Willow/Freezeout Creeks
Watershed Analysis

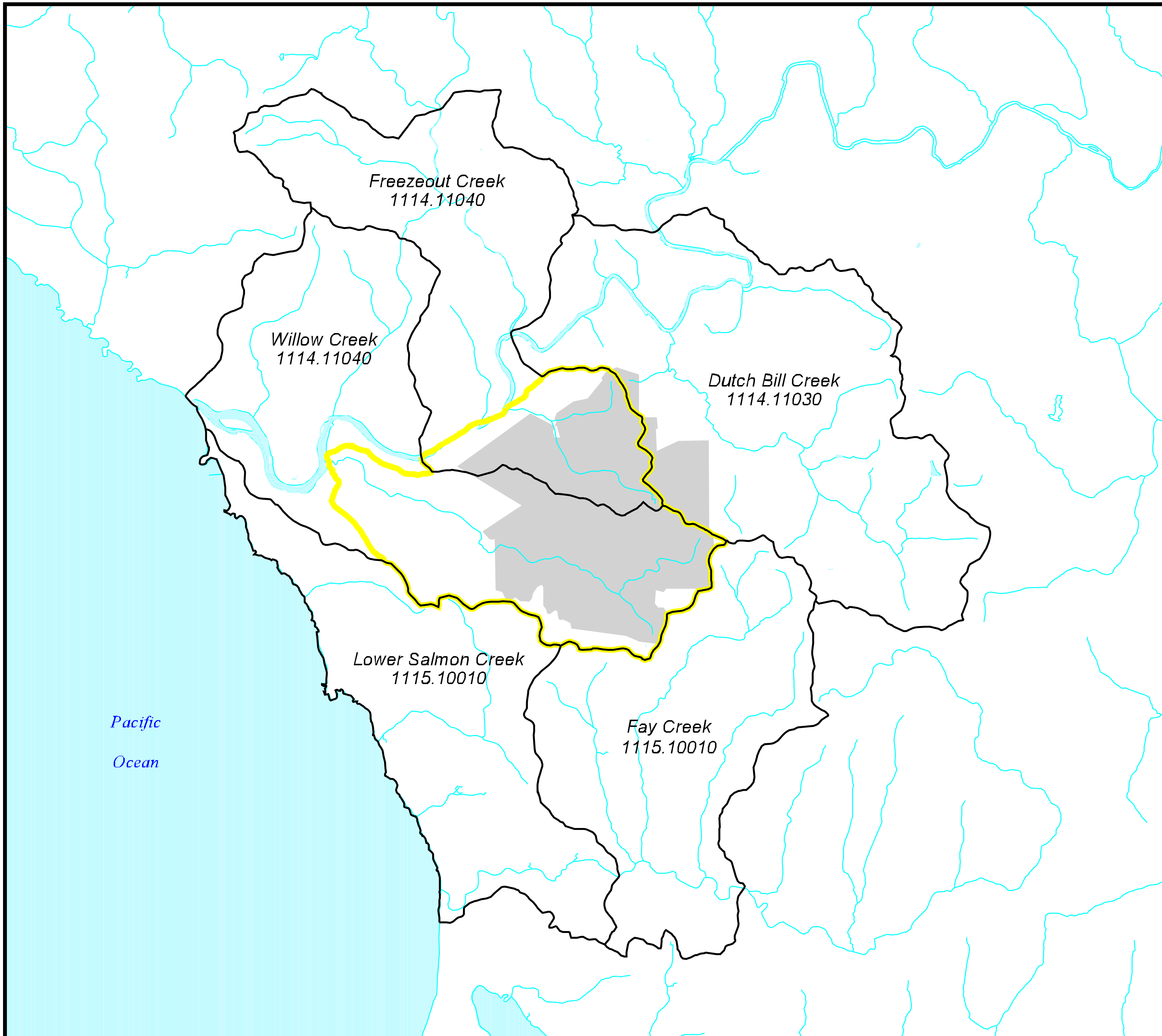
EXECUTIVE SUMMARY

This report presents the results of a watershed analysis performed by Mendocino Redwood Company (MRC) on their ownership primarily in the Willow and Freezeout Creeks watersheds, lands in the Dutch Bill Creek watershed were also evaluated. This watershed analysis was developed to provide a focused approach to evaluating watershed conditions, developing mitigation measures to maintain or improve watershed conditions, and develop significant watershed data to make decisions on how best to manage the aquatic resources within MRC's ownership. This report has also been developed in an attempt to meet the California Board of Forestry's 45 Day Notice for a Watershed Evaluation and Mitigation Addendum (WEMA) or the proposed Interim Watershed Mitigation Addendum (IWMA) also being considered by the Board of Forestry. This study was initiated as a pilot WEMA (or IWMA) for consideration by the Board of Forestry, and it is the intent of MRC to submit this report for that regulatory purpose should the Board of Forestry make a WEMA or IWMA part of the Forest Practice Rules.

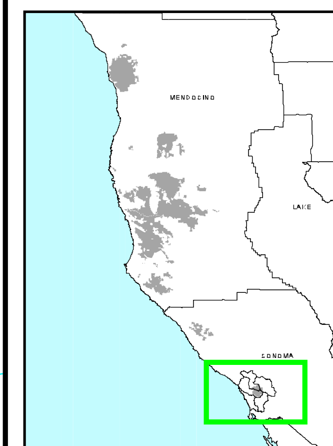
The MRC ownership in the Willow/Freezeout Creeks watersheds is considered the Willow/Freezeout Creeks watershed analysis unit (WAU). Some analysis for the MRC ownership in the Dutch Bill Planning watershed is presented as part of the Willow/Freezeout Creeks watershed analysis. This area in Dutch Bill Creek planning watershed is not intended to be part of the WEMA or IWMA; should this report be used for that purpose. However, that land will be managed with the same land management prescriptions that are determined from this analysis process.

The analysis of the Willow/Freezeout Creeks WAU was conducted following modified guidelines from the Standard Methodology for Conducting Watershed Analysis (Version 4.0, Washington Forest Practices Board). MRC's approach to the Willow/Freezeout Creeks watershed analysis was to perform resource assessments of mass wasting, surface and point source erosion (roads/skid trails), hydrology, fish habitat, riparian condition and stream channel condition. The results of the resource assessments are synthesized and land management prescriptions are developed to address the issues and processes identified in the watershed analysis. Finally, monitoring is suggested to determine the efficacy of the prescriptions to protect sensitive aquatic resources.

Willow Creek / Freezeout Creek Watershed Analysis Unit



Planning Watershed Boundary
Watershed Assessment Unit
Streams
Ocean, Lake, Pond
MRC Ownership



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April 30, 2001

Results

Mass Wasting

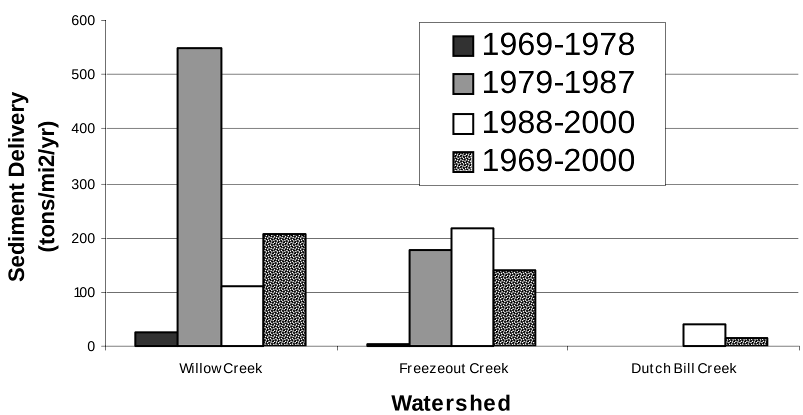
A total of 104 shallow-seated landslides (debris slides, torrents or flows) and 43 deep-seated landslides (rock slides or earth flows) were identified and characterized in the Willow Creek WAU representing the time period 1969-2000. This equated to mass wasting sediment inputs estimated to be at least 160 tons/sq. mi./ yr. over the 1969-2000 time period for the entire Willow Creek WAU. Overall, in the Willow/Freezeout Creeks WAU, sediment delivery from mass wasting was highest in the Willow Creek planning watershed in the 1979-1987 time period (Chart ES-1). This area was particularly high due to legacy harvest practices, compounded by the occurrence of a few very large landslides that significantly increased the sediment delivery amounts that may have been affected by particularly large storms of the 1981-1982 winter.

The forest harvesting technique utilized in the 1950's and 1960's was tractor skidding of logs. This skidding was performed on steep slopes and often in streamside environments and inner gorges, compacting and destabilizing the soil, increasing the frequency of mass wasting.

Approximately 1/3 of the number of shallow-seated landslides are road associated in the Willow Creek WAU, though road related mass wasting only represented 23% of the sediment delivery. The reason that the sediment delivery proportion is so low is due to an abundance of mid-slope road associated failures that do not deliver sediment. Road construction proves to be a significant factor in the cause of shallow-seated mass wasting events. Better road construction practices combined with design upgrades of old roads will lower this amount over time. This mitigation measure will need to be a focus of concern.

The Willow/Freezeout Creeks WAU was partitioned into eight Mass Wasting Map Units (MWMU) representing general areas of similar geomorphology, landslide processes, and sediment delivery potential for shallow-seated landslides. MWMU 3 (the unit representing steep convergent topography) represented the greatest mass wasting sediment delivery for any one unit, providing 54% of the sediment delivered from 1969-2000. Streamside mass wasting (combining MWMUs 1 and 2) yields 21% of the total sediment input.

Chart ES-1. Total Mass Wasting Sediment Input Rate (tons/yr./sq. mi.) from Landslides for MRC Ownership Shown by Watershed and Time Period.



Surface and Point Source Erosion (Roads/Skid Trails)

The overall road surface and point source erosion rate for the Willow/Freezeout Creeks WAU is at least 105 tons/sq. mi./yr. Proportionately Freezeout Creek watershed has the highest level of sediment contributing road areas. The amount of sediment contributing road area needs to be considered for road improvements and erosion reduction throughout the Willow/Freezeout Creeks WAU. By reducing contributing road area the amount of road that contributes sediment during forest management operations is reduced. Road density is currently averaging 7.2 miles of road to every square mile of land MRC owns.

Table ES-1. Road Surface Areas, Contributing Road Surface Areas, Road Lengths and Road Densities for the Willow/Freezeout Creeks WAU.

Planning Watershed	**Road Surface Area (ac)**	**Road Contributing Area (ac)**	**Road Length (miles)**	**Road Density (mi/sq mi)**
Willow Creek	63	9	33.0	7.2
Freezeout Creek	36	7	18.5	7.2
Willow/Freezeout Creeks WAU Total	***99***	***16***	***51.5***	***7.2***

The road network is classified as high, moderate and low surface erosion hazard (Map B-1). The roads with the high hazard are the highest priorities for improvements, monitoring or maintenance. The moderate hazard roads are a medium priority for improvements, monitoring or maintenance. The low hazard roads are not much of a concern for sediment delivery.

High and moderate treatment immediacy controllable erosion and diversion potential sites were identified along the roads in the Willow/Freezeout Creeks WAU and needs to be a focal point of ongoing forest operations. The Willow/Freezeout Creeks WAU currently has 9 high treatment immediacy sites, 23 moderate immediacy sites and 54 sites with a diversion potential. Potentially 26 culverts are too small to pass the 50 year flood and 3 additional culverts likely will not pass the 100 year flood. These sites will be a priority for improvement of the road network in the Willow/Freezeout Creeks WAU. The road number, site number for each individual site is shown on Map B-2 and in Appendix B of this report.

Sediment delivery from skid trails was found to be highest in Willow Creek in the 1950s and 1960s. Freezeout Creek had high sediment delivery in the 1980s, while Dutch Bill Creek had sediment delivery peaks in the 1960s and 1980s. This is mainly due to a high amount construction and use of skid trails during these time periods. Future skid trail sediment delivery rates will be lower than past rates because California Forest Practice Rules and MRC policy mandate better managed tractor yarding activities. Better erosion control measures are used on skid trails such as increased water bar spacing and a practice by MRC of packing the trails with logging debris (slash), when available, after operations to prevent surface erosion. Furthermore, skid trail operation is limited next to watercourses and prohibited directly in watercourses.

Forested and grassland gullies have been observed to be large sediment production areas in Willow Creek. Trihey and Associates (1997) estimate forested gully sediment production over the last 40 years at 160 tons/mi^2/year and grassland gully erosion at 100 tons/mi^2/year.

Hydrology

Throughout the last 40-50 years, in the Russian River watershed, there have been numerous large flood events (Figure C-1). These flood events have the capacity to re-shape river or stream channels and transport large sediment loads. Using the peak flow record from 1940-1998 for the Russian River, the flood of record is 1986 (102,000 cfs) calculated to be a 30 year event for the Russian River (Table C-1). The second highest peak flow of record occurred in 1995 (93900 cfs) and the third highest peak flow was in 1964 (93400 cfs). Although is unlikely that these peak flows directly correlate with storm patterns for Willow and Freezeout Creeks. It is very probable that the magnitude of these storms influenced Willow and Freezeout Creeks. Thus some of the largest storms to influence Willow and Freezeout Creeks likely occurred in 1986 and 1995. The Salmon Creek peak flow data record does not have either the 1986 or 1995 peak flows in its record (Appendix C). However, the time period it does cover shows 1982 as the highest flood of record. The 1982 flood for the Russian River was not that impressive in a relative sense, it registers as about a 7-8 year return interval. Yet, locally on the coast the 1982 storm was very large as shown by the Salmon Creek data.

An analysis of streambed sediment mobility shows several stream segments have high bed mobility. An upper segment of the Willow Creek channel has a low width to depth ratio therefore the bankfull discharge is deeper and more apt to produce a higher predicted D50. However, there is a high amount of stored gravel deposits in the channel and banks of this area and it likely that the high bed mobility is a function of the high sediment supply available to the channel. The two segments along Freezeout Creek both have high predicted median particle size (D50) yet low observed D50 making it rank as having high bed mobility potential. These segments have very high gradients that typically show a tendency toward a larger stream bed size. However, the confounding factor is when a high amount of friction or drag is introduced in the channel, thus slowing water velocities and the ability to transport smaller sediment sizes. This is likely the case in the Freezeout Creek segments. Both channels are stable with large wood debris dams storing sediment, and creating drag on the flow regime thus lowering the segments median particle size. In the case of the Freezeout Creek segments a high bed mobility is expected given the high gradient and frequent wood accumulations.

Riparian Function

The riparian function assessment is divided into two groups: 1) the potential of the riparian stand to recruit large woody debris (LWD) to the stream channel along with the level of concern about current LWD conditions in the stream, and 2) a canopy closure and stream temperature assessment.

Our analysis showed a need for large woody debris in most of the channel segments of the Willow/Freezeout Creeks WAU. Channel segments with LWD levels that are well below targets will need to be a priority for future recruitment and restoration work. Riparian LWD recruitment potential in the Willow Creek/Freezeout WAU is moderate to low (See Map D-1, Riparian module). Past harvesting activities in riparian areas have resulted in small hardwood or mixed conifer/hardwood streamside stands. These streamside stands need to be managed to be become large conifer stands to provide a natural source of LWD over time.

Stream canopy cover and stream temperatures in the Willow Creek/Freezeout Creeks WAU are at favorable levels for salmonids. The three temperature sites in the Willow/Freezeout Creeks WAU show maximum average weekly temperatures (MWAT) that are well below the maximums for coho salmon (17-18C^o)(Brett, 1952 and Becker and Genoway, 1979). These MWAT values almost always fall within the preferred temperature range of coho as defined by Brett (1952). The MWAT values observed range from 13.0 to 15.3 during the stream monitoring period of 1994-2000. Instantaneous maximum temperatures recorded at the three temperature sites in the Willow/Freezeout Creeks WAU are higher than the preferred temperature ranges for coho salmon (12-14 C^o) and steelhead trout (10-13 C^o)(Brett, 1952 and Bell, 1986). However, these are maximums and are infrequent or of short duration. The MWAT values for these streams are the best indicators of stream temperature conditions.

Stream Channel Condition

Baseline information on the stream channels of the Willow/Freezeout Creeks WAU was collected and reported (see Table E-1, Stream Channel Condition module). Individual channel segments were categorized into geomorphic units using the baseline stream channel information, topography the channel segments are found in, position in the drainage network, and gradient/confinement classes. Four geomorphic units were established to represent the range of channel conditions and sensitivities to input factors of coarse and fine sediment and LWD (Table ES-2) (see Map E-2, Stream Channel Condition module).

Table ES-2. Stream Geomorphic Units and Sensitivities for the Willow/Freezeout Creeks WAU.

Stream Geomorphic Unit	Approximate Location(s)	Channel Sensitivity		
		Coarse Sediment	**Fine Sediment**	**LWD**
I. Depositional Channels Entrenched in Streamside Terraces.	Willow Creek near outlet of MRC lands.	Moderate	High	High
II. Highly Confined Depositional Channels within Steep Canyon Walls.	Majority of Class I watercourses of Willow and Freezeout Creeks	High	High	High
III. Moderate Gradient Transport Segments of Willow and Freezeout Creeks.	Tributary stream channels with slope gradients of 2-8%.	High	Moderate	High
IV. High Gradient Transport Segments of Willow and Freezeout Creeks.	Typically Class III, but some Class II watercourses with slope gradients of 8-20 percent.	Moderate	Low	High

Fish Habitat Assessment

Coho salmon (*Oncorhynchus kisutch*) historically resided in the Willow/Freezeout Creeks WAU. It is uncertain if coho are currently present in this WAU. Coho were not observed in this WAU during fish distribution surveys conducted by LP / MRC between 1994 and 2001.The fish species found during these surveys were steelhead (*Oncorhynchus mykiss*), prickly sculpin (*Cottus asper*), coastrange sculpin (*C. aleuticus*), and stickleback (*Gasterosteus aculeatus*) (MRC 2002). See Section F - Fish Habitat Assessment for distribution.

Fish habitat quality for the 3 main life stages; spawning, rearing, and overwintering habitat were evaluated for salmonids for 2000 (see Table F-3, Fish Habitat Assessment module). For almost all stream segments assessed, habitat conditions are found to be currently poor to fair. Historic information suggests better habitat conditions in the past. The combination of high sediment inputs in the 1970's and 1980's along with low large woody debris has resulted in lower habitat quality.

Sediment Input Summary

A high amount of sediment inputs are estimated for Willow Creek watershed in the 1950s and 1960s, primarily from skid trail and gully erosion. Mass Wasting is highest in Willow Creek during the 1980s when the largest storms on record created a large amount of debris slide failures. Sediment inputs for mass wasting were only estimated for the past 30 years and road associate erosion for the last decade. However, to provide context for the last 50 years the average rate of erosion for roads and mass wasting was extrapolated for comparison to the gully and skid trail estimates. This extrapolation show gully erosion as the highest contributor (34%) with roads as the lowest (16%)(Table ES-3).

Table ES-3. Proportion of Sediment Inputs by Process for the Willow/Freezeout Creeks WAU, 1950-2000.

Watershed	Road Assoc. Fluvial and Surface Erosion *	Skid Trail Erosion	Gully Erosion (Trihey)	Mass Wasting **
Willow Creek	16%	22%	34%	27%
Freezeout Creek	35%	23%	n/a	42%
Dutch Bill	44%	45%	n/a	10%

* - 1990s estimate used to extrapolate 1950-1990 inputs
** - 1970-2000 estimate use to extrapolate for 1950-1970 inputs

The highest amount of sediment inputs for Freezeout Creek watershed occurred in the 1980s. This is from a high amount of tractor yarding creating skid trail associated erosion and a high amount of mass wasting from large storm events that decade. The proportion of erosion is fairly evenly spread between mass wasting, skid trail and road erosion for Freezeout Creek watershed. However, mass wasting is the largest contributor (42%) in the Freezeout Creek watershed. The land in Dutch Bill Creek primarily has the sediment inputs split between road and skid trail with some mass wasting erosion as well.

Factors Limiting Salmonid Production in the Willow/Freezeout Creeks WAU

The watershed analysis performed in the Willow/Freezeout Creeks WAU identified several factors that likely limit the production of anadromous salmonids in those watersheds. This section summarizes these factors and potential linkages to sources of the limiting factors in the watersheds. The limiting factors considered are migration barriers, water quality, water quantity, sedimentation, temperature, large woody debris, and nutrients.

Table ES-4. Primary factors limiting salmonid production in the Willow/Freezeout Creeks WAU.

Anadromous Salmonid Life Stage	Factor	Reason	Current and Future Source(s)
Spawning	Fish migration barrier, Willow Creek.	High sediment inputs from past forest management activities and straightening of lower reaches of Willow Creek have created coarse sediment aggradation and resulted in adult fish migration barrier.	• Stored sediments in upper channel reaches. • Mass wasting from shallow and deep seated landslides. • Sediment delivery from point source erosion created from roads and skid trails. • Degradation and bank erosion in headwater streams.
Spawning	Fish migration barrier, Freezeout Creek.	Just within the MRC property the Freezeout Creek channel does not facilitate anadromous fish migration.	• Naturally occurring high gradient channel with cascades and waterfalls limits anadromous fish migration.
Rearing	Sedimentation	High sediment inputs from past forest management activities has filled pools and lowered the diversity of rearing habitat	• Stored sediments in upper channel reaches. • Mass wasting from shallow and deep seated landslides. • Sediment delivery from point source erosion created from roads. • Sediment delivery from skid trail erosion. • Degradation and bank erosion in headwater streams.
Rearing, Over-wintering	Large woody debris (LWD)	LWD need is high in the majority of the watercourses in the WAU. This limits pool formation, high flow refuge, habitat cover and sediment routing.	• Conifer trees adjacent to watercourses.
Rearing, Spawning	Water Quality	High erosion rates suggest a possibility of high fine sediment in transport in the watersheds increasing storm water turbidity.	• Surface erosion from roads and skid trails. • Point source erosion from roads and skid trails. • Bank erosion and stored sediments in stream channels.

Watershed Analysis Unit Specific Prescriptions

The following prescriptions were specifically prepared for use in the Willow/Freezeout Creeks Watershed Analysis Units (WAU). These prescriptions are meant to help address issues to aid in the stewardship of aquatic resources of the Mendocino Redwood Company ownership in the Willow/Freezeout Creeks WAU. The prescriptions are meant to be used in addition to the current California Forest Practice Rules and company policies. At the time of the publication of this watershed analysis the forest management policies are governed by interim guidelines prior to the issuance of a Habitat Conservation Plan and Natural Community Conservation Plan (HCP/NCCP). Once the HCP/NCCP is approved then the conservation strategies set forth in these documents will become the company policies. A prescription is only presented if it deviates from these regulations or policies.

Mass Wasting Prescriptions:

Mass Wasting Map Unit 1:

Road placement, construction and management:

- New road construction in MWMU 1 on slopes greater than 50 percent will not occur unless it is the only access available. If new road construction must occur on slopes of 50 percent slope or greater in MWMU 1 it will only be to gain entry in and out of MWMU 1 and construction developed with the approval of a Certified Engineering Geologist.
- Seasonal roads (gets used annually) in MWMU 1 will have the surface of new road construction or re-opened existing roads armored with rock.
- Temporary roads (roads only used periodically, every few years or decades) in MWMU 1 will be storm-proofed (such a suggested in Weaver and Hagans, 1994) prior to the winter period and the surface stabilized with grass seed, mulch or other cover product.
- Any road that is within MWMU 1 will not have winter period heavy truck or log hauling traffic unless armored with a rock surface.

Adjacent to Class I watercourses:

- MWMU 1 will receive no harvest on inner gorge slopes unless approved by a California Licensed Geologist. On other areas (non-inner gorge slopes) within MWMU 1 in addition to the riparian protections set as company policy timber harvest must retain a minimum of 50% overstory canopy dispersed evenly across the slopes.
- The MWMU 1 protections will extend from the edge of the watercourse transition line up to the break in slope of the inner gorge and 25 feet slope distance after the break in slope of the inner gorge or a maximum of 190 feet.
- For those areas that do not have a well defined inner gorge topography in MWMU 1 protections will be 190 feet slope distance in width from the watercourse transition line. Timber harvest must retain 50% overstory canopy.
- The area of protection in MWMU 1 will be an equipment limitation zone (ELZ) except when slopes are less than 40%, or at designated crossings, or on established stable roads or tractor trails.

- The slopes of the inner gorge or the first 50 feet, whichever is longer, will be an equipment exclusion zone (EEZ) except for designated crossings and existing truck roads.
- The area directly adjacent to the break in slope of the inner gorge will retain those trees with a root mass that maintains the stability of that slope break.
- Trees within 10 feet of the bankfull channel will be retained, except for redwood clumps, at least 50% of the clump must be retained with emphasis on leaving the largest trees on the clump.

Adjacent to Class II watercourses:

- MWMU 1 will receive no harvest on inner gorge slopes unless approved by a California Licensed Geologist. On other areas (non-inner gorge slopes) within MWMU 1 in addition to the riparian protections set as company policy timber harvest must retain a minimum of 50% overstory canopy dispersed evenly across the slopes.
- The MWMU 1 protections will extend from the edge of the watercourse transition line up to the break in slope of the inner gorge and 25 feet slope distance after the break in slope of the inner gorge to a maximum distance of 150 feet. For those areas that do not have a well defined inner gorge topography in MWMU 1 protections will be 150 feet slope distance in width from the watercourse transition line.
- MWMU 1 will be an equipment limitation zone (ELZ) except when slopes are less than 40%, at designated crossings, and on established stable roads or tractor trails.
- The slopes of the inner gorge or the first 50 feet, whichever is longer, will be an equipment exclusion zone (EEZ) except for designated crossings and existing truck roads.
- Trees within 10 feet of the bankfull channel will be retained, except for redwood clumps, at least 50% of the clump must be retained with emphasis on leaving the largest trees on the clump.

Mass Wasting Map Unit 2:

Road construction, placement or management:

- Alternatives to road construction or road use, such as cable yarding, helicopter yarding or alternative road placement, will be pursued in MWMU 2.
- New road construction will be avoided in MWMU 2 except when no other feasible route is available. In situations where a new road must go through MWMU 2 new road construction is required to have full bench construction with all construction materials end hauled or a similar treatment and the road operation that meets the lowest risk for erosion will be utilized. If the new road construction occurs in MWMU 2 it must avoid areas where there is a significant likelihood of sediment delivery. The exception is when a qualified certified engineering geologist approves the operations.

Adjacent to Class II watercourses:

- MWMU 2 will receive no harvest on inner gorge slopes unless approved by a California Licensed Geologist. On other areas (non-inner gorge slopes) within MWMU 2 in addition to the riparian protections set as company policy timber harvest must retain a minimum of 50% overstory canopy dispersed evenly across the slopes.

- The MWMU 2 protections will be 100 feet slope distance in width extending from the edge of the watercourse transition line.
- MWMU 2 will be an equipment limitation zone (ELZ) except when slopes are less than 50%, or designated crossings, or on established stable roads.
- The slopes of the inner gorge or the first 50 feet, whichever is longer, will be an equipment exclusion zone (EEZ) except for designated crossings and existing truck roads.
- Trees within 10 feet of the bankfull channel will be retained, except for redwood clumps, at least 50% of the clump must be retained with emphasis on leaving the largest trees on the clump.

Adjacent to Class III watercourses:

- The MWMU 2 protections adjacent to Class III watercourses will extend from the edge of the watercourse transition line on both sides of the watercourse up to a break in slope <70% gradient or 100 feet slope distance, whichever is shortest.
- On slopes adjacent to Class III watercourses in MWMU 2 timber harvest must retain a minimum of 50% overstory canopy dispersed evenly across the slopes.
- MWMU 2 protection area is an equipment limitation zone except when slopes are less than 50%, at designated crossings, and on established stable roads.
- Trees within 10 feet of the bankfull channel will be retained, except for redwood clumps, at least 50% of the clump must be retained with emphasis on leaving the largest trees on the clump.

Mass Wasting Map Unit 3 and 7:

Forester will utilize available resources for identification of unstable areas or areas with predicted slope instability. These include Map A-1 of Mass Wasting Assessment for the Willow/Freezeout Creeks WAU, Division of Mines and Geology landslide maps (if available), or past Timber Harvest Plans.

Forester will walk the ground of this unit prior to prescribing operations. If upon field review the unit is confirmed to meet the definition of MWMU 3 the following guidelines apply:

- No road or landing construction activity will occur in areas identified in the field as having a significant likelihood of sediment delivery to a watercourse from mass wasting unless a site-specific assessment is conducted and operations approved by a California Registered Geologist.
- Harvest operations must retain at least 50% of the overstory canopy unless a site-specific assessment is conducted and operations approved by a California Registered Geologist.

In MWMU 7 Road drainage must be dispersed off of roads in this unit. Concentrated road drainage must be corrected. If new roads are developed in this terrain then concentrated drainage must be avoided.

Mass Wasting Map Unit 6:

No regeneration harvest treatments will be allowed in MWMU 6 unless 50% overstory canopy is retained (averaged across the stand). In those areas of MWMU 6 where an earthflow is active no harvest will occur unless approved by a registered geologist.

Road or tractor trail drainage must be dispersed off of roads/trails in this unit. Concentrated road/trail drainage must be corrected. If new roads/trails are developed in this terrain then concentrated drainage must be avoided.

Aquatic Management Zone Prescriptions:

The company policies for streamside stands are considered appropriate at this time. The exception to this is in MWMU 5, the AMZ will only require a 75 slope distance width.

Trees within 10 feet of the bankfull channel of all watercourses will be retained, except for redwood clumps, at least 50% of the clump must be retained with emphasis on leaving the largest trees on the clump.

If harvest activity is proposed in the APZ along Class I and Large Class II watercourses then effective shade of the watercourse must be managed for. A large Class II watercourse is defined as having greater than 100 acres watershed area. Effective shade is a function of vegetation height, stream width and/or topographic barriers. Effective shade over perennial watercourses will not be reduced below 85 percent canopy, unless as part of an approved riparian restoration project (hardwood conversion to conifer). Cumulatively across the entire the WAU area the shade canopy must average above 85 percent stream shading for Class I and Large Class II watercourses. Those areas with natural grassland openings in the Willow/Freezeout Creek WAU are excluded from the shade averaging.

Road Associated Prescriptions:

High Erosion Hazard Roads:

The long undrained road approaches to watercourse crossings on these roads will be treated with one or a combination of several of these options:

1) Ditch relief culverts can be installed to drain water and sediments concentrated in inside ditches. The ditch relief culverts would be placed such that the majority of long undrained approaches to watercourse crossings of the road would be relieved prior to the watercourse crossing. The discharges of water and sediment from the ditch relief culverts would drain on to the adjacent hillslope where no additional erosion is predicted.
2) Rocked rolling dips or rolling dips can be installed in the road prism. The rolling dips would be placed such that the majority of long undrained approaches to watercourse crossings of the road would be relieved prior to the watercourse crossing. The discharges of water and sediment from the ditch relief culverts would drain on to the adjacent hillslope where no additional erosion is predicted.

3) Long road approaches to watercourse crossings can have the road prism re-shaped such that the road is outsloped toward its outside edge. This out-sloped road would be done so that it allows continuous drainage of the road surface away from the watercourse crossings.

Section of these roads with high controllable erosion areas will be upgraded. The road prism will be out-sloped, perched fill material will be removed and the road prism narrowed where feasible. Unnecessary culverts will be removed and replaced with rocked fords, additional rocked rolling dips will be installed as needed.

Where possible these roads should be a high priority for decommissioning.

Moderate Erosion Hazard Roads:

Maintenance and observation of road conditions on these roads will be conducted by the high road design standards, such as set in the Handbook for Forest and Ranch Roads (Weaver and Hagans, 1994).

Roads that have not been abandoned in the Willow/Freezeout Creeks WAU will be monitored at least once annually during the winter period to look for potential culvert problems, road fill failures, trespassing damages, road drainage problems, or excessive sediment delivery.

High Treatment Immediacy Road Points:

The high treatment immediacy controllable erosion sites will be the highest priority for erosion control, upgrade or modifications to existing design. These sites will be scheduled for repair based on operational considerations of harvest scheduling, proximity and availability of equipment, magnitude of the problem, and accessibility to the site.

Moderate Treatment Immediacy Road Points:

The moderate treatment immediacy controllable erosion sites will be the next highest priority (relative to the high treatment immediacy sites) for erosion control, upgrade or modifications to existing design. The moderate treatment immediacy sites will be addressed when in close proximity to high treatment immediacy sites.

Diversion Potential Road Points:

These diversion potential sites will be a high priority for correction. These sites will be scheduled for repair based on operational considerations of harvest scheduling, proximity and availability of equipment, magnitude of the problem, and accessibility to the site. It is very likely that these sites will be addressed when in close proximity to high treatment immediacy sites.

Under-sized Culverts:

The 23 culverts that will not pass the 50 year flood will be visited in the field and a determination will be made if the culverts are indeed under-sized (identification of under-sized culverts was done by an office-based evaluation that could be inaccurate). If after field review the culverts are found to be under-sized it will be a high priority for replacement to a watercourse crossing structure that will pass the 100-year flood.

The 3 culverts that will not pass the 100 year flood will be visited in the field and a determination will be made if the culverts are indeed under-sized for this sized flood event (identification of under-sized culverts was done by an office-based evaluation that could be inaccurate). If after field review the culverts are found to be under-sized for the 100 year flood it will be a moderate priority for replacement to a watercourse crossing structure that will pass the 100-year flood. Typically the upgrade will occur once the culvert has reached the end of its operational life.

The field review will consist of determining the cross section area of the bankfull channel and comparing it the cross sectional area of the culvert in question. A rule of thumb is that to pass the 100 year flood the culvert opening area needs to be 3 times as large as the bankfull channel cross section area (Cafferata, Spittler, and Wopat, 2000).

WLPZ (aka AMZ roads) sections of road HC:

Road surface and prism treatment and road management:

- Roads used annually in the AMZ will have the surface of new road construction or re-opened existing roads armored with a rock surface.
- Roads used periodically, every few years or decades in AMZ will be storm-proofed (as per Weaver and Hagans, 1994) prior to the winter period and the surface stabilized with grass seed, mulch or other cover product.
- Any road that is within a Class I or II watercourse AMZ will not have winter period heavy truck or log hauling traffic, except emergency situations, unless the road tread is armored with a rock surface.

The road prism and drainage design for AMZ roads will be based on high road design standards such as found in the Handbook for Forest and Ranch Roads (Weaver and Hagans, 1994). If the AMZ road does not currently meet those standards then these roads will be a high priority for upgrades.

Winter period hauling conditions will be monitored carefully. In order to avoid sediment movements and damage to road surface, there will be no log or heavy equipment hauling during periods of rainfall or when roadside ditches are flowing surface runoff, or when road is saturated and cannot support heavy loads, except in emergency situations. At the first sign of measurable rain, trucks will make their final trip out on the road, and trucks not yet on the road will be asked to return home. The road will not be used until rainfall has stopped and the road surface has dried sufficiently so that the surface will not be damaged by use. Only a

Mendocino Redwood Company employee will make or grant the authority to a contractor for this determination.

Gully erosion (Grassland areas and forested areas):

Where road drainage is concentrating water on grassland slopes or in depressions or watercourses in forested areas, the road will be re-shaped to provide for more dispersed water drainage. Where road drainage has previously created gully erosion, the drainage point will be armored to prevent further erosion.

Tractor roads (skid trails) will have erosion control structures placed on them prior to rainy season to disperse water off surfaces and away from potential gully erosion areas. Skid trails, where feasible, will have slash, debris or mulch placed on them to lower surface and gully erosion hazard.

MRC will pursue restoration opportunities to slow or stop gully erosion in Willow Creek.

MRC will develop a grazing plan for the grassland areas of Willow Creek to attempt to regulate the amount of vegetation removal and timing of grazing.

Monitoring

Aquatic resources monitoring will be conducted in the Willow/Freezeout Creeks WAU. The monitoring is a combination of hillslope and in-stream assessments.

Monitoring Plan Goals:

- Test the efficacy of the Willow/Freezeout Creeks WAU prescriptions to address impacts to aquatic resources from timber harvest and related forest management activities.
- To assess long term channel conditions. Are current and future forest management practices inhibiting, neutralizing or promoting stream channel conditions for aquatic habitat?

A monitoring report will be produced each year that monitoring is conducted in the Willow/Freezeout Creeks WAU. The report will cover the monitoring and analysis that has occurred up to that year. If no monitoring is conducted in a given year than no report will be produced. The goal will be to have a report completed by spring of the year following the monitoring.

The monitoring matrix (Table I-1) outlines the hillslope and in-stream monitoring MRC will be conducting in the Willow/Freezeout Creeks WAU. The monitoring will be performed periodically. MRC will be developing a property wide aquatic monitoring strategy. Once that monitoring strategy is complete, the precise timing of the monitoring in the Willow/Freezeout Creeks WAU will be finalized. The information collected in this monitoring effort will be used as part of an adaptive management approach to the Willow/Freezeout Creeks WAU. The monitoring results will be compared to the baseline information generated in the Willow/Freezeout Creeks Watershed Analysis to discover if aquatic habitat or water quality concerns are improving, staying the same or degrading. If aquatic habitat or water quality concerns are not improving then the land management prescriptions will be altered to better protect those impaired resources.

In addition to the aquatic resources monitoring, monitoring of the roads that have not been abandoned in the Willow/Freezeout Creeks WAU will be monitored at least once annually during the winter period.

Table I-1. Monitoring Matrix for Willow/Freezeout Creeks Watershed Analysis Unit.

Monitoring Objectives	Reasoning, Comments	Technique
1. Determine effectiveness of measures to reduce management created mass wasting.	Management created mass wasting is significant contributor of sediment delivery.	Evaluation of mass wasting following a large storm events or after approximately 20 years.
2. Determine effectiveness of erosion control practices on high and moderate surface erosion hazard roads and landings.	Roads provide sediment delivery in the Willow/Freezeout Creeks WAU.	Randomly selected watercourse crossings, landings and road lengths for erosion evaluation.
3. Determine in-stream large woody debris amounts over time.	Large woody debris is needed for stream channel and aquatic habitat improvement in the Willow/Freezeout Creeks WAU.	Stream LWD inventories and mapping of LWD designation areas in select stream reaches and long term channel monitoring sites.
4. Determine if stream temperatures are staying within properly functioning range for salmonids.	Stream temperature can be a limiting factor for salmonid growth and survival.	Stream temperature probes and modeling conducted in strategic locations.
5. Determine if fine sediment in stream channels is creating effects deleterious to salmonid reproduction.	Many forest practices can produce high fine sediment amounts. Need to ensure fine sediments are not impacting salmonid reproduction.	Permeability measurements on select stream reaches (bulk gravel samples if necessary).
6. Determine long-term channel morphology changes from coarse.	Channel morphology can be altered from sediment increases, possibly affecting aquatic habitat.	Thalweg profiles and cross section surveys on select stream reaches.
7. Determine presence and absence of fish species in Class I watercourses.	Management practices and resource protections can affect distribution of aquatic organisms.	Electro-fishing at select locations to determine species composition and presence.
8. Determine rate or erosion and effectiveness of mitigation measures for gullies.	Gully erosion is a significant sediment delivery process in the WAU.	Transect and permanent cross section monitoring.

Watershed Analysis
for Mendocino Redwood Company's Ownership
in the
Willow and Freezeout Creeks Watersheds

Introduction

This report presents the results of a watershed analysis performed by Mendocino Redwood Company (MRC) on their ownership in the Willow/Freezeout Creeks watersheds. This report has been developed in an attempt to meet the California Board of Forestry's 45 Day Notice for a Watershed Evaluation and Mitigation Addendum (WEMA). However, the WEMA has evolved into a different proposal and notice by the Board of Forestry titled an Interim Watershed Mitigation Addendum (IWMA). This study was a pilot WEMA for consideration by the Board of Forestry, and it is the intent of MRC to submit this watershed analysis as a WEMA or IWMA should the Board of Forestry pass the notice as a Forest Practice Rule. Should the Board of Forestry not approve the notice, MRC will continue to use the analysis, land management prescriptions and monitoring presented in this watershed analysis.

The MRC ownership in the Willow/Freezeout Creeks watersheds is considered the Willow/Freezeout Creeks watershed analysis unit (WAU). Some analysis for the MRC ownership in the Dutch Bill Planning watershed is presented as part of the Willow/Freezeout Creeks watershed analysis. This area in Dutch Bill Creek planning watershed is not intended to be part of the WEMA or IWMA; should this report be used for that purpose. However, that land will be managed with the same land management prescriptions that are determined from this watershed analysis process.

This section presents an overview of the watersheds and the watershed analysis process followed by MRC. More specific information is found in the individual modules of this report.

Mendocino Redwood Company's Approach to Watershed Analysis

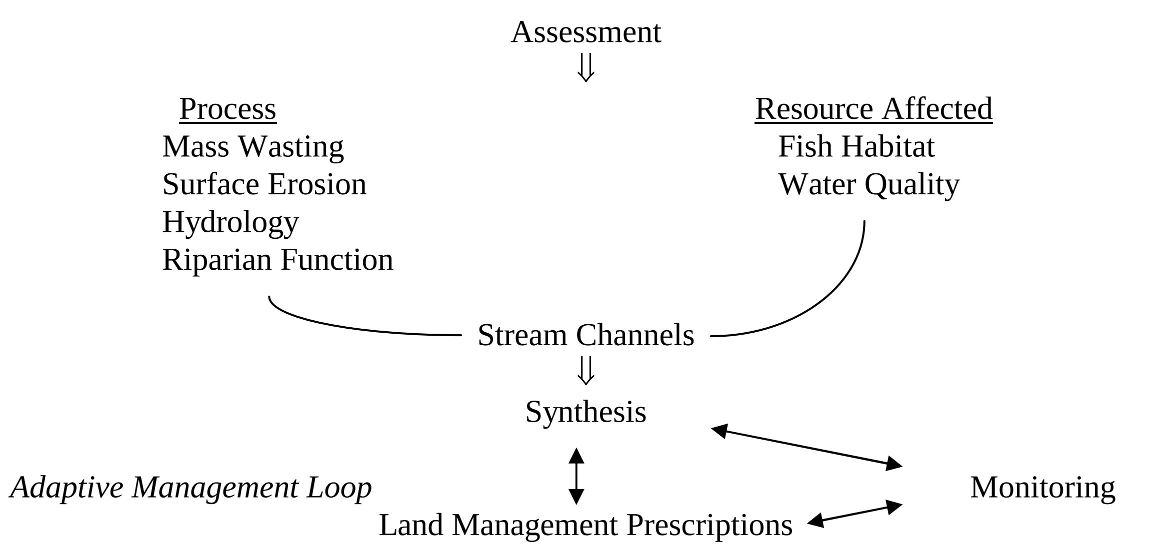
MRC is conducting watershed analysis on watersheds within its ownership in Northern California. The criteria for a watershed to be selected for intensive analysis are: 1) impaired waterbodies pursuant to the Clean Water Act Section 303(d), and 2) key fish populations and 3) forestry operation-related concerns.

The Willow/Freezeout Creeks watersheds are tributaries to the Russian River that is on the 303(d) list as sediment impaired and a total maximum daily load (TMDL) must be developed for sediment reduction. Willow and Freezeout Creeks and their tributaries support populations of coho salmon and steelhead trout, two fisheries of concern in northern California. For this reason MRC conducted a watershed analysis to assist in their efforts to reduce non-point source pollution, evaluate current and past land management practices and establish a baseline for monitoring of watershed conditions over time. The watershed analysis will also be used to identify needs for site-specific management planning in the watershed to reduce impacts to aquatic resources and potentially to improve fish and stream habitat conditions.

The watershed analysis of the Willow/Freezeout Creeks WAU was conducted following modified guidelines from the Standard Methodology for Conducting Watershed Analysis (Version 4.0, Washington Forest Practices Board). Some variations of the methods in this manual were performed when it was determined that the methodology better served the purpose of this assessment. MRC is using this process to address cumulative effects from forest practices and provide baseline information of watershed conditions for aquatic habitat and water quality for their ownership.

MRC's approach to the Willow/Freezeout Creeks watershed analysis or WEMA was to perform resource assessments of mass wasting, surface and point source erosion (roads/skid trails), hydrology, fish habitat, riparian condition and stream channel condition. Mass wasting, riparian condition and surface and point source erosion modules address the hillslope hazards. The physical processes and potential triggering mechanisms for each hillslope hazard are described in the module reports. The fish habitat and stream channel condition modules address the vulnerability of aquatic resources. The results of the resource assessments are synthesized and reported in a causal mechanism report (Figure 1). A casual mechanism report is produced for each hillslope hazard that has affected or has the potential to adversely affect aquatic resources. The causal mechanism report contains a description of the hillslope hazard and how land use activities trigger or route key input variables such as coarse sediment, fine sediment, wood and heat energy to sensitive resources. A prescription is developed to address the issues and processes identified in each causal mechanism report. Finally, monitoring is suggested to determine the efficacy of the prescriptions to protect sensitive aquatic resources. The monitoring will provide the feedback for MRC's adaptive management approach to resource conservation.

Figure 1. Watershed Analysis Overview



Assessment Overview

This watershed analysis was produced from a combination of field observations, performed during the summer of 2000, aerial photograph interpretation, and use of existing analysis on the Willow/Freezeout Creeks WAU.

Existing data or analysis used in this watershed analysis included: Louisiana-Pacific's (L-P) Coastal Mendocino Sustained Yield Plan, California Department of fish and Game Stream Inventory for Willow Creek (CDFG,1995), Sediment Supply and Sediment Transport Conditions Willow Creek report (Trihey and Assoc., 1995), Geology for Planning, Sonoma County (Huffman and Armstrong, 1980) and monitoring data collected by L-P and MRC. These information sources are cited in each module as they are used.

Aerial photograph interpretation was performed using available aerial photographs for the recent time period. The delineation of time periods for analysis was based on the available aerial photographs. The aerial photographs used are cited in each module as they are used.

The synthesis of the field observations, aerial photo interpretation and existing analysis on the WAU constitutes the resource assessment modules in this report.

Willow/Freezeout Creeks Watershed Analysis Unit Overview

Physical Characteristics

General Location and Assessment Area

The Willow/Freezeout Creeks WAU is located in the California Coast Range drains into the Russian River only a few miles inland from the Pacific Ocean in Sonoma county, California. The outlet of Willow Creek is in close proximity to the town of Jenner and the Freezeout Creek outlet is adjacent to the town of Duncan Mills.

The assessment area for the watershed analysis are the watersheds of Willow Creek and Freezeout Creeks, physical watershed not planning watershed, and the MRC lands in Dutch Bill Creek. The physical watersheds are used for the analysis because the planning watersheds for both Willow and Freezeout Creeks encompass areas that have no hydrologic connectivity to the MRC lands (both planning watersheds have area on both sides of the Russian River).

The MRC ownership and areas of the physical watersheds for Willow and Freezeout Creeks are shown in Table 1.

Table 1. Selected Physical Characteristics by Watershed for the Willow/Freezeout Creeks WAU.

Characteristics	Willow Creek	Freezeout Creek	Dutch Bill Creek
Watershed Area (ac)	5,650	1,900	12,614
MRC Owned Area (ac)	2,928	1,647	777
MRC Owned Area (%)	52%	87%	6%
Mean Annual Precipitation	50	55	50

Fisheries

Coho salmon (*Oncorhynchus kisutch*) historically resided in the Willow/Freezeout Creeks WAU. It is uncertain if coho are currently present in this WAU. Coho were not observed in this WAU during fish distribution surveys conducted by LP / MRC between 1994 and 2001.The fish species found during these surveys were steelhead (*Oncorhynchus mykiss*), prickly sculpin (*Cottus asper*), coastrange sculpin (*C. aleuticus*), and stickleback (*Gasterosteus aculeatus*) (MRC 2002). See Section F - Fish Habitat Assessment for distribution.

Geology

Lithologically the Willow and Freezeout Creeks WAU are characterized by the Coastal and Central Belts of the Franciscan Complex, and by the Upper Cretaceous sandstone of the Great Valley Sequence. Rocks of the Coastal Belt are highly sheared, and comprise structurally deformed massive, hard greywacke sandstone and shale interbeded with small amounts of limestone and pebble conglomerate. Rocks of the Central Belt underlie most of the area. Central Belt is a tectonic assemblage of fragmented Eastern Belt rocks and Mesozoic volcanic and metavolcanic rocks; it is in fault contact with the Coastal Belt. For much of its location this unit is comprised of Franciscan Melange. Due to high erodibility of the sheared shale (melange), this area is likely to be unstable and prone to mass wasting, especially earthflows. Rocks of the upper Cretaceous unit consist of consolidated, thick bedded, gently homoclinally folded sandstone with interbedded shale or mudstone, siltstone and conglomerate.

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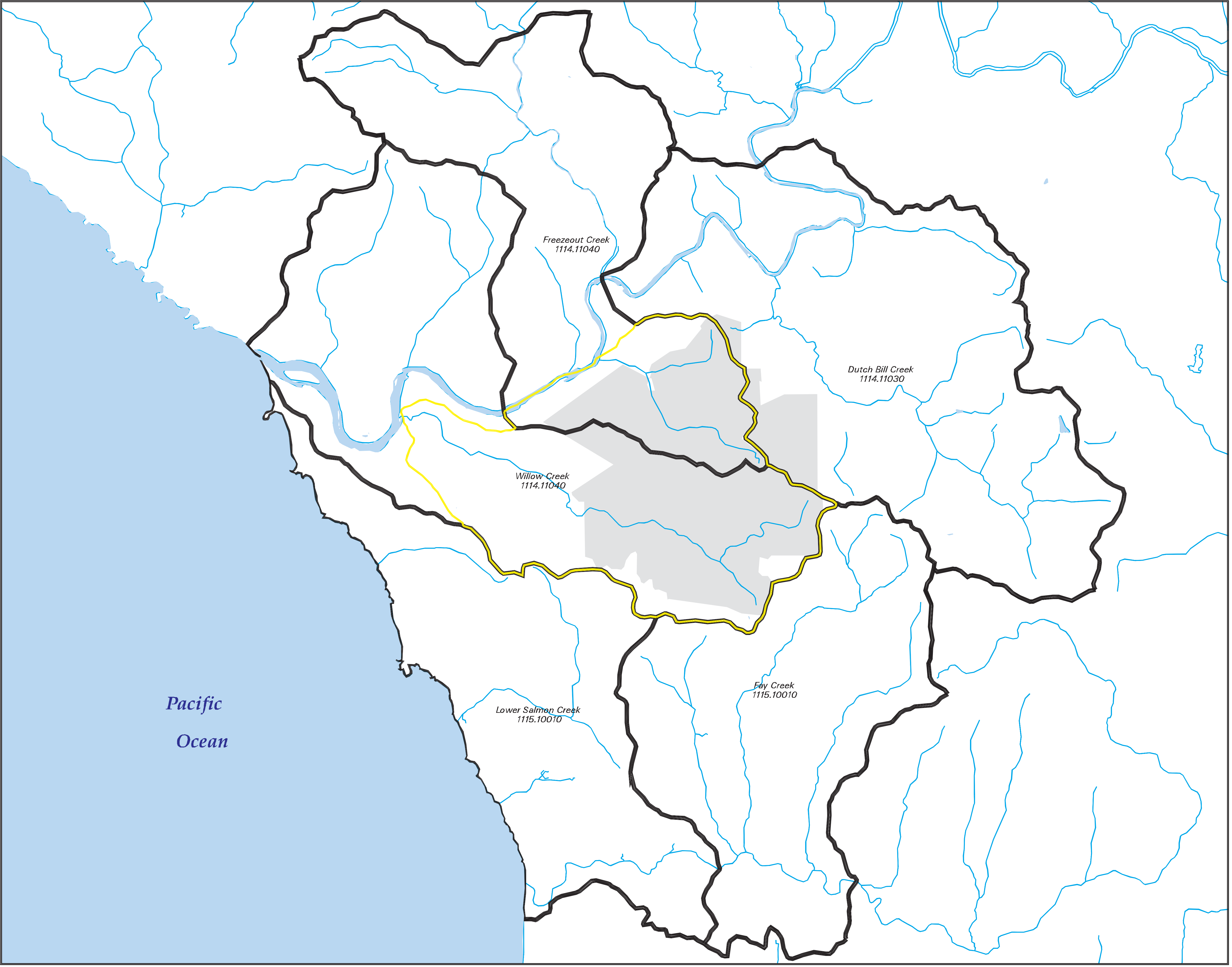
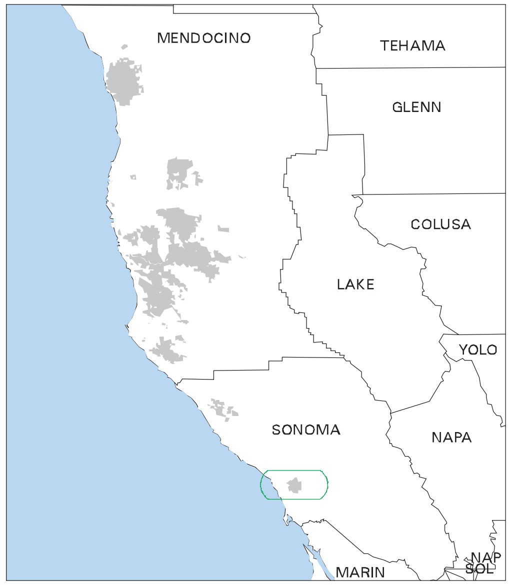
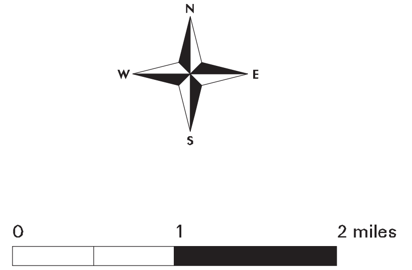


Willow Creek / Freezeout Creek Watershed Analysis Unit

Willow Creek / Freezeout Creek Watersheds

Streams
Watershed Assessment Unit
Planning Watershed
Ocean, Lake, Pond
MRC Ownership

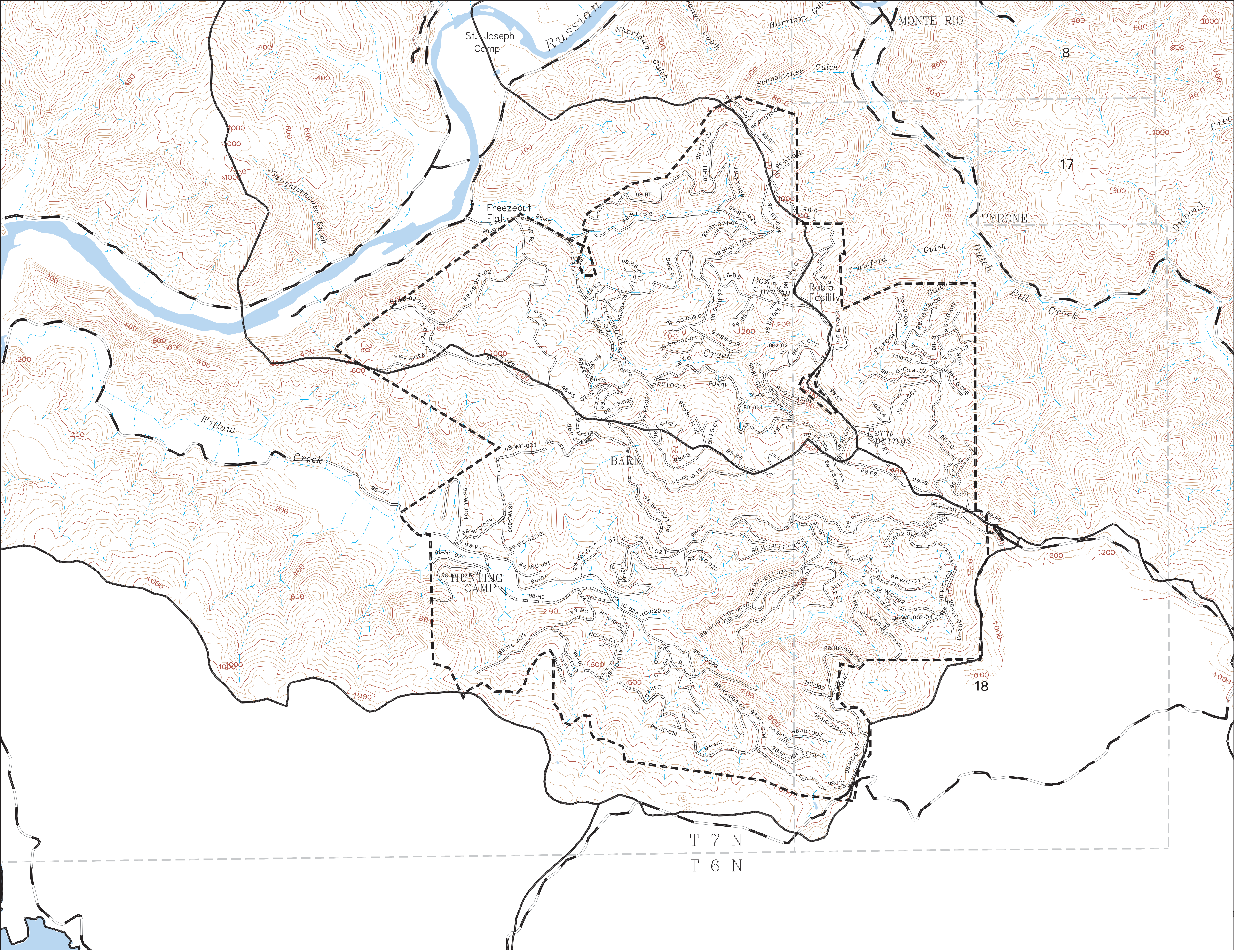




February 12, 2001

Willow Creek / Freezeout Creek Watershed Analysis Unit

Base Map



MRC Ownership

Planning Watershed Boundary

Transportation

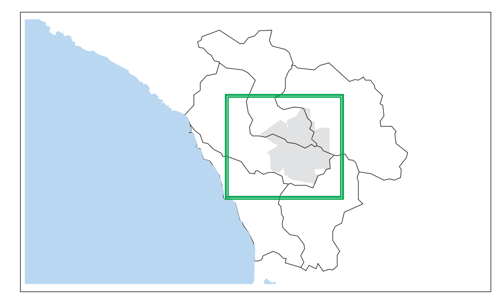
- Paved Road
- Rocked Road
- Native Road
- Jeep Trail
- Railroad

Flow Class

- Class I
- Class II
- Class III

Topography

- Index Contour (200′ interval)
- Regular Contour (40′ interval)



0 1/2 1 Mile

February 16, 2001

Section A
MASS WASTING

INTRODUCTION

This section summarizes the methods and results of a mass wasting assessment conducted on the Mendocino Redwood Company, LLC (MRC) ownership in the Willow Creek, Freezeout Creek, and Dutch Bill Creek watersheds. Throughout this report, ownership in these three watersheds will collectively be termed the Willow Creek Watershed Analysis Unit (Willow Creek WAU). This assessment is part of a Watershed Analysis initiated by MRC and utilizes watershed analysis modified methodology adapted from procedures outlined in the Standard Methodology for Conducting Watershed Analysis manual (Version 3.0, Washington Forest Practices Board).

The principle objectives of this assessment are to:

1) Identify the types of mass wasting processes active in the basin.
2) Identify the link between mass wasting and management related activities.
3) Identify where the mass wasting processes are concentrated.
4) Partition the ownership into zones of relative mass wasting potential (Mass Wasting Map Units) based on the likelihood of future mass wasting and sediment delivery to stream channels.

Additionally, the role of mass wasting sediment input to watercourses is examined. This information combined with the results of the surface erosion module will be used to construct a sediment input summary for the Willow Creek WAU, contained in the Sediment Input Summary section of this watershed analysis.

The products of this report are: a landslide inventory map (Map A-1), a mass wasting map unit (MWMU) map (Map A-2), a mass wasting inventory database (Table A-1), and a SHALSTAB (digital terrain slope stability model)(Dietrich and Montgomery, 1998) map (Map A-3) for the WAU. The basis for these products are: aerial photograph interpretation of 4 sets of aerial photographs (scales 1:12000 to 1:15840), dated 1978, 1987, 1996, and 2000, field observations during the summer of 2000, and interpretation of SHALSTAB data. Due to incompleteness of the MRCs 1987 aerial photograph set, select photographs from a 1990 photo set were used to complete coverage. The analysis was done without the use of historic aerial photographs (pre-1970s). Therefore the analysis presented is only representative for current mass wasting conditions (last 40 years).

The assembled information will enable forestland managers to make better forest management decisions to reduce management created mass wasting. The mass wasting inventory will provide the information necessary to understand the spatial distribution, causal mechanisms, relative size, and timing of mass wasting processes active in the basin with reasonable confidence.

The Role of Mass Wasting in Watershed Dynamics

Mass wasting is defined as the downslope movement of soil or rock material under the influence of gravity and water without the direct aid of other media such as air, or ice (Selby, 1993). Mass wasting is the dominant process in developing the morphology of steep, mountainous terrain. Mass wasting events are episodic and sometimes catastrophic in nature.

Mass wasting is a naturally occurring process, but can be accelerated by anthropogenic disturbances. Forest management practices can accelerate the natural frequency of mass wasting events by altering slope steepness, saturating soil and bedrock, altering soil cohesiveness, or removing root strength from a slope. Accelerated mass wasting can disrupt the dynamic equilibrium between hillslopes and channels, resulting in a decline of anadromous fish habitat.

Mass Wasting Influence on Stream Channels

Mass wasting is a natural process and provides a vital sediment link between hillslopes and stream channels. Mass wasting events are able to alter stream environments by increasing bed and suspended sediment loads, redistributing existing channel-bed sediments, introducing woody debris, changing channel morphology, damming and obstructing the channel, and in extreme cases scouring the channel to bedrock. Stream systems will adjust to major alterations downstream, as well as upstream of individual mass wasting events.

Mass Wasting Influence on Fish Habitat

In the Pacific Northwest where anadromous fish are present, mass wasting can have both beneficial and adverse effects on salmonid habitat. Beneficial effects include formation of new spawning, rearing, and over-wintering habitat due to addition of coarse gravels to the channel. The introduction of woody debris and boulders from landslides can increase cover and improve pool:riffle ratios. Adverse effects include filling of pools and scouring of riffles, blockage of fish access, disturbing side-channel rearing areas, and siltation of spawning gravels. The magnitude of these effects are dependent on the frequency, location, and intensity of mass wasting events, as well as the sediment transporting capabilities of a particular stream. Larger streams and rivers adjust to mass wasting perturbations faster than smaller streams.

Landslide Types and Processes in the Willow/Freezeout Creeks WAU

The terminology used to describe landslides in this report closely follows the definitions of Cruden and Varnes (1996). This terminology is based on two nouns, the first describing the material that the landslide is composed of and the second describing the type of movement. Landslides identified in the Willow Creek WAU were described using the following names: debris slides, debris torrents, debris flows, rockslides, and earth flows. These names are described in Cruden and Varnes (1996) with the exception of our use of debris torrent and debris flow.

Shallow-Seated Landslides

Debris slides, debris flows, and debris torrents are the shallow-seated landslide processes that were identified in the Willow Creek WAU. The material composition of debris slides, flows, or torrents is considered to be soil with a significant proportion of coarse material; 20 to 80 percent of the particles larger than 2 mm. Shallow-seated slides generally move quickly downslope and commonly break apart during failure. Shallow-seated slides commonly occur in converging topography where colluvial materials accumulate and subsurface drainage concentrates. Susceptibility of a slope to fail by shallow-seated landslides is affected by slope steepness, saturation of soil, soil strength (friction angle and cohesion), and root strength. Due to the shallow depth and fact that debris slides, flows, or torrents involve the soil mantle, these are landslide types that can be significantly influenced by forest practices.

Debris slides are, by far, the most common landslide type observed in the WAU. The landslide mass typically fails along a surface of rupture or along relatively thin zones of intense shear strain. The landslide deposit commonly slides a distance beyond the toe of the surface of rupture and onto the ground surface below the failure. While the landslide mass may deposit onto the ground surface below the area of failure, it generally does not slide more than the distance equal to the length of the failure scar. Landslides with deposits that traveled a distance below the failure scar would be defined by debris flow or debris torrent. Debris slides commonly occur on steep planar slopes, convergent slopes, along forest roads and on steep slopes adjacent to watercourses. They usually fail by translational movement along an undulating or planar surface of failure. Upon reaching a watercourse, by definition debris slides do not continue downstream.

A debris flow is similar to a debris slide with the exception that the landslide mass continues to “flow” down the slope below the failure a considerable distance on top of the ground surface. A debris flow is characterized as a mobile, potentially rapid, slurry of soil, rock, vegetation, and water. High water content is needed for this process to occur. Debris flows generally occur on both steep, planar hillslopes and confined, convergent hillslopes. Often a failure will initiate as a debris slide, but will change as its moves downslope to a debris flow. During this analysis these types of failures were mapped as debris flows.

Debris torrents are relatively rare, but have the greatest potential to destroy stream habitat and deliver large amounts of sediment. The main characteristic distinguishing a debris torrent is that the failure “torrents” downstream in a confined channel and scours the channel. As the debris torrent moves downslope and scours the channel, the liquefied landslide material increases in mass. A highly saturated soil is required for this process to occur. Debris torrents move rapidly and can potentially run down a channel for great distances. They typically initiate in headwall swales and torrent down intermittent watercourses. Often a failure will initiate as a debris slide, but will develop into a debris torrent upon reaching a channel. While actually a combination of two processes, these features were considered debris torrents.

Sediment Input from Shallow-Seated Landslides

The overall time period used for mass wasting interpretation and sediment budget analysis is thirty-two years. Sediment input to stream channels by mass wasting is quantified for three time periods (1969-1978, 1979-1987, 1988-2000). This is assumed because of the use of 1978, 1987/90, 1996, and 2000 aerial photographs and field observations in 2000. The evaluation is initiated at 1969 based on the earliest aerial photograph year of 1978 and the assumption that landslides farther back than about ten years are too difficult to detect, with much certainty, from aerial photographs. This is because landslide surfaces can re-vegetate quickly, making them too difficult to see. We acknowledge that we have likely missed some small mass wasting events during the aerial photograph interpretation. However, we assume we have captured the majority of the larger mass wasting events in this analysis. It is the large mass wasting events that provide the greatest sedimentation impacts. In the case of the landslides observed in the Willow Creek WAU, landslides greater than 300 cubic yards in size represented over 85% of the sediment delivery estimated. Landslides greater than 200 and 100 cubic yards in size represented approximately 90% and 97%, respectively of the sediment delivery estimated.

Sediment delivery estimates from mapped shallow-seated landslides were used to produce the total mass wasting sediment input. Some of the sediment delivery from shallow-seated landslides is the result of conditions created by deep-seated landslides. For example, a deep-seated failure could result in a debris slide or torrent, which could deliver sediment. Furthermore, over-steepened scarps or toes of deep-seated landslides may have shallow failures associated with them. These types of sediment delivery from shallow-seated landslides associated with deep-seated landslides are accounted for in the delivery estimates.

Deep-Seated Landslides

The two deep-seated landslide processes identified in the Willow Creek WAU are rockslides and earth flows. The failure dates of the deep-seated landslides generally could not be estimated with confidence and the landslides are likely to be of varying age with some landslides potentially being over 10,000 years old. Many of the deep-seated landslides are considered “dormant”, but the importance of identifying them lies in the fact that if reactivated or accelerated, they have the potential to deliver large amounts of sediment and destroy stream habitat. Accelerated or episodic movement in some landslides is likely to have occurred over time in response to seismic shaking or infrequent high rainfall events. Deep-seated landslides can be very large, exceeding tens to hundreds of acres.

Rockslides are deep-seated landslides with movement involving a relatively intact mass of rock and overlying earth materials. The failure plane is below the colluvial layer and involves the underlying bedrock. Mode of rock sliding generally is not strictly rotational or translational, but involves some component of each. Rotational slides typically fail along a concave surface, while translational slides typically fail on a planar or undulating surface of rupture. Rockslides commonly create a flat, or back-tilted bench below the crown of the scarp. A prominent bench is usually preserved over time and can be indicative of a rockslide. Rockslides can fail in response to triggering mechanisms such as seismic shaking, adverse local structural geology, high rainfall, or channel incision. The stream itself can be the cause of chronic movement, if it periodically undercuts the toe of a rockslide.

Earth flows are deep-seated landslides composed of fine-grained materials and soils derived from clay-bearing rocks. Earth flow materials consist of 80% or more of the particles smaller than 2mm. Materials in an earth flow also commonly contain boulders, some very large, which move downslope in the clay matrix. Failure in earth flows is characterized by spatially differential rates of movement on discontinuous failure surfaces that are not preserved. The “flow” type of movement creates a landslide that can be very irregularly shaped. Some earth flow surfaces are dominantly grassland, while some are partially or completely forested. The areas of grassy vegetation are likely due to the inability of the unstable, clay-rich soils to support forest vegetation. The surface of an earth flow is characteristically hummocky with locally variable slope forms and relatively abundant gullies. The inherently weak materials within earth flows are not able to support steep slopes, therefore slope gradients are low to moderate. The rates of movement vary over time and can be accelerated by persistent high groundwater conditions. Timber harvesting can have the effect of increasing the amount of subsurface water, which can accelerate movement in an earth flow. A principal source of anthropogenic created sediment from earthflows is often gully erosion resulting from concentrated or diverted water.

Sediment Delivery from Deep-Seated Landslides

A large, active deep-seated slide can deliver large volumes of sediment. Delivery generally occurs over long time periods compared to shallow-seated landslides, with movement delivering earth materials into the channel. These materials are then confined to the channel, resulting in an increased sediment load downstream of the failure. Actual delivery can occur by over-steepening of the toe of the slide and subsequent failure into the creek, or by the slide pushing out into the creek. Sediment delivery could also occur in a catastrophic manner. In such a situation, large portions of the landslide essentially fail and move into the watercourse “instantaneously”. These types of deep-seated failures are relatively rare and usually occur in response to unusual storm events or seismic ground shaking.

Movement of deep-seated landslides has definitely resulted in some sediment delivery in the Willow Creek WAU. Quantification of the sediment delivery from deep-seated landslides was not determined in this watershed analysis. Factors such as rate of movement, or depth of the deep-seated landslide are difficult to determine without in-depth geotechnical observations that were not included in this analysis. Sediment delivery to watercourses from deep-seated landslides (landslides typically ≥10 feet thick) can occur by several processes. Such processes can include surface erosion and shallow- or deep-seated movement of a portion or all of the deep-seated landslide deposit.

The ground surface of a deep-seated landslide, like any other hillside surface, is subject to surface erosion processes such as rain drop impact, sheet wash (overland flow), and gully/rill erosion. Fresh, unprotected surfaces that develop in response to recent or active movement could become a source of sediment until the bare surface becomes covered with leaf litter, re-vegetated, or soils developed.

Clearly, movement of a portion or all of a deep-seated landslide can result in delivery of sediment to a watercourse. To determine this the slide surface should be carefully explored for evidence of movement. However, movement would need to be on slopes immediately adjacent to or in close proximity to a watercourse and of sufficient magnitude to push the toe of the slide into the watercourse. A deep-seated slide that toes out on a slope far from a creek or moves only a short distance downslope will generally deliver little to a watercourse. It is also important to realize that often only a portion of a deep-seated slide may become active, though the portion could be quite variable in size. Ground cracking at the head of a large, deep-seated landslide does not necessarily equate to immediate sediment delivery at the toe of the landslide.

Use of SHALSTAB by Mendocino Redwood Company for the Willow/Freezeout Creeks WAU

SHALSTAB, a coupled steady state runoff and infinite-slope stability model, is used by MRC as one tool to demonstrate the relative potential for shallow-landslide hazard across the MRC ownership. A detailed description of the model is available in Dietrich and Montgomery (1998). In the watershed analysis mass wasting hazard is expanded beyond SHALSTAB. Inner gorge or steep streamside areas are mapped and designated as mass wasting map units. Relative areas of mass wasting and sediment delivery hazards are mapped using field and aerial photograph interpretation techniques. However, SHALSTAB output was used to assist in this interpretation of the landscape and mass wasting map units.

METHODS

Landslide Inventory

The mass wasting assessment relies on an inventory of mass wasting features collected through the review of aerial photographs and field observations. All aerial photograph sets used to interpret landslides are in color and are owned by MRC, with the 2000, 1996, and 1990/1987 sets at a photograph scale of 1:12,000, and 1:15,840 for the 1978 aerial photograph set. MRC collected data regarding characteristics and measurements of the identified landslides. Since mass wasting events were essentially “sampled”, we acknowledge that some landslides may have been missed, particularly small ones that may be obscured by vegetation. A description of select parameters inventoried for each landslide observed in the field and during aerial photograph interpretation is presented below and tabulated in Figure A-2. These parameters are similar to the type of information being collected by the California Division of Mines and Geology for the North Coast Watershed Assessment Program.

The landslide inventory work was done under the supervision of Certified Engineering Geologist, John Coyle.

Figure A-2. Description of Select Parameters used to Describe Mass Wasting in the Mass Wasting Inventory.

- Slide I.D. Number: Each landslide is assigned a number in the inventory. Since section lines and numbers of the Willow Creek WAU map were not available, landslides were numbered consecutively with their observation.
- Planning Watershed: Denotes the MRC planning watershed in which the landslide is located.
  - SF = Freezeout Creek
  - SW = Willow Creek
  - SD = Dutch Bill Creek
- MWMU # – Mass Wasting Map Unit in which landslide is located.
- Landslide Process:
  - DS = debris slide
  - DT = debris torrent
  - DF = debris flow
  - RS = rockslide
  - EF = earth flow
- Certainty: The certainty of identification is recorded.
  D - Definite, P - Probable; Q - Questionable.
- Approximate Failure Date: Minimum failure date is typically the photo year that the slide first appears on or the year observed in the field.
- Slope Form: Geomorphology of slope (D – divergent, P – planar, C – convergent).
- Physical Characteristics: Include average length, width, depth, and volume of individual slides.
- Sediment delivery and routing: Includes sediment delivered to streams (N - no sediment delivered; Y - sediment delivered), estimate of the percent of landslide mass delivered, the type of stream that sediment was delivered to (perennial or ephemeral).
- Land Use Association: Road, landing, or skid trail association.
- Deep seated landslides morphologic descriptions: toe, body, lateral scarps, and main scarp (see following for descriptions).

Landslides identified in the field and from aerial photograph observations are plotted on a landslide inventory map (Map A-1). Shallow-seated landslides are represented as a point on the map, and deep-seated landslides are shown as a polygon representing the landslide deposit. Following movement of a deep-seated failure, the geomorphic expression of the head and lateral scarps changes over time by erosional processes. Delineation of the landslide scarps as we see them today on aerial photographs does not truly represent the slide scarps at the time of failure, and mapping them becomes interpretive. Therefore, the deep-seated landslides identified and mapped in this analysis are strictly the landslide deposits.

Physical and geomorphic characteristics of shallow-seated landslides are categorized in a database including identification number, planning watershed, type of landslide, approximate failure date, slope gradient, length, width, depth, volume, sediment delivery, sediment routing, and associated land use (Table A-1). Landslide dimensions and depths can be variable for a given landslide, therefore length, width, and depth values that are recorded should be considered the estimated average of these attributes. The attributes of the deep-seated landslides received less attention in the landslide inventory than shallow-seated landslides mainly due to the fact that complicated geotechnical analyses would have to be done to estimate such features as depth, failure date, and sediment delivery. In conversion of the landslide masses from volumes to tons, we assume a uniform bulk density of 1.35 g/cc.

The certainty of landslide identification is also designated for each landslide. Three designations of certainty of identification are used: definite, probable, and questionable. Definite means the landslide definitely exists. Probable means the landslide probably is there, but there is some doubt (by the analyst) about its existence. Questionable means that the interpretation of the landslide identification may be inaccurate, the analyst has the least amount of confidence in the interpretation. Accuracy in identifying landslides on aerial photographs is dependent on the size of the slide, scale of the photographs, thickness of canopy, and logging history. Landslides mapped in areas recently logged or through a thin canopy are identified with the highest level of confidence. Characteristics of the particular aerial photographs used affects confidence in identifying landslides. For example, sun angle creates shadows that may obscure landslides, the print quality of some photo sets varies, and photographs taken at smaller scale makes identifying small landslides difficult. The landslide inventory results are considered a minimum estimate of sediment production. This is because landslides that were too small to identify on aerial photographs may have been missed, landslide surfaces could have reactivated in subsequent years and not been quantified, and secondary erosion by rills and gullies on slide surfaces is difficult to assess. However, small landslides cumulatively may not deliver amounts of sediment that would significantly alter total sediment delivery.

Dimensions (average length and width) for landslides not visited in the field were determined by measuring the failure as interpreted directly from aerial photographs and extrapolating the dimension to represent slope distance for a 70% slope gradient. The 70% slope gradient is assumed to be representative of average conditions for development of a shallow-seated landslide. To extrapolate depth to the shallow-seated landslides not visited in the field, the mean value of slide depths was extrapolated for shallow-landslides that were not visited in the field. It was determined that there was insignificant overall difference among depths of debris slides, flows, torrents, road-related failures, and non road-related failures. Therefore, the mean depth of 3 feet was calculated from all field verified shallow-seated landslide depths, regardless of shallow failure process type or land use association.

Two techniques were employed in order to extrapolate a sediment volume delivery percentage to shallow-seated landslides not visited in the field. Landslides that were determined to be directly adjacent to a watercourse were assigned 100% delivery. Landslides that were determined to deliver, but were not directly adjacent to a watercourse, were assigned the mean delivery percentage determined from shallow-seated landslides observed in the field.

The likelihood that some land use practice was associated with a shallow-seated slope failure was also noted. In this analysis, different silvicultural techniques were not recorded. This was because almost all of the Willow Creek WAU has been managed, both currently and historically, for timber production, and the effect of these different silvicultural practices was too difficult to confidently interpret. There have been too many different silvicultural activities over time for reasonable confidence in a landslide evaluation based on silviculture. The land use practices that were assigned to shallow-seated landslides were associations with roads, skid trails, or landings. It was assumed that a landslide adjacent to a road, landing, or skid trail was triggered either directly or indirectly by these land use practices. If a landslide appeared to be influenced by more than one land use practice, the more causative one was noted. If a cutslope failure did not cross the road prism, it was assumed that the failure would remain perched on the road, landing, or skid trail and would not deliver to a watercourse. Some surface erosion could result from a cutslope failure, this is assumed to be addressed in the road surface erosion estimates (Surface Erosion module).

Systematic Description of Deep-seated Landslide Features

Deep-seated landslides were only interpreted by reconnaissance techniques (aerial photograph interpretation rather than field observations). Reconnaissance mapping criteria consist of observations of four morphologic features of deep seated landslides -- toe, internal morphology, lateral flanks, main scarp--and vegetation (after McCalpin 1984 as presented by Keaton and DeGraff, 1996, p. 186, Table 9-1). The mapping and classification criteria for each feature are presented in detail below.

Aerial photo interpretation of deep seated landslide features in the Gualala watershed in Sonoma County suggest that the first three morphologic features above are the most useful for inferring the presence of deep-seated landslides. The presence of tension cracks and/or sharply defined and topographically offset scarps are probably a more accurate indicator of recent or active landslide movement. These features, however, are rarely visible on aerial photos.

Sets of four descriptions have been developed to classify each deep-seated landslide characteristic. The four descriptions are ranked in descending order from characteristics of active landslides to dormant to relict landslides. One description should characterize the feature most accurately. Nevertheless, some overlap between classifications is neither unusual nor unexpected. We recognize that some deep-seated landslides may lack evidence with respect to one or more of the observable features, but show strong evidence of another feature. If there is no expression of a particular geomorphic feature (e.g. lateral flanks), the classification of that feature is considered “indeterminate”. If a deep-seated landslide is associated with other deep-seated landslides, it may also be classified as a landslide complex.

In addition to the classification criteria specific to the deep-seated landslide features, more general classification of the strength of the interpretation of the deep-seated landslide is conducted. Some landslides are obscured by vegetation to varying degrees, with areas that are clearly visible and areas that are poorly visible. In addition, weathering and erosion processes may also obscure geomorphic features over time. The quality of different aerial photograph sets varies and can sometimes make interpretations difficult. Owing to these circumstances, each inferred deep-seated landslide feature is classified according to the strength of the evidence as definite, probable or questionable.

Finally, based on all the feature descriptions of a landslide, an assessment is made as to whether a deep-seated landslide is “active”, or of “indeterminate activity”. The range of interpretation of activity level allowed here is restricted in recognition of the limitations of aerial photo interpretation. It is expected that few deep-seated landslides will show unmistakable evidence of activity, in part because movement is usually slow. Most deep-seated landslides will probably be of indeterminate activity based on typical aerial photo observations.

At the project scale (THP development and planning), field observations of deep-seated landslide morphology and other indicators by qualified professionals are expected to be used to reduce uncertainty of interpretation inherent in reconnaissance mapping. Field criteria for mapping deep-seated landslides and assessment of activity are presented elsewhere.

Deep Seated Landslide Morphologic Classification Criteria:

I. Toe Activity

1. Steep streamside slopes with extensive unvegetated to sparsely vegetated debris slide scars. Debris slides occur on both sides of stream channel, but more prominently on side containing the deep-seated landslide. Stream channel in toe region may contain coarser sediment than adjacent channel. Stream channel may be pushed out by toe. Toe may be eroding, sharp topography/geomorphology.
2. Steep streamside slopes with few unvegetated to sparsely vegetated debris slide scars. Debris slides generally are distinguishable only on streamside slope containing the deep-seated landslide. Stream channel may be pushed out by toe. Sharp edges becoming subdued.
3. Steep streamside slopes that are predominantly vegetated with little to no debris slide activity. Topography/geomorphology subdued.
4. Gently sloping stream banks that are vegetated and lack debris slide activity. Topography/geomorphology very subdued.

II. Internal Morphology

1. Multiple, well defined scarps and associated angular benches. Some benches may be rotated against scarps so that their surfaces slope back into the hill causing ponded water, which can be identified by different vegetation than adjacent areas. Hummocky topography with ground cracks. Jack-strawed trees may be present. No drainage to disorganized drainage.
2. Hummocky topography with identifiable scarps and benches, but those features have been smoothed. Undrained to drained but somewhat subdued depressions may exist. Poorly established drainage.
3. Slight benches can be identified, but are subtle and not prominent. Undrained depressions have since been drained. Moderately developed drainage to

established drainage but not strongly incised. Subdued depressions but are being filled.

4. Smooth topography. Body of slide typically appears to have failed as one large coherent mass, rather than broken and fragmented. Developed drainage well established, incised. Essentially only large undrained depressions preserved and would be very subdued. Could have standing water. May appear as amphitheater slope where slide deposit is mostly or all removed.

III. Lateral Flanks

1. Sharp, well defined. Debris slides on lateral scarps fail onto body of slide. Gullies/drainage may begin to form at boundary between lateral scarps and sides of slide deposit. Bare spots are common or partially unvegetated.
2. Sharp to somewhat subdued, rounded, essentially continuous, might have small breaks; gullies/drainage may be developing down lateral edges of slide body. May have debris slide activity, but less prominent. Few bare spots.
3. Smooth, subdued, but can be discontinuous and vegetated. Drainage may begin to develop along boundary between lateral scarp and slide body. Tributaries to drainage extend onto body of slide.
4. Subtle, well subdued to indistinguishable, discontinuous. Vegetation is identical to adjacent areas. Watercourses could be well incised, may have developed along boundary between lateral scarp and slide body. Tributaries to drainage developed on slide body.

IV. Main Scarp

1. Sharp, continuous geomorphic expression, usually arcuate break in slope with bare spots to unvegetated; often has debris slide activity.
2. Distinct, essentially continuous break in slope that may be smooth to slightly subdued in parts and sharp in others, apparent lack of debris slide activity. Bare spots may exist, but are few.
3. Smooth, subdued, less distinct break in slope with generally similar vegetation relative to adjacent areas. Bare spots are essentially non-existent.
4. Very subtle to subdued, well vegetated, can be discontinuous and deeply incised, dissected; feature may be indistinct.

V. Vegetation

1. Less dense vegetation than adjacent areas. Recent slide scarps and deposits leave many bare areas. Bare areas also due to lack of vegetative ability to root in unstable soils. Open canopy, may have jack-strawed trees; can have large openings.
2. Bare areas exist with some regrowth. Regrowth or successional patterns related to scarps and deposits. May have some openings in canopy or young broad-leaf vegetation with similar age.

3. Subtle differences from surrounding areas. Slightly less dense and different type vegetation. Essentially closed canopy; may have moderately aged to old trees.
4. Same size, type, and density as surrounding areas.

This classification scheme is only to be used to provide some reconnaissance level interpretations of deep seated landslides prior to actual field observations. The lower the number designation is each of the four morphological characteristics might suggest more recent activity by the landslide, but not always. Furthermore, a landslide may be active or have recent movement yet not show characteristics representing the low number descriptions in this classification. This classification can only be used to develop hypothesis about potential landslide activity prior to field observations.

Landslides and Landslide Hazard in Willow and Freezeout Creeks Not within Mendocino Redwood Company Property

A reconnaissance level interpretation of landslides and shallow-seated landslide hazard was done in the watersheds of Willow and Freezeout Creeks on land that was not within the MRC ownership in these watersheds. This presentation is to provide a context for the mass wasting issues for the watersheds compared to just MRC property. Shallow-seated landslide risk was also determined by use of SHALSTAB data for both watersheds. Landslides off the MRC property were primarily identified from maps in the Geology and Planning in Sonoma County (1980) report. However, an aerial photograph interpretation was conducted from aerial photographs available from the California Department of Forestry and Fire Protection for 2000 (1:24000). The aerial photograph interpretation was to identify any large shallow-seated landslides (due to small scale photos) or additional deep seated landslides not mapped in the Sonoma County report (1980) plus observe potential activity of the deep seated landslides already mapped.

Mass Wasting Map Units

Mass Wasting Map Units (MWMUs) are delineated by partitioning the landscape into zones characterized by similar geomorphic attributes, shallow-seated landslide potential, and sediment delivery potential to stream channels. A combination of aerial photograph interpretation, field investigation, and SHALSTAB output were utilized to delineate MWMUs. The MWMU designations for the Willow Creek WAU are only meant to be general characterizations of similar geomorphic and terrain characteristics related to shallow-seated landslides. Deep-seated landslides are also shown on the MWMU map (Map A-2). The deep-seated landslides have been included to provide land managers with supplemental information to guide evaluation of harvest planning and subsequent needs for geologic review. The landscape and geomorphic setting in the Willow Creek WAU is certainly more complex than generalized MWMUs delineated for this evaluation. The MWMUs are only meant to be a starting point for gauging the need for site-specific field assessments.

The delineation of each MWMU described is based on landforms present, mass wasting processes, sensitivity to forest practices, mass wasting hazard, delivery potential, hazard potential, and forest management related trigger mechanisms for shallow-seated landslides. In the MWMU description the mass wasting process section is a summary of the landslide types found in the MWMU. Sensitivity to forest practice and mass wasting hazard is, in part, a subjective call by the analyst based on the relative landslide hazard and influence of forest practices. Sediment delivery potential is based on proximity of MWMU to watercourses and the likelihood of earth materials generated by mass wasting in the unit to reach a watercourse. If greater than 66% of the landslides in a MWMU deliver sediment then the MWMU is designated as having a high delivery potential. If between 33% and 66% of the landslides in a MWMU deliver sediment then the MWMU is designated as having a moderate delivery potential, <25% delivery would be a low delivery potential. The hazard potential is based on a combination of the mass wasting hazard and delivery potential (Figure A-1.). Finally in the MWMU description the trigger mechanisms are a list of forest management practices that may have the potential to create mass wasting in the MWMU.

Figure A-1. Ratings for Potential Hazard of Delivery of Debris and Sediment to Streams by Mass Wasting (letters designate hazard: L= low, M= moderate, H = high)(Version 3.0, Washington Forest Practices Board, 1995).

		Mass Wasting Potential		
		Low	Moderate	High
Delivery Potential	Low	**L**	**L**	**M**
	Moderate	**L**	**M**	**H**
	High	**M**	**M**	**H**

RESULTS

Mass Wasting Inventory

A Landslide Inventory Data Sheet (Table A-1) was used to record attributes associated with each landslide. The spatial distribution and location of landslides is shown on Map A-1.

<u>Table A-1.</u> Landslide Inventory for the Willow Creek WAU.

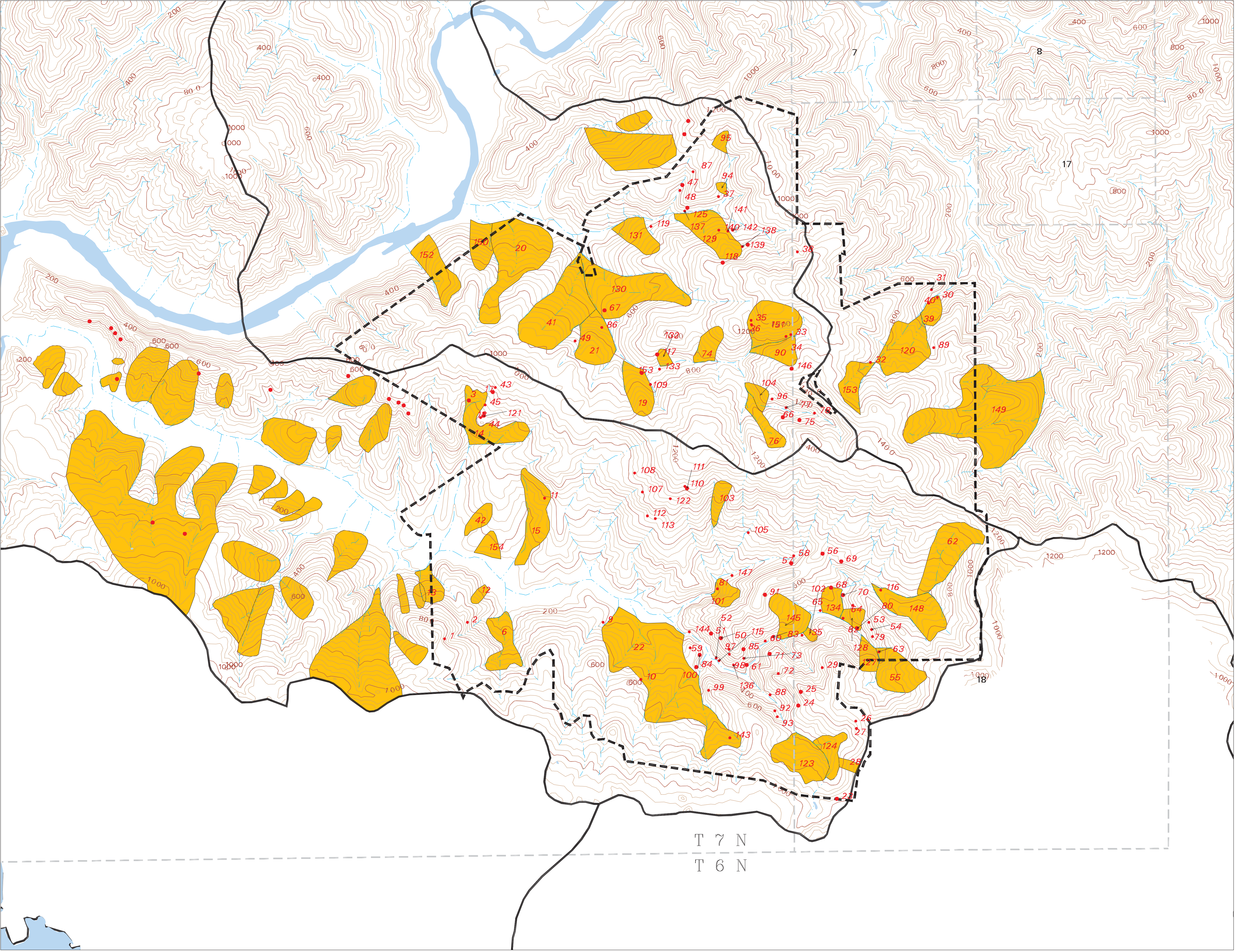
Slide Number	Plng WS	MWMU	Landslides: Process	Landslides: Certainty	Approx. Failure Date	Field Checked	Slope Gradient (%) Field	Slope Form	Average Landslide Dimensions (feet): Length	Average Landslide Dimensions (feet): Width	Average Landslide Dimensions (feet): Depth	Vol (cu. Yds)	Sediment Delivery	Delivery (%)	Delivery Volume (cu. yds.)	Delivery Mass (tons)	Sediment Routing	Land Use Assoc.	Deep Seated Landslide Morphologcal Descriptions: Toe	Body	Lat. Scarps	Main Scarps	Veg.	Complex	DSL Area (Acres)	Comments
1	SW	4	DS	D	90	N		C	32	16	3	57	Y	74	42	57	ephemeral									
2	SW	4	DS	D	90	N		C	48	16	3	85	Y	74	63	85	ephemeral									
3	SW	7	DS	D	90	N		C	112	112	3	1394	Y	74	1032	1393	ephemeral									on possible deep-seated slide. failure into gully.
6	SW		EF	P					1300	600									4	3	3	4	4	N	22.85	
9	SW	3	DS	D	90	N		P	32	48	3	171	Y	100	171	231	ephemeral									
10	SW	4	DS	D	90	N		P	16	16	3	29	Y	74	21	29	ephemeral									
11	SW	7	DS	Q	90	N		C	32	32	3	114	Y	74	85	114	ephemeral									
12	SW		RS	D					620	280									3	2	3	3	4	N	3.62	
13	SW		RS	P					1160	600									3	2	3	3	4	N	12.43	
14	SW		EF	D					1080	1820									4	2	3	2	3	Y	32.78	EF complex-multiple DS on scarp
15	SW		EF	D					2100	580									4	3	3	3	4	Y	33.2	EF complex
17	SW	8	DS	D	90	N		C	73	64	3	519	N	0	0	0										DS in melange. grassy
18	SW	8	DS	D	90	N		P	16	16	3	29	N	0	0	0										
19	SF		RS	Q					1160	620									2	3	3	4	4	N	21.64	
20	SF		EF	P					2300	900									3	2	3	4	4	N	67.03	
21	SF		RS	P					680	480									3	3	3	3	4	N	28.06	
22	SW		EF	P					2800	1050									3	3	3	3	4	Y	145.6	
23	SW	8	DS	D	87	N		P	279	64	3	1985	N	0	0	0		road								initiates at county road, onto property
24	SW	4	DT	D	87	N		C	990	25	3	2750	Y	74	2035	2747	ephemeral	skid								
25	SW	5	DS	D	87	N		P	297	32	3	1056	Y	74	781	1054	ephemeral	road								
26	SW	8	DS	Q	87	N		C	99	24	3	265	N	0	0	0		road								could not locate in field
27	SW	8	DS	Q	87	N		C	99	32	3	354	N	0	0	0		road								could not locate in field
28	SW		RS	D					450	380									3	2	5	3	4	N	3.6	active - ground cracks
29	SW	4	DS	D	87	N		P	83	48	3	444	N	0	0	0		road								
30	SD	4	DS	Q	90	N		P	50	32	3	178	Y	74	132	178	perennial									terrace above inner gorge
31	SD	4	DS	P	90	N		P	50	16	3	89	N	0	0	0										midslope
32	SD	4	DS	Q	90	N		P	50	64	3	358	Y	74	265	358	ephemeral									
33	SF	3	DS	D	90	N		P	37	20	3	82	Y	100	82	111	ephemeral									
34	SF	3	DS	Q	90	N		P	32	16	3	56	Y	100	56	76	ephemeral									
35	SF	8	DS	Q	90	N		P	17	32	3	60	Y	100	60	81	ephemeral									
36	SF	8	DS	Q	90	N		P	34	32	3	121	Y	100	121	163	ephemeral									
37	SF	8	DS	Q	90	Y	62	P	45	30	3	150	Y	10	15	20	ephemeral									
38	SF	8	DS	P	90	N		C	53	25	3	149	N	0	0	0										
39	SD		RS	P					540	540									3	3	3	3	4	N	8.29	
40	SD	3	DS	D	90	N		P	38	30	3	126	Y	74	93	126	ephemeral									fill failure
41	SF		RS	P					1770	1230									3	3	3	4	4	N	67.78	
42	SW		EF	P					960	320									4	3	5	4	4	N	8.61	
43	SW	8	DS	D	90	N		C	22	16	3	39	N	0	0	0										DS in melange. grassy
44	SW	8	DS	D	90	N		P	17	18	3	35	N	0	0	0										DS in melange. grassy
45	SW	8	DS	D	90	N		P	9	24	3	23	N	0	0	0										DS in melange. grassy
47	SF	3	DS	P	90	N		C	124	56	3	770	Y	100	770	1040	ephemeral									
48	SF	3	DS	Q	90	N		C	106	40	3	473	Y	100	473	639	ephemeral									
49	SF	8	DS	Q	90	N		P	27	24	3	71	Y	74	53	71	ephemeral									
50	SW	4	DT	D	87	N		C	286	64	3	2035	Y	74	1506	2033	perennial									slide=256'longX64'wide. runout=240'X10'
51	SW	4	DS	D	87	N		C	303	50	3	1684	Y	74	1246	1682	perennial									toe reaches creek
52	SW	1	DS	Q	87	N		C	27	16	3	48	Y	100	48	65	perennial									inner gorge
53	SW	4	DS	D	87	N		C	141	32	3	503	N	0	0	0										
54	SW	4	DT	D	78	Y	94	C	60	40	3	267	Y	90	240	324	perennial	road								slide=60'LX40'w. runout=110'LX6'w
55	SW		RS	Q					1200	730									3	2	3	3	4	N	28.49	
56	SW	5	DS	D	90	Y	58	P	120	50	3	667	N	0	0	0		road								field estimate 10 yrs old
57	SW	4	DS	D	97	Y	79	C	130	35	3	506	Y	40	202	273	ephemeral	road								
58	SW	3	DS	D	2000	Y	85	C	20	30	3	67	Y	100	67	90	ephemeral	road								directly into creek
59	SW	5	DS	D	2000	Y	106	P	10	30	8	89	Y	100	89	120	perennial	road								streambank failure
60	SW	1	DS	D	2000	Y	80	C	25	65	3	181	Y	100	181	244	perennial									inner gorge
61	SW	1	DS	D	95	Y	65	C	160	50	3	889	Y	100	889	1200	perennial	road								legacy road failure. Inner gorge
62	SW		EF	D					1300	1360									2	1	2	3	3	N	40.89	active EF. 12" deep gullies near toe.
63	SW	2	DS	P	87	N		C	57	24	3	151	Y	100	151	204	ephemeral									streamside
64	SW	4	DS	Q	87	Y	84	C	48	40	3	213	N	0	0	0		road								fill failure
65	SW		RS	Q					680	570									3	3	3	2	4	N	10.3	
66	SF	4	DS	D	87	Y	87	P	230	148	3	3782	Y	60	2269	3064	ephemeral	road								fill failure
67	SF	8	DS	Q	87	N		P	193	32	3	685	Y	74	507	684	perennial									slight vegetation 87 photo
68	SW	4	DS	D	87	N		C	174	56	3	1084	Y	74	802	1082	perennial									
69	SW	5	DS	D	87	N		C	175	200	3	3888	Y	74	2877	3884	ephemeral									stream undercut
70	SW	2	DS	Q	87	N		P	68	128	3	972	Y	100	972	1312	perennial									inner gorge
71	SW	5	DF	D	87	N		P	245	48	3	1308	Y	74	968	1307	perennial									
72	SW	4	DS	Q	87	N		C	39	64	3	280	N	0	0	0										
73	SW	4	DS	Q	87	N		C	59	72	3	475	N	0	0	0										
74	SF		RS	Q					1030	380									3	3	5	3	3	N	12.62	
75	SF	4	DF	D	90	Y	92	P	280	42	3	1307	Y	90	1176	1588	ephemeral	road								fill failure
76	SF		EF	P					1350	300									4	3	3	4	4	N	13.07	
77	SF	2	DS	Q	87	N		C	50	45	3	252	Y	100	252	341	ephemeral									steep slope

Table A-1 (continued). Landslide Inventory for the Willow Creek WAU.

Slide Number	Plng WS	MWMU	Landslides		Approx. Failure Date	Field Checked	Slope Gradient (%)	Slope Form	Average Landslide Dimensions (feet)			Vol (cu. Yds)	Sediment Delivery	Delivery (%)	Delivery Volume (cu. yds.)	Delivery Mass (tons)	Sediment Routing	Land Use Assoc.	Deep Seated Landslide Morphologcal Descriptions						DSL Area (Acres)	Comments
			Process	Certainty			Field		Length	Width	Depth								Toe	Body	Lat. Scarps	Main Scarps	Veg.	Complex		
78	SF	2	DS	P	87	N		C	76	25	3	211	Y	100	211	285	ephemeral									
79	SW	4	DS	P	87	N		P	96	20	3	212	Y	74	157	212	ephemeral									
80	SW	2	DS	P	82	N		P	160	60	3	1067	Y	74	790	1066	ephemeral									some vegetation on 1987 photo
81	SW	2	DS	P	87	N		C	58	60	3	386	Y	100	386	521	ephemeral									
82	SW	2	DS	P	87	Y	113	P	45	30	3	150	Y	100	150	203	perennial									steep streamside
83	SW	1	DS	P	87	N		C	52	90	3	520	Y	100	520	702	ephemeral									could not locate in field due to age. Inner gorge
84	SW	4	DF	P	87	N		C	248	90	3	2481	Y	100	2481	3350	perennial									failure is in draw
85	SW	4	DF	Q	80	N		P	262	83	3	2421	Y	74	1791	2418	ephemeral									moderate veg. regrowth - 87 photo
86	SF	4	DS	D	96	Y	72	P	80	45	3	400	Y	25	100	135	perennial	road								complex of multiple debris slides
87	SF	4	DS	P	87	N		C	117	30	3	389	N	0	0	0		road								
88	SW	2	DS	D	96	N		P	53	15	3	89	Y	100	89	120	ephemeral									steep streamside
89	SD	8	DS	Q	96	N		C	129	40	3	571	N	0	0	0										
90	SF		RS	P					620	810									3	3	3	3	4	N	14.04	
91	SW	4	DS	D	96	Y	64	C	114	57	3	722	N	0	0	0		road								shadowy in photo. road impassible
92	SW	5	DS	D	96	N		P	109	50	3	604	Y	100	604	815	ephemeral									
93	SW	4	DF	D	96	N		C	146	36	3	584	Y	100	584	789	ephemeral									
94	SF		RS	Q					200	340									3	3	5	2	4	N	1.93	
95	SF		RS	Q					580	260									3	3	3	4	4	N	4.36	
96	SF	4	DF	P	96	N		C	133	15	3	222	Y	74	164	222	ephemeral									
97	SW	5	DS	Q	96	N		P	67	24	3	178	N	0	0	0										steep slope
98	SW	5	DS	Q	96	N		D	67	24	3	179	N	0	0	0										steep slope
99	SW	4	DS	D	96	N		C	113	40	3	500	Y	74	370	500	ephemeral									
100	SW	4	DS	D	87	Y	88	C	100	83	5	1537	Y	90	1383	1868	ephemeral									
101	SW		RS	D					470	500									2	3	3	2	4	N	9.84	
102	SW		RS	P					480	350									3	3	3	2	4	N	2.38	
103	SW		EF	P					1520	530									4	3	3	4	4	N	9.76	
104	SF		RS	P					310	630									3	2	5	3	4	N	6.89	
105	SW	4	DS	D	99	Y	69	P	20	40	2.5	74	Y	15	11	15	perennial	road								fill failure adjacent to culvert on county road. delivers to MRC
107	SW	4	DS	D	95	Y	43	P	50	50	3	278	N	0	0	0		road								cutbank slide. revegetating
108	SW	8	DS	D	98	Y	64	P	25	27	1.5	38	N	0	0	0		road								DS in grassy melange area
109	SF	3	DS	P	95	Y	89	C	30	45	2	100	N	0	0	0		road								
110	SW	4	DS	D	99	Y	79	C	25	45	3	125	N	0	0	0		road								in swale of older slide #SW111
111	SW	4	DS	P	80	Y	74	P	120	80	4	1422	Y	30	427	576		road								in HW swale of slide SW 111
112	SW	8	DS	D	98	Y	43	P	25	15	2	28	N	0	0	0		road								DS in melange terrain
113	SW	4	DS	D	90	Y	48	P	65	75	2	361	N	0	0	0		road								DS in melange terrain. est. 10yrs old in field
115	SW	1	DS	D	2000	Y	100	C	40	70	2	207	Y	100	207	280	perennial									meander bend. Inner gorge
116	SW	3	DS	D	2000	Y	105	D	50	35	3	194	Y	100	194	263	perennial									DS on divergent nose of meander bend
117	SF	4	DS	D	98	Y	57	C	230	55	4	1874	Y	40	750	1012	perennial	land								skid trails downslope of landing
118	SF	4	DS	D	98	Y	59	C	170	45	3	850	N	0	0	0		road								toe makes road impassible
119	SF	4	DS	D	98	Y	82	C	70	59	3	459	Y	50	229	310	perennial	road								
120	SD		RS	Q					1800	820									4	3	3	3	4	N	39.15	
121	SW	8	DS	D	98	N		P	31	62	3	216	N	0	0	0										failure between DS 18 & 44. DS in melange. grassy
122	SW	4	DS	D	98	N		P	32	45	3	158	N	0	0	0										DS in melange. grassy
123	SW		RS	Q					890	1390									3	3	3	3	4	N	32.98	
124	SW		RS	P					710	1120									3	3	5	4	4	N	13.39	
125	SF	8	DS	D	90	Y	98	C	75	58	4	644	Y	90	580	783	perennial									trees on unit surface
127	SW		RS	Q					590	590									3	3	3	4	4	N	9.76	
128	SW		RS	D					470	360									2	2	3	3	4	N	6.93	
129	SF		RS	D					2030	930									2	2	2	2	4	N	30.7	likely active-hummocky surface with multiple DS
130	SF		RS	D					2100	910									4	3	3	2	4	N	62.6	
131	SF		RS	D					1250	720									3	3	3	4	4	N	17.99	
132	SF		RS	D					510	300									3	3	2	3	4	N	3.57	
133	SF	1	DS	Q	78	N		C	55	33	3	201	Y	100	201	272	perennial									inner gorge
134	SW	2	DS	D	90	Y	104	C	29	47	3	151	Y	90	136	184	perennial									streambank failure
135	SW	2	DS	D	98	Y	112	P	22	27	3	66	Y	100	66	89	perennial									
136	SW	4	DS	D	95	Y	88	C	38	29	4	163	Y	85	139	187	perennial									
137	SF	2	DS	D	99	Y	120	P	18	32	3	64	Y	100	64	86	perennial									steep streamside
138	SF	4	DS	D	94	Y	68	C	45	37	3	185	N	0	0	0		road								DS nested on RS. veg regrowing
139	SF	8	DS	D	99	Y	62	C	105	38	5	739	N	0	0	0		skid								many skids across slide. road gone at scarp
140	SF	8	DS	D	99	Y	52	P	8	143	3	127	N	0	0	0		road								fill failure on RS
141	SF	8	DS	D	99	Y	33	P	10	115	2	85	N	0	0	0		road								fill failure on RS
142	SF	8	DS	D	99	Y	49	P	10	125	3	139	N	0	0	0		road								fill failure on RS
143	SW	4	DS	Q	78	N		C	147	44	3	717	Y	74	530	716	ephemeral									
144	SW	2	DS	P	78	N		C	103	37	3	425	Y	74	315	425	perennial									likely high % delivery
145	SW		RS	D					1100	580									3	2	3	2	4	N	21.61	
146	SF	8	DS	P	78	N		C	241	48	3	1284	N	0	0	0		road								
147	SW	2	DS	Q	78	N		C	78	35	3	304	Y	74	225	304	perennial									high % delivery likely
148	SW		EF	P					1280	730									3	3	3	3	4	Y	33.69	
149	SD		EF	P					2070	1830									3	3	3	3	4	N	142.61	
150	SF		RS	D					1090	470									3	2	3	3	4	N	17.28	

Table A-1 (continued). Landslide Inventory for the Willow Creek WAU.

Slide Number	Plng WS	MWMU	Landslides		Approx. Failure Date	Field Checked	Slope Gradient (%)	Slope Form	Average Landslide Dimensions (feet)			Vol (cu. Yds)	Sediment Delivery	Delivery (%)	Delivery Volume (cu. yds.)	Delivery Mass (tons)	Sediment Routing	Land Use Assoc.	Deep Seated Landslide Morphologcal Descriptions						DSL Area (Acres)	Comments
			Process	Certainty			Field		Length	Width	Depth								Toe	Body	Lat. Scarps	Main Scarps	Veg.	Complex		
151	SF		RS	P					1100	1450									2	2	3	3	4	N	34.64	
152	SF		RS	P					1410	500									3	3	3	3	4	N	26.64	contours do not represent slide very well
153	SF	8	DS	D	98	N		P	205	96	3	2184	Y	74	1616	2181	perennial	road	3	3	5	3	4	N		
153	SD		EF	Q					1020	420									3	3	3	3	4	Y	16.56	
154	SW		RS	Q					650	400									3	3	5	4	4	N	8.16	



Willow Creek / Freezeout Creek Watershed Analysis Unit

Map A-1
Mass Wasting Inventory

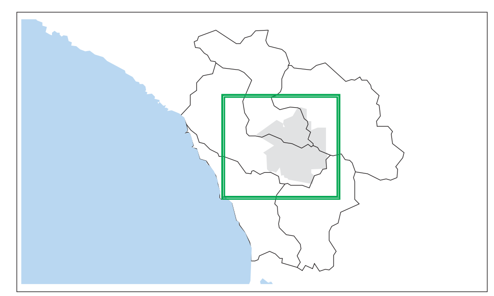
Large Deep-Seated Landslides

Shallow-Seated Landslides
- < 500 cubic yards
- 500 - 5000 cubic yards
- > 5000 cubic yards

Flow Class
- Class I
- Class II
- Class III

MRC Ownership

Planning Watershed Boundary



0 1/2 1 Mile

February 19, 2001

A total of 104 shallow-seated landslides (debris slides, torrents or flows) were identified and characterized in the Willow Creek WAU. A total of 43 deep-seated landslides (rockslides or earth flows) were mapped in the Willow Creek WAU. A considerable effort was made to field verify as many landslides as possible to insure greater confidence in the results. A total of 36% of the identified shallow-seated landslides were field verified. From this level of field observations, extrapolation of landslide depth and sediment delivery was performed with a reasonable level of confidence. The difference between the mean depth of road-related shallow landslides and the mean depth of non road-related shallow landslides was calculated and determined to be insignificant. Therefore, a mean depth of 3 feet was assigned to all shallow landslides that were not visited in the field. The mean sediment delivery percentage assigned to shallow landslides determined to deliver sediment, but not visited in the field, is 74%. Deep-seated landslides did not have depth or sediment delivery statistics calculated.

The temporal distribution of the 104 shallow-seated landslides observed in the Willow Creek WAU is listed in Table A-2. The spatial distribution by landslide process is shown in Table A-3.

Table A-2. Shallow-Seated Landslide Summary for the Willow Creek WAU Divided into Time Periods.

Planning Watershed	1969-1978 Landslides	1979-1987 Landslides	1988-2000 Landslides
Willow Creek	4	27	37
Freezeout Creek	2	5	24
Dutch Bill Creek	0	0	4

Table A-3. Slide Summary by Type and Planning Watershed for MRC Ownership in the Willow Creek WAU.

Watershed	Debris Slides	Debris Torrents	Debris Flows	Rock Slides	Earth Flows	**Total**	*Road Assoc.*
Willow Creek	61	3	4	14	8	**90**	*20*
Freezeout Creek	29	0	2	15	2	**48**	*13*
Dutch Bill Creek	5	0	0	2	2	**9**	*0*

The majority of landslides observed in the Willow Creek WAU are debris slides and rockslides. Only a few of the rockslides are known to be active in the Willow Creek WAU, the remaining are assumed to be dormant features. Of the 104 shallow-seated landslides in the Willow Creek, 33 are determined to be road-related. This is approximately 1/3 of the total number of shallow-seated landslides.

Three debris torrents and and 6 derbis flows were observed in the Willow Creek WAU. This is approximately 3 and 6 percent, respectively, of the total shallow landslides observed in the Willow Creek WAU. Debris torrents or flows are not common in the Willow Creek WAU, but do occur and are processes that should be taken into account in relation to forest management practices.

Ninety one percent of the shallow landslides inventoried were initiated on slopes greater than 60% gradient, eight landslides occurred on slopes with gradients in the 40s and 50s and one landslide on a slope of 33%. Those nine landslides are attributed to skid trails or road practices and may have been influenced to some degree by the unstable nature of the mélange terrain present in the WAU. Some of them are mid-slope failures in grassland topography that do not deliver any sediment. The majority of inventoried landslides originated in convergent topography where subsurface water tends to concentrate. However some also occurred on areas of steep, planar topography where sub-surface water can be concentrated at the base of slopes, in localized topographic depressions, or by subsoil geologic structures. Few landslides originated in divergent topography, where sub-surface water is routed to the sides of ridges. These observations were, in part, the basis for the delineation of the Willow Creek WAU into Mass Wasting Map Units.

Mass Wasting Map Units

The landscape was partitioned into seven Mass Wasting Map Units (MWMU) representing general areas of similar geomorphology, landslide processes, and sediment delivery potential by shallow-seated landslides (Map A-2). The delineation for the MWMUs was based on qualitative observations and interpretations from aerial photographs, field evaluation, and SHALSTAB output. The units are to be used by forest managers to assist in making decisions that will minimize future mass wasting sediment input to watercourses. Deep-seated landslides are also shown on the MWMU map (Map A-2). The deep-seated landslides have been included to provide land managers with supplemental information to guide evaluation of harvest planning and subsequent needs for geologic review.

Shallow-seated landslide characteristics considered in determination of map units are size, frequency, delivery to watercourses, and spatial distribution. Hillslope characteristics considered are slope form (convergence, divergence, planar), slope gradient, magnitude of stream incision, and overall geomorphology. The range of slope gradients was determined from USGS 1:24000 topographic maps and field observations. Hillslope and landslide morphology varies within each individual Mass Wasting Map Unit and the boundaries are not exact. This evaluation is not intended to be a substitute for site-specific field assessments. Site-specific field assessments will still be required in some MWMUs and deep-seated landslides or specific areas of some MWMUs to assess the risk and likelihood of mass wasting impacts from a proposed management action. The Mass Wasting Map Units are compiled on the entitled Mass Wasting Map Unit Map (Map A-2).

MWMU Number: 1

Title: Steep slopes along low-gradient watercourses

Materials: Shallow soils formed from weathered marine sedimentary rocks. Often bedrock slopes with a veneer of colluvial or alluvial soil deposits. Also, may be comprised of soil deposits of the toe of deep-seated landslides.

Landform Description: Characterized by steep slopes or inner gorge topography adjacent to low gradient watercourses. Slope form is generally planar or convex with slope gradients typically exceeding 65%. The upper extent of the unit is variable, often delineated by a break in slope. Landslides in this unit generally deposit sediment directly into Class I and II streams. Small areas of incised terraces may be locally present. Due to the highly erosive nature of the melange terrain, inner gorge in this terrain may be intermittent. Steep streamside slopes or inner gorge slopes that are controlled by bedrock exhibit greater stability at steeper slope angles, though slopes underlain by thick soils are gentler.

Slope: >65% to vertical, (mean slope of observed mass wasting events is 99%, range: 65-120%)

Total Area: 105 acres; 2.1 % of the total WAU area.

MW Processes: *1 road-associated landslide*

- 1 debris slides

18 non-road associated landslides

- 18 debris slides

Non Road-related Landslide Density: 0.17 landslides per acre for the past 32 years

Forest Practices Sensitivity: High sensitivity to roads due to steep slopes adjacent to watercourses, high to moderate sensitivity to harvesting and forest management due to steep slopes next to watercourses. Localized areas of steeper slopes have an even higher sensitivity to forest practices.

Mass Wasting Potential: High; localized potential for landslides in both unmanaged and managed conditions.

Delivery Potential: High

Delivery Criteria Used: Steep slopes adjacent to stream channels, all landslides delivered sediment into streams.

Hazard-Potential Rating: **High**

Forest Management Related Trigger Mechanisms:

- Sidecast fill material placed on steep slopes can initiate debris slides or flows in this unit.
- Concentrated drainage from roads onto unstable areas can initiate debris slides or flows in this unit.
- Poorly sized culvert or excessive debris at watercourse crossings can initiate failure of the fill material creating debris slides, torrents or flows in this unit.
- Cut-slope of roads can expose potential failure planes creating debris slides, torrents or flows in this unit.
- Sidecast fill material created from skid trail construction placed on steep slopes can initiate debris slides or flows in this unit.
- Concentrated drainage from skid trails onto unstable areas can initiate debris slides or flows in this unit.
- Cut-slope of skid trails can remove support of slope creating debris slides, torrents or flows in this unit.
- Root decay of hardwood or non-redwood conifer species can be a contributing factor in the initiation of debris slides, torrents or flows in this unit.
- Concentrated drainage from roads can increase groundwater, accelerating movement of rockslides or earth flows and over-steepening inner gorge slopes.
- Removal of vegetation above these slopes can result in loss of evapo-transpiration and thus increase pore water pressures that could create debris slides in this unit.

Confidence: High confidence for susceptibility of landslides and sediment delivery in this unit. Moderate to low confidence in placement of this unit, particularly the upper boundary, because of variable materials of mélange terrain and lack of continuous, bedrock-controlled slopes. This unit is locally variable and exact boundaries are better determined from field observations.

MWMU Number:	2
Title:	Steep slopes adjacent to intermittent or ephemeral streams.
Materials:	Shallow soils formed from weathered marine sedimentary rocks with localized areas of thin to thick colluvial deposits.
Landform Description:	Characterized by steep slopes along intermittent or ephemeral streams. Slope form is largely concave with gradients >70%. The upper extent of this unit is typically about 120 feet from the watercourse (based on maximum observed debris slide length of 112 feet; mean landslide length is 49 feet). Landslides in this unit commonly are debris slides that deposit sediment directly into Class II and III watercourses. Occasionally the debris slides can form debris torrents that can transport material down the slope through and out of this unit. This unit typically extends upstream from MWMU 1. The area within this unit is highly correlated to potential landslide hazard areas defined by SHALSTAB (using a log q/t threshold of –2.8).
Slope:	>70% (mean slope of observed mass wasting events is 93%, range: 85%-105%)
Total Area:	108 acres; 2.1 % of total WAU area
MW Processes:	*2 road-associated landslides* • 2 Debris slides *7 non-road associated landslides* • 7 Debris slides
Non Road-related Landslide Density:	0.06 landslides per acre for the past 32 years
Forest Practices Sensitivity:	High sensitivity to roads due to steep slopes adjacent to watercourses, high to moderate sensitivity to harvesting and forest management due to steep slopes next to watercourses. Localized areas of steeper and/or convergent slopes may have an even higher sensitivity to forest practices.
Mass Wasting Potential:	High, due to the steep converging topography of the slope in both unmanaged and managed conditions.
Delivery Potential:	High

Delivery Criteria Used: Steep slopes adjacent to stream channels, 87% of landslides observed in this unit delivered sediment to watercourses.

Hazard-Potential Rating: **High**

Forest Management Related Trigger Mechanisms:

- Sidecast fill material placed on steep slopes can initiate debris slides, torrents or flows in this unit.
- Concentrated drainage from roads onto unstable areas can initiate debris slides, torrents or flows in this unit.
- Poorly sized culvert or excessive debris at watercourse crossings can initiate failure of the fill material creating debris slides, torrents or flows in this unit.
- Cut-slope of roads can over-steepen the slope creating debris slides, torrents or flows in this unit.
- Cut-slope of roads can remove support of the toe or expose potential failure planes of rockslides or earth flows.
- Sidecast fill material created from skid trail construction placed on steep slopes can initiate debris slides, torrents or flows.
- Concentrated drainage from skid trails onto unstable areas can initiate debris slides, torrents or flows.
- Cut-slope of skid trails can remove support of the toe or expose potential failure planes of rockslides or earth flows.
- Root decay of hardwood or non-redwood conifer species can be a contributing factor in the initiation of debris slides, torrents or flows in this unit.
- Loss of evapo-transpiration from forest harvest can increase groundwater levels initiating or accelerating movement in rockslides or earth flows or aid in the initiation of debris slides, torrents or flows.

Confidence: High confidence for susceptibility of unit to landslides and delivery of sediment. Moderate confidence in placement of this unit. This unit is highly localized and exact boundaries are better determined from field observations. Within this unit there are areas of low gradient slopes that are less susceptible to mass wasting.

MWMU Number: 3

Title: Steep, dissected and convergent topography

Materials: Shallow soils formed from weathered marine sedimentary rocks with localized thin to thick colluvial deposits.

Landform Description: Steep gradient hillslopes typically converging on confined watercourse channels. The topography has dissected or strongly convergent slope forms, though very steep planar terrain also occurs in this unit. This unit is associated with steep colluvial hollows or headwater swales. All debris torrents and all but one debris flow mapped in the entire Willow Creek WAU originate in MWMU 3. Some of the headwater swales in this unit transition into active gully erosion. Identification of the terrain that fits this unit is a description of high-risk sites for shallow seated landslides. Slopes are greater than 65%, with slopes greater than 80% the greatest risk. Strong topographic convergence or multiple convergent depressions combined with shallow soils typify this terrain. However the lower 1/3 of long steep planar slopes will also be associated with this unit. Often there are seeps, springs or an unusual amount of water present or there is evidence of recent or historic landslides associated with the steep or convergent topography. Tension cracks, jack strawed trees, scraps or benches with scattered tree blowdown can also indicate unit 3 terrain.

Slope: >65%, (mean slope of observed mass wasting events is 74% range: 43 %-94%)

Total Estimated Area: 697 ac., 13.7% of the total WAU

MW Processes: *19 road associated landslides*

- 17 Debris slides, 1 Debris torrent, 1 Debris flow

22 *non-road associated slides*

- 17 Debris slides,1 Debris torrent, 4 Debris flows

Non Road-related Landslide Density: 0.03 landslides per acre for the past 32 years

Forest Practices Sensitivity: High sensitivity to road building, moderate to high sensitivity to harvesting and forest management practices due to moderately steep slopes within this unit. Localized areas of steeper and/or convergent slopes can have higher sensitivity to forest practices.

Mass Wasting Potential: High

Delivery Potential: High

Delivery Criteria Used: The converging topography directs mass wasting down slopes toward watercourses. Delivery potential may be high based on relatively high potential for debris flows and torrents. Failures in headwater swales can torrent or flow down watercourses. Approximately 66% of landslides in this unit delivered sediment.

Hazard-Potential Rating: **High**

Forest Management Related Trigger Mechanisms:

- Sidecast fill material placed on steep slopes can initiate debris slides, torrents or flows in this unit.
- Concentrated drainage from roads onto unstable areas can initiate debris slides, torrents or flows in this unit.
- Concentrated drainage from roads can increase groundwater, accelerating movement of rockslides or earth flows in this unit.
- Poorly sized culvert or excessive debris at watercourse crossings can initiate failure of the fill material creating debris slides, torrents or flows in this unit.
- Cut-slope of roads can over-steepen the slope creating debris slides in this unit.
- Cut-slope of roads can over-steepen the slope creating debris slides, torrents or flows in this unit.
- Cut-slope of roads can remove support of the toe or expose potential failure planes of rockslides or earth flows.
- Sidecast fill material created from skid trail construction placed on steep slopes can initiate debris slides, torrents or flows.
- Concentrated drainage from skid trails onto unstable areas can initiate debris slides, torrents or flows.
- Cut-slope of skid trails can remove support of the toe or expose potential failure planes of rockslides or earth flows.
- Root decay of hardwood or non-redwood conifer species can be a contributing factor in the initiation of debris slides, torrents or flows in this unit.
- Loss of evapo-transpiration from forest harvest can increase groundwater levels initiating or accelerating movement in rockslides or earth flows or aid in the initiation of debris slides, torrents or flows.

Confidence: High, some areas within this unit could have higher susceptibility to landslides and higher delivery rates due to localized areas of steep slopes with weak soils, and unusually adverse ground water conditions.

MWMU Number:	4
Title:	Non-dissected topography
Materials:	Shallow to moderately deep soils formed from weathered marine sedimentary rocks.
Landform Description:	Moderate to moderately steep hillslopes with planar, divergent or broadly convergent slope forms with isolated areas of steep topography or strongly convergent slope forms. Generally a midslope region differentiated from unit 7 by containing relatively competent bedrock.
Slope:	>35%, (mean slope of observed mass wasting events 82%, range: 58%- 106%)
Total Area:	316 acres, 6.2% of the total WAU
MW Processes:	*3 road-associated landslides* • 3 Debris slides *5 non-road associated slides* • 4 Debris slides • 1 Debris flow
Non Road-related Landslide Density:	0.02 landslides per acre for the past 32 years
Forest Practices Sensitivity:	Moderate to low sensitivity to road building, moderate to low sensitivity to harvesting and forest management practices due to moderate slope gradients and non-converging topography within this unit. Localized areas of steeper slopes have and even higher sensitivity to forest practices
Mass Wasting Potential:	Moderate
Delivery Potential:	Moderate
Delivery Criteria Used:	Sediment delivery in this unit is localized to landslides that occur adjacent to watercourses, or have long run-outs to a watercourse. Approximately 62% of landslides in this unit delivered sediment.
Hazard-Potential Rating:	**Moderate**

Forest Management Related Trigger Mechanisms:

•Sidecast fill material placed on steep slopes can initiate debris slides, torrents or flows in this unit.
•Concentrated drainage from roads onto unstable areas can initiate debris slides, torrents or flows in this unit.
•Concentrated drainage from roads can increase groundwater, accelerating movement of rockslides or earth flows in this unit.
•Poorly sized culvert or excessive debris at watercourse crossings can initiate failure of the fill material creating debris slides, torrents or flows in this unit.
•Cut-slope of roads can over-steepen the slope creating debris slides in this unit.
•Cut-slope of roads can over-steepen the slope creating debris slides, torrents or flows in this unit.
•Cut-slope of roads can remove support of the toe or expose potential failure planes of rockslides or earth flows.
•Sidecast fill material created from skid trail construction placed on steep slopes can initiate debris slides, torrents or flows.
•Concentrated drainage from skid trails onto unstable areas can initiate debris slides, torrents or flows.
•Cut-slope of skid trails can remove support of the toe or expose potential failure planes of rockslides or earth flows.
• Root decay of hardwood or non-redwood conifer species can be a contributing factor in the initiation of debris slides, torrents or flows in this unit.
•Loss of evapo-transpiration from forest harvest can increase groundwater levels initiating or accelerating movement in rockslides or earth flows or aid in the initiation of debris slides, torrents or flows.

Confidence: High, some areas within this unit could have higher susceptibility to landslides and higher delivery rates due to localized areas of steep slopes with weak soils, and adverse groundwater conditions.

MWMU Number:	5
Description:	Low relief topography
Material:	Moderately deep to deep soils, formed from weathered marine sedimentary rocks. Also stream terrace deposits of the lower Willow Creek stream channel.
Landforms:	Characterized by low gradient slopes generally less than 30%, although in some places slopes can be steeper. This unit occurs on ridge crests, low gradient side slopes, and well-developed terraces of lower Willow Creek. This unit can have some localized areas of moderately steep (>35%), concave topography which can be more prone to mass wasting processes. Shallow-seated landslides seldom occur and usually do not deliver sediment to stream channels. Deep gullies exist in this unit and primarily originate in MWMU units 3,6, and 7 and are propagating upslope into unit 5.
Slope:	<30% (based on field observations)
Total Area:	498 acres, 9.8% of WAU area
MW Processes:	*No observed shallow-seated landslides*
Non Road-related Landslide Density:	0 landslides per acre for past 32 years.
Forest Practices Sensitivity:	Low sensitivity to road building and forest management practices due to low gradient slopes
Mass Wasting Potential:	Low
Delivery Potential:	Low
Delivery Criteria Used:	Sediment delivery in this unit is low. Delivery which occurs is primarily associated with gully erosion.
Hazard-Potential Rating:	**Low**

Forest Management Related Trigger Mechanisms:

- Poorly sized culvert or excessive debris at watercourse crossings can initiate failure of the fill material creating debris slides, torrents or flows in this unit.
- Concentrated drainage from roads and skid trails can initiate or accelerate gully erosion, which can increase the potential for mass wasting processes.

Confidence: Moderate, due to inexactness of boundary locations between this MWMU unit and units 7, 4, and where earth flows of unit 6 are mapped as questionable deep-seated landslides. High confidence in mass wasting potential and sediment delivery potential ratings.

MWMU Number: 6

Title: Identified Earth Flow Complexes

Materials: Fine-grained soils and clays derived highly weathered and sheared marine sedimentary rocks and melange terrain. Soils contain >80% particles less than 2mm in size with rock fragments, some very large, within the soil matrix.

Landform Description: Boundaries of this unit correspond to mapped earth flows, regardless of state of activity. Characterized by hummocky moderate gradient slopes with localized areas of steep or flat topography. Slopes commonly contain areas of backtilted topography, creating ponded water. Ground surfaces in this unit commonly contain areas of grassy vegetation, which may be attributed to a long history of cattle grazing , and the inability of the clay-rich soil to support dense forests. Gullies are abundant in this unit. Rate of movement within earth flows typically is variable and likely fluctuates seasonally according to groundwater conditions. Unit 6 is composed of both individual earth flows and earth flow complexes with many scarps and benches that can create a step-like profile.

Slope: No field-verified mass wasting slope values.

Total Area: 405 acres; 7.9% of the total WAU.

MW Processes: *2 non-road associated landslides*

- 2 Debris slides

Non Road-related Landslide Density: 0.005 landslides per acre for past 32 years.

Forest Practices Sensitivity: High sensitivity to roads, harvesting, and forest management practices on active earth flow surfaces. Moderate sensitivity to roads, harvesting, and forest management practices on non-active earth flow surfaces due to localized areas of variable topography. Potential forest practices in this unit should be assessed on a very local scale due to variable topography and differing rates of movement within an earth flow.

Mass Wasting Potential: High

Delivery Potential: High

Delivery Criteria Used: Many of the earth flows in the Willow/Freezeout Creek WAU have the toe or lateral edges along watercourses. If earth flow movement occurs the landslides will deliver sediment.

Hazard Potential Rating: **High**

Forest Management Related Trigger Mechanisms:

- Sidecast fill material placed on locally steep slopes can initiate debris slides, torrents or flows in this unit.
- Concentrated drainage from roads onto unstable areas can initiate debris slides, torrents or flows in this unit.
- Concentrated drainage from roads can increase groundwater, accelerating movement of earth flows of this unit.
- Poorly sized culvert or excessive debris at watercourse crossings can initiate failure of the fill material creating debris slides, torrents or flows in this unit.
- Cut-slope of roads can over-steepen the slope creating debris slides in this unit.
- Concentrated drainage from skid trails onto unstable areas can initiate debris slides, torrents or flows in this unit.
- Loss of evapo-transpiration from forest harvest can increase groundwater levels initiating or accelerating movement of earth flows of this unit or aid in initiation of debris slides, torrents or flows.
- Concentrated drainage from roads and skid trails can initiate or accelerate gully erosion, which can increase the potential for mass wasting processes.
- Cut-slope of skid trails can remove support of the toe or expose potential failure planes of earth flows.
- Sidecast fill material created from skid trail construction placed on locally steep slopes can initiate debris slides, torrents or flows.
- Root decay of hardwood or non-redwood conifer species can be a contributing factor in the initiation of debris slides, torrents or flows in this unit.

Confidence: Confidence in delineation of unit is consistent with confidence level in mass wasting inventory mapping of deep-seated earth flows. Moderate confidence in hazard potential rating due to variability in geomorphology of unit 6.

MWMU Number: 7

Title: Accelerated Creep Terrain

Materials: Fine-grained soils from highly weathered and sheared marine sedimentary rocks and melange terrain. Soils contain blocks of rock, some very large, within the soil matrix. Very large rock blocks are generally hard and commonly known as “knockers”.

Landform Description: Characterized by hummocky slopes with localized areas of steep or flat topography. Ground surfaces in this unit commonly contain areas of grassy vegetation, which may be attributed to a long history of cattle grazing or the inability of the clay-rich soil to support dense forests. Gullies were observed in the headwalls of some drainages. Unit 7 is identified by “rumpled” look of ground surface, similar to unit 6, but lacking scarps and benches. This unit will transition to Unit 6 when earth flows are present.

Slope: 30-70%; mean slope of observed mass wasting events is 58%, range is 33-98%. If the single 98% slope landslide is excluded, mean is 52%, range is 33-64%.

Total Area: 3074 acres; 60.3% of the total WAU

MW Processes:

10 road associated landslides
10 debris slides

1 skid trail associated landslide
1 debris slide

14 non-road associated landslides
14 debris slides

Non Road-related Landslide Density: 0.005 landslides per acre for the last 32 years

Forest Practices Sensitivity: Moderate sensitivity to roads, harvesting, and forest management practices particularly where localized areas of steep slopes exist.

Mass Wasting Potential: Moderate

Delivery Potential: Moderate

Delivery Criteria Used: 28% of shallow landslides in this unit delivered sediment.

Hazard Potential Rating: **Moderate**

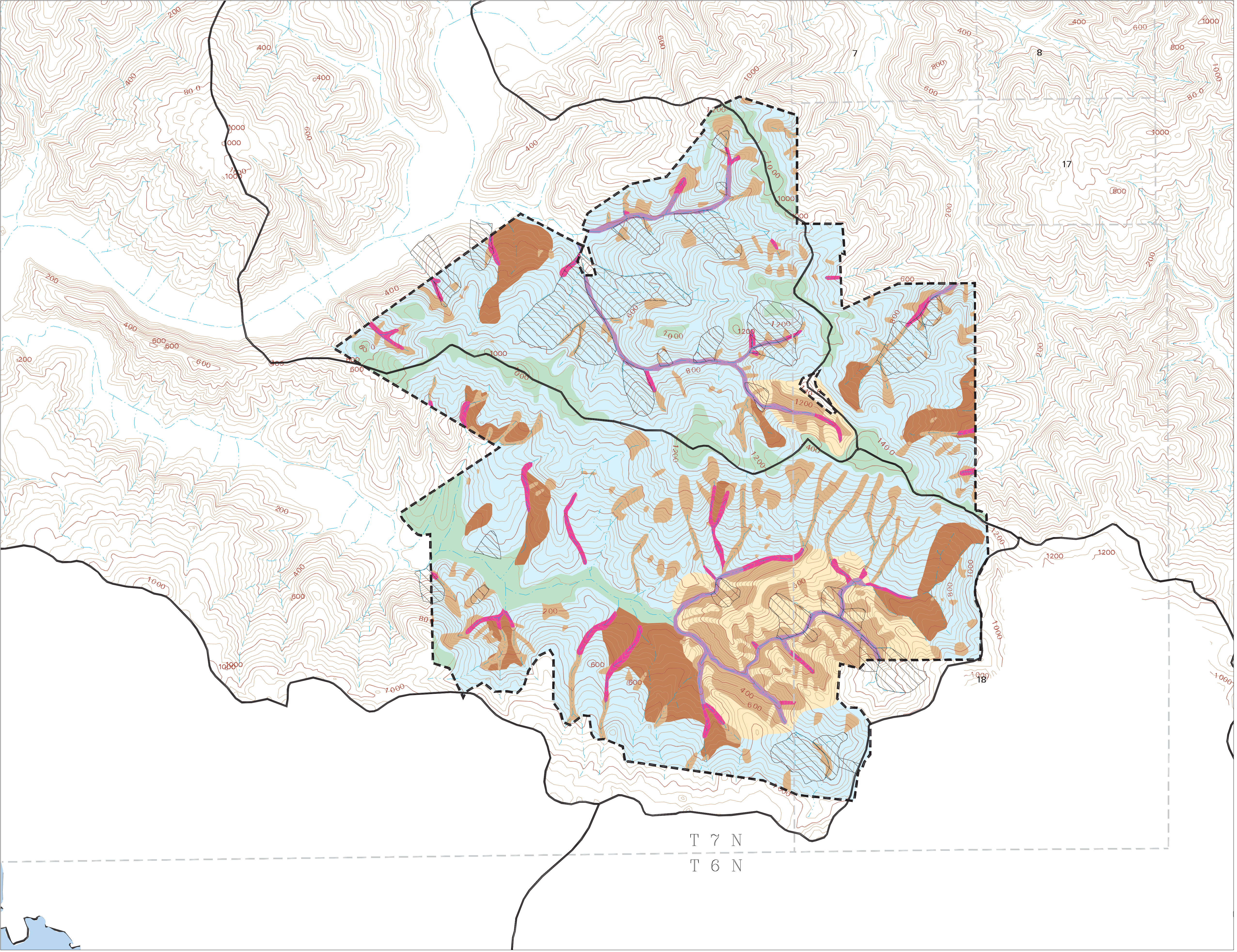
Forest Management Related Trigger Mechanisms:

- Sidecast fill material placed on locally steep slopes can initiate debris slides, torrents or flows in this unit.
- Concentrated drainage from roads onto unstable areas can initiate debris slides, torrents or flows in this unit.
- Concentrated drainage from roads can increase groundwater, accelerating movement of rockslides in this unit.
- Poorly sized culvert or excessive debris at watercourse crossings can initiate failure of the fill material creating debris slides, torrents or flows in this unit.
- Cut-slope of roads can over-steepen the slope creating debris slides in this unit.
- Concentrated drainage from skid trails onto unstable areas can initiate debris slides, torrents or flows in this unit.
- Loss of evapo-transpiration from forest harvest can increase groundwater levels initiating or accelerating movement of rockslides in this unit or aid in initiation of debris slides, torrents or flows.
- Concentrated drainage from roads and skid trails can initiate or accelerate gully erosion, which can increase the potential for mass wasting processes.
- Cut-slope of skid trails can remove support of the toe or expose potential failure planes of earth flows.
- Sidecast fill material created from skid trail construction placed on locally steep slopes can initiate debris slides, torrents or flows.
- Root decay of hardwood or non-redwood conifer species can be a contributing factor in the initiation of debris slides, torrents or flows in this unit.

Confidence: Moderate confidence in the delineation of this unit due to similarities of terrain of this unit with that of units 4,5, and 6.

Willow Creek / Freezeout Creek Watershed Analysis Unit

Map A-2
Mass Wasting Map Units



Unit 1: Steep slopes along low gradient watersourses

Unit 2: Steep slopes adjacent to select intermittent or ephemeral streams

Unit 3: Steep dissected or convergent topography

Unit 4: Non-dissected topography

Unit 5: Low relief topography

Unit 6: Identified earthflow complexes

Unit 7: Accelerated creep terrain

Rockslides

Flow Class

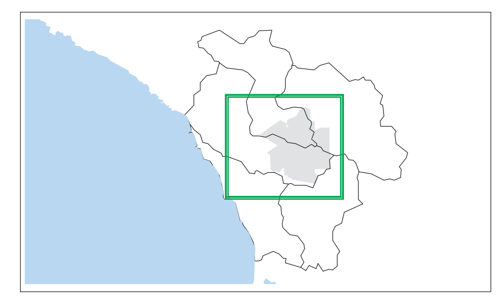
Class I

Class II

Class III

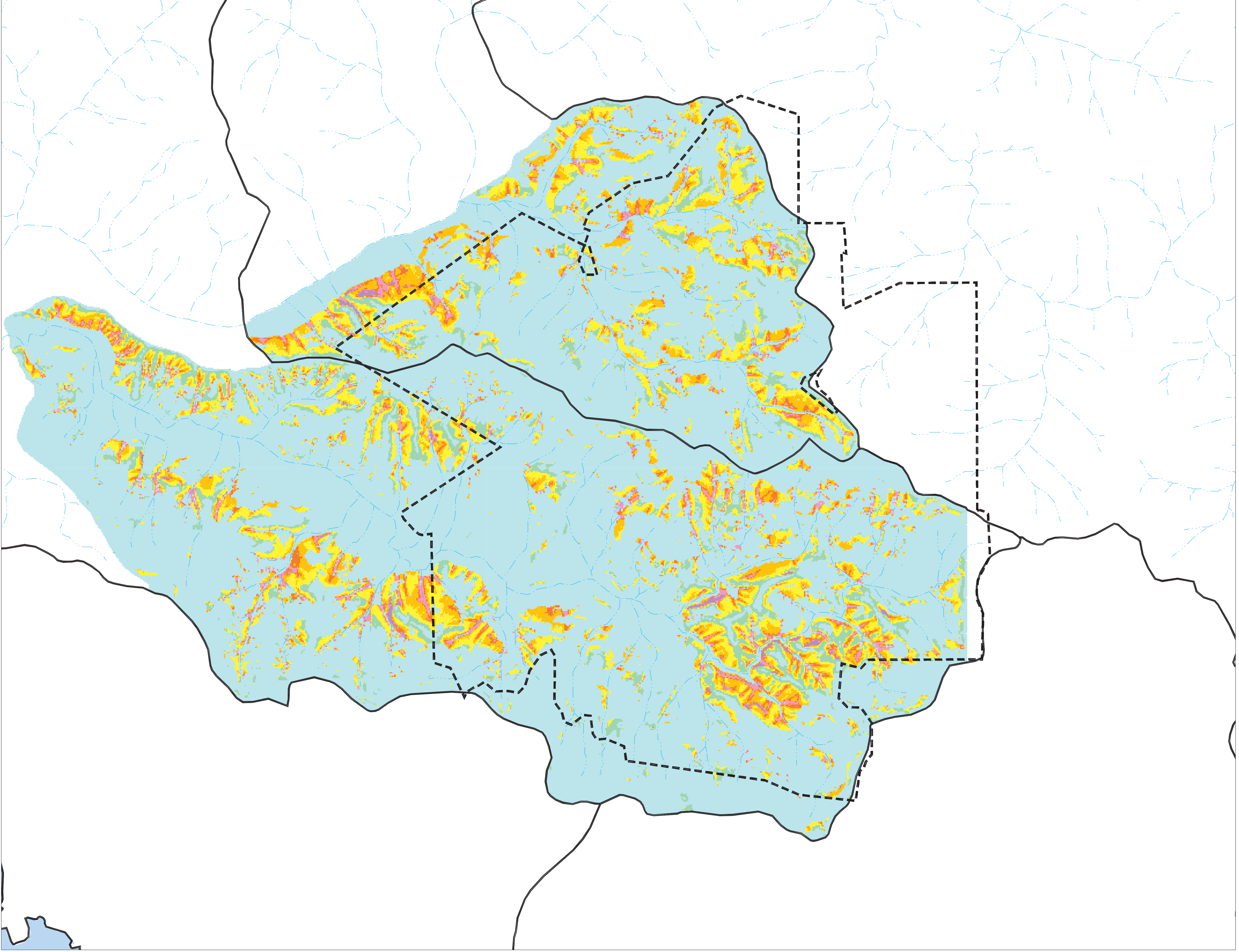
MRC Ownership

Planning Watershed Boundary



0 1/2 1 Mile

September 17, 2001



Willow Creek / Freezeout Creek Watershed Analysis Unit

Map A-3

Shallow Landslide Model SHALSTAB

MRC Ownership

Planning Watershed Boundary

Value of log(q/T)

-10.1 to -9.9

-9.9 to -3.1

-3.1 to -2.8

-2.8 to -2.5

-2.5 to -2.2

-2.2 to 9.8

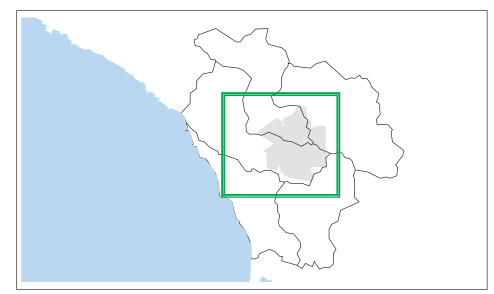
9.8 to 10.1

Flow Class

Class I

Class II

Class III



0 1/2 1 Mile

March 15, 2001

Sediment Input from Mass Wasting

Sediment delivery was estimated for shallow-seated landslides in the Willow Creek WAU. Landslides were determined to have either no sediment delivery or to deliver all or a percentage of their total volume. Of the shallow-seated landslides mapped by MRC in this watershed analysis, 65 percent of the landslides delivered some amount of sediment (Table A-4).

Table A-4. Total Shallow-Seated Landslides Mapped for each Watershed in the Willow Creek WAU. (Road Associated Landslides are Included).

Planning Watershed	Total Slides	Landslides with Sediment Delivery	Landslides with No Sediment Delivery
Willow Creek	68	44	24
Freezeout Creek	31	21	10
Dutch Bill Creek	5	3	2
sum	104	68	36
percentage	100%	65%	35%

Mass wasting was separated into three time periods for data analysis. The first time period is for mass wasting that occurred from 1969-1978, the second time period assessed is from 1979-1987, and the third time period assessed is from 1988-2000. The cut-off dates from each of the time periods are based on the date of aerial photographs used to interpret landslides (1978, 1987/1990, 1996, and 2000) and field observations (2000). While the available aerial photograph years did not allow for perfect ten-year time periods for mass wasting assessment, the time periods were reasonable close to ten-year periods. The periods used in this analysis are useful to provide a general idea of the relative magnitude of sediment delivery for the time periods analyzed particularly the sediment delivery rate estimates.

Approximately 42,000 tons of mass wasting sediment delivery was estimated for the time period 1969-2000 in the Willow Creek WAU. This equates to about 160 tons/sq. mi./yr. Of the total estimated amount, approximately 1300 tons (3% of total) occurred from 1969-1978, approximately 27,000 tons (63% of total) occurred from 1979-1987,and 14,00 tons (34% of total) occurred in the 1988-2000 time period (Table A-5).

For the Willow Creek and Freezeout Creek planning watersheds, sediment input from mass wasting was highest during the 1979-1987 period (Table A-5)(Chart A-1). For the Dutch Bill Creek planning watershed, sediment input was only observed within the 1988-2000 time period, due to few observed landslides in a relatively small amount of MRC ownership.

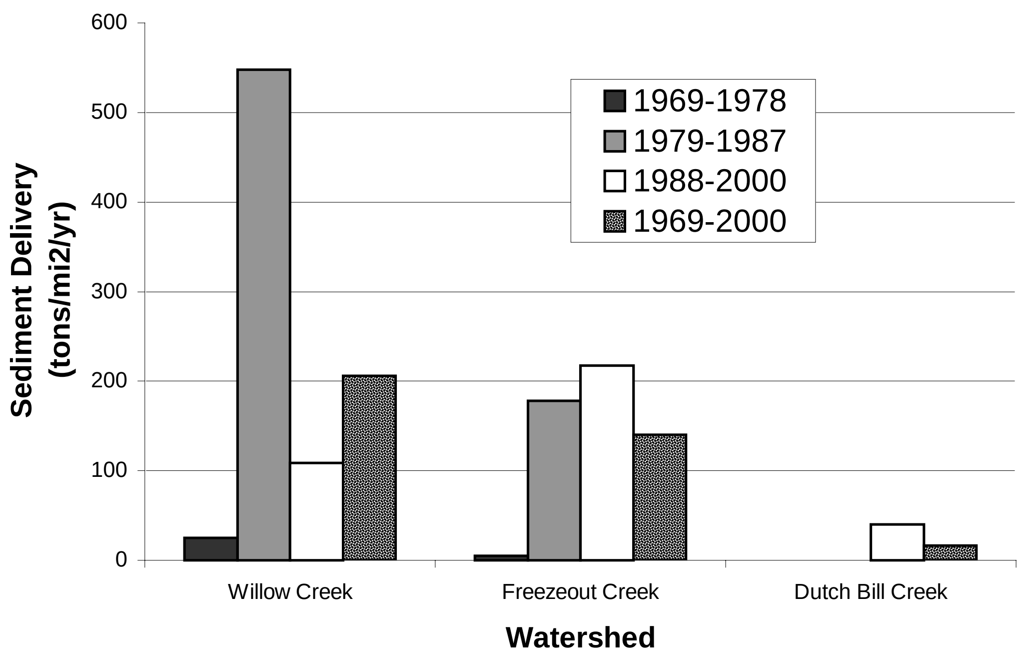
The highest sediment input from mass wasting occurs in the Willow Creek planning watershed. The higher sediment delivery appears to be due to a combination of extensive tractor yarding, and a long history of intense forest management prior to forest practice rules, and a few very large landslides that contributed a high amount of sediment in those planning watersheds. In particular, the high sediment delivery estimate for the

Willow Creek planning watershed from 1979-1987 is mainly from a few, voluminous landslides which may have occurred during the significant storms of 1981/1982. In contrast, Dutch Bill Creek planning watershed has an extremely low mass wasting input. The low input for Dutch Bill Creek, on Mendocino Redwood Company property is attributable to a low number of mapped landslides (5).

Table A-5. Estimated Sediment Volume Input by Watershed for MRC Ownership. Data are Reported in Tons of Sediment Delivered. (*Data based on limited sampling and should only be considered as relative quantities for comparison*).

Planning Watershed	1969-1978	1979-1987	1988-2000
Willow Creek	1100	23000	6500
Freezeout Creek	200	4000	7000
Dutch Bill Creek	0	0	500
Total	1310	27000	14000

Chart A-1. Total Mass Wasting Sediment Input Rate (tons/yr/sq. mi.) from Landslides for MRC Ownership Shown by Watershed and Time Period. (*Data based on limited sampling and should only be considered as relative quantities for comparison*).



Road associated mass wasting was found to contribute approximately 10,000 tons (40 tons/sq. mi./yr) of sediment over the 32 years analyzed (1969-2000) in the Willow

Creek WAU (Table A-6). This represents approximately 23% of the total mass wasting inputs for the Willow Creek WAU for 1969-2000. In the Freezeout Creek planning watershed, road associated landslide sediment delivery was the major sediment source, contributing 54% of the Freezeout Creek delivery. However, in the Willow Creek planning watershed, only 12% of the sediment delivery is from road associated landslides.

Table A-6. Road Associated Sediment Delivery for Shallow-Seated Landslides for the Willow Creek WAU by Watershed, 1969-2000.

Watershed	Road Associated Mass Wasting Sediment Delivery (tons)	Percent of Total Sediment Delivery
Willow Creek	4000	12%
Freezeout Creek	6000	54%
Dutch Bill Creek	0	0%
Total	**10,000**	**23%**

Sediment Input by Mass Wasting Map Unit (MWMU)

Total mass wasting sediment delivery for the Willow Creek WAU, from mass wasting estimates, was separated into respective mass wasting map units. It should be noted that not all planning watersheds contain all eight MWMUs.

The mass wasting map unit with the highest sediment delivery is MWMU 3 (Table A-7); which is estimated to deliver 23,000 tons of sediment over the last thirty-two years, 54% of the total sediment input. Combining the streamside units (MWMU 1 and 2) would yield 9,000 tons, 21% of the total sediment input. MWMU 4 is estimated to have delivered a moderate amount of sediment (6000 tons) suggesting its moderate landslide hazard. No delivery was estimated for MWMU 5 due to the fact that it is a low hazard area with very gently sloping to flat topography and typically does not deliver landslide material except in extraordinary events.

Mass wasting sediment delivery for MWMUs 6 and 7 are artificially low due to the fact that we did not attempt to quantify deep seated landslide sediment inputs or accelerated creep inputs. Only the shallow-seated landslides that were observed in these units were quantified.

Table A-7. Total Sediment Delivery for Shallow-seated Landslides of Mass Wasting Map Units in the Willow Creek WAU (1969-2000). (*Data based on limited sampling and should only be considered as relative quantities for comparison*).

MWMU

	1	2	3	4	5	6	7
Sediment Delivered (tons)	6500	2500	24000	6000	0	1500	3000
% of total delivered	16%	6%	54%	14%	0%	4%	7%

Mass Wasting within the Context of the Willow and Freezeout Creeks Watersheds

There appears to be a greater concentration of area with a high risk of shallow-seated landslides in the upper areas of the MRC ownership of Willow Creek, compared to the lower watershed area on the State Park, due to concentration steep topography there. The landslides mapped within the Willow and Freezeout Creeks watersheds confirm this. A few very large shallow landslides were mapped in the lower watershed areas of Willow and Freezeout Creeks. The majority of shallow-seated landslides are located in the steep swales at the heads of watercourses. The remainder of the large shallow-seated landslides mapped in the lower portion of the Willow Creek watershed are found on very steep slopes on the what appears to be the outside of an ancient meander bend. Furthermore, SHALSTAB output shows that throughout Willow and Freezeout Creeks the greatest hazard for shallow-seated landslides exists at the head and along the margins of watercourses in steep topography (Map A-3).

Deep-seated landslides (earth flows or rockslides) are very prevalent throughout both Willow and Freezeout Creeks. This prevalence is for both on and off the MRC ownership. Furthermore, many of the deep-seated landslides appear to have morphological characteristics suggesting recent activity, particularly in lower Willow Creek.

CONCLUSIONS

In natural forest environments of the California Coast Ranges, mass wasting is a common occurrence. In the Willow Creek WAU this is due to relatively steep slopes, the weak rocks (weathered interbedded sandstone, shale and melange terrain), locally thick colluvial soils, legacy timber harvest practices, and the occurrence of high intensity rainfall events. The topography of the Willow Creek WAU is unique when compared to that of MRC ownership in other Coast Range watersheds. The presence of significant mélange terrain here explains the abundance of the grassy, earth flow topography which overall is less steep than slopes of other MRC watersheds.

Mass wasting features of variable magnitude are observable throughout the Willow Creek WAU. The vast majority of the landslides visited in the field during this assessment occurred on slopes greater than 60%, in areas of convergent and or very steep planar topography.

Approximately 1/3 of the number of shallow-seated landslides are road associated in the Willow Creek WAU, though road related mass wasting only represented 23% of the sediment delivery. The reason that the sediment delivery proportion is so low is due to an abundance of mid-slope road associated failures that do not deliver sediment. MWMU 3 has the highest risk of road associated mass wasting sediment delivery. Roads prove to be a significant factor in the cause of shallow-seated mass wasting events in this unit. Better road construction practices combined with design upgrades of old roads will lower the amount over time.

MWMU 3 represented the greatest mass wasting sediment delivery for any one unit, providing 54% of the sediment delivered from 1969-2000. Streamside mass wasting (combining MWMU 1 and 2) yields 21% of the total sediment input. The combined delivery for MWMUs 5, 6, and 7 comprises 24% of the total shallow seated landslide sediment delivery, while encompassing most of the landscape in the WAU.

Mass wasting sediment input is estimated to be at least 158 tons/sq. mi./ yr. over the 1969-2000 time period for the entire Willow Creek WAU. Overall, in the Willow Creek WAU, sediment delivery from mass wasting was highest in the Willow Creek planning watershed in the 1979-1987 time period. This area was particularly high due to legacy harvest practices, compounded by the occurrence of a few very large landslides that significantly increased the sediment delivery amounts that may have been triggered by particularly large storms of the 1981-1982 winter. The forest harvesting technique utilized in the 1950's and 1960's was tractor skidding of logs. This skidding was performed on steep slopes and often in streamside environments and inner gorges, compacting and destabilizing the soil, increasing the frequency of mass wasting. Evidence of past harvesting practices can be seen in upper Willow Creek, where portions of rail lines still exist within the stream channel.

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Section B

SURFACE AND POINT SOURCE EROSION
(ROADS/SKID TRAILS)

Introduction

The surface and point source erosion module examines the past and present soil erosion from roads and skid trails of the Mendocino Redwood Company (MRC) ownership in the Willow/Freezeout Creeks watersheds, the watershed analysis unit (WAU). This module also provides a hazard assessment of the potential for future surface and point source erosion from roads in the Willow/Freezeout Creeks WAU. The potential erosion assessment is to assist in development of mitigation measures and actions to minimize future soil erosion from the road network. The road data that is the basis for most of this analysis was collected by MRC during a 100% road inventory of the Willow/Freezeout Creeks WAU. The erosion estimates utilize a combination of field observations and the use of the surface erosion model presented in the Standard Methodology for Conducting Watershed Analysis (Version 3.0, Washington Forest Practices).

Surface erosion is defined as the removal of soil particles from the surface of the soil. Processes such as rill erosion, sheetwash, biogenic transport (animal burrows, treefall, etc.) and ravel are considered surface erosion. Gullies, road crossing wash-outs, and large erosion features created by erosion from overland flow of water are considered point source erosion. In contrast, the largest discrete erosion event, landslides, are considered mass wasting.

This module examines road and skid trail associated surface and point source erosion delivering sediment into watercourses. The module also presents results from analysis done on hillslope point source erosion (grassland and forested gullies) by Trihey and Associates (1995) in the Willow Creek watershed. Excessive levels of fine sediments from surface and point source erosion can get trapped in porous streambed gravels; and can increase water turbidity and suspended sediment concentrations. Excessive coarse sediments from point source erosion can adversely affect stream channel morphology. These can reduce the survival of salmonids in their redds or affect habitat needs and physiological characteristics of rearing salmonids. Excessive surface and point source erosion when delivered to a watercourse can also affect other downstream uses such as water supplies, agricultural diversions and recreation users. It is important that best management practices be utilized in forest management operations to minimize the impacts of surface and point source erosion.

Surface and Point Source Erosion from Roads

Methods

Past, current and potential surface and point source erosion from roads was determined from field observations and a road surface erosion model. All of the roads in the Willow/Freezeout Creeks WAU were visited in the field during a road inventory of the Willow/Freezeout Creeks WAU (2000).

The road inventory consisted of traveling the road with a Global Positioning System (GPS) unit, identifying, mapping and inventorying all major features of the road network. Some of the features that are inventoried include watercourse-crossings and crossing structures (culverts, bridges, etc.), landings, erosion features and controllable erosion amounts (as defined below). Information relating to erosion and sediment delivery from the road inventory is analyzed in this report. Also dimensions of the road network such as length, width and sediment contributing road lengths are summarized. The road inventory collects information on the entire road infrastructure. This road infrastructure information allows for better management and tracking of the MRC road network, but is not presented in this report.

All road features (watercourse crossings, landings, road fill, etc.), during the road inventory, have the past deliverable point source erosion volume estimated for that feature. Deliverable point source erosion from a road is defined as rill or gully erosion which is observed in close proximity to a watercourse or which showed evidence of eroding directly into a watercourse. These measurements were used to calculate the volume of point source erosion delivered from the road. The volume of erosion was converted to a weight (in tons) assuming a soil bulk density of 100 lbs./cubic foot.

Future or potential point source erosion (gully or road fill wash-outs, not sheetwash) observations were collected during the road inventory. This potential future erosion is called controllable erosion, a term developed by the North Coast Regional Water Quality Control Board for Total Maximum Daily Load (TMDL) purposes. Controllable erosion is defined as soil that could potentially deliver to a watercourse in the next 40 years (the duration of a TMDL), is human created, and can be reasonably controlled by human actions. Typically controllable erosion is a measure of the fill material from a road that could erode if a road feature is left un-maintained or fails in the next 40 years. The controllable erosion amount is the volume of soil that can be controlled with high design standards for a road feature (i.e. watercourse crossing, side-cast fill, etc.).

The controllable erosion sites are further designated by the potential for sediment delivery and the immediacy of treatment for the site. Both the sediment delivery potential and the treatment immediacy are ranked low, moderate or high. The ranking of each controllable erosion site by these variables provides a hazard or risk assessment of the controllable erosion. This allows prioritization of road improvements and erosion control work.

Another important variable of potential future point source erosion from a road is the likelihood of diversion of water down the road prism. This diversion potential, as it is called, was evaluated for every watercourse crossing of every road in the

Willow/Freezeout Creeks WAU. A site has a diversion potential if when the watercourse crossing plugged, dammed or failed water could be diverted out of the “natural” watercourse channel and down the road prism. Water diverted out of its “natural” channel would erode the road prism creating potentially high sediment delivery. Sites with a diversion potential can be engineered such that the diversion of water down a road prism does not occur if the watercourse crossing plugged, dammed or failed.

Proper culvert sizing is another important characteristics for consideration of road erosion potential. Culverts that do not have the capacity to pass debris, water and sediment in high flow events can plug creating road prism failures with high sediment inputs. MRC currently designs all new culvert installations to pass the 100 year flood to ensure enough capacity in the pipe to pass water, debris and sediment in high flows. To determine if culvert sizing is appropriate for existing culverts the area behind each culvert inventoried is determined from topography data in the MRC Geographic Information System (GIS). The regression equation for the North Coast region (Waananen and Crippen, 1977) is used to predict the 50 and 100 year peak flow. A culvert sizing nomograph is used to determine the appropriate size for 50 and 100 year peak flow magnitudes and that predicted size is compared to the existing culvert sizing to determine if the culvert is large enough.

Surface erosion (sheetwash from the road tread and prism) from roads was not directly estimated in the field, the contributing length or extent of road that delivers erosion to a watercourse is measured in the field then used for surface erosion calculations. The contributing length of a road is the length of road prism that drains water and associated eroded soil into a watercourse. Thus it defines the length of surface erosion of any particular site on the road. The model used to calculate surface erosion from roads is from the Standard Methodology for Conducting Watershed Analysis (Version 3.0, Washington Forest Practices Board) and is described below.

Surface erosion from the road surface is influenced by the amount of road traffic (high use mainline, moderate use active secondary, etc.), the type of road surface material, precipitation, width and size of road (the more surface area to erode the more erosion), and vegetative cover (Reid, 1981). The Standard Methodology for Conducting Watershed Analysis (Version 3.0, Washington Forest Practices Board) provides relationships based on these factors to estimate the amount of surface erosion from different road types and conditions. For a complete description of all of the parameters used in calculating surface erosion from roads see the Standard Methodology for Conducting Watershed Analysis (Version 3.0, Washington Forest Practices Board).

Field observations from the road inventory determined the length of the road delivering sediment to a watercourse (contributing length), the road width, the road surface material and the type of road (seasonal or temporary) to aid in the surface erosion calculations. In some cases the road inventory lacked contributing road length. In these cases the contributing road length was assumed to be 200 feet. Typically culverts that drain an inside ditch of a road (cross-drain culverts) put the water and eroded soil on a hillslope and do not deliver to a watercourse. The exception to this is when the cross drain culvert is in close proximity to a watercourse. To account for this all cross-drain culverts within 200 feet of a watercourse were assumed to deliver sediment and surface erosion. If a contributing road length was not collected for these features a 200 foot contributing length is assumed for the surface erosion modeling.

The following parameters were used to calculate surface erosion from roads in the Willow/Freezeout Creeks WAU. All of the observed roads were assumed to be older than 2 years, a base erosion rate of 60 tons/acre/year was used. This initial value was altered (multiplied) by the factors of traffic on the road, cut- and fill-slope vegetation cover, road surface type, annual precipitation and road type in an attempt to model the actual sediment volume contributed by a given road segment. The road tread width was determined in the field during the road inventory and is assumed to be 40% of the road prism. The cut- and fill-slopes are assumed to 60% of the road prism; their dimensions for the surface erosion model were determined by multiplying the tread width by 1.5.

Road cut- and fill-slopes usually had approximately 50% vegetative cover, giving a cover factor of 0.37. The majority of hauling on roads occurs during drier times of the year (i.e. late spring, summer and early fall). Therefore the lowest annual precipitation category is used (<47 in. precipitation annually). In this annual precipitation category a road with at least a 6 inch rock surface is given a factor of 0.2, while a native surface road has a factor of 1.

There were 4 traffic factors used in surface erosion modeling:

1) *Mainline roads with heavy traffic* have a factor of 20; these roads are actively used and maintained for log haul traffic.
2) *Mainline roads with moderate traffic* have a factor of 2; these roads are used for log haul traffic 2-3 times each decade.
3) *Seasonal roads* have a traffic factor of 1.2; these are tributary roads which receive moderate log haul traffic 1-2 years each decade and light traffic the remainder of the time.
4) *Temporary roads* receive a traffic factor of 0.61; these roads receive moderate log haul traffic 1-2 times per every 1-2 decades with little to no use in between.

The result of the surface erosion modeling is added to the total past point source erosion observed during the road inventory from a given road and presented as tons/year of sediment delivery (see Appendix B for erosion estimates of each road in the Willow/Freezeout Creeks WAU). For relative sediment contributions from each planning watershed for roads for sediment input evaluation the tons/year calculations for all roads was totaled by planning watershed and normalized by dividing by the MRC ownership, in square miles, for the planning watershed. The result is a tons/square mile of MRC ownership/year estimate of road surface and point source erosion.

Finally, with this information each road in the Willow/Freezeout Creeks WAU is assigned an erosion hazard class. The erosion hazard class is used to classify the roads in the Willow/Freezeout Creeks WAU by their current and potential erosion hazard. The erosion hazard class was determined by the amount of erosion a road produced and the likelihood for that erosion to be delivered to a watercourse. High levels of traffic, road surface, proximity to the stream, high past point source erosion, and high modeled surface erosion all were considered when ranking roads for their erosion hazard. The roads with the highest risk of sediment delivery and soil erosion were given a high erosion hazard classification. The roads with medium risk of sediment delivery and soil erosion were given a moderate erosion hazard classification. The roads with the lowest risk of sediment delivery and soil erosion were given a low erosion hazard classification. A description of what each erosion hazard classification means can be found in the Road results and discussion sub-section of this Surface and Point source Erosion report.

Road Surface and Point Source Erosion Results and Discussion

The surface and point source erosion estimates by planning watershed are presented in Table B-1. The breakdown of estimated erosion, road areas, road lengths and hazard rating by individual roads is in Appendix B of this report.

Roads in the MRC ownership in the Willow Creek planning watershed are estimated to generate, on average, 119 tons/mi^2/yr of sediment from road associated surface and point source erosion. Roads in the MRC ownership in the Freezeout Creek planning watershed are estimated to generate, on average, 138 tons/mi^2/yr of sediment from road associated surface and point source erosion. (Table B-1). Roads in the Dutch Bill Creek watershed are estimated to generate 68 tons/mi^2/yr of sediment. It must be noted that observations of road erosion at one point in time do not accurately reflect the characteristics of the road over time. For example, a culvert or road erosion site may have failed several times over its life, but it is not possible to determine that from current observations. Therefore the estimates of sediment yield are likely a minimum estimate.

Table B-1. Road Associated Surface and Point Source Erosion Estimates by Planning Watershed for the Willow/Freezeout Creeks WAU.

Planning Watershed	**Total Road Assoc. Erosion (tons/yr)**	**Total Acres PLWS**	**MRC Owned Acres**	**Road Assoc. Erosion Rate (tons/sq mi/yr)**
Willow Creek	546	11558	2928	119
Freezeout Creek	355	8954	1647	138
Willow/Freezeout Creeks WAU	***901***	***-***	***4575***	***105***

The erosion rate, though only an estimate, provides a good indicator of where road associated surface and point source erosion issues are currently occurring. However, the timing and amount of road use affects the amount of erosion estimated from a road. If the assumptions on the timing or amount of road used change, the erosion rate estimates may lose their reliability as an indicator of problem areas. Another indicator that can help in interpreting a potential road associated surface of point source erosion risk is the amount and density of road, and the amount of road that contributes erosion to a watercourse (contributing area). The road density and road area totals are presented for each planning watershed in the Willow/Freezeout Creeks WAU (Table B-2).

Road length and surface area is highest in the Willow Creek planning watershed (Table B-2). The amount of contributing road area (sediment delivery area) is similar between Willow Creek and Freezeout Creek, however proportionately Freezeout Creek has much less road so the contributing road area is of greater concern for the Freezeout Creek roads. It should be a goal to lower the contributing road area in the Willow/Freezeout Creeks WAU particularly in the Freezeout Creek watershed.

Table B-2. Road Surface Areas, Contributing Road Surface Areas, Road Lengths and Road Densities for the Willow/Freezeout Creeks WAU.

Planning Watershed	**Road Surface Area (ac)**	**Road Contributing Area (ac)**	**Road Length (miles)**	**Road Density (mi/sq mi)**
Willow Creek	63	9	33.0	7.2
Freezeout Creek	36	7	18.5	7.2
Willow/Freezeout Creeks WAU Total	***99***	***16***	***51.5***	***7.2***

The road erosion hazard classification for each road in the Willow/Freezeout Creeks WAU is presented on Map B-1 and for each individual road in the appendix of this module. The categorizing of roads into hazard classes is intended to identify current problem areas, consider reconstruction and prioritize maintenance. The following are the definitions for each road erosion hazard class.

High Road Erosion Hazard Class - These roads have the highest amount of recent deliverable surface erosion to watercourses and a high potential for future deliverable erosion. These roads can be active, abandoned or closed. Often roads in this class are close to watercourses creating a high sediment delivery potential. Erosion is typically due to long contributing road lengths or native surfaces near watercourses: a result of too few waterbars and/or rolling dips or lack of rock surface. Erosion may also be a product of problem areas such as watercrossing wash-outs, poor road drainage, plugged road watercrossings, water diverted down the road surface, culverts not fitted with downspouts, etc. Active roads in this class should get the highest priority for maintenance or improvements. Closed roads in this class will need improvements before opening again. Opening abandoned roads in this class should be avoided.

Moderate Road Erosion Hazard Class - These roads have moderate amounts of recent deliverable surface erosion to watercourses and potential for future deliverable erosion. These roads can be active, abandoned or closed. Erosion problems on roads in this class can usually be handled with good road maintenance. Erosion is typically from problem areas such as poor road drainage, water diverted down the road surface, culverts not fitted with downspouts, and an occasional plugged culvert or watercourse crossing wash-out. Active roads in this class should be a priority for maintenance. Closed or abandoned roads in this class will need some improvements before opening again.

Low Road Erosion Hazard Class - These roads have low amounts of recent deliverable surface erosion to watercourses and low potential for future deliverable erosion. These roads can be active, abandoned or closed. Active roads in this class do not need to be a priority for maintenance. Closed or abandoned roads in this class will need only some improvements before opening again.

Potential controllable (point source) erosion sites were identified and prioritized in the Willow/Freezeout Creeks WAU. In the Willow/Freezeout Creeks WAU 6 controllable erosion sites have a high treatment immediacy and 20 controllable erosion sites have a moderate treatment immediacy. In addition to these controllable erosion sites 54 culverts in the Willow/Freezeout Creeks WAU have a diversion potential. These diversion potential sites need to be considered a high priority for road improvement as they can represent a significant potential point source erosion hazard. The treatment immediacies, road site numbers and road numbers are found on Map B-2. The road number and site number of each controllable erosion and diversion potential site is in Appendix B of this report.

The culvert size analysis has determined that 26 culverts are likely too small to pass the 50 year flood and an additional 3 culverts will not pass the 100 year flood. These culverts need to be a high priority for upgrade should they indeed be under-sized. The analysis of culvert sizing is only an estimate based on culvert location from the MRC road inventory and area behind the culvert based on MRC GIS topographic data. A field review will be required at each site to determine if the culvert is indeed under-sized, as our confidence in the analysis is low. However, the identification of these culverts as under-sized is a good hypothesis to work from and provides information to address potential road problems in Willow/Freezeout Creeks WAU.

Surface and Point Source Erosion from Skid Trails

Methods

Sediment delivery from surface and point source erosion from skid trails was determined from aerial photograph interpretation and sediment delivery estimates developed in previous MRC watershed analysis's (MRC, 1998 and MRC, 2000). Aerial photographs from 1961, 1971, 1978, 1980, 1996 and 2000 were used to identify skid trail activity.

The aerial photograph interpretation for skid trail activity consisted of determining the area harvested by ground based yarding by skid trail density (high, moderate, low) for each photo year. High-density skid trail activity is defined as having greater than 100 watercourse crossings per square mile. Moderate-density skid trail activity is defined as having between 50-100 watercourse crossings per square mile. Light skid trail density has less than 50 watercourse crossings per square mile or were trails with significant re-vegetation observed in the aerial photograph.

The amount of sediment delivery from the various densities of skid trail activity was estimated from sediment delivery rates estimated during previous watershed analysis by MRC (MRC, 1998 and MRC, 2000). A combination of surface erosion modeling and field observations of point source erosion from skid trails were used develop the skid trail estimates. High skid trail density is estimated to contribute 300 tons/square mile/year of sediment. Moderate skid trail density is estimated to contribute 200 tons/square mile/year of sediment, while low skid trail density contributes 50 tons/square mile/year.

For each photo year the area in each skid trail density category was multiplied by the sediment delivery rate for that density. The estimated rate was then assumed to represent the decade previous to the photo year observed (i.e. 1961 photo represent activity in the 1950s). The exception being photo years that were in mid-decade or near the end of a decade, these were considered as part of that decade (i.e. 1978 is considered an observation for the 1970s).

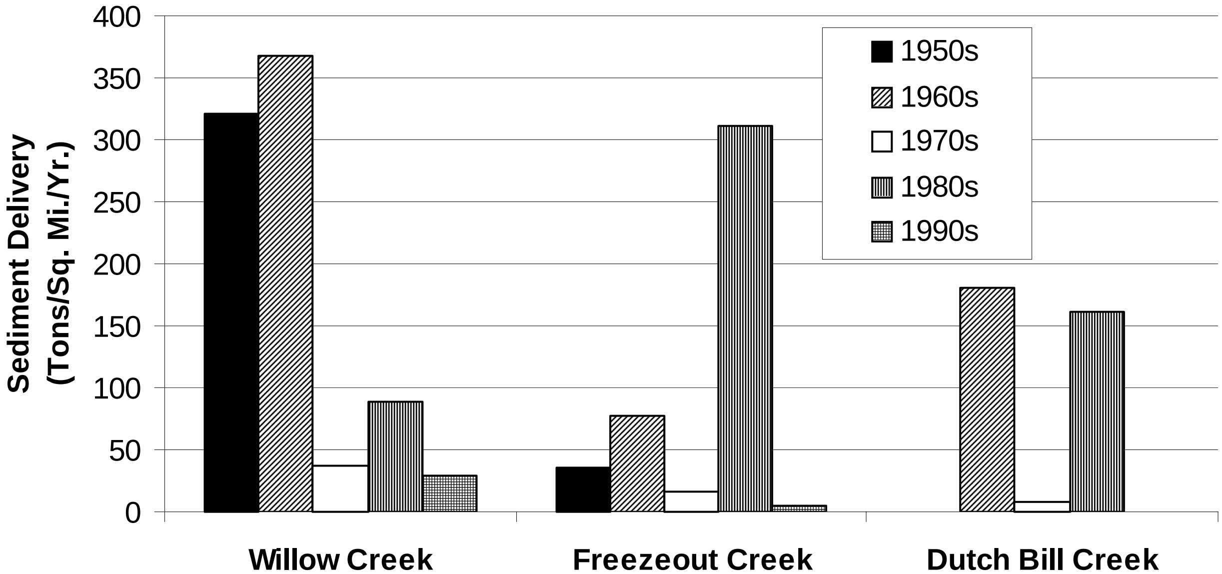
Skid Trail Erosion Results and Discussion

The results by time period for the skid trail sediment delivery estimates are summarized in Table B-3 and Chart B-1. The estimates should be considered only as a minimum sediment delivery for skid trails constructed and used in the decade. Undoubtedly, some if not many, sediment delivering skid trails were vegetated enough to be overlooked during the inventory. In particular are those trails constructed or used greater than five years prior to aerial photograph reconnaissance may be re-vegetated and not observed.

Table B-2. Skid Trail Use and Sediment Delivery Estimates for Willow/Freezeout Creek WAU by Decade.

	Willow Creek		**Freezeout Creek**		**Dutch Bill Creek**	
	Skid Trail Use Area (acres)	Sediment Delivery (tons/mi^2/yr)	Skid Trail Use Area (acres)	Sediment Delivery (tons/mi^2/yr)	Skid Trail Use Area (acres)	Sediment Delivery (tons/mi^2/yr)
1950s	1225	320	370	35	0	0
1960s	1200	370	260	80	774	180
1970s	500	40	200	15	97	10
1980s	275	90	1120	300	380	160
1990s	375	30	55	5	0	0

Figure B-1. Estimated Skid Trail Sediment Delivery Rate by Watershed and Decade for the Willow/Freezeout Creek WAU.



In Willow Creek the entire forested portion of what is now the MRC ownership was harvested using tractor based yarding during the 1950s and 1960s. This high level of skid trail construction and use is estimated to contribute a high level of sediment delivery. The sediment delivery estimated from skid trails in Willow Creek is by far the highest in the 1950s and 1960s (Figure B-1). Freezeout Creek was almost completely harvested using tractor based yarding during the 1980s and thus the highest sediment delivery for that watershed occurred during that decade. Dutch Bill Creek lands had high skid trail use and sediment delivery in both the 1960s and the 1980s.

Skid trail sediment delivery diminishes in the 1990s in all watersheds. This is produced from a combination of less harvest activity and stricter regulations on tractor based yarding use. Future skid trail sediment delivery rates will be lower than past rates because California Forest Practice Rules and MRC policy mandate better managed tractor yarding activities. Better erosion control measures are used on skid trails such as increased water bar spacing and a practice by MRC of packing the trails with logging debris (slash), when available, after operations to prevent surface erosion. Furthermore, skid trail operation is limited next to watercourses and prohibited directly in watercourses.

Surface and Point Source Erosion from Gullies

Active gully erosion is prevalent in the Willow Creek watershed. Analysis by Trihey and Associates (1997) suggest both forested and grassland gullies have had accelerated erosion since the tractor logging in the 1950s and 1960s. The Trihey and Associates definition of forested gullies could be interpreted to be created from channel degradation and bank erosion processes and therefore be discussed in the Stream Channel

Condition module. However, it is being discussed in this section to keep the discussion together with the grassland gully evaluation.

Trihey and Associates conclude that creation of the forested gullies in Willow Creek are the result of clearing of stream-side trees in the 1950s and 1960s that would have been recruited to the stream channel. This lack of a large wood source has destabilized the bed of the channels creating down cutting and bank failures. Trihey and Associates assume that 80 percent the channel downcutting has occurred since the early 1950s. Measurements of cross section areas of the downcut channels has yielded an estimated 160 tons/mi^2/year in sediment production. This estimate is averaged over time, it is likely that the forest gully creation was episodic with a large amount of the erosion created in early years of this time frame following large storm events. It is not likely that the current erosion from forested gullies persist at as high a level, though continued erosion is prevalent.

The grassland gullies in Willow Creek are active erosion features. This type of gully erosion is common in the Franciscan complex found in the Willow Creek area. Highly sheared and weathered siltstones and sandstones often produce a plastic or clay texture to the soils. This high clay texture creates lower water infiltration capacity, increased surface water flow and thus a greater tendency for point source erosion. This higher clay texture is particularly prevalent in the grassland areas of the Franciscan complex as the lack of woody vegetation suggests poor growing conditions from the soil properties. This greater tendency for point source erosion in the grassland areas is exacerbated by concentrated drainage from road outfalls, re-routing of natural drainage by roads, grazing, or forest clearing for increased grassland. Trihey and Associates estimate the rate of grassland gully erosion at about 100 tons/mi^2/year.

Conclusions

The overall road surface and point source erosion rate for the Willow/Freezeout Creeks WAU is 105 tons/sq. mi./yr. Proportionately Freezeout Creek watershed has the highest level of sediment contributing road areas. The amount of sediment contributing road area needs to be considered for road improvements and erosion reduction throughout the Willow/Freezeout Creeks WAU. By reducing contributing road area the amount of road that contributes sediment during forest management operations is reduced.

Road density is currently averaging 7.2 miles of road to every square mile of land MRC owns. This density is high and needs to be a source of improvement.

The road network is classified as High, Moderate and Low surface erosion hazard (Map B-1). The roads with the high hazard are the highest priorities for improvements, monitoring or maintenance. The moderate hazard roads are a medium priority for improvements, monitoring or maintenance. The low hazard roads are not much of a concern for sediment delivery.

High and moderate treatment immediacy controllable erosion and diversion potential sites were identified along the roads in the Willow/Freezeout Creeks WAU and needs to be a focal point of ongoing forest operations. The Willow/Freezeout Creeks WAU currently has 6 high treatment immediacy sites, 20 moderate immediacy sites and 54 sites with a diversion potential. Potentially 26 culverts are too small to pass the 50 year flood and 3 additional culverts likely will not pass the 100 year flood. These sites will be a priority for improvement of the road network in the Willow/Freezeout Creeks WAU. The road number, site number for each individual site is shown on Map B-2 and in Appendix B of this report.

Sediment delivery from skid trails was found to be highest in the Willow Creek in the 1950s and 1960s. Freezeout Creek had high sediment delivery in the 1980s, while Dutch Bill Creek had sediment delivery peaks in the 1960s and 1980s. This is mainly due to a high amount construction and use of skid trails during these time periods. Future skid trail sediment delivery rates will be lower than current or past rates because California Forest Practice Rules and MRC policy requires cable yarding on steep ground. Much of the skid trail erosion in the WAU came from skid trail use on steep terrain before the current Forest Practice Rule restrictions. Furthermore, skid trail operation next to or directly in watercourses is now restricted.

Forested and grassland gullies have been observed to be large sediment production areas in Willow Creek. Trihey and Associates (1997) estimate forested gully sediment production over the last 40 years at 160 tons/mi^2/year and grassland gully erosion at 100 tons/mi^2/year.

Literature Cited

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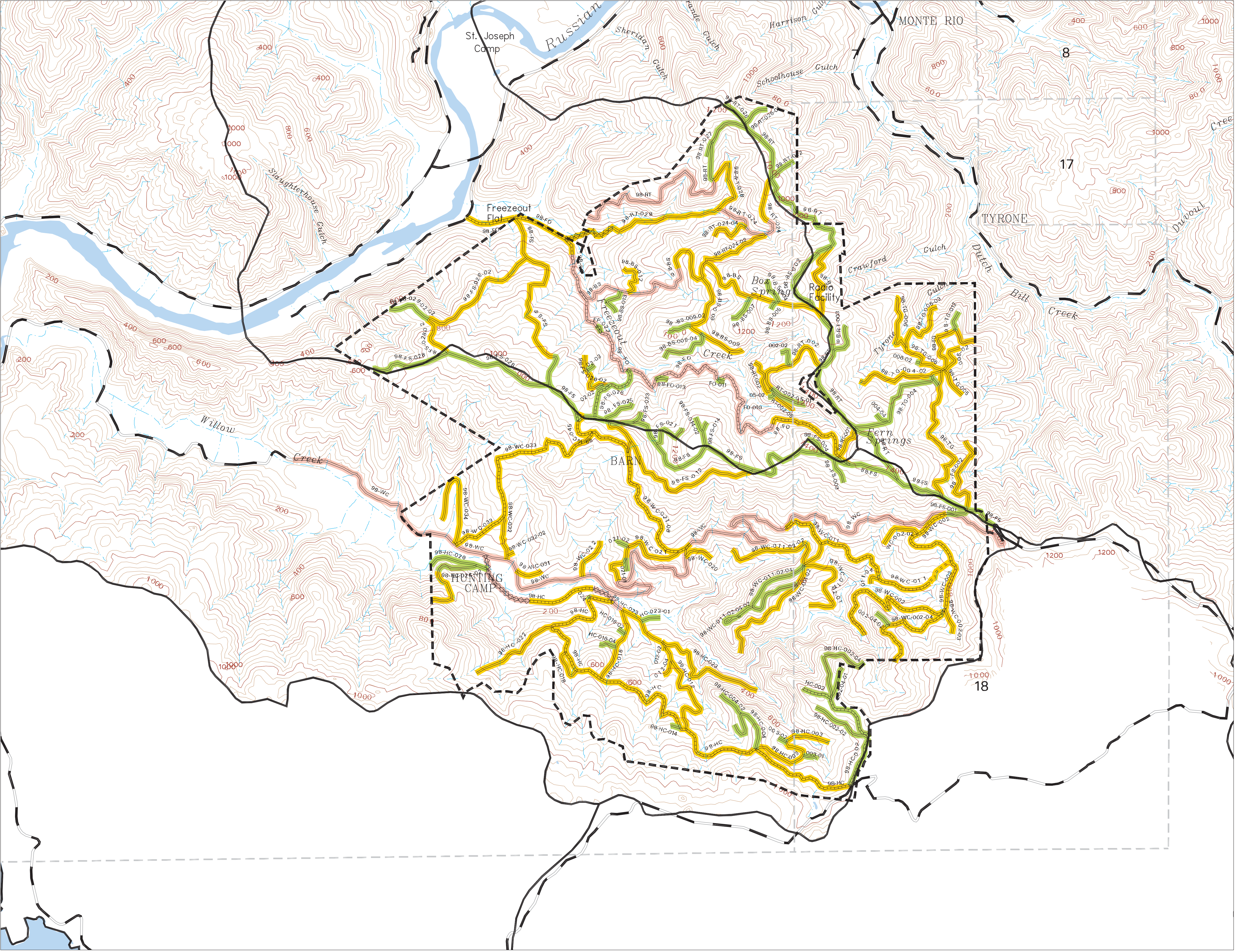
Washington Forest Practice Board. 1995. Standard methodology for conducting watershed analysis. Version 3.0. WA-DNR Seattle, WA.

Willow Creek / Freezeout Creek Watershed Analysis Unit

Map B-1 Road Surface Erosion Hazard Ratings



Erosion Hazard Rating
- Low
- Moderate
- High
- MRC Ownership
- Planning Watershed Boundary

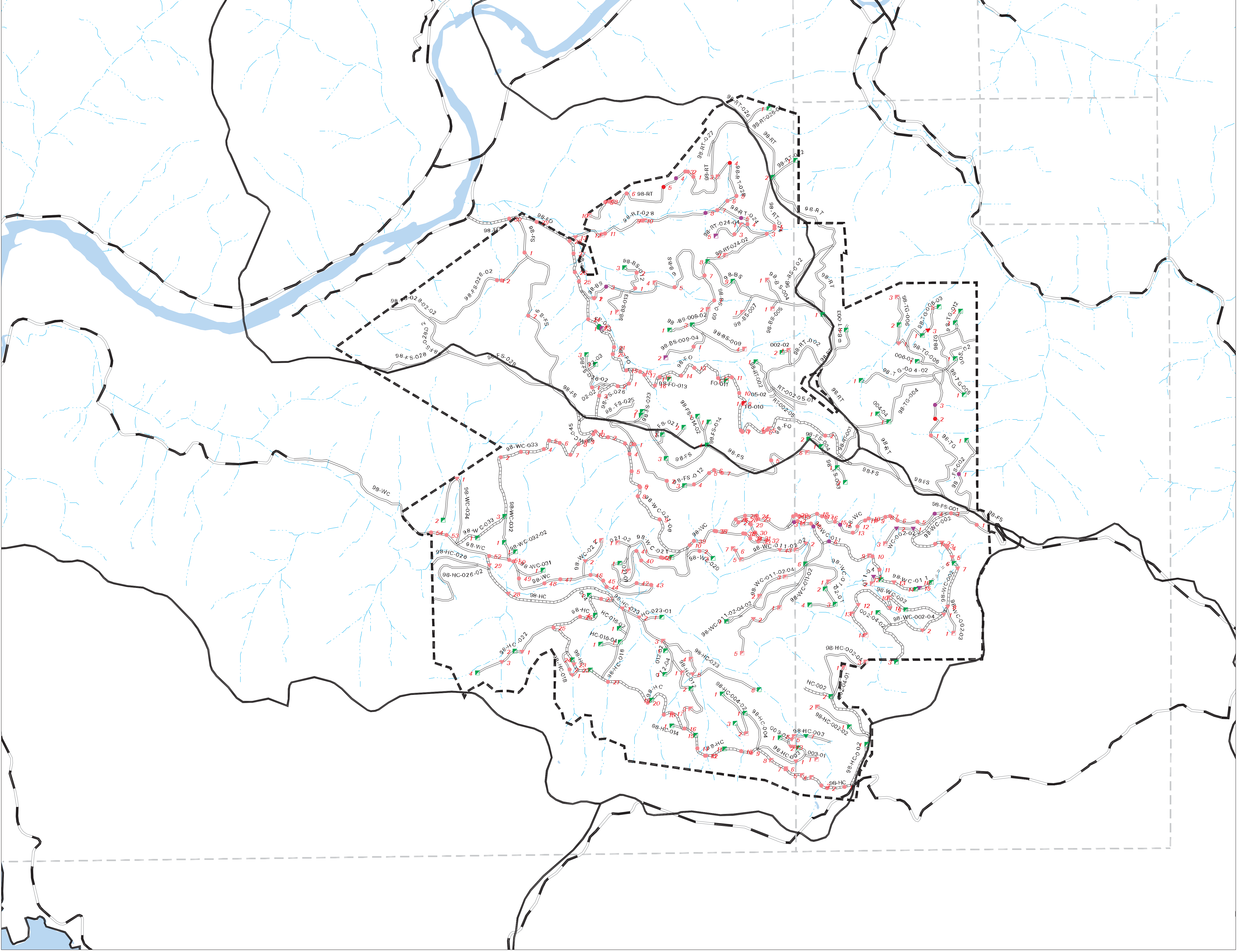
Transportation
- Paved Road
- Rocked Road
- Native Road
- Jeep Trail
- Railroad
- WLPZ Roads

Flow Class
- Class I
- Class II
- Class III

Topography
- Index Contour (200′ interval)
- Regular Contour (40′ interval)

0 1/2 1 Mile

February 12, 2001



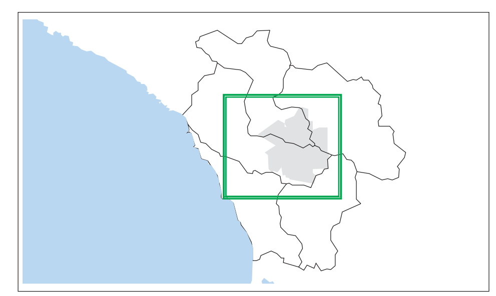
Willow Creek / Freezeout Creek Watershed Analysis Unit

Map B-2 Road Feature Treatment Immediacy

Culverts	Crossings	Landings
High	High	High
Moderate	Moderate	Moderate
Low	Low	Low
None	None	None
Undetermined	Undetermined	Undetermined

MRC Ownership
Planning Watershed Boundary

Transportation	Flow Class
Paved Road	Class I
Rocked Road	Class II
Native Road	Class III
Jeep Trail	
Railroad	



N W E S

0 1/2 1 Mile

February 12, 2001

Appendix B

Surface Erosion Module

Treatment Immediacies and Controllable Erosion for Road Points in Willow/Freezeout Creeks WAU.

Road_num	Site_num	Feature	Del_ers_pt	Contrl_vo	Treat_imm	Comments
98-TG-006-03	3	humboldt	high	380	high	REALLY BAD-STORED SED. ABOVE HUMBOLDT
98-FO-011	1	Landing	high	230	high	STREAM RUNING IN LANDING
98-TG-006-03	2	major rilling	high	200	high	
98-RT-028	4	watercourse	high	80	high	
98-RT	5	watercourse	moderate	370	high	
98-TG	2	watercourse	moderate	30	high	CULVERT EXPOSED IN ROAD
98-FS004	1	ditch relief	high	200	moderate	CONTROL WITH SLIDE FAILING MORE
98-RT028	8	watercourse	high	75	moderate	
98-RT-024	5	watercourse	high	10	moderate	
98-BS-009-04	2	Landing	high	0	moderate	
98-BS	3	watercourse	moderate	300	moderate	CULVERT ON OLD HUMBOLDT
98-FO-022	1	Landing	moderate	180	moderate	
98-WC-011	6	watercourse	moderate	140	moderate	
98-RT	4	watercourse	moderate	130	moderate	
98-WC-011	5	watercourse	moderate	110	moderate	
98-WC-011	15	bridge	moderate	80	moderate	
98-WC-011	15	bridge	moderate	80	moderate	
98-WC-011	1	watercourse	moderate	60	moderate	washout filled w/rock
98-WC-011-04	1	other	moderate	50	moderate	
98-FS-002-02	2	dipped	moderate	45	moderate	
98-FS-002-02	1	dipped	moderate	35	moderate	
98-TG	3	watercourse	moderate	30	moderate	0
98-BS	6	gully	moderate	30	moderate	WATERCOURSE
98-RT-024-04	5	Landing	moderate	0	moderate	
98-WC	14	ditch relief	low	15	moderate	
98-WC	4	ditch relief	low	10	moderate	
98-BS-012	1	watercourse	high	925	low	OLD CULVERT BELOW NEW
98-BS-012	2	watercourse	high	200	low	
98-RT028	13	bridge	high	150	low	RAILS NEED REPAIR
98-TG-006	1	dipped	high	130	low	
98-WC--022	2	dipped	high	72	low	
98-BS	1	bridge	high	70	low	
98-RT-024	4	watercourse	high	60	low	
98-RT028	9	Landing	high	50	low	
98-RT028	7	watercourse	high	50	low	50 ft FROM INTERSECTION
98-RT028	10	ditch relief	high	15	low	
98-RT-028	6	ditch relief	high	10	low	300 ft FROM LAST CULVERT
98-FO	30	watercourse	high	7	low	
98-FO	29	watercourse	high	7	low	
98-BS	2	ditch relief	high	2	low	CULVERT UNDER BRIDGE LOG RAIL
98-RT	6	watercourse	moderate	500	low	
98-FO	7	watercourse	moderate	230	low	
98-WC-021	3	watercourse	moderate	120	low	FRIST MAJOR DRAW FROM LAST GPS POINT
98-RT-024-02	2	Landing	moderate	90	low	
98-BS-009	1	watercourse	moderate	90	low	
98-HC-022	1	other	moderate	70	low	
98-FO	25	watercourse	moderate	60	low	
98-HC-022	3	other	moderate	60	low	
98-RT028	12	Landing	moderate	55	low	
98-RT-024	2	watercourse	moderate	50	low	
98-FO	24	watercourse	moderate	50	low	
98-WC	22	gully	moderate	46	low	
98-FO	9	watercourse	moderate	45	low	ON ROAD UP FROM LANDING
98-FS-002-03	1	Landing	moderate	35	low	class 3 through landing
98-BS	4	Landing	moderate	30	low	SLASH OVER SIDE
98-RT-028	5	watercourse	moderate	25	low	NEXT WATERCOURSE ON MAP
98-TG	1	watercourse	moderate	20	low	
98-RT-024	1	watercourse	moderate	20	low	
98-FS-26-02	1	watercourse	moderate	20	low	
98-RT028	11	watercourse	moderate	15	low	TWO CULVERTS
98-FO	8	watercourse	moderate	15	low	100 FT FROM CROSSING ON MAP
98-RT-024-04	3	watercourse	moderate	10	low	DRAINS WATERCOURSES UP ROAD
98-FO	26	ditch relief	moderate	10	low	
98-FO	27	ditch relief	moderate	10	low	

Treatment Immediacies and Controllable Erosion for Road Points in Willow/Freezeout Creeks WAU.

Road_num	Site_num	Feature	Del_ers_pt	Contrl_vo	Treat_imm	Comments
98-RT-024	3	watercourse	moderate	9	low	300 ft DOWN ROAD FROM CULVERT
98-BS	5	watercourse	moderate	3	low	
98-WC-011	7	gully	moderate	0	low	
98-WC	28	watercourse	low	890	low	
98-WC	29	watercourse	low	660	low	CULV. SPLIT ROAD SLIP OUT
98-RT	9	watercourse	low	555	low	COW DESTROIED ROAD
98-FS-28-02	1	watercourse	low	520	low	
98-RT	3	watercourse	low	500	low	ROOT WAD IN FRONT OF INLET
98-RT	2	watercourse	low	460	low	
98-RT	1	watercourse	low	370	low	
98-WC	32	watercourse	low	350	low	
98-WC-011-02	5	Landing	low	160	low	
98-FO	20	watercourse	low	160	low	
98-WC	8	watercourse	low	160	low	
98-WC-011	2	watercourse	low	150	low	
98-WC	7	watercourse	low	150	low	
98-WC-011-02	2	humboldt	low	150	low	
98-WC	30	watercourse	low	140	low	
98-WC	18	watercourse	low	140	low	
98-WC	16	watercourse	low	140	low	
98-WC	15	watercourse	low	140	low	
98-WC	10	watercourse	low	140	low	
98-WC	19	watercourse	low	125	low	
98-FO	16	watercourse	low	120	low	
98-WC	6	watercourse	low	120	low	
98-WC-011	4	watercourse	low	100	low	
98-FS-002	12	other	low	100	low	old logs covered w/fill
98-FS-002	12	other	low	100	low	old logs covered w/fill
98-RT	7	Landing	low	90	low	
98-BS-009	2	Landing	low	90	low	
98-HC	20	watercourse	low	90	low	
98-WC	38	watercourse	low	90	low	
98-WC	35	watercourse	low	90	low	
98-FO	19	watercourse	low	80	low	
98-WC	25	watercourse	low	80	low	
98-WC	11	watercourse	low	75	low	
98-WC	24	watercourse	low	70	low	
98-WC	23	watercourse	low	70	low	
98-WC-021-02	8	watercourse	low	70	low	
98-HC	3	watercourse	low	62	low	
98-FO	14	watercourse	low	60	low	
98-HC	18	watercourse	low	60	low	
98-WC-021	2	watercourse	low	60	low	
98-BS-009	4	Landing	low	55	low	
98-FS-28-02	2	watercourse	low	55	low	
98-TG-006	3	Landing	low	50	low	
98-WC-011-02-01	1	Landing	low	50	low	
98-FO	13	ditch relief	low	50	low	
98-WC-011	10	watercourse	low	50	low	
98-WC	37	watercourse	low	50	low	
98-WC	34	watercourse	low	50	low	
98-WC	20	watercourse	low	50	low	
98-HC	23	bridge	low	50	low	
98-HC	21	watercourse	low	45	low	
98-WC	51	watercourse	low	45	low	CEMENT
98-HC	1	watercourse	low	40	low	
98-HC	2	ditch relief	low	40	low	
98-HC	10	watercourse	low	40	low	
98-HC	12	watercourse	low	40	low	
98-HC	13	watercourse	low	40	low	
98-WC	53	watercourse	low	40	low	CEMENT
98-WC	50	watercourse	low	40	low	CEMENT
98-WC	43	watercourse	low	40	low	
98-WC	41	watercourse	low	40	low	

Treatment Immediacies and Controllable Erosion for Road Points in Willow/Freezeout Creeks WAU.

Road_num	Site_num	Feature	Del_ers_pt	Contrl_vo	Treat_imm	Comments
98-WC-021-02	9	watercourse	low	40	low	
98-HC	29	bridge	low	40	low	
98-WC-011-02	3	gully	low	40	low	
98-WC	39	watercourse	low	35	low	
98-WC	42	watercourse	low	35	low	
98-HC-023	2	low water (temp)	low	35	low	
98-FO	12	watercourse	low	30	low	
98-FO	21	watercourse	low	30	low	
98-FS-002	1	watercourse	low	30	low	
98-WC-011	11	watercourse	low	30	low	
98-WC	54	watercourse	low	30	low	CEMENT
98-WC	46	watercourse	low	30	low	CEMENT
98-WC	21	watercourse	low	30	low	
98-WC-021-02	2	watercourse	low	30	low	
98-WC-021-02	6	watercourse	low	30	low	
98-WC-021-02	7	watercourse	low	30	low	
98-HC	6	watercourse	low	25	low	
98-HC	9	watercourse	low	25	low	
98-HC	14	watercourse	low	25	low	
98-HC	16	watercourse	low	25	low	
98-WC	45	watercourse	low	25	low	
98-WC	17	ditch relief	low	25	low	
98-FS	1	watercourse	low	25	low	
98-WC-033	6	watercourse	low	25	low	
98-WC-033	5	watercourse	low	25	low	
98-WC-021-02	1	watercourse	low	25	low	
98-HC	28	bridge	low	25	low	
98-WC-021-01	1	Landing	low	20	low	
98-FO	28	ditch relief	low	20	low	
98-FO	6	ditch relief	low	20	low	
98-FS-26	1	watercourse	low	20	low	
98-HC-018	2	watercourse	low	20	low	
98-HC	25	ditch relief	low	20	low	
98-WC	9	ditch relief	low	20	low	
98-WC	5	ditch relief	low	20	low	
98-FS	2	watercourse	low	20	low	
98-WC-021-02	4	watercourse	low	20	low	
98-WC-011	13	dipped	low	20	low	
98-WC-011	13	dipped	low	20	low	
98-WC-011-02-02	2	dipped	low	20	low	
98-WC-011-02-02	6	dipped	low	20	low	
98-WC	36	ditch relief	low	18	low	
98-FS-26-02	2	gully	low	17	low	
98-HC	26	ditch relief	low	15	low	
98-HC	27	ditch relief	low	15	low	
98-WC	52	ditch relief	low	15	low	
98-WC	49	ditch relief	low	15	low	
98-WC	48	ditch relief	low	15	low	
98-WC	47	ditch relief	low	15	low	
98-WC	44	ditch relief	low	15	low	
98-WC	40	ditch relief	low	15	low	
98-WC	33	ditch relief	low	15	low	
98-WC	31	ditch relief	low	15	low	
98-WC	13	ditch relief	low	15	low	
98-WC	12	ditch relief	low	15	low	
98-WC	3	ditch relief	low	15	low	
98-WC	1	ditch relief	low	15	low	
98-FS-12	5	ditch relief	low	15	low	
98-FS-12	4	ditch relief	low	15	low	
98-FS-12	2	ditch relief	low	15	low	
98-FS-12	1	ditch relief	low	15	low	
98-WC-033	9	ditch relief	low	15	low	
98-WC-033	8	ditch relief	low	15	low	
98-WC-033	7	ditch relief	low	15	low	

Treatment Immediacies and Controllable Erosion for Road Points in Willow/Freezeout Creeks WAU.

Road_num	Site_num	Feature	Del_ers_pt	Contrl_vo	Treat_imm	Comments
98-WC-021-02	3	ditch relief	low	15	low	
98-WC-021-02	10	ditch relief	low	15	low	
98-FS-002	5	dipped	low	15	low	
98-FS-002	4	dipped	low	15	low	
98-FS-002	2	dipped	low	15	low	
98-FS-002	5	dipped	low	15	low	
98-FS-002	3	dipped	low	15	low	
98-HC-003	1	dipped	low	15	low	
98-WC	27	ditch relief	low	14	low	
98-WC	26	ditch relief	low	14	low	
98-FO	5	watercourse	low	12	low	
98-HC	17	ditch relief	low	12	low	
98-WC-033	10	ditch relief	low	12	low	
98-WC-033	4	ditch relief	low	12	low	
98-WC-033	3	ditch relief	low	12	low	
98-WC-033	2	ditch relief	low	12	low	
98-WC-021-02	5	ditch relief	low	12	low	
98-RT-002-02	1	Landing	low	10	low	
98-WC-021-02	1	Landing	low	10	low	
98-RT	8	ditch relief	low	10	low	COW DESTROIED ROAD
98-FO	17	ditch relief	low	10	low	
98-FS	5	ditch relief	low	10	low	
98-WC-021	2	watercourse	low	10	low	40 FEET DOWN FROM LAST CULVERT
98-FS-002-04	1	dipped	low	10	low	dipped w/downspout
98-FS-002	7	dipped	low	10	low	
98-FS-002	8	dipped	low	10	low	
98-FS-002	7	dipped	low	10	low	
98-FS-002	8	dipped	low	10	low	
98-HC-003	3	dipped	low	10	low	
98-HC-003	4	dipped	low	10	low	
98-HC-003	5	dipped	low	10	low	
98-HC-018	1	dipped	low	10	low	
98-WC-011-02-02	4	dipped	low	10	low	
98-FS-002	11	dipped	low	10	low	
98-HC-023	5	dipped	low	10	low	
98-FO	10	ditch relief	low	8	low	
98-FO	18	ditch relief	low	7	low	
98-FO	11	ditch relief	low	5	low	
98-FO	15	ditch relief	low	5	low	
98-FS-002-04	2	dipped	low	5	low	
98-BS	7	watercourse	low	4	low	
98-BS-009-04	1	ditch relief	low	3	low	
98-FO	2	ditch relief	low	3	low	SLASH COVERING OUTLET
98-FS-26	2	ditch relief	low	3	low	
98-FS-26	3	ditch relief	low	3	low	
98-RT-028	3	Landing	low	0	low	
98-RT	10	Landing	low	0	low	
98-BS-013	1	Landing	low	0	low	
98-BS-007	1	Landing	low	0	low	SLASH OVER SIDE
98-BS-005	1	Landing	low	0	low	
98-BS-004	1	Landing	low	0	low	
98-RT-024-04	1	Landing	low	0	low	
98-FO	4	Landing	low	0	low	
98-FS-002	10	Landing	low	0	low	
98-FS-002	14	Landing	low	0	low	
98-WC-011-04	2	Landing	low	0	low	class 3 through landing
98-WC-011	3	Landing	low	0	low	
98-WC-011	9	Landing	low	0	low	
98-FS-002	13	Landing	low	0	low	
98-FS-002-02	3	Landing	low	0	low	
98-HC-002-02	2	Landing	low	0	low	
98-HC	4	Landing	low	0	low	
98-HC	5	Landing	low	0	low	
98-HC	7	Landing	low	0	low	

Treatment Immediacies and Controllable Erosion for Road Points in Willow/Freezeout Creeks WAU.

Road_num	Site_num	Feature	Del_ers_pt	Contrl_vo	Treat_imm	Comments
98-HC	8	Landing	low	0	low	
98-HC-004	2	Landing	low	0	low	
98-HC-003-01	1	Landing	low	0	low	
98-HC-003	6	Landing	low	0	low	
98-HC-012	3	Landing	low	0	low	
98-WC-011-02-02	3	Landing	low	0	low	
98-WC-011-02-02	5	Landing	low	0	low	
98-WC-011-02-02	7	Landing	low	0	low	
98-WC-011-02-04	3	Landing	low	0	low	
98-WC-011-02-04	2	Landing	low	0	low	
98-WC-011-02	1	Landing	low	0	low	
98-FS	6	Landing	low	0	low	
98-HC-012	1	Landing	low	0	low	
98-HC-023	3	Landing	low	0	low	
98-HC-023	4	Landing	low	0	low	
98-HC-002-04-01	1	Landing	low	0	low	
98-HC-002-04	3	Landing	low	0	low	
98-WC--022	1	Landing	low	0	low	
98-FS-12	7	watercourse	low	0	low	
98-FS-12	6	watercourse	low	0	low	
98-HC-023	1	low water (temp)	low	0	low	
98-WC-034	1	dipped	low	0	low	
98-FS004	1	Landing	moderate	0	none	
98-WC-021	4	Landing	low	50	none	
98-TG-005-02	1	Landing	low	40	none	SLASH OVER SIDE
98-TG-012	1	Landing	low	40	none	0
98-TG-012	2	Landing	low	40	none	0
98-RT-002	1	Landing	low	10	none	
98-FO	23	ditch relief	low	4	none	
98-FO-022	2	ditch relief	low	3	none	
98-TG-005	1	Landing	low	0	none	
98-TG-006-03	5	Landing	low	0	none	
98-TG-006-03	1	Landing	low	0	none	
98-TG-006	2	Landing	low	0	none	
98-TG-006-02	1	Landing	low	0	none	
98-TG-004-02	1	Landing	low	0	none	
98-TG-004	1	Landing	low	0	none	
98-RT-002-02	2	Landing	low	0	none	
98-RT-003	1	Landing	low	0	none	
98-RT-026-01	1	Landing	low	0	none	
98-RT	2	Landing	low	0	none	
98-RT	1	Landing	low	0	none	
98-BS-009	3	Landing	low	0	none	
98-BS-009-02	1	Landing	low	0	none	
98-BS-012	3	Landing	low	0	none	
98-BS	8	Landing	low	0	none	
98-BS	9	Landing	low	0	none	
98-FS-004	2	Landing	low	0	none	
98-FO-013	1	Landing	low	0	none	
98-FS-26-02-03	1	Landing	low	0	none	
98-FS-023	2	Landing	low	0	none	
98-FS-023	1	Landing	low	0	none	
98-FS-21	1	Landing	low	0	none	
98-FS-21	2	Landing	low	0	none	
98-FO-011	1	Landing	low	0	none	
98-FS-004	1	Landing	low	0	none	
98-FS-26-02	3	Landing	low	0	none	
98-RT-022	1	Landing	low	0	none	
98-WC-011	12	Landing	low	0	none	
98-FS-002	6	Landing	low	0	none	
98-FS-002-04	3	Landing	low	0	none	
98-WC-011-02-01	2	Landing	low	0	none	
98-WC-011	14	Landing	low	0	none	
98-WC-011	16	Landing	low	0	none	

Treatment Immediacies and Controllable Erosion for Road Points in Willow/Freezeout Creeks WAU.

Road_num	Site_num	Feature	Del_ers_pt	Contrl_vo	Treat_imm	Comments
98-FS-002-04-02	1	Landing	low	0	none	
98-FS-002	9	Landing	low	0	none	
98-WC-011-02-01	3	Landing	low	0	none	
98-HC-002	1	Landing	low	0	none	
98-HC-002	2	Landing	low	0	none	
98-HC-002-02	1	Landing	low	0	none	
98-HC-004	1	Landing	low	0	none	
98-HC-004	3	Landing	low	0	none	
98-HC-003	2	Landing	low	0	none	
98-HC-003-02	1	Landing	low	0	none	
98-HC	11	Landing	low	0	none	
98-HC	15	Landing	low	0	none	
98-HC-014	1	Landing	low	0	none	
98-HC	19	Landing	low	0	none	
98-HC	22	Landing	low	0	none	
98-HC	24	Landing	low	0	none	
98-HC-022	2	Landing	low	0	none	
98-WC-011-02-02	6	Landing	low	0	none	
98-WC-011-02-04-0	1	Landing	low	0	none	
98-FS	3	Landing	low	0	none	
98-FS-14	1	Landing	low	0	none	
98-FS-14-02	1	Landing	low	0	none	
98-FS-14	4	Landing	low	0	none	
98-FS-003	1	Landing	low	0	none	
98-FS-003	2	Landing	low	0	none	
98-WC-011-02-01	4	Landing	low	0	none	
98-HC-022	4	Landing	low	0	none	
98-FS-12	3	Landing	low	0	none	
98-WC-033	1	Landing	low	0	none	
98-WC-034	2	Landing	low	0	none	
98-HC-012	2	Landing	low	0	none	
98-HC-023-01	1	Landing	low	0	none	
98-HC-012-04	1	Landing	low	0	none	
98-HC-012-02	1	Landing	low	0	none	
98-HC-004-02	1	Landing	low	0	none	
98-HC-023	6	Landing	low	0	none	
98-TG-004-04	1	Landing	low	0	none	
98-WC-032-02	1	Landing	low	0	none	
98-WC-032	1	Landing	low	0	none	
98-WC-031	1	Landing	low	0	none	
98-HC-016-04	1	Landing	low	0	none	
98-HC-016	1	Landing	low	0	none	
98-HC-016-02	1	Landing	low	0	none	
98-HC-024	1	Landing	low	0	none	
98-HC	4	Landing	low	0	none	
98-WC-021	3	Landing	low	0	none	
98-WC-033	3	Landing	low	0	none	
98-WC-021	1	Landing	low	0	none	
98-HC-003	7	low water (temp)	low	0	none	

Culverts with a Diversion Potential for Willow/Freezeout Creeks WAU

Road Number	Site Number	Culvert Type	Diversion Potential	Diversion Potenial Prevention
98-FS004	1	ditch relief	yes, ditch	n/a
98-TG	1	watercourse	yes, road	ditch
98-RT	1	watercourse	yes, road	none
98-RT	2	watercourse	yes, ditch	none
98-RT	6	watercourse	yes, road	water bar
98-RT	8	ditch relief	yes, road	none
98-RT	9	watercourse	yes, road	none
98-BS	5	watercourse	yes, road	rolling dip
98-BS	7	watercourse	yes, ditch	none
98-BS-009-04	1	ditch relief	yes, road	water bar
98-RT-024	1	watercourse	yes, road	none
98-RT-024-04	3	watercourse	yes, road	none
98-RT-024	4	watercourse	yes, road	water bar
98-RT-024	5	watercourse	yes, road	rolling dip
98-RT-028	4	watercourse	yes, road	rolling dip
98-FO	2	ditch relief	yes, road	none
98-FO	12	watercourse	yes, road	none
98-FO	19	watercourse	yes, ditch	none
98-FO	28	ditch relief	yes, ditch	none
98-FO	30	watercourse	yes, road	none
98-FS-26	2	ditch relief	yes, ditch	none
98-FS-26	3	ditch relief	yes, ditch	none
98-FO	5	watercourse	yes, road	none
98-FO	6	ditch relief	yes, road	none
98-FO	7	watercourse	yes, road	none
98-FO	8	watercourse	yes, road	none
98-FO	9	watercourse	yes, road	none
98-FO	14	watercourse	yes, road	none
98-FO	21	watercourse	yes, ditch	none
98-FO	23	ditch relief	yes, road	none
98-FO	24	watercourse	yes, ditch	none
98-FO	25	watercourse	yes, ditch	none
98-FO	26	ditch relief	yes, road	ditch
98-FO	27	ditch relief	yes, road	none
98-FS-26	1	watercourse	yes, road	none
98-RT	5	watercourse	yes, road	water bar
98-RT-024	3	watercourse	yes, road	water bar
98-RT-028	5	watercourse	yes, road	rolling dip
98-RT-028	6	ditch relief	yes, road	rolling dip
98-RT028	8	watercourse	yes, road	water bar
98-HC	1	watercourse	yes, road	water bar
98-HC	2	ditch relief	yes, road	water bar
98-HC	16	watercourse	yes, road	water bar
98-HC	25	ditch relief	yes, road	none
98-WC	32	watercourse	yes, road	none
98-WC	31	ditch relief	yes, ditch	ditch
98-WC	17	ditch relief	yes, ditch	ditch
98-WC	14	ditch relief	yes, ditch	ditch
98-WC	9	ditch relief	yes, ditch	ditch
98-WC	4	ditch relief	yes, ditch	ditch
98-WC-033	2	ditch relief	yes, ditch	ditch
98-WC-021-02	10	ditch relief	yes, ditch	ditch
98-WC-021	2	watercourse	yes, road	rolling dip

Culvert Size Analysis for Willow/Freezeout Creeks WAU annual precip (in): 55

Road Number	**Site #**	**Culvert Type**	**Culvert Diameter (in) currently**	**Area (ac)**	**50 year flood (cfs)**	**100 year flood (cfs)**	**50 yr Culvert Size (in) needed**	**100 yr Culvert Size (in) needed**	**50 yr pass**	**100 yr pass**
98-TG	1	watercourse	18	35	32	35	30	36	NO	NO
98-BS	3	watercourse	18	12	13	14	24	24	NO	NO
98-BS	5	watercourse	30	92	74	80	42	42	NO	NO
98-BS	7	watercourse	12	6	7	7	18	18	NO	NO
98-BS-009	1	watercourse	24	43	38	41	36	36	NO	NO
98-FO	12	watercourse	18	8	9	10	24	24	NO	NO
98-FO	19	watercourse	24	26	25	27	30	30	NO	NO
98-FO	5	watercourse	18	19	19	20	30	30	NO	NO
98-FO	7	watercourse	24	23	22	24	30	30	NO	NO
98-FO	9	watercourse	18	8	9	10	24	24	NO	NO
98-FO	29	watercourse	24	21	21	22	30	30	NO	NO
98-FS-26	1	watercourse	18	23	22	24	30	30	NO	NO
98-FS-26-02	1	watercourse	18	16	16	17	24	24	NO	NO
98-HC	6	watercourse	18	9	10	11	24	24	NO	NO
98-HC	9	watercourse	18	15	15	17	24	24	NO	NO
98-HC	14	watercourse	18	16	16	17	24	24	NO	NO
98-HC-018	2	watercourse	18	94	76	82	42	48	NO	NO
98-WC	41	watercourse	18	29	27	29	30	30	NO	NO
98-WC	39	watercourse	24	23	22	24	30	30	NO	NO
98-WC	24	watercourse	24	28	26	28	30	30	NO	NO
98-FS-28-02	1	watercourse	24	29	27	29	30	30	NO	NO
98-FS	2	watercourse	18	17	17	18	24	24	NO	NO
98-WC	42	watercourse	24	56	48	52	36	42	NO	NO
98-FS-12	7	watercourse	12	2	3	3	18	18	NO	NO
98-WC-021-02	4	watercourse	18	25	24	26	30	30	NO	NO
98-WC-021-02	8	watercourse	18	10	11	12	24	24	NO	NO
98-HC	13	watercourse	24	18	18	19	24	30	YES	NO
98-FS	1	watercourse	18	7	8	9	18	24	YES	NO
98-WC-021-02	6	watercourse	18	7	8	9	18	24	YES	NO
98-TG	2	watercourse	30	5	6	6	18	18	YES	YES
98-RT	1	watercourse	18	4	5	5	18	18	YES	YES
98-RT	2	watercourse	24	1	1	2	18	18	YES	YES
98-RT	3	watercourse	36	21	21	22	30	30	YES	YES
98-RT	4	watercourse	24	2	3	3	18	18	YES	YES
98-RT	6	watercourse	36	17	17	18	24	24	YES	YES
98-RT	9	watercourse	24	7	8	9	18	24	YES	YES
98-BS-012	1	watercourse	36	20	20	21	30	30	YES	YES
98-BS-012	2	watercourse	48	107	85	91	48	48	YES	YES
98-RT-024	1	watercourse	18	4	5	5	18	18	YES	YES
98-RT-024	2	watercourse	48	18	18	19	24	30	YES	YES
98-RT-024-04	3	watercourse	18	3	4	4	18	18	YES	YES
98-RT-024	4	watercourse	48	11	12	13	24	24	YES	YES
98-RT-024	5	watercourse	24	3	4	4	18	18	YES	YES
98-RT-028	4	watercourse	36	20	20	21	30	30	YES	YES
98-RT028	11	watercourse	18	6	7	7	18	18	YES	YES
98-FO	16	watercourse	48	37	34	36	30	36	YES	YES
98-FO	20	watercourse	48	41	37	40	36	36	YES	YES
98-FO	30	watercourse	36	30	28	30	30	30	YES	YES
98-FO	8	watercourse	18	4	5	5	18	18	YES	YES
98-FO	14	watercourse	24	14	14	16	24	24	YES	YES
98-FO	21	watercourse	18	5	6	6	18	18	YES	YES
98-FO	24	watercourse	36	44	39	42	36	36	YES	YES
98-FO	25	watercourse	36	41	37	40	36	36	YES	YES
98-TG	3	watercourse	36	13	14	15	24	24	YES	YES
98-RT	5	watercourse	24	2	3	3	18	18	YES	YES
98-RT-024	3	watercourse	36	31	29	31	30	30	YES	YES
98-RT-028	5	watercourse	24	14	14	16	24	24	YES	YES
98-RT028	7	watercourse	48	115	90	97	48	48	YES	YES
98-RT028	8	watercourse	30	18	18	19	24	30	YES	YES
98-WC-011	4	watercourse	36	42	38	40	36	36	YES	YES
98-WC-011	5	watercourse	18	6	7	7	18	18	YES	YES
98-FS-002	1	watercourse	24	17	17	18	24	24	YES	YES

Road Number	Site #	Culvert Type	Culvert Diameter (in)	Area (ac)	50 year flood (cfs)	100 year flood (cfs)	50 yr Culvert Size (in)	100 yr Culvert Size (in)	50 yr pass	100 yr pass
98-WC-011	6	watercourse	36	29	27	29	30	30	YES	YES
98-WC-011	1	watercourse	18	1	1	2	18	18	YES	YES
98-WC-011	2	watercourse	36	33	30	33	30	30	YES	YES
98-WC-011	10	watercourse	36	52	45	49	36	36	YES	YES
98-WC-011	11	watercourse	36	41	37	40	36	36	YES	YES
98-HC	1	watercourse	18	2	3	3	18	18	YES	YES
98-HC	3	watercourse	48	30	28	30	30	30	YES	YES
98-HC	10	watercourse	36	18	18	19	24	30	YES	YES
98-HC	12	watercourse	36	19	19	20	30	30	YES	YES
98-HC	16	watercourse	18	5	6	6	18	18	YES	YES
98-HC	18	watercourse	60	47	41	45	36	36	YES	YES
98-HC	20	watercourse	36	50	44	47	36	36	YES	YES
98-HC	21	watercourse	36	52	45	49	36	36	YES	YES
98-WC	54	watercourse	60	112	88	95	48	48	YES	YES
98-WC	53	watercourse	60	216	156	168	60	60	YES	YES
98-WC	51	watercourse	60	59	50	54	36	42	YES	YES
98-WC	50	watercourse	60	64	54	58	42	42	YES	YES
98-WC	46	watercourse	60	251	178	192	60	60	YES	YES
98-WC	45	watercourse	18	4	5	5	18	18	YES	YES
98-WC	43	watercourse	24	11	12	13	24	24	YES	YES
98-WC	38	watercourse	48	25	24	26	30	30	YES	YES
98-WC	37	watercourse	48	14	14	16	24	24	YES	YES
98-WC	35	watercourse	48	41	37	40	36	36	YES	YES
98-WC	34	watercourse	24	4	5	5	18	18	YES	YES
98-WC	32	watercourse	18	4	5	5	18	18	YES	YES
98-WC	30	watercourse	18	4	5	5	18	18	YES	YES
98-WC	29	watercourse	48	30	28	30	30	30	YES	YES
98-WC	28	watercourse	24	12	13	14	24	24	YES	YES
98-WC	25	watercourse	36	11	12	13	24	24	YES	YES
98-WC	23	watercourse	24	15	15	17	24	24	YES	YES
98-WC	21	watercourse	18	1	1	2	18	18	YES	YES
98-WC	20	watercourse	48	29	27	29	30	30	YES	YES
98-WC	19	watercourse	18	2	3	3	18	18	YES	YES
98-WC	18	watercourse	36	32	30	32	30	30	YES	YES
98-WC	16	watercourse	36	4	5	5	18	18	YES	YES
98-WC	15	watercourse	48	22	21	23	30	30	YES	YES
98-WC	11	watercourse	18	4	5	5	18	18	YES	YES
98-WC	10	watercourse	36	15	15	17	24	24	YES	YES
98-WC	8	watercourse	18	2	3	3	18	18	YES	YES
98-WC	7	watercourse	36	12	13	14	24	24	YES	YES
98-WC	6	watercourse	24	9	10	11	24	24	YES	YES
98-FS-28-02	2	watercourse	24	14	14	16	24	24	YES	YES
98-FS-12	6	watercourse	18	3	4	4	18	18	YES	YES
98-WC-033	6	watercourse	240	8	9	10	24	24	YES	YES
98-WC-033	5	watercourse	18	3	4	4	18	18	YES	YES
98-WC-021-02	1	watercourse	18	2	3	3	18	18	YES	YES
98-WC-021-02	2	watercourse	18	1	1	2	18	18	YES	YES
98-WC-021-02	7	watercourse	18	3	4	4	18	18	YES	YES
98-WC-021-02	9	watercourse	36	14	14	16	24	24	YES	YES
98-WC-021	2	watercourse	36	31	29	31	30	30	YES	YES
98-WC-021	3	watercourse	30	4	5	5	18	18	YES	YES
98-WC-021	2	watercourse	18	3	4	4	18	18	YES	YES

Section C

Hydrology

Introduction

This section provides the available river peak flow data for the Russian River and Salmon Creek with analysis of the bed mobility in response reaches of the Willow/Freezeout WAU. The peak flow data is used to show the magnitude of storm events and when they occurred. High river peak flow events are indicative of the largest storms, with large storms typically comes high erosion and sediment transport events. The Russian River peak flow data was the only long-term river flow data available in close proximity to Willow/Freezeout Creeks. The Russian River peak flow data probably does not provide a direct relationship with the peak flows of Willow or Freezeout Creeks. However, for the purpose of showing the timing and magnitude of large storm events of the area, the Russian River and Salmon Creek peak flow data provides insight.

The Willow/Freezeout Creeks WAU does not receive any significant snow accumulations which could contribute to rain-on-snow events. Current research shows possible cumulative effects from increased peak flows from forest harvest in rain-on-snow dominated areas (Harr, 198l). However, in rain dominated areas increases in large stream peak flows (>20 year return interval) from forest harvesting are not found (Ziemer, 1981; Wright et. al., 1990). The Willow/Freezeout Creeks WAU is in a rain dominated area in the temperate coastal zone of Northern California therefore analysis on peak flow hydrologic change was not considered necessary.

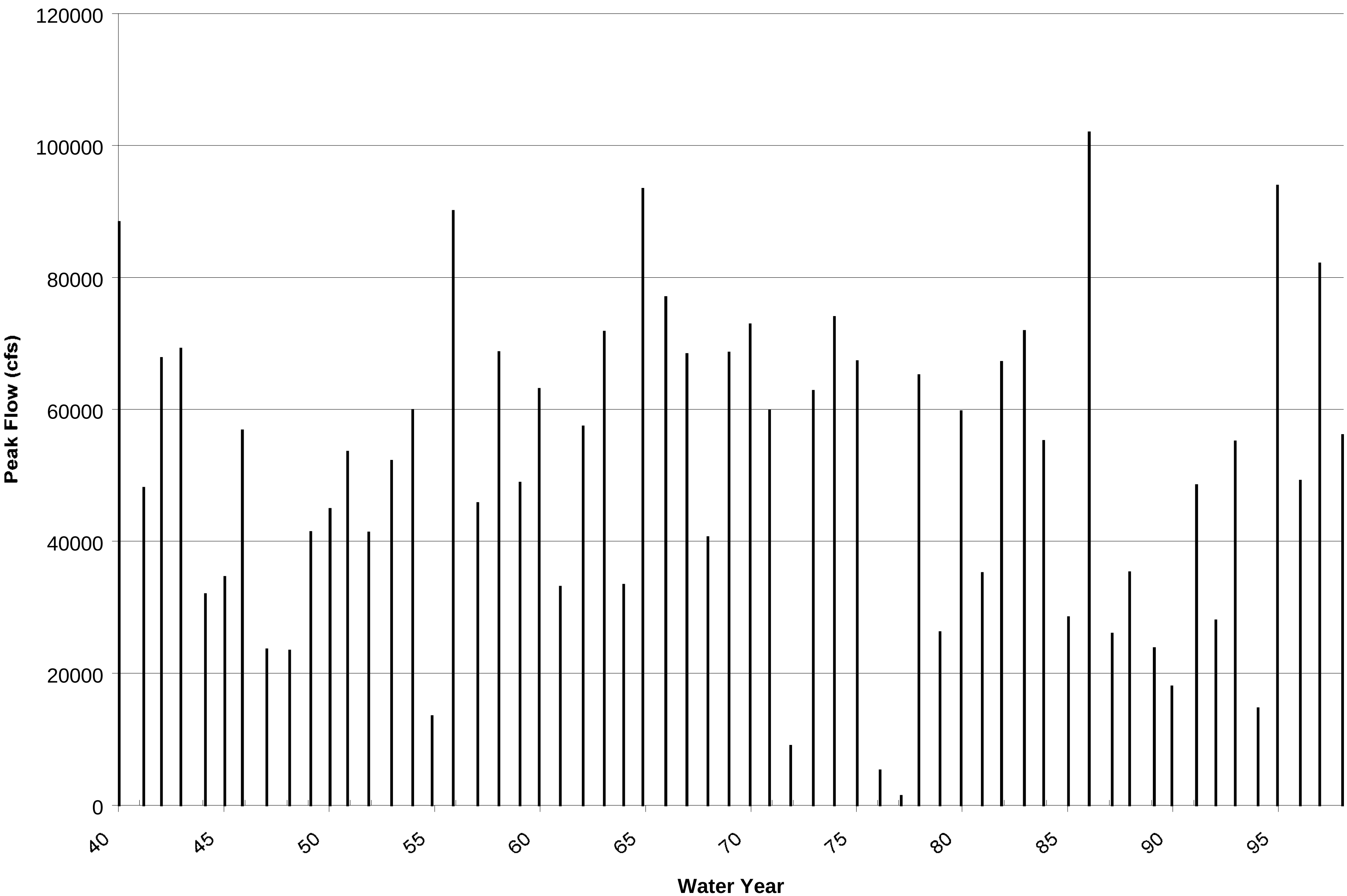
Peak Flows

The peak flow information was taken from the United States Geological Survey (USGS) gage 11467000, Russian River near Guerneville, from water years 1940-1998. Salmon Creek, a creek that drains to the Pacific Ocean close to Willow Creek, peak flow data was taken from the Trihey and Associates report on Willow Creek (1995). All annual peak flows are shown over the period of record for the Russian River near Guerneville (Figure C-1). To estimate the recurrence interval of the flood events of the Russian River near Guerneville the USGS annual peak flow series was used. An extreme value type I distribution (Gumbel, 1958) was fitted to the data. Table C-1 shows the estimated recurrence interval for peak discharges in the basin.

Table C-1. Flood Recurrence for Peak Flows of the Russian River near Guerneville, 1940-1998.

Recurrence Interval (years)	Peak Discharge (cfs)
1.1	24175
2	47052
10	81777
25	99255
50	112220
100	125091

Figure C-1. Annual Peak Flows for Russian River near Guerneville, CA, 1940-1998.



Using the peak flow record from 1940-1998, the flood of record is 1986 (102,000 cfs) calculated to be a 30 year event for the Russian River (Table C-1). The second highest peak flow of record occurred in 1995 (93900 cfs) and the third highest peak flow was in 1964 (93400). Although is unlikely that these peak flows directly correlate with storm patterns for Willow and Freezeout Creeks. It is very probable that the magnitude of these storms influenced Willow and Freezeout Creeks. Thus some of the largest storms to influence Willow and Freezeout Creeks likely occurred in 1986 and 1995. The Salmon Creek peak flow data record does not have either the 1986 or 1995 peak flows in its record (Appendix C). However, the time period it does cover shows 1982 as the highest flood of record. The 1982 flood for the Russian River was not that impressive in a relative sense, it registers as about a 7-8 year return interval. Yet, locally on the coast the 1982 storm was very large as shown by the Salmon Creek data.

Throughout the last 40-50 years, in the Russian River watershed, there have been numerous large flood events (Figure C-1). These flood events have the capacity to re-shape river or stream channels and transport large sediment loads. The meteorological events that created these large floods also can be assumed to be a major contributor to the erosion and mass wasting delivered to the watercourses in the Willow/Freezeout Creeks WAU.

Hydrologic Change due to Forest Management

Hydrologic change of the size of peak flows, the discharge at low flows, or annual water yield can be affected by forest harvesting. Forest harvesting influences these parameters by: changes in evapotranspiration from removal of vegetation, increased surface run-off from compacted soil surfaces of skid trails and roads, changes in snow accumulation from openings created by vegetation removal, and loss of interception from vegetation removal. The extent or magnitude of the hydrologic change is influenced by the parameter changed, and the physical and geographical characteristics of the watershed where the changes occur.

Change in size of peak flows, the highest instantaneous discharge of a hydrologic event, from forest harvest has long been a source of misunderstanding and public concern. The misunderstanding comes from the belief that vegetation removal increases the amount of water available for stream flow thus the peak flow must be increased as well. The first premise of this statement is correct. Annual water yield has been found to increase following forest harvest (Harr et. al., 1979; Keppeler and Ziemer, 1990; Rothacher, 1970). However, the annual water yield increase does not equate to an increase in the peak flow.

Current research shows possible cumulative effects from increased peak flows from forest harvest in rain-on-snow dominated areas (e.g. Harr, 198l). However, in rain dominated areas increases in large stream peak flows (>20 year return) from forest harvesting are not found (Ziemer, 1981; Wright et. al., 1990; Ziemer, 1998). Typically the largest peak flows, in rain dominated watersheds of coastal California, occur during the winter months when soil moisture is at its highest. Evapotranspiration levels during the winter are at the lowest and the intervals between storms are short. Therefore during the winter the water available for stream flow is not strongly affected by vegetation differences and the largest peak flows are not increased. Research conducted in watersheds which have had forest harvesting typically show increased peak flows in the fall, when soil water storage is depleted, but do not discern peak flow increases in the largest winter floods (Ziemer, 1981; Wright et. al., 1990; Rice et. al., 1979; Rothacher, 1973). This is significant when considering that the peak flows of interest for road design, channel formation, and sediment transport are the events with a 50-year recurrence interval, the largest flow events.

Water yield is typically increased following forest harvest. This increase is typically short lived, effects diminish after 5 years (Keppeler and Ziemer, 1990), due to re-growth of vegetation following harvest. Unfortunately the increased water yield is not of great utility to water managers or fishery concerns. This is because the timing of the augmented yield is not when the demand for greater water yield is needed, in the summertime. Secondly, that portion of the flow increase which did increase during the summer diminished rapidly following forest harvest, due to new vegetation demands (Keppeler and Ziemer, 1990).

Low flow is similar to water yield in that summer low flows tend to increase following forest harvest but diminish within 5 years (Keppeler and Ziemer, 1990), due to re-growth of vegetation following harvest. A slight decrease in low flows is observed after 5 years due to the new water demands of the regenerated forest following forest harvest (Keppeler and Ziemer, 1990). The impact of changes of low flows to summertime stream ecology are not known. However, it might be assumed that increased low flow in the summer provides more water for summer fish and macroinvertebrate use and stream temperature reductions. While a decrease in summer low flows would lower the amount of fish and macroinvertebrate habitat and facilitate higher stream temperatures. However, in both scenarios the summer low flow would need to be increased or decreased substantially, something which does not appear to occur.

The Mendocino Redwood Company (MRC) ownership in northern California does not receive any significant snow accumulations which could contribute to rain-on-snow events. The hydrology of the watersheds in the MRC ownership will always be a consideration to the company especially during watershed analysis. However, due to the lack of rain-on-snow event occurence on the MRC ownership no standards for hydrologic change due to forest harvest are considered necessary.

Bed Mobility Analysis

Bed mobility analysis is used to determine whether the bed particles of the streambed (usually represented by D_{50}) are likely to be transported at a given flow. The predicted bed particle size is then compared to the measured particle size to assess whether or not the bed material is likely to be mobilized for the bankfull flow (Version 3.0, Washington Forest Practices Board). The ratio of predicted particle diameter to the actual particle diameter provides a measure of bed mobility potential. Bed mobility is high if the ratio is much greater than 1 and low if the ratio is less than 1.

Uncertainty associated with the use of bedload transport equations is relatively high, differing field conditions can produce a range of results. Even with the greatest care in calculating a predicted D_{50}, there is still considerable margin for error. Because of this a range of values is probably most appropriate for assigning sensitivity ratings. For this analysis high bed mobility potential was assigned to ratios greater than 2, moderate bed mobility potential was assigned to ratios greater than 1 and less than 2, and low bed mobility potential was assigned to ratios less than or equal to 1.

The median grain diameter at which the streambed is entrained can be calculated by:

$D_{50} = \rho_w g R S/(\rho_w - \rho_s) 0.047 g$

where ρ_w is the density of water, ρ_s is the density of the grain particle material (assumed to be 2.65 g cm^{-3}), g is the acceleration of gravity, 0.047 is a constant defining the critical shear stress (i.e. Shield's number)(Dietrich, pers. comm.), R is the hydraulic radius, and S is channel slope. The hydraulic radius was approximated by bankfull depth, which was observed during the stream channel assessment. The D_{50} value calculated from this equation is compared to the actual observed D_{50} of the different locations for determination of bed mobility potential. The results of the bed mobility potential calculations are presented in Table C-2.

Table C-2. Bankfull Discharge Bed Mobility Potential for Channel Segments of the Willow/Freezeout Creeks WAU.

Stream Name	Segment ID#	Observed D50 (mm)	Predicted D50 (mm)	Predicted/ Observed Ratio	Bed Mobility Potential
Willow Creek	SW1	52	36	0.7	Low
Willow Creek	SW2	34	43	1.3	Moderate
Willow Creek	SW2(2)	36	141	3.9	High
Willow Creek	SW3	35	51	1.5	Moderate
North Fork Willow Creek	SW20	31	69	2.2	High
Willow Creek	SW23	51	154	3.0	High
Freezeout Creek	SF1 and 2	106	415	3.9	High
Freezeout Creek	SF10	79	190	2.4	High

* - see Section E -Stream Channel Condition module for channel segment locations.

Bed mobility tends to be directly proportional to scour, and thus provides an index of scour potential of the bed (Version 3.0, Washington Forest Practices Board). Bed mobility also tends to be directly proportional to sediment supply, and may reflect large supplies of sediments supplied either naturally or from accelerated erosion in the watershed. Low bed mobility may indicate that the channel bed is inherently stable and not subject to scour; on the other hand, it can also mean large floods have scoured the channel of finer materials.

Several stream segments show high bed mobility. Segment SW2(2) has a low width to depth ratio therefore the bankfull discharge is deeper and more apt to produce a higher predicted D50. However, there is a high amount of stored gravel deposits in the channel and banks of this area and it likely that the high bed mobility is a function of the high sediment supply available to the channel. The two segments along Freezeout Creek both have high predicted D50s yet low observed D50 making it rank as a high bed mobility potential. These segments have very high gradients that typically show a tendency toward a larger D50. However, the confounding factor is when a high amount of friction or drag is introduced in the channel, thus slowing water velocities and the ability to transport smaller sediment sizes. This is the case in the case of the Freezeout segments. Both channels are stable with large wood debris dams storing sediment, and creating drag on the flow regime thus lowering the segments D50. In the case of the Freezeout Creek segments a high bed mobility is expected given the high gradient and frequent wood accumulations in the channel. Segment SW20, North Fork of Willow Creek also is predicted to have high bed mobility likely due to high sediment supply being routed through the segment.

Stream channel segments that show low or moderate bed mobility potential are assumed to have beds that are well armored and not influenced by small changes in peak discharges or sediment supply. The remaining response reaches analyzed for bed mobility with low and moderate bed mobility potential are better interpreted in the Stream Channel Condition module of this report. The low potential sites could still have problems with scour potential or changes in sediment supply and transport. Also low bed mobility might occasionally occur in a channel recovering from previous high sediment impacts. The interactions between sediment supply, present and past channel conditions, and bed mobility all must be considered.

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Hydrology Module
Appendix

US GEOLOGICAL SURVEY
PEAK FLOW DATA
#
Station name : Russian R Nr Guerneville Ca
Station number: 11467000
latitude (ddmmss)............................ 383031
longitude (dddmmss).......................... 1225536
state code................................... 06
county....................................... Sonoma
hydrologic unit code......................... 18010110
basin name................................... Russian
drainage area (square miles)................. 1338
contributing drainage area (square miles).....
gage datum (feet above NGVD)................. 20.14
base discharge (cubic ft/sec)................ 23000
Gage heights are given in feet above gage datum elevation.
Discharge is listed in the table in cubic feet per second.
#
Peak flow data were retrieved from the
National Water Data Storage and Retrieval System (WATSTORE).
#
Format of table is as follows.
Lines starting with the # character are comment lines describing the data
included in this file. The next line is a row of tab-delimited column
names. The next line is a row of tab-delimited data type codes that
describe the width and type of data in each column. All following lines
are rows of tab-delimited data values.
#
----Water Years Retrieved----
1940 - 1998

Type	Station	Date	Water Year	Date	Discharge
1s	15s	10d		10d	6n
3	11467000	40	1940	40	88400
3	11467000	41	1941	41	48100
3	11467000	42	1942	42	67800
3	11467000	43	1943	43	69200
3	11467000	44	1944	44	32000
3	11467000	45	1945	45	34600
3	11467000	45	1946	45	56800
3	11467000	47	1947	47	23600
3	11467000	48	1948	48	23400
3	11467000	49	1949	49	41400
3	11467000	50	1950	50	44900
3	11467000	50	1951	50	53600
3	11467000	51	1952	51	41300
3	11467000	53	1953	53	52200
3	11467000	54	1954	54	59900
3	11467000	54	1955	54	13500
3	11467000	55	1956	55	90100
3	11467000	57	1957	57	45800

3	11467000	58	1958	58	68700
3	11467000	59	1959	59	48900
3	11467000	60	1960	60	63100
3	11467000	61	1961	61	33100
3	11467000	62	1962	62	57400
3	11467000	63	1963	63	71800
3	11467000	64	1964	64	33400
3	11467000	64	1965	64	93400
3	11467000	66	1966	66	77000
3	11467000	67	1967	67	68400
3	11467000	68	1968	68	40600
3	11467000	69	1969	69	68600
3	11467000	70	1970	70	72900
3	11467000	70	1971	70	59800
3	11467000	71	1972	71	8990
3	11467000	73	1973	73	62800
3	11467000	74	1974	74	74000
3	11467000	75	1975	75	67300
3	11467000	76	1976	76	5260
3	11467000	77	1977	77	1370
3	11467000	78	1978	78	65200
3	11467000	79	1979	79	26200
3	11467000	80	1980	80	59700
3	11467000	81	1981	81	35200
3	11467000	81	1982	81	67200
3	11467000	83	1983	83	71900
3	11467000	83	1984	83	55200
3	11467000	85	1985	85	28500
3	11467000	86	1986	86	102000
3	11467000	87	1987	87	26000
3	11467000	88	1988	88	35300
3	11467000	89	1989	89	23800
3	11467000	90	1990	90	18000
3	11467000	91	1991	91	48500
3	11467000	92	1992	92	28000
3	11467000	93	1993	93	55100
3	11467000	94	1994	94	14700
3	11467000	95	1995	95	93900
3	11467000	96	1996	96	49200
3	11467000	97	1997	97	82100
3	11467000	98	1998	98	56100

SALMON CREEK (15.7 mi^2): Recurrence interval for annual maximum flood

Water Year	Q (cfs)	Rank (M)	Recurrence Interval T= N + l/M	Notes
1963	1430	11	1.45	Bankfull discharge**
1964	1220	12	1.33	
1965	1540	10	1.60	
1966	1960	4	4.00	
1967	1760	7	2.29	
1968	1370	13	1.23	
1969	1650	9	1.78	
1970	1790	6	2.67	
1971	1380	12	1.33	
1972	537	15	1.07	
1973	2260	3	5.33	
1974	1760	7	2.29	
1975	1950	5	3.20	
1982	7400	1	16.00	actual recurrence interval is probably longer*
1983	6020	2	8.00	actual recurrence interval is probably longer*

Footnotes: *short period of record and recurrence interval definition probably lead to underestimation of return periods for these floods.

**The 1.5 year flood under the annual maximum series usually corresponds to "bankfull discharge"

Section D

Riparian Function

Introduction

Mendocino Redwood Company conducted an assessment of riparian function in the Willow/Freezeout Creeks Watershed Analysis Unit (WAU) during the summer of 2000. This assessment is divided into two groups: 1) the potential of the riparian stand to recruit large woody debris (LWD) to the stream channel and 2) a canopy closure and stream temperature assessment. The LWD potential assessment evaluates short-term (the next 2-3 decades) LWD recruitment. It shows the current condition of the riparian stands for generating LWD for stream habitat or stream channel stability. Field observations of current LWD levels in the stream channels and the riparian stand's ability to recruit LWD are presented in relation to channel sensitivity to LWD in order to determine current instream needs. The canopy closure and stream temperature assessment presents current canopy closure conditions and how these are related to the stream temperature monitoring that has been conducted. The goal of these evaluations is to provide baseline information on the current LWD loading in the channel and current status of riparian stand function in the Willow/Freezeout CreeksWAU.

Large Woody Debris Recruitment

Large woody debris (LWD) is widely recognized as an important part of the aquatic ecosystem (Swanson and Lienkaemper, 1978; Bilby and Likens, 1979; Bisson et. al., 1978) and has been recognized as a vital component of high quality habitat for anadromous fish (Bisson et. al., 1978). LWD provides an organic energy source for aquatic organisms, controls the routing of sediment through stream systems, and provides structure to the streambed and banks (Swanson and Lienkaemper, 1978; Bilby and Likens, 1979). Forest harvesting activities have affected large woody debris recruitment by removal of vegetation which could have been delivered to watercourses and salvage of downed LWD from the watercourse or adjacent banks. In 1970, excessive amounts of slash attributed to land use practices had created many log jams in the upper portion of the drainage. Black Mountain Conservation Camp was contracted to work on removal of these jams (CDFG 1995). As a result, riparian stands on industrial timberlands may not be adequate to provide future LWD to stream channels which are already LWD deficient. Identifying where problems exist and then tailoring management activities to these needs will have long-term benefits to aquatic habitat.

Large Woody Debris Recruitment Potential and In-stream Demand Methods

Short-term LWD recruitment potential (next 20-30 years) was evaluated in designated stream segments within the Willow/Freezeout CreeksWAU. Stream segments were designated in the stream channel condition assessment and are shown on map E-1(Stream Channel Condition module). Generally, stream segments were designated on any watercourse with less than a 20 percent gradient. In this assessment, vegetation type, size and density is assumed to influence LWD recruitment with the best riparian vegetation being large conifer trees.

To determine the LWD recruitment potential, riparian stands were classified using year 2000 aerial photographs and field observations from the summer of 2000. The riparian stands were evaluated for a distance of approximately one tree height on either side of the watercourse. Riparian stands were evaluated seperately for each side of the watercourse. The following vegetation classification scheme for the Mendocino Redwood Company (MRC) timber inventory was used to classify the riparian stands:

Vegetation Classes

RW- greater than 75% of the stand basal area in coast redwood.
RD- combination of Douglas-fir and coast redwood basal area exceeds 75% of the stand, but neither species alone has 75% of the basal area.
MH- mix of hardwood basal area exceeds 75% of the stand, but no one hardwood species has 75% of the basal area.
CH- mix of conifer and hardwood basal area exceeds 75% of the stand, but no one hardwood or conifer species has 75% of the basal area.
Br- Brush

Vegetation Size Classes

1 - <8inches dbh
2 - 8 to 15.9 inches dbh
3 - 16 to 23.9 inches dbh
4 - 24 to 31.9 inches dbh
5 - >32 inches dbh

The size class is determined by looking at the diameters of the trees in the riparian stand. The size class which exceeds 50% of the total basal area is the size class assigned to the stand.

Vegetation Density

O - 5-20% tree canopy cover range
L - 20-40% tree canopy cover range
M - 40-60% tree canopy cover range
D - 60-80% tree canopy cover range
E - >80% tree canopy cover

The codes for vegetation classification of riparian stand condition are based on the three classes listed above. The vegetation code is a string of the classes with the vegetation class first, the size class second, and the vegetation density last. For example, the vegetation code for a redwood stand with greater than 50% of the basal area with 16-23.9 inch dbh or larger and 60-80% canopy cover would be classified RW3D.

In this assessment, vegetation type, size and density is assumed to affect LWD recruitment to the stream channel with the best riparian vegetation being large conifer trees. The LWD recruitment potential ratings reflect this. The following table presents the vegetation classification codes for the different LWD recruitment potential ratings (Table D-1)

Table D-1. Description of LWD Recruitment Potential Rating by Riparian Stand Classification for the Willow/Freezeout CreeksWAU.

Vegetation Type	Size and Density Classes					
	Size Classes 1-2 (Young)		Size Class 3 (Mature)		Size classes 4-5 (Old)	
	Sparse (O,L)	Dense (M, D, E)	Sparse (O,L)	Dense (M, D, E)	Sparse (O,L)	Dense (M, D, E)
RW	Low	Low	Low	Moderate	Moderate	High
RD	Low	Low	Low	Moderate	Moderate	High
CH	Low	Low	Low	Moderate	Low	High
MH	Low	Low	Low	Low	Low	Moderate

LWD was inventoried in watercourses during the stream channel assessment. All "functional" LWD was tallied within the active channel and the bankfull channel for each sampled stream segment. Functional LWD was that which was providing some habitat or morphologic function in the stream channel (i.e. pool formation, scour, debris dam, bank stabilization, or gravel storage). There was no minimum size requirement for functional LWD. The LWD was classified by tree species class, either redwood, fir (Douglas-fir, hemlock, grand fir), hardwood (alder, tan oak, etc.), or unknown (if tree species is indeterminable). Length and diameter were recorded for each piece so that volume could be calculated.

LWD associated with an accumulation of 3 pieces or more was recorded and the number of LWD accumulations in the stream survey reach was tallied. LWD pieces are also assigned attributes if they fell into certain categories. These categories are: if the LWD piece was part of a living tree, root associated (i.e. does it have a rootwad attached to it), was part of the piece buried within stream gravel or the bank, or associated with a restoration structure. By assigning these attributes, the number of pieces in a segment which, for example, have a rootwad associated with the LWD can be noted. This is important as these types of pieces can be more stable or have ecological benefits above that which a LWD piece alone may have.

Pieces that were partially buried were noted, as calculated volume for these pieces represent a minimum. There may likely be a significant amount of volume that is buried that we cannot measure. Also, these pieces are more stable in the channel during high flows. The percentage of total pieces which are partially buried was calculated for each stream segment. Some consideration was given as to what percentage (0-25%, 25-50%, 50-75% and 75-100%) of the LWD pieces in the stream were recently contributed (<10 years). The LWD is further classified as a key LWD piece if it meets the following size requirement:

Table D-2. Key LWD Piece Size Requirements (adapted from Bilby and Ward, 1989)

Bankfull width (ft)	Diameter (in)	Length (ft)
0-20	12	20
20-30	18	30
30-40	22	40
40-60	24	60

Debris jams (>10 pieces) were noted and total dimensions of the jam recorded. This volume was calculated and added to total LWD volume with a correction factor of 50%. In other words, 50% of the total volume of a debris jam was considered to be “air space.” Total number of pieces and number of key pieces were noted. Species and dimensions were not recorded for individual pieces contained in debris jams. All volume estimates and piece counts were seperated in two groups, one not considering jams and one considering all LWD pieces in the segment, debris jams included. The percentage of total volume and total pieces per segment which was contained in debris jams was also calculated.

The quantity of LWD observed was normalized by distance, for comparison through time or to other similar areas, and was presented as a number of LWD pieces per 100 meters. This normalized quantity, by distance, was performed for functional and key LWD pieces within the active and bankfull channel. The key piece quantity in the bankfull channel (per 100 meters of channel) is compared to the target for what would be an appropriate key piece loading. The target for appropriate key piece loading was derived from Bilby and Ward (1989) and Gregory and Davis (1992) and presented in Table D-3.

Table D-3. Target for Number of Key Large Woody Debris Pieces in Watercourses of the Willow/Freezeout CreeksWAU.

	# Key Pieces		
Bankfull Width (ft)	**Per 100 meters**	**Per 1000 feet**	**Per mile**
<15	6.6	20	106
15-35	4.9	15	79
35-45	3.9	12	63
>45	3.3	10	53

An in-stream LWD demand is identified in addition to the riparian stand recruitment potential, discussed previously. The in-stream LWD demand is an indication of what level of concern there is for in-stream LWD for stream channel morphology and fish habitat associations within the Willow/Freezeout CreeksWAU. The in-stream LWD demand is determined by stream segment considering the overall LWD recruitment, the stream segment LWD sensitivity rating (as determined in the Stream Channel and Fish Habitat Assessment for stream geomorphic units), and the level of LWD currently in the stream segment (on target or off target). Table D-4 shows how these three factors are used to determine the in-stream LWD demand.

Table D-4. In-stream LWD Demand

		Channel LWD Sensitivity Rating		
	LWD On Target / **LWD Off Target**	**LOW**	**MODERATE**	**HIGH**
Recruitment Potential Rating	**LOW**	LOW	MODERATE	HIGH
		HIGH	HIGH	HIGH
	MODERATE	LOW	MODERATE	MODERATE
		HIGH	HIGH	HIGH
	HIGH	LOW	MODERATE	MODERATE
		MODERATE	HIGH	HIGH

Low In-stream LWD Demand - this classification suggests that current riparian LWD recruitment conditions and in-stream LWD are at levels which are sufficient for LWD function in these stream channel types.

Moderate In-stream LWD Demand - this classification suggests that current riparian LWD recruitment conditions and in-stream LWD are at levels which are moderately sufficient for fish habitat and stream channel morphology requirements. Consideration must be given to these areas to improve the LWD recruitment potential of the riparian stand. These areas may also be considered for supplemental LWD or stream structures placed in the stream channel.

High In-stream LWD Demand - this classification suggests that current riparian LWD recruitment conditions and in-stream LWD are at levels which are not sufficient for LWD function in these stream channel types. These areas must consider improvement of the LWD recruitment potential of the riparian stand. These areas should be the highest priority for supplemental LWD or stream structures placed in the stream channel.

Large Woody Debris Recruitment Potential and In-stream Demand Results

The large woody debris recruitment potential and in-stream LWD demand for the Willow/Freezeout CreeksWAU is illustrated in Map D-1. The large woody debris recruitment potential and in-stream LWD demand provides baseline information on the structure and composition of the riparian stand and the level of concern about current LWD conditions in the stream. This map provides a tool for prioritizing riparian and stream management for improving LWD recruitment and in-stream LWD. These areas must be monitored over time to ensure that the recruitment potential is improving and that large woody debris is providing the proper function to the watercourses.

Current LWD loading is shown in Tables D-5a and b . Only one of the channels in Willow Creek, SW2(2), met the LWD target. LWD was determined to be sparse in all segments in Willow Creek except for segments SW2(2) and SW23. One segment in Freezeout Creek (SF1/2) did meet the target.

Debris jams, where they occurred, were shown to be a significant portion of the total number of piece and total volume. In the Willow/Freezeout Creek WAU, debris jams occurred in three segments and contained up to 48.3% of the total pieces and 30% of the total volume (see Table D-5a and b). In the case of segment SW2(2), debris jams actually affected whether or not the segment met the LWD target. It was only with adding in the key pieces that were contained in debris jams that the segment exceeded the LWD target. Although there obviously can be a significant amount of LWD trapped in debris jams, the ecological function may not be accurately represented by numbers alone. All of the pieces in a debris jam may actually have more habitat value if they were spread out in the stream as opposed to being piled up in one spot.

A significant amount of the LWD volume in the Willow/Freezeout CreeksWAU was also contained in debris accumulations (>3 pieces). Up to 61 % of the volume of a segment could be found in these accumulations. Buried LWD pieces were common in these streams. Up to 50% of the pieces in any given segment were at least partially buried. This indicates that we are unable to quantify a significant portion of the LWD volume which may eventually be useful to the stream

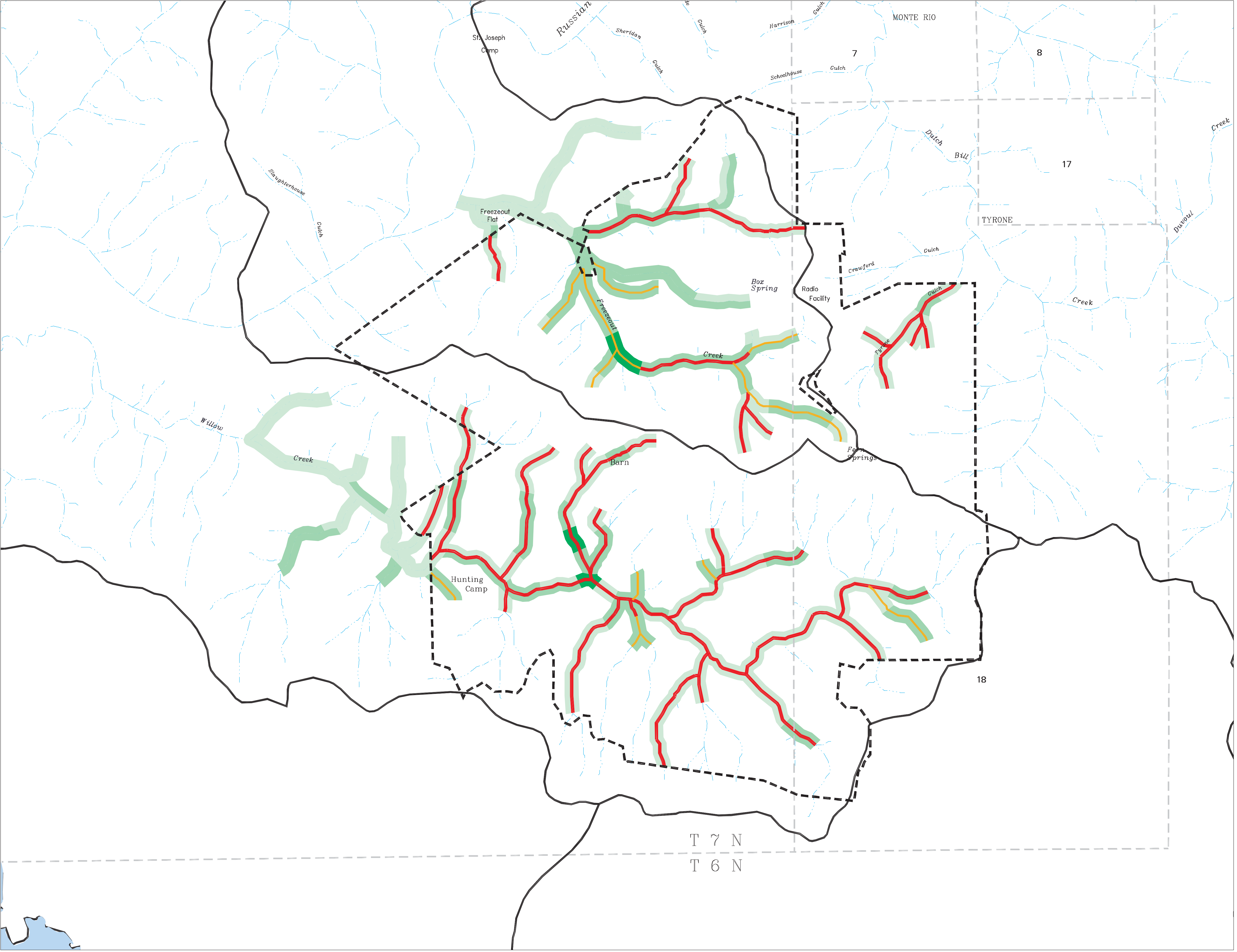
LWD species composition was largely redwood dominated (Table D-5b). This analysis was limited to pieces not contained within debris jams. Almost 90% of all LWD pieces in the Willow/Freezeout Creeks WAU were redwood. The remainder of pieces consisted of an even mixture of fir, alder, hardwood, and unknown species. This may not be surprising as these streams flow through a redwood forest but it does show that the LWD currently found in Willow and Freezeout Creeks is more stable as redwood breaks down more slowly in streams than hardwood species.

All segments in the Willow/Freezeout Creeks WAU contained LWD that was not recently contributed to the stream. All inventoried segments fell into a 0-25% category for pieces recently contributed (<10 yrs). It did not appear that many of the LWD pieces had been contributed within the last 10 years. This may be a result of past riparian harvest and more LWD must be contributed to the stream channel in future years.

As shown in tables D-5a and b, there is a need for large woody debris in most of the channel segments of the Willow/Freezeout Creeks WAU. Channel segments with LWD levels that are well below the target will need to be the priority for monitoring future recruitment and restoration work. Even the segment that met the target need LWD levels to be maintained to ensure LWD is providing fish habitat and morphological function in the stream channels.

Riparian recruitment potential in the Willow/Freezeout Creeks WAU is moderate to low (See Map D-1). Past harvesting activities in riparian areas have resulted in many streamside small hardwood or mixed conifer/hardwood stands. These streamside stands need to be managed to be become large conifer stands to provide a natural source of LWD over time.

Currently, all of the stream segments in the Willow/Freezeout CreeksWAU are in the high and moderate in-stream LWD demand classification (Map D-1). The high in-stream LWD demand in the WAU are primarily due to low levels of LWD in the stream channels compounded by many riparian stands with moderate to low LWD recruitment potential.



Willow Creek / Freezeout Creek Watershed Analysis Unit

Map D-1 Large Woody Debris Recruitment Potential and Demand

LWD Recruitment Potential Classes

- High
- Moderate
- Low

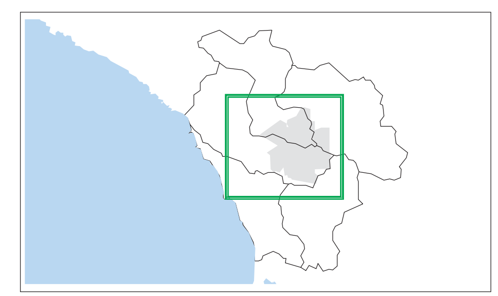
Instream LWD Demand

- High
- Moderate
- Low

Flow Class

- Class I
- Class II
- Class III

- MRC Ownership
- Planning Watershed Boundary



0 1/2 1 Mile

February 15, 2001

Table D-5a.-Large Woody Debris Piece Count in Selected Stream Segments of the Willow/Freezeout Creeks WAU.

Stream Segment Name	Stream Segment ID#	Functional LWD Pieces w/o Debris Jams	Functional LWD Pieces w/ Debris Jams	Total # of Debris Jams	Total # of Debris Accumulations	Functional LWD (#/100m) w/o Debris Jams	Functional LWD (#/100m) w/ Debris Jams	Key LWD Pieces w/o Debris Jams	Key LWD Pieces w/ Debris Jams	Key LWD Pieces/100m w/o Debris Jams	Key LWD Pieces/100m w/Debris Jams	% of Total Pieces in Debris Jams
Willow Creek	SW1	48	48	0	2	21.6	21.6	3	3	1.3	1.3	0.0%
Willow Creek	SW2	42	65	1	6	22.0	34.1	2	5	1.0	2.6	35.0%
Willow Creek	SW2(2)	92	178	3	9	50.9	98.5	7	13	3.9	7.2	48.3%
Willow Creek	SW3	43	43	0	3	23.7	23.7	5	5	2.8	2.8	0.0%
Willow Creek	SW20	31	57	1	4	24.4	44.8	3	4	2.4	3.1	45.6%
Willow Creek	SW23	62	62	0	4	48.3	48.3	0	0	0.0	0.0	0.0%
Freezeout Creek	SF1/2	49	49	0	2	39.5	39.5	7	7	5.6	5.6	0.0%
Freezeout Creek	SF10	79	79	0	6	51.9	51.9	4	4	2.6	2.6	0.0%

Table D-5b.-Large Woody Debris Volume Information in Select Stream Segments of the Willow/Freezeout Creeks WAU.

Stream Segment Name	Stream Segment ID#	Total Volume (yd^3) w/o Debris Jams	Total Volume (yd^3) w/ DebrisJams	Total Vol/100m (yd^3) w/o Debris Jams	Total Vol/100m (yd^3) w/ Debris Jams	% of Total Volume in Debris Accumulations	% of Total Volume in Debris Jams	% of Vol in Key Pieces w/o Jams	% of Total Volume By Species w/o Jams					% Current Recruitment (<10 yrs)
									Redwood	Fir	Alder	Hardwood	Unknown	
Willow Creek	SW1	50.2	50.2	22.6	22.6	25.9%	0.0%	33.0%	87.2%	0.0%	12.0%	0.8%	0.0%	0-25
Willow Creek	SW2	56.6	78.9	29.7	41.4	61.1%	30.0%	24.0%	80.7%	0.0%	9.4%	0.9%	9.0%	0-25
Willow Creek	SW2(2)	104.1	137.4	57.6	76.0	42.3%	24.0%	59.0%	88.4%	0.0%	9.6%	1.4%	0.6%	0-25
Willow Creek	SW3	42.1	42.1	23.2	23.2	40.5%	0.0%	45.0%	86.2%	0.0%	4.8%	3.6%	5.4%	0-25
Willow Creek	SW20	29.6	40.7	23.3	32.0	39.9%	27.0%	64.0%	98.7%	0.0%	0.6%	0.4%	0.3%	0-25
Willow Creek	SW23	35.3	35.3	27.5	27.5	17.8%	0.0%	0.0%	95.2%	0.0%	0.0%	1.4%	3.5%	0-25
Freezeout Creek	SF1/2	25.5	25.5	20.5	20.5	21.4%	0.0%	51.0%	93.7%	0.0%	0.0%	4.0%	2.3%	0-25
Freezeout Creek	SF10	39.4	39.4	25.9	25.9	14.6%	0.0%	30.0%	59.1%	19.4%	20.8%	0.5%	0.1%	0-25

Canopy Closure and Stream Temperature

Canopy cover is important in reducing the net gain of solar radiation. Stream water temperature responds to the input of solar radiation and is directly proportional to exposed stream surface area (Brown and Krygier, 1970) and inversely proportional to discharge (Sullivan et. al., 1990). Wide stream exposures receive greater solar radiation then streams with good canopy cover and narrow solar exposure. Several studies have shown that an intact streamside forest canopy will shade streams and minimize increases in summer water temperature. Brown and Krygier (1970) found diurnal variations in a well-shaded coastal Oregon stream to be less than 1^{o} C. However, complete removal of the forest canopy has been shown to increase summer maximum temperatures 3-8^{o} C (see review Beschta et. al., 1987). In a comparison of 20 years of temperature records from Steamboat Creek, Oregon, Hostetler (1991) found that streamside canopy cover was the most important variable linked to changes in stream temperature.

Many physical factors can influence stream temperature. These include: solar radiation, air temperature, relative humidity, water depth and ground water inflow. Forest management can most influence solar radiation input, riparian air temperature and relative humidity by alteration of streamside vegetation and cover. Water depth and ground water inflow are more difficult to correlate to forest management practices. Therefore, our analysis focused on present canopy cover conditions for consideration for future forest management actions.

The optimal temperature for Pacific salmonids has been hypothesized to range from between 12 and 14^{o} C (Brett, 1952), though there is considerable debate about what exactly is the optimal temperature and what it means. Temperatures lethal to salmonids have been determined in the laboratory and range from 23-29 ^{o}C (Beschta et. al., 1987). Though these temperatures are possible in some small, forested streams, they would generally only occur for short periods of time in the summer.

Methods

Canopy closure, over watercourses, was estimated from year 2000 aerial photographs. Five canopy closure classes were determined using the aerial photographs. These classes are shown in Table D-6. A map was produced for the Willow/Freezeout CreeksWAU based on the aerial photograph interpretations.

Table D-6. Estimated levels of Canopy Closure from Aerial Photographs.

Stream surface not visible	>90% shade
Stream surface visible or visible in patches	70-90% shade
Stream surface visible but banks are not visible	40-70% shade
Stream surface visible and banks visible at times	20-40% shade
Stream surface and banks visible	0-20% shade

During year 2000 field measurements of canopy closure over select stream channels were performed. The field measurements were taken during the stream channel assessments in the Willow/Freezeout Creeks WAU. The field measurements consisted of estimating canopy closure over a watercourse using a spherical densiometer. The densiometer estimates were taken at approximately 3-5 evenly spaced intervals along a channel sample segment, typically a length of 20-30 bankfull widths. The results of the densiometer readings were averaged across the channel to represent the percentage of canopy closure for the channel segment. The streamside canopy for the Willow/Freezeout Creeks WAU is mapped in Map D-2.

Stream temperature has been monitored in the Willow/Freezeout Creeks WAU, by Louisiana-Pacific Corp., 1994-97 and MRC in 1999 and 2000. Stream temperature monitoring involved use of electronic temperature recorders (Stowaway, Onset Instruments) which monitor the water temperature continuously at 2 hour intervals. Stream temperatures are monitored during the summer months when the water temperatures are highest. The stream temperature recorders were typically placed in shallow pools (<2 ft. in depth) directly downstream of riffles. Map D-2 shows the temperature monitoring locations and Table D-7 describes the temperature monitoring locations.

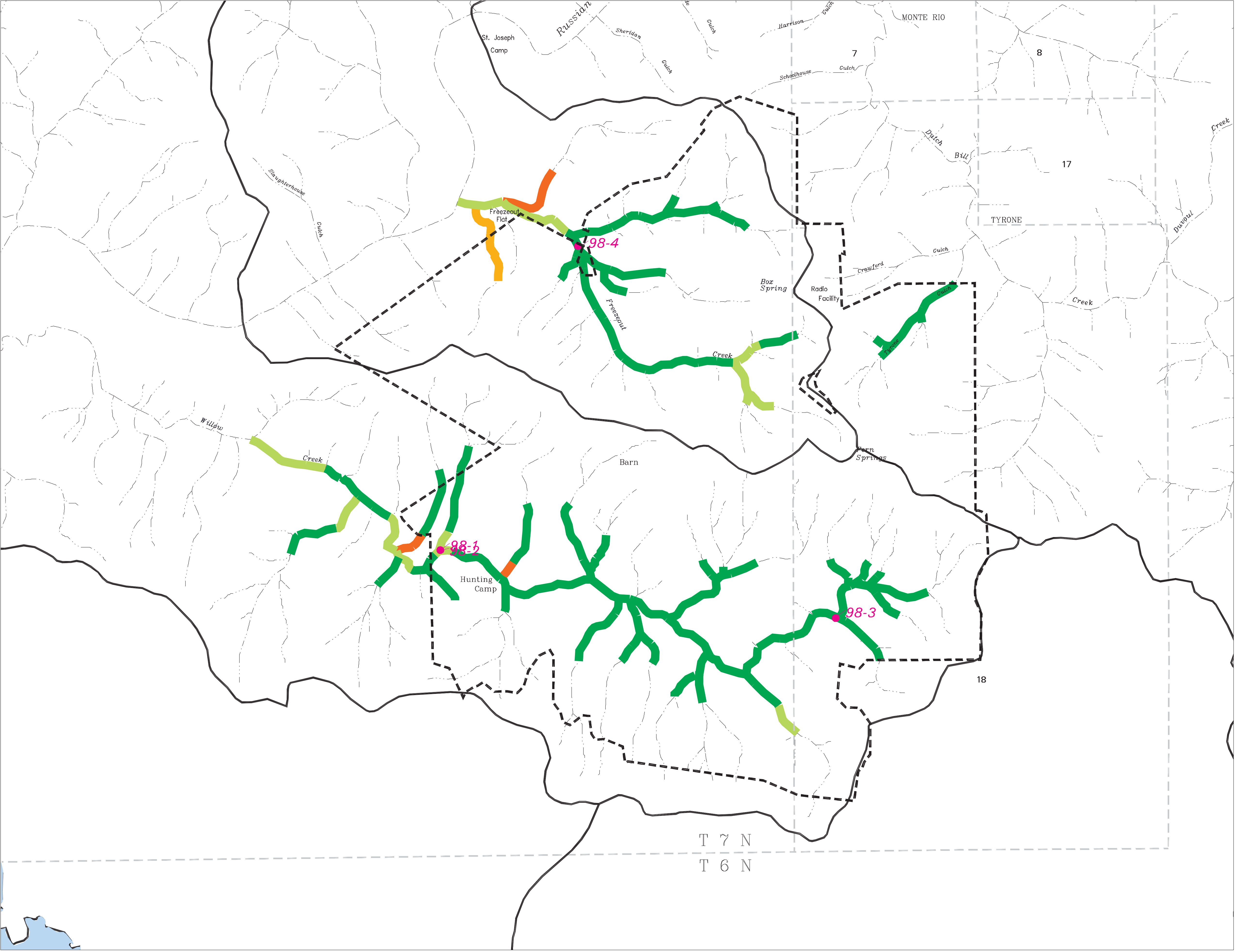
Table D-7. Stream Temperature Monitoring Locations and Time Periods in the Willow/Freezeout CreeksWAU (see map D-2)

Temperature Monitoring Station	**Stream Segment Number**	**Stream Name**	**Years Monitored**
98-1	SW1	Willow Creek	’94, ’95, ’96, ’99, ‘00
98-3	SW3	Willow Creek	’94, ’95, ’96, ’99, ‘00
98-4	SF10	Freezeout Creek	’96, ’97, ’99, ‘00

Maximum and mean daily temperatures were calculated for each temperature monitoring site and year and are presented in Appendix D. Maximum weekly average temperatures (MWATs) and maximum weekly maximum temperatures were calculated for the stream temperatures by taking a seven day average of the mean and maximum daily stream temperature.

Results

Canopy closure over watercourses is generally very good throughout the Willow/Freezeout CreeksWAU (Map D-2 and Table D-8). The canopy closure map shows almost all Class I and II stream with a high streamside canopy classification (>90% cover)(Map D-2). Only a few channels have a moderate streamside canopy classification (70-90% cover) with just a fraction of the channels having a low streamside canopy classification (20-40% or <20% cover).



Willow Creek / Freezeout Creek Watershed Analysis Unit

Map D-2 Stream Canopy Cover Classification and Temperature Monitoring Locations

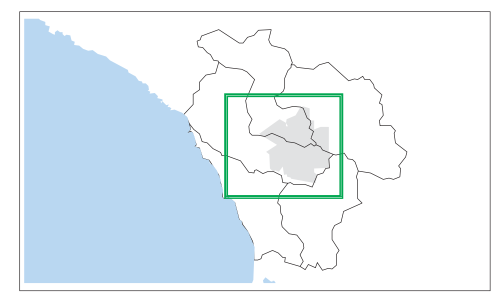
Canopy Cover

- > 90%
- 70-90%
- 40-70%
- 20-40%
- 0-20%
- Temperature Monitoring Locations

Flow Class

- Class I
- Class II
- Class III

- MRC Ownership
- Planning Watershed Boundary



0 1/2 1 Mile

February 21, 2001

Table D-8. 2000 Field Observations of Stream Canopy Closure for Select Stream Channel Segments in the Willow/Freezeout CreeksWAU.

Stream Name	Segment Number	Mean Shade Canopy
Willow Creek	SW1	94%
Willow Creek	SW2	94%
Willow Creek	SW2(2)	94%
Willow Creek	SW3	95%
Willow Creek	SW20	97%
Willow Creek	SW23	97%
Freezeout Creek	SF1/2	98%
Freezeout Creek	SF10	90%

Stream temperatures in the Willow/Freezeout CreeksWAU are at favorable levels for salmonids. Instantaneous maximum temperatures recorded in Lower Willow Creek, Upper Willow Creek and Freezeout Creek are higher than the preferred temperature ranges for coho salmon (12-14 C^{o}) and steelhead trout (10-13 C^{o})(Brett, 1952 and Bell, 1986). However, these are maximums and are infrequent or of short duration. More important are MWAT values for these streams. The three temperature sites in the Willow/Freezeout CreeksWAU show MWATs which are well below the maximums for coho salmon (17-18C^{o})(Brett, 1952 and Becker and Genoway, 1979). These MWAT values almost always fall within the preferred temperature range of coho as defined by Brett (1952). See Tables D-9, D-10 and D-11.

Table D-9. Maximum Daily Temperatures for each station in the WillowCreek/Freezeout WAU.

Station No.	1994	1995	1996	1997	1998	1999	2000
98-1	13.7	16.8	15.1	n/a	n/a	16.2	16.3
98-3	17.2	16.9	15.9	n/a	n/a	14.5	17.6
98-4	n/a	n/a	14.8	n/a	n/a	15.8	15.1

Table D-10. Maximum Weekly Average Temperature (MWAT) for each station in the Willow/Freezeout CreeksWAU.

Station No.	1994	1995	1996	1997	1998	1999	2000
98-1	13.0	15.3	13.9	n/a	n/a	13.6	14.5
98-3	13.9	15.1	13.9	n/a	n/a	13.9	14.6
98-4	n/a	n/a	13.4	15.1	n/a	14.1	13.6

Table D-11. 7-Day Moving Average of the Daily Maximum for each station in the Willow/Freezeout CreeksWAU.

Station No.	1994	1995	1996	1997	1998	1999	2000
98-1	13.2	16.2	14.6	n/a	n/a	15.2	15.2
98-3	16.4	16.0	15.2	n/a	n/a	14.1	15.9
98-4	n/a	n/a	14.3	16.3	n/a	14.8	14.6

Canopy cover and stream temperatures in the Willow/Freezeout CreeksWAU are not of immediate concern. The relatively favorable stream temperatures in the Willow/Freezeout CreeksWAU can generally be attributed to high stream canopy levels and the small, coastal nature of the streams in these watersheds.

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Appendix

Riparian Function

Figure 162. Mean and Maximum Daily Stream Temperatures During Summer 2000 at Willow Creek (Site 98-3), Sonoma County, California.

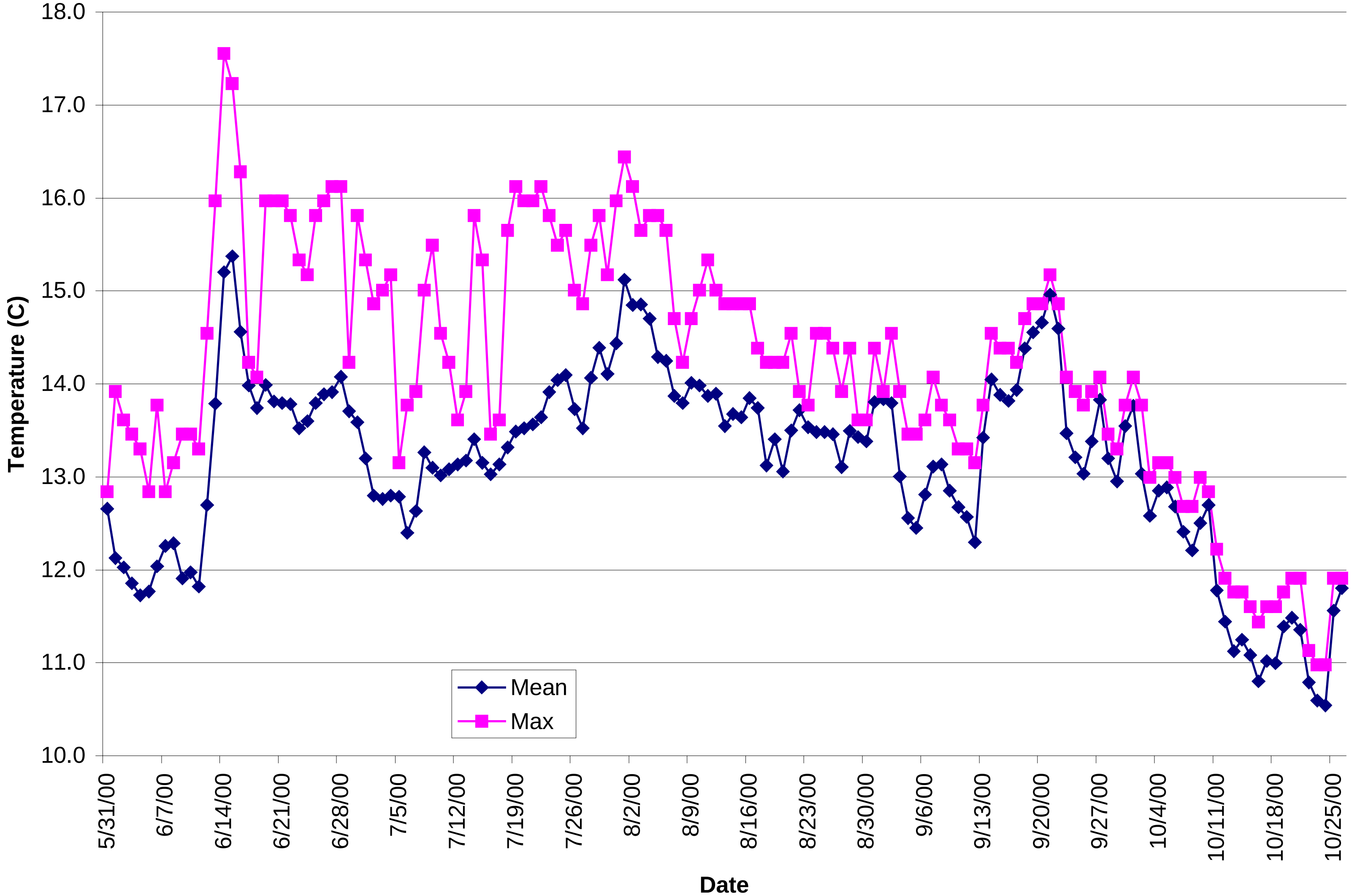


Figure 160. Mean and Maximum Daily Stream Temperatures During Summer 2000 at Willow Creek (Site 98-1), Sonoma County, California.

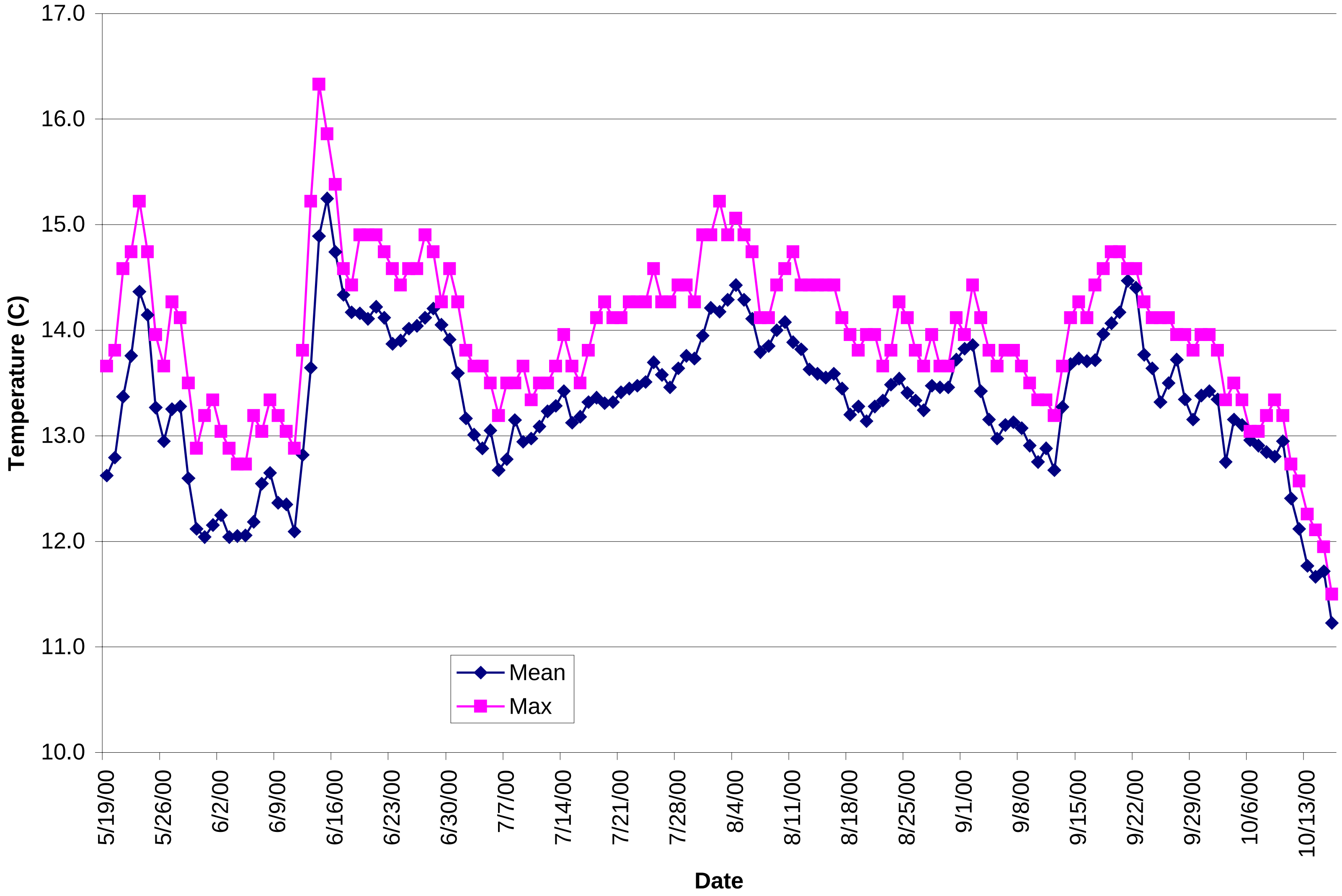


Figure 159. Mean and Maximum Daily Stream Temperatures During Summer 1999 at Willow Creek (Site 98-1), Sonoma County, California.

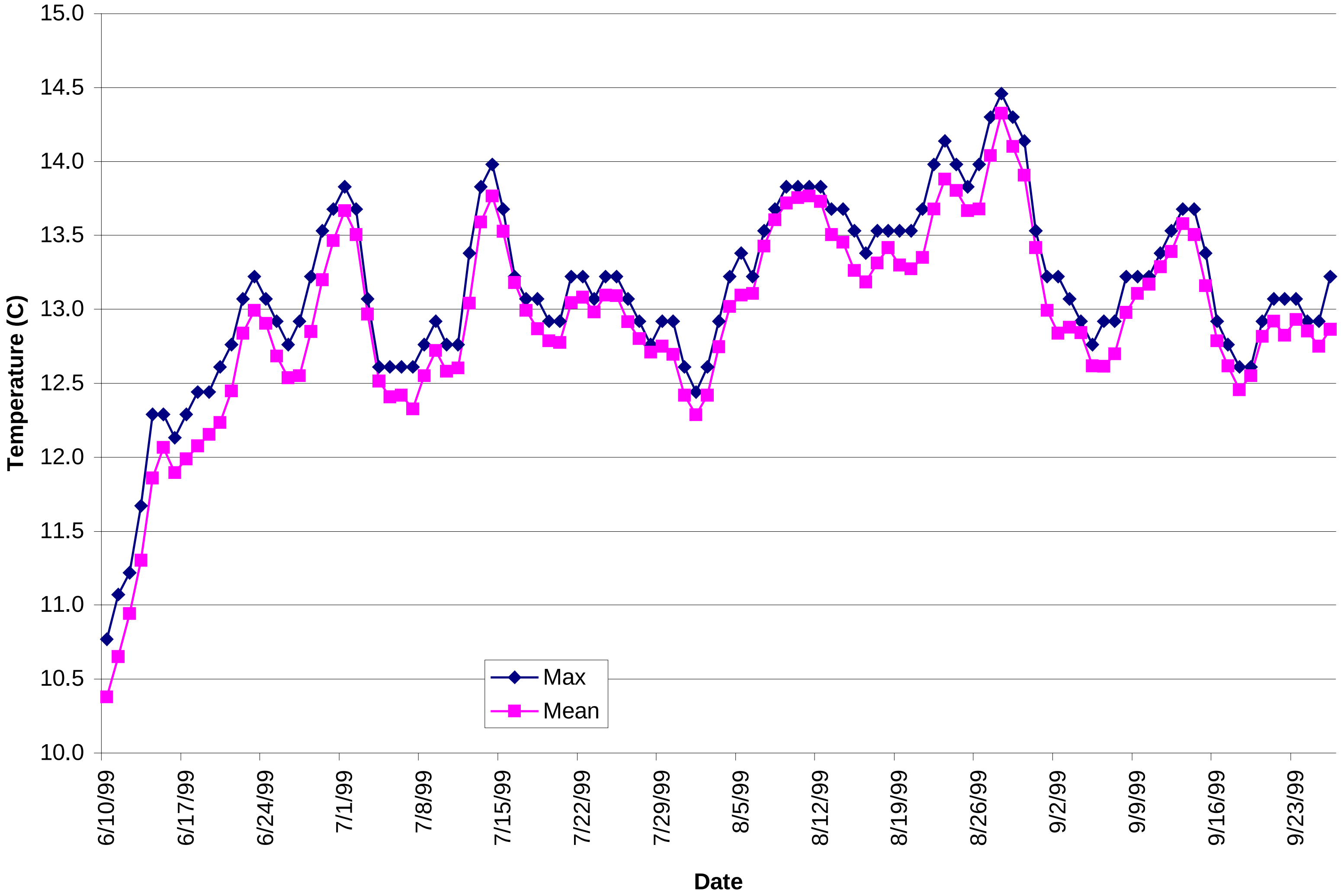


Figure 161. Mean and Maximum Daily Stream Temperatures During Summer 1999 at Willow Creek (Site 98-3), Sonoma County, California.

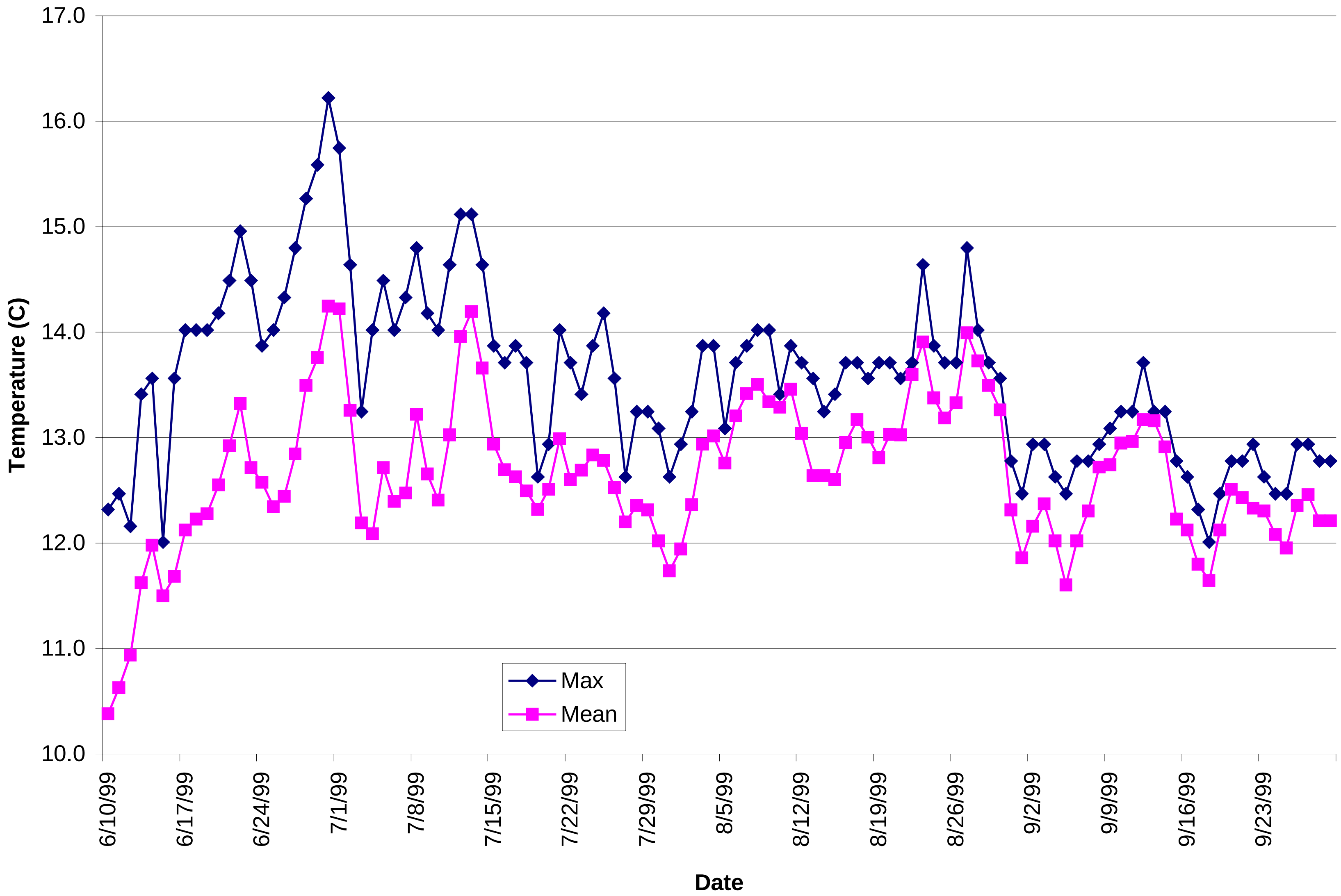


Figure 164. Mean and Maximum Daily Stream Temperatures During Summer 1999 at Freezeout Creek (Site 98-4), Sonoma County, California.

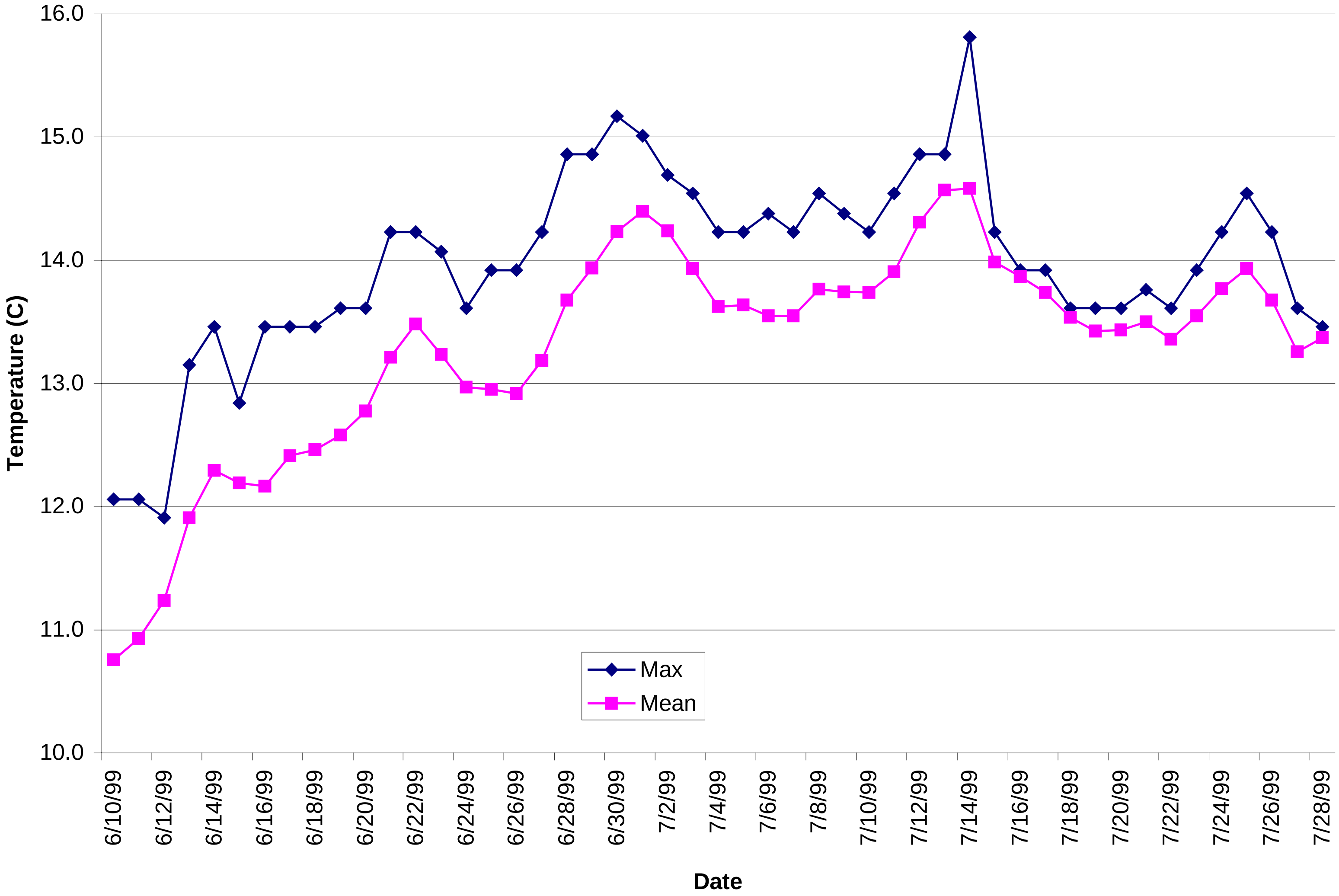


Figure 163. Mean and Maximum Daily Stream Temperatures During Summer 1997 at Freezeout Creek (Site 98-4), Sonoma County, California.

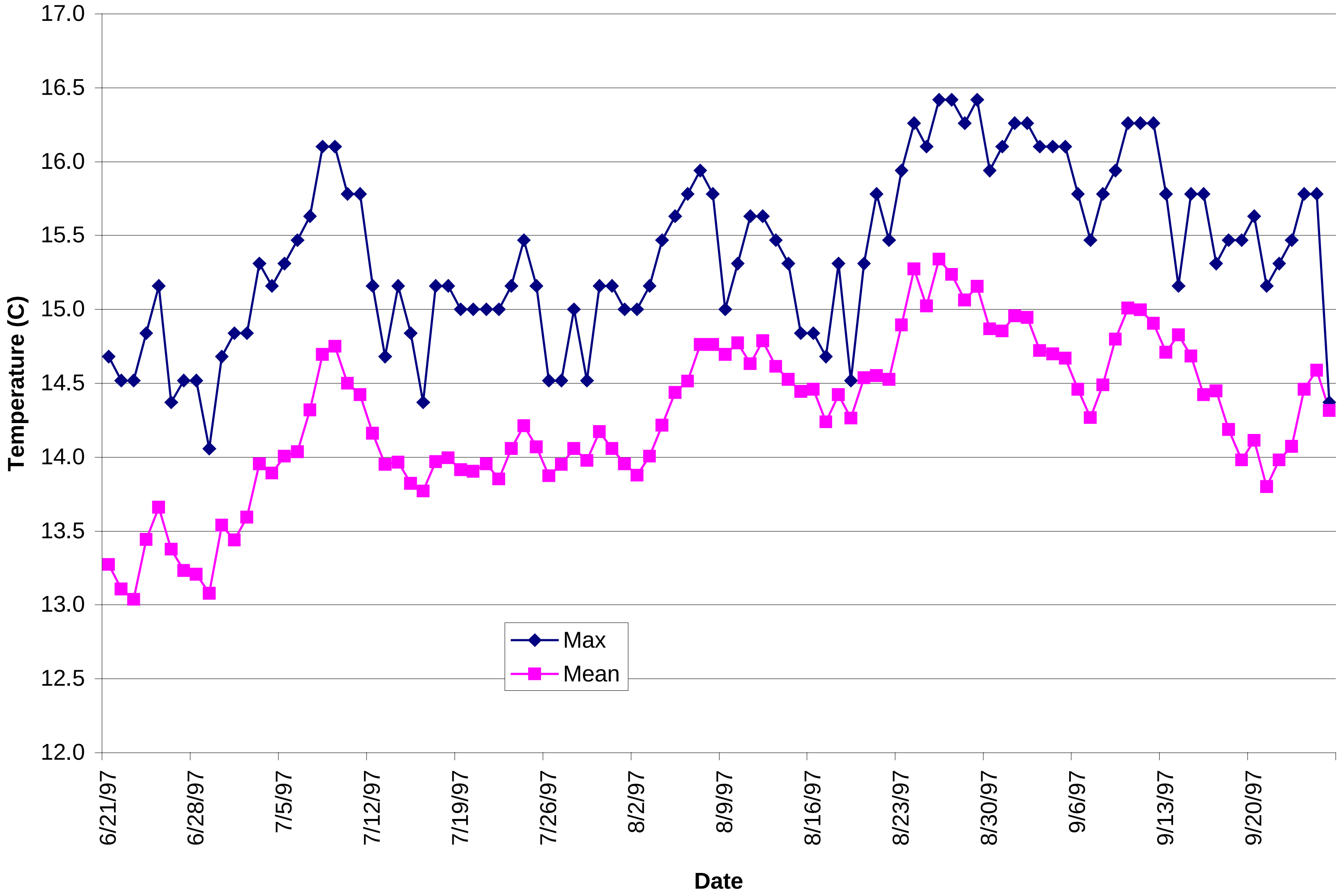


FIGURE 118. MEAN, MAXIMUM, AND MINIMUM DAILY STREAM WATER TEMPERATURES DURING SUMMER (JUNE-SEPTEMBER 1996) AT FREEZEOUT CREEK (MAP NO. 26; MONITORING SITE NO. 98-4), SONOMA CO., CALIFORNIA.

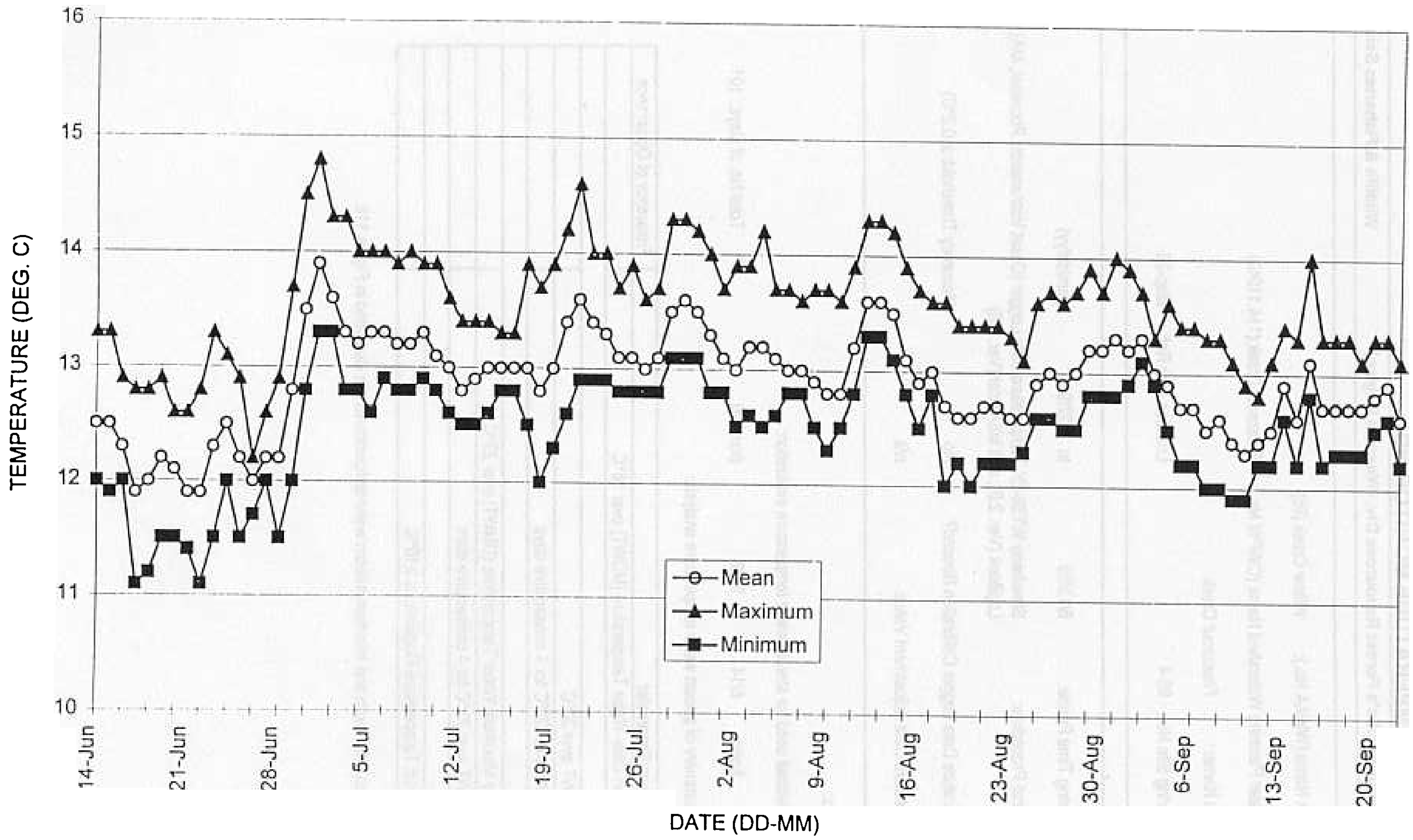


FIGURE 114. MEAN, MAXIMUM, AND MINIMUM DAILY STREAM WATER TEMPERATURES DURING SUMMER (JUNE-SEPTEMBER 1996) AT WILLOW CREEK (MAP NO. 26; MONITORING SITE NO. 98-1), SONOMA CO., CALIFORNIA.

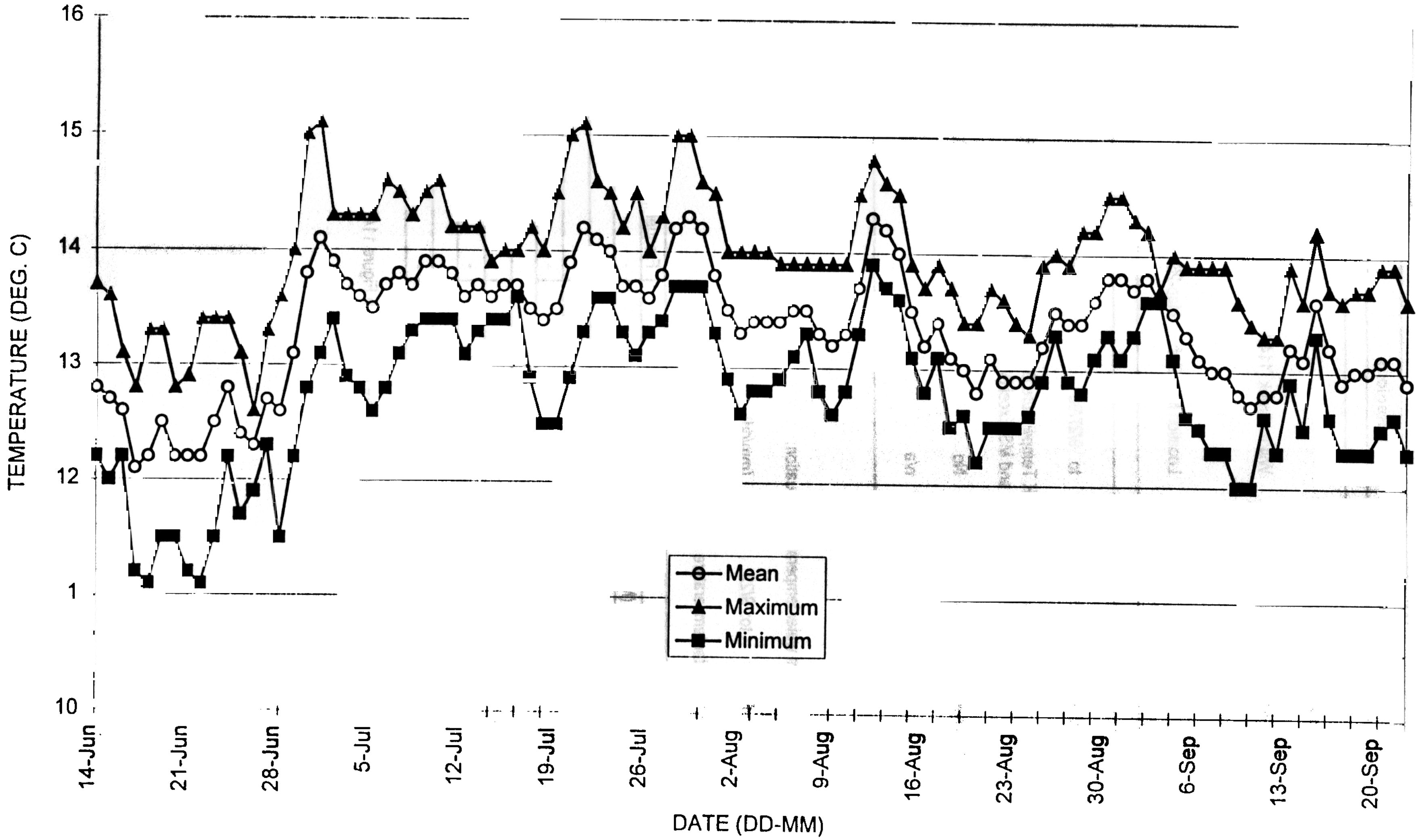


FIGURE 117. MEAN, MAXIMUM, AND MINIMUM DAILY STREAM WATER TEMPERATURES DURING SUMMER (JUNE-SEPTEMBER 1996) AT WILLOW CREEK (MAP NO. 26; MONITORING SITE NO. 98-3), SONOMA CO., CALIFORNIA.

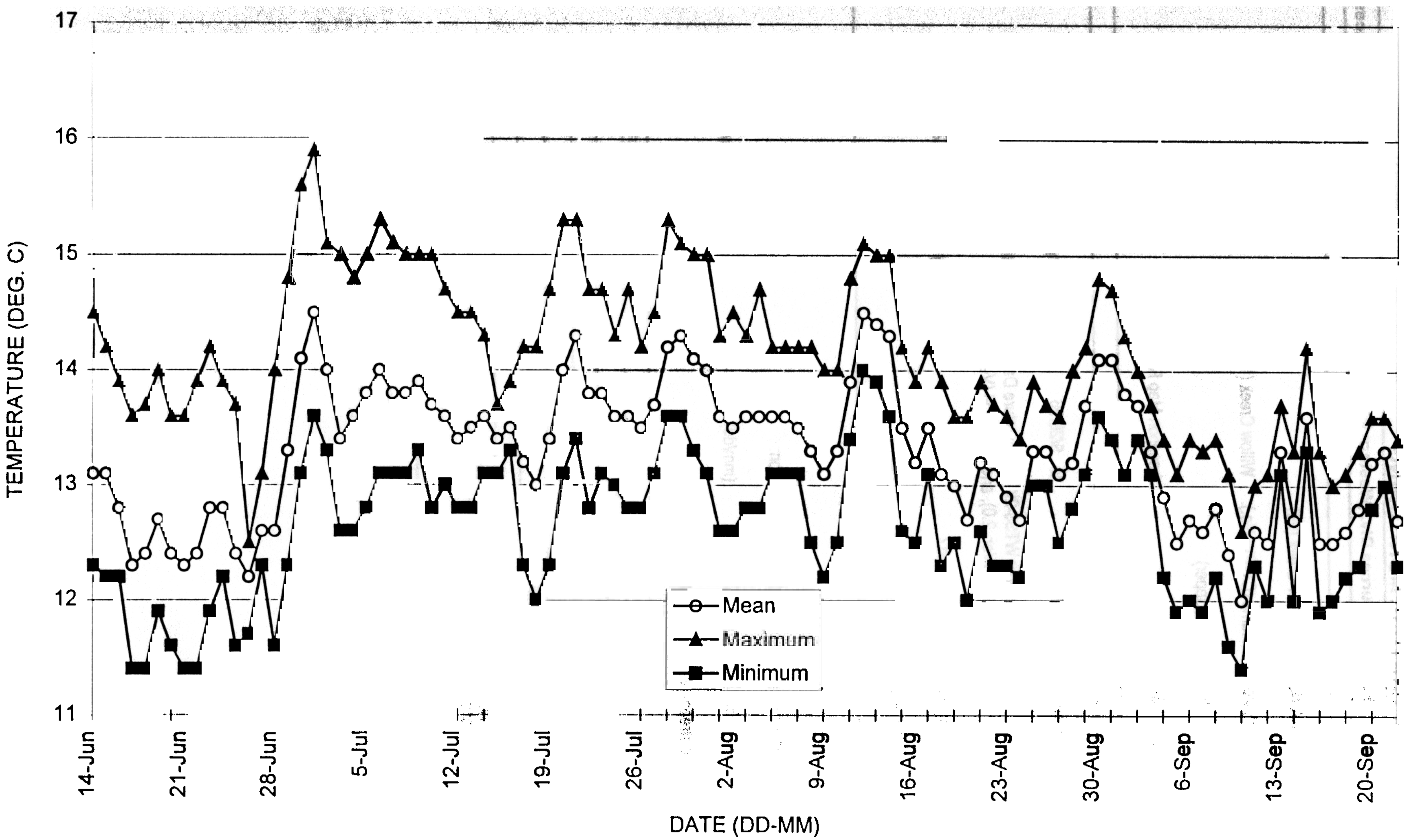


FIGURE 116. MEAN, MAXIMUM, AND MINIMUM DAILY STREAM WATER TEMPERATURES DURING SUMMER (JULY- SEPTEMBER 1995) AT WILLOW CREEK (MAP NO. 26; MONITORING SITE NO. 98-3), SONOMA CO., CALIFORNIA.

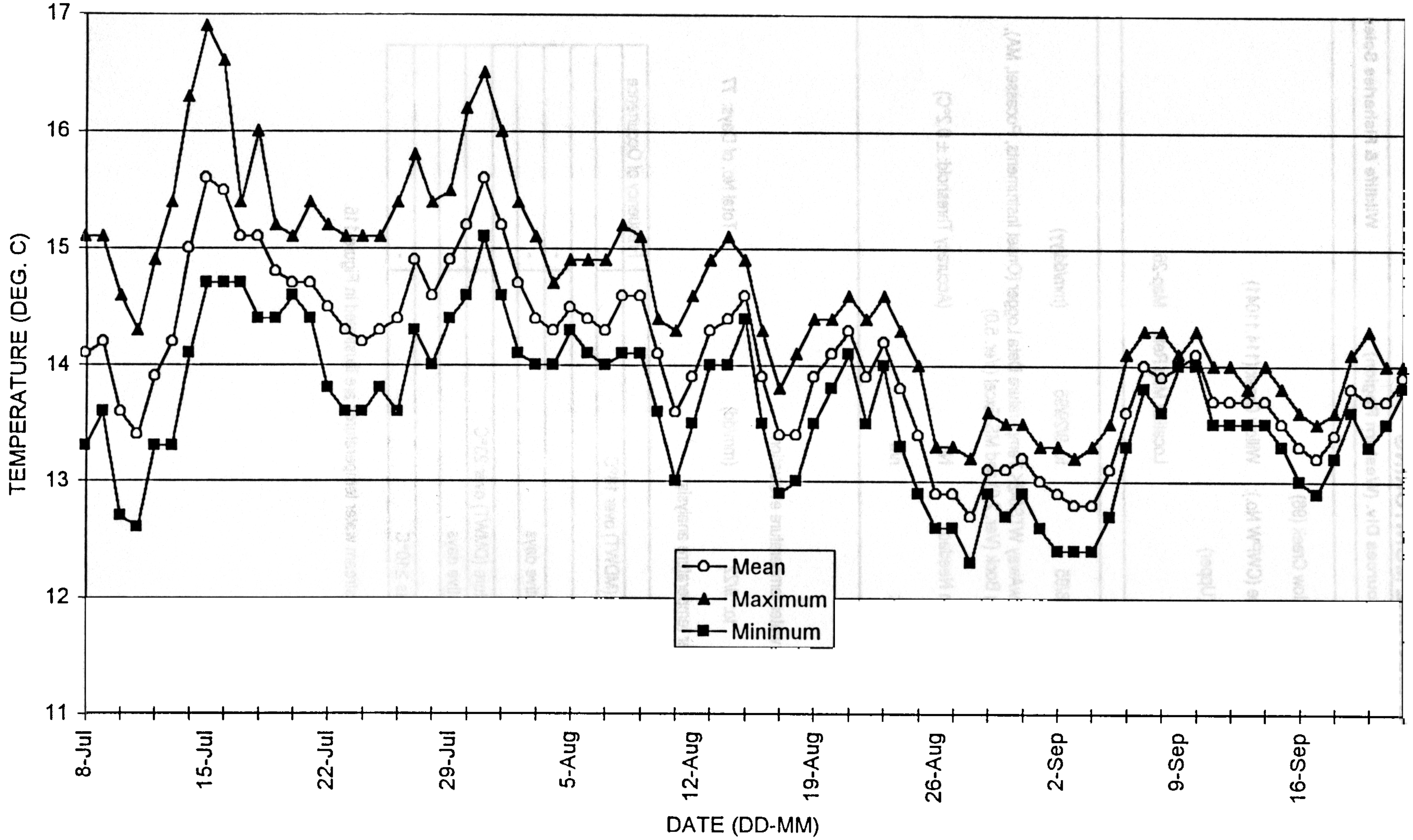


FIGURE 113. MEAN, MAXIMUM, AND MINIMUM DAILY STREAM WATER TEMPERATURES DURING SUMMER (JULY-SEPTEMBER 1995) AT WILLOW CREEK (MAP NO. 26; MONITORING SITE NO. 98-1), SONOMA CO., CALIFORNIA.

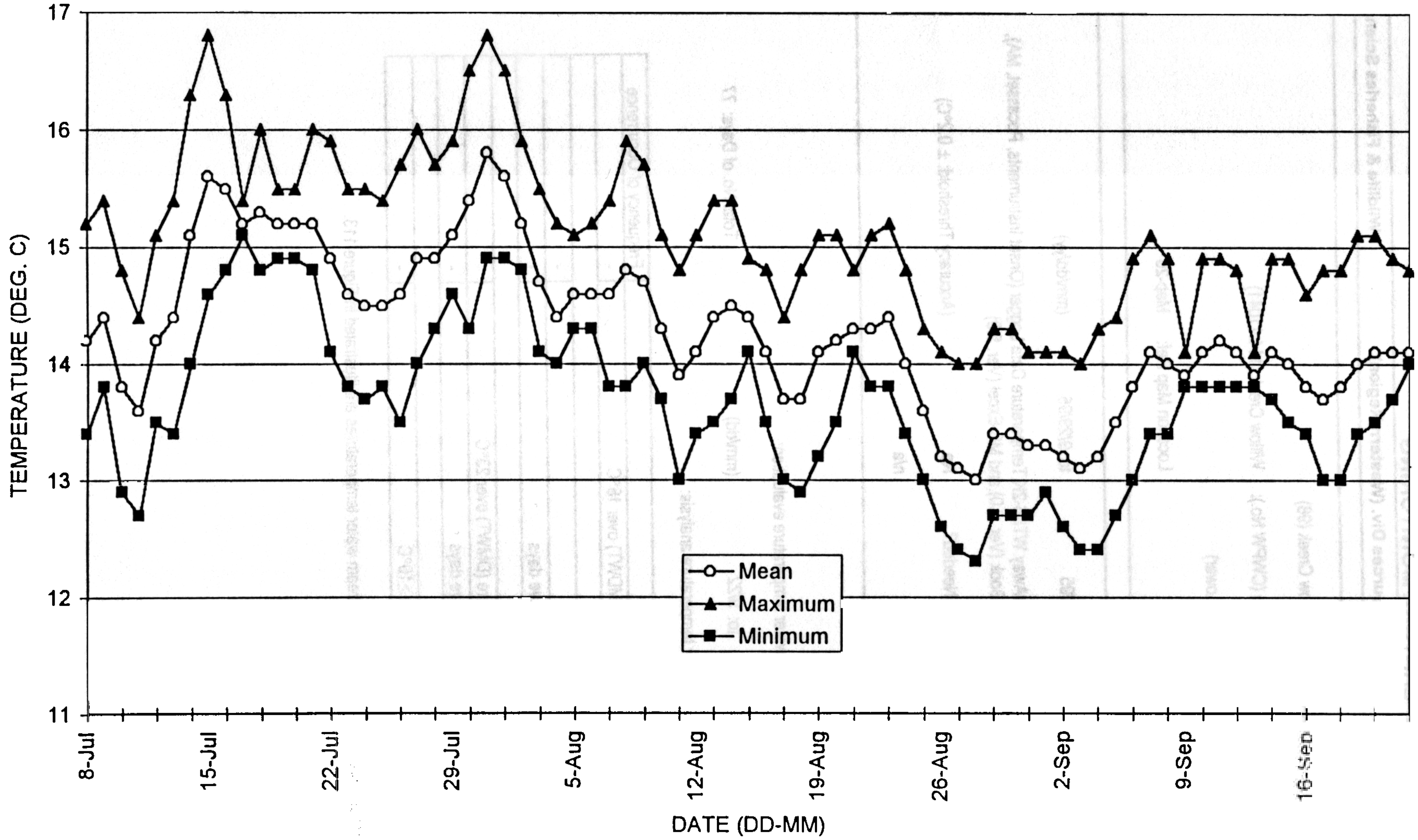


FIGURE 113. MEAN, MAXIMUM, AND MINIMUM DAILY STREAM WATER TEMPERATURES DURING SUMMER (JULY-SEPTEMBER 1995) AT WILLOW CREEK (MAP NO. 26; MONITORING SITE NO. 98-1), SONOMA CO., CALIFORNIA.

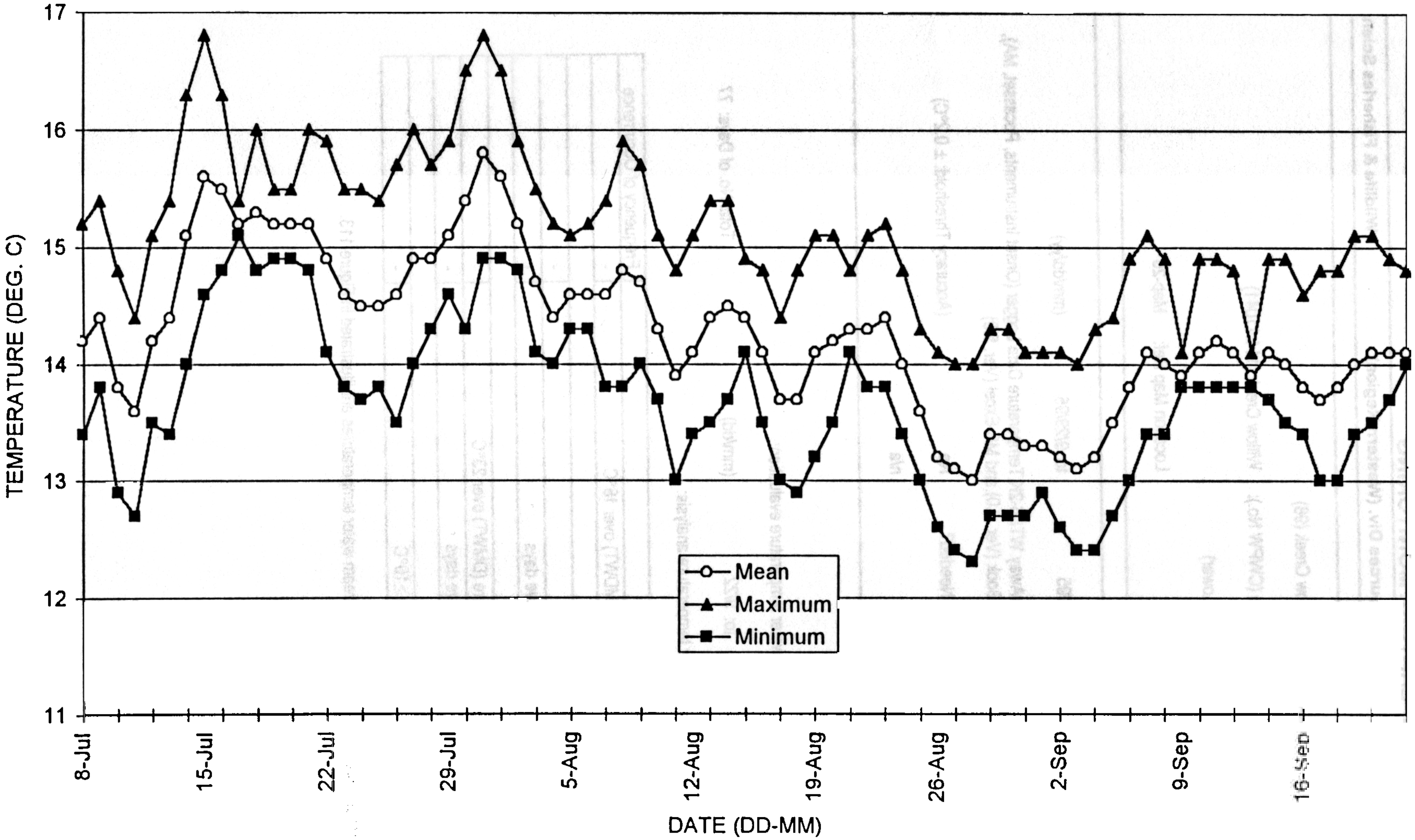


FIGURE 115. MEAN, MAXIMUM, AND MINIMUM DAILY STREAM WATER TEMPERATURES DURING SUMMER (JUNE-SEPTEMBER 1994) AT WILLOW CREEK (MAP NO. 26; MONITORING SITE NO. 98-3), SONOMA CO., CALIFORNIA.

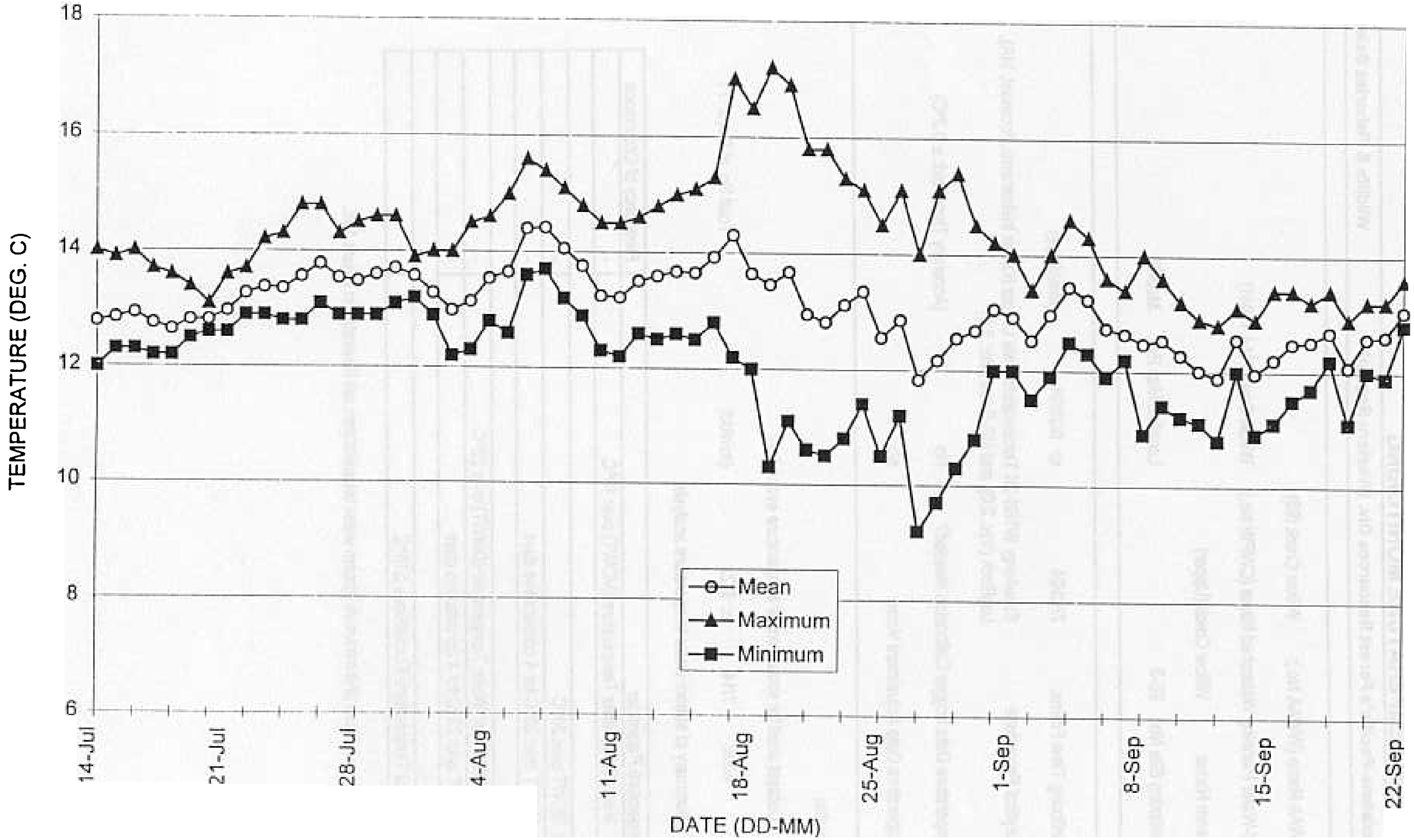
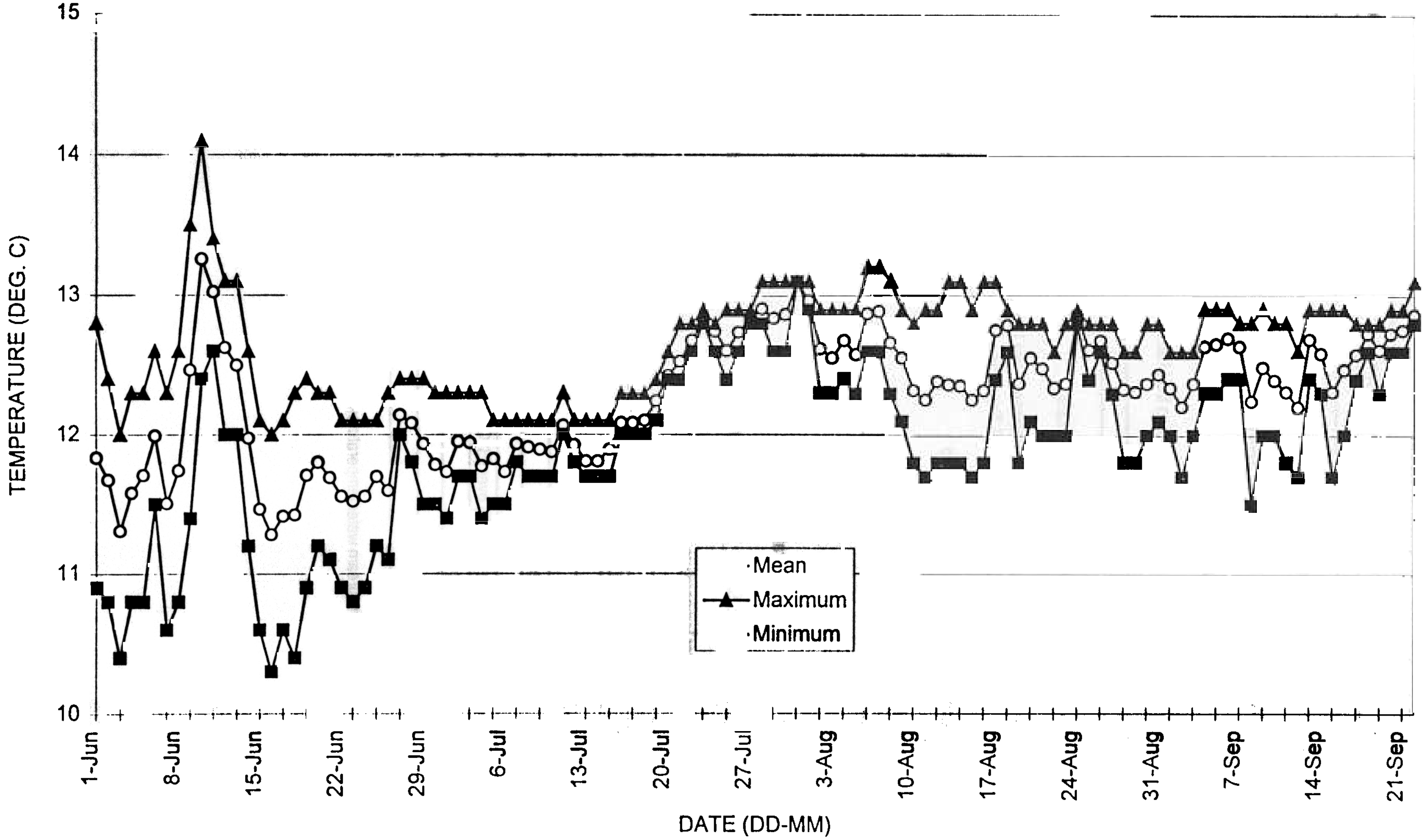


FIGURE 112. MEAN, MAXIMUM, AND MINIMUM DAILY STREAM WATER TEMPERATURES DURING SUMMER (JUNE-SEPTEMBER 1994) AT WILLOW CREEK (MAP NO. 26; MONITORING SITE NO. 98-1), SONOMA CO., CALIFORNIA.



Section E

Stream Channel Condition

Introduction

This report provides the results of an assessment of the stream channels of the Mendocino Redwood Company (MRC) ownership in the Willow and Freezeout Creeks watershed analysis unit (WAU). The assessment was done following a modified methodology from the Watershed Analysis Manual (Version 3.0, Washington Forest Practices Board). The stream channel analysis is based on field observations and stream channel slope class and channel confinement information developed from a digital terrain model in the company's Geographic Information System (GIS). The stream channel conditions below the MRC property were not evaluated with field observations. However, the channel conditions, particularly of Willow Creek, have been evaluated in previous studies (i.e. Trihey and Assoc., 1995, CDF&G, 1995). This information is included in the discussions of this report.

The goals of the assessment were to determine the existing channel conditions and identify the sensitivity of the channels to wood and sediment. Stream channels are defined by the transport of water and sediment. A primary structural control of a channel in a forested environment, besides large rock substrate, is from woody debris. Channel morphology and condition therefore reflect the input of sediment, wood and water relative to the ability of the channel to either transport or store these inputs (Sullivan et. al., 1987)

Stream channel conditions represent the strongest link between forest practices and fisheries resources. Changes in channel condition typically reflect changes to fish habitat. Because of this the fish habitat and stream channel assessments were done in the same reaches. The results for the fish habitat parameters are presented in Section F - Fish Habitat Assessment.

Methods

The methods of the stream channel assessment are designed to identify channel segments that are likely to respond similarly to changes in sediment or wood and group them into distinct geomorphic units. These geomorphic units enable an interpretation of habitat-forming processes dependent on similar geomorphic and channel morphology conditions. The channels are also evaluated for current channel condition to provide baseline information for the monitoring of channel conditions over the long term.

Stream Segment Delineation

The stream channel network for the Willow/Freezeout Creeks WAU was partitioned into stream segments based on three classes of channel confinement and several classes of channel gradient. These classifications were based on channel classifications prepared from digital terrain data in Mendocino Redwood Company's Geographic Information System (GIS). The slope classes used for delineation are 0-3%, 1-2%, 3-7%, 7-12%, and 12-20%. Channel confinement was classified by confined, moderately confined, and unconfined. Confined channels have a valley to channel width ratio of <2, moderately confined channels have a valley to channel width ratio of <4, and unconfined channels have a valley to channel width ratio of >4. Channel slope class or confinement information from the GIS was re-classified based on field observations.

Channel segments were delineated based on either a change in slope class or change in channel confinement. The channel segments were numbered with a two letter code, corresponding to the planning watershed the channel segment is located, followed by a unique number (*1 through n* for each planning watershed). For the Willow and Freezeout Creeks WAU data, channels for two planning watersheds are delineated. The channels for the Willow Creek planning watershed have a two-letter code of SW, the channels for the Freezeout Creek planning watershed have a two-letter code of SF. The stream segment delineations are shown on Map E-1.

Field Measurements and Observations

Selection of field sites for stream channel observations was based on gathering a representative sample of response (0-3% gradient) and transport (3-20% gradient) channels from each planning watershed of the WAU. Little attention was focused on the source reaches (>20% gradient), this was assumed to be covered in the mass wasting analysis.

For each channel segment the bankfull width, bankfull maximum depth, bankfull average depth, floodprone depth, floodprone width, and channel bankfull width to depth ratio are measured at a cross section representative of the channel segment. A peeble count of 50 randomly selected peebles is counted at the cross section to determine the D50 (median particle size) of the stream bed. Stream-bed sediment characteristics are interpreted from observations of gravel bars, channel aggradation or degradation, and particle size of the stream bed material. The segment is classified by morphology types based on Montgomery and Buffington (1993) and Rosgen (1994). The channel morphology is further interpreted by flood plain interaction for segment (continuous, discontinuos, inactive, none) and channel roughness characteristics. Large woody debris (LWD) funtioning the in channel is tallied (presented in detail in Riparian Condition section). The number and type of pools (LWD forced, bank forced, boulder forced, free formed) are observed. The field observations are summarized and defined in Table E-1.

Geomorphic Units

Channel segments were grouped into geomorphic units by similar attributes of channel condition, position in the drainage network, and gradient/confinement classes. The intent of the geomorphic units are to stratify channel segments of the WAU into units which respond similarly to the input factors of coarse and fine sediment, and LWD. These geomorphic units can then be interpreted to have similar habitat-forming processes.

Interpretations related to sediment supply, transport capacity and LWD response were the basis for development of sensitivity of geomorphic units to coarse sediment, fine sediment and LWD inputs. These interpretations were based primarily on existing conditions observed in the stream channels of the WAU. The channel sensitivity to changes to coarse sediment, fine sediment and LWD are based on how the current state of the channel is likely to respond to inputs of these variables.

Long-Term Stream Monitoring Sites

To monitor stream channel morphology conditions and stream sediment characteristics related to fish habitat, a long-term stream channel monitoring segment was established in Willow Creek. Along this segment a thalweg profile, four cross sections and streambed D50 measurements were surveyed. Stream gravel bulk samples and permeability of spawning gravels are also measured (methods and results presented in the Fish Habitat section). This long-term segment will be re-surveyed and monitored over time to provide insight into long term trends in channel morphology, sediment transport and fish habitat conditions. The long-term stream channel monitoring segment location is shown on Map E-1.

The stream monitoring segment for thalweg profile and cross section surveys on Willow Creek starts approximately 600 below the confluence with the North Fork Willow Creek and continues past the confluence approximately 130 feet. The stream monitoring segment is within 20-30 bankfull channel widths in length. Permanent bench marks (PBMs) are placed at the upstream and downstream ends of the monitoring segment. The PBMs are monumented with nails in the base of large trees along with a re-bar pin in the ground adjacent to the nail.

The thalweg profile is a survey of the deepest point of the flowing channel, excluding any detached or “dead end” scours and/or side channels. At every visually apparent change in thalweg location or depth, the distance along the channel is measured and the elevation is recorded. In the absence of visually apparent changes, thalweg measurements are taken every 15-20 feet along the channel. A profile graph of the channel’s thalweg is created from the survey (see Appendix E for Thalweg profile for Willow Creek, 2000).

Along the thalweg profile, 4 channel cross sections are surveyed (locations are permanently monumented). The cross sections are located along relatively straight reaches in the monitoring segment. Cross sections are surveyed from above the floodprone depth of the channel. A graph of the cross section is created from the survey (see Appendix E for cross sections graphs for Willow Creek, 2000). At each cross section a pebble count is done, to determine the D50 of the cross section, by measuring 100 randomly selected pebbles along the cross section fall line.

Results

Current Stream Channel Observations for MRC Property in Willow/Freezeout Creeks' Watersheds

Field channel surveys were done on 8 stream segments in the Willow/Freezeout WAU during the summer of 2000. Table E-1 provides a summary of the data collected (see appendix of this module for field form). Further detail specific to in-channel fish habitat relationships is found in Section F - Fish Habitat Assessment of this report.

Key to Table E-1.

Stream Channel Dimensions

Category	Description
Seg. #	the stream identification number (see Map E-1), two letter planning watershed code followed by unique number for the planning watershed.
Geomorphic Unit	number of the geomorphic unit the channel segment is in.
Surveyed Length-	length of segment surveyed.
Observed Slope	mean slope of segment as observed in field.
Maximum Bankfull Depth	maximum bankfull depth of representative cross section.
Average Bankfull Width	average bankfull width of representative cross section.
Width/Depth Ratio	bankfull channel width to depth ratio.
Floodprone depth	maximum depth during flooding, estimated by 2 times max. bankfull depth (Rosgen, 1996).
Floodprone width	width of water during flooding (Rosgen, 1996).
Entrenchment Ratio	ratio of floodprone width to bankfull channel width.

Channel Morphology

Category	Description
Montgomery/ Buffington Class	the channel type: p/r = pool/riffle, fp/r = forced pool/riffle, stp = step pool, plnbed = plane bed, cas = cascade.
Rosgen Class	Rosgen channel classification, (Rosgen, 1994).
Floodplain	description of floodplain/channel interaction.
Channel Roughness	B =boulders, C=cobbles, F=bedforms, V=live woody veg., W=large woody veg., R=bedrock, Bk=banks and roots.

Sediment/Bedform Characteristics

Category	Description
Gravel Bar Abundance	F=few, C=common, A=abundant
Gravel Bar Type	A=alternate, F=forced, P=point, M=medial
Gravel Bar Proportion Class	Proportion of stream segment in gravel bars: 0-25%, 25-50%, 50-75%, 75-100%.
Past Aggr. or Degr.	evidence of past aggregation or degradation of channel.
Current Aggr. or Degr.	current aggregation or degradation of channel.
Fine Sediment Abundance	sparse, moderate, abundant

Fine Sediment Type	type of fine sediment accumulation: P=isolated pockets, M=moderate accumulations, B=high accumulations including bars
D50	the median gravel size of the stream bed.

Pool Characteristics

Category	Description
Free	number of free formed pools in segment.
LWD Forced	number of LWD forced pools in segment.
Boulder Forced	number of boulder forced pools in segment.
Bank Forced	number of bank forced pools in segment.
Total # Pools	total number of pools in segment.
Pool Spacing	average space between pools by bankfull widths

Table E-1 (a). Stream Channel Field Observations for Willow/Freezeout Creek WAU, Channel Dimensions

Stream Name	Seg. #	Geomorphic Unit	Surveyed Length (ft)	Observed Slope (%)	Maximum Bankfull Depth (ft)	Average Bankfull Depth (ft)	Bankfull Width (ft)	Width to Depth Ratio	Floodprone Depth (ft)	Floodprone Width (ft)	Entrenchment Ratio
Willow Creek	SW1	I	729	0.5	2.8	1.95	34.0	17.4	5.6	42	1.2
Willow Creek	SW2	I	625	0.6	2.3	1.8	27.1	15.1	4.6	33.1	1.2
Willow Creek	SW2(2)	I	593	1.6	2.65	2.2	16.4	7.5	5.3	19.5	1.2
Willow Creek	SW3	II	595	1.0	1.8	1.3	24.2	18.6	3.6	26	1.1
North Fork Willow Creek	SW20	III	417	4.0	1.8	1.1	17.5	15.9	3.6	19	1.1
Unnamed Tributary	SW23	III	421	2.9	1.9	1.37	18.6	13.6	3.8	26.6	1.4
Freezeout Creek	SF1/2	IV	407	8.1	2.3	1.3	24	18.5	4.6	36	1.5
Unnamed Tributary	SF10	III	499	3.0	2.3	1.6	13	8.1	4.6	17	1.3

Table E-1 (b). Stream Channel Field Observations for Willow/Freezeout Creek WAU, Channel Morphology

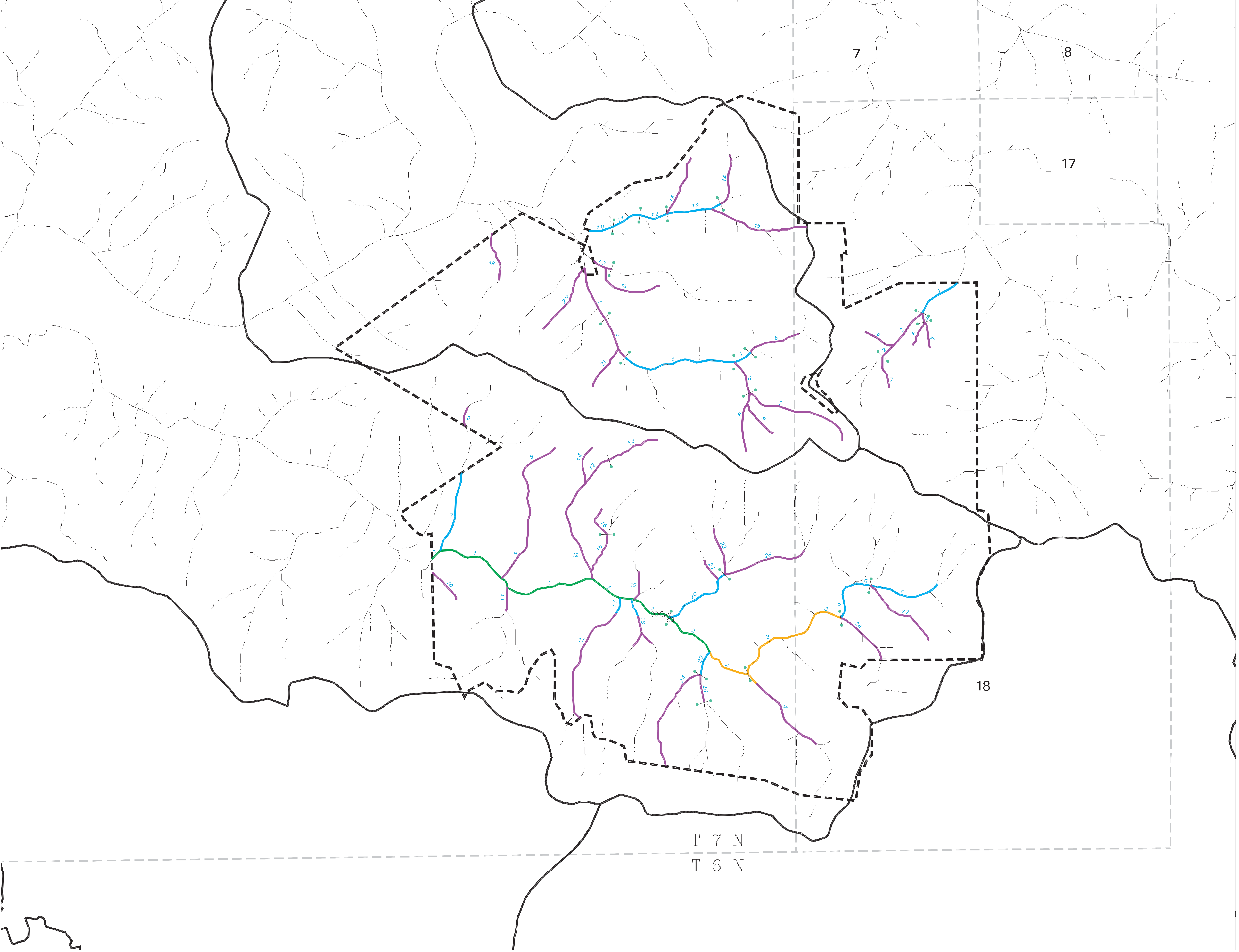
Stream Name	Seg. #	Montgomery/ Buffington Class(s)	Rosgen Class(s)	Floodplain	Channel Roughness (in order influence)
Willow Creek	SW1	P/R	F4	Inactive	F-BK-LWD
Willow Creek	SW2	P/R	F4	Inactive	F-BK-LWD
Willow Creek	SW2(2)	P/R	F4	Inactive	LWD-F-BK
Willow Creek	SW3	P/R	F4	None	F-BK-LWD
North Fork Willow Creek	SW20	P/R, FP/R	F4,F4,E4,F4	Discontinuous	BK-F-LWD
Unnamed Tributary	SW23	FP/R,FP/R,P/R	B4,G4,G4	None	F-LWD-BK
Freezeout Creek	SF1/2	CAS	Aa2, Aa3	None	B-C-R
Unnamed Tributary	SF10	SP	G4,B4	None	C-LWD-BK

Table E-1 (c). Stream Channel Field Observations for Willow/Freezeout Creek WAU, Sediment and Bedforms

Stream Name	Seg. #	Gravel Bar Abundance	Gravel Bar Type(s)	Gravel Bar Proportion	Past Agg.or Degr.	Current Agg.or Degr.	Fine Sed. Abundance	Fine Sed. Type	D50 (mm)
Willow Creek	SW1	C	P-A	50-75%	DEGR	AGG	Moderate	B	52
Willow Creek	SW2	C	P	50-75%	DEGR	AGG	Abundant	B	34
Willow Creek	SW2(2)	C	P	50-75%	DEGR	AGG	Abundant	B	36
Willow Creek	SW3	C	P	25-50%	AGG & DEGR	AGG	Abundant	B	35
North Fork Willow Creek	SW20	C	P	25-50%	NONE	NONE	Moderate	M	31
Unnamed Tributary	SW23	C	F,P	25-50%	NONE	AGG	Sparse	P	51
Freezeout Creek	SF1/2	C	F	25-50%	NONE	NONE	Sparse	P	106
Unnamed Tributary	SF10	n/a	n/a	n/a	NONE	NONE	Moderate	M	79

Table E-1 (d). Stream Channel Field Observations for Willow/Freezeout Creek WAU, Pools

Stream Name	Seg. #	Free	LWD Forced	Boulder Forced	Bank Forced	Total # Pools	Pool Spacing (bkfull widths)	Mean Residual Pool Depth (ft.)
Willow Creek	SW1	0	10	0	3	13	1.6	1.6
Willow Creek	SW2	2	8	0	2	12	1.9	1.5
Willow Creek	SW2(2)	0	10	1	1	12	3.0	1.4
Willow Creek	SW3	0	3	0	1	4	6.1	1.2
North Fork Willow Creek	SW20	0	5	0	4	9	2.6	0.9
Unnamed Tributary	SW23	0	6	0	4	10	2.3	1.3
Freezeout Creek	SF1/2	NA	NA	NA	NA	NA	NA	n/a
Unnamed Tributary	SF10	2	3	3	0	8	4.8	0.8



Willow Creek / Freezeout Creek Watershed Analysis Unit

Map E-1 Stream Channel Geomorphic Units and Segments

Depositional Channels Entrenched in Streamside Terraces

Highly Confined Depositional Channels within Steep Canyon Walls

Moderate Gradient (2-8%) Transport Segments of Willow and Freezeout Creeks

High Gradient (8-20%) Transport Segments of Willow and Freezeout Creeks

Long Term Monitoring Sites

Flow Class

Class I

Class II

Class III

MRC Ownership

Planning Watershed Boundary

0 1/2 1 Mile

February 16, 2001

Stream Geomorphic Units

Stream geomorphic units were developed for the stream network on the MRC property in the Willow/Freezeout Creeks watersheds. These units are general representations of stream channels with similar sensitivities to coarse sediment, fine sediment and large woody debris inputs. Four stream geomorphic units were developed for interpretation of stream channel response to forest management interactions. The four stream geomorphic units are described below.

Geomorphic Unit I. Depositional Channels Entrenched in Streamside Terraces.

Includes Segments: Field verified – SW1, SW2(lower)

General Description:
Stream channel segments in this unit flow in an entrenched channel within streamside terraces varying from 5 to 8 feet deep. These channels are highly confined within terraces with no floodplain and little channel migration capability. The terrace deposits adjacent to the channel are composed primarily of consolidated sand, silt and clay sized particles. Cohesion of the terrace substrate is high and moderately susceptible to bank erosion. Channel gradients are low (<1 percent), but sediment transport capacity is relatively high during high flows due to the highly confined channel keeping water energy directed with the entrenched channel. The channel bed is composed primarily of gravel sized particles.

Associated Channel Types:
This unit primarily exhibits pool/riffle morphology. The Rosgen (Rosgen, 1994) classification for channels is this unit is F4.

Fish Habitat Associations:
Sediment supply in this unit is high but despite the lower gradient transport of sediment through this unit can be adequate because of the entrenched channel helping to focus the power of winter flows. Large woody debris is in high demand to aid in sorting of sediment, promote pool scour, and to offer salmonids refuge from high winter flows in this confined channel. The addition of wood into this unit could greatly improve the habitat for all life stages of anadromous salmonids.

Conditions and Response Potential

Coarse Sediment: Moderate Response Potential
Coarse gravel accumulations are primarily in point and alternating point gravel bars. Gravel bars are common within this unit and currently store a high amount of coarse sediment. Currently the channel does show evidence of aggradation. The highly confined water flow of this unit creates high coarse sediment transport capacity. However, based on evidence of current aggradation, if the coarse sediment supply is high the bed will aggrade reducing channel complexity and habitat.

Fine Sediment: High Response Potential

Moderate to high accumulations of fine sediment is observed in this unit. Fine sediment deposition is on the top of gravel bars, accumulated in the bed of pool tail-outs, along pool margins, and in some pools. The channels of this unit have high fine sediment transport capacity due to high flow capacity of the channel. However, when there is a high fine sediment supply in transport, accumulations of fine sediment occur in this unit.

Large Woody Debris: High Response Potential

Large woody debris loading is currently below targeted conditions in this unit. The LWD that is present is providing stream habitat development, cover and sediment storage. Additional LWD would continue to improve habitat conditions. The high flows that are confined in the channel of this unit require LWD pieces to be braced in the channel or debris jams to keep the LWD in place. Ample LWD needs to be recruited to this unit over time to sustain levels of LWD.

Geomorphic Unit II. Highly Confined Depositional Channels within Steep Canyon Walls.

Includes Segments: Field verified – SW2(upper), SW3, SW4(lower)

General Description:
Stream channel segments in this unit are confined within steep canyon walls. These channels are highly confined within the canyon with little floodplain development or channel migration capability. Currently young terrace deposits (<40 years) are developed adjacent to the channel. These terrace deposits are composed primarily of unconsolidated gravel sized particles, hypothesized to be from severe channel aggradation in the 1960's to 1970's. The current channel is entrenched, intermittently within these terrace deposits. Cohesion of the terrace substrate is low and highly susceptible to bank erosion. Channel gradients are low to moderate (1-2 percent). Sediment transport capacity is relatively high during high flows due to the highly confined channel keeping water energy directed within the confined channel. The channel bed is composed primarily of gravel sized particles, but lacks complexity or diverse aquatic habitat due to the high flux of sediment aggradation and degradation.

Associated Channel Types:
This unit primarily exhibits pool/riffle morphology. The Rosgen (Rosgen, 1996) classification for channels is this unit is F4.

Fish Habitat Associations:
Sediment supply in this unit is high but despite the lower gradient transport of sediment through this unit can be adequate because of the entrenched channel helping to focus the power of winter flows. Large woody debris is in high demand to aid in sorting of sediment, promote pool scour, and to offer salmonids refuge from high winter flows in this confined channel. The addition of wood into this unit could greatly improve the habitat for all life stages of anadromous salmonids.

Conditions and Response Potential

Coarse Sediment: High Response Potential
Coarse gravel is stored in streamside terraces and in the active channel in point and alternating point gravel bars. Gravel bars are common within this unit and currently store a high amount of coarse sediment. Channel segments in this unit have had severe aggradation in the past when the sediment supply is high. Currently the channel has degraded through the past aggradation and is intermittently entrenched in unconsolidated gravel deposits. These gravel deposits are a source of sediment delivery over time. The current channel lacks complexity due to the high flux of coarse sediment aggradation and degradation.

Fine Sediment: High Response Potential

Moderate to high accumulations of fine sediment is observed in this unit. Fine sediment deposition is on the top of gravel bars, accumulated in the bed of pool tail-outs, along pool margins, and in some pools. The channels of this unit have high fine sediment transport capacity due to high flow capacity and moderate gradients of the channel. A lot of sand size particles were observed in this unit, presumably from erosion of the banks of the young terraces in the unit. When there is a high fine sediment supply in transport, accumulations of fine sediment occur in this unit.

Large Woody Debris: High Response Potential

Large woody debris loading is currently below targeted conditions in this unit. The LWD that is present is providing stream habitat development, cover and sediment storage. Additional LWD would continue to improve habitat conditions. Due to the high amount of sediment in the channels of this unit LWD would greatly improve sediment storage and sorting, improving aquatic habitat conditions.

Geomorphic Unit III. Moderate Gradient (2-8%) Transport Segments of Willow and Freezeout Creeks.

Includes Segments: Field verified - SW20, SW23, SF10
Extrapolated – SW5, SW6, SW7, SW17(lower), SW18(lower), SF3, SF4, SF11, SF12, SF13

General Description:
Stream channel segments in this unit are confined within canyons with steep side slopes. Typically entrenchment ratios (flood prone to bankfull width ratio) are between 1.1 and 1.5. This high degree of confinement does not allow much terrace formation or channel meandering. The channel segments in this unit are predominantly transport reaches, but isolated areas of depositional reaches occur in this unit depending on channel gradient. These channels typically have active fans forming at the outlet of these channels. Due to the moderate gradient (2-8 percent) the channels are responsive to aggradation and degradation from changes in the stream sediment supply. The substrate of the channels in this unit varies from gravel to boulder sized particles. The fans or terraces in this unit appear to be created from large episodic sediment loads. The moderate gradient of the stream allows channels to down-cut through the terrace deposits.

Associated Channel Types:
This unit primarily exhibits forced pool/riffle and step pool morphology, with some isolated areas of pool/riffle morphology. The Rosgen (Rosgen, 1996) classification for these channels varies between F4 and G4 depending primarily on channel slope. However, some areas of E4 and B4 channel types are observed in this unit.

Fish Habitat Associations:
This unit is characterized by larger substrate that provides a roughness element to the stream. Larger sized cobbles and small boulders break up the flow of water creating velocity breaks promoting resting spots for salmonids. This unit has low amounts of large woody debris, however due to the high entrenchment wood recruitment would be beneficial in increasing complexity of cover and help to improve habitat for all life stages of salmonids.

Conditions and Response Potential

Coarse Sediment: High Response Potential
Accumulations of coarse sediment are found in point and LWD forced gravel bars. The gravel bar abundance is common with some abundant accumulations. Currently the channels show evidence of down-cutting and occasional evidence of aggradation in response to coarse sediment fluctuations. There is evidence of past aggradation and degradation of the channels in this unit as well.

Fine Sediment: Moderate Response Potential

Accumulations of fine sediment were observed in this unit. Fine sediment accumulations varied from sparse to moderate primarily on the top of gravel bars, but also in isolated pockets in pools. The discontinuous floodplain and moderate slope gradient promotes high fine sediment transport due to concentrated stream power within confined channels.

Large Woody Debris: High Response Potential

LWD in this unit was observed to force storage of coarse sediments and create scour and pool formation. The areas of down-cut channels in this unit would likely benefit and stabilize with increased large woody debris loading do to increased sediment storage capacity raising the elevation of the stream bed.

Geomorphic Unit IV. High Gradient (8-20%) Transport Segments of Willow and Freezeout Creeks.

Includes Segments: Field observed – SF1, SF2
Extrapolated – SW4, SW9, SW10, SW11, SW12, SW13,SW14, SW15, SW16, SW17(upper), SW18(upper), SW19, SW21, SW22, SW24, SW25, SW26, SW27, SW28, SF5, SF6, SF7, SF8, SF9, SF14, SF15, SF16, SF17, SF18, SF19, SF20, SF21

General Description: to do
Channel segments in this unit are high gradient transport reaches from 8-20% with high sediment transport capacity. The channel segments in this unit typically flow through tightly confined, steep-sided canyons. These are typically zones of scour during high flows or debris flows. Stream substrate is typically from cobble to large boulders.

Associated Channel Types:
This unit varies it morphology from step pool to cascades with some occasional waterfalls. The cascades and waterfalls occur in the steepest segments of this unit. The Rosgen (Rosgen, 1996) classification for these channels varies between A2, A3, and Aa2, Aa3 depending on channel gradient and substrate composition.

Fish Habitat Associations:
The high gradient channels of this unit pose potential barriers to coho salmon although they may be accessible to steelhead up to about 12% at 20% it is highly unlikely any salmonids will be present. Much of these segments that could be accessible to steelhead are subject to subsurface flow in summer months.

Conditions and Response Potential

Coarse Sediment: Moderate Response Potential
Accumulations of coarse sediment are found primarily in LWD forced gravel bars. The gravel bar abundance is common but mainly associated with the LWD distribution in the channels. Currently the channels show evidence of down-cutting. However, the high gradient of the channels produces high stream power that creates high coarse sediment transport capacity. Coarse sediment deposited in these channels typically does not stay stationary for long, with the exception of the largest most competent particles.

Fine Sediment: Low Response Potential

Accumulations of fine sediment were not frequently observed in this unit. Fine sediment accumulations varied from sparse to moderate primarily on the top of gravel bars. The entrenched and high gradient channel promotes high fine sediment transport and little fine sediment deposition due to concentrated stream power within confined channels.

Large Woody Debris: High Response Potential

LWD in this unit was observed to force storage of coarse sediments. The areas of down-cut channels in this unit would likely benefit and stabilize with increased large woody debris loading do to increased sediment storage capacity raising the elevation of the stream bed.

Stream Conditions and Response for Stream Channels below Mendocino Redwood Company Ownership in the Willow and Freezeout Creek Watersheds

The primary focus of the stream channel analysis is the condition and response of stream channels to forest management on the MRC ownership of Willow and Freezeout Creeks. However, MRC does not own the property around the lowest most stream channels in the watersheds. In Freezeout Creek approximately 1 mile of low gradient fish bearing stream is below the MRC ownership prior to entering the Russian River. In Willow Creek approximately 3 miles of low gradient stream channel receives inputs from the stream channel network of the MRC ownership.

Freezeout Creek

In Freezeout Creek the bottom most 1 mile of stream, below the MRC ownership, is low gradient with stream gradient less than 1 percent. The channel appears entrenched within streamside terraces with some interaction with a floodplain. Anadromous salmonids use this low gradient reach for spawning and rearing habitat as no known barriers exist on lower Freezeout Creek. The end of anadromous fish on Freezeout Creek is at or near the MRC property line. The end of anadromous fish usage corresponds with a significant change in stream gradient just as Freezeout Creek leaves the MRC ownership (segment SF1). The stream gradient of Freezeout Creek is so steep at this location (greater than 30 percent gradient) that fish passage is impossible. An unnamed tributary to Freezeout Creek (SF10) has anadromous fish use for approximately 800-900 feet until the gradient steepens significantly with a series of rock and LWD created waterfalls making fish migration impossible.

The lower 1 mile of Freezeout Creek, due to its low gradient, is a depositional reach for sediment and LWD. The boulder cascade channels coming out of the MRC ownership will not likely provide delivery of LWD. LWD is important in these high gradient reaches for its sediment storage capability but the boulders in the channel coupled with a narrow canyon will likely trap mobile LWD making downstream transport of LWD unlikely. Sediment (fine and coarse) will be transported out of the MRC ownership where it can deposit in lower Freezeout Creek. Consideration of the inputs of coarse and fine sediment within the Freezeout Creek watershed is important so to not adversely impact the lower 1 mile of low gradient stream habitat on Freezeout Creek.

Willow Creek

Approximately 3 miles of low gradient (less than 1 percent gradient) stream channel of Willow Creek is below the MRC property in the Willow Creek watershed. A high amount of stream aggradation is occurring in the lower Willow Creek channels with the source of the high sediment coming primarily from what is now the MRC ownership. A combination of high sediment inputs from past management practices in the watershed and poor channel conditions to transport that sediment has resulted in significant stream channel aggradation between the 2nd and 3rd bridges along the County Road on lower Willow Creek (Trihey and Assoc., 1995). The aggradation is significant enough to limit fish migration above the aggraded reach. Indeed, fish migration is probably only likely in certain favorable streamflow conditions.

Trihey and Associates (1995) stated that high sediment delivery from the upper watershed is expected to continue. Our observations support this conclusion. A high amount of sediment is stored in streamside terraces, particularly in stream geomorphic unit II along Willow Creek. This sediment is going to be eroded out of these upper reaches over time contributing sediments downstream. Considerable channel down-cutting was observed in tributary channels of Willow Creek. The bank erosion and down-cutting of tributary channels (Trihey and Associates referred to this as forested gullies) is a fairly high source of sediment in the upper Willow Creek watershed (Trihey and Assoc., 1995). The majority of the Willow Creek watershed is composed of Franciscan melange geology. This type of geology has high erosion and sediment rates associated with it. The naturally high geologic erosion rate from the Franciscan melange will likely contribute sediments affecting the lower channel reaches.

The aggradation of the lower channel of Willow Creek has created conditions such that high flows that in the past would stay confined in a channel transporting stream sediments now spread out onto the floodplain, reducing the ability to scour sediments from the aggraded channel. Streamflow has been observed to be almost completely diverted out of the channel during high flows between the 2nd and 3rd bridges (Trihey and Assoc., 1995).

The aggradation of the lower channel also creates conditions that increase the frequency of high water flows accessing the floodplain. This increase in flooding will likely continue until a channel can form or be restored that will route both the sediment and water loads from Willow Creek.

The combination of high sediment inputs and low sediment transport capacity has lead to the conclusion that the lower Willow Creek channel will likely continue to aggrade (Trihey and Assoc., 1995). The solution that seems to have the best merit for restoration of the Willow Creek is a combined approach of reducing sediment inputs from the upper watershed and restoring the sediment transport capacity of the lower channel. Without both parts being accomplished the likelihood of Willow Creek to be restored for anadromous fish spawning and rearing is unlikely. This will be extremely challenging given that cost effective solutions may not be easily found.

Long Term Stream Monitoring

During the Summer of 2000 a long term channel monitoring segment was surveyed for thalweg profiles, cross sections, stream gravel permeability and stream gravel composition along Willow Creek. This was the first year that this data was collected, so there is no temporal or comparative analysis that can be done. This represents the base line condition for future monitoring. The plots of the surveys are included in the appendix of this module (Appendix E) for display. The results of the stream gravel bulk samples and permeability are presented in section F - Fish Habitat Assessment of this report.

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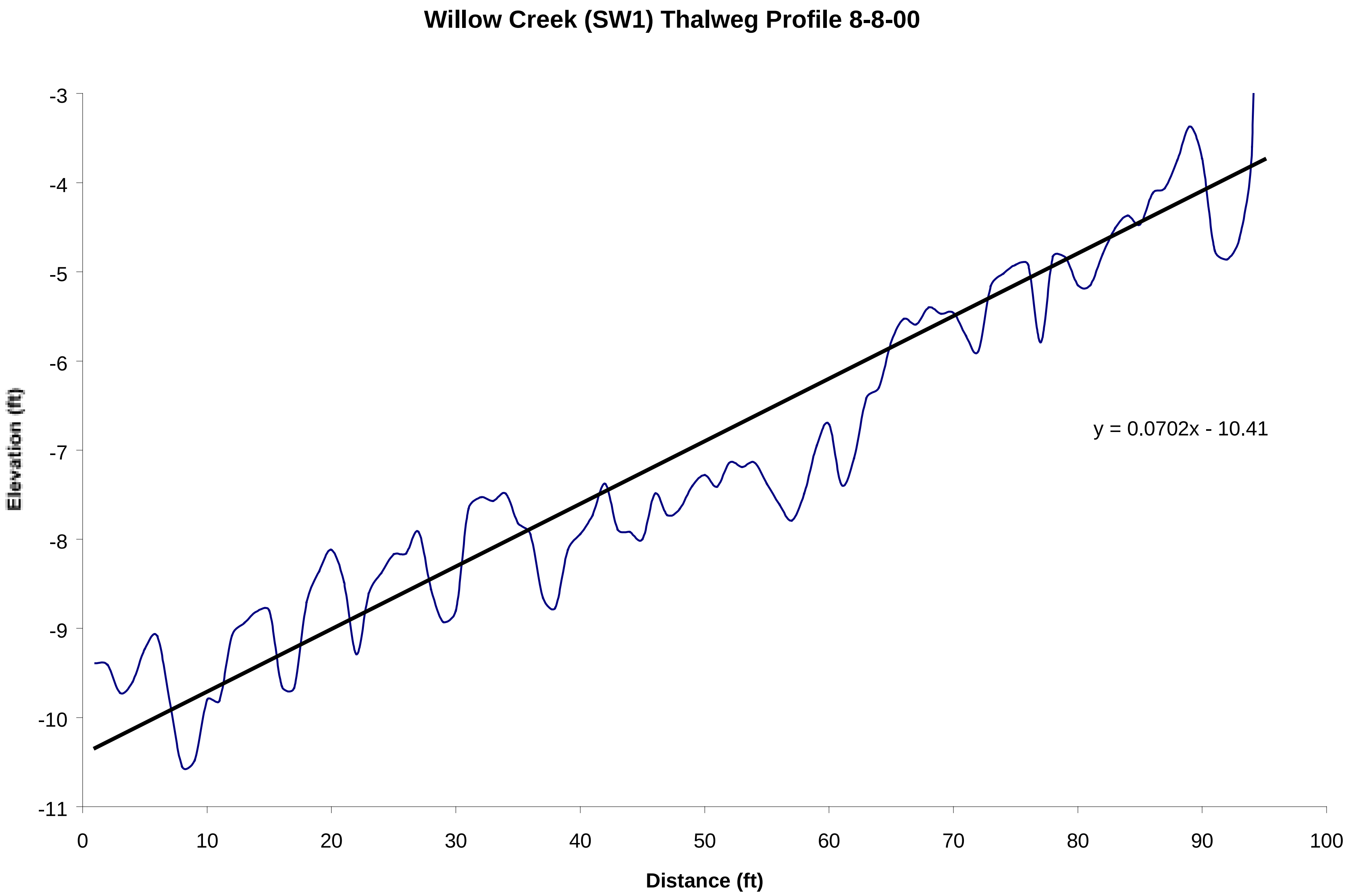
Appendix E

Stream Channel Condition Module


Willow Creek (SW1) Thalweg Profile 8-8-00
Elevation (ft)
-3
-4
-5
-6
-7
-8
-9
-10
-11
0
10
20
30
40
50
60
70
80
90
100
Distance (ft)
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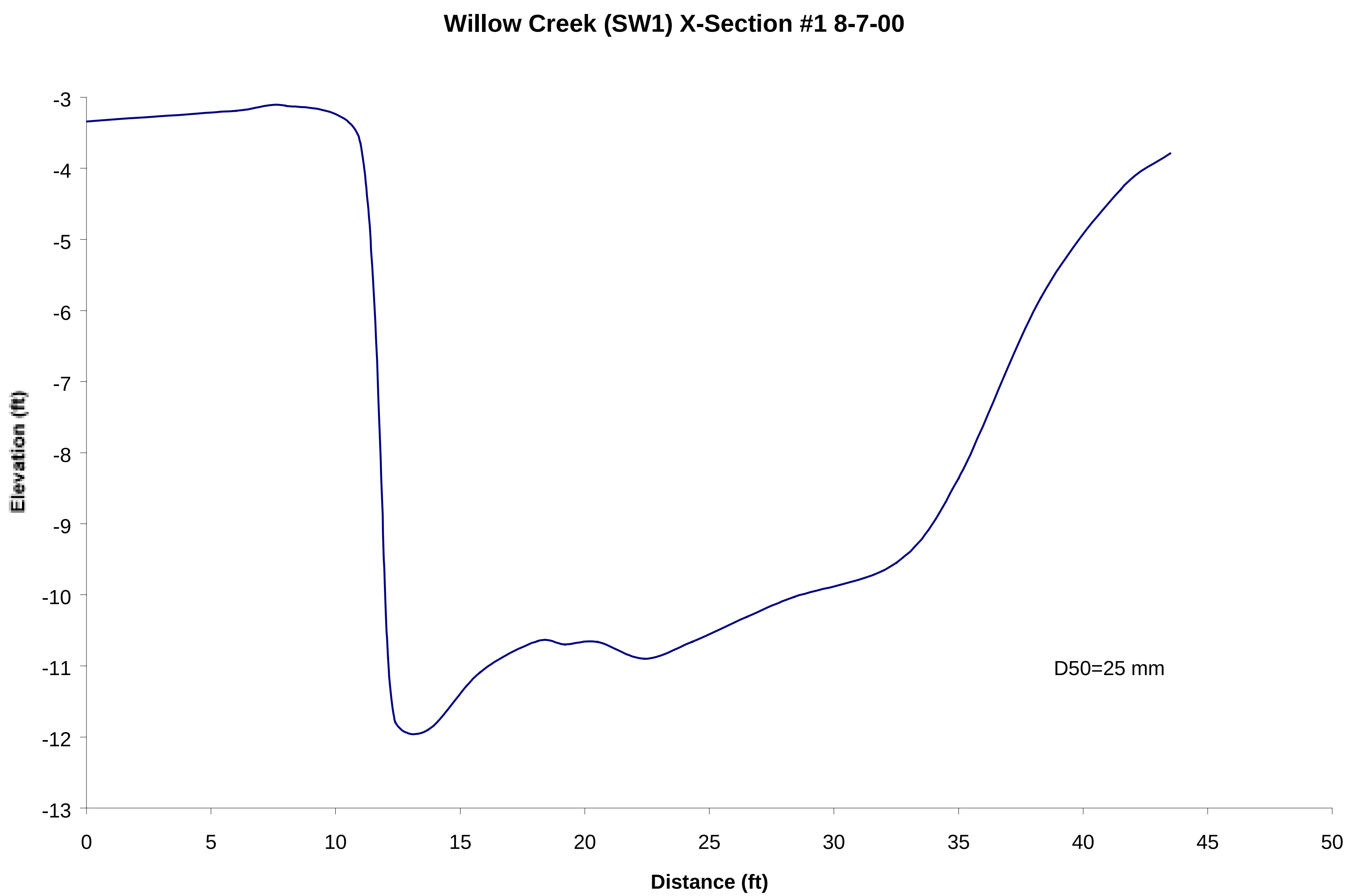
Willow Creek (SW1) X-Section #1 8-7-00
Elevation (ft)
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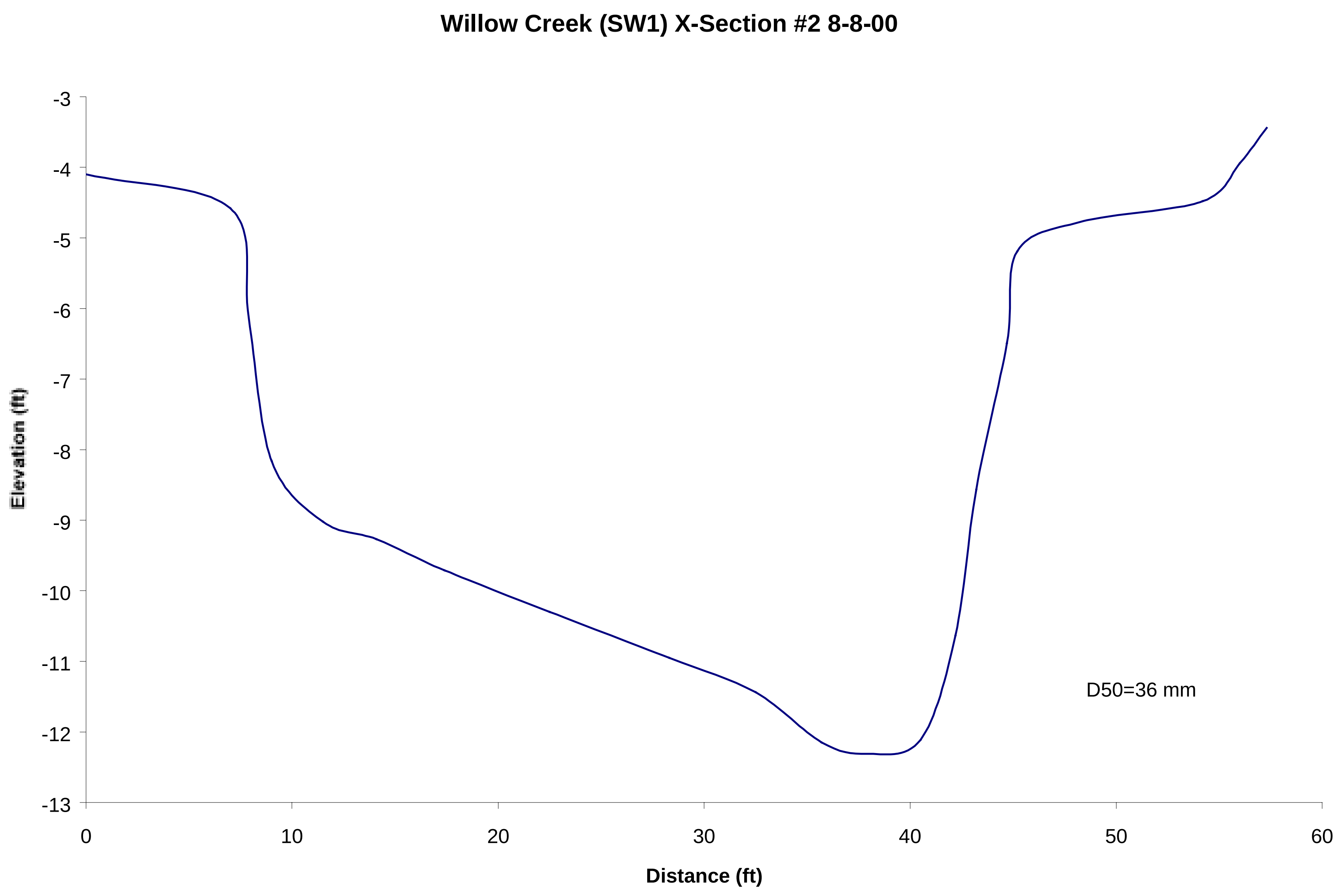
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
0
5
10
15
20
25
30
35
40
45
50
Distance (ft)
D50=25 mm



Willow Creek (SW1) X-Section #2 8-8-00
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
Elevation (ft)
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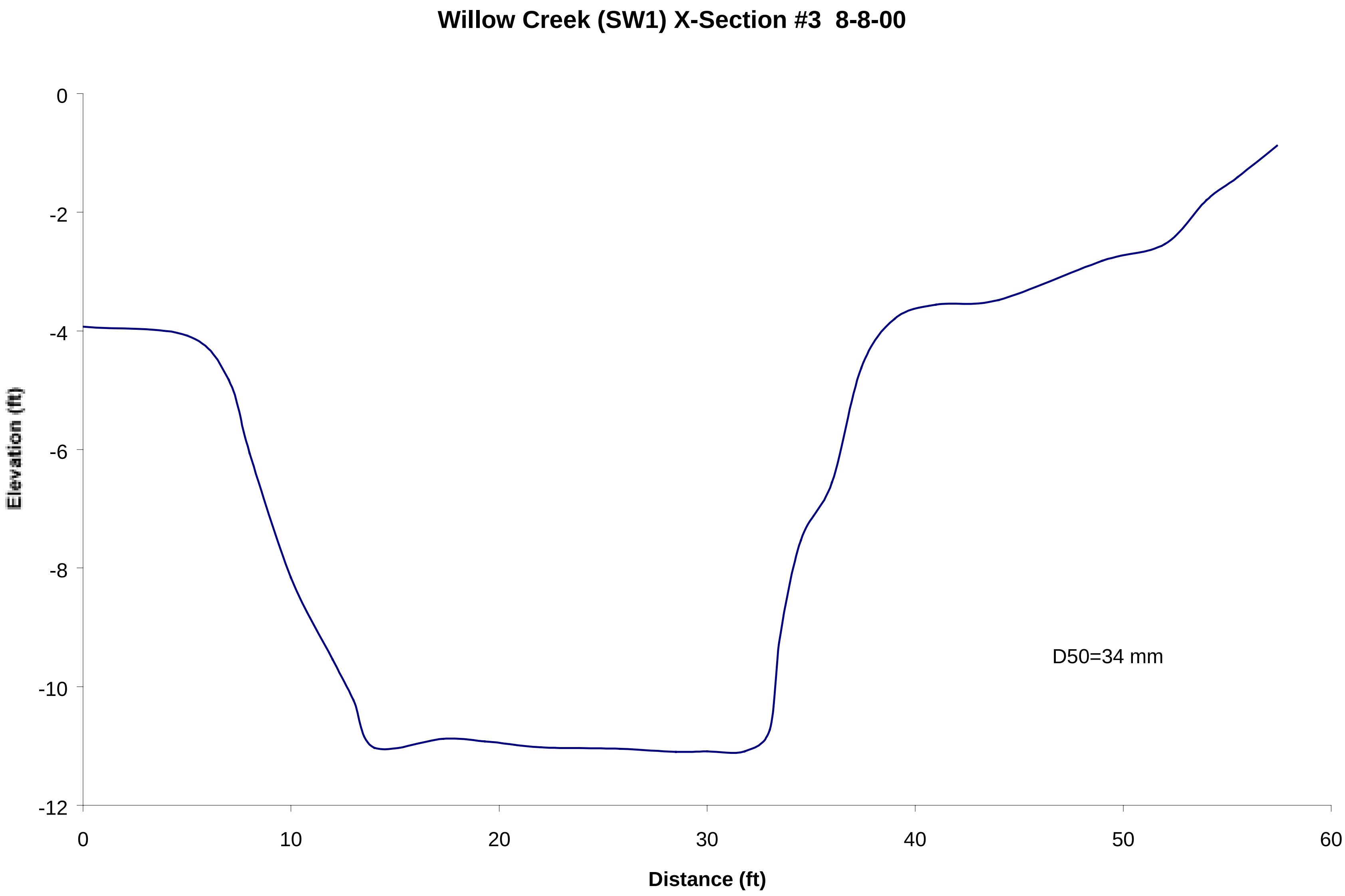
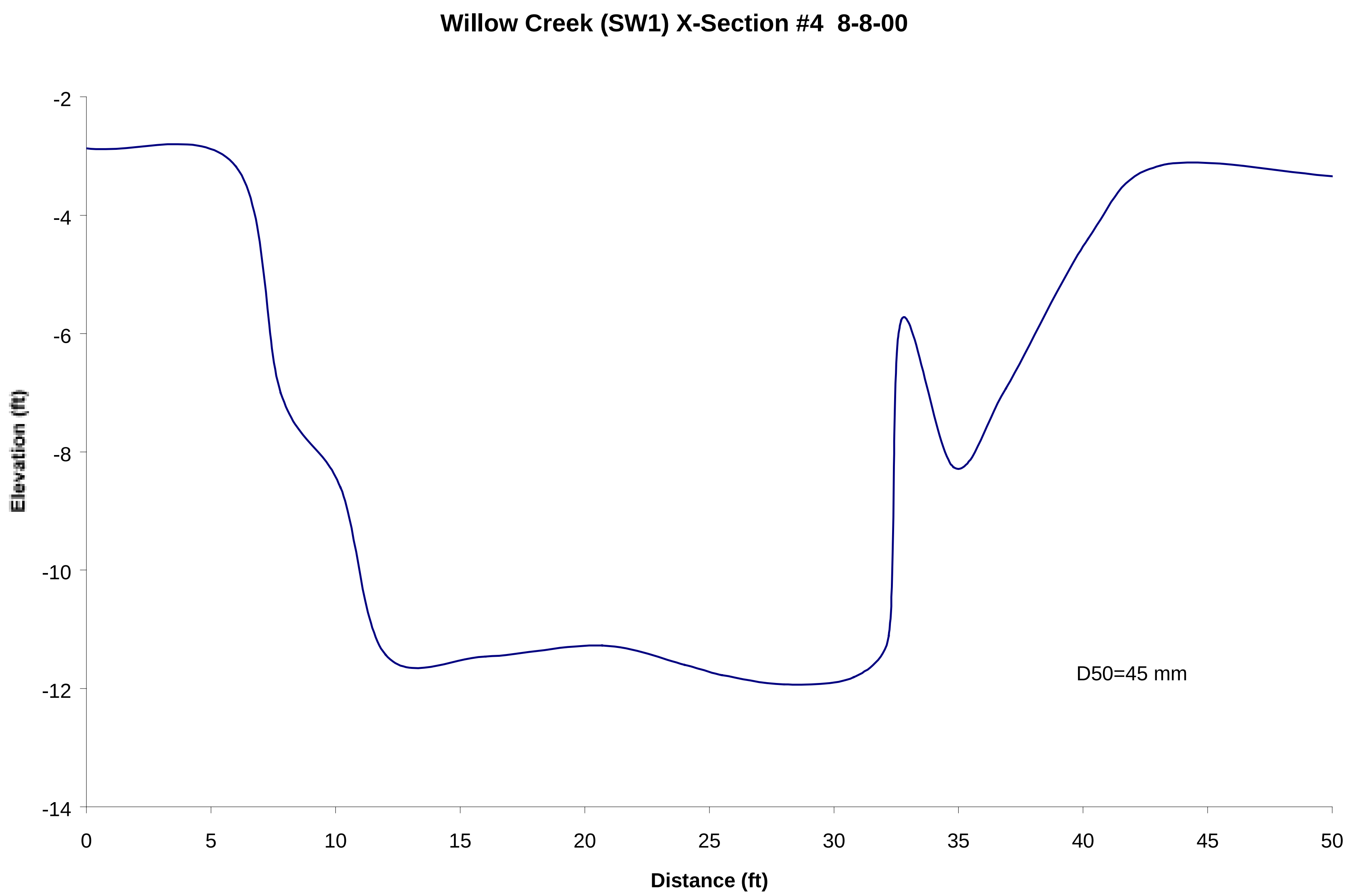
10
20
30
40
50
60
Distance (ft)
D50=36 mm



Willow Creek (SW1) X-Section #3 8-8-00
0
-2
-4
-6
-8
-10
-12
Elevation (ft)
0
10
20
30
40
50
60
Distance (ft)
D50=34 mm



Willow Creek (SW1) X-Section #4 8-8-00
Elevation (ft)
-2
-4
-6
-8
-10
-12
-14
0
5
10
15
20
25
30
35
40
45
50
Distance (ft)
D50=45 mm

Section F

Fish Habitat Assessment

Introduction

The Anadromous fish species inhabiting the Willow/Freezeout Creeks WAU are steelhead trout (*Oncorhynchus mykiss)* and coho salmon (O. kisutch). Other non-salmonid species include northern pikeminnow (*Ptychocheilus grandis*), sculpin (*Cottus* spp.), three-spine stickleback (Gasterosteus *aculeatus),* California Roach (*Lavina symmeticus),* Sacramento Sucker (*Castomus occidentalis)* and pacific lamprey (*Lampetra tridentata)*. A level II fish habitat assessment was conducted in the Willow/Freezeout Creeks WAU to identify the current habitat conditions and areas of special concern regarding the three life stages of salmonids: spawning, summer rearing, and overwintering.

Willow Creek drains a watershed of approximately 8.8 square miles. Elevation ranges from about 4 feet at the mouth of the creek to 2,900 feet in the headwater area (CDFG 1995). The upper to mid sections of Willow Creek are in steep-sided canyons. The lower section opens into a wide U shaped depositional valley comprised of a marsh-like environment. This habitat is subject to tidewater influence daily. High water temperatures in this marshy lowland create poor summer rearing habitats for salmonids.

Field surveys conducted to evaluate the quality and quantity of fish habitat in the Willow/Freezout Creek WAU include fish habitat assessment, stream temperature monitoring, stream gravel permeability measurements, and bulk gravel samples. The evaluation of fish habitat conditions is based on target conditions presented in the Watershed Analysis Manual (Version 4.0, Washington Forest Practice Board), the Louisiana–Pacific Watershed Analysis Manual, the California Salmonid Stream Restoration Manual and on inherent geomorphic characteristics of the stream. The target conditions for pools, wood, and fine sediment defined in these manuals are based on research of unmanaged drainages, technical studies, and professional judgement by fisheries biologist.

Stream temperatures were monitored to obtain average temperature conditions. Stream temperature monitoring has been conducted in Willow/ Freezeout Creek WAU since 1990 and sites were monitored through 2000. Relevant to fish, stream temperature regimes are an important aspect to consider when evaluating salmonid summer rearing habitat. A primary assumption for stream temperature monitoring is that increases in stream temperature conditions are associated with streamside shade canopy conditions. Streamside shade canopy affects local air temperature, solar radiation, and relative humidity. Stream temperature information is summarized in the riparian module of this watershed assessment.

Permeability and bulk gravel composition samples were taken in a fish bearing reach of the Willow/Freezeout Creeks WAU, SW1, to establish baseline quality of spawning gravel and to monitor overtime. Permeability and gravel particle size distributions are stream substrate parameters, which affect survival of incubating salmonid embryos. Salmonid eggs buried under as much as a foot of gravel depends on sufficient intra-gravel water flow for their survival and development. Fine sediment within spawning gravel can impede intra-gravel water flow, reducing the delivery of dissolved oxygen to eggs, which can increase mortality in the egg to emergence stage. Forest management practices may increase the delivery of fine sediment to the stream channel, potentially impacting spawning gravel. The assessment of substrate permeability and composition are useful in monitoring the effects of increased sediment delivery on salmonid spawning and incubation conditions.

Aquatic species distribution surveys were conducted within the Willow/Freezeout Creeks WAU conducted from 1994-1996 and repeated in the summer of 2000. Surveys were conducted in the summer months to assess present juvenile salmonid distribution and composition as well as collecting information on other fish species and stream dwelling amphibians.

Steelhead Trout

Steelhead (*Onchorhynchus mykiss)* migrate upstream to spawn during the winter. Steelhead begin entering spawning streams in October and November and continue through February and March. The mainstem and major tributaries of Willow Creek and Freezeout Creek provide the primary portion of steelhead spawning and rearing habitat. Smaller tributaries were observed inaccessible to fish because of waterfalls and characterized by steep gradient and high confinement limit the availability of habitat for anadromous fish.

After completing their upstream migration, adult females construct redds for spawning by excavating gravel four to twelve inches deep and fifteen inches in diameter (Needham and Taft 1934; Shapovalov and Taft 1954). Redds are oval-shaped depressions excavated by the tail of a female. Suitable gravel for steelhead spawning ranges in size from one quarter of an inch to five inches in diameter (Barnhart 1991). Eggs are deposited in excavated depressions. Gravel that has been cleaned and sorted through the excavation process is used to cover the eggs. Male steelhead fertilize the eggs during the redd construction process and aggressively defend the area against other males. Redd construction takes place in pool tail-outs or riffle heads where water is the most oxygenated. Incubation time for eggs is temperature dependent and ranges between twenty and 100 days (Roelofs 1985: Barnhart 1991). Adult steelhead are capable of returning to the ocean and spawning again in subsequent years, although some die after the first year of spawning.

Fry emerge at approximately 25 to 30mm from egg pockets with egg sacks on their ventral surface. During this time, areas of low velocity (shallow water habitats such as stream margins and low gradient riffles) are preferred. Foraging takes place in open areas lacking instream cover (Hartman1965; Everest et al. 1986; Fontaine 1988). In the late summer and fall, fry increase in size and habitat preference changes to higher velocity, deeper mid-channel pools (Hartman 1965; Everest and Chapman 1972;Fontaine 1988). Juvenile steelhead, also called parr, rear in freshwater from one to four years before migrating to the ocean as smolts. Parr show a preference for habitat with rocky substrates (Hartman 1965; Fausch 1993). Foraging typically occurs in scour and plunge pools where there is more cover and higher velocity. Steelhead are opportunistic feeders, utilizing the roughness element provided by boulders and log clusters to rest and pick off food as it drifts in the current (Fontaine 1988; Bisson et al. 1988).

During the winter, steelhead prefers pool habitats; especially deeper low velocity pools with rocky substrate and LWD for cover (Hartman1965; Fontaine 1988). The size of substrate preferred differs, depending on age class. Fry are able to make use of small to large cobble substrate for cover while parr tend to use large cobbles and boulders (Everest et al. 1986). During the winter months deeper pools with cover are preferred because they prevent displacement of fish during high flows.

Coho Salmon

Coho Salmon (*O. kisutch*) begin entering streams in mid-December and continue through mid-February. Similar to steelhead, the mainstem and major tributaries provide a majority of the habitat for coho because steep channel gradients and high channel confinement limit habitat in smaller tributaries. Lack of LWD, high summer stream water temperatures and low structural complexity are factors that can limit the ability of coho to maintain viable populations.

Females arriving on spawning grounds select redd sites and defend the area against other females. Like other salmonids, females excavate a depression in the gravel by using their tail. The preferred spawning locations for coho are low gradient (<3%) tributary streams. Egg pockets in coho redds are 20 to 47 in. wide and 4 to 9 in. deep (Tautz 1977, van den Berghe and Gross 1989). Optimum gravel particle size is 1.3 to 10.2 cm (Stilllwater 1998). Females continue to guard the redd against other females until they are too weak to maintain their position in the current (Briggs 1953). Males and females die soon after spawning. Coho salmon eggs incubate from 35 to 50 days at temperatures of 9°C to 11° C (Shapovalov and Taft 1954).

Juvenile coho salmon select habitat primarily based on water velocity, although light intensity and depth are also considerations (Shirvell 1990). After emergence, fry disperse upstream and downstream into areas of suitable habitat. Usually, side channels and backwaters or other areas of slow velocity and low light intensity are utilized during the rearing period (Stillwater 1998). Coho juveniles typically use woody debris as cover, rather than rock and other substrate, which is primarily used as cover by steelhead parr (Bugert 1985).

One of the primary components of rearing habitat for coho is LWD. In addition to providing shelter, LWD promotes scour, which lead to deeper pools. In coastal northern California streams, the presence or absence of LWD has an overwhelming influence on the suitability of the stream for rearing coho. McMahon and Reeves (1989) have suggested that LWD is a “keystone” feature for salmonids because of its dominating influence on stream morphology (e.g. bank condition, pool creation), sediment and organic matter retention, water velocity and shelter (Stillwater 1998).

Deep pools are an important habitat feature for juvenile coho salmon during the summer months. These pools provide cold water refugia. In the winter months, deep pools prevent displacement of young fish. The ideal pools for coho have slow areas with woody cover, logs, rootwads and flooded brush. Deep pools, which are structurally complex, offer juveniles the most protection from predation and displacement in swiftly moving current.

Historic Perspective

The oldest stream survey on record for Willow Creek is a survey done in the summer months of 1962, by the California Department of Fish and Game (CDFG). The CDFG also conducted stream surveys in the summer months of 1965, 1970, 1982 and 1995. According to the 1995 CDFG Stream Inventory Report, CDFG has surveyed areas covering the mouth to the upper forks, a total area of 6.0 miles from 1962 to 1995. Juvenile fish census data indicate coho and steelhead were present in the watershed between 1962 and 1990 (CDFG, 1995).

Early surveys (1962,1965) results showed good to excellent pool rating. Larger, deeper pools were found in lower areas. Pools averaged 20 feet in length, 6 feet in wetted width, and 2 feet in depth. These early surveys recorded good to excellent instream cover for its entire length, with small logjams and undercut banks predominating. The 1962 stream survey reported steelhead trout and silver salmon throughout most of the watershed.

CDFG’s later surveys (1970, 1982) indicated pool depth and width decreased, particularly in the lower section. In the 1970 stream survey, surveyors observed a decline in canopy particularly in the upper reaches. CDFG attributed the cause of decline to the land use practices, which created many logjams from high amounts of “slash,” introduced into the upper portion of the drainage. By the 1982 stream survey, the riparian canopy in the upper section had improved to a second growth alder/bay forest. Shelter in the lower section of Willow Creek consisted of thin strips of willows and alders with blackberries on either side of the creek.

In February 1988, DFG, Trout Unlimited and L-P representatives walked the stream to look at the impacts of pre L-P ownership logging practices. Here, it was decided that the storm of 1982 was responsible for the massive slides that introduced a heavy load of fine-grained sediment into the stream. Early logging was also noted as contributing to the severity of these slides (CDFG 1995).

It is believed that logging in Willow Creek started in the 1850's. In 1890, narrow gauge railroad was constructed in the stream channel and ran to the headwaters. In order to construct the rail system, it was likely that large trees that had naturally fallen into and "obstructed" the channel were removed. Sections of the narrow gauge rail can be found in the streambed today. Steam donkey engines were used to facilitate the extraction of logs. Logging occurred again starting in the 1950's and progressing through the 1970's. Aerial photographs illustrate the interconnecting network of skid trails; landings and roads were common to tractor logging of that era. Logging occurred in extensive areas of the watershed, including the inner gorge. Roads were developed for ranch access and general transportation in addition to logging purposes. The unimproved Willow Creek road, which provides the only access through the valley remains in a high state of erosion. This road is unpaved. Sonoma County maintains the Willow Creek road.

Juvenile Surveys

In 1962, juvenile coho salmon and steelhead were found throughout the mid-lower, mid and upper sections up to the rock falls (CDFG 1995)(end of Segment SW3). The rock falls reach a height of approximately 50 feet, presenting an obvious barrier for fish passage. CDFG, in 1962, reported the lower section to contain low concentrations of salmonids while containing abundant numbers California roach and Sacramento sucker. Here, pools contained coho in schools of fifteen to twenty (CDFG 1995). A 1965 survey conducted by CDFG resulted in the most abundant residence of three-spined stickleback and less abundant numbers of steelhead and coho presence. Of the coho salmon found, the (1+) size-class was most numerous. Northern pikeminnow (*P. grandis*) and Sacramento sucker (*C. occidentalis*) presence was also noted by CDFG in 1965. The 1970 stream survey indicated spawning gravels to be extremely embedded for stream length entirety. This embeddedness was thought to consist of heavy deposition by detritus and silt. The 1982 CDFG Stream Inventory Report detected no coho in Willow Creek. Young of the Year (YOY) steelhead were the only salmonid species observed here by CDFG in that years survey effort.

Louisiana-Pacific Corporation conducted multi-pass depletion electrofishing surveys. An Upper and Lower site were electrofished from 1990-1994 (Map F-1). In 1990,1992 and 1993 the Willow Creek watershed had almost equal numbers of steelhead represented in the 0+ and 1+ age classes. The only year that had many more fish in the 0+ age class was 1991. Steelhead biomass at the Willow Creek-Lower site increased from 1.4 g/m2 in 1990 to 2.8 g/m2 in 1993. This site was not monitored in 1994. At the Willow Creek-Upper site, steelhead biomass decreased from 3.1g/m2 in 1990 to 0.8g/m2 in 1993. In 1994, biomass was up to a high of 4.3g/m2. Coho were found at the Willow Cr.- Upper site in 1990 only. Seventeen coho with lengths ranging from 52-70mm were found. Biomass was calculated as 1.3g/m2. A note should be made that although this watershed was surveyed for five years, coho were last found in 1990 at the upper monitoring site. In this case, fish from 1990 would be returning in 1993 and none were detected at either Willow Creek site during this year.

Adult Surveys:

In the 1960's surveys, the spawning area of Willow Creek was estimated as good to excellent throughout, with the exception of the upper forks where the rock falls created a fish barrier. The 1970 survey resulted in poor ratings for spawning habitat due to high silt concentrations in the stream below the forks. However, redds were observed above the forks in the North Fork where spawning gravels were more plentiful and less embedded. In December 1980, the Sonoma County Water Agency and the Dept. of Fish and Game noted ten logjams on Willow Creek. All jams were causing erosion and all were located above the second bridge. A particular log jam (stream mile 2.8) caused a large mud slide and completely blocked the original stream channel causing the stream to alter it's course and run out over adjacent fields. However, YOY steelheads were still observed, by CDFG, above this area. In 1995, CDFG conducted a spawning/carcass survey in the upper and lower reaches of Willow Creek. The Upper site, resulted in findings of several redds and gravel quality was rated as fair habitat. In the lower site, large quantities of fine sediment were observed on the inside edge of gravel bars. High bank erosion was encountered at a large bend and numerous cattle crossing the creek was observed (CDFG 1995).

Methods

The habitat inventory method used to evaluate the habitat condition of the Willow/Freezeout Creeks WAU is a modified version of survey methods in the California Salmonid Stream Habitat Restoration Manual (Flosi et. al.) Stream segments were created based on stream gradient and channel confinement (see Stream Channel Condition module). Other factors included the presence of fish, accessibility, stream channel type (response, transport or source reach), and representative segments that were likely to respond similar to other stream channel types within the watershed. Since high gradient streams were likely to be non-fish bearing, survey efforts were concentrated on low gradient reaches of the streams.

A survey was conducted in seven stream segments of Willow/Freezeout Creeks WAU. SW1, SW2, SW2 (2) and SW3 were located in the mainstem of Willow Creek. SW20 was located in the North Fork of Willow Creek. SW23 was located in the Unnamed Tributary to Willow Creek SF10 was located in an Unnamed Tributary to Freezeout Creek. Habitat inventory methods were surveyed for 100% of the wetted width, a distance of 20-30 bankfull widths in length to ensure that at least two meander bends of the stream channel were observed. In addition to survey length, the length of the channel (beyond the designated survey length) was walked, taking note of any change in habitat. Data collected during the fish habitat and stream channel surveys provided information on pool frequency, pool spacing, spawning gravel quantity and quality, overwintering substrate, shelter complexity, and large woody debris (LWD) frequency, condition and future recruitment.

Stream gravel permeability and bulk gravel samples were collected on one stream monitoring segment in the Willow Creek watershed (SW1, similar segment for thalweg profile and cross section surveys). The stream gravel permeability was measured using a 1 inch diameter stand-pipe similar to the stand-pipe discussed in Terhune (1958) and Barnard and McBain (1994) with the exception that our stand-pipe is smaller in diameter. We used the smaller diameter stand-pipe because we hypothesize that it will create less disturbance to the stream gravels when inserted. Bulk stream gravel samples were taken with a 12 inch diameter sampler as described in Platts, Megahan and Minshall (1983).

The monitoring segment for permeability had a total of 7 pool tail-outs and was approximately 20-30 bankfull channel widths in length. Permeability measurements were taken in all 7 pool tail-outs and bulk gravel samples were taken in the first 4 pool tail-outs. At each pool tail-out permeability was measured at 6 sites randomly selected from a grid of 12 sample points. Permeability measurements were taken at a depth of 25 cm. A bulk gravel sample was taken on the permeability site closest to the thalwag of the channel (the deepest spot). The bulk gravel sample was taken to a depth of 33 cm to ensure collection of gravel below typical salmon spawning depths.

After the bulk gravel samples were collected the gravel is dried and sieved through 7 different size-class screens (45, 22.4, 11.2, 5.6, 4, 2, 0.85 mm). The weight each gravel size class was determined for each of the bulk gravel samples using a commercial quality scale. From the sieved bulk gravel samples the fredle index, geometric mean and percent fine particles less than sieve size classes were determined. The survival index for steelhead trout was calculated from the bulk gravel samples using the method described in Tappel and Bjorn (1983). An index calculated from data from Tagart (1976) and McCuddin (1977) (Stillwater Sciences, 2000) was used to estimate survival to emergence from permeability data.

The primary survey method for aquatic species distribution surveys was electrofishing using a Smith-Root Model 12 (Smith-Root Inc., Vancouver, WA) backpack electrofisher. One person operated the backpack electrofisher while one or two other individual(s) used dip nets to capture the stunned species. The captured specimens were placed into a five-gallon bucket containing stream water. When the survey time ended, aquatic species were enumerated, measured to fork length (salmonids) or total length, or snout vent length for amphibians and released back into the units from which they are captured. If stream water temperature was in excess of 70° Fahrenheit (21° Centigrade) the units were snorkeled. All fish and vertebrate species were identified to the lowest possible taxonomic level.

Snorkeling was used to assess species presence at stream segments where the channel was large enough to preclude electrofishing or where elevated stream temperatures had the potential to adversely impact the health of the animals being electrofished. The basic survey unit for snorkeling consisted of a minimum of three pools, however if riffles were deep enough to allow underwater observation these units were sampled. Depending on the channel width, one to four divers were used for the field surveys. The diver(s) entered the survey unit from the downstream end, and waited approximately one-half to one-minute at the downstream end of the survey unit before proceeding upstream to observe species. If the water velocity is too excessive for diver(s) to proceed upstream, then the survey unit would be snorkeled by floating downstream. Dive slates are used to record data underwater. During the survey time, salmonid species were enumerated by age-class according to pre-determined size-age class categories (0 = <70mm, 1+ = 70 – 140mm, 2+ = >140mm). All other fish and vertebrate species observed during the field surveys were identified to the lowest possible taxonomic level, recorded and enumerated.

Table F-1 displays the indices used for rating measured parameters. Measured fish habitat parameters were weighted and given a numeric scale to develop a quality rating for individual life history stages. Parameters were divided into subsets that correspond with individual life history stages (spawning, summer rearing, and overwintering habitat). Parameters were scored as follows: 1 (poor), 2 (fair), and 3 (good). Parameter weights were applied to the total score calculated as shown below. The parameter numbers are in bold and the weights in parentheses.

The overall score would be rated as follows:

Spawning Habitat

E (0.25) + **F** (0.25) + **G** (0.25) + **H** (0.25)

Summer Rearing Habitat

A (0.20) + **B** (0.15) + **C** (0.15) + **D** (0.15) + **F** (0.15) + **I** (0.20)

Overwintering Habitat

A (0.20) + **B** (0.15) + **C** (0.15) + **D** (0.10) + **I** (0.20) + **J** (0.20)

The overall score would be rated as follows:

1.00 - 1.66 = Poor
1.67 - 2.33 = Fair
2.34 - 3.00 = Good

TableF-1. Fish Habitat Condition Indices for Measured Parameters

Fish Habitat Parameter	Feature	Fish Habitat Quality Poor	 Fair	 Good
Percent Pool (Of survey site length) **(A)**	Anadromous Salmonid Streams	<25%	25-50%	>50%
Pool Spacing (Reach length/bankfull/#pools) **(B)**	Anadromous Salmonid Streams	≥ 6.0	3.0 - 5.9	≤ 2.9
Shelter Rating (Shelter value x % Of habitat covered) **(C)**	Pools	<60	60-120	>120
% Of Pools that are ≥3 ft. residual depth **(D)**	Pools	<25%	25-50%	>50%
Spawning Gravel **(E)**	Pool Tail-outs Quantity	<1.5%	1.5-3%	>3%
Percent Embeddedness **(F)**	Pool Tail-outs	>50%	25-50%	<25%
Subsurface Fines (L-P watershed analysis manual) **(G)**	Pool Tail-outs	2.31-3.0	1.61-2.3	1.0-1.6
Gravel Quality Rating (L-P watershed analysis manual) **(H)**	Pool Tail-outs	2.31-3.0	1.61-2.3	1.0-1.6
Key LWD +Rootwads / 328 ft. Of Stream **(I)**	Streams≤40 ft. BFW	<3.3	3.4-6.7	>6.8
	Streams ≥40 ft. BFW	<5	5.1-10	>10.1
Substrate for Over-wintering **(J)**	All Habitat Types	<20% of Units Cobble or Boulder Dominated	20-40% of Units Cobble or Boulder Dominated Units	>40% of Units Cobble or Boulder

Results

Tables F-2, F-3 and maps F-1, F-2 summarize the 2000 fish habitat assessment data. Map F-1 displays the current fish distribution for the Willow/Freezeout CreeksWAU with barriers to anadromy marked. Map F-2 illustrates the potential anadromous fish use by life history stage. Table F-2 presents the scores and ratings for each fish habitat parameter. A weighted average of physical parameters was used to develop the rating for each segment's current condition for the three life stages; spawning, summer rearing and overwintering listed in Table F-3.

Spawning Habitat

All seven segments contained the exact same ratings for spawning indices E, F, G and H. Spawning gravel scored >3% and quality rated as "Good." Embeddedness scored as >50% with a habitat rating of "poor." Quality of gravel was rated and scored as being "fair." Subsurface fines were scored and rated as "fair" habitat for spawning.

The four segments surveyed in the mainstem of Willow Creek (SW1, SW2, SW2(2), and SW3) ranged between 0-3% slope. Spawning habitats rated "fair" in all four segments. The remaining three segments (SW20, SW23 and SF10) also rated as "fair."

Owl Creek, SW20, was given an overall spawning score of 2.0 and an overall rating of "fair." The stream gradient of this site was 7-12%.

For the unnamed tributary to Willow Creek, SW23, an overall rating of "fair" was calculated. The stream gradient of this site was between 3-7%.

For the unnamed tributary to Freezeout Creek, SF10, an overall rating of 'fair" was also applied to the segment evaluation. The stream gradient of this site ranged from 3-7%.

Summer Rearing

Of the seven segments surveyed none were rated as "good" habitats for summer rearing. Four of the total seven segments were given "fair" ratings. The remaining three segments were given "poor" ratings. The summer rearing indices for embeddedness was continually given a score of >50% resulting in a "poor" rating for all seven segments. The indices for % pools with residual depth greater than or equal to 3 feet was also rated as "poor" for all seven segments as there were virtually no pools found in Willow Creek greater than 3 foot in depth. Key LWD per 328 ft. rated "poor" for six of the seven segments. The remaining segment, SW2(2) was rated "good" for Key pieces of LWD. These three indices factored into the six variable equations for summer rearing.

SW1 and SW2 were calculated with scores that gave them overall ratings of "fair" for summer rearing. SW1 was also the only segment to contain a pool with a residual depth greater than 3 feet in depth. This did not affect overall rating; it just reconfirms the lack of deep pool depths in Willow Creek.

SW2(2) was given an overall rating of “fair.” SW2(2) had the only “good” rating for Key LWD loading (6.8 pieces/100 meters) of any of the segments surveyed.

SW3 was given a summer rearing habitat score of 1.15, the lowest of any segment surveyed. The overall rating is “poor.” Percent pool and pool spacing was inadequate in this reach, any restoration in this segment should focus on pool development.

Segment SW20 was given an overall rating of “fair.” SW20 only received a “good” rating for pool spacing.

Segment SW23, unnamed tributary to Willow Creek, received an overall rating of ”poor.” Pool spacing was “good” but percent pools by length were very low. Key LWD was rated “poor” as no wood was recorded for this segment.

Segment SF10 was rated as “poor” habitat for summer rearing.

Overwintering Habitat

Of the seven segments surveyed for overwintering habitat, SW3 was given a “poor” habitat rating. All other segments received an overall rating of “fair” overwintering habitat.

SW2 (2) and SW3 each had no overwintering substrate in the channel. SW2 (2) and SW3 also did not have any pools with a residual depth greater than 3 feet. SW2 (2) had a shelter rating of “poor.” SW2(2) received the only “good” rating for presence of Key LWD. This “good” rating for large woody debris allowed SW2(2) to receive an overwintering score 1.80, higher than SW3, resulting in its “fair” not “poor” rating. SW3 in addition to not having good instream shelter did not have high percentage of pools per segment length. SW3 was a confined channel containing long sections of riffles. Of the few pools present, spacing was poorly rated with a score of 6.2.

SW20 was rated as “fair” habitat for overwintering. SW20 had no overwintering substrate. SW20 also did not have the presence of more than 3.1 pieces of Key LWD’s in the stream channel. SW20 was rated as having a “fair” % of pools by stream length with “good” pool spacing. Shallow pools and lack of wood for pool scours inhibited this section from having the conditions needed to be a “good” habitat.

SW23 had an abundance of overwintering substrate with a score of 100%. SW23 also had a “good” amount of pool spacing within its segment length. However, SW23 did not have any Key LWD nor did it contain any pools with a residual depth greater than three feet. SW23 was rated as having “fair” habitat conditions for overwintering.

Table F-2. Summary of Fish Habitat Parameters, with Scores and Corresponding Ratings. Willow/Freezeout Creeks Watershed Analysis Unit, Sonoma county, CA, Summer, 2000.

Segment	**A.** % Pool by stream length		**B.** Pool Spacing		**C.** Shelter rating		**D.** % of all pools with residual depth ≥3 ft.		**E.** Spawning gravel quantity		**F.**% Embeddedness		**G.** Sub-surface fines		**H.** Gravel Quality		**I.** Key LWD + rootwads / 328 ft.		**J.** % Over-wintering substrate	
	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating
SW 1	78	Good	1.7	Good	84	Fair	7.7	Poor	>3	Good	3	Poor	2	Fair	2	Fair	1.3	Poor	15	Poor
SW 2	54	Good	1.9	Good	53	Poor	0	Poor	>3	Good	4	Poor	2	Fair	2	Good	2.6	Poor	7	Poor
SW 2 (2)	46	Fair	3.0	Fair	59	Fair	0	Poor	>3	Good	3	Poor	2	Fair	2	Good	7.2	Good	0	Poor
SW 3	20	Poor	6.2	Poor	78	Fair	0	Poor	>3	Good	3	Poor	2	Fair	2	Good	2.8	Poor	0	Poor
SW 20	35	Fair	2.7	Good	64	Fair	0	Poor	>3	Good	3	Poor	2	Fair	2	Good	3.1	Fair	0	Poor
SW 23	20	Poor	2.3	Good	72	Fair	0	Poor	>3	Good	3	Poor	2	Fair	2	Fair	0.0	Poor	100	Good
SF 10	42	Fair	4.8	Fair	81	Fair	0	Poor	>3	Good	3	Poor	2	Fair	2	Good	2.6	Poor	23	Fair

Table F-3. Summary of Fish Habitat Ratings for Three Life History Stages. Willow/Freezeout Creeks Watershed Analysis Unit, Sonoma county, CA. 2000.

Segment	Slope gradient class (percent)	Spawning habitat score	Spawning habitat rating	Rearing habitat score	Rearing habitat rating	Over-wintering habitat score	Over-wintering habitat rating
SW 1	0-3%	2.00	Fair	1.85	Fair	1.85	Fair
SW 2	0-3%	2.25	Fair	1.70	Fair	1.70	Fair
SW 2 (2)	0-3%	2.25	Fair	1.70	Fair	1.80	Fair
SW 3	0-3%	2.25	Fair	1.15	Poor	1.15	Poor
SW 20	7-12%	2.25	Fair	1.85	Fair	1.85	Fair
SW 23	3-7%	2.00	Fair	1.45	Poor	1.85	Fair
SF 10	3-7%	2.25	Fair	1.50	Poor	1.70	Fair

SF10 received a “poor” rating for indices D, F, I, and J. SF10 was rated as a “fair” habitat for the indices A, B, and C. Thus, SF10 was rated as an overall “poor” habitat for overwintering.

SW1 and SW2 were the only two segments to receive “good” ratings for both pool spacing and % pool by stream length. However, SW1 and SW2 rated as “fair” habitats for overwintering due most likely to the lack of LWD and shallow pools.

The results from the bulk gravel samples and permeability measurements are presented in Table F-4. Percent survival-to-emergence indices for spawning gravel were calculated from the bulk gravel samples and permeability samples. The Tappel/Bjorn index (1983) was used to calculate survival-to-emergence from the bulk gravel samples. The index for percent survival of steelhead was used because Tappel and Bjorn (1983) only present two survival indices for chinook salmon and steelhead trout. The steelhead index was used because it more closely approximates the fishery in the Noyo WAU, coho salmon and steelhead trout. Chinook salmon are larger fish than coho or steelhead and can spawn in larger substrate making the index based on Chinook salmon impractical for Willow Creek. An index calculated from data from Tagart (1976) and McCuddin (1977) (Stillwater Sciences, 2000) was used to estimate survival to emergence from permeability data. This index is not robust and additional work is needed, but it is useful for interpreting permeability information.

The estimated percent survival of emerging steelhead, from Tappel and Bjorn (1983), varied from 62% to 83% with one sample being calculated at 0% (Table XX-1). The survival-to-emergence index calculated for the permeability data showed survival rates that ranged from 37% to 55% (Table F-4). The mean survival to emergence rate for all tail-outs from permeability data is 49%. These survival indices reflect conditions at pool tail-outs where a spawning fish has not worked the gravel into a redd. Therefore they reflect the relative quality of stream gravels that a spawning fish has to work with. Areas of stream gravels with a high survival percentage would likely be preferred by spawning fish and likely have better survival success for emerging fish. Areas of stream gravels with a low survival index percentage may not be completely poor quality, particularly because they will have permeability and gravel quality improved following redd development, but likely will not be the preferred condition.

Generally, the percentage of fine sediment (<0.85 mm) was not found to be high in the Willow Creek tail-outs except for 1 tail-out. Three bulk gravel samples had percent fine particles less than 0.85 mm under 8 percent, which is considered within a properly functioning range, especially considering that when a fish spawns a significant portion of these fines will be cleaned. However one tail-out had 16% fine particles less than 0.85 mm, which is not desirable for spawning. Fredle indices and the geometric means for the sampled locations were low, however, when a spawning fish works stream gravels these values will change.

We feel the use of permeability as the indicator of current stream gravel quality is the better indicator of conditions necessary for developing fish embryos. In most of the laboratory studies of fish emergence from incubating eggs, survival is related to the proportion of fine particles or the size class distribution of the gravel fish embryos are developed in. These measures are used to indicate the ability of water borne nutrients and dissolved oxygen to reach the embryos. Therefore, measures of fine particles or size class distribution indices, etc. are surrogates for gravel permeability. Direct measure of the permeability conditions that occur in the stream gravels is the best indication of this quality. When using permeability as an indicator of spawning gravel quality in Willow Creek, the results suggest improvement needed for the quality of spawning gravels.

Table F-4. Bulk Gravel Sample and Permeability Measurements for Willow Creek Monitoring Segment (SW1).

Pool Tail-out Number	Percent <0.85 mm	Geometric Mean	Fredle Index	Percent Survival (Tappel/Bjorn)	Mean Permeability (cm/hr)	Percent Survival (from permeability)
1	5%	4.8	0.7	85%	10,518	55%
2	7%	2.8	0.4	70%	10,358	55%
3	16%	3.0	0.2	0%	6,202	47%
4	8%	3.6	0.3	62%	5,523	46%
5	-	-	-	-	8,059	51%
6	-	-	-	-	3,263	38%
7	-	-	-	-	3,098	37%

Discussion

A fish habitat assessment is intended to evaluate stream reaches for the presence and overall health of three types of anadromous salmonid habitats: spawning, summer rearing and overwintering. Habitat limitations on production during the freshwater portion of their life history are typically found in one of these habitat types (CDFG 1994). No single component of habitat quality can effectively reflect overall habitat conditions because different life stages use different types of microhabitats. Integration of the quality of many habitat components provides a better understanding of overall habitat conditions. The seven survey segments (SW1, SW2, SW2 (2), SW3, SW20 SW23 AND SF10) will be discussed in the following text according to these three respective life history stages.

Spawning Habitat

A good habitat for spawning is dependent on variables such as: sufficient number of gravels, quality of gravel (size and distribution in the tailout of a pool), amount of fines predominating and the amount at which the present gravels are embedded in sediment. If fines and sediment are depositing at a fast rate, cementation of spawning gravels occurs. Cementation confines the gravels to anoxic conditions, no longer filtering dissolved oxygen through multiple layers of gravel and cobble.

In the Willow/Freezeout Creeks WAU, all segments exhibited an abundance of spawning gravel with high levels of embeddedness and a moderate amount of fine sediment. In each case, the habitat was rated as a “fair” habitat for spawning. Willow Creek contains many segments with pools moderately to heavily filling in with fines. It is believed that this is due in part, to erosional activity occurring along the banks of Willow Creek. However, in each case, cementation was not yet a problem, as gravels were still loose and aerated. These gravels are thought to remain aerated due to the abundant presence of spawning gravels still remaining in pool tail-outs. In the unnamed tributary to Freezeout Creek, SF10, the gradient and good cobbles were thought to aid in the filtering out of sediment but the channel was still moderately filling in with fines. Thus, it had fair habitat for spawning.

In segment SW2 (2,) two consecutive slides had resulted, exposing predominately sandy soil, continually introducing fines and sediment to the channel below. In segment SW23, a slide located on the left bank of the survey segment has introduced gravel, cobble and fines into the channel below. The rock falls were located in survey segment SW23 and reached a height of approximately 50 feet, thus creating an obvious barrier for fish passage and spawning any further along this section of the creek.

Summer Rearing Habitat

Summer rearing habitat conditions for salmonids are evaluated on the availability of pools, sizes of pools, embeddedness of gravels and the complexity and quantity of cover (particularly large woody debris) in the channel.

The limiting factors for providing a “good” habitat for summer rearing involve embeddedness, Key LWD and pool depth greater than 3 ft. For all seven segments, embeddedness was greater than 50%. As fine sediment rises, spaces between cobbles fill in, smoothing out the floor of the streambed. Filling of the streambed eliminates cobble surface area. This eliminates spaces between cobbles. This results in loss of habitat for macro-invertebrates, a food source for rearing salmonids and loss of instream shelter for small parr avoiding predation.

Six of the seven segments received “poor” ratings for Key pieces of LWD. Key LWD with debris jams only exceeded more than 3 key pieces in one segment. LWD provides instream shelter and refuge from predation. LWD also creates scour thus providing depths to pools for further shelter and refugia. The scouring process also helps to clean and sort gravels improving quality of salmonid spawning habitat. LWD has the potential to provide the stream with much needed nutrients by introducing detritus and/or capturing detritus in its porous cambium and providing habitat for larval stages of macro-invertebrates. Of the 68 total pools surveyed in all seven segments only one pool exceeded 3 ft in residual depth. This result is directly related to lack of wood creating scours and the influx of sediment embedding and filling in pool depth.

Rearing habitats in segments SW1, SW2, SW20 and SW2(2) rated “fair,” while SW3, SW23 and SF10 rated “poor.” Segments SW1 and SW2 have a high frequency of pools, which increased their rating to “fair.” However, all segments lacked pool depth, Key LWD and high % embeddedness, which prevented any ratings from being “good”. SW2 (2) was the only segment to exhibit a “good” amount of Key LWD however, this did not affect its pool depth and shelter rating from being “poor.” It is believed that erosional activity has contributed to the “filling in” of pools. This is supported by the fact that only segment SW1 has a singular pool exceed 3 feet at its residual depth and overall subsurface fines for all seven segments were rated as fairly depositing.

Overwintering Habitat

Overwintering habitat is evaluated on the availability of deep pools, pool cover, the presence of backwater and side channels, proportion of habitat units with cobble-or boulder-dominated substrate and the presence of riparian vegetation. Riparian vegetation can provide water velocity refugia during overbank flow events in moderately confined to confined channels. Riparian vegetation can also introduce much-desired nutrients from insects to detritus matter. Fish cannot overwinter in the main current of the channel with out objects that provide a roughness element that can break up the flow of the direct current. Fish will overwinter off-channel where water velocity is less vigorous and large boulders and trees are most likely to sit thus creating back water eddies for refugia to help prevent displacement.

In Willow Creek, the limiting factors inhibiting a “good” habitat rating were the lack of overwintering substrate, key LWD and pool depth.

Overwintering habitats in segments SW1, SW2, SW2(2), SW20, SW23, and SF10 rated “fair,” while SW3 rated as “poor” habitat. Thus Willow/Freezeout Creeks WAU provides a better overwintering than a summer rearing habitat for salmonids.

Segment SW23 contained the only “good” rating for overwintering substrate. An abundant piling of LWD at the confluence with Mainstem Willow Creek was thought to be the result of a massive slide ~ 200ft above the confluence. Although this slide introduced a fair amount of fines and poorly embedded gravels, it also introduced rootwads, LWD and significant amounts of cobble and boulders. Overall, SW23 was rated “fair” due in part to LWD not being of “Key” size and sediment loading decreasing pool presence and pool depth.

The presence of backwater eddies in the root scour pools of SW1 and SW2 provided key locations for overwintering. However, fine deposition kept the pools from having any depth for fish utilize as sanctuary from wintertime flows. SW1 was also impacted with a “poor” rating for instream shelter. SW1 and SW2 remained “fair” habitats for overwintering.

Segment SW2 (2) also rated “fair” for overwintering. SW2 and SW2 (2) were the only segments to receive “poor” ratings for shelter. However, SW2(2) was the only segment to receive a “good” rating for the presence of Key LWD. A slide on the Right Bank ~445 ft above the confluence with SW23 introduced fallen trees and sediment into the channel. A second slide, ~150 above the first slide also occurred. Shallow pools, moderately filling with fines could be a result of this slide. These two consecutive slides could be the distinguishing factors affecting the “good” rating for wood loading. However, these two slides could also be the distinguishing factors hindering SW2(2)’s overall rating from being “good” wintering grounds.

SF10 is a cobble/boulder dominated stretch of the watercourse with LWD littered throughout. High gradient and lack of deep pools may deter potential of this segment for fish utilization for overwintering.

SW3 was rated “poor” for every indices but shelter rating. SW3 was a confined channel with no off channel habitat. There was little wood loading for cover and long riffle sections did not allow for a break in water velocity. These resulting factors deterred the surveyor from rating the segment as “good” or even “fair” habitat for overwintering.

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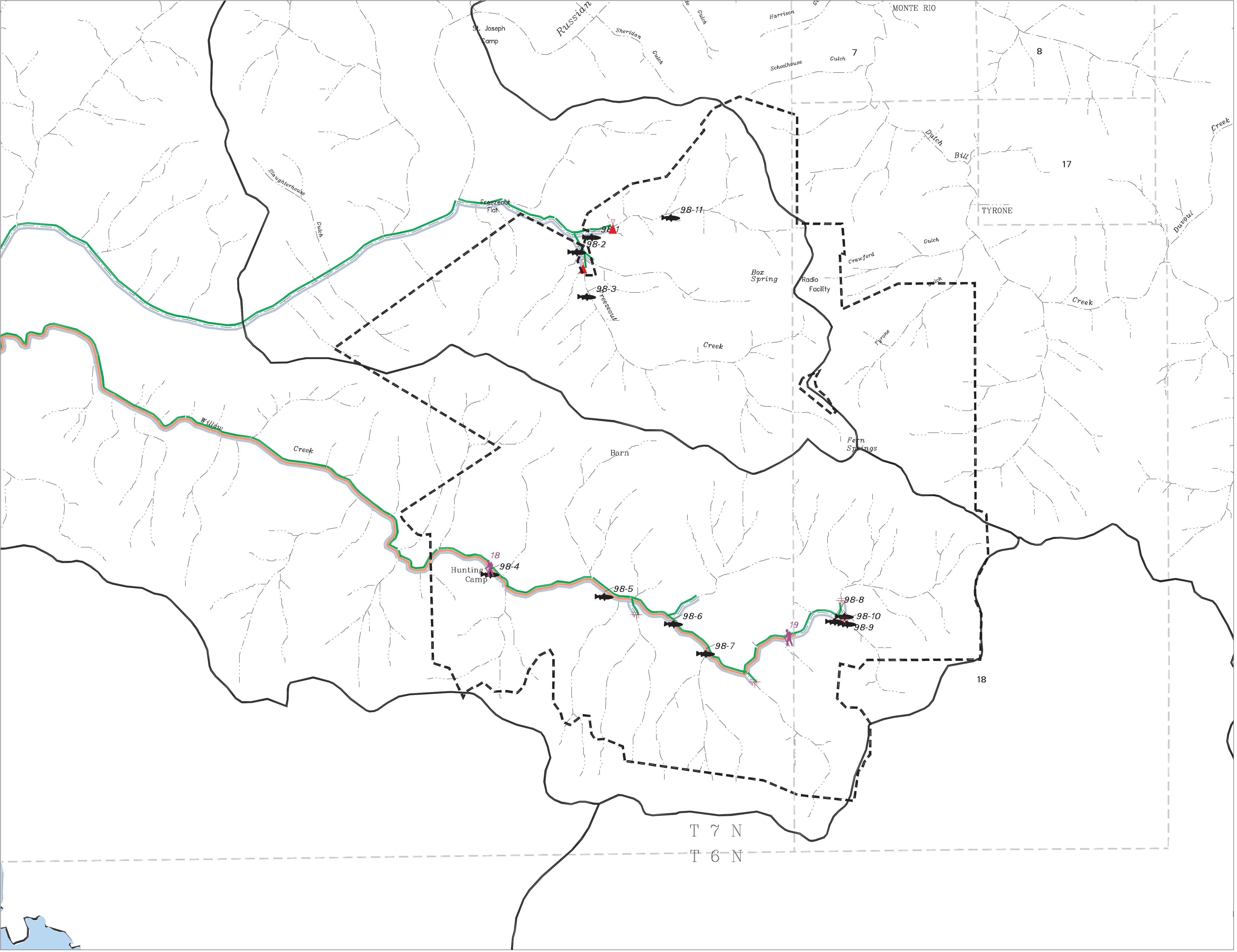
Willow Creek / Freezeout Creek Watershed Analysis Unit

Map F-1 Potential Fish Distribution



Potential Fish Distribution

- Coho Salmon Distribution
- Steelhead Distribution
- Non-Salmonid Fish Distribution
- Fish Distribution Sampling Locations
- Fish Index Monitoring Sites

Barriers to Adult Migration

- Gradient
- Waterfall

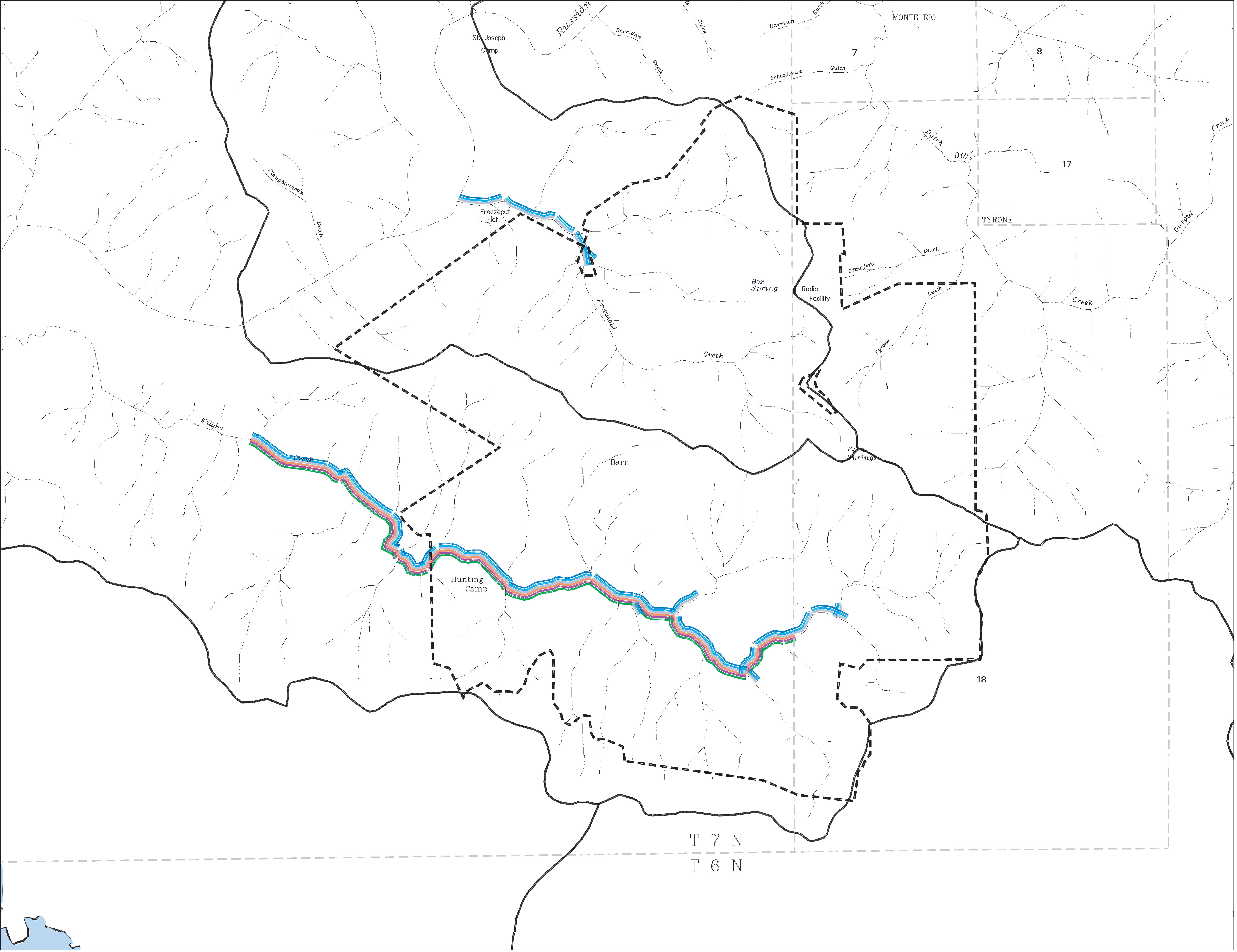
Flow Class

- Class I
- Class II
- Class III

- MRC Ownership
- Planning Watershed Boundary

0 1/2 1 Mile

February 16, 2001



Willow Creek / Freezeout Creek Watershed Analysis Unit

Map F-2 Potential Anadromous Fish Habitat and Life History

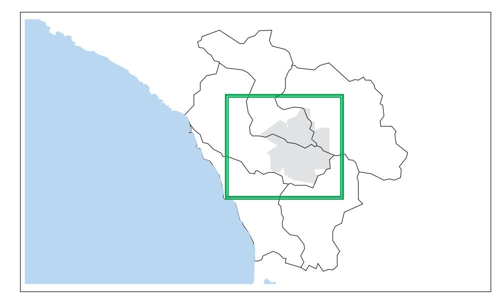
Present Habitat Usage by Salmonid Life History Phases

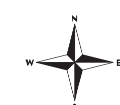
- Coho Spawning
- Coho Rearing
- Coho Over-Wintering
- Steelhead Spawning
- Steelhead Rearing
- Steelhead Over-Wintering

Flow Class

- Class I
- Class II
- Class III

- MRC Ownership
- Planning Watershed Boundary





0 1/2 1 Mile

February 16, 2001

Section G

SEDIMENT INPUT SUMMARY

Introduction

The estimated sediment inputs for the Willow/Freezeout Creeks WAU have been summarized and are presented. The purpose of this summary is to determine the relative amount of different sediment sources, determine priorities for erosion control, and assist in interpretation of stream channel conditions in relation to sediment deposition and transport. A sediment budget provides quantification of sediment inputs, transport, and storage in a watershed (Reid and Dunne, 1996). In this case we are not doing a true sediment budget, only an estimation of the sediment inputs. However, this estimation is useful for source analysis, numeric targets, and allocation of responsibility as needed in a Total Maximum Daily Load (TMDL) for 303(d) listed rivers, such as the Russian River where the Willow/Freezeout Creeks WAU is located. However, care must be used when interpreting these estimated values; by no means can the estimates be considered absolute. Rather, sediment input estimates are best interpreted for relative comparisons between processes and planning watersheds.

This section combines and summarizes sediment input results from the Mass Wasting and Surface and Fluvial Erosion modules of the watershed analysis for the Willow/Freezeout Creeks WAU. Sediment input for the Willow/Freezeout Creeks WAU is estimated from mass wasting, road surface and fluvial erosion, skid trail erosion and gully erosion. The sediment inputs have been estimated for the past fifty years (1950-2000).

Sediment Inputs

The major sediment inputs in the Willow/Freezeout Creeks WAU over the last 50 years have come from mass wasting, road associated surface and fluvial erosion, skid trail associated surface and fluvial erosion and gully erosion. The breakdown of estimated sediment inputs is presented by watershed for the Willow/Freezeout Creeks WAU (Table G-1).

A high amount of sediment inputs are estimated for Willow Creek watershed in the 1950s and 1960s, primarily from skid trail and gully erosion. Mass Wasting is highest in Willow Creek during the 1980s when the largest storms on record created a large amount of debris slide failures. Sediment inputs for mass wasting were only estimated for the past 30 years and road associate erosion for the last decade. However, to provide context for the last 50 years the average rate of erosion for roads and mass wasting was extrapolated for comparison to the gully and skid trail estimates. This extrapolation show gully erosion as the highest contributor (34%) with roads as the lowest (16%)(Table G-2).

Table G-1. Estimated Sediment Inputs by Watershed and Decade for the Willow/Freezeout Creeks WAU.

Watershed by Decade	Road Assoc.Fluvial and Surface Erosion (tons/sq mi/yr)	Skid Trail Assoc. Erosion (tons/sq mi/yr)	Gully Erosion (Trihey) (tons/sq mi/yr)	Mass Wasting (tons/sq mi/yr)
Willow Creek				
1950s	n/a	322	260	n/a
1960s	n/a	368	260	n/a
1970s	n/a	38	260	25
1980s	n/a	89	260	548
1990s	119	29	260	110
Freezeout Creek				
1950s	n/a	36	n/a	n/a
1960s	n/a	77	n/a	n/a
1970s	n/a	16	n/a	2
1980s	n/a	311	n/a	266
1990s	138	4	n/a	217
Dutch Bill Creek				
1950s	n/a	0	n/a	n/a
1960s	n/a	181	n/a	n/a
1970s	n/a	8	n/a	0
1980s	n/a	161	n/a	0
1990s	68	0	n/a	40

Table G-2. Proportion of Sediment Inputs by Process for the Willow/Freezeout Creeks WAU, 1950-2000.

Watershed	Road Assoc. Fluvial and Surface Erosion *	Skid Trail Erosion	Gully Erosion (Trihey)	Mass Wasting **
Willow Creek	16%	22%	34%	27%
Freezeout Creek	35%	23%	n/a	42%
Dutch Bill	44%	45%	n/a	10%

* - 1990s estimate used to extrapolate 1950-1990 inputs
** - 1970-2000 estimate use to extrapolate for 1950-1970 inputs

The highest amount of sediment inputs for Freezeout Creek watershed occurred in the 1980s. This is from a high amount of tractor yarding creating skid trail associated erosion and a high amount of mass wasting from large storm events that decade. The proportion of erosion is fairly evenly spread between mass wasting, skid trail and road erosion for Freezeout Creek watershed. However, mass wasting is the largest contributor (42%) in the Freezeout Creek watershed. The land in Dutch Bill Creek primarily has the sediment inputs split between road and skid trial with some mass wasting erosion as well.

The estimated proportion of sediment inputs for the Willow/Freezeout Creeks WAU is an average of process inputs over the last 50 years (see Table G-2). The estimates are not necessarily indicative of future inputs, rather it provides an indication of where protections or restoration should be emphasized. Particularly, the skid trail estimates should be considerably lower over time because much of practices that created the high skid trail erosion amounts are no longer used.

Literature Cited

Reid, L. and T. Dunne. 1996. Rapid evaluation of sediment budgets. Catena Verlag GMBH. Reiskirchen, Germany.

Section H

Causal Mechanisms and Prescriptions

Introduction

The following Causal Mechanism Reports and Prescriptions were specifically prepared for use in the Willow/Freezeout Creeks Watershed Analysis Units (WAU). These prescriptions are meant to help address issues for the entire watershed to aid in the stewardship of aquatic resources of the Mendocino Redwood Company ownership in the Willow/Freezeout Creeks WAU. The prescriptions are meant to be used in addition to the current California Forest Practice Rules and company policies. At the time of the publication of this watershed analysis the forest management policies are governed by interim guidelines prior to the issuance of a Habitat Conservation Plan and Natural Community Conservation Plan (HCP/NCCP). Once the HCP/NCCP is approved then the conservation strategies set forth in these documents will become the company policies. A prescription is only presented if it deviates from these regulations or policies.

The land management prescriptions presented here are the protections that Mendocino Redwood Company will pursue to provide protection of aquatic resources. In addition to these prescriptions Mendocino Redwood Company will build and maintain all of its roads at high design standards such as presented in the Handbook for Forest and Ranch Roads (Weaver and Hagans, 1994).

The causal mechanism reports present the situations where watershed conditions are a likely source of a primary limiting factor. By addressing each of these situations with an appropriate prescription the situations that could impact sensitive resources will either be removed or their impact significantly lessened. This is to attempt to provide protection to watershed values from receiving significant or cumulative impacts from future management actions.

Monitoring will be conducted in the Willow/Freezeout Creeks WAU to ensure that these prescriptions are providing necessary protection to aquatic resources (see Section I, Willow/Freezeout Creeks WAU Monitoring Plan). This monitoring is part of an adaptive management approach that tests the hypothesized protections the prescriptions are developed to meet. If it is found that the prescriptions are not providing the appropriate protections, then they will be updated and improved.

Factors Limiting Salmonid Production in the Willow/Freezeout Creeks WAU

The watershed analysis performed in the Willow/Freezeout Creeks WAU identified several factors that likely limit the production of anadromous salmonids in those watersheds. This section summarizes these factors and potential linkages to sources of the limiting factors in the watersheds. The limiting factors considered are migration barriers, water quality, water quantity, sedimentation, temperature, large woody debris, and nutrients.

Table 1. Primary factors limiting salmonid production in the Willow/Freezeout Creeks WAU.

Anadromous Salmonid Life Stage	Factor	Reason	Current and Future Source(s)
Spawning	Fish migration barrier, Willow Creek.	High sediment inputs from past forest management activities and straightening of lower reaches of Willow Creek have created coarse sediment aggradation and resulted in adult fish migration barrier.	• Stored sediments in upper channel reaches. • Mass wasting from shallow and deep seated landslides. • Sediment delivery from point source erosion created from roads and skid trails. • Degradation and bank erosion in headwater streams.
Spawning	Fish migration barrier, Freezeout Creek.	Just within the MRC property the Freezeout Creek channel does not facilitate anadromous fish migration.	• Naturally occurring high gradient channel with cascades and waterfalls limits anadromous fish migration.
Rearing	Sedimentation	High sediment inputs from past forest management activities has filled pools and lowered the diversity of rearing habitat	• Stored sediments in upper channel reaches. • Mass wasting from shallow and deep seated landslides. • Sediment delivery from point source erosion created from roads. • Sediment delivery from skid trail erosion. • Degradation and bank erosion in headwater streams.
Rearing, Over-wintering	Large woody debris (LWD)	LWD need is high in the majority of the watercourses in the WAU. This limits pool formation, high flow refuge, habitat cover and sediment routing.	• Conifer trees adjacent to watercourses.
Rearing, Spawning	Water Quality	High erosion rates suggest a possibility of high fine sediment in transport in the watersheds increasing storm water turbidity.	• Surface erosion from roads and skid trails. • Point source erosion from roads and skid trails. • Bank erosion and stored sediments in stream channels.

The consideration of primary limited factors (Table 1) is based on conclusions drawn from the various modules of the watershed analysis performed in the Willow/Freezeout Creeks WAU. The land management prescriptions developed in this watershed analysis attempt to address the source(s) of the primary factors limiting salmonid production.

Causal Mechanism and Prescription Reports

Each Causal Mechanism Report and Prescription has specific headings to provide background on the watershed situation and prescription. The following is the description of these headings.

Resource Sensitive Area: the area encompassed by the prescription, the module describing the input process is referenced here.

Source Variable and Process: this briefly states what is the source variable of a primary limiting factor. These inputs can be both detrimental and beneficial to the aquatic resource.

Limiting Factor Vulnerability: this is the vulnerability of the limiting factor. See the appropriate modules (stream channel condition, riparian function or fish habitat) for justification of this vulnerability.

Delivered Hazard Rating: this is the relative hazard of inputs (sediment, wood, or heat) delivering or affecting the limiting factor being discussed. See the mass wasting, surface erosion, or riparian module for justification of these hazards.

Rule Call: the rule call is the guidance for the prescription. Rule calls of prevent mean that the prescription must prevent the action described in the situation sentence. A minimize rule call means that the prescription must minimize the action described in the situation sentence. A standard rule call means no prescription needs to be developed that Company Policy or standard California Forest Practice Rules will be utilized. The rule call is determined by using the limiting factor vulnerability and the input process in the rules matrix (Table H-1).

Table H-1. Rule Call Matrix for Prescription Development

		Likelihood of Adverse Change and Deliverability		
		Low	**Moderate**	**High**
Limiting Factor Vulnerability	**Low**	Standard	Standard	Standard
	Moderate	Standard	Minimize	Prevent
	High	Standard	Prevent	Prevent

Situation Sentence: presents the situation that will be addressed by the prescription.

Triggering Mechanisms or Issues: presents the list of management actions that could impact the identified input process or sensitive resource. These actions should be addressed by the prescription.

Prescriptions: specific land management actions for the proposed causal mechanism.

Causal Mechanism Report and Prescription #1

Resource Sensitive Area: Mass Wasting Map Unit (MWMU) 1
Stream Channel Geomorphic Units II, III and IV
See Mass Wasting and Stream Channel Condition modules

Source Variable(s) and Limiting Factor(s): Sedimentation from mass wasting and bank erosion.
Fish migration barrier from sediment aggradation in Willow Creek.
Water quality; turbidity from fine sediment.

Delivered Hazard Rating: High

Limiting Factor Vulnerability: High to Moderate

Rule Call: Prevent

Situation Sentence:
Small shallow seated landslides and bank erosion are common within the over-steepened slopes of the MWMU 1 topography. The immediate proximity of watercourses to these landslides provides direct delivery of fine and coarse sediment. Poor rearing habitat due to high coarse sediment levels is common in Willow Creek. Downstream aggradation and channel widening from coarse sediment in the downstream reaches of Willow Creek has created fish migration problems to the upstream habitat of Willow Creek. Fine sediment inputs are likely creating higher than natural turbidity during storm flows potentially affecting fish physiology, reduce feeding or in the worst cases increase mortality.

Triggering Mechanisms or Issues:
Road Construction
Road Placement
Timber removal
Ground yarding equipment and skid trails

Prescriptions:
MWMU 1 road placement, construction and management:
Road placement, construction and management:
- New road construction in MWMU 1 on slopes greater than 50 percent will not occur unless it is the only access available. If new road construction must occur on slopes of 50 percent slope or greater in MWMU 1 it will only be to gain entry in and out of MWMU 1 and construction developed with the approval of a Certified Engineering Geologist.
- Seasonal roads (gets used annually) in MWMU 1 will have the surface of new road construction or re-opened existing roads armored with rock.

- Temporary roads (roads only used periodically, every few years or decades) in MWMU 1 will be storm-proofed (such a suggested in Weaver and Hagans, 1994) prior to the winter period and the surface stabilized with grass seed, mulch or other cover product.
- Any road that is within MWMU 1 will not have winter period heavy truck or log hauling traffic unless armored with a rock surface.

Adjacent to Class I Watercourses:

- MWMU 1 will receive no harvest on inner gorge slopes unless approved by a California Licensed Geologist. On other areas (non-inner gorge slopes) within MWMU 1 in addition to the riparian protections set as company policy timber harvest must retain a minimum of 50% overstory canopy dispersed evenly across the slopes.
- The MWMU 1 protections will extend from the edge of the watercourse transition line up to the break in slope of the inner gorge and 25 feet slope distance after the break in slope of the inner gorge or a maximum of 190 feet.
- For those areas that do not have a well defined inner gorge topography in MWMU 1 protections will be 190 feet slope distance in width from the watercourse transition line. Timber harvest must retain 50% overstory canopy.
- The area of protection in MWMU 1 will be an equipment limitation zone (ELZ) except when slopes are less than 40%, or at designated crossings, or on established stable roads or tractor trails.
- The slopes of the inner gorge or the first 50 feet, whichever is longer, will be an equipment exclusion zone (EEZ) except for designated crossings and existing truck roads.
- The area directly adjacent to the break in slope of the inner gorge will retain those trees with a root mass that maintains the stability of that slope break.
- Trees within 10 feet of the bankfull channel will be retained, except for redwood clumps, at least 50% of the clump must be retained with emphasis on leaving the largest trees on the clump.

Adjacent to Class II watercourses:

- MWMU 1 will receive no harvest on inner gorge slopes unless approved by a California Licensed Geologist. On other areas (non-inner gorge slopes) within MWMU 1 in addition to the riparian protections set as company policy timber harvest must retain a minimum of 50% overstory canopy dispersed evenly across the slopes.
- The MWMU 1 protections will extend from the edge of the watercourse transition line up to the break in slope of the inner gorge and 25 feet slope distance after the break in slope of the inner gorge to a maximum distance of 150 feet. For those areas that do not have a well defined inner gorge topography in MWMU 1 protections will be 150 feet slope distance in width from the watercourse transition line.

- MWMU 1 will be an equipment limitation zone (ELZ) except when slopes are less than 40%, at designated crossings, and on established stable roads or tractor trails.
- The slopes of the inner gorge or the first 50 feet, whichever is longer, will be an equipment exclusion zone (EEZ) except for designated crossings and existing truck roads.
- Trees within 10 feet of the bankfull channel will be retained, except for redwood clumps, at least 50% of the clump must be retained with emphasis on leaving the largest trees on the clump.

Causal Mechanism Report and Prescription #2

Resource Sensitive Area: Mass Wasting Map Unit (MWMU) 2
Stream Channel Geomorphic Unit IV and some III
See Mass Wasting and Stream Channel Condition modules

Limiting Factor(s) and Source Variable(s): Sedimentation from mass wasting and bank erosion.
Fish migration barrier from sediment aggradation in Willow Creek.
Water quality; turbidity from fine sediment.

Delivered Hazard Rating: High

Limiting Factor Vulnerability: High to Moderate

Rule Call: Prevent

Situation Sentence:

The incised topography adjacent to watercourses of MWMU 2 has high risk for shallow seated landslide sediment delivery. The landslides in MWMU 2 are typically associated with destabilization of the toe of a watercourse's steep side slopes. Landslides or soil failures could be aggravated by soil disturbance by heavy equipment, road building or removal of ground stabilizing vegetation. The immediate proximity of watercourses to these soil failures provides direct delivery of fine and coarse sediment. Poor rearing habitat due to high coarse sediment levels is common in Willow Creek. Downstream aggradation and channel widening from coarse sediment in the downstream reaches of Willow Creek has created fish migration problems to the upstream habitat of Willow Creek. Fine sediment inputs are likely creating higher than natural turbidity during storm flows potentially affecting fish physiology, reduce feeding or in the worst cases increase mortality.

Triggering Mechanisms or Issues:
Road construction
Road placement
Loss of soil cover or stability from timber removal
Ground yarding equipment and skid trails

Prescriptions:
Road construction, placement or management:
- Alternatives to road construction or road use, such as cable yarding, helicopter yarding or alternative road placement, will be pursued in MWMU 2.
- New road construction will be avoided in MWMU 2 except when no other feasible route is available. In situations where a new road must go through MWMU 2 new road construction is required to have full bench construction with all construction

materials end hauled or a similar treatment and the road operation that meets the lowest risk for erosion will be utilized. If the new road construction occurs in MWMU 2 it must avoid areas where there is a significant likelihood of sediment delivery. The exception is when a qualified certified engineering geologist approves the operations.

Adjacent to Class II watercourses:

- MWMU 2 will receive no harvest on inner gorge slopes unless approved by a California Licensed Geologist. On other areas (non-inner gorge slopes) within MWMU 2 in addition to the riparian protections set as company policy timber harvest must retain a minimum of 50% overstory canopy dispersed evenly across the slopes.
- The MWMU 2 protections will be 100 feet slope distance in width extending from the edge of the watercourse transition line.
- MWMU 2 will be an equipment limitation zone (ELZ) except when slopes are less than 50%, or designated crossings, or on established stable roads.
- The slopes of the inner gorge or the first 50 feet, whichever is longer, will be an equipment exclusion zone (EEZ) except for designated crossings and existing truck roads.
- Trees within 10 feet of the bankfull channel will be retained, except for redwood clumps, at least 50% of the clump must be retained with emphasis on leaving the largest trees on the clump.

Adjacent to Class III watercourses:

- The MWMU 2 protections adjacent to Class III watercourses will extend from the edge of the watercourse transition line on both sides of the watercourse up to a break in slope <70% gradient or 100 feet slope distance, whichever is shortest.
- On slopes adjacent to Class III watercourses in MWMU 2 timber harvest must retain a minimum of 50% overstory canopy dispersed evenly across the slopes.
- MWMU 2 protection area is an equipment limitation zone except when slopes are less than 50%, at designated crossings, and on established stable roads.
- Trees within 10 feet of the bankfull channel will be retained, except for redwood clumps, at least 50% of the clump must be retained with emphasis on leaving the largest trees on the clump.

Causal Mechanism Report and Prescription #3

Resource Sensitive Area: Mass Wasting Map Unit (MWMU) 3
Stream Channel Geomorphic Units II - IV
See Mass Wasting and Stream Channel Condition Modules

Limiting Factor(s) and Source Variable(s): Sedimentation from mass wasting.
Fish migration barrier from sediment aggradation in Willow Creek.
Water quality; turbidity from fine sediment.

Delivered Hazard Rating: High

Limting Factor Vulnerability: Moderate

Rule Call: Prevent

Situation Sentence:
Steep and/or convergent slopes of MWMU 3 can have shallow seated landslides associated with them. These landslides can travel moderate distances across hillslopes to reach streams or draws where sediment delivery and sometimes debris flows occur. When sediment delivery occurs with these landslides, sediments will travel down the watercourses and are delivered to river and stream channels. If the frequency and amount of shallow seated landslides are increased from management actions in MWMU 3 this can contribute to poor rearing habitat, downstream aggradation or high turbidity.

Triggering Mechanisms or Issues:
Road Construction
Road Placement
Vegetation removal
Ground yarding equipment and skid trails

Prescriptions:
Forester will utilize available resources for identification of unstable areas or areas with predicted slope instability. These include Map A-1 of Mass Wasting Assessment for the Willow/Freezeout Creeks WAU, Division of Mines and Geology landslide maps (if available), or past Timber Harvest Plans.
Forester will walk the ground of this unit prior to prescribing operations. If upon field review the unit is confirmed to meet the definition of MWMU 3 the following guidelines apply:

- No road or landing construction activity will occur in areas identified in the field as having a significant likelihood of sediment delivery to a watercourse from mass wasting unless a site-specific assessment is conducted and operations approved by a California Registered Geologist.

- Harvest operations must retain at least 50% of the overstory canopy unless a site-specific assessment is conducted and operations approved by a California Registered Geologist.

Causal Mechanism Report and Prescription #4

Resource Sensitive Area: Mass Wasting Map Unit (MWMU) 6
Stream Channel Geomorphic Units II - IV
See Mass Wasting and Stream Channel Condition Modules

Limiting Factor(s) and Source Variable(s): Sedimentation from mass wasting.
Fish migration barrier from sediment aggradation in Willow Creek.
Water quality; turbidity from fine sediment.

Delivered Hazard Rating: Moderate

Limiting Factor Vulnerability: Moderate

Rule Call: Minimize

Situation Sentence:
MWMU 6 is identified earthflows or earthflow complexes. These features can be active, dormant or have sections of the landslide active with sections of the landslide dormant. Increases in sub-surface water from loss of evapo-transpiration or concentrated water from road drainage can activate or accelerate movement and sediment delivery from these features. The increased sediment delivery could contribute to adverse fish habitat by pool filling, increased channel scour, fine sediments smothering spawning gravel and loss of stream channel complexity.

Triggering Mechanisms or Issues:
Road Construction
Road Placement
Vegetation removal
Ground yarding equipment and skid trails

Prescriptions:
No regeneration harvest treatments will be allowed in MWMU 6 unless 50% overstory canopy is retained (averaged across the stand). In those areas of MWMU 6 where an earthflow is active no harvest will occur unless approved by a registered geologist.

Road or tractor trail drainage must be dispersed off of roads/trails in this unit. Concentrated road/trail drainage must be corrected. If new roads/trails are developed in this terrain then concentrated drainage must be avoided.

Causal Mechanism Report and Prescription #5

Resource Sensitive Area: Mass Wasting Map Unit (MWMU) 7
Stream Channel Geomorphic Units II - IV
See Mass Wasting and Stream Channel Condition Modules

Limiting Factor(s) and Source Variable(s): Sedimentation from mass wasting or point source erosion.
Fish migration barrier from sediment aggradation in Willow Creek.
Water quality; turbidity from fine sediment.

Delivered Hazard Rating: Moderate to Low

Resource Vulnerability: Moderate

Rule Call: Minimize

Situation Sentence:
MWMU 7 is typically divergent or mildly convergent slopes with moderately steep topography. The hazard for shallow seated landslides is relatively low, but MWMU 8 can have shallow seated landslides associated it. Shallow seated landslides in MWMU 8 will occur in isolated areas of steep convergent topography. These areas are infrequent in MWMU 7 (typically associated with MWMU 4) but do occur and must be considered. MWMU 7 has a risk for earthflows, however, none were mapped in this unit. The high clay content of the accelerated creep terrain makes it particularly vulnerable for gully development if water is concentrated from road drainage.

Triggering Mechanisms or Issues:
Road Construction
Road Placement
Vegetation removal
Ground yarding equipment and skid trails

Prescriptions:
Forester will utilize available resources for identification of unstable areas or areas with predicted slope instability. These include Map A-1 of Mass Wasting Assessment for the Willow/Freezeout Creeks WAU, Division of Mines and Geology landslide maps (if available), or past Timber Harvest Plans.

Forester will walk the ground of this unit prior to prescribing operations. If upon field review the unit is confirmed to meet the definition of MWMU 7 the following guidelines apply:

- No road or landing construction activity will occur in areas identified in the field as having a significant likelihood of sediment delivery to a watercourse from mass wasting unless a site-specific assessment is conducted and operations approved by a California Registered Geologist.

- Harvest operations must retain at least 50% of the overstory canopy unless a site-specific assessment is conducted and operations approved by a California Registered Geologist.

Road drainage must be dispersed off of roads in this unit. Concentrated road drainage must be corrected. If new roads are developed in this terrain then concentrated drainage must be avoided.

Causal Mechanism Report and Prescription #6

Resource Sensitive Area: High Erosion Hazard Roads
Roads or sections of: BS, FO, HC, RT-024, HC-023
Stream Channel Geomorphic Units I to IV
Surface and Point source Erosion Module

Limiting Factor(s) and Source Variable(s): Sedimentation from surface and point source erosion.
Water quality; turbidity from fine sediment.

Delivered Hazard Rating: High

Limiting Factor Vulnerability: Moderate

Rule Call: Prevent

Situation Sentence:
These roads have areas of long watercourse contributing road lengths that increase the amount of fine sediment delivery. The roads are typically without a rock surface (native surface) that makes the road surface a higher fine sediment source. Sections of these roads are directly adjacent to watercourses. Water drainage off these roads can increase or cause point source erosion contributing both fine and coarse sediment deliveries to watercourses. If the frequency and amount of erosion is increased from management actions this can contribute to poor rearing habitat, downstream aggradation or high turbidity.

Triggering Mechanisms or Issues:
Long undrained tread approaches to watercourse crossings.
Sections of road within the AMZ.
Wet weather use

Prescriptions:
The long undrained road approaches to watercourse crossings on these roads will be treated with one or a combination of several of these options:

1) Ditch relief culverts can be installed to drain water and sediments concentrated in inside ditches. The ditch relief culverts would be placed such that the majority of long undrained approaches to watercourse crossings of the road would be relieved prior to the watercourse crossing. The discharges of water and sediment from the ditch relief culverts would drain on to the adjacent hillslope where no additional erosion is predicted.
2) Rocked rolling dips or rolling dips can be installed in the road prism. The rolling dips would be placed such that the majority of long undrained approaches to watercourse crossings of the road would be relieved prior to the watercourse crossing. The discharges of water and sediment from the ditch relief culverts would drain on to the adjacent hillslope where no additional erosion is predicted.

3) Long road approaches to watercourse crossings can have the road prism re-shaped such that the road is outsloped toward its outside edge. This out-sloped road would be done so that it allows continuous drainage of the road surface away from the watercourse crossings.

Section of these roads with high controllable erosion areas will be upgraded. The road prism will be out-sloped, perched fill material will be removed and the road prism narrowed where feasible. Unnecessary culverts will be removed and replaced with rocked fords, additional rocked rolling dips will be installed as needed.

Where possible these roads should be a high priority for decommissioning.

Causal Mechanism Report and Prescription #7

Resource Sensitive Area: Moderate Road Erosion Hazard Rating Roads
Geomorphic Units I - IV
Surface and Point Source Erosion Module

Limiting Factor(s) and Source Variable(s): Sedimentation from surface and point source erosion.
Water quality; turbidity from fine sediment.

Delivered Hazard Rating: Moderate

Limiting Factor Vulnerability: Moderate

Rule Call: Minimize

Situation Sentence:
The majority of roads in the Willow/Freezeout Creeks WAU have a moderate road surface erosion hazard. These roads have current and potential erosion associated with them and the likelihood of delivery of that erosion to watercourses. In some cases a few large, discrete erosion problems occur on these roads. There are also some potential erosion problems associated with these roads and that need to be repaired or corrected. However, the overall condition of these roads does not require a high priority for repairs.

Triggering Mechanisms or Issues:
Road maintenance
Controllable sediment repairs

Prescriptions:

Maintenance and observation of road conditions on these roads will be conducted by the high road design standards, such as set in the Handbook for Forest and Ranch Roads (Weaver and Hagans, 1994).

Roads that have not been abandoned in the Willow/Freezeout Creeks WAU will be monitored at least once annually during the winter period to look for potential culvert problems, road fill failures, trespassing damages, road drainage problems, or excessive sediment delivery.

Causal Mechanism Report and Prescription #8

Resource Sensitive Area: High treatment immediacy with high or moderate sediment delivery potential sites on roads in the Willow/Freezeout Creeks WAU.
Geomorphic Units I - IV
Surface and Point Source Erosion Module

Limiting Factor(s) and Source Variable(s): Sedimentation from surface and point source erosion.
Water quality; turbidity from fine sediment.

Delivered Hazard Rating: High

Limiting Factor Vulnerability: Moderate

***Rule Call**:* Prevent

Situation Sentence:
Individual culverts, bridges, landings and road erosion sites were inventoried and ranked based on their priority for treatment and relative degree of likelihood of sediment delivery. In the Willow/Freezeout Creeks WAU 9 sites were identified as having a high treatment immediacy along with at least a moderate potential of future sediment delivery. These 9 sites are those sites with potential controllable erosion that are in need of immediate action or maintenance. All have a significant concern for a large discrete input of coarse and fine sediment to watercourses. If the frequency and amount of erosion is increased from management actions this can contribute to poor rearing habitat, downstream aggradation or high turbidity.

Triggering Mechanisms or Issues:
Road infrastructure upgrades

Prescriptions:
The high treatment immediacy controllable erosion sites will be the highest priority for erosion control, upgrade or modifications to existing design. These sites will be scheduled for repair based on operational considerations of harvest scheduling, proximity and availability of equipment, magnitude of the problem, and accessibility to the site.

Causal Mechanism Report and Prescription #9

Resource Sensitive Area: Moderate treatment immediacy with high or moderate sediment delivery potential sites on roads in the Willow/Freezeout Creeks WAU.
Geomorphic Units I - IV
Surface and Point Source Erosion Module

Limiting Factor(s) and Source Variable(s): Sedimentation from surface and point source erosion.
Water quality; turbidity from fine sediment.

Delivered Hazard Rating: Moderate

Limiting Factor Vulnerability: Moderate

Rule Call*:* Minimize

Situation Sentence:
Individual culverts, bridges, landings and road erosion sites were inventoried and ranked based on their priority for treatment and relative degree of likelihood of sediment delivery. In the Willow/Freezeout Creeks WAU 14 sites were identified as having a moderate treatment immediacy along with at least a moderate potential of future sediment delivery. These 14 sites are those sites with potential controllable erosion that are in need of action or maintenance in the near future. All have a concern for a large discrete input of coarse and fine sediment to watercourses. If the frequency and amount of erosion is increased from management actions this can contribute to poor rearing habitat, downstream aggradation or high turbidity.

Triggering Mechanisms or Issues:
Road infrastructure upgrades

Prescriptions:
The moderate treatment immediacy controllable erosion sites will be the next highest priority (relative to the high treatment immediacy sites) for erosion control, upgrade or modifications to existing design. The moderate treatment immediacy sites will be addressed when in close proximity to high treatment immediacy sites.

Causal Mechanism Report and Prescription #10

Resource Sensitive Area: Diversion potential sites along roads in the Willow/Freezeout Creeks WAU.
Geomorphic Units I - IV
Surface and Point Source Erosion Module

Limiting Factor(s) and Source Variable(s): Sedimentation from surface and point source erosion.
Water quality; turbidity from fine sediment.

Delivered Hazard Rating: High

Limiting Factor Vulnerability: Moderate

Rule Call*:* Prevent

Situation Sentence:
When roads cross watercourses the resulting crossing structure (culvert or bridge) has a potential to fail. When the crossing fails the watercourse has potential to either stay within the "natural" channel or be diverted away from the channel. Typically a diversion away from a "natural" channel in a failed crossing is due to low areas adjacent to the crossing that allows water to be routed either down the road surface or through fill material. This potential for diversion of water if a crossing failed can be a secondary erosion process that can create significant sediment inputs, sometimes greater than the actual crossing failure itself. This water diversion potential is an important concern to correct on roads. Within the Willow/Freezeout Creeks WAU 53 sites have been identified as having a water diversion potential. If the frequency and amount of erosion is increased from management actions this can contribute to poor rearing habitat, downstream aggradation or high turbidity.

Triggering Mechanisms or Issues:
Improved road drainage and infrastructure upgrades

Prescriptions:
These diversion potential sites will be a high priority for correction. These sites will be scheduled for repair based on operational considerations of harvest scheduling, proximity and availability of equipment, magnitude of the problem, and accessibility to the site. It is very likely that these sites will be addressed when in close proximity to high treatment immediacy sites.

Causal Mechanism Report and Prescription #11

Resource Sensitive Area: Undersized culverts in the Willow/Freezeout Creeks WAU.
Geomorphic Units I - IV
Surface and Point Source Erosion Module

Limiting Factor(s) and Source Variable(s): Sedimentation from surface and point source erosion.
Water quality; turbidity from fine sediment.

Delivered Hazard Rating: High

Limiting Factor Vulnerability: Moderate

Rule Call*:* Prevent

Situation Sentence:
Culverts must pass not only water beneath roads but the sediment and debris that is transported down the watercourses. If a culvert is not properly sized for the water, sediment and debris that must be conveyed through it can plug or be over topped. This can cause water to flow over road fill material creating surface or point source erosion of the road or potentially having the fill material at the crossing completely fail. In the Willow/Freezeout Creeks WAU 23 culverts were determined (remotely) to not be able to pass the 50-year flood. Additional 3 culverts were determined not to be able to pass the 100-year flood.

Triggering Mechanisms or Issues:
Road crossing failure from plugged culverts or culverts that lack the capacity to pass the necessary water and debris.

Prescriptions:
The 23 culverts that will not pass the 50 year flood will be visited in the field and a determination will be made if the culverts are indeed under-sized (identification of under-sized culverts was done by an office-based evaluation that could be inaccurate). If after field review the culverts are found to be under-sized it will be a high priority for replacement to a watercourse crossing structure that will pass the 100-year flood.

The 3 culverts that will not pass the 100 year flood will be visited in the field and a determination will be made if the culverts are indeed under-sized for this sized flood event (identification of under-sized culverts was done by an office-based evaluation that could be inaccurate). If after field review the culverts are found to be under-sized for the 100 year flood it will be a moderate priority for replacement to a watercourse crossing structure that will pass the 100-year flood. Typically the upgrade will occur once the culvert has reached the end of its operational life.

The field review will consist of determining the cross section area of the bankfull channel and comparing it the cross sectional area of the culvert in question. A rule of thumb is that to pass the 100 year flood the culvert opening area needs to be 3 times as large as the bankfull channel cross section area (Cafferata, Spittler, and Wopat, 2000).

Causal Mechanism Report and Prescription #12

Resource Sensitive Area: WLPZ (aka AMZ roads) sections of road HC in the Willow/Freezeout Creeks WAU.
Stream Channel Geomorphic Unit I

Limiting Factor(s) and Source Variable(s): Sedimentation from surface and point source erosion.
Water quality; turbidity from fine sediment.

Delivered Hazard Rating: High

Limiting Factor Vulnerability: Moderate

Rule Call: Prevent

Situation Sentence:
HC road has sections of road in the watercourse and lake protection zone (WLPZ) of a Class I watercourse. Section of this road is directly adjacent to or in close proximity to the watercourse. Because the road sections are in such close proximity to a class I watercourse surface erosion and cut and fill slope failures from this road often deliver sediment directly to the watercourse. If the frequency and amount of erosion is increased from management actions this can contribute to poor rearing habitat, downstream aggradation or high turbidity.

Triggering Mechanisms or Issues:
Road surface treatment
Road prism upgrade
Road drainage improvement
Wet weather use

Prescriptions:
Road surface and prism treatment and road management:
- Roads used annually in the AMZ will have the surface of new road construction or re-opened existing roads armored with a rock surface.
- Roads used periodically, every few years or decades in AMZ will be storm-proofed (as per Weaver and Hagans, 1994) prior to the winter period and the surface stabilized with grass seed, mulch or other cover product.
- Any road that is within a Class I or II watercourse AMZ will not have winter period heavy truck or log hauling traffic, except emergency situations, unless the road tread is armored with a rock surface.

The road prism and drainage design for AMZ roads will be based on high road design standards such as found in the Handbook for Forest and Ranch Roads (Weaver and Hagans, 1994). If the AMZ road does not currently meet those standards then these roads will be a high priority for upgrades.

Winter period hauling conditions will be monitored carefully. In order to avoid sediment movements and damage to road surface, there will be no log or heavy equipment hauling during periods of rainfall or when roadside ditches are flowing surface runoff, or when road is saturated and cannot support heavy loads, except in emergency situations. At the first sign of measurable rain, trucks will make their final trip out on the road, and trucks not yet on the road will be asked to return home. The road will not be used until rainfall has stopped and the road surface has dried sufficiently so that the surface will not be damaged by use. Only a Mendocino Redwood Company employee will make or grant the authority to a contractor for this determination.

Causal Mechanism Report and Prescription #13

Resource Sensitive Area: Aquatic Management Zone

Limiting Factor(s) and Source Variable(s): Large woody debris recruitment (see Riparian section, Map D-1)

Delivered Hazard Rating: High

Limiting Factor Vulnerability: High

Rule Call: Prevent

Situation Sentence:
Large woody debris (LWD) is an important component of stream habitat. Large woody debris provides sediment storage in channels, creates areas of scour for pool creation, provides cover for fish habitat and adds channel roughness for habitat complexity. Historic forest management practices did not require watercourse protection measures like current California Forest Practice Rules mandate. Historic removal of LWD from the Willow/Freezeout Creeks River WAU has created a deficient of LWD available for fish habitat and stream channel diversity. Historic harvesting practices has removed many of the large conifer trees which provide the current and future large woody debris recruitment needed in these areas. Therefore, the stream channels in the above listed areas have a high in-stream LWD demand and need increased LWD recruitment.

Triggering Mechanisms or Issues:
Recruitment of large woody debris
Big tree retention in riparian zone

Prescriptions:

The company policies for streamside stands are considered appropriate at this time. The exception to this is in MWMU 5, the AMZ will only require a 75 slope distance width.

Causal Mechanism Report and Prescription #14

Resource Sensitive Area: Canopy closure over Class I and II watercourses
Riparian Function module

Limiting Factor(s) and Source Variable(s): Canopy closure and stream temperature

Delivered Hazard Rating: Low

Limiting Factor Vulnerability: Low

Rule Call: Standard

Situation Sentence:
Stream temperatures in the Willow/Freezeout Creeks River WAU are in good range of maximum weekly average temperature (MWAT) suggested for salmonids. High water temperature from lack of shade can be deleterious and even fatal to many fish and aquatic species and warrant concern. Therefore, maintaining these good water temperature values is important.

Triggering Mechanisms or Issues:
Recruitment of shade
Tree retention in riparian zone

Prescriptions:
If harvest activity is proposed in the APZ along Class I and Large Class II watercourses then effective shade of the watercourse must be managed for. A large Class II watercourse is defined as having greater than 100 acres watershed area. Effective shade is a function of vegetation height, stream width and/or topographic barriers. Effective shade over perennial watercourses will not be reduced below 85 percent canopy, unless as part of an approved riparian restoration project (hardwood conversion to conifer). Cumulatively across the entire the WAU area the shade canopy must average above 85 percent stream shading for Class I and Large Class II watercourses. Those areas with natural grassland openings in the Willow/Freezeout Creek WAU are excluded from the shade averaging.

Causal Mechanism Report and Prescription #15

Resource Sensitive Area: Gully erosion (Grassland areas and forested areas)
Surface and Point source Erosion module

Limiting Factor(s) and Source Variable(s): Sedimentation from point source erosion.
Water quality; turbidity from fine sediment.

Delivered Hazard Rating: High

Limiting Factor Vulnerability: High

Rule Call: Prevent

Situation Sentence:
The grassland gullies in Willow Creek are a significant source of sediment delivery. The Franciscan Melange terrain found in Willow Creek is prone to gully development and has been shown to have a large sediment delivery load associated with it. This sediment delivery is often in the headwater areas of tributary streams to Willow Creek. However, when transported downstream can affect fish bearing reaches of Willow Creek.

Triggering Mechanisms or Issues:
Loss of vegetation in gully prone areas
Increased water delivery from poor road or skid trail drainage
Lack of large woody debris in forested watercourses

Prescriptions:
Where road drainage is concentrating water on grassland slopes or in depressions or watercourses in forested areas, the road will be re-shaped to provide for more dispersed water drainage. Where road drainage has previously created gully erosion, the drainage point will be armored to prevent further erosion.

Tractor roads (skid trails) will have erosion control structures placed on them prior to rainy season to disperse water off surfaces and away from potential gully erosion areas. Skid trails, where feasible, will have slash, debris or mulch placed on them to lower surface and gully erosion hazard.

MRC will pursue restoration opportunities to slow or stop gully erosion in Willow Creek.

MRC will develop a grazing plan for the grassland areas of Willow Creek to attempt to regulate the amount of vegetation removal and timing of grazing.

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Section I

Aquatic Resources Monitoring Plan for the Willow/Freezeout Creeks Watershed Analysis Unit

Introduction

Aquatic resources monitoring will be conducted in the Willow/Freezeout Creeks WAU. This monitoring is to assist Mendocino Redwood Company to assess impacts to aquatic resources associated with past or future timber harvest and related forest management activities in the Willow/Freezeout Creeks WAU. The monitoring suggested in this plan is developed primarily from the watershed analysis of the Willow/Freezeout Creeks WAU. However, other monitoring efforts have been conducted over time in the Willow/Freezeout Creeks WAU by the previous landowner and are continued in this monitoring plan.

The monitoring is a combination of hillslope and in-stream assessments. Forest harvesting and related activities can influence or alter inputs of sediment, wood and heat (solar radiation). It is these inputs that are the focus of the monitoring. Methods to evaluate factors that could alter the input of sediment, heat or wood are the hillslope monitoring portion of this plan. Evaluation of factors which could be influenced in the stream channel, water or fish habitat due to sediment, wood or heat are the focus of the in-stream monitoring.

Monitoring Plan Goals

- Test the efficacy of the Willow/Freezeout Creeks WAU prescriptions to address impacts to aquatic resources from timber harvest and related forest management activities.
- To assess long term channel conditions. Are current and future forest management practices inhibiting, neutralizing or promoting stream channel conditions for aquatic habitat?

A monitoring report will be produced each year that monitoring is conducted in the Willow/Freezeout Creeks WAU. The report will cover the monitoring and analysis that has occurred up to that year. If no monitoring is conducted in a given year than no report will be produced. The goal will be to have a report completed by February of the year following the monitoring.

The monitoring matrix (Table I-1) outlines the hillslope and in-stream monitoring MRC will be conducting in the Willow/Freezeout Creeks WAU. The monitoring will be performed periodically. MRC will be developing a property wide aquatic monitoring strategy. Once that monitoring strategy is complete, the precise timing of the monitoring in the Willow/Freezeout Creeks WAU will be finalized. The information collected in this monitoring effort will be used as part of an adaptive management approach to the Willow/Freezeout Creeks WAU. The monitoring results will be compared to the baseline information generated in the Willow/Freezeout Creeks Watershed Analysis to discover if aquatic habitat or water quality concerns are improving, staying the same or degrading. If aquatic habitat or water quality concerns are not improving then the land management prescriptions will be altered to better protect those impaired resources.

In addition to the aquatic resources monitoring, monitoring of the road infrastructure will be performed annually, particularly during the Winter period

Table I-1. Monitoring Matrix for Willow/Freezeout Creeks Watershed Analysis Unit.

Monitoring Objectives	**Reasoning, Comments**	**Technique**
1. Determine effectiveness of measures to reduce management created mass wasting.	Management created mass wasting is significant contributor of sediment delivery.	Evaluation of mass wasting following a large storm events or after approximately 20 years.
2. Determine effectiveness of erosion control practices on high and moderate surface erosion hazard roads and landings.	Roads provide sediment delivery in the Willow/Freezeout Creeks WAU.	Randomly selected watercourse crossings, landings and road lengths for erosion evaluation.
3. Determine in-stream large woody debris amounts over time.	Large woody debris is needed for stream channel and aquatic habitat improvement in the Willow/Freezeout Creeks WAU.	Stream LWD inventories and mapping of LWD designation areas in select stream reaches and long term channel monitoring sites.
4. Determine if stream temperatures are staying within properly functioning range for salmonids.	Stream temperature can be a limiting factor for salmonid growth and survival.	Stream temperature probes and modeling conducted in strategic locations.
5. Determine if fine sediment in stream channels is creating effects deleterious to salmonid reproduction.	Many forest practices can produce high fine sediment amounts. Need to ensure fine sediments are not impacting salmonid reproduction.	Permeability measurements on select stream reaches (bulk gravel samples if necessary).
6. Determine long-term channel morphology changes from coarse.	Channel morphology can be altered from sediment increases, possibly affecting aquatic habitat.	Thalweg profiles and cross section surveys on select stream reaches.
7. Determine presence and absence of fish species in Class I watercourses.	Management practices and resource protections can affect distribution of aquatic organisms.	Electro-fishing at select locations to determine species composition and presence.
8. Determine rate or erosion and effectiveness of mitigation measures for gullies.	Gully erosion is a significant sediment delivery process in the WAU.	Transect and permanent cross section monitoring.