

1:10 – 1:30: **Matilija Dam: History and Current Status**
Mark Capelli, Friends of the Ventura River

1:30 - 1:50: **Matilija Dam and Beach Sand Supply**
Dr. James A. Bailard,
Beach Erosion Authority for Control Operations & Nourishment

1:50 - 2:10: **Matilija Dam and Steelhead Recovery**
Sara Lee Chubb, U.S. Forest Service,
Los Padres National Forest

2:10 - 2:30: **Break**

2:30 – 3:15: **Decommissioning Matilija Dam: Issues and Options**
Dr. John Gray, URS Greiner Woodward-Clyde

3:15 – 4:30: **Round-Table Discussion**

4:30 – 4:45: **Wrap-Up**
Supervisor John K. Flynn

MATILIJA DAM REMOVAL - ISSUES AND OPTIONS

John Gray, URS Greiner Woodward-Clyde*

Presentation at the Matilija Dam Decommissioning Round Table Discussion
May 3, 1999 Ventura, California

The following is an outline of a slide presentation at a Round Table Discussion on the Decommissioning of Matilija Dam. The objective of the presentation was to identify major issues and concerns associated with dam removal options, particularly alternative removal methods, environmental impacts of dam removal, and regulatory issues.

1. DAM REMOVAL OPTIONS

The primary challenge associated with dam removal is the removal, stabilization, and/or management of the sediments behind the dam because they represent a significantly larger mass than the dam itself, and because they are difficult to manage compared to concrete. There are three basic methods for managing sediments during dam removal:

1. Retain and stabilize sediments in place in the original reservoir area after dam removal
2. Remove sediments by natural erosion from the river, carrying sediments downstream
3. Actively remove sediments (e.g., hydraulically or mechanically) and haul away for disposal

2. METHOD NO. 1: STABILIZE SEDIMENTS

In this method, the dam is progressively notched or reduced in height over successive years. At the same time, a channel is excavated in the sediments in the reservoir area by heavy equipment (in the dry season) or by flushing (in the winter). The channel alignment is designed to mimic natural meanders and the banks are protected from erosion. The objective is to create a stable incised channel in the reservoir area, while stabilizing the adjacent floodplain which consists of sediments. The channel invert would be progressively lowered to meet the existing natural channel below the dam. The floodplain would be stabilized by creating riparian woodland vegetation. See Figure 1 for a summary of this approach.

3. METHOD NO. 2: NATURAL EROSION

For this approach, the dam is progressively lowered and sediments in the reservoir area are exposed to allow flood flows to erode sediments and carry them to the ocean or to a downstream basin for dewatering and hauling. The channel and floodplain at the reservoir site would be returned to their natural gradient and configuration. This is an event-based method, dependent on substantial river flows to erode and convey sediments. See Figure 2 for a summary of this approach.

4. METHOD NO. 3: ACTIVE SEDIMENT REMOVAL

This method utilizes standard engineering and construction procedures and equipment as listed below. See Figure 3 for a summary of this approach.

- *Removal methods*: There are three methods: (1) hydraulic dredging using a floating dredge with cutter head; (2) wet/dry excavation using equipment such as a clamshell, excavator, loader, opr scrapers; and (3) flushing/sluicing sediments in the reservoir through a notch or gate at the dam during high river flows.
- *Conveyance methods*: There are five possible methods: (1) slurry pipeline; (2) laundering channel (e.g., open flume with sediments carried by water); (3) dump trucks; (4) conveyor belt (dry sediments only); and (5) river channel using natural river flows.
- *Disposal methods*: There are four methods: (1) off-stream landfill, such as a nearby canyon; (2) downstream man-made basin where sediments would be dewatered then hauled away; (3) ocean for beach replenishment; and (4) direct use as commercial fill or aggregate.

5. FACTORS AFFECTING THE SELECTION OF A REMOVAL OPTION

❖ Objectives and Timeframe. The objectives of removing the dam must be clearly articulated to determine most appropriate removal method and timeframe. Similarly, a strong and compelling statement of need must be developed to elicit support for the project. To date, there are two primary objectives identified for removing the dam: Steelhead passage to historic spawning habitat; and beach sand replenishment. Other objectives are restoration of public access to National Forest lands, and outdoor recreational and educational opportunities.

❖ Work Area and Access. The work area is extremely limited at the dam site due to steep topography. Access to the dam (via Matilija Hot Springs Road) and the reservoir (via Matilija Road) is poor because these roads are narrow and winding, and because the intersection of Matilija Road and Route 33 is not suited for large trucks. In addition, sections of Route 33 from the dam site to the ocean are also narrow. Route 33 is a high-volume roadway that is near capacity during peak commuting hours. The road has numerous signalized intersections and traverses many residential/commercial. neighborhoods.

❖ Downstream Flood Hazard. Flushing sediments downstream could raise the channel bed or re-direct the river channel below the dam, causing flooding of adjacent lands. Unicorporated residential communities such as Casitas Springs, Live Oak Acres, and Hawthorne Acres would be very vulnerable.

❖ Robles Diversion. This diversion, operated by Casitas Municipal Water District, is located several miles downstream of the dam. It diverts flows from the Ventura River to Lake Casitas for M&I and irrigation uses. Diversions occur in the winter as high, sediment laden flows recede. Flushing sediments from Matilija Reservoir could adversely affect the operation of the diversion due to increased turbidity of river flows, limiting the amount of time that the diversion can operate. Sediments could also be deposited in the basin at Robles Diversion, used to facilitate diversions. Finally, sediments could also affect the operation of a proposed steelhead screen and passage facility at Robles Diversion.

- Amount and Quality of Sediments. There is no reliable estimate of the amount of sediments behind the dam. Based on the original capacity of the dam, it is estimated that there is about 4.6 million cubic yards. However, the total amount could be up to 5 or 6 million cubic yards due to accumulated sediments in upper Matilija Creek. The characteristics of the sediments (e.g., sediment size distribution, contaminants, etc.) are also unknown. It is likely that there is a mixture of fine and coarse material with layers of organic material from floods and wildfires. The suitability of the sediments for use as commercial aggregate, engineered fill, or road base is unknown.

- Off-Site Disposal Sites. The dam is located in a very remote area. There are few nearby canyons that area suitable for landfill, none of which could store all of the sediments from the reservoir. Hence, there would be significant distances for the conveyance of sediments for disposal or direct use by conveyor belt or haul trucks. For example, the distance to haul sediments to the ocean for beach replenishment would be about 16 or more miles. Hydraulic conveyance to the beach using river flows would likely be more energy efficient.

- Fluvial Characteristics of River. Large runoff events can carry significant amounts of sediment in the Ventura River. However, such events are infrequent and difficult to predict. In addition, the downstream river channel could be altered due to sedimentation, causing flooding. Data on the hydrology of the Ventura River indicate that most sediments are transported as suspended sediments rather than as bedload sediments. The sediments in the river consist of 40% coarse and 60% fine sediments. A USGS study on the river indicated that 12.9 million cubic yards of sediments were transported over a 12-year period (1969-81). However, 96% of these sediments were transported in five flood events during 1969, 1978, and 1980. Based on these data, it is expected that sediments would only be conveyed significant distances along the river when there are flood flows over 20,000 cfs. Such flows would occur every 5 years, on average.

- Dam Safety Considerations. The dam is currently considered safe. It is monitored by the Ventura County Flood Control District pursuant to requirements of the Division of Safety of Dams. If the dam deteriorates in the future, there could be an additional reason for dam removal. It should also be noted that dam safety conditions could be affected during removal actions as the sediment load and structural properties of the dam are altered. Hence, there should be provisions to ensure dam safety during removal operations.

6. POSSIBLE APPROACHES FOR DAM REMOVAL

- Approach 1 – Natural Erosion. Under this approach, the dam would be progressively lowered to a suitable height for a fish passage facility or to the original channel invert by a natural erosion process, primarily during flood flows. There would need to be a cautious progression of lowering and erosion, coupled with observations to avoid downstream impacts. This approach is risky with many unknowns. It may also require many years, or perhaps decades. However, it would be relatively inexpensive compared to other approaches, and would rely on natural forces and processes.

- Approach 2 – Dredge and Slurry Pipeline. This approach would involve an initial dry excavation behind the dam to increase its water storage. The stored water would be used for hydraulic dredging and the conveyance of sediments to the ocean by a slurry pipeline. The dam would be progressively notched or lowered as sediments are removed. The remaining portions of the dam would be removed after all the sediments have been dredged. It is estimated that about 1 million cubic yards could be dredged per year and conveyed to the ocean using about 3,000 acre-feet, a 10-inch diameter pipeline, and a 400-ton per hour dredge. This approach would be more expensive than Approach 1, but would have low risks and high predictability.

- <u>Approach 3 – Combination</u>. This approach would use a combination of methods to allow flexibility. Sediments in the reservoir would be stabilized and a channel excavated through the sediments. The dam would be progressively notched or lowered. There would be limited flushing/sluicing during winter, with dredging/slurry pipeline procedures in the late winter and early spring. During the summer, dry sediments would be excavated for disposal in a landfill, direct commercial use, or beach replenishment. The dam would ultimately be lowered to a suitable elevation for fish passage.

7. ENVIRONMENTAL IMPACTS

All dam removal alternatives would involve environmental impacts, many of which would be potentially significant. However, all impacts would be temporary and reversible, while the environmental benefits would be long-term and self-sustaining. A list of key potentially adverse impacts is provided below:

- Public safety – risk of dam failure during dam removal or flooding from sediment flushing
- Water quality degradation during erosion or flushing events
- Impacts to steelhead due to increased turbidity and sedimentation
- Impacts to other aquatic species due to sedimentation
- Truck traffic and air quality impacts due to excavation and hauling
- Beach and nearshore impacts during disposal of sediments for beach sand replenishment

8. INSTITUTIONAL, REGULATORY, AND LEGAL ISSUES

There are many institutional, regulatory, and legal issues associated with dam removal that pose unique challenges for the planning and implementation of the project. A list of these issues is presented below in the form of questions that need to be addressed:

- What is the appropriate agency to provide overall management of the project?
- What funds (local, state, or federal) are available for this type of project?
- How can downstream facilities and properties be protected during dam removal?
- What is the role of the Division of Safety of Dam?

9. PERMIT REQUIREMENTS

The following permits will be required for the project. Permitting will represent a major effort because the project could result in short-term significant impacts that are inconsistent with many wetland, water resources, air, and traffic policies.

- NPDES or waste discharge permit from RWQCB
- Corps of Engineers 404 and 10 permits
- Endangered species consultation with NMFS, USFWS

- 401 certification from RWQCB
- Coastal Development Permit and Federal Consistency Determination
- Permit for stationary emissions from the Air Pollution Control District

10. FUTURE ACTIONS

In order to pursue the possible removal of Matilija Dam, the following actions are recommended:

1. Define objectives and statement of need
2. Organize a task force of elected officials, public agencies, and involved groups
3. Develop political and public support
4. Acquire near-term funding; begin long-term funding program
5. Conduct engineering and environmental feasibility studies:

    - Sediment amount and characteristics
    - Sediment transport modeling
    - Engineering feasibility/cost studies

6. Conduct environmental review process (NEPA/CEQA)

*John Gray, URS Greiner Woodward-Clyde, 130 Robin Hill Road, Suite 100, Santa Barbara, CA 93117 805-964-6010. Additional information on dam removal options is presented in "Preliminary Evaluation of Matilija Dam Removal," Appendix B of the Ventura River Steelhead Restoration and Recovery Plan, prepared by ENTRIX and Woodward-Clyde, December 1997.

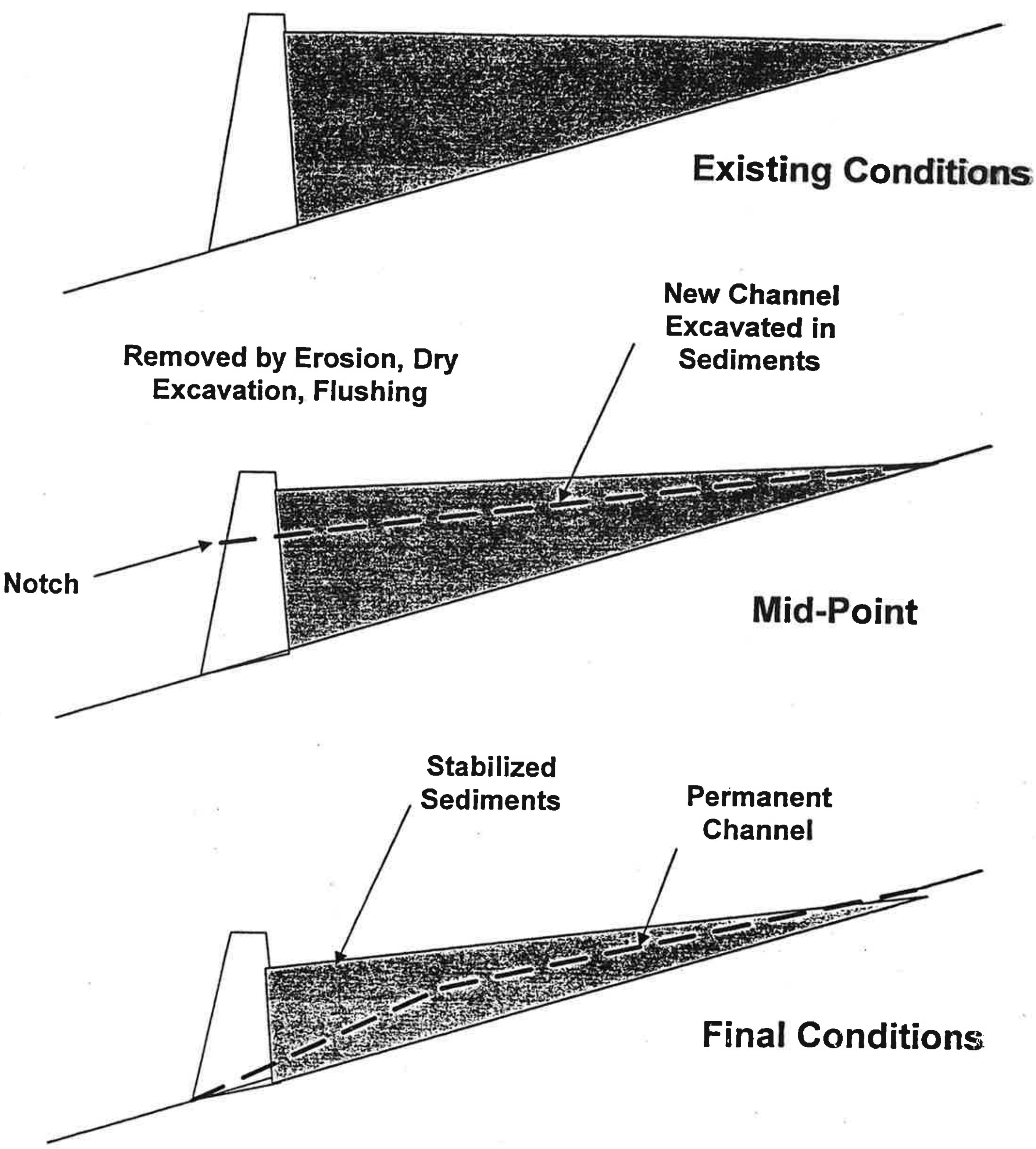

Figure 1. Stabilize Sediments Method

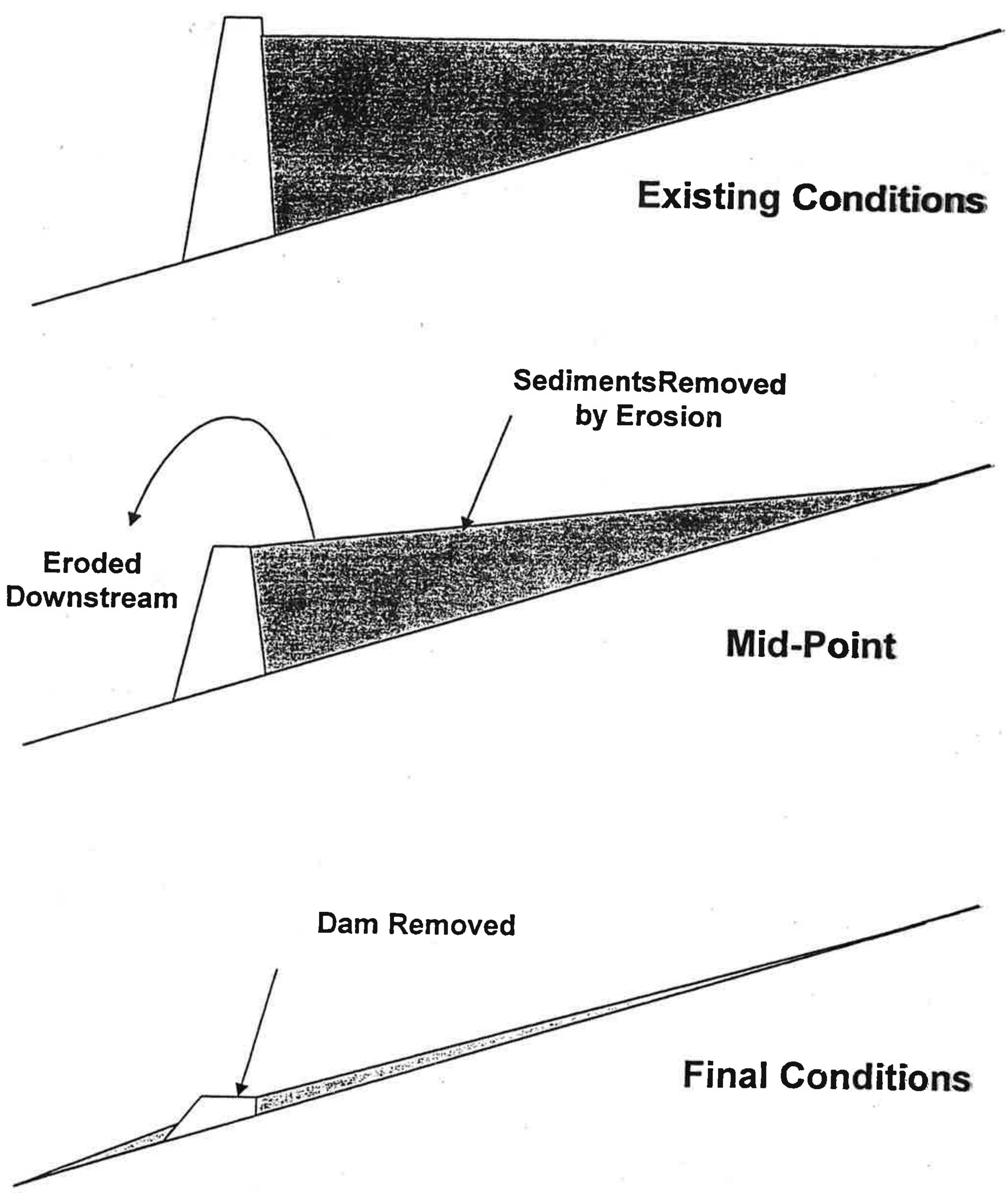

Figure 2. Natural Erosion Method

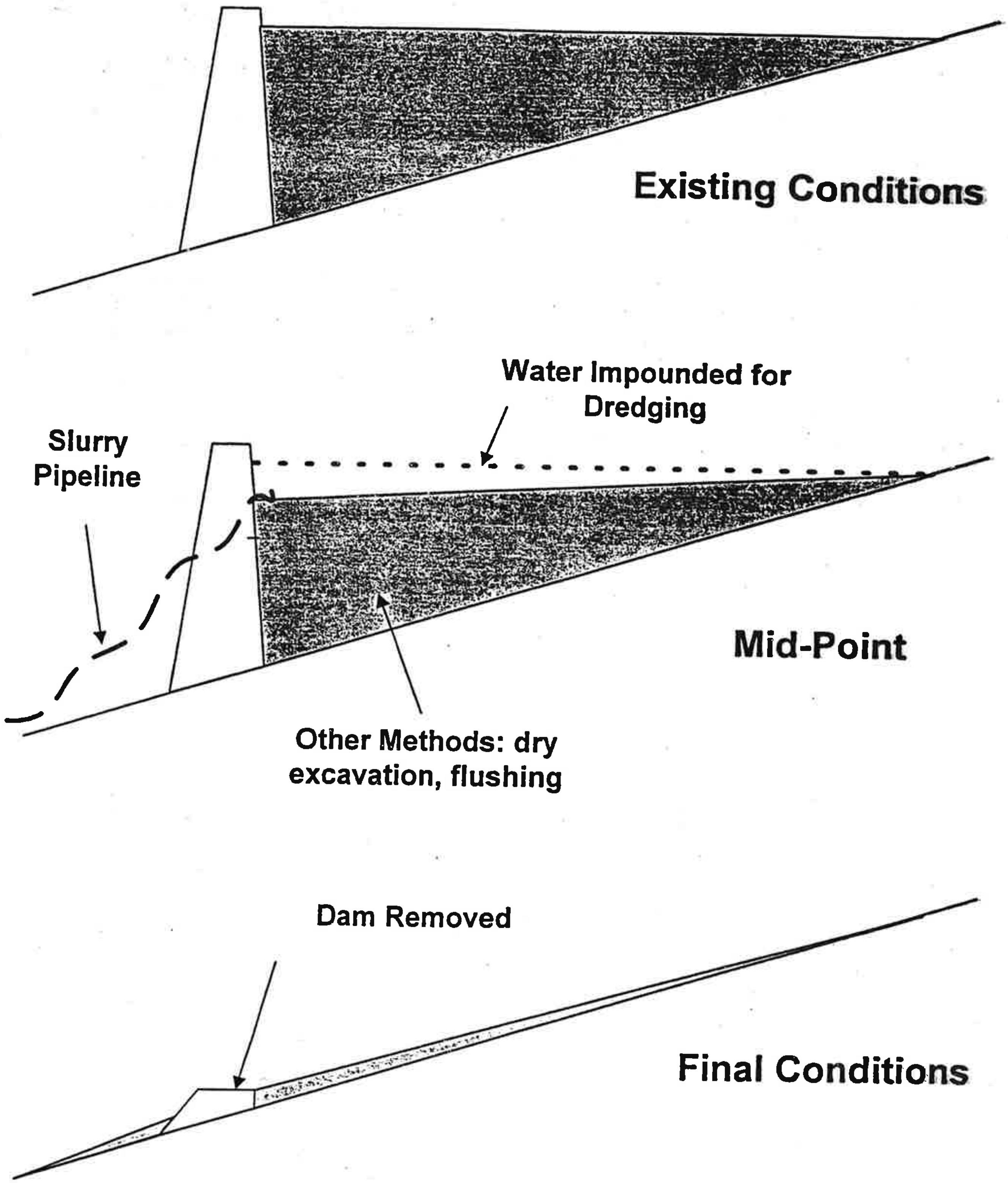

Figure 3. Active Removal Method

PRELIMINARY EVALUATION OF MATILIJA DAM REMOVAL VENTURA RIVER STEELHEAD RESTORATION AND RECOVERY PLAN

Prepared by Woodward-Clyde Consultants
Santa Barbara, California
November 1997

Information on the feasibility of removing Matilija Dam to allow passage of steelhead trout to historic spawning grounds in upper Matilija Creek is presented in this section. The benefits of this action for the Ventura River steelhead population, and its contribution for restoring a viable steelhead fishery along the river, are discussed in the Ventura River Steelhead Restoration and Recovery Plan.

1.0 BACKGROUND INFORMATION

1.1 Construction of Matilija Dam

Chronic water supply shortages for residents and farmers had occurred in the Ventura River watershed since the early 1920s. In 1925, there was a proposal by a group of residents called the Matilija Water Project Committee to import water to the Ojai Valley through a tunnel from Sespe Creek. This proposal was never financed. In 1933, the state Division of Water Resources issued its Bulletin No. 46 outlining the water supply shortages in Ventura County. In 1934, the City of Ventura conducted a water supply study that ultimately was placed on the ballots and rejected. In 1940, the Corps of Engineers (Corps) began a study of flooding along the Ventura River, considering a water storage facility at Foster Park; the Corps eventually decided to construct a levee along Ventura Avenue for flood control purposes in 1948. In 1944, a small dam project along Coyote Creek for the City of Ventura was defeated at the polls.

In 1944, the Ventura County Flood Control District (VCFCD) was formed by a special act of the State Legislature. Four zones were established for the watersheds in the County: Ventura, Santa Clara, Calleguas, and Zone 4, which encompasses the remaining watersheds of which only a portion lies within Ventura County. In 1944, the VCFCD proposed a water conservation and flood control project involving Matilija Dam and Hoffman Dam (on Coyote Creek) with interconcnections between the two reservoirs. A $3 million bond was approved by the voters of Zone 1. The dam was designed for the VCFCD by Donald R. Warren Company Engineers, and it was constructed by Atkinson-Kier-Bressi and Bevanda. The construction contract was signed on June 18, 1946, and construction began later that year. On March 14, 1948, the sluice gate was closed and the reservoir began its initial storage of water from the Matilija Creek watershed.

Construction of Matilija Dam and a pipe into Ojai Valley nearly exhausted the available bond funds, so a second dam and interconnecting pipeline were not constructed. Residents were initially unhappy with the dam, for its water conservation value was not realized because there were three years of drought following the completion of the dam in 1948. However, in the winter of 1951-52, there was a large storm that produced flood flows that filled the reservoir within hours. In the following years, the water supply benefits of Matilija Reservoir were realized as the project produced about 1,000 acre-feet per year. From 1948 through calendar year 1958, a total of 3,085 acre-feet of water from Matilija Reservoir was sold for beneficial use in the Ojai area, and 9,613 acre-feet were spread in the Ojai spreading basin.

By the time that Matilija Dam was completed, it become clear that additional water supply facilities would be needed to meet future demands in the watershed. In late 1948, VCFCD began a study that, when completed in 1951, recommended a 90,000 acre-foot reservoir on Coyote Creek with a canal conveying diverted surplus water from the Ventura River. In 1952, local residents formed the Ventura River Municipal Water District (now the Casitas Municipal Water District, or CMWD) which immediately invited the Bureau of Reclamation to conduct a water supply study in the watershed. A feasibility report was issued in 1954 for what was called the Ventura River Project, and involved construction of Casitas Dam, Robles Diversion Dam, and the Robles-Casitas Canal. Construction of the project was authorized by Congress in 1956, and the project was completed in 1959. Matilija Reservoir was an integral part of the Ventura River Project from its inception because it was used to regulate flows to Robles Diversion Dam, thereby increasing the yield of the Ventura River Project.

On January 1, 1959, the Ventura River Municipal Water District (VRMWD) assumed responsibility for the operation and related maintenance of Matilija Dam and pipelines to Ojai for the purpose of integrating their conservation capabilities with the Casitas Project. Flood flows were to be stored in Matilija Reservoir and later released for diversion to Lake Casitas in the Robles-Casitas Diversion Canal. As payment for rental of Matilija Dam for the agreed-upon 50-year operating period (1959-2009), VRMWD agreed to pay the remaining bonded indebtedness on the dam amounting to $2,388,750. Final payment was to be made on June 1, 1979, after 20 years of the 50-year agreement period.

1.2 Current Operations

VCFCD owns and maintains Matilija Dam, while Casitas operates the dam outlet works to maximize diversions at the Robles Diversion Dam under an agreement with VCFCD executed in 1954 and amended in 1958. The agreement ends in 2009. Casitas has responsibility for maintaining the outlet works, conduit, and associated water conveyance facilities at the dam.

Since the construction of Casitas Dam, Lake Matilija has been used to increase the yield from Lake Casitas as described below. Reclamation initially estimated that Matilija Reservoir would increase the safe annual yield of Lake Casitas by about 1,900 acre-feet per year. At this time, the estimated capacity of Matilija Reservoir is 930 acre-feet (J. Johnson, pers. comm., CMWD). Under its present condition, Matilija Reservoir contributes about 400 acre-feet per year of additional safe annual yield to Lake Casitas. This contribution will decrease in the future as the lake continues to be filled with sediments. It was recently estimated that the lake will have no active storage by the year 1999 after several years of high runoff and sediment loading or after a major wildfire in the watershed. Under a dry weather cycle, it is estimated that active storage would be present until the year 2010.

Water in Matilija Reservoir is temporarily stored each winter and released for diversion at the Robles Diversion Dam. The maximum release from Matilija Dam is 250 cfs. Releases are made from the 42-inch outlet works at the base of the dam. Periodic releases are made each year during the period January through April when flows in the river are no longer sufficient for diversion at Robles. Releases from Matilija Dam continue until depleted. Several releases occur during most winters, allowing diversions during receding flows and providing available storage in Lake Matilija for future runoff events.

Trespassers at the dam and Lake Matilija are frequent in the summer. VCFCD maintains the fences and gates around the dam; there are no fences around the lake. The Sheriff's Department conducts regular security patrols at and near the dam to exclude trespassers. Trails and access points to Matilija Reservoir are periodically checked by the Sheriff's Department to remove trespassers.

1.3 Structural and Operational Changes

The structure is a concrete arch dam with an average height of 190 feet and a crest length of 620 feet. The original spillway had 13 concrete cells with a concrete footbridge on top. The center six cells had crest elevations of 1,125 feet. The arch section varies in thickness from 8 feet at the original crest, to 35 feet at the base of the dam. The original reservoir capacity was about 7,000 acre-feet. Floods are passed over the crest of the dam onto the downstream concrete apron. The original dam had a 48-inch diameter sluice gate at the center of the dam a elevation 1,000 feet, and a 36-inch diameter outlet gate at elevation 1025 feet.

In early 1964, the State Division of Safety of Dams (DSOD) conducted its periodic inspections of Matilija Dam and noted cracking in several cells of the top five lifts of the dam arch. DSOD ordered the VCFCD to take concrete cores and perform sonic tests to evaluate the extent of deterioration in the concrete. On August 20, 1964, Bechtel Corporation (Bechtel) was authorized to perform a preliminary review of Matilija Dam for the purpose of evaluating the condition of the structure with respect to its safety.

The Bechtel (1965) report confirmed that concrete had deteriorated due to alkali-aggregate reaction with the cement. The deterioration was not uniform, and was most severe in the upper four or five lifts of the structure. Bechtel noted that arch dams can absorb the effects of local deficiencies in strength by transferring the loads to more competent portions of the structure. Hence, they concluded that the overall structural integrity of the dam was likely at an acceptable factor of safety. However, the upper portion of the structure had a safety factor below acceptable minimums, and the integrity of the dam would likely be reduced over time as the alkali-aggregate reactions continued.

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The alkali-aggregate reaction is caused by active silica components of certain types of aggregates and the sodium and potassium alkalies of the cement. The alkaline hydroxides of the cement attack the silicaceous mineral in the aggregate to form an alkali-silicate gel that damages the aggregate. The gel swells as it absorbs water, increasing internal pressures that eventually crack the cement paste. The reaction is controlled by selecting aggregates with low expansion potential and using cement with low alkali content. Most of the coarse aggregate used for Matilija Dam was derived from the San Gabriel River which contains a non-reactive aggregate. However, fine aggregates for the dam were obtained from the Santa Clara River near Saticoy which has more reactive aggregates.

Bechtel (1965) conducted a limited analysis of the stability of the dam foundation and abutments by examining the site geology, construction records, and dam movement data from previous surveys. Their investigations indicated that the quality of the entire foundation is poor, and that movement of the left abutment may indicate stability problems. In general, the dam had shown upstream movement since its initial filling, particularly along the left abutment. The Bechtel (1965) analysis was preliminary, and they recommended installation of strain gauges on the dam to measure movement under different loading conditions over many years to confirm this conclusion. Bechtel also noted that the spillway of the dam was undersized, and that the base of the dam could be susceptible to erosion from the maximum probable flood in its current condition.

Because there is no feasible way to repair the concrete damaged by the alkali-aggregate reactions, or retard the process, Bechtel (1965) recommended continued concrete testing and dam movement monitoring, then implementation of one of the following options depending upon the final assessment of abutment stability:

1. Remove and replace only those seriously deteriorated concrete cells in the upper lift if the rate of concrete deterioration is found to be very slow and the abutments are sound.

2. Lower the crest of the spillway in the center of the dam from 1,125 to 1,100 feet, then place a new cap on the rim for a final elevation of 1,105 feet. This would remove most of the badly deteriorated concrete, relieve stress on the abutments, and reduce maximum water loadings. This alternative should be considered if the dam and the abutments are judged to be sound after further tests.

3. Remove the dam if the whole mass of the concrete should developed an unexpectedly rapid rate of deterioration, or if the abutments are found to be critically unstable.

In March 1965, DSOD directed VCFCD to take immediate steps to further assess the problems with the dam and to consider actions necessary to reduce the uncertainty about the risk to life and property. VCFCD and CMWD decided to remove the top 30 feet of the center of the dam, which reduced the capacity of the reservoir from 7,000 to 3,800 acre-feet. It was decided that removal of only a portion of the top 30 feet (i.e., about 280 linear feet in the center of the dam) would provide necessary spillway capacity The work involved removing the original spillway, consisting of six concrete cells in the center of the dam that had spillway elevations of 1,125 feet. Essentially, a 280-

foot long notch with a spillway elevation of 1,095 feet was created, with a wooden footbridge over the notch. This work was performed in late 1965. In addition, a new system of yield measuring devices was installed and a program of surveillance was initiated. Finally, a new 36-inch diameter valve was installed on the existing 36-inch diameter outlet pipe.
In 1967, following the dam modifications, Bechtel conducted various tests were conducted to measure the movement of the dam under varying loads. The water level in the reservoir was raised and lowered in control stages over a two-year period to observed its effect on abutment movement. The measured deformations were extremely small and were not caused by stresses in the dam. The results from these more rigorous tests indicated that the abutment rock was considered adequately stable. Structural analysis assuming adverse temperatures, seismic, and silt loading conditions indicated that dam stresses would be within the capacity of the dam concrete.

In 1967, Bechtel also conducted additional concrete tests on the dam which indicated continued rapid deterioration in the remaining portions of the dam above elevation 1,095 feet. However, this deterioration presented no hazard to the structural integrity of the dam. Careful examination of the concrete below elevation 1,095 feet showed no evidence of concrete cracking, expansion, or deterioration.

Bechtel (1967) recommended continued monitoring of the dam by: (1) biweekly monitoring abutment movement though the use of meters or other devices; (2) measurements of survey plates on the face of the dam to detect upstream movement of the dam, on a 1 - 3 month interval; (3) periodic visual inspections of the dam conditions; and (4) testing of concrete every five years. Based on the Bechtel (1967) studies, the dam, in its modified condition, was determined to be sound by DSOD. The monitoring program recommended by Bechtel (1967) was subsequent implemented.

In January 1969, the maximum storm of record occurred in the Ventura River system and a second storm of similar magnitude followed in February. Runoff filled the reservoir, causing the dam to spill a total of 27 days during the 1968-69 water year. The storms deposited over 1,000 acre-feet of debris in the reservoir during the 1969 storm and further reduced the storage capacity to 2,473 acre-feet. Significant sediments were also deposited in the reservoir after the 1985 Wheeler fire.

In 1967 and 1970, VCFCD modified the intake structures of the 48-inch diameter sluice gate and the 36-inch diameter outlet gate, respectively, to raise the effective level of the intake structure above the elevation of the siltation.

In 1972, the International Engineering Company, Inc. (IECO) conducted a structural stability study of the dam. They found continued chemical expansion from the alkali-aggregate reaction on either side of the new spillway, above elevation 1,095 feet. The footbridge spanning the notch was determined to be unstable under earthquake conditions. IECO recommended expanded testing of the concrete, additional movement monitoring, and removal of the footbridge. Based on these recommendations, VCFCD conducted a study in 1975 on possible modifications to Matilija Dam. Based on this study, the following modifications were completed: (1) the footbridge was removed; (2) the 48-inch diameter sluice gate in the center of the dam was abandoned due to siltation; (3) the

42-inch diameter Howell-Bunger regulating valve at the sluice gate was relocated to the 36-inch diameter outlet.

1.4 Current Studies and Coordination with DSOD

DSOD has broad authority under the California Water Code over dams and reservoirs. For dams and reservoirs of a certain height and capacity, construction, modification, maintenance, operation, and removal are subject to DSOD approval. The agency has authority to inspect all dams and reservoirs, and to require all necessary actions by responsible parties to correct conditions that constitute a danger to life or property, to DSOD's satisfaction. DSOD requires all dam owners to keep operations and maintenance records, and to alert DSOD of any unusual or alarming conditions or circumstances. The agency regularly inspects all dams to determine their safety, and may require owners to conduct additional inspections and studies to further determine safety conditions.

The past modifications of Matilija Dam described above were conducted with the approval of DSOD. The agency conducts inspections of the dam every year or so, involving a physical examination of the dam and associated facilities, with an emphasis on monitoring the conditions of concrete on the face of the dam, such as the extent, depth, and width of cracking. If unusual conditions were noted, DSOD has requested additional information from VCFCD. All annual inspections by DSOD engineers are documented and filed. The last inspection occur in August 1996 at which time DSOD requested that VCFCD obtain concrete samples for testing in order to compare the condition of the concrete since the last concrete testing, which occurred in 1979. DSOD is currently reviewing the results of these tests. In early 1997, DSOD also requested that VCFCD conduct a engineering structural evaluation of the dam. Results of this analysis are expected in 1998. At this time, the dam is certified as safe by DSOD.

VCFCD conducts annual surveys of the dam to detect movement. These results are submitted to DSOD annually. VCFCD also conducts weekly inspections of the dam to detect any adverse conditions.

2.0 APPROACHES TO DAM REMOVAL

2.1 Methods for Dam Removal

Decommissioning a dam becomes an issue as dams age, and in some cases, because of environmental or economic considerations. For example, when projects become uneconomic to operate, decommissioning may be a viable option. In other cases, there may be a regulatory requirement to partially or completely remove a dam due to safety reasons. For example, the Federal Energy Regulatory Commission (FERC) declared a policy in 1994 that FERC can require decommissioning of a dam when a hydroelectric project is considered for relicensing.

Determining the feasibility of decommissioning is a complex process because it usually involves re-establishing the natural fluvial processes along a river where sediments have been impounded for many decades. In general, the issue of sediment removal and management is the single-most important consideration for dam removal. For example, the cost of sediment management for the proposed decommissioning of the Elwha River dams in Washington represents about 48% of the total costs, while the remainder of the costs are divided between environmental engineering (22%) and removal of structures (30%). In this section, the overall approach to dam decommissioning is discussed, as well as factors affecting the decision to remove a dam and the specific methods. Information for this section was derived primarily from Morris and Fan (1997) and ASCE (1997).

There are three major alternative methods for decommissioning a dam - leave the dam in place, partially remove the dam, or completely remove the dam. Dam removal can occur over a short or long period of time. The first approach is appropriate if the structure is sound and removal of the sediments would be cost prohibitive or would result in unacceptable environmental impacts. Partial removal of a dam would entail lowering or notching the crest, while leaving the base of the dam or abutments. The remaining structures would continue to have a hydraulic effect on the river, including retarding peak discharges and retaining upstream sediments. Complete removal is appropriate when the structure is unstable and cannot be repaired in place, or when there is a need to remove the sediment to reestablish natural river processes.

The approach to sediment removal and management will usually dictate what dam removal method will be selected. The four basic sediment management options are as follows (Morris and Fan, 1997):

1. Leave the sediments in place
2. Allow natural erosion to remove some or all of the sediments
3. Construct a channel through the deposits and stabilize off-channel deposits and maintained them in place
4. Remove all sediments by mechanical excavation or hydraulic dredging

The selection of an option will depend on factors such as cost; potential for downstream flooding due to sediment release; and impacts to downstream facilities, water quality, and aquatic habitat. Often, a combination of these methods may be used. A brief summary of options 2 through 3 is presented below.

Natural Erosion

This method is similar to the flushing technique used to periodically clean reservoirs of sediments. It has a low cost, but may result in severe environmental impacts downstream. Eroded fines can adversely affect fish and aquatic species, while coarse sediments can infill downstream channels and cause flooding. Sediment release can be controlled by removing the dam in stages to allow sediments to be eroded and discharged downstream in an incremental manner in order to minimize downstream impacts.

Natural erosion may not remove all sediments from a wide reservoir, but is effective in a narrow or gorge-type reservoir. Lowering the water level in the reservoir will create a channel-floodplain configuration in the area of sediment deposition. Revegetation of the sediment deposits on the floodplain will stabilize these deposits and allow them to remain in place.

The rate of dam lowering and sediment release will be determined by rate of inflow, erodibility of materials, and restrictions on downstream sedimentation to avoid impacts to aquatic systems and flood hazards. The amount and characteristics of the sediments will also vary with depth, and thereby affect the rate of each stage. In order to manage the erosion process, hydraulic modeling of the river system and reservoir is needed prior to the work.

Channeling and Stabilization

Sediment management by channeling and stabilization may be the last phase of a staged dam removal. The objective is to leave a significant amount of sediment in the reservoir, allowing the river to pass through a stabilized channel that will not erode the deposits. The procedure begins with draining the reservoir and removing the dam, followed by excavation of a channel through the sediment deposits. The design of the channel is critical for this method. The channel configuration must be stable or evolve into a stable configuration over time. The objective is to create a natural river configuration through the deposits using channel widths and slopes to produce a stable configuration rather using costly bank protection. However, it will be necessary to establish riparian vegetation on the floodplain to stabilize the deposits.

Complete Removal of Sediments

Complete sediment removal can be accomplished by dry land excavation or hydraulic dredging. The former method will require dewatering the sediments to allow access and handling, and the use of conventional earthmoving equipment. The latter method involves the use of clamshells, draglines, or a hydraulic dredge. Dredged materials will need to be dewatered.

2.2 Factors Affecting Feasibility of Dam Removal

There are several key factors that will affect the decision to remove a dam, as noted below:

- Water and Sediment Quality - Sediments in a reservoir may contain contaminants such as pesticides, mine wastes, and nutrients depending upon upstream land uses. Erosion of sediments from a reservoir may release these contaminants and adversely affect public health or aquatic systems. Erosion of fine grained sediments will adversely affect downstream aquatic species and habitats by increasing water turbidity, covering spawning gravels, and altering water temperatures.

- Fluvial Morphology - Dam removal affects the morphology of the fluvial system upstream and downstream of the reservoir. Sediments are deposited in streambeds upstream of a reservoir; hence, removal of the dam and sediments will cause upstream streambed degradation. Impacts below the dam can be substantial if a significant amount of sediment is released to the river system. Fine grained sediments are generally rapidly flushed through the system and the impacts are short-term. However, coarse-grained sediments move through the river a slower rate in a "sediment wave," often taking years to reach the ocean. The slow downstream migration of a sediment wave can cause flooding by raising the channel bed, causing extreme meanders or blocking tributaries.

- Regulatory and Legal Factors - The adverse downstream impacts of dam and sediment removal could preclude dam removal because such impacts may not be considered acceptable or in compliance with applicable local ordinances, state laws and codes, and federal laws and regulations. Dam and sediment removal in California would require permits from the Corps of Engineers, California Department of Fish and Game, and Regional Water Quality Control Board, and others. Laws and regulations protecting wetlands and water quality (e.g., Endangered Species Act, Clean Water Act, Porter-Cologne Act) may prohibit dam removal, or greatly restrict the rate and amount of sediment removal due to environmental considerations. In addition, downstream property owners would need assurances that there would be no loss of property, obstruction of drainage, or impairment of water rights from dam removal. Finally, flood control and transportation agencies may prohibit sediment removal by downstream erosion if eroded sediments would increase flooding and threaten bridges and floodplain development.

3.0 EXAMPLES OF DAM OR SEDIMENT REMOVAL PROJECTS

3.1 Introduction

There are over 75,000 dams in the United States, most of which are privately owned (58%). Only a small percentage are federally owned (3%) or locally owned (17%). The primary uses of impounded water are recreation (35%), farm ponds (17%), flood control (15%), and water supply (10%). The oldest dams date to the late 1800s, although most of the existing dams in the United States were built in the 1950s through the 1970s. In the past few years, there has been a marked increase in dam decommissioning studies and projects to address aging dams and reservoirs, as well as to restore fisheries or to avoid ongoing costly maintenance expenses. For example, in 1996 the Federal Energy Regulatory Commission (FERC) approved the removal of Edwards Dam in Maine and Stonach Dam in Michigan. In 1997, the Clyde Dam in Vermont was removed by FERC and work began on the removal of the Mounds Dam in Wisconsin. The 1992 Elwha River Ecosystem and Fisheries Restoration Act authorized the removal of the Elwha and Glines Canyon dams in Washington.

Ten case studies of dam decommissioning are summarized in American Society of Civil Engineers (ASCE 1997). The dams were located throughout the United States, ranged from 12 to 108 feet in height, and involved both earthen and concrete dams. Reasons for the dam removal included dam safety, economics, sediments, and fisheries. Both partial and complete dam removal were involved in these case studies. The methods to remove sediment included both dry excavation, erosion of sediment, and stabilization of sediments.

As the decommissioning and removal of dams becomes more frequent with time, there will be more and more examples of different methods to remove, in whole or in part, dams and sediments in a cost effective and environmentally sound manner. At this time, there are very few examples of dam removal that are "models" for addressing the issue at Matilija Dam. Most dam removal projects in the United States to date have involved much smaller dams along rivers with perennial flows. However, three examples are provided below to demonstrate the project-specific factors that must be considered when selecting a dam and sediment removal approach.

3.2 Rindge Dam

Overview

Rindge Dam was constructed in 1926 along Malibu Creek, about 2.5 miles from the ocean. It was built to store water for irrigation. Its original capacity was 574 acre-feet. Significant siltation occurred after its construction such that the reservoir was completely filled with sediment by the mid-1950s. The dam was declared non-jurisdictional by the Division of Safety of Dams (DSOD) in 1967. The dam is a concrete arch structure about 100 feet high, with an arc length of 175 feet at the crest. The thickness of the dam is two feet at its crest and 12 feet at the base. A gated spillway was installed in a rock outcrop adjacent to the right abutment. Estimates of the sediment behind the reservoir range from 800,000 to 1,600,000 cubic yards (Reclamation 1995).

In 1994, the California Department of Fish and Game (CDFG) retained the Bureau of Reclamation (Reclamation) to conduct an appraisal level technical evaluation of the removal of Rindge Dam to allow passage of steelhead trout upstream to historic spawning grounds. Three methods of dam and sediment removal were addressed. Each of these alternative methods are summarized below from Reclamation (1995).

Sediment Characteristics and Uses

Geotechnical testing by Law-Crandall (1993) indicated that the sediment is composed of the following materials, in deceasing order: sand and gravel (42%), silty sand (34 %), silts and clays (16%), and cobbles and boulders (8%). Sediments are more fine grained with depth and nearer to the dam. The transmissivity of the sediments decreases substantially with depth, such that dewatering the lower sediments from wells or drain outlets in the dam would be very slow and incomplete. There are localized high concentrations of organic material due to vegetation washing down the canyon during storms. Groundwater is within 10 feet of the ground surface. No contaminants are present in the sediments above applicable threshold limit concentrations.

Use of the sediments would require sorting into different size classes and removal of organic material Possible uses of the finer grained sediments include fill soils and liner or cover for landfills. Oversized rock and boulders could be salvaged for commercial landscaping, road construction, and channel improvements. Coarse grained materials would be suitable for beach sand replenishment. Lab tests on the sediment indicate that it is a poor quality aggregate that would not be economically viable as a commercial aggregate product.

Alternative 1: Mechanical Removal of Dam and Sediments

A temporary cofferdam would be installed to prevent streamflows into the work area and a pipeline would be installed to convey diverted flows around the construction site to the spillway. The dam would be removed by blasting 10-foot high lifts that would fall back into a trench on the upstream face of the dam. Self-loading scrapers and bulldozers would collect and convey sediments to a conveyer belt, which in turn, would dump into haul trucks. Sediments would be conveyed by trucks on public roads to a designated disposal site, which may include nearby beaches or landfills. Most of the excavation would occur under dry conditions following dewatering procedures. However, even after dewatering, the fine grained materials will retain considerable water that would adversely affect equipment usage. Hence, special excavation equipment such as a dragline would likely be necessary, as well as mud mats for equipment movement.

Dewatering would be accomplished by a combination of wells and drain holes drilled in the dam. The creek would need to be diverted around the sediments during dewatering to prevent recharge. The slopes surround the dam and reservoir are very steep. Construction of the reservoir has raised groundwater levels in these slopes and the sediments have buttressed the adjacent slopes. Removal of the sediments and dewatering may adversely affect the stability of these slopes if this process is too rapid, causing a build up of hydrostatic pressure in the canyon walls.

The total cost of this alternative is estimated at $17.5 million based on a 8-mile-long haul route to Calabasas Landfill and a two-year construction period.

Alternative 2: Engineered Landfill in Canyon

Under this alternative, sediments would be mechanically removed and transported downstream to an engineered fill slope in Malibu Canyon. Excavation and dewatering would be the same as for Alternative 1, but the sediments would be transported to the fill site by conveyor belt. At the fill site, sediments would be spread and compacted with 2:1 side slopes and rock armoring. Two fill slope locations have been identified, 0.75 and 1.25 miles downstream. The costs of this alternative were estimated at $12.8 million. This alternative would be completed in one year due to longer work hours because there would be no trucks on public roads.

Alternative 3: Removal of Sediment by Stream Erosion

Under this alternative, the dam would be removed in six lifts over a number of years and sediment behind the dam would erode from natural streamflow. Temporary berms would be constructed with sediment excavated from behind the dam to divert river flows. River flows would be diverted so that removal of lifts can be accomplished under dry conditions. Once a lift has been removed from one half of the dam, the river would be diverted to that area to erode the uncontained sediments. The feasibility of this alternative cannot be determined without a sediment transport modelling study to determine if eroded sediments would be transported to the ocean, about 2.5 miles downstream. Estimated costs of this alternative are $4 million. The period of time to accomplish the sediment removal could range from 8 to 18 years.

Conclusions

The study concluded that combining alternatives would be most desirable rather than selecting one single method. For example, marketable sediments could be sold, while undesirable materials could be disposed in an engineered landfill. Significant environmental impacts are associated with all three alternatives. Alternatives 1 and 2 would have significant pollutant emissions from equipment and haul trucks. Alternative 1 would also have significant traffic and noise impacts from haul trucks on public roads. Alternative 3 would have significant impacts on aquatic habitat downstream due to sedimentation. The study concluded that Alternatives 1 and 2 were most desirable, but relatively expensive. Additional engineering and environmental studies are necessary to estimate costs and environmental impacts.

Current Status of Study

A Rindge Dam Task Force was established to sponsor studies on the removal of the dam and restoration of a steelhead run. The committee is comprised of various local, state, and federal agencies involved in the larger Malibu Creek Watershed Management Plan. The Task Force secured the funding for the Reclamation (1995) study from a special congressional appropriation. The geotechnical study (Law-Crandall, 1993) was funded by the CDFG. A second feasibility level study will be conducted by the Corps of Engineers in 1998, also funded by a special congressional appropriation.

3.3 Elwha and Glines Canyon Dams

The Elwha and Glines Canyon dams are located on the Elwha River in the Olympic Peninsula of Washington. Elwha Dam is a concrete dam about 108 feet in height that impounds about 8,100 acre-feet. Glines Canyon Dam is also a concrete dam, about 210 feet high with 40,000 acre-feet capacity. Both dams were built for hydroelectric power over 50 years ago. Fish passage structures were not installed at either dam. During the FERC relicensing process in the 1980s, significant controversy arose over the lack of fish passage for anadromous fish. The controversy led to litigation, and eventually Congress enacted a legislative settlement call the Elwha River Ecosystem and Fisheries Restoration Act of 1992 which called for restoration of the anadromous fisheries and riverine ecosystems (among other actions).

In 1994, the Elwha Report was issued by the Department of the Interior that identified dam removal as the only alternative that would meet the goals of the Act. Draft and final EIS documents for the dam removal project were issued in 1996. For Elwha Dam, the reservoir will be drained and the river directed through a newly constructed channel in the bedrock to allow removal of the concrete under dry conditions. Following removal, the river will be diverted to its historic location. In contrast, the lake behind Glines Canyon Dam will be lowered 80 feet, and the dam removed to this new elevation. Then the river will be diverted through progressively deeper notches in the dam cut by blasting.

The total cost of the program is $111 million, which include all costs of ecosystem and fisheries restoration. The cost of dam removal alone is estimated at $33 million. Water quality, wildlife, and flooding mitigation would be about $37 million.

There is about 8.5 million cubic yards of course sediments and 9.2 million yards of fine sediments behind the two dams, for a total of 17.5 million cubic yards. The proposed approach is to excavate a new river channel through the existing sediment deposits in the reservoirs, and to store the excavated sediments on top of the existing sediments in other areas of the reservoirs. Excavation and sediment stabilization would occur in the dry period. A dragline would be used to excavate the new channel, while conventional earthmoving equipment would be used to move sediments once drawdown has occurred. Trucks would haul the sediments to terraces on the floodplain where they would be revegetated. Most of the fine sediments released during the drawdown are expected to flushed to the ocean, while coarse sediments will be trapped in pools during the drawdown and retrieved. Excavation and terracing of sediments will require about three years. It is estimated that about 5 to 8 million cubic yards of sediments will be flushed downstream. Stabilization of the sediments on the floodplain will require 5 to 8 years. Full restoration of fisheries is estimated to require about 20 years.

3.4 San Gabriel River Watershed Sediment Management Project

Los Angeles County Public Works Department owns and operates three dams located along the San Gabriel River (Cogswell, San Gabriel, and Morris reservoirs) for flood control and water conservation purposes. These reservoirs have accumulated significant amounts of sediments since their construction in the 1930s, such that their capacity for storing flood waters has been reduced and downstream urban areas are subject to increased flooding.

Several sediment management methods were identified to remove sediments from the reservoirs at the same rate as the inflow of sediments, estimated to be about 787 acre-feet of sediments per year (or 1.27 million cubic yards per year). Major alternatives included: (1) sluicing sediments from one reservoir to another by draining a reservoir in the spring or summer, allowing sediments to be carried out a sluice gate, while mechanically agitating sediments in the reservoir to increase the amount of sediment removed; (2) dry excavation of sediments in the reservoir in the summer when water levels are down, then hauled away as commercial aggregate or to an engineered landfill site; (3) flow assisted sediment transport in which winter storm flows are passed through the sluice gate of the upstream reservoir to emulate sediment-laden storm flows and carry sediments downstream; and (5) hydraulic dredging or dry excavation, then conveyance to disposal site by conveyor system where the material is processed and hauled away as commercial aggregate. Unit costs for the various alternatives ranged from $4 to $5 per cubic yard (Engineering Science 1992).

The impacts of the various alternatives were evaluated in a draft and final EIS/EIR (County of Los Angeles and Corps of Engineers 1994). Significant impacts included traffic, noise, and air quality impacts from haul trucks and earthmoving equipment; increased downstream turbidity; degradation of aquatic habitat and fisheries; and loss of riparian habitats.

4.0 CONSIDERATIONS REGARDING REMOVAL OF MATILIJA DAM

4.1 Introduction

The partial or complete removal of Matilija Dam for purposes of improving conditions for steelhead along the Ventura River, or for any other purpose, would represent a very ambitious, expensive, and controversial endeavor. The removal of the dam would require considerable engineering and planning studies, institutional agreements, construction work, and trade-offs between short-term environmental impacts and long-term benefits associated with an improved steelhead population in the watershed. It is likely that many agencies would be involved in order to secure funding and accomplish the work. In addition, the proposal would require funding from state or federal agencies would be needed and widespread public support from the Ojai Valley, State Route 33 communities, and the Ventura area in general.

Clearly, removal of the dam would be a daunting effort for local public agencies and the affected communities. Hence, there must be a clear understanding of the benefits of this proposal, and assurances that it can be accomplished in a cost-effective and environmentally sound manner, taking into account issues of public safety, property rights, and the wise use of public funds.

A preliminary assessment of the feasibility of removing Matilija Dam for the steelhead purposes of restoring access to upstream habitat for steelhead is presented below. It includes a consideration of the engineering, hydraulic, environmental, and financial constraints associated with removing the dam and the impounded sediments. The most feasible approach to dam removal is also described, based on available information and reasonable assumptions. Finally, a process is described below to more fully consider the proposal to remove the dam and to formally evaluate its feasibility in a comprehensive and scientific manner.

4.2 Objectives and Benefits of Dam Removal

Removal of Matilija Dam has been proposed by various interested parties as a measure to increase the steelhead population in the watershed by returning those fish to the historic spawning grounds along Matilija Creek, Upper North Fork of Matilija Creek, and Murrietta Creek, most of which are located in the National Forest. In order for this proposal to be considered seriously by all agencies involved, there must be compelling reasons why it is necessary, and what type of benefits would be realized by the steelhead population along the Ventura River. For example, the motivation for dam removal may be to:

> Reestablish the historical steelhead distribution as a voluntary environmental enhancement of the watershed.
>
> Increase the number of steelhead along the Ventura River to sufficient numbers to meet recovery goals for the watershed, or to ensure that recovery goals of the South-Central ESU are met, thereby making progress towards delisting the species.

The first reason is primarily due to local desires, while the second reason is driven by regulatory requirements. These reasons would be given greater weight if there is a clear regulatory requirement under the ESA, and/or if there is widespread public and agency support over a broad geographic area. The incentive to remove the dam for steelhead purposes will be directly related to both regulatory requirements and broad public support.

The proposal to remove Matilija Dam for steelhead purposes must also be accompanied by clear and compelling scientific analysis and data on the ecological benefits of the action for the species in the watershed and in the Southern California Evolutionary Significant Unit (ESU). The Ventura River Steelhead Restoration and Recovery Plan indicates that Matilija Creek was a significant historic spawning tributary in the watershed, but that spawning habitat has been degraded along much of the mainstem of Matilija Creek since the construction of Matilija Dam. Suitable spawning and rearing habitat reportedly occurs in the upper mainstem and tributaries to Matilija Creek. More information on the potential amount and quality of steelhead habitat above Matilija Dam and the year to year variability of habitat conditions would be needed to support any proposal to remove the dam. The benefits of opening this tributary to steelhead use would also need to be considered in light of other improvements in the watershed for steelhead that would be less costly and less environmentally damaging.

It should also be noted that removal of the dam for steelhead passage would also require providing a fish ladder and fish screen at Robles Diversion, and ensuring adequate passage from the ocean to Matilija Creek during years with suitable flows along the mainstem. Chapter 2 of the Steelhead Restoration and Recovery Plan identified that steelhead probably have access to the upper watershed in approximately 50 to 65% of the years. Factors that may adversely affect upstream or downstream passage along the mainstem (described in the Steelhead Restoration and Recovery Plan) would need to be corrected. In addition, human activities in the Matilija Creek watershed on both private land and in the National Forest that adversely affect steelhead would need to be addressed to ensure successful use of Matilija Creek. For example, the impact of residences, human intrusion, septic systems, pets, invasive weeds and predators, off-road vehicles, and illegal fishing in the Matilija Creek watershed would need to be removed or minimized. Hence, removal of the dam for the benefit of steelhead will require an integrated program that considers the whole of the watershed, and does not focus solely on the dam.

4.3 Constraints on Dam and Sediment Removal

As noted in Section 2.0, there are several methods to partially or completely remove a dam and its impounded sediments. The major factors affecting the choice of methods for Matilija Dam are listed below:

- Specific requirements for fish passage - If the primary purpose of the dam removal is to allow fish passage over the dam to allow spawning in the upper tributaries of Matilija Creek, it may not be necessary to remove the entire dam. Instead, the dam and sediments could be lowered to a certain height from the channel invert below the dam, then a fish ladder could be installed to provide passage over the remaining vertical lift. This alternative would require careful consideration of the effectiveness of fish passage structures (both upstream and downstream passage), site-specific conditions below the dam to provide for a successful passage structure, and the maintenance and operations requirements of such a structure. At this time, there is no information on the maximum vertical height of a modified Matilija Dam that would allow the use of a fish passage structure.

- Construction work area and access requirements - Removal of the dam, and under certain scenarios, removal of the sediments, would require heavy equipment and haul trucks. Access to the dam is along a very narrow road that connects to SR 33 at a small intersection without a left turn lane. The reservoir would be accessed along Matilija Road, which is also very narrow and unsuitable for heavy trucks. In addition, Matilija Road connects to SR 33 by a steep and narrow hairpin turn. Finally, there is very little work area around the reservoir for sediment removal and processing because the reservoir is situated in a steep and narrow canyon. These conditions may severely limit the dry excavation and hauling of sediments.

- Downstream flooding - Eroding the sediments from the reservoir through progressive lowering of the dam would flush sediments downstream, and possibly cause increased flooding due to a raised channel bed, obstruction of tributary flows, or creation of in-channel sand bars. The location and magnitude of this potential effect cannot be predicted without sophisticated sediment transport modeling studies. However, the potential for this impact is high because of the close proximity of structures and houses along the river, particularly near the dam, and at Camino Cielo, Live Oaks Acres, and Casitas Springs.

- Downstream diversions - Flushing of sediments from the reservoir would also adversely affect the operations of Robles Diversion Dam which diverts water in the winter to the Robles-Casitas Canal for storage in Lake Casitas for water supply purposes. Diversions at Robles can only occur under certain water level, discharge, and turbidity conditions. The passage and possible deposition of sediments at Robles could render this facility inoperative for extended periods of time, and would require continual clearing of sediments from the diversion basin.

- Amount of sediments - At this time, there are no estimates of the amount of sediments in Matilija Reservoir. The reservoir capacity after the modifications in 1965 was 3,800 acre-feet, and the remaining capacity in 1997 is estimated at 930 acre-feet. Hence, the reservoir space is occupied by 2,870 acre-feet of sediments, or about 4.63 million cubic yards (one acre foot equals 1613 cubic. yards, so 2,870 acre-feet equals 4.63 million cubic yards), not accounting for voids filled with air or water. Additional sediments have accumulated along Matilija Creek upstream of the reservoir due to channel aggradation. There are no estimates of this amount, which could exceed a million cubic yards. For example, if one assumes that there is an average of four feet of sediments along 10,000 linear feet of Matilija Creek upstream of the reservoir, with an average width of 500 feet, the total sediment amount would be 740,740 cubic yards. Hence, the amount of sediment to be removed for a total dam decommissioning could exceed 5 or 6 million cubic yards.

- Nature of sediments - The nature and characteristics of the sediments in the reservoir will have a significant effect on the type of sediment removal method and cost. If the sediments have suitable grain sizes and other properties, they may be marketable as concrete aggregate, engineering fill, speciality sands and gravels, and decorative boulders. However, if the material is mostly fine grained with no engineering properties, or if there is significant amounts of boulders and organic matter, then removal and processing of the sediments may not be economically attractive. The sediments at Matilija Reservoir have not been tested for size classes, or spatial distribution. Hence, this constraint or opportunity is unknown.

- Opportunity for off-site sediment disposal - The potential use of the sediment for beach sand or for commercial aggregate are unknown due to the lack of information on the sediment characteristics. However, the remote location of the reservoir may have an overriding influence on the ability to use the sediments elsewhere. Transport of the sediments to the beach and to primary aggregate markets would require haul trucks along SR 33, a very narrow road with high traffic volumes (that include a variety of local residents, commuters, and industrial traffic) and several sinuous curves and dangerous intersections. In addition, there are many commercial and residential areas located along the highway frontage. Hence, significant haul truck traffic along SR 33 for extended periods (i.e., potentially years) may be unacceptable based on traffic safety and volume concerns, as well as noise and air quality concerns by the community.

- Opportunity for near-site sediment disposal - The reservoir is surrounded by steep mountains with numerous narrow side canyons. There are no large side canyons with flat or low-gradient hillsides where sediments could be placed in an engineered landfill. The nearest potential location is about one half mile downstream of the dam, at the base of the hills on the west side of the river between Camino Cielo and Kennedy Canyon. The amount of sediment that could be placed on the lower portion of this hill above the river is unknown. The lack of several potential sediment disposal sites near the reservoir may limit sediment removal options.

- Fluvial Characteristics of the Ventura River - The Ventura River has one of the highest sediment yields in southern California due to its steep gradient and high sediment production from the mountains, particularly after wildfires. Matilija Reservoir is located in the steeper part of the watershed where water and sediment are produced. Downstream of the dam, the river flattens and sediments are temporarily stored, then transferred during large storm events to the mouth of the river (Dames & Moore 1992). The river channel is considered relatively unstable due to the steep gradient and bankful discharge, and is characterized as a braided channel below Matilija Dam. There is a tendency for braided channels to fill with sediment on the rising stage of a flood, then scour on the receding stage. Hence, channel capacity is reduced at the peak flood stage. This characteristics would suggest that flushing of sediments downstream must be carefully controlled to not exacerbate a fluvial system that is naturally prone to sediment-related flooding.

4.4 Potential Dam and Sediment Removal Scheme

Based on the above constraints and the information presented in Section 3, the following scheme may represent the most feasible approach to achieving the objective of providing fish passage over Matilija Dam:

- Progressively lower the dam while creating a meandering channel through the reservoir area and stabilizing the floodplain on either side of the channel. Then flush sediments downstream in a highly controlled manner in order to minimize impacts to aquatic habitat, flood hazard conditions, and diversions at Robles. Lower the dam and channel to the maximum elevation suitable for installation of a fish passage structure, then stabilize the dam, channel, and reservoir floodplain. Construction of the channel would require both hydraulic dredging and dry excavation. Sediments would be sorted and processed on-site, with a small amount exported for beach sand or commercial uses, while other materials would be used for bank stabilization or disposed in an upland area purchased for a permanent landfill. The entire process may require decades to accomplish due to the great costs and the need to slowly flush sediments. The greatest unknowns associated with this scheme are the amount of sediments that need to be removed, the feasibility of a fish passage structure at the modified dam and the ability to stabilize the floodplain in the reservoir. The costs, engineering feasibility, and environmental and social acceptance of this scheme are unknown.

The presentation of this scheme is not an endorsement of this approach, nor a scientific- or fact-based determination of the most suitable or feasible method of dam and sediment removal. Instead, this scheme represents a preliminary approach that appears suitable based on the various known constraints and the overall objectives of dam removal. Collection of more data and completion of key engineering and environmental analyses are likely to identify new approaches. The costs of the above approach cannot be estimated at this time because of the numerous uncertainties; however, it is likely to require tens of millions of dollars.

4.5 Steps to Further Evaluate Dam and Sediment Removal

If the removal of Matilija Dam is considered further by agencies and parties interested in steelhead restoration, a series of studies should be implemented in a phased and incremental manner to determine if dam removal is feasible and acceptable. A series of narrowly focused investigations should be completed on key issues that could represent fatal flaws. If one of these analysis indicate that dam removal will not achieve the desired effect, or is infeasible or otherwise unacceptable, then the proposal should no longer be considered. The recommended investigations are as follows:

1. More precisely evaluate the amount, location, and quality of spawning and rearing habitat above the dam, and assess the benefits of this habitat for the steelhead population along the river and in the Southern California ESU

2. Conduct an investigation on the type and height of a fish passage structure for a shorter Matilija Dam

3. Conduct field tests of the sediments in Matilija Reservoir, and estimate the amount of sediment by use of old topographic maps

4. Seek outside funding for continued studies through state or federal sources, including Congressional appropriations

5. Investigate the availability of suitable sediment disposal sites near the reservoir, or in downstream areas

6. Conduct a sediment transport study for the river system to predict conditions suitable for sediment flushing from Matilija Reservoir; develop topographic maps of the reservoir and river channel

7. Conduct an engineering feasibility study on dam and sediment removal methods; identify and rank alternatives; estimate costs; coordinate with permitting agencies

8. Conduct an environmental impact assessment of alternative methods; conduct public outreach program to elicit opinions and concerns

9. Seek funding from outside sources for implementation

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VENTURA WATERSHED ANALYSIS -- FOCUSED FOR STEELHEAD RESTORATION
LOS PADRES NATIONAL FOREST
OJAI RANGER DISTRICT
July 1997

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I. INTRODUCTION

Southern California steelhead populations have decreased to less than 5% of their historical size and range and are in immediate danger of extinction (Nehlsen et al. 1991). The Ventura River once supported runs of several thousand anadromous steelhead (Clanton and Jarvis 1946) but numbers have dwindled to less than a few hundred, at best.

Steelhead are currently being reviewed by the National Marine Fisheries Service for listing under the Endangered Species Act. The USDA Forest Service (1995) is operating under interim National "PacFish" direction incorporated into the Forest Land and Resource Management Plan as part of a Riparian Conservation Strategy (USFS 1994). Los Padres National Forest is in the process of establishing "Riparian Habitat Conservation Areas" (special management zones), applying new standards to projects and ongoing activities, and managing to meet specified habitat objectives so as to lead to steelhead recovery. Watershed analyses are required in order to determine the most effective approach to managing for steelhead restoration. A coalition of various agencies have also initiated a Ventura River Steelhead Restoration and Recovery Plan with the goal of identifying and better coordinating actions which will restore steelhead while maintaining opportunities for ongoing and new public and private human activities. This report discusses results of a watershed analysis conducted with the primary goals of meeting PacFish direction and providing timely information and recommendations for the multi-agency Steelhead recovery planning effort.

II. THE SETTING

The Ventura River basin is situated along the southern California coastline less than 60 miles to the north of the Los Angeles metropolitan area (Figure 1). The city of Ventura is located near the Ventura River mouth and estuary.

The Ventura River basin encompasses a total of 577 km^2 (142,000 acres) and is composed roughly of half Forest Service lands (284 km^2) and half private lands. Private inholdings compose less than 7% of the area within the Forest boundaries. Over 95 km^2 (17%) are designated as Wilderness encompassing 89 miles of stream. Some 30 miles of the upper Main Fork Matilija and it's tributaries are designated as "Wild and Scenic Rivers". (Figure 2)

The mainstem of the Ventura River spans 31 miles from headwaters (upper Main Fork Matilija Creek) through the Main Fork Matilija and the Ventura River proper. Major subwatersheds with substantial Forest Service lands include in descending order of area: North Fork Matilija, Coyote, San Antonio, Upper North Fork, Gridley, Fall, and Murietta (Figure 3).

North Fork Matilija Creek runs parallel to Highway 33 through Wheeler Gorge in the lower reaches. Human use recreational and residential use is intense through this section. The upper reaches are less impacted, with denser stream shading and habitat diversity. Coyote Creek flows through a upper narrow bedrock and boulder lined cascade section, a mid lower gradient area of windthrow alder, and a lower moderate gradient and open reach before entering Casitas Reservoir. Only the headwaters of San Antonio Creek are on Forest Service lands. Gridley Creek flows through upper steep boulder cascade canyon reaches before entering private orchard lands and flowing into San Antonio Creek. Murietta Creek flows through dense alder thickets in the upper reaches, picks up flow from a side tributary in a more open middle section that has been impacted by past road related landslides, and may go subsurface in the lower less vegetated moderate gradient section before joining the mainstem Matilija Creek. Upper North Fork Matilija headwaters are boulder/bedrock cascades and step pools with good shading within a narrow canyon. The middle section is a more open lower gradient and wider section of shallow pools and riffles. Lower sections are steeper boulder/bedrock step runs and pools within a narrow canyon. The mainstem Matilija flows through upper steep narrow canyons into a middle section of moderate gradient bedrock dominated pool and riffle sequences. The lower sections of the mainstem are low gradient, wide, open, and shallow from the confluence of the Upper North Fork to Matilija Reservoir.

III. HISTORICAL CONDITIONS

Prehistoric conditions are difficult to determine. Analysis of sediment core samples from the Santa Barbara channel indicate that prior to 1500 C.E. Fire occurred less frequently but in greater intensity and to a wider extent than in the last century. Fire has likely always been a major formative factor of the watershed. Local geology also suggests that the landscape has undergone intense periods of uplift, channel incision, and landslides.

Historically, steelhead (*Oncorhynchus mykiss*) were a common inhabitant of California coastal streams as far south as Baja. The Ventura River supported a substantial steelhead run of at least 2,000 to 3,000 spawning fish (Clanton and Jarvis 1946). Historical accounts do not differentiate between steelhead and rainbow trout creating difficulty in determining the extent and magnitude of early anadromous runs. Newspaper articles of the late 1800's repeatedly mention the large angler catches from through out much of the length of the mainstem Ventura River (Appendix A). Flows were apparently adequate to support both resident and anadromous fish through out most mainstem reaches except during drought years. Sections of the mid to upper Matilija Creek are thought to have been the primary spawning habitat representing over half of the historically used habitat (Moore 1980). Approximately half of the river basin perennial and seasonal flowing streams may have once supported anadromous steelhead (Figure 4).

Other fish species native to the Santa Clara basin included Pacific lampreys, Santa Ana suckers (*Catostomus santaanae*), arroyo chub (*Gila orcutti*), and three-spine stickleback(*Gaasterosteus aculeatus aculeatus*). Pacific lamprey (*Lampetra tridentata*), were usually found in association with steelhead. Adult lampreys migrated upstream at the same time period and utilized the same spawning riffles as steelhead. Unlike steelhead, however, lamprey only spawn once and die in large numbers at the spawning grounds. Such die-offs must have been a seasonally significant food source for scavenging wildlife (including the grizzly bears that were once common in the area) and a important nutrient input to small tributary streams.

Santa Ana suckers and Santa Ana speckled dace, *Rhinichthys osculus*, historically inhabited the larger coastal streams throughout southern California (Swift et al. 1993). It is not clear that suckers and dace were native to the Ventura River basin, although they were inhabitants of the nearby Santa Clara River.

Arroyo chub, *Gila orcutti*, were historically endemic to the Los Angeles River basin (Swift et al. 1993) and may have been a early introduction throughout much of southern California. If present, chubs may have been a significant food source for migrating or held-over adult steelhead.

Three-spine stickleback, *Gasterosteus aculeatus*, were native to many of the streams of southern California (Swift et al. 1993). The unarmored three-spine stickleback was the native form in the nearby Santa Clara River. The partially armored variety was native further north. Intercrossed forms may have inhabited the Ventura River.

Several species of sculpin (staghorn sculpin *Leptocottus armatus*, prickly sculpin *Cottus asper*) and tidewater goby (*Eucyclogobius newberryi*) coexisted with steelhead and were native to the Ventura River lagoon and estuary. Sculpin may also have inhabited the mainstem but were not likely to have extended far into the upper basin and tributaries. Neither of these species interacted with steelhead to any great degree, except possibly as a food source for migrating adults.

Chumash Indians have inhabited the Ventura River basin for over 4,000 years. The Chumash likely had minimal impact on the landscape and resources. Several large villages were located in the lower coastal portion of the watershed. The primary use of the upper watershed was in dispersed hunting and fishing camps. Prior to the late 1700s Chumash were known to burn sage scrub and grasslands but not chaparral. It is thought that some of the prescribed fires would have escaped into chaparral however, perhaps altering vegetation patterns and fire intensities or intervals.

Grazing and vineyards were the most noticeable alterations associated with the Spanish missions in the 1700s and the Spanish rancheros in the early 1800s. Vineyards and intensive farming rapidly spread through out the Slower Ventura River Valley. During this period, grazing may have been heavy within portions of the watershed reducing grassland fuel loads. With the decline in the Chumash population, prescribed burning was no longer practiced. Historical accounts of 1793 describe chaparral stands as continuous, heavy, and decadent. It is not clear how fire patterns were affected during this period.

Homesteading began in earnest in the late 1800s, as did small hard rock mining operations and oil exploration. Grazing may have declined around the turn of the century and could have been a contributing factor to fuels build up and later major fires. During this period, ranches and small communities began to divert surface flows from the mainstem Ventura River. As the number and volume of these diversions increased, impacts on steelhead increased by reducing available instream water and habitat and by the high mortality of young fish diverted into unscreened water conveyance systems. Some of the structures associated with these diversions also may have at least partially blocked upstream steelhead migrations. The Foster Park Diversion in the lower mainstem Ventura River was completed in 1906. (Appendix B)

As populations increased, so did numerous non-native species. Carp (*Cyprinus carpio*) were introduced to local farm ponds and irrigation ditches in the late 1800s (Ventura Free Press, January 13, 1883). Brook trout (*Salvelinus fontinalis*) were brought in from the eastern United States by railroad and transported on horseback into many locations within the area (Ventura Free Press, January 4, 1882). Brook trout introductions may not have been successful, as there is no mention of brook trout being caught around the turn of the century. Brown trout were also introduced in the 1930's. Both brook and brown trout likely did not do well in this area since they are fall spawners that require cooler water temperatures, cleaner gravels, and more constant water flows. Experimental stocking of Atlantic salmon (Ventura Free Press, February 23, 1878) and "Lake Tahoe trout" (=kokanee salmon?) may also have taken place (Ventura Star Press, August 1, 1887), perhaps explaining the reports of what locals called "dog salmon" (Henke 1995). Stocking of non-native rainbow trout (usually domesticated varieties of more northerly and interior fish) began in the 1890s (Ventura Free Press, September 15, 1893) diluting native genes and the long term viability of native steelhead stocks. Stocking of non-native trout reached a peak around the turn of the century. In spite of continued stocking efforts well into the 1960's, angler catch rates and observed fish densities seemed to decline.

Steelhead transplants were also from those "rescued" from above newly built reservoirs both within and outside the Ventura River basin. Thousands of steelhead from the nearby Santa Ynez River were stocked into Matilija and Santa Ana Creeks between 1938 and 1944 (Titus et al 1994).

Beaver were introduced to the region sometime after 1917. It is not clear to what extent beaver may have inhabited and influenced the Ventura River. If beaver were present they may have altered habitat by removal of trees, widening of channels, and increasing of summer water temperatures. Beaver dams likely did not block upstream steelhead migrations as the dams would regularly washed out during winter storms. Regionally, beaver declined in the 1950s due to trapping and flooding.

As more people moved into the area and populations grew over utilization of the resource became a problem. Steelhead were likely taken as bycatch in commercial seining operations within the ocean and lagoon (Ventura Free Press 1876). Recreational and subsistence fishing also had a noticeable impact. Local newspapers bragged about the taking of hundreds of "trout" in a couple hours of fishing (Ventura Free Press, February 9, 1878). Matilija and other easily accessible drainages were the first to suffer the consequences of severe overfishing.

Fire suppression activities began in earnest as early as the 1920s. Thereafter, the first documented major fire occurred in 1932. The Matilija fire of 1983 burned 3,900 acres within the watershed and was noted as resulting in accelerated erosion that continued for at least a decade (USFS files). Woody debris washed downstream causing log jams that temporarily trapped sediment only to break loose and cause severe downcutting and lateral stream bank erosion with each successive storm. Fires altered riparian vegetation, often from mid or late seral alder and cottonwood to early seral alder or willow thickets. (Appendix B)

Inadequate flows appeared to be a noticeable problem in the 1940s. Increasing agricultural and municipal water demands expanded water diversions. Many water diversion structures were potentially impediments to upstream and downstream steelhead movements. Most water diversions were unscreened causing the loss of countless steelhead juveniles and smolts.

From what few accounts that are available, steelhead appeared to begin their most precipitous decline in the late 1950s. The Matilija Dam completed in 1948, and Robles Diversion Dam and Casitas Dam completed in 1958, effectively cut-off steelhead access to over 50% of their historical spawning habitat. These dams also captured much of the supply of sand and gravels and began a process which has drastically altered downstream channels and floodplains.

Road building, maintenance, and use, has also had an effect on steelhead and stream corridors. Many of the present day access roads were built around the turn of the century. Highway 33 (Maricopa Highway) was constructed in the 1930's. As continues to date, lengthy highway sections run parallel and impinge upon the North Fork River corridor greatly influencing riparian habitat, the floodplain, channel morphology, and water quality.

Comparisons of historical photos to present day conditions does not indicate a fundamental change in channel morphology although bedload and riparian vegetation has changed over time (Appendix C). Many of the historical photos were taken after humans had already altered the landscape. Other photos were taken shortly following a fire or flood and serve to illustrate that the only constant is change. Stream channels successively fill and scour, large boulders move downstream, logs are present either as massive debris jams or small clusters left on the floodplain, and riparian vegetation fluctuates from dense and continuous to sparse and discontinuous.

IV. CURRENT CONDITIONS

Steelhead and Rainbow Trout

The Ventura River anadromous steelhead population continues to be severely depressed. While it is likely that steelhead pass upstream without detection, it is certain that their numbers are low and well below the 200 fish threshold associated with a high risk of extinction (Franklin 1980). There have been no confirmed reports of anadromous adult steelhead in the Ventura River since 1993 and only a few scattered reports since the 1960s (Appendix A).

Southern steelhead and rainbow trout are of the same species and potentially intermixing populations. As has been observed in other steelhead populations (Shapovalov and Taft 1954) resident populations may coexist and geographically overlap with the anadromous form. Steelhead and rainbow trout eggs, fry, and juveniles can not easily be differentiated. They can conclusively be identified as "steelhead" when they go through the smoltification process which prepares their system for salt water and gives them the characteristic sleek silvery appearance. Smoltification probably occurs when fish achieve a length of 15 cm within the first or second year (Moore 1980). Smolts move downstream with receding storm flows in April through June (Shapovalov and Taft 1954).

Southern steelhead have adapted to their unpredictable climate by retaining the flexibility to remain landlocked through many years or generations before returning to the ocean when conditions allow (Titus et al. 1994). Such traits and behaviors appear to be inherited and there could very well be differences in the extent of anadromy between different river basins and even within a single drainage (Waples 1991). Research into the movements of inland trout has also shown that different populations have vastly differing degrees of mobility ranging from a few feet to 50 miles within a year (Schmal and Young 1994). Both anadromous and resident trout have likely adapted to periodic flood extremes and droughts through upstream movements. Success of restoration may be dependant on retaining the appropriate genetics for physiology and behaviors adaptive to local situations. Research is needed.

It is not clear to what extent overstocking with non-native rainbow trout may have caused introgression in the Ventura steelhead. Genetic analysis of what appeared to be resident rainbow trout from the upper Ventura/Matilija basin indicated that only 2 out of 31 of the sampled fish had clear native ancestry (Nielsen et al. 1997). It is possible, however, that some of the more isolated populations may retain a greater proportion of native steelhead genes. It is not known if the progeny of resident trout will ever be able to smolt and regain the anadromous life-style of their ancestors.

Resident rainbow trout are fairly well dispersed throughout the Ventura River basin, inhabiting much of the main Fork Matilija and upper North Fork, North Fork, Murietta, Coyote, Santa Ana, and Gridley subwatersheds (Figure 5). They extend upstream as far as there is good perennial water (Figure 6) and stream gradients are not too steep (generally less than 10%) (Figure 7). In drought years their distribution shrinks, and in high water years their distribution expands where falls, boulder cascades, or man-made barriers do not block their upstream migration. Only one instance of fish-less perennial water is known at this time (approximately 1 mile upstream of barrier falls on the Santa Ana drainage). Many of the highest densities of juvenile trout are found within seasonally intermittent reaches (upper Main Fork and upper North Fork for example) (Figure 8), suggesting that a lack of late summer holding water and periodic floods limit retention of older fish but enough survive to successfully reproduce and re-populate the area. The apparently high juvenile trout densities may be a function of less competition and predation from older fish and/or an inherent richness of habitat and productivity. It is likely not feasible to get steelhead up and over the multiple natural barriers and into these areas. And it may not be desirable, since many of these upper reaches may harbor other sensitive aquatic and riparian species, such as red-legged frogs that do better without fish competition and predation.

Ventura River waters support moderate ("good" according to Smith 1982) overall trout densities (0.3-0.6 fish per m^2), comparing favorably to more northerly small coastal streams (Burns 1971; Shapovalov and Taft 1954) and of similar densities to other south coast streams (Entrix 1994; USFS data files). Adult population densities are estimated at 800-1500/mi which is comparable to nearby Santa Paula Creekc but 25-50% lower than Sespe Creek. Juvenile densities ranged from 0.01-3.0 per m^2 with the average around 0.09, which is comparable to other southcoast resident trout densities but low when compared to known juvenile steelhead densities (0.18/m^2 in the lower and larger Santa Ynez River; Entrix 1994). In short, Ventura River fish production is largely what would be expected for resident fish and while resident production can be an indicator of potential steelhead production, steelhead productivity could be higher.

Projecting residential trout production out across historically accessible reaches within the Ventura basin, Forest lands could yield roughly 199,500 juvenile trout on the whole, or potentially enough smolts to support an adult steelhead run of approximately 2,800 (Table 1). A similar estimate of potential steelhead production (2,100 adult spawners) can be derived from the quantity and quality of spawning habitat which could be made accessible to spawning steelhead within the Forest Service System lands. These estimates are comparable to the historical projections of over 2,000 steelhead historically utilizing Matilija Creek (Clanton and Jarvis 1946).

There is an insufficient sample size to determine age-class size ranges, frequencies, and growth rates of upper Ventura River basin salmonids. Of the fish that were measured (n=50) in June of 1993, their sizes ranged from 82 to 242 mm and averaged 116 mm. Growth rates and population age classes are likely similar to those encountered on nearby Sespe Creek. Within the Sespe, at least four age classes of resident trout are identifiable: Juvenile trout typically range between 5 and 8 cm in their first growing season; First year fish are between 12 and 18 cm; Two year old fish are between 20 and 25 cm; Three year old fish may attain lengths over 28 cm. Smolts captured at the Vern Freeman Diversion on the Santa Clara River range between 20 and 30 cm and may include young-of-year fish. A similar pattern of rapid growth and early smoltification was observed in the lower Ventura River (Moore 1980). High growth rates of 0.9 to 2.8 cm per month were documented.

Other Aquatic Species

Pacific lamprey (*Lampetra tridentata*) share many of the same habitat requirements as steelhead and may spawn and rear within similar areas. Lamprey larvae are not easily detected, however, and although they were not observed in Forest Service surveys they may be there. Lamprey are also hampered in their upstream migrations by natural and artificial barriers, but possibly to a lesser extent than steelhead.

Arroyo chub (*Gila orcutti*) and three spine stickleback (*Gasterosteus aculleatus aculleatus*) are found in abundance (10-20 fish per 100 feet) throughout much of the mainstem Matilija and the lower North Fork (Figure 9). Optimal stickleback habitat includes small pools with constant flow and low water velocities (Baskin and Bell 1975). Chubs appear to be associated with low gradient riffles and runs (USFS 1995). Both species are known to coexist with steelhead and resident trout and may serve as a food source for migrating or held-over adult steelhead.

Speckled dace (*Rhinichthys osculus*) have not been observed in recent surveys. Dace are adapted to warm water (>28°C) and prefer cobble riffle habitats. It is unlikely that trout and dace would compete for the same food resources since dace are bottom feeders and trout generally feed up in the water column (Moyle 1976).

Exotic species that have been observed in the upper Ventura River basin include largemouth bass (*Micropterus salmoides*), smallmouth bass (*Micropterus dolomieui*), and Pacific crayfish (*Procambarus clarki*). Highest densities of the exotics appear to be found in and downstream from Matilija Reservoir (Figure 9). Bass are notorious predators on other fish including trout and steelhead. Crayfish are scavengers that readily will feed upon eggs and fry in gravel spawning beds (Hobbs et al. 1989; Page 1985). Periodic floods likely limit upstream expansion of these species. Droughts may limit populations but can also increase the impacts of exotics on native species as there is increased competition for shrinking habitat.

Native species which may impact trout and steelhead include western pond turtles (*Plemmys marmorata pallida*) and two striped garter snakes (*Thamnophis hammondii*). Turtles prey upon fish but only if the fish are stranded, dead, or sluggish. Two-striped garter snakes are highly effective predators, taking juvenile salmonids of up to five inches in length (Chubb personal observation). Their impacts on local fish populations can be substantial during dry summers when fish are concentrated in limited habitat.

Other native aquatic species that appear not to negatively impact trout or steelhead include red-legged Frogs (*Rana aurora*), California treefrog (*Hyla cadaverina*), Pacific treefrog (*H. regila*), Western Toads (*Bufo boreas*), and California newt (*Taricha torosa*). All of these species except California newts overlap with trout in the use of stream channel types, reaches, and to some extent, instream habitat. California newts are generally only found in substantial numbers in perennial stream reaches where trout densities are low to non-existent.

Habitat Quality -- Migrations

Water flow is highly variable. In a "normal" water year (15-40 inches of rainfall) there are adequate peak flows to allow steelhead and trout to migrate upstream to their spawning grounds if there are not barriers. Usually, several successive winter storms would allow for multiple spawning migrations and assist with the movements of steelhead smolts downstream to the ocean.

An average of one out of five years is well below normal precipitation (less than 15 inches over the year) potentially severely limiting steelhead spawning migrations and trapping smolts. Fish passage at low to moderate flows is thought to be provided if depths are over 0.6 feet across at least 25% of the wetted channel (10% should be contiguous areas >0.6 feet deep) and velocities are less than 8 feet per second (Thompson 1972).

Low flow barriers become more significant during the dry years, not only for limiting upstream spawning steelhead, but also for limiting movements of steelhead juveniles and wild resident trout into late summer refugia habitats (see later section on summer habitat). Resident trout have been shown to also undergo seasonal migrations over great distances (>50 miles in some cases) (Schmal and Young 1994).

Migrating steelhead can generally navigate upstream against flows up to 6 feet per second and leap over 4-6 foot heights (Evans and Johnston 1972). Deep water (>half of the vertical jump) is necessary to gain the leaping momentum. Resting pools (>6") are necessary in long sections of high velocity flows.

During low flows, boulder cascades, bedrock slides, and low gradient riffles may become barriers to upstream fish movement. Steelhead may become stranded on their upstream migration if flows rapidly decline. The presence of good deep pools is essential during this period as fish may need to wait out the period between storms.

Swimming and jumping abilities are size dependant (Evans and Johnston 1972), so that fewer but larger individuals may be able to reach the upper reach spawning beds. The spawners that do make the effort would be compensated with less competition for available habitats, larger and more numerous fry, and healthier progeny.

Low flow barriers are likely found throughout many of the reaches of the upper Ventura River basin. Surveys were not of sufficient detail to describe all low flow barrier locations. The greatest numbers of complete barriers were noted within the North Fork and upper mainstem Matilija (Figure 8). Many of these barriers are formed by water plunges through boulders jammed against bedrock streambanks and canyon walls. Some of the barriers are waterfalls over bedrock ledges. Boulder barriers have the potential for shifting through natural processes of floods and earthquakes. There is also opportunity for human intervention to blast open a channel for fish passage. The rather immutable waterfalls, however, are often situated at the lower end of reaches with numerous boulder barriers, and thus the potential for opening up additional access for steelhead may be limitedt.

Artificial barriers to steelhead migrations include Casitas Dam on Coyote Creek, the Robles Diversion and Matilija Dam on the mainstem Matilija, and Wheeler Gorge Campground road crossing on the North Fork. Removal of these barriers provide opportunities to open up substantial additional areas (5, 2, 10, and 7 miles respectively) of steelhead habitat. Water diversions on Santa Ana and Gridley Creeks may be barriers for downstream migrating juvenile trout as they are not screened and remove a large proportion of the base flow.

<u>Habitat Quality -- Spawning</u>

As previously discussed, steelhead, and likely wild rainbow trout, will move into seasonally flowing reaches to spawn. They are not limited to only perennial waters and may utilize intermittent reaches to avoid crowding and potential predators (Carroll 1985; Everest 1973). Riffles provide the predominant spawning habitat, although small gravel pockets associated with pool tails may also be utilized by steelhead rainbow trout. Coyote, North Fork, Murietta, and Oldman Creeks have the highest proportions of riffle habitat. The mainstem Matilija Creek appears to have relatively low percentages of riffles except in reaches near the confluence of Old Man Creek.

Not all riffle habitat is good spawning habitat, however. Good spawning habitat should have a high percentage of gravels (>20%), no more than 15% fine sediments, and channel morphology (width/depth ~ 15) offering the good oxygen and silt carrying velocities. Given these parameters, the most suitable spawning areas would be predicted to be in Coyote, lower North Fork, and a short section of the Main Fork Matilija (Figures 10 and 11). Siltation in Murietta may be severe enough to limit spawning success and fry survival, although juvenile trout densities are moderate to high within these reaches (Figure 8). The lower sections of the mainstem Matilija do not offer good stable spawning conditions. Storm flows gain power as they sweep down through the canyon. Eggs and fry of the lower Matilija are susceptible to being washed downstream, smothered in silts and sands, or damaged in debris flows. The most useful spawning habitat resides in the mid sections of the side forks and tributaries.

Rearing Habitat

Soon after hatching steelhead and trout fry swim up through the gravel and disperse downstream into shallow slow water stream margins (Bisson et al. 1981). Low gradient riffles, runs, and glides provide the primary rearing habitat into the early summer. The quality of rearing habitat is largely determined by the continuation of water flow of moderate temperatures and the availability of cobble and small woody debris for use as cover from predators and protection from high water velocities.

The best rearing areas do not completely overlap with the localities of the best spawning reaches (Figure 12); There is overlap within Murietta and North Fork drainages but additional rearing habitat is to be found within Upper North Fork. Rearing habitat appears to be lacking within Coyote Creek. It would seem that there is a greater correspondence between observed juvenile trout densities and potential rearing habitat than with potential spawning habitat (not a unexpected result). The similarity between production estimates derived from spawning habitat availability and actual juvenile densities (i.e. reflecting limitations of both actual spawning and rearing success) suggests that spawning and rearing habitat suitability are similar and neither habitat factor is the key limitation on salmonid recruitment.

As mentioned above, cover structure such as that provided by woody debris is important as refuge from predators and high water velocities. Instream cover is in low abundance through out much of the upper Ventura River Basin (Figure 13), a situation common to most southern California coastal streams. Woody debris (>8"dbh) densities range from 0 to 220 pieces per mile with an average of 15. This compares favorably and may indicate slightly higher woody debris densities than nearby Sespe Creek (USFS 1997). Less than 5% of the surveyed reaches would retain enough wood to meet the National "PacFish" standard for at least 120 pieces of "large" (>12") woody debris. This standard is being modified to better apply to the southern California ecosystem. Smaller sized wood is of importance to rearing juvenile trout, although it is still a uncommon element in this region.

Woody debris is found in higher densities within very localized reaches in Coyote, Santa Ana, North Fork, Upper North Fork, Murietta, and Old Man Creek. These areas are all associated with mid to late seral alder stands (Figure 14) which are prone to windthrow particularly after fires.

Food Producing Habitats

Good spawning riffles and pool tails are usually also good food production zones. Highest productivity would be expected where substrate size is dominated by cobble, however. Woody debris contributes nutrients and substrate for primary and secondary production. Less than 15% fines and moderate sunlight but ample streamside vegetation (canopy 40-60%) would be ideal for aquatic insect production. Based upon limited aquatic invertebrate sampling, food availability is good throughout most of the upper Ventura River basin and may not be the key factor limiting trout recruitment.

Late Summer Habitat

As fish grow in late summer and fall they move into swifter and deeper water, inhabiting runs and pools (Chapman and Bjornn 1969). Runs are quite common and not limiting. Pools and coolwater refugia from the summer heat are likely the most restrictive bottleneck that reduces population size and limits growth and recruitment. During dry years, summer conditions of high temperatures and low dissolved oxygen are particularly severe reducing fish growth, survival, and health. By August particularly in drought years, only isolated deep pools retain fish, and complete or partial fish die-offs can occur. If there are barriers to upstream movements it is possible that tributaries may become fishless after extreme drought.

The southern variety of steelhead rainbow trout is thought to have evolved to be able to withstand higher temperatures (Higgens 1991) but they are not immune to lethal temperatures (>75 ^{o}F). High but sublethal water temperatures can also affect growth (Barnhardt 1986), smoltification, immunity to disease, and behavior (Reeves et al. 1987).

As shown in Figure 15, reaches with denser canopy cover are likely to maintain the coolest water temperatures into late summer. Likewise, cool water springs and seeps may be important. Much of the mainstem Matilija experiences high temperatures (>75^{o}F) that likely limit trout survival and production. Hot springs in the North Fork and mainstem further increase surface water temperatures. The best refugia are to be found in mid Coyote, mid North Fork, upper Upper North Fork, a side tributary of Murietta, and the upper mainstem. Temperatures within these reaches usually stay below 65 ^{o}F. These areas appear to correspond with the areas of greatest trout densities (Figures 5 and 8).

Pool densities may also be related to trout abundance (Figure 16). Deep pools have been shown to retain cooler water near the bottom, offering thermal refugia to fish in late summer (Matthews 1996). Salmonids, and particularly steelhead require deep pools as resting areas and refuges from high flows and water temperatures (Dunn 1981). As juvenile steelhead grow they gradually shift from shallow to deeper water habitat, including pools (Bisson et al. 1981).

Generally, the best and most abundant pool habitat is situated within the mid to upper reaches of side drainages. The mainstem is pool poor which when coupled with higher solar influx with a less dense shade canopy and lack of cool water springs and lesser late summer flows equates to inhospitable summer habitat. The side forks are presently the most significant trout habitat and have the greatest potential for restoration of anadromous steelhead runs, if access can be restored.

Riparian Vegetation

Two general types of riparian communities are encountered in the Ventura River basin: southern alluvial woodlands and southern riparian woodlands. Southern alluvial woodlands consist of various combinations of Fremont cottonwood, western sycamore, willows and mulefat and are found in lower gradient reaches. The southern riparian woodland type is the dominant vegetation community throughout most of the upper Ventura River basin and includes a mixed assemblage of primarily alder, willow, and oak. Conifers are only an extremely minor component within the headwaters of the upper mainstem.

Tamarisk is a early seral exotic colonist species of low value as fish and wildlife habitat (Cohan et al. 1978). It is found in mainstem reaches below Matilija Reservoir and needs continued vigilance to control. If it has a chance to develop into large monotypic stands as it has elsewhere in southern California, it can crowd out native vegetation, reduce available surface water, limit species and habitat diversity, and contribute to adverse water temperatures and chemistry. Tamarisk is of high concern for it's negative effects on wild trout and potential steelhead restoration efforts.

As mentioned elsewhere in this report, alder stands appear to contribute the most woody debris to channels. Alder is also highly effective in withstanding the erosive power of debris flows and floods. One of the reasons for this effectiveness is alder's propensity for forming dense root mats in and among boulders and bedrock. Alder rootmats are virtually indestructible unless there is disease, fire, drought, or other forms of extreme stress. In healthy alder stands, stream banks are well armored and stable. Alder roots may also span across the active channel protecting the channel bed from downcutting. Typical alder dominated reaches are composed of highly stable step pool sequences of habitat.

Water Quality

Detailed water quality sampling has not been conducted within the upper Ventura River basin. As observed in the nearby Sespe watershed, water quality is likely to be adequate for trout and other biota. PH, mineralization, and alkalinity may be high, especially within reaches with a large influx of groundwater springs and seeps. White crusty sodium chloride and sulfide deposits are common where evaporation is high near spring influxes. In some reaches (as noted in Upper North Fork) calcium carbonates will precipitate out forming a layer of cement across the stream bottom. Such cementing could lessen the quality of spawning beds although winter high flows appear to dissolve the minerals and break up much of the cement prior to the spawning period. Scattered small iron rich seeps may contribute to local precipitation of iron flocculent which can be damaging to fish eggs and gills (McKee and Wolf 1970). Many of springs are likely high in total dissolved solids, aluminum, copper, and iron.

The water chemistry suggests a moderately productive aquatic community, although nutrient levels have not been measured. Aquatic productivity may be limited at total dissolved solids over 400 ppm (Bell 1973) as may be encountered immediately downstream from high mineral hot springs.

Economics

Based upon the recreationl and tourism money ($106-$111/fish) (RPA 1990) that can be associated with steelhead trout (RPA, 1990), the Ventura watershed is potentially worth at least half a million dollars per year, probably more. Additional economic value can be derived from non-consumptive use of steelhead resources. Other values associated with the presence of a healthy steelhead run can not be assigned a monetary figure.

Disturbance Processes

Fire and post-fire floods and debris slides are the most significant disturbance processes in the upper Ventura River basin. Chaparral fires are expected to occur every 30-60 years (Davis et al. 1988) and seem to burn hot over large areas of the landscape (Figure 18). In normal water or wet years the incidence of fire is low, it burns only at low intensities, and rarely burns through moist riparian zones. The riparian network thus is protected from fire and may contain fires within smaller patches of the watershed. Such is also the case if nearby hillslopes have recently burned and lack the fuels to carry the fire. Many recent fires have originated in or near streams in areas of greatest concentration of fire causing human activity (campfires, vehicles, etc.).

Alders are a less fire resistant species than willows, sycamores, and oaks and appear to be slower to recover and regenerate after intense riparian fires (Davis et al. 1988). If fire ignition and fuel build up continue to lead to intense riparian corridor burns alders may decline in their distribution within the watershed. Such a decline would likely contribute to a reduction in late seral riparian communities resulting in less woody debris, reduced canopy cover leading to higher tributary water temperatures, more channel instability, decreased fish habitat complexity, and reduced availability of summer and winter refugia for salmonids. A comparison of fire frequencies (Figure 18) and the time since last burn (Figure 19) indicates that some areas of the upper Ventura River basin have not burned for a number of years and present a risk for intense and potentially damaging future fire. Key areas to consider are around Casitas Reservoir and portions of the San Antonio drainage. Fuels will also be building up to dangerous levels within most of the remainder of the upper basin within the next 10 years. There is an opportunity for pro-active fire and fuels management.

Precipitation and resulting stream flow is highly variable and cyclic (Figure 21). Stream flow as measured at the lower Sespe indicates a typical three year low to one year high peak monthly flows. Recurrent cycles of drought (1895-1905, 1928-1937, 1945-1957, 1984-1990) almost always precede the most devastating periods of fires followed by floods (1917, 1932, 1986, 1991). An overlying 20 year cycle of high to low average flows may also be evident. Although it is unclear how patterns of global climatic change may affect local conditions, a renewed cycle of drought and floods is inevitable.

Major channel defining floods occur once every 5 years (Figure 20). Such flood flows replace gravels, flush out silts, transport and deposit woody debris and leaf litter, scour out pools, and facilitate regeneration of riparian vegetation (Yanosky 1982). Cottonwood, sycamore, and alder may only successfully regenerate during sustained flood years when the soil is continuously saturated for several weeks (Zimmermann 1964). Floods may be detrimental to fish by flushing them downstream away from their preferred habitat. Under normal circumstances rainbow trout quickly rebound within one or two years since they have an innate life cycle that drives them to move upstream in fall and winter. Research has shown that even "resident" populations of trout may move great distances (up to 50 mi) each year (Schmal and Young 1994). Therefore, trout recolonization could take approximately five to ten years if impassible barriers do not block upstream movements.

Floods after severe fires are much more destructive, ripping out riparian vegetation, flushing out woody debris, widening channels, reducing shade and increasing temperatures, smothering riffles with sands and silts, killing or displacing fish downstream, filling and reducing available fish habitat, and creating new fish barriers (logs or boulders). Davis et al. (1989) estimates that post-fire floods have contributed to up to 50% of the channel deposition that has occurred in our southern California rivers within the last 1000 years. Roughly 75% of the increased sediment yield occurs during the first winter after one such fire event (Rice 1994). Lower gradient channels fill up past bank full with sediment during the first major storm event and then return to base level over the course of several more moderate storms within the first or second winter (Davis et al. 1989).

Regeneration of riparian vegetation appears to take up to five years after major fires depending on hydrologic and climatic conditions. A post fire pulse in nutrients, plant, and algal growth continues over several years. Regenerated riparian corridors may be denser and more continuous than pre-fire conditions. Channel sedimentation is most devastating during the first year but may continue for several additional years. Secondary effects of channel downcutting, streambank erosion, sheet and rill erosion, and mass wasting may continue for a decade or more. The time to recover is also dependant on the size of the drainage, the steepness of the channel, and it's position within the watershed (Keller et al. 1988). The lower gradient third and fourth order reaches which are of primary importance for steelhead spawning and rearing are typically the slowest to recover to pre-fire conditions.

Windthrow generated pulses of woody debris may also be tied to fires. Windthrow frequently occurs in older alder stands after fire. The effects can continue for ten years or more. Deciduous logs last up to 5 years prior to decomposition (Armantrout 1991) and may greatly contribute to instream habitat and productivity during this period. Wood does not stay in place for long. At the next flood most of the wood ends up either high and dry within small pockets on floodplain terraces or 50 miles downstream on Pacific coast beaches. While dead wood may play a less significant role than in more northerly streams, it does greatly contribute to the erosion potential of floods and may increase the risk of destructive riparian fires.

Minor landslides appear to be an occasional disturbance (once every 20 years). Major landslides are associated with earthquakes and occur once every 100-1000 years (Davis et al. 1988). In the short-term (1-5 years), landslides can be quite destructive, denuding the riparian zones, smothering downstream channels with sand and silts, killing or displacing fish downstream, filling and reducing available fish habitat, and acting as fish barriers. Landslides may cause a complete or partial blockage until additional flows cut through and restore the channel grade. Within 5-10 years, high flows will transport and distribute gravels and boulders to downstream reaches greatly enhancing instream habitat. Murietta, North Fork, and upper San Antonio drainages appear to be prone to landslides (Figure 17).

While there is ample evidence of historical slope instability, it is unclear to what extent human activities have affected these patterns of disturbance. It is clear, however, that changes in patterns of fire and associated erosion during floods have accelerated landslide activity. Many of the chronic slides are associated with present or past roads, trails, or mining activities. Human activities such as construction of roads, trails, channel clearing, channelization, and development have contributed to changes in the timing of peak flows. With increased runoff, floodwaters may rapidly rise and descend, subjecting stream channels to greater erosive force with less water infiltrating into the ground, the health of riparian vegetation may decline. Increased sediment input can result in increased channel width and loss of continuous vegetation (Grant 1988). Over 40% of the upper Ventura River basin contains highly erosive soils which are subject to gullying and sheet erosion (Figure 22). Within the Forest boundaries of the upper watershed there are approximately 15 miles of roads requiring maintenance grading, 20 miles of road associated with stream crossings, 25 miles of foot trails, 8 miles of off-highway vehicle trails, 4 acres of dispersed recreational camps, and a five acre developed campground (Wheeler Gorge).

People have also directly disturbed the Ventura River watershed and the riparian corridors. Historical channelization and bank revetment work has straightened and constricted mainstem channels to the detriment of fish and other aquatic life. After fires, large amounts of woody debris have been removed from the upper basin channels. This was the case in the Wheeler Fire of 1985 when approximately 50 miles of channels in the North Fork and Main Fork Matilija, Murietta, Gridley, Senior, and Santa Ana drainages were cleared of woody debris. Channel clearing for purposes of flood control continues within the lower River basin.

People have introduced a number of exotic plants and animals that out-compete native species and alter riparian habitat. Tamarisk and arundo continue to be a problem that will need ongoing inter-agency efforts at control.

Stocking of non-native rainbow trout may be detrimental to native trout through direct predation, competition, or transmission of disease (Carline et al. 1991; Moyle 1986). There are continued concerns with the risks of introgression and dilution or compromise of native genetic variation in southern steelhead. According to genetic analysis results, most of the resident trout in the upper Ventura River basin have already been intercrossed to some extent (Carpanzano 1996). It is not entirely clear how stocking would effect the restoration of anadromous steelhead. Filmore Hatchery rainbow trout are stocked in the North Fork Matilija Creek near Wheeler Gorge Campground and in the Matilija Reservoir. Fingerling stocking is usually avoided where there is potential for overlap with anadromous fish. The potential impacts of continued stocking of catchable non-native rainbow trout would need to be examined if steelhead gain access into the Wheeler Gorge area. Tributaries have been stocked in the past but have not been stocked for the last ten years.

Until recently, the regular five fish limit without gear restrictions was applied throughout the Ventura River basin. Since 1993, only catch and release fishing with barbless artificial flies is allowed from May through December below Robles Diversion in order to protect anadromous steelhead trout. The five fish limit continues in upstream reaches. Most angling activity is concentrated in North Fork Matilija near Wheeler Gorge, lower sections of Upper North Fork, and sections of the main Fork in and around the reservoir. The extent that angling has impacted wild trout populations is not clear. Steelhead populations have been shown to be highly susceptible to angling in the northwest (Pollard and Bjornn 1973). Even catch and release angling can be stressful during periods of warm water temperatures and reduced flows (Wright 1992).

Angling as well as other recreational activity may affect trout and their habitat. Recreationists concentrate their activity along fragile streambanks and may wade in the prime shallow water spawning areas. Research has indicated that a single wading across salmonid spawning redds can kill 40% of the eggs. Mortality increases to over 90% with multiple wadings (Roberts and White 1992). Recreationists build flimsy small boulder and cobble dams for ponding water for summer soaking. At lower flows these small dams act as barriers to fish movements and create additional pool habitats that may favor exotic species such as bass, mosquitofish, sunfish, and bullfrogs to the detriment of native species and trout. Recreationists potentially have the greatest impacts on stream fish and biota from May through August with the highest potential impacts on steelhead and resident trout during April and May when the eggs and fry are sensitive to damage or habitat loss.

There are three small grazing allotments totalling about 100 acres within the upper Ventura River Basin. One in Coyote Creek, one along the lower mainstem of Matilija Creek, and one in the headwaters of the San Antonio watershed. All allotments are stocked at low densities and with active management to minimize riparian and channel disturbance. If steelhead are listed and restored to these drainages, Biological Assessments will be conducted to assess if grazing activities are in need of further changes in management in order to meet the Endangered Species Act.

A number of water developments are also scattered throughout the upper Ventura River basin (Figure 23). Most are livestock tanks, drinking spigots, or emergency fire water tanks tapping springs or collecting rainwater in upland areas. Seven surface water diversions are permitted on Forest Service lands. A unknown number of direct surface water diversions may be operating on the private inholdings. Subsurface flows are likely also tapped through shallow wells. A more detailed review of existing water rights and Forest Special Use Permits would be conducted to ensure there are not conflicts with restoration of steelhead trout.

The Robles water diversion is downstream from Forest Service lands but effectively blocks all upstream fish movements. Modification of the Robles Diversion so as to allow fish passage would open 2 miles of fair to excellent spawning and rearing habitat with the potential for producing 11,000 smolts (200 equivalent adults). If the boulder barriers and road crossings in the lower North Fork can be modified to allow for fish passage, an additional 5 miles of fair to good habitat would be available potentially producing 43,000 smolts (860 adults). Restoration of fish passage above Matilija Reservoir would open an additional 8 miles of fair, 5 miles of good, and 6 miles of excellent spawning and rearing habitat potentially producing 40,000 smolts or 1,100 equivalent adults. If all of the above measures are taken, an additional 26 total miles of spawning and rearing habitat could be utilized to produce nearly a million steelhead smolts or the equivalent of 2,160 steelhead adults. If steelhead access is restored above Casitas reservoir, an added mile of excellent and 2 miles of good spawning and rearing habitat would be available representing 50-200 equivalent adults. The range in figures for the Coyote drainage reflects a discrepancy between predicted numbers based upon available spawning habitat and actual trout production, perhaps indicating that rearing habitat is the limiting factor.

V. SUMMARY AND CONCLUSIONS

Different disturbances occur at differing rates and frequencies which may coincide with additional human impacts on the Ventura River basin. Low intensity flooding, as is beneficial for steelhead reproduction and survival, occurs every year except drought years that appear to come in clusters every 10-20 years. Low intensity flooding may benefit steelhead survival for 3 years thereafter. High intensity floods occur every 4 years and depending on the season and timing may negatively affect steelhead for up to 3 years (Noland and Marron 1985). Moderate fires associated with moderate floods occur every 10 years and have effects lasting for over 5 years. Extreme and catastrophic fires associated with major floods occur every 20 years and may reduce steelhead survival for 10 years thereafter. Minor landslides occur every 5-10 years and negatively affect steelhead for 1-2 years and positively affect steelhead for up to 10 years; Major landslides occur every 100 years and may continue to negatively affect steelhead for several decades.

Ventura River face many challenges. At the currently suspected low population size (<200 spawning adults) even minor disturbances could be devastating. The Ventura watershed should be managed for a diversity of steelhead habitat areas so as to minimize the risks of simultaneous catastrophic disturbance. Overall steelhead population viability can best be maintained by restoring multiple (ideally at least three) spawning subpopulations within the Ventura watershed and managing these populations to allow for, but not encourage, intermixing. Based upon the estimates of steelhead smolt production and habitat capabilities, restoring fish passage up through the Robles Diversion is essential. The potential for habitat and production gains are relatively balanced between upper North Fork or Main Fork. An analysis of costs and engineering feasibility would help determine whether additional effort should be expended on ensuring access further up North Fork or up and over Matilija Dam, or both. Other factors such as the presence of exotic species, land ownership complications, and recreational use should also be considered. The opportunities for long term and unimpeded recovery and restoration of steelhead may be greater in the less heavily used and readily accessed upper Main Fork. The Main Fork also has the advantages of multiple side tributaries which could also support spawning and rearing steelhead and thus serve to distribute the population into additional subpopulations which may be able to better withstand disturbances such as floods, drought, and fire. Of course, the ideal situation would be restoration of steelhead to their entire historic range in the North Fork, Main Fork, Coyote Creek, and San Antonio drainages.

Steelhead live at most 8 years; Five years without successful reproduction is the likely limit beyond which the population would be at extreme risk of extinction. The ability of steelhead to survive the challenges of the last 40 years attests to their resiliency. However, each reduction in steelhead numbers places the population (and by extension the overall southern California steelhead stock) at further risk.

Linkages Beyond the Sespe Watershed

Peak flows are usually associated with El Nino weather patterns which may bring higher nearshore productivity. Ocean productivity may thus be synchronous with peak steelhead spawning activity. An underlying 40 year cycle of ocean productivity has also been identified (Ware and Thompson 1991). Applying this cycle to southern California suggests that ocean productivity was low in the 1980s but should peak around the turn of the century. Ocean conditions are thus likely to be a positive benefit for the recovery of Ventura River steelhead.

The key factors for steelhead restoration will be ensuring access to a diversity of quality spawning and rearing habitats both within and outside the Ventura River basin. The risk of watershed wide catastrophic events must be moderated to the extent possible. The risks of widespread fire and cumulative watershed effects can be mitigated through modified management. The risk of human caused barriers to migration can be addressed. Steelhead restoration should include actions to ensure there is at least one other viable subpopulation of steelhead within the nearby Santa Clara River Basin and at least one other river basin (Santa Ynez?) that can support steelhead in southern California.

VI. RECOMMENDATIONS

From a strictly fisheries perspective, the most important actions that need to be taken are those that will allow steelhead to access their prime spawning grounds in the upper Ventura River basin. The Forest Service can contribute to this effort by providing the best available information on the consequences of various alternatives and by addressing opportunities to restore steelhead to Forest lands. The Forest Service will need to analyze the Wheeler Gorge road crossing for fish passage modifications if steelhead can gain access past Robles Diversion.

Protective measures to decrease migratory mortality will also require multi-agency involvement since most of the potential problem areas are in the mainstem Matilija and Ventura Rivers downstream of Forest Service lands. As steelhead are able to return to their historical spawning grounds, restoration and/or enhancement of these areas becomes important. Measures to reduce streambank instability and control run-off of silts may be indicated. A more detailed analysis of overall watershed conditions would be necessary to identify, prioritize, and plan projects. Although there are some localized areas which could be treated to reduce erosion, efforts to return the watershed to a more natural or desirable cycle of fire return may be the most significant contribution to restoration of steelhead habitat. Not only would siltation be lessened, but watershed hydrology could be improved to lessen the effects of drought and scouring floods and thus enhance habitat. Development of a fire management plan may also be warranted.

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Ventura Watershed Historical Habitat Analysis
Last Update May 31, 1997 by Nicolas Romero

Ventura Watershed Historical Habitat Analysis

Year	Source	Location	Event	Comments
00/00/1832	21	Ventura River	Flood	Discharge info not available
00/00/1862	21	Ventura River	Flood	Discharge info not available
00/00/1867	21	Ventura River	Flood	Discharge info not available
00/00/1884	21	Ventura River	Flood	Discharge info not available
00/00/1906	2	Ventura River		Foster Park Diversion completed
00/00/1911	21	Ventura River	Flood	Discharge info not available
00/00/1914	21	Ventura River	Flood	Discharge info not available
00/00/1932	1	Coyote Cr.	Fire	10 ft fish barrier filled by sediment deposition
00/00/1933	1	Coyote Cr.		7 miles surveyed. Riparian, substrate, spawning and physical info.
00/00/1934	1	Coyote Cr.	Flood	Debris and sediments from 1932 fire fllushed
00/00/1938	21	Ventura River	Flood	Peak flow measured at 39,200 cfs
00/00/1943	21	Ventura River	Flood	Peak flow measured at 35,000 cfs
10/30/1947	2	Ventura River		Stream dry at Hwy 150
00/00/1948	19	Matilija Cr.		Matilija Dam completed
00/00/1948	19	Ventura River		Army Corp of Engineers constructs levee to potect San Buena Ventura
01/15/1949	3	Matilija Cr.	Fire	Fire denuded north side of canyon at Sopers Ranch. Nice pools, gravel, Sycamore, Alder, and
01/15/1949	3	Matilija Cr.		Rocky gravel susbstrate, aquatic plant growth common, semi-open Alder margin with deep pools 0.5 mi Surveyed from NF Matilija junction to Matilija Reservoir (temp, flow, and physical measure info)
01/15/1949	4	Ventura River		Notes 2 diversions at Foster Park. First upstream barrier to Steelhead
03/21/1949	5	North Fork Matilija	Fire	Turbid water. Heavy siltation. Entire upper drainage denuded by fire. (Temp, flow, width and depth info)
03/21/1949	6	Matilija Cr.		Creek surveyed 1/2 mile above reservoir at bridge crossing. Cobble bottom, semi-open Alder margin with slight gradient. Area to be inundated by reservoir (Temp, flow, width and depth info)
03/28/1950	7	Matilija Cr.		Heavy algae growth. Tules near lake inlet potentially blocking any spawning run. 2.2 miles surveyed (above dam) Below dam heavy growth of aquatic vegetation. Pools, heavy siltation and clear water near Hwy. 0.7 mi surveyed (Flow and Temp info)
03/29/1950	8	North Fork Matilija	Fire	Surveyed from Sopers Store to Wheeler Gorge campground. Abundant shade, pools, and food Minimal shade above campground due to fire. (Temp and flow info)
07/12/1951	9	Matilija Cr.		Stream in good condition with pools and shade at Hwy 399 Junction (Temp and flow info)
04/14/1952	10	Matilija Cr.		No pools, white water forms some cover (Above dam). Matilija full and spilling. 3 mi. surveyed (flow and temp info)
04/14/1952	11	North Fork Matilija		Good pools and cover. Section of stream planted. 3 mi. surveyed. (Temp and flow info)
04/06/1956	13	NF/Ventura River		Physical dimensions of sampled pools
08/01/1956	13	Matilija Cr.		Road constructed from USFS gate (below NF Matilija) to upper end of claims. Crosses stream 2x
00/00/1958	19	Ventura River		Robles Diversion Dam completed
00/00/1958	19	Coyote Cr.		Casitas Dam completed
00/00/1960	18	Ventura River		So. Pacific Milling Company begins strip mining 152 acre site, extracting up to 250,000 cubic yards of rock annualy
01/18/1969	20	Ventura River	Flood	16,600 cfs. River reaches critical saturation level (precipitation and discharge info)
01/23/1969	20	Ventura River	Flood	52,900 cfs. Greatest flood flows in recorded history (precipitation and discharge info)
02/22/1969	20	Ventura River	Flood	40,000 cfs. Severe flood damage. Jan and Feb storms reduce Matilija Reservoir storage capacity 3500 AF to 1400 AF. Additionally, extensive channel sedimentation, bank erosion and landslides occured.
1976-1978	19	Ventura River	Drought	Moore sites confluence of San Antonio Cr with Ventura River to Foster Park to hold the most i important Steelhead rearing habitat
00/00/1978	21	Ventura River	Flood	63,600 cfs peak flow
00/00/1980	21	Ventura River	Flood	37,900 cfs peak flow
01/21/1983	16	Ventura River	Flood	27,000 cfs peak flow. El Nino driven (precipitation and discharge info)
09/18/1985	15	Matilija Cr.	Fire	Wheeler Fire reduces midstory cover of White Alder and Black Cottonwood. Influx of sediment expected
00/00/1985	15	North Fork Matilija	Fire	Wheeler Fire reduces midstory of White Alder, Cottonwood and Big Leaf Maple. Willows accout for 50% cover. Abundances of pools. High sediment influx expected.
00/00/1985	15	Murietta Cr.	Fire	Impacted by Wheeler Fire. Large nursery pools. Perennial up to 3/4 mi. above confluence. Alders Sycamores and Willows.
08/25/88	17	Ventura River		Ca Supreme Court upholds Appellate Court decision prohibiting diversions during low flow periods
02/00/92	21	Ventura River	Flood	46, 700 cfs peak flow. River overflowed primarychannel and reoccupied old distributory channel
10/00/92	21	Estuary		19% Estuarine, 2% Riverine, 37% Palustrine, 17% Upland, 20% Ruderal, 5% other. Vegetated flood plain between Main St. and ocean reduced from 127 acres in 1855 to 82 acres in 1993
00/00/1993	13	Ventura River		So. Pacific Milling Company operation closed
09/09/1994	14	Upper NF Matilija		Riparian, aquatic, hydrological, biological and physical information

Ventura Watershed Historical Habitat Analysis References

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19.Moore, Mark. R.. 1980. *Factors Influencing The Survival of Juvenile Steelhead Rainbow Trout (Salmo gairdneri gairdneri) In The Ventura River*. Master Thesis. June 1980.

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Historical Distribution and Abundance of Fish in the Ventura Watershed

Year	Source	Location	Comments
10/23/1875	25	Arroyo Los Coyotes Cr.	Surveyors kill 25" RBT
02/23/1878	26	Ventura County	New Hamphire RBT and Maine salmon to be stocked in county streams
04/29/1882	27	Ventura River	Ventura man catches 1.835 RBT in 8 days
05/27/1882	28	Ventura River	1,000 RBT taken every Sunday
02/16/1884	29	Ventura River	River teeming with young RBT after great flood
05/31/1884	30	Matilija Cr.	312 RBT caught by two men in two days
08/11/1887	31	Matilija Cr.	Depleted of trout; to be stocked
04/10/1891	32	Ventura River	Four men catch 438 RBT in 1 day
05/01/1891	33	Matilija Cr.	One man catches 1.000 RBT in 1 week
05/15/1891	34	Matilija Cr.	Two men catch 753 RBT in 1 day. Largest being 28.75"
04/23/1892	35	North Fork Matilija Cr.	Fish ladder constructed.
06/17/1892	36	North Fork Matilija Cr.	RBT observed 2 1/2 miles above falls where fish ladder installed
08/26/1892	37	Ventura Pier	RBT caught off pier
03/16/1894	38	Ventura River	20,000 Eastern Brook Trout planted in headwaters
09/21/1894	39	Ventura County	10,000 RBT and 15,000 Tahoe Trout to be planted in county streams (streams not specified)
05/31/1895	40	Ventura County	62,500 RBT planted (streams not specified)
04/03/1896	41	Ventura County	Free Press maintains wild fish doomed if strict conservation measures not taken
03/24/1899	42	Ventura River	Steelhead weighing 14 lbs. caught at mouth
09/27/1938	1	Ventura River	10,000 RBT planted in 12 mi. length of stream
10/22/1939	2	Ventura River	5,000 RBT planted in 12 mi. length of stream
02/11/1942	3	Murietta Cr.	1,200 RBT planted above confluene with Matilija Cr. Hot Cr. egg source from Filmore
07/05/1944	4	North Fork Matilija Cr.	1,000 fingerlings transplanted from San Antonio Cr.
07/06/1944	5	Santa Ana Cr.	525 fingerlings rescued from Gridley Cr. and planted in Santa Ana Cr.
07/26/1944	6	Matilija Cr.	53,000 fingerlings rescued from SYR and planted in Matilija Cr.
02/26/1945	7	Senor Canyon Cr.	10,000 fingerlings planted. Mt. Whitney strain from Filmore Hatchery
00/00/1945	20	Coyote Cr./Santa Ana Cr.	2,500 Steelhead adults used creeks. 3,000 adults in normal years.
01/03/1946	8	Ventura River	Final year Brown Trout stocked. King Salmon recorded
03/27/1947	9	Ventura River	Steelhead oberved in every hole. Low flow conditions28
06/21/1948	10	Upper North Fork Matilija Cr	4,800 RBT planted. Mt. Shasta egg source from Filmore Hatchery
00/00/1948	43	Matilija Cr.	Historical estimates place Steelhead run @ 2,000-6,000 prior to construction of Matilija Dam.
01/15/1949	11	Matilija Cr.	Stickleback common. One 10" RBT observed
03/06/1950	12	Ventura River	Bar at mouth breached and Steelhead observed
03/28/1950	13	Matilija Cr.	Three spined stickleback common
11/18/1950	14	Ventura River	Engineers report large schools of Steelhead observed at mouth
07/12/1951	15	Matilija Cr.	Abundant Stickleback (Temp and Flow info)
00/00/1953	16	North Fork Matilija Cr.	3,762 catchables planted
00/00/1956	17	North Fork Matilija Cr.	5,000 catchables planted
00/00/1956	17	Matilija Cr.	NF Matilija Cr. to Matilija Reservoir utilized as YOY nursery. Well stocked w/ 3" RBT
00/00/1956	17	Upper Matilija Cr.	Sustains native RBT population
08/20/1958	18	Ventura River	120 Stickleback and 15 Gila caught in 1.25 mi. seined
08/20/1958	18	Coyote Cr.	500+ Stickleback, 50 LMB, 35 Gila and 4 G's found in 2 units near Foster Park
08/20/1958	18	San Antonio Cr.	280 Stickleback, 75 Gila and 2 LMB in 2 surveyed units
08/20/1958	18	Ventura River	Biologists states future of Steelhead to be "mighty bleak" one Casitas Reservoir flooded and Robles Diversion completed (survey info)
09/18/1961	19	Deep Cat/Coyote Cr.	Liquid retonone released to kill exotic fish (see results)
00/00/1976	24	Ventura River	9,000 fingerlings planted. Mad River strain from Filmore Hatchery
00/00/1977	24	Ventura River	11,000 fingerlings planted. Mad River strain from Filmore Hatchery
00/00/1978	24	Ventura River	20,000 fingerlings planted. Mad River strain from Filmore Hatchery
09/18/1985	21	North Fork Matilija Cr.	High RBT productivity level
09/18/1985	21	Murietta Cr.	Good RBT productivity level
05/05/1991	22	Ventura Estuary	14-25 adult O. mykiss ranging between 350-650 mm in upper estuary
01/04/1993	23\	Ventura River	2 RBT approximately 20" length and 5-6 lbs. at Shell Bridge

HABITAT CAPABILITY AND PRODUCTION ESTIMATES FOR VENTURA STEELHEAD

Prepared by S.Chubb for U.S.Forest Service

May 1997

DRAINAGE	Reach	Chan Type	(1) Flow Type	Miles	average Width (m)	%Rifl	%Gravl	%Fine	Barrier Type	(2) Spawning Habitat (m^2)	YOY Trout Densities (#/100m)	(3) Total from Habitat	(4) #YOY from Densities
Coyote	1	B3	P	2.0	3.0	20	30	15		386	30	7,720	1,920
	2	A2	P	3.0	4.0	10	15	0	bldr	113	30	2,260	2,880
Gridley	1	C?	S	1.0	2.5	-	-	-	silt	?	?		
	2	B3	PI	1.0	1.5	20	20	30	bldr	97	30	970	80
	3	A2	P	1.0	1.5	20	15	0	falls	72	0		
Santa Ana	1	C?	SI	2.0	3.0	-	-	-		?	?		
	2	B3	P	1.0	2.5	20	20	5		161	15	6,440	480
	3	A3	SI	2.0	1.5	20	20	0	flow		0		
Matilija (N.Fork)	1	B3	P	3.0	3.0	40	15	5	xing	869	200	34,760	19,300
	2	B2	P	4.0	2.0	25	15	5	""	483	500	19,320	64,360
	3	A3	P	3.0	1.0	15	20	5	bldr	145	150	5,800	14,480
	4	A+	I	2.0	1.0	10	5	5	falls	16	0	640	
Bear	1	D1?											
	2	B6											
	3	A3											
Matilija (M.Fork)	00		P	2.0	9.0	20	10	0			10		
	0		P	8.0							50?		
	1	C3?	P	1.5	4.0	25	10	10		241	50	4,820	2,400
	2	B3?	P	2.5	4.0	15	15	5	slides	362	200	14,480	16,080
	3	A3	P	2.0	4.0	15	15	5	falls	290	500	11,600	32,180
Cannon	1	?	P	1.0	3.0	10	20	5		97	10	3,880	320
Old Man	1	B2	P	2.0	2.5	25	10	5		81	400	3,240	25,740
	2	A2a	P	1.0	2.5	30	10	10		40	30	800	960
Matilija UpperNF	1	B3	P	2.0	2.0	10	20	10		129	30	2,580	1,920
	2	B2	P	1.5	2.0	15	10	10		72	45	1,440	2,160
	3	C3b	P	3.5	2.0	20	15	5	bldr	338	40	13,522	4,500
	4	B2	P	1.0	2.0	15	10	5	""	48	200	1,920	6,440
	5	B2a	P	1.0	3.0	25	10	5	""	121	300	4,840	9,660
	6	A2	P	1.0	2.0	40	5	5	slides	64	200	2,560	6,440
	7	Asa+	I	1.0	2.5	50	5	5	falls	100	0	4,000	
Murietta	1	C3b	S	0.8	2.5	30	20	10	flow	193	90	3,860	2,300
	2	B2a	PI	1.2	2.5	30	20	10	slides	290	210	5,800	3,060
	3	A2	PI	3.0	3.0	20	20	5	bldr	579		23,160	

(1) P=perennial, S=seasonal, I= intermittent

(2) Spawning Habitat available = reach lengthxwidth x %riffles x %gravels

(3) Estimated potential salmonid smolts derived from available spawning habitat multiplied by 0.20 redds/m^2 (Reiser and White 1981), 2000 eggs/redd (Bulkley 1967) and 0.50 egg survival (Bley and Moring 1988) and 0.10-0.40 fry survival depending on %fines in gravels.

(4) Estimated current salmonid young-of-year production derived from observed salmonid fry densities projected over total reach length and multiplied by 0.20 for fry to YOY (or smolt) survival.

Ventura Watershed - Los Padres National Forest

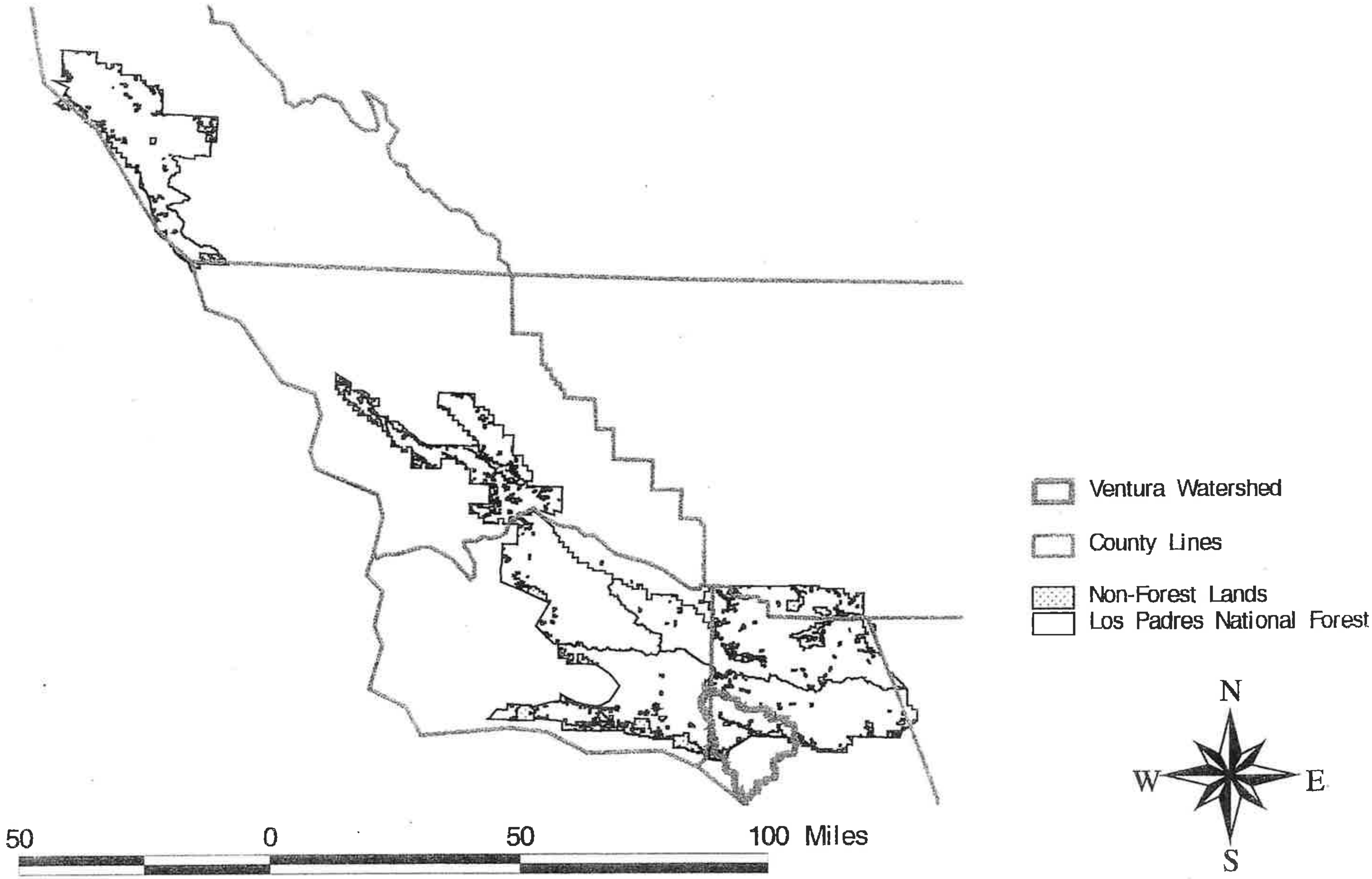


Figure 1. Map of the Southern California coastline showing the location of the Ventura River basin within the Los Padres National Forest.

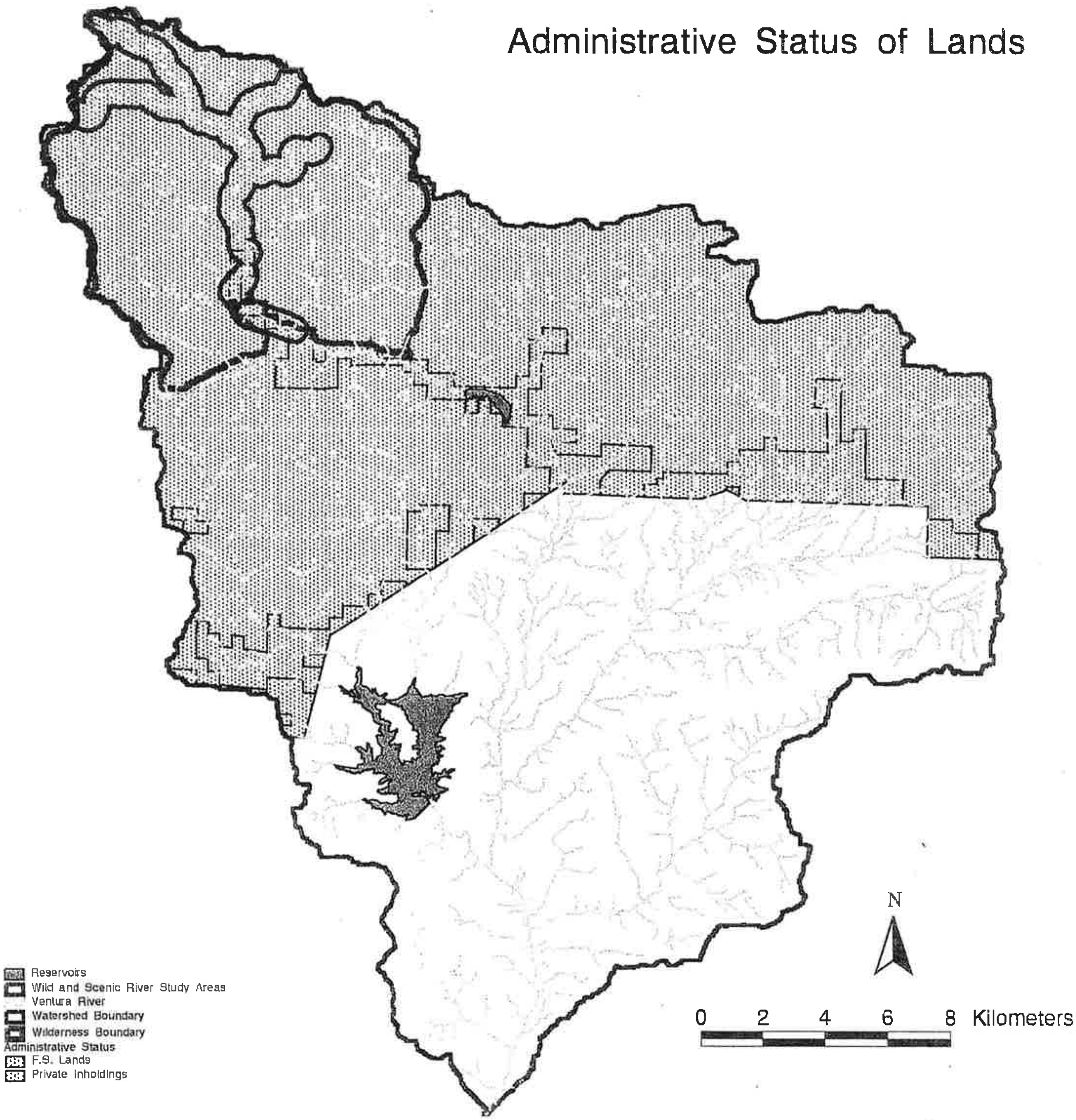


Figure 2. Map showing administrative status of lands within the Ventura Watershed.

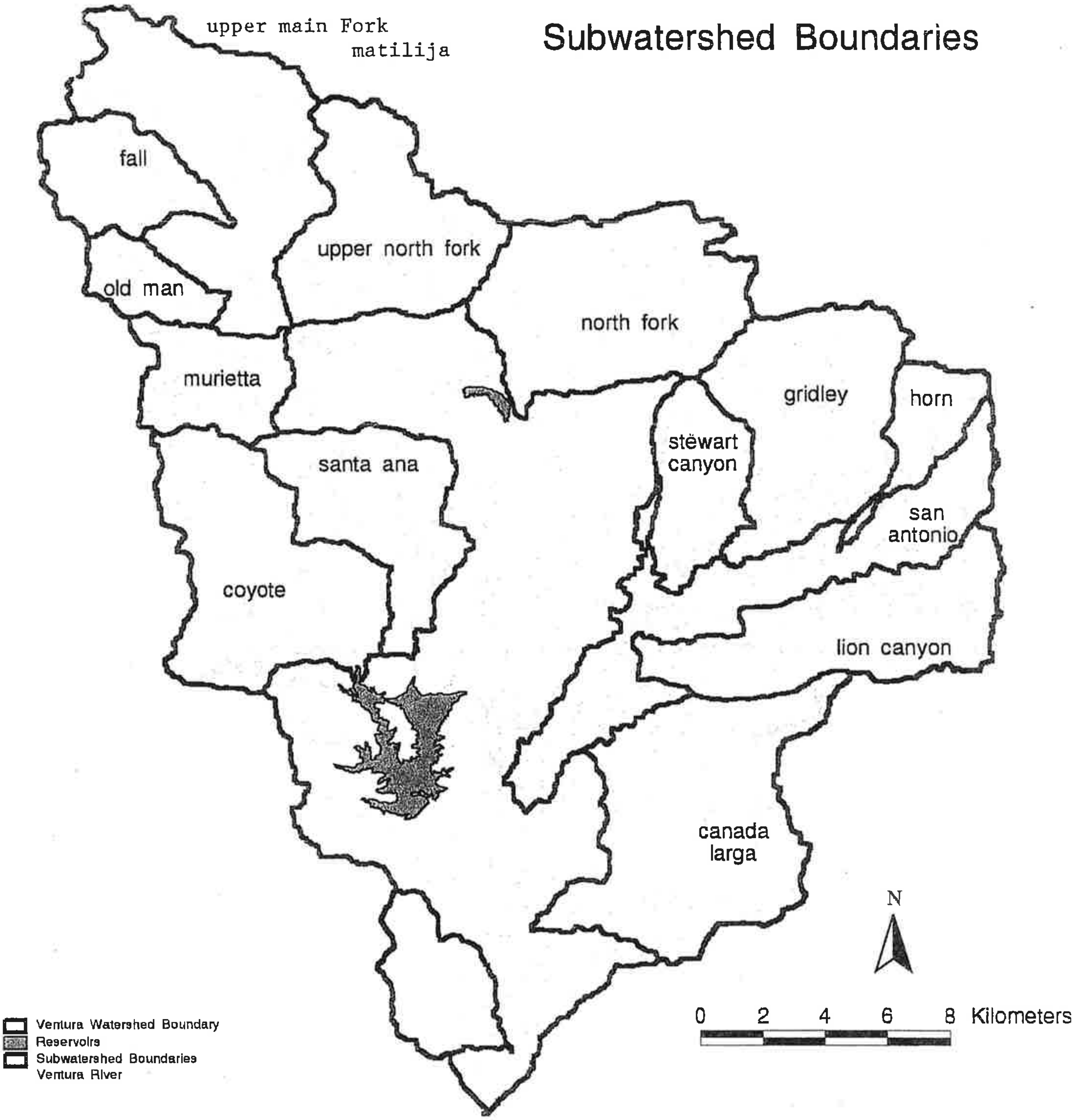


Figure 3. Subwatersheds of the Ventura River Basin.

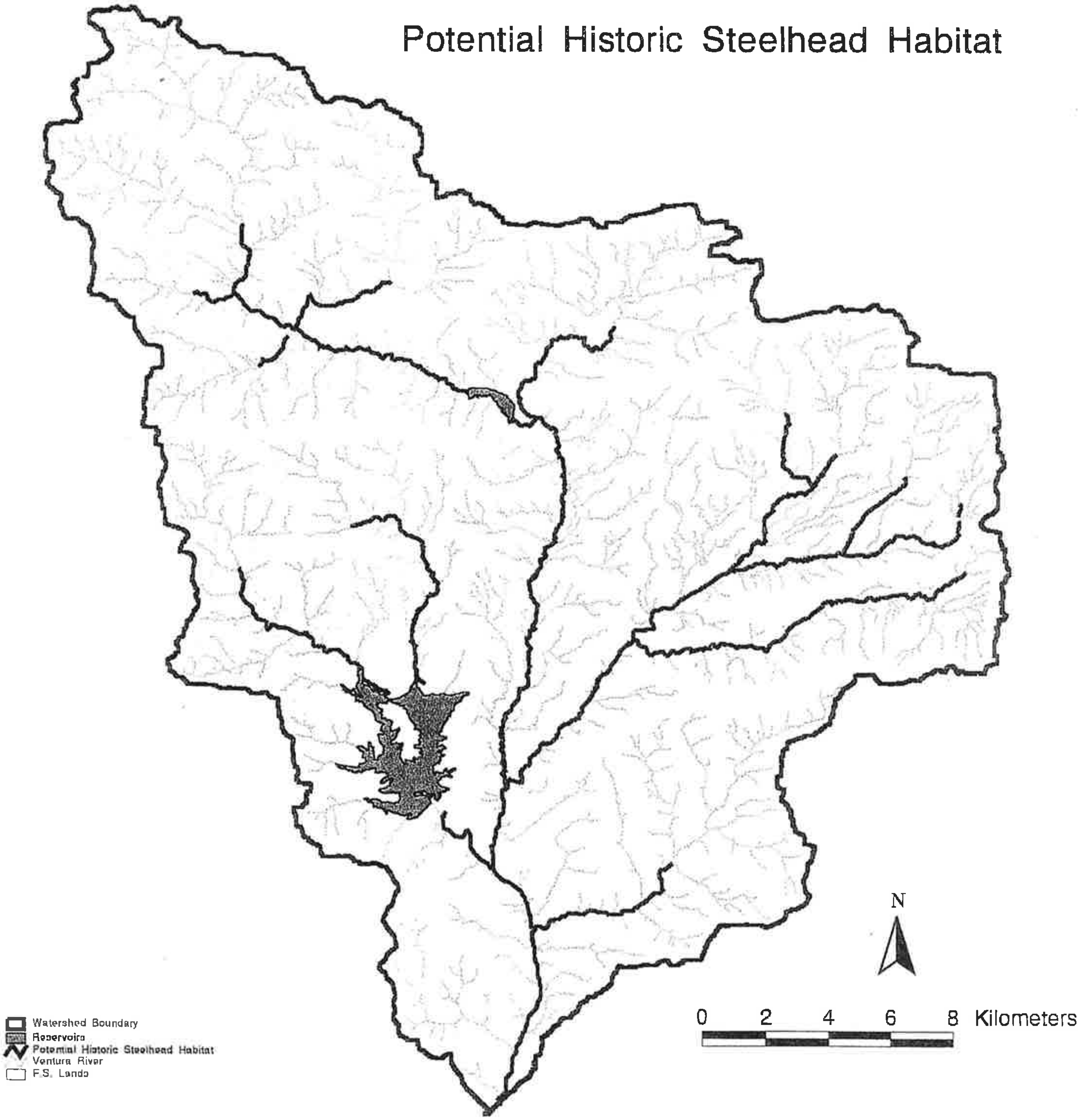


Figure 4. Potential habitat for restoration of anadromous steelhead in the Ventura Watershed based upon the location of historical barriers and various accounts.

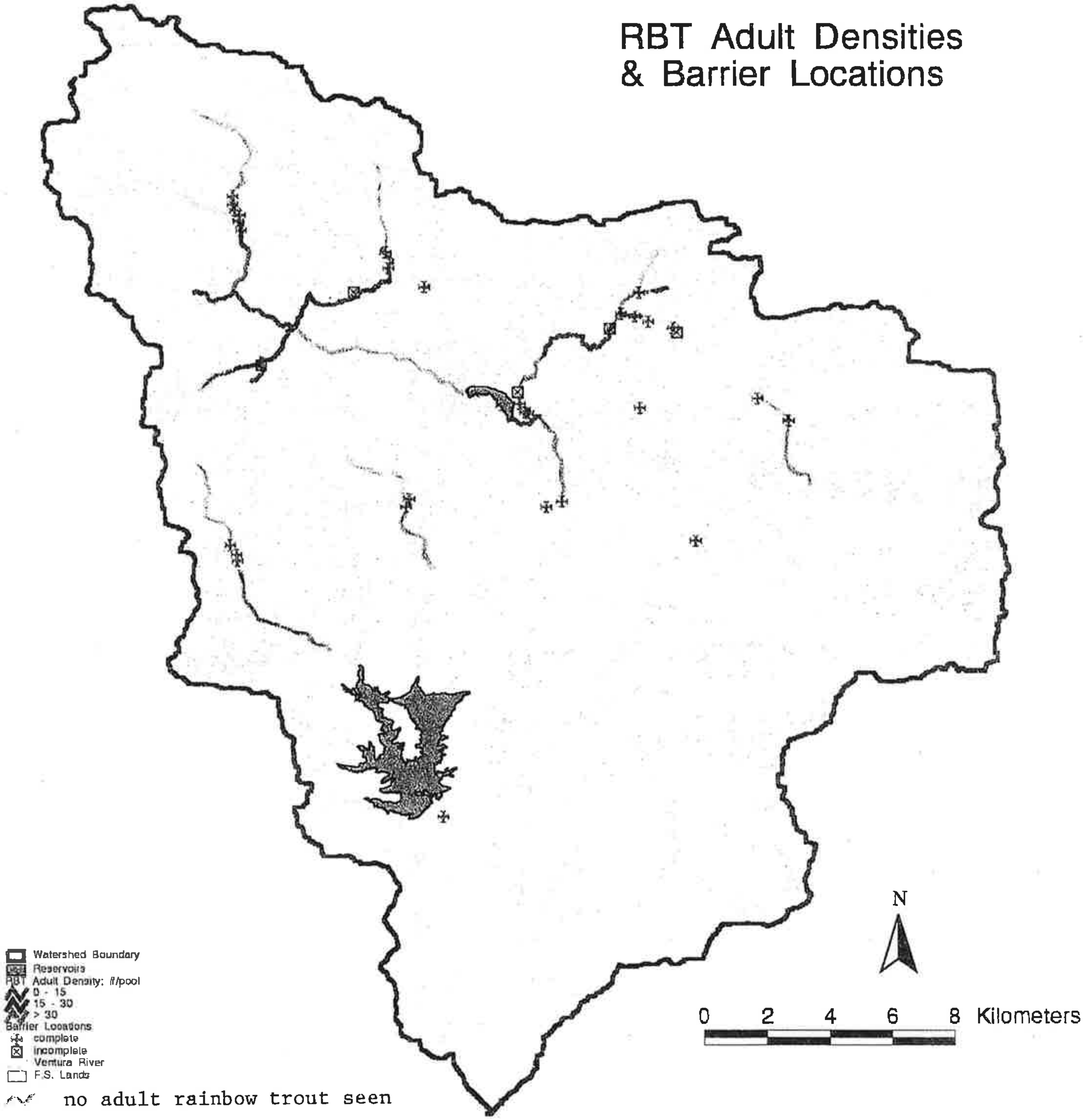


Figure 5. Densities of adult rainbow trout and locations of potential fish barriers within the Ventura River basin.

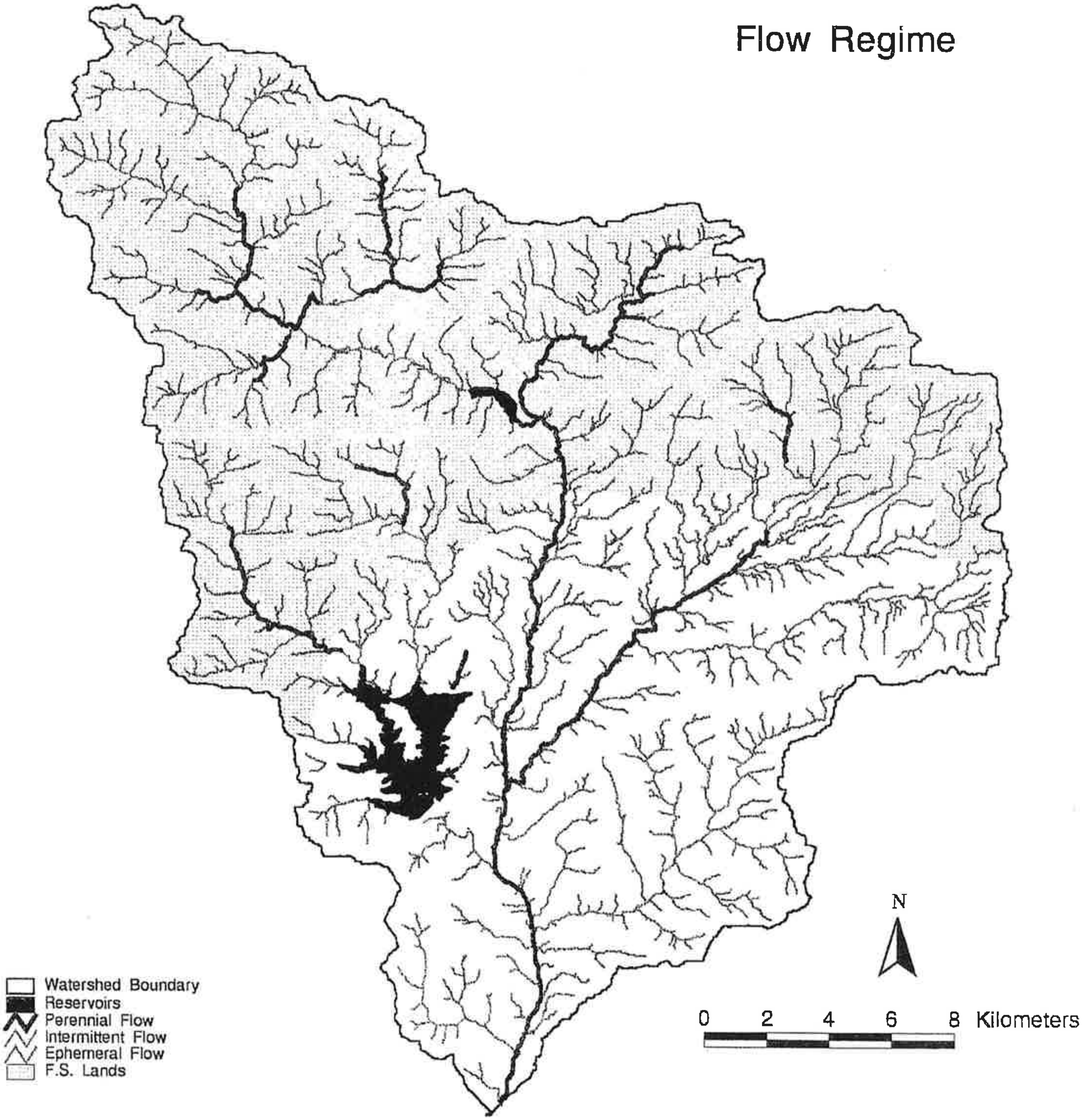


Figure 6. Flow regimes of the stream network of the Ventura watershed.

Figure 7. Stream gradients of the Ventura Watershed.

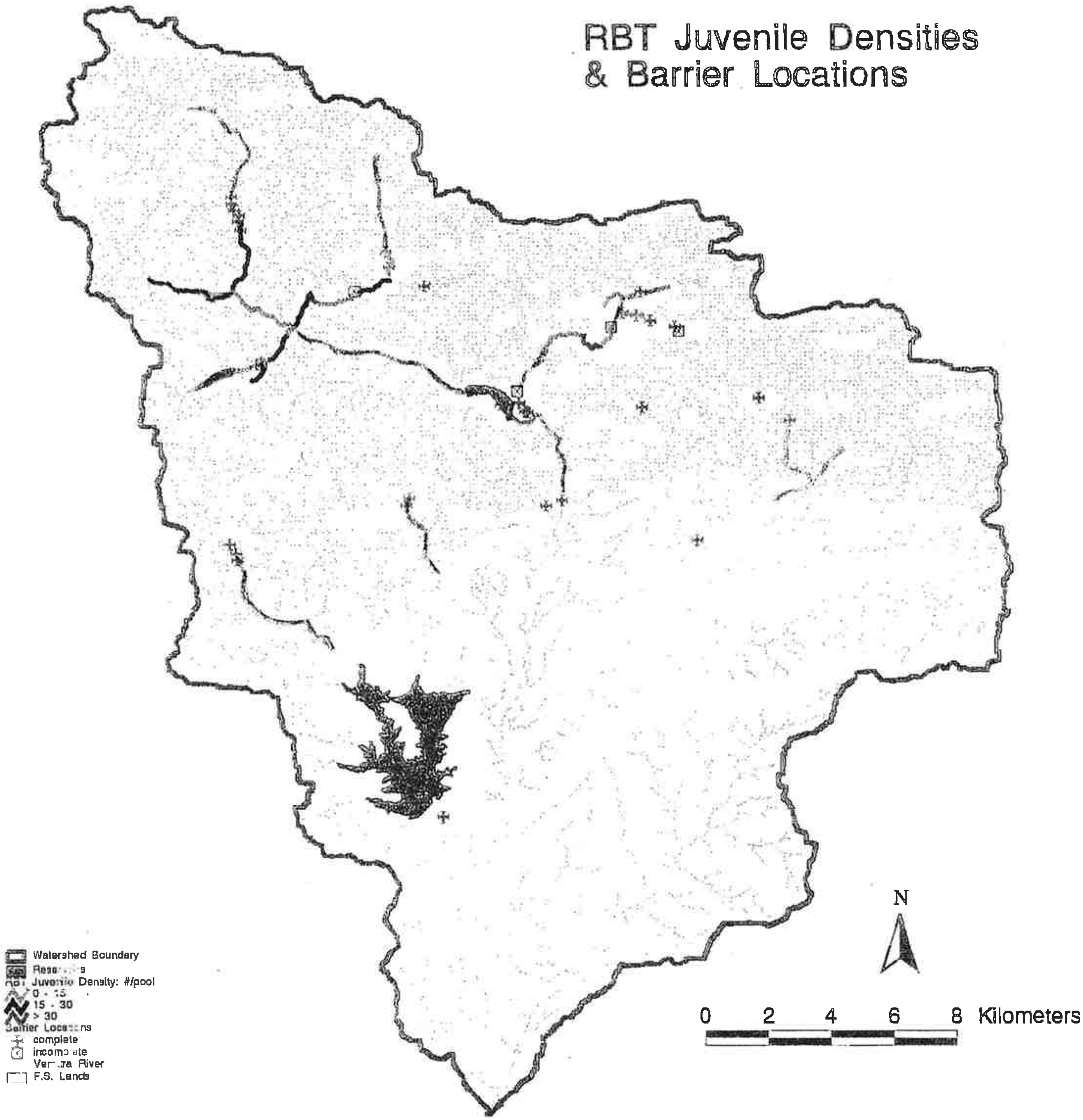


Figure 8. Densities of juvenile rainbow trout and locations of potential fish barriers within the Ventura River Basin.

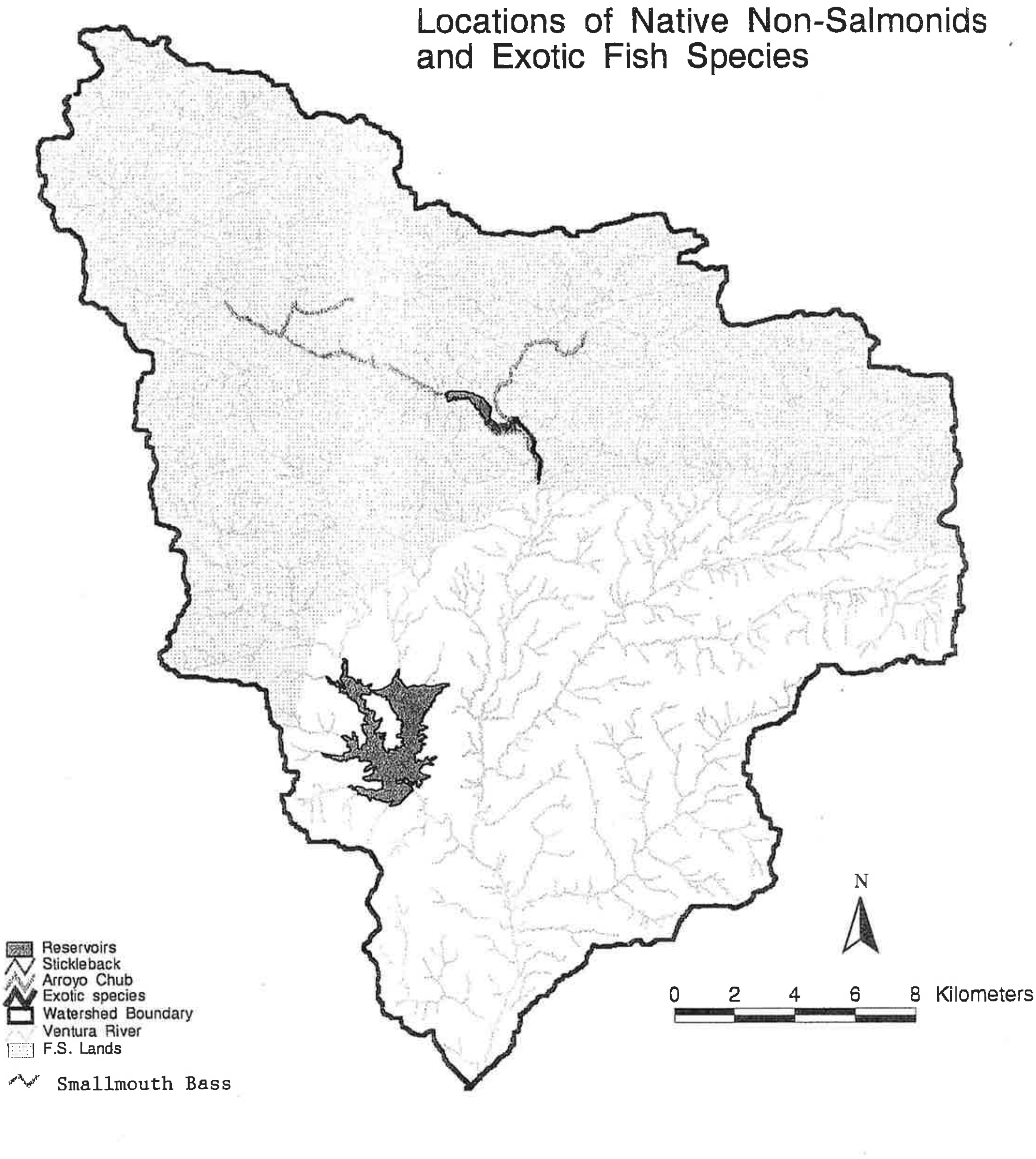


Figure 9. Locations of various fish species within the Ventura River Basin.

Potential Steelhead Rearing Habitat

Figure 12. Potential steelhead rearing habitat within the Ventura Watershed as determined by the availability of flow, run and pool habitats, and cover components (1980-1995 USFS data).

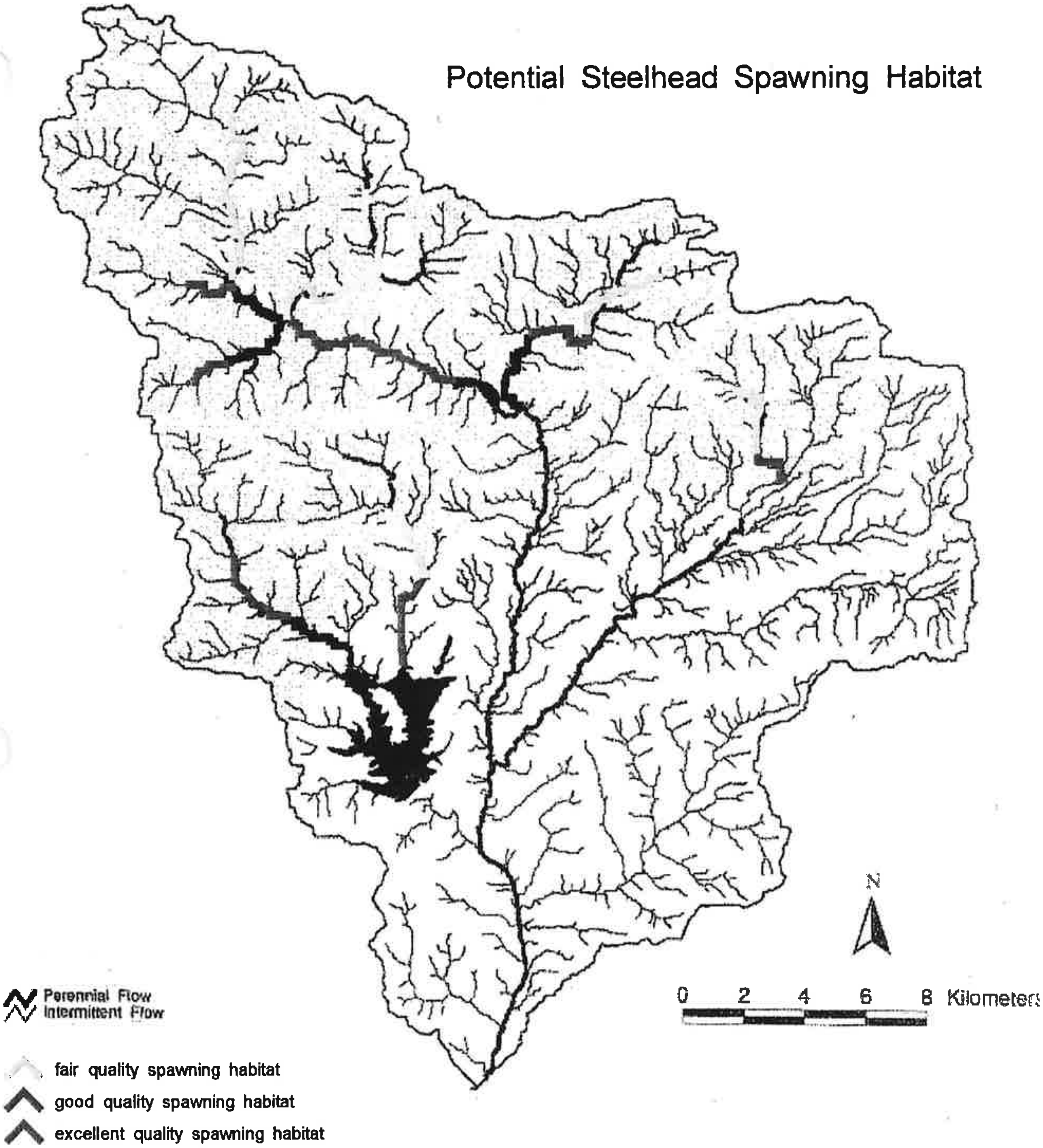


Figure 10. Potential steelhead spawning habitat within the Ventura Watershed as determined by the availability of riffle habitats and gravel substrates (1980-1995 USFS data).
gravels (1980-1995 USFS data).

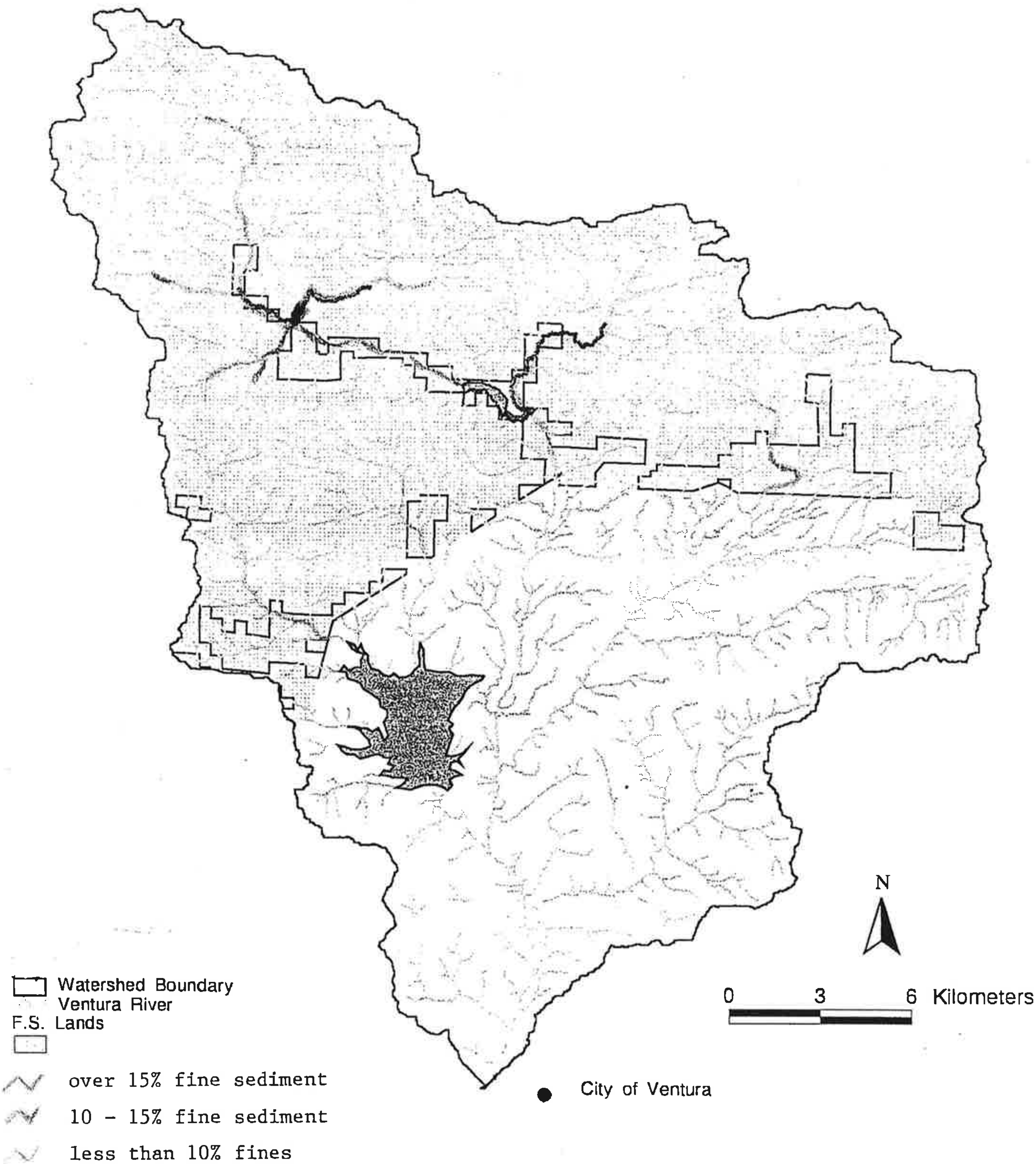


Figure 11. Distribution of fine sediments within the Ventura River basin.

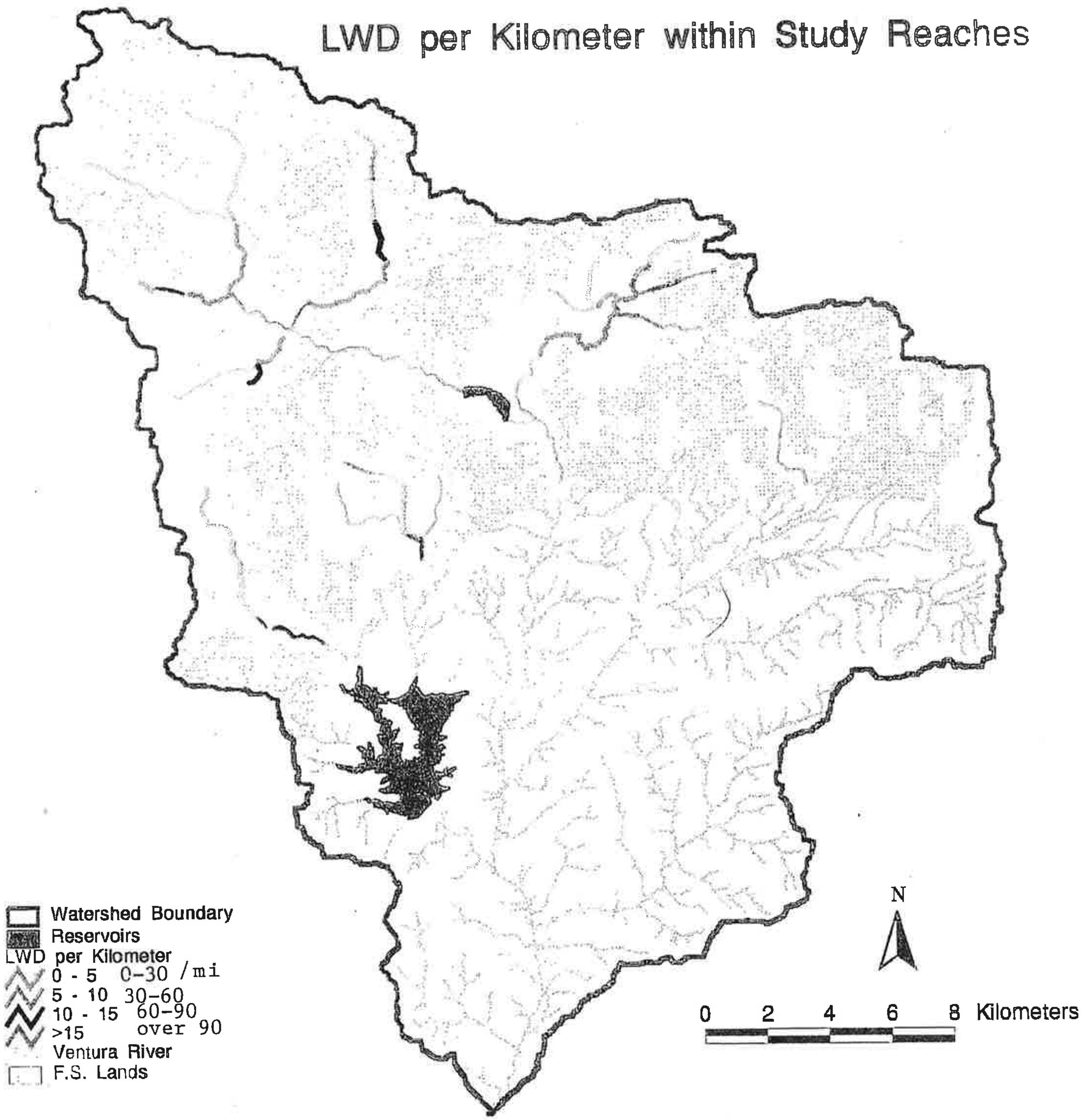


Figure13 . Ventura River basin densities of large and small (over 8 inch diameter) woody debris.

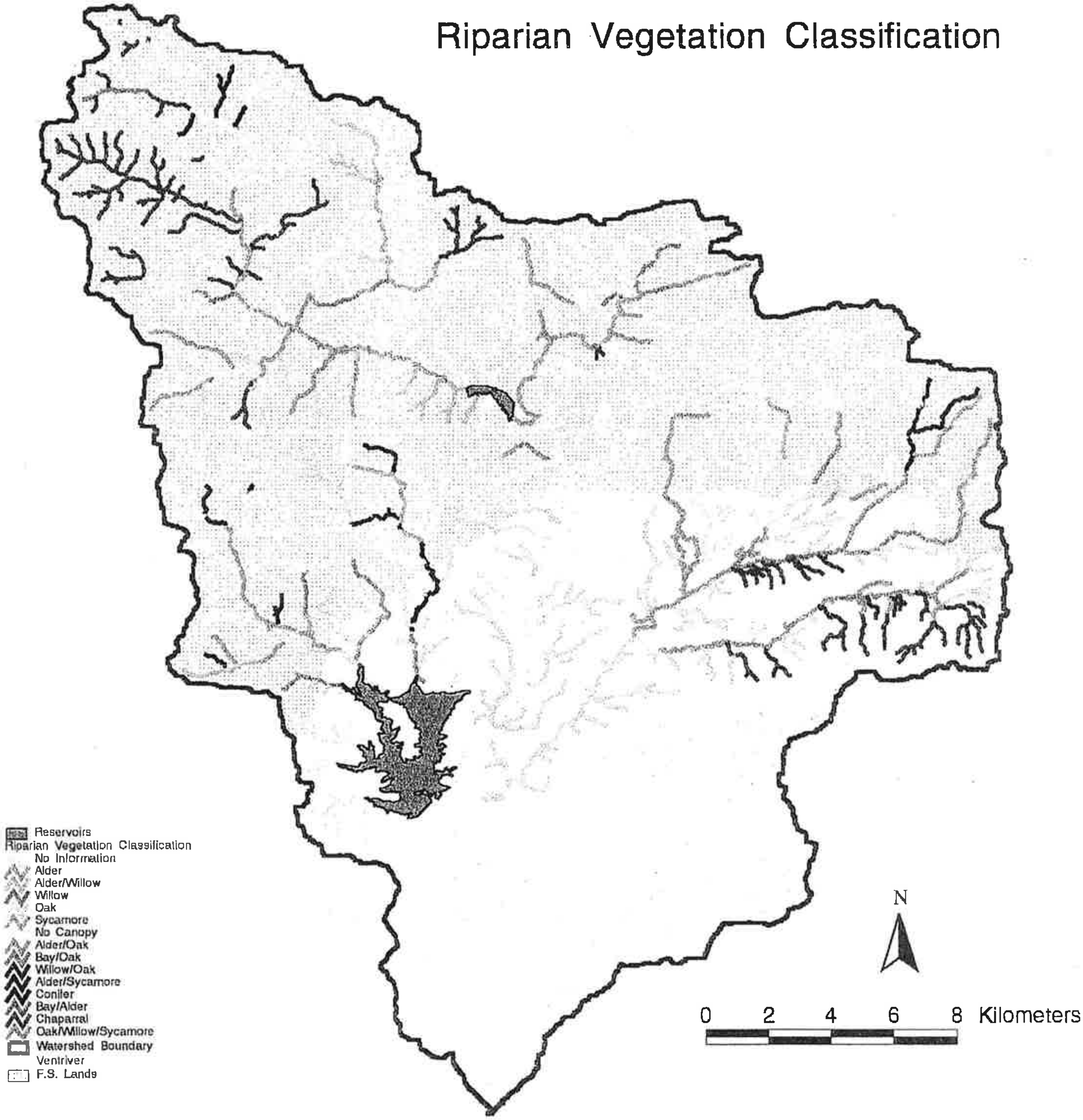
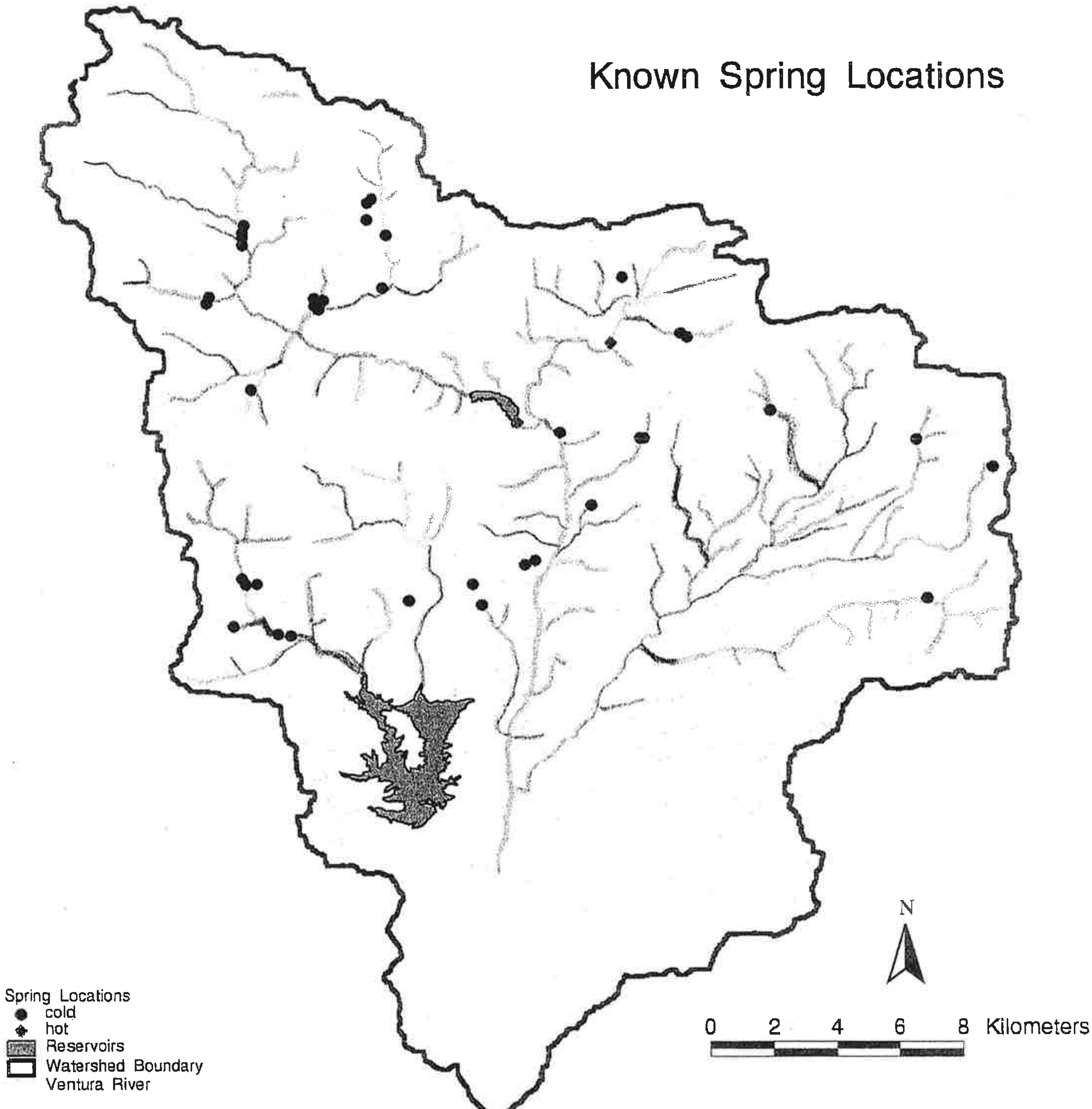


Figure 14. Riparian vegetation of the Ventura Watershed.



low canopy cover
moderate canopy cover
dense canopy cover

Figure 15. Location of springs and stream shade of Ventura River basin.

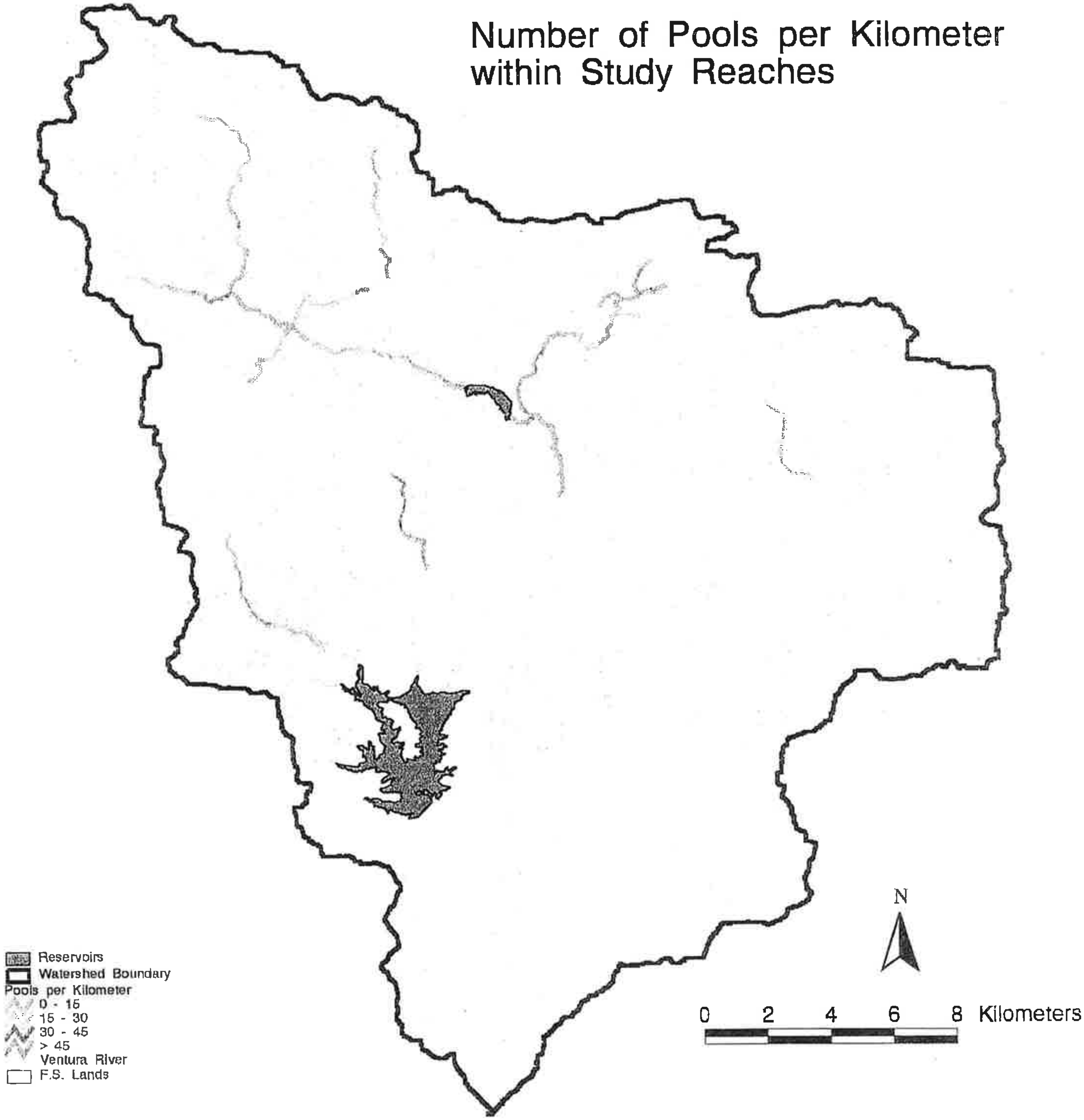


Figure 16. Pool densities within the Ventura River Basin.

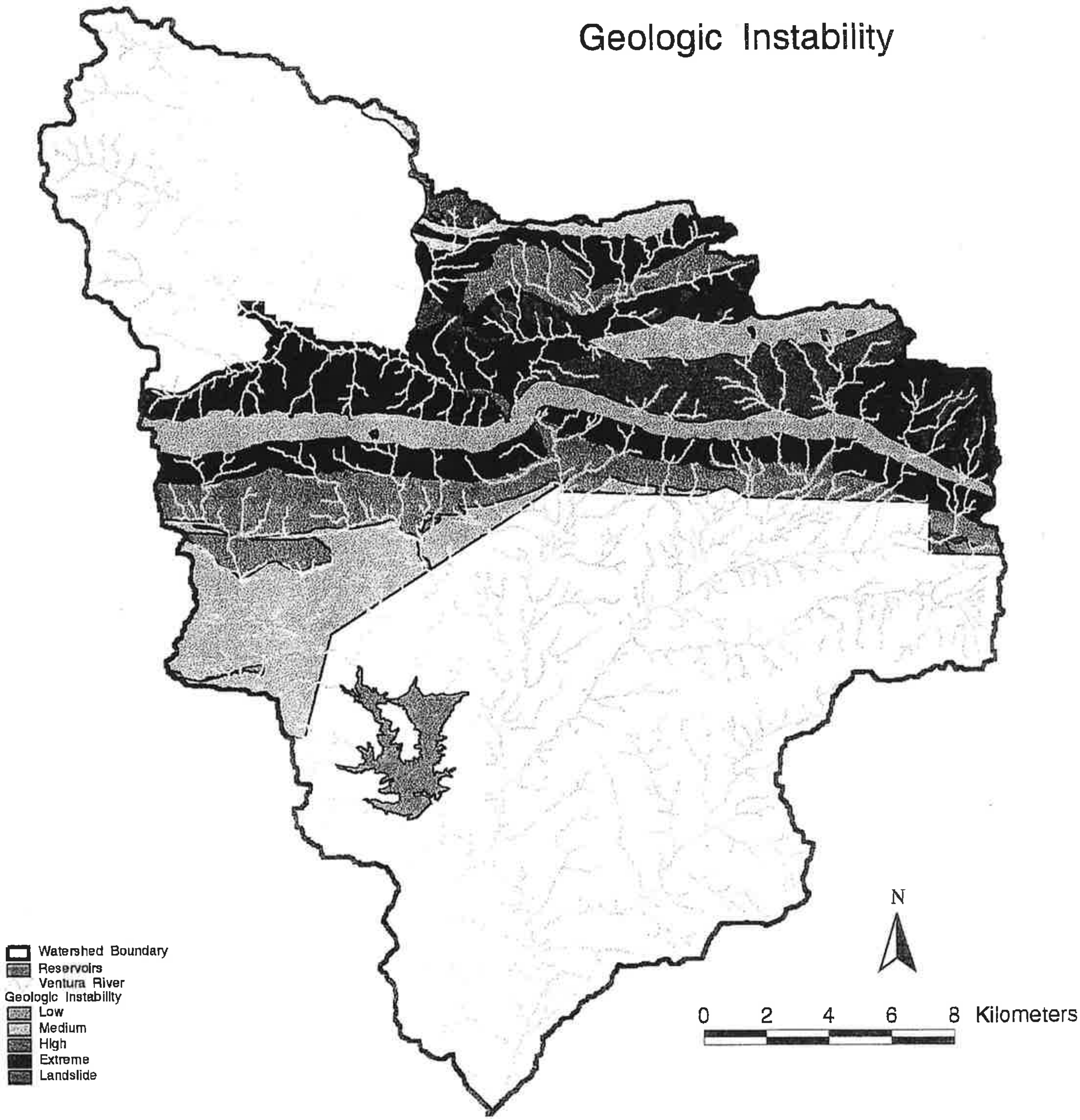


Figure 17. Geologic instability of Ventura Watershed.

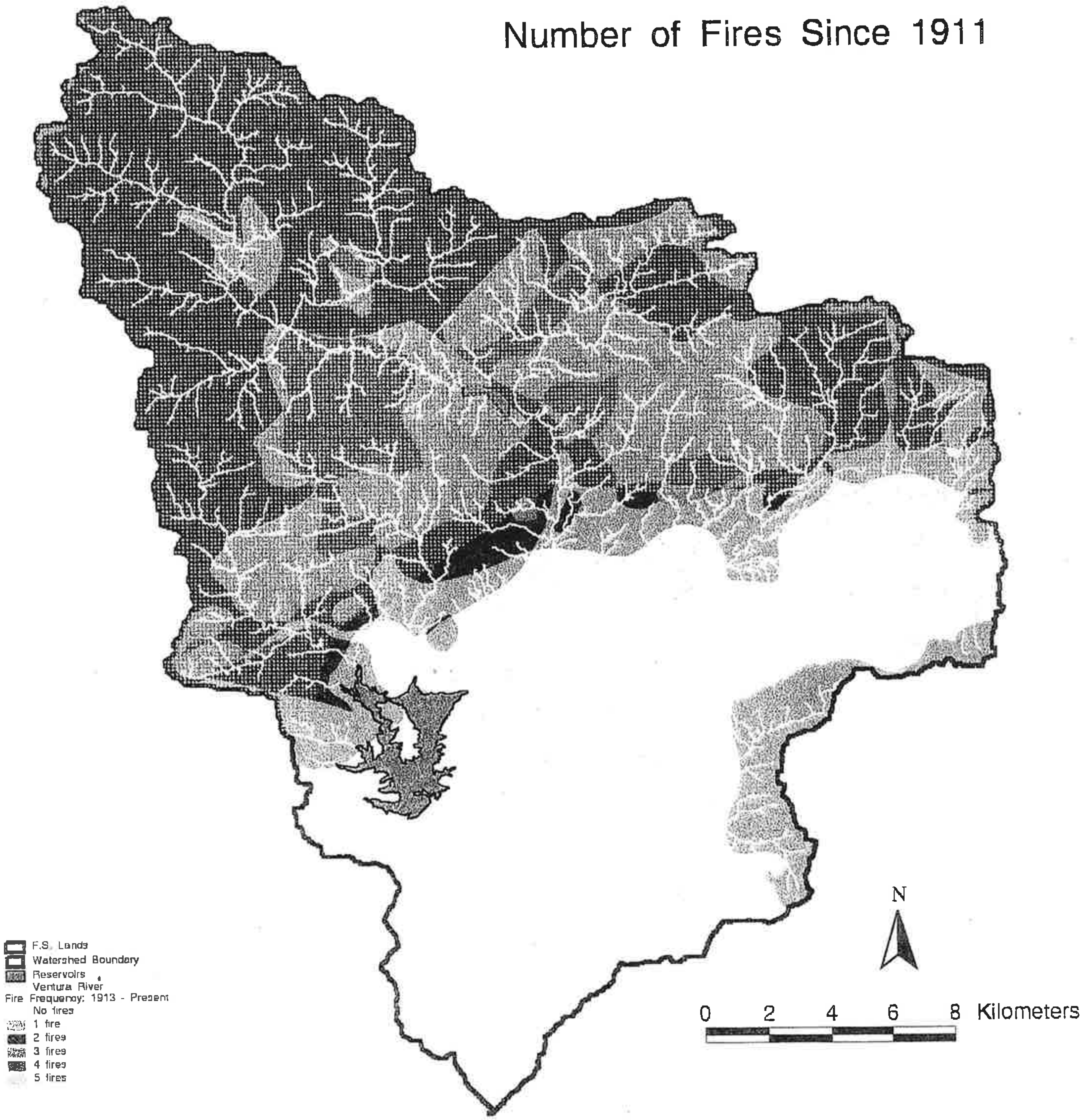


Figure 18. Fire frequencies of the upper Ventura Watershed.

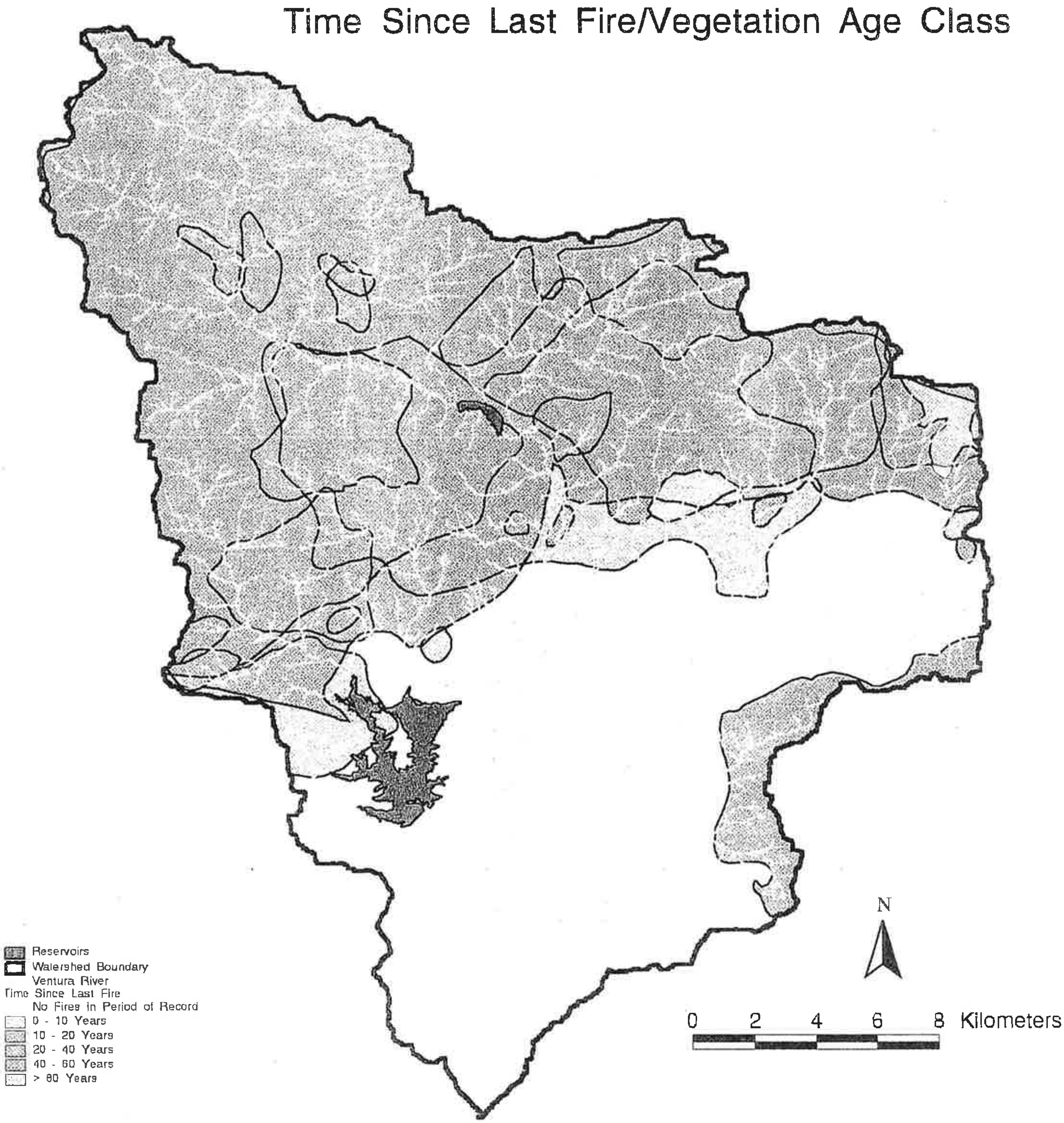


Figure 19. Time since last fire in the upper Ventura Watershed.

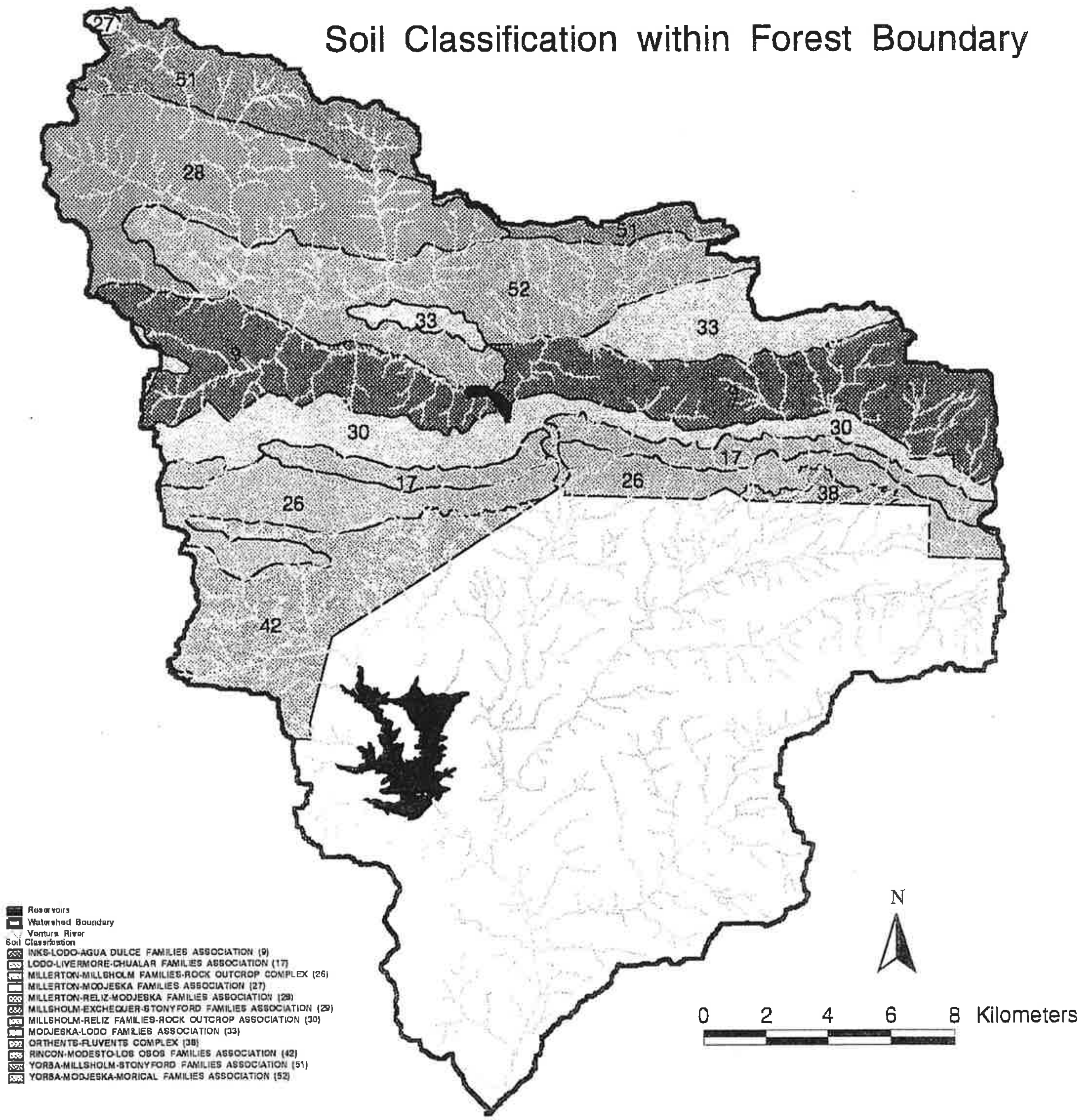


Figure 20. Soil classification within the Forest Boundary of the Ventura Watershed.

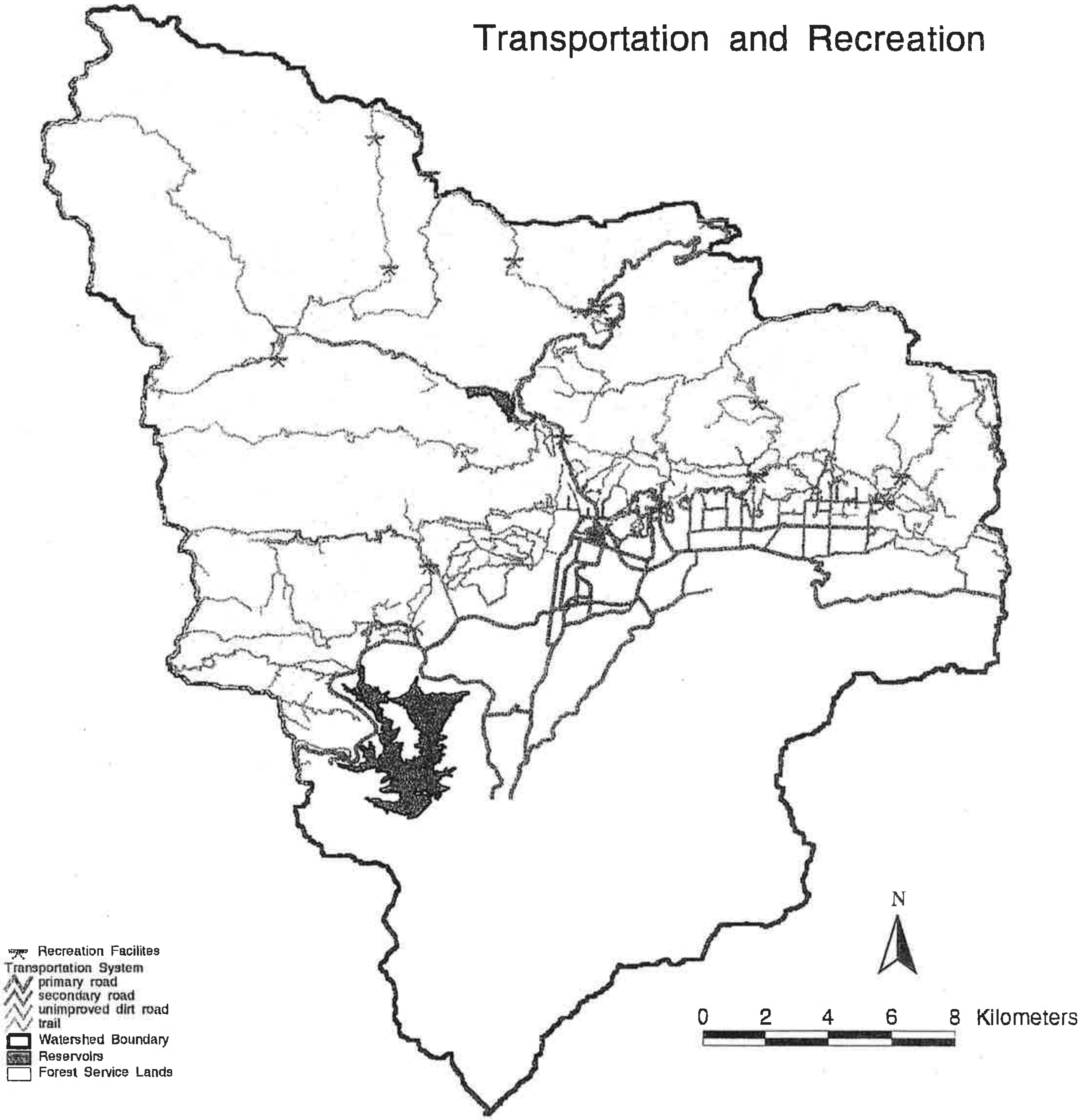


Figure 21. Transportation and recreation facilities within the Ventura Watershed.

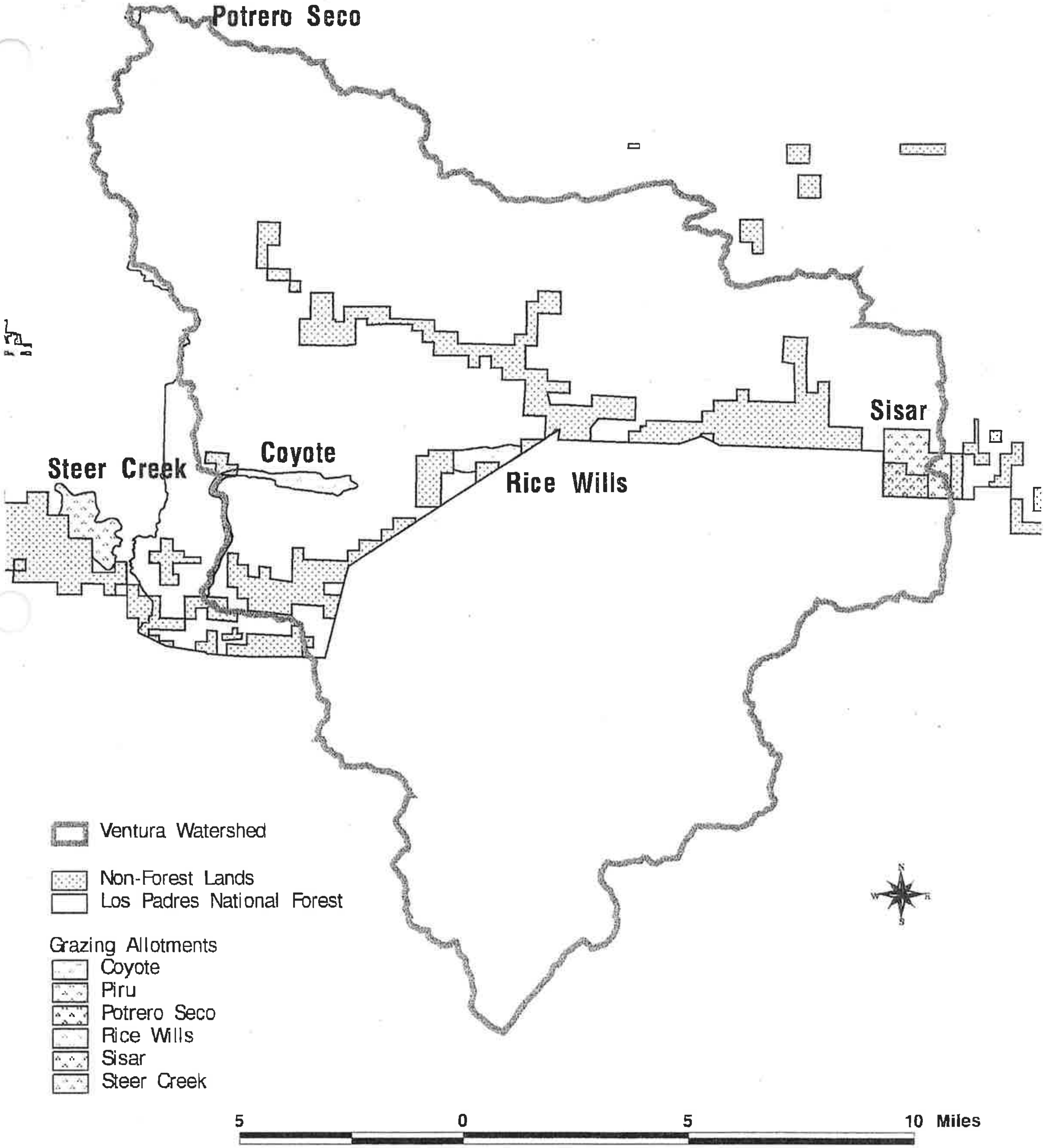


Figure 22. Grazing allotments within the Los Padres National Forest and Ventura Watershed.

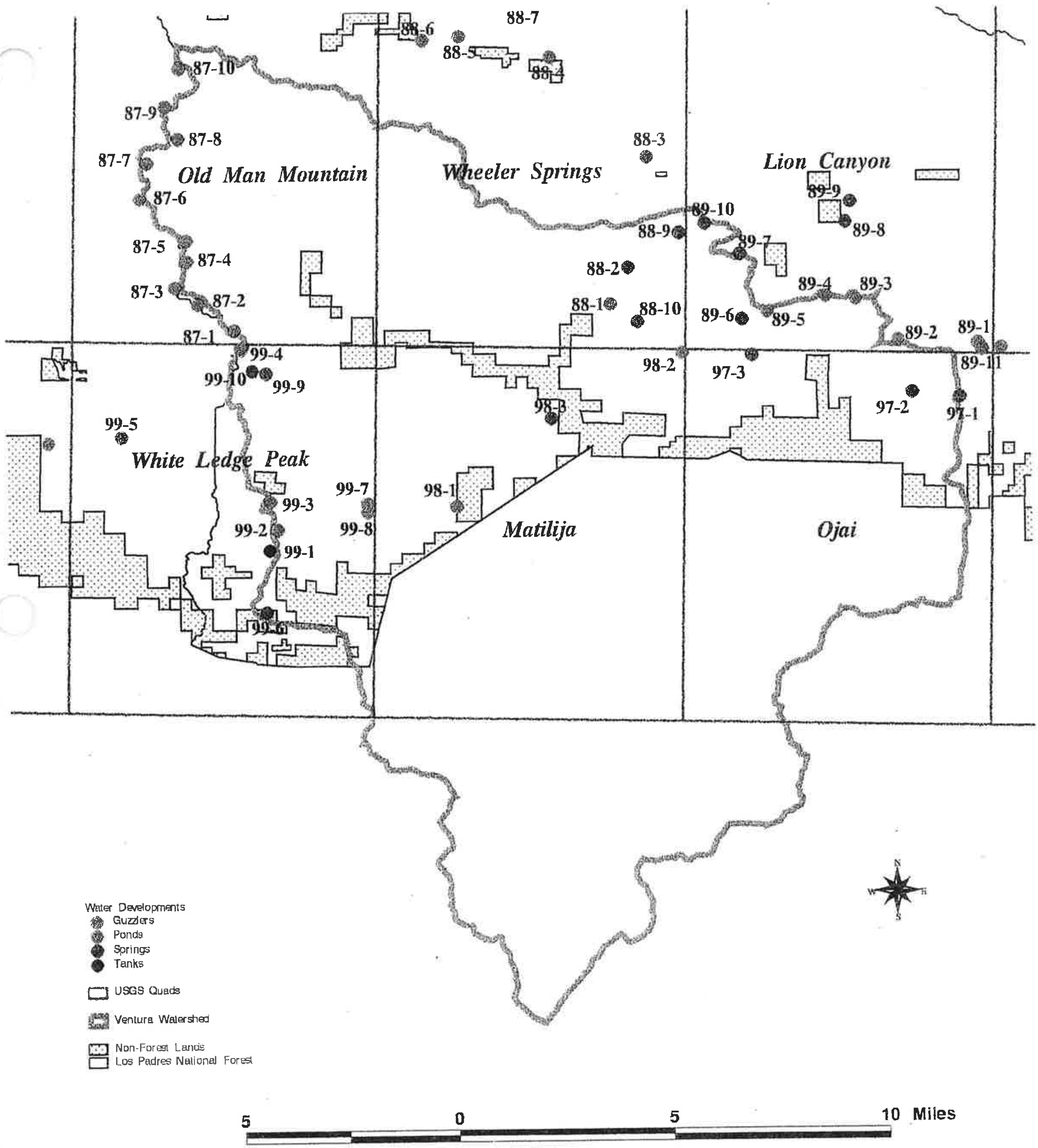


Figure 23. Water developments within Los Padres National Forest and Ventura Watershed.

Lower Ventura River

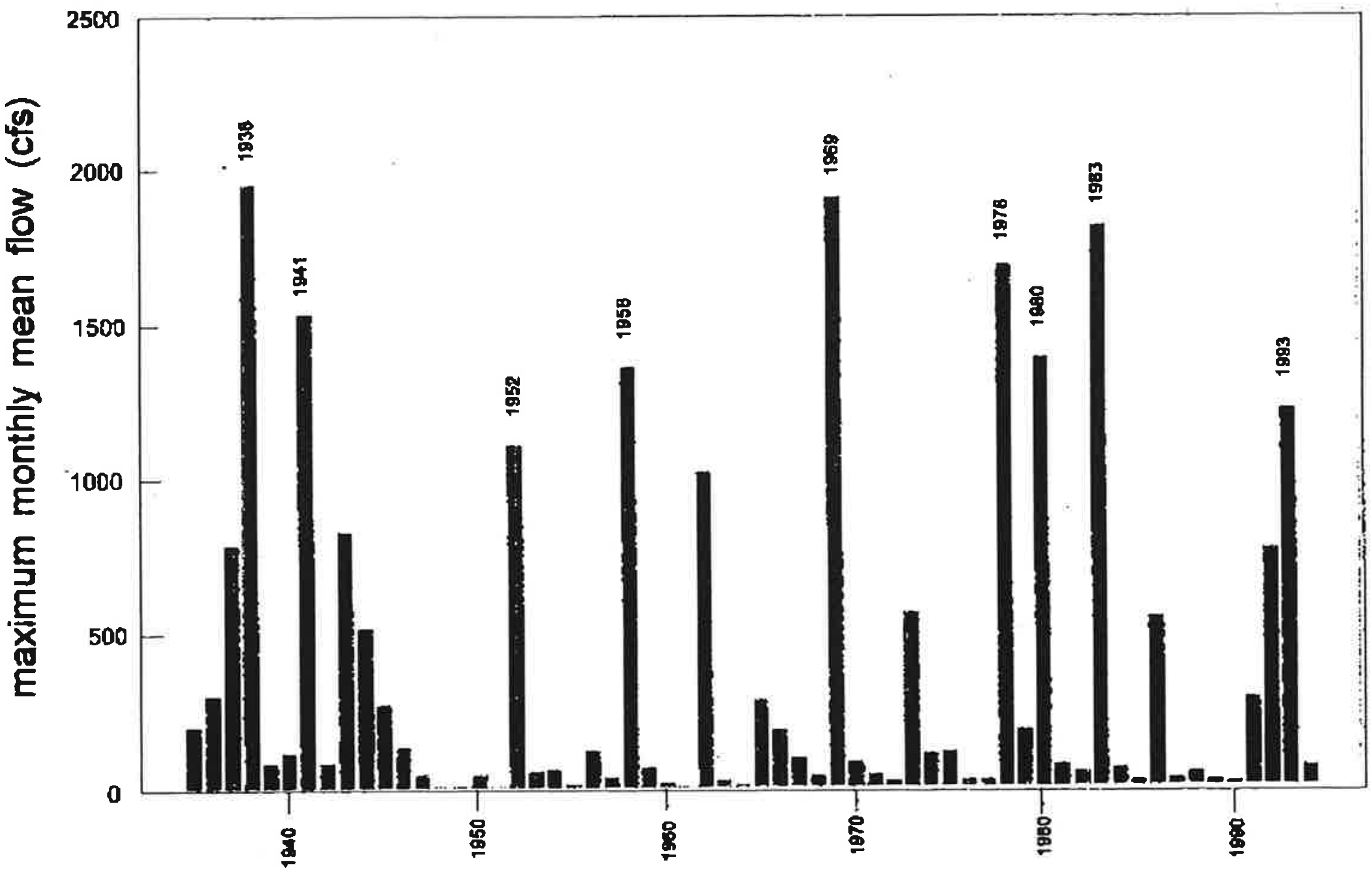


Figure 24. Comparison of average seasonal high flows from 1935 to 1995 in the lower Ventura River (USGS data).

Sediment Loads in the Ventura River Basin, Ventura County, California, 1969-81

By Barry R. Hill and Christopher E. McConaughy

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 88-4149

Prepared in cooperation with the
CALIFORNIA DEPARTMENT OF BOATING AND WATERWAYS

5030-03

Sacramento, California
1988

DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS

The inch-pound system of units is used in this report. For readers who prefer metric (International System) units, the conversion factors for the terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
acre-foot (acre-ft)	1,233.0	cubic meter
acre-foot per square mile (acre-ft/mi^2)	476.1	cubic meter per square kilometer
acre-foot per square mile per year [(acre-ft/mi^2)/yr]	476.1	cubic meter per square kilometer per annum
foot (ft)	0.3048	meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
inch (in.)	25.4	millimeter
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
short ton (ton)	0.9072	megagram
short ton per day (ton/d)	0.9072	megagram per day
short ton per year (ton/yr)	0.9072	megagram per annum
short ton per square mile per year [(ton/mi^2)/yr]	0.5638	megagram per square kilometer per annum
cubic yard (yd^3)	0.7646	cubic meter

Particle size is given in millimeters. To convert from millimeters to inches, multiply value in millimeters by 0.03937.

Degrees Fahrenheit (°F) is converted to degrees Celsius (°C) by using the formula:

$$\text{Temp. °C} = (\text{temp. °F}-32)1.8.$$

Abbreviations and symbols used:

mg/L (milligrams per liter)
< (less than)
> (greater than)

DEFINITIONS OF TERMS

Terms used in this report adhere to the definitions of the U.S. Geological Survey (1977) except where otherwise noted.

Bedload is the material moving on or near the streambed by rolling, sliding, and sometimes making brief excursions into the flow a few diameters above the bed.

Bedload discharge is the quantity of bedload passing a transect in a unit of time.

Bed material is the sediment mixture of which the streambed is composed.

Cubic foot per second-day (cfs-day) is the volume of water represented by a flow of 1 cubic foot per second for 24 hours. It is equivalent to 86,400 cubic feet.

Coarse-sediment discharge is that fraction of the total-sediment discharge composed of particles equal to or larger than 0.062 mm intermediate grain diameter. It usually includes all the sediment moving as bedload and part of the suspended sediment.

Coarse-suspended-sediment discharge is that fraction of suspended-sediment discharge composed of particles equal to or larger than 0.062 mm intermediate grain diameter.

Measured suspended-sediment discharge is the part of the suspended-sediment discharge that can be computed from the total water discharge and mean sediment concentration in the depth actually sampled with the suspended-sediment sampling equipment. Measured suspended-sediment discharge is published annually in the U.S. Geological Survey Water-Data Reports and is generally considered to be the suspended-sediment discharge, expressed in tons per day.

Sediment is solid material that is derived mostly from disintegrated rocks and is transported by, suspended in, or deposited from water; it includes chemical and biochemical precipitates and decomposed organic material such as humus. The quantity, characteristics, and cause of occurrence of sediment in streams are influenced by environmental factors. Some major factors are degree of slope, length of slope, soil characteristics, land usage, and quantity and intensity of precipitation.

Sediment concentration is the mass of dry solids divided by the volume of water and is expressed in milligrams per liter.

Sediment discharge is the rate at which the dry mass of sediment passes a section of a stream, or is the quantity of sediment, as measured by dry mass or volume, that is discharged in a given time.

Sediment load is the sediment in suspension and (or) transport. Load usually is expressed in terms of mass or volume (for example, grams, tons, or cubic feet).

Sediment-transport curve is the curve that defines the average relation between the rate of sediment discharge and rate of streamflow. Transport curves may be classified according to either the period of the basic data that define the curve or the kind of sediment discharge that a curve represents (Colby, 1956).

Sediment yield is the quantity of sediment, total or suspended, that is transported from or produced per unit area. Sediment yield usually is expressed as a mass or volume per unit area and time (for example, tons per square mile per year) (U.S. Geological Survey, 1986).

Streamflow is the mixture of water, sediment, and solutes discharged by a natural channel (Porterfield, 1980).

Suspended sediment is sediment that is moved in suspension in water and is maintained in suspension by the upward components of turbulent currents or by colloidal suspension.

Total-sediment discharge is the sum of the suspended-sediment discharge and the bedload discharge, as measured by dry mass or volume, that is discharged during a given time (Colby and Hembree, 1955).

Water year is the 12-month period that starts October 1 and ends September 30; it is designated by the calendar year in which it ends. In this report, all yearly designations refer to water year, except as otherwise noted.

SEDIMENT LOADS IN THE VENTURA RIVER BASIN, VENTURA COUNTY, CALIFORNIA, 1969-81

By Barry R. Hill and Christopher E. McConaughy

ABSTRACT

To estimate the replenishment of beach sands by fluvial transport from the Ventura River, sediment data collected during a 12-year period (1969-81) were used to develop relations between bedload and coarse-suspended-sediment loads and streamflow. These relations were used to calculate coarse- and total-sediment loads from the Ventura River, and to assess the effects of major storms on sediment transport. Sediment data collected on an unregulated tributary over a 2-year period were used to assess effects of dam construction on sediment loads and to identify major sediment-source areas in the Ventura basin.

Total-sediment load from the Ventura River for the 12 years of data collection was 12,800,000 tons, of which 5,100,000 tons, or 40 percent, consisted of coarse material potentially available for replenishment of beach sands. Suspended-sediment transport was the dominant process supplying sediment to the coast, accounting for more than 98 percent of the total-sediment load and 96 percent of the coarse-sediment load. Higher streamflows carried proportionately more coarse-suspended sediment than low flows. Major storm events transported more than 96 percent of both total- and coarse-sediment annual loads during three high-flow years. The sequence of storm events may influence storm-period sediment transport, as sediment removed rapidly during high flows is gradually replenished by hillslope processes.

The sediment yield of the unregulated part of the basin was higher than that of the regulated part. Consideration of the trap efficiencies of reservoirs in the basin, however, indicates that actual yields may be highest in areas affected by impoundments.

INTRODUCTION

The beaches of southern California are maintained by the erosion of coastal drainage basins and subsequent fluvial transport of sediment to the coastline (Rice and others, 1976). Coarse sediments deposited at the mouths of coastal rivers are reworked by wave action and transported by littoral currents, providing material for the beaches.

In the Ventura River basin (fig. 1), the natural flux of sediment to the coast has been altered by developments such as dams and diversions. Since 1948, reservoirs have been constructed on two principal tributaries of the Ventura River (table 1). These reservoirs trap substantial quantities of coarse sediment (Lustig, 1965; Scott and Williams, 1978). Although the net delivery of sediment to the coastline has decreased, the littoral-drift process has not. The reduction in sediment supply has raised concerns about present beach erosion and effects of future developments on the supply of beach sand. To evaluate the potential for increased beach erosion under present and future water-management operations, an assessment of sediment-transport relations in the Ventura River basin is needed. The analysis of sediment data presented in this report was completed in cooperation with the California Department of Boating and Waterways.

Table 1.--Reservoirs and diversion structures in the Ventura River basin upstream from station 11118500

[Storage capacity is given as of 1968. Trap efficiency is given as calculated by the storage capacity-drainage area method (Brune, 1953); --, not determined]

Reservoir or structure	Year of construction	Storage capacity, in acre-feet	Drainage area, in square miles	Trap efficiency, in percent	Remarks
Matilija Reservoir	1948	2,500	55	82	Original capacity was 7,000 acre-feet.
Robles-Casitas Diversion	1959	19	76 (21 below Matilija Reservoir)	--	Diverts maximum of 500 cubic feet per second; not operated during high flows.
Lake Casitas	1959	254,000	39	99	

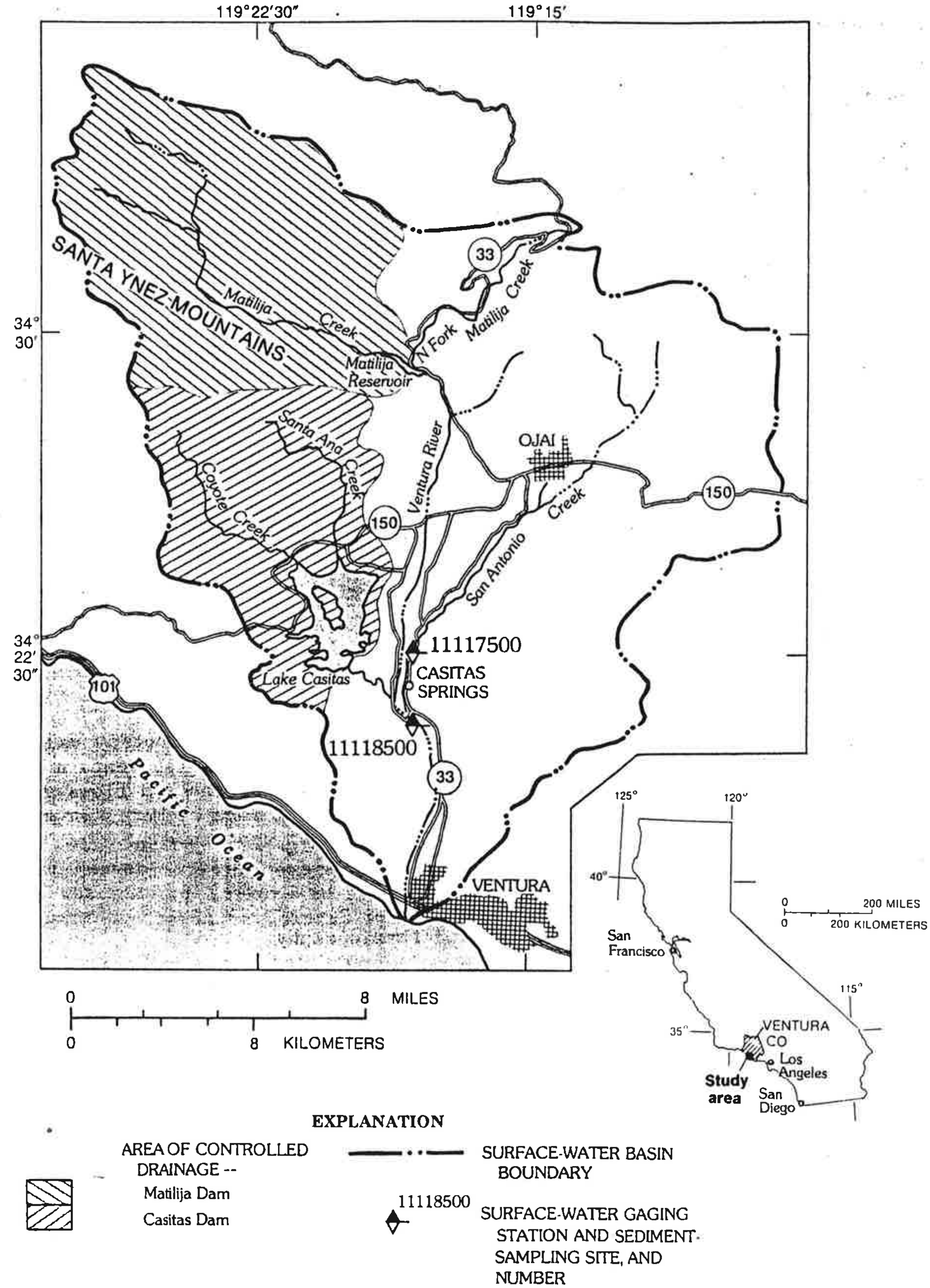

FIGURE 1.--Study area and location of gaging stations and sediment-sampling sites.

Purpose and Scope

This report describes the results of a study to estimate the loads of coarse and total sediment from the Ventura River basin under existing conditions of flow regulation and land use. Comparisons were made between results of this study and other recent studies of sediment transport in coastal southern California, and between sediment-transport characteristics of regulated and unregulated parts of the basin. Effects of major storms were evaluated, and possible sources of coarse sediment were considered in the context of geomorphic processes.

The analyses of sediment transport were made by using published and unpublished data previously collected by the U.S. Geological Survey. Sediment and streamflow data collected at two stations in the basin between 1969 and 1981 were used to define empirical relations between streamflow and the transport of bedload and coarse-suspended sediment. By use of these relations, annual values of coarse-suspended sediment load, bedload, and total sediment load were calculated.

Basin Description

Location

The Ventura River basin, in southern California, is about 60 miles west-northwest of Los Angeles (fig. 1). The drainage area of the Ventura River is 226 mi^2. The river originates in the Santa Ynez Mountains and flows generally southward for approximately 15 miles from the confluence of Matilija and North Fork Matilija Creeks to its mouth near the city of Ventura.

Geology and Physiography

Uplands in the basin are underlain primarily by sedimentary rocks consisting of Tertiary sandstones, shales, and limestones; valley bottoms contain fills of Quaternary alluvium (Putnam, 1942). Active tectonism and contrasts in erodibility of rock types have produced a rugged topography, with narrow valleys and steep streambeds in the upland sections (Putnam, 1942). Nearly 45 percent of the basin may be classified as mountainous, 40 percent as foothill, and 15 percent as valley area (U.S. Bureau of Reclamation, 1954). Basin relief is about 6,000 feet.

Geomorphic Processes

Geomorphic processes contributing sediment to channel systems in southern California coastal watersheds include sheet erosion (Lustig, 1965) and several forms of mass wasting. Mass-wasting processes of particular significance in the Ventura River basin are dry sliding (Scott and Williams, 1978), slumping and earthflows (Putnam, 1942), and debris flows (Scott and Williams, 1978). Scott and Williams (1978) described a conceptual model of headwater-basin sediment transport in which channel infilling by dry sliding and sheet erosion during dry and moderate years alternates with channel scour by debris flows during major storms. Their conceptual model supports the finding of Anderson and others (1959) that dry-season hillslope processes contribute more sediment to channels than do fluvial processes.

The significance of channel-bed and bank erosion as a sediment source in the Ventura River basin may approach that of hillslope processes (Taylor, 1981). Lustig (1965), however, suggested that channel erosion might provide only 20 percent of the sediment yield in the nearby Castaic watershed, which has lithology similar to that of the Ventura basin over about half its area. Because alluvial channels throughout the southern California coastal mountains may be undergoing a period of entrenchment and erosion (Putnam, 1942; Scott and others, 1968; Cooke and Reeves, 1976; Scott and Williams, 1978; and Knott, 1980), channel erosion must be considered a potentially significant sediment source.

Climate

The Ventura River basin has a Mediterranean-type climate, with warm, dry summers and mild and relatively wet winters. Rainfall distribution is highly seasonal, with nearly all precipitation falling during the winter months (Cooke and Reeves, 1976). Average annual precipitation ranges from about 15 inches at the city of Ventura to as much as 30 inches in the mountains of the northern part of the basin (Rantz, 1969).

Vegetation and Land Use

Vegetation cover is primarily chaparral, with limited amounts of sagebrush, conifers, and grass (Wells and Palmer, 1982). There may have been a reduction in density of chaparral and coniferous forest during the late 19th century due to overgrazing and burning (Cooke and Reeves, 1976).

Land use in the steep upland areas of the Ventura River basin is restricted to livestock grazing and recreation. Lowland areas have been affected to some degree by cultivation and urbanization.

Previous Studies

Several previous studies have provided estimates of sediment yields in the Ventura River and adjacent basins, but these estimates are difficult to compare because of differences in methods, types and periods of data considered, and units used to report results. In particular, it is difficult to relate erosion rates reported as volumes of sediment per unit time to records of sediment that are determined as weight or mass per unit time, because estimates of bulk densities of eroded materials are not readily available. For purposes of comparison, all sediment yields reported by other authors as volumes per unit time have been converted to acre-feet per square mile per year ((acre-ft/mi^2)/yr) and are summarized in table 2.

Table 2.--Results from previous studies of average sediment yield in and adjacent to the Ventura River basin

[Sediment yield is given in acre-feet per square mile per year]

Study[1]	Drainage basin	Type of data considered	Sediment yield	Remarks
Lustig, 1965	Castaic	Reservoir sedimentation	1.82	
Scott and others, 1968	Matilija (Ventura)	do.	.96	
Do.	Piru	Physiographic characteristics	.79	
Scott and Williams, 1978	Ventura headwaters	do.	1.60-6.80	
Knott, 1980	Cañada de los Alamos (Piru)	do.	.26	
Taylor, 1981, 1983	Ventura	Sediment discharge	4.20	
California Department of Navigation and Ocean Development, 1977	Ventura	do.	.27	Coarse sediment
			.62	Prior to dam construction

[1]For full citations, see "References Cited" section.

Regression analysis has been used by various authors to obtain predictive equations for sediment yields in the southern California mountains based on data obtained from basins with known rates of reservoir sedimentation. Lustig (1965) used this approach to calculate a sediment yield of 1.82 (acre-ft/mi^2)/yr for the Castaic watershed in western Los Angeles County. Scott and others (1968) reported the average sediment yield above Matilija Reservoir (fig. 1) in the upper Ventura basin to be 0.96 (acre-ft/mi^2)/yr. Using a variety of empirical methods, these authors estimated the long-term sediment yield of the Piru Creek basin, northeast of and adjacent to the Ventura basin, to be 0.79 (acre-ft/mi^2)/yr. Scott and Williams (1978), in an extensive study of erosion in the southern California mountains, estimated that sediment yields resulting from the heavy storms of 1969 in the headwaters of the Ventura River ranged from 19.3 to 52.2 acre-ft/mi^2. Estimated long-term yields for this area ranged from approximately 1.6 to 6.8 (acre-ft/mi^2)/yr. Knott (1980) estimated a long-term yield of 0.26 (acre-ft/mi^2)/yr for the Cañada de los Alamos, a tributary of Piru Creek. Taylor (1981, 1983) calculated an upland erosion rate of 4.2 (acre-ft/mi^2)/yr for the Ventura basin; of the material eroded, 20 percent was estimated to be sand size or larger.

Other investigators have considered streamflow and sediment-discharge records compiled for gaging stations in the basin. Shiller (1972) showed that the mean grain size of suspended sediment in the Ventura River during the high flows of 1969 was proportional to stream velocity, streamflow, and sediment concentration. The California Department of Navigation and Ocean Development (1977) applied the modified Einstein bedload formula (Burkham and others, 1977) to records of streamflow to obtain an estimated annual coarse-sediment yield of 0.27 (acre-ft/mi^2)/yr for the Ventura basin for 1969-75. This report included a sediment-yield estimate of 0.62 (acre-ft/mi^2)/yr prior to construction of dams in the basin. Brownlie and Taylor (1981) used existing suspended-sediment data and the modified Einstein formula to obtain load estimates of 2.28 million tons of coarse sediment and 8.12 million tons of total sediment for the period 1969-75 at the Ventura River near Ventura (station 11118500).

Data Available

Ventura River near Ventura (11118500)

Records of daily streamflow at station 11118500 extend from October 1929 to the present (1984). Streamflow data for the period of this study are contained in reports by the U.S. Geological Survey (1972-75a, 1976, 1976-82). Drainage area is 188 mi^2. Periods of flow regulation and drainage-basin areas affected are given in table 1, and locations of reservoirs are shown in figure 1. All existing regulation structures were operational prior to 1969; no changes in regulation occurred during the period of sediment-data collection. Average daily streamflow for 1912-13 and 1930-82 was 58.3 ft^3/s. Streamflow is intermittent in most years. Maximum instantaneous streamflow was 63,600 ft^3/s on February 10, 1978.

Sediment data were collected at station 11118500, Ventura River near Ventura, from 1969 to 1973 and from 1975 to 1981. Daily values of suspended-sediment discharge and monthly values of bedload discharge were published previously (U.S. Geological Survey, 1972-75b, 1974a, 1974b, 1976-82). Additionally, some hydraulic and particle-size data and bedload measurements made using the method of Helley and Smith (1971) (available in U.S. Geological Survey data files) were used in the computations described below. Total suspended-sediment load for the period of data collection was 12,600,000 tons, with an average annual load of 1,050,000 tons. Minimum annual suspended-sediment load was 957 tons in 1977 and maximum annual load was 6,650,000 tons in 1969. Bedload values were computed independently for this report as described below, and previously published values were not used. No sediment data were collected in water year 1974, and all references to "period of data collection" for station 11118500 apply to water years 1969-73 and 1975-81.

San Antonio Creek at Casitas Springs (11117500)

Streamflow data at station 11117500 have been collected from October 1949 to the present. Streamflow data for the period of this study are contained in reports by the U.S. Geological Survey (1972-75a, 1976, 1976-82). Drainage area is 51 mi^2. Flow is unregulated above the station. Average daily streamflow for 1949-82 was 13.2 ft^3/s. Streamflow is intermittent in most years. Maximum instantaneous streamflow was 16,200 ft^3/s on January 25, 1969.

Daily suspended-sediment data were collected from October 1976 to September 1978 at station 11117500. Suspended-sediment load was 2,420 tons in 1977 and 1,390,000 tons in 1978 (U.S. Geological Survey, 1976-82). Unpublished hydraulic and particle-size data collected during streamflow measurements and sampling (available in U.S. Geological Survey data files) were used, as were bedload-discharge measurements made using the method of Helley and Smith (1971). Previously published bedload-discharge values (U.S. Geological Survey, 1976-82) were not used, for reasons discussed below.

METHODS

Because sediment discharge is related to streamflow (Guy, 1970), continuous streamflow records provide a means of estimating annual sediment load at sites where instantaneous measurements or calculations of sediment discharge have been made. The relation between sediment discharge and water discharge is commonly expressed in graphic form as an average curve on logarithmic paper. Such curves, known as sediment-transport curves, can be developed from instantaneous discharges of suspended sediment, bedload, or any sediment-size fraction for which data are available (Colby, 1956). Under some circumstances, instantaneous sediment-transport curves can be used in conjunction with average daily streamflow values as discussed by Colby (1956) to provide average daily values of sediment load. These daily values can then be summed to give estimates of annual sediment load for the type of sediment for which the transport curve was developed.

For this report, previously collected data were used to define relations between coarse-suspended-sediment and bedload transport and streamflow at the Ventura River near Ventura and at San Antonio Creek at Casitas Springs. These relations were then applied to existing records of average daily streamflow to estimate coarse-suspended-sediment load and bedload for the periods of sediment-data collection.

Ventura River Near Ventura (11118500)

To estimate bedload for the Ventura River near Ventura (11118500), an average-bedload-transport curve (fig. 2) was developed for the entire period of record. This curve is based on both direct measurements of bedload transport using methods described by Helley and Smith (1971) and calculated values determined with the Meyer-Peter and Muller bedload formula using the modifications of the U.S. Bureau of Reclamation (1960). Input data required for this formula are:

1. Instantaneous water discharge;
2. Width and average depth of stream cross section;
3. Water-surface slope;
4. Roughness factors (Manning roughness coefficient, n) for bed and banks; and
5. Bed material particle-size distribution.

The hydraulic data needed for the calculations were obtained from streamflow measurements. A composite bed-material sample (table 3) was used for particle-size distribution. No correction was applied to the optical and particle-count data, following the method of Kellerhals and Bray (1971) who found that those types of data are equivalent. This sample was believed to more accurately represent average conditions over the period of record than individual samples, and was used in all calculations. Use of this composite sample resulted in discrepancies with previously published values of bedload discharge (U.S. Geological Survey, 1972-75b, 1974a, 1974b, 1976-82). Daily values of bedload discharge were obtained for the period of record by using the bedload-transport curve to estimate average bedload corresponding to average daily streamflows. Daily values were summed to obtain annual values.

To estimate coarse-suspended-sediment discharge, a relation was determined between streamflow and the percentage of suspended sediment, by weight, that was 0.062 mm in diameter or larger. This relation was based on all existing size analyses for suspended-sediment samples collected at instantaneous streamflow of at least 100 ft^3/s. Samples collected at lower streamflows were not used because the great scatter of the data points would result in decreased accuracy at higher flows, which are most important for sediment transport, as discussed below. First, values for instantaneous streamflow and suspended-sediment concentration were log-transformed, and a relation between the transformed values was determined by linear regression. The resulting equation is:

$$\log C_T = 1.12 + 0.754 \log Q, \qquad (1)$$

where C_T is the concentration of total-suspended sediment, in milligrams per liter, and Q is instantaneous streamflow, in cubic feet per second. The r^2 value for this regression is 0.70, adjusted for degrees of freedom. The concentrations of coarse-suspended sediment were obtained by multiplying the percentage of coarse material in each sample by the concentration of total-suspended sediment (C_T). These values were then log-transformed, and a second equation was determined by linear regression:

$$\log C_C = -1.88 + 1.38 \log Q, \qquad (2)$$

where C_C is the concentration of coarse-suspended sediment. The r^2 value for this regression is 0.75, adjusted for degrees of freedom. Both regression lines and all data points used to derive them are shown in figure 3. Data points representing samples collected at streamflows less than 100 ft³/s also are included. A range of values of log Q was selected, and corresponding values for log C_T and log C_C were determined from equations 1 and 2. The antilogs for these values were then used to compute the percentage of coarse material for the selected values of log Q. The resulting relation is:

$$\log \%SAND = -3.00 + 0.626 \log Q \quad \text{or} \quad \%SAND = 0.001\, Q^{0.626}, \qquad (3)$$

where $\%SAND$ is the percentage of coarse material in the suspended-sediment load. Equation 3 was used to determine the percentage of coarse-suspended sediment for all average daily values of suspended-sediment discharge using log-transformed values of average daily streamflow for log Q. Values of daily streamflow below 100 ft³/s were included, as the wide scatter of the size data at low flows precluded defining any more accurate relation. Resulting errors are believed to be minor because only a small fraction of the annual sediment load is transported at low flows, as discussed below. Daily values were summed to give annual totals.

Estimates of total coarse-sediment load were calculated as coarse-suspended-sediment load plus bedload. Estimates of total-sediment load were calculated as the sums of suspended-sediment load and bedload. These estimates may misrepresent the actual coarse- and total-sediment loads because sediment concentrations, particularly concentrations of coarse-size fractions, are often not uniform with depth (Colby, 1956). Concentrations of suspended sediment determined from suspended-sediment samples may not, therefore, be representative of suspended-sediment concentrations below the sampled zone, that is, from the surface of the stream bed to 0.3 foot above the bed (Colby, 1963). Bedload samples collected using the method of Helley and Smith (1971) also may fail to adequately represent sediment transport near the bed because the normal mesh size used with the bedload sampler, 0.2 mm, allows finer particles to escape. Consequences of these sampling problems for determining sediment loads are discussed by Hubbell (1964).

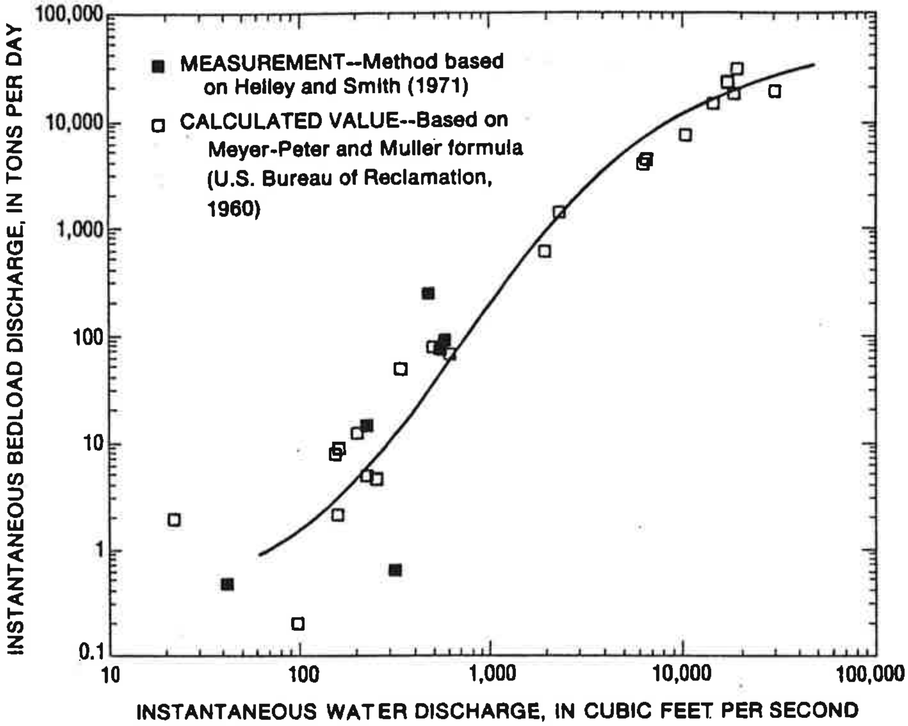

FIGURE 2.--Bedload-transport curve, Ventura River near Ventura (11118500).

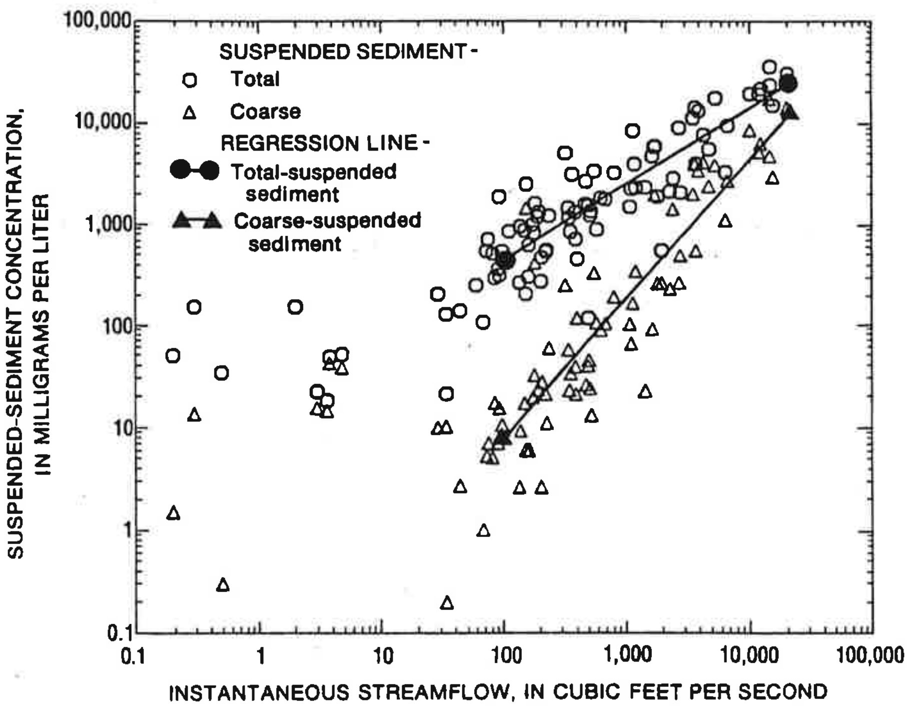

FIGURE 3.--Concentration curves for total-suspended and coarse-suspended sediment, Ventura River near Ventura (11118500).

Table 3.--Particle-size distribution of surficial bed material, Ventura River near Ventura (11118500)

[Discharge is given in cubic feet per second. Method of analysis/remarks: S, sieve; O, optical; PC, particle count; PU, previously unpublished. --, no data]

Date	Time (24 hour)	Sampling point	Discharge	Bed material Percent finer than size, in millimeters, indicated 0.062	0.125	0.250	0.500	1.00	2.00	4.00	8.00	16.0	32.0	64.0	128	256	512	1024/2048	Method of analysis/remarks
11-21-68	1130	2	--	4	6	11	20	32	42	50	60	66	80	100	--	--	--	--	S/PU
02-19-69		3	--	2	3	7	12	18	24	31	42	55	73	100	--	--	--	--	S/
09-18-73	0900	3	12.0	3	7	21	36	47	56	65	75	93	100	--	--	--	--	--	S/
09-30-75			--	--	--	--	--	--	--	--	--	6	15	43	84	100	--	--	O/PU
09-16-77	1030	4	0	2	4	6	11	16	24	31	42	55	65	100	--	--	--	--	S/
08-29-79		15	--	--	--	--	--	--	--	--	--	19	38	71	95	100	--	--	O/PU
08-08-80	1015	4	9.3	2	7	25	61	82	40	94	97	100	--	--	--	--	--	--	S/PU
			--	--	--	--	--	--	--	--	--	--	--	33	49	74	86	99/100	PC/
09-30-81	0930	2	.76	1	1	3	8	18	25	32	43	58	82	100	--	--	--	--	S/PU
Average for all optical counts												13	27	57	90	100	--	--	
Average for all sieve samples				2	5	12	25	36	44	51	60	71	83	100	--	--	--	--	
Average of all optical counts averaged with the particle count														44	74	92	97	99/100	
Composite of last two averages above[1]				1	2	5	11	16	19	22	26	31	37	44	74	92	97	99/100	

[1]This distribution used for bedload calculations.

San Antonio Creek at Casitas Springs (11117500)

Bedload discharge and coarse-suspended-sediment discharge for the San Antonio Creek at Casitas Springs were calculated using the methods described previously. A single bed-material sample was used for the bedload calculations using the Meyer-Peter and Muller method (U.S. Bureau of Reclamation, 1960). The size distribution of this sample is shown in table 4. Direct measurements of bedload transport using the Helley and Smith (1971) method as well as values calculated with the Meyer-Peter and Muller formula (U.S. Bureau of Reclamation, 1960) were used to develop the bedload-transport curve shown in figure 4. Use of the Meyer-Peter and Muller calculation allowed extension of the bedload-transport curve to the high flows of 1978; values obtained from this curve are therefore probably more accurate than values published previously by the U.S. Geological Survey (1976-82).

Only 15 suspended-sediment size analyses were available for station 11117500, and of these, only 6 were from samples collected at or above 100 ft^3/s. These six analyses were used to develop relations between streamflow and concentrations of total- and coarse-suspended sediment. The resulting equations are:

$$\log C_T = 1.04 + 0.922 \log Q \; (r^2 = 0.93) \quad (4)$$

and

$$\log C_C = -2.09 + 1.68 \log Q \; (r^2 = 0.73), \quad (5)$$

where C_T, C_C, Q, and r^2 are as defined in equations 1-3. From equations 4 and 5, the resulting relation for percentage of coarse material in suspended sediment (*%SAND*) is:

$$\log \%SAND = -3.13 + 0.758 \log Q \quad \text{or} \quad \%SAND = 0.00074 \, Q^{0.758}. \quad (6)$$

Equation 6 was used to determine the percentage of coarse material in the suspended-sediment load in the same manner as used for the Ventura River. Estimates of total coarse-sediment load were calculated as coarse-suspended-sediment load plus bedload. Estimates of total-sediment load were calculated as the sums of suspended-sediment load and bedload. The concentration curves for total-suspended sediment and coarse-suspended sediment are shown in figure 5.

Table 4.--Particle-size distribution of surficial bed material, San Antonio Creek at Casitas Springs (11117500)

[Method of analysis: sieve. Discharge is given in cubic feet per second. Sample was collected with shovel]

Date	Time (24 hour)	Sampling point	Discharge	Bed material Percent finer than size, in millimeters, indicated										
				0.062	0.125	0.250	0.500	1.00	2.00	4.00	8.00	16.0	32.0	64.0
09-16-77	0945	5	0.0	12	19	28	44	54	61	68	77	86	95	100

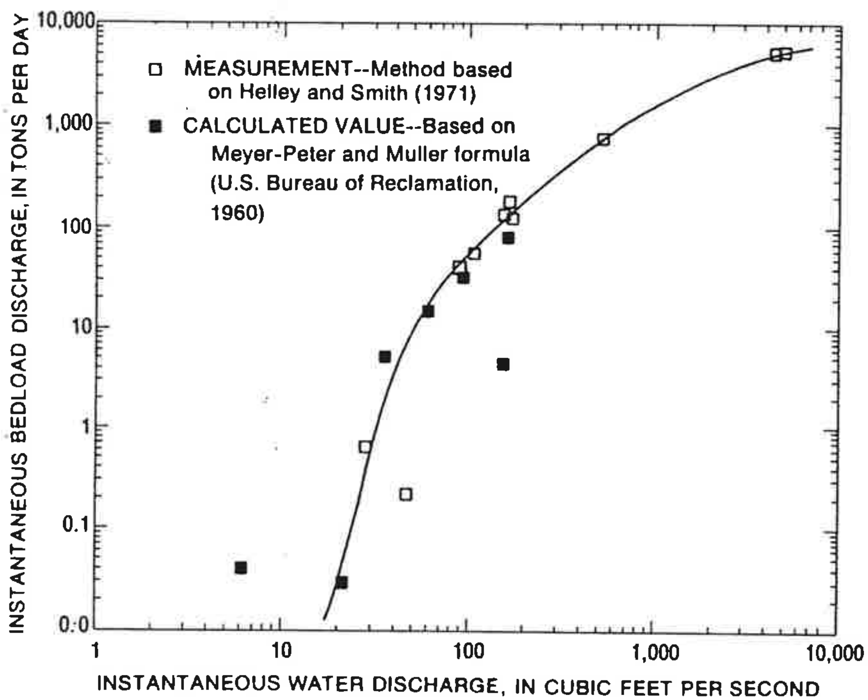

FIGURE 4.--Bedload-transport curve, San Antonio Creek at Casitas Springs (11117500), 1977-78.

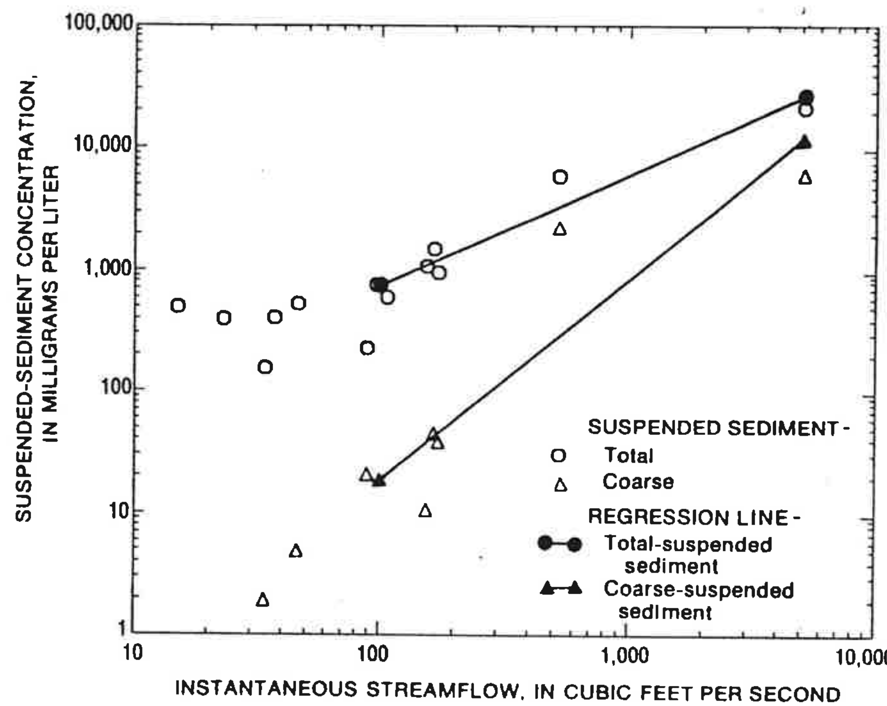

FIGURE 5.--Concentration curves for total-suspended sediment and coarse-suspended sediment, San Antonio Creek at Casitas Springs (11117500).

SEDIMENT-TRANSPORT PROCESSES IN THE VENTURA RIVER BASIN

Ventura River Coarse-Sediment Transport

Percentages of coarse sediment in suspended sediment and in total sediment, percentage of bedload in total sediment, and total-sediment yield for the Ventura River near Ventura during the period of data collection are given in table 5. During the 12 years of sediment-data collection, more than 98 percent of the sediment was transported as suspended sediment and less than 2 percent as bedload. Of the total-sediment transport, 40 percent consisted of coarse particles potentially available for replenishment of beach sand. Of this coarse fraction, 96 percent was moved as suspended sediment, and the remainder as bedload. All the coarse-suspended sediment was within the sand-size range (0.062 to 2.00 mm). Particles transported as bedload ranged from silt to gravel size (less than 0.062 to greater than 32 mm).

The relation of coarse-suspended-sediment concentration to streamflow is not well defined for the Ventura River. This is apparent from the relatively low value of the correlation coefficient for equation 2 as well as from the scatter of the data points plotted in figure 3. Factors other than the magnitude of streamflow evidently are important in determining the variability of coarse-suspended-sediment concentration. Until these factors are better understood, however, relations such as those defined by equations 1-3 will provide the most reasonable means of estimating the transport of coarse-suspended sediment.

The relation between streamflow and the percentage of coarse material in suspended sediment indicates that at higher flows a larger proportion of the suspended load will consist of coarse sediment. Thus, as shown in table 4, high annual streamflows will not only result in high sediment loads, but those loads will contain greater percentages of coarse sediment. The implications of this relation are considered further in the section "Effects of Major Storms."

Comparison of Ventura River Near Ventura and San Antonio Creek at Casitas Springs

The water years during which sediment data were collected on San Antonio Creek at Casitas Springs represent hydrologic extremes, with 1977 being the second of two drought years and 1978 being a year of exceptionally high streamflow (tables 5 and 6). Both streamflow and the suspended-sediment load were higher at San Antonio Creek (station 11117500) than at the Ventura River (station 11118500) during the dry year of 1977, presumably because of seepage losses into the streambed between the two stations. During 1978, streamflow at the Ventura River station exceeded that at the San Antonio Creek station by over four times, but the total-sediment load was only twice as great at the Ventura River station. These results suggest that channel aggradation may occur along San Antonio Creek during dry years, but that during years of high flow, its contribution of suspended sediment to the Ventura River is proportionately greater than its contribution of streamflow.

Table 5.--Estimated sediment load at Ventura River near Ventura (11118500), 1969-81

[Streamflow is given in cubic foot per second-days. Total sediment yield is given in tons per square mile per year. --, no data]

Water year	Streamflow	Load, in tons: Total-suspended sediment	Load, in tons: Coarse-suspended sediment	Load, in tons: Bedload	Load, in tons: Total coarse sediment	Load, in tons: Total sediment	Percentage of coarse sediment in: Suspended sediment	Percentage of coarse sediment in: Total sediment	Percentage of bedload in total sediment	Total sediment yield[1]
1969	126,000	6,650,000	2,680,000	88,100	2,770,000	6,740,000	40.3	41.1	1.3	35,800
1970	5,040	32,800	1,550	233	1,790	33,000	4.7	5.4	.7	176
1971	5,700	37,100	2,290	470	2,760	37,600	6.2	7.3	1.3	200
1972	1,510	7,090	339	79	418	7,170	4.8	5.8	1.1	38.1
1973	24,400	491,000	100,000	9,320	110,000	501,000	20.4	21.9	1.9	2,660
1974	--	--	--	--	--	--	--	--	--	--
1975	6,750	35,700	3,340	1,190	4,530	36,900	9.4	12.3	3.2	196
1976	701	1,610	65	39	104	1,650	4.0	6.3	2.4	8.8
1977	403	957	14	3	17	960	1.5	1.8	.3	5.1
1978	120,000	3,510,000	1,630,000	71,800	1,700,000	3,590,000	46.4	47.5	2.0	19,100
1979	15,700	36,700	3,010	1,210	4,220	37,900	8.2	11.1	3.2	202
1980	66,100	1,760,000	476,000	29,000	505,000	1,790,000	27.0	28.2	1.6	9,520
1981	3,940	4,650	165	96	261	4,740	3.5	5.5	2.0	25
Total........	376,240	12,600,000	4,900,000	202,000	5,100,000	12,800,000	--	--	--	--
Average annual......	31,354	1,050,000	408,000	16,800	425,000	1,070,000	14.7	16.2	1.7	5,660

[1]Calculated using drainage area of 188 mi^2.

Table 6.--Estimated sediment load at San Antonio Creek at Casitas Springs (11117500), 1977-78

[Streamflow is given in cubic foot per second-days]

Water year	Stream-flow	Load, in tons: Total-suspended sediment	Load, in tons: Coarse-suspended sediment	Load, in tons: Bedload	Load, in tons: Total coarse sediment	Load, in tons: Total sediment	Percentage of coarse sediment in: Suspended sediment	Percentage of coarse sediment in: Total sediment	Percentage of total-sediment load: Suspended sediment	Percentage of total-sediment load: Bedload
1977	434	2,420	38.2	41	79.2	2,280	1.7	3.5	98.2	1.8
1978	27,200	1,390,000	496,000	26,800	523,000	1,420,000	35.7	36.8	97.9	1.9
Average annual..	13,800	696,000	248,000	13,400	252,000	710,000	18.7	20.2	98.1	1.8

The San Antonio Creek basin constitutes 27 percent of the drainage area of the Ventura River at station 11118500. During 1977-78, San Antonio Creek contributed 23 percent of the streamflow, 40 percent of the total sediment load, and 31 percent of the coarse-sediment load to the Ventura River near Ventura. These percentages indicate that the undeveloped San Antonio Creek basin contributes slightly less streamflow but more coarse and total sediment per unit area than the regulated parts of the Ventura basin. The average-annual total sediment yield for water years 1977 and 1978 was 9,550 $(ton/mi^2)/yr$ for the Ventura River near Ventura (table 5) and 13,900 $(ton/mi^2)/yr$ for San Antonio Creek at Casitas Springs. The difference in yields for the two stations reflects, to some degree, the effects of dams and diversions on the Ventura River and its tributaries, as part of the sediment delivered to reservoirs is retained (Scott and others, 1968) and is not transported further downstream.

A more realistic value for the actual sediment yield of the entire Ventura River basin can be calculated by considering the trap efficiencies of reservoirs in the basin. Trap efficiencies for reservoirs in the Ventura River basin, calculated by the storage capacity-watershed area method (Brune, 1953), are given in table 1. These trap efficiencies were used to calculate effective drainage areas for regulated portions of the basin using the formula:

$$DA_{effective} = (1 - TE/100) \times DA_{regulated}, \qquad (7)$$

where $DA_{effective}$ and $DA_{regulated}$ represent the effective and actual drainage areas, in square miles, above dams, respectively, and TE is trap efficiency, in percent. The effective drainage areas were summed and added to the area of the unregulated parts of the basin. This total effective drainage area was used to calculate an effective total sediment yield of 17,200 $(ton/mi^2)/yr$ by dividing the average-annual total sediment load for 1977-78 at station 11118500 by the total effective drainage area. This figure is an estimate of what the actual sediment yield would have been at station 11118500 for 1977-78 had no sediment been deposited behind dams.

If both the drainage area and the total sediment load for San Antonio Creek are subtracted from the total drainage area and sediment load, respectively, at station 11118500, the resulting sediment yield for the Ventura basin, exclusive of the San Antonio Creek basin, for 1977-78 was 7,910 $(ton/mi^2)/yr$. If, however, the effective drainage area exclusive of the San Antonio basin is used in the above calculation, the resulting sediment yield for this area becomes 20,300 $(ton/mi^2)/yr$. This figure probably represents a more accurate estimate of the actual production of sediment per unit area in the parts of the basin outside the San Antonio Creek basin than does the sediment yield calculated using the total drainage area and total sediment load. Thus, although the sediment yield during 1977-78 was higher for the San Antonio Creek basin than for the rest of the Ventura basin under existing conditions of flow regulation, the actual production of sediment per unit area seems to be highest in areas other than the San Antonio Creek basin. These include the areas downstream of Matilija and Casitas Reservoirs. With the available data, it is not possible to determine the relative importance of the areas downstream from dams as sources of sediment; however, in other areas, channel erosion has increased along reaches below dams due to release of relatively sediment-free water into the channels (Williams and Wolman, 1984; Andrews, 1986).

Records of the Casitas Municipal Water District indicate that an estimated 63,000 yd^3 of sediment were removed from the Robles-Casitas stilling basin after the 1969 flood, and that estimated volumes of 50,000 yd^3 and 91,000 yd^3 were removed in 1973 and 1978, respectively. Photographs of this material show that it included many large boulders, but the actual particle-size distribution is not known. It is unlikely that much coarse sediment was transported through Matilija Reservoir. Thus, most of this coarse sediment must have been supplied by a relatively small area drained by unregulated tributaries and by channel erosion between Matilija Dam and the stilling basin. These observations support the contention that these areas may be significant sediment sources.

Effects of Major Storms

Major storms affected the Ventura basin in 1969, 1978, and 1980. Streamflow, total-suspended-sediment load, and coarse-suspended-sediment load for five major storm periods during these years are given in table 7, along with percentages of annual total-suspended-sediment and coarse-suspended-sediment load represented by each storm. In each of the three years considered, over 98 percent of the coarse-suspended sediment and over 96 percent of the total-suspended sediment were transported during one or two storm periods lasting an average of 10 days each. The storm-period sediment loads given in table 7 represent 92 percent of the total-suspended-sediment load and 97 percent of the coarse-suspended-sediment load for the entire period of data collection. The relatively infrequent long-duration, high-intensity storm events, therefore, dominate the movement of sediment from the Ventura basin to the ocean.

Table 7.--Sediment transport at Ventura River near Ventura (11118500) during major storm periods, 1969-81

[Streamflow is given in cubic foot per second-days]

Storm period	Streamflow (Q)	Load, in tons: Total-suspended-sediment (Q_{ss})	Load, in tons: Coarse-suspended-sediment (Q_{css})	Percentage of annual coarse-suspended-sediment load	Percentage of annual suspended-sediment load	Ratio of suspended-sediment load to streamflow (Q_{ss}/Q)
1969						
Jan. 19-29	56,100	3,650,000	1,520,000	56.7	54.9	65.1
Feb. 23-27	40,300	2,860,000	1,170,000	43.7	43.0	71.0
Total				[1]100.4	97.9	
1978						
Feb. 5-15	45,800	2,080,000	1,040,000	63.8	59.3	45.4
Mar. 1-6	30,900	1,300,000	568,000	34.8	37.0	42.1
Total				98.7	96.3	
1980						
Feb. 14-24	36,200	1,740,000	475,000	99.8	98.9	48.1

[1]Exceeds 100 percent due to rounding of values.

Scott and Williams (1978) suggested that after sediment is flushed from the channel system during a major flood, sediment-transport rates will be lowered because of removal of accumulated sediment by high flows. The chronology of storm events may therefore affect the relation of sediment discharge to streamflow during storms because less sediment will be available for storms occurring shortly after preceding storms. Table 7 gives the ratios of suspended-sediment load to streamflow (Q_{SS}/Q) for each of the five major storm periods listed. The storms of early 1969, the first major storms to affect the region since 1938, have both the highest streamflow total and the highest ratio of suspended-sediment load to streamflow of these storms listed. A decrease in Q_{SS}/Q is apparent for subsequent storms, but because none of these events equaled or exceeded the streamflow of the January 1969 storm, it is unclear whether this decrease can be ascribed to flushing of the channel system in 1969.

Comparison With Results of Previous Studies

The only previous study in which sediment loads on the Ventura River were estimated in units of mass is that of Brownlie and Taylor (1981). These authors reported estimates of 827,000 tons of bedload, 2,270,000 tons of coarse sediment, and 8,090,000 tons of total sediment for the Ventura River (station 11118500) for the period 1969-75, excluding 1974 (all estimates rounded to three significant figures). Estimates determined for this report represent 12 percent of the bedload, 127 percent of the coarse-sediment load, and 92 percent of the total-sediment load estimated by Brownlie and Taylor (1981) for this period. The large discrepancy in the bedload estimates may result from differences in methods of analysis. The use of the modified Einstein formula (Burkham and others, 1977) by Brownlie and Taylor (1981) is a possible cause for the higher estimate of these authors. As shown in table 2, bed material of the Ventura River is composed largely of gravel- and cobble-size particles. The modified Einstein procedure used by Brownlie and Taylor has been tested only on sand-size sediments (Burkham and Dawdy, 1980), and its accuracy for other size classes has not been established. As noted by Williams (1979), the Meyer-Peter and Muller formula is generally the accepted method for coarse-bed streams.

To permit comparisons with results given in volumes of sediment per unit time in other studies, the annual total-sediment loads at station 11118500 were converted to acre-feet per square mile per year using the total drainage area above the gage and an estimated value of 94 lb/ft^3 for sediment bulk density. This density value represents a reasonable estimate for geologic materials. Use of this estimate results in a mean estimated yield of 2.78 $(acre\text{-}ft/mi^2)/yr$. This result agrees reasonably well with results of Scott and Williams (1978) and Taylor (1981, 1983), but is an order of magnitude greater than those of the California Department of Navigation and Ocean Development (1977).

CONCLUSIONS

At the Ventura River near Ventura during the period 1969-81, excluding 1974, total-sediment load was 12,800,000 tons. Of this total, 5,100,000 tons, or 40 percent, was composed of coarse particles potentially available for replenishment of beach sand. Suspended-sediment load constituted 12,600,000 tons, of which 4,900,000 tons was coarse sediment. Suspended-sediment transport was therefore the most important process moving sediment to the coast, supplying 98 percent of the total-sediment load and 96 percent of the coarse-sediment load. Bedload transport contributed less than 2 percent of the total-sediment load and less than 4 percent of the coarse-sediment load. The proportion of coarse sediment in the suspended-sediment load was directly related to streamflow; thus high flows contribute proportionately more coarse sediment than do lower flows.

Results of this study agree closely with results published by earlier investigations. Differences in methods of analysis probably account for discrepancies in estimates of bedload.

The unregulated San Antonio basin contributes more sediment per unit of total basin area than do the regulated parts of the Ventura basin, as would be expected from consideration of the sediment-trapping properties of reservoirs. Comparison of sediment loads on the Ventura River near Ventura and San Antonio Creek as Casitas Springs, however, indicates that because only a fraction of the sediment supplied to the channel system upstream from the reservoirs can be expected to be transported to reaches downstream from the dams, the actual sediment production per unit area is lower in the unregulated San Antonio Creek basin than in the rest of the Ventura basin. This may be in part the result of the discharge of sediment-free water to channels downstream from dams.

Major storm events dominate sediment transport. Infrequent high-intensity rainstorms resulted in 93 percent of the annual total-suspended-sediment load and 98 percent of the coarse-suspended-sediment load for the period of data collection. The chronology of storm events may exert some influence over storm-sediment transport, as sediment removed rapidly from channels during high flows is gradually replenished by hillslope processes.

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