Use of Spatial Data for Battle Creek Watershed Conditions Assessment

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The aquatic data for the *Battle Creek Watershed Assessment* (*WA): Characterization of stream conditions and an investigation of sediment source factors in 2001 and 2002* (Terraqua, 2004)) were collected in the field, but the assessment of upland conditions required use of electronic mapping data, typically referred to as a geographic information system or GIS data. These data were assembled and organized into a KRIS Battle Creek Version 2.0 by a team from Kier Associates, which has been working on watershed information projects throughout northwestern California. The Klamath Resource Information System or KRIS is custom software developed in the Klamath and Trinity River basins to track restoration program success and has been subsequently employed under the Institute for Fisheries Resources with funding from the California Department of Forestry (CDF) and the Sonoma County Water Agency (Figure 1). These projects not only compile data and analyze trends of fisheries and watershed conditions but also publish CDs and posts global contents to the Internet (http://www.krisweb.com).

Version 1.0 of KRIS Battle Creek was completed in 1998 and supported the *Battle Creek Restoration Plan* (Ward and Kier, 1998), and like the study was restricted in scope to examining only factors related to hydropower dams within lower Battle Creek. KRIS Battle Creek Version 2.0 captures data watershed-wide and integrates the *Battle Creek WA* (Terraqua, 2004). Due to the accumulated experience of the KRIS team in analysis of upland conditions, GIS support was provided to Terraqua Inc. at their request. The draft of this upland conditions report was provided to Terraqua in November 2003 (Kier Associates, 2003), but many conclusions below regarding potential cumulative watershed effects and their linkage to aquatic conditions are not reflected in the final *Battle Creek WA.*

The KRIS Battle Creek project drew together electronic mapping data using Arc Info and Arc View that are useful for this analysis. Remote sensing data based on Landsat, provided by the U.S. Forest Service and California Department of Forestry, allow assessment of vegetation and tree sizes and the change in vegetation from 1991 to 1999. Road data were provided by the U.S. Geologic Survey (USGS), Lassen National Forest (LNF) and Sierra Pacific Industries (SPI). Other electronic mapping data used are geology, rain-on-snow risk and steepness of slope, which Lassen National Forest has found of use in examining cumulative watershed effects (Armentrout et al., 1998; USFS, 1999). Data were also obtained from Lassen National Park. These data can be used to understand the extent of land uses, including timber harvest, which may potentially change hydrology, sediment yield and the quality of aquatic habitat (Reeves et al., 1993). Queries were run to derive summary statistics by Dr. Paul Trichilo, the spatial data analyst for the KRIS project.

METHODS

Methods of analysis follow those of other KRIS projects (IFR, 2004). For further reading on each of the subjects below, please see the Background pages in KRIS, which are a distillation of

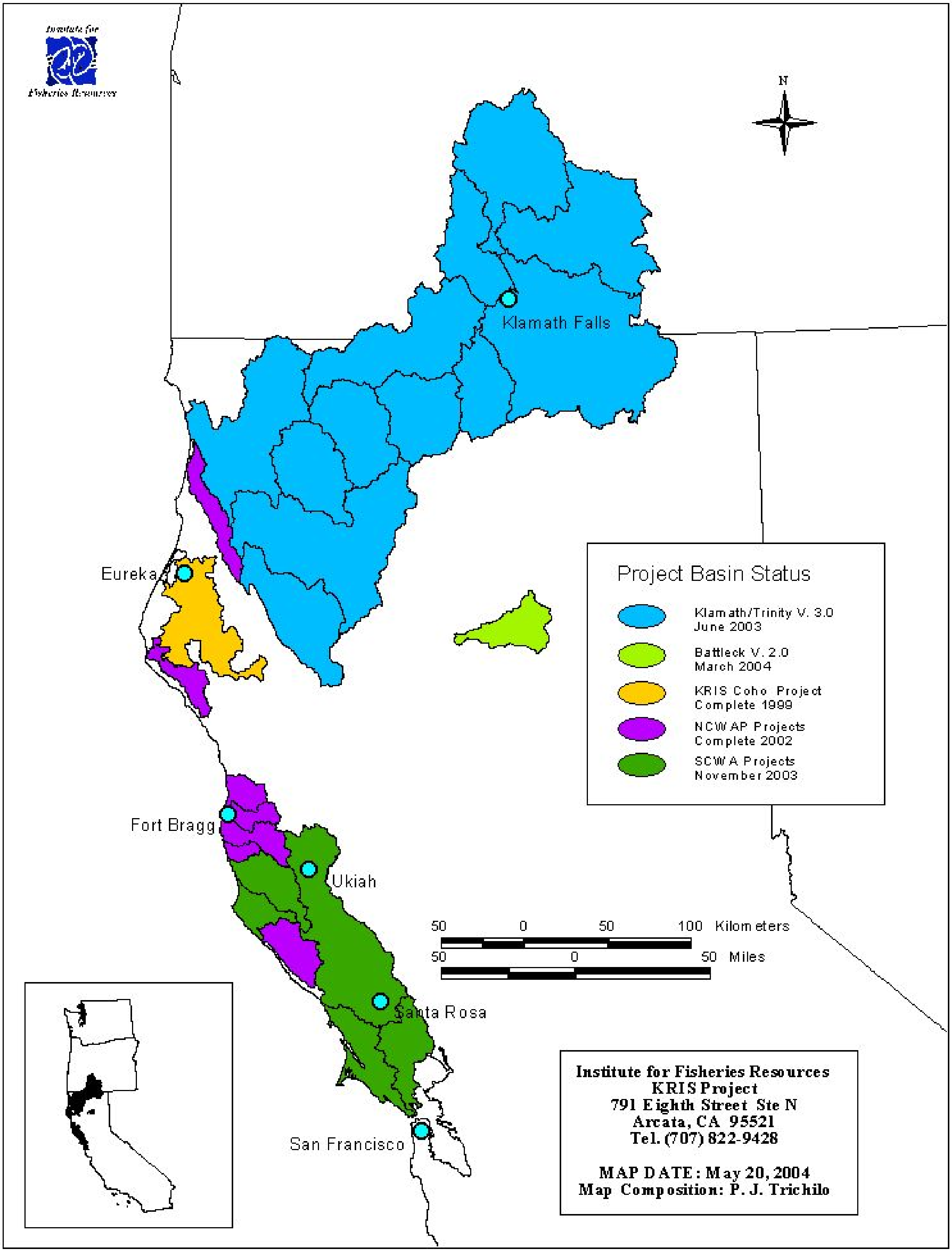

Figure 1. Realm of KRIS projects in northwestern California. Map by Dr. Paul Trichilo, KRIS Project.

"best science" regarding Pacific salmon and watersheds (IFR, 2004) and reflect extensive peer review and revision during previous projects.

Upland and Riparian Vegetation and Change Scene Detection

Timber harvest is well recognized as causal mechanism for cumulative watershed effects, reduced aquatic habitat diversity and as a factor for decline of Pacific salmon species (Ligon et al., 1999; Dunne et al., 2000; Collison et al., 2003; Reeves et al., 1993; Nehlsen et al., 1991; Higgins et al., 1992). Currently, CDF does not map timber harvests in the Sierra Nevada in electronic form, which requires use of corollary GIS data to discern the patterns and rate of timber harvest and potential disturbance that could trigger cumulative watershed effects.

Tree Size/Vegetation Type: Data regarding vegetation, tree size, timber types are derived from a Landsat multi-spectral image taken in 1996 analyzed by the U.S. Forest Service (USFS) Pacific Southwest Regional Remote Sensing Lab in cooperation with the CDF's Fire and Resource Assessment Program (FRAP). Spatial data from 1996 were the most recent year for which the entire Battle Creek watershed was available in electronic form. The USFS and CDF have been working cooperatively to assess California State-wide vegetation in association with the Northwest Forest Plan (Warbington et al., 1998; LaVien, 2002). The vegetation classification for northeastern California and the Battle Creek watershed are accurate to a one hectare scale. While this data scale is coarse, data have been checked using a number of different methods as described by Warbington et al. (1998):

> "Ground-based field observations, existing vegetation samples, aerial photography, digital ortho photography, SPOT imagery and field review of draft maps were all used in validating and correcting classification and modeling errors where observed."

The resolution of Landsat images is about 30 meters and each square in the grid coverage is referred to as a pixel (Derksen et al., 1993). The USFS vegetation coverage characterizes stand conditions at the hectare scale and is not accurate to the pixel level. Schwind (1999) discussed how problems such as topographic shading were corrected for in the vegetation maps. The USFS data were quarried by the KRIS team as part of this study for tree size or community type (Table 1). This allows quantitative assessment of vegetation types for seral stage based on tree size for selected study basins. Beardsley at al. (1999) used a breast height tree diameter of 40 inches in queries for discerning current distribution of Old Growth forests, as part of the Sierra Nevada Ecosystem Project, while Terraqua used 20 inch diameter as a gauge for mature forests. The USGS orthophotos were used to check vegetation patterns for this reconnaissance.

Table 1. Vegetation and timber size classifications chosen for upland analysis.

Size Class/Vegetation Type	**Diameter of Trees**
Very Large Trees	40" in diameter or greater
Large Trees	30-39.9" in diameter
Medium/Large Trees	20-29.9" in diameter
Small/Medium Trees	12-19.9" in diameter
Small Trees	5-11.9" in diameter
Saplings	1- 4.9" in diameter
Non-Forest	Non-tree species such as shrubs, grasses or bare soil

<u>Riparian Condition Assessment Using USFS Landsat Data</u>: The same vegetation data based on 1996 Landsat interpreted by the USFS and CDF can be used to assess riparian conditions at a one hectare scale. The KRIS project chose a 100 meter (328') distance as a zone of biological influence for the riparian corridor based on Spence et al. (1996). This represents between one and two site potential tree heights recognized by FEMAT (1993). Data may not pick up individual large trees or narrow buffer strips retained during timber harvest, if they do not comprise a significant portion of a hectare, but the age and size of the trees at the water's edge and buffer area are represented accurately enough to be used as reconnaissance tools for estimating potential effects on microclimate, stream temperature influence and large wood recruitment potential.

The 100 meter buffer is was applied to the 1:100000 U.S. Geologic Survey hydrology layer, which was modified to eliminate diversion canals. The stream GIS coverage for hydrology of Battle Creek is very limited and under-represents the stream network. Therefore, potential estimate of the true riparian condition in smaller order streams may not be reflected. In addition, misplaced center lines of streams may sometimes skew the area represented by the 100 meter query (see Hydrology discussions below).

Keithley (1999) suggested that remote sensing vegetation data could be used as "a proxy for canopy cover, large woody debris recruitment and overall riparian habitat characteristics." He used 24 inches diameter as a break point for mid seral conditions in California coastal redwood forest and as a size class sufficient to provide long lasting wood. Cedarholm et al. (1997) found that hardwoods and small diameter conifers lasted from five to ten years when recruited to streams, and that larger conifers were needed for creating stable aquatic habitat complexity.

Following Terraqua (2004), the KRIS Battle Creek Version 2.0 analysis focuses on trees sizes greater or less than 20 inches as indicating mid-late seral conditions. This size class break on the USFS vegetation data was the closest approximation to the 24 inches chosen by Keithley (1999), who characterized trees from 24-36 diameter as mid-seral and those greater than 36 inches as late seral. Tree species in Battle Creek are different than those on the coast and have smaller diameter and height potential, although Beardsley et al. (1999) characterized Sierra Nevada old growth timber as greater than 40 inches in diameter. Comparisons of riparian are made both spatially and quantitatively on selected *Battle Creek WA* (Terraqua, 2004) study polygons that represent different land management regimes across the watershed.

<u>Change Scene Detection</u>: CDF FRAP and the USFS Spatial Analysis Lab have also conducted joint exercises to show the changes in the Sierra Nevada landscape in a 1991-1996 "first assessment" (Fischer, 2001) and then 1994-1999 as part of the second wave of assessment for all California (Lavien et al, 2002). *Monitoring Land Cover Changes in California Northeastern California Project Area* (Lavien et al., 2002) describes this "change scene detection" method and its application for the region of the State that includes the Battle Creek watershed. It attempts to assign causes for changes for all northeastern California counties. Change scene detection gives indications of reduction in canopy and ground cover, but also shows areas of re-growth from previously harvested areas. Green polygons of re-growth were roughly estimated as having been cut in the previous 15 years, although there was insufficient budget to check this assumption versus aerial photographs. Terraqua (2004) chose not to use quantified change scene data as a surrogate for timber harvest, although timber harvest appears to be at levels recognized as contributing to cumulative watershed effects (Reeves et al., 1993).

USDA Agricultural Survey: The U.S. Department of Agriculture Natural Resource Conservation Service (NRCS) has mapped agricultural land of significance in the Battle Creek watershed from Landsat imagery and other data, which in turn allows a stratification of the watershed to examine where impacts related to agricultural activity may be occurring.

Land Use from U.S. EPA: The U.S. Environmental Protection Agency used 1992 Landsat data for an inventory of the Western United States. This coverage is particularly useful for analyzing the effects of residential and commercial development, but the fact that the coverage is over a decade old requires that it be used be used in conjunction with change scene detection.

Roads: Densities, Stream Crossings, Near Streams and on Steep Slopes

Road failures can contribute both fine and course sediment to streams, and accumulated road failures in large storm events can have catastrophic effects, such as filling in pools and reducing habitat complexity (Hagans et al, 1986; Woods-Smith and Buffington, 1996). Roads on ranch lands and those leading to rural and suburban parcels may also contribute to sediment problems in a watershed (Weaver and Hagans, 1994). The U.S. Forest Service in Battle Creek and adjacent watersheds found that roads constructed next to streams may be chronic contributors of fine sediment (Napper, 2001), particularly if they are used in winter months.

Road Density: The road density information used for upland analysis was derived using roads data provided by Sierra Pacific Industries (SPI), the U.S. Forest Service, the National Park Service and the U.S. Geologic Survey. The linear miles of road are divided by the area of the watershed in square miles to derive road density. Mapping data for roads in Battle Creek are incomplete and very inconsistent across ownership, which may lead to false conclusions if not considered in analysis. USGS roads represent data mapped when the last topographic map series was generated and are very outdated. Another example is that many roads on National Forest lands are not mapped, while SPI road maps are much more accurate. None the less, the latter only consider main hauls roads and do not include spur and temporary roads, skid trails and landings, which makes the calculation of road densities very conservative.

While Terraqua (2004) used a threshold of 4.8 mi./sq. mi. as a level of concern for watershed disturbance, Armentrout et al. (1998) used a reference of 2.5 mi./sq. mi. of roads as a watershed management objective on USFS lands in the Sierra Nevada and southern Cascades, and this reference is used on charts presenting road density data in KRIS Battle Creek V 2.0. The National Marine Fisheries Service (1996) has required that when road densities exceed 2 mi./sq. mi. on USFS and BLM land in the Interior Columbia Basin that road mileage must be reduced with an emphasis on "road closure, obliteration, and revegetation”. Haynes et al. (1997) found that bull trout in the Interior Columbia River Basin were not found in watersheds with road densities higher than 1.7 mi./sq. mi.

Road/Stream Crossings: The 1:100000 USGS hydrology layer and roads data were used to generate a road/stream crossing theme in Arc Info. Since both the roads layer and stream layer are both very incomplete, the road stream crossings should also be considered a conservative estimate. The USFS (Armentrout, et al., 1998) proposed a target of fewer than two road crossings per mile in the Mill, Deer and Antelope Creek watersheds, but also indicated that these targets applied to other Northern California watersheds with anadromous salmonids. The latter threshold is used in comparisons of road crossing data in KRIS Battle Creek Version 2.0.

Roads Near Streams and on Steep Slopes: Armentrout et al. (1998) and Napper (2001) recognize that roads located in riparian zones and near stream areas were often a major cause of sediment pollution in Battle Creek and watersheds adjacent to the south. Roads within 100 meters were queries for KRIS Battle Creek Version 2.0 and the Terraqua (2004) *Battle Creek WA* similar to methods followed by Kondolf et al. (1996). Keithley (1999) used the intersection of roads with steep areas as an index of potential sediment yield and roads on slopes over 35% were quantified using electronic data in Arc Info based on Armentrout et al. (1998), which used a similar risk threshold. Armentrout et al. (1998) also indicate that less than 3% of streamside areas should be impacted by road segments and that no more than 5% disturbance be allowed including roads, landings and near-stream timber harvests.

Near stream road density thresholds were calculated by Terraqua (2004) using an average road width of 25 feet based in McGurk and Fong (1995) and Armentrout et al. (1998), which lead to a near stream road density reference of 5.8 mi./sq. mi. for a threshold of impacts in the *Battle Creek WA*. This is logically inconsistent with the 4.8 mi./sq. mi. advanced by Terraqua (2004) for upland roads, which are less prone to yield sediment, and higher than most Pacific Northwest literature suggests for upland conditions. Because of the lack of foundation in regional literature, the Terraqua (2004) calculated near stream road density is not adopted in KRIS Battle Creek V 2.0 but rather the 2.5 mi./sq. mi. USFS (Armentrout et al., 1999) guide for overall watershed areas is used to apply to near stream roads as well.

Rhyolite

Soils derived from rhyolite are recognized as being the most erodible in the Battle Creek watershed (Napper, 2001) and in the watersheds of Mill, Deer and Antelope creeks to the south (Armentrout et al., 1998). Armentrout et al. (1998) described erosion risk and rhyolite:

> "When looking at erosion potential, an important factor to consider is parent material. Some materials are more prone to erosion than others, such as rhyolitic dacite. Rhyolite and rhyolitic dacite is a light colored rock, similar to granite, that easily separates from the base rock, especially at slopes greater than 35%."

Geology data in KRIS Battle Creek V 2.0 are from Chico State University but were digitized from U.S. Geologic Survey or USFS maps. USFS. The KRIS team calculated the area of rhyolite in each Battle Creek WA (Terraqua, 2004) sub-basin. *The Aquatic Condition Report: Upper Battle Creek Watershed* (USFS, 1999) notes that rhyolite derived soils often fall in the Lyonsville and Jiggs gravelly loam soil categories, which are prone to sliding on slopes of over 35% and to mass wasting on slopes of over 60%. They also noted a history of mass wasting on these rock types in upper South Fork Battle Creek tributaries, such as Nanny, Martin and Summit Creeks.

Identifying Rain on Snow Potential

Warm rain storms that melt snow packs can create extreme flood conditions. The rain-on-snow phenomenon is of particular interest in watersheds, such as Battle Creek, that contain substantial areas within the transient-snow zone that occupies the altitude band between 1,000 and 3,000 meters above sea level in the northern Oregon Cascades (Harr, 1986). Armentrout et al. (1998) used 3,500 to 5,000 feet as the rain-on-snow zone for adjacent Mill, Deer and Antelope basins. but roughly 3,500 to 5,000 feet and this elevation was adopted by Terraqua (2004) and used as a reference in KRIS Battle Creek V 2.0. Summary statistics in KRIS show the percentage of the area of overlap with various *Battle Creek WA* (Tearraqua, 2004) study basins. Napper (2001) noted that rain-on-snow effects took place on Lassen NF holdings in upper South Fork Battle Creek in 1997.

Land management practices in the transient-snow zone can have significant effects on the hydrologic response during rain-on-snow events. The additional water available for runoff increases the potential for downstream flooding and channel and hillslope erosion (Harr, 1981). Harr (1986), Berris and Harr (1987), and Heeswijk et al. (1995) found that forest canopy removal can alter local characteristics of snow pack and the microclimate that drives the energy transfer of the snowmelt processes. Snow depth, snow water equivalent, and the free water content of snow pack are increased in forest openings making more water available for snowmelt. The insulating effects of the forest canopy are not available and the energy available for snowmelt is increased. Berris and Harr (1987) reports that clear-cut areas had:

- Higher air temperatures
- Higher wind speeds
- Higher short-wave radiation than areas under forest canopy during rain-on-snow events
- Sensible and latent energy (wind driven) inputs to snow packs were 2 to 3 times greater in clear-cut areas than in forested areas.

Steep Slopes

The KRIS Battle Creek V 2.0 project uses 30 meter Digital Elevation Model (DEM) from the U.S. Geologic Survey to generate maps of slope to identify areas of higher risk for land use management. Armentrout et al. (1998) found that "erosion rates increase dramatically on steeper slopes" and broke slope classes at 35%-65% moderate risk and greater than 65% as high risk or extreme for the purpose of analysis. The KRIS Battle Creek slope theme shows separate risk classes, but also has one theme with everything over 35%. Risk of erosion was identified as heavily dependent on soil type, with rhyolitic soils on steep slopes having the greatest risk (Napper, 2001). Napper (2001) also found that roads, timber harvest and landings intersecting with steep slopes or stream side areas caused increased erosion risk in the upper SF Battle Creek watershed.

Fire

Fire is a potential factor in sediment yield and fire information for Battle Creek was available from the USFS and CDF from the early 1900's to 1997. The combined public and private land GIS coverage includes attributes like date, size of the fire, where it started and other relevant information. Attributes are not complete, however, for many fire events, particularly those that occurred early in the last century. The data were assimilated into the Arc View-based KRIS Battle Creek Map project and grouped in periods of 20 year intervals (i.e. 1900-1920). Fires between 1981 and 1997 were considered more important in the scope of this study than fires that burned prior to 1980. There were no extensive burns in steep upland areas of Battle Creek to warrant analysis of the 1961-1980 period.

RESULTS

Upland Condition

Vegetation types, forest age and changes in vegetation and tree size between 1991 and 1999 are characterized for all upland areas and riparian zones using Landsat imagery from the U.S. Forest Service Spatial Analysis Lab in Sacramento and CDF Fire and Resource Assessment Program (FRAP). Roads, their locations and where they cross streams all have bearing on sediment yield, and were consequently analyzed. Steep slopes and the patterns of land use on them were also studied using GIS, as was the location of rhyolite, the most unstable of geologic types in the Battle Creek watershed. Fires may increase erosion risk and the fire history of the Battle Creek watershed for the last 100 years is discussed below. Findings are displayed in map form or sometimes as charts, when overall or selective sub-basin comparisons are illustrative.

Tree Size and Vegetation Type, Riparian, and Change Scene Detection

Vegetation types of the Battle Creek watershed (Figure 2) show lowlands in the west dominated by grasses, blue oak woods and farm and ranch land. The middle watershed is a mix of Eastside Pine forest and Mixed Chaparral. Higher elevations in the east are covered in the Sierran Mixed Conifer forest interspersed with Montane Chaparral and bare rock on the shoulders of Mt Lassen. Tree size and change scene detection can be used in the forested zone to examine timber harvest.

Vegetation Types/Indicator of Land Use: The tree size and vegetation map based on 1996 Landsat data (Figure 3) yield more detailed patterns. The grasslands and agricultural areas show as Non-Forest and Saplings, while the blue oak woodlands are showing as Small Trees (5-11.9"

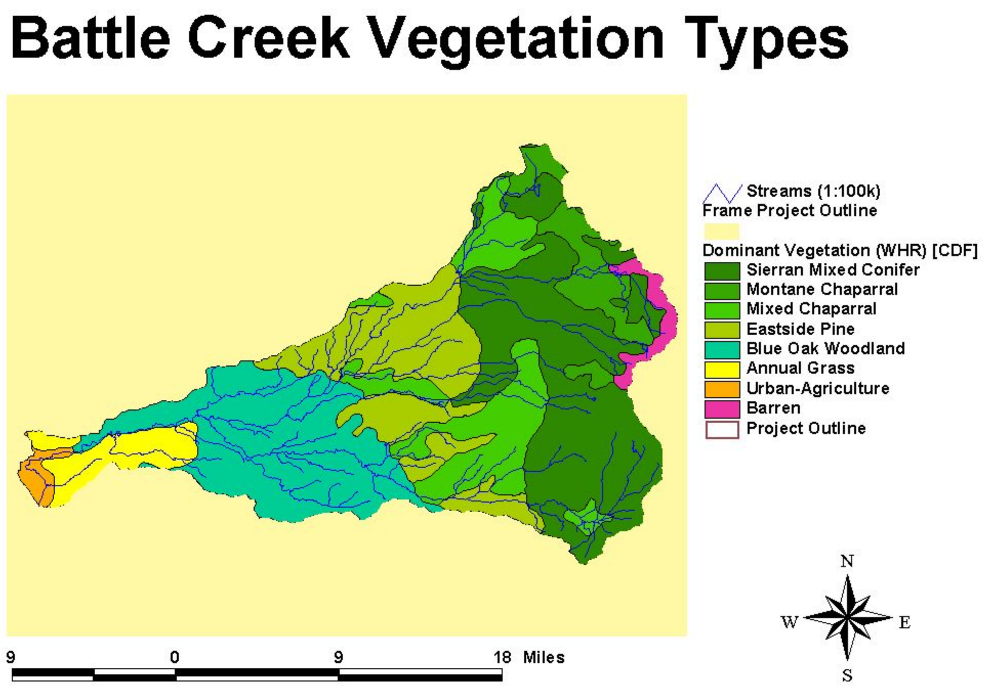

Figure 2. Dominant Vegetation Types of the Battle Creek Watershed. Data from USFS Spatial Analysis Lab and CDF FRAP, Sacramento, CA.

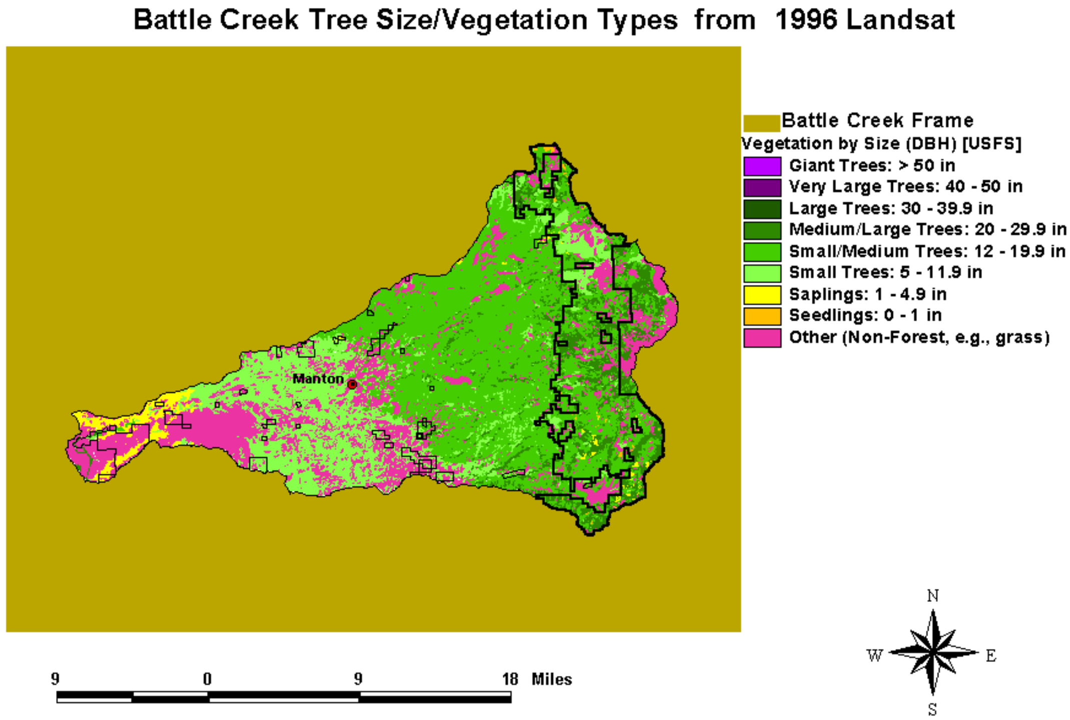

Figure 3. This map shows the tree size and vegetation types based on 1996 Landsat imagery. Note larger tree sizes by ownership boundaries: Lassen National Park to the east, USFS bracketed by the black lines and private lands to the west (at left). Data from USFS and CDF.

dbh). Both extend to just below the mid point in the Battle Creek watershed near Manton. The portions of the watershed to the east are in the timber producing zone except at the highest elevations above the tree line on Mt Lassen and in patches where vegetation is limited by soil or geologic conditions. Tree sizes include more Medium Large (20-29.9" dbh) and Large Trees (30-39.9" dbh) on USFS lands, whereas industrial timber ownership further west is dominated by Small-Medium (12-19.9" dbh) trees, indicating more active timber harvest.

The northeastern corner of the Battle Creek watershed tree size and vegetation data are displayed close up in Figure 4 as an example. Lassen National Forest and Lassen National Park have large stands of Medium-Large (20-29.9" diameter) or Large (30-39.9" dbh) trees, while there are few such trees except in small patches on adjacent private industrial timberland. Non-Forest (hot pink) may be large patches of bare rock resulting from lava flows on National Forest lands and in the Lassen National Park and large contiguous patches along streams may represent meadows. The same Non-Forest signature, however, as represented by small, disbursed patches may also be indicative of recent clear cuts, such as those above the North Fork Battle Creek Reservoir. Small (5-11.9" dbh) trees in Lassen National Forest may be as a result of stunting due to bedrock geology, although some of these areas observed on U.S. Geologic Survey orthophotos appear to have a history of management. Timber on harsh sites at high elevations may have been harvested and shown poor regeneration.

A close up of the North Fork Battle Creek Reservoir watershed is shown using a USGS orthophoto quad as backdrop (Figure 5) that allows comparison with the Landsat vegetation data. Old forest stands along the National Forest boundary contrast with recent timber harvests that are evident on private lands adjacent, although older USFS patch cuts are also apparent.

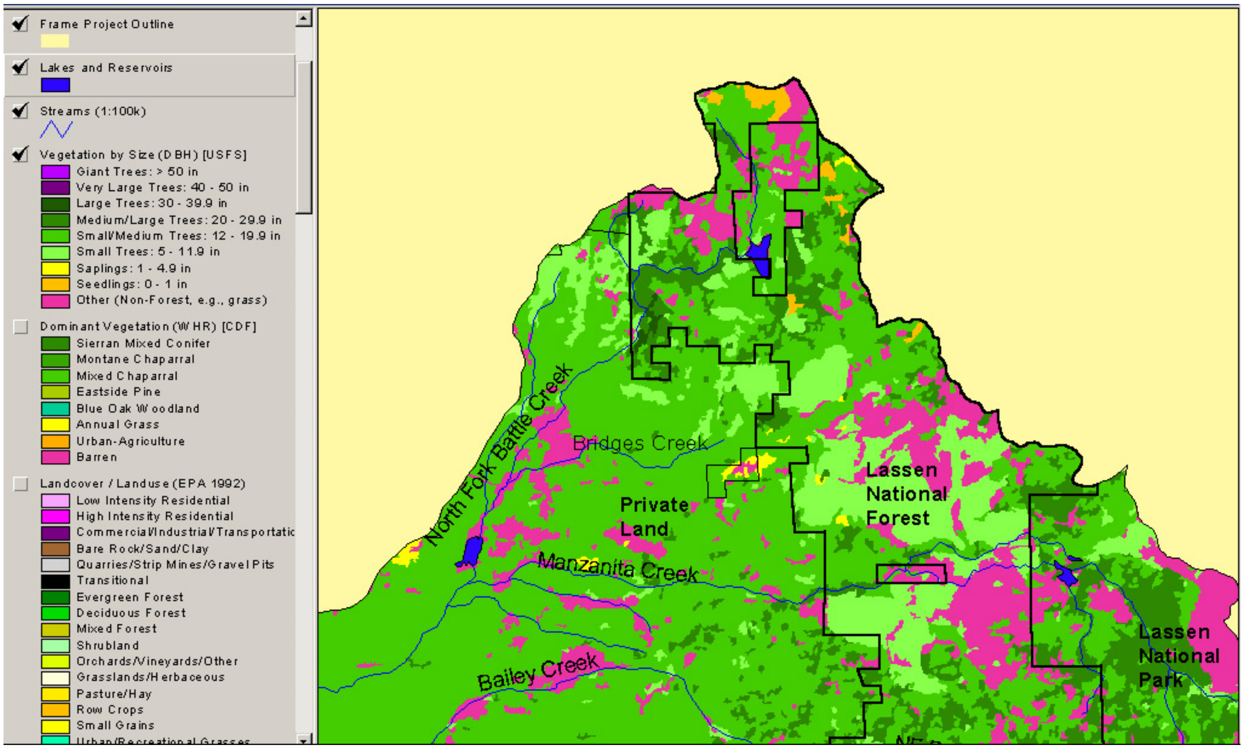

Figure 4. Upper North Fork Battle Creek tree size and vegetation type showing different size classes of trees on private and public land. The figure below is a zoom in on the top of this area. Data from the USFS Spatial Analysis Lab and CDF FRAP, Sacramento, CA.

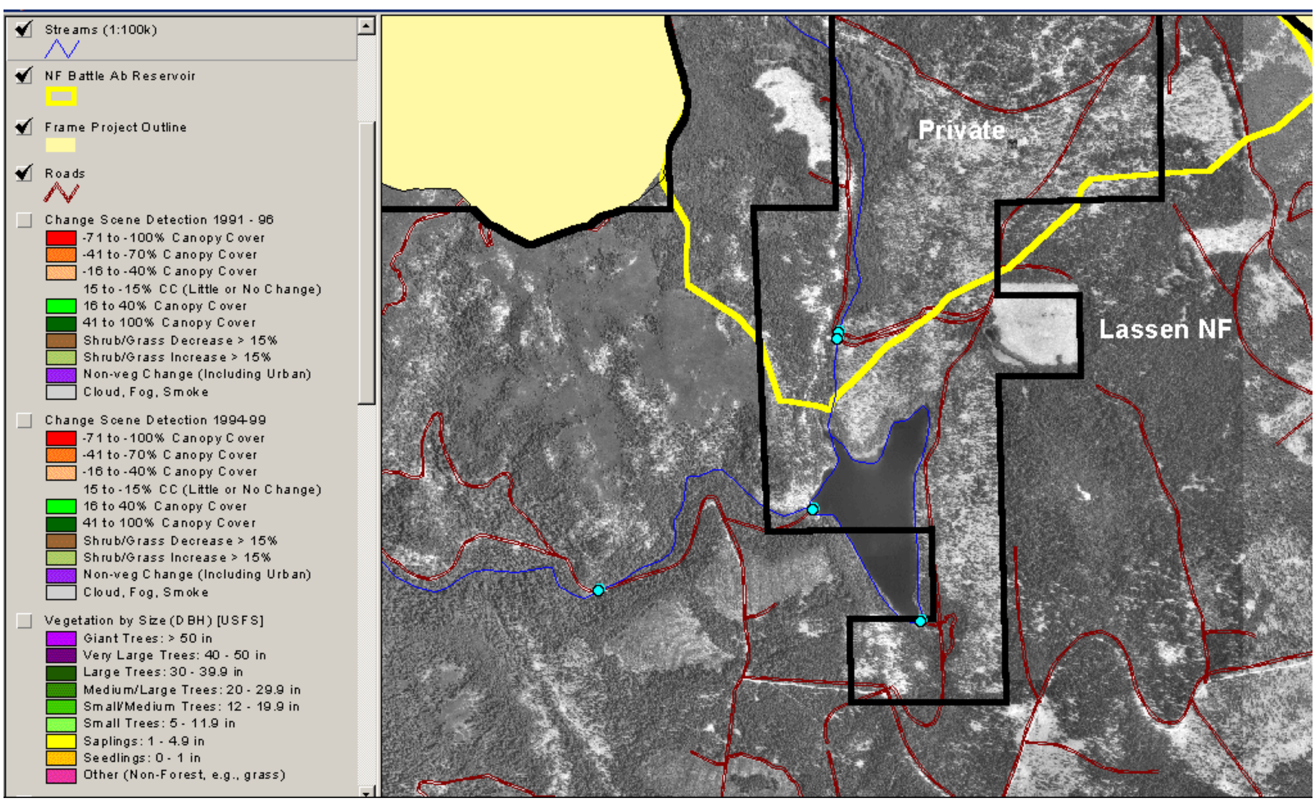

Figure 5. The USGS 1996 orthophoto above shows the NF Battle Creek Reservoir with clear cuts and younger forests on the private lands above it and older forests to the east on Lassen National Forest (darker patch at right). The yellow outline is *Battle Creek WA* sub-basin #59. (See Fig. 9)

The central portion of the upper Battle Creek watershed from Bailey Creek through upper Digger and Panther Creeks shows the same pattern of forest age across public and private land boundaries (Figure 6). Larger trees prevail on colluvial areas in Lassen National Park, whereas bare rock predominates in steeper areas. Small (5-11.9” dbh) trees in the National Park and on some USFS lands may be due to poor soils or up-crops of bedrock Lassen National Forest has more and larger stands of Medium-Large (20-29.9” dbh) and Large (30-39.9” dbh) trees, but the patches of Seedlings (0-1” dbh) in the southern (lower) part of the image indicate fragmentation by past public land timber harvest. Non-Forest patches on USFS and private land to the west may also represent clear cuts that have not regenerated (as indicated by checking orthophotos).

While larger trees are still more prevalent in the upper South Fork Battle Creek watershed on National Forest lands (Figure 7), fragmentation of the forest is clear with patches of Seedlings and Saplings (1-4.9” dbh) evident in Summit, Nanny and upper Panther Creeks. Although Non-Forest is the expected signature of the large grassy area of Battle Creek Meadows in the valley floor at the headwaters of the South Fork, smaller patches of Non-Forest on both USFS and private land also indicate timber harvest. Again past clear cuts on poor sites that have not regenerated, recent clear cuts and concentrations of roads and/or landings may also show as Non-Forest, as indicated by checking orthophotos in areas where these signatures were present.

Summary charts can also help to quantify the difference in size and age structure on USFS and private lands. Basins chosen for the *Battle Creek WA* (Terraqua, 2004) the chart in Figure 8 are representative of management across ownerships in the Battle Creek watershed. The Medium/Large tree category is much more prevalent on USFS and National Park lands which are the six streams at left in the Figure 8. Upper North Fork Bailey (#14), Upper Digger Creek (#42), and upper Nannie Creek (#51) are either lightly managed or undisturbed. Summit Creek (#1), an upper SF Battle tributary above Battle Creek Meadows (#17), and the upper South Fork Digger Creek (#26) represent managed USFS lands. The three bars at left are South Fork Digger (#24), upper South Fork Rock Creek (#37) and the North Fork Battle Creek above NF Battle Reservoir (#59), which are heavily managed and mostly in private lands, except for the latter sub-basin, which is partially in USFS ownership.

The control or lightly logged sub-basins (#14, #42, #51) may occupy steeper slopes at higher elevation at the top of the Battle Creek watershed, where timber stands may be less dense than on the gradual benches below. Consequently, the managed watersheds on USFS lands have similar components of Medium/Large trees (24-52%) to the unmanaged areas (29-51% Medium/Large). The private industrial timberlands have a lower component of Medium/Large trees with 6-29% of the watershed in this size class. This is similar to the findings of Beardsley et al. (1999) who noted that old growth conifers were more prevalent at lower elevations on USFS lands outside Wilderness, and that only 2% of remaining old growth in the Sierra Nevada was on private lands. The larger bars for Non-Forest, Seedlings, Saplings (<5” dbh) and Small trees (5-11.9” dbh) are indicative of recent timber harvests and early seral conditions that result in totals for these three components of 40%, 7% and 37%, respectively, for the SF Digger Creek, upper Rock Creek and the NF Battle above the NF Battle Creek Reservoir. Bedrock and meadows may add to Non Forest totals, but concentrated areas of roads and landings may also result in a Non Forest signature when they are large enough to register at the one hectare scale. Upper Rock Creek registers 86% Small-Medium (12-20” dbh) trees, which indicates that the majority of the watershed has likely been harvested in the last 30 years. Change scene detection indicates active logging in widespread areas of Rock Creek between 1991 and 1999 (see below).

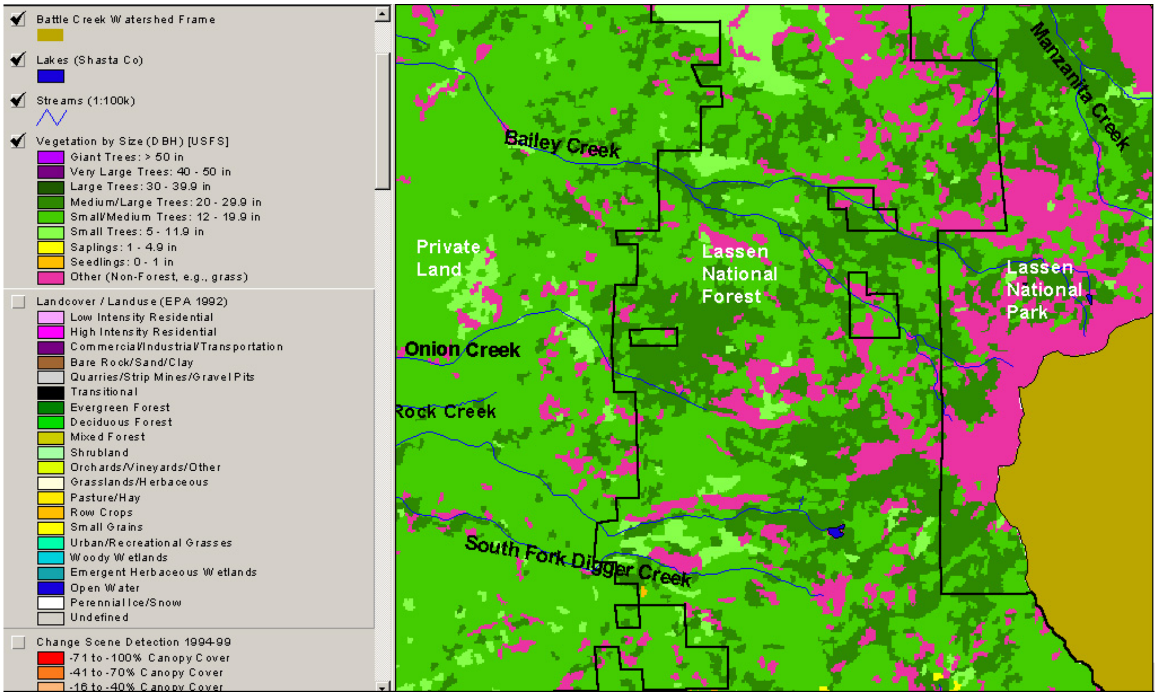

Figure 6. The central portion of the upper Battle Creek watershed is shown here with 1996 Landsat vegetation data showing tree sizes and areas of non-forest for upper Bailey, Onion and Digger Creeks. Data from the USFS Spatial Analysis Lab and CDF FRAP, Sacramento, CA.

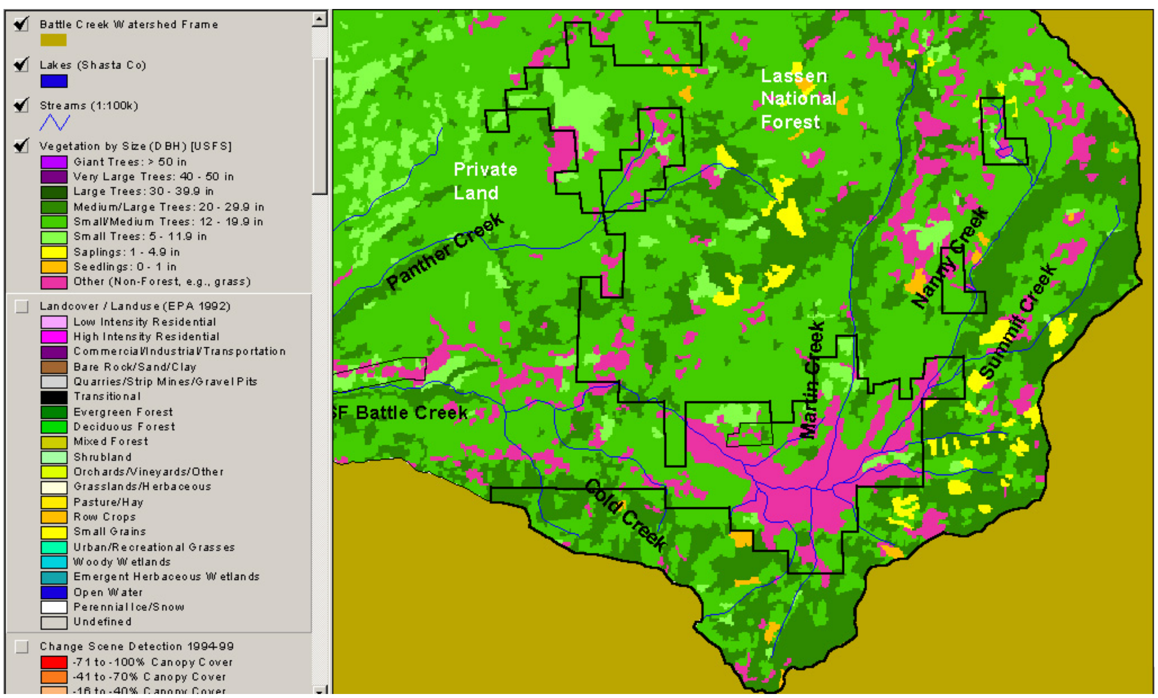

Figure 7. The upper South Fork Battle Creek watershed showing 1996 Landsat tree size and vegetation type data, which has a one hectare resolution. Data from the USFS Spatial Analysis Lab and CDF FRAP, Sacramento, CA.

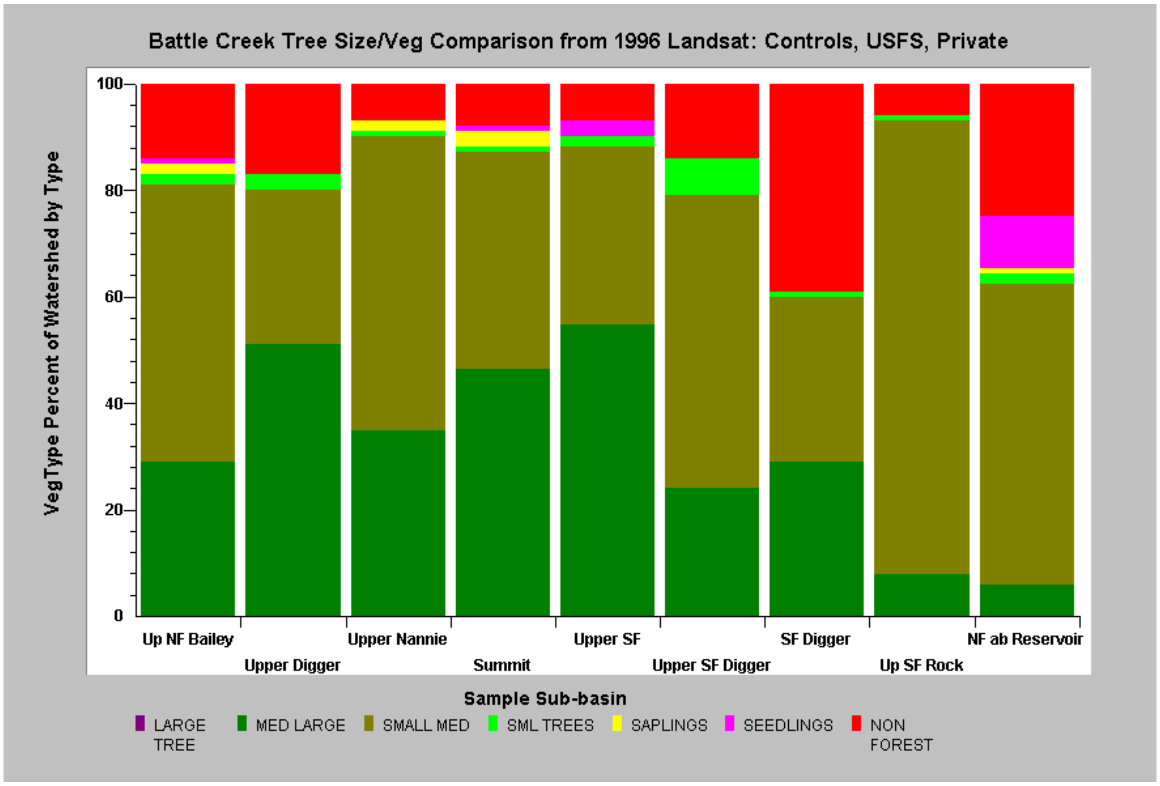

Figure 8. This chart shows the summaries from Landsat imagery of tree size and vegetation type for selected *Battle Creek WA* study sub-basins. The three basins at left are lightly managed but at high elevation, the middle three are USFS watersheds managed for timber and the three to the right are mostly private industrial timber lands. Note the latter has fewer large trees and more non-forest, which indicates more active timber harvest. Data from USFS and CDF.

Change scene detection results from 1991 to 1996 and 1994 and 1999 are combined in Figure 9 as an overlay to the USGS orthophotos with land ownership boundaries and roads displayed for the upper NF Battle Creek, similar to the location of Figures 5. The image shows vigorous growth in past clear cuts in green and also decreased canopy cover in shades of orange and red to the east on National Forests in this period. The decreased vegetation patterns can be used to determine approximate timber harvest since 1991. Patterns of vigorous re-growth likely indicate harvests 10-15 years prior, although no budget was available to test this assumption. The private area above the reservoir must have been harvested in 1990, just before the change scene detection. This explains why it shows neither canopy decrease nor increase, because its major growth spurt did not occur before 1999.

Figure 10 shows the change scene detection for the area of the Battle Creek watershed effected by timber harvest, which is mostly east of Manton. The data reflects decreases of forest canopy and patterns of re-growth in areas harvested previously. The data suggest that changes in tree size and canopy are much more rapid on private lands than on public lands. While logging activities are less widespread on USFS lands, which are to the east of private lands but west of Lassen National Park, some timber harvest took place from 1991-1999 and green areas showing re-growth suggest a slightly higher rate of harvest in the 10-15 years preceding. Changes at high elevation in Lassen National Park may be as the result of landslides during major storm events, small fires and resulting subsequent re-growth or different effects from varying in snow pack. Changes at lower elevations around Manton could be related to agriculture and development.

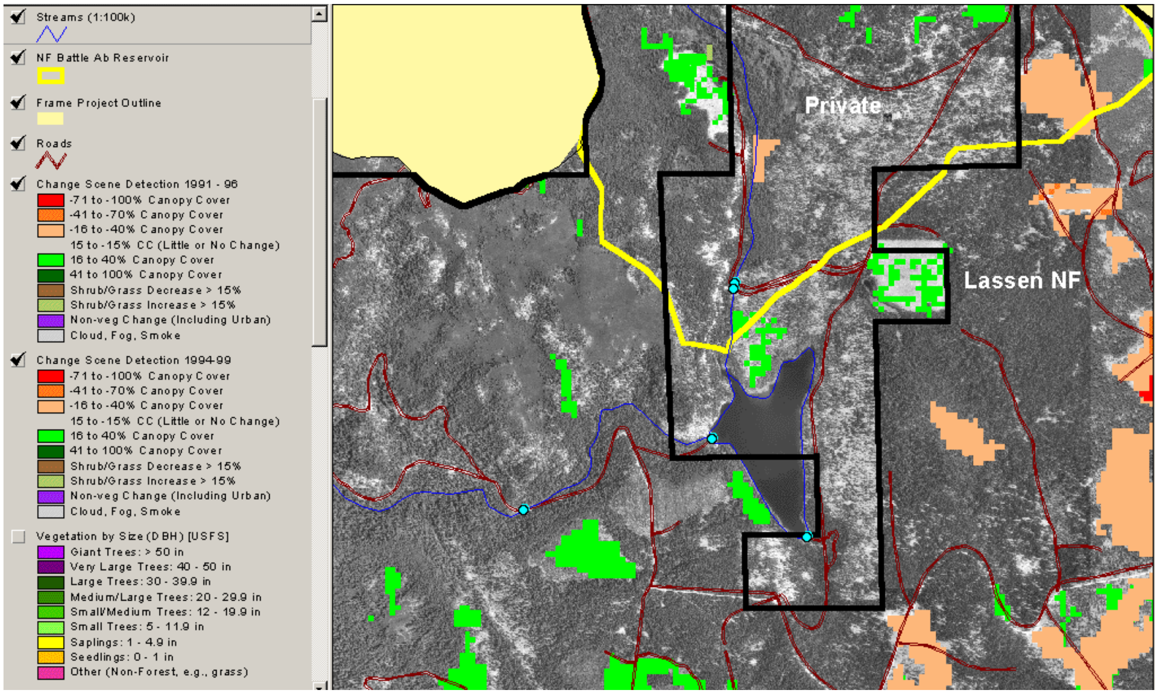

Figure 9. Change scene detection from 1991-1996 and 1994-1999 are displayed above over the USGS orthophoto for the NF Battle Reservoir area. Bright green indicates vigorous re-growth in previously harvested areas and red and orange indicate depletion of the canopy or logging. Data from the USFS and CDF FRAP.

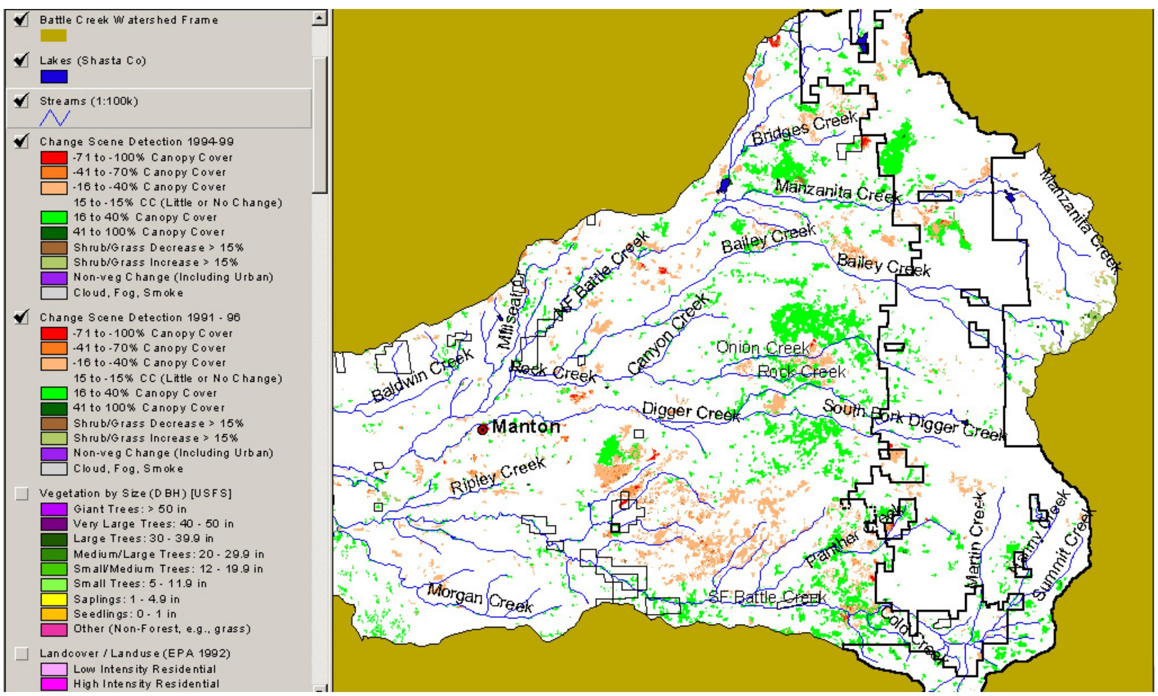

Figure 10. The combined change scene detection from 1991 to 1999 for the Battle Creek watershed is displayed above with shades of red and orange indicating reduced canopy, while green indicates re-growth in areas timber harvested or otherwise disturbed previously. Black lines indicate ownership of Lassen NP to the east (right), USFS (middle) and private land to the west (left) with industrial timber land extending down toward Manton.

The results from Lavien et al. (2002) for all northeastern California are consistent with the patterns of change in the Battle Creek watershed:

- "Approximately 360,000 acres (5%) show a decrease in cover and 263,000 acres (4%) show an increase, with the majority of decrease falling within private ownership and the majority of increase falling within public ownership.
- The Sierran Mixed Conifer class exhibits the largest change of all conifer types with a decrease in cover on 237,869 acres (8%) and an increase in cover on 167,120 acres (5%).
- Harvesting accounts for most of the conifer change.

Riparian Zone Landsat Assessment: The Landsat imagery from 1996 from the USFS Spatial Analysis Lab and CDF were used to judged riparian condition using a 100 meter buffer around USGS 1:100000 hydrography. Larger trees indicate later successional stages, more thermal buffer capacity and better ability to supply large wood to streams. Similar difference in size classes or trees on private and public lands in upland areas persist in riparian zones, with tree sizes smaller on private land indicating active timber harvest. An example is in the northeastern Battle Creek watershed is displayed as Figure 11. Older and larger trees characterize the riparian on Lassen National Forest below the North Fork Battle Creek Reservoir, with Medium-Large (20-29.9" dbh) and Large (30-39.9" dbh) trees predominating. Small (5-11.9" dbh) and Small-Medium (12-19.9") trees are the most common on private land. Non Forest signatures in the riparian may be indicative of meadows, rocky terrain (near headwaters), timber harvest or roads and landings.

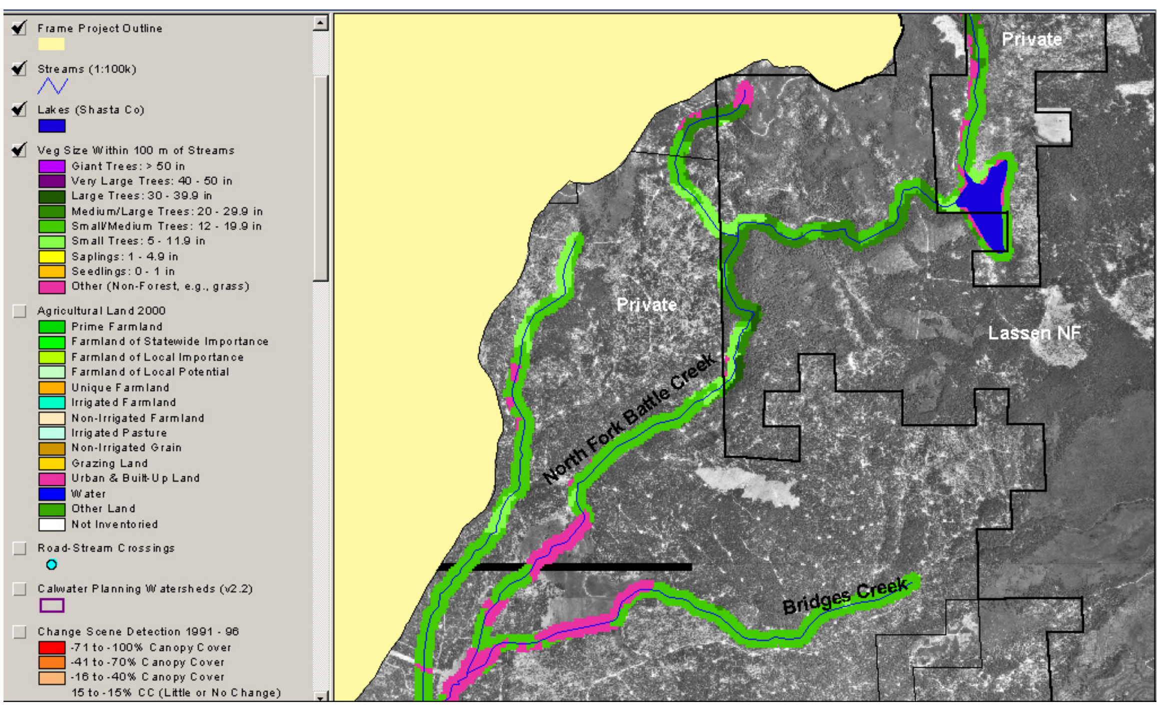

Figure 11. Riparian conditions are shown here by using USFS/CDF 1996 Landsat tree size and vegetation type data in a 100 meter buffer on 1:100000 USGS hydrography for the upper NF Battle Creek and Bridges Creek. Note larger tree diameters on public land. The backdrop is a 1994 USGS orthophoto quad.

Lack of Accuracy in Hydrography Poses Problems for Riparian Analysis: A quantitative analysis of riparian conditions using Landsat vegetation data was not possible because of the problems with existing hydrography for the basin. Riparian summary statistics on the same sub-basins as those used in upland analysis (Figure 8) were found to be skewed in runs of test queries because the length of stream arcs did not extend far enough into headwater areas. Also, the 1:100000 stream coverage stream center line is in some cases well off the actual stream channel. This can result in upland vegetation being included in the riparian summaries and stands that are actually within 100 meters of the stream being excluded (Figure 12). The example of this problem was observed along South Fork Digger Creek (Figure 13), but other areas checked versus orthophotos did not seem to have the same degree of problems with regard to the stream center line. Consequently, the riparian tree size and vegetation data make useful visual representations, but would be of more use if more accurate and detailed hydrography were available.

Agricultural Land Map and EPA Land Cover

The USDA NRCS regional farmland surveys show where agricultural activities take place, but US EPA land use maps from Landsat are a useful tool in judging rural residential impacts.

Figure 14 indicates that the lower Battle Creek watershed is important grazing land. The Unique Farming Value category includes vineyards, which have been expanding rapidly in Battle Creek in recent years. Reconnaissance of agricultural impacts on aquatic resources will be focused on the lower watershed as will consideration of cumulative effects related to rural residential development.

The U.S. Environmental Protection Agency Landsat imagery interpretation for land use includes areas of residential and commercial development (Figure 15), which are small pink and purple

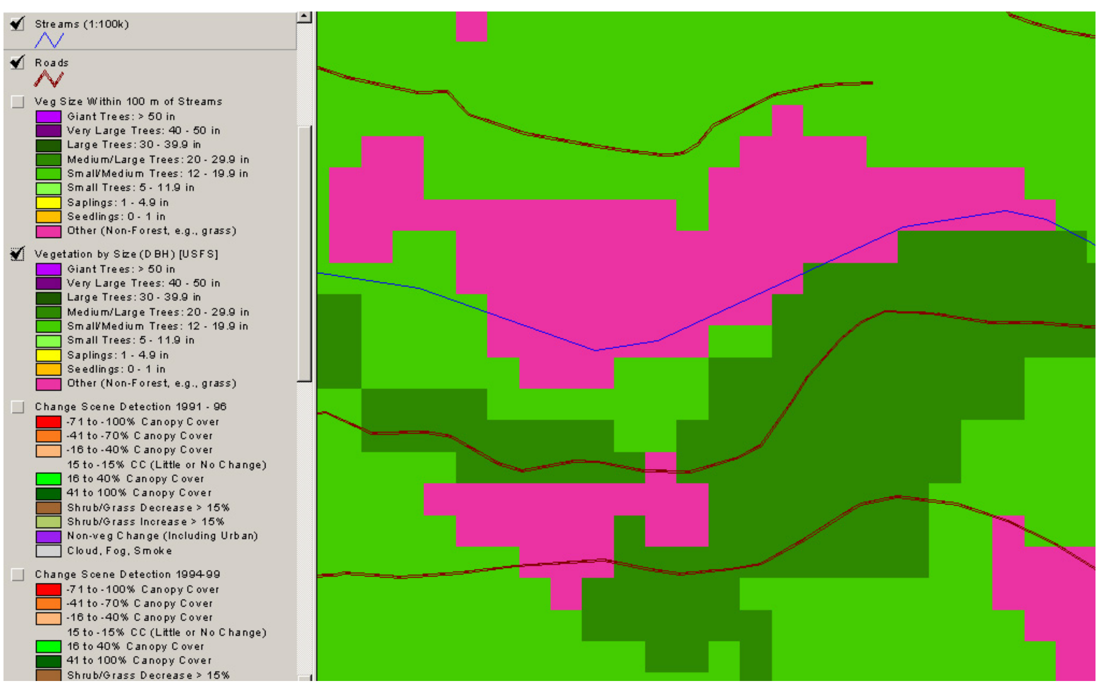

Figure 12. This map shows the center line of the South Fork Digger Creek in blue with roads in brown. Figure 13 shows that Medium/Large trees are actually nearer the stream.

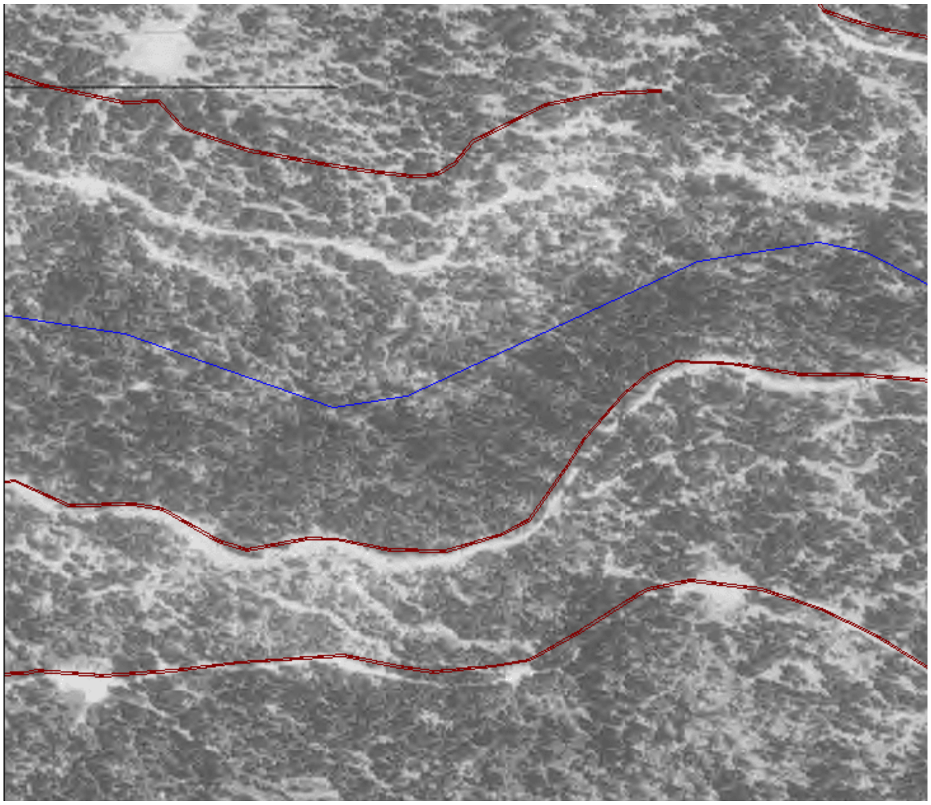

Figure 13. This shows a zoom in on an orthophoto of South Fork Digger Creek at the same location as Figure 12. Note that the dark, sinuous line of larger trees is closely paralleled by the road but that the stream course is very obviously incorrect. Disturbance of the road in the upper part of the image and associated activities are sufficient to register as Non-Forest in Figure 12.

spots near Mineral in the southeast and Manton in the west at center left. Vineyards are being developed around Manton and residential development there and below Shingletown are better reflected by change scene detection than the U.S. EPA cover because it is based on 1992 data.

Road Densities, Stream Crossings per Mile, Roads on Steep Slopes

While electronic road maps are incomplete for the Battle Creek watershed, they do provide some reference for potential erosion. Figure 16 shows the road map generated from Sierra Pacific Industries, USFS and USGS data with large land ownership delineated. Road densities were calculated for all *Battle Creek WA* (Terraqua, 2004) sub-basins as road miles per square mile (Figure 17) with values ranging from 1.06 mi./sq. mi. in the upper South Fork Digger Creek to 6.26 mi./sq. mi. in Rock Creek. Values on the road density chart are referenced against a target of 2.5 mi./sq. mi. from the USFS for all anadromous watersheds on Lassen National Forest (Armentrout et al., 1999).

The higher road density on private timber lands west of the National Forest boundary somewhat reflects watershed conditions, but actually USFS road maps are incomplete. Using USGS orthophoto quads for reconnaissance, it is evident that roads are under-represented on USFS maps. The orthophoto zoom in Figure 18 shows an example of high road densities in the northeastern Battle Creek watershed on USFS lands.

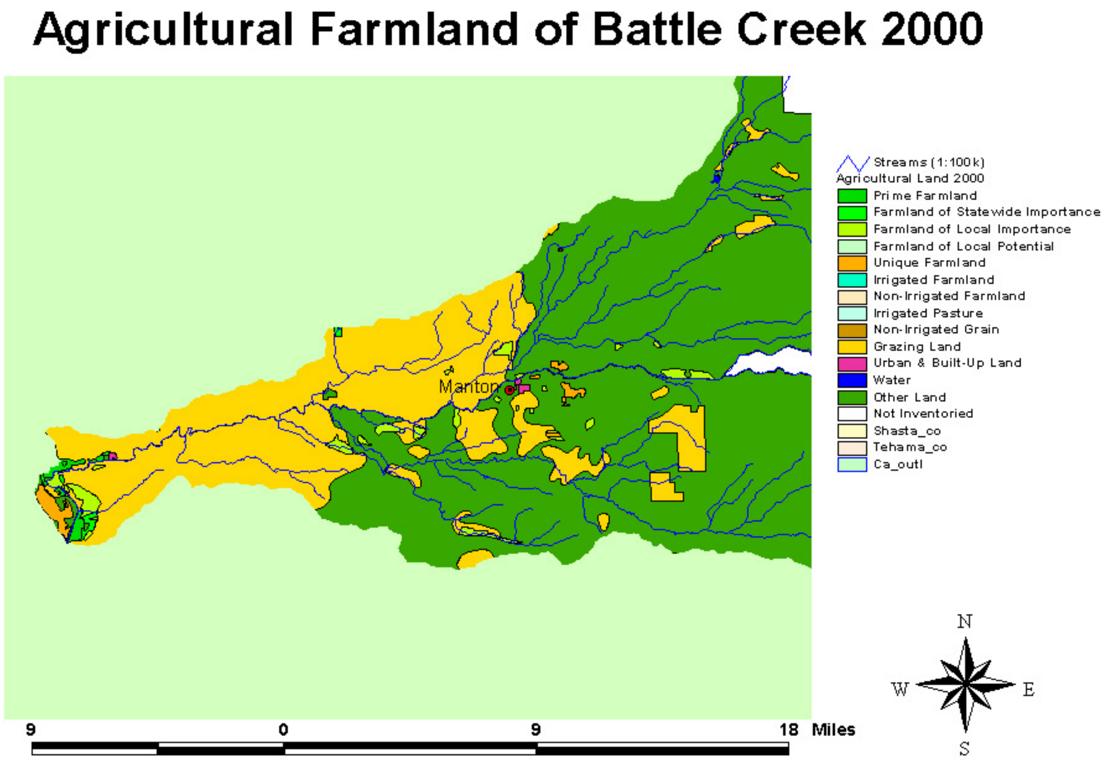

Figure 14. This map shows agricultural land by type in 2000 according to the U.S. Department of Agriculture, Natural Resource Conservation Service.

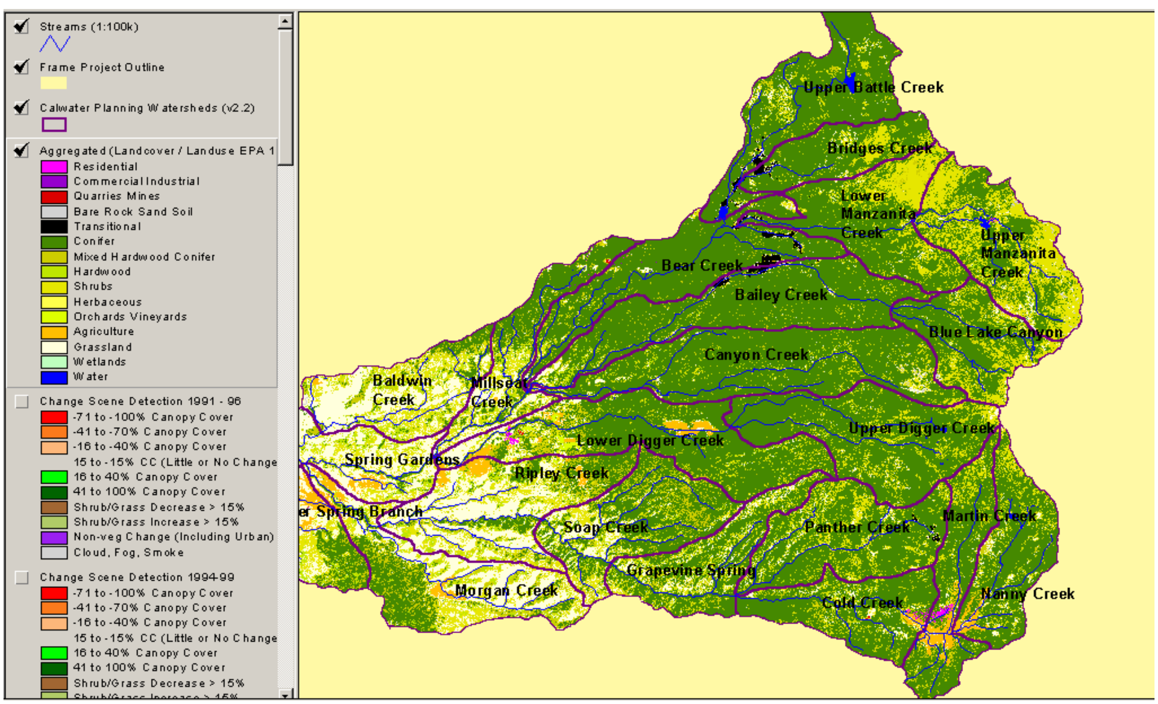

Figure 15. Landscape conditions and land use are indicated by this 1992 Landsat image as interpreted by the U.S. Environmental Protection Agency. Residential development around Manton and Mineral constitute a very small area of the watershed.

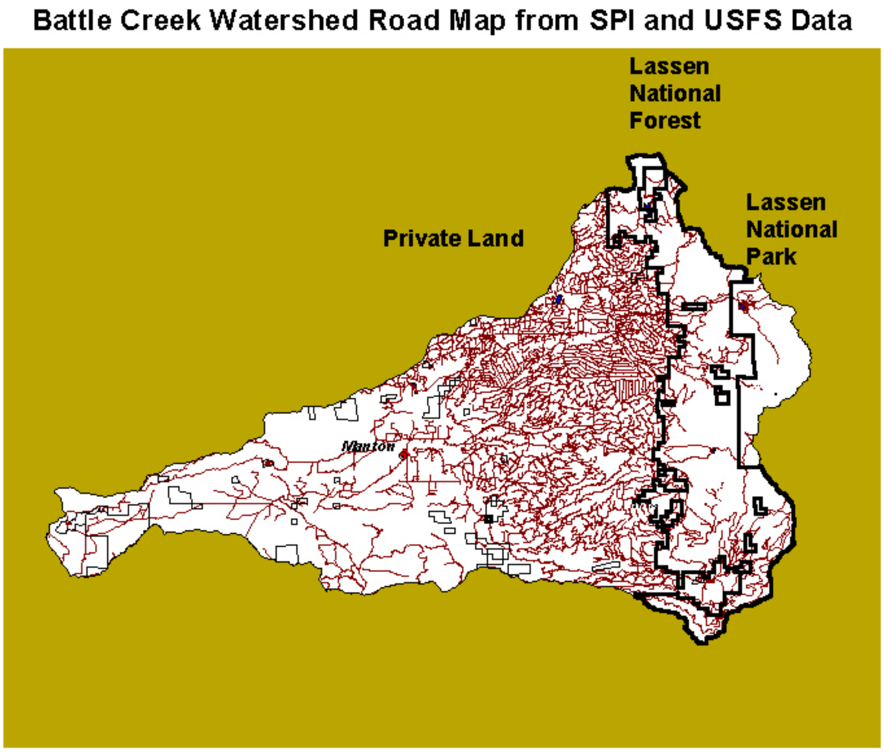

Figure 16. This map shows roads in the Battle Creek watershed according to best available data from Sierra Pacific Industries, the USFS and USGS.

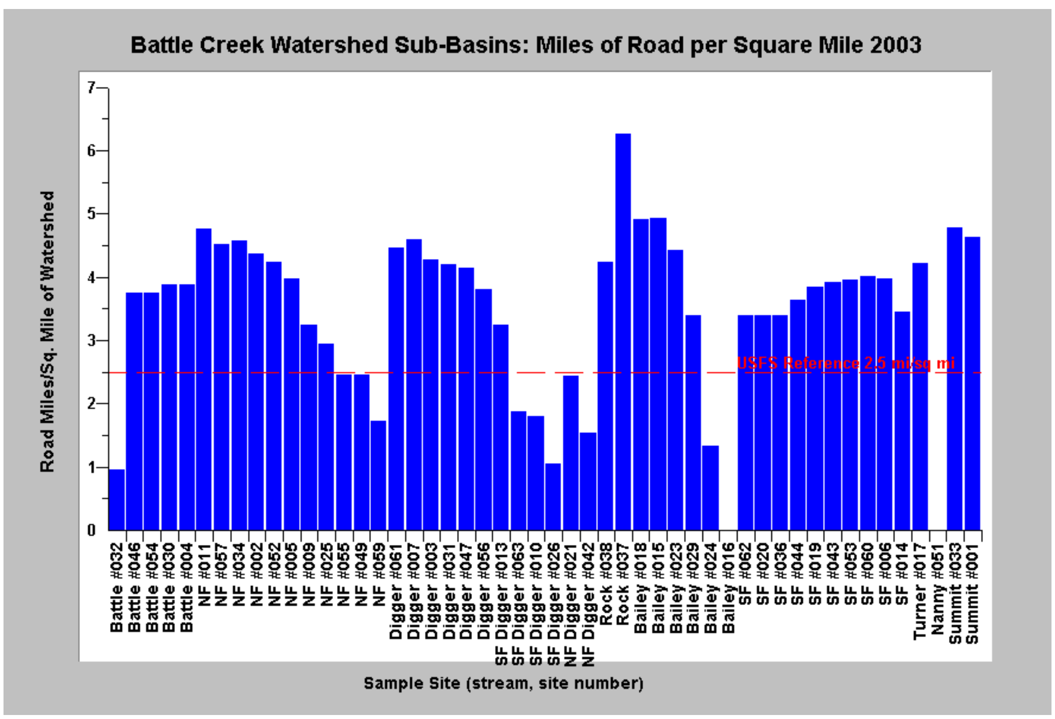

Figure 17. Road densities for various *Battle Creek WA* study sub-basins referenced against a threshold of 2.5 mi./sq. mi. based on Armentrout et al. (1998).

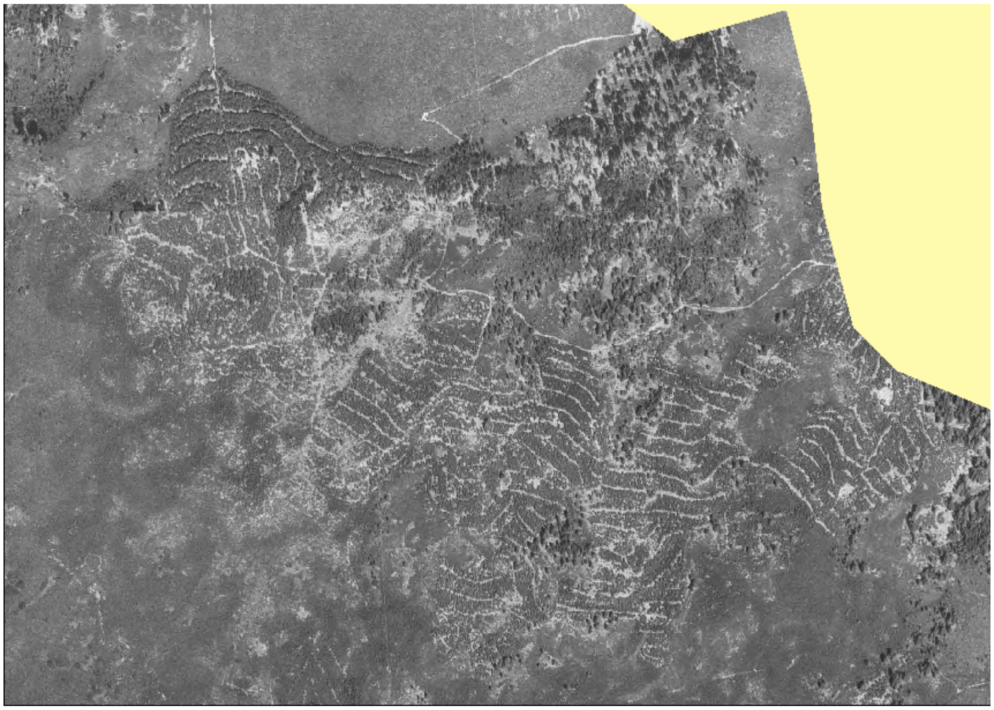

Figure 18. This close up of the northeast border of the Battle Creek watershed shows high road densities on USFS land in what appears to be an area previously harvested. These roads are not indicated in the USFS electronic road data. Re-growth of forests appears to be poor on this site.

Both road and hydrology electronic maps for the Battle Creek watershed are incomplete; consequently, the road-stream crossing map under-represents actual stream crossings (Figure 19). Quantitative relationships of the number of stream crossings per mile in various *Battle Creek WA* sub-basins are displayed as Figure 20 referenced against the USFS target of less than two stream crossings per mile (Napper, 2001). Values range from a low of 0.81 crossings per mile in upper Bailey Creek to 2.89 crossings per mile in Rock Creek.

The USFS recognizes that roads near streams pose a greater risk of chronic and catastrophic erosion (Armentrout et al., 1998). The coverage of roads near streams generated in the Arc Info shows all road segments within 100 meters of Battle Creek streams (Figure 21). It suffers from the same deficiency as the road stream crossings because both the hydrography and roads layers for the Battle Creek watershed are incomplete. Also, misplaced center lines of streams may lead to some road segments being left out or others incorrectly categorized as stream side roads when they are actually further than 100 meters away. None the less, the map of roads near streams shows a very similar pattern to road crossings, with many more areas with roads near streams on private timber land. Some near stream roads are actually major highways, such as where Highway 44 parallels Manzanita Creek as it flows west from Lassen National Park. Similarly, the upper South Fork and its tributaries are crossed by both Highway 36 and Highway 89. Armentrout et al. (1999) has a target of no more than 3% of the riparian zone having roads or timber harvest for streams on Lassen National Forest. Terraqua (2004) calculated this target using a 25 foot road width and came up with 5.8 mi./sq. mi. for near stream disturbance, which was not a finding of the specific finding of the USFS and is not reflected in other regional literature. See Background page *Roads and Potential Erosion in the Battle Creek Watershed* in KRIS Battle Creek V 2.0 for more information and examples.

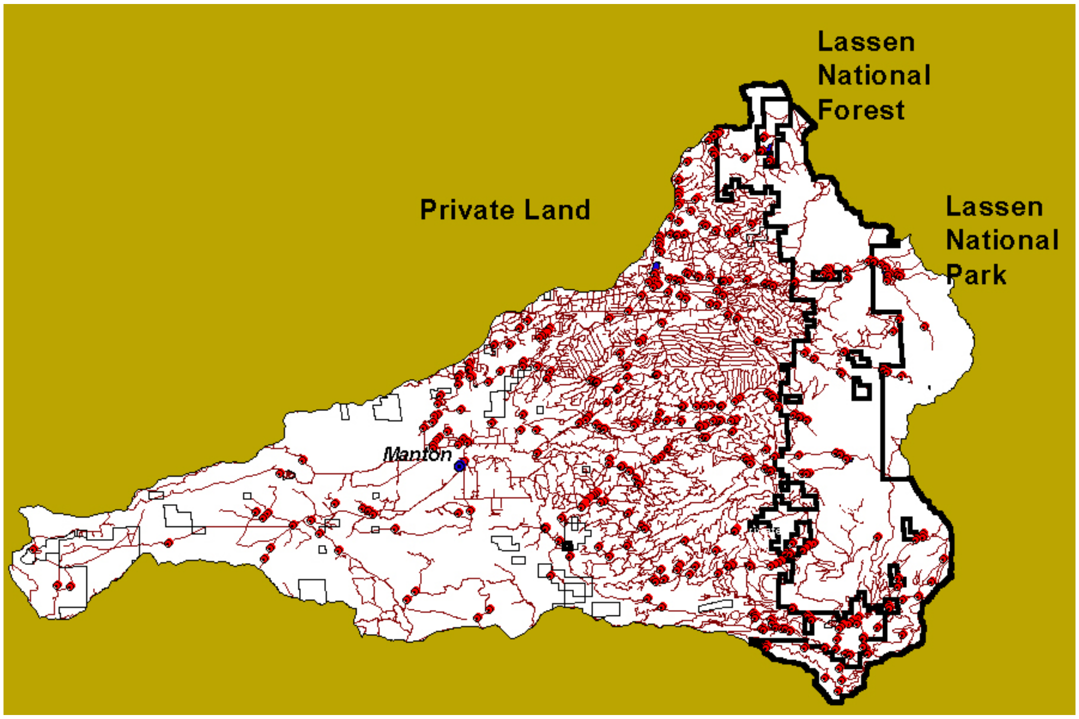

Figure 19. This map includes both roads and road crossings in the Battle Creek watershed with crossings represented by red dots. Data are from the KRIS Battle Creek Map project based in USGS 1:100000 hydrography and best available roads data from SPI and USFS.

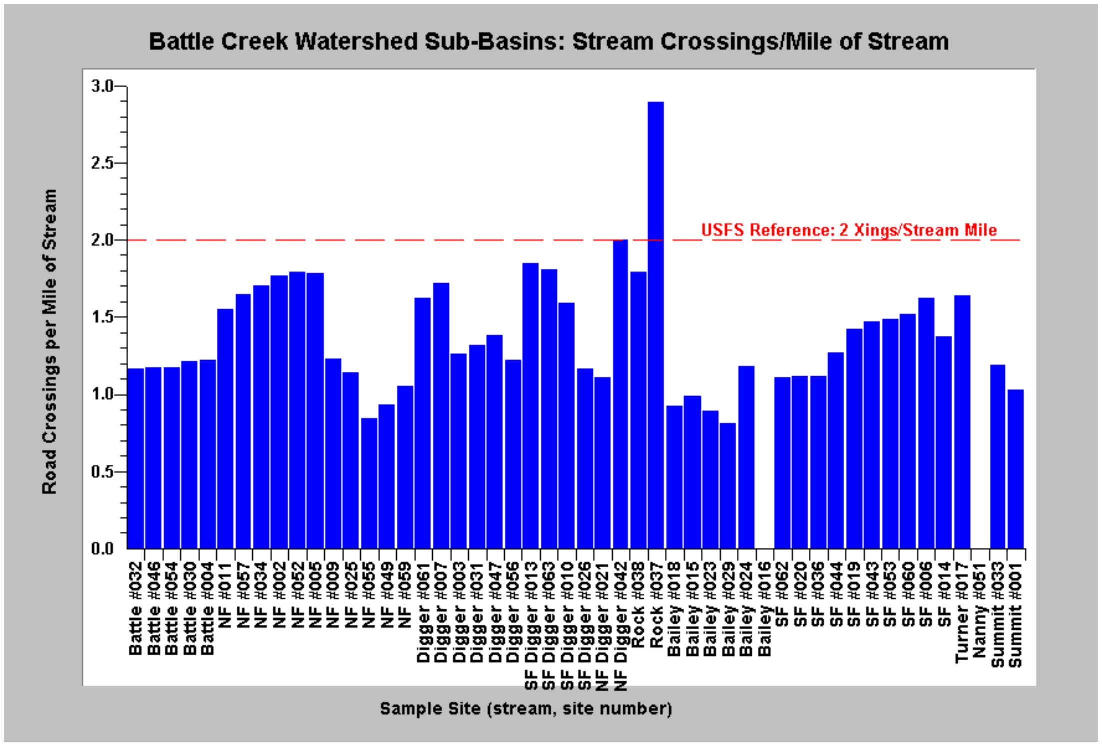

Figure 20. Road crossings per mile of stream are displayed above for the Battle Creek watershed based on USGS 1:100000 hydrography and best available road maps from SPI and the USFS.

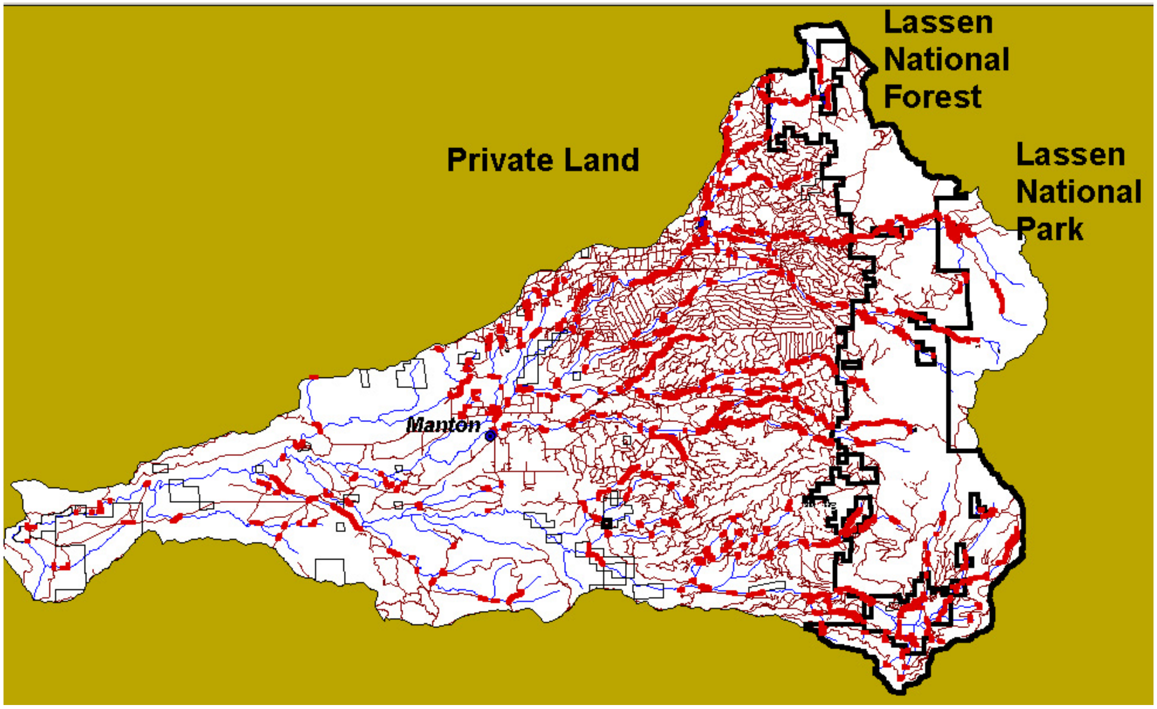

Figure 21. Red areas indicate where roads are within 100 meters of streams. Data based on roads from SPI and the USFS and 1:100000 USGS hydrography.

Napper (2001) indicated that roads crossing steep slopes posed higher erosion risk than roads on less steep terrain. Slopes greater than 35% were chosen as a reference and Figure 22 shows all such steep areas and roads in the Battle Creek watershed. Steep areas are most concentrated near Mt Lassen, in the South Fork Battle Creek basin, and in inner gorge areas throughout the watershed.

Rhyolite in the Battle Creek Watershed

Rhyolite is recognized as one of the most erodible rock types in the Battle Creek basin (Napper, 2001) and in the Mill, Deer and Antelope Creek watersheds to the south (Armentrout et al., 1998). Rhyolite is present in two large patches shown in yellow (Figure 23) according to data from Chico State University, which were derived by digitizing USGS 1:250000 geologic maps. While one large area of rhyolite is in the Manzanita Creek and upper North Fork Bailey Creek basins, the second area is in the South Fork in the Soap Creek and North Fork Panther Creek area. The percent rhyolite of various Battle Creek Watershed Analysis sub-basins is displayed in Figure 24. Values range as high as 40% for some Digger Creek sub-basins, but many others have no rhyolite what so ever.

Risk of Rain on Snow Events in the Battle Creek Watershed

Armentrout et al. (1998) and the USFS (1999) have characterized the transient snow zone in Battle Creek and nearby watersheds as between 3500 and 5000 feet in elevation. This area occupies a band that lies mostly west of Lassen National Forest and extends down

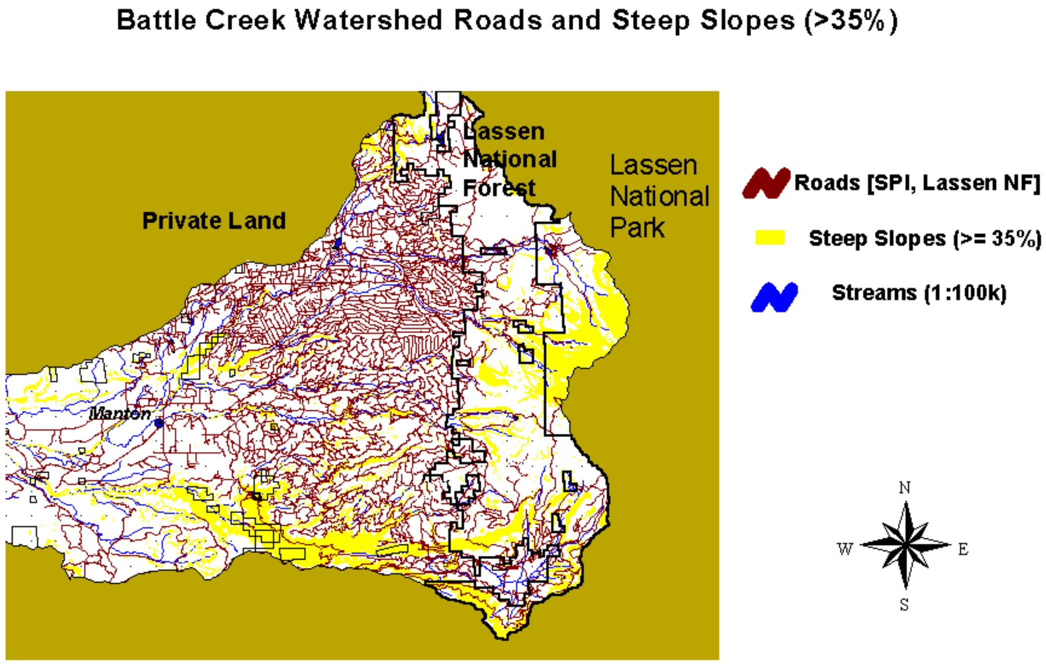

Figure 22. This map shows the areas of steep slopes and roads in the Battle Creek watershed. Slope data from USGS DEMs.

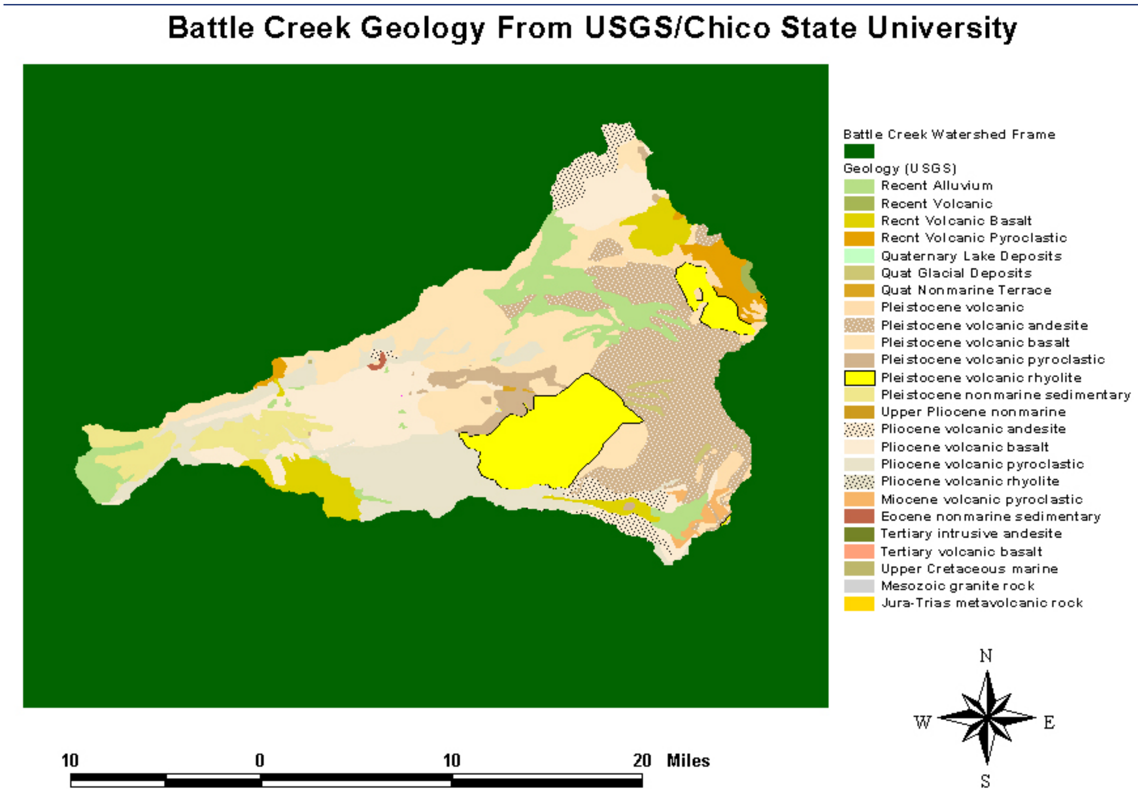

Figure 23. This map shows the geology of the Battle Creek watershed with areas with rhyolite highlighted in yellow. Data from Chico State University and USGS.

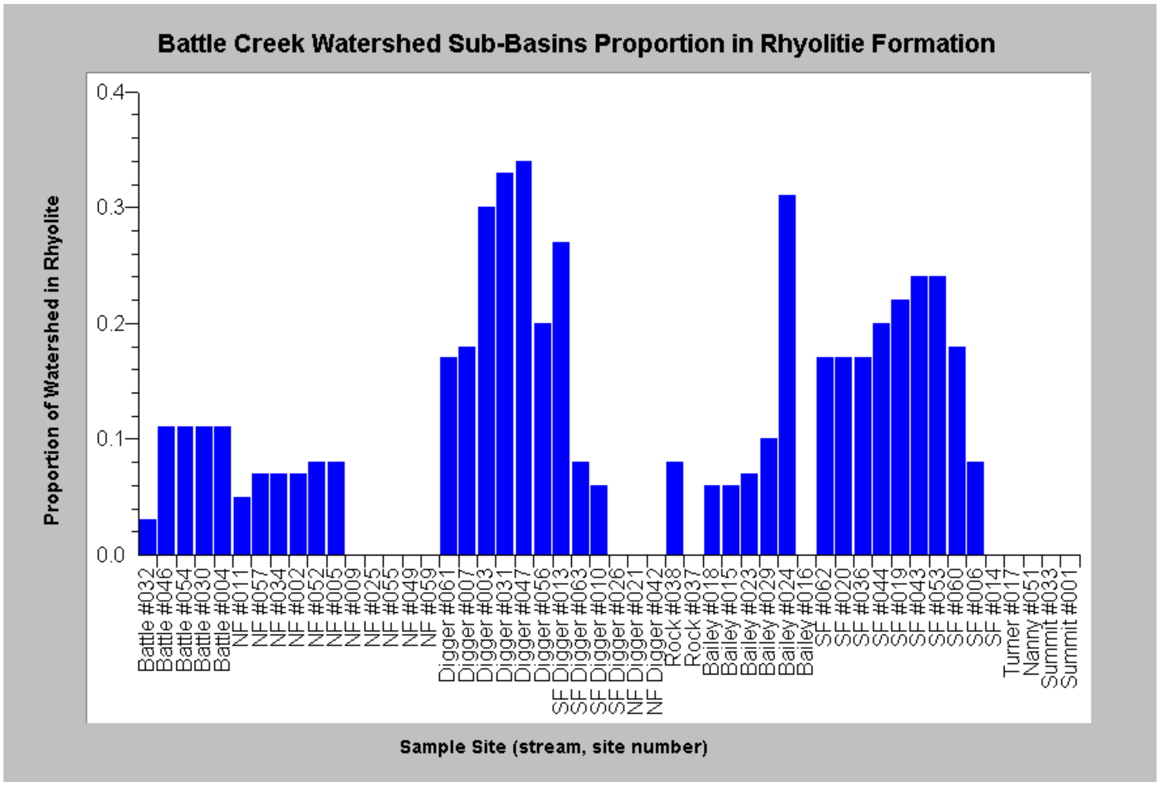

Figure 24. This chart shows percentage of *Battle WA* sub-basins with rhyolite geology.

the watershed towards Manton (Figure 25). The South Fork Battle Creek inner gorge and the valley floor of the upper South Fork in Battle Creek Meadows are all included in this elevation band. Rain on snow risk was characterized by percent of area for all *Battle Creek WA* sub-basins (Figure 26).

Change scene detection also provides results for landscape changes from 1991 to 1999 in agricultural and rural residential areas around Manton (Figure 28). Small patches indicative of rural residential development can be seen in the northern part of the watershed near Shingletown and around Manton. Some large scale indications of change around Manton are also related to installation or expansion of vineyards. Changes in riparian canopy conditions along the North and South Forks of Battle Creek suggest that some land use activity is also being conducted there.

Fire History of the Battle Creek Watershed

Fire is recognized as a factor in destabilization of soils and potential increased erosion risk (Napper, 2001). The USFS and CDF have combined to provide a fire history for northeastern California and the Battle Creek watershed from 1900 to 1997 (Figure 29). Only the south-central portion of the watershed has burned in recent years (1980-1997) in the in the vicinity of Morgan Creek. This area is not in tall, coniferous timber but rather in blue oak woodlands. The assumption used in the Battle Creek Watershed Analysis is that more recent fires are much more likely to pose elevated risk of erosion.

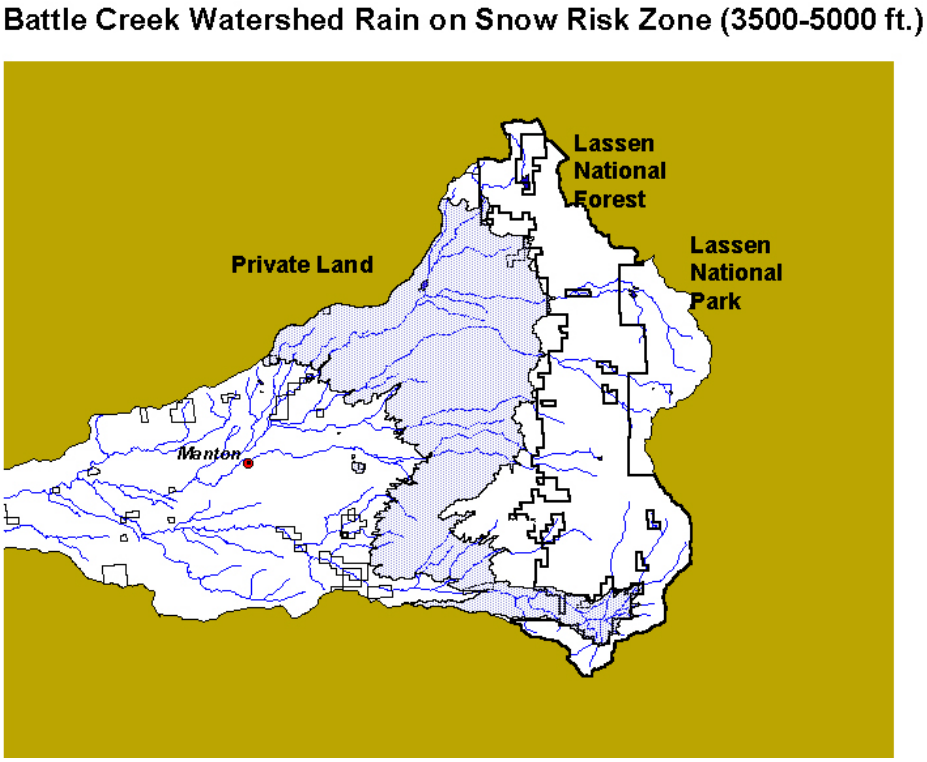

Figure 25. This map of the Battle Creek watershed has the transient snow zone (3500’-5000’) in stippled blue, which represents the rain-on-snow risk. Map from KRIS Battle Creek Map project based on USGS 30 M DEM.

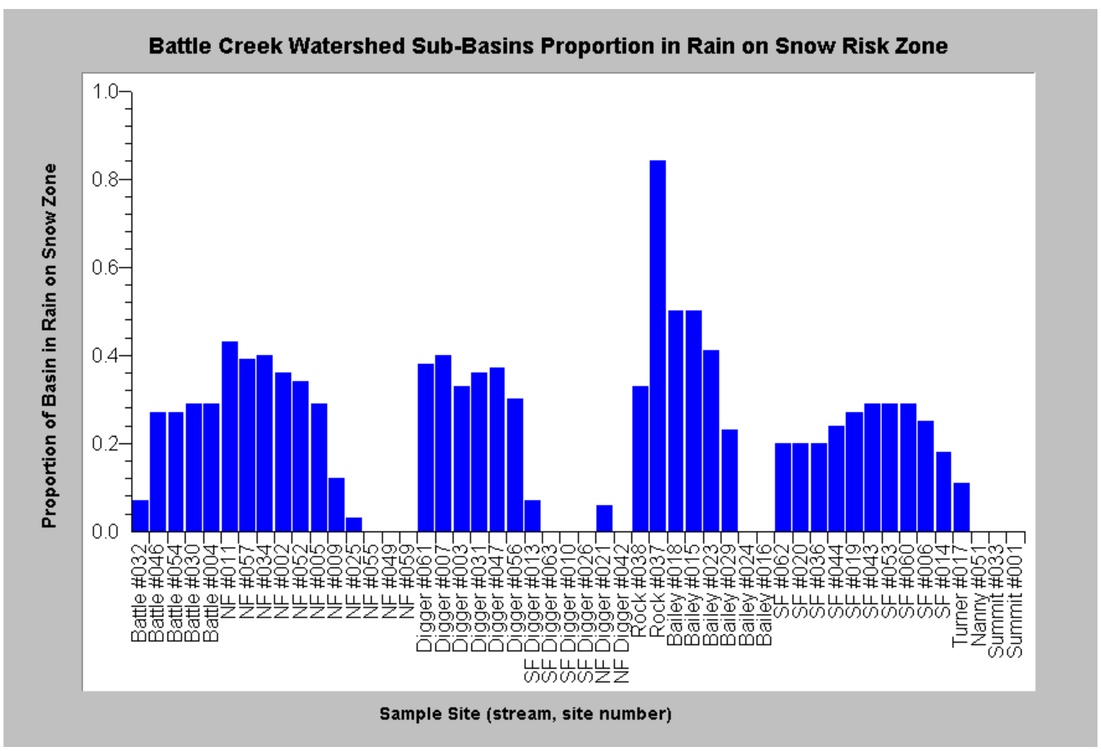

Figure 26. This chart shows the percentage of each Battle Creek Watershed Analysis sub-basin within the rain on snow zone from 3500 to 5000 feet in elevation.

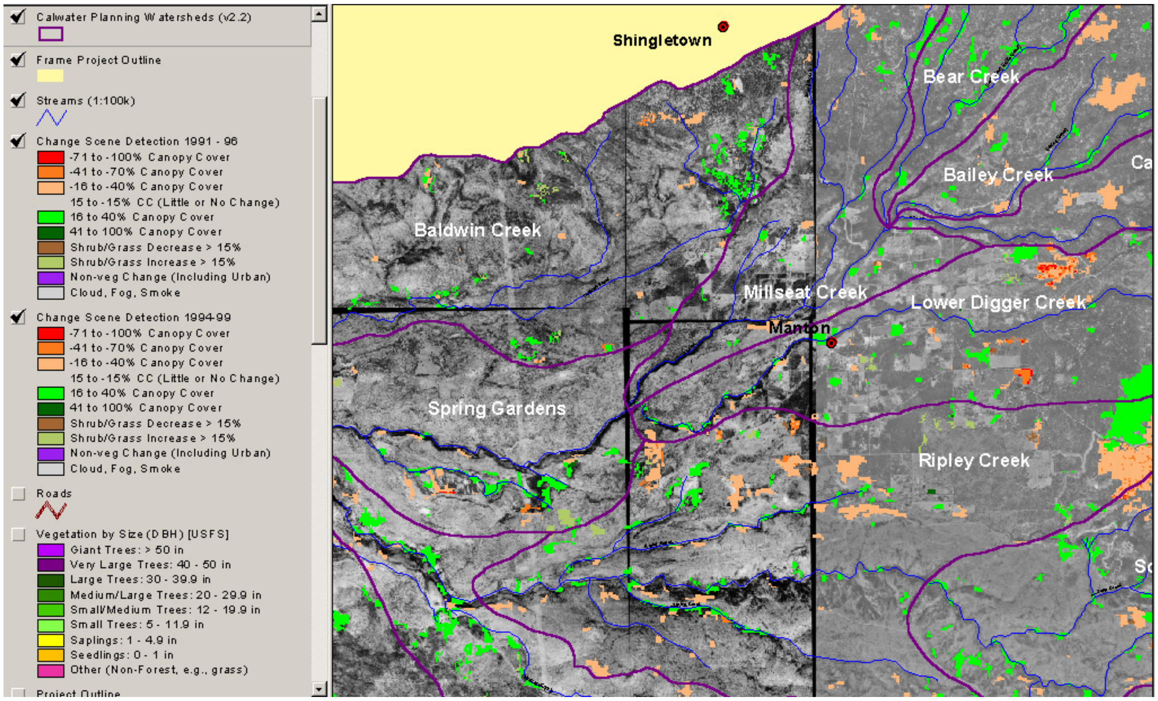

Figure 27. Change scene detection using Landsat imagery shows canopy reduction and vegetative cover decrease in red and orange and re-growth of vegetation and canopy increase in shades of green around Manton. The USGS orthophoto backdrop has seams that create black line artifacts. Data from the USFS and CDF FRAP, Sacramento, CA.

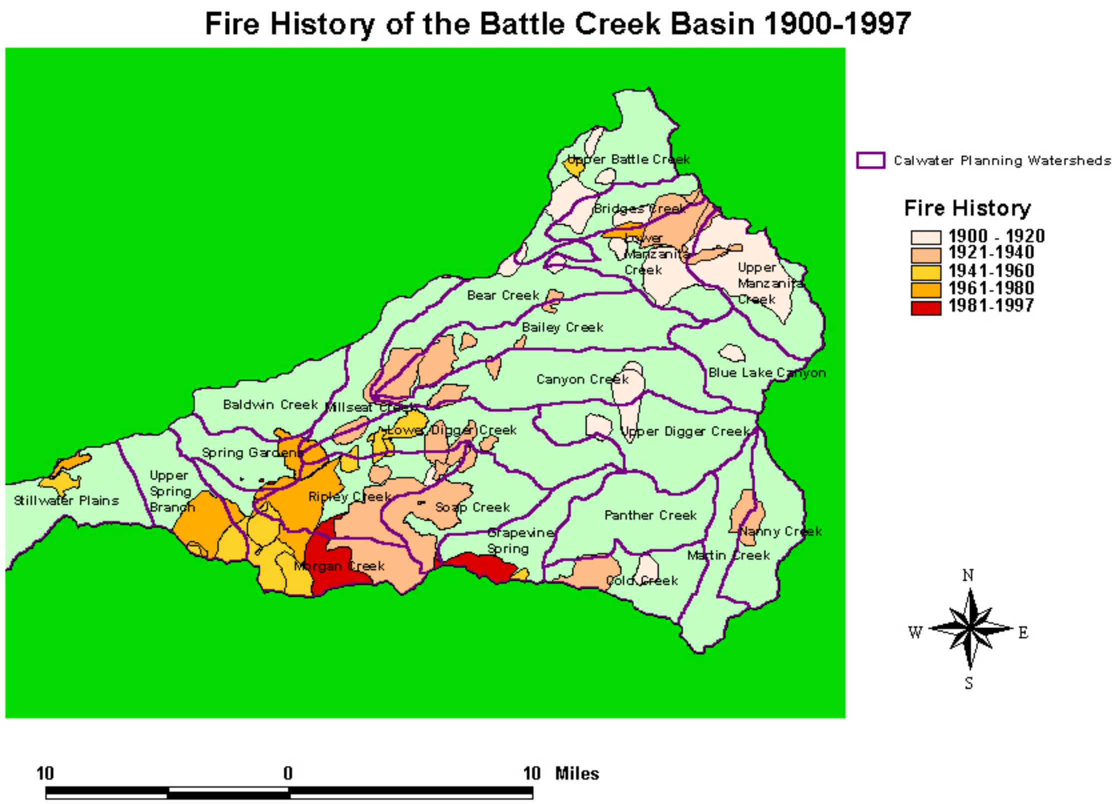

Figure 29. The fire history of the Battle Creek watershed from 1900 to 1997 is displayed above. Data are from the USFS and CDF.

DISCUSSION

Some uplands in Battle Creek have conditions that pose risk of elevated sediment yield according to results of reconnaissance using of remote sensing tools and applying regional standards for disturbance (Armentrout et al., 1998; Napper, 2001; NMFS, 1995; Haynes et al., 1997). Armentrout et al. (1998), Napper (2001) and USFS (1999) all acknowledged that timber harvest and associated road building were responsible for chronic and pulse sediment impacts in the Battle Creek watershed and those to the immediate south. While development of vineyards and rural residential parcels may pose some risk of cumulative watershed effects, they are located mostly away from streams and on gentle slopes as well as below the rain-on-snow zone. Consequently, erosion risk is thought to be low and there will be no discussion of these factors. Napper (2001) noted that: “Range management affects sediment delivery primarily as a result of impacts to channels and riparian vegetation”, but grazing impacts are not analyzed here because none of the reconnaissance tools used by the KRIS team were of the appropriate scale.

Timber Harvest Effects

While timber harvest maps in electronic form were not available for the Battle Creek watershed, logging is a major concern with regard to sediment yield and is a recognized contributor to cumulative watershed effects (Napper, 2001). The focus on timber harvest is stratified to that area east of Manton on private land and USFS land to the west of Lassen National Park. Linkage between timber harvest and sediment yield is well recognized in recent studies (Ligon et al., 1999; Dunne et al., 2002; Collison et al., 2003). The combined change scene signatures of decreased canopy, in combination with those areas showing vigorous growth reflecting logging in the 1980’s (Figure 10), indicate logging took place in at least appears to be at least 30% of the timber producing area of the Battle Creek watershed with some sub-basins cut at higher rates (see Battle Creek Watershed Potential Cumulative Watershed Effects Background page).

Reeves et al. (1993) found that timber harvest of over 25% of a watershed’s area in the 30 years prior resulted in decreased aquatic habitat diversity and diminished Pacific salmon species diversity. They noted the following associations between high timber harvest rates and fish and aquatic habitat:

> “Assemblages in basins with high levels of harvest were more dominated by a single species than were assemblages in basins with low harvest. Percent of basin harvested was more strongly associated with assemblage diversity (P = 0.07) than were basin area (P = 0.90) or gradient (*P* = 0.22) when the influence of the other two factors was controlled. Habitat features were compared between three pairs of streams. Streams in basins with low timber harvest had more complex habitat, as manifested by more large pieces of wood per 100 m (*P* < 0.01). We conclude that a community and basin-level perspective is necessary to fully assess the effects of timber harvest and other human activities on stream fish.”

Some sub-basin exhibit widespread canopy decrease indicating more than 25% of small watersheds were logged in the short period between 1991-1999, including Soap Creek, Snoqualimie Creek, and Grapevine Gulch (Figure 30). Patterns in canopy decrease are 70-100% (red) canopy reduction, 40-70% (orange) and 15-40% (beige). Shades of green are re-growth

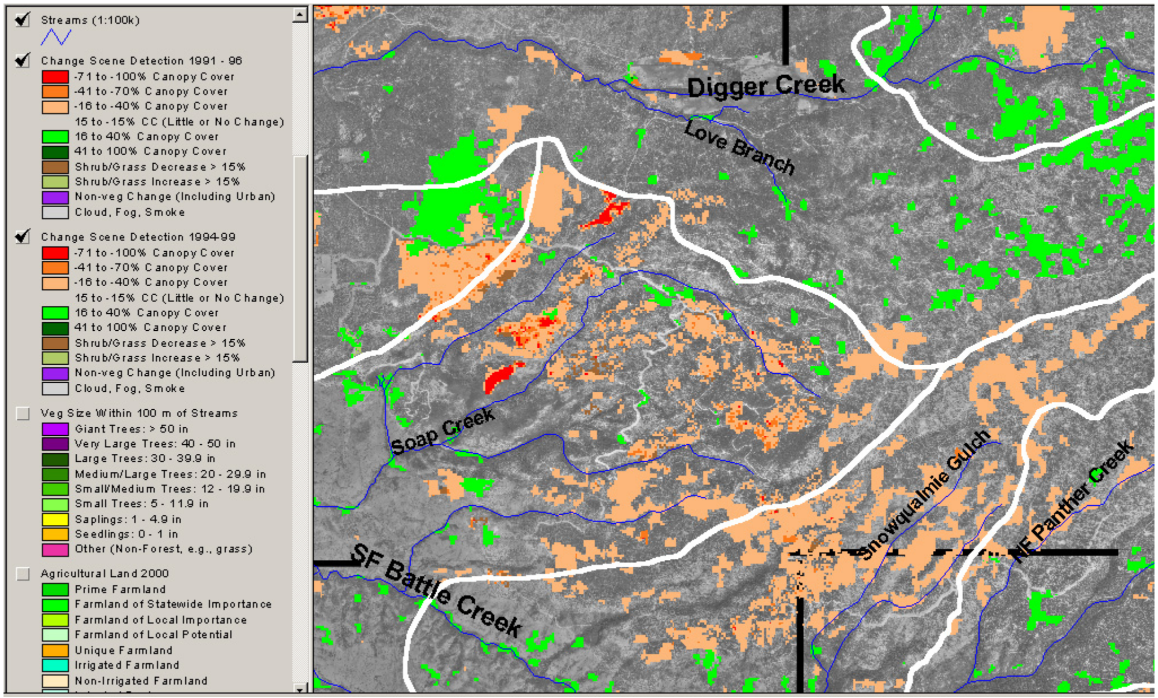

Figure 30. This map shows changes in vegetation in the Soap Creek, Snoqualmie Gulch and North Fork Panther Creek watersheds. These are tributaries of the lower South Fork Battle Creek, which flows at the bottom left of the image. Data from the USFS and CDF.

from prior harvests that could still have different hydrology and lesser ground cover due to early successional conditions. This high harvest rate since 1991 poses a risk of elevated sediment yield, particularly since this area is within the rain-on-snow-zone, has steep slopes and is underlain in part by rhyolitic bedrock, issues which will be revisited below.

Other Battle Creek sub-basin areas with similarly high concentration of timber harvest, although some of it prior to 1991, are Rock Creek, the South Fork Battle Creek watershed area below Battle Creek Meadows, Panther Creek and the upper South Fork. The high cut rates and fragmentation of the forest are visible on USFS land above Battle Creek Meadows and in private lands on the downstream in Figure 7 with yellow, orange and pink colored polygons representing past harvests. The USFS (1999) recognized that watersheds above Battle Creek Meadows and upper Panther Creek were cumulatively effected by timber harvest and roads and that sediment yield had been high during the January 1997 storm. Although no data or reports are available for private land, similar patterns of timber harvest on steep, unstable lands in the rain-on-snow zone in lower Battle Creek likely had similar, but undocumented sediment yield.

Riparian Condition Assessment

The question of current cumulative effects problems and past logging damage can was studied by comparing changes in riparian conditions between 1966 and 1996. Fisk et al. (1966) inventoried reaches of the North Fork Battle Creek and several other northern California streams to determine logging damage (Figure 31). They noted three levels of damage with "Severely damaged" defined as having 1) 75-100 percent of the stream bottom was covered with silt, 2) streamside canopy and pools were totally eliminated, and/or there was a total loss of shelter for fish. "Lightly damaged" stream reaches had: 1) 50 percent or less of the bottom was covered

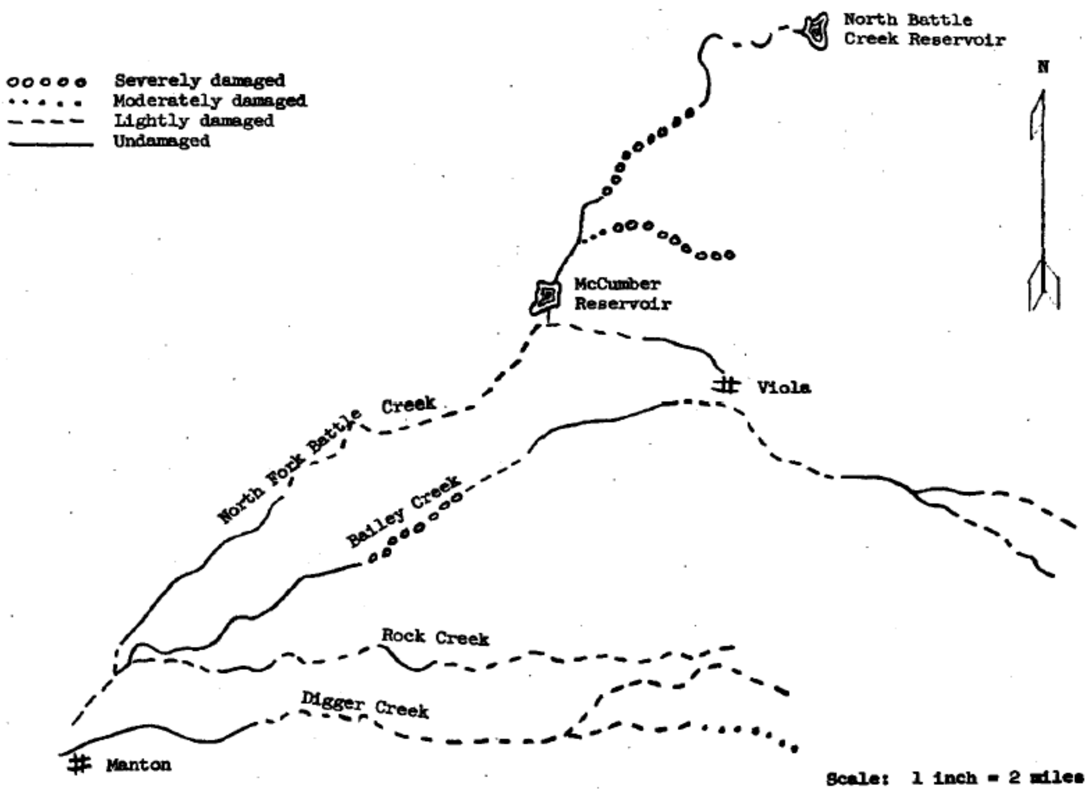

FIGURE 3. North Fork Battle Creek, Shasta County, stream damage.

Figure 31. This map is Figure 3 from Fisk et al. (1966) and shows logging damage by reach for the North Fork Battle Creek and some of its tributaries.

with silt, together with a partial loss of pools or streamside canopy, 2) shelter was partially removed 3) pools were eliminated, 4) canopy was removed, or 5) debris was present and abundant in stream channel and “Moderately damaged” reaches were intermediate between these conditions.

Riparian reconnaissance of areas study by Fisk et al (1966) based on tree sizes in the 100 meter band show that there are still mostly less than 20 inches in diameter in the riparian areas of the North Fork Battle Creek, Bailey Creek and Bridges Creek (Figure 32). Reaches of Digger, Rock and the NF Battle Creek “Lightly” damaged also appear to be in equally early seral stage. While the hypothesis that small tree size is a result of past logging, Figure 33 shows a zoom on the riparian zone of Onion and Rock Creeks with indications of recent timber harvest using change scene detection. Riparian logging opens up pathways for sediment to streams but the related problem of depletion of large wood may also decrease sediment storage and change the way it is routed through streams (Napper, 2001). Road building in riparian zones may also decrease recruitment of large woody debris (Kondolf et al., 1996).

Roads and Erosion

Napper (2001) noted that roads were a major source of erosion in the Battle Creek watershed, particularly roads near streams or on steep slopes. Meadowbrook and Associates (1997) estimated that roads contribute from 5-20% of the total average sediment yield from Deer and Mill Creeks to the south. Figure 22 shows that logging

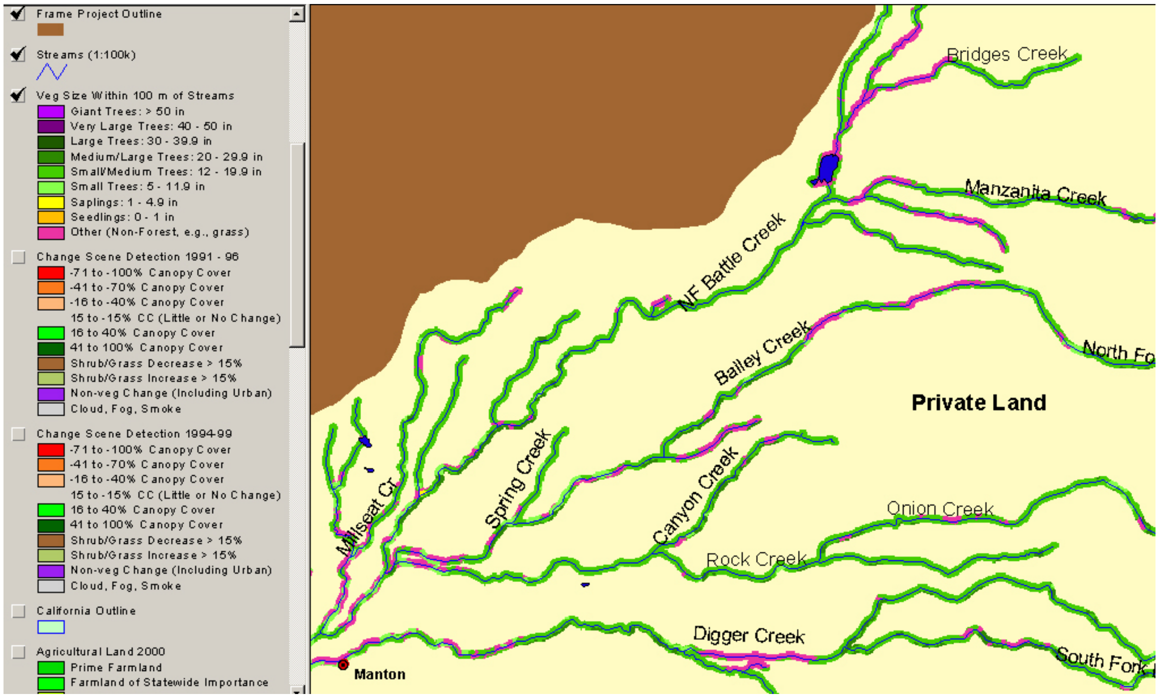

Figure 32. Tree sizes according to 1996 Landsat imagery show within a 100 meter buffer zone are shown here for the same reaches described as damaged by logging in 1966. There are few trees over 20 inches in diameter, which means riparian areas remain in early seral conditions. Data from the USFS and CDF.

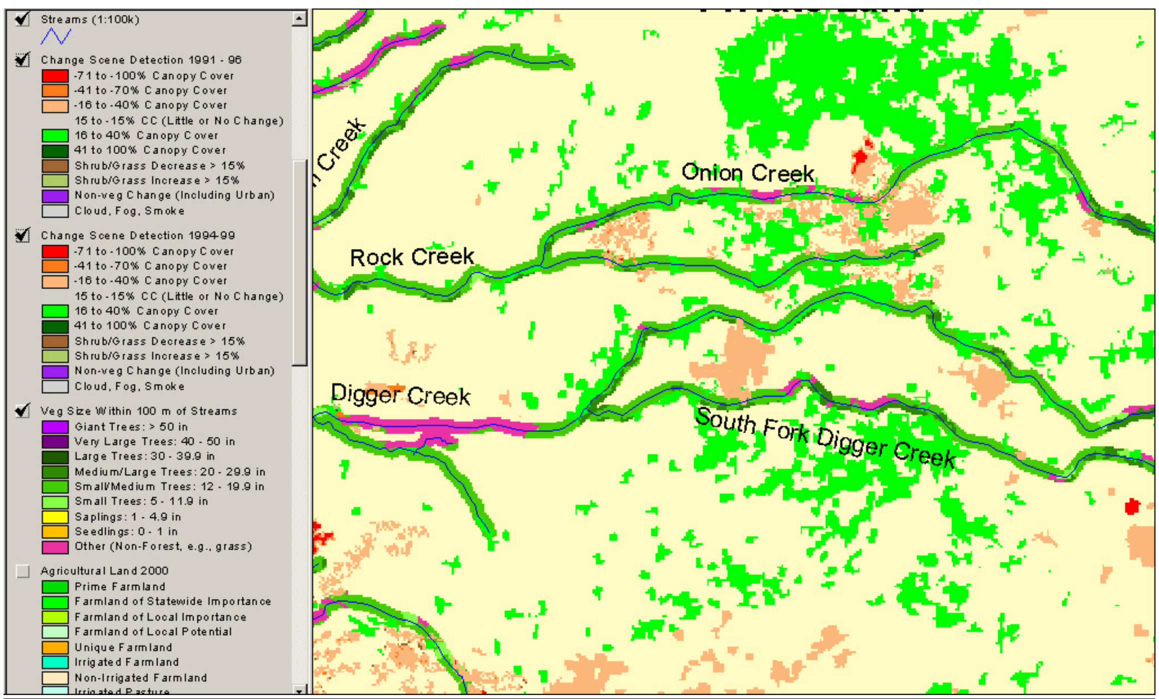

Figure 33. Change scene detection between 1991 and 1999 are displayed above over the 100 meter riparian zone derived from 1996 Landsat imagery. The areas of orange overlapping with the riparian zone indicate active logging with 100 meters of the stream in Onion, Rock and Digger Creeks.

roads parallel streams in many locations in the Battle Creek watershed, increasing opportunities for sediment pollution. While few roads cross steep slopes in the watershed, Napper (2001) and the USFS (1999) noted road failures on steep slopes in tributaries to the upper South Fork above Battle Creek Meadows. Another steep area is between Soap Creek and the North Fork Panther Creek (Figure 34), which has a concentration of steep slopes (>35%) and high road densities. Roads and timber harvest may combine to create elevated sediment risk when additional factors such as geology and rain on snow events are considered (Napper, 2001), although sediment yield from this area during recent storms, such as the one in January 1997, is unknown.

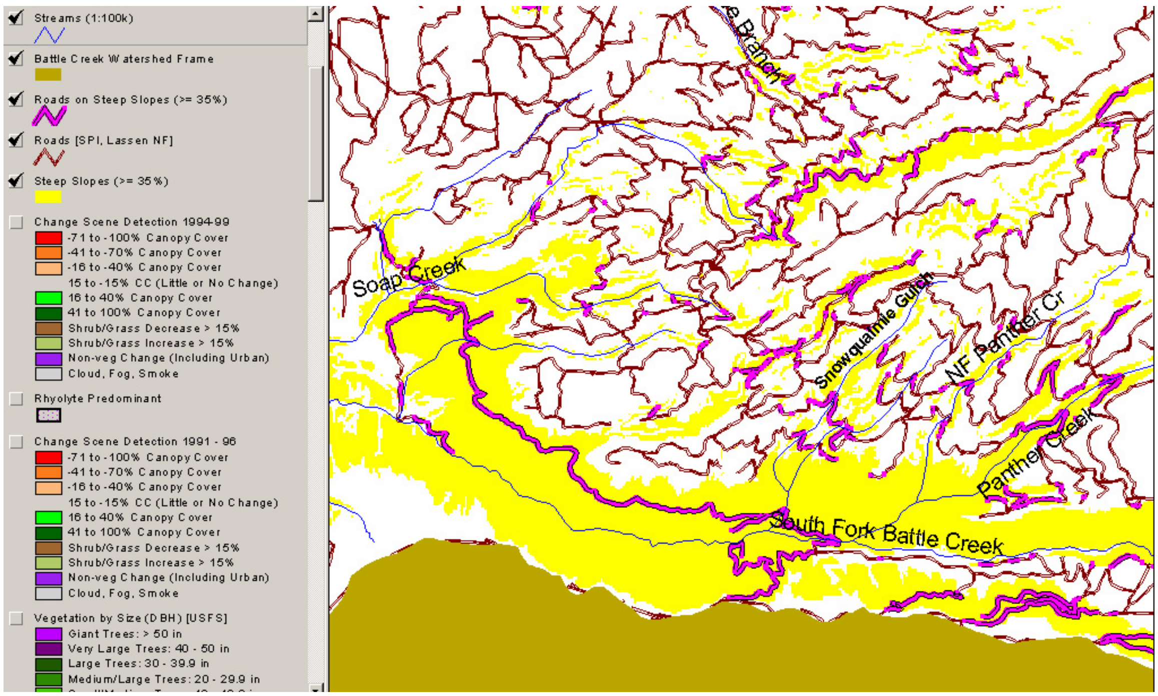

Figure 34. Hillslopes with more than 35% slope are shown above in yellow for the area between Soap Creek and Panther Creek in the South Fork Battle Creek watershed. Roads crossing steep slopes have higher erosion risk and are highlighted in pink. Slope derived in KRIS Battle Creek Map project and roads data from SPI and USFS.

Rhyolite

Napper (2001) noted that rhyolitic soils "tend to have a moderate to high erosion hazard rating, which increases based on slope. As vegetation is disturbed the erosion potential increases ……Concentration of water on these slopes may result in deep gullies, and mass failures. Maintaining adequate effective ground cover is important to preventing accelerated erosion and to reducing displacement. Road construction and road drainage is important for these soils so to prevent accelerated erosion." Armentrout et al. (1998) found that: "roads on rhyolitic soils were responsible for delivered sediment estimates almost four times greater than the other parent materials" in the Mill, Deer and Antelope Creek watersheds, which are adjacent to Battle Creek. The major up crop of rhyolite in the Battle Creek watershed (Figure 23) coincides with the highly roaded area shown in Figure 34 and Napper (2001) noted that rhyolite became more unstable over 25% slope. Figure 30 also shows that the rhyolite area bounded by Soap Creek, North Fork Panther, South Fork Digger and the South Fork Battle Creek has been intensively timber harvested. These factors combine to make this area on of the highest risk areas in the Battle Creek watershed.

Rain-on-Snow Events and Sediment Yield

Berris and Harr (1987) found that the output of melt water was 21% greater in clear-cut areas than in intact forest areas and that flows were more than double the expected flow for the storm recurrence interval rating. Napper (2001) noted the relationship between increased erosion of unstable soils and rain on snow events as well as the increased occurrence of road failures. She described the 1997 rain on snow event in the upper South Fork Battle Creek and its effect on sediment yield:

> “Pulse sedimentation has occurred in the analysis area as a result of rain on snow events that overwhelmed the drainage features on the roads in the area. Large amounts of material including snowmelt, debris, and bedload began to move through the fluvial system. Where roads intercepted this process, many of the drainage structures were breached and the channel either removed large road fills, or was diverted. As the stream cut a new channel tremendous volumes of sediment entered the system. Although every system receives some sedimentation due to natural processes this was above what would occur naturally.”

The risk of increased erosion from rain on snow events is heightened because widespread timber harvest has taken place in the transient snow zone as indicated by change scene detection (Figure 35). Figure 36 also shows that there are high road densities in the northern areas of the Battle Creek watershed in the transient snow zone. This area tends to have less steep slopes and more stable soils and is, therefore, less likely to yield sediment. High road density can contribute to increased peak flows in rain-on-snow events, but stream density is low in the northern Battle Creek watershed and surface water may perk into the ground in some areas, not flow into streams.

Steep Slopes

Roads cross steep slopes in the Battle Creek watershed in the upper South Fork, the Soap Creek area (Figure 34), and a patch of the watershed on the northeastern boundary. Timber harvest in Battle Creek mostly avoids steep slopes except for USFS activities on upper South Fork tributaries and on private industrial timberland in the Soap Creek to North Fork Panther Creek area previously described.

Cumulative Watershed Effects

Discussing each factor above and its contribution to sediment separately ignores evidence that all the factors are likely to couple in what is known as cumulative watershed effects (Dunne et al., 2000; Ligon et al., 1999). The *Battle Creek WA* (Terraqua, 2004) is restricted to sediment yield as its focus, but other effects such as increased peak flows, may also be destructive to stream channels. For example, large flows associated with rain-on-snow events may trigger bank erosion or even streamside landslides, where neither timber harvest nor roads have disturbed the slopes. Napper (2001) describes factors that increased the destructiveness of the January 1997 rain on snow event on USFS lands in upper Battle:

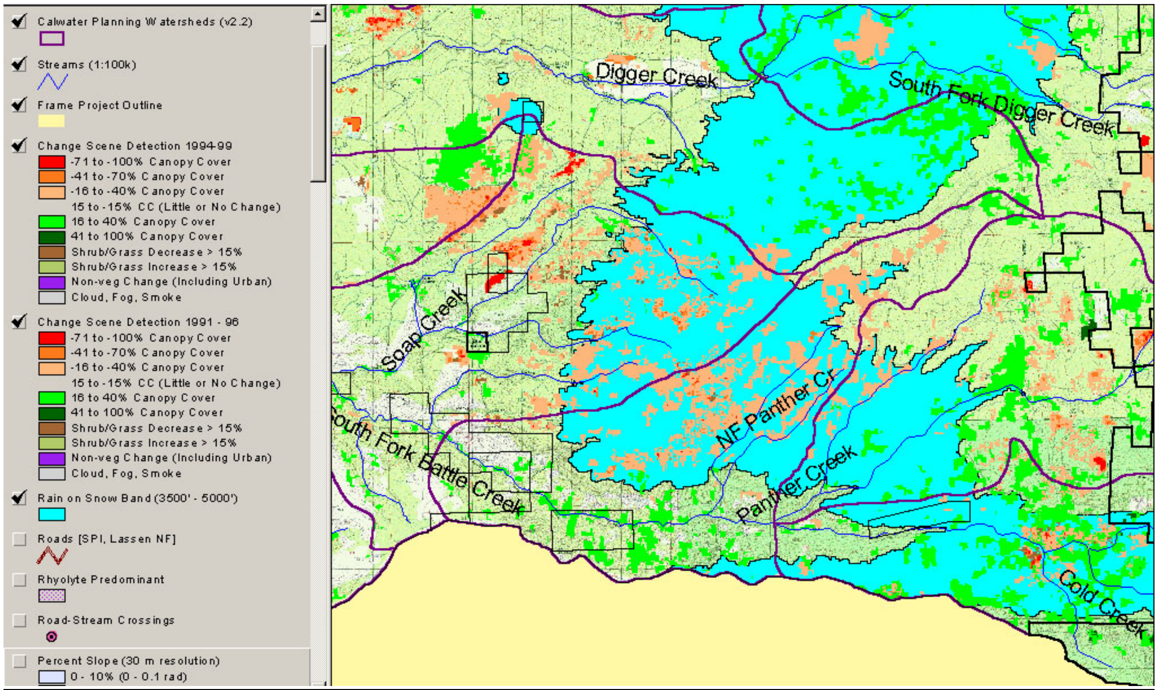

Figure 35. The light blue represents the rain-on-snow zone from 3500’ to 5000’ in the Battle Creek watershed. Change scene detection using Landsat images from 1991 to 1999 indicate substantial canopy removal in the zone and re-growth from logging since 1980. Elevation data from USGS and change scene from the USFS and CDF.

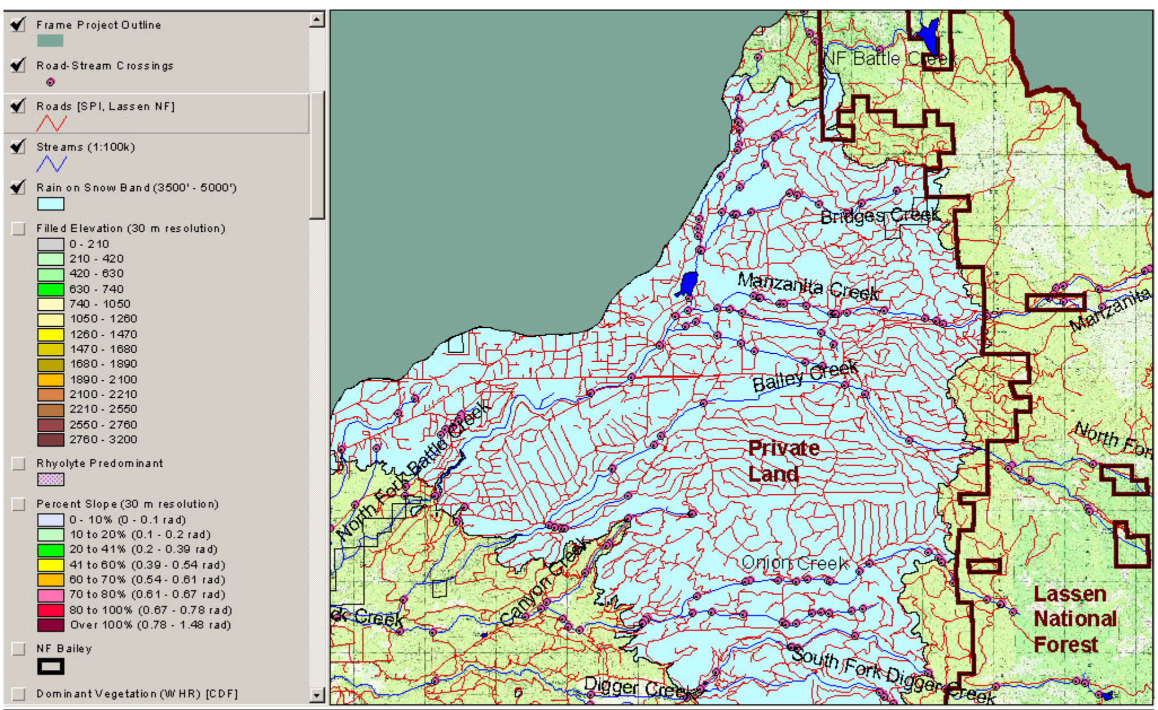

Figure 36. The light blue of the rain-on-snow zone is overlain with roads data provided by SPI and the USFS. Elevation data from the USGS.

"In addition to lying within areas subject to snow pack melt from rainfall events, several other factors influence the risk of increased peak flows. These include the amount of road density, the location of these roads relative to drainage ways and the extent to which road ditches flow to channels. Other factors include the amount of timber harvest that has occurred, particularly the degree to which young stands have replaced old growth, the drainage density of the watersheds, and the amount of precipitation an area receives…..

Changes in flow regimes, especially peak flows, and sediment introduced to streams can combine to upset the dynamic sediment transport/stream flow equilibrium conditions. In addition, management practices can alter soil condition. This may affect infiltration rates and increase the amount of compacted soils within a sub watershed. Modification of surface ground cover can also change run-off rates and erosion processes. All of these factors have the ability to create cumulative watershed effects."

There is no reason that similar sediment yield as described above would not have come from more intensively managed private lands, also in the rain on snow zone, lower in the Battle Creek watershed. In channel measurements made by Terraqua (2004) as part of the Battle Creek WA often show values recognized as impaired by the USFS EMDS criteria employed for analysis (Reynolds et al., 2001). While statistical analysis employed by Terraqua (2004) did not discover relationships between uplands and aquatic habitat, cumulative effects risk as described above is consistent with compromised aquatic habitat values (see Background pages in KRIS Battle Creek V 2.0 for more discussion. See Battle Creek Watershed Potential Cumulative Watershed Effects Background page

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