FLUVIAL GEOMORPHIC ASSESSMENT OF GRAVEL MINING, GUALALA RIVER PERMIT AREA, SONOMA COUNTY, CALIFORNIA

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EXECUTIVE SUMMARY

This report provides an assessment of geomorphic conditions in stream channels following gravel mining operations from 1996 to 2002 in the Wheatfield and South Forks of the Gualala River, northern Sonoma and southern Mendocino Counties. Gravel recharge rates are estimated quantitatively; these rates are the basis for an evaluation of gravel extraction rates that can be maintained without causing channel bed degradation. This report also provides recommendations regarding future monitoring studies and methods for regulating gravel skimming operations.

In 1996, Gualala Redwoods Inc. was granted a permit to extract 40,000 cubic yards (~64,000 t) of gravel per year by skimming gravel bars in the Gualala River. Gravel mining operations have been focused near the confluence of the Wheatfield Fork and South Fork Gualala ("Valley Crossing"), including reaches above and below the confluence, but are permitted in the South Fork Gualala River downstream to the confluence of the North Fork Gualala. The current gravel extraction permit requires that channel cross sections are surveyed at each extraction site each year, in addition to some cross sections surveyed for monitoring purposes. The cross section data were collected by Dimensions 4 Engineering, and are the primary basis for this assessment.

Gravel extraction in the Gualala River has occurred on a small scale periodically since settlement in the late 1800's (EIP Associates, 1994), but began in earnest in the 1950's. Commercial extraction began in the 1960's, and accelerated in the late 1960's with increased demand for aggregate for building and roads associated with the development of Sea Ranch. For the period 1996-2002, gravel extraction rates have varied from 13,000 to 36,000 tons per year, with an average annual rate of gravel extraction of about 19,000 tons per year.

Analysis of mean bed level changes and observations of surveyed cross sections measured between 1996 and 2002 show that the South Fork and the Wheatfield Fork of the Gualala River at Valley Crossing are aggrading. The upper South Fork aggraded at a rate of about 0.2 ft/yr (56-67 mm/yr) from 1996 to 2002. The South Fork just below the confluence aggraded at a rate of about 0.1 ft/yr (26-28 mm/yr). The Wheatfield Fork is aggrading at 0.1 ft/yr (27 mm/yr) just upstream of the confluence, however 0.3 miles upstream, the Wheatfield Fork appears to be generally stable, although slight degradation at a rate of 0.01 to 0.02 ft/yr (1-6 mm/yr) did occur in this reach.

Significant degradation at monitoring cross-sections of 1 foot or more associated with gravel extraction has not occurred over the 5 year permit period. Degradation of the thalweg of 1 foot or more occurred at some cross sections in some years, but was neither consistent nor occurred in consecutive years. Thalweg elevations fluctuated from year to year, representing typical variation in bed elevations in a dynamic alluvial river channel. The overall trend in thalweg elevations was for aggradation. No significant changes to the morphology of the river were detected in aerial photographs or from field observations, however, riparian vegetation established on banks and some bars prior to 1996 has grown.

An assessment of fish habitat (NRMC, 2003) comparing pool depths in 1991 to pool depths in 2002 found an increase in the proportion of channel occupied by pools > 2 ft deep. Cross-section monitoring data do not corroborate this trend, nor would cross-section data generally be expected to detect changes in pool depths. Cross-section surveys are not methodologically appropriate for monitoring changes in pool depths because pool location and topography is dynamic. There are several possible explanations for the reported trend of increasing pool depth:

1. Differences in streamflow and water level at the time of the two surveys may have influenced field observations of pool depth.
2. Higher streamflows occurred in the years prior to the 2002 survey and may have induced greater sediment transport, whereas drought conditions characterized the years prior to 1991 surveys and sedimentation may have dominated over transport.
3. The growth of riparian vegetation (primarily willows and alders) on the edges of many gravel bars and banks may have confined and focused flow energy in the established thalweg, thus encouraging scour and the deepening of existing pools.
4. A reduction in sediment load in the mainstem South Fork and Wheatfield Fork Gualala would be expected to allow for the development of deeper pools. The NCWAP report concluded that there was a watershed-wide trend over the period 1984-2000 toward channel "recovery" from excess sedimentation attributed to earlier logging activity. Aggregate extraction further reduces the sediment load to downstream reaches.

We calculated an estimated annual rate of gravel replenishment for the Wheatfield Fork and the South Fork at Valley Crossing of approximately 25,000 t/yr (15,700 yd^3) from analysis of channel cross sections and reported aggregate extraction over the period 1996-2002. Short term replenishment rates would be expected to vary over time. Uncertainty exists regarding long-term sediment supply and bed load transport rates in the Wheatfield Fork and South Fork watersheds where short term replenishment rates were calculated from monitoring data. An assessment by the California Geologic Survey (CGS) of long term sediment production from the likely dominant sediment source in the Gualala River watershed (rockslides and earthflows), however, indicates that observed short term gravel replenishment rates are near the lower end of the range of estimated long term sediment production rates.
The calculated replenishment rate in the vicinity of Valley Crossing (25,000 t/yr) does not include gravel replenishment to the permit area from two other major tributaries: Buckeye Creek and Rockpile Creek. Sediment production estimates for these watershed developed by CGS were calibrated based on sediment production estimates for the South Fork and Wheatfield Fork and monitoring data. The calibrated watershed sediment production estimates were used to calculate an estimated gravel replenishment rate of 11,000 t/yr in the reach downstream of Buckeye Creek. Hence, the total estimated replenishment rate of the permit reach based on available data is 36,000 t/yr. This rate of

replenishment is lower than the existing permitted extraction rate of about 64,000 t/yr (40,000 yd^3).

Based on the replenishment rate to the Valley Crossing reach of 25,000 t/yr, it is likely that the average annual extraction rate for 1996-2002 of 19,000 t/yr in this reach could be increased by about 6,000 t/yr without causing channel degradation. Extraction of the full permitted amount from the Valley Crossing reach alone (about 64,000 t/yr) would likely cause degradation of the channel in this reach, which could potentially cause changes in channel morphology. Extraction of 36,000 t occurred in 1996 in the Valley Crossing reach did not cause significant channel degradation or significant changes in channel morphology, indicating that short-term extraction in excess of average recharge rates are feasible.

A detailed set of recommendations pertaining to mining standards and monitoring requirements are presented at the end of the report. The analysis of aggregate extraction rate and channel response suggests the following strategy for future management of aggregate resources in the project area. This strategy presumes that avoidance of channel bed degradation is the governing criterion for management of environmental risks.

INTRODUCTION

This report provides an assessment of the degree of geomorphic change associated with instream gravel mining operations in the Wheatfield and South Forks of the Gualala River, northern Sonoma and southern Mendocino Counties. Gualala Redwoods Inc. was granted a permit from Sonoma County Permit & Resource Management Department (PRMD) to extract 40,000 cubic yards (~64,000 t)of gravel per year from the channel of the Wheatfield and South Forks of the Gualala River. The gravel mining operations have been focused near the confluence of the two tributaries, and in South Fork in the reach downstream from the confluence (this area is referred to as the Valley Crossing reach). The purpose of this report is to evaluate potential geomorphic impacts to the channel in this reach, and to determine whether the maximum allowable gravel extraction limit should be modified. Suggestions regarding future monitoring procedures are also presented.

In the EIR prepared by EIP Associates (1994) a significant geomorphic impact is defined as an effect that:

> *"causes a change to the sediment transport regime of the river, and therefore affects the river channel's size, shape, planform or profile to the extent that the performance or stability of adjacent structures is affected, property is lost, the quantity or quality of fish and wildlife habitat is substantially changed, or the quality and quantity of surface or groundwater supplies is substantially affected"*

This report is based on the analysis of cross section data collected by Dimensions 4 Engineering Inc. over the 6 year period, field reconnaissance carried out in October, 2002, and a review of available information including topographic profiles of the river and aerial photographs from 1959, 1996, 1998 and 2002. Additional information was provided in the initial Environmental Impact Report (EIP Associates, 1994). This report includes information on:

- Gravel replenishment rates
- Changes or trends in the channel thalweg
- Bank erosion
- The location and estimated amount of channel aggradation or degradation
- Stability of the river near the Sea Ranch wells and highway bridges

Changes to the aquatic habitat, including changes in pool width, depth and frequency associated with the permitted gravel extraction operations are discussed in the companion report prepared by Dennis Halligan, Natural Resources Management Corporation of Eureka (NRMC, 2003).

The gravel extraction permit required that channel cross sections were surveyed at each extraction site, including observations of thalweg and water surface elevation. Cross sections were surveyed on every bar on which skimming was completed during the year, before and after mining was completed. The cross section data obtained from these surveys was provided by Dimensions 4 Engineering, and was used as the primary basis of this assessment.

BACKGROUND

The Gualala River watershed is located along the southern Mendocino and northern Sonoma Coast (See Figure 1), and drains to the Pacific Ocean near the town of Gualala. The total catchment area is 298 square miles. The two largest tributaries to the Gualala are the Wheatfield Fork (110.3 mi^2) and the South Fork (59.6 mi^2), whose combined catchment area makes up 57% of the total Gualala drainage area. Topography in the catchment consists of moderate to steep slopes, flat-topped ridges, and marine terraces. Coastal conifer forests of redwood and Douglas fir occupy most of the northwestern, southwestern and central portions of the watershed, while oak-woodland and grassland occupy many slopes in the interior basin. Coho salmon and steelhead populations were known to inhabit stream channels in the Gualala River, however, few coho salmon have been observed in the Gualala River since the 1970's, and in recent years steelhead populations have declined as well (Klampt *et al*, 2002).

Hydrology

Precipitation in the Gualala Watershed is highly seasonal, with the majority of precipitation falling between October and April. Mean annual precipitation ranges from about 33 inches at the coast to 63 inches at higher elevations. The highest rainfall amounts occur along the drainage divide in the southeastern region, in the headwaters of the Wheatfield and South Forks. The following information was summarized from the North Coast Watershed Assessment Program (NCWAP) Gualala Watershed Synthesis Report (Klampt *et al*, 2002).

A single stream flow gauge existed in the watershed historically, located downstream of the Valley Crossing on the South Fork (USGS Gauge No. 11467500). The gauge measured runoff from 57% of the watershed area during the period from 1950 to 1971, and from 1991 to 1994. Significant flood events over 30,000 cfs were experienced in 1974, 1983, 1986, 1993, 1995, and 1997. The average annual peak discharge (2 year flood) is approximately 28,000 cfs, and the mean daily discharge is 43 cfs in summer and 823 cfs in winter. The maximum discharge of 55,000 cfs was recorded in 1956, and the 100 year flood is estimated to have a discharge of between 41,000 cfs and 65,000 cfs. Stream gauges were re-established on the Wheatfield and South Forks at the Valley Crossing in February 2002.

Two major municipal water users currently extract water from the Gualala River: the North Gualala Water Company, and the Sea Ranch. The Sea Ranch once drew water directly from the South Fork Gualala, but they currently draw from the aquifer beneath the riverbed by offset wells located at cross-section 16, 0.6 miles downstream from the confluence with the Wheatfield Fork. The Sea Ranch water permit allows for a maximum pumping rate of 2.8 cfs, although historically the actual rate has been substantially less. The Sea Ranch water take is also dependent on minimum fish by-pass flows stipulated in the SWRCB permit.

Geology and geomorphology

The Gualala River is a gravel bed river that exhibits extensive gravel bars and a meandering low flow channel configuration. The low flow channel is approximately 10 to 30 feet wide, and the gravel bars are occasionally vegetated. The bed material is composed of particle sizes ranging from silt to cobbles, but consists primarily of medium to coarse gravel underlain by finer gravel and sand. The surface bed material D_{90} was estimated in the field in October 2002 at approximately 63-90 mm (where D_{90} represents the diameter (D), in millimeters, of which 90% of the bed material is finer), and the surface D_{50} was about 22-31 mm. The subsurface D_{50} was estimated at about 6 mm, and it appeared to contain a substantial proportion of sand. The channel banks were composed of sand and silt, and in the vicinity of the project area were approximately 10 ft high. Aggradation in the lower reaches of the Wheatfield and South Forks has probably resulted in subsurface water flow in these areas, especially in the summer months.

In the Gualala watershed, the distribution of landslides, channel types, and sediment are primarily controlled by the distribution and physical properties of the underlying geologic formations (Klampt *et al*, 2002). The resistance of the bedrock to erosion is highly variable and depends on the rock composition and the degree of deformation. The Gualala watershed developed in response to a complex series of episodes of subsidence and uplift probably associated with strike-slip faulting on the San Andreas Fault. The majority of the Wheatfield and South Fork catchments are underlain by the Franciscan formation, and the whole of the Gualala watershed is within the boundaries of the San Andreas Fault System and the Tombs Creek Fault Zone. As a result the underlying rocks

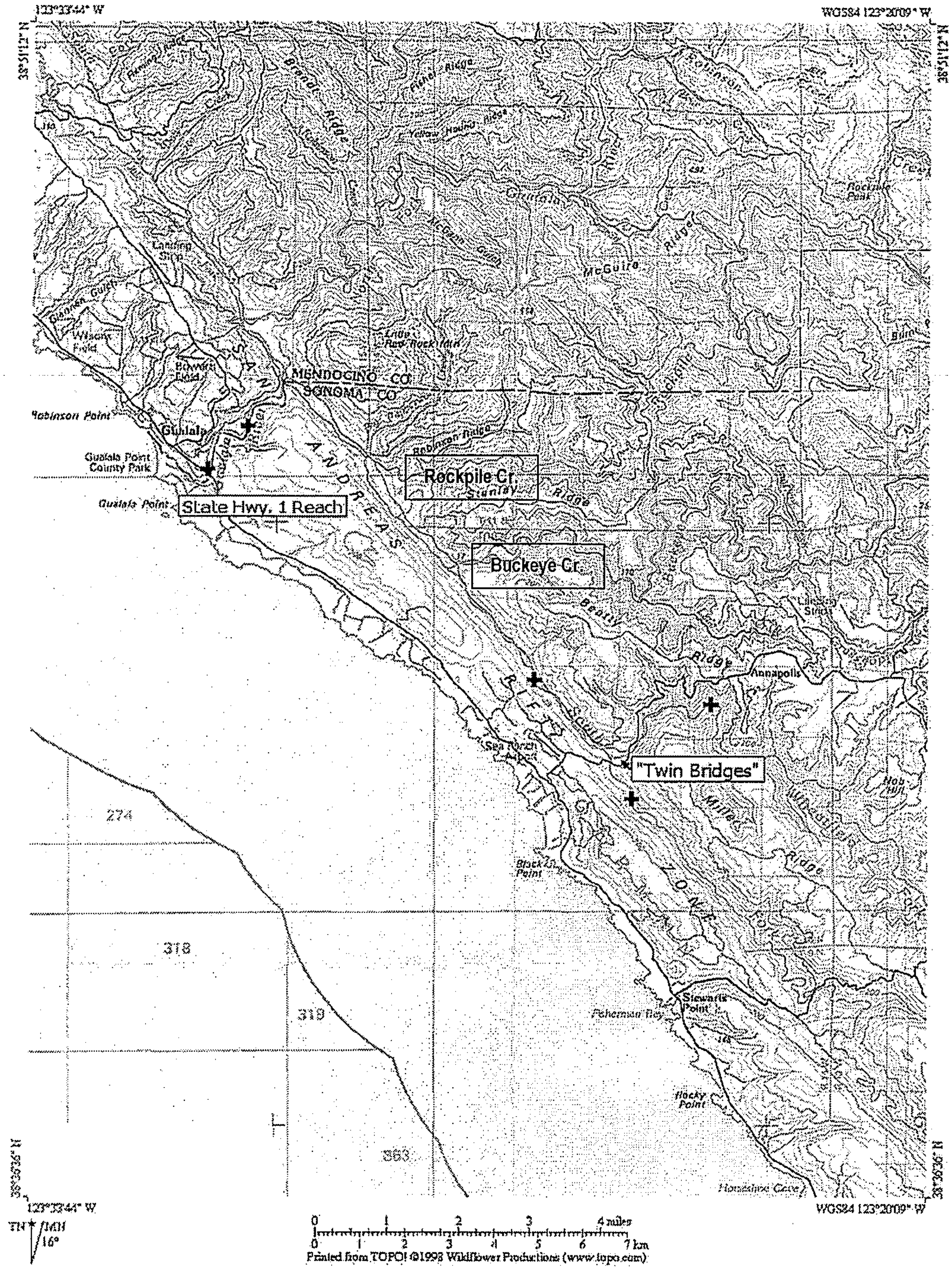


Figure 1 Map of the Gualala River showing the location of the State Highway 1 (SH1) and Valley Crossing study reaches (between the crosses).

are generally intensely sheared and inherently unstable, and mass wasting is common and sediment supply rates to both tributaries are high. The underlying geology and potential for landslides is similar in both catchments (Landslide Potential Map prepared by California Geologic Survey, included in Klampt *et al*, 2002).

South Fork: Most of the South Fork flows within a linear valley formed by the San Andreas Fault (Klampt *et al*, 2002). The upper reaches, however, are incised into bedrock and occupy a valley parallel to and east of the San Andreas Fault. Large active earthflows are common and small historically active landslides are abundant (Klampt *et al*, 2002). The majority of the historically active small landslides occur within the generally more stable Coastal Belt Franciscan rocks, which have been severely weakened by shearing within the San Andreas Fault Zone. Of particular interest is a zone of very high landslide potential, including active landslides and debris flows, near the confluence of the South Fork and the Wheatfield Fork, and extending upstream along the South Fork for approximately 3 miles (Landslide Potential Map prepared by California Geologic Survey, included in Klampt *et al*, 2002). This area of very high landslide potential may be a significant sediment source to the South Fork upstream of the gravel extraction zone.

Wheatfield Fork: The headwaters of the Wheatfield Fork lie on the east side of the Tomb Creek Fault Zone, within the Central Belt of the Franciscan Formation, however Coastal Belt Franciscan rocks underlie the majority of the catchment (Klampt et al, 2002). Multiple generations of movement along strike-slip faults associated with the San Andreas Fault Zone have progressively disrupted and rearranged the drainage pattern. The Wheatfield Fork basin is entirely underlain by the Franciscan Formation, however on some ridge tops the Ohlson Ranch Formation overlies the Franciscan. The Ohlson Ranch formation was deposited during the Pliocene when much of the basin was below sea level, and resulted in the formation of several marine terraces and flat-topped ridges with a veneer of marine sediments. The Ohlson Ranch Formation is poorly consolidated and is subject to landsliding along the edges of terraces or along incised channels. There are also large areas of high and very high landslide potential in the Wheatfield Fork watershed (Landslide Potential Map prepared by California Geologic Survey, included in Klampt *et al*, 2002).

Gravel extraction

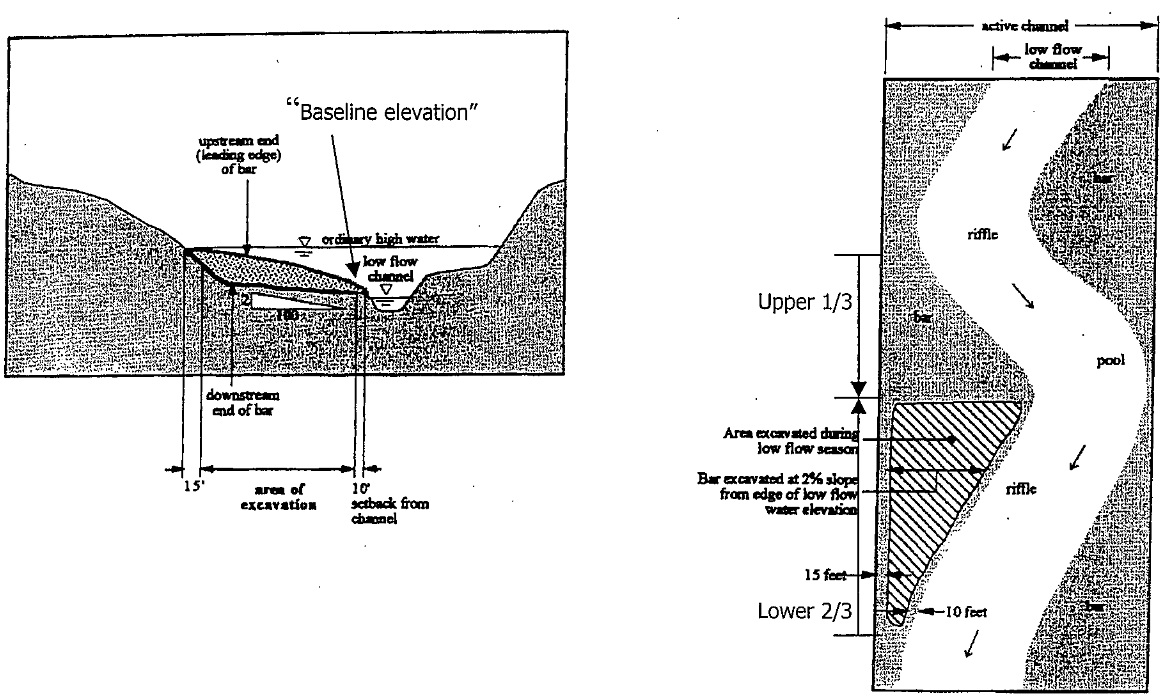
Gravel extraction in the Gualala River has occurred on a small scale periodically since settlement in the late 1800's (EIP Associates, 1994), but began in earnest in the 1950's with the removal of 1,000 to 5,000 yd^3/yr (1,600 to 8,000 t/yr) of material for the construction of logging roads. Commercial extraction began in the 1960's with rates of about 20,000 yd^3/yr (32,000 t/yr) and accelerated to 40,000 yd^3/yr (64,000 t/yr) in the late 1960's with increased demand for aggregate for building and roads associated with the development of Sea Ranch. No information was available on gravel extraction rates during the period from the early 1970's to 1984. The average rate of gravel extraction from 1984 to 1990 was approximately 23,000 yd^3/yr (37,000 t/yr). For the period 1996-2002, gravel extraction rates have varied from 13,000 to 36,000 tons per year, with an average annual rate of gravel removal since 19,000 tons per year. A summary of gravel extraction rates and corresponding aggradation or degradation rates are shown in Table 1.

Table 1. Summary of gravel extraction rates in the Gualala River from the 1950's to present day (data prior to 1995 from EIR). Volumes converted to mass using density of 1.59 t/yd^3

Time period	Approximate extraction rate		Bed elevation change	Comments
	(yd^3/yr)	(t/yr)	(ft)	
1950's	1,000 to 5,000	1,600 to 8,000	+1.5	Logging road construction
1960-1964	20,000	32,000	-1	Commercial extraction
1965-1971	40,000	64,000	-0.75	Sea Ranch development
1984 to 1990	23,000	37,000	-1	At Clipper Mill Bridge
1996 to 2002	12,000	19,000	+0.1	Permit period

Gravel mining is conducted by bar skimming during the summer and fall months. The minimum bar elevation after mining under the terms of the permit is defined by the elevation of the low flow; the bar is skimmed such that the surface slope of the bar after mining is 2% transverse to flow from the low flow elevation to the bank. In addition, a buffer zone 10 feet wide separates the low flow channel from the excavation area. See Figure 2 illustrating the bar skimming method. At present the maximum allowable extraction limit is 40,000 cubic yards per year. The gravel extraction permit allows removal of gravel from the channels of the Wheatfield and South Forks of the Gualala River, in the vicinity of the Valley Crossing and downstream to the confluence with the North Fork Gualala River. The entire permit reach is approximately 20 miles in length.

Figure 2. Gravel mining operations on the Gualala River (reproduced from the EIR, EIP Associates, 1994). The allowable extraction area is based on the baseline elevation at a 2% outward slope from the water surface elevation in the first year of survey.



Environmental Impact Report:
In the environmental impact report, all existing cross sectional data on the Gualala River was reviewed. The following is a summary of the results of the analysis of cross section data.

At the Clipper Mill Bridge at the upstream end of the project area on the South Fork, bridge construction drawings indicated no significant change in bed elevation from 1921 to 1982, however, approximately 3 ft of degradation was indicated during the period from 1982 to 1993. The data points from 1993 were derived by measuring the distance from the channel bed to the bridge deck in two locations. By comparison of construction drawings of the Annapolis Rd Bridge on the Wheatfield Fork, approximately 3 ft of degradation appears to have occurred between 1975 and 1992, however the South Fork did not show any significant bed level change over the same period.

The site of the USGS gauging station, just downstream from the confluence of the Wheatfield and South Forks, also provided information on bed level changes through analysis of gauging records. There was 1.5 ft of aggradation indicated on the lower south Fork from 1950 to 1960 when extraction rates were 1,000 to 5,000 cy/yr (see Table 1), followed by 1 ft of degradation between 1960 and 1964 when the rate of gravel extraction increased to 20,000 cy/yr, and a further 0.75 ft of degradation between 1964 and 1971 when extraction was being carried out at 40,000 cy/yr. Data from a cross section referred to as A/2 in the EIR just below the confluence indicated approximately 1 ft of degradation from 1984 to 1992. A change in the form of the cross section was also noted, with the section becoming considerably flatter due to an increase in thalweg elevation, and a decrease in bar height. The change in cross section shape was presumably due to gravel bar skimming operations.

In the Environmental Impact Report, the following potential effects of gravel extraction on the Gualala River were identified: channel degradation (a decline in bed elevation) might occur at the specific mining sites, as well as in reaches upstream and downstream, especially if the rate of gravel removal exceeds the rate of gravel replenishment. The removal of gravel may also cause a reduction in gravel bar height, leading to the erosion or destabilization of the channel banks. Mining of gravel from bar surfaces temporarily removes the armor layer. Sediment transport may then occur at lower flows than before until the armour layer is re-established, possibly leading to a general increase in sediment transport through the reach; this in turn may lead to an increase in the mobility of gravel bars, and an overall reduction in channel stability. Alternatively, the removal of gravel may cause a local reduction in sediment supply, and lead to erosion of downstream bars.

Gravel extraction by bar skimming has been implemented in Sonoma County in part as an alternative to extraction by dredging of the channel bed. A study of dredging impacts in the Vedder River in British Columbia (Martin and Church, 1995) found that within reach channel instability was in large part attributable to dredging, which also contributed significantly to the total mobile sediment volume. Bar skimming has been adopted in

Sonoma County and in the Gualala River as the method of aggregate extraction to minimize geomorphic impacts.

METHODS

A combination of methods was used to assess channel geomorphic conditions and gravel (aggregate) recharge rates. These include field reconnaissance, interpretation and analysis of historical aerial photography, analysis of monitoring data, including cross-sections and thalweg elevations, and analysis of recent aggregate extraction in combination with monitoring data to estimate mean changes in channel elevations and gravel recharge rates.

Field survey

A field reconnaissance of the Wheatfield Fork and South Fork Gualala River in the vicinity of the confluence (Valley Crossing) was conducted on October 18, 2002. We walked the channel from XS 16 at the Sea Ranch Well site upstream to the confluence, and several hundred feet upstream on each tributary. During the field reconnaissance we noted bed and bank conditions including bed material characteristics, bank erosion, bar composition and height, and any evidence of channel aggradation or degradation. Particular note was taken at the location of the Sea Ranch Wells, and at the Annapolis Road bridges. The location of the cross sections was noted, and the general form of the channel observed. Other relevant observations such as the location of bar skimming operations and bank stabilization efforts were also noted. A brief reconnaissance of the lower Gualala River in the vicinity of State Highway 1, including observations of the bridge footings at State Highway 1, was conducted in May, 2003.

Aerial photo interpretation

Aerial photographs of the Valley Crossing area taken in 1959, 1996, 1998 and 2002 were analyzed. Pairs of photos were observed in stereo at 3x magnification and observations were made regarding bank erosion, channel pattern, extent of bars, channel width, channel form and general appearance, position of the low flow channel, and the amount and location of in-channel vegetation. Bank erosion was identified on the aerial photographs by the observation of a fresh scarp, that often is associated with a different color or a lack of riparian vegetation. Sometimes bank erosion was identified by the presence of downed trees on the edges of the channel, or a greater channel width than the preceding years' photography. Qualitative observations from aerial photography were supplemented by field observations in October 2002.

Analysis of cross sections

Cross section surveys have been carried out on the Gualala River over a significant period of time, however, prior to 1995, few of the cross sections had permanent monumented benchmarks. The location of cross section surveys conducted under monitoring provisions of the gravel mining permit typically varied from year to year, depending in large part on where annual mining operations occurred. This lack of consistent cross section locations limits the usefulness of the data when interpreting changes in bed elevation and cross section form through time. Each cross section represents only a snapshot of channel conditions at the time of surveying, and only cross sections that were surveyed regularly and at consistent locations were used to identify channel changes. The analysis focused on the use of trends through time as well as trends in each reach, where there were several cross sections in each reach (i.e. no conclusions were drawn from the analysis of individual, isolated cross sections).

Dimensions 4 Engineering supplied cross section plots from the reach upstream of State Highway 1, and in the vicinity of the confluence of the South Fork with the Wheatfield Fork. The plots were visually inspected to gain a general impression of the behavior of the river during the period 1996 to 2002. A visual determination of mean bed level was made and areas of aggradation or degradation were noted. Cross section data for cross sections with dates spanning the permit period 1996–2002 was supplied by Dimensions 4 was analyzed quantitatively. The mean bed level of the active bed at each cross section was calculated using distance and elevation data extracted from plan drawings and data listings supplied by Dimensions 4. The active bed is defined as the portion of the channel that readily responds to the flow and is generally composed of unconsolidated sand, silt and gravel.

Mean bed levels were calculated for the active bed portion of the cross sections from the 1996 and 2002 surveys. These survey dates were chosen to determine gross rates of channel aggradation or degradation over the whole period during which gravel mining operations were conducted under the permit. Fluctuations in the bed elevation may have occurred between 1996 and 2002, however analysis over a longer period of time was considered preferable to identify trends through time because short-term fluctuations in bed elevation are expected in gravel-bed rivers. Mean bed levels were derived for each cross section by calculating a weighted average of the bed elevations, using the distance across the channel as the weighting factor. The total amount of aggradation or degradation was derived by subtracting the 2002 mean bed level from the 1996 mean bed level. A positive result indicates aggradation and a negative result indicates degradation. The aggradation rate was then calculated by dividing the total change in mean bed level by the number of years between surveys.

For the purpose of this investigation the Gualala River was divided into four reaches:

1. Gualala Reach near State Highway 1 (SH1; xs 1-5)
2. South Fork downstream of the confluence with the Wheatfield Fork (lower South Fork: xs 1-21), includes South Fork -Valley Crossing Reach, South Fork - Buckeye Reach, and South Fork - Rockpile Reach
3. Wheatfield Reach above the confluence with South Fork Gualala (xs 23-27, 36-46)
4. South Fork Reach above the confluence with Wheatfield Fork (upper South Fork; xs 22, 28-35)

The length of each reach and the distance from each cross section to the mouth was determined from topographic maps and plan drawings. Longitudinal profiles of the South

Fork and Wheatfield Forks were also constructed using distance and elevation data from USGS topographic maps. Reach slope was calculated using the difference in mean bed level between successive cross sections, divided by the distance between them. The width of each cross section was determined using the survey data and cross section plots. An average width was then determined for each reach.

Total bedload transport into the reach was estimated as the mass of accumulated material from aggradation, plus the mass of extracted material. Yearly extraction data (in tons) were reported to PRMD by Gualala Aggregates, Inc. The total volume of accumulated material was calculated by multiplying the total amount of aggradation (or degradation) in each reach, by the length and the average width of the reach. The volume of accumulated material was converted to a mass by multiplying by a density of 1.59 t/yd^3. The sediment yield was calculated by dividing the total mass of accumulated gravel by the contributing drainage basin area.

Analysis of cross section data to infer a bedload transport rate assumes that the material is being measured on its passage through the surveyed reach. The time period between surveys must be short enough relative to the length of the reach and the sediment transport rate such that bedload material does not move through the reach more rapidly than the interval of cross-section observations. The project reach is just over 1 mile in length, and the critical time interval over which cross sections were compared to infer transport rates was 6 years. Typical annual bedload velocity in gravel bed rivers determined from a review of gravel tracer studies (NCASI, 1999; Bunte and MacDonald, 2002) is about 0.06 miles per year (100 m). Over the study reach, the expected transport distance during the 6 year study period would be about one-third of a mile. Therefore it is likely that the cross section surveys adequately recorded the movement of gravel through the project reach, and bedload transport estimates are reasonably accurate.

Thalweg elevation changes

Dimensions 4 Engineering supplied the cross section data. The elevation of the channel thalweg (the deepest point in the channel), were tabulated for each cross section each year. The thalweg elevations were then compared between years to determine if the channel had aggraded or degraded between consecutive years.

Longitudinal profile

Longitudinal profiles of the South Fork and Wheatfield Fork were constructed using the distance along the channel, between the 40 ft contour lines on USGS Topographic maps. Separate longitudinal profiles of both tributaries in the Valley Crossing area were constructed using the mean bed level data from 1996 and 2002 cross section data.

Water level fluctuations and minimum baseline elevations

Minimum baseline elevations to be maintained after mining are determined by the water surface elevation of the low flow channel in the first cross section survey performed prior to gravel extraction at a given location. In the Gualala River, these surveys have taken place in different dry-season months each year, ranging from October in 1996 to May in 1998. Water levels are expected to fluctuate both from month to month as the dry season progresses and water table flows to channels decline, and from year to year. The magnitude of month to month variations are inferred from water level observations at monitoring cross-sections, and placed in perspective of relative amounts of annual rainfall over the period 1996-2002.

RESULTS and DISCUSSION

Field survey

We observed several large gravel bars in the channel between the Sea Ranch well site and the confluence of the Wheatfield and South Fork (between cross sections 16 and 21). The bars were composed of sand and gravel, with smaller patches of sorted sand, and were all approximately 4-5 ft above the channel bed. Willows growing on these bars indicates that they have remained relatively stable over a period of several years. The low flow channel was primarily single thread, and the bank full channel typically had two channels with some medial bars.

There was no direct evidence of degradation near the Sea Ranch wells, or at the Annapolis Road bridges, however, there was a scour hole about 3 ft deep at the Wheatfield Fork bridge footings. The channel did not appear to be unstable. On the South Fork, surface water was discontinuous, and was approximately 3 ft below the bed surface. We observed some bank erosion on both tributaries, and on the right bank of the South Fork just upstream of the Annapolis Road bridge we observed efforts to stabilize the banks with willow plantings and jute netting.

There were several older terrace or floodplain surfaces present adjacent to the channel. These surfaces were all approximately 13 ft (4 m) above the channel bed, and 30-40 year old redwoods were growing on these surfaces. These terrace or floodplains are composed of interbedded sand and gravel strata, with approximately 3 to 6 ft (1 to 2 m) of fine sediment at the top of the deposit. Terrace/floodplain deposits might have been substantially mobilized and enlarged during a large flood event in 1974. Overbank deposits of fine sediment appeared to have occurred more recently (perhaps in 1997) in some locations on these terrace/floodplain surfaces adjacent to the channel.

Based on field observations, channel conditions in the project area are relatively stable. Bank erosion affected a low proportion of the channel length and there was no evidence of significant degradation in the vicinity of the Sea Ranch wells or the Annapolis Road bridges. Many gravel bars are well vegetated with willows and alders about 5 to 10 years old. The presence of several large gravel bars suggests that the aggregate extraction has not exceeded sediment supply to the reach.

At State Highway 1, the right bank of the active channel is currently adjacent to the northernmost bridge pylon, with relatively high water depth. On the opposite edge of the channel, a large gravel bar is present. These conditions appear to be normal alluvial channel conditions, and no evidence of unusual scour was observed.

Aerial photo interpretation

In general, there was minimal channel change observed in aerial photographs over the period 1996 to 2002, during which time gravel mining occurred under the terms of the current permit. The channel is essentially single thread, and there were only minor changes in low flow channel position that were probably associated with the switching of channel positions in response to migrating gravel bars. It was evident based on the overall stability of channels and minor changes in channel pattern that widespread significant bank erosion has not occurred since 1996. Some bank erosion would be expected under any circumstances.

The oldest photographs available for our analysis were from 1959. A number of substantial changes were identified between 1959 and more recent years. The channel had a more aggraded appearance in 1959, with a wider channel that showed evidence of channel migration, particularly in the area immediately below the confluence of the Wheatfield with the South Fork. The channel appears substantially narrower in more recent years, and there are more vegetated bars evident from 1996-2002 compared to 1959, which indicates that the bars are stable enough to allow willows and alder to become established, and that summer water levels are in the root zone. The decrease in channel width and the increase in the amount of vegetated bars suggests relative stability of the channel over the last decade. It was noted also in the EIR (pg 3-25) that the low flow channel appeared to have narrowed slightly from 1980 to 1990, despite several large floods in the 1980's, and that the amount of in-channel vegetation increased from 1961 to 1971. The NCWAP stream channel assessment also noted similar trends throughout the watershed, and concluded that a decline of sediment inputs between 1984 and 2000 is manifested by channel narrowing and the recovery of riparian vegetation.

Observations of bank erosion, channel pattern, extent of bars, channel width, channel form and general appearance, position of the low flow channel, and the extent and location of in-channel vegetation were made from detailed aerial photograph interpretation. These observations are summarized in Table 2. These narrative descriptions of channel change support the general conclusion that although changes occur at specific locations, significant geomorphic change has not occurred in response to aggregate extraction.

There was a minor amount of bank erosion detected in all years of photography, and there did not appear to be any trends of increasing bank erosion during the period of gravel extraction. The channel appeared to have stabilized since the 1959 photography, which showed evidence of greater bank erosion, and channel avulsions on the South Fork and in the main stem. Bank erosion and channel avulsions observed in 1959 photography are likely the result of a large flood event combined with relatively high sediment supply.

The persistence of bank erosion in the control reaches, which were located 2000 ft upstream of the highest extent of gravel extraction, indicate that some bank erosion is expected to occur with or without gravel extraction. There does not appear to be an increase in channel instability (indicated by an increased level of bank erosion and or changes in channel pattern), associated with recent gravel mining.

Qualitative analysis of cross sections

Each cross section plot prepared by Dimensions 4 Engineering (Appendix 2) was examined qualitatively to assess whether the mean bed level and the thalweg elevations had increased (aggraded) or decreased (degraded) during the permit period (1996 to 2002). In addition, the position of the banks was inspected to determine if bank erosion or sedimentation on the banks had occurred. Each comparison of a cross-section from one year to the next was treated as a separate observation. A summary of the observed qualitative changes in cross section mean bed level, thalweg elevation and bank erosion between survey years is listed in Table 3.

Percentages of cross sections exhibiting aggradation or degradation through time are shown in Table 3. Interpretation of these data is difficult because comparisons generally span only one year at a gravel extraction site. In addition, interpretation of the cross-section plots was uncertain with respect to bank position because stream banks did not appear to be consistently located and surveyed. Finally, the number and location of cross-sections varied over time, making it difficult to develop a consistent interpretation. Although the percentage of cross sections exhibiting degradation of the thalweg increased from 1996 to 2002, the total number cross sections surveyed in 2002 was 12, much less than for the other years. Although there is some indication of a trend toward declining thalweg elevation, there is a contrary trend in channel bed toward aggrading conditions. There is an apparent trend toward increasing bank erosion in Table 3, however, observations of bank erosion in aerial photography (Table 2) did not corroborate the bank erosion trend suggested in Table 3.

Table 2 Observations from aerial photo interpretation for each reach

Reach	Observations
Mainstem xs 1-5 (SH1)	Slight bank erosion was detected on the LB downstream of SH1 bridge; it was present in all years of photography from 1959 to 2002, most of the reach appears stable and the banks are well vegetated. This reach is tidal and may be affected by changes in long shore sediment transport, as well as changes in sediment supply rates from upstream.
xs 1-15	Minor bank erosion observed in the 1996 and 1998 photos near xs 15, mining was conducted in this reach in 1996 and 2002, there were no obvious changes in planform pattern, thalweg position or riparian vegetation.
xs 16-21	In the 1959 photos, there was some bank erosion on the RB associated with an avulsion at the confluence of South Fork, this area had revegetated by 1996. Some minor bank erosion occurred on the RB near xs 16 and 21 in 1996, and near xs 17 in 1998 and 2002; there appeared to be several medial bars formed in the channel at xs 17 in the 1998 photos that were vegetated, and they appeared enlarged relative to 1996; this may have encouraged bank erosion by deflecting the flow around the outside of the bars towards the bank. The presence of medial bars suggests that the sediment supply to the reach remains high enough for the formation of new bars (if the upstream sediment supply was significantly reduced we would not expect to see the formation of new medial bars).
South Fork xs 22-33	There was no bank erosion observed on the left bank through this reach, however there was persistent bank erosion between xs 30/31 and at xs 33 in all years of aerial photography. In the 1959 photos there appeared to be a channel avulsion with two small channels cutting across the meander bend. In the 1996 photos there was a large log jam in the channel near xs 33. The thalweg shifted slightly in the vicinity of xs 30/31 between 1996, 1998 and 2002. This reach has been mined every year since 1996.
xs 34-35	Control reach. There was a small landslide on the LB in the 1959 photographs, and there was also a road crossing in the channel in this reach. There was a small patch of bank erosion on the RB near xs 35 in the 1998 photography. Between 1998 and 2002 there was logging on the RB, but a riparian buffer was left adjacent to the river. There was minimal change in the position of the thalweg, and a continuous riparian buffer in all photo years. No gravel extraction has occurred in this reach.
Wheatfield Fork xs 23-27	Bank erosion was observed at several locations in the1959 photography; at xs 26 on the LB, and at xs 23 on the RB. Trees appeared to be down on the edge of the channel at xs 23. A small gully had developed between xs 23/24 on the RB in the 1996 photographs, and enlarged slightly by the 1998 photos. The gully had revegetated and appeared inactive by 2002. There was also some minor bank erosion between xs 25 and 27in the 1998 photos, and at xs 27 in the 2002 photos. The planform pattern and the thalweg position remained essentially stable from 1996 to 2002. Gravel extraction occurred intermittently in this reach since 1996.
xs 36-44	Minor bank erosion was observed on the RB near xs 36 in the 1959 and the 1996 photography. There were no changes in the thalweg position or planform pattern, and a continuous riparian strip was present in all years of photography. Gravel extraction was conducted in this reach from 1998 to 2002.
xs 45-46	Control reach. There was no photo coverage of this reach for 1959. Slight bank erosion was observed near xs 45 (LB) in the 1998 photography, and upstream of xs 46 (RB) in the 2002 photography. There were no obvious changes in thalweg position or planform pattern from 1996 to 2002. No gravel extraction has occurred in this reach.

Table 3 Summary of the changes in mean bed level, thalweg elevation and bank erosion for cross section pairs between survey years. The data are presented as the percentage of the total number of observations for each year.

Observation		year of survey			
		96/97	97/98	98/99	99/02
Thalweg	% Aggradation	58	52	39	33
	% Degradation	13	12	31	66
	% No change	28	32	31	0
	Total number of xs pairs	40	25	36	12
Channel Bed	% Aggradation	38	32	28	50
	% Degradation	18	28	17	33
	% No change	45	36	56	17
Banks	% Erosion	15	12	47	58
	% Accretion	40	38	27	33
	% No Change	45	50	26	9

Quantitative analysis of cross-sections

Analysis of mean bed level changes and observations of cross sections measured between 1996 and 2002 revealed that both the South Fork and the Wheatfield Fork of the Gualala River in the vicinity of the at Valley Crossing are aggrading. The cross section locations are shown in Appendix 1. A summary of the results from the analysis of the cross sections is shown in Table 4.

The South Fork just upstream of the confluence with the Wheatfield Fork aggraded at a rate of 0.2 ft/yr (56-67 mm/yr) from 1996 to 2002. The South Fork just below the confluence also aggraded at a rate of 0.08 to 0.09 ft/yr (26-28 mm/yr). The Wheatfield Fork is also aggrading at 0.09 ft/yr (27 mm/yr) just upstream of the confluence, however 0.3 miles upstream (sections 25-27), the Wheatfield Fork appears to be degrading slightly at a rate of 0.01 to 0.02 ft/yr (1-6 mm/yr). Further upstream in the Wheatfield at cross sections 36 to 46, the bed elevations were essentially stable, with a few minor fluctuations but overall there seemed to be a net balance in bed elevation. Cross sections 34 and 35 on the South Fork, at the upstream end of the project area, also show aggradation at a similar rate to the sections in the extraction zone

The cross sections were surveyed over a 6 year period. During this time the watershed experienced a broad range of hydrologic and climatic conditions that included wet and dry years. Of particular note were a regional flood event on January 1, 1997, and the El Nino winter that caused unusually high runoff during the 1998 Water Year. The hydrologic and climatic conditions during the period over which the observations were made represent reasonably average conditions, and can be thought of as a fairly good representation of the range of flow conditions expected in the South Fork and Wheatfield

Fork of the Gualala River. Conclusions drawn from analysis of these cross sections therefore apply to average conditions in the river, rather than the response of the river to anomalous climatic conditions that may have caused changes in the sediment transport regime. To the best of our knowledge, no other major, short-term changes in watershed conditions occurred that might have altered the sediment supply or transport regime of the tributaries. The changes we observed in bed elevation therefore most likely reflect the response of the river to the gravel mining operations.

The channels of the Wheatfield and South Forks in the vicinity of Valley Crossing appear to be aggrading in most areas despite gravel mining. This suggests that the current rate of gravel extraction has not caused a significant geomorphic response, and that more gravel could feasibly be removed from the Valley Crossing reach without causing significant adverse geomorphic changes.

Gravel replenishment rates

We estimated an average rate of gravel replenishment of approximately 25,000 t/yr using channel aggradation rates calculated from cross sections, and extraction data. This value is consistent with the estimate of between 7,000 and 58,000 t/yr in the EIR (EIP Associates, 1994) for the lower South Fork. A best estimate of 23,000 t/yr (16,000 cy/yr) was given in the EIR as an estimate of the long-term average gravel replenishment rate for the Valley Crossing reach. This gravel replenishment rate in the EIR was calculated by USGS rating curve analysis, giving an indirect measure of bed level changes through the relationship between stage, flow and cross sectional area (i.e. the stage height for a given flow varies with bed elevation changes). The similarity of the two estimates derived through different methods gives confidence that the estimates adequately represent the actual rate of gravel replenishment in the project area. For further confirmation, we calculated a sediment yield for bed load (gravel and sand) of approximately 120 t/mi^2/yr for the South and Wheatfield Forks in the Valley Crossing area. This rate compares favorably to other estimated bed load sediment yield for rivers in the same region. A bedload sediment supply of 100 t/mi^2/yr was estimated by O'Connor Environmental, Inc. (Forest Soil & Water, Inc. et al 1998, Table 3-10) for the Garcia River, the adjacent catchment to the north. The Garcia River is expected to have a similar sediment yield to the Gualala River because the geology and climate of the catchment is similar.

The apparent aggradation rate in the monitoring reach between State Highway 1 and the North Fork Gualala confluence was less than what we estimated at the Valley Crossing area. This might indicate declining transport capacity near the river mouth relative to upstream reaches with higher gradients. Observed sediment deposition in the South Fork mainstem and at Valley Crossing is generally consistent with a downstream decline in sediment transport capacity. Sediment production from major tributaries in this reach is discussed below.

Table 4a Results of cross section analysis. The elevation change is calculated by comparing mean bed elevations from 1996 and 2002. The resulting volume of sediment accumulated in the reach was calculated by multiplying the average width of the active channel by the length of the reach and the change in mean bed elevation. Gravel extraction and recharge values for the Valley Crossing reach are shown in Tables 4b to 4d.

Reach	Section	Mean Bed Elevation 1996 (ft)	Mean Bed Elevation 2002 (ft)	Elevation change 1996-2002 (ft)	Rate (ft/yr)	Elevation Change 1996-2002 (m)	Rate (mm/yr)	Distance from Mouth (ft)	Active Channel Width (ft)		Reach length (ft)	Average volume delivered (ft^3)
									1996	2002		
Gualala												
MS	1	0.92	0.73	-0.19	-0.03	-0.059	-9.8	7090	300.0	315.2		
MS	2	1.80	1.98	0.18	0.03	0.055	9.1	11030	262.4	257.6		
MS	3	1.60	1.88	0.28	0.05	0.085	14.2	11410	261.6	257.6		
MS	4	2.79	3.05	0.26	0.04	0.079	13.2	14050	211.2	203.2		
MS	5	2.77	2.95	0.18	0.03	0.055	9.1	14330	189.6	184.8	7240	250473
Valley Crossing												
SF (lower)	16	30.71	31.22	0.51	0.08	0.155	25.9	54763	154	155		
SF (confluence)	21	37.80	38.36	0.56	0.09	0.171	28.4	57763	357	358	3000	410880
SF (upper)	29	39.06	40.17	1.11	0.19	0.338	56.4	58513	98	86		
SF (upper)	33	41.34	42.67	1.33	0.22	0.405	67.6	59263	131	135	750	103212
WF	23	39.08	39.61	0.53	0.09	0.162	26.9	58313	202	214		
WF	25	39.75	39.72	-0.03	-0.01	-0.009	-1.5	59136	198	190		
WF	27	41.61	41.49	-0.12	-0.02	-0.037	-6.1	60063	147	131	1750	39989
									Total for Valley Crossing reach =			554,081

Table 4b Accumulation totals (from Table 4a)

Accumulation (from Table 4a)	**Valley Crossing**	**Gualala**
Volume (ft^3)	554,081	250,473
Volume (yd^3)	20,500	9,277
Mass (tons)	32,600	13,526
Rate (tons/yr)	5,430	2,254

Table 4c Extraction totals reported to Sonoma County by permittee. Note that no extraction has occurred in the State Highway 1 reach to date.

Extraction[d,e] Valley Crossing	
1996	35,845
1997	15,695
1998	16,276
1999	17,843
2000	16,784
2001	(a) 13,232
Total	(b) 116,600

a. converted from reported extraction volume using density of 1.59 t/yd^3
b. excludes data prior to current permit

Table 4d Estimated recharge to Valley Crossing reach (1996-2002)

Recharge (short tons) Valley Crossing (1996-2002)	
Accumulation (c)	32,600
Extraction	116,600
Recharge (Acc + Ext)	149,200
Rate (tons/yr)	**24,900**

Notes: (a) converted from reported extraction volume using density of 1.59 t/yd^3
(b) excludes extraction data prior to current permit year
(c) used density of 1.59 t/yd^3
(d) as reported to Sonoma County PRMD by permittee
(e) no extraction has occurred in State Highway 1 (Gualala main stem) reach

Gravel extraction rates in relation to replenishment
At present, the maximum permitted aggregate extraction rate is 40,000 yd^3/yr (64,000 t/yr), over twice the estimated gravel replenishment rate in the Valley Crossing reach. The rate of aggregate extraction over the past 6 years (average rate 19,000 t/yr) was well below the maximum allowed , but much nearer the estimated replenishment rate of 25,000 t/yr in the Valley Crossing reach. The peak extraction rate was 36,000 t in 1996. Gravel extraction at this time was apparently focused in the reach downstream of the Sea Ranch wells, and at the confluence of the Wheatfield and South Forks. Inspection of the cross section data downstream of the Sea Ranch well before and after mining revealed only minor changes to the channel with most sections remaining stable up to one year after extraction was completed. It was not possible, however, to determine any long-term channel response in terms of bed elevation changes to this amount of gravel extraction because monitoring in this reach was only conducted before extraction, and the summer following extraction (i.e. the site would have only experienced one winter), although there was a significant flood event in January 1997. It was not possible to determine from the available data what proportion of the 36,000 t of sediment extracted was from the confluence area, and what proportion was extracted from the reach downstream of the Sea Ranch wells. Historic extraction prior to the 1996 appears to have caused measurable channel degradation (see Table 1), suggesting that the maximum allowable rate of about 64,000 t/yr (about 40,000 yd^3) concentrated in the Valley Crossing reach could be expected to induce channel degradation. However, if extraction is distributed over the entire permit reach (approximately 20 miles), the potential for channel degradation would be reduced.

The upper South Fork (above the Wheatfield confluence) appears to deliver approximately 2.5 times more sediment to the lower South Fork than the Wheatfield Fork, even though the South Fork catchment area is approximately half the size of the Wheatfield fork. The South Fork flows along the San Andreas Fault zone, and as a result sediment supply to the river would be expected to be relatively high. Aggradation rates of about 0.2 ft/yr were calculated for the Upper South Fork for the 1996 to 2002 period, whereas a maximum aggradation rate of 0.09 ft/yr was calculated for the Wheatfield Fork just upstream of the confluence, and slight degradation (-0.015 ft/yr) occurred at cross sections 25 and 27 further upstream on the Wheatfield Fork. Future mining operations should consider the higher gravel replenishment rate in the South Fork.

The majority of cross sections near State Highway 1, far downstream from the recent extraction sites near Valley Crossing, also exhibited channel aggradation of between 0.03 and 0.05 ft/yr (9-14 mm/yr). However, the most down stream cross section located near SH1 exhibited slight degradation (0.03 ft/yr) from 1996 to 2002. Cross section 1 is located nearest to the coast and experiences the strongest tidal influence and is probably subject to bed level changes associated with the opening and closing of the river-mouth and the formation of a seasonal lagoon. Continued aggradation of the downstream reaches suggests that the present rate of gravel removal from the upstream project site has not yet caused degradation of downstream reaches due to a decline in sediment supply. However, owing to the relatively slow movement of bedload sediment, no effects from recent gravel mining (since 1996) are anticipated at SH1 at this time

Thalweg elevation changes

Thalweg elevations are expected to fluctuate from year to year in gravel bed rivers reflecting changes in river flow and sediment delivery to the channel system. However long-term trends in thalweg elevations may indicate whether the channel is aggrading or degrading. Thalweg elevation for each cross section for each survey year are listed in Appendix 2. The number of cross sections exhibiting degradation, aggradation and the average change in thalweg elevation are listed for each year and reach in Table 5. The total number of cross section pairs varied each year because cross sections were only surveyed in reaches where mining occurred. Thalweg elevation data are also shown in Figures 3a, 3b, 4 and 5.

Table 5 Changes in thalweg elevation from cross section surveys: number aggrading, degrading and average change in thalweg elevation. The number of cross sections that exhibited more than one foot of degradation is also tabulated.

Reach	Year	No. of xs pairs	No. xs with aggradation	No. xs with degradation	No. xs with >1 ft degradation	Average change in Thalweg elevation
SH1	2002*	5	0	5	1	-0.59
MS	1997	16	11	5	0	0.94
	1998	3	3	0	0	1.55
	1999	3	0	3	2	-1.44
	2002	2	2	0	0	0.37
SF	1997	2	1	1	1	-0.77
	1998	2	1	1	1	-0.25
	1999	6	2	4	0	0.25
	2002	2	2	0	0	0.59
WF	1997	5	2	3	1	-0.15
	1998	0	0	0	0	na
	1999	9	7	2	0	0.53
	2002	3	0	3	2	-0.78
Valley Crossing (Aggregated MS, SF, WF)	1997	23	14	9	3	0.24
	1998	5	4	1	0	0.83
	1999	18	9	9	2	0.11
	2002	7	4	3	2	-0.17

*Data were only available for 1996 and 2002 for this reach

The overall trend in thalweg elevation was for aggradation during the period from 1996 to 2002: 55% of cross sections exhibited aggradation and 45% of cross sections exhibited degradation. Degradation greater than 1 foot occurred at 14% of cross-sections (7 out of 49 xs pairs). The sections that showed more than 1 foot of degradation were located in the lower South Fork reach in 1997 (xs 3) and 1999 (xs 19 and 20), in the Wheatfield Fork in

1997 (xs 23) and 2002 (xs 23 and 27), and in the South Fork in 1997 (xs 22). The maximum amount of thalweg degradation (-2.02 ft) was recorded in 1999 at xs 20 just downstream from the confluence of the Wheatfield Fork with the South Fork Gualala River. Pool scour processes at river confluences is the likely explanation for the maximum thalweg degradation observation in this dynamic environment. The only reach that exhibited average degradation greater than 1 foot was the South Fork, downstream from the Valley Crossing area, in 1999. All three sections surveyed in this reach in 1999 exhibited degradation. Thalweg degradation was also observed in other reaches but it was less than 1 foot. No reach consistently exhibited degradation in all of the survey years, instead thalweg elevations fluctuated as expected, showing aggradation in some years followed by degradation in others. If degradation were a significant process occurring in the Gualala River, we would expect consistent degradation in each survey year. The yearly deviations in thalweg elevations are shown in Figure 4, and the deviations in all data compared to the 1996 base level are shown in Figure 5.

The results from analysis of thalweg elevation data differ somewhat from the analysis of mean bed elevation data. The thalweg represents only the deepest part of the channel and responds more readily to changes in flow and sediment supply (e.g. it may reflect isolated scour during floods), whereas the mean bed elevation represents the elevation over the whole active channel and is more likely to reflect changes in the balance between sediment supply and sediment transport at the reach scale. For example, at the monitoring cross-sections in the SH1 reach, thalweg elevations declined while mean bed elevations increased over the period 1996-2002 (Table 6).

Table 6 Comparison of bed elevation changes as measured by thalweg elevations and mean bed elevation in the Gualala main stem monitoring reach.

Data Type	Cross-section Number				
	1	2	3	4	5
Thalweg (ft)	-0.17	-0.57	-0.62	-0.49	-1.09
Mean Bed Elevation (ft)	-0.19	0.18	0.28	0.26	0.18

Figure 3 Yearly thalweg profiles for a) South Fork main stem and b) Wheatfield fork reaches. Data points were extracted from data provided by D4 Engineering.

a)

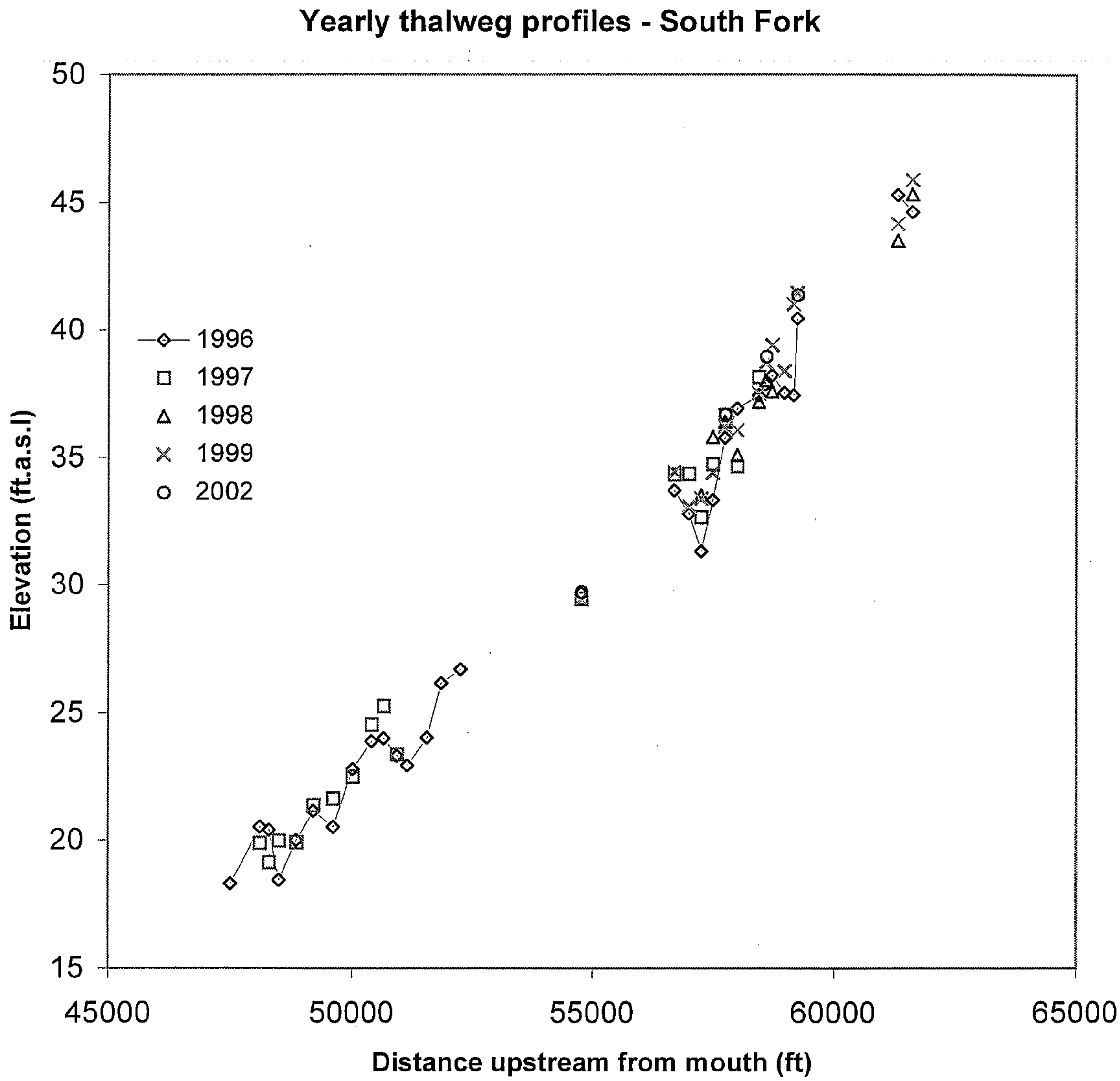


Figure 3b) Wheatfield Fork

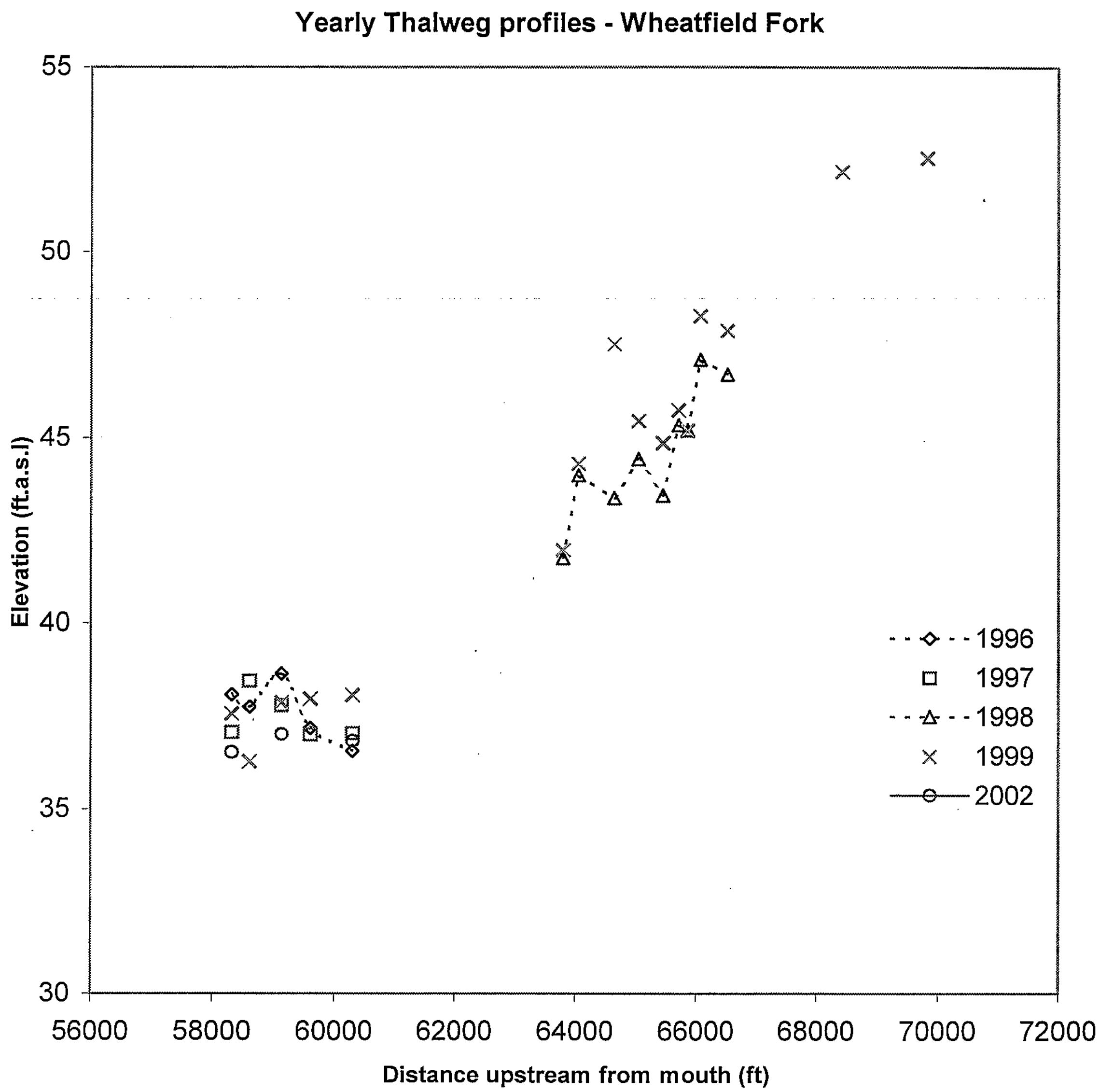


Figure 4 Deviations in thalweg elevations between successive years shown in relation to the distance of each cross section upriver from the mouth of the Gualala River. Distances upriver were measured from plan maps provided by D4 Engineering.

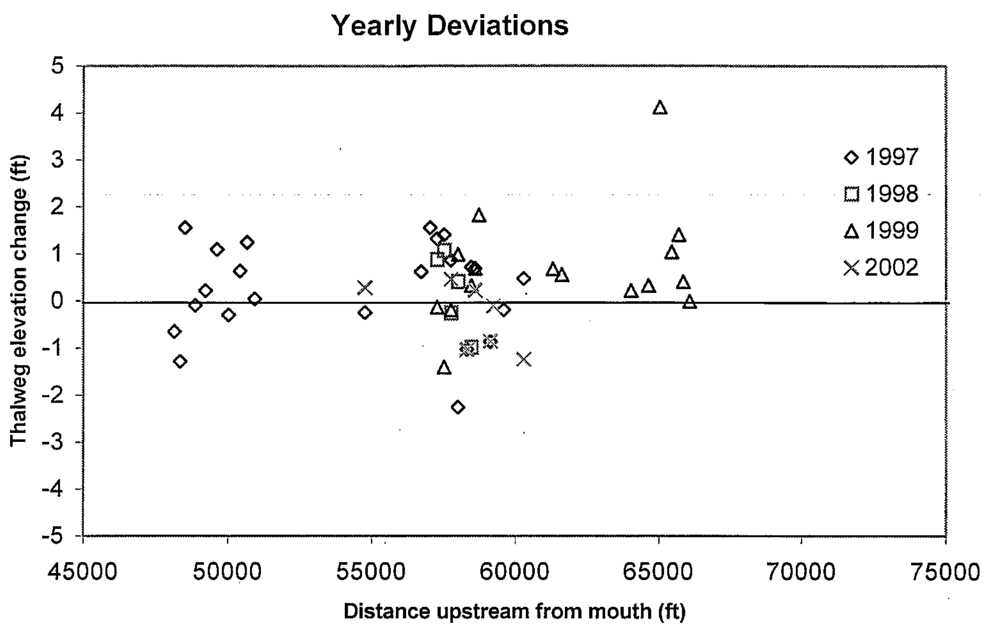
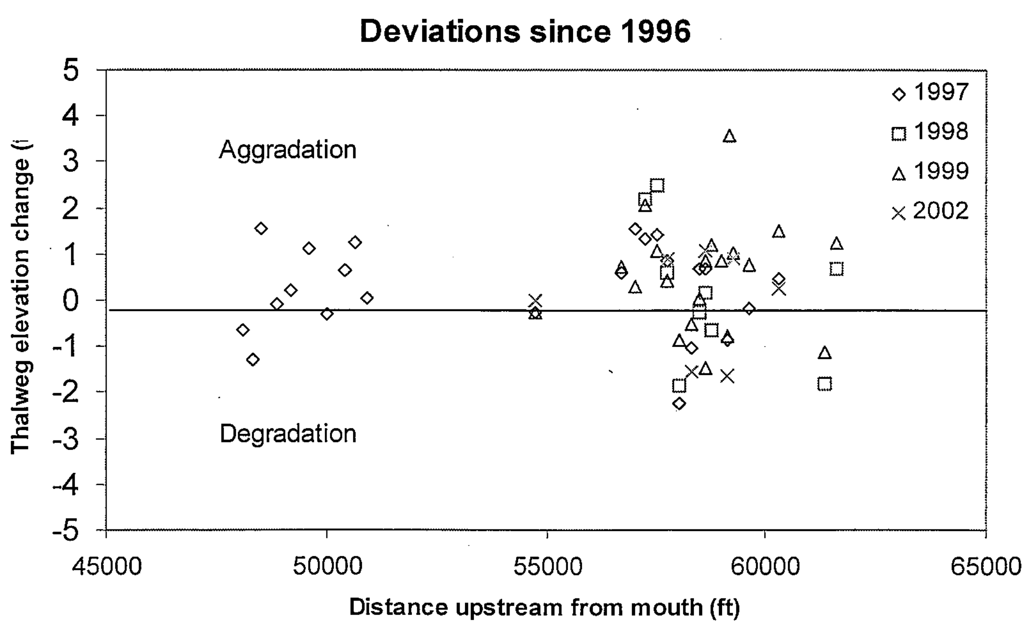


Figure 5 Deviations in thalweg elevations for each survey year in relation to the 1996 thalweg elevations.



Longitudinal profile

The longitudinal profiles of the South Fork and Wheatfield Fork of the Gualala River are shown in Figure 6. The longitudinal profiles at the Valley Crossing confluence constructed from mean bed elevation data from cross section surveys from 1996 and 2002 are shown in Figure 7. Inspection of the longitudinal profiles revealed that both Wheatfield Fork and South Fork exhibit a decline in slope at their confluence suggesting a decrease in stream power and sediment transport capacity in this location. The decrease in stream power presumably results in the accumulation of gravel at this location. Figure 7 shows that most of the cross sections aggraded between 1996 and 2002, despite continued gravel extraction.

The upper South Fork is steeper than the Wheatfield Fork, and the upper South Fork appears to be transporting a greater sediment load. When this sediment is deposited in the channel of the Wheatfield Fork (greater catchment area but lower slope than the South Fork), the river is unable to transport this increased load and as a consequence aggradation occurs at the confluence. The longitudinal profile of the Wheatfield Fork appears to be controlled by bedrock, and both rivers exhibit several knick-points at similar elevations. Alternatively these knick-points may be related to some other factors such as sea level changes, tectonic uplift rates, or the local influence of large deep-seated landslides.

Figure 6. Longitudinal profile of the South and Wheatfield Forks of the Gualala River. The arrow shows the approximate location of the confluence.

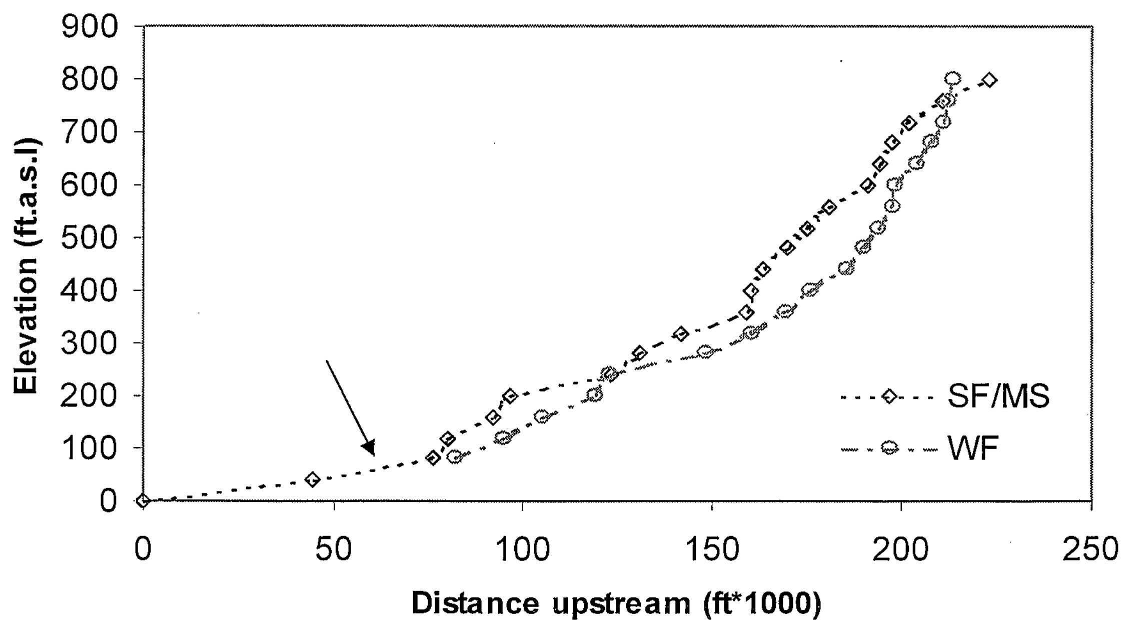
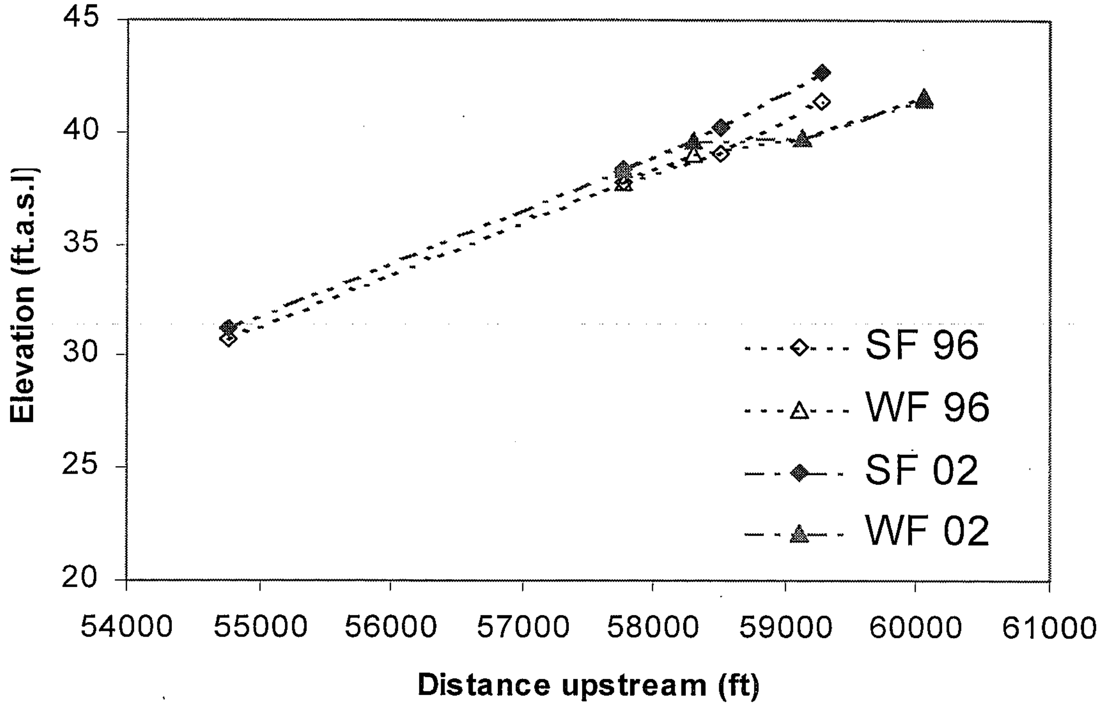


Figure 7. Mean bed levels of cross sections in 1996 and 2002 in the confluence area. Most cross sections exhibited aggradation.



Additional sediment supply from other tributaries

The preceding discussion of aggregate recharge based on calculated channel aggradation rates and extraction data pertains to the Valley Crossing reach, extending approximately 1.3 miles downstream of the confluence of the Wheatfield Fork with the South Fork. This is the historic area of gravel extraction. To provide a quantitative estimate of gravel recharge rates applicable to the entire 20 mile reach of the permit area, we utilized the estimated sediment yield data for the Gualala River watershed from a recent Califorina Geologic Survey review (CGS , 2002, page 9) of North Coast watershed TMDL's derived by the EPA (2002). The CGS sediment yield data were based on geologic mapping in the Gualala River watershed (Fuller et al, 2002) and review of available geologic and sediment yield literature (CGS, 2002). The CGS sediment yield data are higher than previous estimates from the EPA (2002) due to a larger area of deep-seated landslides identified than was assumed in the EPA (2002) analysis. CGS (2002) estimated sediment yields for historic active and dormant deep-seated landslides, earthflows, rockslides, and soil creep, and compiled high and low-range estimates of the annual sediment yield for the entire watershed as well as for major sub-watersheds. A separate estimate was not derived for smaller, shallow landslides because 58% of the smaller landslides mapped by CGS occurred within larger deep-seated landslides or geomorphic terrains created by landsliding (CGS, 2002). We used the overall watershed estimates of annual unit sediment load (in t/mi^2/yr) to estimate total sediment load (in t/yr) and bedload for each of the sub-basins. We assumed that bedload comprised 10% of the total sediment load. Studies of north coast California rivers have found bedload to range from 4 to 30% of the suspended sediment load (Hawley and Jones, 1969; Janda and Nolan, 1979). Estimated total sediment load and bedload for sub-watersheds in the Gualala River watershed are listed in Table 7.

Table 7 Estimated total sediment load and bedload for sub-watersheds in the Gualala River watershed based on sediment yield data from CGS (2002).

Sub-watershed	Area (mi^2)	Total sediment load (t/yr)		Bedload (t/yr)*	
		Low-range estimate	High-range estimate	Low-range estimate	High-range estimate
Wheatfield	112	110,930	336,920	11,090	33,690
South Fork	63	59,240	192,310	5,920	19,230
Valley Crossing to Buckeye subtotal	175	170,170	529,230	17,020	52,920
Buckeye	40	40,060	121,660	4,010	12,170
Rockpile	35	34,790	105,660	3,480	10,570
Buckeye to Hwy 1. subtotal	75	74,850	227,320	7,490	22,740
Total	**250**	**245,020**	**756,550**	**24,510**	**75,660**

*Bedload estimated at 10% of total sediment load

Our estimate of annual gravel recharge (bedload) of 25,000 t/yr in the Valley Crossing area, based on cross section and extraction data, falls within the range estimated from the CGS analysis and near the lower estimate of bedload from the CGS sediment yield data for the combined Wheatfield and South Fork watersheds (17,000 to 53,000 t/yr). An additional 7,500 t/yr to 23,000 t/yr of bedload is expected to be delivered to the South Fork Gualala River main stem from Rockpile Creek and Buckeye Creek. According to this estimate, the total amount of gravel recharge to the entire 20 mile permit reach therefore probably ranges from about 25,000 t/yr to 76,000 t/yr.

Estimated gravel recharge rate downstream of Buckeye Creek

The observed gravel recharge rate for the Wheatfield Fork and upper South Fork can be used to "calibrate" the CGS estimates for the combined Buckeye and Rockpile watersheds. The observed rate for the Wheatfield and South Fork is 1.47 times greater than the low-range estimate (25,000 t/yr divided by 17,000 t/yr = 1.47). Using this calibration factor, gravel recharge to the reach downstream of Buckeye Creek is estimated to be 11,000 t/yr (7,500 t/yr x 1.47). Hence, the total estimated replenishment rate of the permit reach based on available data is about 36,000 t/yr, a rate that is substantially lower than the permitted rate of 40,000 yd^3/yr (about 64,000 t/yr).

Effects of gravel extraction on fish habitat

An aquatic habitat assessment of the South Fork Gualala River (NRMC, 2003), included field surveys of habitat conditions in the fall of 2002. The survey reach was located between the confluence of the South Fork with Wheatfield Fork, downstream to Rockpile Creek. NRM found a significant increase in the percentage of pools greater than 2 feet deep between 1991 (when EIP data collected) and 2002. Although monitoring data on channel and thalweg elevations demonstrate local declines in bed elevation, consistent with increasing pool depth, the monitoring data also demonstrate that the overall trend is one of bed aggradation (Figures 3, 4 and 5). There is also evidence suggesting that channel thalweg elevations and mean bed elevations may not change uniformly (Table 6). Cross-section data cannot be expected to detect changes in pool depths. Cross-section surveys are not methodologically appropriate for monitoring changes in pool depths because pool location and topography is dynamic.

There are several possible explanations for the reported trend of increasing pool depth. Differences in streamflow and water level at the time of the two surveys may have influenced field observations of pool depth. Higher streamflows occurred in the years prior to the 2002 survey and may have induced greater sediment transport, whereas drought conditions characterized the years prior to 1991 surveys and sedimentation may have dominated over transport. Another explanation may be that riparian vegetation has become established on the edges of many gravel bars, thus confining and focusing flow energy in the low flow channel. Furthermore, reduction in sediment load in the mainstem South Fork Gualala would be expected to allow for the formation of deeper pools. The NCWAP report that there is a watershed-wide trend over the period 1984-2000 toward channel "recovery" from excess sedimentation from earlier logging activity assessment, and aggregate extraction further reduces excess sedimentation.

Bar skimming operations in the Gualala River are restricted to deposits above the water surface elevation of the low flow channel, which maintains the position of the thalweg. Monitoring data for the Gualala River (cross section plots in Appendix 2, thalweg elevation variation in Figure 3a & 3b), do not indicate pervasive simplification of channel cross-section morphology. Short-term, localized cross-section simplification does occur as a result of bar skimming, however these changes have not been observed to persist over a period of years.

Minimum baseline elevations

The use of a minimum baseline elevation as a regulatory standard for bar skimming is evaluated below based on observed fluctuations in water surface elevations at monitoring cross-sections of the period 1996-2002. One element of this evaluation is consideration of annual rainfall totals over the period of interest. We obtained rainfall data from the Fort Ross rain gauge for the period 1996 to 2002. Streamflow data was not available for this period. The yearly rainfall totals, measured from October 1 to September 30 are presented in Table 8. The percentage of average rainfall was calculated with respect to the average yearly rainfall over the entire period of record from 1948 to 2003 (a total of 55 years of record).

Table 8 Annual rainfall at Fort Ross, California.

Year	Annual rainfall	% of average
95-96	39.71	103
96-97	38.33	100
97-98	65.78	172
98-99	38.9	101
99-00	35.46	93
00-01	24.56	64
01-02	36.85	96
02-03	20.51	93

The 1995-1996 water year experienced average rainfall, and therefore the flow and bedload transport rates in the Gualala River were also likely to be average, and represent the amount of sediment transport that can be expected in an average year. Most years that the extraction permit applies to (1996 to 2002) also experienced average rainfall, except for 1997-1998 which had higher than average rainfall (172 % of average), and 2000-2001 which experienced lower than average rainfall (64 % of average). From the standpoint of annual variations in water levels, unusually wet (e.g. 1997-1998) or dry years (e.g. 2000-2001), are less desirable for establishing baseline water elevations than average years. With respect to existing Gualala River baseline elevations, the 1996 low flow water level therefore is probably representative of typical baseflow conditions. Baseflow observations from summer 1998 are probably substantially higher than usual (particularly since these cross-sections were surveyed in May), and are therefore relatively conservative with respect to limiting aggregate extraction. The minimum baseline elevations for each previously established cross section are listed in Table 9.

Table 9 Minimum baseline elevations for each cross section, based on the water surface elevation in the first year of survey (usually 1996, unless otherwise denoted). Water surface elevations that were adjusted to preserve the downstream decrease in baseline elevations are shown in brackets.

Reach	xs	Minimum baseline elevation	Reach	xs	Minimum baseline elevation	Reach	xs	Minimum baseline elevation
SF	1	20.31	SF	21	36.81	WF	41	**46.86
SF	2	21.00	SF	22	38.14	WF	42	**46.97
SF	3	(22.26) 21.35	WF	23	(39.36) 37.89	WF	43	**47.88
SF	4	21.69	WF	24	*(40.35) 39.49	WF	44	**48.58
SF	5	22.33	WF	25	39.19	WF	45	***53.21
SF	6	22.13	WF	26	39.31	WF	46	***53.66
SF	7	23.73	WF	27	39.22			
SF	8	23.49	uSF	28	38.06			
SF	9	24.88	uSF	29	38.55			
SF	10	25.19	uSF	30	39.23			
SF	11	25.31	uSF	31	(40.72) 39.98			
SF	12	25.66	uSF	32	40.07			
SF	13	26.52	uSF	33	41.15			
SF	14	27.34	uSF	34	45.71			
SF	15	27.41	uSF	35	45.87			
SF	16	30.22	WF	36	**44.63			
SF	17	34.42	WF	37	**44.62			
SF	18	34.63	WF	38	**45.08			
SF	19	34.65	WF	39	**45.54			
SF	20	34.69	WF	40	**46.52			

* surveyed in 1997
** surveyed in 1998
*** surveyed in 1999

In Table 8, an adjustment was applied to some cross section minimum baseline elevations (the original elevations are enclosed by brackets) to maintain the downstream decrease in baseline elevations. In circumstances where outliers created an adverse slope that was greater than 0.001, the slope was adjusted by linear interpolation between the upstream and downstream bed elevation levels. Adverse slopes less than 0.001 were considered insignificant and were not adjusted. The goal of the adjustment was to avoid situations where baseline elevations appeared to cause the channel to flow uphill in the downstream direction, as well as to avoid operational inconsistencies where gravel extraction might require unreasonably abrupt changes in excavation grade lines. This sometimes occurs because of different flow conditions that may exist when baseline elevations are established in different years and/or months (see discussion page….). For the case at the confluence of the Wheatfield and South Forks where two consecutive points appear to be outliers, the average of the whole reach was used to determine the mean elevation. It appears to be a special case at the confluence with the Wheatfield fork gradient flattening

out at this position. The flattening of the Wheatfield Fork gradient may be an artifact of previous extraction or reflect the response of the river to conditions at the confluence and the faster rate of aggradation in the South Fork compared to Wheatfield Fork.
Variations in water surface elevations and annual rainfall are characterized in Table 9 below. Cross section surveys were carried out in different months each summer: October 1996, July 1997, May 1998, June 1999, August 2002. The water surface elevations are expected to vary over the summer, with the water elevation generally declining from May to October. Relative to water surface elevations measured in 1996, maximum variations at specific locations ranged from +2.64 ft to –2.35 ft. Median differences are smaller, but variations on the order of ±0.5 ft are common. These data indicate that baseflow water elevation levels used to regulate mining operations can be expected to vary over ±2 ft in extreme conditions (particularly wet or dry years with observations either early or late in the dry season), and on the order of ±0.5 ft under ordinary conditions.

Table 9 Summary of median changes in water surface elevations (ft) at monitoring cross-sections relative to October 1996 baseflow water surface elevations.

Cross-sections	1997	1998	1999	2002
1-15 (Mainstem)	0.53	--	--	--
16-22 (Mainstem)	-0.05	--	0.38	0.17
28-35 (South Fork)	--	0.43	0.34	--
23-27 (Wheatfield)	0.48	1.53	-0.09	-0.71

CONCLUSIONS

Aggradation continues to occur in the channel of the Wheatfield and South Forks of the Gualala River, despite annual extraction of gravel from the channel bed from 1996 to 2001. We calculated a yearly rate of gravel replenishment of for the Valley Crossing reach of the Wheatfield and South Forks of approximately 25,000 t/yr from analysis of channel cross sections, surveyed over the 6 year period, and cumulative extraction rates over the same period. During that 6 year period, 13,000 t/yr to 36,000 t/yr (with an average rate of about 19,000 t/yr) of aggregate were extracted from the channel by bar skimming operations. No significant changes to the plan form morphology of the river or an increase in bank erosion were detected by aerial photograph interpretation. Aggregate extraction over the past five years has not caused a significant geomorphic impact in the vicinity of the mining site.

At present the maximum permitted extraction rate is 40,000 yd^3/yr. The current average extraction rate of 19,000 t/yr is substantially less than the estimated recharge rate of about 25,000 t/yr, suggesting that extraction rates could be increased without causing channel degradation, however, annual extraction of the full permitted amount from the Valley Crossing reach alone would likely cause degradation of the channel, which may lead to changes in channel morphology. Estimated recharge downstream of Buckeye Creek is 11,000 t/yr; no extraction has occurred in this area. The total gravel replenishment rate to the entire 20 mile permit reach (including the reach downstream of Buckeye and

Rockpile Creeks, to the confluence with the North Fork) was estimated to be about 36,000 t/yr. The maximum allowable extraction rate of 64,000 t/yr is roughly twice the estimated rate of replenishment.

Some changes in the morphology of the channel associated with channel degradation may be considered positive for aquatic habitat. For example, a general lowering of the channel bed in relation to the water table could result in a more continuous and/or deeper surface flows in summer with positive effects on fish habitat. However, other morphological changes associated with degradation, such as increased bank erosion and general channel instability might adversely affect the aquatic habitat.

Aggradation in the Gualala River is a long term process; drill-holes adjacent to North Fork revealed a 200 foot deposit of alluvial sediment (Klampt *et al*, 2002) that accumulated during the past 15,000 years at an approximate rate of 0.013 ft/year (39 mm/yr). Sedimentation over the last 15,000 years is the result of the interaction between uplift, river down cutting and sediment supply from the watershed.

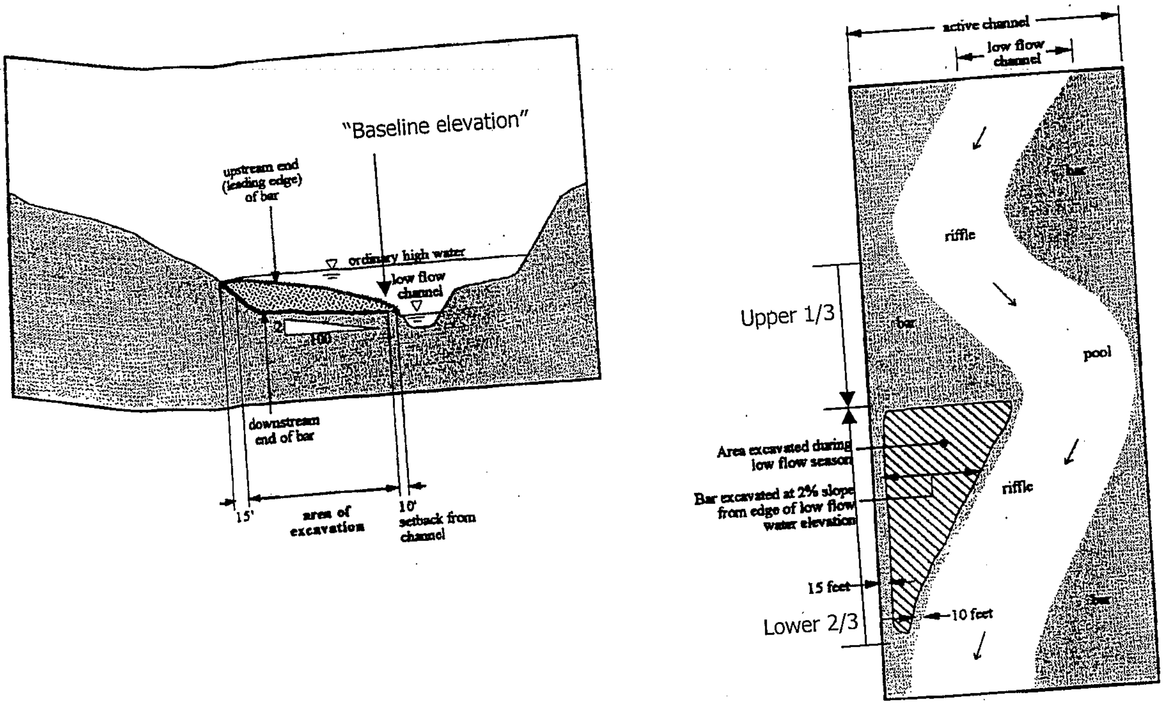
RECOMMENDATIONS

Mining standards

1. Extraction rates
    a. The extraction rate in the Valley Crossing reach (the permit area of the Wheatfield and South Fork Gualala upstream of Buckeye Creek – refer to Appendix 1 for map) over any 5-year period should be less than or equal to the estimated 5-yr recharge rate of 125,000 t (about 78,600 yd^3/yr), except as described in 1c.
    b. The annual average extraction rate in the lower reach of the permit area (from Buckeye Creek downstream to the North Fork Gualala River) over any 5-year period should be less than or equal to the estimated 5-year recharge rate of about 55,000 t/yr (about 34,600 yd^3/yr), except as described in 1c.
    c. Extraction rates in excess of the rates stated above are allowable provided that extraction is limited to the gravel that has accumulated within the approved bar skimming areas above the minimum baseline elevations, established pursuant to 2a and 2b below. This provision recognizes the uncertainty in recharge estimates, and allows for higher extraction rates if recharge rates are greater.
    d. Limitations on aggregate extraction in reaches upstream of Annapolis Road bridges to not more than once in three years should be discontinued; extraction rates in these areas should be governed by provisions 1a and 1c above.

2. Bar skimming procedures:
    a. Bar skimming activities within the permit area shall be confined to that portion of the gravel bars which are in the downstream 2/3 of the gravel bar and are at least 15 feet away from the active channel bank, 10 feet away from the low flow channel as of July 1, and outside of areas of significant riparian vegetation unless modified by PRMD following consultation with CDFG. The upper 1/3 of the bars tend to have coarser material, and avoiding disturbance of these areas helps maintain channel form (refer to Figure 8, pg 36). Notwithstanding the above, gravel bars within the area of the confluence of the Wheatfield Fork and South Fork of the Gualala River may be skimmed in the upper 1/3 of the gravel bar provided all other setbacks are complied with. For purposes of implementation, the confluence shall be considered that portion of the permit area which lies above cross section 18, and below cross sections 29 and 25.
    b. Within the permitted bar skimming areas, the depth of excavation shall be limited to removing the gravel which accumulates above the required final slopes. The final grade slopes shall be defined as a 2 percent lateral cross slope ascending toward the stream bank measured from the higher of: 1) the existing low flow channel water surface elevation at the time of mining, or 2) the minimum baseline elevation. The minimum baseline elevation shall generally be based on the initial low flow channel elevation in the first year of mining unless otherwise adjusted by PRMD or for other hydrological considerations. (This provision provides a more effective method of preventing channel degradation and restricting the level of gravel extraction to the actual level of aggregate recharge that occurs in subsequent years.)
    c. The required 2 % final grade cross-slope based on the minimum baseline elevation determines the quantity of aggregate that can be extracted, the finished configuration of the skimmed bar, and determines when sufficient aggregate has accumulated to allow subsequent rounds of aggregate extraction.
    d. Bar skimming operations may occur from June 1 to November, 1 unless other PRMD or agency restrictions apply.

Figure 8 Gravel mining operations on the Gualala River (reproduced from the EIR, EIP Associates, 1994). As defined in #2 above and in the diagrams below, the allowable extraction area in the horizontal plane is determined by the permit area, the setback requirements from the water and riparian vegetation, and the restrictions on the upper 1/3 of the bar. In the vertical plane, the allowable extraction depth is determined by the minimum 2% cross slope measured toward the stream bank from the higher of the low flow channel elevation or the baseline reference water elevation.



Monitoring procedures

1. Prior to extraction at new sites, a minimum of 2 operational cross sections will be surveyed at skimming areas less than 1,000 ft long, and a minimum of 3 cross sections will be surveyed at skimming areas more than 1,000 ft long; the maximum distance between cross-sections should be 500 ft.
2. Water surface elevations measured during the initial survey or prior to the first year of extraction at each cross-section will be used to establish the minimum baseline elevations. These minimum baseline elevations will be maintained for all subsequent extraction activity for each extraction site. Water surface elevations will be tabulated and submitted to PRMD with recommendations for actual minimum baseline elevations.
3. Volumes or tonnage of extracted aggregate should be reported in a manner that explicitly links extraction data, including year of extraction, with the extraction sites.
4. Annual spring surveys should be conducted only at the Sea Ranch well site (section 16), and at the Annapolis Road bridges (sections 23 and 29); if significant gravel extraction begins in the reach downstream of Buckeye Creek, an annual cross section

survey should be instituted at or near the State Highway 1 bridge beginning after the next 5-year review.

5. The following monitoring requirements that are currently required every year need only be done at 5-year intervals
    a. Routine monitoring of selected cross sections should be conducted at 5-year intervals. Drawing on the existing set of cross-sections, four sets of long-term monitoring cross-sections have been identified and are summarized in the table below. The symbol "*" indicates that the cross-section was not surveyed in 2002 and should be surveyed in 2004.

Monitoring Reach	Cross Sections
Gualala mainstem	1, 2, 3, 4, 5
South Fork – Rockpile Reach	To be determined
South Fork – Valley Crossing	1*, 7*, 15*, 16, 21
South Fork Reach	29, 33, 34*, 35* plus one additional section upstream of 35
Wheatfield Reach	23, 25, 27, 36*, 37*, 45*, 46*

    b. Additional long-term cross-section monitoring sites should be identified and surveyed if new extraction areas outside the monitoring reaches identified above are developed. Long-term monitoring reaches should consist of at least 5 cross-sections distributed at intervals of approximately 1,000 ft and resurveyed at a maximum time interval of 5 years. These monitoring cross-sections may be chosen from cross-section sites surveyed for extraction implementation and compliance purposes. This will supersede the requirement for at least 5 cross-sections per bar.
    c. Once baseline surveys have been conducted at new extraction sites, additional surveys should be limited to supplemental surveys at previous extraction sites being considered for additional extraction, and monitoring surveys conducted at 5-yr intervals.
    d. Replenishment rates should be recalculated in a manner similar to that in this analysis at 5-year intervals covering the period of record beginning in 1996; an analysis of channel conditions (aggradation/degradation, morphology) should also be conducted at 5-year intervals that coincide with acquisition of monitoring data. Revisions to estimated replenishment rates and extraction rates should be considered based on the results of each 5-year review.
    e. Assessment by a geomorphologist and fisheries biologist
    f. Acquisition and review of aerial photography
6. Annual spring and fall cross-sections of mining sites will be replaced by annual spring surveys on reaches where mining occurred in the previous year or is planned for the upcoming year. In lieu of the fall surveys, grade stakes shall be placed in the spring survey to indicate the depth to which the bar may be excavated at different points. These stakes will help guide equipment operators in the field.
7. The cross section data should be collected and stored in a manner that allows for easy analysis of the data. Ideally, the data required for geomorphological analysis are the raw distance and elevation data for each cross section so that mean bed elevations and thalweg elevations can be easily computed.

8. Cross section survey protocols should include specific measurement of the top and base of the channel banks. This would allow for identification of changes in bank position due to either bank erosion or accretion. Bank locations are not always well defined in the existing set of cross section survey data.

It should be noted the flow monitoring stations were installed on the Wheatfield, South Fork and North Fork Gualala Rivers in 2002. The streamflow data collected will provide an opportunity to analyze, model and predict sediment transport on these rivers, and may prove useful as a tool to evaluate the impacts of gravel mining in the future. Existing flow records from historic gauging data could also be used to predict transport and evaluate potential impacts of different management scenarios. These data resources and modeling opportunities could prove useful in subsequent years.

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Appendix 1

Gualala River aggregate and monitoring cross section locations

1. Gualala River Cross Sections
2. Gualala Hiway-1 Bridge Profiles
3. Gualala Main, South, & Wheatfield Cross Sections
4. Valley Crossing Aggregate Sites

(Source: Gualala Redwoods, Inc.)

Appendix 2

Thalweg and Water Surface Elevation Data from Cross Section Monitoring

			Thalweg elevations						Yearly Thalweg deviations					Thalweg deviations cf 1996		
Reach	xs	distance u/s	1996	1997	1998	1999	2002		1997	1998	1999	2002		1998	1999	2002
MS	1	47513	18.31													
MS	2	48113	20.54	19.89					-0.65							
MS	3	48313	20.41	19.12					-1.29							
MS	4	48513	18.44	19.99					1.55							
MS	5	48863	20.01	19.91					-0.10							
MS	6	49213	21.16	21.37					0.21							
MS	7	49613	20.53	21.63					1.10							
MS	8	50013	22.78	22.48					-0.30							
MS	9	50413	23.88	24.51					0.63							
MS	10	50663	24.01	25.26					1.25							
MS	11	50938	23.31	23.35					0.04							
MS	12	51163	22.94													
MS	13	51563	24.02													
MS	14	51863	26.15													
MS	15	52263	26.71													
MS	16	54763	29.70	29.46		29.43	29.71		-0.24			0.28			-0.27	0.01
MS	17	56713	33.71	34.33		34.43			0.62						0.72	
MS	18	57013	32.79	34.35		33.08			1.56						0.29	
MS	19	57263	31.32	32.65	33.53	33.39			1.33	0.88	-0.14			2.21	2.07	
MS	20	57513	33.33	34.74	35.81	34.41			1.41	1.07	-1.40			2.48	1.08	
MS	21	57763	35.78	36.65	36.40	36.21	36.67		0.87	-0.25	-0.19	0.46		0.62	0.43	0.89
SF	22	58013	36.92	34.67	35.08	36.07			-2.25	0.41	0.99			-1.84	-0.85	
SF	28	58463	37.45	38.16	37.17	37.50			0.71	-0.99	0.33			-0.28	0.05	
SF	29	58613	37.87		38.03	38.72	38.95				0.69	0.23		0.16	0.85	1.08
SF	30	58738	38.23		37.59	39.42					1.83			-0.64	1.19	
SF	31	58988	37.53			38.38									0.85	
SF	32	59188	37.45			41.02									3.57	
SF	33	59263	40.46			41.48	41.37					-0.11			1.02	0.91
SF	34	61338	45.30		43.51	44.19					0.68			-1.79	-1.11	
SF	35	61638	44.64		45.33	45.89					0.56			0.69	1.25	
WF	23	58313							-1.03			-1.03			-0.52	-1.55
WF	24	58603							0.69						-1.47	
WF	25	59136							-0.86			-0.85			-0.78	-1.63
WF	26	59603							-0.19						0.79	
WF	27	60303							0.47			-1.24			1.51	0.27
WF	36	63803														
WF	37	64053									0.21					
WF	38	64653									0.32					
WF	39	65053									4.12					
WF	40	65453									1.04					
WF	41	65703									1.4					
WF	42	65853									0.4					
WF	43	66078									-0.01					
WF	44	66528									1.18					
WF	45	68428									1.17					
WF	46	69828														
							avg		0.36	0.22	0.73	0.48		0.18	0.74	0.99
							min		-2.25	-0.99	-1.40	0.23		-1.84	-1.11	0.01
							max		1.56	1.07	4.12	0.46		2.48	3.57	1.08

				1996		
Reach	xs		mean WL 96	Thalweg 96	water depth	
MS	1		20.31	18.31	2.00	
MS	2		21.00	20.54	0.46	
MS	3		22.27	20.41	1.86	
MS	4		21.69	18.44	3.25	
MS	5		22.33	20.01	2.32	
MS	6		22.13	21.16	0.97	
MS	7		23.73	20.53	3.20	
MS	8		23.49	22.78	0.71	
MS	9		24.88	23.88	1.00	
MS	10		25.19	24.01	1.18	
MS	11		25.31	23.31	2.00	
MS	12		25.66	22.94	2.72	
MS	13		26.52	24.02	2.50	
MS	14		27.34	26.15	1.19	
MS	15		27.41	26.71	0.70	
MS	16		30.22	29.70	0.52	
MS	17		34.42	33.71	0.70	
MS	18		34.63	32.79	1.84	
MS	19		34.65	31.32	3.33	
MS	20		34.69	33.33	1.36	
MS	21		36.81	35.78	1.03	
SF	22		38.14	36.92	1.22	
WF	23		39.36	38.07	1.29	
WF	24			37.74		
WF	25		39.19	38.63	0.56	
WF	26		39.31	37.16	2.15	
WF	27		39.22	36.54	2.68	
SF	28		38.06	37.45	0.61	
SF	29		38.55	37.87	0.68	
SF	30		39.23	38.23	1.00	
SF	31		40.73	37.53	3.20	
SF	32		40.07	37.45	2.62	
SF	33		41.15	40.46	0.69	
SF	34		45.71	45.30	0.41	
SF	35		45.87	44.64	1.23	
WF	36					
WF	37					
WF	38					
WF	39					
WF	40					
WF	41					
WF	42					
WF	43					
WF	44					
WF	45					
WF	46					

1998						
Reach	xs	Mean WL	Thalweg	water depth	WL chng	TH chg
MS	1					
MS	2					
MS	3					
MS	4					
MS	5					
MS	6					
MS	7					
MS	8					
MS	9					
MS	10					
MS	11					
MS	12					
MS	13					
MS	14					
MS	15					
MS	16					
MS	17					
MS	18					
MS	19	36.65	33.53	3.12	0.88	0.88
MS	20	37.32	35.81	1.51	1.07	1.07
MS	21	37.86	36.40	1.46	-0.25	-0.25
SF	22	38.26	35.08	3.18	0.41	0.41
WF	23					
WF	24					
WF	25					
WF	26					
WF	27					
SF	28	38.50	37.17	1.33	-0.99	-0.99
SF	29					
SF	30	39.72	37.59	2.13		
SF	31					
SF	32					
SF	33					
SF	34	45.92	43.51	2.41		
SF	35	46.05	45.33	0.72		
WF	36	44.63	41.76	2.87		
WF	37	44.62	43.98	0.64		
WF	38	45.09	43.38	1.71		
WF	39	45.54	44.41	1.13		
WF	40	46.53	43.45	3.08		
WF	41	46.87	45.33	1.54		
WF	42	46.97	45.19	1.78		
WF	43	47.88	47.08	0.80		
WF	44	48.58	46.69	1.89		
WF	45					
WF	46					

		1999				
Reach	xs	mean WL	Thalweg	water depth	WL chge	TH chge
MS	1					
MS	2					
MS	3					
MS	4					
MS	5					
MS	6					
MS	7					
MS	8					
MS	9					
MS	10					
MS	11					
MS	12					
MS	13					
MS	14					
MS	15					
MS	16	29.62	29.43	0.19		
MS	17	35.10	34.43	0.67		
MS	18	34.98	33.08	1.90		
MS	19	35.04	33.39	1.65	-1.62	-0.14
MS	20	35.30	34.41	0.89	-2.02	-1.40
MS	21	37.19	36.21	0.98	-0.67	-0.19
SF	22	37.48	36.07	1.41	-0.78	0.99
WF	23	37.77	37.55	0.22		
WF	24	39.24	36.27	2.97		
WF	25	39.14	37.85	1.29		
WF	26	39.18	37.95	1.22		
WF	27	40.10	38.05	2.05		
SF	28	37.78	37.50	0.28	-0.71	0.33
SF	29		38.72			
SF	30	39.84	39.42	0.41	0.12	1.83
SF	31	41.07	38.38	2.69		
SF	32	41.29	41.02	0.26		
SF	33	42.15	41.48	0.67		
SF	34	45.28	44.19	1.09	-0.65	0.68
SF	35	46.02	45.89	0.13	-0.02	0.56
WF	36	44.34	41.97	2.37	-0.29	0.21
WF	37	44.91	44.30	0.61	0.29	0.32
WF	38	48.48	47.50	0.98	3.40	4.12
WF	39	45.93	45.45	0.47	0.38	1.04
WF	40	46.93	44.85	2.08	0.41	1.40
WF	41	46.83	45.73	1.10	-0.04	0.40
WF	42	47.18	45.18	2.00	0.21	-0.01
WF	43	48.28	48.26	0.02	0.39	1.18
WF	44	48.61	47.86	0.75	0.03	1.17
WF	45	53.21	52.18	1.03		
WF	46	53.66	52.54	1.12		

		2002				
Reach	xs	mean WL	Thalweg	water depth	WL chng	TH chg
MS	1					
MS	2					
MS	3					
MS	4					
MS	5					
MS	6					
MS	7					
MS	8					
MS	9					
MS	10					
MS	11					
MS	12					
MS	13					
MS	14					
MS	15					
MS	16	30.10	29.71	0.38	0.47	0.28
MS	17					
MS	18					
MS	19					
MS	20					
MS	21	37.28	36.67	0.60	0.09	0.46
SF	22					
WF	23	37.01	36.52	0.49	-0.76	-1.03
WF	24					
WF	25	38.57	37.00	1.57	-0.58	-0.85
WF	26					
WF	27	38.51	36.81	1.70	-1.59	-1.24
SF	28					
SF	29	?	38.95			0.23
SF	30					
SF	31					
SF	32					
SF	33	?	42.43			0.95
SF	34					
SF	35					
WF	36					
WF	37					
WF	38					
WF	39					
WF	40					
WF	41					
WF	42					
WF	43					
WF	44					
WF	45					
WF	46					