HYDROLOGIC IMPACTS OF GRAVEL MINING ON THE RUSSIAN RIVER

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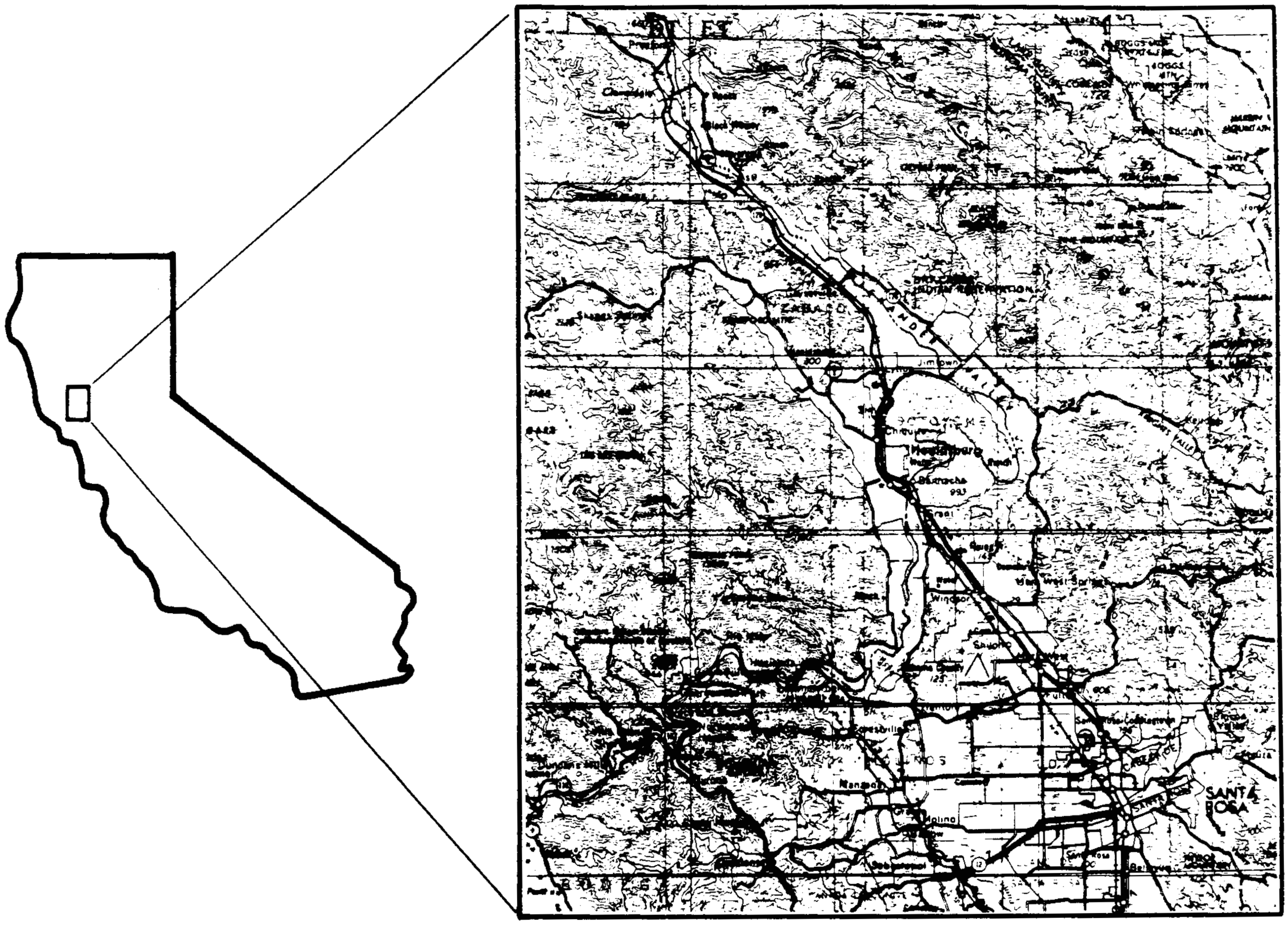

Prepared for:

SONOMA COUNTY DEPARTMENT OF PLANNING

sla

FINAL REPORT

HYDROLOGIC IMPACTS
OF GRAVEL MINING ON
THE RUSSIAN RIVER

Prepared for:

Sonoma County Department of Planning
575 Administration Drive, Room 105A
Santa Rosa, CA 95401

Prepared by:

Simons, Li & Associates, Inc.
3636 Birch Street, Suite 290
Newport Beach, CA 92660

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I. INTRODUCTION

The Sonoma County Board of Supervisors on October 17, 1978, instructed the Department of Planning to develop an Aggregate Resources Management Plan. The adopted plan consists of three parts. The aggregate mining plan specifies which lands will be available for the extraction of aggregate materials for the next fifty years. The managed resource and open space plan provides for the protection of the environmental quality and the reclamation of mined lands. The hydrologic change plan includes a program for monitoring the hydrologic characteristics of the Russian River in order to determine the annual rate of replenishment of aggregates and the long-term stability of the channel. The Sonoma County Department of Planning retained Simons, Li & Associates, Inc. to assist in the third part of this plan, preliminary assessment of the hydrologic impacts of gravel extraction in the Russian River based upon the first six years of data from the monitoring program.

1.1 Project Description

The hydrologic assessment deals mainly with the Russian River miles 23 to 33 and miles 44 to 63. These two reaches contain most of the instream and terrace mining activity in the county. The project consists of four major tasks: (1) Collection of data and review of the current hydrologic monitoring program, (2) Documentation of the channel changes and mining activity for the study period (fall, 1981 to spring, 1986) and description of historical river trends, (3) Analysis of information obtained from task 2 in order to determine relationships between gravel extraction and river responses such as bar movement or bank erosion (a preliminary assessment based upon the first six years of the monitoring program) and (4) Recommendation of revisions to current operation standards and to the hydrologic data collection and management program based upon the study results.

The first task involves the collection of the relevant literature and contact with the public entities involved with the Russian River such as the County of Sonoma and the Sonoma County Water Agency. The County Department of Planning currently conducts aerial surveys of the study reach two times a year. The U.S. Army Corps of Engineers, San Francisco District performed several studies and took cross-section data as early as 1964. The

California Department of Water Resources performed a gravel mining study on the upper Russian River in 1984. The U.S. Geological survey maintains both streamflow and sediment gaging stations along the river. Several studies were done on the applicability of computer program HEC-6 for sedimentation analysis. The Sonoma County Department of Planning produced the Aggregate Resources Management Plan which is an important source of information for this study. A list of the information sources used in this study is included in the references.

The second task includes a detailed study of channel changes, gravel bar movement, bank erosion and mining activity in the study reach. The period for this detailed study is from the fall of 1981 to the spring of 1986. Aerial photos were taken two times each year and used to develop cross-sections. The base map is from the fall, 1981 photos. Lines drawn on the base map show the low flow channel and river bank locations for other end of the study period (May, 1986). Approximately 100 river features are identified and their characteristics are monitored for each of the 10 sets of photos. This information is recorded on forms which are included in Appendix A. Because two large flood events occurred during the study period (March, 1983 and February, 1986), the general historical river trends are briefly compared to the study period. This gives an indication if the period 1981 to 1986 is characteristic of other five year periods in the past. As much as possible, channel changes are correlated to the major flow events of 1983 and 1986.

The third task relates gravel mining activity to local river response and determines the amount of aggregate replenishment that occurred during the study period. The County Department of Planning provided 10 sets of cross-section surveys for the study reach. Each set was made 6 months apart so the amount of mining at the end of each fall could be determined. By analyzing gravel bar movement, channel changes and rate of replenishment, current mining practices can be evaluated. A discussion of data base management is also included in this task.

The fourth task involves the evaluation of the current hydrology monitoring program and the evaluation of current mining policies. Based upon the results of the analysis of safe yield for in-channel mining, recommendations are made about mining methods, extraction amounts, new potential sites and existing sites that adversely affect the river and its adjacent lands. Data needs will be refined and alternative collection methods discussed.

1.2 Report Structure

Chapter 2 of this report presents the detailed documentation of channel changes for the study period. The river maps are included in Appendix B. There are 15 plates at a scale of 1 inch = 400 feet. Areas of major bank erosion and increased mining activity are discussed in the text while the year to year description of approximately 100 river features is included in Appendix A. Chapter 3 discusses data management. Chapter 4 presents the analysis of gravel mining impacts and the discussion of the rate of replenishment. Chapter 5 contains the recommendations for changes in the current mining standards and the hydrologic data collection program. Chapter 6 presents the conclusions of the report. The major sources of information used in this study are presented in Chapter 7.

II. DESCRIPTION OF CHANNEL BEHAVIOR

2.1 General Description

The Russian River originates in central Mendocino County, approximately 15 miles north of Ukiah, according to the U.S. Geological Survey. It drains an area of 1485 square miles, including much of Mendocino and Sonoma Counties, and empties into the Pacific Ocean at Jenner, about 20 miles west of Santa Rosa, California. In general, the river flows in a south to southeasterly direction, draining a ten to thirty mile wide corridor including Dry Creek and Alexander Valley. After negotiating the mountainous area just east of Healdsburg, the river turns south and then to the southwest to the ocean. Also included in the drainage basin are Santa Rosa, Sebastopol, and the Cotati Valley, all to the southeast of the river's path.

There are several significant tributaries to the Russian River main stem (see Figure 2.1). North of Ukiah, the East Fork Russian River drains the Potter Valley, including diversion flow from the Eel River. Lake Mendocino is formed on the East Fork by the Coyote Dam, shortly before flow enters the main stem. Big Sulphur Creek enters from the east above Cloverdale, near the upper limit of this study at River Mile 63. In the Middle Reach, Dry Creek empties much of the western half of the basin into the Russian River at Mile 30. Warm Springs Dam, located about 14 miles upstream of the Dry Creek/Russian River confluence, regulates flow of Dry Creek. Mark West Creek enters the Russian River at Mirabel Park, just below the project boundary of this study.

In addition to these major tributaries, other small creeks contribute to the Russian River at various points. These include Icaria Creek, Miller Creek, Sausal Creek, Maacama Creek, Brooks Creek, and Austin Creek. With the exception of Austin Creek, these streams enter the Russian River within the project boundaries.

2.2 Historic Changes

Over geologic time, several events have caused significant changes in the Russian River system. Ice accumulation during the Pleistocene epoch caused a lowering of sea level of several hundred feet, which resulted in downgrading of the river channel to this new level through the underlying rock formations. As the Ice Age gave way to warmer temperatures, the river

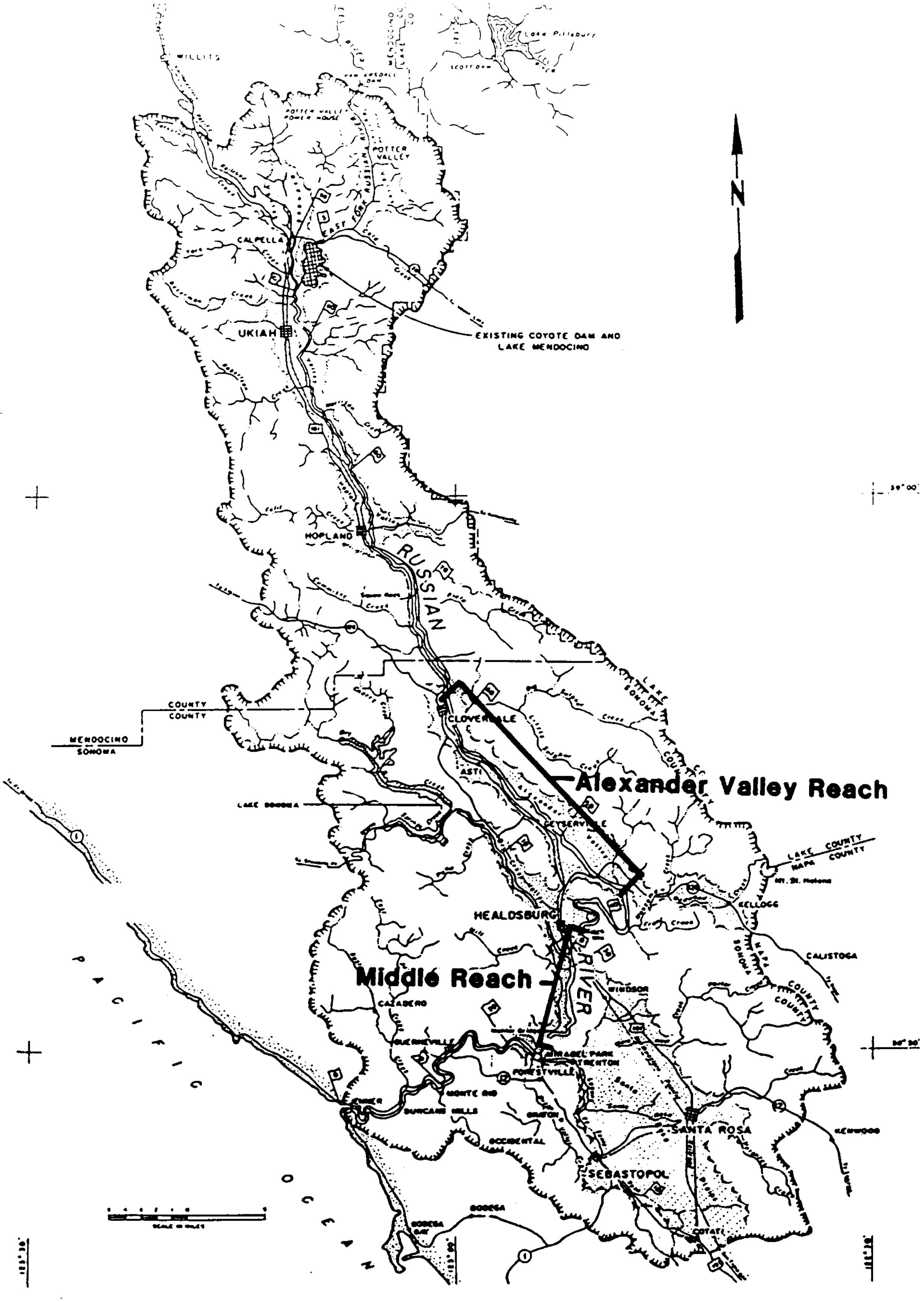

Figure 2.1 Map of Russian River Basin

channels aggraded in response to the rising sea level, forming wide meanders in their valleys. As a result, gravel deposits of between 50 and 200 feet in depth exist along the downstream reaches of the Russian River (Sonoma County Water Agency, 1972). Recently, however, there has been renewed general downcutting of channels which may be attributed to uplift of the region (Gaeley, 1951) in the past 10,000 years.

2.3 Factors Affecting Channel Stability

There are several major factors which can affect the channel behavior on a less-than-geologic timescale. Large magnitude storm events within a natural drainage system invariably cause some degree of change. Variability in tributary contribution of water and sediment from storm to storm also affects river form and function. Changes in land use, such as urbanization, cultivation of rangeland, clearing of timberland and terrace mining each affect both water and sediment yield for a given rainfall amount.

Other factors which directly affect the flow patterns are instream structures. For example, Coyote Dam on the East Fork and Warm Springs Dam on Dry Creek not only regulate these tributaries' outflow of water to the Russian River, they also inhibit the transport of bed material. Similarly, summer dams with concrete footings, such as Healdsburg Dam, affect passage of bedload sediment. Low flow crossings consisting of earthen dams, as found at Asti and below Healdsburg, definitely affect the characteristics of the low flow channel. Levees constructed close to the channel can restrict river capacity and, if flow velocities increase as a result of the levees, reduce the amount of sediment deposited in that reach.

Excessive sediment loading, and the aggradation which results, can dramatically affect the flood-conveyance capacity and overall stability of a river channel. If a given reach of the channel is supplied by more sediment than it has the capacity to transport, the channel begins to aggrade. Flow paths may be disrupted and/or below-bank capacities may be lessened, increasing the likelihood of channel movement during flood events.

In-stream mining of the excess deposits within a river channel can help to alleviate the problems associated with aggradation. However, overmining, or mining where aggradation is not a concern, can disrupt the sediment balance and induce erosion. This may result in the creation of a more deeply incised main channel, with steep-walled banks of marginal stability. The potential for bank failure increases as the bank height increases and erosion of the bank toe progresses.

In many cases, local activities, including mining and bank protection projects, can have an effect elsewhere and alter channel behavior both upstream and downstream of that location. Mining can change the river gradient, as has been reported in Dry Creek, while bank protection such as that found under bridges and other places can inhibit channel migration and even cause erosion and bank losses in other locations.

The natural progression of meander bends down a river channel can cause significant loss of near-bend properties. Scour along the outside bends and deposition along the inside bends of a meandering channel translate the bends downstream. With erosion and deposition occurring on a local basis, the overall channel may be in sediment equilibrium. Local bank protection measures may be used to limit the lateral motion of these meander bends, but their down-valley progression is more difficult to control.

2.4 Study Reaches

The Hydrology Monitoring Program on the Russian River is concentrated on two separate reaches of the study channel. The first, known as the Alexander Valley Reach, extends from RM 63 above the Big Sulphur Creek confluence north of Cloverdale to RM 44 upstream and to the east of Healdsburg. The Alexander Valley Reach is characterized by a meandering low flow channel within a fairly wide general river bottom. Under flood conditions, this reach of the Russian River may be classified as braided in form, with indefinite and time-varying main channel paths. The banks are typically lined with a narrow belt of riparian vegetation in front of cultivated orchard, vineyard, and farmland.

Downstream of the Alexander Valley Reach, the river enters the mountainous region east of Healdsburg. This portion of the Russian River channel is confined by steep banks and is very stable. Below this reach, the Russian River emerges in the Healdsburg area (RM 33). The second reach of particular concern to this study, known as the Middle Reach, extends from this point to Wohler Bridge, RM 23.

There are significant differences between the Alexander Valley and the Middle Reach. The Middle Reach is in general both flatter in gradient and narrower in section than the Alexander Valley Reach. Bank erosion has been observed to be more prevalent in the Alexander Valley Reach than in the Middle Reach. This is probably due to the steeper slope and braided form of the Alexander Valley Reach, which make it naturally less stable. Bank protection measures along the Middle Reach have also contributed to its relative stability.

The Middle Reach contains more permanent in-stream man-made structures than does the Alexander Valley Reach. These include the Healdsburg dam, the Wohler Road bridge, two bridges within the city of Healdsburg, and Highway 101.

Tributary inflow to the Alexander Valley Reach is less than for the Middle Reach. The Middle Reach contains, in addition to small tributaries, the confluence with Dry Creek just below Healdsburg.

With the assistance of the Planning Department staff, the Alexander Valley Reach and Middle Reach were further divided into 8 and 3 subreaches, respectively. This subreach delineation was performed to enable a more detailed evaluation of the changes occurring along each of the major reaches. The boundaries of each subreach correspond in general to the boundaries between areas of detailed monitoring. The 11 subreaches within the Alexander Valley Reach and Middle Reach may be visualized through use of the plates included in Appendix B, with reference to the information provided in Table 2.1.

The base map included in Appendix B of this report was prepared using aerial photographs taken October 20, 1981 on a scale of 1" = 400 ft. A set of similar photos had been taken in the spring and fall of each year of the study period, and were provided by the Sonoma County Department of Planning.

To photograph the entire 20 miles of river, a group of fifteen straight-line series of photos were taken. Each series covers from one to four miles of channel length and the series number corresponds to the plate number in this report, Appendix B. Photos were taken in order from the downstream end of the study reach (Series 1) to the upstream end (Series 15). The mountainous reach between RM 33 and RM 44 was not included; this section falls between Series 6 and 7.

River Mile markers are measured along the path of the channel, beginning at the Pacific Ocean (RM 0). Although the exact length of the channel is subject to continual change, this system is most convenient for

Table 2.1 Subreach Limits

Middle Reach

Subreach No.	Range of River Miles
1	23+0000 to 28+1000
2	28+1000 to 31+1800
3	31+1800 to 33+0000

Alexander Valley Reach

Subreach No.	Range of River Miles
4	44+0000 to 46+0000
5	46+0000 to 48+0000
6	48+0000 to 50+1000
7	50+1000 to 52+3000
8	52+3000 to 54+0000
9	54+0000 to 57+4000
10	57+4000 to 58+5000
11	58+5000 to 62+2240

indicating locations along the channel. For this report, the river mile locations were taken from the Aggregate Resources Management Plan Final EIR (Sonoma County Department of Planning, 1981).

The following paragraphs describe the major features along each of the 11 subreaches of Russian River delineated for this study.

Subreach 1 (RM 23+0000 to RM 28+1000, shown on Plates 1 through 4) includes the relatively narrow (generally less than 200 ft wide) reach of the Russian River extending approximately 5 miles upstream of Wohler Bridge. Abundant vegetation is notable along both banks, and few gravel bars are evident. The channel appears to be less incised in the upstream portions of this subreach.

Within subreach 2 (RM 28+1000 to 31+1800, shown on Plates 4 and 5), the channel width is greater than in subreach 1, and less definite in plan. The main channel shifts mildly from bank to bank along this subreach, and some gravel bars are evident. Several tributaries contribute to the main channel along this subreach, including Dry Creek (RM 30+3000). Highway 101 crosses the Russian River at the upstream end of this subreach.

Subreach 3 (RM 31+1800 to RM 33+0000, shown on Plates 5 and 6) is crossed by several major bridges. Healdsburg Dam is located near the downstream end of this subreach. The distance between banks increases at major bends (approximately 600 ft near RM 33), and multiple channels are evident at some locations. Several major gravel bars are evident.

Subreach 4 (RM 44+0000 to RM 46+0000, shown on Plates 7 and 8) consists of the two miles of Russian River downstream of Jimtown bridge. The channel is extremely narrow (150 ft at some locations) and well defined through a large portion of this reach, but is distorted near tributary confluences (between RM 44+0000 and RM 44+4000). The Jimtown bridge appears to be inhibiting the lateral movement of the channel at the upstream end of this subreach.

Subreach 5 (RM 46+0000 to RM 48+0000, shown on Plates 8 and 9) extends two miles upstream of Jimtown Bridge. Within this subreach, the lowflow channel shifts from side to side, and gravel bars are evident along each of the inside bends. No major river crossings, other than Jimtown bridge at the downstream boundary, occur along this subreach.

Subreach 6 (RM 48+0000 to RM 50+1000, shown on Plate 9) contains a succession of meanders of somewhat regular wavelength (approximately 3000 ft) and amplitude (approximately 1000 ft). Massive gravel deposits are evident along the inside bend of each major bend.

Within subreach 7 (RM 50+1000 to RM 52+3000, shown on Plates 9, 10 and 11), the meanders are also regular and fairly well developed, but of greater wavelength and lesser amplitude (approximately 4500 ft and 700 ft, respectively) than those present in subreach 6. A large meander scar is evident between RM 51 and RM 52, indicating the historic instability within this reach. Highway 128 crosses the study channel near the upstream end of this subreach (RM 52). The Miller Creek confluence is located near RM 51.

In subreach 8 (RM 52+3000 to RM 54+0000, shown on Plate 11), the meanders are less evident. However, the large meander scar near RM 53, and the abundant deposits along the overbanks attest to the natural instability of this reach. Gill Creek joins the Russian River at the upstream end of this subreach.

Subreach 9 (RM 54+0000 to RM 57+4000, shown on Plates 11 and 12) is relatively narrow (approximately 400 ft) at its upstream end, but becomes extremely wide (up to 1200 ft) and braided between RM 56+2000 and RM 55+4000. The low flow path is irregular and undefined.

Within subreach 10 (RM 57+4000 to RM 58+5000, shown on Plates 12 and 13), the channel is fairly uniform and narrow. The low flow paths shifts from bank to bank in regular cycles, with wavelength of approximately 4000 ft and amplitude of approximately 400 ft.

Containing the upstream portions of the Alexander Valley Reach, subreach 11 (RM 58+5000 to 62+2240, shown on Plates 13 through 15) is very similar to subreach 10. At the upstream end of subreach 11 the channel is extremely defined and narrow (approximately 150 ft wide). Crocker Road crosses subreach 11 at RM 62. Downstream of this crossing, the low flow path is well defined, and gently meanders between banks. Large gravel deposits are present within wide bends of approximately 5000-ft wavelength and 800-ft amplitude.

2.5 Channel Changes from Fall 1981 to Spring 1986

In general, maps of channel changes (Appendix B) and the detailed descriptions of river features (Appendix A) were prepared by analysis of the 10 sequential photographs available for each location. To facilitate discussion in the text, as well as clearly relate the two Appendices, each river feature is given an index number. The number is assigned according to the River Mile below the feature and the letter is assigned in upstream sequence from that mile marker. For example, the third feature upstream from RM 28 to be identified is assigned index 28C.

Phase I of this study sought to map the following six changes in the study reach:

1. Bank erosion
2. Gravel bar migration
3. Mining activity
4. Terrace pit activity
5. Other features (dams, crossings, bank protection, etc.)

Any changes in each category were noted on forms in Appendix A and broken into six month periods. A notation appearing with a time line below the "F83" heading designates a change which occurred after the spring 1983 photo and before the fall 1983 photo. The time lines associated with many of the comments are not intended to indicate periods any more specific than the six month intervals. Comments without time lines are general in nature and not made with respect to specific time intervals.

The following subsections discuss each category as it relates to the overall project reach.

2.5.1 Bank Erosion

For the purposes of this survey, the bank was taken to be the general vegetation line which was not regularly washed away by winter flows. Where the bank has been altered, the levee or armored slope was considered to be the river's bank. Migration of the channel across the bottom between the banks so designated was considered normal and did not constitute erosion. There were, however, many places where the channel sought wider meander loops than the width between banks would allow, and erosion at the outside of these loops occurred. The latter erosion events are included as features on the photo series.

The most notable instances of bank erosion were the result of two particularly high flows, one in March, 1983 and the other in February, 1986. It must be realized that this five year period may not be indicative of the general rate of change associated with similar time periods, due to the effect of these two events.

In the Alexander Valley Reach (RM 63 to RM 44) there were two particular sections which were changing extensively. First, the section from RM 57 to RM 53 (subreaches 8 and 9) featured several wide loops which migrated downstream, progressively widening the banks by eroding the riparian vegetation and mostly undeveloped land. In addition, the section from RM 51 to Jimtown Bridge at RM 46 (subreaches 5 6 and 7) displayed similar behavior, as well as washing away parts of several cultivated fields behind formerly vegetation-protected banks.

There were only a few other isolated locations which experienced bank losses in the Alexander Valley Reach. The undeveloped area at the beginning of the study reach (index 62D, subreach 11) was eroded in 1986, while the bank opposite the Miller Creek confluence appeared to erode, potentially due to Miller Creek flows (index 51A, subreach 7).

The Middle Reach (RM 33 to RM 23) of the Russian River remained quite stable between its banks throughout the study period. Riparian vegetation outside a sharp bend (index 32G, subreach 3) may have experienced some loss in 1981 but was exceptionally stable otherwise. The only significant bank erosion occurred in 1982 at index 26B (subreach 1), but no further losses were observed. The lateral stability of this reach is due in large part to the system of levees along the channel.

A total of 150 acres were lost to bank erosion along the Alexander Valley Reach and the Middle Reach over the course of the study period.

2.5.2 Gravel Bar Migration

Between the river banks a significant amount of sand and gravel is stored in the form of erodible bars. It is common for these bars to gradually move downstream as part of the sediment transport process. Other factors may also control the location or movement of the bars, including regional geology and geography.

In the Russian River study area two types of migration occur. The Alexander Valley Reach behaves as a dynamic, meandering system with the associated migrating loops and bars. This is especially the case along the stretch from RM 59 (Cloverdale Airstrip) to RM 49 (subreaches 6 through 10). Referring to Plate 9 in Appendix B., a one-half wavelength migration of the bars is evident, along with a widening of the meander loops. Migration was not evident throughout the entire Alexander Valley Reach, but where it did occur, the migration distance was on the order of 1400 ft. Considering the five year study period, this averages out to a migration rate of 280 ft/yr. The constantly changing orientation of the main flow channel of the Russian River makes it difficult to control the channel behavior on a localized scale.

The Middle Reach, however, is not dominated by such a dynamic process. In this reach, very little movement of the sand and gravel deposits, which are located where flow velocities are lowered along the stable channel path, apparently occurs. Restrictions at bridge crossings and tributary entrances are two types of features which tend to affect bar migration in both the Alexander Valley and Middle Reach.

2.5.3 Mining Activity

Most gravel bars where mining was permitted that could be accessed by skimming equipment were mined to some degree during the course of the study period. Skimming operations were the only means of production used in the Alexander Valley Reach. The most significant amounts of production in the Middle Reach were on the terraces outside the channel, as there were fewer deposits above the water level within the river banks. Table 2.2 shows the index number of each bar or skimming site and the years during which skimming occurred. More descriptive information on these locations may be found in Appendix A.

2.5.4 Terrace Pit Activity

At the beginning of the project study period in 1981, there had already been extensive mining of the river terraces outside of the Middle Reach channel. These terrace pits, as well as new ones dug during the study period, have been limited to the stretch below the Dry Creek confluence (RM 30). New pits were begun throughout subreach 1: at RM 26 adjacent to index location 26A, as well as at RM 25, where farmland was taken out of production at index 24C. The extensive pits at index 27B were enlarged, as

Table 2.2 Instream Mining Activity During the Study Period

INDEX NUMBER	1981	1982	1983	1984	1985	1986
23A**						
28B	X				X	
29C	X	X	X	X	X	X
30D	X	X	X	X	X	X
30E	X	X			X	
31A					X	X
31B	X	X	X	X	X	X
31E		X	X	X		
32D	X	X	X	X		
32F		X	X			
43A				X		
43B				X		
44D**	X	X	X	X	X	X
46C	X	X	X	X		
46E		X				
46F	X	X	X	X		
47A	X			X	X	
47C				X	X	
48B						X
48C	X	X	X	X	X	X
48D**	X	X	X	X		
49A				X		
49B	X	X	X	X	X	X
49C	X	X	X	X	X	X
49D		X	X	X	X	X
50A		X	X	X	X	X
50D	X	X		X		
52B		X				
52D		X				
53B**	X	X	X	X		
54A		X		X		
55C					X	
56A					X	
57D					X	
58A		X				
58C		X				
59A		X		X	X	
59D		X	X	X	X	
61A	X				X	
61B		X	X	X		
62B**	X	X	X	X	X	X
62C	X	X	X			

NOTES:
1. MINING GENERALLY OCCURS IN THE SUMMER OF EACH YEAR
2. "**" INDICATES THAT SOME PROCESSING OCCURRED ON SITE AT LEAST ONE YEAR

were the pits at 30A (subreach 2). Processing operations near to these pits (27D) were ended and the area was smoothed and leveled.

2.5.5 Other Features

There are various bridges, dams and summer crossings along the study reach. No new construction was initiated during the study period, however. Several changes of bank features were noted which were not covered in the previous subsections. Among these, a riprap-protection section at index 54B (subreach 9) was eroded and reduced in length over the course of the study. Similarly, a short protection measure on the left bank below RM 50 (subreach 6) was damaged, partially by skimming which took place there. A rather long section of eroding bank was protected by riprap at index 46E (subreach 5), aiding the defense of cultivated fields there.

2.6 Summary

Some significant channel changes occurred during the study period especially in the Alexander Valley Reach. The Middle Reach channel remained fairly stable while an increase in terrace pit mining took place nearby. Most of the gravel bars in the Alexander Valley that were accessible by equipment were mined at some time during the study period. All major bank erosion occurred in the Alexander Valley Reach especially between river miles 53 to 57 and between 46 to 51. In these two subreaches gravel bar migration (down-valley migration of the meander bends) was observed. In general, the bars moved about 1,400 feet in the 5 year period. This corresponds to an annual migration of approximately 280 feet per year, which is comparable to the rate of 375 feet per year estimated by Sonoma County Water Agency (1972). The stream changes documented in this section will be used in Chapter IV to quantify the stream response due to gravel mining impacts and to determine rates of replenishment.

III. DATA MANAGEMENT

The thorough documentation of cross-section data performed by the Sonoma County Department of Planning, the Sonoma County Water Agency and the Corps of Engineers provides a unique opportunity to quantitatively describe the river response during the last several decades and especially during the study period (fall, 1981 to spring, 1986). Alternatives for the management of existing and future data are discussed in this section.

3.1 River Simulation Using HEC-6

Several reports have been compiled discussing the applicability of the Corps of Engineers' computer program HEC-6 to the Russian River (see, for example Storm 1980). This program computes the effective change in bed elevation given the channel geometry, bed material size and water discharge. The program has been successfully used in many river and reservoir studies. Its primary utility is for determining short and long term effects of channel modifications on overall river behavior for a given hydrologic event. A description of the model follows:

3.2 Description of HEC-6 Program

General

HEC-6 is a simulation program designed to analyze scour and deposition in a stream by modeling the interaction between the water-sediment mixture, the sediment of the streambed, and the flow hydraulics. The program computes the total sediment load discharge and gradation, the volume of scour or deposition, the change in bed elevation and the extent of bed armoring for a given hydrologic event.

Boundary and Initial Conditions

Sediment inflow into the upper end of the study reach is specified by a water discharge - sediment discharge rating table. A stage-discharge rating table is used to establish the water surface elevation at the downstream boundary of the study reach. Initial bed material gradations for each cross-section are also specified.

Geometry

The geometry of the study reach is specified by cross-section coordinate points similar to those used in the HEC-2 backwater model. A cross-section is divided into areas subject to scour and deposition and areas which are not.

Hydraulics

The flow hydrograph is approximated by a series of steady discharges, each having a specific duration. The standard-step backwater procedure is used to solve the one-dimensional energy equation and the flow velocity, depth, width, and slope are calculated at each cross-section. In order to account for the lateral distribution of flow resistance, each cross-section can be divided into subsections.

Sedimentation

The sediment-continuity equation is used to adjust the bed elevations for scour or deposition. One of five methods may be used to calculate the potential transport capacity for each of several classes of grain sizes: (1) Laursen's method; (2) Toffaleti's method; (3) a user supplied relationship; (4) Yang's stream power method; and (5) Duboys method.

If the transport capacity exceeds the sediment discharge, available sediment is removed from the bed and/or banks until the capacity is achieved. The fractions of grain sizes in the bed are recalculated as material is exchanged with the stream.

The transport rate is corrected for armoring of the streambed. Manning's and Strickler's equations along with Einstein's bed-load function are used to calculate an equilibrium depth for each grain-size class. An equilibrium depth for the mixture of grain sizes and accompanying maximum transported grain size is calculated such that there are enough larger grains to completely armor the surface. This equilibrium depth is the limit of scouring.

A new equilibrium depth for the mixture is calculated for each discharge. The armor layer formed by previous discharges is tested and disturbed if unstable. All or part of the old armor layer may be destroyed.

3.3 Description of HEC-6 Data Requirements

Bed Material Gradation

The average gradation of the bed material is required to a depth equal to the expected depth of scour. Bed samples are needed for conditions approximating those at the beginning of the simulation. For example, to simulate the first large winter flood, samples should be taken during the previously dry period.

Gradations are needed for each cross-section of the geometric model. Therefore, the bed should be sampled at various places along the river representing different sediment conditions.

Inflowing Sediment Load

For the lower Russian River and Dry Creek, the suspended sediment load and particle size distribution for various discharges can be estimated from USGS records of sediment samples at both Dry Creek and Russian River near Guerneville.

Water Discharge Hydrograph

The inflow hydrograph can be developed from an appropriate gage record in USGS "Water Resources Data."

Cross-Sectional Data

Cross-sectional data can be obtained from the numerous surveys available.

N-Values and Expansion Coefficients

N-Values and expansion coefficients can be estimated using standard procedures.

Limits of the Movable Bed

The horizontal limits of the movable bed can be estimated by studying aerial photographs of the river for the bank locations.

Stage-Discharge Curve for Downstream Limit of Study

The downstream limit of a study reach should experience little aggradation or degradation. This will ensure a stage-discharge curve for the starting water surface elevation which is constant with respect to time. Points in the curve for very large flows can be obtained from stream gage data.

Water Temperature

The average temperature of the water under the study conditions can be estimated from the USGS "Water Resources Data." This is necessary to compute sediment fall velocity.

3.4 Constraints and Assumptions of Model

HEC-6 is a one-dimensional model. It cannot simulate the development of meanders, nor can it specify a lateral or vertical distribution of sediment in a river. Density and secondary currents are not accounted for in the model.

The formation of bed forms cannot be directly accounted for by the model. The Manning's n-value can be made a function of discharge but cannot be changed to account for bed form development.

HEC-6 is a steady-flow model. A discharge hydrograph must be discretized into a series of constant flows. This may not be a reasonable method for simulating dynamic events in long rivers.

The entire movable bed is assumed to aggrade or degrade the same vertical distance. The boundary between the movable and fixed portions of the bed remains constant. It is therefore difficult to simulate bank erosion and channel widening with the model. It cannot predict the exact locations where bank erosion will occur. The extent of degradation, however, is an indicator of where bank erosion is likely to occur.

An HEC-6 prediction of the bed change for a future flood event requires a knowledge of the discharge and duration of that event. Thus replenishment rates and safe yield volumes cannot be determined unless the hydrologic events for a given season are known in advance. This, of course, is not possible. The HEC-6 program can be used to estimate replenishment rates after a flood event has occurred but this would still need to be verified by an aerial survey. An aerial survey is the most direct way of determining the river response after an event has occurred.

3.5 Other Sedimentation Computer Models

Several other computer programs exist that compute river channel changes due to scour and deposition. The Simons, Li & Associates, Inc. (SLA) model and the FLUVIAL-12 model by Howard Chang are similar to HEC-6. The FLUVIAL-12 Model has the capability to simulate bank erosion but since it is a one dimensional model, it cannot predict the movement of stream meanders or the development of gravel bars. the current state-of-the-art of sediment transport technology has not yet been able to develop mathematical descriptions of the complex physical processes involved in a stream that meanders through a non-homogeneous geologic medium. Even if such capabilities are realized, they could not replace the qualitative cause and effect relationships that are derived from observation of the river during different flow conditions.

3.6 Recommendation

Several computer programs have been developed which manage large amounts of data and allow convenient access. The Sonoma County Department of Planning currently uses such a program to store cross-section data for the hydrology monitoring program. Cross-sections at the same location can be plotted on top of each other for several years to determine if the river is degrading or being replenished at that location. Bank erosion and channel meanders can also be monitored.

Analysis of the channel changes after the 1983 and 1986 flood events will yield qualitative relationships that can be generalized to predict potential areas of bank erosion, bed scour and deposition that may occur for a large flood event. This combined with the database management computer program can be used on a day-to-day basis by the Department of Planning to monitor problem areas along the Russian River and to anticipate flood impacts upon river stability. All computational aids need data for verification so the program of conducting periodic river surveys will need to be continued.

The above discussion indicates that predictive modeling may not be the answer to effective management of in-stream mining. A well organized, accurate aerial survey updated on a regular basis is the most direct method of obtaining the information needed to manage gravel extraction from the Russian River. It is recommended that a database program be used to manage the large amounts of cross-section data involved. This program can be used with plotting software on any IBM compatible personal computer. Correlating historical events with channel response will give the County the general predictive capabilities it desires and the data management system will provide the current aggregate mining situation to the level of accuracy required.

IV. ANALYSIS OF GRAVEL MINING IMPACTS

4.1 Introduction

This chapter presents the results of analysis of Russian River behavior during the study period 1981 to 1986. The first section discusses some historical river trends. The second section presents the analysis of the available survey data collected so far in the County's hydrology monitoring program. The third section estimates the sand and gravel deposit amounts based upon the particular hydrologic events that occurred during the study period. The fourth section discusses the river response to mining activity. The last section draws conclusions from the analysis and includes a discussion of the "safe yield" of sand and gravel deposits. "Safe yield", in the context of this report, represents the amount of sand and gravel that can be extracted from the river without increasing instabilities such as channel degradation and bank erosion.

4.2 Historical Trends of the Russian River

4.2.1. Channel Gradient and Elevations

Before 1965, Sonoma County's aggregate production was mostly centered at instream mines in the Russian River. Gravel mining had been accompanied by a noticeable drop in bed elevation over the period from 1940 to 1971 in the Middle Reach and Dry Creek. Table 4.1 and Table 4.2 (Aggregate Resources Management Plan, Sonoma County Planning Department, October 1981) provide the changes in streambed elevation and gradient in the Middle Reach and Alexander Valley, respectively, during that period.

4.2.2. Channel Alignment

In the report "Russian River Basin Study" done by the Corps of Engineers (1980), it was determined that the Russian River meandered across large areas of the valley floor in the past. The meandering patterns between the site of Wohler Bridge and Healdsburg (the Middle Reach) formed a band as wide as 4,000 feet. After the Coyote Dam was built upstream in 1958, the Corps of Engineers made some channel modifications in the Alexander Valley in an experimental attempt to stabilize the channel. The modifications included dredging, clearing vegetation, and installing jacklines and flexible fencing bank protection when necessary. Although some of these measures are still evident, most met with little success.

TABLE 4.1

CHANGE IN STREAMBED ELEVATION* AND GRADIENT
MIDDLE REACH
RUSSIAN RIVER
(In Feet)

River Mile	1940 Elevation	1971 Elevation	Change
23.2	37.5	30.5	— 7.0
24.1	37.5	31.5	— 6.0
25.1	43.6	33.1	—10.5
25.7	48.7	35.0	—13.7
26.8	55.0	36.5	—18.5
27.7	53.0	37.3	—15.7
28.7	58.8	43.7	—15.1
29.7	59.5	52.1	— 7.4
31.4	61.0	59.6	— 1.4

*Based on thalweg elevations from surveys conducted by U.S. Army Corps of Engineers: 1940, 1972.

Year	Distance Surveyed (Miles)	Change in Elevation (Feet)	Gradient (Feet/Miles)
1940	8.2	23.5	2.9
1972	8.2	29.1	3.6

TABLE 4.2

CHANGES IN STREAMBED ELEVATION AND GRADIENT
ALEXANDER VALLEY
RUSSIAN RIVER

River Mile	1940 Elevation*	1972 Elevation*	1975 Elevation*	1978 Elevation*
41.2	119.2(42.0)	117.5	122.0	119.5
46.0	145.0	146.5	145.5	143.5
49.8	179.0(49.7)	178.5	178.0	176.5
50.2	—	178.5	181.5	179.5
50.5	183.4(50.7)	183.0	182.0	179.5
51.0	—	187.0	185.0	184.5
52.0	193.0	190.5	191.0	188.5
56.8	234.0	234.5	237.0	233.0
62.0	283.0(61.9)	280.0	277.0	272.5
63.8	290.0(63.3)	296.0	297.5	299.0

*Based on thalweg elevations from surveys conducted by U. S. Army Corps of Engineers (1940).

*Based on thalweg elevations from surveys conducted by the Sonoma County Water Agency (1971-1978).

Year	Distance Surveyed (Miles)	Change in Elevation (Feet)	Gradient (Feet/Miles)
1940	22.6	170.8	8.0
1972	22.6	178.5	7.9
1975	22.6	175.5	7.7
1978	22.6	179.5	7.9

The Middle Reach, since its channelization, has remained fairly stable. The Alexander Valley continues to exhibit its naturally unstable behavior. This is not a new development, however, as mentioned above.

4.3 Analysis of Hydrology Monitoring Program Data

The hydrology monitoring program consists of two types of data: aerial photographs and detailed river channel cross-sections. Descriptions based on the photographs were discussed in Chapter 2. What follows is a description of the analysis of the channel cross-sections which were logged on computer spreadsheets. With additional time and staff, additional data from the photographic record of the monitoring program could be produced.

The data had been transferred by the county from handwritten logs into computer spreadsheet files which occupy 30 floppy disks. Data representing 470 different river section locations are available for one or more of the ten semi-annual periods over the project time span from fall 1981 through spring 1986. In order to facilitate analysis of this large amount of information, all data was transferred from the micro-computer spreadsheets onto a mainframe computer. Once this was done, extensive sorting and reconfiguring yielded two significant products: first, a listing of all cross-sections by season showing data gaps in the monitoring program (see Table 4.3), and second, a compilation of low point elevations, used to plot longitudinal river profiles for each season. Based on this information, further analysis was carried out.

4.3.1 Qualitative Analysis

Table 4.3 and Figures 4.1 and 4.2 show the compilation of existing cross-section locations listed by season. Several reaches lacked significant data, notably the lower end of the Middle Reach (RM 23-RM 29), as well as the Healdsburg area for the most recent year (fall 85-spring 86). A selection of cross-sections, supplemented with cross-sections furnished by Sonoma County Water Agency, were chosen for use in the HEC-2 hydraulic analysis and sediment continuity analysis, which is discussed in the next chapter.

Qualitative analysis of river low point profile plots showed general rises in low point elevation between fall and spring, particularly in the high flow water years 1983 and 1986. Low point elevations generally

Table 4.3 Surveyed Cross Sections for the Hydrology Monitoring Program

Fall 81	Spr 82	Fall 82	Spr 83	Fall 83	Spr 84	Fall 84	Spr 85	Fall 85	Spr 86
SUBREACH 1									
		23+ 300				23+ 300		23+ 300	
23+2300									
24+1530		24+1530				24+1530		24+1530	
24+3200		24+3200						24+3200	
25+2500		25+2500				25+2500		25+2500	
26+3800		26+3800		26+3800		26+3800		26+3800	
27+2300		27+2300		27+2300		27+2300		27+2300	
28+ 900		28+ 900		28+ 900		28+ 900		28+ 900	
SUBREACH 2									
28+3900		28+3900		28+3900		28+3900		28+3900	
29+3000		29+3000		29+3000		29+3000		29+3000	
30+2250		30+2250		30+2250				30+2250	
							30+2840	30+2840	30+2840
								30+2940	30+2940
							30+3040	30+3040	30+3040
								30+3140	30+3140
							30+3240	30+3240	30+3240
								30+3340	30+3340
							30+3440	30+3440	30+3440
								30+3540	30+3540
							30+3640	30+3640	30+3640
								30+3740	30+3740
							30+3840	30+3840	30+3840
								30+3940	30+3940
							30+4040	30+4040	30+4040
								30+4140	30+4140
							30+4240	30+4240	30+4240
								30+4340	30+4340
							30+4440	30+4440	30+4440
								30+4540	30+4540
							30+4640	30+4640	30+4640
								30+4740	30+4740
							30+4840	30+4840	30+4840
								30+4940	30+4940
							30+5040	30+5040	30+5040
								30+5140	30+5140
							30+5240	30+5240	30+5240
								31+ 60	31+ 60
							31+ 160	31+ 160	31+ 160
								31+ 260	31+ 260
							31+ 360	31+ 360	31+ 360
								31+ 460	31+ 460
							31+ 560	31+ 560	31+ 560
								31+ 660	31+ 660
							31+ 760	31+ 760	31+ 760
								31+ 860	31+ 860
							31+ 960	31+ 960	31+ 960
								31+1060	31+1060
							31+1160	31+1160	31+1160
								31+1260	31+1260
							31+1360	31+1360	31+1360
								31+1460	31+1460
							31+1560	31+1560	31+1560
31+1700		31+1700		31+1700				31+1700	
SUBREACH 3									
32+3200	32+3200	32+3200				32+3200	32+3200		
	32+3300	32+3300		32+3300	32+3300	32+3300	32+3300		
32+3400	32+3400	32+3400		32+3400	32+3400	32+3400	32+3400		
	32+3500	32+3500	32+3500	32+3500	32+3500	32+3500	32+3500		
32+3600	32+3600	32+3600	32+3600	32+3600	32+3600	32+3600	32+3600		
	32+3700	32+3700		32+3700	32+3700	32+3700	32+3700		
32+3800	32+3800	32+3800	32+3800	32+3800	32+3800	32+3800	32+3800		

Table 4.3 (continued)

Fall 81	Spr 82	Fall 82	Spr 83	Fall 83	Spr 84	Fall 84	Spr 85	Fall 85	Spr 86
	32+3900	32+3900	32+3900	32+3900	32+3900	32+3900	32+3900		
32+4000	32+4000	32+4000	32+4000	32+4000	32+4000	32+4000	32+4000		
	32+4100	32+4100	32+4100	32+4100	32+4100	32+4100	32+4100		
32+4200	32+4200	32+4200	32+4200	32+4200	32+4200	32+4200	32+4200		
	32+4300	32+4300	32+4300	32+4300	32+4300	32+4300	32+4300		
32+4400	32+4400	32+4400	32+4400	32+4400	32+4400	32+4400	32+4400		
	32+4500	32+4500	32+4500	32+4500	32+4500	32+4500	32+4500		
32+4600	32+4600	32+4600	32+4600	32+4600	32+4600	32+4600	32+4600		
	32+4700	32+4700	32+4700	32+4700	32+4700	32+4700	32+4700		
32+4800	32+4800	32+4800	32+4800	32+4800	32+4800	32+4800	32+4800		
	32+4900	32+4900	32+4900	32+4900	32+4900	32+4900	32+4900		
32+5000	32+5000	32+5000	32+5000	32+5000	32+5000	32+5000	32+5000		
	32+5100	32+5100	32+5100	32+5100	32+5100	32+5100	32+5100		
32+5200	32+5200	32+5200	32+5200	32+5200	32+5200	32+5200	32+5200		
33+ 0	33+ 0	33+ 0		33+ 0	33+ 0	33+ 0	33+ 0		
SUBREACH 4									
44+2200	44+2200	44+2200	44+2200	44+2200	44+2200	44+2200	44+2200		
									44+2300
44+2400	44+2400	44+2400	44+2400	44+2400	44+2400	44+2400	44+2400		44+2400
								44+2500	44+2500
44+2600	44+2600	44+2600	44+2600	44+2600	44+2600	44+2600	44+2600	44+2600	44+2600
	44+2700	44+2700	44+2700	44+2700	44+2700	44+2700	44+2700	44+2700	44+2700
44+2800	44+2800	44+2800	44+2800	44+2800	44+2800	44+2800	44+2800	44+2800	44+2800
	44+2900	44+2900	44+2900	44+2900	44+2900	44+2900	44+2900	44+2900	44+2900
44+3000	44+3000	44+3000	44+3000	44+3000	44+3000	44+3000	44+3000	44+3000	44+3000
	44+3100	44+3100	44+3100	44+3100	44+3100	44+3100	44+3100	44+3100	44+3100
	44+3200	44+3200	44+3200	44+3200	44+3200	44+3200	44+3200	44+3200	44+3200
	44+3300	44+3300	44+3300	44+3300	44+3300	44+3300	44+3300	44+3300	44+3300
44+3400	44+3400	44+3400	44+3400	44+3400	44+3400	44+3400	44+3400	44+3400	44+3400
	44+3500	44+3500	44+3500	44+3500	44+3500	44+3500	44+3500	44+3500	44+3500
44+3600	44+3600	44+3600	44+3600	44+3600	44+3600	44+3600	44+3600	44+3600	44+3600
	44+3700	44+3700	44+3700	44+3700	44+3700	44+3700	44+3700	44+3700	44+3700
44+3800	44+3800	44+3800	44+3800	44+3800	44+3800	44+3800	44+3800	44+3800	44+3800
	44+3900	44+3900	44+3900	44+3900	44+3900	44+3900	44+3900	44+3900	44+3900
44+4000	44+4000	44+4000	44+4000	44+4000	44+4000	44+4000	44+4000	44+4000	44+4000
44+4200	44+4200	44+4200		44+4200	44+4200	44+4200	44+4200	44+4200	44+4200
45+1930									
45+2000	45+2000	45+2000		45+2000	45+2000	45+2000	45+2000		
45+2200	45+2200	45+2200		45+2200	45+2200	45+2200	45+2200		
45+2400	45+2400	45+2400		45+2400	45+2400	45+2400	45+2400		
45+2600	45+2600	45+2600	45+2600	45+2600	45+2600	45+2600	45+2600		
45+2800	45+2800	45+2800	45+2800	45+2800	45+2800	45+2800	45+2800		
45+3000	45+3000	45+3000	45+3000	45+3000	45+3000	45+3000	45+3000		
45+3200	45+3200	45+3200	45+3200	45+3200	45+3200	45+3200	45+3200		
45+3400	45+3400	45+3400		45+3400	45+3400	45+3400	45+3400		
45+3600	45+3600	45+3600		45+3600	45+3600	45+3600	45+3600		
45+3800				45+3800	45+3800	45+3800	45+3800		
				45+4200					
			45+4400			45+4400	45+4400	45+4400	45+4400
45+4600	45+4600	45+4600	45+4600	45+4600	45+4600	45+4600	45+4600	45+4600	45+4600
45+4800	45+4800	45+4800	45+4800	45+4800	45+4800	45+4800	45+4800	45+4800	45+4800
45+5000	45+5000	45+5000	45+5000	45+5000	45+5000	45+5000	45+5000	45+5000	45+5000
45+5200	45+5200	45+5200		45+5200	45+5200	45+5200	45+5200	45+5200	45+5200
SUBREACH 5									
46+ 120	46+ 120	46+ 120		46+ 120	46+ 120	46+ 120	46+ 120	46+ 120	46+ 120
46+ 320	46+ 320	46+ 320		46+ 320	46+ 320	46+ 320	46+ 320	46+ 320	46+ 320
46+ 520	46+ 520	46+ 520		46+ 520	46+ 520	46+ 520	46+ 520	46+ 520	46+ 520
46+ 720	46+ 720	46+ 720		46+ 720	46+ 720	46+ 720		46+ 720	46+ 720
46+ 920	46+ 920		46+ 920	46+ 920	46+ 920	46+ 920	46+ 920	46+ 920	46+ 920
		46+1020							
46+1120	46+1120	46+1120	46+1120	46+1120	46+1120	46+1120	46+1120	46+1120	46+1120
46+1220	46+1220	46+1220	46+1220	46+1220	46+1220	46+1220	46+1220		
46+1320	46+1320	46+1320		46+1320	46+1320	46+1320	46+1320	46+1320	46+1320
46+1420	46+1420	46+1420	46+1420		46+1420	46+1420	46+1420		
46+1520	46+1520	46+1520	46+1520	46+1520	46+1520	46+1520	46+1520	46+1520	46+1520

Table 4.3 (continued)

Fall 81	Spr 82	Fall 82	Spr 83	Fall 83	Spr 84	Fall 84	Spr 85	Fall 85	Spr 86
46+1620	46+1620	46+1620	46+1620	46+1620	46+1620	46+1620	46+1620		
46+1720	46+1720	46+1720	46+1720	46+1720	46+1720	46+1720	46+1720	46+1720	46+1720
46+1820	46+1820	46+1820	46+1820	46+1820	46+1820	46+1820	46+1820		
46+1920	46+1920	46+1920	46+1920	46+1920	46+1920	46+1920	46+1920	46+1920	46+1920
46+2020	46+2020	46+2020	46+2020	46+2020	46+2020	46+2020	46+2020		
46+2120	46+2120	46+2120	46+2120	46+2120	46+2120	46+2120	46+2120	46+2120	46+2120
46+2220	46+2220	46+2220	46+2220		46+2220	46+2220	46+2220		
46+2320	46+2320	46+2320	46+2320	46+2320	46+2320	46+2320	46+2320	46+2320	46+2320
46+2420	46+2420	46+2420	46+2420	46+2420	46+2420	46+2420	46+2420		
46+2520	46+2520	46+2520	46+2520		46+2520	46+2520	46+2520	46+2520	46+2520
46+2620	46+2620	46+2620		46+2620	46+2620	46+2620	46+2620		
46+2720	46+2720	46+2720	46+2720	46+2720	46+2720	46+2720	46+2720	46+2720	46+2720
46+2820	46+2820	46+2820	46+2820	46+2820	46+2820	46+2820	46+2820		
46+2920	46+2920	46+2920	46+2920	46+2920	46+2920	46+2920	46+2920	46+2920	46+2920
46+3020	46+3020	46+3020	46+3020	46+3020	46+3020	46+3020	46+3020		
46+3120	46+3120	46+3120	46+3120	46+3120	46+3120	46+3120	46+3120	46+3120	46+3120
46+3220	46+3220	46+3220	46+3220	46+3220	46+3220	46+3220	46+3220		
46+3320	46+3320	46+3320	46+3320	46+3320	46+3320	46+3320	46+3320	46+3320	46+3320
46+3420	46+3420	46+3420	46+3420	46+3420	46+3420	46+3420	46+3420		
46+3520	46+3520	46+3520	46+3520	46+3520	46+3520	46+3520	46+3520	46+3520	46+3520
46+3616	46+3616	46+3616	46+3616	46+3616	46+3616	46+3616	46+3616		
46+3720	46+3720	46+3720	46+3720	46+3720	46+3720	46+3720	46+3720	46+3720	46+3720
46+3820	46+3820	46+3820	46+3820	46+3820	46+3820	46+3820	46+3820		
46+3920	46+3920	46+3920	46+3920	46+3920	46+3920	46+3920	46+3920	46+3920	46+3920
46+4020	46+4020	46+4020		46+4020	46+4020	46+4020	46+4020	46+4020	46+4020
46+4120	46+4120	46+4120		46+4120	46+4120	46+4120	46+4120	46+4120	46+4120
46+4220	46+4220	46+4220	46+4220	46+4220	46+4220	46+4220	46+4220	46+4220	46+4220
46+4320	46+4320	46+4320	46+4320	46+4320	46+4320	46+4320	46+4320	46+4320	46+4320
46+4420	46+4420	46+4420	46+4420	46+4420	46+4420	46+4420	46+4420	46+4420	46+4420
46+4520	46+4520	46+4520	46+4520	46+4520	46+4520	46+4520	46+4520	46+4520	46+4520
46+4620	46+4620	46+4620	46+4620	46+4620	46+4620	46+4620	46+4620	46+4620	46+4620
46+4720	46+4720	46+4720	46+4720	46+4720	46+4720	46+4720	46+4720	46+4720	46+4720
46+4820	46+4820	46+4820	46+4820	46+4820	46+4820	46+4820	46+4820	46+4820	46+4820
46+4920	46+4920	46+4920	46+4920	46+4920	46+4920	46+4920	46+4920	46+4920	46+4920
46+5020	46+5020	46+5020	46+5020	46+5020	46+5020	46+5020	46+5020	46+5020	46+5020
46+5120	46+5120	46+5120	46+5120	46+5120	46+5120	46+5120	46+5120	46+5120	46+5120
46+5220	46+5220	46+5220	46+5220	46+5220	46+5220	46+5220	46+5220	46+5220	46+5220
47+ 40	47+ 40	47+ 40	47+ 40	47+ 40	47+ 40	47+ 40	47+ 40	47+ 40	47+ 40
47+ 140	47+ 140	47+ 140	47+ 140	47+ 140	47+ 140	47+ 140	47+ 140	47+ 140	47+ 140
47+ 240	47+ 240	47+ 240	47+ 240	47+ 240	47+ 240	47+ 240	47+ 240	47+ 240	47+ 240
							47+ 340	47+ 340	
47+ 440	47+ 440	47+ 440	47+ 440	47+ 440	47+ 440	47+ 440	47+ 440	47+ 440	47+ 440
									47+ 540
47+ 640	47+ 640	47+ 640	47+ 640	47+ 640	47+ 640	47+ 640	47+ 640	47+ 640	47+ 640
47+ 840	47+ 840	47+ 840	47+ 840	47+ 840	47+ 840	47+ 840	47+ 840	47+ 840	47+ 840
47+1040	47+1040	47+1040	47+1040	47+1040	47+1040	47+1040	47+1040	47+1040	47+1040
47+1240	47+1240	47+1240	47+1240	47+1240	47+1240	47+1240	47+1240	47+1240	47+1240
							47+1260		
47+1440	47+1440	47+1440	47+1440	47+1440	47+1440	47+1440		47+1440	47+1440
47+1640	47+1640	47+1640	47+1640	47+1640	47+1640	47+1640	47+1640	47+1640	47+1640
									47+1740
	47+1840	47+1840	47+1840	47+1840	47+1840	47+1840	47+1840	47+1840	47+1840
									47+1940
47+2040	47+2040	47+2040	47+2040	47+2040	47+2040	47+2040	47+2040	47+2040	47+2040
47+2140									
47+2240	47+2240	47+2240	47+2240	47+2240	47+2240	47+2240	47+2240	47+2240	47+2240
47+2340									
47+2440	47+2440	47+2440	47+2440	47+2440	47+2440	47+2440	47+2440	47+2440	47+2440
47+2540									
47+2640	47+2640	47+2640	47+2640	47+2640	47+2640	47+2640	47+2640	47+2640	47+2640
47+2740									
47+2840	47+2840	47+2840	47+2840	47+2840	47+2840	47+2840	47+2840	47+2840	47+2840
47+2940	47+2940	47+2940	47+2940	47+2940	47+2940	47+2940	47+2940	47+2940	47+2940
47+3140	47+3140	47+3140	47+3140	47+3140	47+3140	47+3140	47+3140	47+3140	47+3140
47+3340	47+3340	47+3340	47+3340	47+3340	47+3340	47+3340	47+3340	47+3340	47+3340
							47+3540	47+3540	47+3540
							47+3740	47+3740	47+3740
							47+3940		47+3940
							47+4140	47+4140	47+4140
							47+4340	47+4340	47+4340
							47+4540	47+4540	47+4540

Table 4.3 (continued)

Fall 81	Spr 82	Fall 82	Spr 83	Fall 83	Spr 84	Fall 84	Spr 85	Fall 85	Spr 86
							47+4740	47+4740	47+4740
							47+4940	47+4940	47+4940
							47+5140	47+5140	47+5140
SUBREACH 6									
							48+ 60	48+ 60	48+ 60
							48+ 260	48+ 260	48+ 260
							48+ 460	48+ 460	48+ 460
							48+ 660	48+ 660	48+ 660
							48+ 860	48+ 860	48+ 860
							48+1060	48+1060	48+1060
								48+1260	48+1260
							48+1460	48+1460	48+1460
							48+1660	48+1660	48+1660
								48+1860	48+1860
								48+2060	48+2060
								48+2260	48+2260
								48+2460	48+2460
		48+3636							
	48+3660	48+3660							
	48+3760	48+3760							
	48+3860	48+3860							
	48+3960	48+3960							
	48+4060	48+4060							
	48+4160	48+4160							
	48+4260	48+4260							
	48+4360	48+4360							
	48+4460	48+4460							
	48+4560	48+4560							
	48+4660	48+4660							
	48+4760	48+4760							
	48+4860	48+4860							
	48+4960	48+4960							
	48+5060	48+5060							
	48+5160	48+5160							
48+5260	48+5260	48+5260				48+5260	48+5260	48+5260	48+5260
					49+ 0				
49+ 80	49+ 80	49+ 80	49+ 80	49+ 80	49+ 80	49+ 80	49+ 80		
49+ 180	49+ 180	49+ 180	49+ 180	49+ 180	49+ 180	49+ 180	49+ 180	49+ 180	49+ 180
49+ 280	49+ 280	49+ 280	49+ 280	49+ 280	49+ 280	49+ 280	49+ 280		
49+ 380	49+ 380	49+ 380	49+ 380	49+ 380	49+ 380	49+ 380	49+ 380	49+ 380	49+ 380
49+ 480									
49+ 580	49+ 580	49+ 580	49+ 580						49+ 580
49+ 680		49+ 680							
49+ 780	49+ 780	49+ 780	49+ 780	49+ 780	49+ 780	49+ 780	49+ 780	49+ 780	49+ 780
49+ 880									
49+ 980	49+ 980	49+ 980	49+ 980						49+ 980
49+1080	49+1080	49+1080	49+1080						
49+1180	49+1180	49+1180	49+1180	49+1180	49+1180	49+1180	49+1180	49+1180	49+1180
49+1280	49+1280	49+1280	49+1280	49+1280	49+1280	49+1280	49+1280		
49+1380	49+1380	49+1380	49+1380		49+1380			49+1380	49+1380
49+1480	49+1480	49+1480	49+1480		49+1480				
49+1580	49+1580	49+1580	49+1580						49+1580
	49+1680	49+1680	49+1680	49+1680	49+1680	49+1680	49+1680		
49+1780	49+1780	49+1780	49+1780				49+1780	49+1780	49+1780
	49+1880	49+1880	49+1880		49+1880	49+1880	49+1880		
49+1980	49+1980	49+1980	49+1980	49+1980	49+1980	49+1980	49+1980	49+1980	49+1980
49+2180	49+2180	49+2180	49+2180	49+2180	49+2180	49+2180	49+2180	49+2180	49+2180
49+2380	49+2380	49+2380	49+2380	49+2380	49+2380	49+2380	49+2380	49+2380	49+2380
49+2580	49+2580	49+2580	49+2580	49+2580	49+2580	49+2580	49+2580	49+2580	49+2580
	49+2680	49+2680	49+2680						
49+2780	49+2780	49+2780	49+2780	49+2780	49+2780	49+2780	49+2780	49+2780	49+2780
49+2880	49+2880	49+2880	49+2880	49+2880	49+2880	49+2880		49+2880	49+2880
49+2980	49+2980	49+2980	49+2980				49+2980		
49+3080									49+3080
49+3180	49+3180	49+3180	49+3180	49+3180	49+3180	49+3180	49+3180	49+3180	
49+3280				49+3280	49+3280	49+3280	49+3280	49+3280	49+3280
49+3380	49+3380	49+3380	49+3380	49+3380	49+3380	49+3380		49+3380	
49+3480							49+3480		49+3480

Table 4.3 (continued)

Fall 81	Spr 82	Fall 82	Spr 83	Fall 83	Spr 84	Fall 84	Spr 85	Fall 85	Spr 86
49+3580	49+3580	49+3580	49+3580				49+3580	49+3580	49+3580
49+3680	49+3680	49+3680	49+3680						
	49+3780	49+3780	49+3780	49+3780	49+3780	49+3780		49+3780	49+3780
49+3880	49+3880	49+3880	49+3880		49+3880	49+3880	49+3880	49+3880	
49+3980					49+3980				49+3980
49+4080	49+4080	49+4080	49+4080	49+4080	49+4080	49+4080	49+4080	49+4080	
49+4180					49+4180	49+4180	49+4180	49+4180	49+4180
49+4280	49+4280	49+4280	49+4280	49+4280	49+4280	49+4280	49+4280	49+4280	
49+4380									49+4380
49+4480	49+4480	49+4480	49+4480						
49+4580	49+4580	49+4580	49+4580						49+4580
49+4680	49+4680	49+4680	49+4680	49+4680	49+4680	49+4680	49+4680	49+4680	
49+4780	49+4780	49+4780	49+4780						49+4780
49+4880	49+4880	49+4880	49+4880						
49+4980	49+4980	49+4980	49+4980						49+4980
49+5080			49+5080	49+5080	49+5080	49+5080	49+5080	49+5080	
49+5180			49+5180						49+5180
			50+ 0	50+ 0	49+5280	49+5280	49+5280	49+5280	50+0000

SUBREACH 7

51+2280	51+2280	51+2280	51+2280	51+2280		
51+2480	51+2480	51+2480	51+2480	51+2480		
51+2680	51+2680	51+2680	51+2680	51+2680		
51+2880	51+2880	51+2880	51+2880	51+2880		
51+3080	51+3080	51+3080	51+3080	51+3080		
51+3280	51+3280	51+3280	51+3280	51+3280		
51+3480	51+3480	51+3480	51+3480	51+3480		
51+3680	51+3680	51+3680	51+3680	51+3680		
51+3880	51+3880	51+3880	51+3880	51+3880		
51+4080	51+4080	51+4080	51+4080	51+4080		
51+4280	51+4280	51+4280	51+4280	51+4280		
51+4480	51+4480	51+4480	51+4480	51+4480		
51+4680	51+4680	51+4680	51+4680	51+4680		
51+4880	51+4880	51+4880	51+4880	51+4880		
51+5080	51+5080	51+5080	51+5080	51+5080		
51+5280	52+ 0	52+ 0	52+ 0	52+ 0		
52+ 200	52+ 200	52+ 200	52+ 200	52+ 200		
52+ 400	52+ 400	52+ 400	52+ 400	52+ 400		
52+ 600	52+ 600	52+ 600	52+ 600	52+ 600		
52+ 800	52+ 800	52+ 800	52+ 800	52+ 800		
52+1000	52+1000	52+1000	52+1000	52+1000		
52+1200	52+1200	52+1200	52+1200	52+1200		
52+1400	52+1400	52+1400	52+1400	52+1400		
52+1600	52+1600	52+1600	52+1600	52+1600		
52+1800	52+1800	52+1800	52+1800	52+1800		
52+2000	52+2000	52+2000	52+2000	52+2000		
52+2200	52+2200	52+2200	52+2200	52+2200		
52+2400	52+2400	52+2400	52+2400	52+2400		
52+2600	52+2600	52+2600	52+2600	52+2600	52+2600	52+2600
52+2800	52+2800	52+2800	52+2800	52+2800	52+2800	52+2800

SUBREACH 8

52+3000	52+3000	52+3000	52+3000		52+3000	52+3000	
52+3200	52+3200	52+3200	52+3200	52+3200	52+3200	52+3200	
	52+3400	52+3400	52+3400	52+3400	52+3400	52+3400	52+3400
	52+3500	52+3500	52+3500	52+3500			
	52+3600	52+3600	52+3600	52+3600	52+3600	52+3600	52+3600
	52+3700	52+3700	52+3700	52+3700			
	52+3800	52+3800	52+3800	52+3800	52+3800	52+3800	52+3800
	52+3900						
52+4000	52+4000	52+4000	52+4000	52+4000	52+4000	52+4000	52+4000
52+4100							
52+4200	52+4200	52+4200	52+4200	52+4200	52+4200	52+4200	52+4200
52+4300							
52+4400	52+4400	52+4400	52+4400	52+4400	52+4400	52+4400	52+4400
52+4500							
52+4600	52+4600	52+4600	52+4600	52+4600	52+4600	52+4600	52+4600

Table 4.3 (continued)

Fall 81	Spr 82	Fall 82	Spr 83	Fall 83	Spr 84	Fall 84	Spr 85	Fall 85	Spr 86
52+4700	52+4700	52+4700	52+4700						
52+4800			52+4800	52+4800	52+4800	52+4800	52+4800		
	52+4900	52+4900	52+4900						
52+5000			52+5000	52+5000	52+5000	52+5000	52+5000	52+5000	52+5000
	52+5100	52+5100	52+5100	52+5100				52+5100	52+5100
52+5200			52+5200	52+5200	52+5200	52+5200	52+5200	52+5200	52+5200
53+ 20	53+ 20	53+ 20	53+ 20	53+ 20				53+ 20	
53+ 120			53+ 120	53+ 120	53+ 120	53+ 120	53+ 120	53+ 120	53+ 120
53+ 220	53+ 220	53+ 220	53+ 220	53+ 220	53+ 220	53+ 220		53+ 220	53+ 220
53+ 320	53+ 320	53+ 320	53+ 320	53+ 320		53+ 320	53+ 320	53+ 320	
53+ 420		53+ 420	53+ 420	53+ 420	53+ 420	53+ 420	53+ 420	53+ 420	
53+ 520	53+ 520		53+ 520		53+ 520	53+ 520	53+ 520	53+ 520	
53+ 620	53+ 620	53+ 620	53+ 620	53+ 620	53+ 620	53+ 620	53+ 620	53+ 620	53+ 620
53+ 720	53+ 720				53+ 720	53+ 720			
53+ 820	53+ 820	53+ 820	53+ 820	53+ 820	53+ 820	53+ 820	53+ 820	53+ 820	53+ 820
53+ 920					53+ 920				
53+1020	53+1020	53+1020	53+1020	53+1020	53+1020	53+1020	53+1020	53+1020	53+1020
53+1120									53+1120
53+1220	53+1220	53+1220	53+1220	53+1220	53+1220	53+1220	53+1220	53+1220	53+1220
53+1320									
53+1420	53+1420	53+1420	53+1420	53+1420	53+1420	53+1420	53+1420	53+1420	53+1420
53+1520								53+1520	53+1520
53+1620	53+1620	53+1620	53+1620	53+1620	53+1620	53+1620	53+1620	53+1620	53+1620
53+1720					53+1720	53+1720	53+1720	53+1720	
53+1820	53+1820	53+1820	53+1820	53+1820	53+1820	53+1820	53+1820	53+1820	53+1820
53+1920								53+1920	
53+2020	53+2020	53+2020	53+2020	53+2020	53+2020	53+2020	53+2020	53+2020	53+2020
53+2120			53+2120						
53+2220	53+2220	53+2220	53+2220	53+2220	53+2220	53+2220	53+2220	53+2220	53+2220
53+2320		53+2320							
53+2420	53+2420		53+2420	53+2420	53+2420	53+2420	53+2420	53+2420	
53+2520					53+2520				
53+2620	53+2620	53+2620	53+2620	53+2620	53+2620	53+2620	53+2620	53+2620	53+2620
53+2720	53+2720								53+2720
53+2820	53+2820	53+2820	53+2820	53+2820	53+2820	53+2820	53+2820	53+2820	53+2820
53+2920	53+2920	53+2920	53+2920	53+2920	53+2920	53+2920	53+2920		53+2920
								53+3020	
SUBREACH 9									
	54+4480	54+4480	54+4480	54+4480	54+4480	54+4480	54+4480	54+4480	54+4480
	55+3880	55+3880	55+3880	55+3880	55+3880	55+3880	55+3880	55+3880	55+3880
	56+3780	56+3780	56+3780	56+3780	56+3780	56+3780	56+3780	56+3780	56+3780
	57+3380	57+3380	57+3380	57+3380	57+3380	57+3380	57+3380	57+3380	57+3380
SUBREACH 10									
58+4880	58+4880	58+4880	58+4880	58+4880	58+4880	58+4880	58+4880	58+4880	
SUBREACH 11									
									59+ 0
									59+ 135
				59+ 330	59+ 330	59+ 330	59+ 330		
									59+ 335
									59+ 535
				59+ 730	59+ 730	59+ 730	59+ 730		
									59+ 735
									59+ 935
				59+1130	59+1130	59+1130	59+1130		
									59+1135
									59+1335
				59+1530	59+1530	59+1530	59+1530		
									59+1535
									59+1735
				59+1930	59+1930	59+1930	59+1930		
									59+1935
									59+2135

Table 4.3 (continued)

Fall 81	Spr 82	Fall 82	Spr 83	Fall 83	Spr 84	Fall 84	Spr 85	Fall 85	Spr 86
				59+2330	59+2330	59+2330	59+2330		
					59+2335				
				59+2730		59+2730	59+2730		
					59+2735				
				59+3130		59+3130	59+3130		
					59+3135			59+3135	
59+3430	59+3430	59+3430	59+3430	59+3430	59+3430	59+3430	59+3430	59+3430	59+3430
				59+3535	59+3535	59+3535	59+3535		
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				59+3735	59+3735	59+3735	59+3735	59+3735	59+3735
				59+3835	59+3835	59+3835	59+3835	59+3835	59+3835
				59+3935	59+3935	59+3935	59+3935	59+3935	59+3935
				59+4035	59+4035	59+4035	59+4035	59+4035	
				59+4135	59+4135	59+4135	59+4135	59+4135	59+4135
				59+4235	59+4235	59+4235	59+4235	59+4235	59+4235
				59+4335	59+4335	59+4335	59+4335	59+4335	59+4335
				59+4435	59+4435	59+4435	59+4435	59+4435	59+4435
				59+4535	59+4535	59+4535	59+4535	59+4535	59+4535
				59+4635	59+4635	59+4635	59+4635	59+4635	59+4635
				59+4735	59+4735	59+4735	59+4735	59+4735	59+4735
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				59+4935	59+4935	59+4935	59+4935	59+4935	59+4935
				59+5035	59+5035	59+5035	59+5035	59+5035	59+5035
				59+5135	59+5135	59+5135	59+5135	59+5135	59+5135
				59+5235	59+5235	59+5235	59+5235	59+5235	59+5235
				60+ 55	60+ 55	60+ 55	60+ 55	60+ 55	60+ 55
				60+ 155	60+ 155	60+ 155	60+ 155	60+ 155	60+ 155
				60+ 255	60+ 255	60+ 255	60+ 255	60+ 255	60+ 255
				60+ 355	60+ 355	60+ 355	60+ 355	60+ 355	60+ 355
				60+ 455	60+ 455	60+ 455	60+ 455	60+ 455	60+ 455
				60+ 555	60+ 555	60+ 555	60+ 555	60+ 555	60+ 555
				60+ 655	60+ 655	60+ 655	60+ 655	60+ 655	60+ 655
				60+ 755	60+ 755	60+ 755	60+ 755	60+ 755	60+ 755
				60+ 855	60+ 855	60+ 855	60+ 855	60+ 855	60+ 855
				60+ 955	60+ 955	60+ 955	60+ 955	60+ 955	60+ 955
				60+1055	60+1055	60+1055	60+1055	60+1055	60+1055
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				60+1255	60+1255	60+1255	60+1255	60+1255	60+1255
				60+1355	60+1355	60+1355	60+1355	60+1355	60+1355
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				60+1555	60+1555	60+1555	60+1555	60+1555	60+1555
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						60+1855	60+1855		
						60+1955	60+1955		
						60+2355	60+2355		
						60+2755	60+2755		
						60+3045	60+3045		
						60+3445	60+3445		
						60+3845	60+3845		
							61+1080	61+1080	61+1080
							61+1280	61+1280	61+1280
							61+1480	61+1480	61+1480
							61+1680	61+1680	61+1680
							61+1880	61+1880	61+1880
							61+2080	61+2080	61+2080
							61+2280	61+2280	61+2280
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							61+3280	61+3280	61+3280
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								61+3780	
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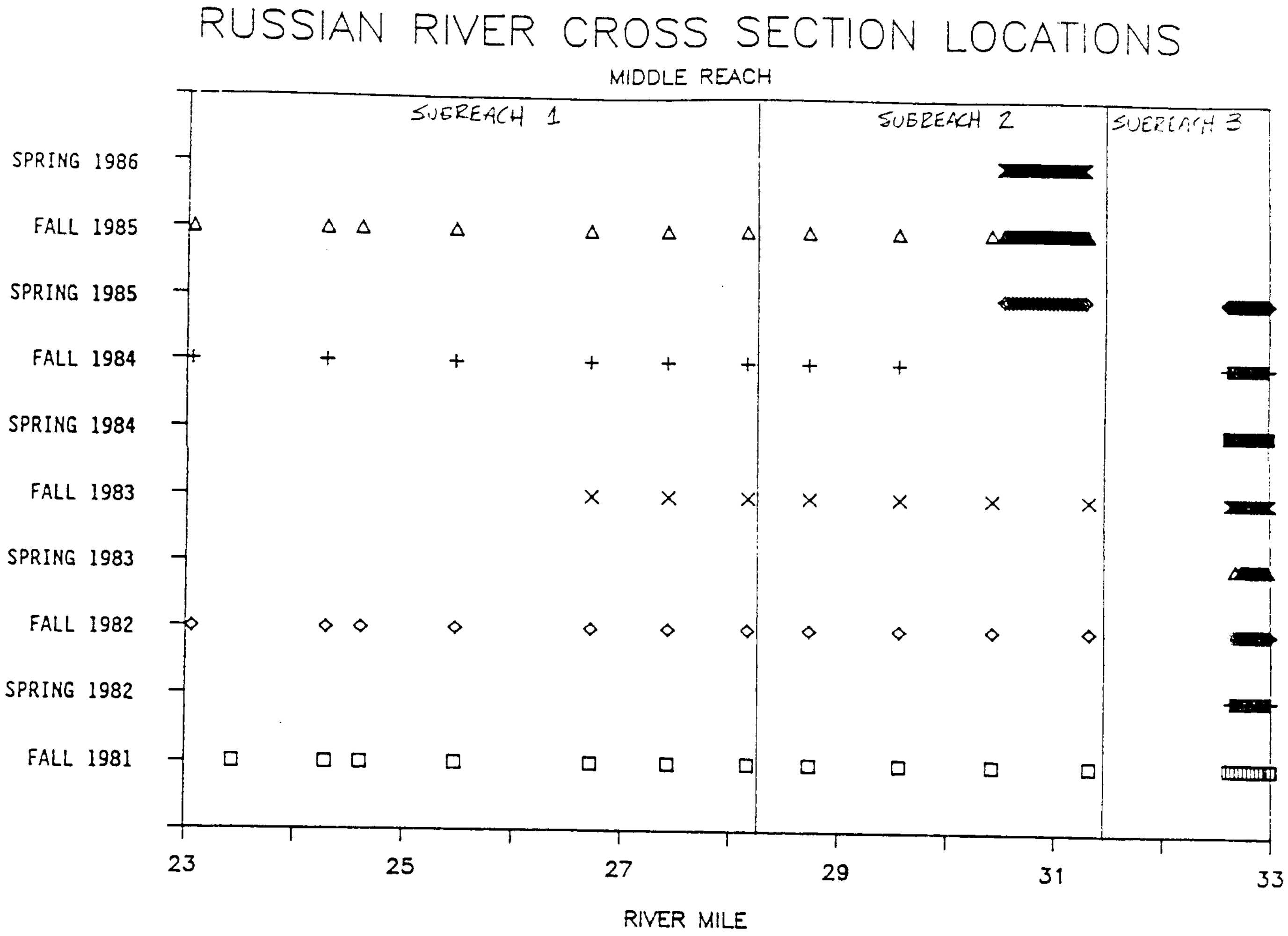
61+4080	61+4080	61+4080		61+4080	61+4080	61+4080	61+4080	61+4080	61+4080
								61+4180	
61+4280	61+4280	61+4280		61+4280	61+4280	61+4280	61+4280	61+4280	61+4280
61+4480	61+4480	61+4480	61+4480	61+4480	61+4480	61+4480	61+4480	61+4480	61+4480
61+4680	61+4680	61+4680	61+4680	61+4680	61+4680	61+4680	61+4680	61+4680	61+4680

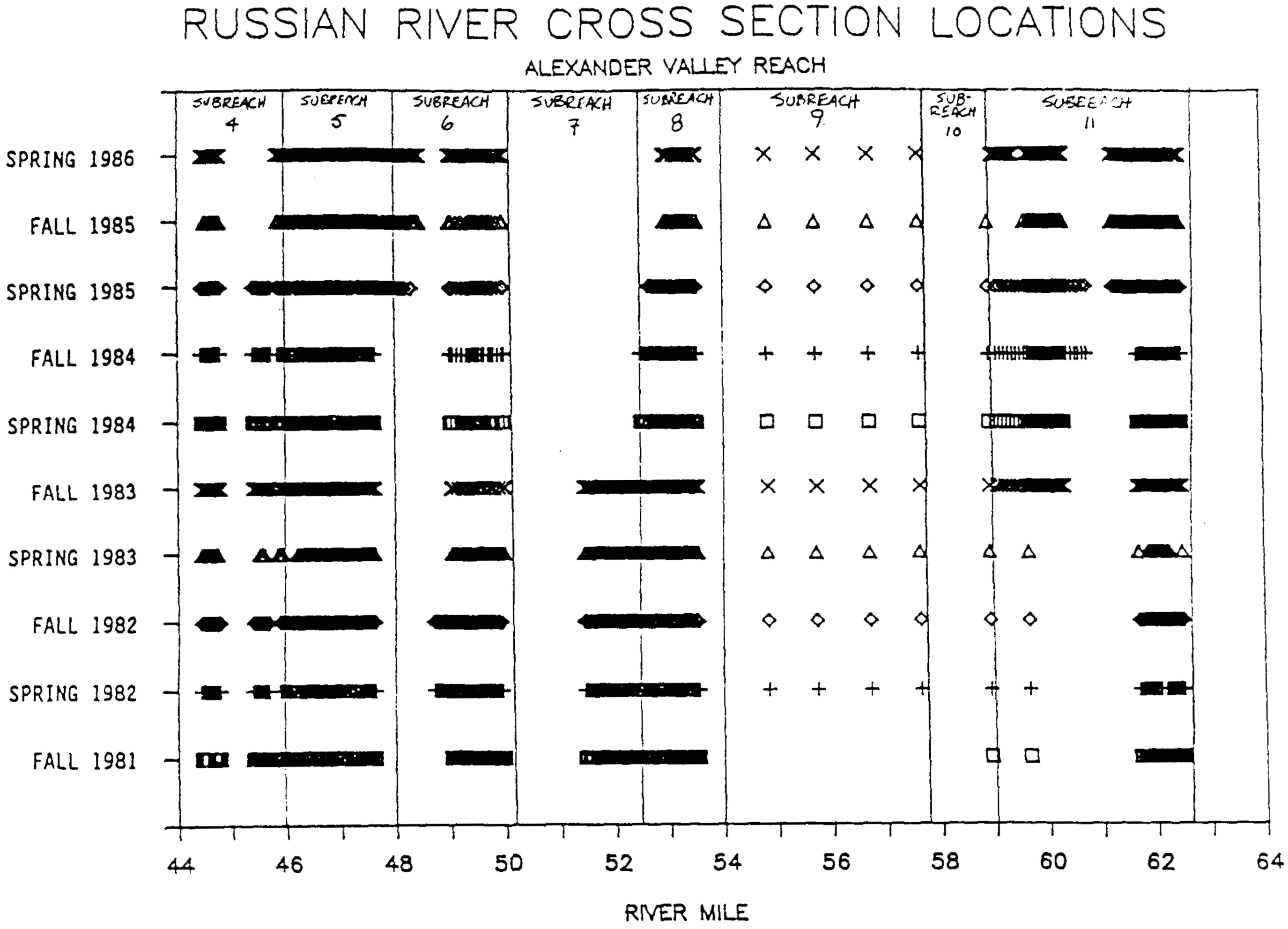
Table 4.3 (continued)

Fall 81	**Spr 82**	**Fall 82**	**Spr 83**	**Fall 83**	**Spr 84**	**Fall 84**	**Spr 85**	**Fall 85**	**Spr 86**
61+4880	61+4880	61+4880	61+4880	61+4880	61+4880	61+4880	61+4880	61+4880	61+4880
61+5080	61+5080	61+5080	61+5080	61+5080	61+5080	61+5080	61+5080	61+5080	61+5080
62+ 0	62+ 0	62+ 0	62+ 0	62+ 0	62+ 0	62+ 0	62+ 0	62+ 0	62+ 0
62+ 200	62+ 200	62+ 200	62+ 200	62+ 200	62+ 200	62+ 200	62+ 200	62+ 200	62+ 200
62+ 400	62+ 400	62+ 400	62+ 400	62+ 400	62+ 400	62+ 400	62+ 400	62+ 400	62+ 400
62+ 600		62+ 600	62+ 600	62+ 600	62+ 600	62+ 600	62+ 600	62+ 600	62+ 600
62+ 800	62+ 800	62+ 800	62+ 800	62+ 800	62+ 800	62+ 800	62+ 800	62+ 800	62+ 800
62+1000	62+1000	62+1000	62+1000	62+1000	62+1000	62+1000	62+1000	62+1000	62+1000
62+1200	62+1200	62+1200	62+1200	62+1200	62+1200	62+1200	62+1200	62+1200	62+1200
62+1400	62+1400	62+1400	62+1400	62+1400	62+1400	62+1400	62+1400	62+1400	62+1400
62+1600	62+1600	62+1600		62+1600	62+1600	62+1600	62+1600	62+1600	62+1600
62+1800	62+1800	62+1800		62+1800	62+1800	62+1800	62+1800	62+1800	
62+2000	62+2000	62+2000		62+2000	62+2000	62+2000	62+2000	62+2000	62+2000
62+2200	62+2200	62+2200		62+2200	62+2200	62+2200	62+2200	62+2200	62+2200
62+2400	62+2400	62+2400		62+2400	62+2400	62+2400	62+2400	62+2400	62+2400
62+2600	62+2600	62+2600	62+2600	62+2600	62+2600	62+2600	62+2600	62+2600	62+2600
62+2640	62+2640	62+2640		62+2640	62+2640	62+2640	62+2640	62+2640	62+2640



NOTE: EACH SYMBOL INDICATES THE LOCATION OF A FULL OR PARTIAL CROSS-SECTION SURVEYED AT THE TIME INDICATED THE SOLID BAR APPEARANCE IN SOME AREAS IS CAUSED BY SYMBOL OVERLAP, AND INDICATES REACHES OF RELATIVELY DENSE SURVEY COVERAGE

Figure 4.1 Survey Coverage within the Middle Reach During the Study Period



NOTE: EACH SYMBOL INDICATES THE LOCATION OF A FULL OR PARTIAL CROSS-SECTION SURVEYED AT THE TIME INDICATED THE SOLID BAR APPEARANCE IN SOME AREAS IS CAUSED BY SYMBOL OVERLAP, AND INDICATES REACHES OF RELATIVELY DENSE SURVEY COVERAGE

Figure 4.2 Survey Coverage within the Alexander Valley Reach during the Study Period declined from spring to fall of each year, due to mining and/or changes in flow discharges at the time the aerial surveys were made (see Table 4.4). Pertinent low point profile plots (fall surveys, spring surveys, and a comparison of earliest and latest surveys) for each subreach are included in Appendix C. Changes noted in the low point profiles for each subreach over the study period are discussed in Section 4.3.3.

Appendix D contains illustrations of the surveyed portions of typical cross-sections within each subreach. These figures demonstrate the variations that occurred in cross-sectional geometry of selected sites throughout the study period. Analysis of these figures indicates that a lowering of the low point elevation does not necessarily imply that the section is degrading (see Figures D.1 and D.16), nor does a rise in the low point elevation necessarily imply general aggradation (see Figures D.5 and D.15). Further discussions of these cross-sectional changes are presented in Section 4.3.3 of this report.

4.3.2 Database Management System

The cross-section data were processed using a special computer program developed by SLA. The procedure computes the area of each cross-section above an arbitrary datum. When this value is compared to the value for the same cross-section location of a different season, the change in cross-sectional area can be computed for that point. The average change in area multiplied by the distance between cross-sections is the change in volume from the first season to the second. If the change in volume is negative then degradation occurred at that point. If the change is positive, then aggradation occurred.

One possibility that is accounted for by the SLA program is if the two cross-sections being compared have different starting and ending points. If the area under the entire cross-section is compared, then an erroneous volume computation results. To avoid this, the program determines which part of the cross-sections are common and then compares just that part. For certain cases the amount of overlap was less than 50%. In general, however, the overlap was greater than 80%.

There are several possible effects caused by having less than total overlap of section data. First, when comparing sections before and after a mining season, incomplete overlap may show a smaller volume of mined

Table 4.4 Average Daily Flow along Russian River during Survey Flights

Flight Date	Average Daily Flow, cfs USGS No. 11463000 near Cloverdale	USGS No. 11467000 near Guerneville
10/20/81	159	158
5/03/82	854	1,790
11/04/82	519	433
5/03/83	2,280	6,100
11/05/83	166	255
5/05/84	285	679
11/03/84	367	285
4/18/85	278	625
11/05/85	179	214
5/08/86	281	639

material than was actually taken. This could occur, for example, in places which are being mined for the first time and were not previously surveyed over the entire channel width. Second, when comparing sections before and after a flooding season, incomplete overlap may show less deposition/scour than actually occurred across the entire width. Finally, lateral bank erosion may not be shown due to incomplete overlap. As a result, contributions of material from the bank are not distinguished from contributions from the stream. Unless the cross-sections each cover the eroded area, bank erosion will appear as if it was material contributed by the watershed.

The overall results may not show any substantial changes if additional data were made available, due to the fact that overlap was usually at least 80%. Mined areas were covered to a very high degree by the cross-section surveys.

4.3.3 Results of Monitoring Program Data Analysis

As described above, area values were computed at each cross-section location for each season. Comparison of these values from one season to another shows the net change in cross-sectional area. By averaging this net change with that of an adjacent cross-section and multiplying by the distance between the two, the net change of volume is derived. Using this procedure, the aggradation/ degradation volumes in Table 4.5 were computed. This table shows the net volume change in cubic yards for the nine alternate mining and flooding seasons.

Appendix E shows computed volume changes for all cross-section data. Note that changes from spring to fall of a given year show the net amount of mining for that year; likewise, changes from fall to the subsequent spring show the effects of that winter's storms. The figures presented in Appendix F were constructed based on this process. Referring to Figure F.1 as an example, the cross-section area change was computed for each location common to both spring 1982 and fall 1982. A point is plotted at each of these locations. Most, if not all, of these values are negative, resulting from summer mining activities. Next, cross-section area change was computed for each location common to fall 1982 and spring 1983. These values are positive for locations of deposition and negative for locations of scour during winter flooding. Therefore, three data sets are incorporated into

Table 4.5
Summary of Survey Data for each Season and Total Period

Net Volume Change in cubic yards

Season	F81-S82	S82-F82	F82-S83	S83-F83	F83-S84	S84-F84	F84-S85	S85-F85	F85-S86
Subreach									
1									
2									
3	20,530	(68,062)	61,703	(67,405)	48,186	4,019	13,422		
Middle Reach Total	**20,530**	**(68,062)**	**61,703**	**(67,405)**	**48,186**	**4,019**	**13,422**		
4	80,755	(40,926)	21,178	(36,245)	13,866	(37,277)	16,915	(26,217)	56,300
5	27,238	(69,171)	153,303	(118,366)	59,376	(238,020)	73,160	(282,078)	361,027
6	(26,225)	(70,673)	54,224	(89,209)	56,897	(198,895)	69,956	(162,370)	267,382
7	(33,239)	(14,078)	122,987	(8,851)	2,707	(4,185)			
8	(60,074)	(124,207)	184,170	(40,657)	53,572	(50,387)	44,879	(76,402)	99,164
9									
10									
11	(5,863)	(24,728)	49,489	(50,784)	(71,224)	(62,633)	33,136	(116,815)	139,069
Alexander Valley Reach Total	**(17,408)**	**(343,783)**	**585,351**	**(344,112)**	**115,194**	**(591,397)**	**238,046**	**(663,882)**	**922,942**
Combined Total	**3,122**	**(411,845)**	**647,054**	**(411,517)**	**163,380**	**(587,378)**	**251,468**	**(663,882)**	**922,942**

NOTE: PARENTHESES INDICATE NEGATIVE CHANGE one plot: spring 1982, fall 1982 and spring 1983. If summer mining and winter deposition are similar in both location and magnitude of material, then the plot will look like a reflection ("mirror image") about the zero axis. This means winter flows restored material in the same amount and at the same location it was taken out. The degree of similarity about the zero axis represents the degree of equilibrium of mining and flood deposition from spring 1982 to spring 1983 (one complete annual cycle). For complete cycles are included in the study period, with graphical representation shown in Figures F.1 through F.28.

Cumulative effects over the study period are illustrated through use of similar figures, also included in Appendix F (Figures F.29 through F.37). In these figures, the area changes at common locations between the earliest and latest surveys for each subreach are compared.

The following paragraphs discuss the changes within each subreach formulated through evaluation of the available monitoring data.

Subreach 1 (RM 23.00 to 28.19)

There was little or no instream mining in subreach 1 during the study period, therefore few cross-sections were available. Bank erosion in this reach was negligible.

The average decrease in channel low point elevation varied between 1 to 4 ft between fall 1981 and fall 1985 in subreach 1 (see Fig. C.1). The period of available data does not include the occurrence of the large 1986 flood, which may have added a large amount of material to the streambed. Even though the channel bottom elevations decreased in this subreach, the full-width cross-sections generally showed aggradation on the gravel bars during the period (see Figs. D.1 and D.2). Comparison of cross-sectional areas of the fall 1981 and fall 1985 surveys indicates aggradation occurred within four of the six locations during this period (see Fig. F.29). In the remaining two locations, degradation occurred but was minor.

Subreach 2 (28.19 to 31.35)

Mining was minimal within subreach 2 during the study period. Only four cross-sections are available for evaluation of the study period changes, with more detailed data available for the upstream portion of the reach from spring 1985 on.

The fall 1985 low point profile is 0.5 to 3.0 ft lower than that of fall 1981 (see Fig. C.2). The fall 1985 low point profile is approximately equal to the 1972 thalweg profile between RM 28 and 29, but is up to 3 ft lower in the upstream portions of the subreach. The 1986 flood raised the low point profile to above the 1972 thalweg in the upstream portion (see Fig C.3).

Of the four cross-sections available for comparison, two showed net aggradation, and two showed net degradation between fall 1981 and fall 1985 (see Fig. F.29). Figures D.3 and D.4 show the cross-sectional variation that occurred within this subreach during the study period.

Subreach 3 (31.35 to 33.00)

No cross-sectional data was available in this subreach during the fall 1985 and spring 1986 seasons. Data for all periods was unavailable between RM 31.35 and Rm 32.60.

During the summer of 1982 and 1983, there was fairly significant mining activity from RM 32.65 to 33.00. A total of 130,000 cubic yards was removed over the two summers. In each instance the mined volumes were replaced by approximately equal amounts of sediment during the subsequent winter runoff. No mining was evident in the 1984 or 1985 mining seasons; hence, the lowest low flow profile throughout most of the reach occurred in fall of 1983 (see Figures C.4 and C.5). Figure C.6 indicates that the low point profile of spring 1985 is up to 1 ft lower than the fall 1981 low point profile between RM 32.8 and 33. Between RM 32.6 and 32.8, the spring 1985 low point profile is up to 2 ft higher than the fall 1981 low point profile.

As indicated in Figure F.30, both aggradation and degradation occurred along subreach 3 during the period of fall 1981 to spring of 1985. Figures D.5 and D.6 show the variable changes that occurred along the gravel bars within this subreach.

Channel banks were stable throughout the study period in the entire Middle Reach (subreaches 1-3).

Subreach 4 (44.00 to 46.00)

Mining in subreach 4 was generally restricted to RM 44.35 to 44.80, with annual volumes ranging from 40,000 cubic yards in 1982 down to 26,000 cubic yards in 1985. During the 1983, 1984, and 1985 flooding seasons, mined amounts were not fully replaced by new deposits. In addition, as much as nine acres of undeveloped area was lost due to bank erosion along the outside of a major channel bend immediately downstream, at RM 43.9-44.3, in 1983. Approximately one acre was lost adjacent to the mining site in 1986. There was substantial deposition in the spring of 1986, which brought total deposition during the study period up to about 90 percent of the total extracted. Figure F.31 identifies the cumulative changes that occurred along subreach 4 -- net degradation between fall 1981 and 1985, and alternating degradation and aggradation between fall 1981 and spring 1986. Figures D.7 and D.8 indicate the typical changes to the gravel bars which occurred during the study period. No significant meander loop translation was evident in this subreach.

The fall 1985 low point profile is between 1 and 3 ft lower than the fall 1981 low point profile. The low point profile of fall 1985 was higher than the fall 1983 and fall 1984 low point profiles near the downstream end of the subreach, but was the lowest low point profile near the upstream end (see Fig. C.7). The lowest spring low point profiles occurred in spring of 1985 (see Fig C.8). From spring 1982 to spring 1986, the low point elevations increased by about one foot from mile 44.5 to 44.7. The low point elevations dropped by about one foot from mile 44.8 to 50.0. All the low point profiles are higher than the 1978 thalweg profile through subreach 4. The spring 1986 low point profile is approximately equal to the fall 1981 profile in the upstream portion of subreach 4, and alternates (generally higher) above and below the fall 1981 low point profile in the downstream portion (see Fig. C.9).

Subreach 5 (46.00 to 48.00)

The locations and relative amounts of mining varied widely in subreach 5 over the course of the study period. Mining was very limited in 1982, with 69,000 cubic yards taken from the channel between RM 46.00 and 46.75. Subsequent flooding in 1983 deposited material equal to about twice the amount mined, with these deposits spread from RM 46.25 to 47.60.

Approximately four acres of bank erosion occurred along the mined reach, with another four acres lost upstream at RM 47.3, in 1983.

Mining in the summer of 1983 was much more intense, with nearly 120,000 cubic yards taken from RM 46.20 to 46.80 (slightly farther upstream than the previous year). Flooding in 1984 replenished only about half of mined amounts, with some scour around RM 47.25 but no lateral bank erosion.

Significant extraction continued in 1984 at the same locations as the previous two years, with an additional 100,000 cubic yards being taken from RM 46.75 to 47.10. Altogether, 238,000 cubic yards of material were removed. Only 30% replenishment was accomplished at the old sites, while 1985 flooding replaced virtually none of the extracted amounts from the new site. No new bank erosion was incurred in 1984 or 1985.

Mining in 1985 was sharply curtailed at the previously used sites, but was very intense farther upstream, from RM 46.80 to 47.35. Large deposits due to heavy 1986 flooding replaced much of the deficit of material from 1982-1984 mining, while also replacing the large amount (over 280,000 cubic yards) taken in 1985. Nearly six acres of lateral erosion resulted from the 1986 flows at RM 46.6 to 46.8, immediately downstream of the new mining. Nine acres were lost from the west bank upstream of the mining site at RM 47.4 to 48.0 in the 1986 flood. This may be the result of two consecutive years of heavy mining in RM 46.8 to 47.35 (more than 300,000 cubic yards) without replenishment from a large flood; also, this was the first time this area was mined during the study period.

Erosion of the banks which occurred along subreach 5 during the study period was mainly along the outside bends of the meandering main channel. No major down-valley translation of the meandering bends was evident, but a single meander cutoff developed just upstream of RM 46.

The average low point elevation from RM 46.2 to 46.8 dropped by almost 2 feet from spring 1982 to spring 1986 (see Fig C.11). From RM 47.0 to 47.4 the drop was only one foot. The fall 1985 low point profile is 1 to 2 ft lower than the fall 1981 low point profile (see Fig C.10). All low point profiles are higher than the 1978 thalweg. The spring 1986 low point profile is, in general, 0 to 1.5 ft lower than the fall 1981 low point profile through this subreach (see Fig. C.12).

Cumulative changes occurring along subreach 5 over the study period are illustrated in Figure F.32. Net degradation is indicated between the fall 1981 and fall 1985 surveys, and the aggradation occurring during the 1986 flood was not able to balance the deficit, especially in the vicinity of RM 47. Of the 708,000 cubic yards mined, 647,000 cubic yards were replaced by deposition (91% replenishment). Gravel bar reduction and growth within this subreach are illustrated in Figures D.9 and D.10, respectively.

<u>Subreach 6</u> (48.00 to 50.20)

Mining intensity and location varied somewhat in this subreach, generally increasing in amount and progressing upstream from beginning to end of the study period. In this subreach, replenishment and extraction were not as closely correlated as in other subreaches of the Russian River; although total deposition amounted to 86% of extraction, the locations of deposition varied widely from mining locations, and some scour occurred during the 1983 flood. Bank erosion occurred only in the spring 1986 flood, when over 23 acres were eroded.

Extraction was about 71,000 cubic yards in 1982, with locations in the range of RM 49.15 to 49.80. Subsequent flows both deposited sediment in and scoured the channel in 1983, with the net effect of depositing about 80% of extracted amounts.

1983 extraction of 89,000 cubic yards occurred in two locations, RM 49.00 to 49.30 and RM 49.60 to 49.80. Deposition in 1984 covered both areas, as well as between the two sites. Scouring occurred upstream, at RM 49.80 to 54.00.

Mining in 1984 was moderately heavy from RM 49.00 to 50.00, with subsequent 1985 replenishment of only 35% of the 199,000 cubic yards mined. Extraction was heavy once again in 1985 from RM 49.30 to 50.00. The large flow in 1986 replaced much of the volume extracted throughout the study period in this subreach, but a 73,000 cubic yard deficit remained and bank erosion was severe. Nearly six acres was eroded near RM 48.4, three acres at RM 49.4, and 4-1/2 acres at RM 49.6. Each of these locations was along the mined portion. In addition, ten acres were lost at RM 50.00, just upstream from recent heavy 1985 mining.

The bank erosion which occurred along this subreach was located along the outside bends of the meandering main channel. Between RM 49 and RM 50, the meander loops translated approximately 1400 ft downstream over the study period.

From spring 1982 to spring 1986 the low point profile between RM 49.0 and 50.00 dropped from 0 to 5 ft (see Fig. C.14). The fall 1985 low point profile is from 0 to 2 ft lower than the fall 1981 profile through the same reach (see Fig. C.13). Both the fall 1985 and spring 1986 lowpoint profiles are lower than the 1978 thalweg profile upstream of RM 49. In general, the spring 1986 low point profile is 0 to 3 ft lower than the fall 1981 low point profile (see Fig. C.15).

Figure F.33 shows that the cumulative effects of mining between fall of 1981 and fall of 1985 were degradation. Between fall of 1981 and spring of 1986 both net aggradation and net degradation occurred at various locations. Figures D.11 and D.12 illustrate net degradational and net aggradational, respectively, cross-sections within this subreach.

<u>Subreach 7 and 8</u> (50.20 to 54.00)

The heaviest mining in these subreaches occurred in 1982, when 138,000 cubic yards of material were removed. For the total period, 319,000 cubic yards were mined, but replenishment was over 500,000 cubic yards. There was also bank erosion in each year except 1985. Over eleven acres were lost on the outside of a meander bend between RM 53.2 and 53.6, along a mined area. (The channel meanders shifted some 1200 ft downstream in this vicinity.) Three acres were lost in the vicinity of a meander shift at RM 51.1, downstream of mining, in 1986.

Most of the data for subreach 7 corresponds to the fall 1981 through fall 1983 surveys. The low point profiles for these years (Figs. C.16 and C.17) exhibit no discernable trend, although they are all higher than the 1978 thalweg profile. The changes in cross-sectional area were minimal between fall 1983 and fall 1981, with the exception of significant aggradation which occurred near RM 51.5 (see Fig. F.34). Figures D.13 and D.14 show typical cross-sections along subreach 7.

Within subreach 8, the fall 1985 low point profile is generally 1 to 2 ft lower than that of fall 1981 (see Fig. C.18). The fall 1983 low point profile is the lowest in many places. Between RM 52.9 and 53.5, the low point profile dropped by 0 to 2 ft between spring 1982 and spring 1986 (see Fig. C.19). The spring 1986 low point profile is between 0 and 4 ft lower than the fall 1981 low point profile; however, general aggradation is noted in this subreach through the same period (see Figs. C.20 and F.35). All low point profiles are higher than the 1978 thalweg profile through this reach. Figures D.15 and D.16 illustrate the major shifting that occurred within this subreach over the study period.

Subreach 9 and 10 (54.00 to 58.95)

Very few cross-sections were taken in these subreaches, in which little or no mining took place. Deposition or scour volumes could not be computed, but large amounts of bank erosion were evident on aerial photographs. Over 50 acres were lost, including 21 acres in 1982, 18 acres in 1983, 6 acres in 1984, and 7-1/2 acres in 1986. All bank erosion occurred along the outside bend of the meandering main flow channel. The meanders in subreach 9 were observed to have shifted some 1000 to 1400 ft downstream over the study period.

There was some variation in low point elevation for the available cross-sections in these reaches, although no major trend was noted (see Figs C.21 and C.22). The lowest fall survey low point elevations occurred in the fall of 1983, and the lowest spring low point elevations occurred in the spring of 1982. The low point elevations are higher than the 1978 thalweg in subreach 10 and upper subreach 9, but approach the 1978 thalweg elevation at the downstream end of subreach 9.

Within subreach 10 and the upstream end of subreach 9, net aggradation was noted over the period of available record. (see Figs. F.36 and F.37). The three lower cross-sections of subreach 9 exhibited net degradation between spring 1982 and spring 1986 (Fig. F.36). Typical sections within subreach 9 are illustrated in Figures D.17 and D.18, and the single cross-section available for subreach 10 is shown in Figure D.19.

Subreach 11 (58.95 to 62.40)

Mining in subreach 11 gradually increased through the study period from 24,000 cubic yards in 1982 to 117,000 in 1985. Locations of mining through the entire period were between RM 61.50 to 62.50, with additional activity between RM 59.8 and 60.3 in 1984 and 1985. This subreach was basically stable, although only 60% of the 254,000 cubic yards mined was replaced. Two locations experienced bank losses in 1986: 4-1/2 acres were lost along a 2000-ft down-valley shift of a meander bend near RM 59.0, and 4-1/2 acres were lost along the outside bend of the channel near RM 62.7.

The erosion near RM 62.7 occurred upstream of a site which was mined from 1983 to 1985 with very little replenishment.

Low point profiles for subreach 11 indicate general lowering of the channel throughout the study period (Figs. C.23 through C.25). The spring 1986 low point profile is 0 to 4 ft lower than the fall 1981 low point profile between RM 61.5 and 62.5 (Fig. C.25). All low point profiles are higher than the 1978 thalweg through this subreach.

The cumulative cross-sectional changes are indicated in Figure F.37. Net degradation is noted for both the fall 1981 to fall 1985 and fall 1981 to spring 1986 periods throughout the subreach. Figures D.20 and D.21 illustrate the typical cross-sectional changes that occurred over the study period.

4.4 Sediment Continuity Analysis

Based upon measured sediment data and the principles of sediment transport analysis, an approximate method for computing the amounts of sediment deposition during flood flows was developed. In this section, the term "sediment" refers to the coarse grained material (predominantly sand and gravel) which makes up the bed of the Russian River (see Figure 4.4), and not the silts and clays which may also be carried by the flood waters. Silts and clays are not found in significant quantities in the channel bed of the study reach. These finer materials typically remain suspended within the runoff flow, and are not deposited on the channel bed. The source of the suspended fine material, or "wash load," is from erosion of the contributing watershed, and, possibly, the channel banks.

The sediment deposition analysis approach is based upon the continuity equation, which states that the sediment inflow to a reach minus the sediment outflow equals the amount of deposit. If the outflow is greater than the inflow, then the volume of sediment within the reach is decreased. Sediment inflow occurs from three sources: (1) the Russian River main stem, above Cloverdale, (2) the local tributaries along the Alexander Valley Reach including Sulphur Creek, Crocker Creek, Icaria Creek, Gill Creek, Miller Creek and Sausal Creek, and (3) the local tributaries along the Middle Reach including Dry Creek (downstream from Warm Springs Dam)/Pena Creek/Mill Creek. The model computes the sediment deposition in the Alexander Valley Reach and the Middle Reach. It also computes the amount of sediment that passes through the end of the study area (downstream of Wohler Bridge). Figure 4.3 shows the study area and the locations where sedimentation quantities are computed.

4.4.1 Sediment Transport Relationships

The sediment transport capacity for the Russian River was computed using the Meyer-Peter, Muller bed load equation in conjunction with Einstein's procedure for integration of the suspended bed material load. The channel hydraulics (depth, velocity, etc.) were determined using the computer program HEC-2, "Water Surface Profiles." By using the results of both programs, relationships for sediment discharge as a function of water discharge are obtained. These equations are of the form

$$Q_s = CQ_w^n$$

where Q_s is the sediment discharge in tons per day, C and n are empirical constants and Q_w is the water discharge in cfs.

Referring to Figure 4.3 the sediment inflow to the Alexander Valley Reach, Q_{s4}, was computed using measured sediment loading data to calibrate the sediment transport equation. Q_{s3} is the transport capacity of the river at the downstream end of the Alexander Valley. Q_{s6} is the sediment contribution of local tributaries along the Alexander Valley Reach, estimated based on the ratio of the drainage area to be approximately one-eighth of Q_{s4}. The deposition in the Alexander Valley Reach, Q_{D2}, is the difference between the inflow and outflow, or:

$$Q_{D2} = Q_{s4} + Q_{s6} - Q_{s3}$$

The river between the Alexander Valley Reach and the Middle Reach is, for the most part, a confined channel where the transport capacity is high. Computations indicate that the sediment transport capacity of this confined channel is greater than the amount supplied to it from the Alexander Valley Reach. However, as minimal additional supply is available within this reach, it is judged that the amount of sediment transported through this

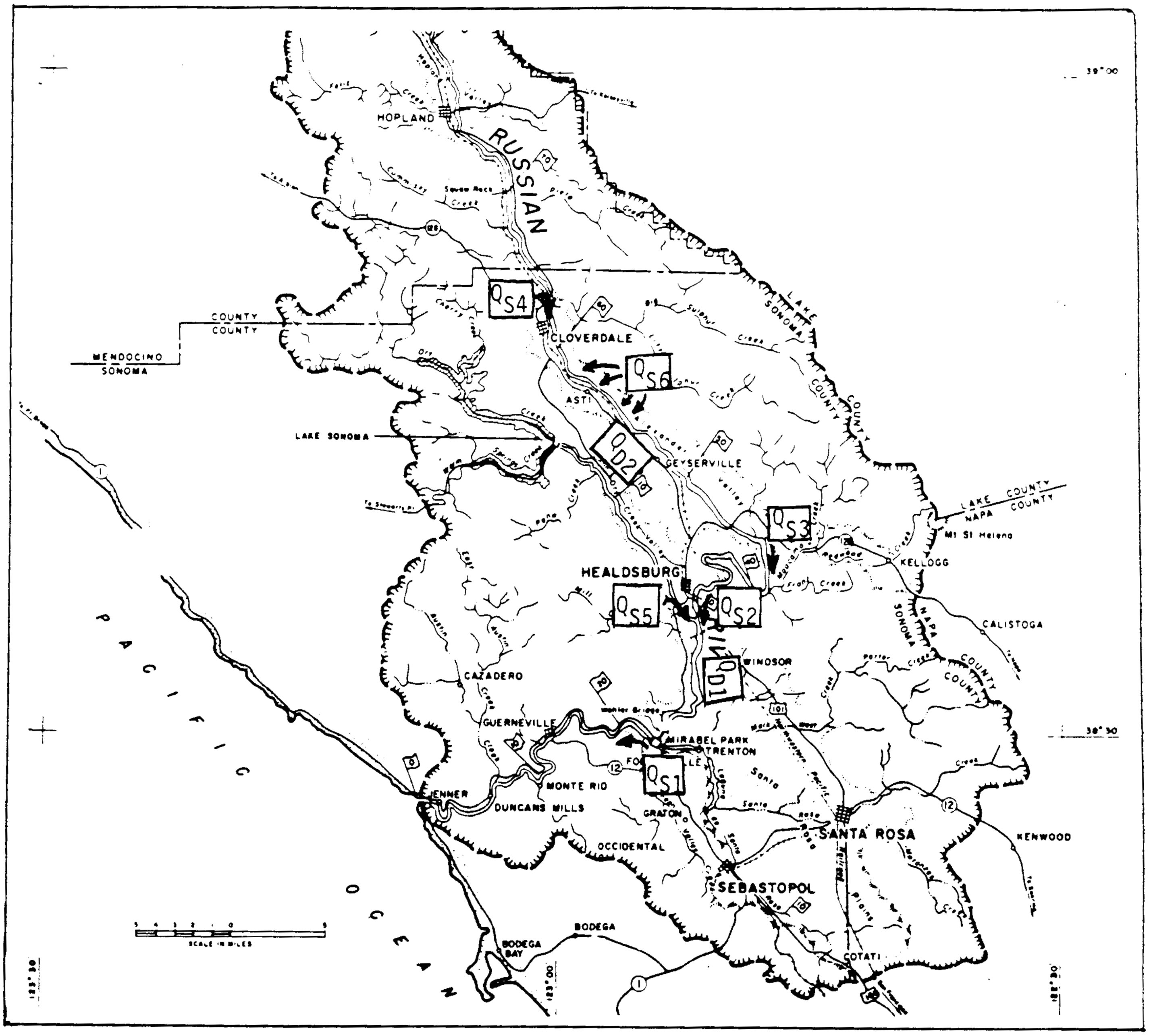


Figure 4.3   Diagram of Sediment Routing Locations

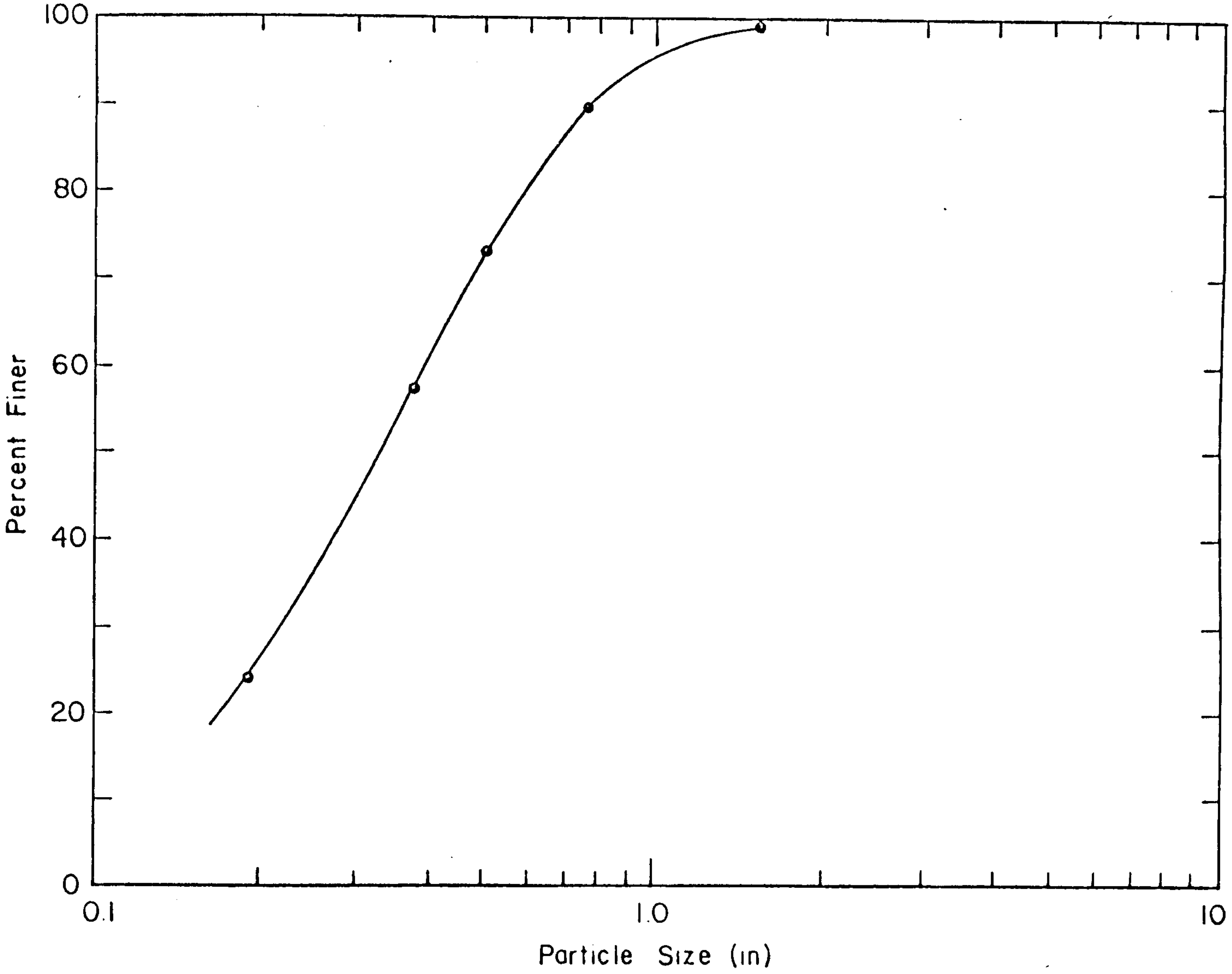


Figure 4.4 Russian River Bed Material Gradation

reach (and into the Middle Reach) is limited to the amount supplied from the Alexander Valley Reach. Thus Q_{s2} is equal to Q_{s3}.

The sediment contribution from Dry Creek, Q_{s5}, has decreased since the construction of Warm Springs Dam. The dam alters the hydrology of the stream, which, in turn, affects the sediment transport capacity. Mill Creek and Pena Creek, however, are downstream from the dam and still contribute sediment. Figure 4.5 shows the discharge frequency curve for Dry Creek before and after the dam was built. Figure 4.6 shows the discharge frequency curve for the Russian River at Healdsburg. For a given return period flood the discharge in Dry Creek is approximately 15% of the Russian River discharge with Warm Springs Dam in place. The sediment contribution from Dry Creek (Q_{s5}) was calculated using hydrology which followed this 15% ratio.

The final quantity in Figure 4.3 is Q_{s1}, the outflow from the Middle Reach. This outflow was computed using the combined water discharge of Dry Creek and the Russian River.

The amount of material deposited in the Middle Reach, Q_{D1}, is equal the supply from both the Alexander Valley Reach and Dry Creek, minus the outflow from this reach, or:

$$Q_{D1} = Q_{s2} + Q_{s5} - Q_{s1}$$

The values of the constants for the equations used to compute Q_{s1} to Q_{s6} are shown in Table 4.6.

This sediment continuity model was programmed into a LOTUS spreadsheet and was used to assess the approximate volumes of sand and gravel deposits for given hydrologic events.

4.4.2 Sediment Deposits for the Study Period 1981 to 1986

Using the procedure described above, the approximate amounts of sand and gravel deposits were determined for each of the five rainfall seasons in the study period. Since the hydrology monitoring program was started in 1981, two major floods have occurred. The first was in March, 1983 and the second was in February 1986. The 1983 event had an unusually long duration while the 1986 event had a high peak discharge. The presence of two large events in such a short period of record keeping increases the usefulness of

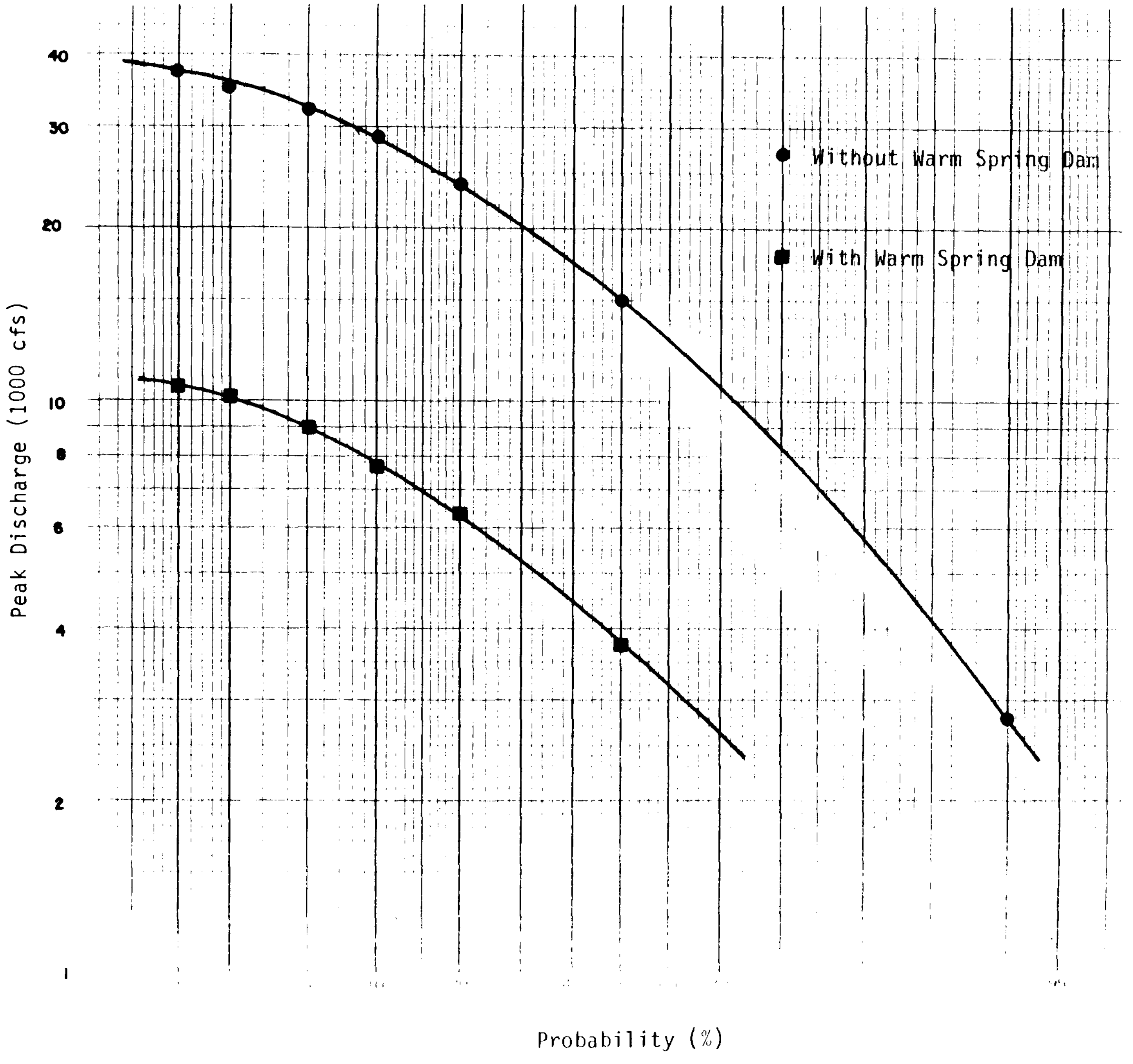


Figure 4.5 Dry Creek Flood-Frequency Curves

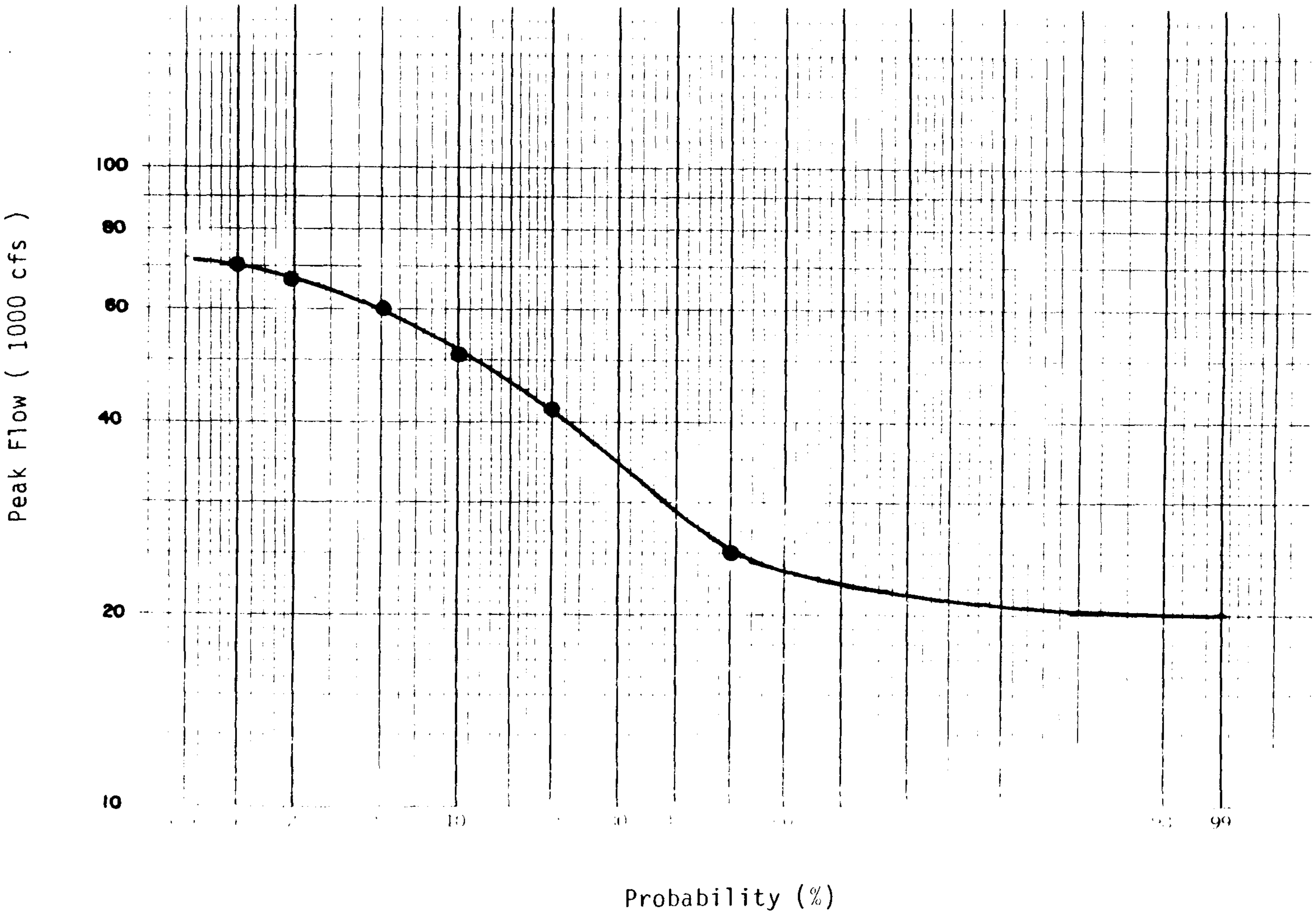


Figure 4.6 Russian River Near Healdsburg Flood-Frequency Curve

Table 4.6 Values of Constants Used in Sediment Routing Equations

Transport Capacity $Q_s = cQ^n$

Downstream End of Middle Reach:	$c_1 = 0.008204$	$n_1 = 1.50$
Upstream End of Middle Reach:	$c_2 = 0.001425$	$n_2 = 1.80$ **
Downstrem End of Alexander Valley Reach:	$c_3 = 0.003874$	$n_3 = 1.65$
Upstream End of Alexander Valley Reach:	$c_4 = 0.002469$	$n_4 = 1.80$
Downstream End of Dry Creek:	$c_5 = 0.011400$	$n_5 = 1.80$
Tributaries to Alexander Valley Reach:	$c_6 = 0.000321$	$n_2 = 1.80$

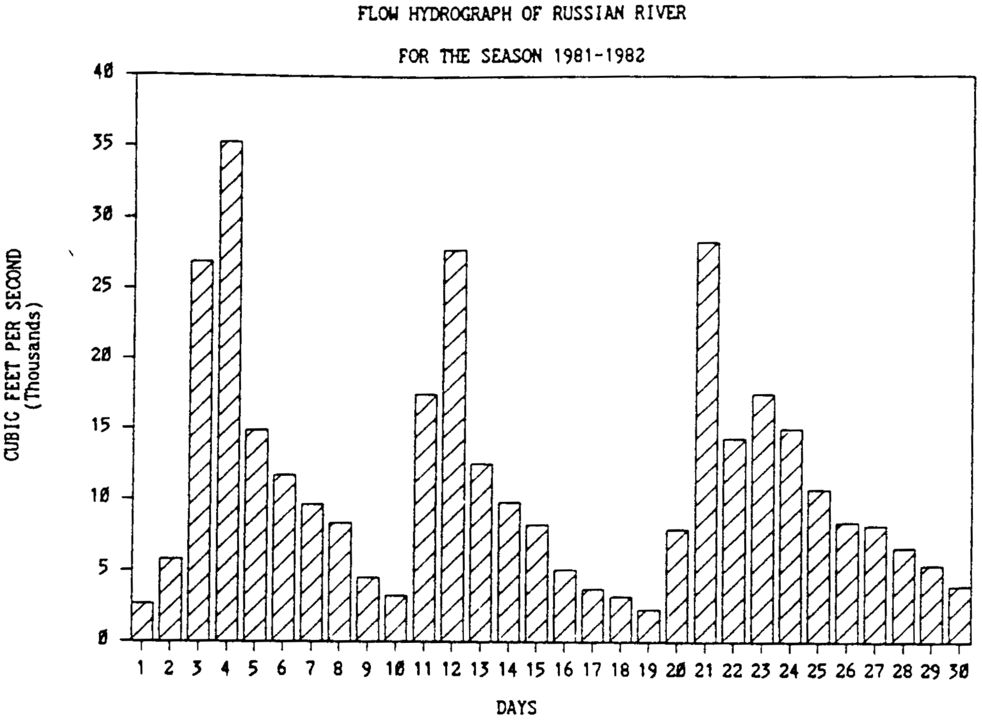
** Transport capacity only: actual transport controlled by upstream supply the monitoring program data dramatically. The hydrographs for the Russian River at Healdsburg are shown in Figures 4.7 to 4.11.

Table 4.7 and Figures 4.12 and 4.13 show the results of the sediment routing analysis. It is estimated that a total of approximately 2,668,000 tons were deposited in the Middle Reach and 5,885,000 tons were deposited in the Alexander Valley Reach during the 5 year study period. Also shown in Table 4.7 are the reported amounts of material mined from the river. The reported amounts mined are less than the estimated sediment deposits for both reaches. This is to be expected since the study period experienced above normal rainfall for most of the years.

Figures 4.14 and 4.15 summarize additional results of the sediment transport analysis: the relative significance of each source of sediment to the study reaches, and the distribution and percentage of the deposits. Approximately 80% of the material was computed to have been supplied by the Russian River main stem; with 10% supplied by the Alexander Valley tributaries; and 10% supplied by Dry Creek. Of this supply, approximately 55% deposited in the Alexander Valley Reach; 25% in the Middle Reach and 20% left the study area.

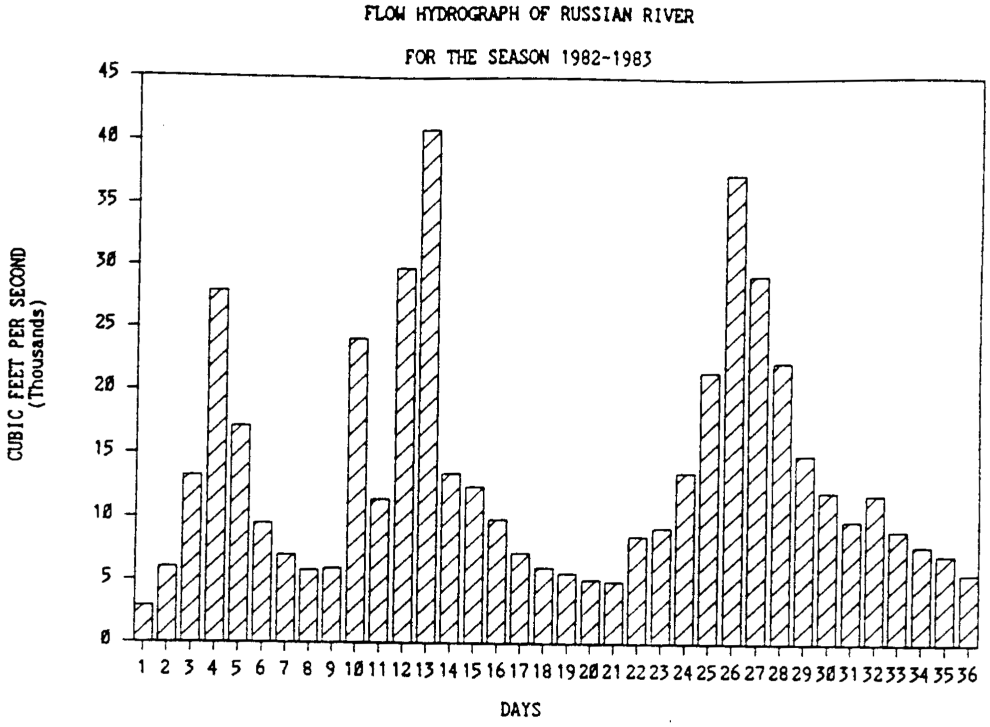
4.4.3 Average Annual Sediment Deposits

Representative discharge hydrographs for the 100-, 50-, 20-, 10-, 5- and 2-year floods for the Russian River at Healdsburg are shown in Figure 4.16. The sediment deposits for these hydrographs were computed using the method described in this section. The results are shown in Table 4.8. The sediment deposit was plotted against the probability of its associated flood, and the graph in Figure 4.17 was obtained. The area under the curve is the statistical average annual deposit. This was computed to be 682,000 tons per year for the Alexander Valley Reach and 284,000 tons per year for the Middle Reach. These amounts are somewhat less than the average annual deposits for the study period which were 533,600 tons per year for the Middle Reach and 1,177,000 tons per year for the Alexander Valley Reach. The reason is that the study period experienced above average rainfall. It is interesting to note that the average annual mining amount for the study period was 297,000 tons per year for the Middle Reach and 735,600 tons per year for the Alexander Valley Reach. These values are very close to the



NOTE: THIS HYDROGRAPH OR FLOW HISTORY IS SHOWN IN BAR GRAPH FORM
EACH BAR REPRESENTS 1 DAY OF FLOW AT THE AVERAGE RATE INDICATED
THE CHART INCLUDES ALL THE SIGNIFICANT FLOW DAYS DURING THE SEASON IDENTIFIED
THE FLOW DAYS SHOWN DID NOT NECESSARILY OCCUR IN SUCCESSION WITHOUT INTERRUPTION

Figure 4.7 Flow Hydrograph of Russian River for the Season 1981-1982



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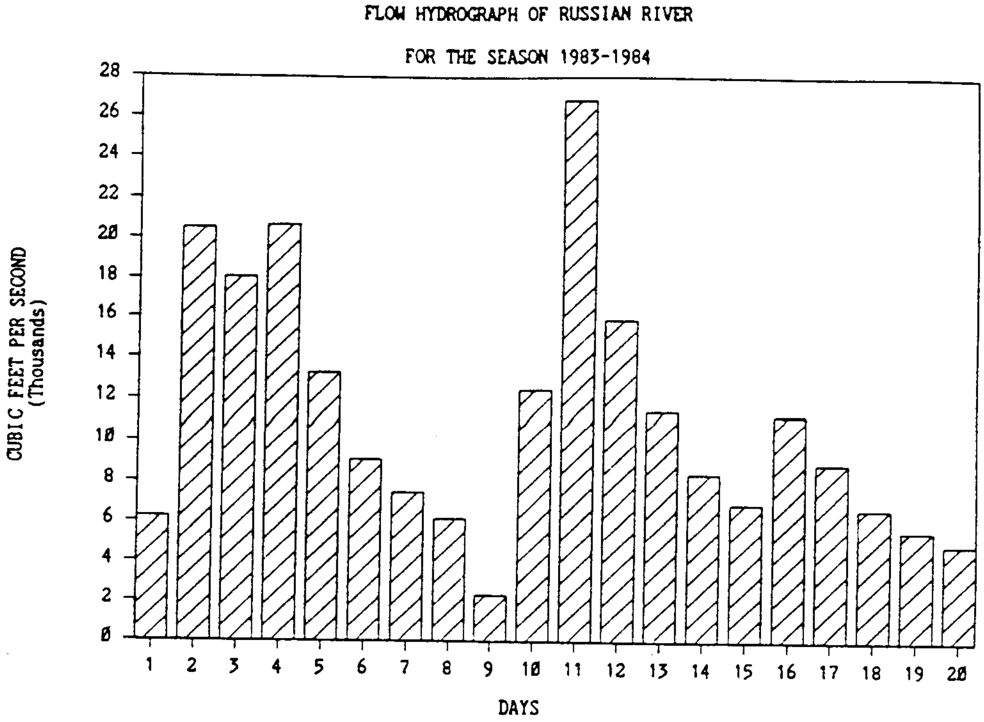
THE CHART INCLUDES ALL THE SIGNIFICANT FLOW DAYS DURING THE SEASON IDENTIFIED
THE FLOW DAYS SHOWN DID NOT NECESSARILY OCCUR IN SUCCESSION WITHOUT INTERRUPTION

Figure 4.8 Flow Hydrograph of Russian River for the Season 1982-1983



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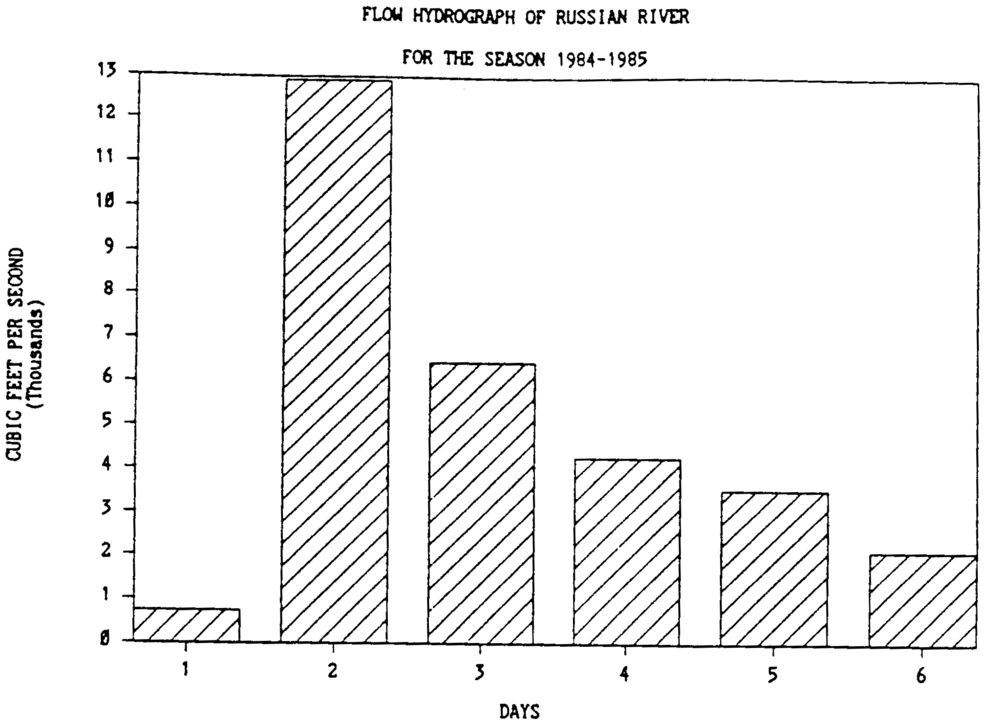
THE CHART INCLUDES ALL THE SIGNIFICANT FLOW DAYS DURING THE SEASON IDENTIFIED
THE FLOW DAYS SHOWN DID NOT NECESSARILY OCCUR IN SUCCESSION WITHOUT INTERRUPTION

Figure 4.9 Flow Hydrograph of Russian River for the Season 1983-1984



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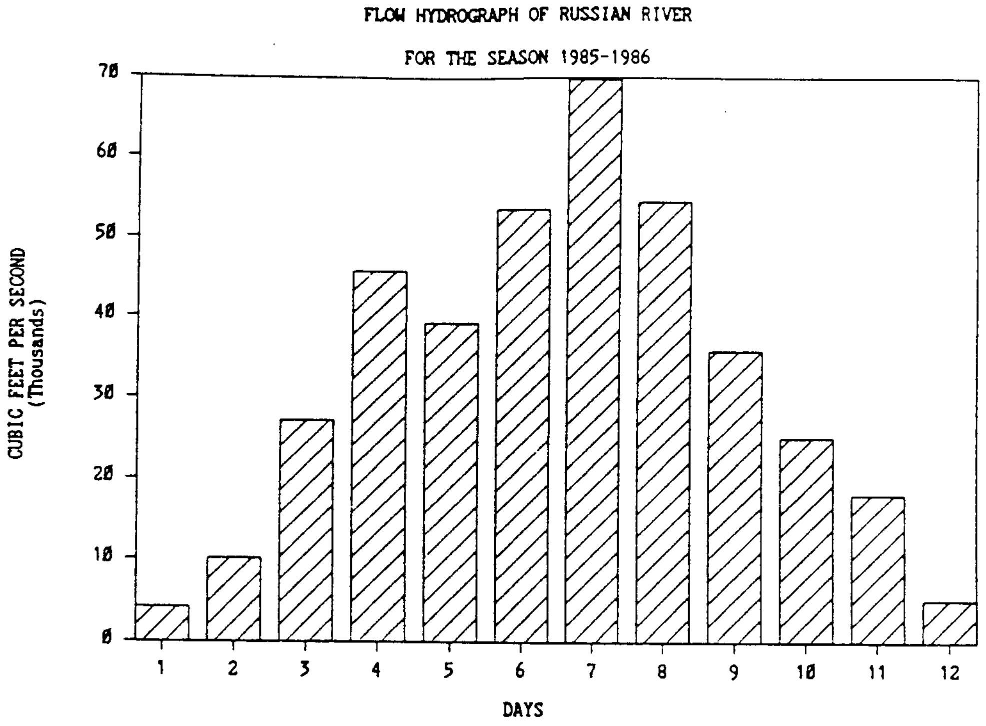
THE CHART INCLUDES ALL THE SIGNIFICANT FLOW DAYS DURING THE SEASON IDENTIFIED
THE FLOW DAYS SHOWN DID NOT NECESSARILY OCCUR IN SUCCESSION WITHOUT INTERRUPTION

Figure 4.10 Flow Hydrograph of Russian River for the Season 1984-1985



NOTE: THIS HYDROGRAPH OR FLOW HISTORY IS SHOWN IN BAR GRAPH FORM
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THE CHART INCLUDES ALL THE SIGNIFICANT FLOW DAYS DURING THE SEASON IDENTIFIED
THE FLOW DAYS SHOWN DID NOT NECESSARILY OCCUR IN SUCCESSION WITHOUT INTERRUPTION

Figure 4.11 Flow Hydrograph of Russian River for the Season 1985-1986

Table 4.7 Results of Sediment Routing Analysis

Flood Year	Middle Reach Computed Deposit (Tons)	Middle Reach Reported Mining (Tons)	Alexander Valley Computed Deposit (Tons)	Alexander Valley Reported Mining (Tons)
81-82	491,000	455,000	1,161,000	409,000
82-83	741,000	318,000	1,609,000	494,000
83-84	298,000	98,000	737,000	968,000
84-85	27,000	379,000	69,000	864,000
85-86	1,111,000	235,000	2,309,000	943,000
Total	2,668,000	1,485,000	5,885,000	3,678,000
Average	533,600	297,000	1,177,000	735,600

NOTE: MINING AMOUNTS ARE FOR THE SEASON FOLLOWING THE SPECIFIED HYDROLOGIC EVENT

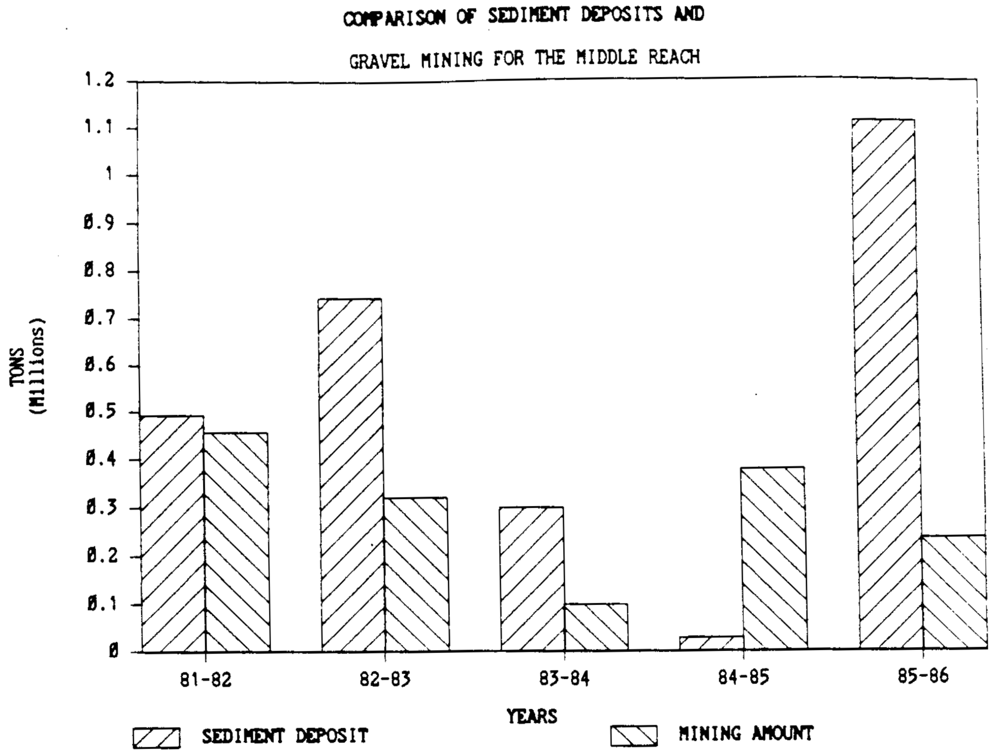


Figure 4.12 Comparison of Sediment Deposits and Gravel Mining for the Middle Reach

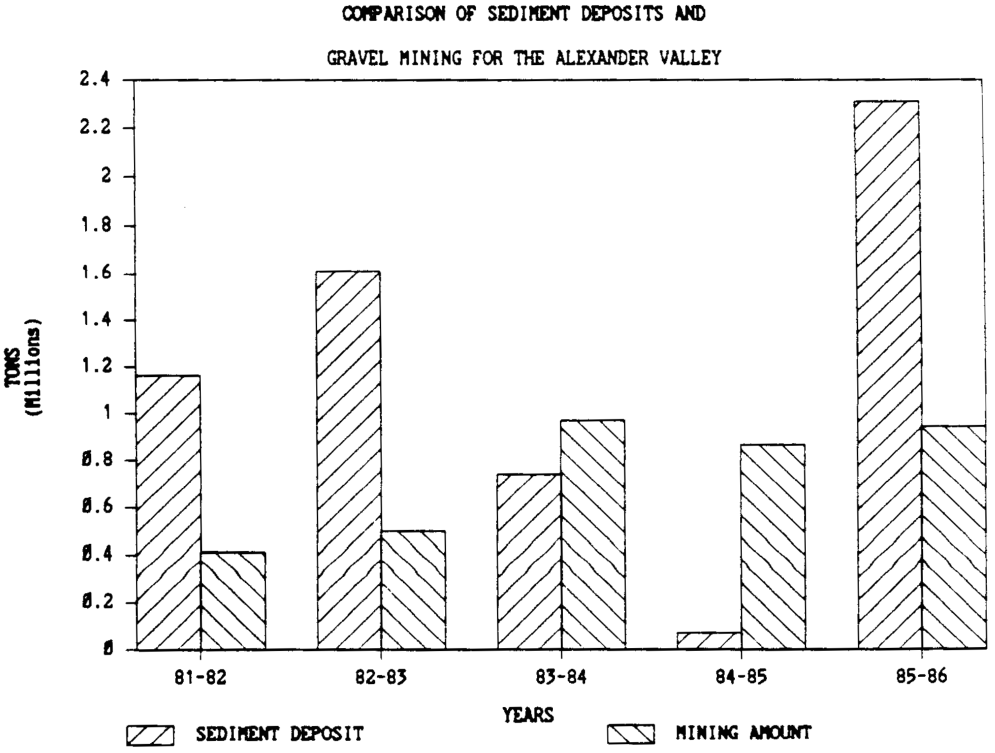


Figure 4.13 Comparison of Sediment Deposits and Gravel Mining for the Alexander Valley

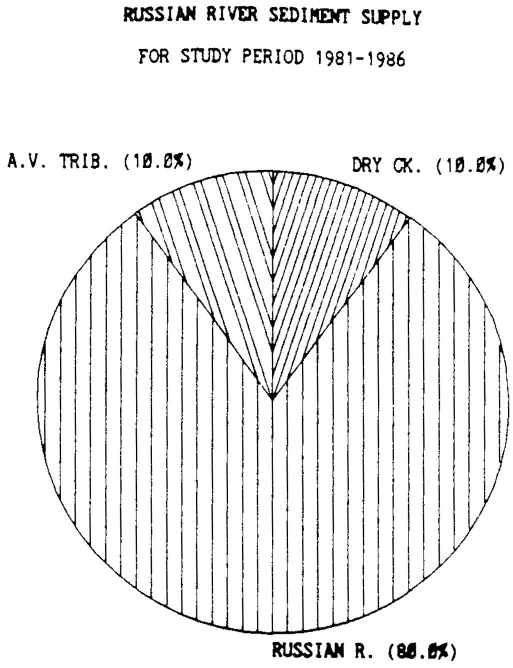


Figure 4.14 Russian River Sediment Supply for 1981-1986

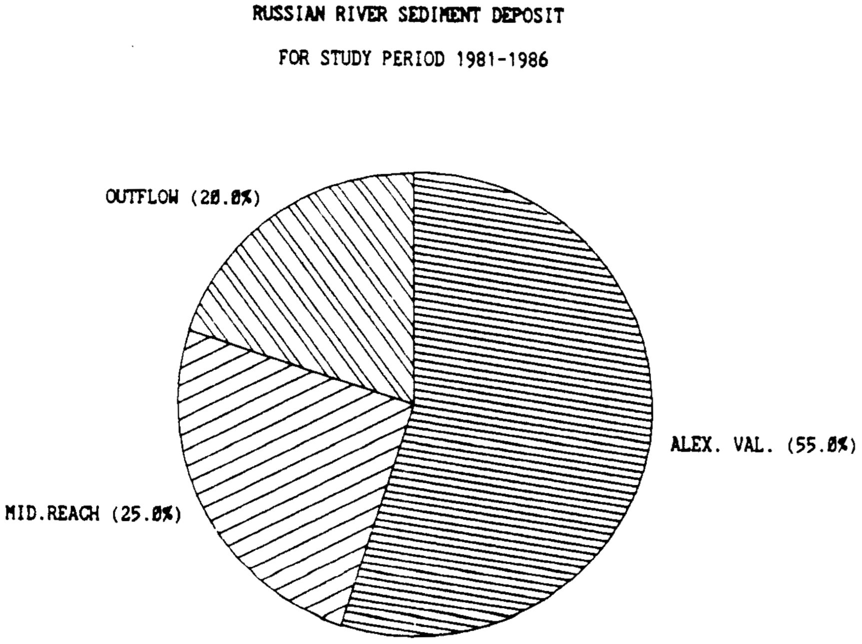


Figure 4.15 Russian River Sediment Deposits for 1981-1986

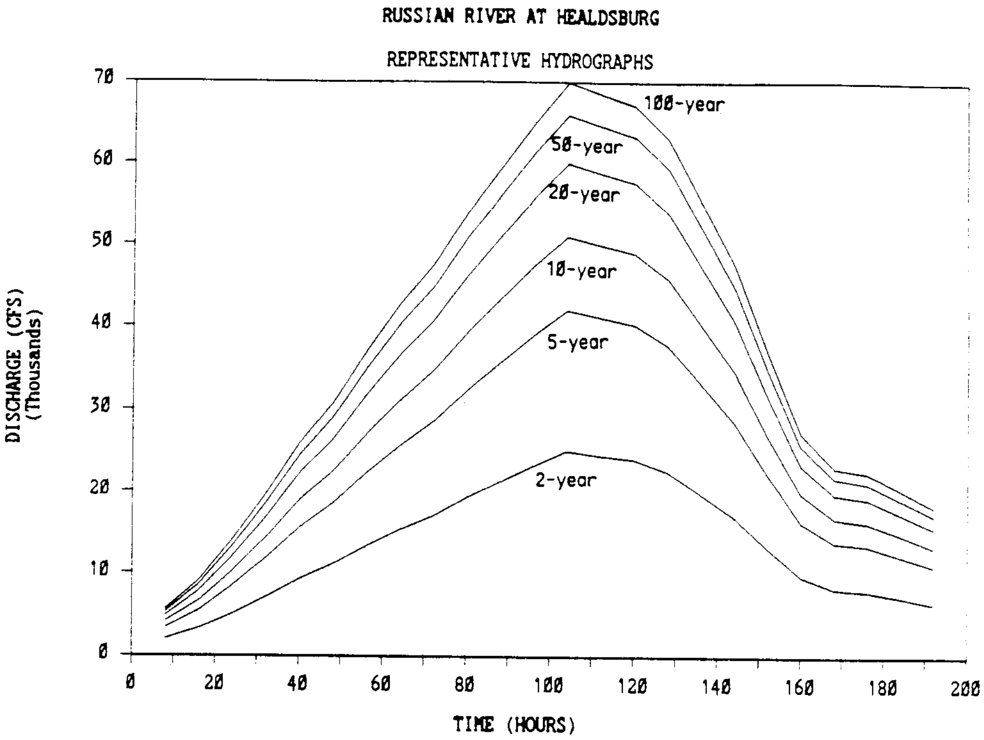


Figure 4.16 Russian River at Healdsburg Representative Hydrographs

Table 4.8 Sediment Deposits for Various Frequency Floods

Return Period (years)	Sediment Deposits Alexander Valley (tons)	Middle Reach (tons)
100	2,067,000	970,000
50	1,969,000	906,000
20	1,729,000	764,000
10	1,402,000	591,000
5	1,065,000	434,000
2	465,000	182,000
Average Annual	682,000	284,000

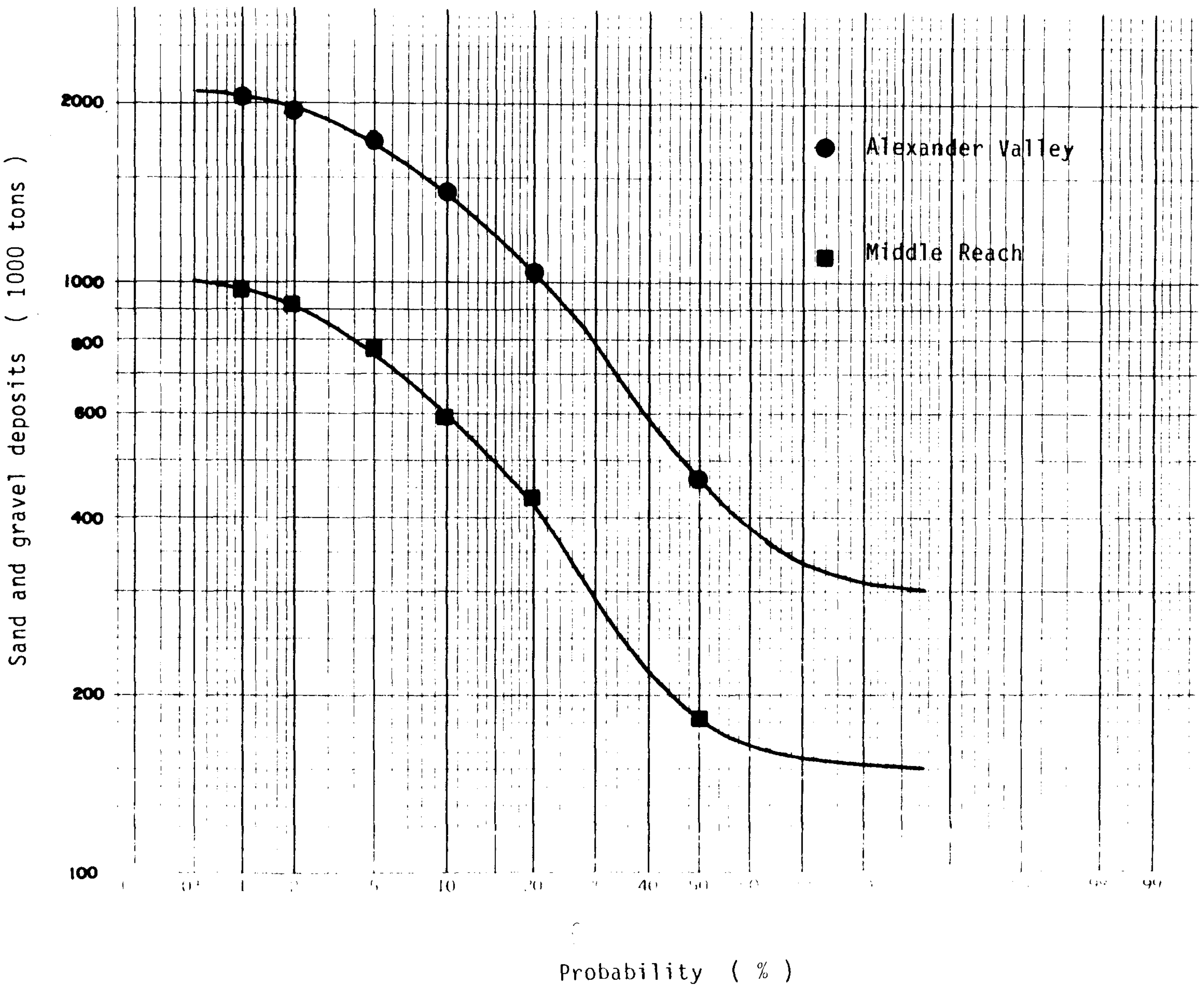


Figure 4.17 Sand and Gravel Deposits vs. Probability

estimated long term average annual deposits (284,000 tons/year and 682,000 tons/year).

4.5 River Response to Mining Activity

4.5.1 Introduction

The potential changes in a river and its alignment include degradation, aggradation and lateral migration. Degradation means vertical downcutting of the river bed, while aggradation is the vertical rising of the river bed due to sediment deposition. Lateral migration is the occurrence of bank line shifting resulting from the natural tendency of a river to meander and also from bank erosion. Bank failure occurs when there is excessive degradation. Therefore degradation in a river can also cause it to migrate.

Instream mining can bring both negative and positive impacts on the Russian River. Excessive mining can cause the river bed to degrade, increasing the potential for bank failure. Bank failure produces added sediment loads into the channel and the bank line is shifted. On the other hand, the meandering of a river can be induced by gravel bar formations that force the flow laterally into the banks, creating large meander loops. Due to the scour that occurs along the outside bends of these meanders, and aggradation which occurs along the inside bends, the meanders will typically translate downstream over time. Because of the unstable nature of a relatively steep meandering channel, there is the potential for more loss of land area due to natural meandering than that due to bank failure.

If the gravel bars are not removed, the flow can be diverted towards banks, resulting in excessive bank loss and the promotion of meander loops. Excessive removal of the gravel may cause the river to become more channelized and prevent the flow being diverted to the banks. However, bank failure may occur if the toe is eroded away. Controlled mining of gravel bars can contribute to increasing channel stability in some cases. Figure 4.18 illustrates the two types of river behavior discussed above.

4.5.2 Types of River Response During the Study Period

This section discusses the river responses other than the general lowering of the cross-section elevation which occur during mining. The most apparent aspect of river behavior is bank movement which leads to land loss.

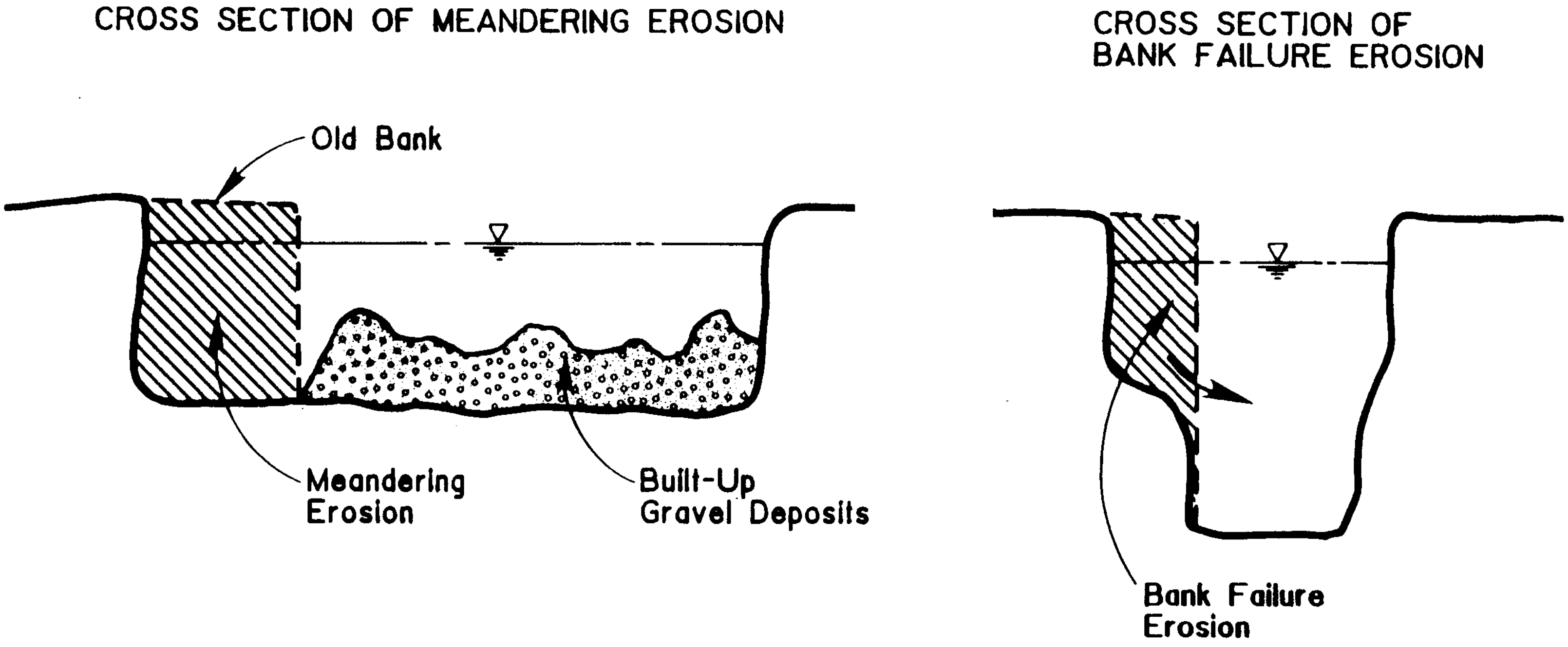


Figure 4.18 River Meandering vs. Bank Failure

This occurred many times in the Alexander Valley Reach. There was only one instance of bank erosion in the Middle Reach and it occurred several miles from the nearest mining operation, so this section will be devoted mainly to the Alexander Valley.

4.5.3 Effect of Mining Upon Bank Erosion in the Alexander Valley Reach

By examining the 10 sets of aerial photos which cover the study period, two areas in the Alexander Valley were found to contain most of the bank erosion: River miles 47 to 50 (contained in subreaches 5 and 6) and river miles 53 to 56 (contained in subreaches 8 and 9). These two areas correspond approximately with the widest parts of the Alexander Valley reach. Figure 4.19 shows a plot of the channel width vs. distance for the Alexander Valley reach. The darker line on this plot is the representative average channel width computed by averaging the channel width at a point with the channel widths at two points on either side. This is called the 5 point average channel width. The shaded areas represent the locations of bank erosion sites during the study period 1981 to 1986. The black dots are the locations where gravel mining occurred at least 3 out of the 5 years in the study period; in other words, mining operations that are relatively continuous. Of the 12 continuous sites identified, 4 of these sites were within miles 47 to 50 and 1 of the sites was in miles 53 to 56. The mining site near mile 59 experienced bank erosion in 1986. The other six continuous mining sites did not appear to be near major erosion sites.

To further explore this topic, the bank erosion which occurred as a result of the 1982 through 1986 floods was plotted on separate graphs. Sites where mining occurred in the summer before each respective flood were also identified on each graph. The results are in Figures 4.20 to 4.24 for the 1982, 1983, 1984, 1985 and 1986 floods, respectively. The approximate area of each erosion event is shown next to the symbol which indicates its location and the bank upon which it occurred.

Some qualitative analyses was performed to establish a relationship between gravel mining and bank erosion. First, the number of mining sites which were within one-half mile upstream or downstream of an erosion site was identified. This conservative one-half mile range of influence was selected as follows: (1) the maximum wavelength of the meandering channel within the study reach is approximately 1 mile (5000 ft in subreach 11); (2)

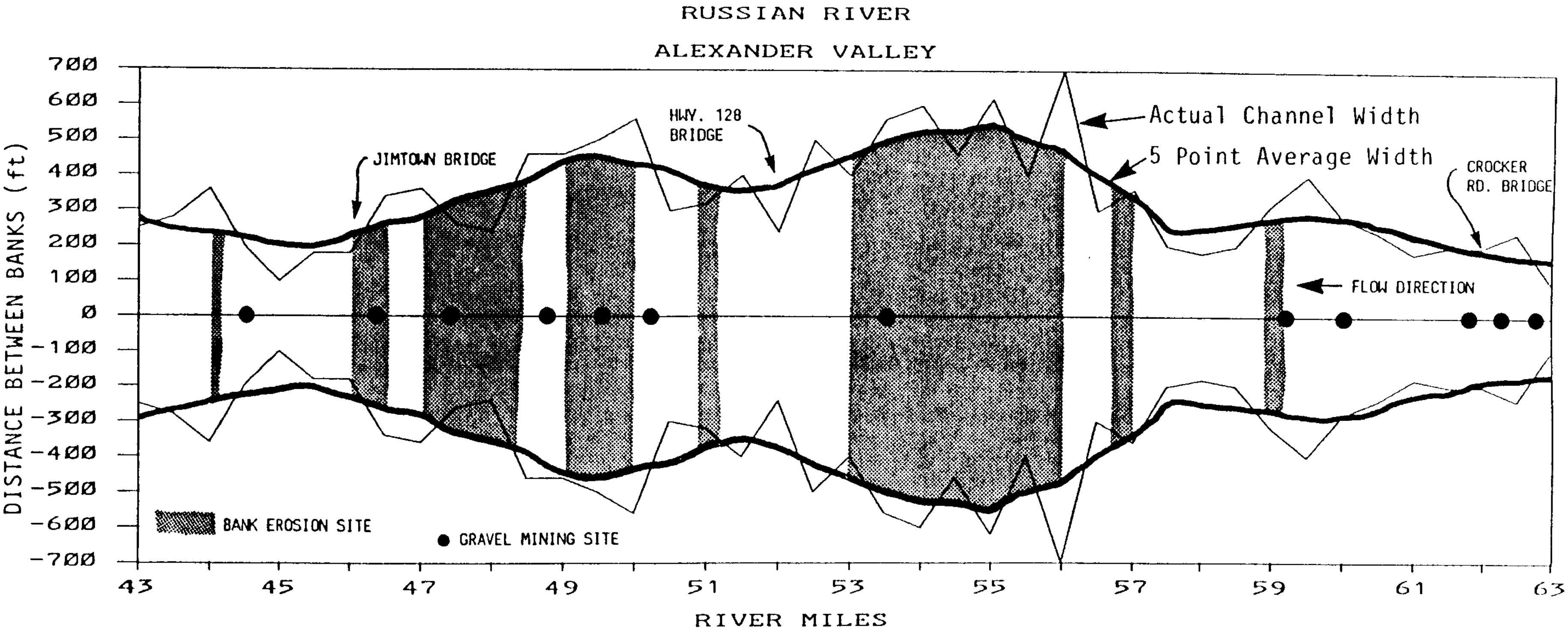


Figure 4.19 Areas of Bank Erosion and Gravel Mining for the Study Period

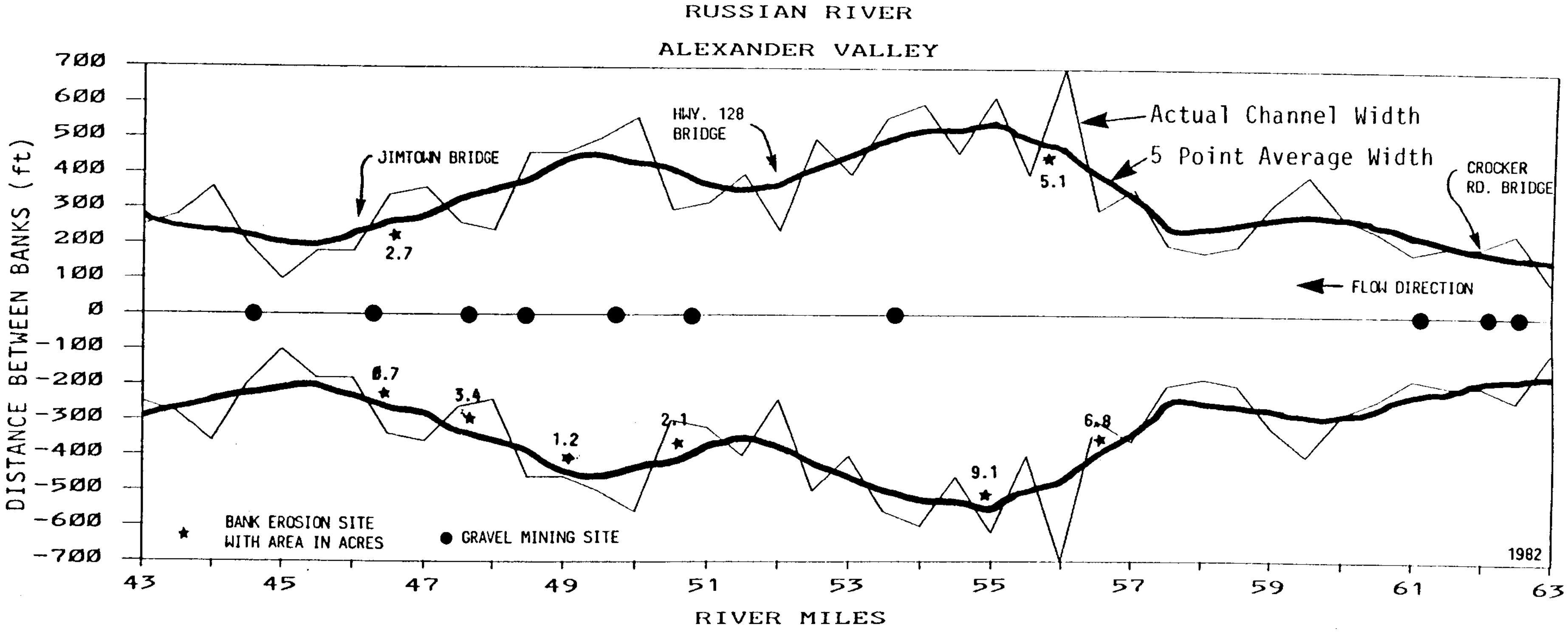


Figure 4.20 Areas of Bank Erosion and Gravel Mining for the 1982 Flood

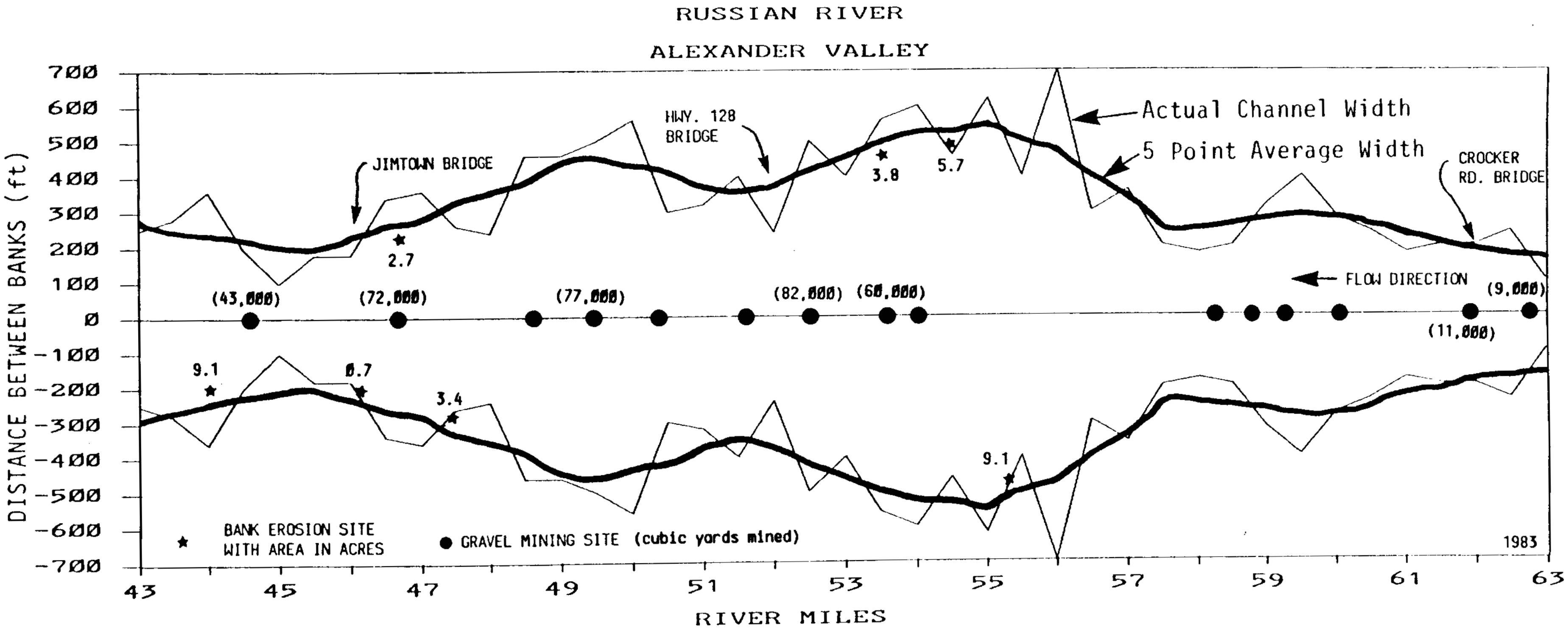


Figure 4.21 Areas of Bank Erosion and Gravel Mining for the 1983 Flood

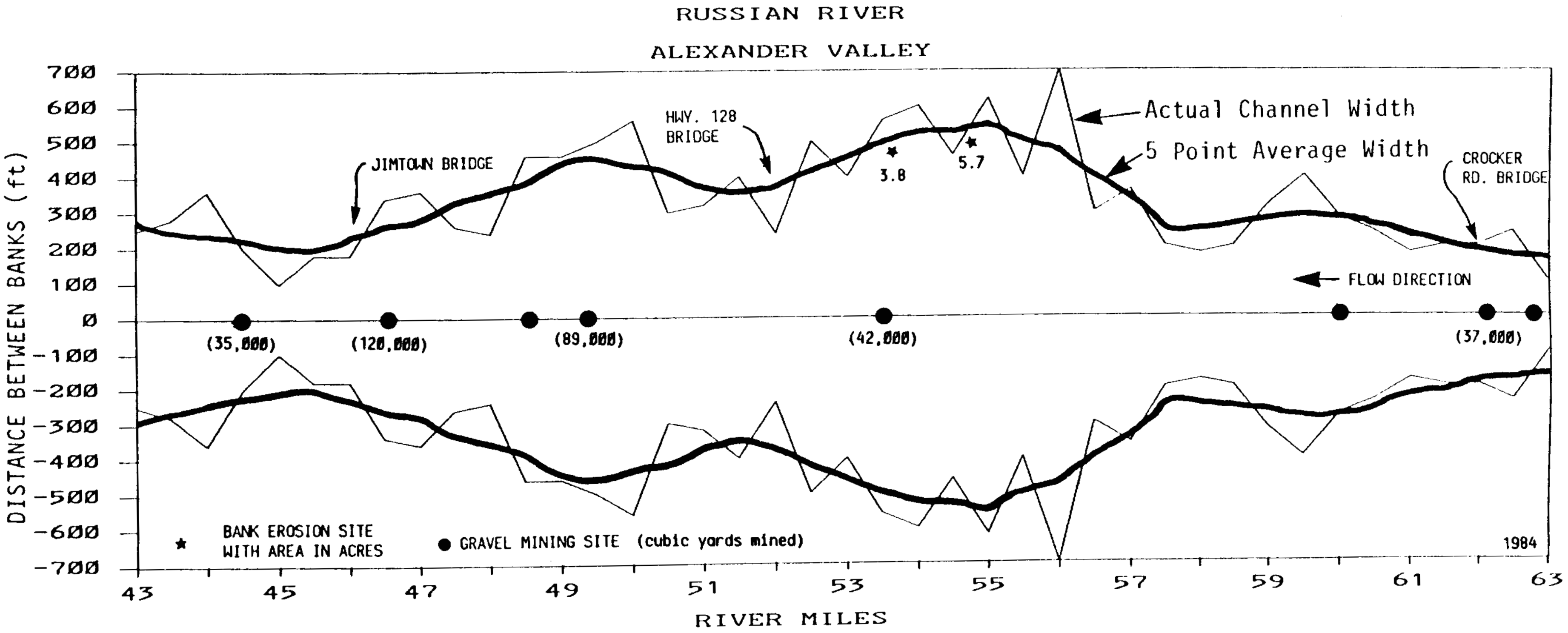


Figure 4.22 Areas of Bank Erosion and Gravel Mining for the 1984 Flood

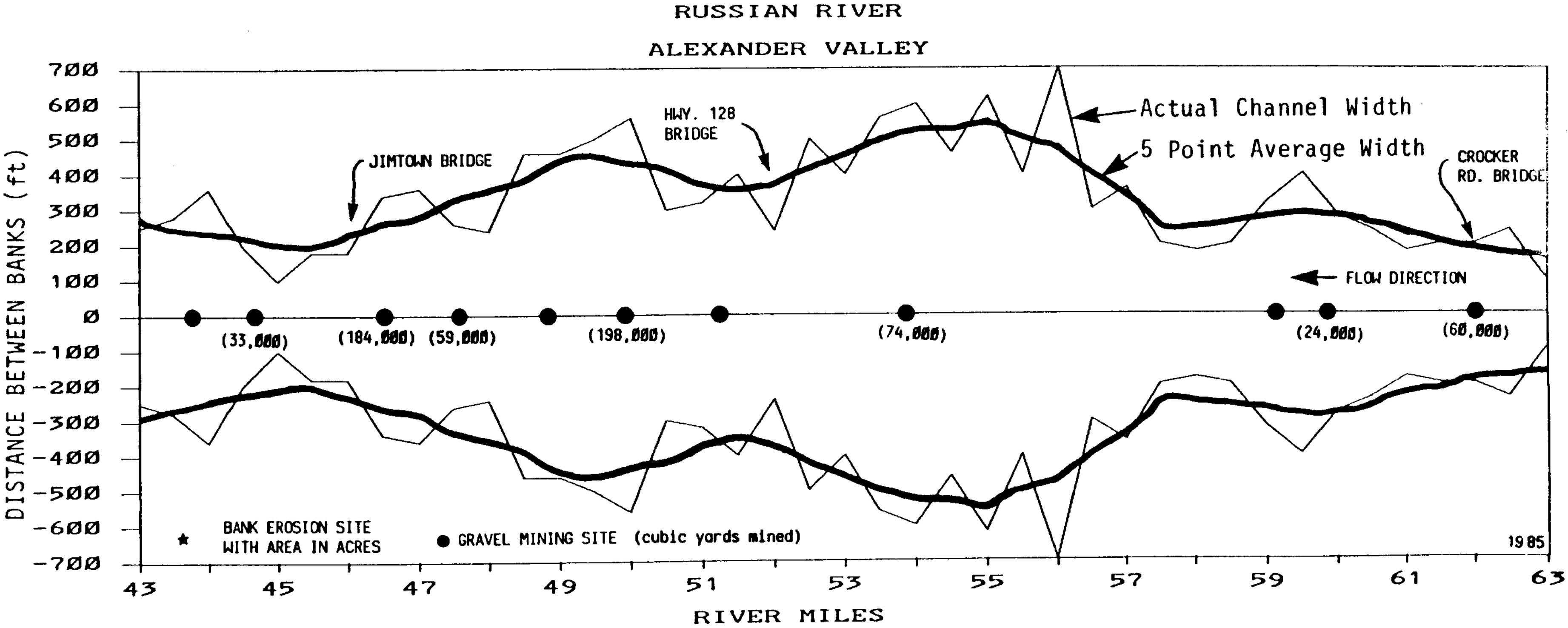


Figure 4.23 Areas of Bank Erosion and Gravel Mining for the 1985 Flood

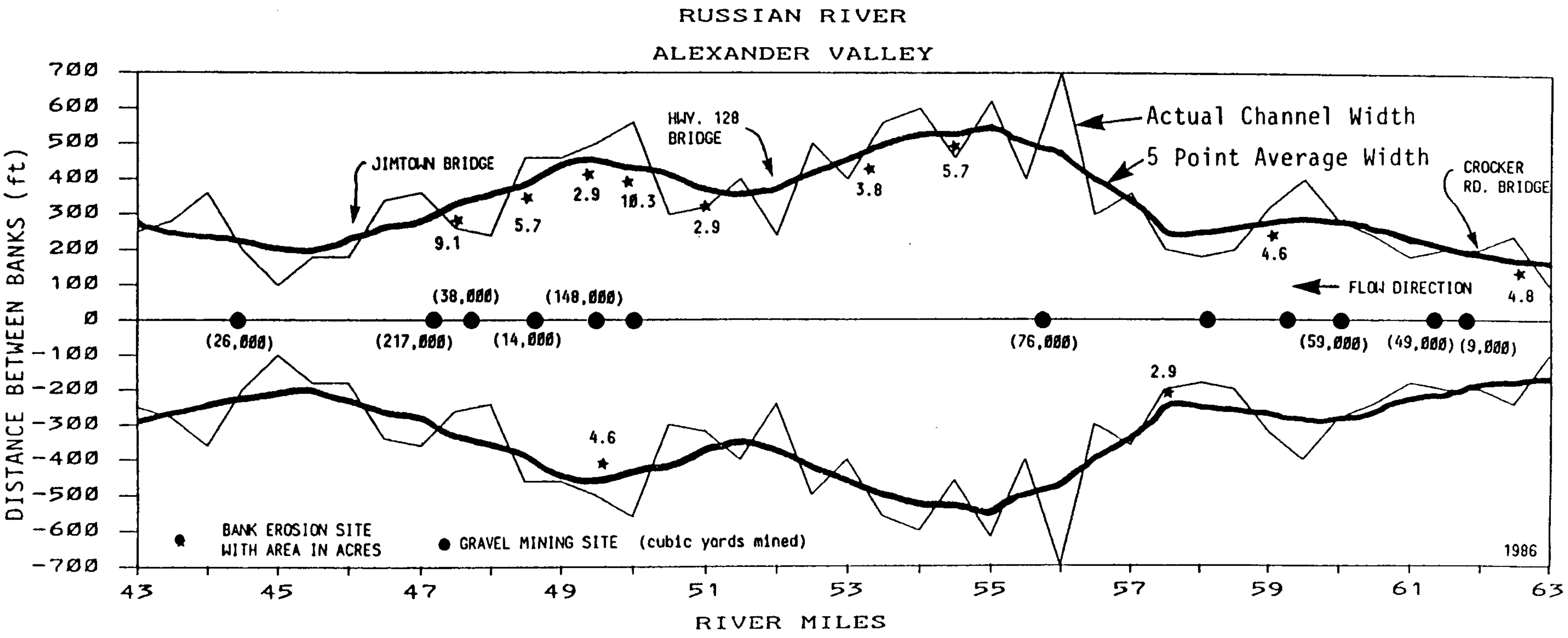


Figure 4.24 Areas of Bank Erosion and Gravel Mining for the 1986 Flood

over the course of one wavelength, the channel alternates through zones of deposition and erosion (two cycles), with the interface between these zones acting as a local pivot point for channel adjustment; (3) one-half mile of the river will cover at least one-half of the maximum wavelength observed along the study reach, and, therefore, will contain at least one interface between erosion and deposition.

If bank erosion occurred more than one-half mile away from a mining site, it is not likely to be a direct result of that mining activity. The erosion sites within a half mile of mining activity may or may not be related to the mining.

For the study period, 53 mining instances were identified. Fifteen of the sites were within a half mile of an erosion site and 38 of the sites were more than a half mile from an erosion site. The conclusion is that most instances of bank erosion in the Alexander Valley Reach are not related directly to gravel mining impacts. These results are summarized in Table 4.9.

A second approach was also taken. The number of erosion sites for each flood were identified and the area for each was measured. The total area of land lost to bank erosion within a half mile of a mining site was determined. These results are also summarized in Table 4.9. Of the total 132 acres of land lost in the Alexander Valley Reach during the major floods of the study period, 72 acres were within a half mile of a mining site and 60 acres were more than a half mile away from a mining site. The conclusion from this is that most of the land lost to bank erosion was with one-half mile of a mining site. This conclusion must be kept in context, however. Gravel mining is typically located in areas of aggradation, which are areas where the river tends to be less defined and shifting. As indicated in Figure 4.19, bank erosion was prevalent in areas where the river is wide -- where the river has historically altered its course from time to time. Since 60 acres of land loss occurred away from mining sites, it is possible that some or even all of the 72 acres would have been lost even if there was no gravel mining.

Table 4.9 Results of Bank Erosion and Gravel Mining Qualitative Analysis

YEAR OF FLOOD	NUMBER OF MINING SITES THE SUMMER PRIOR TO THE FLOOD	NUMBER OF MINING SITES WITHIN A HALF MILE OF AN EROSION SITE	NUMBER OF MINING SITES MORE THAN A HALF MILE AWAY FROM AN EROSION SITE	NUMBER OF EROSION SITES	TOTAL LAND LOST TO BANK EROSION (ACRES)	AMOUNT OF BANK EROSION WITHIN A HALF MILE OF A MINING SITE	AMOUNT OF BANK EROSION MORE THAN A HALF MILE FROM A MINING SITE
1981-82	10	4	6	8	31.1	10.1	21
1982-83	15	4	11	6	34.5	21.3	13.2
1983-84	8	1	7	2	9.5	3.8	5.7
1984-85	8	0	8	none	none	none	none
1985-86	12	6	6	11	57.3	37.2	20.1
TOTALS	53	15	38	27	132.4	72.4	60

NOTE: YEAR OF FLOOD MEANS THE WATER YEAR IN WHICH THE FLOOD OCCURRED. THE MINING DATA CORRESPONDS TO THE SPRING AND SUMMER BEFORE THE FLOOD. FOR EXAMPLE, THE 1982-83 FLOOD IS RELATED TO MINING DATA FOR THE SPRING AND SUMMER OF 1982.

4.5.4 Non-mining Factors Which Affect River Behavior

The type of gravel mining which occurs in the Alexander Valley Reach is mainly the skimming of gravel bars to a controlled depth which is above the low flow water surface elevation. As mentioned earlier. this activity can actually decrease the amount of river meandering by eliminating built up deposits that may deflect the flow into the bank.

The slopes of the Alexander Valley Reach and the Middle Reach are plotted in Figures 4.25 and 4.26. The average slopes are approximately 0.0015 and 0.0008 for the Alexander Valley Reach and Middle Reach, respectively. According to the work of Lane (1957) there is a relationship between a river's general characteristics and the product of its slope and average discharge. Figure 4.27 shows a plot of slope vs. mean discharge for various rivers. Note that under flood conditions, both Dry Creek and the Alexander Valley Reach of the Russian River are in the braided stream region and that the Middle Reach is in the stable, intermediate stream region. This means that the natural state of the Alexander Valley reach is to be somewhat unstable and occasionally shift its main channel location. The Middle Reach was very stable during the study period.

One of the factors that contributes to the instability of the Alexander Valley Reach is instream activities that deflect the flow path during a flood. This can be the construction of temporary crossings in the channel, the presence of low flow diversion dikes or the construction of bank protection that diverts the flow into the opposite bank thus contributing to further erosion. Such factors are not always visible on aerial photos, but an example is shown in Figure 4.28. After erosion occurred near index 49B, bank protection was built to prevent further land loss. The protected bank diverts the flow in the transverse direction and into the bank on the opposite side of the stream. This area is likely to experience erosion during future events; even though there is a mining site nearby, the primary cause of the erosion will probably be the flow deflection from the protected river bank.

4.6 Summary and Conclusions

Through examination of the results of the survey data analysis, the sediment routing analysis and the bank erosion analysis, the conclusions presented in the following paragraphs were developed.

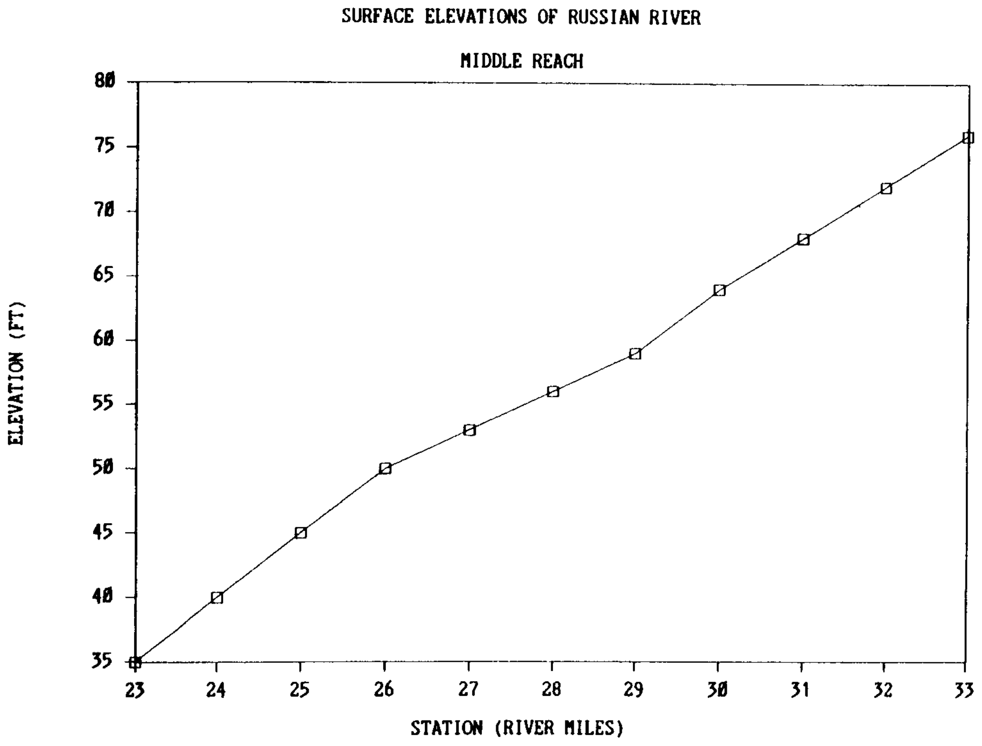


Figure 4.25 Middle Reach River Bed Slope

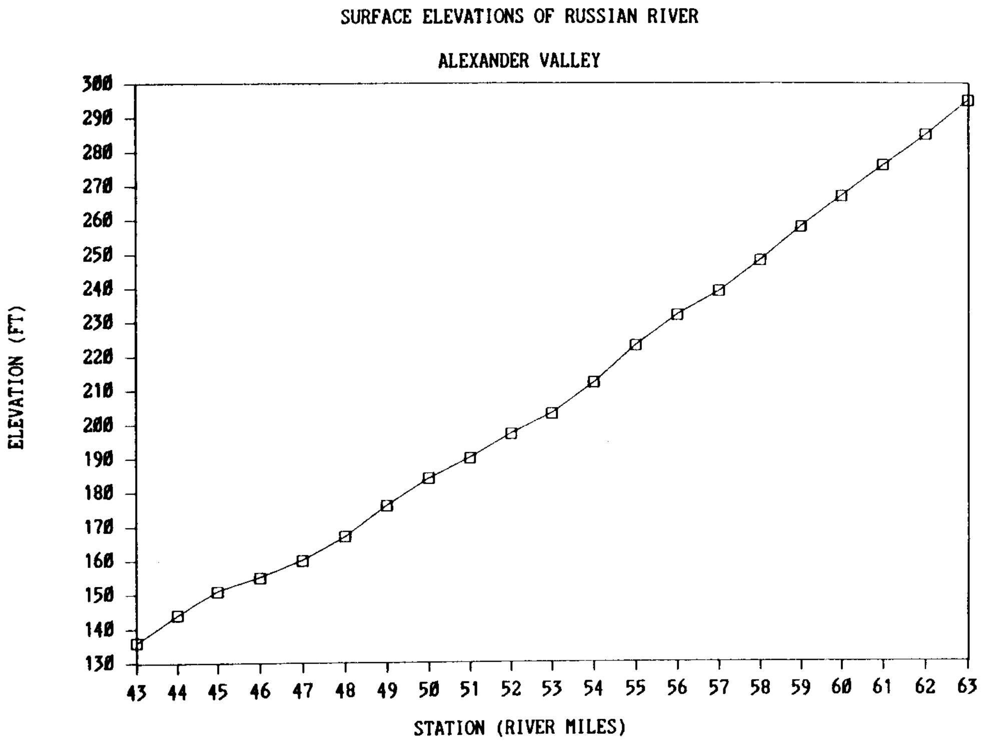
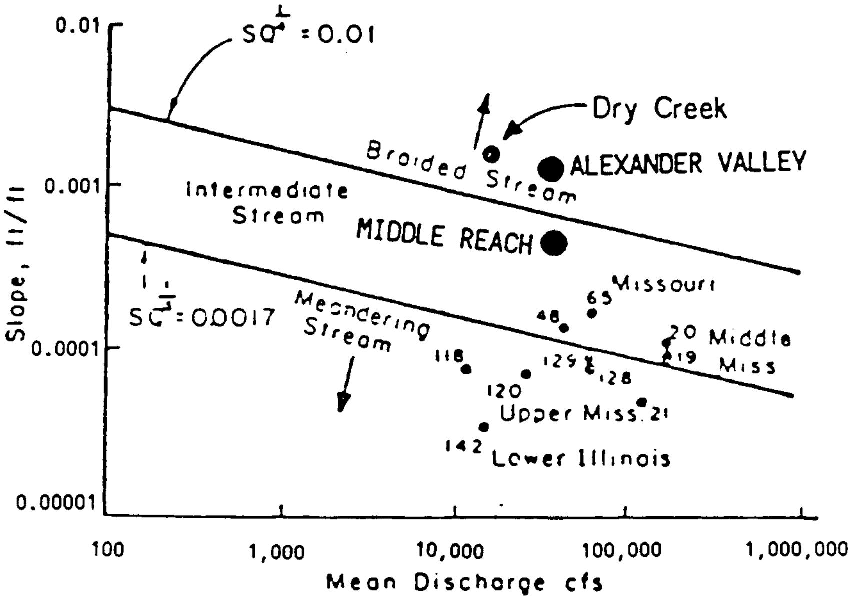


Figure 4.26 Alexander Valley River Bed Slope



Identification of Reaches Plotted

19	St. Louis to Chester	Middle Mississippi	118	St. Paul to Redwing	
20	Chester to Cape Girardeau		120	La Crosse to Lansing	Upper Mississippi
21	Ohio River		128	Hannibal to Louisiana	
48	Lower Arkansas River		129	Louisiana to Grafton	
65	Missouri River		142	Lower Illinois River	

Figure 4.27 Slope Discharge Relationship for Braiding and Meandering in Sand Bed Streams

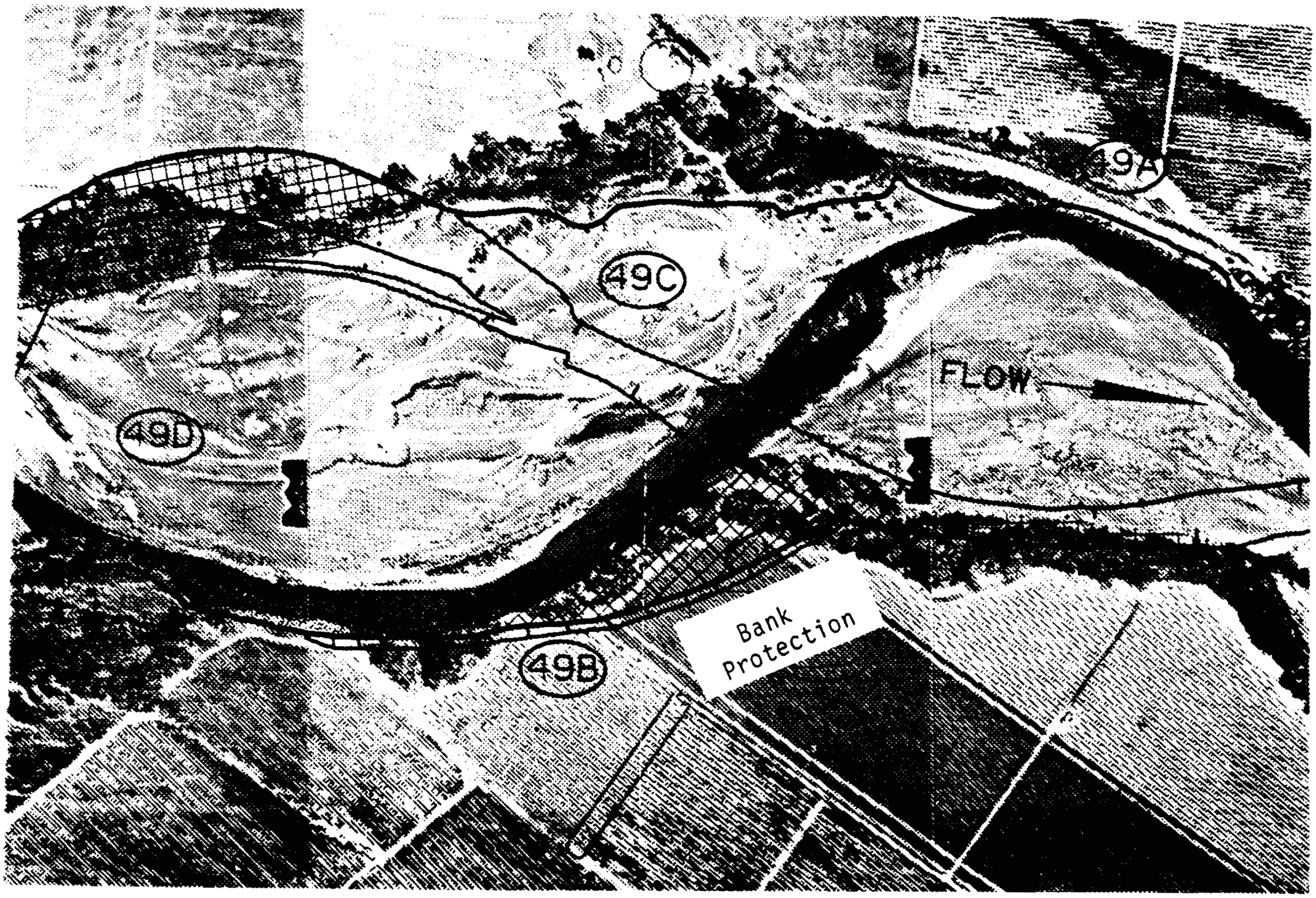


Figure 4.28 Bank Protection Measure Near River Mile 49

Concerning the survey data analysis:

The changes which occurred within the surveyed portions of each subreach do not necessarily reflect what was occurring outside of the concentrated survey limits. Figures 4.1 and 4.2 indicate the scatter of the survey data throughout the study reaches. Figure 4.29 was prepared to illustrate the portion of the total Alexander Valley Reach that was covered by relatively intense survey over each season. It may be noted from this figure that area of intense survey in the Alexander Valley Reach never exceeded 50 percent of the reach during the study period. In addition, the cross-section surveys were concentrated on portions of the channel that were more intensely mined. Thus, the trends identified in the following conclusions must be evaluated with these qualifications in mind.

Comparison of the fall 1981 and fall 1985 cross-section data allows identification of the trends that were evident prior to the 1986 flood. Data corresponding to both surveys was available in subreaches 1, 2, 4, 5, 6, 8, 10 and 11. Low point elevations throughout every subreach except 10 (which is represented by a single section) were generally lower in the fall 1985 survey. Within subreaches 1 and 2 (a total of 10 common cross sections), aggradation was noted at 6 locations, and degradation was noted at the remaining 4. Within the surveyed portions of subreaches 4, 5, 6, and 8, overall degradation was evident during this period. The single cross-section in subreach 10 aggraded.

Less cross-sectional data is available for evaluation of the fall 1981 to spring 1986 aggradation/degradation and low point changes. Data for both seasons was available only for subreaches 4, 5, 6, 8 and 11. Within subreach 4, the common cross-section data indicated a rise in the low point elevation and net aggradation over this period. The low point elevations within subreach 8 lowered over the period. However, the cross-sections generally aggraded throughout this subreach. The remaining subreaches (5, 6 and 11) exhibited both

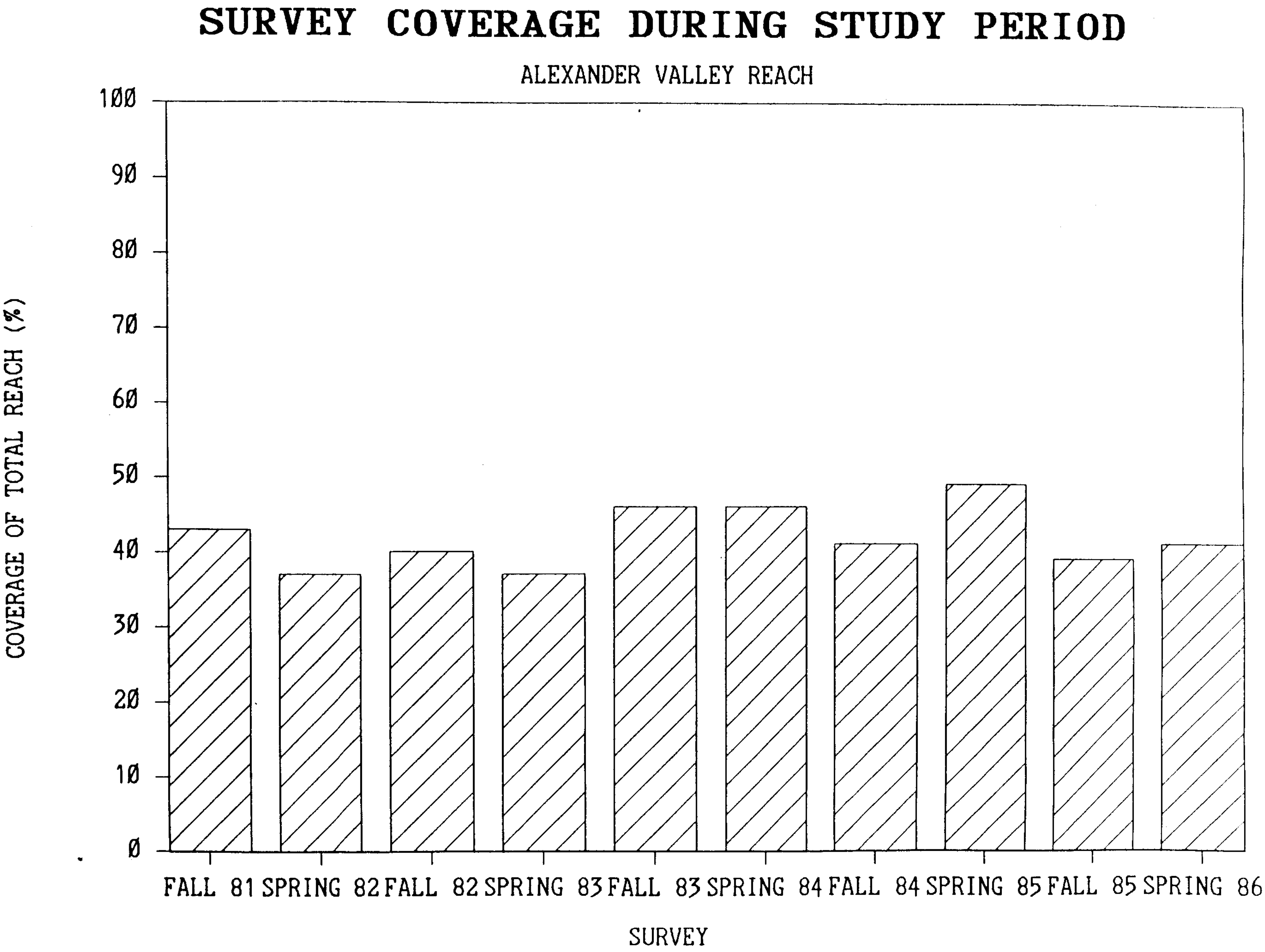


Figure 4.29 Percentage of Alexander Valley Reach Covered by Intensive Survey during the Study Period.

a lowering of the low point and net degradation over the study period.

Significant flood events occurring after previous seasons of mining are effective in reestablishing the mined gravel bars to an extent. Aggradation of unmined gravel bars was noted in non-mining areas.

Within the surveyed portion of subreach 3, approximately 144,000 cubic yards deposited in the winter seasons between fall 1981 and spring 1985 (no cross-sectional data is available within this reach after spring 1985). Assuming a unit weight of 1.5 tons/yd^3, this amount is equivalent to approximately 216,000 tons of deposited material.

Within the surveyed portions of Alexander Valley Reach, approximately 1,840,000 cubic yards (2,760,000 tons) were deposited in the winter seasons between fall 1981 and fall 1986. Since the length of common aerial coverage from consecutive fall and spring surveys averaged approximately 40 percent, if this same amount of deposition were to have occurred over the entire Alexander Valley Reach, the total amount of deposition would have been on the order of 6,900,000 tons.

Comparison of the available cross-section data indicates that approximately 1.94 million cubic yards (2.91 million tons) of material were mined from the Alexander Valley reach between fall 1981 and fall 1986. Approximately 63 percent of this total occurred within subreaches 5 and 6. The reported mining amounts in Alexander Valley reach over this same time period total 2.74 million tons.

Concerning the sediment routing analysis:

Historical reconstruction indicates that, during the study period, an average of almost 1.2 million tons per year were deposited in the Alexander Valley Reach, and an average of 0.5 million tons per year were deposited in the Middle Reach. The deposition estimates are based upon sediment transport theory and represent material deposited along the entire length of all subreaches; thus they are greater than the values obtained in the survey data analysis. However, the total reconstructed deposition within the Alexander Valley Reach over the study period (5,885,000 tons) is comparable to the extrapolated results of the cross-sectional analysis discussed above (6,900,000 tons).

Very little replenishment occurred for small floods as in 1984-1985 (peak discharge 13,000 cfs). A large flood such as in 1985-1986 (peak discharge 70,000 cfs) can make up for several years of below average deposits.

The long term average annual deposition within the Middle Reach and Alexander Valley Reach is estimated to be 284,000 and 682,000 tons per year, respectively. Reported mining estimates over the study period include about 297,000 tons per year from the Middle Reach and 736,000 tons per year from the Alexander Valley Reach. While the mining tonnage slightly exceeds the long-term average deposition, it much less than the study period averages of 533,600 tons and 1,117,000 tons, respectively.

The bank erosion analysis yielded the following results:

The Middle Reach did not exhibit significant bank erosion during the study period.

Approximately 132 acres of bank erosion occurred in the Alexander Valley Reach during the major storms of the study period. About one-half of this total occurred near mining areas. The other half was fairly remote from mining sites. The bank erosion which occurred along the Alexander Valley Reach was generally located along the outside bends of the meandering main channel and along the path of the down-slope travel of these bends.

The majority of the bank loss that occurred along the Alexander Valley Reach was located in subreach 9 (both in terms of total acres and in terms of acres per mile of river). Little or no mining of the gravel bars within subreach 9 was noted during the study period.

There were at least two instances of major bank erosion occurring both upstream and downstream of a new mining site. These were near river miles 47 and 62.7 during the 1986 flood. The mining had started in the spring of 1985 and continued through the spring of 1986 at the same location. There was very little replenishment of gravel deposits during the 1985 flood between the two mining periods.

Table 4.10 summarizes the year-by-year changes in sediment volume within the Alexander Valley Reach and the Middle Reach, considering the theoretical quantities, reported mining quantities, and the results of the analysis of the survey data. The theoretical and survey quantities for the spring 1982 to spring 1986 periods, as well as the estimated bank loss areas for the entire study period, are summarized on a subreach basis in Table 4.11.

TABLE 4.10

THEORETICAL, REPORTED, AND SURVEYED SEDIMENT QUANTITIES WITHIN RUSSIAN RIVER

ALEXANDER VALLEY REACH

	ENTIRE REACH			SURVEY AREA		
Flood Period	Theoretical Deposition cubic yards	Reported Mining cubic yards	Theoretical Net Change cubic yards	Surveyed Deposits cubic yards	Surveyed Mining cubic yards	Surveyed Net Change cubic yards
81-82	774,000	(273,000)	501,000	(17,000)	(344,000)	(361,000)
82-83	1,073,000	(329,000)	744,000	585,000	(344,000)	241,000
83-84	491,000	(645,000)	(154,000)	115,000	(591,000)	(476,000)
84-85	46,000	(576,000)	(530,000)	238,000	(664,000)	(426,000)
85-86	1,539,000	(629,000)	910,000	923,000	(629,000)*	294,000 *
TOTALS:						
FALL 81 - FALL 86	3,923,000	(2,452,000)	1,471,000	1,844,000	(2,572,000)*	(728,000)*
AVG	784,600	(490,400)	294,200	368,800	(514,400)	(182,000)
FALL 81 - FALL 85	2,384,000	(1,823,000)	561,000	921,000	(1,943,000)	(1,022,000)
AVG	596,000	(455,750)	140,250	230,250	(485,750)	(255,500)
SPRING 82 - SPRING 86	3,149,000	(1,823,000)	1,326,000	1,861,000	(1,943,000)	(82,000)
AVG	787,250	(455,750)	331,500	465,250	(485,750)	(20,500)

* Fall 1986 survey information was unavailable, so
reported mining values were assumed for the mining period following the 85-86 floods

Table 4.10 (continued..)

MIDDLE REACH

	ENTIRE REACH			SURVEY AREA		
Flood Period	Theoretical Deposition cubic yards	Reported Mining cubic yards	Theoretical Net Change cubic yards	Surveyed Deposits cubic yards	Surveyed Mining cubic yards	Surveyed Net Change cubic yards
81-82	327,000	(303,000)	24,000	21,000	(68,000)	(47,000)
82-83	494,000	(212,000)	282,000	62,000	(67,000)	(5,000)
83-84	199,000	(65,000)	134,000	48,000	4,000	52,000
84-85	18,000	(253,000)	(235,000)	13,000	N/A	N/A
85-86	741,000	(157,000)	584,000	N/A	N/A	N/A
TOTALS:						
FALL 81 - FALL 86	1,779,000	(990,000)	789,000			
AVG	355,800	(198,000)	157,800			
FALL 81 - FALL 84	1,020,000	(580,000)	440,000	131,000	(131,000)	0
AVG	340,000	(193,333)	146,667	43,667	(43,667)	0
SPRING 82 - SPRING 85	711,000	(580,000)	131,000	123,000	(131,000)	(8,000)
AVG	237,000	(193,333)	43,667	41,000	(43,667)	(2,667)

Notes: The FALL __ - FALL __ periods consist of a FLOOD-MINE-FLOOD-MINE... sequence
i.e. begin with a flood season, and end with a mining season

The SPRING __ - SPRING __ periods start with a mining season and end with a flood season

Mining amounts are for the season following the specified flood period

Table 4.11 Summary of Results for the Study Period

		SPRING 82 TO SPRING 86					
SUBREACH	BANK EROSION (ACRES)	SURVEYED FLOOD DEPOSITS (CU YD)	SEDIMENT ROUTING DEPOSITS (CU YD)	SURVEYED MINING VOLUMES (CU YD)	SURVEYED CHANGE IN VOLUME OF DEPOSITS (CU YD)	4 YEARS OF LONG-TERM AVERAGE DEPOSITS (CU YD)	SUBREACH AVERAGE LOW-POINT ELEVATION CHANGE (FT)
1	0	N/A	754000	0	N/A	394000	-1.0
2	3	N/A	450000	0	N/A	235000	-2.0
3 *	0	123000	248000	-131000	-8000	129000	-0.3
SUBTOTAL	3	123000	1452000	-131000	-8000	758000	
4	10	108000	315000	-140000	-32000	182000	-0.1
5	25	647000	315000	-708000	-61000	182000	-1.3
6	25	448000	347000	-521000	-73000	200000	-1.6
7 **	7	126000	347000	-27000	99000	200000	-0.1
8	15	382000	252000	-292000	90000	145000	-1.0
9	54	N/A	629000	0	N/A	364000	0.0
10	2	N/A	315000	0	N/A	182000	0.1
11	9	150000	629000	-255000	-105000	364000	-1.9
SUBTOTAL	147	1861000	3149000	-1943000	-82000	1819000	
TOTAL	150	1984000	4601000	-2074000	-90000	2577000	

* SURVEY DATA THROUGH SPRING OF 1985

** SURVEY DATA THROUGH FALL OF 1984

NOTES:
1. "N/A" INDICATES THAT THE TOTAL VOLUME OF DEPOSITS COULD NOT BE ESTIMATED FROM THE SURVEY DATA
2. THE SEDIMENT ROUTING AND LONG-TERM AVERAGE DEPOSITS WERE ASSUMED TO BE EQUALLY DISTRIBUTED ALONG THE RIVER
3. THE BANK EROSION AMOUNTS AND LOW-POINT ELEVATION CHANGES COVER THE ENTIRE PERIOD OF AVAILABLE DATA
4. SUBREACH 1 AND 2 LOW-POINT ELEVATION CHANGES WERE DETERMINED FROM CROSS-SECTION DATA SPACED APPROXIMATELY 1 MILE APART AND THUS MAY NOT BE REPRESENTATIVE OF THE ENTIRE SUBREACH

V. HYDROLOGY MONITORING PROGRAM EVALUATION

5.1 Introduction

The hydrology monitoring program was initiated by Sonoma County Department of Planning to obtain data over an extended period of time in order to ascertain the effects of instream and terrace mining on the Russian River. The data collection effort actually serves a dual purpose. First, it documents changes in important river characteristics; second, it allows the County to monitor permit compliance by the various mining entities. This chapter reviews the effectiveness of the program in fulfilling these goals and recommends modifications which could improve the program.

5.2 Monitoring Methods and Product

The principal method of data accumulation is through aerial photography and photogrametry. Twice each year, in early May and early November, the Middle Reach and Alexander Valley are photographed using a photo scale of 1:4800 (1" = 400'). In addition, cross sections in the Middle Reach are recorded by field surveys, which include underwater data points.

For this study, the fall 1981 photos are used for the base map located in Appendix B. Using the photo sets, photogrametry (measuring images on the photographs and reducing them to useful data) yields cross section data at any location along the river. The accumulation of these photo sets over time creates an invaluable source of data. It is possible to refer back to historical channel configurations with excellent detail. Comparison of photo sets with one another can show locations of bank erosion. This has been done for each of the first ten photo sets, which were taken biannually from fall, 1981 through spring, 1986. Changes have also been noted in land use, riparian corridors and drainage patterns above the river banks. In addition, should new sites be considered for instream mining, it is possible to have additional cross sections recorded by photogrametric means in the area in question. This information will be very useful in helping to establish the baseline condition of the potential site, and will allow monitoring of mined volumes during the first year of operation.

5.3 Photo Scale

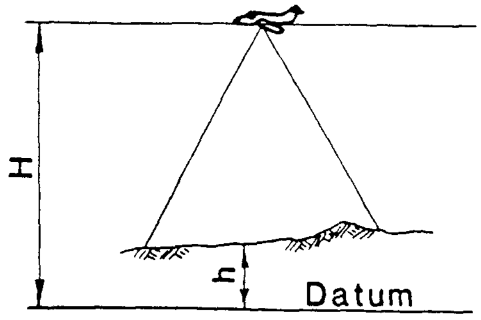
Presently, the specifications for aerial photography are as follows:

Negative format: 9 inches by 9 inches
Lens focal length: 6 inches
Photo scale: 1:4800
Vertical accuracy: ±0.5′
Horizontal accuracy: ±2.5′

The Hydrologic Engineering Center (1987) reports the vertical accuracy of spot elevations taken from 1:4800 orthophotos is ±0.6 feet, while horizontal accuracy is ±2.6 feet. For 1:6000 scale photos, accuracy was determined to be ±0.8 feet vertically and ±3.3 feet horizontally. It can be assumed that the errors are of random nature for a large number of measurements. Thus the chance that all of the measurement errors will equal the maximum error is very small. For the purpose of calculating the volumes of gravel deposits, it is more appropriate to use the average error as a criteria for determining the overall accuracy of the volume calculation. This average error is approximately 70% of the maximum error for a normal distribution. Thus, if the maximum error for the aerial survey is ±0.8 feet, the average elevation error in the volume calculations will be 70% of this, or about ±0.56 feet. Therefore, it is possible to use a survey scale of 1:6000 and maintain the desired average vertical survey accuracy. It is therefore suggested that, if necessary, the flying height for photography can be increased to obtain a scale of 1:6000 (1 inch equals 500 feet). This height can be determined by the following relationship (see Figure 5.1):

$$S_h = \frac{f}{H - h}$$

where S_h is the scale at elevation h [in/ft], f is the lens focal length [inches], H is flying height above datum [feet] and h is average elevation of ground [feet]. Based on this relationship, the flying height could be 3000′ above the ground, which corresponds to an altitude of between 3050′ and 3250′ MSL for the reaches to be photographed. This recommendation can be implemented to decrease the cost of flying time and photography by allowing a larger area to be covered per photo.



$$S_h = \frac{f}{H-h}$$

Where S_h = Scale At Elevation h , in./ft.

f = Focal Length, Inches

H = Flying Height Above Datum, Feet

h = Average Elevation On Ground

ILLUSTRATION

Given: Focal Length, f = 6"

Average h ≈ 980'

Determine: Flying Height For Photo Scale Of 1" = 400' (1" = 4800')

$$S_{980} = \frac{6''}{H-980'} = \frac{1''}{400'}$$

$$H = \frac{(400)(6'')}{(1'')} + 980$$

$$H = 2400 + 980$$

H = 3380' Above Datum

Altitude Above The Ground = 2400 Feet

Ref: Moffitt, Francis and Mikhail, Edward;
Photogrammetry, Harper and Row,
Third Edition, 1980

Figure 5.1 Determination of aerial survey flying height.

SLA concurs with Sonoma County that the vertical accuracy of the survey is the key factor for volume calculations. Assuming an unbiased data set, there are three measured variables contributing to the uncertainty of volume calculations in the river bed. These are length of the prism (distance between sections), width of the section, and net elevation change. The dominant influence on the uncertainty of volume measurements in the river bed is the vertical accuracy of spot elevations (individual data points within a cross section). This conclusion is supported by a simple analysis of uncertainty presented by Holman (1984). Because of this, the current horizontal accuracy of ±2 to ±3 feet is sufficient.

5.4 Cross Section Intervals

Currently, cross sections are recorded by aerial surveys at 100′ or 200′ intervals at mining sites and by field surveys at up to one mile intervals elsewhere. These intervals are adequate only for monitoring the volumes mined and those replaced by winter flooding at the mining sites. However, the amount of gravel buildup or scour at non-mining locations cannot be accurately determined by this system. To obtain an accurate representation of the overall river system and cumulative effects of mining on the Russian River, cross sections are needed at smaller intervals along unmined reaches. Cross sections taken every 1000′ through unmined areas will yield enough data to monitor depth changes due to gravel buildup. It is important that the survey locations are the same from year to year whether or not a cross section is on or near a gravel bar.

It is also important to include the full width of the watercourse in each set of cross section data points. This is necessary to perform hydraulic analysis of high flow situations, as well as to capture bank erosion on cross section plots. If the banks are not included, then no net volume change will be computed in a reach where bank erosion occurs. It should be noted here that this circumstance can still arise if bank erosion occurs entirely between two cross sections. The volume of undetected eroded material would not be significant, however.

If the cross section spacing interval in mined reaches is increased from 100′ to 200′, the decrease in resolution may not be a major factor in the volume calculations. This is because the average length of a mined gravel bar is in excess of 600 feet, meaning the average bar would be represented by at least four cross sections. This is sufficient to provide a close approximation of the bar area, keeping in mind that accurately measuring vertical elevations is more significant than the reduction in detail of horizontal bar dimensions.

Some savings in data acquisition costs could be realized by increasing the cross section spacing interval. When aerial surveys are performed, there is a fixed minimum cost required for setup, airplane and pilot use, etc. There is also a variable cost associated with flying time, number of photos, and number of data points. The cost savings is reduced only marginally when the total number of cross sections is cut in half, however, due to the fixed costs. Figure 5.2 (HEC, 1987) shows the relationship between the number of cross sections recorded and the total cost. Included in this figure is data for "aerial photos--cross sections only" (triangle data points). The most important thing to note is the small difference in total cost for large range of sections taken. For example, if the number of 2000′ wide cross sections is reduced by 50% from 80 to 40, the reduction in total cost is only 18 percent or $1540 ($8690 - $7150).

The 200′ cross section spacing interval can also be used at sites of potential future instream activity. As explained previously, this would provide baseline data for monitoring and analysis of the new site during the first season of operation.

5.5 Additional Data Needs

In addition to the need to make the entire present data set accessible by computer, several other items would enhance the usefulness of the Hydrology Monitoring Program. Permanent structures which affect the channel should be documented. For example, the present configuration of Healdsburg Dam and the various bridges crossing the Russian River can be obtained to enhance the accuracy of channel hydraulic models. Dams and bridges are important control points for channel stability because their locations are fixed, as are their bottom elevations in some cases.

Thalweg elevation surveys are not needed for the program if the surveys are taken when the discharge is sufficiently low. Since only spot elevations are used in the volume calculations, contour maps are not needed. The largest data need identified during the study is the need for cross section data to extend from the top of one bank to the top of the opposite

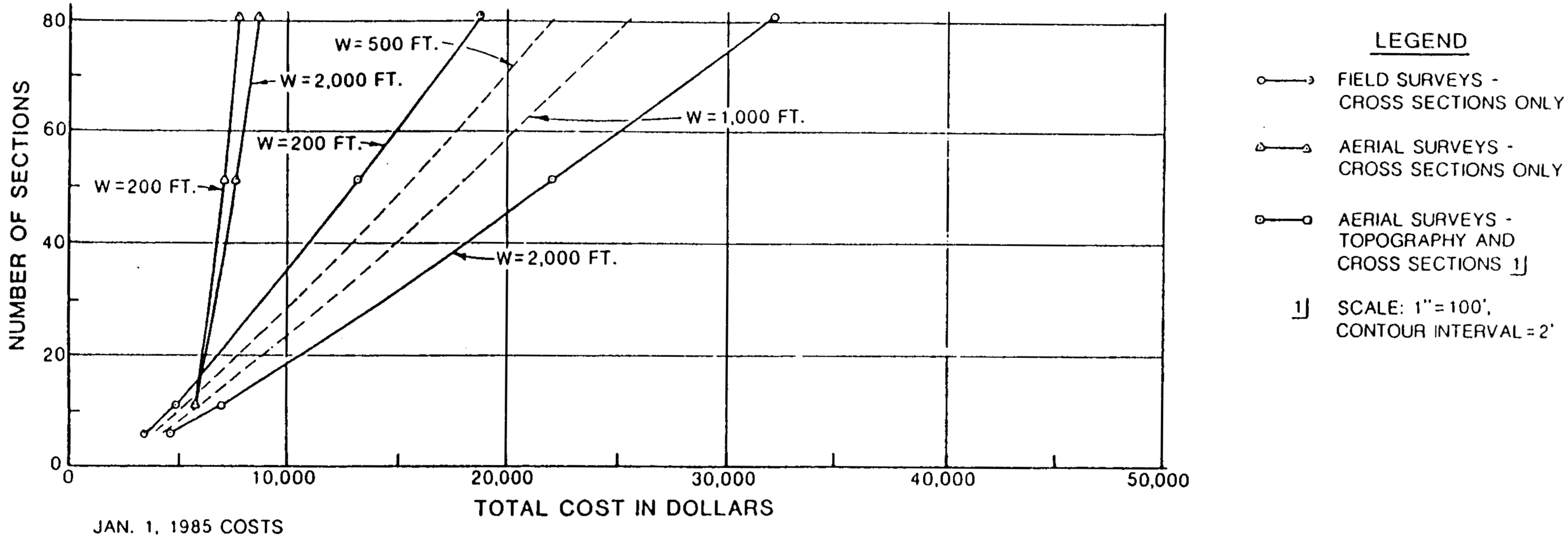


Figure 5.2 Cost information for field and aerial surveys on flat terrain with light cover.

bank and for cross sections to be taken at the same location from year to year.

5.6 Data Acquisition

5.6.1 Current Method

Presently, cross-section data is provided by the survey contractor to the Department of Planning in the form of handwritten logbooks. To be of analytical use, the data must be entered into computer files by Department personnel. This is an inefficient, time consuming process. Typically, this creates a situation where only the specific data needs of an individual task are transcribed, and the complete data set is never put on the computer. Efficiency could be increased by having the survey contractor provide data on a computer disk in a standard format to be specified by the Department of Planning. In this way, the complete data set could be quickly accessed, and individual data needs could be met easily. A complete data management system is described in Section 5.7.

5.6.2 Computer Automation

The technology is readily available to transfer data values directly from orthophotos to computer files. This process would significantly reduce the time required and the chance of a typing error compared to the existing data reduction method.

5.7 Database Management System

In order to make the best use of the survey data, it is necessary to have a system for maintaining, updating and analyzing the large amount of data being accumulated by the Hydrology Monitoring Program. Such a system would reduce data into a form from which Department of Planning personnel can make important planning decisions regarding gravel extraction. The following examples illustrate some of the tasks to be performed by the system.

5.7.1 Entry of New Data

Since each new set of biannual data will be provided on computer disk in the proper format, data entry will be automatic. Simply insert the disk into the computer disk drive and give the proper command.

5.7.2 Analysis of Data

Data will be analyzed by one of a variety of programs, depending on the information sought by the user. Possible data output includes the following:

1) Plotting of cross sections
2) Plotting of river profile
3) Computation of mining volume
4) Computation of deposition/scour volume
5) Computation and plotting of change in volume vs. distance
6) Bank erosion estimation

The most basic task would be to retrieve and plot cross sections. The user would give information including cross section location (or range of locations) and year (or range of years), and the system would produce the plots. The river profile is also important for analysis. To obtain a profile plot, the user would input the range of river miles (or reach number) and the year or years desired, and the system would produce the plot.

In addition to plotting capabilities, the database management system could compute volumes of mining and deposition or scour for user specified reaches and time periods. To do this, two cross sections taken at the same location are compared. To compute mining volume, the fall cross section is compared to that of the previous spring, with the difference in cross section areas being the result. When the same procedure is performed at other cross section locations within the mining area, the volume removed can be calculated. Similarly, the volume of deposition or scour resulting from flood flows can be calculated by comparing spring cross sections with those taken the previous fall at the same locations.

If a reference channel datum is established for the river, then the volume of deposits available for mining can be calculated. This volume would represent the amount of gravel that is above the reference elevation and between the banks. This information would be useful for present sites and for evaluating new mining sites. When combined with other output from the database management system, planning decisions can be made and justified.

5.7.3 Users of System

The database management system will be easy to use and well documented. Any member of the Department staff will be able to operate the system and generate the needed output.

5.8 Recommendations

All cross sections must extend from the top of one bank to the top of the opposite bank.

Cross sections should be taken at the same locations from year to year.

The cross section spacing interval should be reduced to 1000 feet in unmined areas.

Flying height for photos and the cross section spacing interval of 100 feet in mining areas is adequate. If necessary to reduce costs, either the flying height may be increased from 2000 to 3000 feet above the ground or the cross section spacing interval may be increased to 200 feet in mined areas.

The aerial survey contractor should be asked to provide future cross section data on computer disk in County-specified format.

A database management system should be acquired to organize the Hydrology Monitoring Program data on a computer. Hardware required for such a system would include a personal computer with 640K memory and 20 megabyte hard disk. An 8087 math coprocessor and 11" x 17 " plotter would also be necessary.

VI. EVALUATION OF MINING POLICIES AND STANDARDS

6.1 The Russian River Channel as an Aggregate Source

Preliminarily, the results of this report indicate that the Russian River can continue to be used as an aggregate source if careful management is continued. The surveyed volume data collected by Sonoma County indicate that, in most cases, mined gravel bars were replenished after a sufficient hydrologic event (see Figs F.1 through F.28). Comparison of the reported mining totals with the computational estimates indicates that the average annual mining that occurred over the study period is comparable to the expected long term average annual deposition amounts. Continued mining of aggregate, therefore, is generally allowable if amounts extracted annually do not increase greatly.

6.2 Designated Resource Areas

During the study period 1981 through 1986, instream mining occurred in almost every mile of the Alexander Valley Reach and in miles 28 through 32 of the Middle Reach (see Table 2.2). These areas are designated as managed mineral resource areas. The results of this study indicate there need not be a decrease in the amount of land area designated as mineral resource. There should, however, be continued management based upon the results of the hydrology program.

The total amounts being mined from the Alexander Valley reach are not considered excessive, but the concentration of these mining efforts within certain areas may be contributing to the downcutting of the main flow channel throughout this reach. A more even distribution of the future mining throughout the Alexander Valley reach, or rotation of mining areas from year to year, may be advisable

6.3 Mining Operation Standards

6.3.1 Depth of Excavation

The current instream mining operation standards state that gravel bar skimming can take place to a depth that does not go below the line that connects the low flow water surface elevation and top of the channel bank. The main difficulty with this method is that a slight change in the low flow water surface elevation may cause a large change in the amount of material mined. During particularly wet years, or if the low flow channel is aggrading, the low flow elevation will be progressively rise, resulting in a higher elevation as a mining basis. Conversely, if an extended drought occurs, or the low flow channel is degrading, the water surface elevation will be reduced, which will permit excavation to greater depths. An additional problem with this method is that the low flow elevation varies with the amount of discharge released from upstream, which, as shown in Table 4.4, is not constant.

An alternative method would be to establish an actual elevation at each point along the river below which mining should not take place. This elevation could be the average base flow elevation or something similar. There are two problems with this method, however. First, it is difficult to determine an absolute elevation at frequent enough intervals to be used in practice. Second, it is difficult to implement such an elevation at a particular mining site.

6.3.2 Specified Volume Limits

The average annual sediment deposition described in Section 4.4 can be used as an estimate of the annual "safe yield" of sediment from the Alexander Valley and middle reaches of the Russian River. The long term average annual yield is estimated to be 682,000 tons from the Alexander Valley Reach and 284,000 tons from the Middle Reach. Under a "safe yield" plan, this amount of excavation could be allowed every year. However, during extended droughts, yearly mining of this amount could result in significant lowering of the river bed. Conversely, several years of over-average runoff could choke the river bed with aggradation, and increase the likelihood of lateral migration. It is clear that a more flexible mining allowance guideline is desirable.

To maintain a no-net-change condition within a given mining area, the volume of material mined each summer must be completely replenished in the following winter. The mining operation plan could be begun by allowing length-weighted portions of the above "safe yield" amounts to be extracted from each mining site in the first summer of plan application. The actual volume of mined material could be verified with the procedure outlined in this report: comparison of successive seasonal surveys. The actual amount of replenishment that occurred in the following season could be determined in the same way. The amount to be mined in the following summer would then be defined as the amount of replenishment that occurred in the previous winter. Thus, following seasons of drought, minimal mining would be allowed. After winters of major storms, the mining allowance could be increased. In this way, near equilibrium performance of the river would be ensured.

6.3.3 Channelization Versus Skimming

The current County standards allow skimming of gravel bars in designated areas, at elevations above the low water level. The decision to continue with this form of mining standard, or to change the standard and allow channelization mining, depends on the desired objectives for management of the river. If the objective is to maintain the river in its natural state, the skimming standard is most appropriate. If, however, the desired objective is a more efficient channel with defined course and a defined level of flood control effectiveness, then channelization mining will be one means of achieving this objective. However, the channelization mining must follow some overall plan for the river configuration, which must consider the entire river system. Channelization in local areas, without consideration of the upstream sediment loading and downstream sediment requirements, could have dramatic impacts on other areas in the river. A system-wide plan and analysis would be required to change the current mining standard to allow channelization.

6.3.4 Oversize Gravel Use

Oversize gravel may be used to improve bank stability along valuable properties along the river. However, as discussed in Section 4.5.4 of this report, the natural state of the Alexander Valley Reach is to be somewhat unstable, and occasionally shift its main channel location. A protected bank can divert flood flows cross-channel, and increase erosion at alternate locations. Thus, local protection of banks with oversize gravel will aid in local bank stabilization, but can result in merely shifting the area of inpact to some downstream unprotected bank. Full protection of the river banks, or changing the natural regime of the river through a system-wide channelization plan are the safest means of controlling bank erosion.

6.3.5 Setbacks and Final Slopes

Current standards allow skimming of gravel bars above a line which connects the outer bank vegetation elevation to the point at water level along the low flow channel, as long as the slope of this line is not less than 2%. A setback from the outer bank occurs only when the width of the gravel bar is of such extent that the 2% line from the low point daylights prior to the vegetation line.

There are no hard and fast rules for determining whether this standard is too rigid or lenient. It is recommended that the monitoring program be used to determine, on a location-by-location basis, the allowable removal quantities. In areas where deposits are affecting channel stability, the setback and final slope standard may be relaxed somewhat to gain flood control capacity and lessen bank loss. In areas where downcutting is occurring, stricter rules may be advisable, such as setbacks from the water's edge or steeper slopes.

6.4 Sediment Diversion for Terrace Pit Reclamation

The work plan for this study requires some discussion of the potential in the Middle Reach for bedload materials to aggrade sufficiently to increase the rate of terrace pit reclamation by river diversion. As discussed in Section 4.3.3 of this report, the survey data available for evaluation of the Middle Reach changes are limited. However, a general lowering of the low point elevations was evident within this reach, at least up to 1985, whereas the overall channel sections appeared to be relatively stable or agrading. The sediment transport computations indicate that the sediment deposited within this reach over the study period far exceeded the reported mining amounts. It is possible that the gravel bars are agrading during the major flood events and that the low flow channel is degrading during the more frequent low flow periods. Another possibility is that the fluctuations in the discharge within the main flow channel provide survey results which are not indicative of thalweg changes.

Since the Middle Reach appears to be agrading, it is likely that, with limited in-stream mining, the channel thalweg will rise and increase the potential for terrace pit reclamation through diversion of wash load. There are some points to consider regarding the diversion of main channel flows, however.

Sediment in transport is typically divided into two major classes: bed material load and wash load. The bed material load consists of material which is found within the channel bed. The wash load is defined as the generally finer material which is not found in appreciable quantities in the bed, and is typically supplied from watershed rather than from channel bed erosion. The wash load concentration can have some effect on the bed material transport capacity of flood flows, although this effect is often ignored. High wash load concentrations act to make the flowing fluid more viscous, and more capable of transporting the coarser (bed material) sizes.

The bed material load is subdivided into two classes, corresponding to the mode of transport: the bed load and the suspended bed material load. The suspended bed material load is carried in suspension, while the bed load moves along the channel bottom within the active bed layer. Thus, not all of the sediment suspended in flood flows is wash load; the suspended load is composed of suspended bed material as well.

Most wash load is so fine that it remains in suspension as long as the water is flowing. Settlement within the terrace pits may therefore not occur in appreciable quantities unless the diverted flow velocities are reduced to near zero. When the water within the pit becomes relatively still, the wash load will settle to the bottom. Assuming a relatively high concentration of wash load, for instance 20,000 ppm, each foot of water depth would produce 0.013 feet of deposition per flood event. Thus, the filling rates could be very slow.

The diversion of wash load to fill the terrace pits is not expected to have a notable effect downstream, unless the amount of water diverted with the wash load significantly affects the main channel discharge downstream of the diversion area, and/or if significant amounts of bed material load is also diverted, and clear water flows are allowed to reenter the main channel downstream of the terrace pits. Abrupt changes in the main channel discharge would affect the main channel hydraulics and bed material sediment transport characteristics. Diversion and settlement of bed material load, with subsequent release of clear water flows, could have an effect on the sediment balance within the immediately downstream reaches. (Clear water, or non-sediment laden flow, is often termed "hungry water," in reference to its tendency to pick up bed and bank material in order to achieve its sediment transport capacity.)

In a reach where aggradation is currently a problem, the unintentional but potential effects of wash load diversion (i.e. diversion and settlement of bed material) could enhance the local channel stability, by providing an area for excess sediment to deposit. However, in reaches where the sediment loading and transport capacity are in balance, diversion can upset this dynamic equilibrium, and result in local degradation.

The diversion and collection of wash load materials is feasible, but careful design and monitoring are recommended to ensure desirable functioning.

VII. CONCLUSIONS

The following conclusions have been drawn as a result of this study:

1. In general, the Middle Reach stream channel remained fairly stable during the study period which included two major floods (1983 and 1986). Slight lowering of the channel bottom was evident along subreaches 1 and 2, which may be due in part to the presence of Healdsburg Dam.
2. All major bank erosion was confined to the Alexander Valley Reach especially between river miles 53 to 57 and between 46 to 51. Bank erosion was typically concentrated along the outside bends of the meandering low flow channel and/or along the down-slope path of the translating meander loops.
3. Gravel bar migration (meander loop translation) mainly occurred within subreaches 6 through 9. Rate of travel was observed to be approximately 280 feet per year. In previous studies, rates as high as 375 feet per year had been observed.
4. The average low point elevation of the survey data decreased by 1 to 2 feet from spring 1982 to spring 1986 in subreaches 5, 6, 8 and 11. These reaches also happen to have been mined.
5. Subreaches 5,6 and 11 also indicated a net loss in volume of 60,000, 70,000 and 100,000 cubic yards, respectively. Subreaches 7 and 8 indicated a net increase in volume of 100,000 and 90,000 cubic yards, respectively. These volumes cover only the portion of the subreach where active mining occurred. It is likely (see conclusion #6) that a net increase in volume occurred in the unmined portions of each subreach during the study period.
6. Using sediment transport computations to reconstruct the historical sediment transport through the study reaches, it was estimated that an average of almost 1.2 million tons per year were deposited in the Alexander Valley Reach, and an average of 0.5 million tons per year were deposited in the Middle Reach during the study period. These estimates represent material deposited throughout the entire length of all subreaches (surveyed as well as unsurveyed portions), and thus are greater than the amounts of local deposition computed through comparison of cross-sectional

data. Mining estimates were about 300,000 tons per year in the Middle Reach and 740,000 tons per year for the Alexander Valley Reach.

7. Gravel bar replenishment was observed to be on-going throughout the study period. However, net degradation of subreaches 5, 6 and 11 was noted. Although the total amount of mining that occurred during the study period in the Alexander Valley Reach and Middle Reach is of reasonable magnitude, the concentration of the mining efforts in specific locations may have resulted in a general lowering of the channel profile.
8. Between fall 1981 and fall 1985, the entire Alexander Valley Reach accumulated a net increase of 561,000 cubic yards of material, based on theoretical inflows and outflows of sediment and reported mining amounts. However, within the area of survey coverage, a net loss of 1,022,000 cubic yards was estimated for the same period. Over the fall 1981 to fall 1986 period, which includes the 1986 flood, the net increase in the entire reach was estimated at 1,471,000 cubic yards, while the surveyed loss within the mining areas decreased to 728,000 cubic yards. The spring 1982 to spring 1986 period exhibited a net addition of 1,326,000 cubic yards of material within the entire reach, with a net loss of 82,000 cubic yards within the mining area. Thus, the changes which occurred within the Alexander Valley Reach vary with the period of record analyzed, as well as with the area under consideration (i.e. entire reach vs. mining area).
9. Very little replenishment occurred for small floods as in 1984-1985 (peak discharge 13,000 cfs). A large flood such as in 1985-1986 (peak discharge 70,000 cfs) can make up for several years of below average deposits.
10. The Middle Reach did not exhibit significant bank erosion during the study period (3 acres). Approximately 147 acres of bank erosion occurred in the Alexander Valley reach throughout the study period (132 acres of bank erosion during major storms, and 15 acres during other less significant flow periods). Bank loss was most prevalent in subreach 9 (a little-mined subreach). About one-half of the total bank loss occurred near mining areas. The

other half was fairly remote from mining sites. There were at least two instances of major bank erosion occurring both upstream and downstream of a new mining site. These were near river miles 47 and 62.7 during the 1986 flood. The mining had started in the spring of 1985 and continued through the spring of 1986 at the same location. There was very little replenishment of gravel deposits during the 1985 flood between the two mining periods.

11. The hydrology monitoring program should be continued. It is the most accurate way to assess the amount of replenishment from a flood on a reach-by-reach basis. Some recommendations for this program include: All cross sections should extend from the top of one bank to the top of the opposite bank instead of covering just part of the channel. Cross sections should be taken at the same locations from year to year for comparison purposes. The cross section spacing interval should be reduced to 1000 feet in unmined areas. The flying height of 2,000 feet and the cross section spacing interval of 100 feet in mining areas is adequate. If necessary, to reduce costs, either the flying height may be increased to 3,000 feet above ground or the cross section spacing interval for mined areas could be increased to 200 feet.
12. In order to make the monitoring program data more automated and easily accessible, the following is recommended: The aerial survey contractor should be asked to provide future cross section data on computer disk in County-specified format. A database management system should be acquired to organize the Hydrology Monitoring Program data on a computer. Hardware required for such a system would include a personal computer with 640K memory and 20 megabyte hard disk. An 8087 math coprocessor and 11" x 17" plotter would also be necessary.
13. It is likely that, with limited mining, aggradation will continue within the Middle Reach, increasing the potential for the terrace pit reclamation by river diversion. Terrace pit reclamation by diversion of wash load was determined to be feasible, but proper design of the diversion facilities is required to avoid adverse impacts within the main channel. Significant alteration of the discharge along the main channel and/or diversion and settlement

of bed material sediment could affect the sediment transport trends downstream of the diversion. This affect could be beneficial if controlled, and if the diversion is located in subreaches which currently exhibit an overabundance of sediment supply, but could be detrimental if located within subreaches currently in an equilibrium state.

14. The mining standards and policies were determined to be generally sufficient as they exist, however diligent monitoring is recommended. If a no-net-change condition within each subreach of the river is the goal, actual volumes of allowable mining should be determined from a comparison of cross-section survey data before and after the flood season.
15. The designated mineral resource areas need not be decreased in size. However, a more even distribution of mining throughout the Alexander Valley Reach or rotation of mining areas from year to year may be advisable.

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