U.S. Environmental Protection Agency Region 9

Malibu Creek & Lagoon TMDL for Sedimentation and Nutrients Impacting Benthic Community

TECHNICAL APPENDICES

July 2013

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Appendix A. Data Inventory and Sources

A.1 Data Sources

The section below identifies various sources of data used to support these TMDLs. Specific station locations are identified in a table below the descriptions.

A.1.1 Heal the Bay Stream Team Water Quality Sampling

The HtB Stream Team is a citizens' volunteer monitoring group trained by the State Surface Water Ambient Monitoring Program (SWAMP) practitioners or CDFG, and has collected a suite of conventional water quality data in the Malibu Creek watershed and other nearby watersheds since 1998. Although data are collected by volunteers, the team is led by a Heal the Bay Water Quality Monitoring Coordinator. The volunteer monitoring team adheres to established quality assurance/quality control (QA/QC) protocols and procedures. The early years of this effort (1998 – 2002) are described in detail in the dissertation of Luce (2003). Sampling sites were on Malibu Creek and its tributaries. They also included potential reference sites outside of the watershed (Figure 7-1 of the TMDL report, sites with prefix "HtB"). These include three sites on the Malibu Creek main stem: HtB-MC-1, just above the Lagoon near the mouth of Malibu Creek, HtB-MC-15 below the confluence with Cold Creek and also below the Tapia discharge, and HtB-MC-12, upstream of Las Virgenes Creek and upstream of the Tapia Discharge.

Consistent with the discussion in Luce (2003), site SC-14 on Solstice Creek and LCH-18 on Lachusa Creek were initially selected as the most appropriate comparator/reference sites for the Malibu main stem. These sites are at similar elevation (but slightly lower stream order), and have minimal impacts due to development. Luce also treated the Arroyo Sequit station (AS-19) as a potential reference site; however, this site is subject to some development impacts including roads, equestrian uses, and at least one septic system upstream of the sampling station. Therefore, it is not treated as a primary comparator/reference site in this assessment. Similarly, Upper Cold Creek (CC-3), which has consistently good biota, was not consistently used in our comparative analyses because of its very small drainage area and higher elevation. However, data for CC-3 are presented for some parameters as an example of high bioscores, low nutrient concentrations, and high physical habitat scores relative to the other sites in the Malibu Creek Watershed.

SC-14, LCH-18, Cheseboro Creek site CH-6 and Las Virgenes Creek LV-9 (CH-6 and LV-9 drain the Monterey/Modelo Formation) are identified as comparator/reference sites in this TMDL due to their location with respect to minimal impacts, Monterey/Modelo Formation, and relevant coastal characteristics. Other sites with less than five benthic macroinvertebrate samples were excluded due to high year-to-year variability in results for some sites. The selection of comparator/reference sites is described in more detail in Section 8.1.3 of the TMDL report.

A.1.2 Las Virgenes Municipal Water District Sampling

LVMWD has conducted sampling in Malibu Creek since 1971 in conjunction with their discharge permit. These sites are indicated by prefix "LVMWD" on Figure 7-1 of the TMDL report. The sampling sites focused on discharge points to the local creeks, immediate upstream background conditions, and downstream impacts relative to the main Tapia WRF discharge on Malibu Creek and sprayfields on Las Virgenes Creek. LVMWD monitoring has consistently addressed bacteria, general physical parameters, and inorganic nutrients. In 2005, monitoring for heavy metals and organic compounds was added to the routine monitoring to address the CTR.

A.1.3 Malibu Creek Watershed Monitoring Program

The MCWMP was a multi-agency effort conducted under a Proposition 13 grant from February 2005 through February 2007 with the aim of establishing baseline water quality throughout the watershed. The sampling sites appear without prefix on Figure 7-1 of the TMDL report (e.g., "LV1").

A.1.4 Los Angeles County Mass Emissions Station

As part of its MS4 permit, LACDPW conducts sampling at seven mass emissions stations, one of which is collocated with stream gage F-130, in Malibu Creek just below the confluence with Cold Creek (coincident with HtB-MC-15 on the map). This targets wet and dry events with the intention of estimating mass loading past the monitoring station.

A.1.5 USEPA 2010-2011 Creek and Lagoon Monitoring

As part of the effort to more fully evaluate the condition of the Creek and Lagoon, USEPA collected and analyzed additional sampling data in winter 2010 and summer 2011. Monitoring included samples collected for water quality, macroinvertebrate community and physical habitat, which are discussed in this section and the next section on biological and habitat data.

A.1.6 National Park Service Monitoring

The National Park Service's Santa Monica Mountains National Recreation Area has collected surface water data in the watershed since August 2006 as part of its Mediterranean Coast Network program. Data have been retrieved through March 2011 for use in this report. Sampling has occurred at multiple sites throughout the watershed, including nine "Judgmental" sites (prefix "J"; sites where there are identified pollution sources or ecological concerns), fixed "Sentinel" sites (prefix "S") at long term amphibian monitoring locations, and a large number of random sites (prefix "R"). The National Park Service sites are labeled separately in Figure 7-2 of the TMDL report to avoid clutter.

A.1.7 Calabasas Landfill Monitoring

As described in Section 5.3 of the TMDL report, the non-discharging Calabasas Landfill is located near Cheseboro Creek in Agoura Hills. As part of its permit requirements, the Sanitation Districts have monitored water quality in Cheseboro Creek at a station just downstream of the Heal the Bay CH-6 station, reporting 19 samples between 1999 and 2009.

A.2 Monitoring Stations

Table A-1 presents the monitoring stations used in the TMDL analyses for the general watershed sites and comparator/reference sites (indicated by shading in the table). This table includes the stations identification numbers (which correspond with the TMDL report maps), location descriptions, detailed site descriptions, and the type of data evaluated.

Table A-1. Summary of Malibu Creek Freshwater Monitoring Stations

Source	Station ID	Name	Location Description	Site Description	WQ	Benthic	PHAB	Latitude	Longitude
LVMWD	LVMWD-R1F	Las Virgenes Creek	Las Virgenes Creek, downstream of Highway 101	Located on a lined channel downstream of Highway 101. Surrounded by urban lands, but also captures more undeveloped lands from the headwaters.	•			34.144000	-118.700000
LVMWD	LVWMD-R2F	Las Virgenes Creek	Las Virgenes Creek, near Lost Hills Road	Located downstream of developed lands just southwest of the city of Calabasas. Represents loading from the developed lands along Las Virgenes Creek as well as the undeveloped headwaters.	•			34.126000	-118.707000
LVMWD	LVWMD-R3F	Las Virgenes Creek	Las Virgenes Creek, just upstream of Stokes Creek	Just above the confluence with Stokes Creek. Station represents entire Las Virgenes Creek drainage, including developed lands and undeveloped headwaters.	•			34.096000	-118.718000
LVMWD	LVWMD-R4D	Malibu Creek	Malibu Creek at Cross Creek Rd. (below Rindge Dam)	Located downstream of Tapia WRF outfall (6290 feet downstream) near the Malibu Lagoon. Station represents conditions from nearly the entire drainage area and is adjacent to nearby developed lands.	•	•	•	34.043650	-118.684880
LVMWD	LVWMD-R3D	Malibu Creek	Malibu Creek at a point below Rindge Dam	Located in open space just before developed lands. This station is downstream of the Tapia WRF outfall (5860 feet downstream) and represents conditions in most of the watershed.		•	•	34.046217	-118.688470
LVMWD	LVWMD-R13D	Malibu Creek	Malibu Creek at a point 100 feet downstream from Discharge Serial No. 003	Station is just after the confluence with Cold Creek and 930 feed downstream of the Tapia WRF outfall. Considers all major tributaries (including most of the urban land in the watershed) and discharge points to Malibu Creek, but is upstream of Rindge Dam.	•	•	•	34.076417	-118.702300
LVMWD	LVWMD-R2D	Malibu Creek	Malibu Creek at Malibu Canyon	Located 150 feet downstream of the Tapia WRF outfall; this station	•	•	•	34.081050	-118.705000

Source	Station ID	Name	Location Description	Site Description	WQ	Benthic	PHAB	Latitude	Longitude
			Road (County Highway N1)	represents conditions immediately after discharge, while also considering upstream sources.					
LVMWD	LVWMD-R1U	Malibu Creek	Malibu Creek upstream of Discharge Serial No. 001 at the Salvation Army Camp bridge (Dorothy Drive)	Located 560 feet upstream of the Tapia WRF outfall. Station is within open space, but loads represent many land uses throughout the upper 90% of the watershed.	•	•	•	34.084233	-118.712020
LVMWD	LVWMD-R9U	Malibu Creek	Malibu Creek at a point 100 feet upstream of the confluence of Malibu and Las Virgenes Creeks	Station is about 2500 feet upstream of Tapia WRF outfall; on Malibu Creek just upstream of the confluence with Las Virgenes Creek. Located within open space, but this site characterizes loads from many land uses located upstream on Malibu Creek and its tributaries.	•	•	•	34.097980	-118.721700
LVMWD	LVWMD-R7D	Las Virgenes Creek	Las Virgenes Creek in upper watershed	Station is located near urban development (single family residential, office space, institutional, multifamily residential, etc.) in Calabasas. Also drains some open land from the headwaters of Las Virgenes Creek.	•	•		34.134850	-118.706820
SMC	404S02920	Medea Creek Site 2920	Medea Creek, near Medea Creek Park	Station is located within a small industrial area in the upper portion of Medea Creek in Ventura County. Drainage to this station is largely developed, with the exception of some of the headwaters that are open.		•		34.177480	-118.767000
SMC	404S03048	Lindero Canyon Site 3048	Lindero Creek, behind Edgebrook Place	Located in the upper stretch of Lindero Creek. This station is within a residential area with irrigated parks and drainage to this site is residential and parkland with some undeveloped areas in the upper headwaters.		•		34.184260	-118.790890
SMC	404S05992	Medea Creek Site	Medea Creek, behind Rushing	Drainage to this site, which is located in Agoura Hills, is largely developed.		•		34.156980	-118.758800

Source	Station ID	Name	Location Description	Site Description	WQ	Benthic	PHAB	Latitude	Longitude
		5992	Oaks Drive	Single family residential homes make up the majority of land near the sampling site.					
SMC	404S08040	Santa Monica watershed unknown Site 8040	Cheseboro Creek, near Cornell Road	Located in Agoura Hills, this station represents drainage from Palo Comado and Cheseboro Creeks (just upstream of the confluence with Medea Creek). The upper drainage is largely undeveloped, while the lower several miles contain residential, commercial, transportation, and industrial areas.		•		34.143580	-118.755270
SMC	404S08616	Malibu Creek Site 8616	Triunfo Creek, downstream of Miller Park	Located between Malibou Lake and Westlake Lake. This station is located on Triunfo Creek and drains a mix of open and developed lands.		•		34.121880	-118.792402
SMC	404S11406	Malibu Creek Site 11406	Malibu Creek (upstream of Lagoon)	Located in open space just before developed lands. This station is downstream of the Tapia WRF outfall and represents conditions in most of the watershed.		•		34.049390	-118.690000
SMC	404S16516	Medea Creek Site 16516	Medea Creek, east of Hunt Club Court	Located near a single family residential area in Agoura Hills, this station represents drainage from much of Medea Creek. It includes largely developed lands, with some undeveloped areas in the headwaters.		•		34.129980	-118.756480
SMC	404S17266	Las Virgenes Creek Random Site 17266	Las Virgenes Creek, above Mulholland Highway	At the downstream end of Las Virgenes Creek, this station captures loads from developed and undeveloped lands adjacent to Las Virgenes Creek.		•		34.107410	-118.711800
SMC	404S17664	Las Virgenes Creek Site 17664	Las Virgenes Creek, above Ventura Freeway	Station is on a lined channel on Las Virgenes Creek near the City of Calabasas adjacent to Highway 101. Immediately surrounded by urban lands, but also captures more undeveloped lands from the headwaters.		•		34.149940	-118.697600

Source	Station ID	Name	Location Description	Site Description	WQ	Benthic	PHAB	Latitude	Longitude
SMC	404S22464	Las Virgenes Creek Site 22464	Las Virgenes Creek, Lost Hills Road	Located downstream of developed lands near the city of Calabasas on Las Virgenes Creek. Represents loading from the developed lands as well as the undeveloped headwaters.		•		34.126760	-118.706850
MCWMP	MAL	Malibu Creek	Malibu Creek, Palm Canyon Lane and Retreat Court	Located in open space just before developed lands. This station is downstream of the Tapia WRF outfall (nearly 6000 feet downstream) and represents conditions in most of the watershed.	•	•		34.046017	-118.687833
MCWMP	LV2	Las Virgenes Creek	Las Virgenes Creek, Las Virgenes Road and Los Hills Road	Station is located downstream of developed lands just southwest of the city of Calabasas. Represents loading from the developed lands along Las Virgenes Creek as well as the undeveloped headwaters.	•	•		34.125117	-118.708233
MCWMP	LV1	Las Virgenes Creek	Las Virgenes Creek, Las Virgenes Road and Thousand Oaks Blvd.	Near the County border on Las Virgenes Creek and just upstream of developed areas. This station represents drainage from the largely undeveloped headwaters of Las Virgenes Creek, including several smaller tributaries.	•	•		34.168467	-118.702583
MCWMP	MED2	Medea Creek	Medea Creek, Cornell Road and Mulholland Highway	Near the mouth of Medea Creek, drains a mix of developed and undeveloped lands (station is immediately adjacent to a single family residential area).	•	•		34.114417	-118.755467
MCWMP	MED1	Medea Creek	Medea Creek, Conifer Street and Kanan Road	Station is located within a residential area in the upper portion of Medea Creek, just inside of Ventura County. Drainage to this station is largely developed, with the exception of some of the headwaters that are open.	•	•		34.169667	-118.762700
MCWMP	LIN1	Lindero Creek	Lindero Creek, Thousand Oaks Blvd and Sienna Way	Located in the middle of Lindero Creek, just north of Highway 101, this station is associated with urban development, largely residential		•		34.154367	-118.791350

Source	Station ID	Name	Location Description	Site Description	WQ	Benthic	PHAB	Latitude	Longitude
				areas.					
MCWMP	TRI	Triunfo Creek	Triunfo Creek, Lindero Canyon Road and Ridgeford Drive	Station is just downstream of Westlake Lake and is located near residential areas. Overall, the station characterizes loads from a variety of developed lands, many of which drain to Westlake Lake.		•		34.132117	-118.820617
MCWMP	HV	Hidden Valley Creek	Hidden Valley Wash, Potrero Canyon Road and Park Vista Road	Located on Hidden Valley Wash, near the outlet to Lake Sherwood, this station represents drainage from mostly agriculture, residential and open lands.		•		34.141833	-118.878967
MCWMP	CC	Cold Creek	Cold Creek, recreation area	Located in the Santa Monica Mountains National Recreation Area. Drains undeveloped lands and is near the headwaters.	•			34.092222	-118.657028
MCWMP	LC	Liberty Canyon	Liberty Canyon, upper	Located upstream on Liberty Canyon, in the middle of a developed area and immediately downstream of single family residential lands.	•			34.129083	-118.723889
MCWMP	LIN2	Lindero Creek, near dam	Lindero Creek, near Lindero Lake	Located in the middle of Lindero Creek near Lindero Lake, just north of Highway 101, this station is associated with urban development, largely residential areas.	•			34.147694	-118.787583
MCWMP	POT	Potrero Creek	Potrero Creek, near Westlake Lake	Located on Potrero Creek just upstream of Westlake Lake. Immediately surrounded by highly developed residential areas.	•			34.145056	-118.836111
MCWMP	RUS	Russell Creek	Russell Creek, near intersection of Agoura Road and Lindero Canyon Road	Station is located just downstream of the confluence of Russell Creek and Russell Creek Drain, and the Westlake Golf Course	•			34.145694	-118.805806
HtB Stream Team	HtB-MC-1	Malibu Creek	Malibu Creek at Cross Creek Rd.	Located downstream of Tapia WRF outfall (6290 feet downstream) and most major inputs near the Malibu Lagoon. Station represents conditions from nearly the entire	•	•	•	34.042890	-118.684220

Source	Station ID	Name	Location Description	Site Description	WQ	Benthic	PHAB	Latitude	Longitude
				drainage area and is adjacent to nearby developed lands.					
HtB Stream Team	HtB-CC-2	Cold Creek	Cold Creek at Piuma Rd	At the mouth of Cold Creek, this station captures loads from both undeveloped lands in the headwaters as well as residential areas closer to the confluence with Malibu Creek.	•	•		34.079160	-118.700540
HtB Stream Team	HtB-CC-3	Cold Creek	Cold Creek at Stunt Rd	Near the headwaters of Cold Creek, this station drains relatively undeveloped lands in the Santa Monica Mountains National Recreation Area.	•	•		34.092010	-118.647560
HtB Stream Team	HtB-LV-5	Las Virgenes Creek	Las Virgenes Creek, downstream second crossing Malibu Creek State Park	This station is downstream of developed areas near the mouth of Las Virgenes Creek (area immediately surrounding the sampling station is undeveloped).	•	•		34.097240	-118.720880
HtB Stream Team	HtB-MD-7	Medea Creek	Medea Creek, Cornell at Kanan Rd.	Station is located downstream of developed lands. It is after the confluence of Palo Comada and Cheseboro Creeks.	•	•		34.139310	-118.759390
HtB Stream Team	HtB-CC-11	Cold Creek	Cold Creek, middle of reach	About halfway along the length of Cold Creek, this station drains relatively undisturbed land, with some single family residential areas (lot size is greater than 0.5 acres) upstream.	•	•		34.089012	-118.680471
HtB Stream Team	HtB-MC-12	Malibu Creek	Malibu Creek at Malibu Creek State Park just downstream of Rock Pool	Located downstream of Rock Pool, this station characterizes upstream flow from all lands (developed and undeveloped) from much of the watershed. The station is located within the Malibu Creek State Park.	•	•	•	34.096550	-118.729690
HtB Stream Team	HtB-LV-13	Las Virgenes Creek	Las Virgenes Creek, Lost Hills Rd east of Malibu Hills Rd. Apartments	Station located in an urbanized area of City of Calabasas, surrounded by residential, institutional, and office space (among other developed lands).	•	•		34.136440	-118.705310
HtB Stream Team	HtB-MC-15	Malibu Creek	Malibu Creek, downstream of	Located downstream of developed areas and the Tapia WRF outfall	•	•	•	34.077600	-118.701830

Source	Station ID	Name	Location Description	Site Description	WQ	Benthic	PHAB	Latitude	Longitude
			Cold Creek	along Malibu Canyon Road. This station is also just upstream of the LA County stream gauge (F-130).					
HtB Stream Team	HtB-STC-16	Stokes Creek	Stokes Creek Outlet	Located at the outlet of Stokes Creek, a tributary to Las Virgenes Creek. This station represents largely open lands, along with some institutional and residential areas closer to the sampling station.	•	•		34.095650	-118.717191
HtB Stream Team	HtB-TR-17	Triunfo Creek	Triunfo Creek, Corner of Kanan Rd. at Troutdale upstream of bridge	Located upstream of Malibou Lake, but downstream of Westlake Lake. This station drains a mix of open and developed lands.	•	•		34.120730	-118.788820
HtB Stream Team	HtB-WC-10	West Carlisle Creek	West Carlisle Creek	Located upstream of Lake Sherwood and Westlake Lake, draining largely undeveloped lands.		•		34.116371	-118.888882
HtB Stream Team	HtB-MDC-21	Medea Creek	Medea Creek, Cornell Road and Mulholland Highway	Near the mouth of Medea Creek, drains a mix of developed and undeveloped lands (station is immediately adjacent to a single family residential area).		•		34.114550	-118.755650
USEPA	EPA-1	Malibu Creek	Malibu Creek downstream of Rindge Dam	Station is located approximately 1000 feet downstream of the Rindge Dam on Malibu Creek and represents approximately 95% of the watershed drainage area, including all land use categories.		•		34.061667	-118.690000
USEPA	EPA-2	Malibu Creek	Malibu Creek, upstream of Tapia WRF Outfall near Dorothy Drive	Located downstream of the confluence of Malibu Creek and Las Virgenes Creek; upstream of the Tapia WRF outfall. Conditions are representative of approximately 90% of the Malibu Creek watershed.		•		34.085578	-118.713530
USEPA	EPA-3	Malibu Creek	Malibu Creek, downstream of Malibou Lake	Located downstream of Malibou Lake, this station characterizes upstream flow from all lands (developed and undeveloped) from much of the watershed. The station is located within the Malibu Creek State Park.		•		34.099101	-118.740000

Source	Station ID	Name	Location Description	Site Description	WQ	Benthic	PHAB	Latitude	Longitude
USEPA	EPA-4	Las Virgenes Creek	Las Virgenes Creek, above Mulholland Highway	At the downstream end of Las Virgenes Creek, this station captures loads from developed and undeveloped lands adjacent to Las Virgenes Creek.		•		34.105000	-118.706944
LACFCD	SMC01384	Malibu Creek	LACDPW MES; Malibu Creek at Malibu Canyon Road	Located on an unlined channel just upstream of Rindge Dam (and downstream of Cold Creek). This station is located in an undeveloped area; however, it represents drainage from much of the watershed including both developed and undeveloped land.	•	•		34.064170	-118.703590
LACFCD	SMC01640	Las Virgenes Creek	Las Virgenes Creek at Parkmoor Road	Station is on a lined channel on Las Virgenes Creek in the City of Calabasas. Immediately surrounded by urban lands, but also captures more undeveloped lands from the headwaters.		•		34.153020	-118.697520
LACFCD	LACo_15	Medea Creek	Medea Creek at Thousand Oaks Blvd. and Kanan Rd.	Unlined channel located within residential area on Medea Creek, upstream of the confluence of Palo Comado and Cheseboro Creeks. Station drains mostly developed lands.		•		34.150717	-118.757600
LACFCD	LACo_16	Las Virgenes Creek	Las Virgenes Creek near the Los Angeles County line	Located on an unlined portion of Las Virgenes Creek, near the County border. Drains a relatively undeveloped area of Ventura County.		•		34.168883	-118.703200
LACFCD	LACo_17	Cold Creek	Cold Creek at Stunt Rd. at Cold Creek Preserve	On an unlined channel near the headwaters of Cold Creek, this station drains relatively undeveloped lands in the Santa Monica Mountains National Recreation Area.		•		34.095117	-118.648633
LACFCD	LACo_18	Triunfo Canyon	Triunfo Creek downstream of Troutdale Dr. and nursery	Station located on an unlined channel upstream of Malibou Lake. Station represents a mix of undeveloped and developed lands from upstream of Westlake Lake and additional drainage to Triunfo Creek, but station		•		34.114183	-118.779167

Source	Station ID	Name	Location Description	Site Description	WQ	Benthic	PHAB	Latitude	Longitude
				is located in a mostly developed area.					
NPS	J_ LCOLDCRK	Lower Cold Creek	Lower Cold Creek, near confluence with Malibu Creek	At the mouth of Cold Creek, this station captures loads from both undeveloped lands in the headwaters as well as residential areas closer to the confluence with Malibu Creek.	•			34.079156	-118.700619
NPS	J_ MALICRKL	Malibu Creek Lower	Malibu Creek Lower, 2-3 stream miles from the coast	Located in open space before developed lands near Malibu Lagoon. This station is downstream of the Tapia WRF outfall and represents conditions in most of the watershed.	•			34.047717	-118.689797
NPS	J_ MALICRKU	Malibu Creek Upper	Malibu Creek Upper, near Rock Pool	Located downstream of Rock Pool, this station characterizes upstream flow from all lands (developed and undeveloped) from much of the watershed. The station is located within the Malibu Creek State Park.	•			34.096386	-118.729839
NPS	J_ UCOLDCRK	Upper Cold Creek	Upper Cold Creek, headwaters	Near the headwaters of Cold Creek, this station drains relatively undeveloped lands in the Santa Monica Mountains National Recreation Area.	•			34.090792	-118.647407
NPS	R1_ ELEANOR	Carlisle Creek (Eleanor)	Carlisle Creek (Eleanor)	Located near single family residential development on a small tributary discharging downstream of Lake Sherwood. Also drains undeveloped headwater areas.	•			34.126989	-118.856610
NPS	R1_ LIBCYN	Liberty Canyon (at confluence)	Liberty Canyon (at confluence)	Near the confluence with Las Virgenes Creek, this station represents the full drainage from Liberty Canyon, including both developed and undeveloped lands. The last several miles of the reach are through undeveloped land in Los Angeles County.	•			34.105202	-118.712675
NPS	R1_ MALICRK	Malibu Creek (Mott adobe)	Malibu Creek (Mott adobe)	Station is on Malibu Creek in the State Park (downstream of confluence with Las Virgenes Creek). Located in an undeveloped area, the	•			34.090345	-118.720157

Source	Station ID	Name	Location Description	Site Description	WQ	Benthic	PHAB	Latitude	Longitude
				station does represent loads from many upstream land uses, including developed lands.					
NPS	R2_ BULLDOG	Bulldog Motorway (off Malibou Lake)	Bulldog Motorway (off Malibou Lake)	Station is in open space south of Malibou Lake.	•			34.095565	-118.755014
NPS	R2_ LASVIRGENES	Las Virgenes Creek (near City Hall)	Las Virgenes Creek (near City Hall)	Station is on a lined channel on Las Virgenes Creek near the City of Calabasas adjacent to Highway 101 and near City Hall. Immediately surrounded by urban lands, but also captures more undeveloped lands from the headwaters.	•			34.150208	-118.697424
NPS	R2_ TRIUNFO	Triunfo Creek	Triunfo Creek, downstream of Westlake Lake	Station is downstream of Westlake Lake and is located near open areas. Overall, the station characterizes loads from a variety of developed lands, many of which drain to Westlake Lake.	•			34.132284	-118.806652
NPS	R3_ COLDCRK	Cold Creek (off Stunt Road)	Cold Creek (off Stunt Road)	About two miles from headwaters of Cold Creek, this station drains relatively undeveloped lands in the Santa Monica Mountains National Recreation Area and is just off of Stunt Road.	•			34.095035	-118.653104
NPS	R3_ CRAGSRD	Malibu Creek (Crags Road)	Malibu Creek (Crags Road)	Located downstream of Malibou Lake, this station characterizes upstream flow from all lands (developed and undeveloped) from much of the watershed. The station is located within the Malibu Creek State Park.	•			34.102865	-118.738448
NPS	R3_ CROSSCRK	Malibu Creek (at Cross Creek)	Malibu Creek (at Cross Creek)	Located in open space before developed lands in the lower watershed near Malibu Lagoon. This station is downstream of the Tapia WRF outfall and represents conditions in most of the watershed.	•			34.051745	-118.691979

Source	Station ID	Name	Location Description	Site Description	WQ	Benthic	PHAB	Latitude	Longitude
NPS	R3_ LADYFACE	Lady Face	Lady Face, near Agoura Road	Located downstream of Lindero Creek and just upstream of the confluence with Medea Creek in the city of Agoura Hills. Site represents drainage from mostly developed lands.	•			34.142835	-118.764005
NPS	R3_ LIBCYN	Liberty Canyon (above pitfalls)	Liberty Canyon (above pitfalls)	Station is located about half-way up the length of Liberty Canyon. Immediately downstream of developed lands (mostly residential); however, upper portion of the reach is in undeveloped lands.	•			34.124249	-118.723500
NPS	R3_ MALICRKSP	Malibu Creek State Park (rock pool)	Malibu Creek State Park (rock pool)	Station is on Malibu Creek in the State Park (downstream of confluence with Las Virgenes Creek). Located in an undeveloped area, the station does represent loads from many upstream land uses, including developed lands.	•			34.092648	-118.722501
NPS	S_ CARLISLE	Carlisle Canyon	Carlisle Canyon, over 3 miles from Lake Sherwood	Located upstream of Lake Sherwood and Westlake Lake, draining largely undeveloped lands.	•			34.117592	-118.887488
NPS	S_ LLASVIR	Lower (S) Las Virgenes Creek	Lower (S) Las Virgenes Creek, above Liberty Canyon	Towards the downstream end of Las Virgenes Creek, this station captures loads from developed and undeveloped lands adjacent to Las Virgenes Creek.	•			34.109586	-118.712557
NPS	S_ LMEDCRK	Lower Medea Creek	Lower Medea Creek, just west of Cornell Road	Located downstream of a single family residential area in Agoura Hills, this station represents drainage from much of Medea Creek. It includes largely developed lands, with some undeveloped areas in the headwaters.	•			34.123816	-118.751519
NPS	S_ UMEDCRK	Upper Medea Creek	Upper Medea Creek, middle of reach	Station is located within a residential area in the upper portion of Medea Creek, just inside of Los Angeles County. Drainage to this station is largely developed, with the exception of some of the headwaters that are	•			34.166473	-118.761860

Source	Station ID	Name	Location Description	Site Description	WQ	Benthic	PHAB	Latitude	Longitude
				open.					
HtB Stream Team	HtB-CH-6	Cheseboro Creek	Cheseboro Creek near Agoura Hills	Station drains relatively undisturbed areas in the lower portions of Cheseboro Creek in upper Los Angeles County.	•	•	•	34.154831	-118.726005
HtB Stream Team	HtB-PC-8	Palo Comado	Palo Comado Creek (upper)	Located in Ventura County, this station drains relatively undisturbed areas in the Santa Monica Mountains National Recreation Area.	•	•		34.195076	-118.745623
HtB Stream Team	HtB-LV-9	Las Virgenes Creek	Las Virgenes Creek, near headwaters	This station drains relatively undisturbed areas in the upper portions of Las Virgenes Creek in Ventura County.	•	•		34.180768	-118.707384
HtB Stream Team	HtB-SC-14	Solstice Creek	Solstice Creek. National Park Service Area, upstream of bridge	Outside of Malibu Creek Watershed. Solstice Creek inland from the coast and drains a largely undeveloped area; just southwest of Malibu Creek Watershed.	•	•	•	34.038470	-118.751326
HtB Stream Team	HtB-LCH-18	Lachusa Creek	Lachusa Creek, just north of Highway 1	Outside of Malibu Creek Watershed. On Lachusa Creek, near the coast and draining largely undeveloped land.	•	•	•	34.041621	-118.893248
HtB Stream Team	HtB-AS-19	Arroyo Sequit	Arroyo Sequit, up Mulholland Highway 1.1 miles	Outside of Malibu Creek Watershed. South of the western tip of the Malibu Creek Watershed. Station drains a largely undeveloped area and is located several miles inland.	•	•		34.065509	-118.931754
HtB Stream Team	HtB-SC-22	Solstice Creek	Solstice Creek, near coast	Outside of Malibu Creek Watershed. Solstice Creek near the coast; just southwest of Malibu Creek Watershed. Station drains a largely undeveloped area.		•		34.033386	-118.742930
NPS	J_ EFLASVIR	East Fork Las Virgenes	East Fork Las Virgenes, near mouth	This station drains relatively undisturbed areas in the upper portions of East Fork Las Virgenes Creek in Ventura County.	•			34.174839	-118.698708
NPS	R1_ MEDCRK	Medea Creek (at park)	Medea Creek (at park)	Located on upper branch of Medea Creek. Station represents drainage from single family residential areas	•			34.182908	-118.770221

Source	Station ID	Name	Location Description	Site Description	WQ	Benthic	PHAB	Latitude	Longitude
				and undeveloped land in the headwaters.					
NPS	R2_ CHEESEBORO	Cheseboro Creek (above connector)	Cheseboro Creek (above connector)	In the middle stretch of Cheseboro Creek. Station drains mostly undeveloped land	•			34.173808	-118.723858
NPS	S_ ULASVIR	Upper (N) Las Virgenes Creek	Upper (N) Las Virgenes Creek (headwaters, western branch)	This station drains relatively undisturbed areas in the upper portions of Las Virgenes Creek (western branch) in Ventura County.	•			34.176580	-118.706468

Note: Shading identifies comparator/reference sites used in the TMDL.

A.3 Data Inventory

Table A-2, Table A-3, and Table A-4 below identify the data used to support TMDL development for spatial, water quality, and bioassessment data, respectively.

Table A-2. Spatial Datasets Assembled/Created for the Malibu Creek Watershed

Data Type	Source	Description	Date Accessed	Date Created/ Updated
polyline	http://www.horizon-systems.com/nhdplus/	Major waterways selected from NHD plus hydrography	Jan-10	Oct-08
polygon	Ventura County Watershed Protection District	Major waterbodies within the Malibu Creek watershed	Apr-08	
polygon	created by Tetra Tech	Watershed boundary created from subwatershed delineation		Sep-10
polygon	created by Tetra Tech	Subwatershed boundaries created from subwatershed delineation		Sep-10
point	http://waterdata.usgs.gov/nwis	USGS gages located within the Malibu Creek watershed (2 gages)	Nov-10	Nov-10
point	Kevin Jontz	All “Heal the Bay” BMI monitoring locations	Sep-10	Sep-10
point	Kevin Jontz	“Heal the Bay” BMI monitoring locations outside of Malibu Creek watershed	Sep-10	Sep-10
point	Kevin Jontz	“Heal the Bay” BMI monitoring locations within Malibu Creek watershed	Sep-10	Sep-10
point	Aquatic Bioassay, 2005	Bioassessment monitoring location for the MCWMP	Aug-10	Mar-05
Point	LVMWD	Locations for all monitoring sites in the Malibu Creek watershed	May-13	
grid	created by Tetra Tech	Mosaic of 10-meter DEMs obtained from NRCS Data gateway	Sep-10	Sep-10
polygon	created by Tetra Tech	CA Dept. of Forestry and Fire Protection statewide fire history, clipped to watershed	Dec-09	Mar-08
polygon	created by Tetra Tech	Major recent fires extracted from the previous dataset	Dec-09	Mar-08
polygon	created by Tetra Tech	Hydrologic Soil Groups (SSURGO) clipped to watershed	Oct-10	Oct-10
polygon	created by Tetra Tech	1990 SCAG LULC clipped to watershed, aggregated, and then dissolved	Nov-07	Nov-07

Data Type	Source	Description	Date Accessed	Date Created/ Updated
polygon	created by Tetra Tech	2005 SCAG LULC clipped to watershed, aggregated, and then dissolved	Nov-07	Nov-07
Polygon	Created by Tetra Tech	2008 SCAG LULC clipped to watershed, aggregated, and then dissolved	Nov-10	May-12
polygon	created by Tetra Tech	Polygons created and dissolved from Landfire Existing Vegetation Type (EVT) dataset	Oct-10	Oct-10
polygon	created by Tetra Tech	Landfire EVT in 1990 SCAG's "undeveloped" areas	Oct-10	Oct-10
polygon	created by Tetra Tech	Landfire EVT in 2005 SCAG's "undeveloped" areas	Oct-10	Oct-10
polyline	Tele Atlas North America, Inc., ESRI	Major highways	Oct-06	Oct-06
polyline	Tele Atlas North America, Inc., ESRI	Major and minor highways	Oct-06	Oct-06
polygon	Los Angeles County Department of Public Works	Legal city boundaries within Los Angeles County	Mar-05	Apr-03
polygon	Ventura County Watershed Protection District	Legal city boundary of Thousand Oaks	Jan-09	
polygon	Ventura County Watershed Protection District	Various park and open space boundaries	Mar-13	
Point	Ventura County Watershed Protection District	Malibu Creek Dams	Mar-13	
lines	Ventura County Watershed Protection District	Storm drain channels, lateral lines, mains	Mar-13	

Table A-3. Water Quality and Flow Data Assembled for the Malibu Creek Watershed

Data Type	Source	Description	Dates
water quality	CEDEN	Water quality parameters including metals, and Lat/Long for 5 stations	2002-2006 for one station. 2003-2004 for 4 stations
water quality	LADPW	2005-2006 Sampling (wet and dry) results for Malibu Creek at site# S02	2005 and 2006
water quality	LADPW	2006-2007 Sampling (wet and dry) results for Malibu Creek at site# S02	2006 and 2007
water quality	LADPW	Water quality for station S02 in Malibu Creek, includes data for surrounding stations	1995 - 2005
sediment quality, toxicity	SCCWRP	Bight03 sediment chemistry and toxicity results including samples from Malibu Lagoon	2003
sediment quality, toxicity	SCCWRP	Bight98 sediment chemistry and toxicity results, including samples from Malibu Lagoon	1998

Data Type	Source	Description	Dates
flow	MCLC	Presentation containing rainfall and flow data for Malibu Creek; max flows for specific days (2004, 2005; at F130R)	2004 and 2005
Water quality	LACSD	Cheseboro Creek water quality sampling downstream of Calabasas Landfill	11/99 – 2/09
Water quality	LADPW	Database of water quality observations at Mass Emission Stations	1994 - 2005
Water quality	LADPW	Database of water quality observations at Mass Emission Stations	2005 - 2009
Water quality	LADPW	Stormwater Monitoring Reports (containing Mass Emission Station monitoring results, in pdf)	2003 - 2011
Particle size	USEPA	Sediment grab sample particle size analysis at 5 sites	2010
Particle size	USEPA	Sediment grab sample particle size analysis at 5 sites (different from first 5 sites)	2010
Sediment chemistry	USEPA	Malibu Lagoon sediment samples analyzed for TKN, Nitrate, Nitrite, etc. for 3 different sample sites	2011
Particle Size	USEPA	Particle Size analysis and statistics for 3 different Sample IDs.	2011
Sediment chemistry	USEPA	Malibu Lagoon sediment samples analyzed for TKN, Nitrate, Nitrite, etc. for 5 different sample sites	2011
Sediment chemistry	USEPA	Particle Size analysis and statistics on 6 different Sample IDs	2011
Water quality	Heal the Bay	Database of water quality measurements, samples linked to event IDs and site numbers, lat/long not provided	11/7/1998- 6/6/2010
Site Locations	LVMWD	Site descriptions, data type, and latitude/longitude of LA County Bioassessment Monitoring Sites. Note that not all sites are 2003-2009 but specifics are laid out by site in this file	2003-2009
Water quality	LVMWD	Monitoring data at sites monitored for Tapia WRF	1971 - 2011
Water quality	LACFCD	Physical water quality data for LACFCD Bioassessment Sites	2003 - 2011
Water quality	MCWMP	Database of water quality monitoring (also includes Heal the Bay and LVMWD samples 1998-2007)	2/2005 – 2/2007
Water quality	NPS	Water quality monitoring data for NPS monitoring sites, one worksheet per event	2006-2011

Data Type	Source	Description	Dates
Flow data	LVMWD	Records of releases from Tapia WRF	1998 - 2012
Flow data	LADPW	Daily mean discharge for site F130: Malibu Creek Below Cold Creek	1979 - 2010
Flow data	USGS	Gage 11005500 (1931-1979), gage 11005510 (2007-2010)	1931 - 2010

Table A-4. Bioassessment Data Assembled for the Malibu Creek Watershed

Data Type	Source	Description	Dates
toxicology	CEDEN	Toxics data including survival (%), growth (mg/ind), and constituent concentrations	All samples recorded on 3/12/2003
IBI	Heal the Bay	SC-IBI and component metric scores at multiple sites	2000 - 2011
benthic	Heal the Bay	Taxonomic lists of benthic macroinvertebrates sampled in Malibu Creek watershed	2000 - 2011
QA/QC	Heal the Bay	California Stream Bioassessment Procedure Biological and Physical Habitat Field Audit. QA/QC records	September 2005
site description	Heal the Bay	18 sites with lat/long and site location descriptions	N/A
Benthic	LVMWD	Benthic macroinvertebrate data (multiple sites)	2006 – 2011
IBI	LVMWD	IBI scores corresponding to previous data set	2006 – 2011
benthic	USEPA	Taxonomic data at 8 different stations using various methods	2011
Benthic	USEPA	Species data, counts, percentages, indices, and richness for 5 different Malibu Creek sites (biological metrics calculated at 500ct.)	2011
Benthic	USEPA	Taxa list and abundance calculations for benthic macroinvertebrates, calculated at 600ct, LV2.	2011
Benthic	LADPW	Bioassessment Monitoring Program in LA County, Annual Reports	2005 - 2011
benthic	LACFCD	Taxonomic data for multiple sites	2003 - 2011
IBI	LVMWD	LVMWD Malibu and LA River Watersheds Bioassessment Monitoring Reports	2006 - 2010
benthic	LVMWD	Taxonomic data	2006-2011
IBI	LVMWD	Adjusted IBI scores for 7 sites	2006-2011

Data Type	Source	Description	Dates
benthic	MCWMP	Bioassessment Monitoring Report 2005	2005
benthic	MCWMP	Malibu Creek taxonomic data (7 sites)	2005
Physical data	Heal the Bay	Contains 16 word documents with physical habitat data for each site (SWAMP)	2009 and 2010 for all sites except CH6 (2010 only)
Physical data	MCWMP	Physical habitat data for 8 sites	2005
Physical Data	LVMWD	Physical habitat, bank stability, velocity, slope, width, riparian, etc. The period of record varies depending on the file in question, but all sampling dates are accounted for	2007-2011

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Appendix B. Meteorology, Climate, and Fire History and Conditions

B.1 General Climate

The Malibu Creek watershed has a Mediterranean climate like other parts of the coastal region of southern California. The daily average air temperature ranges from 53 °F in January to 71 °F in July, and the annual average temperature is 61 °F (NRCS, 1995). Average winter temperatures have highs in the mid-60s and lows in the mid-40s (Abramson et al., 1998). Coastal fog is common in the morning during the summer months, but usually burns away by mid-day. During the summer, inland temperatures generally remain around 85 °F during the day, but may be 15 degrees cooler at the coast (Abramson et al., 1998; Jorgen, 1995).

Because of the mountainous topography, rainfall varies in different parts of the watershed. Figure B-1 shows the distribution of the long-term average annual rainfall in the watershed based on information from the Los Angeles County Flood Control District (Tetra Tech, 2002). The southern portion of the watershed is coastal mountains and has an average annual rainfall of 24 inches at the higher elevations (SCS, 1967; NRCS, 1995). The northern portion consists of inland basins with small hills and has a lower annual rainfall of 14 inches. The annual rainfall at the bottom of the watershed in Malibu is about 16 inches. Almost all of the rainfall occurs during the November to April wet season. The annual rainfall may vary from near zero during drought years to about five times the average annual precipitation during very wet years (NRCS, 1995). Measurable precipitation occurs on an average of about 35 days per year (Abramson et al., 1998).

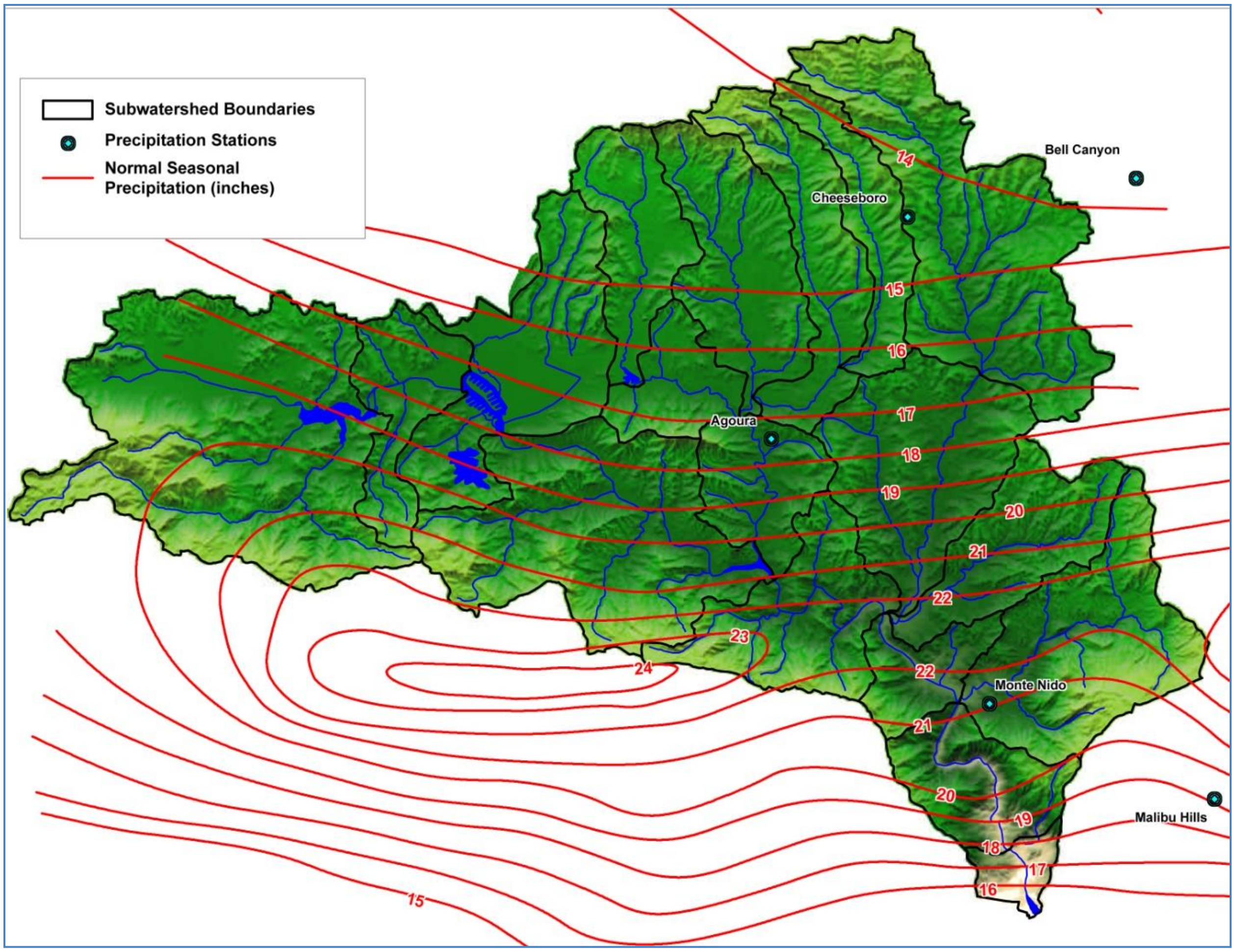

Figure B-1. Long-term Average Rainfall in the Malibu Creek Watershed (Tetra Tech, 2002)

The evaporation rate from open waters such as lakes is about 72 inches per year (NRCS, 1995). These rates vary seasonally with the weather, and range from a low of about 2 to 4 inches per month during January and February to a high of about 8 to 10 inches per month during the summer. Actual evapotranspiration rates vary with vegetation type and density of coverage. Estimated annual evapotranspiration rates in the Malibu Creek watershed are 23 to 24 inches for woodlands and orchards, 17 to 21 inches for chaparral and scrub, 8 inches for grasslands, 14 inches for cultivated areas, and 19 inches for developed areas (NRCS, 1995). The total annual evapotranspiration and evaporation in the watershed has been estimated at about 111,000 ac-ft, or 18.8 inches (NRCS, 1995).

Precipitation intensity in the watershed is strongly influenced by elevation and rainshadow effects. Maps of the 50-year 24-hour storm depth (LACDPW, 2006) show lower intensities at the coast and in the inland valleys, with maximum intensities (up to 10 inches in 24 hours) along the peak of the Santa Monica Mountains (Figure B-2).

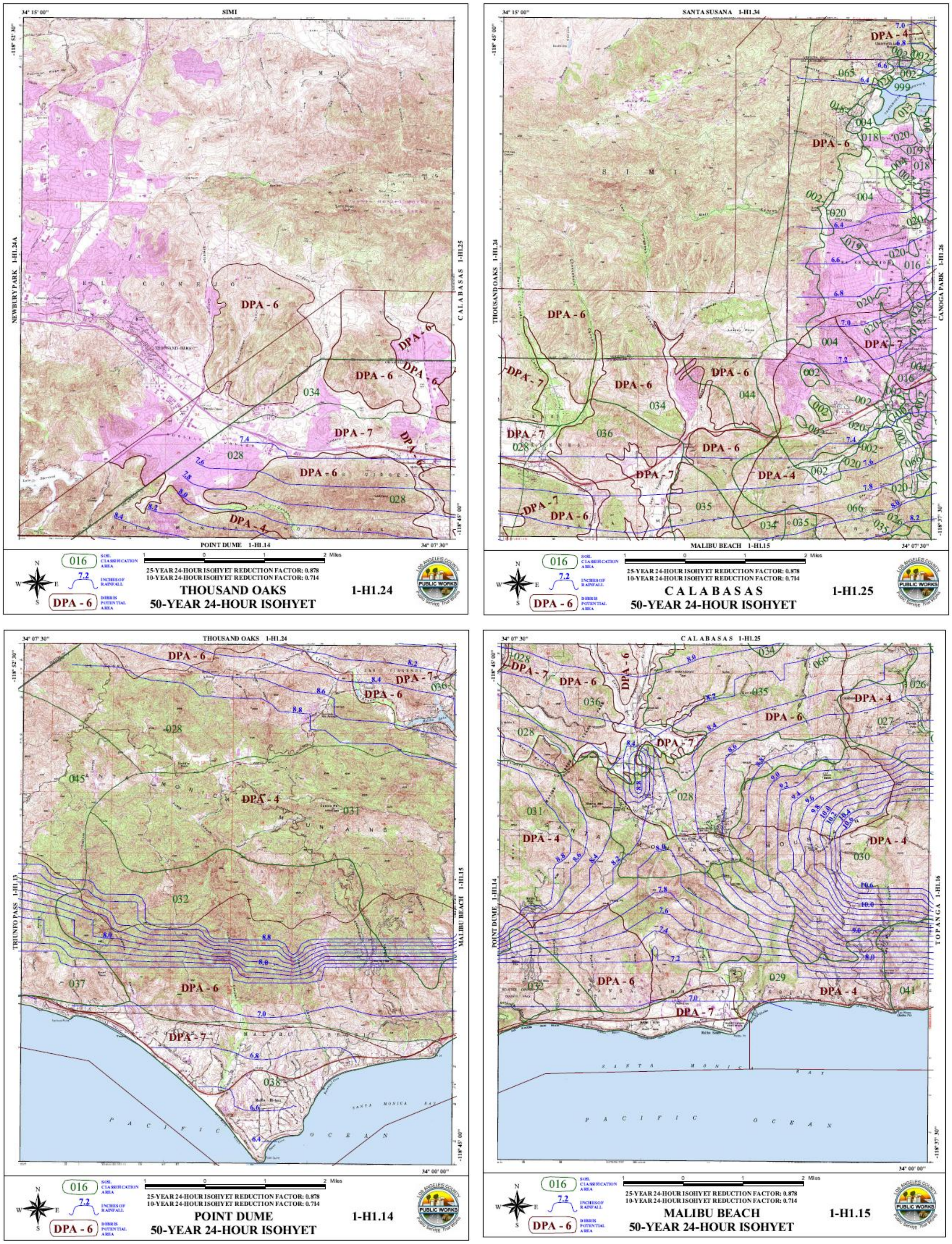

Figure B-2. 50-yr 24-hr Precipitation Depths for Malibu Creek Watershed

B.2 Temporal Trends

Climate is not constant from year to year. In addition to random variability and potential long-term trends (e.g., global climate warming), the climate of southern California is also influenced by strong decadal scale oscillations. It is typical to experience a series of very wet seasons followed by extremely dry seasons. This significantly influences sediment transport regimes and habitat condition. Further, biological condition observed in a given year may in part reflect timing relative to these longer-period cycles. Research on weather patterns in the watershed by Farnsworth and Warrick (2007) showed that stream flow discharges during the warm phases of the El Niño-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) in southern California watersheds are two-fold higher compared to the cool phases.

Of particular note, in the late 1970s the PDO switched from a cold to a warm cycle (Figure B-3) which would result in more intense El Niños and a general pattern of increased rainfall (Mantua, 2009). Long-term trends in annual precipitation for Los Angeles County as summarized by the PRISM system (Daly et al., 2008) are shown in Figure B-4.

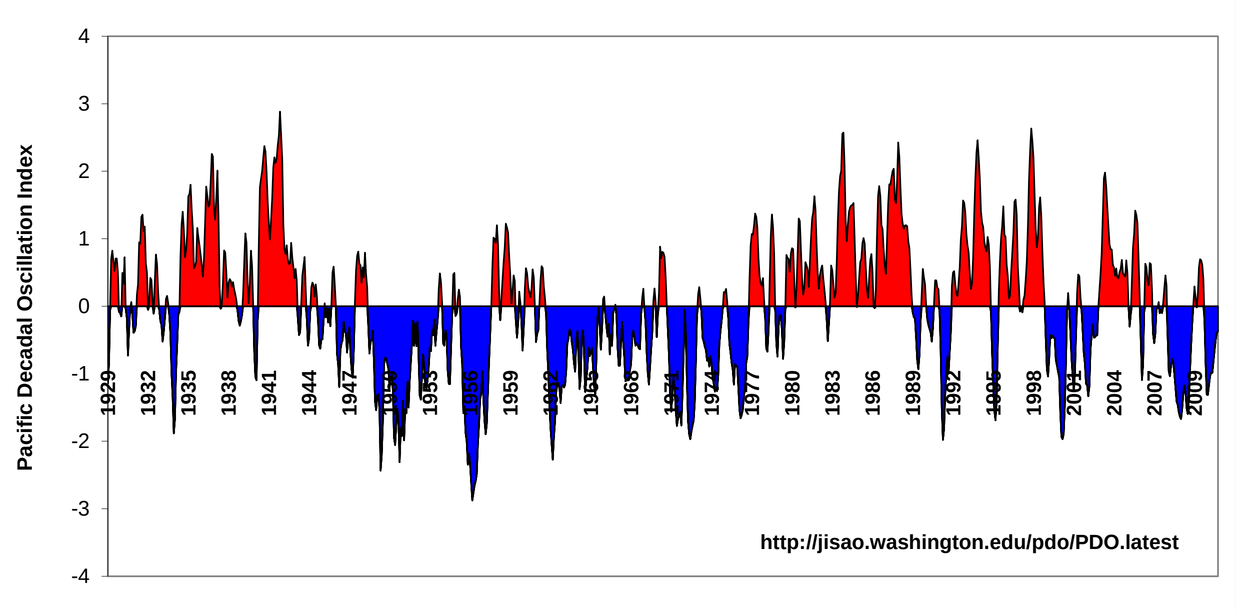

Figure B-3. Pacific Decadal Oscillation Index

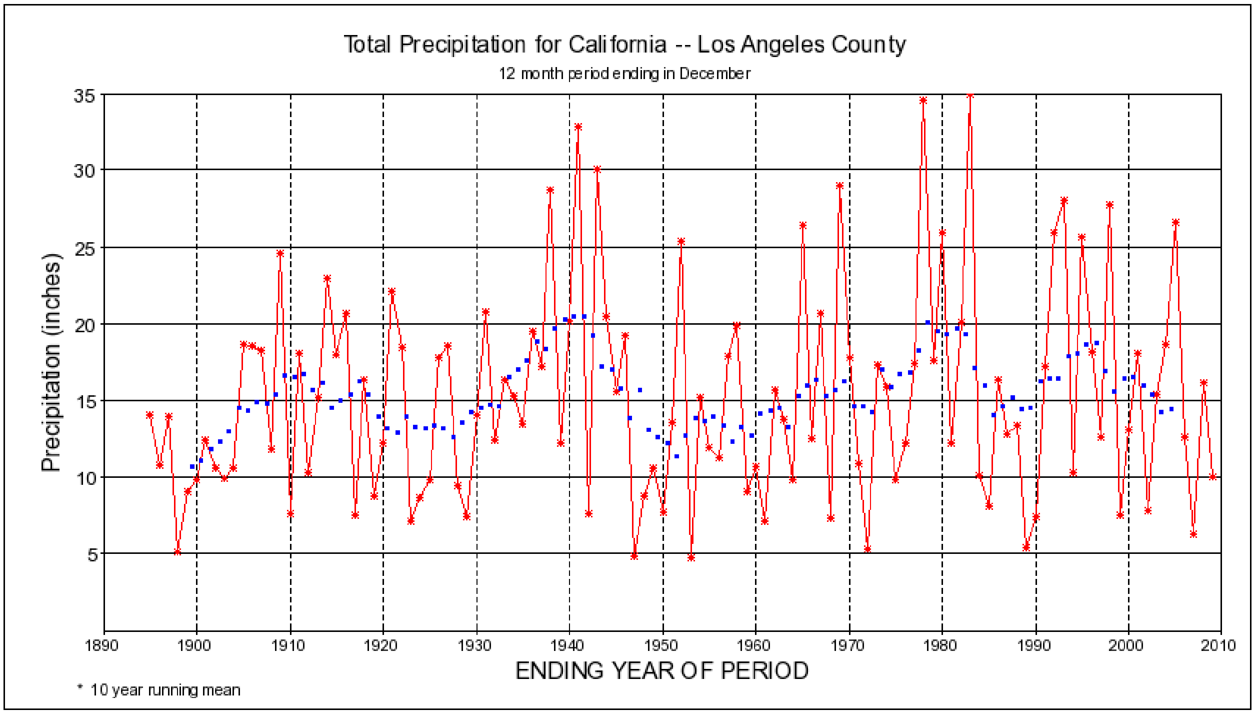

Figure B-4. PRISM Summary of Annual Precipitation for Los Angeles County

Note: Image from WestMap (http://www.cefa.dri.edu/Westmap/Westmap_home.php)

B.3 Fire History and Conditions

Major fires in the watershed were identified for each year from 1949 to the present as well as those affecting the proposed reference sites at LCH-18 and SC-14. These major fires are shown in Table B-1 and spatially in Figure B-5 through B-16 below.

Table B-1. Major Fire Events within Malibu Creek Watershed (1949 to 2009, >1,500 acres in year)

Year	Date	Fire Name	Fire Area in Watershed (acres)	Total Fire Area (acres)
1949	07/31/1949	REINDL NO. 78	2	231
	10/31/1949	SIMI HILLS	12,201	20,579
1956	12/27/1956	HUME FIRE	60	2,194
	12/28/1956	SHERWOOD/ZUMA	4,070	35,170
1958	11/28/1958		3,562	4,240
	12/02/1958		6,168	18,120

Year	Date	Fire Name	Fire Area in Watershed (acres)	Total Fire Area (acres)
1967	10/15/1967	DEVONSHIRE-PARKER	7,606	23,094
	10/16/1967	ROUND MEADOW FIRE	0	100
	10/30/1967	LATIGO FIRE	0[1]	2,869
1970	09/05/1970		12	12
	09/17/1970		47	47
	09/25/1970	CLAMPITT FIRE	13,448	115,537
	09/25/1970	WRIGHT FIRE	16,462	28,202
1978	07/03/1978		6	6
	08/09/1978		5	5
	09/22/1978		38	38
	10/23/1978	KANAN FIRE	10,562	25,589
1982	09/07/1982	HIGHLANDS FIRE	25	188
	10/08/1982	HALL	352	2,648
	10/09/1982	DAYTON CANYON FIRE	29,733	43,097
1985	06/30/1985	SHERWOOD FIRE	2,496	3,795
	07/12/1985	MULHOLLAND FIRE	66	66
	10/14/1985	PARK FIRE	156	156
	10/14/1985	DECKER FIRE	0[2]	6,567
	N/A	PIUMA	2,169	5,391
1993	09/27/1993	MALIBU FIRE 15 AC	14	14
	10/26/1993	GREEN MEADOWS	4,522	38,479
	10/28/1993	CHEESEBORO	845	845
	11/02/1993	OLD TOPANGA FIRE	4,927	16,468
1996	10/21/1996	CALABASAS FIRE	7,629	12,513
2005	09/28/2005	TOPANGA	9,748	23,396
2007	01/22/2007	FOOTHILL	55	56

Year	Date	Fire Name	Fire Area in Watershed (acres)	Total Fire Area (acres)
	10/21/2007	CANYON	1,813	3,839
	11/24/2007	CORRAL	19	4,708

Notes:

[1] Fire not in watershed but affected Reference Site HtB-SC-14

[2] Fire not in watershed but affected Reference Site HtB-LCH-18

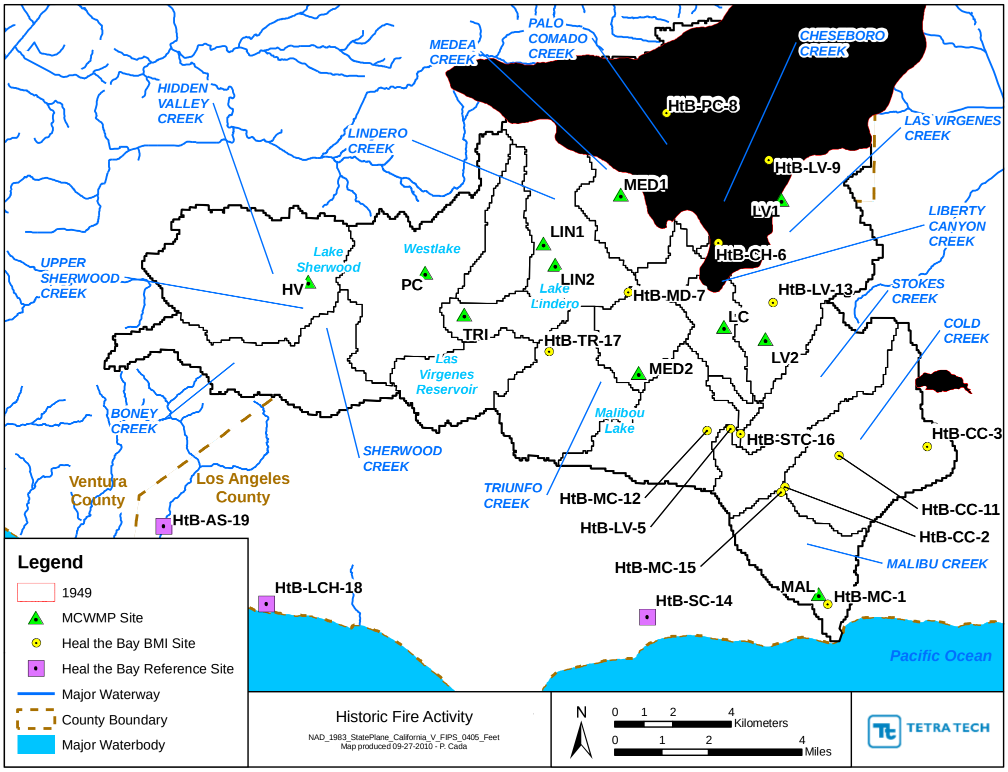

Figure B-5. Major Fire Activity Affecting Malibu Creek Watershed – 1949

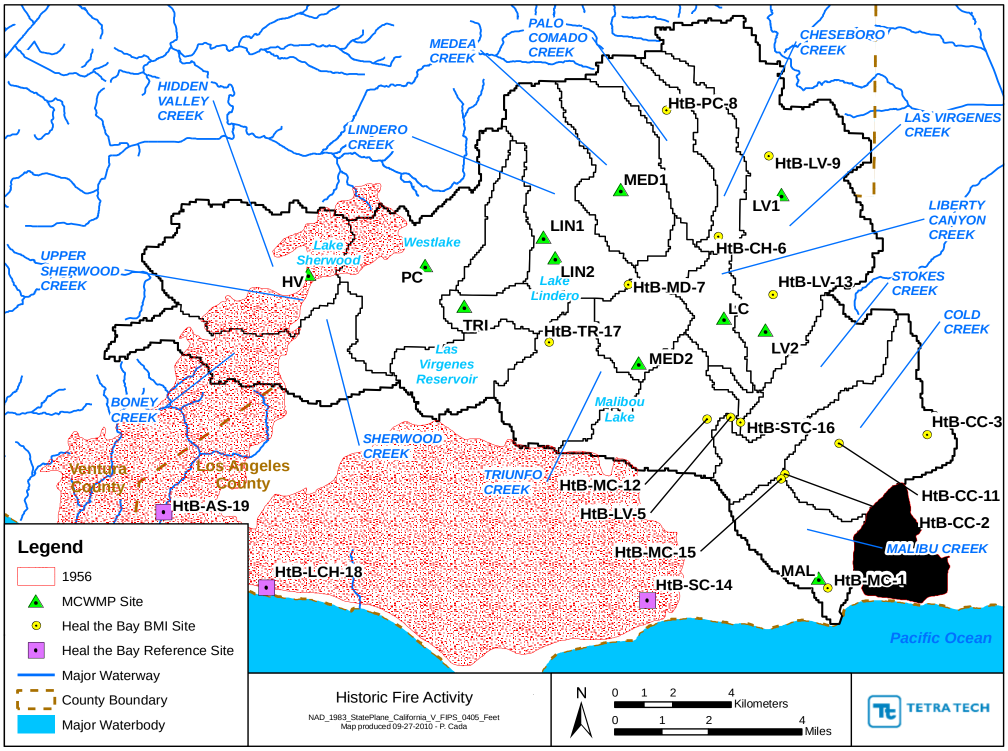

Figure B-6. Major Fire Activity Affecting Malibu Creek Watershed – 1956

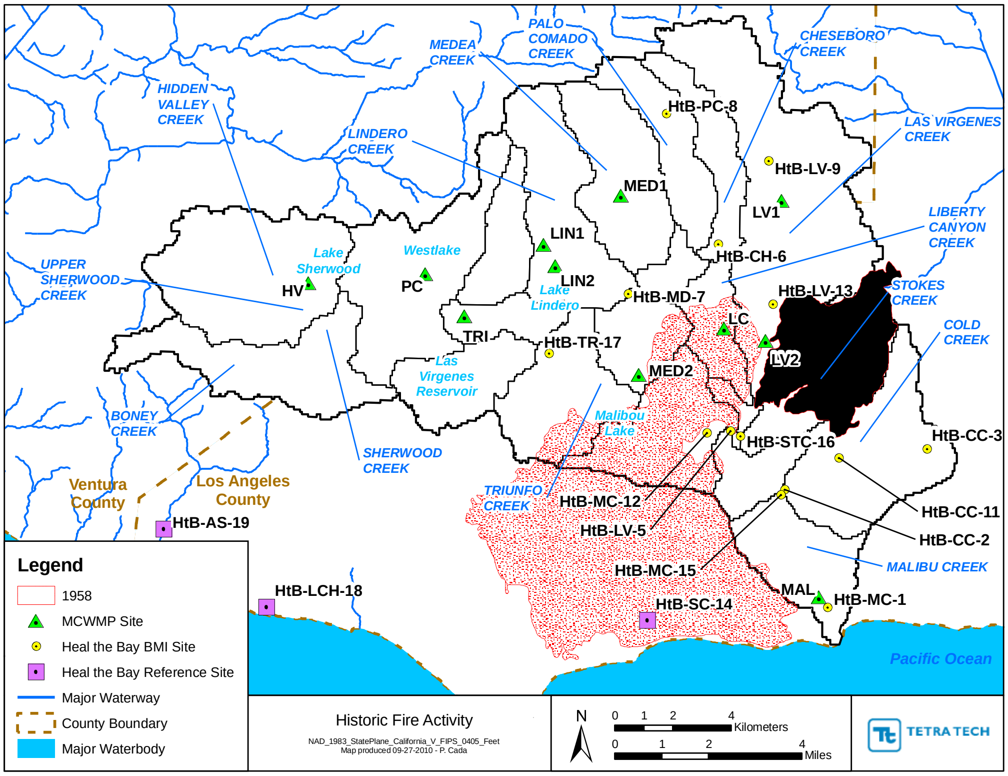

Figure B-7. Major Fire Activity Affecting Malibu Creek Watershed – 1958

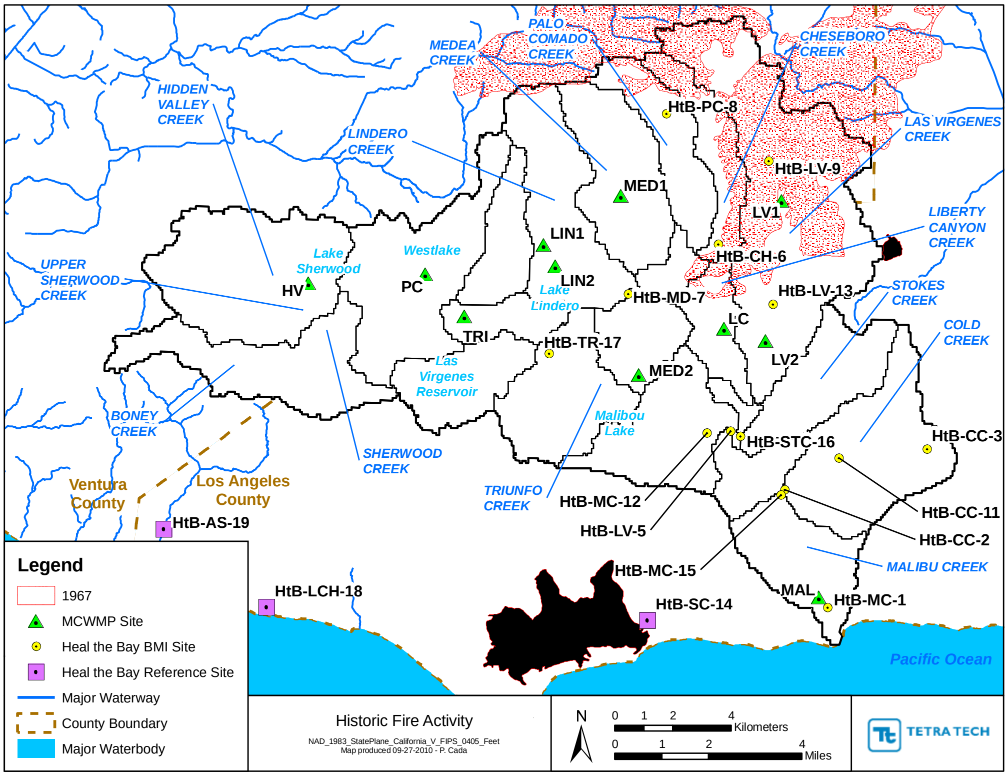

Figure B-8. Major Fire Activity Affecting Malibu Creek Watershed – 1967

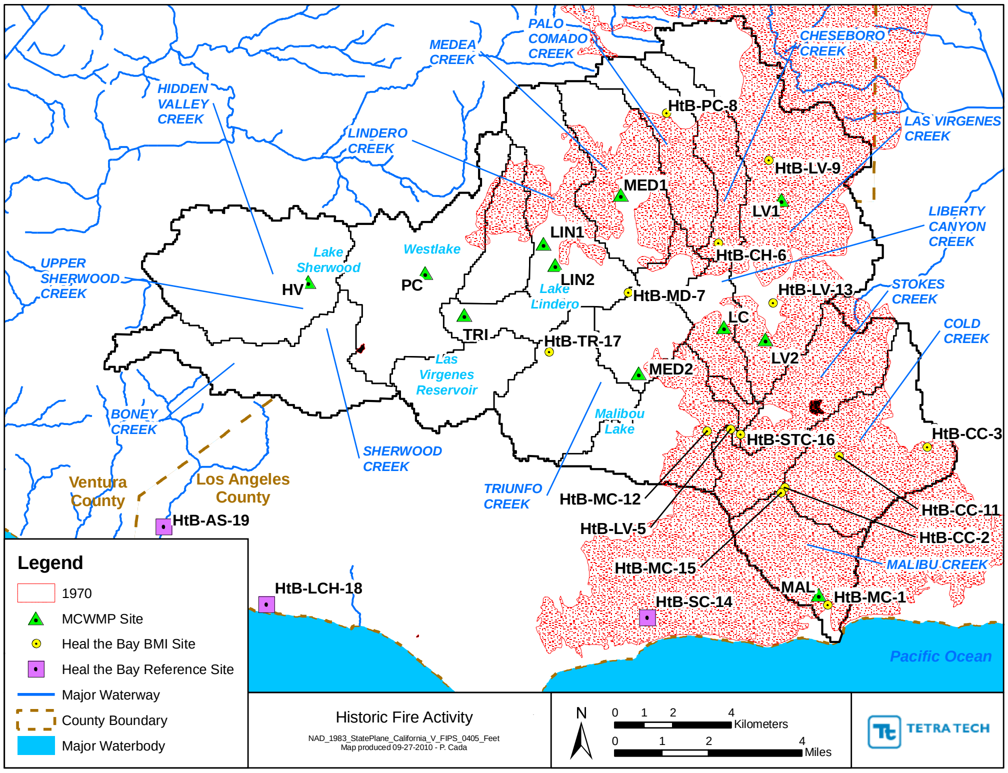

Figure B-9. Major Fire Activity Affecting Malibu Creek Watershed – 1970

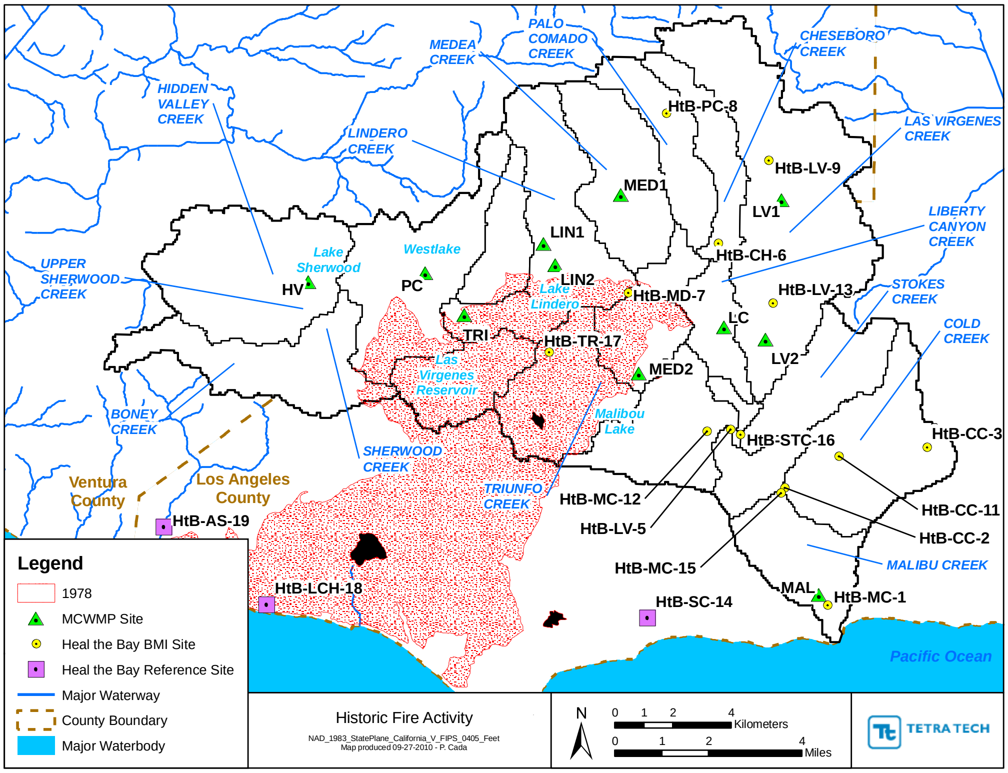

Figure B-10. Major Fire Activity Affecting Malibu Creek Watershed – 1978

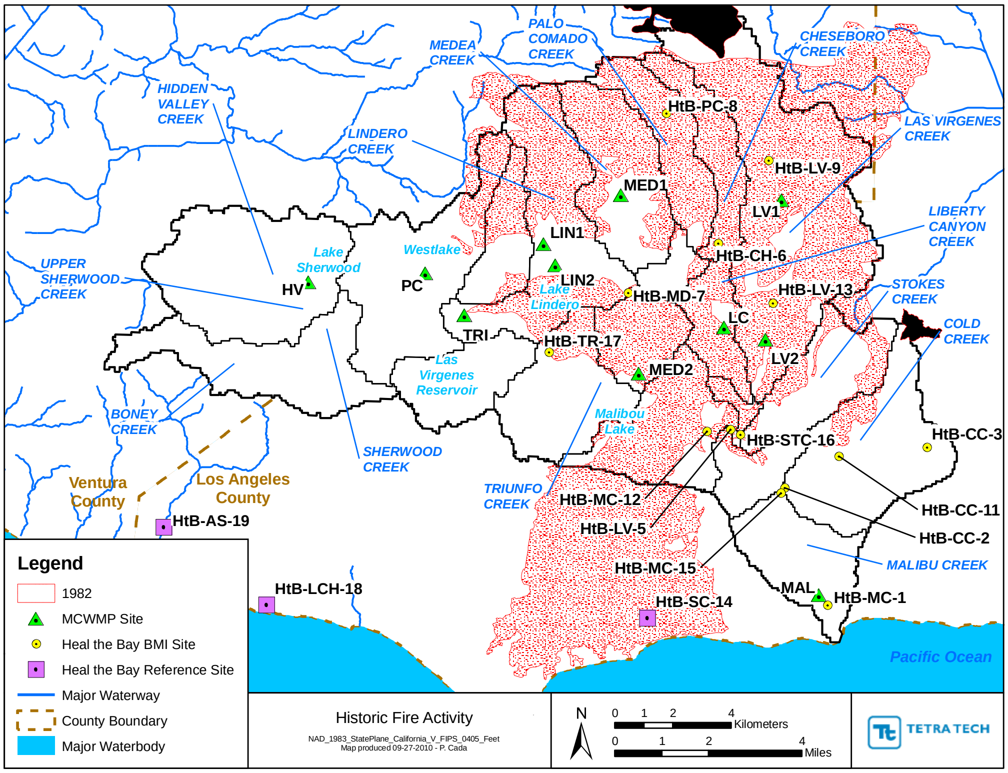

Figure B-11. Major Fire Activity Affecting Malibu Creek Watershed – 1982

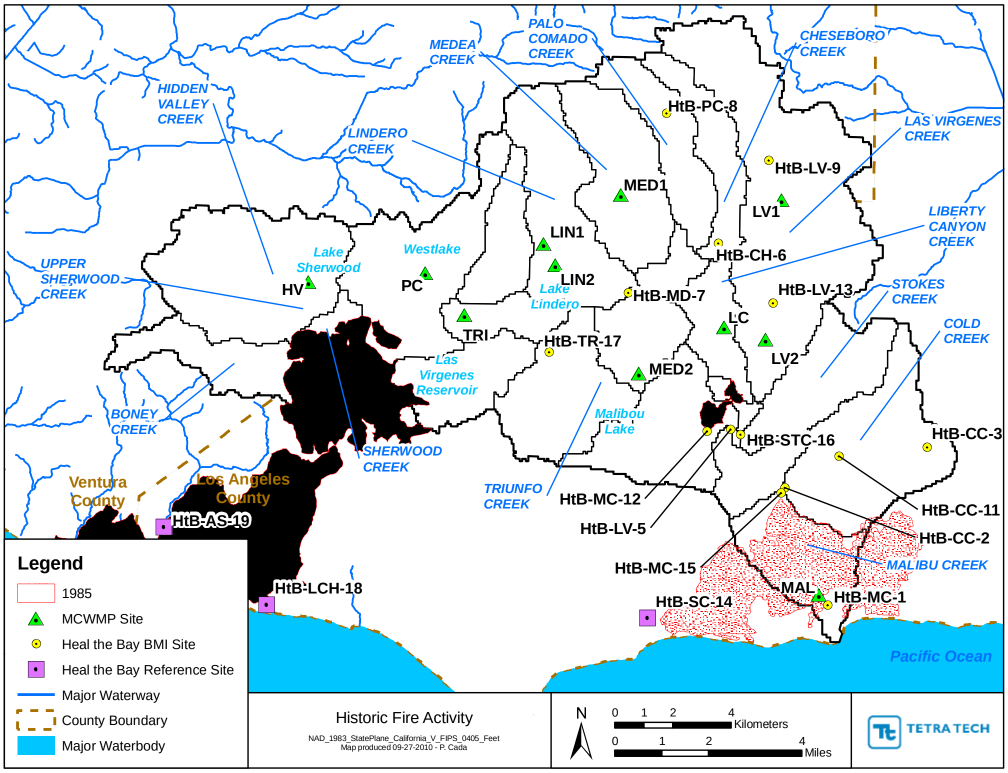

Figure B-12. Major Fire Activity Affecting Malibu Creek Watershed – 1985

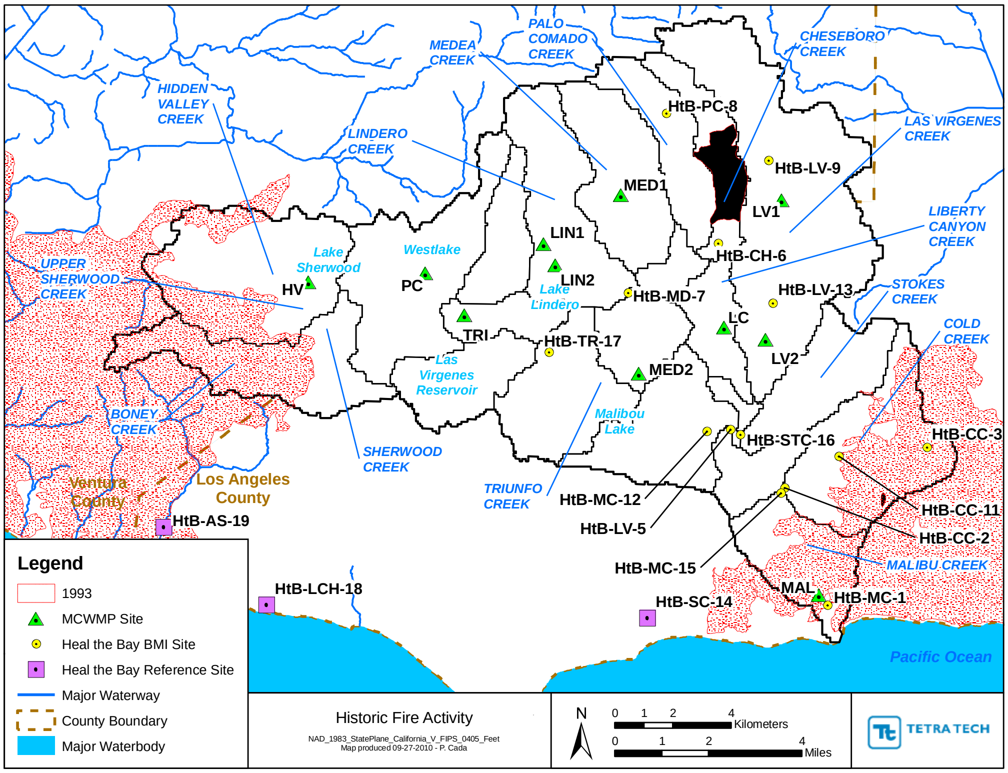

Figure B-13. Major Fire Activity Affecting Malibu Creek Watershed – 1993

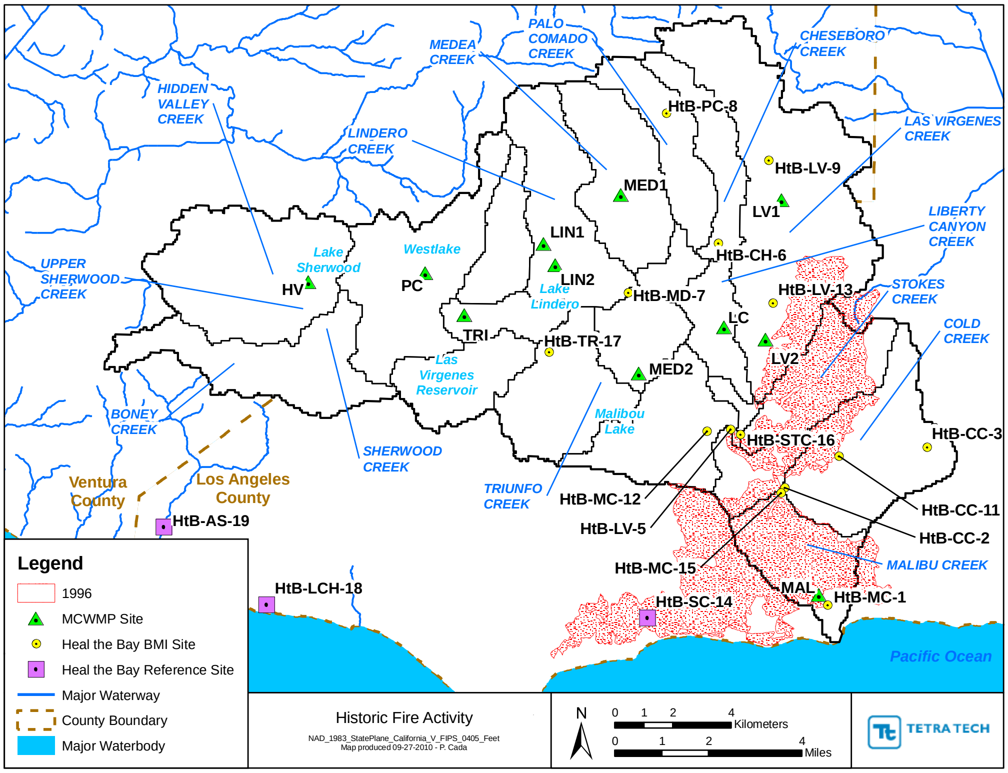

Figure B-14. Major Fire Activity Affecting Malibu Creek Watershed – 1996

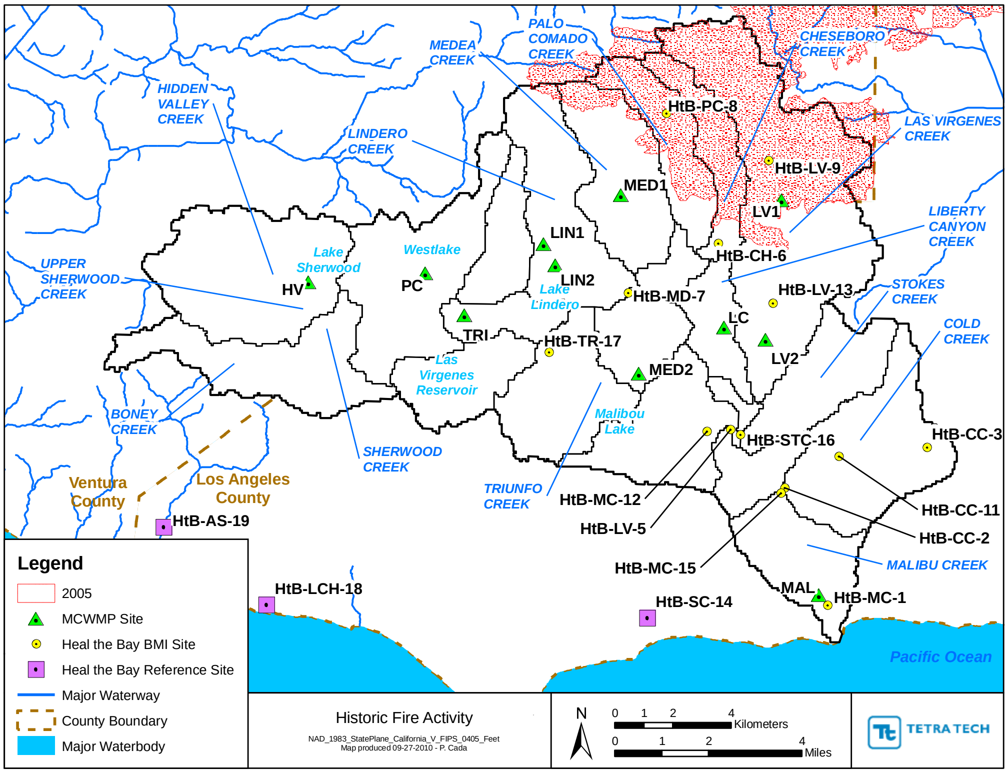

Figure B-15. Major Fire Activity Affecting Malibu Creek Watershed – 2005

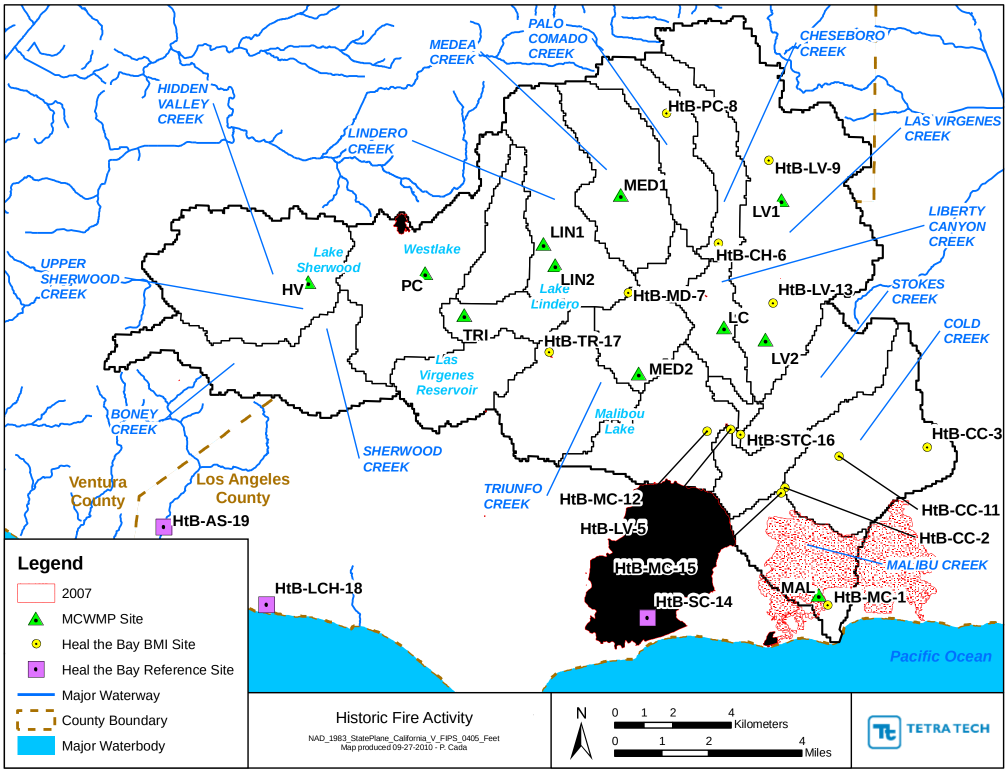

Figure B-16. Major Fire Activity Affecting Malibu Creek Watershed – 2007

Appendix C. IHA Reference Information

Specific ecosystem influences associated with each of the IHA parameter groups are shown in Table C-1 below.

Table C-1. Interpretation of IHA Flow Metrics (Nature Conservancy, 2007)

IHA Parameter Group	Hydrologic Parameters	Ecosystem Influences
1. Magnitude of monthly water conditions	Mean or median value for each calendar month Subtotal 12 parameters	Habitat availability for aquatic organisms Soil moisture availability for plants Availability of water for terrestrial animals Availability of food/cover for fur-bearing mammals Reliability of water supplies for terrestrial animals Access by predators to nesting sites Influences water temperature, oxygen levels, photosynthesis in water column
2. Magnitude and duration of annual extreme water conditions	Annual minima – 1-day mean Annual minima – 3-day mean Annual minima – 7-day mean Annual minima – 30-day mean Annual minima – 90-day mean Annual maxima – 1-day mean Annual maxima – 3-day mean Annual maxima – 7-day mean Annual maxima – 30-day mean Annual maxima – 90-day mean Number of zero-flow days Base flow index: 7-day minimum flow/mean flow for year Subtotal 12 parameters	Balance of competitive, ruderal, and stress-tolerant organisms Creation of sites for plan colonization Structuring of aquatic ecosystems by abiotic vs. biotic factors Structuring of river channel morphology and physical habitat conditions Soil moisture stress in plants Dehydration in animals Anaerobic stress in plants Volume of nutrient exchanges between rivers and floodplains Duration of stressful conditions such as low oxygen and concentrated chemicals in aquatic environments Distributions of plant communities in lakes, ponds, floodplains Duration of high flows for waste disposal, aeration of spawning beds in channel sediments
3. Timing of annual extreme water conditions	Julian date of each annual 1-day maximum Julian date of each annual 1-day minimum	Compatibility with life cycles of organisms Predictability/avoidability of stress for organisms Access to special habitats during reproduction or to avoid predation

IHA Parameter Group	Hydrologic Parameters	Ecosystem Influences
	Subtotal 2 parameters	Spawning cues for migratory fish Evolution of life history strategies, behavioral mechanisms
4. Frequency and duration of high and low pulses	Number of low pulses within each water year Mean or median duration of low pulses Number of high pulses within each water year Mean or median duration of high pulses (days) Subtotal 4 parameters	Frequency and magnitude of soil moisture stress for plants Frequency and duration of anaerobic stress for plants Availability of floodplain habitats for aquatic organisms Nutrient and organic matter exchanges between river and floodplain Soil mineral availability Access for waterbirds to feeding, resting, reproduction sites Influences bedload transport, channel sediment textures, and duration of substrate disturbance (high pulses)
5. Rate and frequency of water condition changes	Rise rates: Mean or median of all positive differences between consecutive daily values Fall rates: Mean or median of all negative differences between consecutive daily values Number of hydrologic reversals Subtotal 3 parameters Grand Total: 33 parameters	Drought stress on plants (falling levels) Entrapment of organisms on islands, floodplains (rising levels) Desiccation stress on low-mobility streamedge (varial zone) organisms

The IHA guide to interpret EFC statistics is shown in Table C-2 below.

Table C-2. Interpretation of IHA Environmental Flow Components

EFC Type	Hydrologic Parameters	Ecosystem Influences
1. Monthly low flows	Mean or median values of low flows during each calendar month *Subtotal 12 parameters*	• Provide adequate habitat for aquatic organisms • Maintain suitable water temperatures, dissolved oxygen and water chemistry • Maintain water table levels in floodplain, soil moisture for plants • Provide drinking water for terrestrial animals • Keep fish and amphibian eggs suspended • Enable fish to move to feeding and spawning areas • Support hyporheic organisms (living in saturated sediments)
2. Extreme low flows	Frequency of extreme low flows during each water year or season Mean or median values of extreme low flow event • Duration (days) • Peak flow (minimum flow during event) • Timing (Julian date of peak flow) *Subtotal 4 parameters*	• Enable recruitment of certain floodplain plant species • Purge invasive, introduced species from aquatic and riparian communities • Concentrate prey into limited areas to benefit predators
3. High flow pulses	Frequency of high flow pulses during each water year or season Mean or median values of high flow pulse event: • Duration (days) • Peak flow (maximum flow during event) • Timing (Julian date of peak flow) • Rise and fall rates *Subtotal 6 parameters*	• Shape physical character of river channel, including pools, riffles • Determine size of streambed substrates (sand, gravel, cobble) • Prevent riparian vegetation from encroaching into channel • Restore normal water quality conditions after prolonged low flows, flushing away waste products and pollutants • Aerate eggs in spawning gravels, prevent siltation • Maintain suitable salinity conditions in estuaries
4. Small floods	Frequency of small floods during each water year or season Mean or median values of small	Applies to small and large floods: • Provide migration and spawning cues for fish

EFC Type	Hydrologic Parameters	Ecosystem Influences
	flood event: • Duration (days) • Peak flow (maximum flow during event) • Timing (Julian date of peak flow) • Rise and fall rates Subtotal 6 parameters	• Trigger new phase in life cycle (i.e., insects) • Enable fish to spawn in floodplain, provide nursery area for juvenile fish • Provide new feeding opportunities for fish, waterfowl • Recharge floodplain water table • Maintain diversity in floodplain forest types through prolonged inundation (i.e., different plant species have different tolerances) • Control distribution and abundance of plants on floodplain • Deposit nutrients on floodplain
5. Large floods	Frequency of large floods during each water year or season Mean or median values of large flood event: • Duration (days) • Peak flow (maximum flow during event) • Timing (Julian date of peak flow) • Rise and fall rates *Subtotal 6 parameters* **Grand Total: 34 parameters**	Applies to small and large floods: • Maintain balance of species in aquatic and riparian communities • Create sites for recruitment of colonizing plants • Shape physical habitats of floodplain • Deposit gravel and cobbles in spawning areas • Flush organic materials (food) and woody debris (habitat structures) into channel • Purge invasive, introduced species from aquatic and riparian communities • Disburse seeds and fruits of riparian plants • Drive lateral movement of river channel, forming new habitats (secondary channels, oxbow lakes) • Provide plant seedlings with prolonged access to soil moisture

The basic IHA flow indicators are divided into five groups; each one representing a different set of hydrologic statistics and related influence on the stream ecosystem. Subsets of the 33 total IHA parameters are shown in Table C-3, separated by impact period. The specific ecosystem influences associated with each of the parameter groups are shown in Table C-1 above. (Note that Tetra Tech used the non-parametric analysis option in IHA.)

Table C-3. Pre- and Post-Impact Median Results for Selected IHA Flow Parameters at the LACDPW F-130 Gage (downstream of Tapia Outfall)

Parameter Group	Parameter	Pre-Period	Post-Period	% Change
Magnitude of monthly water conditions	Median flow in April	3.5 cfs	21.5 cfs	505%
	Median flow in Nov.	0.2 cfs	6.7 cfs	3,237%
Magnitude and duration of annual extreme water conditions	Annual minima, 30-day median	< 0.1 cfs	2.4 cfs	2,310%
	Annual maxima, 30-day median	25.3 cfs	129 cfs	410%
	Number of zero-flow days	0.007	0.08	918%
Timing of annual extreme water conditions	Julian date of annual 1-day max.	275	278	1.0%
	Julian date of annual 1-day min.	40.5	40	11%
Frequency and duration of high and low pulses	# of low pulses within each water year (< 0.2 cfs)	4	0	-100%
	# of high pulses within each water year (> 3 cfs)	3.5	3	-14%
Rate and frequency of water condition changes	Rise rate: mean of all positive differences between consecutive daily values	0.25	0.40	62%
	Fall rate: mean of all negative differences between consecutive daily values	-0.40	-0.66	64%

Selected EFC parameters are shown in Table C-4. The table includes a "Significance Count." To calculate this, the software program randomly shuffles all years of input data and recalculates (fictitious) pre- and post-impact medians 1,000 times. The significance count is the fraction of trials for which the deviation values for the medians were greater than for the real case. Thus a low significance count (minimum value is 0) means that the difference between the pre- and post-impact periods is highly significant, and a high significance count (maximum value is 1) means that there is little difference between the pre- and post-impact periods. The significance count can be interpreted similarly to a p-value in parametric statistics. The IHA guide to the interpretation of EFC statistics is shown in Table C-2 above.

Table C-4. Pre- and Post-Impact Median Results for IHA EFC Parameters (LACDPW F-130 Gage)

EFC Parameter	Pre-Impact	Post-Impact	Significance Count
Extreme low peak (cfs)	< 0.1	NA	
Extreme low timing (Jday)	274	NA	
Extreme low freq. (/yr)	4	0	0.07007

EFC Parameter	Pre-Impact	Post-Impact	Significance Count
High flow pulse peak (cfs)	7.25	3.779	0.05506
High flow pulse timing (Jday)	53.5	272.5	0.03904
High flow pulse rise rate	4.175	0.95	0.2032
High flow pulse fall rate	-2.771	-0.6505	0.1972
Small flood peak (cfs)	1180	1697	0.4605
Small flood timing (Jday)	37	46	0.2943
Small flood rise rate	177.1	18.48	0.1862
Small flood fall rate	-16.7	-11.71	0.3333
Large flood peak (cfs)	5370	7360	0.00
Large flood timing (Jday)	62	9	0.00
Large flood rise rate	169.7	86.57	0.5856
Large flood fall rate	-44.62	-8.635	0.1922

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Appendix D. CSCI Analyses

We estimated CSCI scores for each Malibu Creek Watershed site where such estimates were possible. The calculation of the CSCI scores was conducted in collaboration with the CSCI Science Team. As an effort to ensure that this assessment followed the state's current development of biological objectives, the SWRCB and its CSCI Science Team provided invaluable technical support and time to assist USEPA with the calculation of CSCI bioscores. The CSCI Science Team provided the R programs constituting the CSCI scoring tool, guidance for calculating input parameters and creating the necessary input files, and independently calculated a subset of the bioscores along with USEPA. Following the calculation of the bioscores, USEPA consulted with the CSCI Science Team to evaluate the results to ensure appropriate interpretation of the data.

The CSCI score is the average of the O/E and pMMI bioscores. To compute the O/E and pMMI models, independent predictor variables were collected. The methodology is described below, while the results are presented in the TMDL report.

D.1 CSCI Analysis of Benthic Macroinvertebrate Data

Two input files are required for the CSCI bioassessment scoring tool program (Mazor, 2013, personal communication). The first, Stations, contains a matrix of sampling stations and the predictor variables for those stations. The second, Benthics, contains a list of the benthic macroinvertebrate organisms and their abundance in each sample, for each sampling station, along with lifestage and a "Distinct" flag (see below). We estimated CSCI scores for each Malibu Creek watershed site where such estimates were possible.

D.1.1 Predictor Variables

We collected physical habitat predictors needed for the O/E and pMMI models through communication with CDFG and SCCWRP (Personal Communication 2012-2013). The predictors, shown in Table D-1, comprise location, catchment, geology, and climate variables. Not all predictors are used for each score or metric. Table D-1 also indicates which predictors are used in the O/E model and which are used for each of the pMMI metrics.

Table D-1. Model Predictors for Malibu Watershed

Predictor	Variable Name	Predictor Scale	Data Source	Metrics/Scores using predictor								
				O/E	Shannon Diversity Index	% intolerant taxa	Tolerance value	% collector taxa	Shredder taxa	Clinger taxa	Coleoptera taxa	% non-insect taxa
Location												
Latitude (DD)	New_Lat	Site	HtB, LVMWD, MCWMP, SMC, LACFCD, & EPA	X	X	X	X	X	X	X	X	X
Longitude (DD)	New_Long				X	X	X	X	X	X	X	X
Site Elevation (m)	SITE_ELEV	Site	Gesch 2007 and Gesch et al. 2002	X	X	X	X	X	X	X	X	X
Catchment												
Area (km^2)	AREA_SQKM	Catchment	Gesch 2007 and Gesch et al. 2002	X			X	X	X		X	

Predictor	**Variable Name**	**Predictor Scale**	**Data Source**	**Metrics/Scores using predictor**								
				O/E	**Shannon Diversity Index**	**% intolerant taxa**	**Tolerance value**	**% collector taxa**	**Shredder taxa**	**Clinger taxa**	**Coleoptera taxa**	**% non-insect taxa**
Watershed Elevation Range	ELEV_ RANGE	Catchment	Gesch 2007 and Gesch et al. 2002		X		X	X	X	X		
Climate												
Average Annual Maximum Temperature, 2000-2009 (°C × 100)	TEMP_00_ 09	Site	PRISM Climate Group 2013	X	X	X	X	X	X	X	X	X
Average Annual Precipitation, 2000-2009 (mm/yr × 100)	PPT_00_ 09	Site	PRISM Climate Group 2013	X	X	X	X	X	X	X	X	X
Mean of Mean June-Sept 1971-2000 Monthly Precipitation (mm/yr × 100)	SumAveP	Catchment	PRISM Climate Group 2013		X	X	X	X	X	X	X	X
Geology												
Mean Soil Erodibility (K) Factor	KFCT_AVE	Catchment	Olson and Hawkins 2012		X	X	X	X	X		X	
Mean Bulk Density	BDH_AVE	Catchment	Olson and Hawkins 2012		X		X	X	X	X	X	X
Mean Soil Permeability	PRMH_ AVE	Catchment	Olson and Hawkins 2012		X	X	X	X			X	X
Mean Log Geometric Mean Hydraulic Conductivity	LPREM_ mean	Catchment	Olson and Hawkins 2012			X	X		X		X	X
Percent Sedimentary Geology	PCT_ SEDIM	Catchment	Olson and Hawkins 2012		X			X			X	X
Mean Whole Rock Magnesium oxide	MgO_ Mean	Catchment	Olson and Hawkins 2012		X		X	X	X		X	X
Mean Whole Rock Phosphorus	P_MEAN	Catchment	Olson and Hawkins 2012		X		X	X	X		X	X
Mean Whole Rock Calcium oxide	CaO_ Mean	Catchment	Olson and Hawkins 2012		X		X	X	X		X	X
Mean Whole Rock Sulfur	S_Mean	Catchment	Olson and Hawkins 2012		X		X	X	X		X	
Mean Whole Rock Nitrogen	N_MEAN	Catchment	Olson and Hawkins 2012				X	X			X	

We compared predictor values in the statewide reference calibration data set to the range of predictor data observed for sites in the Malibu Creek watershed. USEPA extracted the CSCI R dataframe containing the predictor data for the statewide reference calibration sites. Table D-2 presents the range of predictor variables for these statewide reference calibration sites, a subset of five reference calibration sites that are located within the Monterey/Modelo Formation outside the Malibu Creek watershed, and sites in the Malibu Creek Watershed for which benthic macroinvertebrate data are available. The Malibu sites all fall within a small area, so the range of predictors among samples of latitude, longitude, and average annual temperature is small, while greater variability is present in the other predictors (Table D-2). This comparison also shows that the Malibu Creek sites generally fall within the range of the statewide reference calibration site predictor values. Site MC1 lies at a slightly lower elevation than the lowest reference calibration site (6.85 m vs 7.15 m), and four sites have greater average mean soil erodibility factors (KFCT_AVE; LACFCD1: 0.332, CC3, SC14, and SC22: 0.335) than the maximum average KFCT value for reference sites (0.307). The pMMI model uses this predictor variable, while the O/E model does not.

Table D-2. Comparison of Predictor Values for Malibu Creek Watershed to Statewide Reference Calibration Site Data

Predictor	**Variable**	**California Statewide Reference Calibration Sites (Mazor, 2013, personal communication)**				**Malibu Creek Sites**	
		473 Sites		**5 Sites in the Monterey/ Modelo Formation**		**57 Sites with Benthic Macroinvertebrate Data**	
		Minimum	**Maximum**	**Minimum**	**Maximum**	**Minimum**	**Maximum**
Location							
Latitude (DD)	New_Lat	32.69398597	41.9159344	34.350789	34.43276	34.033386	34.195076
Longitude (DD)	New_Long	-124.1120887	-116.4509978	-118.900982	-118.579687	-118.931754	-118.64756
Site Elevation (m)	SITE_ELEV	7.15	3,130	196	505	**6.85**	399
Catchment							
Area (km^2)	AREA_ SQKM	0.79	2,029	9.83	19.96	1.41	282.88
Watershed Elevation Range	ELEV_ RANGE	164	3,244	633	1,180	329	934
Climate							
Average Annual Maximum Temperature, 2000-2009 (°C × 100)	TEMP_00_09	644	2,910	2,420	2,482	2,223	2,588
Average Annual Precipitation, 2000-2009 (mm/yr × 100)	PPT_00_09	13,146	210,743	44,011	52,926	36,464	57,303

Predictor	**Variable**	**California Statewide Reference Calibration Sites (Mazor, 2013, personal communication)**				**Malibu Creek Sites**	
		473 Sites		**5 Sites in the Monterey/ Modelo Formation**		**57 Sites with Benthic Macroinvertebrate Data**	
		Minimum	**Maximum**	**Minimum**	**Maximum**	**Minimum**	**Maximum**
June-Sept 1971-2000 Mean Monthly Precipitation (mm/yr × 100)	SumAve_P	284	7,314	319	552	318	381
Geology							
Mean Soil Erodibility (K) Factor	KFCT_AVE	0.094	0.307	0.218	0.307	0.185	**0.335**
Mean Bulk Density	BDH_AVE	0.985	1.698	1.563	1.577	1.503	1.581
Mean Soil Permeability	PRMH_ AVE	0.759	19.469	2.193	5.000	1.249	5.195
Mean Log Geometric Mean Hydraulic Conductivity	LPREM_ mean	-3.419	2.053	-0.799	-0.766	-0.794	0.706
Percent Sedimentary Geology	PCT_ SEDIM	0	100	100	100	16	100
Mean Whole Rock Magnesium oxide	MgO_Mean	0.929	34.425	2.850	6.281	3.100	6.556
Mean Whole Rock Phosphorus	P_MEAN	0.0122	0.674	0.111	0.130	0.112	0.251
Mean Whole Rock Calcium oxide	CaO_Mean	1.069	22.242	5.300	17.546	6.132	17.782
Mean Whole Rock Sulfur	S_Mean	0.0162	1.383	0.366	1.276	0.0186	1.255
Mean Whole Rock Nitrogen	N_MEAN	0.00013	0.682	0.0547	0.0607	0.0199	0.423

Note: Bold values for Malibu Creek sites fall outside of the range exhibited by reference sites.

These predictor variables were extracted using GIS for all sites within the Malibu Creek Watershed for which we had invertebrate samples, using the methods described below.

D.1.1.1 Latitude and Longitude (New_Lat, New_Long)

We received site data from the following organizations:

- Heal the Bay
- Las Virgenes Municipal Water District
- Malibu Creek Water Monitoring Program
- Stormwater Monitoring Coalition
- Los Angeles County Flood Control District
- U.S. Environmental Protection Agency

Each organization provided either geographic coordinates or a GIS point feature class (shapefile) containing the site locations. No adjustments were made to any provided data, except where necessary to convert the datum from NAD27 to NAD83, the current standard.

D.1.1.2 Catchment Digitization and Area (AREA_SQKM)

After mapping the sites using the latitude and longitude data provided by the organizations that sampled each site, we digitized each site's catchment using the National Elevation Dataset (Gersch 2007; Gersch et al. 2002) as the base layer. The digitized catchments were then reviewed against the California Department of Fish and Game transparent topographic base map (http://maps.dfg.ca.gov/ArcGIS/services) for accuracy before collecting additional predictor variables. Inaccuracies were corrected using the topographic base map as a guide. Catchments were also reviewed to ensure that catchment edges abutted exactly, without leaving overlapped segments or gaps between catchment edges. Catchment areas were calculated in square meters using ESRI's Calculate Areas tool, and converted to square kilometers.

D.1.1.3 Elevation data (SITE_ELEV, ELEV_RANGE)

We obtained a Digital Elevation Model (DEM) for California having a 30-m cell size from the National Elevation Dataset (Gersch 2007; Gersch et al. 2002). The DEM was clipped to the extent of the study area prior to extracting data, in order to reduce calculation time. The elevation at the site was determined using ESRI's Extract Values to Points tool, which extracts the cell values of the raster at the point, and adds that value as an attribute of the output point feature class.

To determine the maximum elevation in the catchment, we used ESRI's Zonal Statistics as Table tool. This tool summarizes the values of a raster within the zones of another dataset, in this case, within each of the catchments drained by the sites of interest in the study area. The elevation range of the catchment was defined as the maximum elevation in the catchment minus the elevation at the site.

D.1.1.4 Climatic data (TEMP_00_09, PPT_00_09, SumAve_P)

To determine the climatic data at each site, we obtained climatic data from the PRISM Climate Group (2013). We specifically obtained Annual Maximum Temperature and Precipitation raster data for the years 2000 – 2009, inclusive. After projecting the raster files to match the catchment projections, we used ESRI's Weighted Sum tool to calculate averages. Each year was assigned a weight of 0.1, for a final arithmetic average for each raster cell. We next clipped the rasters to the extent of the study area to reduce calculation time, and used Extract Values to Points to obtain the Average Annual Maximum Temperature and the Average Annual Precipitation at each site of interest.

To determine the average summer precipitation in each catchment, we obtained raster data from the PRISM Climate Group (2013), with data representing the mean June to September monthly precipitation for the 30-year period between 1971 and 2000. We determined the average of the raster cell values in each catchment using Zonal Statistics as Table.

D.1.1.5 Geologic data (KFCT_AVE, BDH_AVE, PRMH_AVE, LPREM_mean, PCT_SEDIM, CaO_Mean, MgO_mean, N_MEAN, P_MEAN, S_Mean)

All geologic data were obtained as raster data or polygon shapefiles from Olson and Hawkins (2012).

We obtained raster data for mean soil erodibility [K] factor, mean bulk density, mean soil permeability, mean log geometric mean hydraulic conductivity, and mean whole rock sulfur content. After ensuring that the raster data were projected identically to the catchments, we identified catchment averages using ESRI’s Zonal Statistics as Table tool.

We obtained polygon shapefiles containing data for percent sedimentary geology, mean whole rock calcium oxide, magnesium oxide, nitrogen, and phosphorus. Using ESRI’s Intersect tool, we first intersected the polygons of the base file with the digitized catchments and next determined the areas of the intersected polygons using Calculate Areas. We then calculated an area-weighted average for each of the predictors required.

D.1.1.6 Quality Control for Predictor Variables

To ensure that the methods we used for estimating predictor variables agreed with the design methods, we compared the predictor variables we identified for a set of 15 of 55 sites (27 percent) to those identified by the CSCI tool development team for the same sites. This step was necessary due to the lack of published methods at the time we performed the analysis. If we had generated erroneous predictor variables, site bioscores generated by the scoring tool would be invalid. Good agreement was observed between the independently-generated predictor variables. Of the 16 variables, 9 had no sites with a relative percent difference of greater than 10% (Table D-3). Of the remaining 7 variables, 6 had one site exhibiting a relative percent difference of greater than 10% (site elevation [SITE_ELEV], catchment area [AREA_SQKM], elevation range [ELEV_RANGE], percent sedimentary geology [PCT_SEDIM], catchment mean whole rock sulfur [S_MEAN], and catchment mean whole rock nitrogen [N_Mean]). One variable had 2 sites with a relative percent difference of greater than 10% (average annual precipitation [PPT_00_09]). One site (404S05992) differed by greater than 10% for three predictors. This site, located in Medea Creek, only has benthic macroinvertebrate data for 2009 and therefore contributes little to the overall analysis of the watershed.

Table D-3. Relative Percent Difference between Independently-Generated Predictor Variables for a 15-Site Subset of Sites in the Malibu Creek Watershed for Quality Control

Predictor	**Station ID**														
	404S02920	**404S03048**	**404S05992**	**404S06456**	**404S08040**	**404S08616**	**404S11406**	**404S16516**	**404S17266**	**404S17664**	**404S22464**	**SMC01172**	**SMC01384**	**SMC01550**	**SMC01640**
Location															
SITE_ELEV	1%	1%	0%	0%	0%	0%	**16%**	0%	1%	1%	1%	8%	4%	2%	6%
Catchment															
AREA_SQKM	4%	1%	**21%**	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%
ELEV_RANGE	1%	1%	1%	0%	3%	2%	2%	1%	0%	1%	0%	**10%**	2%	0%	3%
Climate															
TEMP_00_09	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Predictor	Station ID														
	404S02920	404S03048	404S05992	404S06456	404S08040	404S08616	404S11406	404S16516	404S17266	404S17664	404S22464	SMC01172	SMC01384	SMC01550	SMC01640
PPT_00_09	0%	0%	0%	0%	0%	4%	0%	0%	4%	3%	0%	4%	**13%**	**18%**	3%
SumAve_P	1%	0%	0%	0%	0%	1%	1%	0%	1%	0%	1%	1%	1%	3%	0%
Geology															
KFCT_AVE	3%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%
BDH_AVE	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PRMH_AVE	1%	1%	5%	0%	0%	0%	1%	1%	1%	1%	1%	0%	1%	2%	2%
LPREM_mean	0%	0%	-1%	-1%	-1%	-4%	-1%	-1%	0%	0%	0%	0%	-1%	0%	0%
PCT_SEDIM	2%	2%	**17%**	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%	0%	0%
MgO_Mean	3%	3%	2%	3%	1%	2%	0%	2%	2%	3%	2%	5%	0%	2%	3%
P_MEAN	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CaO_Mean	2%	1%	0%	6%	2%	1%	2%	1%	2%	1%	2%	4%	1%	1%	0%
S_MEAN	0%	0%	0%	6%	4%	1%	1%	0%	1%	0%	0%	**12%**	2%	1%	1%
N_Mean	0%	0%	**18%**	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

D.1.2 Applicability of the CSCI to Malibu Creek Watershed

USEPA considered the applicability of the CSCI scoring tool to Malibu Creek Watershed. For example, the models must be able to accurately predict the expected taxonomic composition and metrics for sites that may be affected by unique geology, like that of the Monterey/Modelo Formation. Table 8-12 of the TMDL report (similar to Table D-2 above) compares the predictor values for five reference calibration sites located in the Monterey Formation north of Malibu Creek Watershed with the predictor variables for sites located in the Malibu Creek Watershed's Monterey/Modelo Formation. The five reference calibration sites lie approximately 12 to 17 miles to the north, but exhibit similar geologic predictors to those in the Malibu Creek Watershed.

When comparing the reference calibration sites in Monterey/Modelo Formation with Malibu Creek Watershed sites in Monterey/Modelo Formation, we noted that the maximum observed pMMI, O/E, and CSCI scores are similar, which suggest that high-quality sites in the Monterey/Modelo Formation in the Malibu Creek Watershed are scored accurately with the CSCI scoring tool. In a few cases, the geology predictors vary somewhat between the Monterey/Modelo reference calibration sites and the Malibu Creek sites. In particular, the maximum observed whole rock mean nitrogen and phosphorus are somewhat higher for Malibu Creek Watershed sites than for these reference calibration sites.

USEPA also noted that the California O/E model does not utilize geology predictors. The predictors used by the O/E model include latitude, elevation, catchment area, average annual maximum temperature and average annual precipitation. Temperature and precipitation are comparable between the reference calibration sites and those in the Malibu Creek Watershed sites. Latitude, catchment size, and elevation differ slightly.

Finally, some concern about the limited number of low gradient coastal sites included in the development of the SC-IBI raised questions about the applicability of bioassessment scoring tools in Malibu Creek Watershed. The CSCI Science Team determined that the models showed a lack of bias to stream gradient

(R. Mazor, 2013, personal communication), and therefore should not be a limiting factor when applying the CSCI bioassessment scoring methods.

D.1.3 Benthic Macroinvertebrate Data

We took existing benthic macroinvertebrate data collected by Heal the Bay (HtB), Las Virgenes Municipal Water District (LVMWD), Malibu Creek Watershed Monitoring Program (MCMWP), Santa Monica County (SMC), Los Angeles County Flood Control District (LACFCD) and from USEPA (Table D-4 and Figure D-1) and condensed them into a list of benthic macroinvertebrate observations for each sample and sampling station. Each observation included taxonomic identification and abundance. In addition, lifestage, and a distinct flag indicating whether or not the specimen was sufficiently distinct for a certain taxonomic identification were maintained for each observation (if lifestage or the distinct flag were provided with the raw taxonomic data). Samples were assigned unique site-date identifiers.

Table D-4. Benthic Macroinvertebrate Sampling Data Available by Organization and Year

Organization	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
HtB Stream Team	X	X	X	X		X	X		X	X	X	X
LVMWD							X	X	X	X	X	X
MCMWP						X						
SMC										X		
LACFCD				X	X	X	X	X	X	X	X	X
EPA												X

Figure D-1. Sites with benthic macroinvertebrate data used in CSCI analysis

We resolved taxonomic nomenclature (e.g., corrected misspellings) using the California Surface Water Ambient Monitoring Program's taxonomic lookup file list (California State Water Resources Control Board, OrganismLookUp - SAFIT Benthic Macroinvertebrate (BMI) list, available at http://ftp.mpsl.mlml.calstate.edu/LookUpLists.php). Sixteen (16) individual taxa or unresolved species pairs were not listed in SWAMP's lookup file. These taxa were resolved in coordination with SCCWRP biologists (Mazor, 2013, personal communication). These taxa, along with the agreed-upon resolution, appear in Table D-5.

Table D-5. Taxa Not Found in the SWAMP Organism Lookup Table

Taxa not matched to SWAMP Table	Resolution Recommended by SCCWRP
Acarina	*Acari*
Archanara	*Lepidoptera*; terrestrial, exclude from input file
Archips	*Lepidoptera*; terrestrial, exclude from input file
Ascidae	*Acari*; terrestrial, exclude from input file
Canonidae	*Ostracoda*
Centroptilum/ Procleon	*Centroptilum*

Taxa not matched to SWAMP Table	Resolution Recommended by SCCWRP
Coenagrion/ Enallagma	*Enallagma*
Discocerina	*Ephydridae*; terrestrial, exclude from input file
Enallagma/ Ischnura	*Coenagrionidae*
Erythemis collocate	*Erythemis collacata*
Estigmene	*Lepidoptera*; terrestrial, exclude from input file
Neotyrrellia/ Tyrrellia	*Neotyrrellia*
Oribatida	*Oribatei*
Pacifasticus lenisculus	*Pacifastacus leniusculus*
Planorbella	*Helisoma*
Radix auricularia	*Lymnaea*

In two cases, resolving these taxa according to the rules provided by SCCWRP resulted in creating duplicate rows, where duplications were identified as those rows having the same station code, sample ID, taxonomic ID, life stage code, and distinct flag. In the case of these duplicates, the rows were compressed to one row, with the final abundance equal to the sum of the abundances in the original rows.

Although most benthic macroinvertebrates collected as part of a benthic sample are larval insects, some are pupae or adults. Non-insect taxa of indeterminate or adult life stage also may occur. California provides a standardized lookup table for accepted life stage codes online (California State Water Resources Control Board, LifeStageLookUp, available at http://ftp.mpsl.mlml.calstate.edu/LookUpLists.php). Valid life stage values for the Benthics input file included larva (L), pupa (P), adult (A), and undefined (X) (Table D-6). Eleven (11) taxonomic observations were identified in the original data as nymphs. These life stage observations were adjusted to larva, since nymph was not an allowed value. Where life stage was not recorded with the raw data, we assigned “larva” to insect taxa, except members of the families Hydrophilidae and Hydraenidae, to which we assigned “adult.” “Undefined” was assigned to non-insect taxa.

Table D-6. Allowed Life Stage Values Relevant to BMI Taxa in the Malibu Creek Watershed

Life Stage Name	Life Stage Description	Life Stage Code
Adult	Life stage is an adult; wide use	A
Larva	Life stage is a larva; primarily used for freshwater benthic macroinvertebrates (BMI)	L
Pupa	Life stage is a pupa; primarily used for freshwater benthic macroinvertebrates (BMI)	P
Undefined	Used when life stage is not defined (e.g., most non-insect taxa for bioassessments); primarily used for freshwater benthic macroinvertebrates (BMI)	X

The distinct flag indicates whether an organism was clearly identifiable (distinct) or if it was immature, damaged, or otherwise indistinct. Identifying indistinct organisms can be difficult, even for very experienced taxonomists, and these identifications are marked to indicate the greater uncertainty inherent in them. Distinct (D) flags were converted to the numeral 1 for the CSCI calculations, and indistinct (N/D) flags were converted to zeros. Observations for which the distinct flag was not available remained blank. Blank values are treated as distinct by the CSCI tool.

D.1.4 Running the CSCI Code

We installed California's CSCI libraries and code by sourcing https://raw.github.com/mengeln/CSCI_bin/master/installCSCI.r using R Statistical Software version 2.15.2. Running this script installs the lookup files necessary for standardizing the benthic macroinvertebrate taxonomic data, running the random forest model for determining each site's probability of belonging to a specific site group, and calculating the probability of capture data for benthic macroinvertebrates in each site group.

Two input files are required, as described above (Section D.1.1 and D.1.2). Six output files are generated, the core output and five supplemental files:

- Core – summarizes the total number of benthic macroinvertebrate individuals (count) in each sample, the number of iterations for each model (O/E and pMMI), the percent of ambiguous individuals and percent of ambiguous taxa, flags for low abundance (insufficient count) and high ambiguity (percent ambiguous individuals), the predicted "E" value (predicted count of taxa), the mean "O" value, O/E, pMMI score, and CSCI score.
- Suppl1_grps – tabulates the probability of group membership for each site in each of the 11 reference site groups, where the sum of probabilities across all 11 groups equals 1.
- Suppl1_mmi – presents the pMMI score and each metric's mean value over all iterations, prediction, and score for each sample.
- Suppl1_oe – displays the Operational Taxonomic Unit (OTU), capture probability, and mean observed number of individuals over all iterations for each possible OTU (including OTUs not observed) in each sample.
- Suppl2_mmi – shows the observed and predicted metric values and the metric score for each iteration and sample.
- Suppl2_oe – presents the observed number of individuals for each observed OTU and each iteration for each sample, and the capture probability for that OTU in that sample.

D.1.5 Warning Flags

Warning flags are provided for two conditions: inadequate organisms in the sample (mmi_count_flag) and inadequate unambiguously identified organisms (ambig_count_flag). Final O/E, pMMI, and CSCI scores are calculated regardless of the presence of warning flags, but results should be interpreted with caution for flagged samples.

pMMI Flags. The target organism count for the pMMI model is 500 individuals; samples with fewer than 450 individuals are given warning flags. A total of seven samples were flagged for inadequate total number of organisms. These samples contained between 51 and 404 organisms. Five of the seven samples contained fewer than 360 organisms. The pMMI metrics, especially those reliant upon number of taxa, are sensitive to sample size. Large variations in sample size affect the ability to compare results, and small sample sizes can result in misclassification. Additionally, while small sample sizes frequently indicate stressed conditions, interpreting metric and final score results from small samples is not straightforward. Ambiguous organisms do not affect the pMMI model, because metrics typically can be determined based on higher taxonomic levels to which the organism belongs.

O/E Flags. The target organism count for the O/E model is 400 organisms, but no separate flag appears for samples having fewer than 360 (10% of target). Instead, warning flags for the number of ambiguous taxonomic identifications (based on individuals) appears; samples with more than 20% ambiguous organisms are flagged as inadequate. This corresponds to an effective sample size of 320 or less. Ambiguous organisms impact the O/E model, which specifically compares samples of observed benthic macroinvertebrate taxa to those that are expected to occur at a site based on independent predictor variables. O/E models are constructed based on operational taxonomic units that are a mix of taxonomic resolutions based on the balance of taxonomic resolution available in the dataset (usually genus and species). Once the operational units are fixed, a capture probability cannot be made for an ambiguous observation (individual of coarser taxonomy than the target unit) because one does not know reliably to which finer taxonomic unit the individual belongs. Estimating a capture probability for such taxa or incorporating their presence into the observed richness would, therefore, skew the prediction.

Many more samples were flagged for having taxonomically ambiguous individuals than for inadequate organism count. Fully 72 samples were flagged for ambiguous organisms. The percentage of ambiguous individuals ranged from 20% to 85%. All but one of the samples flagged for ambiguous organisms was obtained in 2005 or later. According to SCCWRP (R. Mazor, personal communication), the rules for taxonomic resolution changed in 2005 to coarser levels, reflecting the needs of the then newly-published SC-IBI. Thirty-eight ambiguous taxa (with varying numbers of individuals in each sample) appeared in the Malibu benthic macroinvertebrate data set. Table D-7 presents the list of ambiguous taxa and the number of samples in which they appeared.

Table D-7. Ambiguous Taxa and the Number of Samples Containing Each

Taxonomic Identification	Number of Samples	% of all Samples
Aeshnidae	2	0.72
Amphipoda	2	0.72
Baetidae	3	1.09
Belostomatidae	14	5.07
Bivalvia	1	0.36
Brachycera	4	1.45
Ceratopogonidae	60	21.74
Chironomidae	154	55.8
Chloroperlidae	4	1.45
Coenagrionidae	33	11.96
Coleoptera	2	0.72
Corixidae	18	6.52
Corydalidae	2	0.72
Decapoda	5	1.81
Dixidae	7	2.54
Dytiscidae	12	4.35
Elmidae	10	3.62

Taxonomic Identification	Number of Samples	% of all Samples
Empididae	7	2.54
Gomphidae	1	0.36
Hydrophilidae	2	0.72
Hydropsychidae	30	10.87
Hydroptilidae	22	7.97
Lepidoptera	9	3.26
Leptoceridae	1	0.36
Libellulidae	12	4.35
Limnephilidae	1	0.36
Lymnaeidae	3	1.09
Nemouridae	3	1.09
Odonata	1	0.36
Perlodidae	2	0.72
Plecoptera	1	0.36
Polycentropodidae	1	0.36
Psychodidae	3	1.09
Psychomyiidae	1	0.36
Simuliidae	1	0.36
Stratiomyidae	1	0.36
Tabanidae	12	4.35
Tipulidae	18	6.52

Appendix E. Relevant Studies

E.1 Inventory

A number of previous analyses have evaluated water quality stressors and impacts in Malibu Creek and Lagoon. An inventory of identified reports is provided in Table E-1 followed by summaries of a selected subset of key reports.

Table E-1. Previous Analyses of Water Quality and Use Support in Malibu Creek and Lagoon

Author, Date	Report Title	Report Description
Abramson and Grimmer (Heal the Bay), 2005	Fish Migration Barrier Severity and Steelhead Habitat Quality in the Malibu Creek Watershed	Report in which the severity of steelhead trout migration barriers in the Malibu Creek watershed were ranked. Study also rated pool habitat quality to be gained by the removal of each barrier and mapped a total of 201 potential barriers. Report concluded with a list of specific recommendations for removing barriers in the Malibu Creek watershed.
Ackerman et al., 2005	Evaluating HSPF in an arid, urbanized watershed	Paper presenting the findings of a study in which the predictive ability of Hydrologic Simulation Program-FORTRAN (HSPF) on hourly, daily, and annual time scales. Two arid southern California watersheds were selected for the study, one of which was the Malibu Creek watershed. The HSPF model was found to perform well for predicting flow on monthly or annual time scales and on daily time scales during wet weather conditions.
Ambrose and Orme, 2000	Lower Malibu Creek and Lagoon Resource Enhancement and Management	Summary of report is provided in text below.
Ambrose et al., 1995	Enhanced Environmental Monitoring Program at Malibu Lagoon and Malibu Creek	Report summarizing a study performed by UCLA from July 1993 through April 1994. The goal of the study was to assess the effects of anthropogenic inputs into Malibu Creek and Lagoon on the physical, chemical and biological processes in the Creek and Lagoon.
Ambrose et al., 2003	Environmental Monitoring and Bioassessment of Coastal Watersheds in Ventura and Los Angeles Counties	Report detailing a study performed in 2001 to help identify land use factors influencing the abundance of macroalgae and benthic macroinvertebrates within three southern California coastal watersheds. Malibu Creek watershed was one of three watersheds selected for the study. Report presents methods, results, and a discussion of conclusions from the study.
Aquatic Bioassay, 2005	Malibu Creek Watershed Monitoring Program, Bioassessment Monitoring, Spring/Fall 2005	Summary of report is provided in text below.
Badgley et al., 2011	Quantifying environmental reservoir of fecal indicator bacteria associate with sediment and submerged aquatic vegetation	Presence of fecal indicator bacteria (FIB) is used to monitor fecal contamination. Many have also determined that FIB can persist in soils and sediments and is a major concern. Dominant concentrations of enterococci in the system were found in water or sediment (not submerged aquatic vegetation), pending site characteristics and water depth. Concentrations of contaminant vary as a function of depth, but at estuarine sites sediment contained the largest concentrations (rather than water or SAV). Authors suggest additional sampling (especially for TMDLs) to normalize matrix to surface area.

Author, Date	Report Title	Report Description
Bay et al., 1996.	Toxicity of Stormwater from Ballona and Malibu Creeks	Paper detailing a study performed to determine the magnitude and characteristics of toxicity in stormwater samples collected during storms in 1996 from Ballona and Malibu creeks. The magnitude of toxicity found in samples collected in Malibu Creek was usually lower than comparable samples from Ballona Creek. The study concluded that the relative toxicities observed for each creek were consistent with differences in land use between the two watersheds as the Malibu Creek watershed has a lower degree of development than the Ballona Creek watershed.
Bay et al., 2003	Temporal and spatial distributions of contaminants in sediments of Santa Monica Bay, California	Paper detailing a study in which sediment strata dated from 1890 to 1997 were sampled at 25 locations within the Santa Monica Bay. Samples were analyzed to examine the temporal and spatial patterns of sediments contaminated with metals, DDTs, PCBs, TOC, PAHs, and LABs. One sampling location was selected to target influence of stormwater runoff from Malibu Creek. Sediments sampled near Malibu Creek were found to contain low concentrations of both DDTs and PCBs.
Biggs and Price, 1987	A survey of filamentous algal proliferations in New Zealand rivers	In the first paper, in the series of algal proliferation studies, the authors describe the behavior of filamentous algae. Filamentous algae affect water quality, clogging, and aesthetic integrity, especially after long periods of low flow.
Biggs, 1990	Periphyton communities and their environments in New Zealand Rivers	Periphyton are most responsive to changes in habitat and are thus excellent indicators of water quality and invertebrate and aesthetic degradation. This paper illustrates how water conductivity, watershed variables, and temperate contribute to the behavior of periphyton communities.
Biggs, 2000	Eutrophication of streams and rivers: dissolved nutrient-chlorophyll relationships for benthic algae	Paper describing models to predict effects of changes in nutrients on benthic algal biomass in different temperature streams and rivers. Biggs suggests that managing nutrient supply would decrease biomass accrual and reduce benthic algal growth in streams by both frequency and duration. Also indicates a relationship between algal dominance and increasing conductivity.
Brown and Bay, 2005	Organophosphorus pesticides in the Malibu Creek Watershed	Paper presenting a study performed to assess the persistence and magnitude of pesticides in three streams of the Malibu Creek watershed. Water column samples were collected from June 2002 to March 2003 to analyze organophosphorus pesticide contamination and toxicity to *Ceriodaphnia dubia*. Study concluded that the California Department of Fish and Game's acute criterion for organophosphorus pesticides was protective of *C. dubia* survival.
Busse et al., 2003	A Survey of Algae and Nutrients in the Malibu Creek Watershed	Report presents findings from surveys of algal biomass, cover, and composition conducted in streams within the Malibu Creek watershed in 2001 and 2002. Analyses were also performed to identify principal factors promoting excessive algal growth. Both algal biomass and nutrient concentrations were found to be much lower at undisturbed and rural sites compared to findings at developed sites; therefore, it was concluded that human development affects stream algal communities in the Malibu Creek basin.

Author, Date	Report Title	Report Description
Busse et al., 2006	Relationships among nutrients, algae, and land use in urbanized southern California streams	Paper presenting the findings of a study in which algal cover, algal biomass, and physical and chemical factors were surveyed in the Malibu Creek watershed. Nutrient diffuser substrate experiments were also conducted to determine which nutrient was limiting algal growth. Algal biomass was found to increase with urbanization as well as total nitrogen, total phosphorus, and benthic and total chlorophyll concentrations.
Callaway et al., 2009	Technical Memorandum #4, Nitrogen Loads from Wastewater Flowing to Malibu Lagoon are a Significant Source of Impairment to Aquatic Life	Report presents findings from a study performed to quantify cumulative nitrogen loads from onsite wastewater disposal systems in the Malibu Civic Center area to Malibu Lagoon. Results indicated wastewaters transported 30 to 35 lbs/day of total nitrogen to the lagoon. All estimates were above TMDL targets established for restoration of the lagoon.
Greenstein et al., 2003	Toxicity assessment of sediment cores from Santa Monica Bay	Paper presenting a study in which sediment cores were sampled at 25 locations within the Santa Monica Bay in 1997 to assess levels of toxicity. Two sample locations were selected near the discharge of Malibu Creek to the bay. Report concluded that toxicity in sediments sampled at these locations was caused by something other than influence from Malibu Creek.
Hibbs and Ellis, 2009	Geologic and Anthropogenic Controls on Selenium and Nitrate Loading to Southern California Streams	Paper presents findings from a study in which selenium concentrations were measured in three watersheds in the Los Angeles Basin. Malibu Creek was found to have elevated selenium concentrations in dry weather surface flows as well as in shallow groundwater. Study also determined the relationship between measured nitrate and selenium concentrations.
Hibbs et al., 2012	Origin of stream flows at the Wildlands Urban Interface, Santa Monica Mountains, CA, U.S.A	Paper studies the transition from intermittent to perennial streams as a response to urbanization in the Santa Monica Mountains. Impairments derive from flow through the City of Calabasas (Nitrates, Selenium, and Organics). Saline signature of groundwater was found to be more responsible for surface water composition than urban runoff (specifically during dry weather conditions). Source flows and nutrient loading are a function of groundwater composition more than urbanization. Removal of riparian vegetation and deepening of channel may contribute more to the shift from intermittent to perennial flows, than specific change of environment.
Lai, C.P. 2009	Nitrogen mass loading for Malibu Lagoon and review summary of previous studies on mass loadings from OWDS to the Lagoon	A memorandum summarizing previous studies on impact of Nitrogen to Malibu Lagoon. The Stone Report used a groundwater flow model MODFLOW for solute transport analysis along Malibu Creek near Malibu Civic center. The report was then refined to model combination flows, resulting in slightly higher Nitrogen mass loads. Tetra Tech's TMDL modeling report results were also evaluated. From the 3 reports, Lai et al., conclude that the second model is best to determine Nitrogen mass loading to the Lagoon.
Las Virgenes Municipal Water District Tapia Water Reclamation Facility (LVMWD), 2006-2010	Bioassessment monitoring report for the Tapia Water Reclamation Facility	The report details the benthic macroinvertebrate community and metrics for the LVMWD at 8 sampling locations. It also the physical/habitat health and water chemistry of affected systems. Specific details are provided below.

Author, Date	Report Title	Report Description
Lim et al., 2006	Concentration, size distribution, and dry deposition rate of particle-associated metals in the Los Angeles region	Paper presenting the findings of a study in which daily average atmospheric concentrations and dry deposition fluxes of particulate metals were measured at 6 urban sites and 1 non-urban site in the Los Angeles region. Malibu Lagoon was identified as the non-urban site.
Los Angeles County Department of Public Works, 2006-2010	Bioassessment monitoring program in Los Angeles County	The report details the program which serves to assess biological integrity and to detect biological trends and responses to pollution in receiving waters throughout the County. To achieve these goals, the program focuses on the sampling and analysis of freshwater stream benthic macroinvertebrates (BMI). More detail of the report is provided in the section below.
Los Angeles County Sanitation District, 1996	Mineral leaching study Calabasas landfill	This study analyzes background water quality of groundwater from monitoring wells in landfills at the Calabasas landfill in upper Malibu Creek watershed. Rock and soil samples were analyzed for metal, chemical, TOC, pH and other results are presented in the results.
Luce and Abramson, 2005	Periphyton and Nutrients in Malibu Creek	Report summarizing a study performed to compare periphyton cover, nutrient concentrations, and canopy cover between nutrient-enriched and unenriched stream segments. Sites within Malibu Creek and adjacent coastal watersheds were selected and monitored from 1998 to 2002. Report proposed nutrient thresholds that may be useful for managing excess algal growth in Malibu Creek.
Manion, 1993	The Tidewater Goby - Reintroduction of a geographically isolated fish species into Malibu Lagoon: A watershed perspective	Report presenting the findings of a study performed to assess the success of reintroducing the tidewater goby (*Eucyclogobius newberryi*) to the Malibu Lagoon. An additional goal of the study was to describe the human-induced threats to biological diversity within the lagoon's watershed. Results demonstrated successful reintroduction of the tidewater goby and discussed recommendations to alleviate human-induced stressors to the lagoon.
Meyer et al., 1985	Chemistry and aquatic toxicity of raw oil shale cheachates from Piceance Basin, Colorado	Leachates were collected to analyze the composition from several depths in two surfaces, from raw oil shale. They found that alternate shale compositions produce variable leachate ionic concentrations. They also found that toxic mechanisms cannot always be prescribed to single toxicity values, since often the chemical mixture incorporates a variety of constituents.
Moeller et al., 2003	Elements in fish of Malibu Creek and Malibu Lagoon near Los Angeles, California	Paper presenting findings from a study performed to determine if past wastewater discharges increased metal pollutant loads in fish of Malibu Creek and Malibu Lagoon. In addition to the identification of wetland biota, the study included analyses of organic and inorganic chemicals and viruses. The study concluded that further sampling was necessary to prove effluent pollution.
Moffatt & Nichol, 2005	Malibu Lagoon Restoration Feasibility Study, Final Alternatives Analysis	Summary of report is provided in text below.

Author, Date	**Report Title**	**Report Description**
Mount et al., 1997	Statistical models to predict the toxicity of major ions to *ceriodaphnia dubia (C. dubia), daphnia magna (D. magna)* and *pimephales promelas* (fathead minnows)	Fresh water toxicity containing high total dissolved solids (TDS) can be dependent on the water's ionic composition. The authors aimed to provide a predictive tool which would attribute specific toxicity to particular ionic solutions using 3 test species. Initial application illustrates significant accuracy for the C.dubia, but overpredicted D.magna and fathead minnow toxicity.
Nezlin et al., 2005	Stormwater runoff plumes observed by SeaWiFS radiometer in the Southern California Bight	Paper detailing a study in which freshwater plumes found in the near-shore zone of the Southern California Bight were analyzed using reflectance data acquired from 1997 - 2003. Study determined the relationship between plume size and freshwater discharge. The Malibu Creek watershed was associated with one of the regions included in the study and findings indicated that watershed land-use, size, and elevation were influential factors regulating the relationship between rainstorms and plumes.
Pond et al., 2008	Downstream effects of mountaintop coal mining: comparing biological conditions using family- and genus-level macroinvertebrate bioassessment tools	The paper details impacts of surface coal mining in the Central Appalachian region and its influence on aquatic life. From the study, evidence illustrates that mining causes a shift in environmental conditions where it exists. The biological stream conditions are significantly altered due to mining activities. The benthic macroinvertebrate communities showed pronounced negative changes in richness, composition, tolerance, and diversity, under mining activities.
Randal Orton, 2012	Diatom as water quality indicators in Malibu Creek, presentation	Orton found that the diatom community is related to the water's high electrical conductance and sulfate concentration. Diatoms are particularly sensitive to the quantity and type of ions in water, which are particularly raised in Malibu Creek for SO4, Mg, PO4, and HCO3. They determined a new species named "fallacia" as potentially endemic to Malibu Cree. Presence of bicarbonate prevents the waters from being acidic, despite their composition.
Riley et al., 2005	Effects of Urbanization on the Distribution and Abundance of Amphibians and Invasive Species in Southern California Streams	Paper presenting the findings of a study conducted from 2000 to 2002 in which the distribution and abundance of native amphibians and exotic predators was determined. Stream habitat and invertebrate communities were also characterized. Study included 35 streams north of Los Angeles - Lower Malibu Creek served as one of these streams.
Schiff and Bay, 2003	Impacts of stormwater discharges on the nearshore benthic environment of Santa Monica Bay	Paper presenting the findings of a study in which sediment samples collected offshore of Ballona and Malibu creeks were analyzed to examine the effects of stormwater discharges on the benthic marine environment of Santa Monica Bay. Report indicated that changes in sediment texture, organic content, and contamination were observed throughout a gradient of stormwater impact, but no alteration was observed in benthic communities.
Sikich et al., 2012	State of the Malibu Creek Watershed report: Trends in watershed health	An in depth report on the Malibu Creek watershed, including a complete bioassessment and monitoring, performed annually. A detailed summary is provided below.

Author, Date	Report Title	Report Description
Stein and Yoon, 2007	Assessment of water quality concentrations and loads from natural landscapes	The authors assess urban stormwater impacts downstream receiving waters. They found that specific impacts are dependent on time of build-up on land surface. Trace metal concentrations differ based on the point in hydrograph. Peak concentration took place just before peak flow hydrograph. Sections of the report describe particular trace metals, TSS, and FIB results. Authors surmise that geology is most influential in natural water quality. This necessitates an analysis of each geologic setting in order to determine its specific natural background levels of nutrients, algal cover, and biomass.
Sutula et al., 2004	Sediments as a nonpoint source of nutrients to Malibu Lagoon, California (USA), Technical Report #441	Report addressing the refinement of water quality objectives established in the 2003 TMDL for limiting seasonal and/or annual nutrient inputs from the Malibu Creek watershed to the Malibu Lagoon. Among the conclusions of the report is that particulate nitrogen and phosphorus deposited in the lagoon during the wet season provide a significant source of nutrients to the lagoon during the dry season through remobilization as dissolved inorganic nutrients.
Svejkovsky and Burton, 2001	Detection of Coastal Urban Stormwater and Sewage Runoff with Synthetic Aperture Radar Satellite Imagery	Paper detailing a study in which the utility of using Synthetic Aperture Radar (SAR) to discern polluted urban runoff plumes was tested. One sample area was the Santa Monica Bay where water is received from Malibu Creek and Ballona Creek watersheds. Ballona Creek plumes were found to have much less backscatter when compared to Malibu Creek plumes; this finding was attributed to the differences in land use and runoff contributions between the two watersheds.
US EPA Region 9, 2002	Total Maximum Daily Loads for Bacteria in the Malibu Creek Watershed	Document describes the Total Maximum Daily Loads (TMDLs) for coliform bacteria in the Malibu Creek watershed and summarizes the information used by the USEPA and the California Regional Water Quality Control Board to develop wasteload and load allocations for coliform bacteria. Report provides implementation recommendations by which the presented waste load allocations and load allocations may be achieved.
USEPA, 2003	Total Maximum Daily Loads for Nutrients, Malibu Creek Watershed	Summary of report is provided in text below.

E.2 Summary of Key Reports

(Ambrose and Orme, 2000): From 1997-1999, Robert F. Ambrose of UCLA and Antony Orme of the University of Arizona led a multidisciplinary investigation of lower Malibu Creek and Malibu Lagoon with funding from the California Coastal Conservancy. The stated purpose was "to understand better the natural system and human impacts on this system, and to develop strategies for the long-term management of the lower watershed." The resulting massive report contains invaluable information on the system, written from a scientific, rather than regulatory perspective.

Chapter 1 of Ambrose and Orme contains a detailed history of the evolution and development of the creek and lagoon. A key geological control is the uplift of the Santa Monica Mountains, which has occurred at a rate of about 0.30 m/1,000 yrs. This uplift caused the incision of Malibu Canyon. During the last glacial maximum, when sea levels were lower, the canyon incised well out beyond the current shoreline.

As sea levels have risen (at an ongoing rate of approximately 1.8 mm/yr) the submarine canyon has since filled back to create the modern estuarine lagoon. The form of the lagoon represents a dynamic balance between sea level rise and sediment supply. In general the system is aggrading.

Human disturbances play an important role in the current morphology of the system. From the 1860s through the 1920s, the watershed was dominated by ranching, increasing erosion rates. A railway was constructed across the mouth of the lagoon in 1908, which was transformed into the Pacific Coast Highway in 1929. The 1920s saw extensive wetland drainage and beach development. Rindge Dam was constructed upstream of the Lagoon in 1928, reducing sediment throughput, but was subject to such heavy sedimentation that it was 85 percent filled by 1949. Together, these factors resulted in aggradation which began to choke the Lagoon by increasing sediment import while reducing sediment export.

Conditions in the lagoon were likely reset by a large flood in 1938. In 1947-49 most of the lagoon was graded, and parts converted to truck farming. During the 1960s and 1970s a variety of building projects, including shopping centers and a civic center, impinged on the natural footprint of the lagoon, followed by a golf course in 1983 and extensive residential development. By the 1990s the authors conclude that the lagoon was severely constrained and “dysfunctional.”

Chapter 2 examines recent hydrology and morphodynamics of the system. Hydrological alterations are due to three major factors: urban growth in the watershed, altered fire regime, and physical constraints on the Lagoon opening. Under current conditions, the Lagoon cycles between closed and open forms in response to decadal oscillations in the flow regime. A major flood event in 1998 fully opened the Lagoon to the sea, resulting in deepening much of the lagoon by 0.5 to 1 m and increasing storage capacity by about 25 percent. However, these changes were soon reversed in the following season.

Under natural conditions, the barrier beach would be expected to close during the summer and breach during winter high flows. Human impacts have also shifted the temporal pattern of this sequence. Development in the upper watershed, including substantial use of imported water, has resulted in flows that are prolonged into the dry season. Coupled with reduced storage volume this introduces a tendency for the lagoon to overtop during summer, and summer mechanical breaching is regularly employed to alleviate flooding problems. In Chapter 8, perceived poor condition of the benthic invertebrate population in the lagoon is attributed to attenuated tidal flushing. It was unclear whether breaching of the beach is more or less common than under natural conditions, but the nature and timing of breaching has certainly changed. The combination of elevated freshwater flows and reduced volume of the estuarine prism has created a situation in which salinity in the lagoon is reduced.

(Aquatic Bioassay, 2005): While benthic bioinvertebrate samples have been regularly collected in Malibu Creek since 2000, the 2005 effort stands out because it was accompanied by a formal written report. Eight sites were sampled for this round, although only one (Malibu Creek above lagoon) was in the Malibu Creek mainstem. Bioassessment scores (SC IBI) at all sites were poor; however, at four of the sites (Malibu Creek above the lagoon, lower Las Virgenes, lower Medea, and Triunfo) the physical habitat was rated optimal or suboptimal. Therefore, it was concluded that for these four sites “stressors other than habitat conditions may have impacted these sites” – such as nutrients, metals, or organic pollutants. Also at issue was the invasive New Zealand mudsnail, which was dominant in Medea Creek, crowding out other species, and present in lesser numbers at other stations.

(Las Virgenes Municipal Water District Tapia Water Reclamation Facility (LVMWD) Bioassessment, 2006-2010): This report includes the results of bioassessment monitoring conducted for the Las Virgenes Municipal Water District (LVMWD) at eight sampling locations in the Malibu Creek Watershed during the spring of 2010. This report includes all of the physical, chemical, and biological data collected during the spring survey, photographic documentation of each site, QA/QC procedures and documentation followed by the metrics specified in the CSBP and Southern California Index of Biological Integrity (SoCal-IBI), along with interpretation of these results with comparisons between sample locations, and across years. A combined total of 5,161 BMIs were identified from 39 different taxa at the eight stations sampled during the spring 2010 survey. The majority of organisms collected at station R-11(Malibu Lagoon station) were Oligochaeta worms (64% of the total abundance). Physical habitat characteristics and water chemistry of Malibu Creek Watershed (along with other taxonomic information) are also presented within the report.

(Los Angeles Bioassessment Monitoring Program, 2006-2010): As part of the Los Angeles County monitoring program, bioassessment were conducted annually from 2006-2010. The study area includes 18 stream monitoring sites within the 5 watersheds of: San Gabriel, Los Angeles River, Dominguez Channel, Santa Monica Bay (including Malibu Creek and Ballona Creek), and the Santa Clara watershed. The report details sampling methods and describes county-wide results from previous studies. Key findings include the discovery of an overly abundant snail in Malibu Creek and tables of taxa and specific benthic communities in great detail.

(Malibu Creek Watershed Monitoring Program Bioassessment Monitoring, 2005): This report describes the bioassessment IBI results of 11 sampling sites. “Southern California Index of Biological Integrity (IBI) score provides a measure of the aquatic health of a stream reach and is calculated using a multi-metric technique that employs seven biological metrics that were each found to respond to a habitat and/or water quality impairment.” The poor Malibu Creek scores indicate the watershed impaired. The physical/habitat characteristics were also assessed. This report also notes the prevalence of the New Zealand mudsnail, which is a significant and immediate environmental concern, but at present do not have methods for population control.

(Moffatt & Nichol, 2005): Following up on the technical basis provided by Ambrose and Orme, Mofatt & Nichol undertook a restoration feasibility study for Malibu Lagoon. This contains updated information, in particular, on sediment dynamics in the lagoon. They describe the lagoon as consisting of a main channel and three distinct western arms that are stagnant and cut off from the main channel at mean seal level (MSL). (Note, these arms were actually constructed for restoration purposes in 1983 – see Ambrose and Orme, 2000, p. 8-3). Substrate in the main channel was about 95 percent sand, while the western arms were about 45 percent sand and accreting. As noted by Ambrose and Orme, the lagoon experiences strong cycles of sedimentation: The 1997/98 El Niño year resulted in scour, while infilling occurred in 1998 through 2005. Moffatt & Nichol estimate the annual sedimentation rate for 1998-2004 as 0.76 in/yr as a lagoon-wide average, which has resulted in much of the sediment bed being perched above MSL. Fine sediment buildup in the western arms contributes to nutrient retention and recycling, increasing eutrophication impacts. Restoration alternatives included various techniques that might decrease trapping and increase expulsion of sediment from the lagoon.

(Sikich et al., 2012): The report provides a thorough description of the habitat, water quality, and biota within the Malibu Creek Watershed. Chapter 1 analyzes the current state of the watershed and identifies issues of concern; describing the water quality, biota, and stream health. The authors provide a detailed overview of the watershed, describing the sensitive habitats and species, and the improvement efforts in progress, as well as future needs. The watershed contains highly invasive species such as the New Zealand mudsnails, red swamp crayfish, bullfrogs, giant reed, periwinkle, and fennel which can displace local species. It also lies on the migration pathof endangered aquatic life. Chapter 2 speaks to the state of the habitat. Land cover is assessed. The assessment describe significant disturbance in the watershed, due to erosion, riparian habitat loss, and sedimentation. Areas with as low as 6.3% effective impervious areas display singificant biological degradation. Streambank modifications and stability are analyzed, including a sediment survey. From the gathered data, the authors provide a series of recommendations for development within and outside the Coastal Zone. Water quality is described in Chapter 3. Nutrients, algae, dissolved oxygen (DO),bacteria pollution, pH and other relevant parameters are addressed in detail.

The Tapia Water Reclamation Facility (Tapia) is the most prominent source of nutrients, and despite a decade of focused effort to reduce effluent concentrations, parameters remain high. Furthermore, the concentrations of fecal coliform bacteria throughout the watershed are still high, despite intensive effort to reduce the concern. The report recomments targeted monitoring of Tapia's discharge and a centralized wastewater recycling plant in Malibu Civic Center to address these issues specifically. Chapter 4 details regional biota and biological integrity. Index of Biological Integrity (IBI), recommended by the USEPA, evaluates human impact on the "biotic condition of water bodies". Because different species respond differently to stressors, their presence, or lack there of, is an indicator of ecosytstem health. This chapter illustrates Malibu's integrity as well as identifying affecting stressors on the watershed, analyzed in large part by the Heal the Bay organization since 2000. The two major factors influencing the watershed's low biological integrity (via IBI scores) are water quality and high percent effective impervious area. Stormwater pollution from impervious areas has and will be addressed further by local ordinances implementing low impact development (LID) to reduce runoff and associated bacteria and nutrients. Stream health is described in Chapter 5. It presents a background to the status quo and describes the metric used to analyze water quality, biota, and physical habitat in order to assess comprehensive stream health called the Stream Health Index (SHI).

Due to prevalence of so many environmental stressors within the watershed, the impact of multiple and simulatenous effects is necessary. The report develops the SHI using existing data to reveal ecosystem health at particular locations. It utilizes water quality, biotic, and habitat data to formulate a single value from 0-27 (most degraded to least impacted). The report recommends action to actively protect and restore the health of the Malibu Creek watershed. The authors suggest maintaining an emphasis on stream and riparian buffer protection from development and "human encroachment" while maintaining restoration activities to improve the ecological health of the watershed. Sikich et al. advocate a programof stream andriparian habitat protection near the Santa Monica mountains; implementing LID practices of onsite water reclamation for new build and redevelopment; implementation of TMDLs and development of new where necessary; halting the spread of invasive species through comprehensive plans. These efforts would protect open space, reduce sediment and nutrient loads, and limit streambank hardening with BMPs and protective plans.

(**USEPA, 2003**): In 2003 USEPA Region 9 established nutrient TMDLs for the Malibu Creek watershed in accordance with Consent Decree requirements established in *Heal the Bay, Inc., et al. v. Browner*, approved on 22 March 1999. This addresses impairments in the Malibu Creek main stem, Las Virgenes, Lindero, and Medea creeks, lakes Sherwood, Lindero, Malibou, and Westlake, and Malibu Lagoon. All but Malibu Lagoon were listed for algae, while the lagoon and all the lakes were listed for eutrophic conditions. A variety of other listings for scum/odors, ammonia, organic enrichment, and low dissolved oxygen were also associated with the nutrient impairments. The problem statement for the TMDL includes the following: "Excessive algae in the Malibu Creek watershed has resulted in several waterbodies not supporting their designated beneficial uses associated with aquatic life and recreation… Algal biomass can lead to impairment of swimming and wading activities. In addition, the proliferation of algae can result in loss of invertebrate taxa through habitat alteration (Biggs, 2000). Algal growth in some instances has produced algal mats…; these mats may result in eutrophic conditions where dissolved oxygen concentration is low (Briscoe et al., 2002), and negatively affect aquatic life in the waterbody (Ambrose and Orme, 2000)."

The 2003 Nutrient TMDL addressed beneficial uses related to ***nuisance*** effects such as algae, odors, and scum (RWQCB, 1996) (USEPA, 2003). Specifically, the 2003 Nutrient TMDL addressed depressed dissolved oxygen and excess nutrient loads that resulted in "nuisance" impacts to recreational uses, including the negative visual and odorous presence of scum and algae.

USEPA interpreted the narrative criteria for nutrients relative to Biggs (2000) recommendations of a threshold of 30 percent cover for filamentous (floating) algae greater than 2 cm in length and a threshold of 60 percent cover for bottom algae greater than 0.3 cm thick. They found that algal problems were predominantly associated with summer low flow conditions, but that there was evidence of algal impairment in Malibu Creek throughout the year. Nutrient targets were then established for two seasons: During the summer (April 15 – November 15) Nitrate-plus-nitrite-N and total P targets are 1.0 and

0.1 mg/L respectively, while during the winter months (November 16 – April 14) the Nitrate-plus-nitrite-N target is 8 mg/L while no total P target is applied. It is important to note that there was considerable uncertainty as to what factors control algal abundances in Malibu Creek. Therefore, the summer nutrient targets are based primarily on a reference approach reflecting concentrations observed in "relatively undisturbed stream segments" on Upper Malibu Creek and Middle Malibu Creek. The winter target simply represents a 20 percent margin of safety adjustment on the existing 10 mg/L numeric objective provided in the basin plan. The nutrient TMDL document contains a detailed analysis of nutrient loading from nonpoint sources in the watershed in addition to the Tapia WRF.

The nutrient TMDL contains various sources of uncertainty. It was believed that the TMDL and allocations were conservative; however, it was not certain that nutrient-related impairment would be fully resolved as a result of the TMDL. The TMDL discussion notes (p. 44): "Studies are currently underway to improve our understanding of the relationship between nutrient levels in the watershed and algal growth. USEPA strongly recommends that these studies be completed and additional studies carried out if necessary to characterize the limiting factors that control algae growth in the Malibu Creek watershed… Based on results from these studies, the State should consider reviewing and, if necessary, revising the TMDLs, allocations, and/or implementation provisions."

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Appendix F. Nutrient Numeric Endpoints for TMDL Development: Malibu Watershed Case Study

Prepared by:

Tetra Tech, Inc.

January 2007, revised November 2012

In this analysis, the California nutrient numeric endpoints (NNE) tools were applied to three nutrient impaired streams and four lakes in the Malibu Creek watershed. Site-specific information on nutrient levels, physical conditions (e.g. stream temperature, light), and biological response for sites with different land uses and habitat conditions was used to develop site-specific nutrient targets. The analysis indicated that nutrient targets are variable among sites, depending on site characteristics. The results also suggest that the proposed TMDL target of 1 mg/L nitrate plus nitrite N may be too high to achieve desired algal densities in the streams and lakes of this watershed.

F.1 Introduction

Tetra Tech (2006), under contract to U.S. EPA Region IX and California State Water Resources Control Board, has developed a risk-based approach for estimating site-specific nutrient numeric endpoints (NNE) for California waters. In recognizing the limitation of using ambient nutrient concentrations alone in predicting the impairment in beneficial uses, the approach uses secondary indicators. Secondary indicators are defined as parameters that are related to nutrient concentrations, but are more directly linked to beneficial uses than nutrient levels alone, such as benthic algal density.

The CA NNE approach also incorporates risk cofactors other than nutrient concentrations and nutrient supply that affect algal productivity including: light availability, flow rate and variability, and biological community structure. The approach also recognizes that there is no scientific consensus on precise levels of nutrient concentrations or response variables that result in impairment of beneficial uses. Therefore, water bodies in California are classified into three categories, termed Beneficial Use Risk Categories (BURCs).

As part of the NNE process, Tetra Tech (2006) developed simplified scoping tools to estimate algal response to nutrient concentrations. USEPA Region 9 subsequently funded a series of case studies to evaluate the performance of the tools. Tetra Tech, under contract to USEPA, applied the NNE method to develop nutrient endpoints for selected California waterbodies requiring TMDLs. The purpose of these case studies was to demonstrate the NNE process and test and refine the tools. The case study reported here (Malibu Creek watershed) is one of the case studies under this task. The Malibu watershed NNE pilot study provides analyses for three creeks within the watershed including: Medea Creek; Las Virgenes Creek; and Malibu Creek. In addition the pilot study also includes four lakes within the Malibu watershed: Sherwood Lake; Westlake; Lindero Lake; and Malibou Lake.

F.1.1 Site

Malibu Creek watershed, located about 35 miles west of Los Angeles, California, drains an area of 109 square miles. The watershed extends from the Santa Monica Mountains and adjacent Simi Hills to the Pacific coast at Santa Monica Bay (Bowie et al., 2002, Figure F-1). Several creeks and lakes are located in the upper portions of the watershed, and they ultimately drain into Malibu Creek at the downstream end of the watershed. The entire watershed lies within Level 3 subecoregion 6 (Southern and Central California Chaparral) within aggregate nutrient ecoregion 3 (Xeric West; USEPA, 2000d).

The watershed has seen urban development in recent decades, with a high degree of development occurring along portions of the main tributaries of Malibu Creek (Busse et al. 2006). Lower Malibu Creek also receives discharges from the Tapia waste-water treatment plant.

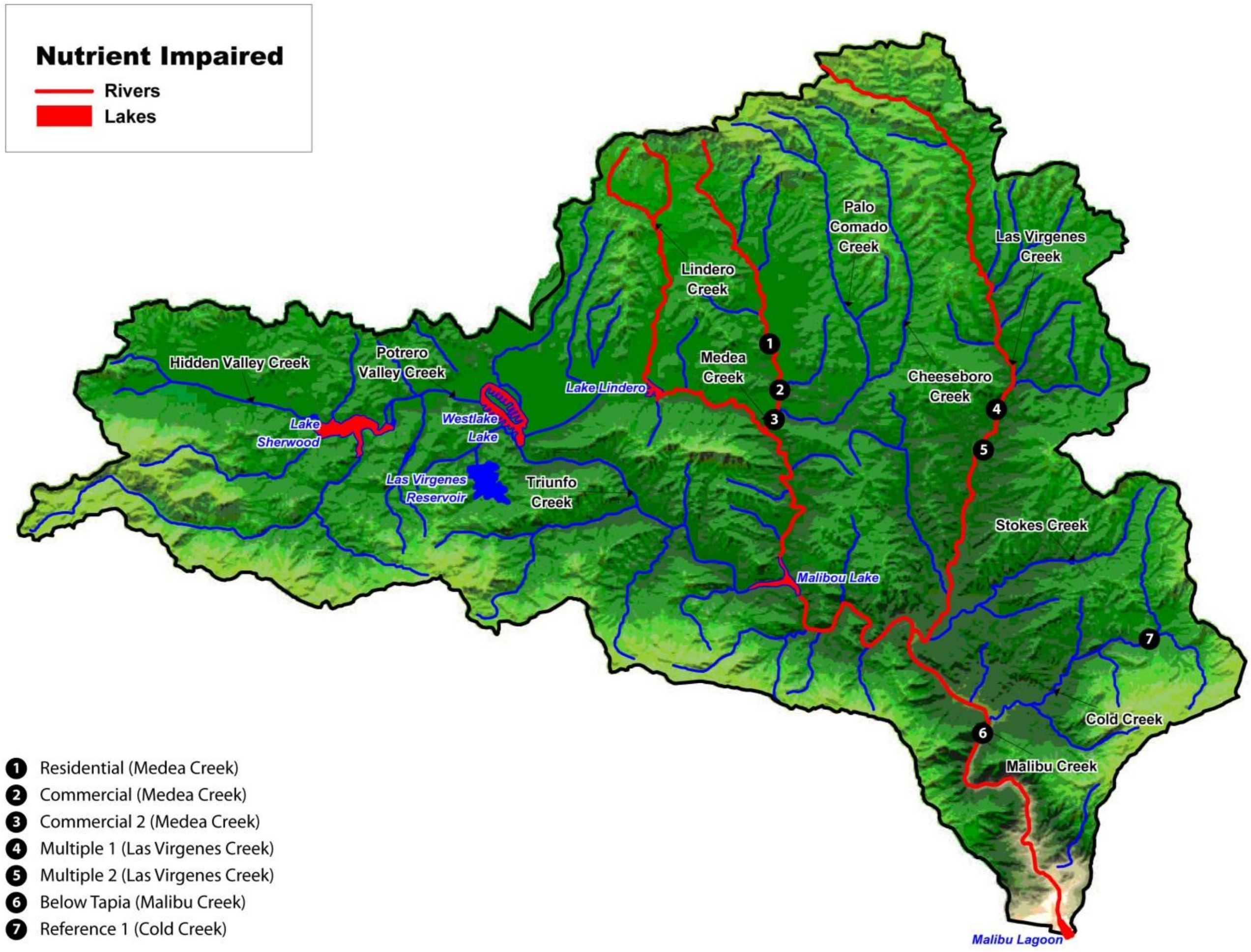

Figure F-1. Map of the Malibu Creek Watershed showing Nutrient-impaired Waterbodies in Red (Bowie et al., 2002).

Note: Also identified on this map are sampling locations near different land uses from Busse et al. 2003 that are discussed in Sections 2 and 3.

In 2003 USEPA Region 9 established nutrient TMDLs for the Malibu Creek watershed in accordance with Consent Decree requirements established in *Heal the Bay, Inc., et al. v. Browner*, approved on 22 March 1999. This addresses impairments in the Malibu Creek main stem, Las Virgenes, Lindero, and Medea creeks, lakes Sherwood, Lindero, Malibou, and Westlake, and Malibu Lagoon. All but Malibu Lagoon were listed for algae, while the lagoon and all the lakes were listed for eutrophic conditions. A variety of other listings for scum/odors, ammonia, organic enrichment, and low dissolved oxygen were also associated with the nutrient impairments. The problem statement for the TMDL includes the following: “Excessive algae in the Malibu Creek watershed has resulted in several waterbodies not supporting their designated beneficial uses associated with aquatic life and recreation… Algal biomass can lead to impairment of swimming and wading activities. In addition, the proliferation of algae can result in loss of invertebrate taxa through habitat alteration (Biggs, 2000a). Algal growth in some instances has produced algal mats…; these mats may result in eutrophic conditions where dissolved oxygen concentration is low (Briscoe et al., 2002), and negatively affect aquatic life in the waterbody (Ambrose and Orme, 2000).”

USEPA interpreted the narrative criteria for nutrients relative to Biggs (2000a) recommendations of a threshold of 30 percent cover for filamentous (floating) algae greater than 2 cm in length and a threshold of 60 percent cover for bottom algae greater than 0.3 cm thick. They found that algal problems were predominantly associated with summer low flow conditions, but that there was evidence of algal impairment in Malibu Creek throughout the year. Nutrient targets were then established for two seasons: During the summer (April 15 – November 15) Nitrate-plus-nitrite-N and total P targets are 1.0 and 0.1 mg/L respectively, while during the winter months (November 16 – April 14) the Nitrate-plus-nitrite-N target is 8 mg/L while no total P target is applied. It is important to note that there was considerable uncertainty as to what factors control algal abundances in Malibu Creek. Therefore, the summer nutrient targets are based primarily on a reference approach reflecting concentrations observed in "relatively undisturbed stream segments" on Upper Malibu Creek and Middle Malibu Creek. The winter target simply represents a 20 percent margin of safety adjustment on the existing 10 mg/L numeric objective provided in the basin plan.

F.1.2 Beneficial Uses and Impairment

The Malibu Creek watershed supports or potentially supports a total of 14 beneficial uses. Among them, 10 of 14 beneficial uses are sensitive to nutrient inputs and related effects, including: REC1 (Water contact recreation), REC2 (Non-contact Recreation), WARM (Warm freshwater habitat), COLD (Cold freshwater habitat), EST (Estuarine habitat), MAR (Marine habitat), WILD (Wildlife habitat), RARE (Preservation of rare and endangered species), MIGR (Migration of aquatic organisms), and SPWN (Spawning, reproduction, and/or early development). Recreational uses (REC1 and REC2) apply to all the listed water bodies. WARM is the existing use for all the impaired streams, except in Lower Medea Creek (reach 1) and Lindero Creek where WARM is an intermittent use.

Streams and lakes in the Malibu Creek watershed are susceptible to the cumulative effects of degradation in water quality because of continuing urban development. Marine sedimentary deposits in the watershed (Modelo formation) may also have elevated levels of nutrients. Data collected in the Malibu Creek watershed has shown elevated algal biomass and macroalgal cover in developed areas, attributed to increases in nutrient and light availability (Busse et al. 2006). Most of the water bodies in the Malibu Creek watershed have been listed under Section 303(d) for coliforms or algae/nutrient problems (Bowie et al. 2002; USEPA Region IX, Table F-1). Malibu Lagoon, Malibu Creek upstream of the lagoon, and several tributaries to Malibu Creek (Las Virgenes Creek, Medea Creek, and Lindero Creek) are major areas of concern. Streams that feed into Malibu Creek were listed under 303(d) for either coliforms, algae/nutrients, or both problems, including Las Virgenes Creek, Stokes Creek, Medea Creek, Lindero Creek, and Palo Comado Creek. In addition, four lakes in the watershed have been listed for eutrophication problems (algae, nutrients, ammonia, low DO): Malibou Lake, Lake Lindero, Westlake Lake, and Lake Sherwood.

Table F-1. Malibu Creek Watershed 303(d)-listed Waterbodies for Nutrients

Waterbody	Algae	Eutrophy	Scum/ Odors	Ammonia	Organic Enrichment	Dissolved Oxygen
Lake Sherwood (acres)	213	213		213	213	213
Westlake Lake (acres)	186	186		186	186	186
Lake Lindero (acres)	14	14	14		14	
Las Virgenes Creek (miles)	11.25		11.25			11.25
Lindero Creek (miles)	6.56		6.56			
Medea Creek (miles)	7.56					
Malibou Lake (acres)	69	69			69	69
Malibu Creek (miles)	8.43		8.43			
Malibu Lagoon (acres)		33				

Note: Streams = linear miles listed; lakes = acres listed; data from USEPA Region IX.

As of January 2007, the Los Angeles Regional Water Quality Control Board had established bacteria TMDLs for the Malibu Creek watershed. TMDLs for the algal/nutrient problems for the impaired water bodies in the watershed were under development.

F.1.3 Summary of the Existing Analysis

In 2002, Tetra Tech conducted nutrient and coliform modeling for the Malibu Creek watershed TMDL studies (Bowie et al. 2002). In the study, the watershed model HSPF was used to model pollutant loading and transformation in the watershed, streams and the Lagoon, and water quality model BATHTUB was used to model the eutrophication in the four lakes. Pollutant loadings from various sources were estimated.

In the summer of 2001 and 2002, a survey of nutrients and algae in the Malibu Creek Watershed was conducted by University of California, Santa Barbara, and Southern California Coastal Water Research Project members (Busse et al. 2003; Busse et al. 2006). In that study, algal biomass (both benthic and floating), nutrient levels (nitrogen and phosphorus), and physical conditions were surveyed in multiple streams with different surrounding land uses and habitat conditions in order to identify factors and land uses that promote excessive algal growth. High algal levels were found at sites with human influence. The study indicated nutrient and light availability significantly affect algal composition and total algal biomass. The study also indicated that at several locations algal growth is saturated by high nutrient levels and is not nutrient limited.

F.1.4 Scope of This Effort

As indicated in the study by Busse et al. (2003, 2006), although nutrient concentrations explained a large portion of the variation in algal density across sites, other physical parameters such as shading and current speeds also affect to algal growth. Sites downstream of commercial land uses with moderate nutrient concentrations can exhibit high benthic algal density due to high temperature and lack of shading. The availability of site specific data on nutrient levels, algal density, and physical parameters provides a useful basis upon which to investigate the use of the CA NNE tools to develop site-specific nutrient concentration targets.

F.2 Data

F.2.1 Algal Response Data

In 2001 and 2002, algal biomass at different sites with a range of different land use patterns were surveyed by Busse et al. (2003, 2006). For the survey in 2002, benthic and floating algal density were measured separately and for each sampling site six sub-habitat types with different shading and flow conditions were surveyed. The 2002 survey locations also contained more sites with human influence. Also for the 2002 survey, more complete data were available for August 2002 than June 2002. Therefore for our analysis, we mostly rely on data obtained in August 2002.

For the survey in 2002, seven locations along the main tributaries (Las Virgenes Creek, Medea Creek) and Malibu Creek were included. The sites include one reference site containing open space, one site with a high density residential area, two commercial sites, two sites with multiple land uses, and one site below the Tapia treatment plant. These sites are shown in Figure F-1. The two multiple land use sites on Las Virgenes Creek were influenced by both residential development and historical sludge injection fields.

Within each site, six sub-habitat types with different combination of shading and flow conditions including shaded pools, shaded runs, shaded riffles, sun pools, sun runs, and sun riffles were surveyed, if that sub-habitat type is available. For each sub-habitat type, three equally spaced cross-stream transects were established. Benthic algae were sampled at five evenly spaced locations along each transect. Chlorophyll *a* concentrations for benthic algae samples were averaged for each sub-habitat type. Besides chlorophyll *a*, ash free dry mass (AFDM) was also measured for each sample in the laboratory. Table F-2 lists algal response data in the August 2002 survey. The observed chlorophyll *a* was highly variable among different sites and sub-habitats. Commercial 1 sun run site showed the highest average benthic chlorophyll *a* concentrations of 969.2 mg/m^2. At two sites there was a significant mass of planktonic chlorophyll *a*. This was also reported on an areal basis for possible combination with the benthic chlorophyll *a* density. The chlorophyll *a* to AFDM ratio ranges from 1.2 to 11.9 among the different sites. As most of the sites have high ratios, high concentrations of benthic chlorophyll *a* can be associated with relatively low algal biomass.

Table F-2. Summary of Chlorophyll *a* and AFDM Data from the August 2002 Survey (Busse et al. 2003).

Creek	Land Use	Sub-Habitat	Benthic chlorophyll *a* (mg/m^2)	Benthic plus Planktonic chlorophyll *a* (mg/m^2)	Average Ash Free Dry Mass (g/ m^2)	Chlorophyll *a* to AFDM ratio
Medea Creek	Residential 1	Sun Riffle	165.1	165.1	34.8	4.7
Medea Creek	Residential 1	Shade Riffle	50.0	50.0	10.7	4.7
Medea Creek	Commercial 1	Sun Run	969.2	969.2	210.3	4.6
Medea Creek	Commercial 1	Sun Riffle	110.9	110.9	44.9	2.5
Medea Creek	Commercial 2	Sun Pool	133.1	413.0	40.6	3.3

Creek	Land Use	Sub-Habitat	Benthic chlorophyll *a* (mg/m^2)	Benthic plus Planktonic chlorophyll *a* (mg/m^2)	Average Ash Free Dry Mass (g/ m^2)	Chlorophyll *a* to AFDM ratio
Medea Creek	Commercial 2	Sun Run	73	123.5	29.2	2.5
Medea Creek	Commercial 2	Sun Riffle	66.9	66.9	24.6	2.7
Las Virgenes	Multiple 1	Shade Run	383.9	383.9	45.7	8.4
Las Virgenes	Multiple 1	Shade Riffle	504.0	504.0	53.5	9.4
Las Virgenes	Multiple 2	Sun Run	102.6	102.6	85.3	1.2
Las Virgenes	Multiple 2	Shade Run	531.1	531.1	79.9	6.6
Las Virgenes	Multiple 2	Shade Riffle	255.9	255.9	21.5	11.9
Malibu Creek	Below Tapia	Shade Run	341	341	32.9	10.4
Malibu Creek	Below Tapia	Sun Riffle	230.3	230.3	40.4	5.7
Malibu Creek	Below Tapia	Shade Riffle	258.1	258.1	25.9	10.0

Note: AFDM data provided by L. Busse; not included in published report.

F.2.2 Chemical Water Quality Data

Water samples at each site were collected downstream of each transect. For each sample, ammonium (NH_4-N), nitrate (NO_3-N), soluble reactive phosphorus (SRP), total phosphorous (TP), and total nitrogen (TN) concentrations were measured. Table F-3 shows the nutrient concentrations obtained in the August 2002 survey. Nitrate concentrations were generally low (below 0.2 mg-N/L) for the residential and commercial sites, while multiple site 1 and 2 (sites with historical sludge injection) exhibit high nitrate concentrations of 2.8 and 3.8 mg/L, respectively. Total N ranged from 0.68 mg/L to 3.8 mg/L among sites. For Multiple 1 and Multiple 2 sites, measured average TN concentrations were less than the average NO_3-N concentrations.

Table F-3. Water Quality Data Obtained from August 2002 Survey (Busse et al. 2003).

Creek	Land Use	Sub-Habitat	NO_3-N (mg/L)	NH_4-N (mg/L)	TN (mg/L)	SRP (mg/L)	TP (mg/L)
Medea Creek	Residential 1	Sun Riffle	0.018	0.043	0.686	0.123	0.186
Medea Creek	Residential 1	Shade Riffle	0.018	0.043	0.686	0.123	0.186
Medea Creek	Commercial 1	Sun Run	0.127	0.05	1.203	0.077	0.137
Medea Creek	Commercial 1	Sun Riffle	0.127	0.05	1.203	0.077	0.137
Medea Creek	Commercial 2	Sun Pool	0.072	0.063	1.418	0.053	0.087

Creek	Land Use	Sub-Habitat	NO_3-N (mg/L)	NH_4-N (mg/L)	TN (mg/L)	SRP (mg/L)	TP (mg/L)
Medea Creek	Commercial 2	Sun Run	0.072	0.063	1.418	0.053	0.087
Medea Creek	Commercial 2	Sun Riffle	0.072	0.063	1.418	0.053	0.087
Medea Creek	Multiple 1	Shade Run	2.804	0.025	2.748/2.829*	0.268	0.296
Las Virgenes	Multiple 1	Shade Riffle	2.804	0.025	2.748/2.829*	0.268	0.296
Las Virgenes	Multiple 2	Sun Run	3.869	0.071	3.806/3.940*	0.301	0.326
Las Virgenes	Multiple 2	Shade Run	3.869	0.071	3.806/3.940*	0.301	0.326
Las Virgenes	Multiple 2	Shade Riffle	3.869	0.071	3.806/3.940*	0.301	0.326
Las Virgenes	Below Tapia	Shade Run	0	0.050	0.686	0.293	0.363
Malibu Creek	Below Tapia	Sun Riffle	0	0.050	0.686	0.293	0.363
Malibu Creek	Below Tapia	Shade Riffle	0	0.050	0.686	0.293	0.363

*TN values used in model as sum of NO_3-N and NH_4-N because reported TN values were less than NO_3-N.

The main source of water quality data for the four listed lakes is a study by UC Riverside for the Los Angeles Regional Water Quality Control Board in 1992-1993 (Lund et al., 1994). Water quality data were collected on a monthly basis at several depths for a one-year period from July 1992 to July 1993 (Table F-4). For the purpose of the analysis that follows, annual averages of these concentrations were used based on the finding that there was little consistent inter-seasonal change in concentration.

Table F-4. Nutrient Measurements in Malibu Creek Watershed Lakes by UC Riverside for 1992-1993 (Mean and Ranges; Lund et al. 1994)

Lake	NO_3-N (mg/L)	NH_3-N (mg/L)	TKN (mg/L)	TN (mg/L)	PO_4-P (mg/L)	TP (mg/L)	Chlorophyll *a* (µg/L)
Sherwood	0.5 <0.1-1.2	0.8 <0.1-2.2	1.7 0.5-3.0	2.23 0.6-4.2	0.25 <0.1-0.5	0.25 <0.1-0.5	16 1-52
Westlake	0.3 <0.1-1.3	0.4 0.1-1.0	1.3 0.7-2.3	1.69 0.8-3.6	0.16 <0.1-0.3	0.16 <0.1-0.3	14 2-35
Lindero	0.4 <0.1-1.3	0.1 <0.1-0.5	1.1 <0.1-2.0	1.58 0.2-4.3	0.09 <0.1-0.2	0.13 <0.1-0.2	23 2-56
Malibou	0.5 <0.1-1.9	0.1 <0.1-0.3	1.2 <0.1-2.7	1.78 0.2-4.6	0.13 <0.1-0.3	0.14 <0.1-0.4	44 2-185

F.2.3 Physical Data

Table F-5 summarizes the observed physical conditions at the stream sites including velocity, percent open canopy, and water temperature for the selected locations surveyed in August 2002. Water velocities for the selected locations ranged from 0.02 to 0.36 m/s. Percent open canopy was around 90 percent for the selected sun sites and around 1-2% the shade sites, with only a few exceptions. Temperature was generally below or around 20 degrees, except at commercial site 1, where temperature was around 30 degrees.

Table F-5. Physical Conditions of Stream Sites in August 2002 Survey (Busse et al. 2003)

Creek	Land Use	Sub-habitat	Velocity (m/s)	% Open Canopy	Water Temperature (° C)
Medea Creek	Residential 1	Sun Riffle	0.28	90	23
Medea Creek	Residential 1	Shade Riffle	0.12	14.9	19.2
Medea Creek	Commercial 1	Sun Run	0.24	89.6	30.3
Medea Creek	Commercial 1	Sun Riffle	0.36	90.9	30.5
Medea Creek	Commercial 2	Sun Pool	0	74.5	28.6
Medea Creek	Commercial 2	Sun Run	0.18	91.1	18.1
Medea Creek	Commercial 2	Sun Riffle	0.23	88.9	20.8
Las Virgenes	Multiple 1	Shade Run	0.1	0.2	20.1
Las Virgenes	Multiple 1	Shade Riffle	0.13	0.2	20.2
Las Virgenes	Multiple 2	Sun Run	0.02	29.7	16.8
Las Virgenes	Multiple 2	Shade Run	0.09	1.6	16.6
Las Virgenes	Multiple 2	Shade Riffle	0.14	2.3	16.7
Malibu Creek	Below Tapia	Shade Run	0.04	0	19.4
Malibu Creek	Below Tapia	Sun Riffle	0.12	54.7	20
Malibu Creek	Below Tapia	Shade Riffle	0.2	1.8	19.6

Physical data for the lakes is summarized in Bowie et al. (2002).

F.3 NNE Tools Application - Streams

F.3.1 Parameter Specification

Depth and Velocity

Velocity for each stream location was measured during the survey and therefore was directly used in the analysis. For August 2002, the depth for surveyed streams is 15.2 (± 8.53) cm (L. Busse, personal communication). In our analyses we assumed a depth of 0.2 m.

Solar Radiation

Solar radiation was estimated for the summer period (June-August) based on the latitude, using the routine embedded in the Benthic Biomass Spreadsheet. Percent canopy openness measured during the survey was directly used in the analysis.

Light Extinction Coefficient

Light extinction coefficient can be calculated as a function of turbidity. An approximate linear relationship of light extinction to turbidity is expected in streams. Regression relationship (Walmsley et al. 1980), Ke (PAR) = 0.1T + 0.44, where Ke (PAR) is the extinction rate of photosynthetically active radiation (PAR, per meter) and T is nephelometric turbidity (NTU). Stream turbidity for Las Virgenes Creek, Medea Creek, and Malibu Creek below Tapia has been monitored by the Heal the Bay Stream team (http://www.healthebay.org/streamteam/). Turbidity for these streams during summer (July-September) generally ranges around 1 NTU. Based on the equation, the estimated light extinction coefficients for these streams are around 0.54 m^{-1}.

Days of Accrual

The days of accrual can be used to adjust maximum algal density based on the frequency of stream scouring events (see more detailed description in Tetra Tech, 2006). The days of accrual for Malibu Creek were examined from daily flow data of 1988-1998 from Los Angeles County Department of Public Works (LACDPW), using the count of hydrological events exceeding three times the median flow, yielding an estimate of 93.4 days. Daily flow data were not available for the Las Virgenes Creek and Medea Creek. Survey data from Busse et al. (2003) indicated stream velocity during summer and fall of 2001 and 2002 were generally below 0.35 m/s. Welch and Jacoby (2004) noted that significant scour usually does not begin until flow velocities reach about 0.7 m/s (2.3 ft/s). Therefore it is expected that during summer and fall no storm events will occur that will cause significant scour of benthic algae. A value of 100 was assumed for the days of accrual for all sites.

F.3.2 Model Results

The NNE Benthic Biomass Predictor tool provides a variety of empirical and simplified parametric methods to predict benthic algae response to ambient conditions. In this analysis, results from the steady-state approximations to the standard QUAL2K, revised QUAL2K, revised QUAL2K with accrual adjustment and Dodds et al. (2002, rev. 2006) methods are presented (Table F-6; see Tetra Tech, 2006, Appendix 3 for description of the methods). Generally, the tool was able to predict the observed maximum benthic chlorophyll *a* concentrations in various locations reasonably well. The Dodds et al. (2006) method, which is based on regression relationship of TN and TP, predicted the higher observed maximum chlorophyll *a* at sites with multiple land use (Las Virgenes Creek) and lower observed maximum chlorophyll *a* at residential land use site (Medea Creek). However without the consideration of physical parameters, the Dodds et al. (2006) method cannot predict the variability exhibited in different sub-habitat condition for the same land use. The parametric (QUAL2K-based) methods performed better in capturing the variation in observed maximum chlorophyll *a* among different sub-habitats. For example, for the residential 1 site (Medea Creek), the standard QUAL2K methods were able to predict the higher chlorophyll *a* concentrations under sun riffle sub-habitat and the lower chlorophyll *a* concentration under the shade riffle sub-habitat.

Table F-6. Observed and Predicted Maximum Benthic Chlorophyll *a* (mg/m^2)

Creek	Name/ Land use	Habitat	Standard QUAL2K	Revised QUAL2K	Revised QUAL2K with Accrual Adjustment	Dodds et al. 2002, 2006	Observed
Medea Creek	Residential 1	Sun Riffle	175	338	277	196	165
Medea Creek	Residential 1	Shade Riffle	85	165	135	196	50
Medea Creek	Commercial 1	Sun Run	307	419	343	221	969
Medea Creek	Commercial 1	Sun Riffle	312	426	349	221	111
Medea Creek	Commercial 2	Sun Pool	291	510	418	208	413*
Medea Creek	Commercial 2	Sun Run	116	203	166	208	123.5*
Medea Creek	Commercial 2	Sun Riffle	149	261	214	208	67
Las Virgenes	Multiple 1	Shade Run	626	679	556	362	384
Las Virgenes	Multiple 1	Shade Riffle	705	766	627	362	504
Las Virgenes	Multiple 2	Sun Run	85	104	86	417	103
Las Virgenes	Multiple 2	Shade Run	396	488	400	752	531
Las Virgenes	Multiple 2	Shade Riffle	719	887	727	417	256
Malibu Creek	Below Tapia	Shade Run	157	354	290	233	341
Malibu Creek	Below Tapia	Sun Riffle	125	282	231	233	230
Malibu Creek	Below Tapia	Shade Riffle	153	346	283	233	258

* Chlorophyll *a* density includes planktonic algae expressed on a mass per area basis.

The QUAL2K-based methods predict biomass as ash free dry mass (AFDM) and rely on a chlorophyll *a* to AFDM ratio to convert AFDM to chlorophyll *a*. For Malibu, site-specific chlorophyll *a* to AFDM ratios are available (Table F-2). With site-specific nutrient concentrations, physical conditions of canopy closure, stream temperature and current velocity as well as site-specific chlorophyll *a* to AFDM ratios, QUAL2K methods generally reproduced the variation in chlorophyll *a* concentrations well, although the methods under-predicted the maximum chlorophyll *a* at a few locations with extremely high chlorophyll *a* concentrations of over 700 mg/m^2 (e.g., shade run of Multiple 2 site, and sun run of Commercial 1). One possible cause is the estimation of nutrient concentrations from a single set of samples.

Overall, the QUAL2K-based methods provide more flexibility than the Dodds et al. (2002) method. The Revised QUAL2K with accrual adjustment results, without modification of the default parameters, performed reasonably well at reproducing the maximum benthic chlorophyll *a* densities. As shown in Figure F-2 the majority of the simulated maxima are close to or slightly greater than the observed concentrations, as expected. The major exception is the very high density reported for the Medea Creek Commercial 1 sun run site.

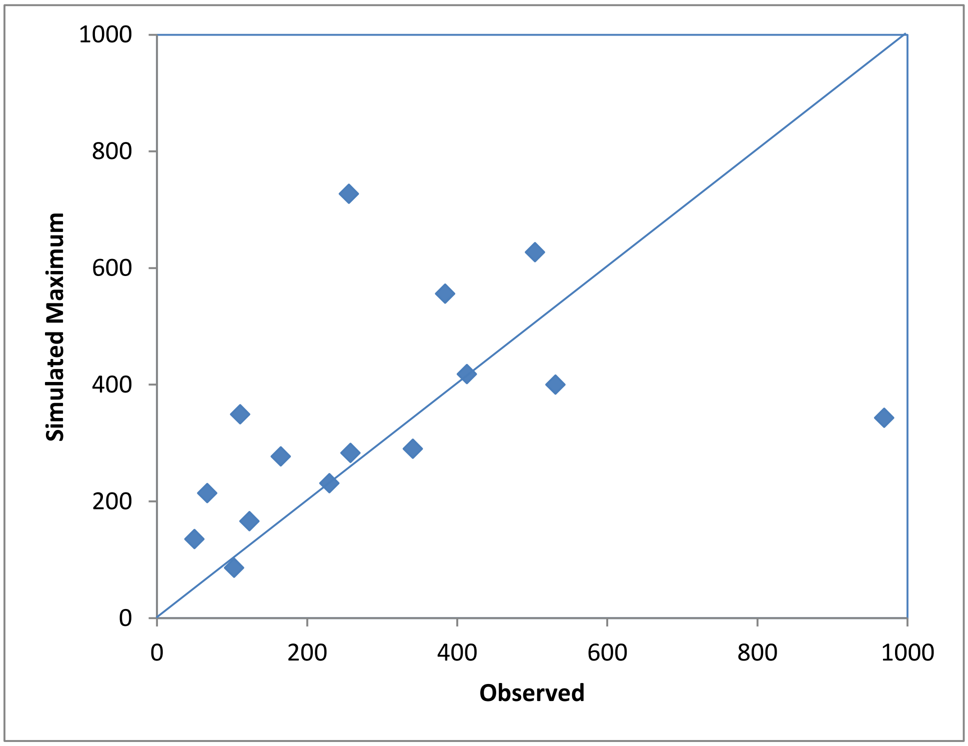

Figure F-2. Comparison of Observed and Simulated Maximum Benthic Chlorophyll a Densities (mg/m2) using the Revised QUAL2Kw Method with Accrual Adjustment

F.3.3 Nutrient Targets

The NNE tool can be used to estimate nutrient targets to achieve a specified maximum algal density. Tetra Tech (2006) recommends a target maximum benthic chlorophyll *a* concentration of 100 mg/m^2 for the BURCI/II boundary (below which conditions may be deemed acceptable) and 150 mg/m^2 for the BURC II/III boundary (above which conditions are deemed unacceptable) for COLD and SPAWN uses. For WARM uses, Tetra Tech (2006) recommends a BURC I/II boundary of 150 mg/m^2 and a BURC II/III boundary of 200 mg/m^2. For Las Virgenes Creek, Medea Creek and Malibu Creek, COLD and SPAWN are the potential and existing uses. Proposed TMDL target for chlorophyll *a* in streams is also at150 mg/m2 for the Malibu Creek Watershed.

The tool was first used to predict target nutrient concentrations that would meet a maximum benthic chlorophyll *a* density of 150 mg/m^2 (BURC II/III for COLD uses and BURC I/II for WARM uses). The revised QUAL2K methods predict target concentrations for total N or total P, either one of which will achieve the target (Figure F-3; Table F-7). The standard QUAL2K method is based on inorganic nutrient concentrations, and the total nutrient limits shown in the table are those that would be required to at the existing average inorganic fraction of nutrient concentrations. The Dodds et al. (2002) methods is based on co-limitation of TN and TP, and the results shown in Table F-7 are the TN concentrations required to achieve the target density under current TP level and the TP concentrations required to achieve the target density at the existing average TN concentrations.

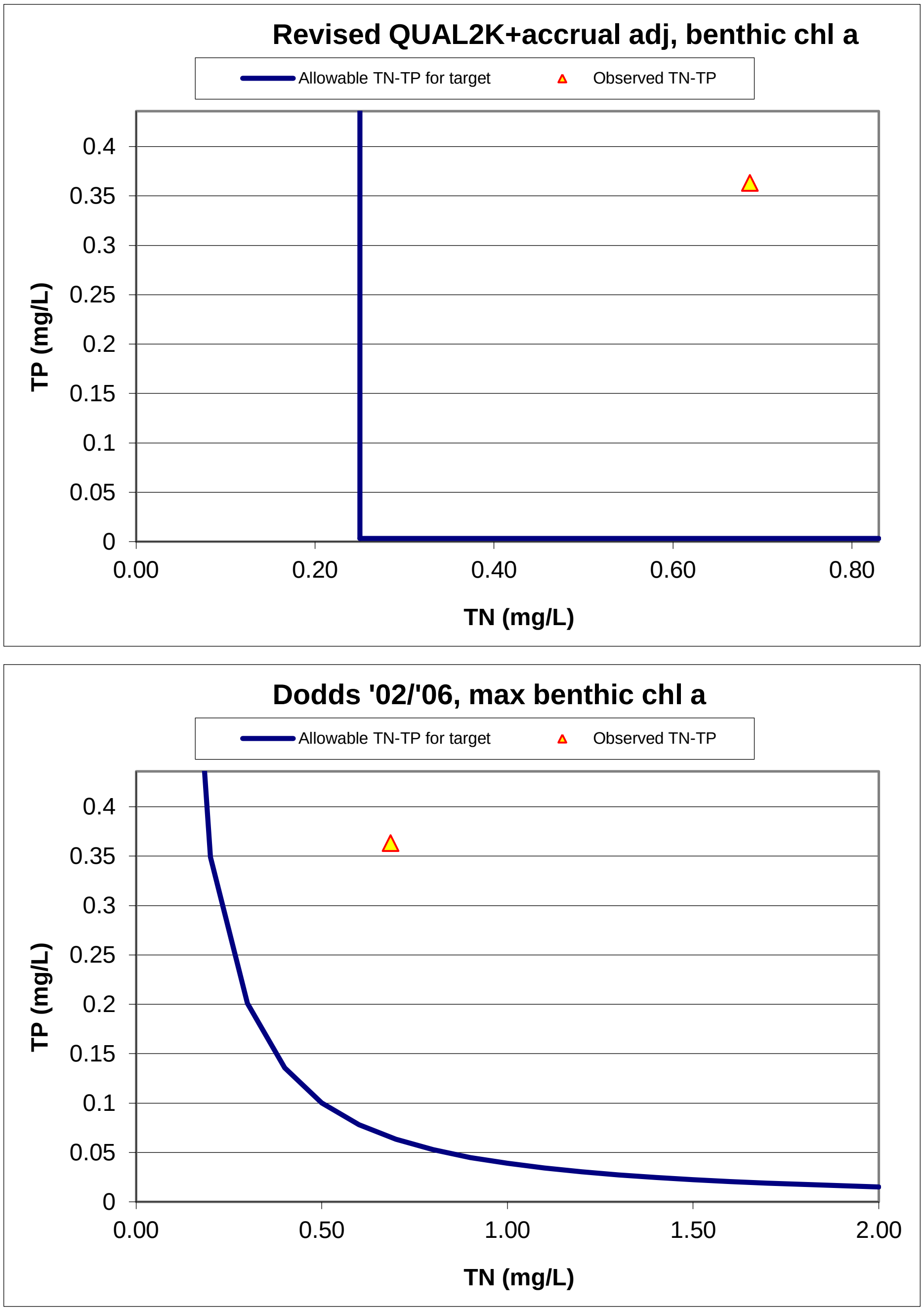

Figure F-3. Revised QUAL2K and Dodds et al. 2002 Tool Results for a Target Maximum of 150 mg/m2-Chlorophyll a at Malibu Creek below Tapia Shade Riffle Sub-habitat

Table F-7. Total Nitrogen and Total Phosphorus Targets (mg/L) to Achieve 150 mg/m^2 Maximum Benthic Chlorophyll *a*

Creek	Name/ Land Use	Habitat	Standard QUAL2K		Revised QUAL2K with Accrual Adjustment		Dodds et al. 2006	
			TN	TP	TN	TP	TN	TP
Medea Creek	Residential 1	Sun Riffle	0.57	0.0036	0.26	0.0033	0.32	0.0651
Medea Creek	Residential 1	Shade Riffle	1.56	0.0099	0.80	0.0185	0.32	0.0651
Medea Creek	Commercial 1	Sun Run	0.41	0.0050	0.32	0.0039	0.40	0.0303
Medea Creek	Commercial 1	Sun Riffle	0.40	0.0049	0.31	0.0038	0.40	0.0303
Medea Creek	Commercial 2	Sun pool	0.55	0.0041	0.27	0.0034	0.55	0.0242
Medea Creek	Commercial 2	Sun Run	2.29	0.0168	1.10	0.0260	0.55	0.0242
Medea Creek	Commercial 2	Sun Riffle	1.44	0.0105	0.79	0.0180	0.55	0.0242
Las Virgenes	Multiple 1	Shade Run	0.06	0.0030	0.31	0.0038	0.23	0.0094
Las Virgenes	Multiple 1	Shade Riffle	0.05	0.0026	0.26	0.0033	0.23	0.0094
Las Virgenes	Multiple 2	Sun Run	0.38	0.0194	NL	NL	0.21	0.0060
Las Virgenes	Multiple 2	Shade Run	0.11	0.0569	0.66	0.0155	0.04	0.0060
Las Virgenes	Multiple 2	Shade Riffle	0.05	0.0026	0.26	0.0033	0.21	0.0060
Malibu Creek	Below Tapia	Shade Run	0.65	0.0028	0.13	0.0022	0.19	0.0651
Malibu Creek	Below Tapia	Sun Riffle	0.87	0.0037	0.34	0.0041	0.19	0.0651
Malibu Creek	Below Tapia	Shade Riffle	0.67	0.0028	0.24	0.0031	0.19	0.0651

Note: The targets calculated by the Dodds method are for one nutrient with the other nutrient held constant and current levels; for the targets calculated by the QUAL2K-based methods control is predicted to be achieved if either the TN or TP target is met.

Predicted TN targets vary under different land uses and different habitat conditions (Table F-7). The predicted large variation in TN targets is in part a result of the highly variable light and temperature conditions observed among these sites. For the QUAL2K-based methods additional variability is introduced by the wide range of chlorophyll *a* to AFDM ratios. Estimated TN targets are mostly less than 1 mg/L, whereas the existing TMDL target is 1 mg/L of nitrate-N only. The analysis suggests that lower nutrient target values may be needed for sections of the streams with poor habitat integrity (loss of riparian zone) or high loading of nutrients as a result of human influence in the surrounding watersheds.

The QUAL2K-based methods (but not the Dodds method) produce targets of TN and TP that are *each* predicted to be sufficient to limit algal growth. Thus, it may be sufficient to achieve *either* the TN or TP target. The models also suggest that very low total phosphorus concentrations would be needed to achieve control of benthic algal growth by phosphorus alone (in many cases below 0.01 mg/L, Table F-7). As with nitrogen, the very low TP targets predicted by the QUAL2K-based methods are in large part due to the high chlorophyll *a* to AFDM ratios reported. Attaining the benthic algal density target based on control of total phosphorus alone might not be feasible at these low levels, as natural background phosphorus concentrations appear to be elevated, and reductions in total nitrogen may be the preferred management approach.

The Revised QUAL2K method appears to provide the most stable basis for setting targets. The Standard QUAL2K results are based on the observed relationship of inorganic nutrient to total nutrient concentrations, which are unlikely to be stable in time, while the Dodds method does not account for factors that influence light availability. In contrast, the Revised QUAL2K method is based on total nutrient concentrations and does

The availability of site-specific data allows the model to calculate site-specific nutrient targets based on nutrient levels and physical condition. The results suggest that appropriate targets vary widely among different land uses and sub-habitats, even for the same stream. For residential site sun riffle and shade riffle conditions, with similar ambient nutrient concentrations, the shade riffle sub-habitat has higher target TN and TP values due to the impact of physical condition (in this case shading). Canopy shading both limits light and reduces water temperature, resulting in the lower algal density that was observed (Table 2 and Table 3). As a result, higher nutrient targets are allowed for the shade riffle sub-habitat. The Commercial 1 site has high percentage of open canopy (90 % open canopy) and higher water temperature (over 30 deg C), which favor benthic algae growth and therefore the calculated nutrient targets for the site are low. For the Multiple 1 and Multiple 2 sites, high nutrient concentrations result in algae growth even under shade conditions. Therefore TN and TP values at these sites need to be reduced to very low levels in order to limit the algal growth. It is known that some diatoms are able to adapt to low light conditions. As indicated in Busse et al. (2003, 2006), the composition of algae vary among sites, with thick diatom and macroalgae dominating in more human influenced sites (Multiple sites, below Tapia). These sites also show higher chlorophyll *a* to AFDM ratios. Therefore, algal community structure is another factor influencing allowed nutrient targets. Overall, the lowest TN/TP target values were calculated at the Multiple 1 sites and the sites below Tapia.

USEPA (2000d) has suggested eco-regional nutrient criteria applicable to this area. Model results are compared to the USEPA statistical criteria and the summary of Region IX RTAG water quality monitoring in Table F-8. The range of targets derived from the CA NNE Scoping Tool for Malibu Creek cover the USEPA eco-regional criteria; however, the median target values derived using the Revised QUAL2K method are lower than the ecoregional criteria for both TN and TP. The median of the Revised QUAL2K TN targets falls between the lower quartile and median of the minimally impacted and unimpaired sites in the Region IX RTAG water quality monitoring data, but the median TP target is less than the lower quartile of these data – again suggesting that the TP targets may not be achievable. As was noted above, the low targets calculated for these sites are in part driven by the very high chlorophyll *a* to AFDM ratios.

Table F-8. Comparison of Model Results to USEPA Ecoregional Nutrient Criteria Recommendations and Region IX RTAG Water Quality Monitoring Data

Chemical	Stream Type	Proposed USEPA 304(a) Criterion – Level III ecoregion 6	Region IX RTAG Water Quality Monitoring Data (Tetra Tech, 2004)				
			Median	Average	Lower Quartile	Upper Quartile	No. of Data points
TN (mg/L)	Minimally Impacted		0.25	0.31	0.13	1.20	156
	Unimpaired		0.40	1.01	0.20	42.70	1425
	Impaired (nutrient)		0.7	1.06	0.40	11.00	868
	Impaired (other)		0.6	0.97	0.30	33.00	1486
	USEPA 304(a) (US EPA 2000d)	0.52					10
	CA NNE scoping tool	Revised QUAL2K median 0.31					
TP (mg/L)	Minimally Impacted		0.08	0.08	0.03	0.30	34
	Unimpaired		0.07	0.36	0.01	24.80	633
	Impaired (nutrient)		0.13	0.77	0.05	7.94	525
	Impaired (other)		0.07	0.34	0.03	45.10	1069
	USEPA 304(a) (US EPA 2000d)	0.03					23
	CA NNE scoping tool	Revised QUAL2K median 0.003					

F.3.4 Suggested Targets - Streams

The California NNE approach is a risk-based approach, with ultimate focus on supporting designated uses. The general NNE guidance and accompanying tools provided initial, scoping-level estimate of nutrient reduction targets that can be used as a starting point for a TMDL. The results may be superseded by detailed watershed models if these become available in future.

F.3.4.1 Response Targets

The California NNE approach (Tetra Tech, 2006) recommends setting response targets for benthic algal biomass in streams based on maximum density as mg/m^2 chlorophyll *a*. For the COLD and SPWN beneficial uses, the recommended BURC I/II boundary is 100 mg/m^2, while the BURC II/III boundary is 150 mg/m^2. Existing conditions in the Malibu Creek and its tributaries are clearly often above the BURC

II/III boundary, indicating impairment of these uses. For Las Virgenes and Medea Creek, COLD and SPWN are not the existing uses but are potential uses. The WARM use boundary of 150 mg/m^2 for BURC I/II can be applied. Therefore a target maximum benthic chlorophyll *a* of 150 mg/m^2 should be appropriate response target for the Malibu Creek and its tributaries.

F.3.4.2 Nutrient Targets

As shown in Table F-7, application of the tool to Malibu Creek watershed using site specific data yields variable results in TN/TP target for various land uses and sub-habitat, suggesting the large influence of land use and habitat conditions on algal growth. Therefore suggesting a single target for a particular stream is difficult given the large influence of land use and physical condition on benthic algae growth and the high variability in observed benthic chlorophyll *a* concentrations and AFDM. One approach would be to implement the lowest calculated target value for each stream; however, this would likely over-credit the ability of the tool to derive targets. A more robust approach may be to examine the median target across multiple sites.

Application of the Revised QUAL2K method with accrual adjustment at the 150 mg/m^2 chlorophyll a target suggests median TN concentration goals of 0.32 mg/L for Medea Creek, 0.26 mg/L for Las Virgenes Creek, and 0.24 mg/L for Malibu Creek proper. The corresponding TP goals are 3.9, 3.6, and 3.1 µg/L – however, the method estimates that impairment can be addressed by meeting *either* the TN or TP target. The very low target concentrations are in part driven by high chlorophyll *a*-to-AFDM ratios; however, minimum targets obtained using Dodds' regression equation are similar, and it may simply be the case that the target chlorophyll *a* density of 150 mg/m^2 is not a realistic goal for this waterbody.

An alternative calculation was also undertaken with a chlorophyll *a* target of 200 mg/m^2. This is the general BURC II/III boundary for the WARM beneficial use stated in Tetra Tech (2006), and is greater than the BURC II/III boundary of 150 mg/m^2 for COLD and SPWN. Use of a higher target for Malibu is possibly justified on the basis of site-specific geology. The resulting targets increase by 50 to 100 percent relative to the targets derived for 150 mg/m^2 – but are still quite low relative to existing conditions (Table F-9).

Table F-9. Total Nitrogen and Total Phosphorus Targets (mg/L) to Achieve 150 mg/m^2 Maximum Benthic Chlorophyll *a*

Creek	Name/ Land Use	Habitat	Revised QUAL2K with Accrual Adjustment	
			TN	TP
Medea Creek	Residential 1	Sun Riffle	0.41	0.0047
Medea Creek	Residential 1	Shade Riffle	1.20	0.0275
Medea Creek	Commercial 1	Sun Run	0.51	0.0059
Medea Creek	Commercial 1	Sun Riffle	0.49	0.0057
Medea Creek	Commercial 2	Sun pool	0.43	0.0049
Medea Creek	Commercial 2	Sun Run	1.90	0.040
Medea Creek	Commercial 2	Sun Riffle	1.20	0.0275
Las Virgenes	Multiple 1	Shade Run	0.49	0.0057
Las Virgenes	Multiple 1	Shade Riffle	0.41	0.0047
Las Virgenes	Multiple 2	Sun Run	NL	NL
Las Virgenes	Multiple 2	Shade Run	1.00	0.0235
Las Virgenes	Multiple 2	Shade Riffle	0.41	0.0047
Malibu Creek	Below Tapia	Shade Run	0.38	0.0044
Malibu Creek	Below Tapia	Sun Riffle	0.54	0.013
Malibu Creek	Below Tapia	Shade Riffle	0.39	0.0045

F.3.5 Discussion of Stream Results

The Malibu case study raises a number of important methodological questions for the CA NNE:

1. ***Definition of "maximum" density***

Several of the scoping methods are designed to predict maximum benthic algal density. What is meant by "maximum"? Use of the maximum ties back to the work of Dodds et al. (2002). There, maximum appears to be intended to represent the maximum algal growth potential (in response to nutrient and light availability) in the absence of temporary reductions in density due to grazing, scour, and other factors. It is thus intended to be a temporal maximum. It is not intended to be a spatial maximum in the sense of representing the single rock or other substrate that has the greatest algal growth within a transect. In other words, it should be a temporal maximum and a spatial average: the (temporal) maximum (spatial) average density. The Malibu sampling effort intentionally selected the surfaces with maximum algal growth, and also occurred in the August period when density appeared to be at a maximum. Under these conditions, the NNE tool predictions should be compared to the transect spatial average densities, recognizing that these densities may in some cases be biased upward relative to the average density across a transect.

2. *Ratio to Ash-Free Dry Mass (AFDM)*

Unlike the other case studies, the Malibu sampling measured AFDM. Some of the Malibu sites had very high chlorophyll *a*-to-AFDM ratios – especially for sites dominated by shade-tolerant diatoms. On the other hand, the QUAL2Kw-based scoping tools were "tuned" to results from the cross-sectional studies of Dodds et al. (2002, 2006), based on an assumed constant (and low) chlorophyll *a*-to-AFDM ratio of 2.5. One question this raises is if chlorophyll *a* density is really the appropriate indicator of impairment. When the ratio to AFDM becomes very high, a high chlorophyll *a* density may be associated with only a moderate biomass density. One alternative might be to assume that the true target is an AFDM of 60 g/m^2 when the target chlorophyll *a* density is 150 mg/m^2 (applying the default ratio of 2.5). Interestingly, a majority of the sampling sites were not found to exceed a AFDM density of 60 g/m^2 (Table F-2). Alternative targets calculated to achieve this AFDM target are shown in Table F-10. These are much higher than the targets presented above for sites with a high chlorophyll *a*-to-AFDM ratio, but converge to the low numbers derived relative to the chlorophyll *a* targets for sites where the ratio is lower.

Table F-10. Alternative Targets from Revised QUAL2Kw (with Accrual Adjustment) based on Achieving AFDM of 60 g/m^2

Creek	Name/ Land Use	Habitat	Revised QUAL2K w Accrual Adjustment	
			TN	TP
Medea Creek	Residential 1	Sun Riffle	0.70	0.017
Medea Creek	Residential 1	Shade Riffle	2.30	0.048
Medea Creek	Commercial 1	Sun Run	0.32	0.004
Medea Creek	Commercial 1	Sun Riffle	0.31	0.004
Medea Creek	Commercial 2	Sun pool	0.43	0.005
Medea Creek	Commercial 2	Sun Run	1.10	0.026
Medea Creek	Commercial 2	Sun Riffle	0.89	0.020
Las Virgenes	Multiple 1	Shade Run	2.30	0.047
Las Virgenes	Multiple 1	Shade Riffle	2.20	0.046
Las Virgenes	Multiple 2	Sun Run	2.60	0.054
Las Virgenes	Multiple 2	Shade Run	3.98	2.030
Las Virgenes	Multiple 2	Shade Riffle	3.43	0.174
Malibu Creek	Below Tapia	Shade Run	2.50	0.051
Malibu Creek	Below Tapia	Sun Riffle	1.20	0.028
Malibu Creek	Below Tapia	Shade Riffle	2.40	0.050

3. *Applicability to Diatoms*

As discussed in the previous item, some Malibu sites were dominated by shade-tolerant diatoms, with very high chlorophyll *a* densities even under fully-shaded conditions. Indeed, increasing the ratio of chlorophyll *a* to mass is an adaptive response to low light. Busse et al. (2003, 2006) found essentially no correlation between chlorophyll *a* density and light availability. In addition to the issue of the chlorophyll *a*-to-AFDM ratio raised above, the work of Dodds et al. appears to be mainly focused on filamentous algae. Applicability to diatom-dominated communities may be open to question.

4. *Planktonic Algae*

Two Malibu sites had significant amount of planktonic algae present in addition to benthic algae. Both floating and attached algae are competing for the available nutrients and light. Properly, both should be considered in the estimation of total algal density. Busse et al. attempted to account for this by estimating the area density of planktonic chlorophyll *a* – enabling an additive analysis. However, the empirical methods established for benthic algae may not be appropriate to planktonic biomass.

5. *Nutrient Concentration Variability*

As is typical in many studies, measurements of algal density were accompanied by simultaneous measurements of nutrients. This introduces a potential temporal disconnect, as the algal density is an integrative measure of nutrient availability over the preceding days and weeks. If the contemporaneous measures of nutrient concentration are not representative of prior exposure, misleading results can be expected. An additional complicating factor in the Malibu watershed is that there is significant documented diurnal variability in nutrient concentrations (Gilbert, 2009).

These issues impede the ability of the tool to predict observed algal densities. They do not necessarily affect the ability of the tool to estimate target concentrations.

F.4 NNE Tool Application - Lakes

Four lakes of the Malibu Creek watershed were listed for eutrophication problems (algae, nutrients, ammonia, low DO) – Malibou Lake, Lake Lindero, West Lake, and Lake Sherwood. All these lakes have existing or intermittent beneficial uses of REC1, REC2, WILD, and WARM. Among the four lakes, Malibou Lake has the highest observed chlorophyll *a* at 44 µg/L, exceeding the endpoint for REC2 and WARM uses.

F.4.1 BATHTUB Tool Application

The NNE BATHTUB spreadsheet tool was applied to all four lakes. The nitrogen and phosphorous loads to the lake as the required inputs to the spreadsheet tool were estimated as the total of loads coming from inflow tributaries and atmospheric deposition to lake surfaces. The predicted nutrient and chlorophyll *a* concentrations in the lakes compared well with the observed values (Table F-11). For Lake Sherwood, predicted and observed chlorophyll *a* concentrations are low, despite elevated nutrient concentrations, due to very high turbidity (Secchi depth of 0.4 m).

Table F-11. Predicted and Observed Nutrient and Chlorophyll *a* Concentrations in Lakes

	Sherwood		West Lake		Lindero		Malibou	
Constituents	**Observed**	**Predicted**	**Observed**	**Predicted**	**Observed**	**Predicted**	**Observed**	**Predicted**
Chlorophyll *a* (µg/L)	16	18.6	14	27.3	23	32.3	44	42.6
TP Concentration (mg/L)	0.25	0.46	0.16	0.21	0.13	0.17	0.14	0.17
TN Concentration (mg/L)	2.23	2.88	1.69	1.6	1.58	1.48	1.78	1.71

F.4.2 Suggested Targets - Lakes

The suggested nutrient numeric endpoints for planktonic algal biomass in lakes are 20 µg/L for REC1 and 25 µg/L for REC2 and WARM for BURC II/III boundary, and 10 µg/L for BURC I/II boundary. Here the tool was used to estimate TN/TP loadings and target TN/TP concentrations to meet a chlorophyll *a* target of 20 µg/L.

Table F-12 listed the predicted probability of exceeding the chlorophyll *a* target of 20 µg/L and the calculated TN loadings (under current TP loadings) and TP loadings (under current TN loadings) needed to meet the target. The target can be achieved by either reducing TN loadings or TP loadings. In the case of Lake Sherwood, current average concentrations are below the 20 µg/L target and algal growth is limited by light availability, so no reduction in nutrient load is needed to achieve the target.

Table F-12. Predicted Probability of Exceeding Chlorophyll *a* Target and Calculated TN/TP Loadings to Meet Targets

	Sherwood	West Lake	Lindero	Malibou
Probability of exceeding 20 µg/L under current loads	34.93%	71.59%	83.77%	95.30%
Calculated TN loading (kg/yr) to meet target at existing TP loading	light-limited	22,147	2,124	22,148
Calculated TP loading (kg/yr) to meet target at existing TN Loading	light-limited	1,734	147	1,334
TN at target (µg/L)	NA	967	771	557
TP at target (µg/L)	NA	76	55	34

For a chlorophyll *a* target of 20 µg/L, the BATHTUB-based tool predicted that the target will be exceeded 95 percent of the time in Malibou Lake. The predicted total nitrogen load to meet the target of 20 µg/L (if the total phosphorus load is held constant at 7,190 kg/yr) is about 22, 000 kg/yr, a 70% reduction from current load of 75390 kg/yr. The reduction in N load would result in an average predicted influent TN concentration of 0.59 mg/L and an in-lake TN concentration of 0.56 mg/L, both less than the proposed TMDL limit of 1 mg/L nitrate plus nitrite N. The chlorophyll *a* target can also be achieved by reducing total phosphorus load; however, this would require a reduction of more than 80 percent relative to existing load. The reduction of total P load would result in an influent total P concentration of 0.036, which is also lower than the proposed TMDL limit of 0.1 mg/L. The average TN and TP concentrations estimated to be consistent with the 20 µg/L target are less than the TMDL targets of 1 mg/L for nitrate plus nitrite N and 0.1 mg/L for total P, although there are substantial lake-to-lake differences that are reflective of their individual assimilative capabilities. The predicted targets for TN generally compare well to the median and average of unimpaired waters and are lower than the third quartile concentrations in RTAG monitoring data (Table F-13). Calculated total P targets were more consistent with the median and average of the unimpaired waters than total N targets. The 304(a) ecoregional recommendations for lakes have very limited data for Level III ecoregion 6; however, the aggregate recommendations for nutrient ecoregion 3 (USEPA, 2001) are 0.31 mg/L for total N and 0.017 mg/L for total P – in both cases lower than the targets derived using the BATHTUB tool.

Table F-13. Comparison of Model Results to RTAG Region IX Monitoring Data (Tetra Tech, 2004)

Chemical	Stream Type	Median	Average	First Quartile	Second Quartile	Third Quartile	Fourth Quartile	No of Data points
NO3 (mg/L)	Unimpaired	0.10	0.43	0.10	0.10	1.00	4.52	190
	Impaired (other)	0.70	1.88	0.23	0.70	2.60	15.81	28
TKN (mg/L)	Unimpaired	0.50	0.73	0.20	0.50	1.00	5.40	315
	Impaired (other)	0.50	0.96	0.30	0.50	0.80	9.40	107
TN (mg/L)	Unimpaired	0.60	1.16	0.30	0.60	2.00	9.92	
	Impaired (other)	1.20	2.84	0.53	1.20	3.40	25.21	
	CA NNE Scoping Tool	0.56 – 0.97						
TP (mg/L)	Unimpaired	0.03	0.08	0.03	0.03	0.08	3.00	252
	Impaired (other)	0.03	0.03	0.01	0.03	0.04	0.11	81
	CA NNE Scoping Tool	0.034 - 0.076						

F.5 Summary

The California NNE method and tools were successfully applied to the analysis of stream periphyton and lake planktonic algae in the Malibu Creek watershed. The standard and revised QUAL2K methods appeared to provide a reasonable fit to observed maximum periphyton density (as chlorophyll *a*). The application however suggested highly variable nutrient targets under different land uses and habitat conditions. Generally lower than 1 mg/L total nitrogen targets are required for stream segments with human influence in the surrounding watershed to achieve a maximum periphyton density of 150 mg/m^2. The four lakes also appear to require total nitrogen less than 1 mg/L.

The 2003 nutrient TMDL for Malibu Creek watershed (USEPA Region IX) with a target nitrate-plus-nitrite nitrogen concentration limit of 1mg/L (and no limit on total nitrogen) and phosphorous limit of 0.1 mg/L is greater than the total nitrogen targets estimated for this watershed using the CA NNE tools. It is acknowledged that NNE tools provide a scoping-level analysis of nutrient targets, and should be superseded by a site-specific calibrated nutrient model where available.

The analysis for both stream and lake sites suggest that the TMDL criteria (USEPA, 2003) for the Malibu Creek watershed of 1 mg/L nitrate plus nitrite N and 0.1 mg/L total phosphorus (from April 15 to November 15) may not be adequate to support uses. As a postscript to this analysis it is noted that continued monitoring of Malibu Creek by Heal the Bay through 2010 has not revealed any excursions of the nitrate plus nitrite goal during the growing season since 2005. In contrast, phosphorus concentrations have remained high. The monitoring does not appear to show improvement in mat algal coverage, which continues to be greater than 60 percent in many samples.

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Appendix G. Stressor Identification Analyses

The linkage analysis identifies the connection between environmental responses and the pollutant sources and is used to construct and support the cause-and-effect model between the selected response indicators, stressors, and identified stressor sources; this model is then used to support the associated numeric targets for the stressors. These analyses provide the basis for estimating total assimilative capacity and any needed load reductions. Additional background information is provided in Appendix E, which summarizes some key studies in the watershed. A hypothetical linkage analysis example is presented in Section G.3 to illustrate how this approach considers the multiple variables to determine the critical stressors and causes.

G.1 Stressor Identification

Macroinvertebrates are a critical part of the ecosystem structure of streams and estuaries. This diverse fauna inhabits the full breadth of aquatic habitats, control algal and detrital resources, and provide a food source for fish, birds, and other animals; in so doing, they have a role in recycling nutrients and supporting the production of commercially and recreationally valuable vertebrate species. Benthic macroinvertebrates include taxa in all consumer categories including herbivores, detritivores, predators, omnivores, and parasites. Additionally, they feed from a variety of food sources using a variety of functional methods that frequently are used in classification. These include filter feeders (collecting plankton or fine organic particulates from the water column or benthos), shredders (consuming terrestrial plant material in the stream), scrapers/grazers (consuming algae/plants from submerged surfaces), piercers (sucking plant or animal fluids), and predators.

As with other taxonomic groups, macroinvertebrates include many species that are sensitive to pollutants and others that are tolerant. Some will tolerate low dissolved oxygen conditions better than others, for example, some midges (Diptera – Chironomidae) typically tolerate very poor conditions while stoneflies (Plecoptera) require well-oxygenated water. Some taxa are highly tolerant to multiple stressors (e.g., many chironomids), while others are highly sensitive to many stressors (many Plecoptera and Ephemeroptera). Benthic macroinvertebrates frequently do not exhibit a large spatial range. Consequently, they often cannot escape stressors in the same manner as animals capable of migrating over a larger range. Moreover, aquatic insects exhibit varied lengths during which they exist in aquatic life stages. Some are aquatic for their entire life histories (e.g., the predaceous diving beetle, *Thermonectus* sp.), while most emerge as adults after some time period. The aquatic stage of some benthic macroinvertebrates is very short (e.g., mosquitoes, Diptera – Culicidae, which may last only a few days) while for many it is long, often greater than one year (e.g., some dragonflies, Odonata, which may last up to four years) (Merritt et al. 2007). These life history traits allow the benthic macroinvertebrate assemblage to integrate the cumulative effects of stressors impacting a waterbody. As a result of their diversity, habitat breadth, ecosystem importance, life histories, and sensitivity, the richness and abundance of macroinvertebrates are good indicators of water quality condition and overall water quality (e.g., Barbour et al. 1999). Under minimally disturbed reference conditions, ecosystems will contain a balanced diversity and abundance of taxa consistent with the limitations presented by the available resources and natural environmental variability alone. As anthropogenic disturbance occurs, the natural environmental condition is altered, novel stressors are introduced, and the macroinvertebrate assemblage changes.

Several methods for evaluating biological condition were presented in Section 8 of the TMDL report. Of these, the SC-IBI scores are lower for impacted sites compared with comparator/reference sites: average SC-IBI scores range between approximately 20 and 25 for impacted sites, compared with scores between 55 and 65 for comparator/reference sites. Similarly, pMMI scores are lower for impacted sites compared with comparator/reference sites: average pMMI scores for impacted sites are approximately 0.53, compared with average scores of 0.96 for comparator/reference sites. O/E scores do not show the same pattern, but the O/E model had low predicted E values in the Malibu Creek watershed and did not incorporate geological predictors, both factors important in interpreting the validity of the O/E model scores in this watershed.

This evaluation of the extensive benthic macroinvertebrate data show that the assemblages in Malibu Creek and Lagoon have been adversely affected and have changed from that expected in the absence of human disturbance. Since a single stressor was not identified as the source of benthic assemblage degradation during the listing of the impairment, USEPA conducted a detailed and structured examination of the potential stressors to identify candidate causes of impairment. To accomplish this, the methodology outlined in USEPA's Stressor Identification Guidance (SIG) (USEPA, 2000b), which constitutes volume 1 of the Causal Analysis/Diagnosis Decision Information System (CADDIS; http://www.epa.gov/caddis/) is followed in this section.

G.1.1 Stressor Identification Process

The ability to accurately identify stressors and defend those findings with evidence is an important step in developing strategies to improve the quality of aquatic resources. The SIG lays out a detailed and rigorous approach for identifying the stressor or combination of stressors causing biological impairment in aquatic ecosystems while providing a structure to organize the scientific evidence supporting the conclusions. The objective of the SIG process in this TMDL is to identify the primary pollutant stressors causing the adverse changes observed in the benthic assemblage.

The Stressor Identification approach involves the following steps:

1. List Candidate Causes
    a. Identify stressor sources
2. Analyze Evidence of the following types, depending on availability:
    a. Measurements of the causes and responses in the Malibu Creek Watershed;
    b. Measurements of similar causes and responses outside of the Malibu Creek Watershed;
    c. Measurements of exposure at the site;
    d. Measures of effects from laboratory studies; and
    e. Site measurements and intermediate steps in a chain of causal processes.
3. Characterize Causes
    a. Eliminate Alternatives
    b. Diagnostic Analysis
    c. Strength of Evidence Analysis
    d. Identification of Probable Cause

The following section briefly reviews these three major steps.

G.1.1.1 List Candidate Causes

The first step in investigating the potential causes of the degraded benthic macroinvertebrate assemblage is to develop a list of potential causes.

In this TMDL, the listed impairments are sedimentation and benthic macroinvertebrate community, which may be stressed by multiple factors, such as:

- Degraded habitat,

- Physical stressors that cause deviations from natural conditions,
- Degraded water quality conditions (e.g., low DO, excessive nutrient levels, temperature, toxic ions etc.), or
- Invasive species.

Furthermore, habitat is itself an integrative indicator as degraded habitat can be caused by factors such as flow alteration, increased sedimentation or poor sediment quality, increased erosion, or excess algal density that reduces favorable habitat conditions.

During this step of the stressor identification, a conceptual model is developed, describing the pathways by which stressor sources generate stressors that impact the benthic macroinvertebrate assemblage. Proximate and interacting stressors and stressor sources are identified. Proximate and interacting stressors (termed Major Stressors in this document) are conditions that occur at an intensity, duration, and frequency of exposure that results in a change in ecological condition. Sources, which are evaluated in Section 2 of this Appendix, are origins of stressors that release or impose a stressor into a waterbody. This conceptual model helps guide the analyses and characterizations.

G.1.1.2 Analyze Evidence

Analyzing evidence requires reviewing the potential relationships between candidate causes and observed impairments to determine if the causal pathway from stressor to impairment is complete. For a causal pathway to be considered complete, a stressor must be present and linked with the resulting impairment. Ideally, evidence from the site comprises the body of the weight of evidence supporting the causal relationship. In many cases, however, sufficient data may not be available from the site to support the entire causal pathway. Additional information from other, similar sites and from laboratory studies may be used to evaluate the strength of the causal relationship. For each potential stressor, this section asks the following questions:

1. Are there associations between measurements of the candidate causes and the observed impairment effects? Do the cause and effect occur at the same time or place? If the cause is not present, is the effect also not present? Is the intensity of the causal factor related to the magnitude of the effect?
2. Do studies performed elsewhere indicate a causal relationship between the candidate cause and the observed impairment effects?
3. Are there intermediate measurements that are associated with the causal mechanism that can proxy for measurements of the cause itself?

This section of the Linkage Analysis produces the information necessary to complete the following section, Characterize Causes.

G.1.1.3 Characterize Causes

This third step evaluates the evidence previously assembled to reach a conclusion and state the levels of confidence in the conclusion. All the types of evidence described above are considered.. This step relies on three substeps:

1. eliminate candidate causes for which case-specific evidence clearly indicates the causal pathway is not supported;
2. diagnose candidate causes for which case-specific evidence clearly and specifically indicates a candidate cause; and finally,
3. perform a strength of evidence analysis.

G.1.1.3.1 Eliminate

The first sub-step is to eliminate those alternatives in which the evidence does not support a significant role in the observed impairment. Elimination of potential causes requires care, as the dominance of one cause may mask other sufficient causes. Only causes where lack of evidence for causality is unambiguous should be eliminated.

G.1.1.3.2 Diagnose

A further technique to narrow the list of candidate causes is to consider diagnostic analyses. Whereas the elimination step relies on negative evidence (e.g., an exposure pathway *is not* present), diagnostic analysis relies on positive evidence (e.g., a particular symptom *is* present). The diagnostic approach is most appropriate for stressor identification when organisms are available for examination, the candidate causes are familiar enough that protocols have been established, and there is a high degree of specificity in the cause, the effect, or both.

G.1.1.3.3 Strength-of-evidence Analysis

This step uses the information developed in the data analysis to evaluate the strength of evidence for a candidate cause having an effect on biological responses. In general, the strength of evidence analysis laid out in the SIG (USEPA, 2000b) follows principles derived from epidemiology ("Hill's Criteria").

The first four case-specific considerations directly evaluate an observed case: *co-occurrence*, *temporality*, *biological gradient* and *complete exposure pathway*. *Co-occurrence* is observed when the cause and the effect occur in the same location. For example, if a discharge is found to contain toxic metals and the benthic macroinvertebrate assemblage near the discharge contains only a few, very tolerant individuals when the upstream assemblage contains a highly abundant and diverse population, there is evidence of co-occurrence. In other words, the effect occurs where the presumed cause occurs, and does not occur where the presumed cause is absent. *Temporality* is observed when the cause precedes the effect. In other words, the toxin must have been discharged before the assemblage became impaired. If the assemblage were impaired prior to the toxin being discharged, while the toxin likely would limit or even prohibit restoration efforts, it's not the cause of the initial impairment. *Biological gradient* is observed when the effect increases with increasing exposure and decreases with decreasing exposure. As the discharged toxin becomes diluted downstream, the benthic macroinvertebrate assemblage might gradually recover with decreasing concentration of the toxin in the water. Lastly, a *complete exposure pathway* is observed when all the necessary links indicate that the stressor is able to reach the receptor. If the discharged toxin is a highly reactive chemical (e.g., hydrogen cyanide), it might enter the discharge stream but react with other components of the discharge while still in the pipe, rendering it non-toxic prior to reaching the outlet. In this case, the exposure pathway is incomplete.

The next four considerations combine information from the case at hand: *plausibility*, *specificity*, *analogy*, and *predictive performance*. A cause and effect relationship is considered *plausible* when it would be expected, given known facts. Again using the discharged toxin example, the hypothesis that the toxin is the cause of the benthic macroinvertebrate assemblage is plausible if the toxin is known to be toxic to the organisms that are found upstream but not near the discharge, based on laboratory studies or field experiments. Other indications of plausibility include a known mechanism by which the toxin causes the observed effect (e.g., cyanide is known to bind strongly to hemoglobin, preventing oxygen from binding), or a known stressor-response relationship (e.g., a metal that is a micronutrient, like selenium, is required by some organisms in low concentration, but as the concentration increases, a toxic effect is observed, leading up to a concentration that causes death). The relationship is said to be *specific* when the observed impact is associated with only one or a few potential causes. The best example of specificity is mesothelioma, a type of cancer that with only rare exceptions occurs as a result of asbestos exposure. (The SIG guidance shows the specificity consideration as applicable to specific symptoms and biomarkers only. This type of evidence is not available for the Malibu Creek Watershed, so the topic is omitted from the strength of evidence presented below.) A stressor may be *analogous* to other, well-established cases. If the toxin of concern is structurally similar to other chemicals of known toxicity (e.g., a halogenated pesticide that is similar to chlorinated pesticides known to be toxic to benthic macroinvertebrates), by analogy, the toxin is likely to be the cause of impairment. Lastly, a stressor may demonstrate *predictive performance* if it is predicted to cause an initially unobserved effect in the receptor. For example, if the toxin suspected to be the cause of the impairment has a specific mechanism of toxicity with a known intermediate and that intermediate is subsequently identified in studies of organisms affected at the site, the toxin exhibits predictive performance.

The last two considerations evaluate the relationships among all of the available lines of evidence: *consistency* (agreement among all lines of evidence), and *coherency of evidence* (whether a conceptual or mathematical model can explain any apparent inconsistencies among the lines of evidence). A proposed causal element is said to show *consistency* when the lines of evidence described above all support the hypothesis that the stressor is the cause of impairment. When there are inconsistencies among the many lines of evidence, if there is a model that explains those consistencies, the stressor is said to be *coherent* with the evidence. For example, the toxin may not be fully bioavailable to some benthic macroinvertebrates, causing only a partial impairment.

G.1.2 List Candidate Causes

Unlike the simple hypothetical example presented in Section G.3, the various potential causes of impairment in Malibu Creek and Lagoon interact with one another in complex ways. Candidate causes (as identified in preceding sections) and key linkages to impaired biology are summarized in a Malibu Creek Watershed site-specific conceptual model (Figure G-1). The items shown at the top are the major human activities and natural conditions that may produce the candidate stressors. These stressor sources have hypothesized links to responses through a variety of causal pathway steps (including interacting stressors and modifying factors) that lead to proximate stressors and ultimate biological responses. For example, channel sedimentation is a proximate stressor impacting stream biology that itself is related to a number of stressor sources (e.g., altered hydrology, channel erosion, urban and agricultural runoff) and human activities (e.g., urbanization, dam management, and agriculture). Note that only a few of the many interactions are explicitly shown in this figure. For example, turbidity can affect algal growth by limiting light availability, but this linkage is not shown in order to reduce the complexity of the diagram.

Stressors are conditions that occur at an intensity, duration, and frequency of exposure that results in a change in the ecological condition (USEPA, 2000b); they can be either proximate or interacting, as shown in Figure G-1. The list of candidate stressors below presents both proximate and interacting stressors to better separate and identify the likely causes of biological impairment in Malibu Creek and Malibu Lagoon. Based on the analyses in the preceding sections of this report, there are five major stressors that are potential causes of biological impairment in Malibu Creek and Lagoon. These are:

A1. **Reduced Habitat Quality from Sedimentation**: Excess sedimentation is documented in Malibu Creek and Lagoon, and is a known cause of habitat degradation with likely adverse impacts on benthic macroinvertebrates (Harrison et al. 2007). Wood and Armitage (1997) provide the following summary of major sedimentation impacts: “Fine sediment suspension and deposition affects benthic invertebrates in four ways: (1) by altering substrate composition and changing the suitability of the substrate for some taxa…; (2) by increasing drift due to sediment deposition or substrate instability…; (3) by affecting respiration due to the deposition of silt on respiration structures… or low oxygen concentrations associated with silt deposits…; and (4) by affecting feeding activities by impeding filter feeding due to an increase in suspended sediment concentrations…, reducing the food value of periphyton…, and reducing the density of prey items.” Sand deposition is also problematic as it provides an unstable substrate and can impede upstream migration or smother benthic communities. Because sediment-related habitat metrics are low, sediment appears to be a plausible cause of stress in Malibu Creek main stem. Increased sediment transport also impacts habitat in Malibu Lagoon by filling in and aggrading the lagoon. In addition to direct impacts on benthic habitat quality, the reduced water volume can increase temperature and dissolved oxygen stresses on lagoon benthic biota.

A2. **Reduced Habitat Quality from Excess Algal Growth**: Excess algal growth associated with nutrient enrichment has long been observed in the Malibu Creek watershed. Sikich et al. (2012) note that high nutrient concentrations in the watershed are likely to contribute to the excessive algal growth observed throughout the watershed, with mat algal cover exceeding 30% at almost all of Heal the Bay's monitoring sites. Excess algal growth can cover suitable habitat (Allan, 1995) and may depress overall invertebrate taxa richness (Yuan, 2010), or shift invertebrate assemblage composition toward grazers and scrapers (Feminella and Hawkins, 1995; Quinn et al., 1997).

A3. **Reduced DO from Excess Algal Growth or Oxygen-demanding Wastes**: Low DO has been observed in both Malibu Creek and its tributaries, although observations of daytime DO meet the minimum DO criterion most of the time (see Section 7.2 of the TMDL report). Data show that early morning DO levels are well below the criterion for some pools in lower Malibu Creek. Additionally, Sikich et al. (2012) report that the Malibu Lagoon "suffers low Dissolved Oxygen (DO) levels…In a 2005 study [Briscoe et al., 2002], pre-dawn dissolved oxygen concentrations averaged 1.15 ± 0.12 mg/L SE, significantly below Basin Plan thresholds." Reduced DO may result from excess algal growth. It can also be caused by discharges of oxygen demanding wastes, such as decomposable or labile organic matter, and is exacerbated by elevated water temperatures, which in turn may be linked to impervious surface runoff, impoundments, and removal of riparian vegetation. Regardless of the cause of low DO, benthic macroinvertebrates require adequate DO for survival, and low DO is a stressor that can potentially cause biological impairment.

A4. **Toxicity from Metals or Organic Toxics**: Occasional water column toxicity has been reported for Malibu Creek since 2005 (Brown and Bay 2005). In Malibu Lagoon, two sediment sites out of eight exhibited toxicity (Meyers et al., 2001). A variety of substances, including various metals, ammonia, and organic chemicals such as pesticides, herbicides, and petroleum products can cause acute (e.g., lethality) or chronic toxicity (e.g., reduced reproductive success) in benthic macroinvertebrates. In many watersheds, toxicity is most commonly associated with anthropogenic loads (wastewater discharges, urban runoff); however, in some instances, it may also reflect naturally elevated water column or sediment concentrations for some chemicals. For instance, sulfate and selenium concentrations are naturally elevated in the Malibu basin due to its geology (LVMWD, 2011).

Stormwater in Malibu Creek often has elevated toxicant concentrations. Those increased pollutant levels have been shown at times to have deleterious effects based on toxicity tests in Malibu Creek (see Section 8.5 of the TMDL report). Monitoring data also indicate that selenium exceeded acute standards in 63 percent of the dry weather samples and exceeded chronic standards in approximately half the wet samples reported at LACDPW's mass emission station on Malibu Creek from 2003-2010. Sulfate acute and chronic standards were exceeded in approximately half of both the wet and dry samples. The toxicity analyses of Brown and Bay (2005) described in Section 8.5 of the TMDL report suggest that sulfate and other dissolved salts were the likely cause of observed dry and wet weather toxicity.

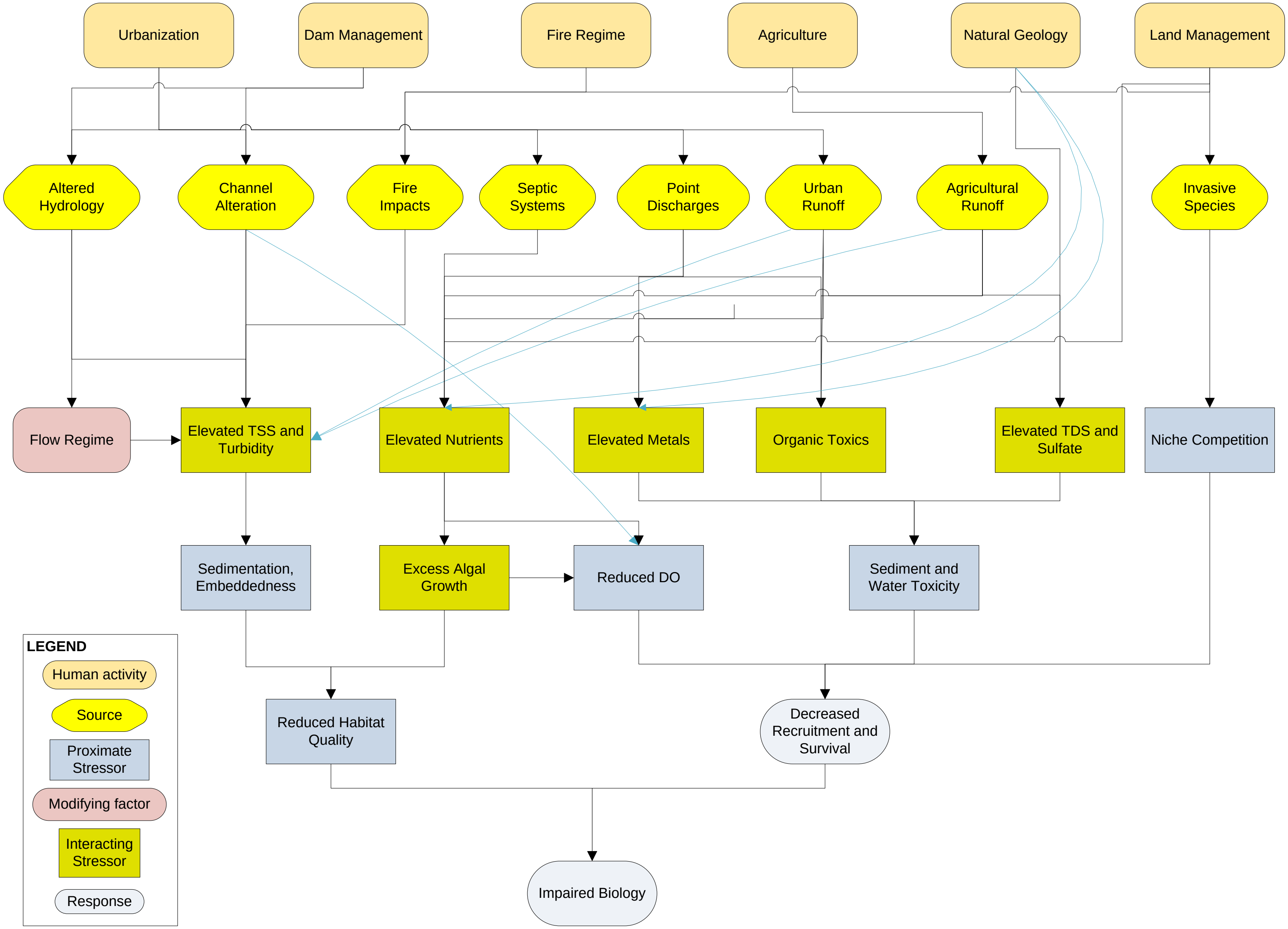


Figure G-1. Conceptual Model of Candidate Causes of Impaired Biology in Malibu Creek and Lagoon

A5. **Niche Competition from Invasive Species**: New Zealand mudsnails have been observed in Malibu Creek since 2005, and are spreading in the watershed. Abramson et al. (2009) report that the New Zealand mudsnail "colonies disrupt the food web by displacing native aquatic invertebrates that fish and amphibians rely on for food" and have been found on more than 70 percent of substrate samples in Malibu Creek. Other non-native invasive plants and animals, including red swamp crayfish, bullfrogs, and mosquitofish, are also reported in the watershed (Sikich et al., 2012). In general, invasive species impair native ecosystems by outcompeting native species for resources such as food or habitat, ultimately reducing species diversity (Strayer, 2010).

G.1.3 Analyze Evidence and Characterize Causes

The previous section, "List Candidate Causes" identified stressors that are present in the impaired watershed and that may have been responsible—either singly or in combination—for the biological impairment. This section presents an analysis of the evidence for each of the five major sets of interacting and proximate stressors that were potential causes of biological impairment in Malibu Creek and Lagoon. Later, potential sources are identified and linkages between them and stressors that have not been eliminated in this section are evaluated (Section G.2). The strength of evidence for each candidate cause is presented within this discussion, to maintain coherence between the presentation of the evidence and the conclusions drawn from it. Additionally, Section G.1.4 summarizes the Characterization and presents the results in tabular format.

Each of the stressors listed as candidate causes above are discussed with respect to the evidence supporting or refuting them as possible causes of benthic macroinvertebrate impairment in Malibu Creek and Lagoon, regardless of the possible sources of the stressors.

A1. Reduced Habitat Quality from Excess Sedimentation: Possible sources of excess sedimentation include altered hydrology (B1), channel alteration (B2), fire impacts (B3), urban runoff (B5) including construction site impacts (often resulting from urban development), agricultural runoff (B7), or natural geology (B8). Each of these sources is discussed in Section G.2; construction site impacts are discussed with urban runoff (B5). Figure G-2 shows the linkage between excess sedimentation and impaired biology, along with the possible sources.

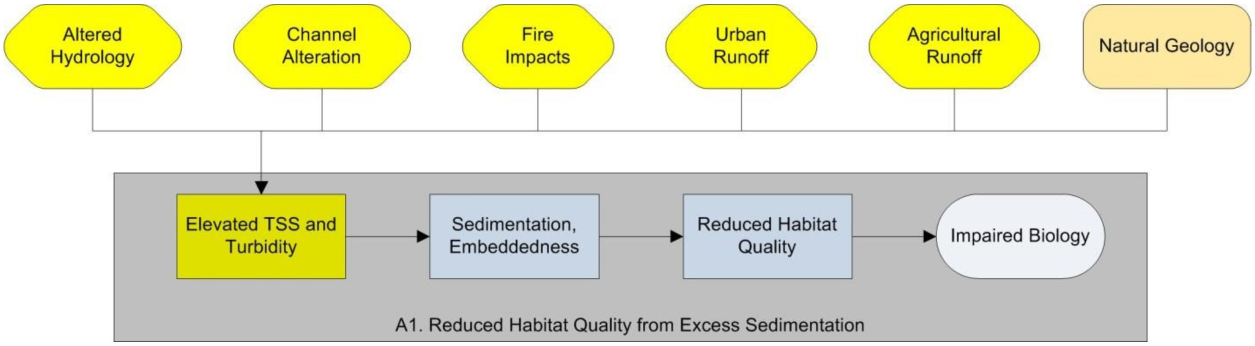


Figure G-2. Illustrated Linkage between Excess Sedimentation and Impaired Biology

The following general information on sedimentation is excerpted from USEPA's CADDIS website (USEPA, 2012):

> *High suspended sediment concentrations can adversely affect aquatic biota by four main pathways: (1) impairment of filter feeding, by filter clogging or reduction of food quality; (2) reduction of light penetration and visibility in the stream, which may alter interactions between visually cued predators and prey, as well as reduce photosynthesis and growth by submerged aquatic plants, phytoplankton, and periphyton; (3) physical abrasion by sediments, which may scour food sources (e.g., algae) or*

> *directly abrade exposed surfaces (e.g., gills) of fishes and invertebrates; and (4) increased heat absorption, leading to increased water temperatures. Deposited and bedded sediments may lead to biological impairment by three main pathways: (1) increased coverage by fine particles, which can alter benthic habitats (e.g., increasing fine substrate habitats favored by burrowing insects and tolerated by nest cleaning fishes, or reducing deeper pool habitats) and bury relatively sessile taxa and life stages (e.g., fish eggs); (2) clogging of interstitial spaces, leading to reduced interstitial flows and habitats; and (3) reduction of substrate size, leading to reduced substrate diversity and stability. Deposited sediments can have indirect effects by reducing oxygen levels either with restricted flow through streambed substrates or by oxygen consumption by bacterial respiration, especially when sediments contain a high concentration of organic matter.*

Many other examples from the literature support the adverse effects of sedimentation on aquatic biota. For example, Wood and Armitage (1997) indicate that sedimentation predominantly impacts primary productivity, faunal diversity, and abundance. Dudgeon (1994) and Armitage (1995) found that increases in fine sediment favor chironomids and oligochaetes. Sensitive Ephemeroptera, Plecoptera, and Trichoptera taxa are most commonly adversely affected (Harrison et al., 2007).

Malibu Creek

Increased sediment loads can arise from both upland and channel sources. Upland sediment loading rates are expected to be naturally high in the steeper portions of the Malibu watershed due the geologically rapid uplift of the Santa Monica Mountains (see Section 4.4 of the TMDL report). Human activities such as historic ranching or modern development may have increased upland erosion rates. However, the combination of naturally high sediment supply and the low gradient of the Malibu Creek mainstem and other valley streams in the watershed means that sediment movement and delivery through the stream network is primarily limited by flow energy, rather than by sediment supply.

In developed watersheds, sedimentation problems are strongly associated with changes in the flow regime that increase sediment transport capacity and cause channel instability. Sediment related problems are frequently associated with areas in the watershed that have increased response to storms due to increases in impervious surface cover, especially where incision, riparian disturbance, or channel alteration have led to unstable banks (see evidence from USEPA physical habitat sampling)-. Increased impervious surface in a watershed can cause increased peak runoff, increased flow energy, channel erosion and subsequent sedimentation impacts. During storms, water runs off impervious surfaces quickly, rather than infiltrating into the ground and slowly draining to streams through groundwater. Rapid runoff increases stream channel flow and power, exacerbating downstream channel erosion and contributing to increased sediment loads (Trimble 1997, Coats et al. 2008, Walsh et al. 2007).

Another factor that may contribute to channel instability is the presence of impoundments, such as Lake Malibou. Dams trap sediment and starve downstream channels of the natural sediment load. High flows passing a dam with reduced sediment load exert increased erosional pressure on stream banks contributing to eventual bank failure, sedimentation, and channel adjustments downstream (Ligon et al. 1995, Brandt 2000, and Wohl and Rathburn 2003). Therefore, increased imperviousness in the watershed, lake sediment storage, and lake discharge would lead to increased runoff, erosion, and sedimentation from already unstable banks and poorly vegetated riparian areas along Malibu Creek main stem.

Elevated suspended sediment concentrations occur on an intermittent basis in Malibu Creek, primarily in association with winter storms. The evidence of the impacts of sedimentation is better documented than suspended sediment concentrations.

Measures of sedimentation include total suspended solids (TSS), suspended sediment concentrations (SSC), turbidity, and physical habitat scores. TSS monitoring data are limited for Malibu Creek. Elevated TSS or SSC concentrations during storm flows are documented for the main stem (at two sites, by USEPA and LACDPW), but TSS data are not available for most other biological sampling sites and therefore do not provide sufficient information for a comparative analysis of evidence. On the other hand, turbidity data are routinely collected by Heal the Bay, predominantly during dry weather. Heal the Bay sites with impaired bioscores on the mainstem (e.g., MC1, MC12, and MC15) all show increased turbidity relative to the comparator/reference sites, with averages at the impacted sites ranging from 1.31 to 2.62 NTU compared to 0.27 to 0.75 NTU at the comparator/reference sites (the averages are low because these are dry weather samples).

Erosion and sedimentation rates are naturally high in the watershed due to the geology, including the comparatively rapid uplift of the Santa Monica Mountains. High natural sedimentation rates are shown by the rapid filling of the pool behind Rindge Dam between 1929 and 1949, prior to major development in the watershed (Ambrose and Orme, 2000). These natural characteristics place the watershed at high risk of excess sedimentation associated with increases in flow volume and flow energy associated with increased impervious surfaces. Excess sedimentation relative to natural conditions has been demonstrated by increased net sedimentation rates in the Lagoon versus historic natural rates (see below). Furthermore, Heal the Bay's Stream Walk program reported that 21.29 miles of 68 surveyed stream miles were impacted by excess fine sediments. Only 0.29 miles of the impacted streams occurred upstream of developed areas. Biological impairment largely occurs in or downstream of areas where excess sedimentation was observed.

Rapid Bioassessment Protocol (RBP) Physical Habitat scores (collected by Heal the Bay, LVMWD, and others), which aggregate ten individual scores including embeddedness, sediment deposition, and bank stability (a measure of erosion potential), range from marginal to optimal on the Malibu Creek mainstem and overlap the range seen at relatively unimpacted comparator/reference sites. Sites with lower average RBP scores tended to have received poor or marginal ratings on the embeddedness, sediment deposition, and riffle frequency measures. The 2005 Malibu Creek Bioassessment Monitoring Program Report (Aquatic Bioassay, 2005) concluded that, for the four sites rated optimal or sub-optimal (of eight total sites), "stressors other than habitat conditions may have impacted these sites." Statistical analyses show that around 45 percent of the variability in bioscores (SC-IBI and pMMI) for the non-mainstem sites is explained by differences in physical habitat scores. Tributary and mainstem sites have similarly poor bioscores at sites with low physical habitat scores; however, the mainstem sites do not show a corresponding improvement in bioscores at sites with higher physical habitat scores, again suggesting that the benthic macroinvertebrate assemblage is limited by multiple factors, including factors other than physical habitat.

USEPA examined the component metric, EPT Taxa, one of the metrics used to form the SC-IBI. Ode et al. (2005) identified the component "EPT taxa count" as a particularly strong indicator of impairment (with < 10 taxa indicating impairment in the southern California mountains). Other similar analysis of benthic macroinvertebrate metrics in Malibu Creek Watershed and nearby Calleguas Creek Watershed similarly showed that certain metrics, such as the EPT Taxa, were better at reflecting impairment (Lin, 2002; Luce et al., 2003). This metric typically shows a strong relationship to most sources of impairment, including nutrients and sedimentation. For Malibu Creek, EPT taxa counts at impacted sites that do not drain the Monterey/Modelo Formation in Malibu Creek were demonstrably lower than at comparator/reference sites having relatively low specific conductivity; however, EPT taxa counts were also low at comparator/reference sites within the Monterey/Modelo Formation area that have elevated specific conductivity. The main stem stations have much lower EPT taxa counts than the Lachusa and Solstice reference/comparator stations; the EPT taxa count at Cheseboro Creek (with elevated conductivity and minimal urban development) also shows lower taxa counts (Figure G-3). This suggests that EPT taxa count, specifically, may be sensitive to the high conductivity associated with marine sedimentary geologic formations in the watershed, in addition to other development related sources. But, it is noted that the Solstice comparator/reference sites also drains the Monterey/Modelo Formation region, and is influenced by the natural geologic marine formation. Furthermore, Malibu Creek main stem bioscores are low, and yet, the conductivity levels in Malibu Creek are lower than those observed in the Monterey/Modelo Formation. Luce (2003) conducted multiple regression analyses of SC-IBI's relationship with other multiple benthic macroinvertebrate measures, such as habitat and chemical variables and found a significant *negative* relationship between EPT Taxa and percent embeddedness. Her study did not find a relationship between benthic macroinvertebrates and EPT taxa. These results suggest that, at least for the Malibu Creek Watershed, EPT taxa, as a standalone metric, provides confounding information, and does not explain the overall benthic macroinvertebrate condition.

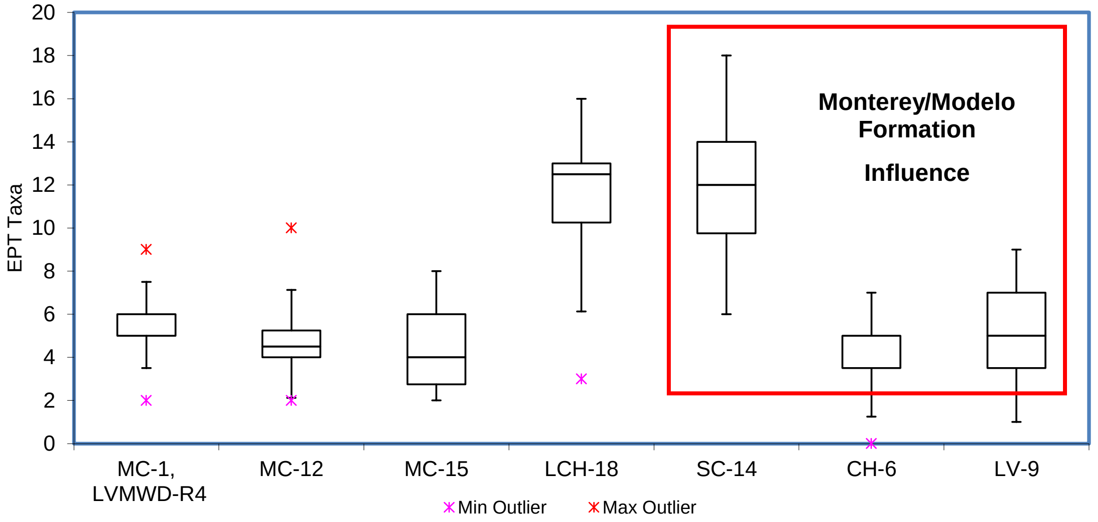


Figure G-3. Comparison of EPT Taxa Count for Malibu Creek to Local Reference Sites

Stepwise multiple regression analyses indicate that benthic bioscores responses are explained well by both physical habitat scores and percent of upstream impervious area. Physical habitat itself may be degraded by increased flow energy and resulting sediment transport associated with increased impervious area. Impervious area is also a surrogate for development and associated increases in loads of pollutants such as nutrients. Results suggest that aspects of physical habitat associated with sediment stability and sediment transport capacity are one important limiting factor on the benthic macroinvertebrate assemblage in the watershed.

Weight of Evidence for Increased Sedimentation Resulting in Biological Impairment

1. Co-occurrence: Excess sedimentation co-occurs spatially with impairment, based on Heal the Bay's Stream Walk observations, Luce's study (2003), and site data presented in Section 7, although the form of excess sediment responsible in each case differed. Co-occurrence is thus compatible.
2. Temporality: Sedimentation has long been present in the watershed, as described by Ambrose and Orme (2000), providing evidence for temporality (sediment stress preceding the biological responses). Temporality is thus compatible.
3. Biological gradient: Nearly half of the variability in SC-IBI and pMMI for stations not on the mainstem of Malibu Creek is explained by physical habitat scores and poorer physical habitat scores are primarily associated with sedimentation and sediment transport effects. Luce (2003) also found significant negative correlations between EPT metrics and percent embeddedness, providing evidence for a biological gradient. Lack of a strong correlation between physical habitat scores and bioscores at the Malibu mainstem stations appears to be due to co-limitation by

other factors, such as excess algal growth. The data are thus consistent with a biological gradient, although somewhat weak for the main stem.

4. Complete exposure pathway: Evidence for the exposure pathway is complete. Sedimentation appears to impact benthic macroinvertebrates, but other factors appear to limit benthic macroinvertebrates as well.
5. Plausibility: Evidence from the literature supports the linkage between excessive sedimentation and benthic macroinvertebrate impairment as plausible.
6. Analogy: Evidence from the literature has documented many cases of sedimentation by fine or coarse sediments adversely impacting benthic macroinvertebrates.
7. Predictive performance: No evidence is available to support predictive performance.
8. Consistency of evidence: Most available lines of evidence are consistent with sedimentation being a cause of impairment in Malibu Creek.
9. Coherence of evidence: Most lines of evidence support sedimentation as a contributing cause of benthic macroinvertebrate assemblage impairment. Luce (2003) found that percent fines did not correlate with EPT metrics. This possible inconsistency can be explained by an understanding that the embeddedness likely results from coarse sediment or sand, which has been demonstrated to cause benthic macroinvertebrate assemblage impairment. In addition, overall physical habitat (PHab) scores range from marginal to optimal, with no sites being rated as poor. This is not inconsistent with sedimentation contributing to impairment because the overall PHab scores aggregate 10 individual scores, only some of which are directly related to sedimentation. The fact that embeddedness correlates with reductions in sensitive taxa is a more direct measure of the causal relationship. Therefore, the evidence for the linkage is coherent.

Malibu Lagoon

Malibu Lagoon is also impacted by sedimentation. The Lagoon is a naturally dynamic system with regards to sediment, where cycles of aggradation and scour occur. Substantial aggradation occurs during lagoon closure, whereas major winter floods that open the barrier beach scour accumulated sediments. Detailed maps of the Lagoon show that increased aggradation combined with proximate development that constricts the Lagoon footprint has resulted in a smaller and fresher Lagoon than was likely the case under natural conditions.

Due to low flushing, sediments accumulate in the Lagoon’s tidal channels. These sediments deliver nutrient loads that contribute to excess algal blooms (Shifting Baseline, 2011; Jones and Stokes, 2006; Moffatt and Nichol, 2005; 2NDNATURE, 2010). In addition, the reduced volume of the Lagoon and isolation of side channels contributes to reduced DO and elevated water temperature.

Measurements in 1987 suggested the average rate of sedimentation since 1983 was 10 cm/year. This level of sedimentation is estimated to be nearly ten times the rate that would have occurred during pre-European settlement periods (Topanga-Las Virgenes Resources Conservation District, 1989). During the flood of February 6, 1999, LACDPW data shows that 2,321 mg/L of suspended sediment was carried through Malibu Creek into the Lagoon.

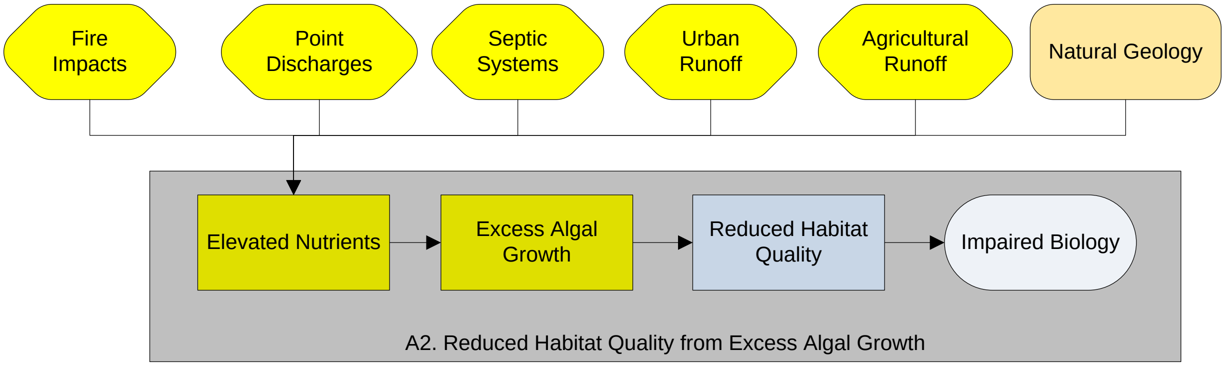
The data evaluating the benthic invertebrate assemblage composition in Malibu Lagoon indicates that the Lagoon invertebrate assemblage is impaired. Recent sampling performed by USEPA found that a site closest to the head of the estuary with consistent upstream freshwater flow had the greatest number of taxa collected. Sites located in back channels with limited flow, or closest to the Lagoon mouth in the central part of the Lagoon, showed the largest abundance of organisms. However, these organisms were primarily highly tolerant species from fewer taxa that can survive in highly impacted conditions. Results of this sampling effort strongly suggest poor benthic macroinvertebrate diversity and abundance.

Several restoration efforts have addressed sedimentation impacts in the Lagoon, including excavation of tidal channels to improve circulation and excavation to increase the main Lagoon depth, both designed to improve habitat, including support for the endangered tidewater goby. These habitat improvements are threatened by ongoing sedimentation.

Weight of Evidence for Increased Sedimentation Resulting in Biological Impairment

1. Co-occurrence: Excess sedimentation co-occurs spatially with impairment, based on many observations since the 1980s. The poorest biology in the lagoon appears to occur in tidal channels subject to the greatest amount of sedimentation infill. Efforts to address impairment in the Lagoon have focused on mechanical restoration of the effects of sedimentation by deepening the Lagoon and its side channels.
2. Temporality: Sedimentation has long been present in the Lagoon, and the Lagoon footprint has been significantly reduced by increasing urban development, with concomitant habitat loss. Moreover, studies have documented sedimentation as a cause of the loss of benthic species such as crabs, shrimps, clams, and other invertebrates (Shifting Baseline 2011, 2NDNATURE 2010).
3. Biological gradient: The Lagoon is a terminal depositional area, all of which is impacted by sedimentation. It is not appropriate to compare conditions in the Lagoon to stations in Malibu Creek. Within the Lagoon, variations in benthic macroinvertebrate communities between sampling stations are most likely due to differences in salinity. However, restoration efforts (e.g., Jones and Stokes, 2006) have demonstrated that poor circulation due to the filling of side channels by sedimentation is a major problem in the Lagoon, thus providing evidence for a biological gradient relative to the extent of sedimentation.
4. Complete exposure pathway: All steps in the exposure pathway support the linkage between increased sediment and biological impairment in the lagoon. Sedimentation has clearly increased over time and continues to present a problem in the lagoon. The benthic macroinvertebrate assemblage consists of predominantly few highly tolerant species.
5. Plausibility: Evidence from the literature supports the linkage between excessive sedimentation and benthic macroinvertebrate impairment as plausible by multiple mechanisms, including smothering and habitat loss.
6. Analogy: Evidence from the literature has documented many cases of sedimentation adversely impacting benthic macroinvertebrates. Both fine and coarse sediments have been shown to impact benthic macroinvertebrates (e.g., Wood and Armitage, 1997; Harrison et al. 2007; Spindler 2004; Longing 2006).
7. Predictive performance: No evidence is available to support predictive performance.
8. Consistency of evidence: All available lines of evidence are consistent with sedimentation being a cause of impairment in Malibu Lagoon.
9. Coherence of evidence: There are no inconsistencies in the evidence.

A2. Reduced Habitat Quality from Excess Algal Growth: Possible sources of excess algal growth include excess nutrients resulting from fire impacts (B3), septic systems (B4), point source discharges (B5), non-point sources attributable to urban runoff (B6), agricultural runoff (B7), and natural geology (B8). Evidence for linkages between these sources and excess nutrients/excess algal growth are discussed in each source's section below (Section G.2). The following discussion presents the evidence for linkage between excess nutrients, excess algal growth, and reduced habitat quality for benthic macroinvertebrates (Figure G-4).



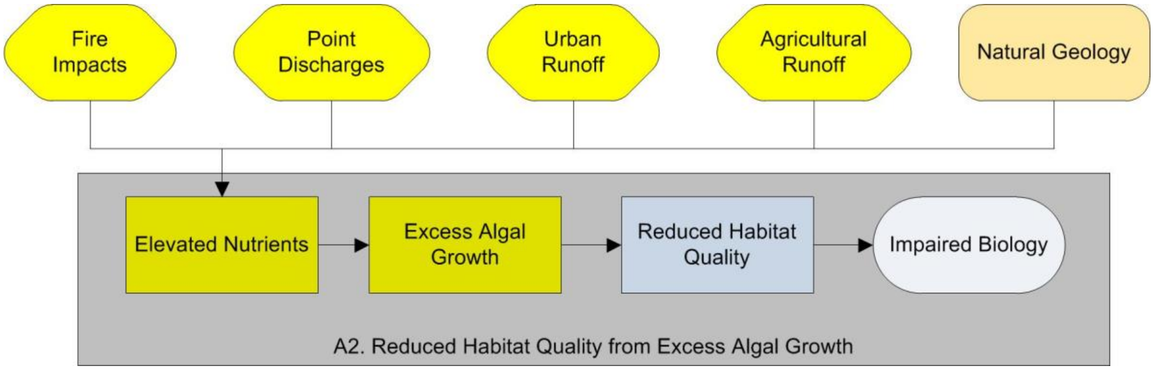


Figure G-4. Illustrated Linkage between Elevated Nutrients and Impaired Biology as a Result of Excess Algal Growth and Reduced Habitat Quality

The following information on nutrients and algal growth is excerpted from USEPA's CADDIS website (USEPA, 2012):

> *Fish and invertebrates are usually not directly adversely affected by excess nutrient concentrations, but rather are affected by other proximate stressors resulting from nutrient enrichment. For example, increases in dissolved N and P can lead to increases in plant and microbial biomass or productivity, which may lead to greater microbial infection of invertebrates or fish, or altered benthic organic matter processing (e.g., faster processing rates). Increased respiration of microbes and plants often leads to decreases in DO concentrations, especially during times when photosynthesis is limited (e.g., at night). In addition, increased photosynthesis may lead to increased pH; this increase may be especially important when N is elevated, as unionized ammonia, a toxic form of N, is more prevalent at high pH. Blooms of certain algal taxa also may result in increased production and release of toxins that can affect fish or invertebrates.*
>
> *Increased plant or algal production may translate to increased food resources, which can benefit herbivorous organisms but may adversely impact other taxa by altering the food resources derived from detritus. Changes in plant assemblage structure also may occur with enrichment, and these changes can affect aquatic fauna by altering habitat structure or by altering the quantity or quality of food resources. Changes in community structure may occur even without overall increases in primary producers, due to alterations of nutrient availability ratios. Increases in suspended organic matter (i.e., phytoplankton or suspended benthic algae) also can negatively affect aquatic biota, for example by increasing turbidity.*

Although algal growth can benefit a stream by providing a food source, habitat (cover), and thermal buffering, excess growth of periphytic and attached algae can have a direct deleterious impact on habitat suitability. Excess algal growth can cover suitable habitat (Allan, 1995) and may depress overall invertebrate taxa richness (Yuan, 2010) or shift invertebrate assemblage composition toward grazers and scrapers (Feminella and Hawkins, 1995; Quinn et al., 1997).

Malibu Creek

Nutrient concentrations in Malibu Creek are elevated in many locations based on measurements of inorganic N and P species; data on total nutrient concentrations are available at only a limited number of sites, but show even higher concentrations. Notably, average concentrations of nitrate- and nitrite-N, ammonia-N, and PO_4 as P in data collected by the Heal the Bay Stream Team are higher at impacted Malibu Creek mainstem sites than at comparator/reference sites (Figures 7-14 and 7-18 of the TMDL report). Orthophosphate-P concentrations appear to be naturally elevated within the Modelo/Monterey Formation; however, both orthophosphate and nitrate concentrations increase dramatically as streams pass through the developed area in the I-101 corridor. Available information suggests that total N concentrations (which include organic forms) are much higher than inorganic N concentrations, except at sites downstream of the Tapia discharge and in the developed areas of Las Virgenes Creek (see Section 7 of the TMDL report). Many organic forms of N (and P) can be rapidly broken down into inorganic forms by biological activity, becoming available to support plant growth. As with the Heal the Bay samples, the LVMWD summary (Table 7-8 of the TMDL report) shows that inorganic P concentrations are elevated in streams that drain the Monterey/Modelo Formation. Concentrations downstream of the Tapia WRF discharge are much higher during the winter discharge season (see Table 7-6 of the TMDL report).

Algal cover has been measured directly at the impacted Malibu Creek sites and percent coverage by algae is much greater than observed at comparator/reference sites; moreover, algal coverage has increased since 2000 (Figures 8-17 and 8-18 of the TMDL report). In addition, a nutrient TMDL was developed for Malibu Creek by USEPA (2003) with a target of achieving not more than 30 percent coverage for filamentous algae greater than 2 cm in length and not more than 60 percent cover for bottom algae greater than 0.3 cm thick. Although the nitrate- and nitrite-N limits proposed in the TMDL appear to have largely been achieved at the downstream station MC-1, the algal density targets have not. Mean mat algae coverage at the impacted mainstem sites range between approximately 65% to approximately 90%, compared to means between 5% and 10% at comparator/reference sites. Busse et al. (2006) measured periphyton chlorophyll *a* densities and nutrients, light, and flow velocity, and concluded that nutrient concentrations were sufficiently high that they were not currently limiting algal growth in Malibu creek. Instead, periphytic algae varied positively with light and negatively with winter season scouring flows, likely requiring further reductions in nutrient concentrations to achieve the algal cover targets. Luce (2003) reported somewhat more complex, but still positive, relationships between nutrient concentrations and algal cover. HtB and MCWMP data from the June to September growing season show a positive correlation between average inorganic nitrogen (NO_x-N) and algal mat cover (Figure G-5).

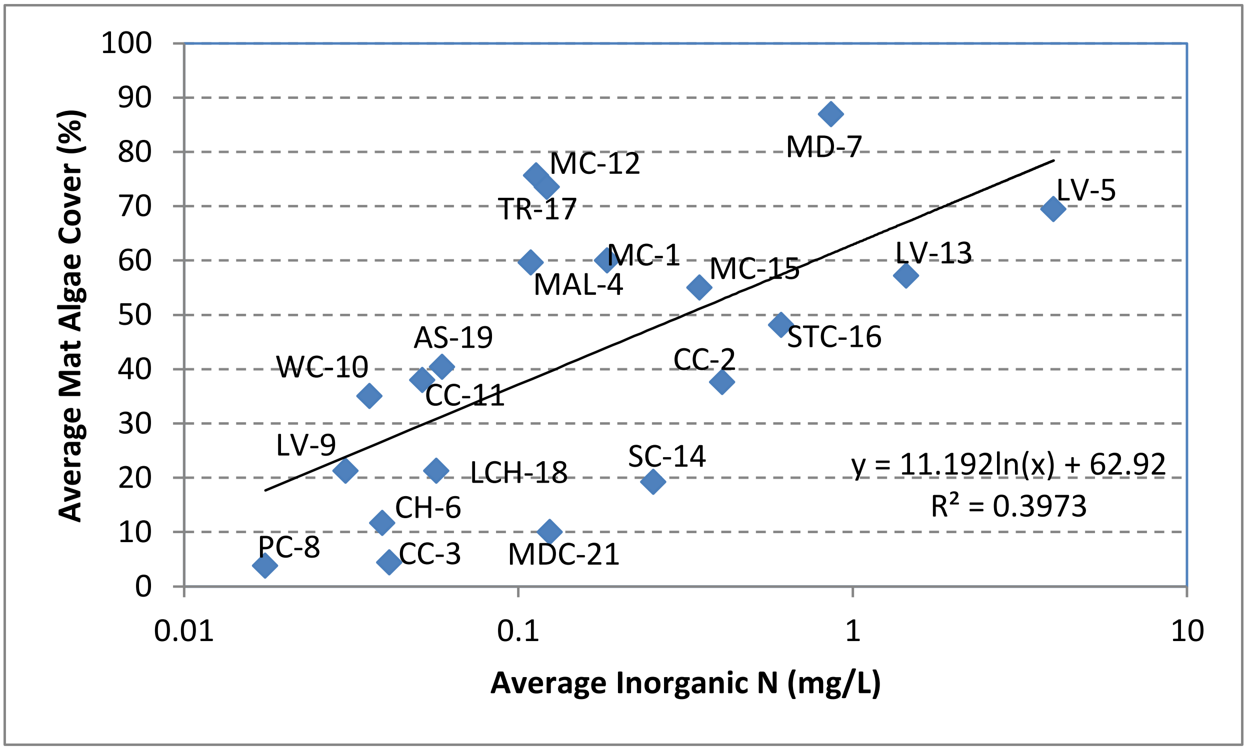


Figure G-5. **Correlation of Algal Mat Cover and Inorganic N Concentrations during the Growing Season in Malibu Creek Watershed Data**

Heal the Bay (Sikich et al., 2012) reported that benthic algal cover was lowest at comparator/reference sites and highest at outlet sites, and that the vast majority of sites with the highest algal coverages occurred downstream of development. Sites exhibiting excess algal growth also exhibit SC-IBI scores lower than comparator/reference sites.

As Figure 8-17 of the TMDL report shows, there is a negative correlation between median SC-IBI score and average total inorganic N concentration. The pMMI also shows a negative relationship with inorganic N that appears very similar to that with the SC-IBI. Moreover, median SC-IBI scores greater than 30 only occur at sites with average nitrate-N concentrations less than 1 mg/L. Similarly, no pMMI scores greater than the lower threshold (5th percentile, 0.86) are found at sites with average nitrate-N greater than 1 mg/L, suggesting that nutrient impacts are likely depressing biological condition in the watershed.

Weight of Evidence for Excess Algal Growth and Reduced Habitat Quality Resulting in Biological Impairment

1. Co-occurrence: Based on the sampling data available for Malibu Creek, excess nutrients co-occur with excess algal growth, excess algal growth co-occurs with lower biological scores, and excess nutrients co-occur with lower biological scores. At many sites, nutrients appear to be present in excess of levels that maximize algal growth; however, only at sites with reduced inorganic-N do we find consistently reduced average algal mat coverage and increased biological scores. Co-occurrence is thus compatible.
2. Temporality: Elevated nutrient concentrations and algal cover have increased with increasing development, beginning in the 1960s. In particular, mat and filamentous algal cover have increased since 2000 (Figures 8-17 and 8-18 of the TMDL report).
3. Biological gradient: Evidence for the biological gradient is strong. Both nutrient concentrations and mat algal coverage are higher in Malibu Creek than at comparator/reference sites, and

nutrient concentrations correlate with increased mat algal growth during the growing season and with decreased biological scores.

4. Complete exposure pathway: There is evidence for all steps in the complete exposure pathway. Nutrients in the stream are associated with increased algal growth and decreased biological scores.
5. Plausibility: A large body of evidence from the literature documents excess algal growth as a cause of benthic macroinvertebrate assemblage impairment via habitat alteration that shifts assemblage composition, and physically covers desirable habitat.
6. Analogy: Evidence from the literature has documented many cases of excess algal growth adversely impacting benthic macroinvertebrates.
7. Predictive performance: There is no evidence of predictive performance.
8. Consistency of evidence: All of the lines of evidence supporting excessive algal growth and associated habitat impacts are consistent.
9. Coherence of evidence: There are no inconsistencies in the evidence; therefore, the evidence are coherent.

Malibu Lagoon

Benthic aquatic life in Malibu Lagoon is “impaired by eutrophication resulting from excessive nitrogen loads” (Callaway et al., 2009). Malibu Lagoon currently shows elevated concentrations of biologically-available nutrients such as nitrate (NO_3), nitrite (NO_2), and ammonium (NH_4) (Moffatt &Nichol, 2005; 2NDNATURE, 2010) and excessive algal growth.

In recent sampling near the upstream end of the Lagoon (LVMWD-R11) median concentrations during the summer non-discharge season (April 15 – Nov. 15) were 1 mg/L total N and 0.13 mg/L orthophosphate-P; the corresponding winter medians are 1.85 mg/L total N and 0.59 mg/L orthophosphate-P (Section 7.6 of the TMDL report).

Excessive algal growth can affect habitat quality in an estuary in much the same way that it affects habitat quality in a stream. Little direct information is available on benthic habitat quality in the Lagoon, except with regard to excessive sedimentation and reduction in quantity due to changes in the Lagoon footprint. The Lagoon does experience excess algal growth that reduces habitat quality directly and also contributes to low dissolved oxygen levels, both of which likely have impacted benthic macroinvertebrates, resulting in decreased diversity and abundance. Although specific habitat quality data are limited, it is likely that the algal growth has reduced habitat quality.

Weight of Evidence for Excess Algal Growth and Reduced Habitat Quality Resulting in Biological Impairment

1. Co-occurrence: Based on the sampling data available for Malibu Lagoon, excess nutrients co-occur with excess algal growth, and excess algal growth co-occurs with reduced benthic macroinvertebrate diversity and abundance.
2. Temporality: Elevated nutrient concentrations have worsened with increasing development, beginning in the 1960s.
3. Biological gradient: Evidence for the biological gradient is strong. Nutrient concentrations correlate with increased algal growth during the growing season and with decreased benthic macroinvertebrate diversity and abundance.
4. Complete exposure pathway: There is evidence for all steps in the exposure pathway. Nutrients in the Lagoon are associated with increased algal growth and decreased benthic macroinvertebrate diversity and abundance.

5. Plausibility: A large body of evidence from the literature documents excess algal growth as a cause of benthic macroinvertebrate assemblage impairment via habitat alteration that shifts assemblage composition, and physically covers desirable habitat.
6. Analogy: Evidence from the literature has documented many cases of excess algal growth adversely impacting benthic macroinvertebrates.
7. Predictive performance: There is no evidence for predictive performance.
8. Consistency of evidence: All the lines of evidence supporting excessive algal growth and habitat alteration are consistent.
9. Coherence of evidence: There are no inconsistencies in the evidence.

A3. Reduced DO: Reduced DO from excess algal growth/excess nutrients can be caused by fire impacts (B3), septic systems (B4), point source discharges (B5), urban runoff (B6), agricultural runoff (B7), or natural geology. Reduced DO can also result from oxygen-demanding wastes from point source discharges (B5) or urban runoff (B6), or from altered hydrology leading to stagnant conditions (B1). Evidence for linkages between these sources and excess nutrients/excess algal growth are discussed in each source's section (see Section G.2). The following discussion presents the evidence for linkage between reduced DO and impact to benthic macroinvertebrates (Figure G-6 through Figure G-8).

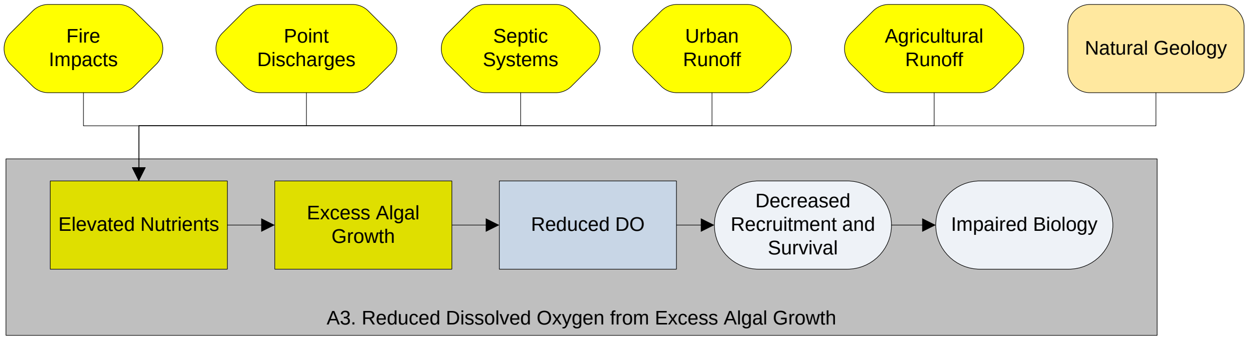


Figure G-6. Illustrated Linkage between Elevated Nutrients and Impaired Biology as a Result of Excess Algal Growth and Reduced Dissolved Oxygen

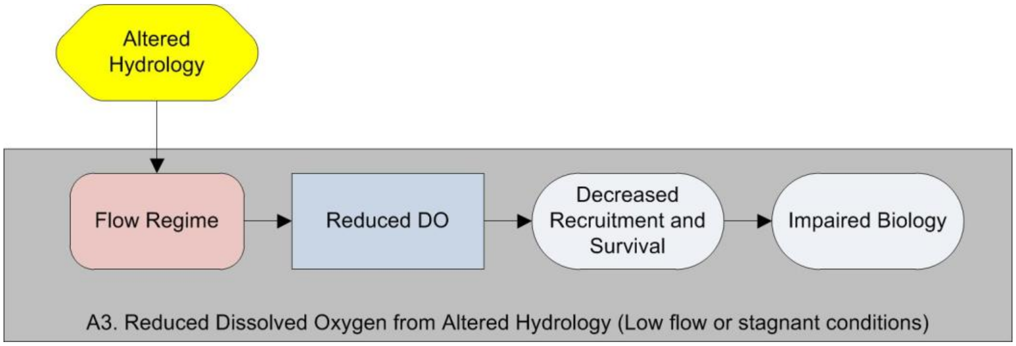


Figure G-7. Illustrated Linkage between Altered Hydrology and Impaired Biology as a Result of Low Flow or Stagnant Conditions and Reduced Dissolved Oxygen

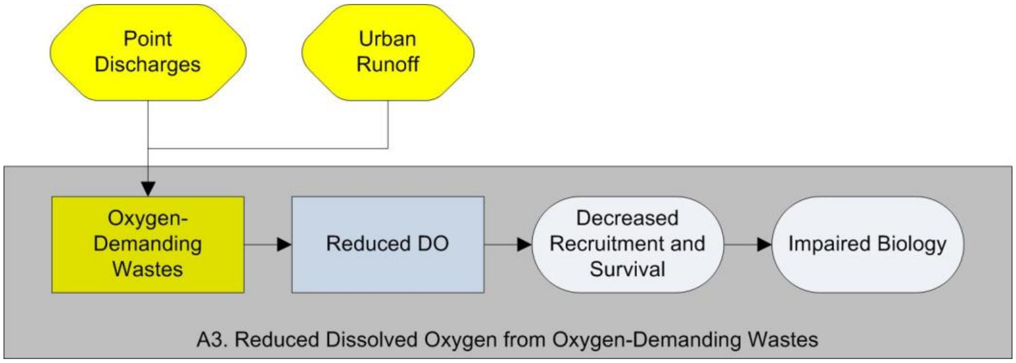


Figure G-8. Illustrated Linkage between Oxygen-demanding Wastes and Impaired Biology as a Result of Reduced Dissolved Oxygen

Decreased dissolved oxygen in Malibu Creek can result from increased water temperature or increased biological oxygen demand. The following information on enrichment/DO is excerpted from USEPA's CADDIS website (USEPA, 2012):

> *Low or extremely high DO levels can impair or kill fishes and invertebrates. In addition, large fluctuations in DO levels over relatively short periods of time (e.g., daily) can stress aquatic organisms. Human activities can significantly affect DO concentrations in streams, most notably by decreasing oxygenation and by increasing chemical or biochemical oxygen demand. Agricultural practices, forestry practices, and other activities may involve channel alteration (e.g., straightening or deepening of streams) or impoundments downstream of a location, which may decrease aeration and the diffusion of oxygen into water. Impoundments upstream of a location may discharge low oxygen water downstream, but releases also may increase turbulence and oxygenate water. These land use practices also may directly introduce nutrients (e.g., fertilizers, animal wastes), chemical contaminants (e.g., heavy metals), or organic matter (e.g., sewage, animal wastes) to streams, or indirectly increase the delivery of these substances to streams via land cover alteration. The resulting chemical reactions and increased respiration of microbes and plants can increase oxygen demand in streams, leading to decreases in DO.*

DO saturation occurs at lower concentrations in warm versus cold water, so factors contributing to increased water temperatures (e.g., loss of riparian cover, warm effluents) may contribute to decreased DO concentrations.

Malibu Creek

Impacted sites in Malibu Creek show average dissolved oxygen concentrations that are similar to concentrations at comparator/reference sites, ranging between 9.09 and 10.90 mg/L at impacted sites for which sufficient data are available, and 9.30 and 9.93 mg/L for comparator/reference sites. These average concentrations are above applicable water quality standards; the data, however, consist of day-time grab samples that are unlikely to measure the minimum overnight concentration due to respiration demand. The frequency of low DO observations (<5 mg/L, the WARM criterion) at impacted sites is higher than at some comparator/reference sites, ranging from 0% to 17.5% at impacted sites compared to 0% at comparator/reference sites SC-14 and LCH-18, and 3.6% to 38.1% at comparator/reference sites CH6 and LV9, respectively. Higher DO criteria of 6 mg/L for the COLD use and 7 mg/L for the SPAWN use apply to most of the streams in the watershed. About 13 percent of observations are less than 7 mg/L at the mouth of Malibu creek (MC-1) and in Malibu Creek upstream of Tapia (MC-12). Concentrations immediately below the Tapia discharge at the F-130 gage are less than 7 mg/L about 3 percent of the time. Sikich et al. (2012) reported continuous DO measurements for lower Malibu Creek (Lunch and Start Pools) between August 11, 2009 and September 1, 2009. The Start Pool site is situated approximately 250 m upstream of the Malibu Creek Outlet. Lunch Pool is located approximately 720 m upstream of Start Pool. Lunch Pool experienced little diel DO variation, with measurements ranging from approximately 6 mg/L to approximately 9 mg/L over the course of the study. On the other hand, Start Pool experienced a wide range of DO measurements, with greater DO (up to approximately 12 mg/L, attributable to algal photosynthesis) occurring in mid to late afternoon, and hypoxia (less than 2 mg/L) occurring from about 11 PM until about 11 AM.

Excess algal growth is present throughout the Malibu Creek watershed, and can lead to increased DO during daytime photosynthesis coupled with depleted DO during nighttime respiration. The extent to which this is a significant problem in the watershed is unclear due to a shortage of continuous DO sampling. Low flow or stagnant conditions have occurred historically in some areas of the watershed during summer/fall; however, recent gage records demonstrate that baseflow has generally increased and the frequency of low flows has decreased following development. Moreover, measurements of biochemical oxygen demand, a measure of oxygen-demanding wastes, shows that most observations are at the detection limit of 2 mg/L. It is clear that DO criteria for protection of aquatic life are not always met in the watershed. The most serious problems are documented for Las Virgenes Creek, which has a SPAWN designation with an accompanying 7 mg/L DO standard, but for which nearly 80 percent of samples were less than 7 mg/L, and 38 percent of samples less than 5 mg/L, at Station LV-9 (see Table 7-2 of the TMDL report); however, the median SC-IBI score at this site is in the "Fair" range.

Weight of Evidence for Reduced DO Resulting in Biological Impairment

1. Co-occurrence: Occasional low DO concentrations are documented to co-occur at sites with impaired bioscores; however, there is little evidence of correlation between DO concentrations and bioscores. Data are generally lacking on overnight DO minima. Therefore, for most of the watershed, the evidence for co-occurrence is uncertain.
2. Temporality: LVMWD monitoring of DO in Malibu Creek shows frequent concentrations less than 5 mg/L in Malibu Creek below Las Virgenes Creek as early as 1991, prior to documented benthic macroinvertebrate assemblage impairment.
3. Biological gradient: Too few DO data were obtained at times when DO might be expected to be low (e.g., night and early morning samples) to fully evaluate the biological gradient. However, the variability in DO measurements downstream, combined with the observation that the frequency of low DO concentrations is greater at impacted sites than comparator/reference sites suggests that a biological gradient exists, although evidence is weak.
4. Complete exposure pathway: Evidence for the exposure pathway is incomplete, since average DO measurements exhibit acceptable concentrations. Basin Plan DO criteria are not met on an occasional to frequent basis at a variety of stations in the watershed. However, these criteria were set primarily to protect fish and it is not clear if the frequency of low DO observations is sufficient to cause impairment of benthic biota.
5. Plausibility: Evidence for low DO as a cause of benthic macroinvertebrate data is plausible, based on a large body of scientific literature.
6. Analogy: Many examples exist in the literature of benthic invertebrate impairment resulting from low DO in eutrophic waters, stagnant waters, or waters exhibiting high biological oxygen demand.
7. Predictive performance: There is no evidence for predictive performance.
8. Consistency of evidence: Most lines of evidence are consistent with low DO as a causal factor, but questions remain due to lack of available diel data.
9. Coherence of evidence: The available data are consistent with expectations regarding DO patterns observed with excess algal growth. Diel data necessary to prove low DO levels during pre-dawn hours are not available, Additional diel DO data from multiple locations in the watershed would resolve gaps in the evidence. Given the high nutrient concentrations, coupled with the excess

algal growth observed in Malibu Creek, diel DO measurements would be expected to demonstrate low DO conditions during pre-dawn hours when algal respiration is greatest.

Malibu Lagoon

Malibu Lagoon also experiences low DO conditions, starting at the Malibu Creek outlet, as demonstrated by the DO results for the Start Pool presented above (Sikich et al., 2012). Sikich et al. (2012) also presented data for Malibu Lagoon, based on a study by Briscoe, stating that pre-dawn DO levels averaged 1.15 ± 0.12 mg/L SE in Malibu Lagoon. Ambrose et al. (1995) obtained diel DO levels between July 1993 and April 1994 at a westerly channel site in the Lagoon and at a mid-Lagoon site. The westerly channel site exhibited bottom water ranges between 2.6 and 10 mg/L DO, and the mid-Lagoon site had bottom water DO concentrations ranging between 5.5 and 12.2 mg/L. The general DO standard of 5 mg/L applies to the Lagoon.

Benthic aquatic life in Malibu Lagoon is "impaired by eutrophication resulting from excessive nitrogen loads" (Callaway et al., 2009). As in the stream, the impacts of excess algal growth due to eutrophication include the potential for depressed DO during nighttime respiration. Natural reaeration in the Lagoon has also been reduced through sedimentation that leads to stagnant side channels. Most observations of 5-day biological oxygen demand downstream of the Tapia WRF discharge are at the detection limit of 2 mg/L. The extent to which the discharge may include more refractory organic compounds that can exert an oxygen demand on a period longer than 5 days is not known. Such refractory compounds, if present, could pose an issue for the Lagoon.

Malibu Lagoon exhibits diminished species richness compared to other, similar California estuaries, and benthic faunal sampling in 2006 and 2007 demonstrated that sites with better hydrologic connection had greater abundance and taxa richness, consistent with greater flow and greater oxygenation.

Weight of Evidence for Reduced DO Resulting in Biological Impairment

1. Co-occurrence: Based on the limited sampling data available for Malibu Lagoon, dissolved oxygen concentrations less than the water quality criterion co-occurs with reduced benthic taxonomic richness.
2. Temporality: Low DO in the Lagoon is documented as early as 1993, prior to the documentation of impaired biota. Thus the evidence is compatible with temporality.
3. Biological gradient: Evidence for the biological gradient is consistent, but weak due to limited data. Sites with greater oxygenation and less sediment deposition show greater taxonomic richness.
4. Complete exposure pathway: Evidence for the exposure pathway is complete.
5. Plausibility: A large body of evidence from the literature supports low DO as a cause of benthic macroinvertebrate assemblage impairment.
6. Analogy: Evidence from the literature has documented many cases of low DO adversely impacting benthic macroinvertebrates.
7. Predictive performance: No evidence for predictive performance exists.
8. Consistency of evidence: The available lines of evidence supporting low DO and reduced taxonomic richness are consistent. However, insufficient data are available on both DO concentrations and the benthic macroinvertebrate assemblage in the Lagoon to draw firm conclusions.
9. Coherence of evidence: It is not clear how widespread or frequently low DO conditions occur. The sensitivity of the natural benthic macroinvertebrate assemblage in the Lagoon to low DO has also not been determined. Additional data would be expected to resolve this inconsistency.

> Moreover, given the high nutrient concentrations and excess algal growth in the Lagoon, low DO levels would be expected during pre-dawn hours, based on the dynamics of plant respiration.

A4. Toxicity from Metals, Elevated Salt Concentrations, or Organic Toxics: Toxicity from metals, elevated salt concentrations, or organic toxics (A4) can be caused by urban runoff (B6), agricultural runoff (B7), or natural geology (B8). Evidence for linkages between these sources and toxicity are discussed in each source's section (Section G.2). The following discussion presents the evidence for linkage between toxicity and impaired benthic macroinvertebrates (Figure G-9).

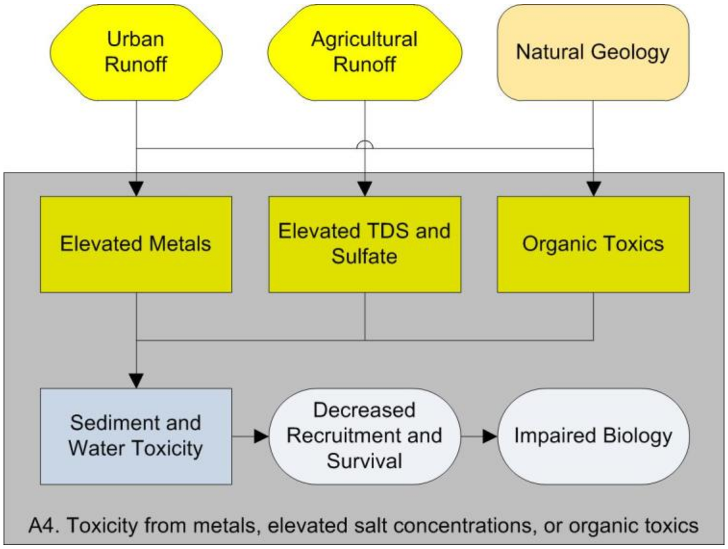


Figure G-9. Illustrated Linkage between Toxics and Impaired Biology

The following information on ionic strength (conductivity) is excerpted from USEPA's CADDIS website (USEPA, 2012):

> *There is debate among scientists as to the exact mechanisms responsible for toxicity associated with ionic strength. Toxicity due to ionic strength could result from disruption of organisms' osmotic regulation processes, decreases in bioavailability of essential elements, increases in availability of heavy metal ions, increases in particularly harmful ions, changes in ionic composition, absence of chemical constituents that offset impacts of harmful ions, a combination of the above, or other as yet unknown mechanisms. In some instances (perhaps the majority), increased ionic strength causes shifts in community composition rather than mortality; thus, specific conductivity, salinity, and TDS levels may be associated with biological impairment and yet be below mortality thresholds.*

Malibu Creek

Occasional water column toxicity has been observed since 2005 in wet and dry weather surface water samples from Malibu Creek, using *Ceriodaphnia dubia* (water flea) survival and reproduction and *Strongylocentrotus purpuratus* (purple sea urchin) fertilization tests. LADPW reports indicated that the toxic effect apparently dissipated after holding the sample, and suggested that the cause might be volatile organic chemicals. In a separate study, Brown and Bay (2005) examined Malibu Creek water near the mouth under both wet and dry conditions. One out of eight dry weather samples showed acute toxicity (survival) and two of eight showed chronic toxicity (reproduction) to *C. dubia*. The authors attribute the results to sulfate and other dissolved salts.

Rowe et al. (2002) present case studies on disposal of coal ash in other watersheds demonstrating biomagnification of selenium resulting in sub-lethal and possibly lethal concentrations in organisms at the highest trophic levels. However, low concentrations of selenium also are essential for animal health and are considered beneficial for plant health (Kapustka et al., 2004).

Although selenium and sulfate data have not been routinely obtained for the Malibu Creek watershed, conductivity data are routinely available. Conductivity presents a readily obtainable and more commonly observed measure of ion concentration in water, and can be used as a surrogate measure for potentially toxic salts. Conductivity measurements at impacted sites in the Malibu Creek mainstem are higher than those in comparator/reference sites, ranging from 1,877 – 2,287 µS/cm on average for the mainstem sites compared to 1,185 – 1,505 µS/cm for comparator/reference sites. Sites upstream within the Monterey/Modelo Formation exhibit much higher specific conductivity measurements of approximately 3,400 µS/cm and include sites that have acceptable bioscores. There is a negative correlation between conductivity and SC-IBI and between conductivity and pMMI; however, stepwise multiple regression analysis shows that there is a stronger correlation to upstream impervious area, much of which is located downstream of the Monterey/Modelo Formation in the highway 101 corridor.

Another possible cause of benthic macroinvertebrate toxicity includes agents used by the Los Angeles County West Vector & Vector-Borne Disease Control District. The Control District primarily uses *Bacillus thuringiensis* var. *israelensis* (*Bti*) or methoprene (Altosid) for mosquito control (LA County West Vector and Vector-borne Disease Control District N.D.). *Bti* has been reported to have no direct effect on aquatic invertebrates other than mosquitos (Culicidae), blackflies (Simuliidae), and chironomids (Glare and O'Callaghan 1998). Methoprene, on the other hand, is toxic to freshwater invertebrates (USEPA 1991). No data are available regarding application agent, locations, dates, rates, or relationship to observed benthic macroinvertebrate impairment.

Any loss of Chironomidae and Simuliidae would not affect the O/E, because these are flagged as ambiguous taxa, and very few Culicidae appear in the data. SC-IBI, and to a lesser extent, pMMI bioscores could be negatively affected by loss of these groups; however, experiments with the CSCI code with and without groups susceptible to *Bti* showed only small differences in bioscores.

Diazinon, an organophosphate pesticide, was detected in creek samples collected in 2002-2003. Concentrations of diazinon in some samples exceeded the California Department of Fish and Game chronic criterion by up to a factor of 14 in Medea Creek. However, concentrations within the Malibu Creek mainstem did not appear sufficiently high to be a significant source of toxicity.

Weight of Evidence for Toxicity from Metals, Elevated Salt Concentrations, or Organic Toxics Causing Biological Impairment

1. Co-occurrence: The spatial pattern of conductivity measurements shows that the highest median conductivity values are in the Monterey/Modelo Formation. Toxicity has only occasionally been observed at sampling locations in Malibu Creek. Stations with high conductivity but upstream of major anthropogenic influences (CH-6, LV-9) have higher bioscores than stations downstream of development or stations in the Malibu Creek mainstem. Insufficient data are available to evaluate the spatial distribution of organic toxics. Therefore, the evidence for co-occurrence of toxicity and biological impairment is uncertain.

2. Temporality: The watershed naturally exhibits high conductivity in areas draining the Monterey/Modelo Formation. Direct toxicity testing results are not consistent in time. Therefore the evidence for temporality is uncertain.

3. Biological gradient: Biological scores (SC-IBI and pMMI) show a negative relationship with conductivity. However, comparator/reference sites within the Monterey/Modelo Formation (CH-6 and LV-9) also exhibited high conductivity, but had high SC-IBI and pMMI scores. Therefore, evidence for the biological gradient is weak or inconsistent for salts and weak for organic toxics. Bioscores decline downstream of developed areas and could possibly reflect toxic chemical exposure sources in those areas; however, direct evidence for this is not available.

4. Complete exposure pathway: Evidence for the exposure pathway is incomplete. Toxicity is not consistently observed, and the gradient is only weakly demonstrated.
5. Plausibility: In addition to observing toxicity in several toxicity tests, there is literature supporting toxicity of selenium, sulfate, and dissolved salts (high conductivity) to aquatic organisms, specifically. Therefore, toxicity resulting from dissolved salts in the water column is plausible.
6. Analogy: The literature contains many analogous cases, especially downstream of mining activity, where salts, which result in increased surface water conductivity, and metals are associated with impacts on invertebrates. Similarly, the literature documents many analogous cases where organic toxins have caused impacts on benthic invertebrates.
7. Predictive performance: Toxicity testing has demonstrated occasional water column toxicity attributed to sulfate and other dissolved salts (Brown and Bay 2005), but mechanisms or endpoints specific to selenium, sulfate, or specific organic chemical toxicity have not been evaluated. Therefore, there is no evidence of predictive performance.
8. Consistency of evidence: Multiple inconsistencies exist in the lines of evidence. Toxicity that is present has the potential to impact organisms, based on some of the toxicity testing showing chronic or acute toxic effects. However, it is unclear if the observed toxicity is sufficiently frequent to explain the impacts.
9. Coherence of evidence: Inconsistencies exist in the evidence linking toxicity from metals, elevated salt concentrations, or organics toxics to biological impairment. No explanation is available for the inconsistent spatial and temporal observations of toxicity, nor is it clear that additional data will sufficiently explain the inconsistencies.

Malibu Lagoon

Sediment toxicity tests using amphipods have shown no toxicity to Malibu Lagoon sediments (Bay et al., 2000; Bay et al., 2005). Anderson et al. (1998) alludes to mussel development tests that apparently showed some impact from exposure to subsurface water in Malibu Lagoon, but results are not available for review. Meyers et al. (2001) performed sea urchin pore water toxicity testing for eight sites in Malibu Lagoon. Of those eight sites, two exhibited toxicity. Both toxic sites were located upstream, and were not the farthest upstream sites tested in the Lagoon. Sites farthest upstream were hypothesized to be the most likely to exhibit toxicity, as they are first to come into contact with water discharging from the watershed. However, these spatial patterns were not upheld in Malibu Lagoon. This likely reflects a flawed hypothesis, as the areas with greatest toxicity are likely those with greater deposition of fine sediments that magnify concentrations of metals and/or organic toxins.

No data are available for specific organic toxins in the Lagoon.

Weight of Evidence for Toxicity from Metals, Elevated Salt Concentrations, or Organic Toxics Causing Biological Impairment

1. Co-occurrence: Two of eight Lagoon pore-water samples showed toxicity to sea urchins, but no sediment toxicity was identified in earlier amphipod tests. Moreover, it is not clear how sample locations for toxicity test samples relate to locations from which benthic macroinvertebrate samples were obtained. Therefore, the evidence for co-occurrence is uncertain.
2. Temporality: Direct toxicity testing results are not consistent in time. Only occasional sediment toxicity has been observed in Malibu Lagoon, whereas biological impairment has been present consistently.
3. Biological gradient: Insufficient data are available to support a biological gradient. No sediment metals data or water column conductivity data are available for the reported toxicity tests, nor are they available for comparison to benthic macroinvertebrate sample results.

4. Complete exposure pathway: Evidence for the exposure pathway is incomplete.
5. Plausibility: In addition to observing toxicity in several toxicity tests, there is literature supporting toxicity of selenium, sulfate, and various organic chemicals to estuarine aquatic organisms. Therefore, toxicity is plausible.
6. Analogy: The literature contains many analogous cases in which metals and organic toxins are associated with impacts on invertebrates.
7. Predictive performance: Toxicity testing has demonstrated occasional sediment toxicity, but mechanisms or endpoints specific to selenium, sulfate, or specific organic chemical toxicity have not been evaluated. Therefore, there is no evidence of predictive performance.
8. Consistency of evidence: There are multiple inconsistencies in the evidence.
9. Coherence of evidence: Inconsistencies exist in the evidence linking toxicity from metals, elevated salt concentrations, or organics toxics to biological impairment. No explanation is available for the inconsistent spatial and temporal observations of toxicity, nor is it clear that additional data will sufficiently explain the inconsistencies.

A5: Niche Competition: Invasive species can impair benthic macroinvertebrate communities through niche competition. This section evaluates the linkage between invasive species (specifically the New Zealand mudsnail) and biological impairment (Figure G-10).

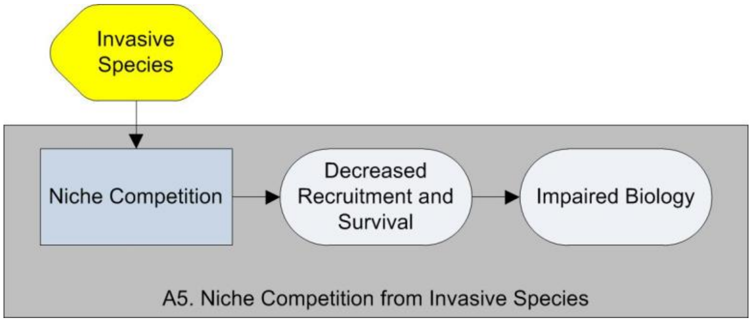


Figure G-10. Illustrated Linkage between Niche Competition and Impaired Biology

Malibu Creek

The presence of the invasive New Zealand mudsnail (*Potamopyrgus antipodarum*) has been increasing in the Malibu Creek and surrounding watersheds. The mudsnail is very easily spread by fishermen and other stream visitors due to its small size and resistance to desiccation (CDFG, 2012). The New Zealand mudsnail was first detected in samples collected by the City of Calabasas in 2005, and they are now found in eight streams in the Santa Monica Mountains. Abramson et al. (2009) report that the New Zealand mudsnail “colonies disrupt the food web by displacing native aquatic invertebrates that fish and amphibians rely on for food” and that mudsnails have been found in more than 70 percent of samples in Malibu Creek.

In general, invasive species impair native ecosystems by outcompeting native species for resources such as food or habitat and ultimately reduce species diversity (Strayer, 2010). Specifically, at high densities, the mudsnail may compete with other invertebrates for food and habitat, resulting in reduced densities and diversities of native benthic macroinvertebrates. Kerans et al. (2005) studied the New Zealand mudsnail in Greater Yellowstone Park and found little evidence for negative interaction between it and other macroinvertebrates in field surveys. However, negative associations did occur in colonization experiments: the mudsnail may limit recolonization of areas by other macroinvertebrates. Additionally, the Riparian Invasive Research Laboratory reports that the mudsnail may aid growth of filamentous algae (e.g., *Cladophora*) by grazing on epiphytic diatoms and removing competition for light (UCSB, 2012).

If the New Zealand mudsnail were causing impairment of benthic biota in the Malibu Creek watershed, sites with a high density of the snails would be expected to have lowered SC-IBI scores. However, in spring 2006, mudsnails constituted three percent of the biological sample at MC-1, which had an SC-IBI score of 30. By spring 2009, the biological sample at the same site contained 81% mudsnails, but the corresponding SC-IBI score was 27. The pMMI scores for MC-1 showed an opposite trend, with spring 2006 scores of 0.64, declining to 0.36 in 2008 and 0.42 in 2009, as snail densities increased; however, similar low pMMI scores are found prior to the documented presence of mudsnails (e.g., 0.43 in 2000). Low SC-IBI scores in spring 2010 also had low densities of mudsnails (from less than 1 percent at MC-1 to 13 percent at MC-15). Further evaluation is necessary to identify the impact of the New Zealand mudsnails on the benthic assemblage in the Malibu Creek Watershed.

Although other invasive species exist in the watershed (e.g., red swamp crayfish, bullfrogs, and mosquitofish), data are not available describing their locations or abundances. Therefore, no evaluation of their potential impacts on the benthic macroinvertebrate assemblage was performed.

Weight of Evidence for Niche Competition by Invasive Species Resulting in Biological Impairment

1. Co-occurrence: New Zealand mudsnails currently occur at several impacted sites, but some impacted sites had no observations of New Zealand mudsnails. Therefore, the evidence for co-occurrence is uncertain.
2. Temporality: New Zealand mudsnails were first documented in 2005, after benthic macroinvertebrate impairment was documented. It is not clear when they first arrived in the watershed, but the available evidence is incompatible with temporality.
3. Biological gradient: No clear evidence exists for a biological gradient.
4. Complete exposure pathway: Evidence for the exposure pathway is incomplete. Mudsnails (and other invasive species) are documented in the watershed, but no data are available at this time to confirm negative interactions with native benthic macroinvertebrates.
5. Plausibility: The scientific literature presents a large body of evidence for deleterious impacts from invasive species in general, by a variety of mechanisms. Although scant literature exist describing deleterious impacts to benthic macroinvertebrates resulting from New Zealand mudsnails, the impact is plausible.
6. Analogy: Analogous cases exist in the literature for similar invasive species (e.g., zebra mussels), but specific information regarding New Zealand mudsnails is not available.
7. Predictive performance: There is no evidence for the predictive performance line of evidence.
8. Consistency of evidence: Multiple inconsistencies exist in the evidence. New Zealand mudsnails are present and growing in abundance in the Malibu Creek watershed. They co-occur at impacted sites, but also are found proximate to one comparator/reference site. No apparent biological gradient exists, temporality appears inconsistent, and the exposure pathway is incomplete.
9. Coherence of evidence: Inconsistencies exist in the evidence linking invasive species to biological impairment. Biological impairment was observed before New Zealand mudsnails were observed in the watershed, so the mudsnails are not the only stressor responsible for impairment. However, sufficient evidence exists to warrant additional study of the mudsnails. Additional monitoring may reveal a linkage.

Malibu Lagoon

The New Zealand mudsnail is a freshwater species that currently is not observed in the Lagoon. No data on invasive species in the Lagoon are available. Therefore, while the linkage between invasive species and biological impairment is plausible and analogies exist in the literature, there is no evidence to support this linkage in Malibu Lagoon.

G.1.4 Characterize Causes

G.1.4.1 Eliminate Candidate Causes

Only stressors where lack of evidence for causing the observed biological impairment is unambiguous are eliminated. As a result, only invasive species in Malibu Lagoon is eliminated as highly unlikely to be a significant and sufficient cause of the observed impairment. The New Zealand mudsnail has not been observed in Malibu Lagoon and therefore cannot be a cause of biological impairment in the Lagoon.

Potential cause A3 (Reduced DO) was considered, but could not be definitively eliminated. DO concentrations below the water quality standard are observed at MC-1 and MC-12, but less than 18 percent of the time – likely not at a sufficient frequency to cause impairment. Hypoxic concentrations less than 2 mg/L have not been observed at these stations. However, better DO conditions are clearly observed at the coastal comparator/reference stations, with no observations below 6 mg/L. Lastly, there is very little diel DO data upon which to evaluate DO conditions fully. Therefore, cause A3 is not eliminated at this stage.

G.1.4.2 Diagnostic Analysis of Stressors

For Malibu Creek and Lagoon, diagnostic protocols are potentially applicable to low DO and acute toxic effects of some chemicals. However, direct observations of organism lethality or condition due to a specific cause are not available. Therefore, the diagnostic analysis step is not applicable to Malibu Creek and Lagoon impairment analysis at this time.

G.1.4.3 Strength of Evidence

Strength of evidence analysis uses the information developed in the data analysis to determine if the candidate causes have an effect on benthic macroinvertebrates. The causal considerations for the strength of evidence analyses used three types of evidence: case-specific evidence, evidence from other situations or biological knowledge, and evidence based on multiple lines of evidence, as described in Section G.1.1.

The results of the strength of evidence analysis, which are presented in narrative form in each analysis of the evidence, are summarized in Table G-1. The bottom of each cell displays the visual scoring recommended in USEPA (2000b), ranging from strongly positive “+++”) to strongly negative (“---”). The full range of symbols is not used for every line of evidence. For instance, co-occurrence has potential values of “+”, “0”, and “---” only.

Table G-1. Strength of Evidence Analysis for Stressors (A1 – A5)

	Consideration	Results	Stream	Lagoon
A1. Reduced Habitat Quality from Sedimentation				
Case-specific Evidence	Co-Occurrence	Compatible.	+	+
	Temporality	Compatible.	+	+
	Biological Gradient	Weak.	+	+
	Complete Exposure Pathway	Evidence for all steps.	++	++
Information from Other Situations or Biological Knowledge	Plausibility	Plausible.	+	+
	Analogy	Many analogous cases.	++	++
	Predictive Performance	No evidence for predictive performance.	NE	NE
Considerations Based on Multiple Lines of Evidence	Consistency of Evidence	Most lines of evidence are consistent (for stream). All lines of evidence are consistent (for Lagoon).	+	+++

	Consideration	Results	Stream	Lagoon
	Coherence of Evidence	Inconsistencies can be explained by a credible mechanism.	+	+
A2. Reduced Habitat Quality from Excess Algal Growth				
Case-specific Evidence	Co-Occurrence	Compatible.	+	+
	Temporality	Compatible.	+	+
	Biological Gradient	Strong.	+++	+++
	Complete Exposure Pathway	Evidence for all steps.	++	++
Information from Other Situations or Biological Knowledge	Plausibility	Plausible.	+	+
	Analogy	Many analogous cases.	++	++
	Predictive Performance	No evidence for predictive performance.	NE	NE
Considerations Based on Multiple Lines of Evidence	Consistency of Evidence	All lines of evidence are consistent.	+++	+++
	Coherence of Evidence	Inconsistencies can be explained by a credible mechanism.	+	+
A3. Reduced DO				
Case-specific Evidence	Co-Occurrence	Uncertain (for stream). Compatible (for Lagoon).	0	+
	Temporality	Compatible.	+	+
	Biological Gradient	Weak.	+	+
	Complete Exposure Pathway	Incomplete evidence (for stream). Evidence for all steps (for Lagoon).	+	++
Information from Other Situations or Biological Knowledge	Plausibility	Plausible.	+	+
	Analogy	Many analogous cases.	++	++
	Predictive Performance	No evidence for predictive performance.	NE	NE
Considerations Based on Multiple Lines of Evidence	Consistency of Evidence	Most lines of evidence are consistent.	+	+
	Coherence of Evidence	Inconsistencies can be explained by a credible mechanism.	+	+
A4. Toxicity from Elevated Salt Concentrations, Metals, or Organic Toxics				
Case-specific Evidence	Co-Occurrence	Uncertain.	0	0
	Temporality	Uncertain (for stream).Incompatible (for lagoon).	0	---
	Biological Gradient	Weak (for stream). No evidence (for Lagoon).	+	-
	Complete Exposure Pathway	Incomplete evidence.	+	+
Information from Other Situations or Biological Knowledge	Plausibility	Actual evidence.	++	++
	Analogy	Many analogous cases.	++	++
	Predictive Performance	No evidence for predictive performance.	NE	NE
Considerations Based on Multiple Lines of Evidence	Consistency of Evidence	Multiple inconsistencies.	---	---
	Coherence of Evidence	No known mechanism explains the inconsistencies.	0	0
A5. Niche Competition from Invasive Species				
Case-specific Evidence	Co-Occurrence	Uncertain.	0	0
	Temporality	Incompatible.	---	---
	Biological Gradient	No evidence.	-	-

	Consideration	Results	Stream	Lagoon
	Complete Exposure Pathway	Incomplete evidence (for stream). Some steps missing or implausible (for Lagoon).	+	-
Information from Other Situations or Biological Knowledge	Plausibility	Plausible.	+	+
	Analogy	Some analogous cases.	+	+
	Predictive Performance	No evidence for predictive performance.	NE	NE
Considerations Based on Multiple Lines of Evidence	Consistency of Evidence	Multiple inconsistencies in the lines of evidence.	---	---
	Coherence of Evidence	Inconsistencies can be explained by a credible mechanism (for stream). No known mechanism explains the inconsistencies (for Lagoon).	+	0

G.1.5 Characterize Causes: Identify Probable Cause

The stressor identification process has identified a number of potential causes for the reduced quality of benthic macroinvertebrate assemblages in Malibu Creek and Lagoon; however, there is not a single primary cause. Instead, it appears that the impaired condition of macroinvertebrate biology in the stream and Lagoon is due to the impact of multiple stressors. For example, bioscores (SC-IBI and pMMI) throughout the watershed appear to be reduced where physical habitat is sub-optimal or worse; however, Malibu Creek main stem stations also show poor bioscores for sites with optimal physical habitat. Biology at these sites is evidently co-limited by other factors such as excess algal growth.

Based on the evidence summarized in the preceding sections, the following two stressors emerge as the likely causes of biological impairment in the streams of Malibu Creek Watershed:

A1. Reduced Habitat Quality from Sedimentation

A2. Reduced Habitat Quality from Excess Algal Growth

The following three stressors emerge as the likely causes of biological impairment in Malibu Lagoon:

A1. Reduced Habitat Quality from Sedimentation

A2. Reduced Habitat Quality from Excess Algal Growth

A3. Reduced Dissolved Oxygen from Excess Algal Growth

A2 (Reduced Habitat Quality from Excess Algal Growth) is closely related to A3 (Reduced DO). DO appears to be a more significant constraint on biology in the Lagoon than in the stream, so candidate cause A3 is also listed for the Lagoon.

All these stressors have previously been proposed as causes of impairment in the watershed (e.g., Ambrose and Orme, 2000; Sikich et al., 2012; USEPA, 2003); the critical concern in this TMDL is to evaluate the causes of impaired bioscores for benthic macroinvertebrates. These stressors rank high on all considerations summarized in Table G-1, with no evident inconsistencies. Each stressor provides a plausible and consistent pathway from exposure to effect.

Toxicity (A4) has been demonstrated occasionally in the watershed, but direct toxicity data are limited. Sulfate and selenium concentrations are present in excess of water quality criteria, apparently due to natural geologic background. LVMWD (2011) has proposed that impaired biotic conditions in the watershed are in part due to high-sulfate discharge coming from the area where the marine Monterey/Modelo Formation is exposed. Stressor A4, Toxicity, can affect the biological potential of the main stem and various tributaries to Malibu Creek. Specifically, elevated conductivity levels appear to reduce EPT taxa. However, this set of stressors alone does not appear sufficient to result in impaired biology, as unimpaired SC-IBI and pMMI scores are found at stations within the Monterey/Modelo Formation with similar stressor levels, and low SC-IBI and pMMI scores are found at stations that do not drain this formation but have elevated levels of the same stressors (see Section 8 of the TMDL report). Therefore, toxicity may be a contributing stressor, but not a primary stressor resulting in impaired biology.

Invasive species, specifically the New Zealand mudsnail (A5) – remains a potential contributor to impairment; however, the mudsnail was not confirmed to be present until 2005, whereas the low bioscores have been documented in the Malibu Creek main stem since 2000. If the mudsnail was absent prior to 2005, it is not clear how this can be a significant cause of impairment. There also does not appear to be a temporal correlation between mudsnail density and SC-IBI scores.

In sum, benthic macroinvertebrates in the Malibu Creek watershed and Malibu Lagoon are impacted by multiple stressors, all of which may contribute to the documented biological impairment. The sum of the evidence suggests that the dominant stressors are sedimentation and nutrients/algae. Mitigating these stressors should improve the conditions of benthic macroinvertebrate communities.

G.2 Source Identification

G.2.1 List Candidate Sources

Sources from human activities represent the origin of stressors that contribute to adverse biological responses in a waterbody. Seven groups of stressor sources are listed as potential causes of observed impairment for further evaluation:

B1. **Altered Hydrology**: Altered hydrology, in addition to changing the flow regime, causes increased erosion and sedimentation. Hydrology in Malibu Creek has been altered by a combination of increased impervious area (which increases flow peaks), irrigation and onsite wastewater disposal (which increase base flow levels), and impoundments (which decrease net flows and smooth out peaks). Hydrology in the Malibu Lagoon has been altered due to changes in upstream flow, filling and constrictions of the Lagoon, and changes in the rate of opening to the ocean.

B2. **Channel Alteration**: Hydromodification of the stream channel has the potential to change the shape of the stream, redistribute sediments, change sediment sizes, and erode channels. The major alterations to the channel of Malibu Creek and its tributaries have been the creation of several lakes or impoundments that trap sediment, changing the sediment balance, modifying the flow, and changing sediment transport capacity. Malibu Lagoon has been extensively modified over the years by sediment fill, surrounding development, construction of railroad and road crossings, and intentional breaching of the barrier beach to allow draw down of impounded water.

B3. **Fire Impacts**: Fire is a recurrent and important factor of the landscape in southern California that can cause important temporary changes in runoff and sediment loading. In the years after intense fires, the lack of vegetation results in increased peak runoff, and elevated sediment loads; these actions can impact biology directly (Minshall, 2002). Although fire is a natural phenomenon in chaparral landscapes, human activity has increased the frequency of accidental and intentionally started fires. Malibu Creek Watershed has experienced many significant fires over the past several decades, including the Topanga fire in late September 2005 and the Foothill, Canyon, and Corral fires in January, October, and November of 2007, respectively.

B4. **Septic Systems:** Septic systems can be significant sources of nutrients, even when they are well sited and functioning properly, since they introduce nutrients to shallow groundwater that may eventually enter surface waters. Nitrogen is particularly mobile in groundwater, while phosphorus has a tendency to be adsorbed by soils. Septic systems are used in low-density rural residential areas and a few communities in the watershed, as well as part of the City of Malibu that falls within the watershed. These septic systems are estimated to contribute significant nitrogen to surface waters in the watershed. LARWQCB staff estimated that current loads from onsite wastewater disposal in the Civic Center area amount to 30-35 lbs/day. This could be a potentially significant source of nutrients into the groundwater and Lagoon.

B5. **Point Source Discharges**: Wastewater treatment plants and other permitted point source discharges can contribute to excess loads of nutrients, oxygen-demanding waste (e.g., decomposable or labile organic matter or organic chemicals), and other pollutants. Within the Malibu Creek Watershed, the only traditional permitted point source discharge is the Tapia Water Reclamation Facility (WRF). The Tapia WRF, built in 1965, originally discharged to Malibu Creek along Malibu Canyon Road throughout the year. Discharges from Tapia were severely restricted by orders of the RWQCB in 1997-1999. Since then, discharges to Malibu Creek have been prohibited from April 15 to November 15 (except as needed for flow augmentation to support steelhead). Much of the reclaimed water is used for irrigation. Winter discharges occur, but are restricted to 8 mg/L total inorganic N and 3 mg/L total P in accordance with the 2003 nutrient TMDL and 2005 and 2010 permit modifications. .

B6. **Urban Runoff**: Urbanization accounts for an increase in impervious surface in the watershed from near zero in the 1960s to 5.26% in 1990 and to 6.95% in 2008. While most of the watershed remains undeveloped, this impervious area percentage increase is concentrated along the I-101 corridor. Impervious surfaces alter the flow regime by reducing infiltration and increasing surface runoff. This leads to increased flood frequencies and magnitudes, resulting in the common “flashiness” of urban streams, and the concomitant channel morphological changes (Paul and Meyer, 2001). Additionally, urban runoff is a potential source of a variety of pollutants, such as bacteria, dissolved solids, nutrients, metals, pesticides, herbicides, and petroleum products (Paul and Meyer, 2001). Active urban development (active construction) results in increased sedimentation from surface runoff. Urban runoff in Los Angeles and Ventura Counties is covered by two unified NPDES MS4 point source discharge permits.

B7. **Agricultural Runoff**: In many watersheds, agricultural runoff (including irrigation return flow) is a potential cause of impairment. Agricultural runoff can contribute to elevated levels of sediment, nutrients, pesticides, and herbicides. Satellite imagery data indicate that agricultural land use in the Malibu Creek watershed had decreased from 1.9% in 1990 to 1.3% in 2008 (Section 4.5 of the TMDL report). However, Goepel et al. (2012) report that many existing vineyards are small, situated adjacent to residential structures, and likely represent “hobby vineyards.” These small, isolated agricultural uses likely aren’t identified on the satellite imagery.

B8. **Modified Exposure of Natural Geology**: In some watersheds, certain natural geological related stressors may be elevated due to unnatural conditions (anthropogenic activities, i.e., construction, mining, etc.). The Malibu Creek Watershed contains the unique geology of the Santa Monica Mountains and the Monterey/Modelo Formation. The Santa Monica Mountains are an area of rapid geologic uplift, resulting in naturally high rates of erosion and sedimentation (see Section 4.4 of the TMDL report). The marine sedimentary Monterey/Modelo Formation outcrops exhibit elevated levels of sulfate, phosphate, and various metals, including selenium, (LVMWD, 2011). These deposits may contribute to selenium, orthophosphate, sulfate, and total dissolved solids concentrations in Malibu Creek. Unnatural conditions, such as accelerated erosion of these deposits from human activities would contribute to unexpected elevated levels of these ions. Impacts or alterations of the natural geology potentially could result in biological impairment from sedimentation and reduced habitat quality or toxicity. The Monterey/Modelo Formation comprises a large area of surficial geology in southern California, and the state has identified several reference sites in the Monterey Formation outside of the Malibu Creek watershed that can be used for comparative purposes.

G.2.2 Analyze Evidence and Characterize Sources

The previous section, "List Candidate Sources" identified sources that are present in the impaired watershed and that may have been responsible—either singly or in combination—for probable stressors. This section presents an analysis of the evidence for each of the seven groups of stressor sources that are also enumerated as potential causes of observed impairment for further evaluation. This section explores the linkages between potential sources and stressors that were not eliminated in Section G.1.4.1. The strength of evidence for each candidate source is presented within this discussion, to maintain coherence between the presentation of the evidence and the conclusions drawn from it. Additionally, Section G.2.4 summarizes the Characterization and presents the results in tabular format.

Section G.1 evaluated the weight of evidence for linkages between each candidate stressor and the observed benthic macroinvertebrate assemblage impairment. Additional evidence is provided by identifying pathways between sources and the stressors. In actuality, the complete pathway flows from source to stressor to impaired receptor; and that pathway may involve one or more interacting stressors or modifying factors. Multiple causal pathways are evaluated for Malibu Creek and Lagoon, as shown in the conceptual model (Figure G-1) and indicated above; however, these causal pathways are not fully independent. Overlap between the pathways results in the following set:

1. Reduced habitat quality from excess sedimentation (A1) can be caused by altered hydrology (B1), channel alteration (B2), fire impacts (B3), urban runoff, including runoff from construction sites (B6), agricultural runoff (B7), or natural geology (B8).
2. Reduced habitat quality from excess algal growth (A2) can be caused by nutrients in septic systems (B4), point source discharges (B5), urban runoff (B6), or agricultural runoff (B7), and is exacerbated by naturally elevated nutrient concentrations in parts of the watershed (B8).
3. Reduced DO (A3) can be caused by altered hydrology leading to stagnant conditions (B1), excess algal growth or oxygen-demanding wastes resulting from septic systems (B4), point source discharges (B5), urban runoff (B6), or agricultural runoff (B7), or natural geology (B8).
4. Toxicity from metals, elevated salt concentrations, or organic toxics (A4) can be caused by urban runoff (B6) or natural geology (B8).
5. Niche competition (A5) can be caused by invasive species (B8).

These pathways, described from stressor to potential sources above, can also be described from source to stressor as shown:

1. **Altered hydrology (B1)** can cause reduced habitat quality from excess sedimentation (A1) or reduced DO (A3)
2. **Channel alteration (B2)** can cause reduced habitat quality from excess sedimentation (A1)
3. **Fire impacts (B3)** can cause reduced habitat quality from excess sedimentation (A1), increased nutrient concentrations that cause excess algal growth and reduced habitat quality (A2), or reduced dissolved oxygen (A3)
4. **Septic systems (B4)** can contribute excess nutrients that cause excess algal growth that diminishes habitat quality (A2) or results in reduced DO (A3), or oxygen-demanding wastes that cause reduced DO (A3)

5. **Point source discharges (B5)** can contribute either excess nutrients that cause excess algal growth that diminishes habitat quality (A2) or results in reduced DO (A3), or oxygen-demanding wastes that cause reduced DO (A3)
6. **Urban runoff (B6)** can cause reduced habitat quality from excess sedimentation (A1), reduced habitat quality from excess algal growth (A2) resulting from increased nutrient concentrations, reduced DO (A3) resulting from increased nutrients or oxygen demanding wastes, or toxicity from metals, elevated salt concentrations, or organic toxics (A4)
7. **Agricultural runoff (B7)** can cause reduced habitat quality from excess sedimentation (A1), reduced habitat quality from excess algal growth (A2) from increased nutrient concentrations, or reduced DO (A3) resulting from excess algal growth or oxygen demanding wastes
8. **Natural geology (B8)** can cause reduced habitat quality from excess sedimentation (A1), reduced habitat quality from excess algal growth (A2), reduced DO from excess algal growth (A3), or toxicity from metals, elevated salt concentrations, or organic toxics (A4)

This section evaluates the weight of evidence for the linkages between potential sources and the stressors, as described in this second list of pathways.

B1. Altered Hydrology: Changes in stream hydrology affect the flow regime and can result in reduced habitat quality from excess sedimentation (A1) and subsequent physical habitat alteration, or reduced DO, when hydrologic changes lead to stagnant conditions (A3). Changes in stream hydrology are related to both channel alteration (B2) and urban runoff (B6), all of which occur as a result of urbanization. Changes in stream hydrology and channel alteration also can result from dam management activities. This section evaluates the linkages between 1) altered hydrology and increased sedimentation and 2) altered hydrology and reduced DO (Figure G-11).

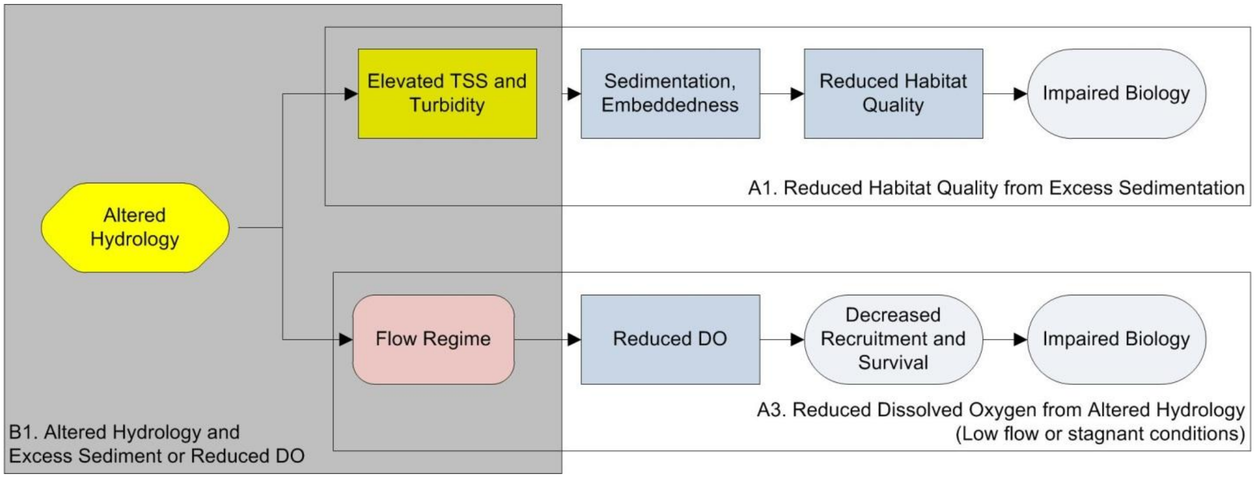


Figure G-11. Illustrated Linkage between Altered Hydrology and Excess Sedimentation or Reduced Dissolved Oxygen

Malibu Creek

Stream flows have been altered in impacted reaches of the watershed, due to urbanization, water importation, reservoir construction, and wastewater discharges to Malibu Creek. An evaluation of flow gauge data revealed that both peak flows and base flows have increased with urbanization.

The Indicators of Hydrologic Alteration analysis showed dramatic changes in both high and low flows, with large increases in both summer low flows and winter storm flow peaks (see Section 6 of the TMDL report). Median low flows increased in all months except February and March when comparing gage data for water years 1992-2009 to 1932-1965. Dramatic changes have also occurred in high flows. The more recent (post-development) stream gage data show an increase in the median 1-day maximum flow of 380 percent and in increase in the median 30-day maximum flow of 410 percent. Increases in the magnitude of large flood peaks and changes in timing of flood peaks, which now occur earlier in the year, are both statistically significant (the probability of these changes occurring by chance is less than 1 percent). These changes have likely modified the physical conditions and morphology of the stream channel bed; the changes in large floods can also have important consequences for the physical habitat of the floodplain.

Altered hydrology, especially increased frequency and magnitude of large flood peaks, can result in increased erosion and excess sedimentation. Heal the Bay's Stream Walk program documented unstable stream banks that had been scoured or eroded by stream flows, surface runoff from outflow pipes, and poorly drained roads and trails, along 19.5 linear miles of 68 miles mapped in the watershed (Sikich et al., 2012). Unstable stream banks occurred in both developed and undeveloped areas. In developed areas, unstable banks typically occurred downstream of channel alteration comprised of bank hardening (see channel alteration, B2, below). In undeveloped areas, additional investigation into the causes of unstable stream banks revealed numerous unpaved roads and trails within 300 feet of eroded banks. Furthermore, 21.29 miles of all surveyed streams were observed to be impacted by excess fine sediments. Only 0.29 miles of the impacted streams occurred upstream of developed areas.

Altered hydrology can also result in reduced dissolved oxygen (DO) when alterations result in very low flows and disconnected or stagnant water. High flows are more likely to experience turbulent mixing, which increases reaeration. Disconnected pools and stagnant water experience less mixing, and tend to be shallower and warmer, resulting in reduced dissolved oxygen. Long-term flow records in Malibu Creek show near-zero base flows during the summer/fall, but more recent gage records demonstrate that baseflow has generally increased and the frequency of low flows has decreased following development. Owen (1998) reported results from the HEC-1 flood forecast model indicated that "…the watershed is yielding a large increase in runoff since predevelopment conditions have changed into the current state of development. Increases greater than 100% are seen in every subshed…"

Weight of Evidence for Altered Hydrology Resulting in Excess Sedimentation

1. Co-occurrence: Based on evidence from the case, evidence for spatial co-occurrence between altered hydrology and increased sedimentation is compatible. Heal the Bay Stream Team data indicate increased sedimentation coincident with impacted sites.
2. Temporality: Evidence for temporality is compatible. Flows have been altered downstream of developed portions of the watershed, altering peak magnitude and frequencies, both of which are associated with alteration in rates of erosion and sedimentation. Increased sedimentation has been observed over the same time frame.
3. Response gradient: Evidence for the response gradient is consistent but incomplete as information on hydrology and sediment transport at comparator/reference sites is limited; however, increased flows and erosive power are expected as a result of increased impervious surface area.
4. Complete exposure pathway: Evidence supporting the linkage between altered hydrology and increased sedimentation is consistent but incomplete due to the lack of evidence for the response gradient. However, evidence for co-occurrence and temporality both support the linkage.
5. Plausibility: A large body of scientific literature supports a linkage between altered flow, especially in peak flow magnitudes and frequencies, and channel erosion and sedimentation.
6. Analogy: Many examples of flow alterations causing increased sedimentation are found in the literature.
7. Predictive performance: There is no evidence of predictive performance.
8. Consistency of evidence: All lines of evidence supporting the causal relationship are consistent.

9. Coherence of evidence: There are no inconsistencies in the evidence, but additional data collection to support the response gradient would be expected to strengthen the linkage.

The strength of the evidence supporting the causal pathway between altered hydrology and sedimentation is consistent.

Weight of Evidence for Altered Hydrology Resulting in Reduced DO

1. Co-occurrence: Multiple analyses indicate that flows have on average increased across the watershed. There are still areas of the watershed that experience low DO; however. For example, impacted sites and some sites within the Monterey/Modelo Formation experience greater frequencies of low DO events (e.g., LV9). In diel measurements, Start Pool experienced low overnight DO during the summer low flow period. Evidence for co-occurrence of low flow and low DO is uncertain due to a lack of data.
2. Temporality: Flows have been altered since development of the watershed, but base flow has increased, not decreased, and the frequency of low flow events has decreased, not increased. Therefore, evidence for temporality is incompatible.
3. Response gradient: Evidence for the gradient is weak, since information on hydrology at comparator/reference sites is not typically available.
4. Complete exposure pathway: Some steps are missing in the evidence supporting the linkage between altered hydrology and low DO, because there is a lack of evidence for the response and temporality is incompatible.
5. Plausibility: Evidence from the literature indicates that a causal linkage between altered hydrology leading to low flow conditions and decreased DO is plausible, but not specific.
6. Analogy: Many examples of flow alterations resulting in low flows or stagnant conditions leading to low DO are found in the literature.
7. Predictive performance: There is no evidence of predictive performance
8. Consistency of evidence: Overall, there are multiple inconsistencies and a lack of data in the lines of evidence supporting the relationship between altered hydrology and reduced DO.
9. Coherence of evidence: The available data are not consistent with expectations regarding DO patterns observed with altered hydrology. Data necessary to prove low DO levels in low-flow pools are limited. Additional DO data from multiple low-flow areas in the watershed would resolve gaps in the evidence for low DO. Additionally, base flows have increased overall, contradicting the evidence for the linkage between altered hydrology (low or stagnant flows) and reduced DO.

The strength of the evidence supporting the linkage between altered hydrology and reduced dissolved oxygen is weak due to inconsistencies in the evidence and limited data.

Malibu Lagoon

As discussed in Section 6.3 of the TMDL report, a review of historical maps for Malibu Lagoon reveals alterations to the Lagoon's morphology, resulting from altered flow regimes in Malibu Creek, increased sedimentation, and development constricting the size and volume of the Lagoon. The physical constraints imposed by development to substantially reduce the surface area over which sediments are deposited, resulting in fine sediments accumulating in tidal channels (Ambrose and Orme, 2000; Moffatt and Nichol, 2005).

Weight of Evidence for Altered Hydrology and Excess Sedimentation

1. Co-occurrence: Flow alterations in Malibu Creek are believed to have increased erosion and sediment transport capacity. Sediment that is flushed from the watershed during storm events is deposited in the Lagoon. Constraints on the lagoon footprint have limited the surface area over which sediments can be deposited, such that fine sediments accumulate in tidal channels. Therefore, the evidence for co-occurrence is compatible.
2. Temporality: The Topanga-Las Virgenes Resources Conservation District (1989) estimate 1987 levels of sedimentation to be nearly ten times the rate that would have occurred pre-development. The physical modifications of the Lagoon, beginning with the railway construction in 1908, pre-date increases in sedimentation. Therefore, the evidence for temporality is compatible.
3. Response gradient: Supporting evidence for a gradient between altered hydrology in Malibu Creek and increased sedimentation is strong, with enhanced sedimentation in side channels of the Lagoon.
4. Complete exposure pathway: There is evidence for all steps in the linkage between altered hydrology and increased sedimentation. Flow alterations co-occur with observations of increased sediment, and rates of sedimentation have increased to their current state.
5. Plausibility: A large body of scientific literature supports a linkage between altered flow, especially in peak flow magnitudes and frequencies, and channel erosion and sedimentation in the Creek as well as enhanced sedimentation in the Lagoon.
6. Analogy: Many examples of flow alterations similar to those described causing increased sedimentation are found in the literature.
7. Predictive performance: There is no evidence of predictive performance.
8. Consistency of evidence: All lines of evidence supporting the linkage between altered hydrology and increased sedimentation in the Lagoon are consistent.
9. Coherence of evidence: No inconsistencies are present in the evidence.

The strength of the evidence supporting the causal pathway between altered hydrology in Malibu Creek and sedimentation in Malibu Lagoon is strong.

Weight of Evidence for Altered Hydrology and Reduced DO

The linkage between altered hydrology and reduced DO in Malibu Lagoon cannot be fully evaluated due to lack of data. Effects of changed morphology are addressed under the heading “Channel Alterations.”

B2. Channel Alteration: Channel alteration is closely related to altered hydrology (B1) and urban runoff (B6), and can result in increased sedimentation (A1) and subsequent physical habitat alteration. This section evaluates the linkages between channel alteration and increased sedimentation (Figure G-12).

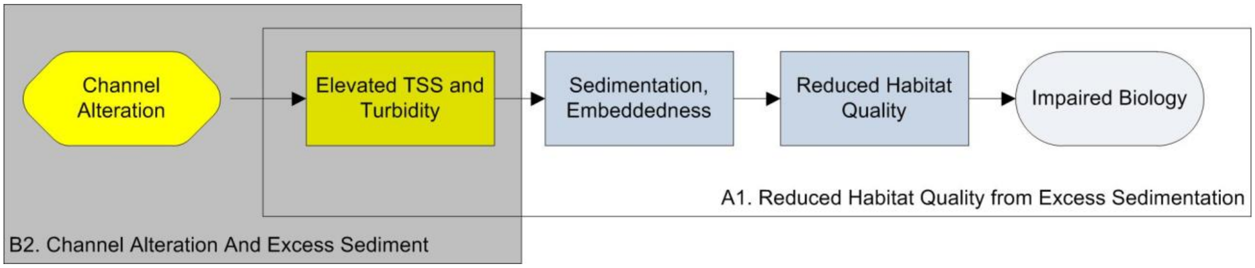


Figure G-12. Illustrated Linkage between Channel Alteration and Excess Sedimentation

Channel alteration can take many forms. The following information on physical habitat alteration is excerpted from USEPA’s CADDIS website (USEPA, 2012):

> *Direct alteration of streams channels also can influence physical habitat, by changing discharge patterns, changing hydraulic conditions (water velocities and depths), creating barriers to movement, decreasing riparian habitat and altering the structure of stream geomorphological units (e.g., by increasing the prevalence of run habitats, decreasing riffle habitats, and increasing or decreasing pool habitats). Typically, physical habitat degradation results from reduced habitat availability (e.g., decreased snag habitat, decreased riffle habitat) or reduced habitat quality (e.g., increased fine sediment cover), which may contribute to decreased condition, altered behavior, increased mortality, or decreased reproductive success of aquatic organisms; ultimately, these effects may result in changes in population and community structure and ecosystem function.*

Malibu Creek

Heal the Bay's Stream Walk program documented 987 streambank modifications, with a total of 20.9 linear miles engineered with hardened materials. Observed modifications included streambank reinforcement with concrete, boulders, fencing, planted vegetation, and other materials, intended to prevent or repair unstable stream banks (Sikich et al., 2012). The Stream Walk program consistently documented increased erosion and sedimentation downstream of modified stream banks. According to Sikich et al. (2012), stream bank modifications are made in an effort to mitigate unstable stream bank erosion, protect adjacent private property, and to allow for access to the stream. These modifications support the suggestion that channel alteration largely resulted from development of the watershed.

Weight of Evidence for Channel Alteration Resulting in Excess Sedimentation

1. Co-occurrence: Heal the Bay's Stream Walk program documented numerous cases of stream bank modifications with increased erosion and sedimentation downstream, providing evidence for co-occurrence.
2. Temporality: Stream bank modification largely occurred as a result of development, providing supporting evidence for temporality.
3. Response gradient: The Stream Walk program provides qualitative descriptions of erosion and sedimentation associated with modified stream banks; however, a quantitative analysis is not available. Therefore, evidence for a gradient is weak.
4. Complete exposure pathway: Evidence for a linkage between channel alterations and excess sedimentation is complete, although the magnitude of response is not known. Channel alterations occur at and immediately upstream of increased sedimentation, and both channel alterations and sedimentation have increased over time.
5. Plausibility: A large body of scientific literature supports a linkage between channel alterations and increased bank erosion.
6. Analogy: Many examples of channel alterations causing increased sedimentation are found in the literature.
7. Predictive performance: There is no evidence of predictive performance.
8. Consistency of evidence: Most lines of evidence for a linkage between channel alterations and increased sedimentation are consistent, with the exception of data for a gradient.
9. Coherence of evidence: There are no inconsistencies in the evidence.

The strength of the evidence supporting the causal pathway between channel alteration and sedimentation in Malibu Creek is moderate.

Malibu Lagoon

Review of historical maps for Malibu Lagoon clearly reveal alterations to the Lagoon's morphology, attributable in part to alterations of the channel through fill and building encroachment constricting the size, volume, and flushing capacity of the Lagoon. The Topanga-Las Virgenes Resources Conservation District (1989) reports a nearly ten-fold greater rate of sedimentation in the Lagoon than would have occurred prior to European settlement periods.

Weight of Evidence for Channel Alterations and Increased Sedimentation in Malibu Lagoon

1. Co-occurrence: Alterations to the Lagoon footprint co-occur with increases in sedimentation in the Lagoon.
2. Temporality: Historical topographic maps and aerial photography depict clear changes in the Lagoon footprint. These changes, particularly physical constraints resulting from increasing development, occurred prior to observations of increased sedimentation. Moreover, channel alterations upstream occurred concurrently with increased sedimentation in the Lagoon.
3. Response gradient: Restoration efforts to address low DO in the Lagoon have focused on restoring circulation in side channels that have been restricted by sedimentation. Therefore, there is evidence for a response gradient from channel alterations to increased sedimentation.
4. Complete exposure pathway: There is evidence for all steps in the pathway between channel alterations in the Lagoon and upstream in the watershed and increased sedimentation in the Lagoon.
5. Plausibility: A large body of scientific literature supports a linkage between increased sedimentation resulting from channel alterations such as those that have occurred at the Lagoon itself as well as upstream.
6. Analogy: Many examples of channel alterations similar to those described causing increased sedimentation are found in the literature.
7. Predictive performance: There is no evidence of predictive performance.
8. Consistency of evidence: All lines of evidence are consistent and support a linkage between channel alteration and increased sedimentation in Malibu Lagoon.
9. Coherence of evidence: There are no inconsistencies in the evidence.

The strength of the evidence supporting the causal pathway between channel alteration in Malibu Creek and Lagoon and sedimentation in Malibu Lagoon is strong.

B3. Fire Impacts: Fire impacts are closely related to altered hydrology (B1) and can cause increased sedimentation (A1) and nutrient concentrations (A2, A3) which increase algal growth reducing habitat quality and dissolved oxygen. This section evaluates the linkages between wildfires and increased sedimentation and nutrient concentrations (Figure G-13).

Figure G-13. Illustrated Linkage between Fire Impacts and Excess Sediment or Elevated Nutrient Concentrations

Malibu Creek

Wildfires can increase sedimentation in streams by altering soil structure, removing vegetation and debris cover from the land surface, and eliminating a functioning riparian buffer. Plants in a functioning buffer help retain stream banks and filter sediment from surface runoff. Additionally, they slow the rate of runoff, which decreases erosion. Wildfires also increase nutrient concentrations in streams because of the amount of dead plant matter that enters the stream after a fire. Instream impacts resulting from wildfires include initial decreases in in-stream woody debris, followed by substantial increases, and increased nutrient concentrations (Gresswell, 1999).

Studies of wildfire impacts reveal that flood flows following severe fire events can be the most damaging impact from wildfires, with floods as much as 100 times greater than pre-fire floods. Loss of terrestrial vegetation reduces water uptake and infiltration, resulting in increased baseflows, annual water yields, and peak flows (Neary et al., 2005). Increased peak flows may substantially increase erosion, sediment transport, and channel modification. Moreover, peak flows frequently will occur more rapidly after precipitation onset resulting in flash flooding. These changes explain the relationship between fire impacts and altered hydrology. The Malibu Creek watershed has experienced many significant fires over the past several decades (see Appendix B). Although fire is a natural phenomenon in chaparral landscapes, human activity has increased the frequency of accidental and intentionally started fires (NPS, 2007)[1].

The fires that overlap in time with physical habitat data collection include fires in 2005 and 2007. The 2005 fire impacted the northern portion of the watershed, while the fires in 2007 impacted the southern part of the watershed. Most affected sites do not have good before-and-after physical habitat information. Two exceptions are LVMWD-R3D and LVMWD-R4D, near the mouth of Malibu Creek. These two sites had physical habitat scores of 135 and 120 in 2006, which had declined to 126 and 74, respectively, in 2008. Individual sub-scores are more informative. Sub-scores for cobble embeddedness went from 17 to 12 and 10 to 4 between 2006 and 2008 at LVMWD-R3D and LVMWD-R4D. Sediment deposition scores went from 15 to 5 and 10 to 2, and riffle frequency scores went from 15 to 1 and 7 to 1, with lower values indicating less favorable conditions. This evidence is consistent with a major increase in

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[1] National Park Service. 2007. Santa Monica Mountains National Recreation Area Fire Management Plan. Thousand Oaks, CA. pp. 204.

sedimentation associated with the 2007 fires. In contrast, RBP scores at HtB station MC-1 declined only from 166 to 151 between 2006 and 2008, both within the optimal range. HtB station LV-9 was impacted by the 2005 fires and in 2006 had an RBP score of 109, below the long term average of 123. Unfortunately, the sub-scores are not available for the HtB data.

Weight of Evidence for Fire Regime and Increased Sedimentation

1. Co-occurrence: Wildfires have occurred in areas where sampling sites are located. Few data are available to assess the potential for increased sedimentation; however the RBP data that are available for before and after comparisons show a decline in habitat condition consistent with increased sedimentation. Co-occurrence is thus compatible.
2. Temporality: RBP scores for LVMWD-R3D and LVMWD-R4D appear to have declined in response to the 2007 fires. Temporality is generally compatible.
3. Response gradient: The data support a response gradient between fires and increased sedimentation.
4. Complete exposure pathway: The exposure pathway is complete.
5. Plausibility: The scientific literature supports a linkage between increased sedimentation resulting from wildfires.
6. Analogy: Examples of wildfires causing increased sedimentation are found in the literature.
7. Predictive performance: There is no evidence of predictive performance.
8. Consistency of evidence: Most lines of evidence are consistent; however, habitat scores at MC-1 remained optimal after the 2007 fires.
9. Coherence of evidence: There are no inconsistencies in the evidence.

There is consistent evidence supporting a causal pathway between wildfires and increased sedimentation in Malibu Creek. However, both RBP habitat scores and benthic bioscores suggest that the impacts of fires are relatively short-lived.

Weight of Evidence for Fire Regime and Increased Nutrient Loads

1. Co-occurrence: Wildfires have occurred in areas where sampling sites are located. However, monitoring data are insufficient to determine whether average nutrient concentrations and loads increased due to fire. Therefore, evidence for co-occurrence is uncertain.
2. Temporality: There are insufficient nutrient monitoring data to detect any significant changes in nutrient loads in response to the temporal sequence of wild fires. Therefore, evidence for temporality is uncertain.
3. Response gradient: The data do not support or disprove a gradient between fires and increased nutrient concentrations.
4. Complete exposure pathway: There are multiple missing steps in the pathway.
5. Plausibility: The scientific literature supports a linkage between increased nutrient concentrations resulting from wildfires; in particular, loads of sediment-associated phosphorus transported during high flow events are likely to increase.
6. Analogy: Examples of wildfires causing increased nutrient concentrations are found in the literature.
7. Predictive performance: There is no evidence of predictive performance.

8. Consistency of evidence: There are multiple inconsistencies in the evidence for a linkage between wildfires and increased nutrient concentrations.
9. Coherence of evidence: Additional data would likely explain the inconsistencies. The available data are not consistent with expectations regarding increased nutrients resulting from wildfires. Additional data may resolve gaps in the evidence.

There is weak evidence supporting the causal pathway between wildfires and increased nutrient loads.

Malibu Lagoon

The effects of fire impacts in the upper reaches of the watershed would be expected to result in increased sediment load and increased nutrient loads delivered to Malibu Lagoon. The October 2007 wildfires in the watershed were severe, leading to extensive damage that would be expected to influence nutrient loading and biogeochemical cycling in Malibu Lagoon. Sediment data (TSS or turbidity) and nutrient data are very limited for the Lagoon during the period following the fires (Lin 2005); therefore is it not possible to evaluate the linkage.

B4: Septic Systems: Septic systems can cause increased sedimentation and nutrient concentrations that cause excess algal growth and reduced habitat quality or reduced DO, and increased oxygen-demanding wastes that reduce DO. This section evaluates the linkages between septic systems and increased nutrient concentrations or oxygen-demanding wastes (Figure G-14).

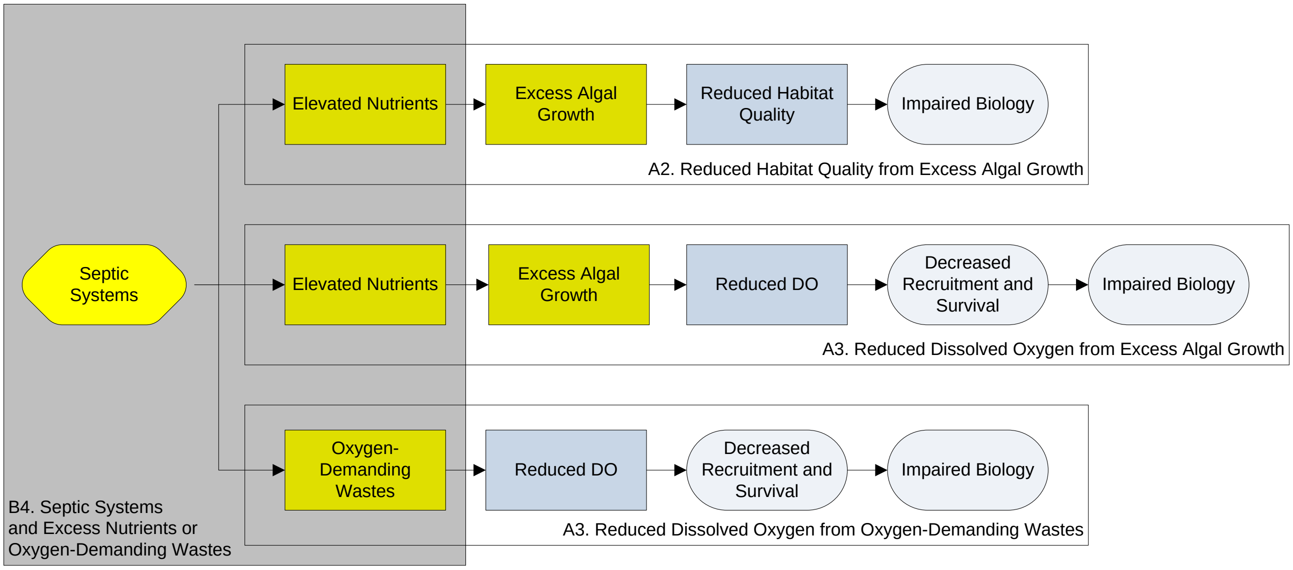

Figure G-14. Illustrated Linkage between Septic Systems and Excess Nutrients or Oxygen-Demanding Wastes

Malibu Creek

Septic systems can be significant sources of nutrient loads, even when they are well sited and functioning properly, since they introduce nutrients to shallow groundwater that may eventually enter surface waters. Nitrogen is particularly mobile in groundwater, while phosphorus has a tendency to be adsorbed by soils. Septic systems are also a potential source of oxygen-demanding wastes if insufficient treatment is achieved.

The upper part of the Malibu Creek watershed is mostly sewered, with sewage being treated by the Tapia WRF (see B5). However, there are septic systems in various areas above the Lagoon, such as on Cold Creek. According to the 2003 Nutrient TMDL (USEPA, 2003), there were an estimated 2,200 septic systems upstream of Malibu Lagoon, with the largest numbers on Triunfo Creek (820), Hidden Valley

Creek (625), and Cold Creek (300). These systems are estimated to contribute 602,800 gpd (675 acre-ft/yr) of effluent, contributing an estimated 300 lbs/day of N. The 2003 Nutrient TMDL (USEPA, 2003, Appendix A) estimated that septic systems contributed 23% of the N and P load to the basin as a whole, including direct loading to the lagoon. For the watershed upstream of the lagoon, the growing season (April 15 – November 15) loads of N were attributed as 16% from septic systems while the growing season P loads were 10% from septic systems.

Weight of Evidence for Septic Systems and Nutrient Loads

1. Co-occurrence: Septic systems occur upstream in the watershed, especially along several tributaries to Malibu Creek. Increased nitrogen concentrations are observed downstream of development, and therefore downstream of septic systems. Evidence for septic systems co-occurring with impairment is therefore compatible.
2. Temporality: The Malibu Creek watershed has exhibited steady growth through time including during the period of concern. Increased nitrogen concentrations downstream of development and downstream of septic systems, are consistent with this increase in development and therefore support temporality.
3. Response gradient: Nutrients (total nitrogen and total phosphorus) were positively correlated with the proportion of upstream land covered by impervious surfaces (Busse et al., 2006). Increased nitrate concentrations are observed at the series of monitoring stations on Cold Creek, where many residences on septic systems are located. The 2003 Nutrient TMDL and supporting modeling found that a significant nitrogen load from septic systems was compatible with monitoring data. Evidence for the gradient between septic systems and increased nitrogen is strong.
4. Complete exposure pathway: There is evidence for all steps in the exposure linking septic systems to excess nitrogen concentrations. The evidence for phosphorus is incomplete as much of the phosphorus load generated by septic systems is likely to be retained in the soil matrix and high natural background concentrations of phosphorus are already present in much of the watershed.
5. Plausibility: A large body of scientific literature supports a linkage between septic systems and increased nutrient concentrations.
6. Analogy: Many examples of septic systems causing elevated nutrient concentrations are found in the literature.
7. Predictive performance: There is no evidence of predictive performance.
8. Consistency of evidence: All lines of evidence for a linkage between septic systems and elevated nitrogen in the creek are consistent.
9. Coherence of evidence: There are no inconsistencies in the evidence for increased nitrogen from septic systems.

The evidence supporting the causal pathway between septic systems and downstream elevated nutrient concentrations is strong.

Weight of Evidence for Septic Systems and Oxygen-Demanding Wastes

Limited data are available regarding oxygen-demanding wastes in Malibu Creek, but there is no evidence for excess levels of such wastes and observed BOD5 concentrations are generally low. While it is plausible that septic systems leach oxygen-demanding wastes into groundwater, it is not known if, or how much, of the wastes enter the surface waters of the Malibu Creek watershed. Most such wastes should be consumed in the septic tank and leach field of properly operating systems. Therefore, we are unable to fully evaluate the linkage between septic systems and oxygen-demanding wastes in Malibu Creek; however, the weight of evidence for this pathway is weak.

Malibu Lagoon

Multiple sources have estimated the seepage of septic tanks into the Lagoon, including an estimated rate of 500 acre-ft/yr (Topanga-Las Virgenes Resources Conservation District, 1995) and a more recent estimate that recharge from OWDS in the Malibu Civic Center area contributes about 1,050 m^3/d (311 acre-ft/yr; McDonald Morrissey, 2010). Soil conditions are such that limited removal of nitrogen in effluent occurs. LARWQCB staff estimated that current loads of inorganic nitrogen to Malibu Lagoon from onsite wastewater disposal in the Civic Center area amount to 30 – 35 lbs/day. Therefore the non-point source discharges of nutrients directly to the Lagoon were of concern.

Based on monitoring conducted by LVMWD in the Lagoon at LVMWD-R11 during the winter discharge season, BOD5 concentrations in the Lagoon (average 2.3 mg/L) are similar to those seen upstream in Malibu Creek. However, the dry, non-discharge season average concentration of 3.3 mg/L appears to be elevated relative to upstream concentrations. This suggests there is an increase in BOD5 in the Lagoon during the non-discharge season that is likely, at least in part, associated with seepage from septic tanks. Increased BOD5 could also result from the growth and decay of algae stimulated by excess nutrient loads derived from the watershed and from the winter discharges from Tapia WRF.

Weight of Evidence for Septic Systems and Excess Nutrients Loads

1. Co-occurrence: Analysis of onsite wastewater disposal seepage to the Lagoon provides evidence for co-occurrence of septic systems and excess nitrogen loads.
2. Temporality: The City of Malibu does not provide centralized wastewater treatment. Onsite wastewater disposal has always been used and has increased over time. Therefore, the evidence is compatible for temporality.
3. Response gradient: The Lagoon is a small, relatively well-mixed volume so there is no evidence available with which to establish a response gradient for direct nutrient loading.
4. Complete exposure pathway: There is evidence for all steps in the pathway between septic systems (onsite wastewater disposal) and excess nutrients in the Lagoon.
5. Plausibility: A large body of scientific literature supports a linkage between septic systems and increased nutrient loads into estuaries.
6. Analogy: Many examples of septic systems causing increased nutrient loads are found in the literature.
7. Predictive performance: There is no evidence of predictive performance.
8. Consistency of evidence: All lines of evidence are consistent with the linkage between septic systems and increased nutrient loads to the Lagoon.
9. Coherence of evidence: No inconsistencies are present in the evidence. The lack of response gradient is explained by the fact that the Lagoon is a well-mixed waterbody, in which all areas are approximately equally affected by nutrient loads.

The strength of evidence supporting the causal pathway between septic systems and increased nutrient loads to Malibu Lagoon is strong.

Weight of Evidence for Septic Systems and Oxygen-Demanding Wastes Direct to Malibu Lagoon

1. Co-occurrence: Septic systems (onsite wastewater disposal) contribute nutrient loads to Malibu Lagoon and are also likely to contribute oxygen-demanding wastes. Slightly elevated BOD5 concentrations within the Lagoon suggest co-occurrence.

2. Temporality: The City of Malibu does not provide centralized wastewater treatment. Onsite wastewater disposal has always been used and has increased over time. Therefore, the evidence is compatible with temporality.
3. Response Gradient: The Lagoon is a small, relatively well-mixed volume so there is no evidence available with which to establish a response gradient for direct loading of oxygen-demanding wastes.
4. Complete exposure pathway: There is incomplete evidence for the pathway between septic systems and increased oxygen demanding wastes in the Lagoon as the amount of loading of BOD5 has not been estimated.
5. Plausibility: Scientific literature supports a linkage between septic systems and increased loads of oxygen-demanding waste.
6. Analogy: Examples of septic systems causing increased loads of oxygen-demanding waste are found in the literature.
7. Predictive performance: There is no evidence of predictive performance.
8. Consistency of evidence: Multiple inconsistencies exist in the lines of evidence for the linkage between septic systems and increased oxygen-demanding waste the Lagoon.
9. Coherence of evidence: It is unclear whether increased BOD5 observations represent oxygen-demanding wastes resulting from septic systems, the Tapia WRF, or the growth and decay of algae stimulated by excess nutrient loads. Additional data might resolve this uncertainty.

The strength of evidence supporting the causal pathway between *septic systems* and increased oxygen-demanding wastes to Malibu Lagoon is weak.

B5: Point Source Discharges: Point source discharges can contribute excess nutrients that contribute to excess algal growth resulting in reduced habitat quality (A2) or reduced DO (A3), or oxygen-demanding wastes that contribute to reduced DO. This section evaluates the linkage between point source discharges and increased nutrients or oxygen-demanding wastes (Figure G-15). Because of Tapia's discharge location in the very lower reaches of Malibu Creek, just before it discharges into Malibu Lagoon, the discussion below evaluates Tapia as a source of nutrients primarily to Malibu Lagoon.

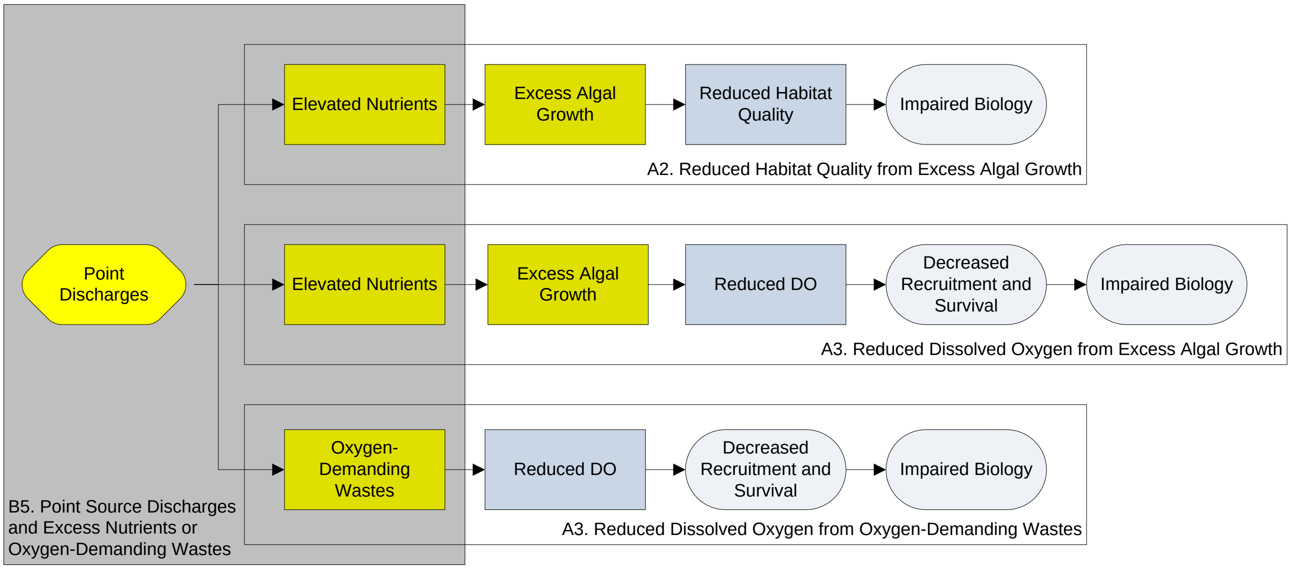

Figure G-15. Illustrated Linkage between Point Source Discharges and Elevated Nutrient Concentrations or Oxygen-demanding Wastes

The Tapia Water Reclamation Facility (WRF) is the only facility with a traditional permitted wastewater discharge to Malibu Creek or its tributaries. Originally built in 1965, the facility has been expanded beyond its original design capacity to a current capacity of 16 MGD. In 2003, discharge prohibitions were extended from April 15th to November 15th of each year (with infrequent exceptions for flow augmentation releases to support steelhead) and a TMDL established nutrient targets for two seasons to address nuisance effects such as algae, odors, and scum. Summer targets (April 15 – November 15) for nitrate- and nitrite-N and total P are 1.0 and 0.1 mg/L, respectively. During the winter months (November 16 – April 14), the nitrate- and nitrite-N target is 8 mg/L and no total P target is applied.

In accordance with the existing nutrient TMDL, Tapia is permitted to discharge significant amounts of nutrient loads during the winter discharge season, while almost no direct discharges occur during the summer growing season. Two unresolved questions are (1) the extent to which winter discharges are retained in the system and subsequent increases in summer concentrations, and (2) the extent to which winter loads of nutrients are stored in the Lagoon and become available to support summer algal growth.

Table G-2 compares the nutrient concentrations at mainstem sites upstream and downstream of the Tapia WRF discharge to TMDL target concentrations. During the discharge season, the presence of the discharge results in high concentrations of nitrate-N and orthophosphate-P downstream of Tapia. Concentrations are much lower in the non-discharge season, but still appear to be elevated relative to the upstream monitoring station.

LVMWD monitoring shows similar results, with non-discharge season median concentrations immediately below Tapia WRF of 0.70 mg/L nitrate N, 1.0 mg/L total N, and 0.26 mg/L orthophosphate as P (see Section 7.5 in the TMDL report).

Table G-2. Average Nutrient Concentrations at Sites Upstream and Downstream of the Tapia WRF Discharge (2005 – 2010) Compared to TMDL Targets

Nutrient Parameter	Measurement	Mainstem Sites			TMDL Target
		Downstream		Upstream	
		MC-1	MC-15	MC-12	
NO_3+NO_2-N (mg/L)	Median	0.35	1.27	0.03	N/A
	Discharge (11/16 – 4/14)	4.27	4.15	0.21	< 8
	Non-discharge (4/15 – 11/15)	0.16	0.67	0.05	< 1
Total NH_3-N (mg/L)	Median	0.06	0.09	0.05	N/A
PO_4-P (mg/L)	Median	0.46	0.21	0.09	N/A
	Discharge (11/16 – 4/14)	0.77	0.90	0.08	No target
	Non-discharge (4/15 – 11/15)	0.32	0.19	0.09	<0.1

Tapia WRF also discharges oxygen-demanding wastes. However, this is an advanced treatment facility that achieves low levels of readily decomposable biochemical oxygen demand (measured as 5-day BOD, or BOD5). LVMWD monitoring shows most BOD5 observations at the detection limit of 2 mg/L with no detectable difference, on average, in concentrations upstream and downstream of the Tapia discharge. The extent to which the discharge may include more refractory organic compounds that can exert an oxygen demand on a period longer than 5 days is not known. Such refractory compounds would likely not have much of an effect in the stream, but could pose an issue for the Lagoon, where residence time is longer. Based on these observations, Tapia WRF does not appear to generate oxygen-demanding wastes in amounts likely to be associated with reduced DO.

Weight of Evidence for Point Source Discharges and Nutrient Loads

1. Co-occurrence: Tapia WRF is a permitted discharge with known nutrient loads during the winter discharge season. The monitoring data also suggests some elevation of nutrient concentrations during the non-discharge season downstream of Tapia relative to the upstream station, suggesting that Tapia is not the only source of nutrients to the stream.
2. Temporality: The increase in nutrient concentration in sites downstream of the Tapia WRF discharge during the discharge season, followed by a decrease during the restricted season provides evidence of temporality.
3. Response gradient: The fact that nutrient concentrations increase downstream of Tapia during both the discharge and non-discharge season provides evidence of a gradient between the Tapia WRF discharge and nutrients.
4. Complete exposure pathway: Evidence for the exposure pathway linking the Tapia WRF point source discharge to elevated nutrient concentrations downstream is complete during the discharge season. Evidence is incomplete for the role of Tapia discharges in increasing downstream nutrient concentrations in Malibu Creek during the non-discharge season.
5. Plausibility: Tapia WRF is a permitted source of nutrient discharges; data provide actual evidence of nutrient discharge during the discharge season. Nutrient cycling, including temporary storage in plant matter and in sediment, suggests that it is plausible that permitted discharges also provide some increase in non-discharge season nutrient concentrations in lower Malibu Creek and in the estuary.
6. Analogy: Many examples of point source discharges similar to those described causing elevated nutrient concentrations are found in the literature.
7. Predictive performance: Reductions in downstream nutrient concentrations following the summer discharge prohibition demonstrate the role of the Tapia discharge.
8. Consistency of evidence: All lines of evidence for a linkage between the Tapia WRF point source discharge and elevated nutrients downstream of the discharge are consistent.
9. Coherence of evidence: There are no inconsistencies in the evidence for increased nutrients from Tapia during the discharge season. Inconsistencies in the evidence for the role of the discharge during the non-discharge season could also be explained by the presence of other nonpoint sources of nutrient load or temporary storage in plant matter and sediment.

The evidence supporting the causal pathway between the Tapia WRF discharge and downstream elevated nutrient concentrations is strong for the winter discharge season. The strength of the evidence supporting the causal pathway between the Tapia WRF point source discharge and elevated nutrients in Malibu Creek downstream of the Tapia WRF discharge during the summer non-discharge season is moderate.

Weight of Evidence for Point Source Discharges and Oxygen-Demanding Wastes

Monitoring data indicate that the Tapia WRF point source discharge does not provide a significant increase in labile oxygen-demanding wastes measured as BOD5. Data are not available to evaluate whether significant loads of more refractory oxygen-demanding wastes not captured by BOD5 measurements have the potential to affect DO conditions in the Lagoon.

B6: Urban Runoff: Urban runoff can cause increased sedimentation (A1), excess nutrients/excess algal growth/reduced habitat quality (A2), reduced DO from excess algal growth or oxygen-demanding wastes (A3), or toxicity from metals, elevated salt concentrations, or organic toxics (A4). It is also related to altered hydrology (B1) and channel alteration (B2). This section evaluates the linkage between urban runoff and increased sediment, increased nutrients, oxygen-demanding wastes, and increased toxicity from metals or organic toxics (Figure G-16).

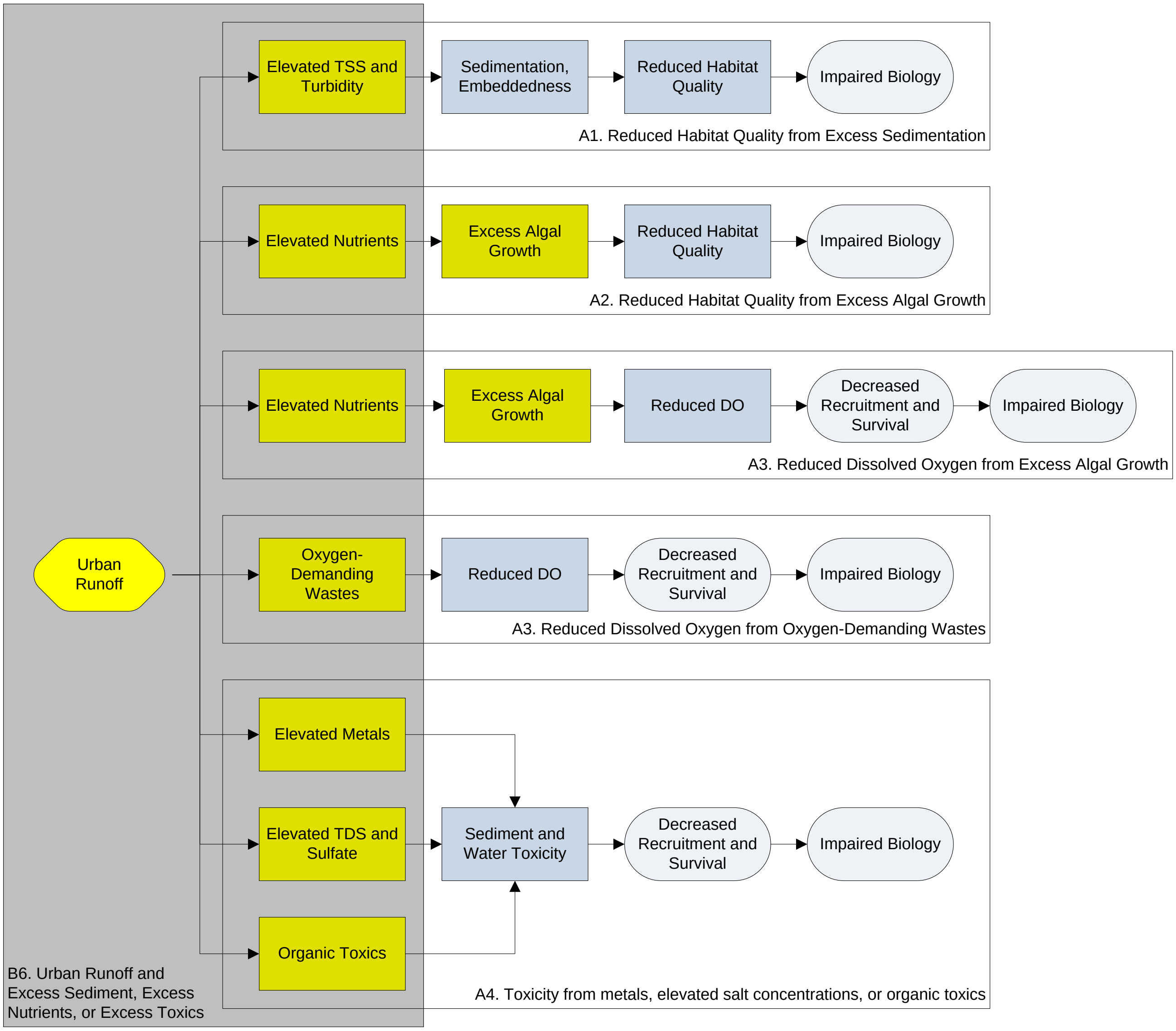

Figure G-16. Illustrated Linkage between Urban Runoff and Excess Sedimentation, Elevated Nutrients, Oxygen-demanding Wastes, and Toxicity

Malibu Creek

Although still largely undeveloped, the Malibu Creek watershed has seen a history of urban growth. Areas of barren and undeveloped land use and land cover (LU/LC) had the largest decrease of all LU/LC types between 1990 and 2008, while both density classes of Single Family Residential land use increased the most. This increased urbanization of portions of the upper watershed increased the amount of impervious surfaces from 3,694 to 4,878 acres. As of the 2008 SCAG land use coverage, the Malibu Creek watershed was 6.95% impervious. Using the Simple method rule (Caraco et al., 1998) that the impervious land generates surface runoff relative to pervious land in a ratio of 0.95/0.05, impervious surfaces are estimated to yield about 59 percent of the surface runoff in the watershed.

The scientific literature contains many examples of the impacts caused by urban development (Paul and Meyer, 2001). Increasing levels of urban development and imperviousness have been directly associated with effects on aquatic life, with biological effect levels perceived at or below 10 percent urban development and 5 percent impervious cover (Yoder et al. 1999; CWP 1999; Roy et al. 2003; Cuffney et al. 2010). Streams in urban areas exhibit multiple, complex, but consistent stressor *symptoms* (termed *urban stream syndrome*; Walsh et al. 2005). Multiple primary stressors and stressor causes are correlated with urban development, including flashier hydrography (B1), altered channel morphology (B2), and elevated concentrations of nutrients (A2), metals (toxicity, A4), and sediments (A1) (Walsh et al. 2005; USEPA, 2012). Although exacerbated by urban development, it is these stressors and not the development itself that directly affect the aquatic biota.

Excess sediment. Increased impervious surface has long been demonstrated to increase stream flashiness (e.g., Walsh et al. 2005; Allan, 1995). Altered flood hydrology increases stream bank erosion, resulting in excess sedimentation downstream and increased turbidity, particularly during storms. Limited sampling shows high TSS/SSC concentrations during storms in the Malibu Creek watershed. USEPA measured both turbidity and suspended sediment concentration concurrently between February 16, 2011 and April 25, 2012, to evaluate the relationship between the two measures. These results showed that for an average range of flows, turbidity is a good surrogate for suspended sediment in the Malibu Creek mainstem. Turbidity has been demonstrated to be higher at impacted sites than at comparator/reference sites (monthly average for most months is 1 NTU for the mainstem and 0.1 NTU for comparator/reference sites), but direct correlations with urban development or impervious surface are not available. Sikich et al. (2012) reported significant channel alteration and stream bank erosion leading to increased sedimentation in the watershed. Creeks adjacent to urban development had a larger proportion of stream banks altered by bank modifications than those surrounded by open space or less developed areas. The Topanga-Las Virgenes Resources Conservation District (1989) estimate 1987 levels of sedimentation to be nearly ten times the rate that would have occurred pre-settlement. It is also important to note that developing areas experience significant construction activity. California's general construction permit does not currently contain a limit for turbidity. Consequently, construction activities could generate significant excess sedimentation. No data currently exist to quantify the potential impact specifically from construction activities, however.

Excess nutrients. Busse et al. (2006) found that total nitrogen, total phosphorus, and total chlorophyll concentrations were all positively correlated with the proportion of upstream land covered by impervious surfaces. For nitrate-N, high concentrations are also found in the northern drainages of the watershed; however, these appear to be associated in part with development rather than just geology. In particular, the median nitrate-N concentrations at stations draining developed areas on Las Virgenes Creek range from 1.19 to 5.63 mg/L, whereas those from the upstream undeveloped areas on Las Virgenes are 0.35 mg/L or less. Furthermore, Sikich et al. (2012) graphically demonstrate that nitrate concentrations increase between LV-9 (R9 in their report) and sites downstream of freeways and high density commercial and residential land use, LV-13 and LV-5 (M13 and O5 in their report).

In contrast, for orthophosphate-P, there appears to be a clear difference, on average, between sites that drain the Monterey/Modelo Formation and those that do not. The undisturbed sites that do not drain the Modelo Formation have median orthophosphate-P concentrations that range from 0.02 to 0.05 mg/L, while the two that drain the Monterey/Modelo Formation have median orthophosphate-P concentrations of 0.14 and 0.18 mg/L. Average phosphate concentrations are elevated at those sites draining the Monterey/Modelo Formation. However, it appears that increased erosion and sediment transport capacity associated with urban runoff lead to increases in phosphorus loading from these natural geological sources.

Oxygen-demanding wastes. Urban runoff can contribute organic detritus (e.g., leaves and lawn clippings) and chemicals (e.g., anti-freeze, oil and grease) that contribute to oxygen demand. However, no data are available concerning the types or amounts of such wastes that might enter Malibu Creek.

Toxics. Surface water runoff from urban areas frequently contains toxic metals (commonly from automobiles, rooftops and gutters, but also from metal-working, manufacturing facilities, and other metal waste-producing activities), pesticides, and other toxic organic chemicals (including PCBs, oil and grease, volatile organic chemicals, and PAHs). However, only occasional water column toxicity has been observed since 2005 in wet and dry weather surface water samples from Malibu Creek, as described above.

Few data are available on potential organic toxics. Brown and Bay (2005) conducted studies of organophosphorus pesticides in the Malibu Creek Watershed, sampling two dry and two storm events in 2002-2003. Diazinon was detected in most of the dry-weather samples from Medea Creek, and both of the stormwater samples from Malibu Creek. Concentrations of diazinon in some samples exceeded the California Department of Fish and Game chronic criterion by up to a factor of 14 in Medea Creek. Concentrations within the Malibu Creek main stem did not appear sufficiently high to be a significant source of toxicity. However, the relationship of the sites containing diazinon to the land use proximate to the site is not known.

Water quality data for both sulfate and selenium reportedly demonstrate frequent excursions of water quality standards. However, selenium and sulfate data have not been routinely obtained across the watershed. Instead, conductivity data may be used as a surrogate measure for toxicity from metals or elevated salt concentrations. The highest median conductivity values were found in the Monterey/Modelo Formation.

Weight of Evidence for Urban Runoff and Excess Sedimentation

1. Co-occurrence: Evidence of sedimentation occurs downstream of areas of urban development. Therefore, the evidence for increased sedimentation in Malibu Creek co-occurring with urban runoff is compatible.
2. Temporality: The Malibu Creek watershed has a history of urban growth. Increased sediment typically occurs during construction activities that are part of development, with stream banks adjacent to developed areas frequently being modified to protect property values. The Topanga-Las Virgenes Resources Conservation District (1989) estimate 1987 levels of sedimentation to be nearly ten times the rate that would have occurred pre-settlement, providing supporting evidence for temporality.
3. Response gradient: Physical habitat scores decline downstream of urbanized areas. These scores are especially linked with sediment-related metrics, so sedimentation increases with urbanization. Therefore, there is implicit evidence for a gradient between urban development/runoff and excess sedimentation.
4. Complete exposure pathway: There is evidence for all steps in the pathway linking urban development/runoff to excess sedimentation.

5. Plausibility: A large body of scientific literature supports a linkage between urban development and increased sedimentation via altered hydrology and channel alteration.
6. Analogy: Many examples of urban development causing increased sedimentation are found in the literature.
7. Predictive performance: There is no evidence of predictive performance.
8. Consistency of evidence: All lines of evidence for a linkage between urban development/runoff and excess sedimentation are consistent.
9. Coherence of evidence: There are no inconsistencies in the evidence.

The strength of evidence supporting the causal pathway between urban runoff and increased sedimentation is strong.

Weight of Evidence for Urban Runoff and Excess Nutrients

1. Co-occurrence: Median nitrate-N concentrations at stations draining developed areas on Las Virgenes Creek range from 1.19 to 5.63 mg/L, whereas those from the upstream undeveloped areas on Las Virgenes are 0.35 mg/L or less. Phosphorus concentrations are affected by drainage from the Monterey/Modelo Formation, but also appear to be somewhat elevated at stations that are downstream of development but with moderate conductivity and thus not strongly affected by marine sedimentary geology relative to comparator/reference stations (e.g., concentrations at HtB station TR-17 and the increasing phosphorus concentration gradient along Cold Creek from CC-3 to CC-11 to CC-2; see Table 7-7 of the TMDL report) Therefore, evidence for co-occurrence of excess nitrogen and urban development/urban runoff is strong and compatible, while evidence for co-occurrence of excess phosphorus and urban development/urban runoff is uncertain.
2. Temporality: The Malibu Creek watershed has exhibited steady urban growth through time including during the period of concern. Increased nutrient concentrations downstream of urban development are consistent with this increase in urban growth and therefore support temporality.
3. Response gradient: Nutrients (total nitrogen and total phosphorus) were positively correlated with the proportion of upstream land covered by impervious surfaces (Busse et al. 2006). Sikich et al. (2012) found that nitrate concentrations increased at sites downstream of developed areas on Las Virgenes Creek. Evidence for the gradient between urban runoff and increased nutrients is strong.
4. Complete exposure pathway: There is evidence for all steps in the exposure linking urban development/runoff to excess nutrient concentrations.
5. Plausibility: A large body of scientific literature supports a linkage between urban development/runoff and increased nutrient concentrations.
6. Analogy: Many examples of urban development/runoff causing increased nutrient concentrations are found in the literature.
7. Predictive performance: There is no evidence of predictive performance.
8. Consistency of evidence: All lines of evidence are consistent and support urban runoff as a source of increased nutrient concentrations.
9. Coherence of evidence: There are no inconsistencies in the evidence.

The strength of evidence supporting the linkage between urban runoff and increased nutrients (especially nitrogen) in Malibu Creek is strong.

Weight of Evidence for Urban Runoff and Oxygen-Demanding Wastes

Limited data are available regarding the types, amounts, or concentrations of oxygen-demanding wastes in the Malibu Creek watershed. The available monitoring conducted by LVMWD is all downstream of development. However, BOD5 concentrations at these stations typically remain low, near 2 mg/L. Therefore, while urban runoff is expected to contribute oxygen-demanding waste, it does not appear to contribute loads significant enough to cause direct impacts on DO in Malibu Creek. Urban runoff may contribute excess organic matter to the Lagoon as well as potentially to pools in lower Malibu Creek that could contribute to longer term oxygen demand; however, evidence for this is not available. Therefore, no evaluation can be performed for the weight of evidence for a linkage between urban runoff and oxygen demanding wastes.

Weight of Evidence for Urban Runoff and Toxics

1. Co-occurrence: Naturally occurring salts and toxic metals are associated with elevated specific conductivity. Elevated specific conductivity appears to be determined primarily by location relative to the Monterey/Modelo Formation. Other toxics have been detected infrequently and data are insufficient to link their origin to specific land areas. Therefore, the evidence for co-occurrence of urban development and specific toxic components is uncertain.
2. Temporality: The Malibu Creek watershed has a history of urban growth. There is thus evidence for temporality for man-made toxic chemicals and urban runoff. Selenium and sulfate loads from the Monterey/Modelo Formation have naturally been present in the watershed and are not associated with urban runoff.
3. Response gradient: There are insufficient data to establish a response gradient for toxics and urban runoff.
4. Complete exposure pathway: Evidence linking urban development to toxics loads is incomplete.
5. Plausibility: The scientific literature supports a linkage between urban development/runoff and increased toxics loads. Man-made toxic chemicals found in the watershed are consistent with urban runoff, but have been detected only infrequently. Urban runoff could also enhance the rate of loading of naturally occurring metals and ions from the Monterey/Modelo Formation.
6. Analogy: Many examples of urban runoff causing increased conductivity are found in the literature.
7. Predictive performance: There is no evidence of predictive performance.
8. Consistency of evidence: There are multiple inconsistencies in the evidence. The evidence is either uncertain or does not support a linkage between urban runoff and biologically significant loads of toxics in the watershed.
9. Coherence of evidence: Inconsistencies exist in the evidence linking urban runoff and toxicity from metals, elevated salt concentrations, or organics toxics. No explanation is available for the inconsistent spatial and temporal observations of toxicity. Some inconsistencies in the evidence can be explained by the confounding effects of the natural geology in the watershed.

The strength of evidence supporting the linkage between urban runoff and increased toxics concentrations in Malibu Creek is weak, due to conflicting evidence, limited frequency at which toxicity is observed and the inconsistent results of natural geology (i.e., conductivity was an indicator).

Malibu Lagoon

Conditions in Malibu Lagoon are affected by loads from the upstream watershed and by direct urban runoff from the adjacent parts of the City of Malibu. Considerations relative to loading from the watershed are described in the previous section and not repeated here. This section addresses direct loading from the City of Malibu to the Lagoon.

Excess sediment. Little information is available on rates of sediment loading in direct runoff from the City of Malibu to Malibu Lagoon.

Excess nutrients. Direct stormwater runoff is a known source of nutrient loading to the Lagoon. Fertilizers used to improve landscaping and lawns often run off with surface runoff when watering lawns, commercial grounds, golf courses, and other landscaped areas. Pet wastes may also be a source of nutrients in urban runoff. Therefore the non-point source discharges of nutrients directly to the Lagoon are of concern.

Oxygen-demanding wastes. Direct urban stormwater loads have the potential to add oxygen-demanding wastes to the Lagoon. Based on monitoring conducted by LVMWD in the Lagoon at LVMWD-R11 during the winter discharge season, BOD5 concentrations in the Lagoon (average 2.3 mg/L) are similar to those seen upstream in Malibu Creek. However, the dry, non-discharge season average concentration of 3.3 mg/L appears to be elevated relative to upstream concentrations. This suggests there is an increase in BOD5 in the Lagoon during the non-discharge season. Increased BOD5 could result from urban runoff, Tapia WRF point source discharges, septic systems, or the growth and decay of algae stimulated by excess nutrient loads derived from the watershed and from the winter discharges from Tapia WRF.

Toxics loads. Urban runoff is a potential source of direct toxics loading to the Lagoon. However, specific evidence is not available.

Weight of Evidence for Direct Urban Runoff and Excess Sedimentation in Malibu Lagoon

1. Co-occurrence: There is substantial evidence for significant sediment load into Malibu Lagoon from the watershed. However, there is no evidence available to indicate significant direct urban runoff loads from lands adjacent to the Lagoon. As co-occurrence is not established for direct sediment loads, the remaining weight of evidence steps are not completed.

Evidence is not available to support a linkage between direct urban runoff and sedimentation impacts in Malibu Lagoon. As described above, the strength of evidence supporting the causal pathway between urban runoff and increased sedimentation upstream in Malibu Creek is strong.

Weight of Evidence for Urban Runoff and Excess Nutrients Loads

1. Co-occurrence: Direct stormwater runoff contributes unquantified nutrient loads, although the amount is likely insignificant compared to the total load from the upstream watershed.
2. Temporality: Development in the watershed has increased over time, and is likely to be coupled with increased fertilizer use and increased pet wastes. Therefore, the evidence is compatible for temporality.
3. Response gradient: The Lagoon is a small, relatively well-mixed volume so there is no evidence available with which to establish a response gradient for direct nutrient loading.
4. Complete exposure pathway: There is evidence for all steps in the pathway between urban runoff and excess nutrients in the Lagoon.
5. Plausibility: A large body of scientific literature supports a linkage between urban runoff and increased nutrient loads into estuaries.
6. Analogy: Many examples of urban runoff causing increased nutrient loads are found in the literature.

7. Predictive performance: There is no evidence of predictive performance.
8. Consistency of evidence: All lines of evidence are consistent with the linkage between urban runoff and increased nutrient loads to the Lagoon.
9. Coherence of evidence: No inconsistencies are present in the evidence. The lack of response gradient is explained by the fact that the Lagoon is a well-mixed waterbody, in which all areas are approximately equally affected by nutrient loads. Additional data on fertilizer use for landscaping and grounds maintenance, and data on pet ownership and compliance with waste disposal policies would elucidate the extent of nutrient contribution from these sources.

The strength of evidence supporting the causal pathway between urban runoff and increased nutrient loads to Malibu Lagoon is moderate.

Weight of Evidence for Urban Runoff and Oxygen-Demanding Wastes Direct to Malibu Lagoon

1. Co-occurrence: Urban runoff contributes nutrient loads to Malibu Lagoon and may also contribute oxygen-demanding wastes. Slightly elevated BOD5 concentrations within the Lagoon suggest co-occurrence.
2. Temporality: Urban development and impervious surfaces have increased over time. Therefore, the evidence is compatible with temporality.
3. Response Gradient: The Lagoon is a small, relatively well-mixed volume so there is no evidence available with which to establish a response gradient for direct loading of oxygen-demanding wastes.
4. Complete exposure pathway: There is incomplete evidence for the pathway between urban runoff and increased oxygen demanding wastes in the Lagoon as the amount of loading of BOD5 has not been estimated.
5. Plausibility: Scientific literature supports a linkage between urban runoff and increased loads of oxygen-demanding waste.
6. Analogy: Examples of urban runoff causing increased loads of oxygen-demanding waste are found in the literature.
7. Predictive performance: There is no evidence of predictive performance.
8. Consistency of evidence: Multiple inconsistencies exist in the lines of evidence for the linkage between urban runoff and increased oxygen-demanding waste the Lagoon.
9. Coherence of evidence: It is unclear whether increased BOD5 observations represent oxygen-demanding wastes resulting from septic systems, the Tapia WRF, or the growth and decay of algae stimulated by excess nutrient loads. Additional data might resolve this uncertainty.

The strength of evidence supporting the causal pathway between urban runoff and increased oxygen-demanding wastes to Malibu Lagoon is weak.

Weight of Evidence for Urban Runoff and Toxics Loads

1. Co-occurrence: There is inconclusive evidence for significant toxics loading into Malibu Lagoon derived from urban runoff in the upstream watershed. There is no evidence available to indicate significant direct urban runoff loads of toxics to the Lagoon. As co-occurrence is not established, the remaining weight-of-evidence steps are not completed.

Evidence is not available to support or refute a linkage between direct urban runoff and significant toxics loading to Malibu Lagoon. Limited toxicity detected in lagoon sediments has not been shown to be derived from urban runoff.

B7: Agricultural Runoff: Agricultural runoff can affect benthic macroinvertebrates by causing increased sediment (A1), increased nutrient concentrations resulting in excess algal growth and reduced habitat quality (A2), and reduced DO resulting from increased nutrient concentrations from excess algal growth (A3). Depending on the type of agriculture, increased toxics (pesticides) can also occur (A4). This section evaluates the linkage between agricultural runoff and increased sedimentation, increased nutrient concentrations, and increased organics toxics (Figure G-17).

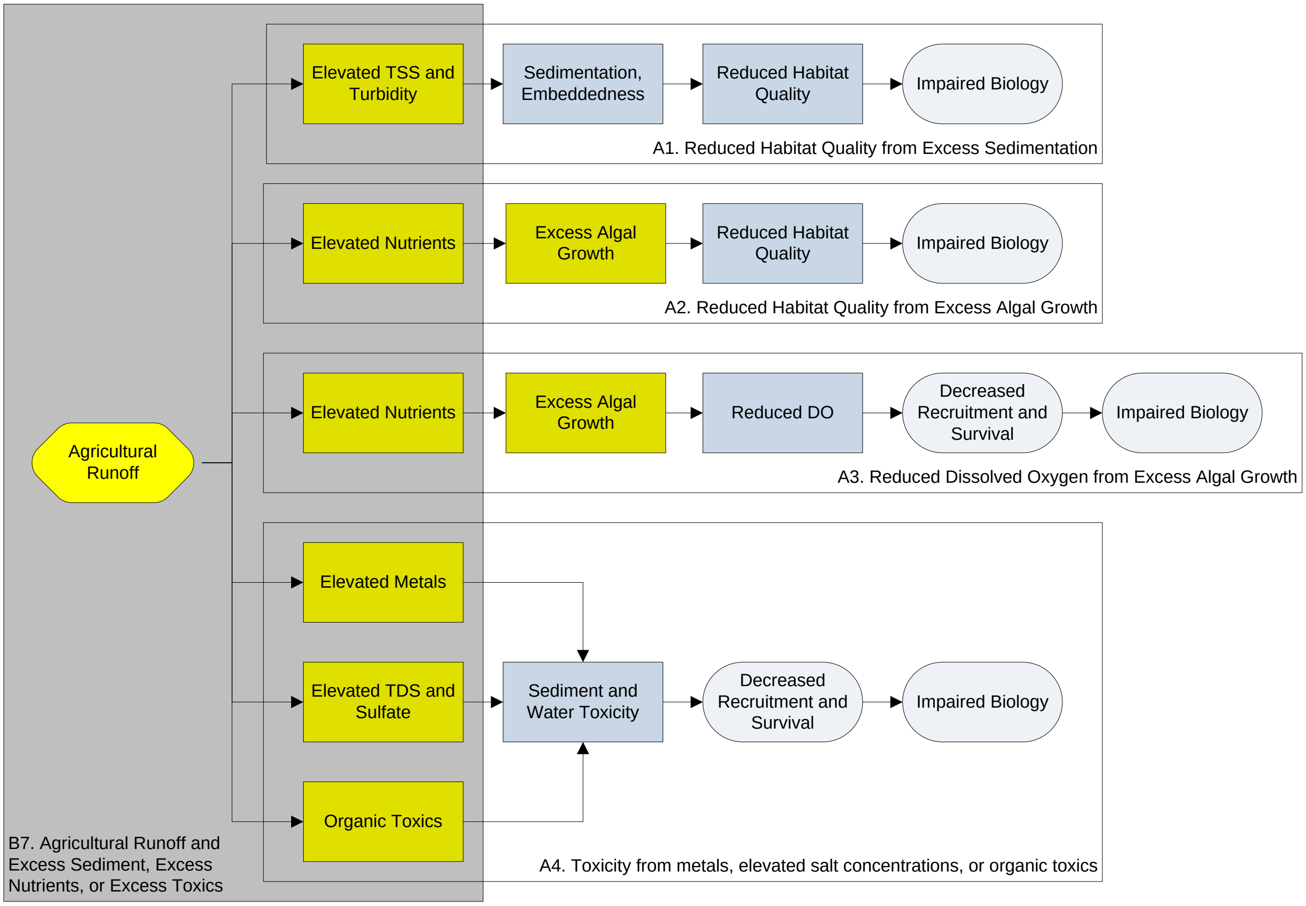

Figure G-17. Illustrated Linkage between Agricultural Runoff and Excess sediment, Elevated Nutrient, Oxygen-demanding Waste, or Toxics Loads

Agricultural land use (as identified in the SCAG coverage) comprises only about 2 percent of the Malibu Creek watershed. Moreover, most of the agricultural land use lies along Hidden Valley Creek, in the upper reaches of the watershed. The nearest downstream site from the dominant agricultural portion of the watershed is HV, a MCWMP site, for which biological data are not available. The next closest site with biological data is TR-17, a Heal the Bay site. However, at more than 4 miles distance from the putative agricultural source, this site is too distant to use for evidence of co-occurrence. In general, the agricultural land use identified in the Malibu Creek watershed occurs upstream, in relatively less impacted areas of the watershed. Goepel et al. (2012) identified small vineyards that appear to exist as accessory uses to structures such as residences, and likely represent “hobby vineyards.” These areas are not identified as agricultural land uses on the interpreted satellite imagery, so agricultural land use may occupy a somewhat larger area than tabulated. Currently, the amount of agricultural runoff within the watershed appears to be minimal, but improved land use information and monitoring data will provide a better indication of this source.

There is a broad body of literature available regarding potential agricultural impacts on streams. Agricultural land uses can alter stream channel morphology and water chemistry in a number of ways (Allan, 1995). Riparian vegetation frequently is diminished if not eliminated, decreasing infiltration. Crop production often results in increased peak runoff rates and increased nutrients, pesticides, and suspended solids in surface water runoff compared to undeveloped land (Skaggs et al., 1994). Grazing can result in increased nutrients and suspended sediments, as well as increased organic matter and bacteria. Moreover, if animals can access the stream directly, channel degradation and increased erosion can occur.

There is insufficient evidence for agricultural land use leading to increased sediment, increased nutrients, reduced DO, or toxicity from metals, elevated salt concentrations, or organic toxics in Malibu Creek watershed, including both the Creek and the Lagoon. Specifically, there is no evidence for co-occurrence or a gradient, contradictory evidence for temporality, and multiple missing steps in the linkage pathway. Therefore, although the linkage between agricultural runoff and any of the stressors is plausible and analogous cases exist in the literature, evidence from the case is both inconsistent and not coherent.

B8: Modified Exposure of Natural Geology: The geologic constituents in the Malibu Creek Watershed (particularly the Santa Monica Mountains and the marine sedimentary deposits associated with the Monterey/Modelo Formation) have been suggested as a potential source of increased sediment (A1), increased nutrients resulting in reduced habitat quality (A2) or reduced DO (A3), and increased toxicity (A4) or other sub-lethal biological impacts associated with elevated conductivity. This section evaluates the linkage between natural geology and increased sediment, nutrients, or toxics (Figure G-18).

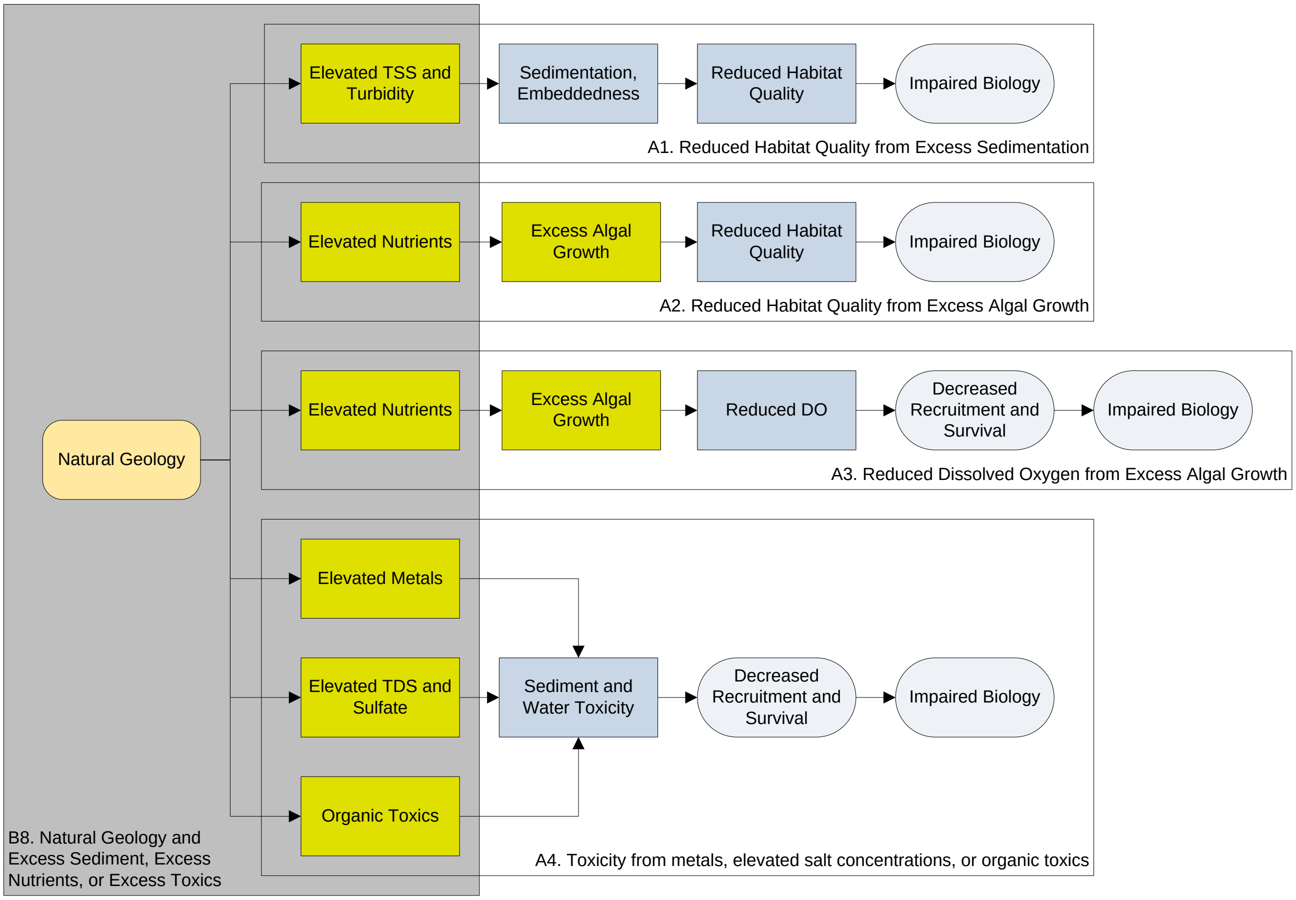

Figure G-18. Illustrated Linkage between Modified Exposure of Natural Geology and Excess Sedimentation, Elevated Loads of Nutrients, or Elevated Loads of Toxics

When evaluating geology as a potential source of the probable stressors affecting benthic macroinvertebrates in the Malibu Creek watershed, it is important to distinguish between undisturbed and disturbed conditions, each of which will be discussed in more detail below. Under natural (undisturbed) conditions, stressors resulting from the underlying geology would always have been present. For this reason, it is important to identify and evaluate sites reflective of these conditions, such as CH-6 and LV-9. The biological community established at undisturbed sites would reflect these natural conditions. This may result in a biological community that appears to be impaired compared with sites outside the watershed, but this level of "impairment" reflects natural conditions at these sites. The underlying geology then can only be responsible for true impairment (impairment beyond what is observed at undisturbed sites) if it somehow contributes excess stressors to the streams. In other words, the underlying geology must be disturbed in such a manner as to cause unnatural erosion, sediment loading, or leaching of toxins. Two issues are considered: 1) if the underlying geology of the Monterey/Modelo Formation contribute stressors at a background level; and 2) if it i possible that disturbance of the Monterey/Modelo Formation contributes stressors in excess of background. Since Malibu Lagoon is the terminus for flow from the Malibu Creek watershed, excess stressors (over background) contributed by the underlying geology impacts the Creek and the Lagoon similarly.

Background Stressor Levels. The Monterey/Modelo Formation, which underlies a portion of the upper watershed, has long been understood to be highly erodible. However, sites draining the Monterey/Modelo Formation exhibit lower slopes (typically 1-2 %) than sites draining non-marine geology (e.g. Cold Creek, 2-11%; Arroyo Sequit, 4%). Lower slopes would be expected to lower the relative sediment yield. Therefore, it is not clear if the geology actually contributes a greater sediment load when undisturbed. Average turbidity measurements at CH-6 and LV-9 are than only slightly higher than those from LCH-18 and SC-14 (Table 2-2).

Some evidence has shown that the Monterey/Modelo Formation contributes high levels of some metals and minerals, such as selenium and sulfate. In its undisturbed state, these and other salts appear to contribute higher conductivity than other areas of the watershed through groundwater leaching and discharge to streams. In fact, undisturbed sites draining the Monterey/Modelo Formation show higher median conductivity values than undisturbed sites draining non-marine geology.

Evidence in this watershed showed that the Monterey/Modelo Formation contributes elevated phosphorus to streams draining this geology. Table G-3 shows that both nitrate-N and ammonia-N concentrations from CH-6 and LV-9 are similar to those observed at SC-14 and LCH-18. Median orthophosphate-P concentrations at CH-6 and LV-9, however, exhibited higher levels compared to SC-14 and LCH-18.

In summary, under natural conditions, sites draining the Monterey/Modelo Formation may exhibit higher conductivity and higher orthophosphate-P concentrations than sites not underlain by this geology. In this watershed, the biota inhabiting these undisturbed regions of Monterey/Modelo Formation appears to still support conditions comparable to those undisturbed sites not draining Monterey/Modelo Formation.

There are many conditions that could result in excess sedimentation, increased nutrient concentrations, or increased toxics include both natural and anthropogenic events. Natural events include naturally-caused wild fires, which can denude the landscape and alter the hydrologic regime. Increased peak flows above natural flow events can substantially increase excess sedimentation and channel modification. Eroded particulates have the potential to release more soluble components (e.g., salts, metals, and nutrients) than the intact parent material, since eroded particulates expose more surface area to water than does the intact parent material. Other anthropogenic events/activities that result in similar effects include, for example, construction/development, agricultural uses, and increased impervious surfaces.

Data are not available to evaluate the effect of ground disturbance (in the absence of other possible sources, e.g., development/increased impervious surface) on the release of salts, nutrients, and sediment from Monterey/Modelo Formation geology. While it appears that disturbances (e.g., ground movement by heavy equipment as during construction, altered hydrology, or channel alteration) would increase erosion and therefore be likely to increase surface water conductivity, nutrient concentrations, or sedimentation, more focused data are needed to evaluate the potential magnitude of the impacts.

Table G-3. Median Nutrient Concentrations in Comparator/Reference Sites Relative to Monterey/Modelo Formation Drainage

Site	Percent Modelo Geology	Average Turbidity (NTU)	Median Conductivity (µS/cm)	Median Nitrate-N (mg/L)	Median Ammonia-N (mg/L)	Median Orthophosphate-P (mg/L)
CH-6[1]	51 %	0.85	3,405	0.005	0.030	0.134
LV-9[1]	20 %	0.83	3,208	0.005	0.020	0.177
SC-14[2]	0 %	0.75	1,211	0.030	0.030	0.026
LCH-18[2]	0 %	0.27	1,550	0.010	0.030	0.039

[1] Comparator/reference site draining the Modelo/Monterey Formation.

[2] Non-marine geology comparator/reference site.

Excess sedimentation. According to Meigs et al. (1999), active geologic uplift of the Santa Monica Mountains results in sediment yields that are noticeably greater than yields from surrounding portions of southern California. Erosion on the south flank of the Santa Monica Mountains, represented in normalized form as denudation rate, is on the order of 0.5 mm/yr (Meigs et al., 1999). Geology in the Malibu Creek watershed is approximately 38 % Miocene marine sedimentary rock, with individual site catchments draining between zero and 62 % marine sedimentary rock. Warrick and Mertes (2009) determined that the similar marine formations of the Western Transverse range were highly erodible and generated approximately five times more sediment than other portions of the range. However, these high rates represent natural conditions for the watershed and thus cannot be considered *excess* sedimentation. Further, net sedimentation in the stream network appears to be controlled more by sediment transport capacity than by sediment supply, particularly within the lower gradient portions of Malibu Creek. Under conditions likely to cause excess erosion or excess sediment loads, such as altered hydrology, channel alteration, or construction (ground-disturbing) activities, the highly erodible nature of the Monterey/Modelo Formation might generate excess sedimentation.

Increased nutrient loads. LVMWD (2011) suggests that high levels of phosphorus are attributable to drainage originating from the Monterey/Modelo Formation. Table G-3 (above) presents a subset of data for comparator/reference sites located both in and outside the Formation. These data indicate that orthophosphate (as P) concentrations are, on average, greater for sites with a greater proportion of their catchment in the Monterey/Modelo Formation than for sites with a smaller proportion of their catchment in the Formation, consistent with LVMWD (2011). In contrast, nitrate concentrations (as N) are comparable between comparator/reference sites draining the Monterey/Modelo Formation (CH-6 and LV-9) and comparator/reference sites outside the formation (SC-14 and LCH-18). Activities or conditions that would cause greater erosion could cause excess nutrient concentrations in surface water.

Toxics loads. LVMWD (2011) shows that the high levels of sulfate, selenium, and total dissolved solids found in portions of the Malibu Creek Watershed are due to drainage originating from the marine sedimentary Monterey/Modelo Formation. Activities or conditions that would cause greater erosion or greater potential for release of toxics into surface water, the potential for toxicity likely would increase. However, no data are available to understand the magnitude of any potential effect of such disturbances.

Weight of Evidence for Natural Geology Causing Excess Sedimentation

1. Co-occurrence: Higher upland erosion rates are associated with areas of naturally erosive geology, mostly in the upper reaches of the watershed. However, these naturally high erosion rates do not constitute *excess* sedimentation in the stream network. Excess sedimentation is believed to co-occur with natural geology only where the flow regime and sediment transport capacity has been increased by other causes, such as increased impervious surface area.
2. Temporality: The natural geology has always been present in the watershed, but increased disturbance of the natural geology, attributable to human activities, has increased over time. Therefore, the evidence is compatible with temporality.
3. Response gradient: Highly erodible soils in the watershed are a natural cause of elevated sediment supply. Under disturbance conditions that increase erosion, it is likely, but not proven, that sedimentation would increase.
4. Complete exposure pathway: The evidence supports all steps in the linkage between natural geology and high upland sediment loads, but does not provide a complete exposure pathway between natural geology and increased instream sedimentation except insofar as sediment transport capacity has been increased by increasing impervious surfaces and urban runoff or other factors.
5. Plausibility: The literature on the Monterey/Modelo Formation supports the linkage between the Formation and increased sedimentation as plausible.
6. Analogy: There are many examples in the literature of natural geology resulting in increased sedimentation.
7. Predictive performance: There is no evidence of predictive performance.
8. Consistency of evidence: Most lines of evidence are consistent; however, more data are needed to support a gradient.
9. Coherence of evidence: There are no inconsistencies in the evidence.

The strength of evidence supporting the causal pathway between disturbance of the natural geology and increased sedimentation is moderate because this geology existed prior to the elevated sediment levels. It may contribute and interact with other stressors to increase instream sedimentation, but it is not the only or primary cause. Moreover, such geologic formations are natural conditions for Malibu Creek Watershed, and have been present since before human related activities. As such, the benthic assemblage likely is adapted to natural rates of sedimentation associated with natural geologic sources, and thus, argues against undisturbed natural geology as being a primary source of stressful levels of sediment in the watershed.

Weight of Evidence for Natural Geology Causing Increased Nutrients

1. Co-occurrence: Increased inorganic phosphorus concentrations occur as a result of natural geology of the Monterey/Modelo Formation, mostly in the upper reaches of the watershed. However, nitrogen concentrations are similar between comparator/reference sites in the Monterey/Modelo Formation and those that do not drain the Formation. Thus, co-occurrence is demonstrated for P but not for N. This is potentially significant as N concentrations appear to exert greater control on algal response in this watershed.
2. Temporality: The natural geology has always been present in the watershed, but increased disturbance of the natural geology, attributable to human activities, has increased over time. Therefore, the evidence is compatible with temporality.
3. Response gradient: Phosphorus concentrations increase with increasing contribution of Monterey/Modelo Formation natural geology to the catchment. Nitrogen concentrations show no change resulting from natural geology.

4. Complete exposure pathway: The evidence supports all steps in the linkage between natural geology and increased phosphorus. However, the evidence does not support a complete exposure pathway between natural geology and increased nitrogen.
5. Plausibility: The literature on the Monterey/Modelo Formation supports the linkage between the Formation and increased nutrients as plausible.
6. Analogy: There are many examples in the literature of natural geology resulting in increased nutrients in water.
7. Predictive performance: There is no evidence of predictive performance.
8. Consistency of evidence: All lines of evidence are consistent for a linkage between natural geology and increased phosphorus; however, the evidence does not support a linkage between natural geology and increased nitrogen.
9. Coherence of evidence: There are no inconsistencies in the evidence.

The strength of evidence supporting the causal pathway between undisturbed natural geology and increased phosphorus is strong. The strength of evidence supporting the causal pathway between undisturbed natural geology and increased nitrogen is weak because this geology is not associated with elevated nitrate where comparator/reference conditions exist. Moreover, the fact that the benthic assemblage likely is adapted to the nutrients associated with natural geologic sources argues against natural geology being a primary source of stressful levels of nutrients.

Weight of Evidence for Natural Geology Causing Increased Toxics Loads

1. Co-occurrence: Drainage from the Monterey/Modelo Formation contains elevated concentrations of salts, selenium, and sulfate. Man-made toxic chemicals are not associated with natural geology.
2. Temporality: The natural geology has always been present in the watershed, but increased disturbance of the natural geology, attributable to human activities, has increased over time. Therefore, the evidence is compatible with temporality.
3. Response gradient: Direct data for selenium and sulfate are limited but show association with the Monterey/Modelo Formation, as summarized in LVMWD (2011). Conductivity data, used to indicate salt concentrations, show that the highest conductivity values are found in the Monterey/Modelo Formation, and that conductivity at downstream locations generally reflects the percentage of the upstream drainage area within the Formation.
4. Complete exposure pathway: The evidence supports the linkage between natural geology, increased conductivity, and potentially increased loads of selenium and sulfate, although few data are available to support conclusions regarding selenium and sulfate as specific stressors.
5. Plausibility: The literature on the Monterey/Modelo Formation supports the linkage between the Formation and increased conductivity, and increased selenium and sulfate loads.
6. Analogy: There are many examples in the literature of natural geology resulting in increased metals and conductivity in water.
7. Predictive performance: There is no evidence of predictive performance.
8. Consistency of evidence: All lines of evidence are consistent for the linkage between the natural geology and loads of sulfate, selenium, and salts. Man-made organic toxics loads are not consistent with natural geology.
9. Coherence of evidence: There are no inconsistencies in the evidence.

The strength of evidence supporting the causal pathway between disturbed natural geology and increased toxicity loads for salts, sulfate, and selenium is strong.

Malibu Lagoon

Malibu Lagoon, located directly downstream of the lower reaches of Malibu Creek, receives all sediment, nutrient, and toxic inputs that are discharged from the Creek. Therefore, the analysis regarding the weight of evidence for natural geology and excess sediment, nutrients, or toxics also applies to impacts in the lagoon. However, it is important to recognize the distance between sites in the Monterey/Modelo Formation and the Lagoon. It is likely that other stressors, with sources between the Monterey/Modelo Formation and Malibu Lagoon, contribute to biological impairment and confound the effects of stressors from the disturbed natural geology.

G.2.3 Characterize Sources

G.2.3.1 Eliminate Sources

Only sources where lack of evidence for causing the likely stressors is unambiguous are eliminated. As a result, two of the eight candidate sources listed above are eliminated as highly unlikely to be a significant and sufficient cause of the likely stressors (these sources may contribute in a minor way to the candidate stressors). The eliminated sources are:

B3. Fire Regime: Periodic fires in the watershed do not appear to be temporally associated with candidate stressors. Physical habitat scores suggest that impacts of fires are relatively short-lived and are thus not a major source of sediment. Evidence supporting a causal pathway between fires and increased nutrient loads is weak.

B7. Agricultural Runoff: Agricultural runoff does not seem to be a primary cause of the candidate stressors. Station MC-12 has little evidence of agricultural land upstream (with the exception of the Ventura County portion of the watershed upstream of Lake Sherwood, which is separated from the lower portion of Malibu Creek by Lake Sherwood, Westlake, and Malibou Lake). Station MC-1, located at the downstream end of the watershed, drains limited amounts of agricultural land on Las Virgenes, Stokes, and Cold creeks.

Additionally, due to the lack of evidence for oxygen-demanding wastes, sources contributing to oxygen-demanding wastes are not evaluate further.

G.2.3.2 Strength of Evidence

Strength of evidence analysis uses the information developed in the data analysis to determine if the candidate sources contribute specific stressors that have been shown to cause benthic macroinvertebrate assemblage impairment. The causal considerations for the strength of evidence analyses used three types of evidence: case-specific evidence, evidence from other situations or biological knowledge, and evidence based on multiple lines of evidence, as described in Section G.2.3.2.

The results of the strength of evidence analysis, which are presented in narrative form in each analysis of the evidence, are summarized in Table G-4. The bottom of each cell displays the visual scoring recommended in USEPA (2000b), ranging from strongly positive “+++”) to strongly negative (“---”). The full range of symbols is not used for every line of evidence. For instance, co-occurrence has potential values of “+”, “0”, and “---” only.

Table G-4. Strength of Evidence Analysis for Sources of Stressors (B1 – B8)

	Consideration	Results	Stream	Lagoon
B1. Altered Hydrology and Excess Sedimentation				
Case-specific Evidence	Co-Occurrence	Compatible.	+	+
	Temporality	Compatible.	+	+
	Response Gradient	Weak (for stream). Strong (for Lagoon).	+	+++
	Complete Exposure Pathway	Incomplete evidence (for stream). Evidence for all steps (for Lagoon).	+	++
Information from Other Situations or Biological Knowledge	Plausibility	Plausible.	+	+
	Analogy	Many analogous cases.	++	++
	Predictive Performance	No evidence for predictive performance.	NE	NE
Considerations Based on Multiple Lines of Evidence	Consistency of Evidence	All lines of evidence are consistent.	+++	+++
	Coherence of Evidence	Inconsistencies can be explained by a credible mechanism.	+	+
B1. Altered Hydrology and Low Flows or Stagnant Water Resulting in Reduced DO				
Case-specific Evidence	Co-Occurrence	Uncertain (for stream). Incompatible (for Lagoon).	0	-
	Temporality	Incompatible.	---	---
	Response Gradient	Weak (for stream). None (for Lagoon).	+	-
	Complete Exposure Pathway	Some steps missing (for stream).Ambiguous (for Lagoon).	-	0
Information from Other Situations or Biological Knowledge	Plausibility	Plausible.	+	+
	Analogy	Many analogous cases.	++	++
	Predictive Performance	No evidence for predictive performance.	NE	NE
Considerations Based on Multiple Lines of Evidence	Consistency of Evidence	Multiple inconsistencies.	---	---
	Coherence of Evidence	No explanation for inconsistencies.	-	-
B2. Channel Alteration and Excess Sedimentation				
Case-specific Evidence	Co-Occurrence	Compatible.	+	+
	Temporality	Compatible.	+	+
	Response Gradient	Weak (for stream). Strong (for Lagoon).	+	+++
	Complete Exposure Pathway	Evidence for all steps.	++	++
Information from Other Situations or Biological Knowledge	Plausibility	Plausible.	+	+
	Analogy	Many analogous cases.	++	++
	Predictive Performance	No evidence for predictive performance.	NE	NE
Considerations Based on Multiple Lines of Evidence	Consistency of Evidence	Most lines of evidence are consistent (for stream). All lines of evidence are consistent (for Lagoon).	+	+++
	Coherence of Evidence	Inconsistencies can be explained by a credible mechanism.	+	+
B4. Septic Systems and Excess Nutrients				
Case-specific Evidence	Co-Occurrence	Compatible (for N). Uncertain (for P).	+/0	+/0
	Temporality	Compatible.	+	+

	Consideration	Results	Stream	Lagoon
	Response Gradient	Strong (for stream). No evidence (for Lagoon).	+++	-
	Complete Exposure Pathway	Evidence for all steps.	++	++
Information from Other Situations or Biological Knowledge	Plausibility	Plausible.	+	+
	Analogy	Many analogous cases.	++	++
	Predictive Performance	No evidence for predictive performance.	NE	NE
Considerations Based on Multiple Lines of Evidence	Consistency of Evidence	All lines of evidence are consistent .	++	++
	Coherence of Evidence	Inconsistencies can be explained by a credible mechanism.	+	+
B5. Point Source Discharges and Excess Nutrient Loads				
Case-specific Evidence	Co-Occurrence	Compatible.	+	+
	Temporality	Compatible.	+	+
	Response Gradient	Weak.	+	+
	Complete Exposure Pathway	Evidence for all steps during the discharge season; incomplete during the non-discharge season.	++/+	++/+
Information from Other Situations or Biological Knowledge	Plausibility	Plausible.	+	+
	Analogy	Many analogous cases.	++	++
	Predictive Performance	No evidence for predictive performance.	NE	NE
Considerations Based on Multiple Lines of Evidence	Consistency of Evidence	All lines of evidence are consistent.	+++	+++
	Coherence of Evidence	Inconsistencies can be explained by a credible mechanism.	+	+
B6. Urban Runoff and Excess Sedimentation				
Case-specific Evidence	Co-Occurrence	Compatible (for stream). No evidence to evaluate (for Lagoon).	+	NE
	Temporality	Compatible (for stream). No evidence to evaluate (for Lagoon).	+	NE
	Response Gradient	Weak (for stream). No evidence to evaluate (for Lagoon).	+	NE
	Complete Exposure Pathway	Evidence for all steps (for stream). No evidence to evaluate (for Lagoon).	++	NE
Information from Other Situations or Biological Knowledge	Plausibility	Plausible.	+	+
	Analogy	Many analogous cases.	++	++
	Predictive Performance	No evidence for predictive performance	NE	NE
Considerations Based on Multiple Lines of Evidence	Consistency of Evidence	Most lines of evidence are consistent.	+	+ NE
	Coherence of Evidence	Inconsistencies can be explained by a credible mechanism (for stream). No evidence to evaluate (for Lagoon).	+	NE
B6. Urban Runoff and Excess Nutrients				
Case-specific Evidence	Co-Occurrence	Compatible (for N). Uncertain (for P).	+/0	+/0
	Temporality	Compatible.	+	+

	Consideration	Results	Stream	Lagoon
	Response Gradient	Strong (for stream). No evidence (for Lagoon).	+++	-
	Complete Exposure Pathway	Evidence for all steps.	++	++
Information from Other Situations or Biological Knowledge	Plausibility	Plausible.	+	+
	Analogy	Many analogous cases.	++	++
	Predictive Performance	No evidence for predictive performance.	NE	NE
Considerations Based on Multiple Lines of Evidence	Consistency of Evidence	All lines of evidence are consistent .	++	++
	Coherence of Evidence	Inconsistencies can be explained by a credible mechanism.	+	+
B6. Urban Runoff and Toxics Loads				
Case-specific Evidence	Co-Occurrence	Uncertain (for stream). No evidence to evaluate (for Lagoon).	0	NE
	Temporality	Compatible (for stream). No evidence to evaluate (for Lagoon).	+	NE
	Response Gradient	No evidence in the data (for stream). No evidence to evaluate (for Lagoon)..	-	-
	Complete Exposure Pathway	Incomplete evidence (for stream). No evidence to evaluate (for Lagoon).	+	+
Information from Other Situations or Biological Knowledge	Plausibility	Plausible.	+	+
	Analogy	Many analogous cases.	++	++
	Predictive Performance	No evidence for predictive performance.	NE	NE
Considerations Based on Multiple Lines of Evidence	Consistency of Evidence	Multiple inconsistencies (for stream). No evidence to evaluate (for Lagoon).	---	NE
	Coherence of Evidence	Inconsistencies can be explained by a credible mechanism (for stream). No evidence to evaluate (for Lagoon).	+	NE
B8. Natural Geology and Excess Sedimentation				
Case-specific Evidence	Co-Occurrence	Compatible.	+	+
	Temporality	Compatible.	+	+
	Response Gradient	Weak.	+	+
	Complete Exposure Pathway	All steps are consistent.	++	++
Information from Other Situations or Biological Knowledge	Plausibility	Plausible.	+	+
	Analogy	Many analogous cases.	++	++
	Predictive Performance	No evidence for predictive performance.	NE	NE
Considerations Based on Multiple Lines of Evidence	Consistency of Evidence	Most lines of evidence are consistent.	+	+
	Coherence of Evidence	Inconsistencies can be explained by a credible mechanism.	+	+
B8. Natural Geology and Excess Nutrient Loads				
Case-specific Evidence	Co-Occurrence	Compatible (for P); incompatible (for N).	+/---	+/---

	Consideration	Results	Stream	Lagoon
	Temporality	Compatible.	+	+
	Response Gradient	Strong (for P). None (for N).	+++/-	+++/-
	Complete Exposure Pathway	Evidence for all steps (for P). Evidence for some steps is missing (for N).	++/-	++/-
Information from Other Situations or Biological Knowledge	Plausibility	Plausible.	+	+
	Analogy	Many analogous cases.	++	++
	Predictive Performance	No evidence for predictive performance.	NE	NE
Considerations Based on Multiple Lines of Evidence	Consistency of Evidence	All lines of evidence are consistent (for P). Multiple inconsistencies exist in the evidence (for N).	+++/---	+++/---
	Coherence of Evidence	Inconsistencies can be explained by a credible mechanism.	+	+
B8. Natural Geology and Toxics Loads				
Case-specific Evidence	Co-Occurrence	Compatible for metals and salts (incompatible for organic toxics).	+	+
	Temporality	Compatible.	+	+
	Response Gradient	Strong (for metals and salts).	+++	+++
	Complete Exposure Pathway	Evidence for all steps for loading.	++	++
Information from Other Situations or Biological Knowledge	Plausibility	Plausible.	+	+
	Analogy	Many analogous cases.	++	++
	Predictive Performance	No evidence for predictive performance.	NE	NE
Considerations Based on Multiple Lines of Evidence	Consistency of Evidence	All consistent (for metals and salt loads; multiple inconsistencies for organic toxics.)	+++	+++
	Coherence of Evidence	Inconsistencies can be explained by a credible mechanism.	+	+

G.2.4 Characterize Sources: Identify Probable Sources

All of the stressor sources presented above are credibly related to one or all of the probable stressors. However, the evidence is stronger for some sources than for others. The following sources are strongly associated with the impairment in the flowing streams of the Malibu Creek watershed:

B1. Altered Hydrology (related to B2, B6)

B4. Septic Systems

B5. Point Source Discharges

B6. Urban Runoff (related to B1, B2)

Both Altered Hydrology and Urban Runoff, in the form of increased peak flows derived from impervious surfaces, contribute to sedimentation in the streams. Septic Systems, Point Source Discharges (Tapia WRF), and Urban Runoff also appear to be key sources of nitrogen loading in the system, which results in excess algal growth. Natural geology, which is a source of increased phosphorus loading, is not listed here as a key source because algal response appears to be controlled primarily by nitrogen availability.

For Malibu Lagoon the key sources are identified as:

B1. Altered Hydrology (related to B2, B6)

B2. Channel Alteration (related to B1, B6)

B4. Septic Systems

B5. Point Source Discharges

B6. Urban Runoff (related to B1, B2)

In the Lagoon, sedimentation and reduced DO stressors are more strongly linked to the physical modifications to the lagoon morphology; therefore, Channel Alteration is listed. In addition, Septic Systems, Point Source Discharges, and Urban Runoff likely play an important role in impairment of conditions in Malibu Lagoon by excess algal growth. Point Source Discharges are listed despite the growing season discharge prohibition because winter discharges of nutrient loads can collect in the lagoon and support excess algal growth later in the season.

Natural geology, when disturbed by human activities or natural occurrences such as wildfire, is associated with runoff from the Monterey/Modelo Formation, and may contribute to some elevated candidate stressors in the main stem and various tributaries to Malibu Creek. These included phosphorus, ions such as sulfate, and metals (see LVMWD, 2011). However, these stressors do not appear to limit the biological potential of the system. Natural geology appears to be a contributing source, but not an unnatural source contributing to these stressors. The sum of the evidence suggests that altered hydrology, septic systems, urban runoff, channel alteration, and point sources (for the Lagoon only) are the dominant sources responsible for generating the dominant stressors.

G.3 Hypothetical Linkage Analysis Example

To illustrate the linkage analysis process, this section presents a hypothetical example.

Babbling Brook recently experienced a series of fish kills. After the first fish kill, scientists investigated the stream and learned that the fish kills occurred downstream of a permitted point source discharge from a chemical manufacturing company. During the course of their investigation, biologists noted impaired fish communities, increased nutrient concentrations, toxic chemicals in the water column exceeding water quality criteria, and low dissolved oxygen. Fish collected from the site showed an unusually high number of deformities, fin erosion, lesions, tumors and anomalies. After collecting sufficient data, a linkage analysis was performed.

The candidate causes listed included the following:

1. Increased nutrients causing algal blooms and reduced DO
2. Point source discharges exceeding thermal permit limits and causing reduced DO
3. Point source discharges exceeding toxic chemical permit limits

Evidence from the case for candidate cause #1 included measurements of increased nutrients in Babbling Brook. The increased nutrient concentrations occurred both far upstream and downstream of the location of the fish kills. However, algal growth was observed to be very low, likely due to heavy canopy cover of the stream resulting in light limitation. Evidence from outside the case strongly supported a linkage between increased nutrients, algal blooms, and reduced dissolved oxygen—as long as light requirements also are met.

Evidence from the case for candidate cause #2 included water temperature measurements in the discharge plume, upstream, and downstream of the discharge. Coincident DO measurements were also available, and showed the expected relationship with temperature: lower DO occurred with higher water temperature. Temperature was lower and DO was higher upstream of the discharge compared with downstream, but temperature and DO returned to near upstream levels within approximately 100 meters of the discharge. Babbling Brook was categorized as a cold-water stream, with a DO criterion of not less than 6 mg/L. Continuous DO monitoring at several locations along the stream revealed that DO dipped to approximately 3 mg/L at the point of discharge. Evidence from outside the case shows that fish and other aquatic organisms frequently cannot survive DO levels less than 5 mg/L. On the other hand, evidence also shows that fish will avoid areas of low DO if possible.

Evidence from the case for candidate cause #3 included water column and sediment measurements of toxic chemicals in multiple locations along the stream, upstream and downstream of the discharge. The toxic chemicals were only detected downstream of the discharge. No water quality criteria are available for the toxic chemicals present, so no clear comparison to aquatic health-based criteria could be made. Evidence from outside the case, however, included laboratory studies of one of the chemicals, showing that the chemical caused a specific anomaly in test fish at low concentrations, and death at high concentrations. These anomalies were among the anomalies observed in fish from the stream. Fish surveys conducted prior to the chemical company's existence made no mention of the specific anomaly.

Candidate cause #1 could be eliminated as a possible stressor, because the lack of algal growth in the stream shows unambiguously that the causal pathway is not complete.

Candidate cause #3 provided diagnostic evidence of at least one toxic chemical released from the point source discharge as a cause of fish community impairment. The anomaly demonstrated by laboratory fish to this chemical was very specific (no other chemicals were known to cause it). The same anomaly and the same chemical were observed in the stream, co-occurring in space. Additionally, the lack of observations of the anomaly prior to the chemical company discharging into the stream, and the occurrence of the anomaly later provided temporal evidence for causality.

Candidate cause #2 could not be eliminated as a causal factor. Evidence from the case indicated that co-occurrence and temporality were both compatible with thermal impacts being a causal factor, but the biological gradient was weak (fish could avoid the area of high temperature and low DO). Therefore, the evidence from the case was incomplete for the exposure pathway. Evidence from outside the case indicated that high temperature and low DO are plausible, but not specific causal factors for fish community impairment. Many cases exist in the literature for high temperature as a cause of fish community impairment, especially to cold-water streams, but there was no evidence for predictive performance. The consistency of evidence was that most evidence was consistent, and the inconsistencies could be explained by a credible mechanism: the evidence was coherent.

In this hypothetical case, the toxic chemical emerged as a primary stressor correlated with fish community impairment, with a high level of confidence. Thermal effects may also be associated with impairment in the stream.

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