Geographic Information System Support for Total Maximum Daily Load Analysis of the Mattole River Watershed, Humboldt County, California

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INTRODUCTION

The Mattole River Watershed (Figure 1), Humboldt County, California, is listed on the Clean Water Act Section 303(d) list of impaired water bodies, for sediment and temperature. As required by this section and subsequent litigation, the North Coast Regional Water Quality Control Board (NCRWQCB) is under consent decree with the Environmental Protection Agency (EPA) to develop Total Maximum Daily Loads (TMDLs) for these constituents. Sediment and temperature are non-point source pollutants that impair the listed beneficial uses for the river, particularly cold water fisheries for endangered salmonid populations. The Information Center for the Environment (ICE), at the University of California, Davis, has developed analysis procedures for assisting the NCRWQCB in addressing the TMDLs in the Mattole Watershed.

To address the sediment TMDL, roads and mass-wasting features were inventoried. The mass-wasting inventory identified all discreet and chronic sediment sources through the use of five sets of stereoscopic aerial photographs spanning five decades. The road inventory focused on contemporary features and was implemented in a similar manner. Current 1:24,000-scale GIS data served as the base for aerial photo-based augmentation.

To support the temperature TMDL, ICE developed GIS-based inputs for the Stream Segment Temperature Model (SSTEMP), such as location, distance upstream from the mouth, elevation, and average shade for each reach in the stream network. Riparian stream shade was calculated using RipTopo, a GIS-based stream shading model, which incorporated streamside vegetation and topography to calculate the amount of effective shade for a given stream reach.

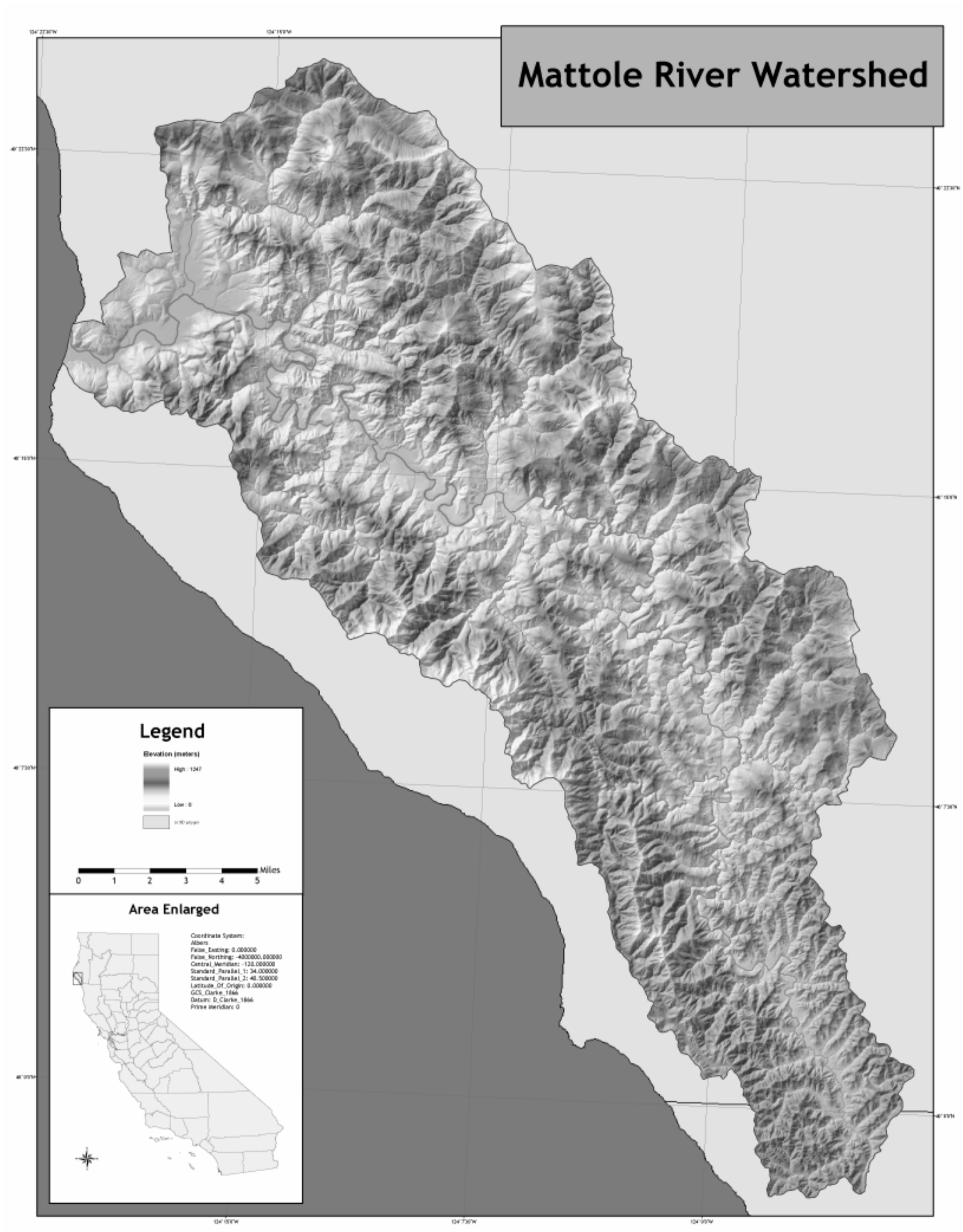

Figure 1 – Mattole River Watershed

SEDIMENT TMDL

Roads and landslides are seen as two chronic and widespread sources of sediment in the stream channels throughout northern coastal watersheds in California. The unconsolidated meta-sediments that form the California Coastal Range are unstable and the cause of natural sediment delivery in the Mattole River watershed system; however, anthropogenic sources of sediment are linked to resource management activities such as road building and timber harvesting. Thus, ICE and NCRWQCB completed road and landslide inventories in order to address elements of the sediment TMDL. Due to land access issues and time constraints, work was completed on a select subset of sub-watersheds within the Mattole River hydrologic watershed. Sub-watersheds were chosen to adequately represent the natural, physical, and anthropogenic conditions across the entire study area and, as such, were stratified using the best professional judgment and geographic independence. ICE performed a detailed inventory on seven sub-watersheds in order to expedite assessment, inventory, and verification of surrogate measures created in our GIS.

Road Inventory

A road inventory was completed so that sediment transport mechanisms and loads could be extrapolated for the entire watershed based on the density of road features. Initially, 1:24,000-scale road data were obtained from the California Department of Forestry and Fire Protection (CDF, 2001). These data were created using USGS Digital Raster Graphics, in which a road feature extraction algorithm was employed to create a vector base. These data include many road features, such as primary and secondary roads. Following that, roads were added from Timber Harvest Plans (THPs) filed with the CDF for the years 1990 – 2000. Subsequently, additional easily-distinguished features were added using USGS Digital Orthophoto Quarter Quadrangle photos (DOQQs) in the background. The mapped sub-basins are Rainbow Creek, Squaw Creek, Dry Creek, Mattole Canyon, Cow Pasture Opening, Honeydew Creek, and Bridge Creek (Figure 2); each is considered a separate sub-area under the Calwater 2.2 cataloging system (CDF, 1999).

Landslide Inventory

All discrete and chronic sediment sources (> 10,000 sq. feet) were identified on sequential, vertical, stereoscopic aerial photographs and digitized for the seven sub-basins mentioned above. Five sets of aerial photographs spanning the 50-year historic period were necessary for the assessment. The years for which photos were readily attainable are; 1941/1942, 1965, 1984, 1996, and 2000. Sediment features included in the mass wasting inventory included larger gullies, earth flows, debris slides, rock falls, and management-related failures. Only features deemed active during the historic period were inventoried, with the exception of long-lived earth flows and rock falls that exhibited minor chronic erosion.

Mapping was done in a three step process. First, landslides were identified on stereo photo pairs and marked on Mylar overlays. Feature identification was performed using a Topcon MS-3 mirror stereoscope with a 4x magnifier. Second, landslides were tracked through the 50-year period. Each feature was labeled with a unique numeric identifier for tracking throughout the historic interval. Lastly, features were digitized in a GIS with geographic reference data, such as roads and streams, and a DOQQ backdrop. In this step, several attributes were populated: photo year; photo number; feature ID number; confidence in feature identification; slope position; status (healed, partially re-vegetated, enlarged); enlargement ratio from previous photo; delivery percent. The mapped sub-basins are the same as those completed in the road inventory (Figure 2).

Analysis

The roads and landslides were intersected with a series GIS datasets to perform necessary analyses. These datasets included geology, vegetation, slope, and streams. All data were provided to NCRWQCB for the development of numeric TMDL criteria, as well as future monitoring and reporting.

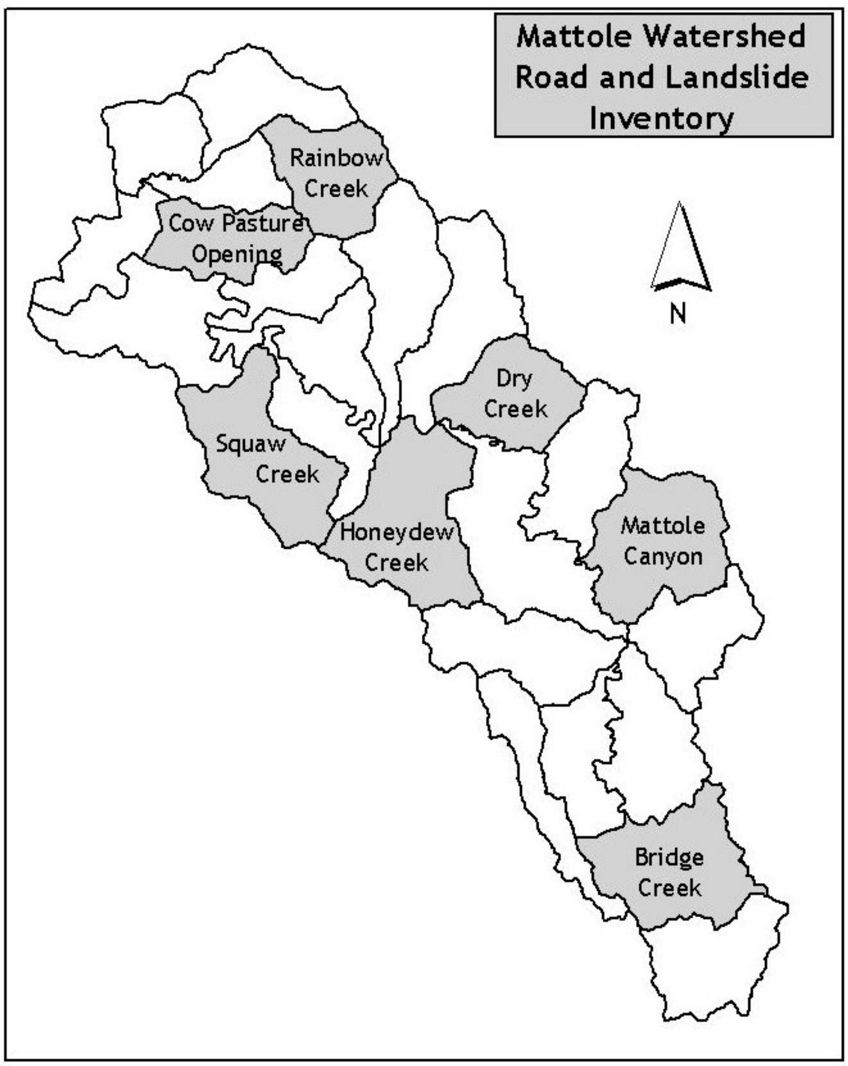

Figure 2 – Seven sub-basins used for road and landslide inventories

TEMPERATURE TMDL

The temperature TMDL generally focuses on shade as a surrogate for the heat entering the stream. While the actual pollutant is heat (i.e., solar radiant energy), we used effective shade as a surrogate measure because it is more easily modeled for the entire watershed with modest data requirements. Although air temperature is the single most important regulator of water temperature, anthropogenic manipulation of air temperature happens at spatial and temporal scales beyond the control of most regulatory agencies. Additionally, riparian-induced stream shade is the one component in water heating on which humans have a direct influence. Stream shade is also the stream temperature factor that is most likely to have been altered from natural conditions (USEPA, 2002). Furthermore, stream shade is a more useful measure when implementing land management plans, because there exist mechanisms for increasing riparian shade and preserving existing shade.

RipTopo Shading Model

While there are field methods for estimating stream shade values, data are not readily-available on a watershed scale, nor is enough data available for the NCRWQCB to effectively determine temperature load as required by the Technical TMDL. In order to maximize efficiency in data analysis and field verification, semi-automated GIS methods were used.

The Riparian Topographic Stream Shading Model (RipTopo) is a GIS-based surrogate method for estimating stream shade data in a spatially explicit manner. RipTopo is fully described by Viers (2003). In essence, it calculates the percent of possible solar radiation received within the riparian zone at each location along the river and its tributaries. The RipTopo model calculates the effective shade for a stream channel based on sun position, topography, stream location and orientation, the unvegetated channel width, the distribution of vegetation types in the watershed, and the adjusted potential height of mature vegetation (Viers, 2003).

Effective shade is the percent reduction of potential solar radiation delivered to the water surface. For example, if the combination of topography and vegetation at a specific location blocks 3/4 of the potential solar radiation from reaching the stream, the effective shade for that location would be 75% (USEPA 2000). Effective shade was calculated for current conditions, as well as the potential maximum conditions, by using vegetation heights converted from vegetation geodata (CDF/USFS, 1994-1997). Our RipTopo analysis used diameter-at-breast-height (DBH) values to estimate tree height for the California Wildlife Habitat Relationship (CWHR) vegetation data types based on conversions from literature (Burns et al, 1990; Hickman, 1993; Munz and Keck, 1968; Sudworth, 1908; Whitney, 1998). Potential conditions represent a theoretical maximum height for each vegetation height; it serves solely as a guide to potential shading conditions and as a measure of deviation from current conditions. RipTopo was run for July 23, 2001 to calculate the average shade for the streams throughout the watershed; this day represents the Maximum Weekly Average Temperature (MWAT) for the period of analysis (Table 1). Shade values from RipTopo were associated with all stream segments in the watershed and used in the temperature model discussed below.

Data are gathered from the following site:		http://www.srrb.noaa.gov/highlights/sunrise/azel.html			
Mattole River	**N 40 13 3**	**W 124 6 21**		0800 hrs UTC	
Date	Time	Solar Azimuth	Solar Elevation	Chart Values	Radians
23-Jul-01	600	66.73	4.03	66.73	0.070337
23-Jul-01	700	75.86	14.73	75.86	0.257087
23-Jul-01	800	84.87	25.97	84.87	0.453262
23-Jul-01	900	94.56	37.4	94.56	0.652753
23-Jul-01	1000	106.22	48.64	106.22	0.848928
23-Jul-01	1100	122.42	59.08	122.42	1.031141
23-Jul-01	1200	148.34	67.2	148.34	1.172861
23-Jul-01	1300	186.76	69.74	186.76	1.217193
23-Jul-01	1400	221.72	64.91	221.72	1.132893
23-Jul-01	1500	243.66	55.74	243.66	0.972847
23-Jul-01	1600	257.92	44.92	257.92	0.784002
23-Jul-01	1700	268.72	33.56	268.72	0.585732
23-Jul-01	1800	278.07	22.15	278.07	0.38659

Table 1 – Sun Position Values in the Mattole Watershed, July 23, 2001

Stream Temperature Modeling

The Stream Network Temperature Model (SNTEMP – Theurer et al., 1984) was a cooperative effort between the Soil Conservation Service and the U.S. Fish and Wildlife Service as one component of the In-stream Flow Incremental Methodology (IFIM; Stalnaker et al., 1995). It was developed to help aquatic biologists and engineers predict the consequences of stream manipulation on water temperatures. Water temperatures may affect aquatic systems in many ways, ranging from acute lethal effects, to modification of behavioral cues, to chronic stresses, to reductions in overall water quality. The goal of the SCS/USFWS project was to produce reasonable in-stream temperature predictions with readily available data.

SNTEMP inputs include hydrological data, as well as stream geometry information. SNTEMP stream geometry information includes the stream network, stream widths, stream gradients, shading parameters, and hydraulic resistance. Data for all but the shading parameters are typically collected as part of a hydrological study.

Subsequently, the Stream Segment Temperature Model (SSTEMP) was developed (Bartholow, 1999) and is currently supported by the United States Geological Survey (USGS). SSTEMP is a scaled-down version of SNTEMP that handles single stream reaches and single time periods. It also allows for more validation of results.

SSTEMP combines information on shade, hydrology, stream geometry, meteorology, and time of year to predict stream temperatures.

Analysis
NCRWQCB originally planned to model the entire watershed using SNTEMP, but time was limited. Thus, NCRWQCB staff used SSTEMP on a subset of representative stream reaches to examine the relative importance of the various factors affecting stream temperatures. They also evaluated the impact that the loss of stream shade has on the stream temperature regime of the Mattole River watershed (USEPA, 2002). Stream shade data from RipTopo were successfully integrated into the NCRWQCB's SSTEMP modeling efforts. NCRWQCB were easily able to define the stream temperature TMDL without spending a lot of time on field work. ICE and NCRWQCB are planning additional research and field work to further validate the results of the temperature modeling.

CONCLUSION

The Information Center for the Environment was able to help the North Coast Regional Water Quality Control Board to quickly develop sediment and temperature TMDLs for the Mattole River Watershed in northern coastal California. ICE used GIS methods and readily-available data to expedite the process. While additional field-based verification is necessary to refine the models, this effort eliminated the need for extensive time-consuming field work throughout the project. ICE is currently performing analyses to evaluate the RipTopo model, as well as investigating methods for converting data into input for models such as SNTEMP and SSTEMP. The methods used for developing these TMDLs are repeatable for other areas with similar problems. They can also be used for monitoring the progress of mitigation efforts in the future.

Our work demonstrates that technical TMDLs for sediment and temperature can be greatly assisted by the use of Geographic Information Systems, Remote Sensing and data modeling. USEPA timetables for establishing work plans in the TMDL process are unrealistically short and extreme pressure is placed on agencies to perform research and develop a reasonable estimate of waterbody loadings, submit the TMDL to USEPA, and subsequently reduce the loading. Methods like those described here clearly demonstrate the ability to use an integrated and collaborative process, including spatial technologies, to quickly and effectively develop TMDLs.

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