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United States Department of the Interior

U. S. GEOLOGICAL SURVEY
California Water Science Center
San Diego Projects Office
4165 Spruance Road, Suite 200
San Diego, CA 92101
Phone: (619) 225-6100 Fax: (619) 225-6101
http://water.wr.usgs.gov

October 29, 2009

Mr. James Thorsen,
City Manager,
City of Malibu,
23815 Stuart Ranch Road,
Malibu, California 90265

Dear Mr. Thorsen;

This letter summarizes preliminary results of our cooperative water-resources study to identify the source of fecal indicator bacteria in the Malibu Lagoon and ocean beaches near Malibu, California. The study was cooperatively funded by the City of Malibu and the U.S. Geological Survey. The study was done under the direction of Dr. John Izbicki in our San Diego Projects Office.

Previous work has shown that fecal indicator bacteria (FIB), indicative of fecal contamination, are present in Malibu Lagoon and at ocean beaches near Malibu, California at concentrations that exceed recreational water-quality standards. The source, or combination of sources, of fecal material to the lagoon and near-shore ocean water is not precisely known but may include: (1) groundwater containing residential or commercial septage; (2) natural sources either directly deposited by birds and other wildlife, or indirectly mobilized as tides and waves wash beach sands and material accumulated at the high-tide line (rack line) along the beach; and/or (3) surface flow into the Malibu Lagoon. FIB present in the lagoon could be a source of contamination to the near-shore ocean by surface flow from the lagoon to the ocean or by groundwater flow from the lagoon through the berm separating the lagoon from the ocean. Data were collected during a falling monthly tidal cycle during the dry summer season from July 21-27, 2009 and reflect conditions present at that time.

The purpose of this letter is to provide a summary of preliminary results from the July 21-27, 2009 sample period. Data collected during the sampling period included: (1) groundwater-level data; (2) Radon-222 (^{222}Rn) data and direct-current (DC) resistivity data to estimate groundwater discharge to Malibu Lagoon and the near-shore ocean; (3) fecal indicator bacteria concentrations in groundwater, Malibu Lagoon, and near-shore ocean water; and (4) bacterial source tracking data (including genetic, molecular, and chemical data. Most data collected as part of the study are publically available in the U.S. Geological Survey's on-line data base NWIS-Web other data are on-file at the U.S.

Geological Survey office in San Diego and are publically available on request. The information presented in this letter is for internal planning and program development purposes. Interpretations presented in this letter have not been reviewed within the U.S. Geological Survey, and as such are preliminary and are not intended for public release.

Although results of this study are preliminary, and reflect the conditions during the sample period, FIB were present at only low concentrations, in 10 of 11 sampled water-table wells. In contrast, high concentrations of FIB were present in Malibu Lagoon. Given the general absence of FIB in groundwater, measured rates of groundwater discharge to the lagoon, and other hydrologic conditions at the time of sample collection groundwater discharge was not a likely source of FIB to the lagoon. Enterococcus concentrations in excess of the U.S. Environmental Protection Agency single sample standard for recreational water (104 MPN per 100 ml) in near-shore ocean water near the lagoon berm were related to movement of water through the berm at the mouth of the lagoon during low tide. FIB concentrations in near-shore ocean water at three sampled beaches were higher at high tide and are more consistent with FIB associated with wave run-up washing fecal material from beach sands and the rack line at high tide, than with discharge of groundwater contaminated with septic wastewater which would be expected to be greater at low tide. Enterococcus concentrations occasionally exceeded the U.S. Environmental Protection Agency single sample standard for recreational water at the three beaches during the sample period.

As stated previously, data collected as part of this study reflect conditions present during sample collection and may not reflect conditions at other times. The results of this initial study are preliminary and will be used to develop a more detailed proposal for future work to address these issues. If you have any questions concerning the study results, do not hesitate to contact me at (619) 225-6127 or Dr. John Izbicki at (619) 225-6131. The U.S. Geological Survey looks forward to working with the City of Malibu on future water-resource investigations.

Sincerely,

Peter Martin
Program Chief

Introduction

Previous work has shown that fecal indicator bacteria (FIB), indicative of fecal contamination, are present in Malibu Lagoon and at ocean beaches near Malibu, California at concentrations that exceed recreational water-quality standards (Ambrose and Orme, 2000; Stone Environmental, 2004). The source, or combination of sources, of fecal material to the lagoon and near-shore ocean water is not precisely known but may include: (1) groundwater containing residential or commercial septage; (2) natural sources either directly deposited by birds and other wildlife, or indirectly mobilized as tides and waves wash beach sands and material accumulated at the high-tide line (rack line) along the beach; and/or (3) surface flow into the Malibu Lagoon. In addition, FIB present in the lagoon could be a source of contamination to the near-shore ocean by surface flow from the lagoon to the ocean, or by groundwater flow from the lagoon through the berm separating the lagoon from the ocean.

Data were collected in the Malibu area during a falling monthly tidal cycle during the dry summer season from July 21-27, 2009. Previous investigations of microbial contamination at beaches near Santa Barbara, California showed that groundwater discharge to the near-shore ocean is greater during the low tides of the falling monthly tidal cycle (Swarzenski and Izbicki, 2009; Izbicki et al., 2009). Data collected during the sampling period included: (1) groundwater-level data; (2) Radon-222 (^{222}Rn) data and direct-current (DC) resistivity data to estimate groundwater discharge to Malibu Lagoon and the near-shore ocean; (3) fecal indicator bacteria concentrations in groundwater, Malibu Lagoon, and near-shore ocean water; and (4) bacterial source tracking data (including genetic, molecular, and chemical data. Sample site locations are shown on figures 1 and 2. Not all data collected during the study period were available for inclusion in this letter.

Groundwater levels

As part of this study, groundwater levels were continuously measured at four wells (SMBRP-12, SMBRP-13, C-1, and P-9) to help determine the interaction between groundwater and the near-shore ocean. Tide, ocean swell, and groundwater-level data are shown in (fig. 3).

Water-levels in wells SMBRP-13 and SMBRP-12 (fig. 3c) in Malibu Colony respond to tidal fluctuations in the ocean. The tidal efficiency (amplitude of tidally affected water levels in the well divided by the tidal amplitude in the ocean) of well SMBRP-13 on the east side of Malibu Colony was 0.13; whereas, the tidal efficiency of well SMBRP-12 near the center of Malibu Colony was about 0.005. Higher tidal efficiency indicates that tides have greater influence on water levels in affected wells. Malibu Colony is protected by a seawall consisting of wooden pilings driven into the sand to a depth of about 15 ft. (fig. 4). The pilings act as a barrier to the interaction between the ocean and groundwater inland of the seawall. Well SMBRP-13 is closer to the eastern edge of the seawall; therefore, the seawall has less effect on the water levels than in well SMBRP-12.

In addition to tidal effects, the water levels in wells SMBRP-12 and SMBRP-13 also were affected by a south swell during the measurement period. The swell produced wave heights of about 5.5 ft between July 25-26, 2009 (fig. 3b) at the Santa Monica Basin bouy (46025), about 20 miles offshore. Wave heights on the beach at Malibu were greater and were reported in excess of 12 feet during this period. Water levels in well SMBRP-13 increased during the swell and reached their peak during the swell (fig. 3c). The maximum water-level response in well SMBRP-12 (fig. 3c) occurred about 1 day after the peak swell intensity and the effect of the swell persisted longer than in well SMBRP-13.

Water levels in wells C-1 and P-9 respond to water-level fluctuations in Malibu Lagoon in addition to tidal fluctuations in the ocean (fig. 3d). The combination of tides and swells caused the ocean to overtop the berm separating the lagoon from the ocean between July 22-25. This allowed ocean water to enter the lagoon at high tide, increasing water levels in the lagoon and in wells C-1 and P-9 during the sample period (fig. 3d). The ocean did not overtop the berm after July 25 and water levels in the lagoon and wells C-1 and P-9 began to decline at that time (fig. 3d).

Groundwater discharge to Malibu Lagoon

^{222}Rn data were collected to estimate groundwater discharge to Malibu Lagoon. Radon is a noble gas, and consequently it is non-reactive and highly mobile in groundwater. ^{222}Rn is radioactive, produced by the decay of radium-226 as part of the uranium-238 decay series, and has a half-life of 3.8 days. ^{222}Rn is present at concentrations several orders of magnitude higher in groundwater than in surface water or ocean water (Swarzenski and Izbicki, 2009). If the average ^{222}Rn concentration in groundwater discharging to a surface water body is known, and the ^{222}Rn concentration of the surface water is known, then the groundwater discharge rate can be calculated. Calculations account for exchange with atmospheric ^{222}Rn and mixing with seawater having low ^{222}Rn concentrations.

^{222}Rn concentrations ranged from 650 to 1,370 dpm/L (disintegrations per minute per liter) in the eight wells sampled for this study (Table 1). In addition to groundwater samples, ^{222}Rn samples were collected continuously from two locations in the lagoon (ML-Upper and ML-Lower, fig. 2) by equilibrating water pumped from the lagoon with air in an enclosed chamber. The radioactive decay of ^{222}Rn in the chamber was measured and the water concentration was calculated according to Henry's law (Swarzenski and Izbicki, 2009). ^{222}Rn concentrations in lagoon water ranged from 8 to 62 dpm/L during the sample period (fig. 5c). ^{222}Rn concentrations in the lagoon were higher at the beginning of the sample period and decreased as seawater (having low ^{222}Rn concentrations) entered the lagoon during high tides.

Preliminary analysis of ^{222}Rn data show groundwater discharge to the upstream part of Malibu Lagoon averaged 2.8 cm/d between July 21-26. Groundwater discharge rates to the upper lagoon decreased during the sample period from about 15 cm/d (6-hour moving average) on July 21-22, to 2.3 cm/d (6-hour moving average) on July 24-25 (fig. 5d). Groundwater discharge rates to the lagoon increased after July 26 after seawater no longer overtopped the berm during high tide (fig. 5d). Groundwater discharge to the downstream part of the lagoon (ML-Lower) was less than discharge in the upstream part of the lagoon and averaged 0.8 cm/d on July 22-23 (not shown in figure 5).

Groundwater discharge to the near-shore ocean

The original study plan included collecting ^{222}Rn data with seepage meter data to measure groundwater discharge along the Malibu Colony beach. However, high surf conditions during the sample period prevented the collection of these data. It was possible to collect DC-resistivity data along the Malibu Colony beachfront near well SMBRP-12 (fig. 1) to determine the location of groundwater discharge to the ocean (fig. 6). The resistivity data shows a thin lens of resistive material, presumably sand containing fresh groundwater, at a depth of about 15 ft below land surface. As stated previously, the seawall pilings extend to a depth of about 15 ft below land surface. Therefore, groundwater must flow beneath these pilings to discharge to the ocean. The lens of resistive material is overlain and underlain by more conductive material, presumably sand containing saline groundwater. The shallower saline groundwater is probably ocean water emplaced in the sand at the base of the seawall during high tides and swells. The deeper saline groundwater probably results from the density contrast between seawater and fresh water, which creates a wedge of seawater extending beneath fresh groundwater within the alluvial deposits.

Occurrence of fecal indicator bacteria

Fecal indicator bacteria (FIB) measured as part of this study included *Escherichia coli* (*E. coli*) and enterococci. Although not necessarily fecal in origin, total coliform bacteria also were measured to assess microbial contamination of sampled water. Total coliform and *E. coli* were analyzed by Colilert and enterococci were analyzed using Enterolert (IDEXX, Westbrook MN). Samples were analyzed within 6 hours after collection in a temporary laboratory established in the study area. A range of dilutions were used to ensure proper quantification of samples in accordance with the manufacturers' specifications.

Fecal indicator bacteria in groundwater

FIB samples were collected from 11 shallow wells in the study area (fig.1 and Table 1). Total coliform, *E. coli*, and enterococcus bacteria were less than the detection limit or were present at low concentrations in water from 10 of the 11 wells sampled (Table 1). FIB were detected in water from well CCPE (Table 1), which is in a commercial area adjacent to Malibu Lagoon (fig, 1). The sample from the well was saline (specific conductance of 10,800 μS/cm), which is similar to water in the lagoon at the time of sample collection. FIB present in the lagoon during the sampling period could be the source of the FIB in well CCPE. However, FIB were not detected in well C-1, adjacent to Malibu Lagoon, which also has saline water that may have originated from the lagoon. FIB also were not detected in well P-9, adjacent to the lagoon. Water from well P-9 is fresh (specific conductance of 2,000 µS/cm) and more similar to groundwater than to water from Malibu Lagoon. FIB also were not detected in water from wells SMBRP-12 and SMBRP-13 in Malibu Colony near the ocean.

Fecal indicator bacteria in Malibu Creek

Malibu Creek was not flowing and as a consequence was not an important source of FIB to the lagoon during the sample period. However, pools of water were present in the stream channel upstream from the lagoon (fig. 2). Total coliform, *E. coli*, and enterococcus concentrations in a sample collected on July 24 from one of these pools were 14,100, 10, and 280 MPN per 100 ml, respectively.

Fecal indicator bacterial in Malibu Lagoon and the adjacent near-shore ocean

Samples from the Malibu Lagoon were analyzed for FIB during the high and low tide at the downstream site near the berm of the lagoon (ML-Berm). FIB concentrations in the lagoon at that site were higher than concentrations in samples from wells or surface water collected during the study period. Total coliform concentrations in Malibu Lagoon ranged from <1,000 to 650,000 MPN per 100 ml (Most Probable Number per 100 milliliters) (fig. 7). *E. coli* concentrations ranged from <10 to 130,000 MPN per 100 ml (fig. 7d). Total coliform and *E. coli* concentrations generally decreased during the sample period as a result of dilution as ocean water overtopped the berm and entered the lagoon during high tide (fig. 7d). The decrease in total coliform and *E. coli* concentrations was accompanied by an increase in water level and specific conductance of water in the lagoon (figs. 7b and 7c). Total coliform and *E. coli* concentrations increased during the later part of the sample period when ocean water was no longer entering the lagoon during high tide. Enterococcus concentrations ranged from <10 to 3,400 MPN per 100 ml (fig. 7d). Enterococcus concentrations in Malibu Lagoon commonly exceeded the U.S. Environmental Protection Agency single sample standard for (marine) recreational water of 104 MPN per 100 ml (U.S. Environmental Protection Agency, 2003). Unlike total coliform and *E. coli* concentrations, enterococcus concentrations did not consistently decrease during the sample period. Instead, enterococcus concentrations show a diurnal pattern with the lowest concentrations in samples collected later in the day (fig.7d), possibly as a result of inactivation of bacteria by UltraViolet (UV) radiation in sunlight.

Ocean water entering Malibu Lagoon during high tide has a higher salinity than lagoon water. As a consequence, ocean water is denser and will tend to sink to the bottom of the lagoon stratifying water in the lagoon by density (fig. 8). Initially it was expected that saline water at the bottom of the lagoon, which originated from the ocean, would have low bacteria concentrations. However, data collected from this study indicate that the deeper saline water had higher bacteria concentrations than near surface water (fig. 8). A possible explanation is that ocean water enters the lagoon during high tide and the denser ocean water sinks to the bottom of the lagoon. As the dense ocean water moves to the lagoon bottom sediment and associated bacteria are resuspended into the water column.

Surface discharge from Malibu Lagoon to the ocean did not occur during the sample period. To determine if water and associated FIB from the lagoon can flow through the sand berm to the near-shore ocean at low tide, data were collected during a 24-hour tidal cycle on July 23-24 from the lagoon, the sand berm separating the lagoon from the ocean, and in the near-shore ocean (fig. 9). The specific conductances of (1) near-shore ocean water adjacent to the berm and at several nearby beaches, (2) Malibu Lagoon, and (3) water from piezometers and seepage samplers in the berm are shown in figure 9b. The enterococcus concentrations of near-shore ocean water and water from Malibu Lagoon are shown in figure 9c. The enterococcus concentrations of water from piezometers and seepage samplers in the berm are shown in figure 9d.

During the falling tidal cycle specific conductance of near-shore ocean water adjacent to the berm (ML-Berm-OF, fig. 9b) decreased and reached a minimum about one hour after low tide. This decrease is the result of water from the lagoon discharging through the berm. As a consequence of this discharge, the specific conductance of near-shore ocean water adjacent to the berm (ML-Berm-OF, fig. 9b) was lower than near-shore ocean water at nearby beaches sampled as part of this study (OF-A, OF-B, and OF-C, fig. 9b). As water from the lagoon discharged to the ocean, enterococcus concentrations increased in near-shore ocean water adjacent to the berm (ML-Berm-OF, fig 9c). Enterococcus concentrations were highest about 1 hour after low tide when the specific conductance of near-shore ocean water was lowest. Enterococcus concentrations exceeded the U.S. Environmental Protection Agency (2003) single sample standard for recreational water at that time. A similar pattern was observed in total coliform and E. coli concentrations (not shown on fig. 9).

Increases in enterococcus concentration also were observed during the falling tide in the piezometer driven into the berm adjacent to Malibu Lagoon at a depth of 5 ft below land surface (Pz 5ft, fig. 9d). However, enterococcus concentrations were low in water from samplers emplaced in the seepage face along the berm near the secondary high-tide line (Seepage-Shallow, fig. 9d) and the secondary low-tide line (Seepage-Deep, fig. 9d). The specific conductance of water from the sampler near the secondary high-tide line (Seepage-Shallow, fig. 9b) was consistent with ocean water emplaced in the berm during the previous high tide. The specific conductance of water from the sampler near the secondary low-tide line was consistent with water from Malibu lagoon (Seepage-Shallow, fig. 9b).

DC-resistivity sections were collected across the berm, perpendicular to the ocean, on July 24 at low tide and at the secondary high tide (fig. 10a and 10b). The DC-resistivity data show water from the lagoon (delineated as less saline on fig. 10) in a thin layer within the sand berm discharging to the ocean near the low tide line (fig. 10). This layer is overlain by more saline water emplaced in the berm during high tide when ocean water flowed over the top of the berm into the lagoon. The less saline water is underlain by water from deeper parts of the lagoon containing moderately saline water originating from the ocean during previous high tides. The DC-resistivity data suggest that most of the water from the lagoon is moving through the berm slightly below the deepest sampler on the seepage face (Seepage-Deep, fig. 10). This result suggests that the enterococcus bacteria present in the near-shore ocean probably moved through the berm with the lagoon water near the altitude of the low tide line, at a depth below the deepest seepage sampler.

Fecal indicator bacteria in the near-shore ocean

FIB concentrations were measured in near-shore ocean water at the Malibu Colony beach (OF-B), a beach about 3 miles to the west Malibu Colony (OF-A), and a beach about 0.25 miles east of the Malibu Lagoon (OF-C) between July 12-26, 2009 (fig. 11). Samples were collected at the high, secondary-high, low, and secondary-low tidal stands. Figure 11 shows the tidal range (11a), ocean swell height (11b), specific conductance of near-shore ocean water (11c), and total coliform, E. coli, and enterococcus concentrations (11d, 11e, and 11f, respectively) at the sampled beaches.

Total coliform and *E. coli* concentrations were generally lower at all tidal stands at the Malibu Colony beach (OF-B) than at the other sampled beaches (fig. 11d, and 11e). Enterococcus concentrations exceeded the U.S. Environmental Protection Agency (2003) single sample standard for recreational water at all three sampled beaches during the sample period, with the most exceedances at the OF-A site to the west of the Malibu Colony beach (fig. 11f). A health advisory, associated high FIB concentrations, was posted for the beach east of OF-C near the beginning of the sample period.

Prior to the high surf associated with the south swell that occurred from July 24-26, total coliform and *E. coli* concentrations were higher during high tide and lower during low tide (fig. 11d and 11e). This pattern is consistent with bacterial contributions from wave run-up on the beach during high tide. The pattern is not consistent with bacteria from groundwater discharge containing septage because groundwater discharge to the near-shore ocean is greatest at low tide. Tidally associated changes in bacteria concentrations also were present for enterococcus but were less pronounced (fig. 11f).

The specific conductance of near-shore ocean water was the lowest at the onset of high surf associated with the south swell beginning July 24 (fig. 11c). Presumably the high surf disturbed the discharge of groundwater to the ocean along the beachfront, although the high surf did not affect tidally associated FIB concentrations in near-shore ocean water until after the swell subsided. After the swell subsided, total coliform, *E. coli*, and enterococcus concentrations were higher during low tide than at high tide (fig. 11d, 11e, and 11f). This may represent drainage of ocean water emplaced in the beach sand during the swell rather than discharge of groundwater from onshore alluvial deposits.

Fecal indicator bacteria in septage water and other sources

FIB concentrations were sampled in the discharge from a traditional septic system (MC-OLD-Septic, fig. 2) and an advanced septic system (MC-ADV-Septic, fig. 2) containing (1) biological treatment media, (2) an aeration tank, and (3) UV disinfection.

Samples were collected October 1, 2009 and bacteria were analyzed within 24 hours of collection at the U.S. Geological Survey office in San Diego. Advanced septic systems in the Malibu area differ in their construction and consequently the quality of water discharged from these systems also may differ. The data show a 2-log-order reduction in FIB concentrations in water discharged from advanced systems compared to more traditional systems (Table 2). FIB concentrations in the discharge from the advanced septic system were generally lower than FIB concentrations in Malibu Lagoon during the July sample period.

FIB were extracted from about 0.5 kg of sand collected on the berm at Malibu Lagoon on October 1, 2009 using about 4 L of water adjusted to seawater salinity. The samples were collected from recently wetted beach sand along the rack line about 1 hour after high tide. Although birds were actively feeding in the area, the sample was not obviously contaminated by guano. Total coliform and *E. coli* concentrations in the extract were low, 10 MPN per 100 ml, while enterococcus concentrations were high, 230 MPN per 100 ml.

Bacterial Source-Tracking

Genetic, molecular, and chemical data were collected to determine the source of FIB to groundwater, Malibu Lagoon, and near-shore ocean water. Genetic material from bacterial cells were analyzed by Terminal-Restriction Fragment Length Polymorphism (T-RFLP) at University of California Santa Barbara (UCSB). Human-specific Bacteroides also were analyzed by UCSB. Molecular data consisted of phospholipid fatty acids (PLFA) from bacterial cells. PLFA are associated with specific metabolic activities by a range of organisms rather than specific organisms. PLFA data were analyzed by a contract laboratory (Microbial Insights, Rockford, Tenn.). Chemical data included a suite of 69 organic compounds including caffeine, fecal sterols, detergent metabolites and other compounds collectively known as wastewater indicators. Chemical data were analyzed by the U.S. Geological Survey National Water Quality Laboratory (NWQL) in Denver. Colo. Samples were delivered to the UCSB laboratory by currier on the day of collection. Samples were shipped on the day of collection to the contract laboratory and the NWQL by overnight delivery. Only PLFA results were available at the time this letter was prepared.

The distribution of PLFA structural groups was analyzed using principal component analysis (PCA). PCA is a multivariate statistical technique that transforms a set of intercorrelated variables into a set of uncorrelated variables having a mean of zero and the same variance as the original data set. The new uncorrelated variables are known as principal components and the value of the principal component are known as scores. Analysis of the transformed principal component scores, rather than the original data, allows for statistically unbiased comparison and contrast of samples from different sources.

The first three principal components explain 91 percent of the total variability in the PLFA data. PCA results show differences in the PLFA composition of microbial communities in samples from water-table wells and from near-shore ocean water (fig. 11). Samples from piezometers and seepage samplers in beach sands are intermediate in composition, and samples from Malibu Lagoon are similar to samples from the near-shore ocean. The first and second principle components for sample collected from near-shore ocean water near Malibu Lagoon at low tide (ML-Berm-OF) are almost identical in PLFA composition to water from the lagoon (ML_Berm), consistent with seepage from the lagoon as a likely source of the enterococcus bacteria in the near-shore ocean water near the lagoon at low tide.

Additional interpretation of PLFA data, with genetic (T-RFLP) and wastewater indicator data is warranted before final conclusions can be drawn.

Summary

Groundwater level, radon-222, direct current resistivity, FIB, and bacterial-source tracking data were collected during a falling monthly tidal cycle during the dry summer season from July 21-27, 2009 near Malibu, California. These data reflect conditions present during the study period and may not reflect conditions at other times. Preliminary results of the study are:.

1. FIB concentrations were less than the detection limit or were present at low concentrations in samples from 10 of the 11 water-table wells sampled. FIB from septic-tank discharge was not a major source of FIB contamination to groundwater sampled by the wells during the study period.

2. Shallow groundwater was discharging to Malibu Lagoon during high tidal stands at an average rate of 2.8 cm/d during the sample period. Discharge rates as high as 15 cm/d (6 hour average) were measured during high tidal stands at the beginning of the sample period. Discharge to the lagoon declined during the sample period as a result of increased water levels in the lagoon resulting from ocean water overtopping the berm of the lagoon during high tide.

3. High concentrations of fecal indicator bacteria were present in Malibu Lagoon during the sample period. Total coliform and *E. coli* concentrations decreased during the sample period as a result of dilution by ocean water entering the lagoon at high tide. Enterococcus concentrations showed a daily variation consistent with inactivation by UV radiation during the day. Enterococcus concentrations rebounded to high concentrations during the night.

4. Water movement through the berm of Mailbu Lagoon was a source FIB, especially enterococcus, to the near-shore ocean at the mouth of the lagoon during low tide. Enterococcus concentrations exceeded the U.S. Environmental Protection Agency single sample standard for recreational water (104 MPN per 100 ml) in near-shore ocean water near the lagoon berm during low tide.

5. FIB concentrations increased during high tide at three sampled beaches. These increases were consistent with wave run-up on the beach washing FIB from the rack line and beach sands. FIB concentrations did not increase in near-shore ocean water during low tide when groundwater discharge to the ocean would be the greatest. As a result, groundwater discharge did not appear to be a source of FIB concentrations to the near-shore ocean at three sampled beaches. Enterococcus concentrations occasionally exceeded the U.S. Environmental Protection Agency single sample standard for recreational water at the three beaches during the sample period.

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EXPLANATION

Resistivity line

Sampled wells and identifier—

C-1

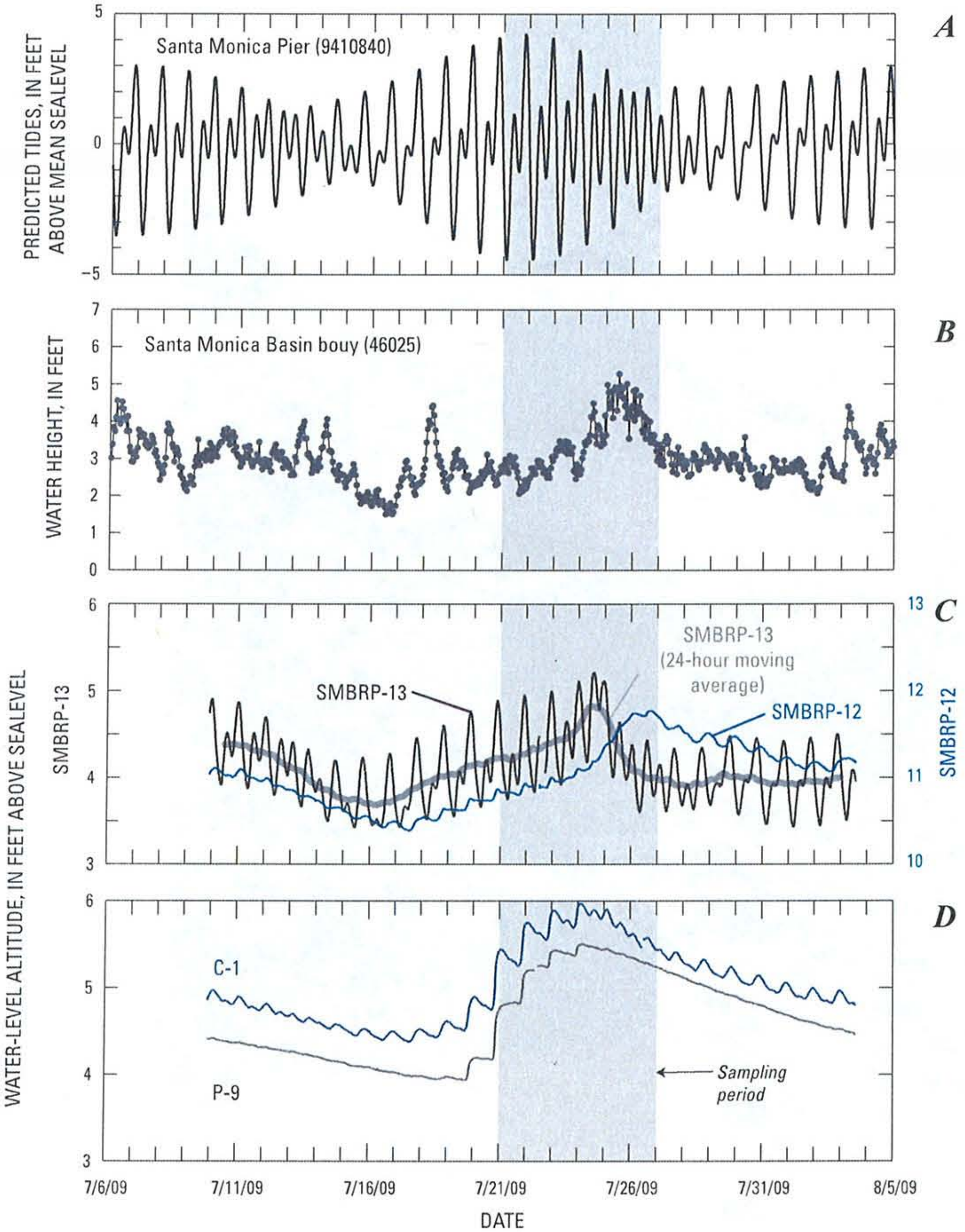
Figure 01

EXPLANATION

Sample sites and identifier—

Surface-water	*Hand-driven piezometers or seepage samplers*	*Other*
▲ ML-middle	▼ ML-Berm-9ft	■ Kelp extract, sand extract, or septic sample

Figure 02



A
Santa Monica Pier (9410840)
PREDICTED TIDES, IN FEET ABOVE MEAN SEALEVEL
B
Santa Monica Basin bouy (46025)
WATER HEIGHT, IN FEET
C
SMBRP-13
SMBRP-13 (24-hour moving average)
SMBRP-12
D
C-1
P-9
Sampling period
WATER-LEVEL ALTITUDE, IN FEET ABOVE SEALEVEL
7/6/09
7/11/09
7/16/09
7/21/09
7/26/09
7/31/09
8/5/09
DATE

Figure 04

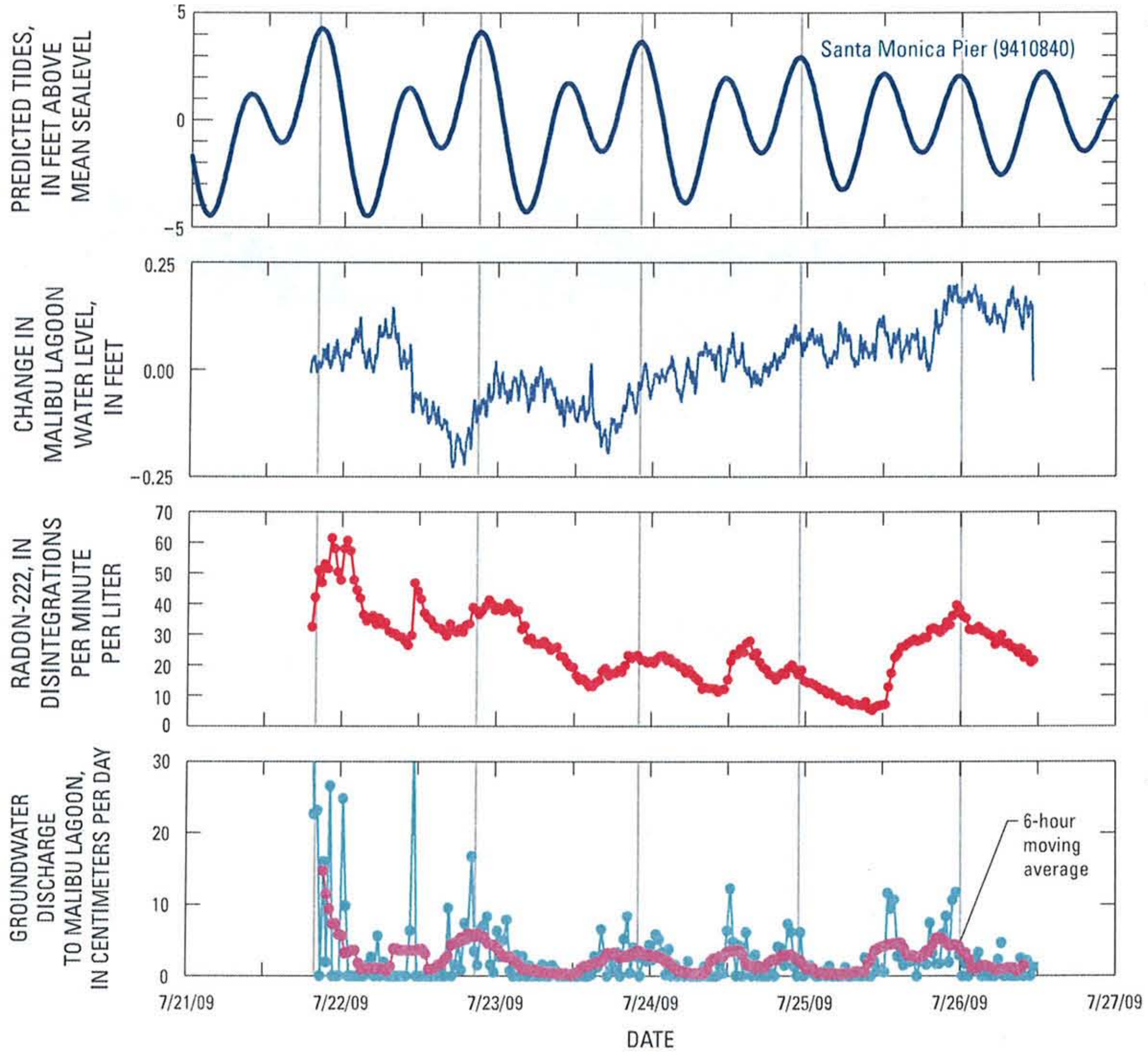
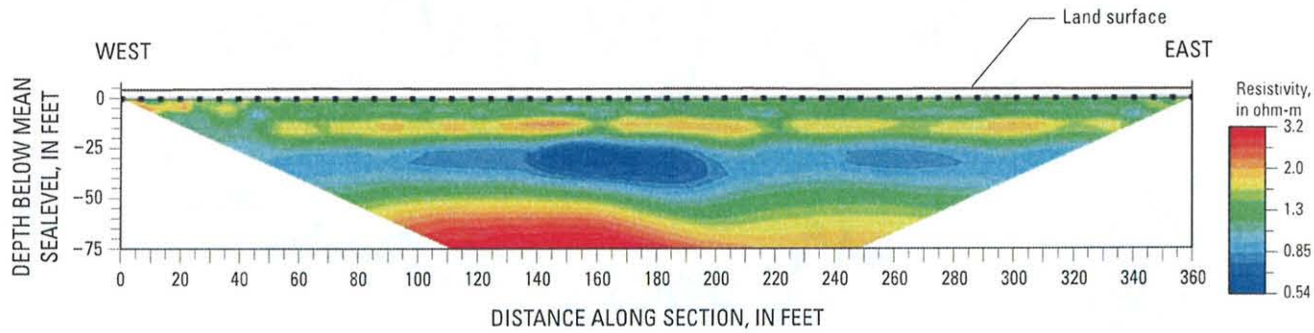

A
B
C
D
PREDICTED TIDES, IN FEET ABOVE MEAN SEALEVEL
Santa Monica Pier (9410840)
5
0
-5
CHANGE IN MALIBU LAGOON WATER LEVEL, IN FEET
0.25
0.00
-0.25
RADON-222, IN DISINTEGRATIONS PER MINUTE PER LITER
70
60
50
40
30
20
10
0
GROUNDWATER DISCHARGE TO MALIBU LAGOON, IN CENTIMETERS PER DAY
30
20
10
0
6-hour moving average
7/21/09
7/22/09
7/23/09
7/24/09
7/25/09
7/26/09
7/27/09
DATE

Figure 05


Land surface
WEST
EAST
DEPTH BELOW MEAN SEALEVEL, IN FEET
0
-25
-50
-75
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360
DISTANCE ALONG SECTION, IN FEET
Resistivity, in ohm-m
3.2
2.0
1.3
0.85
0.54

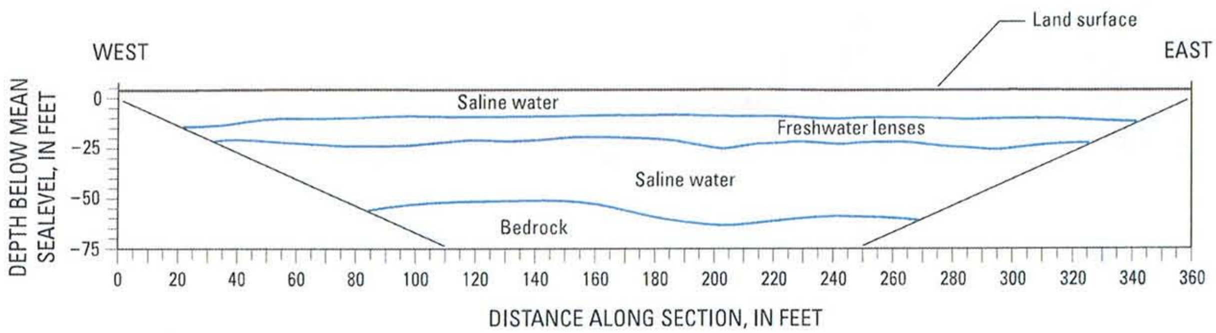
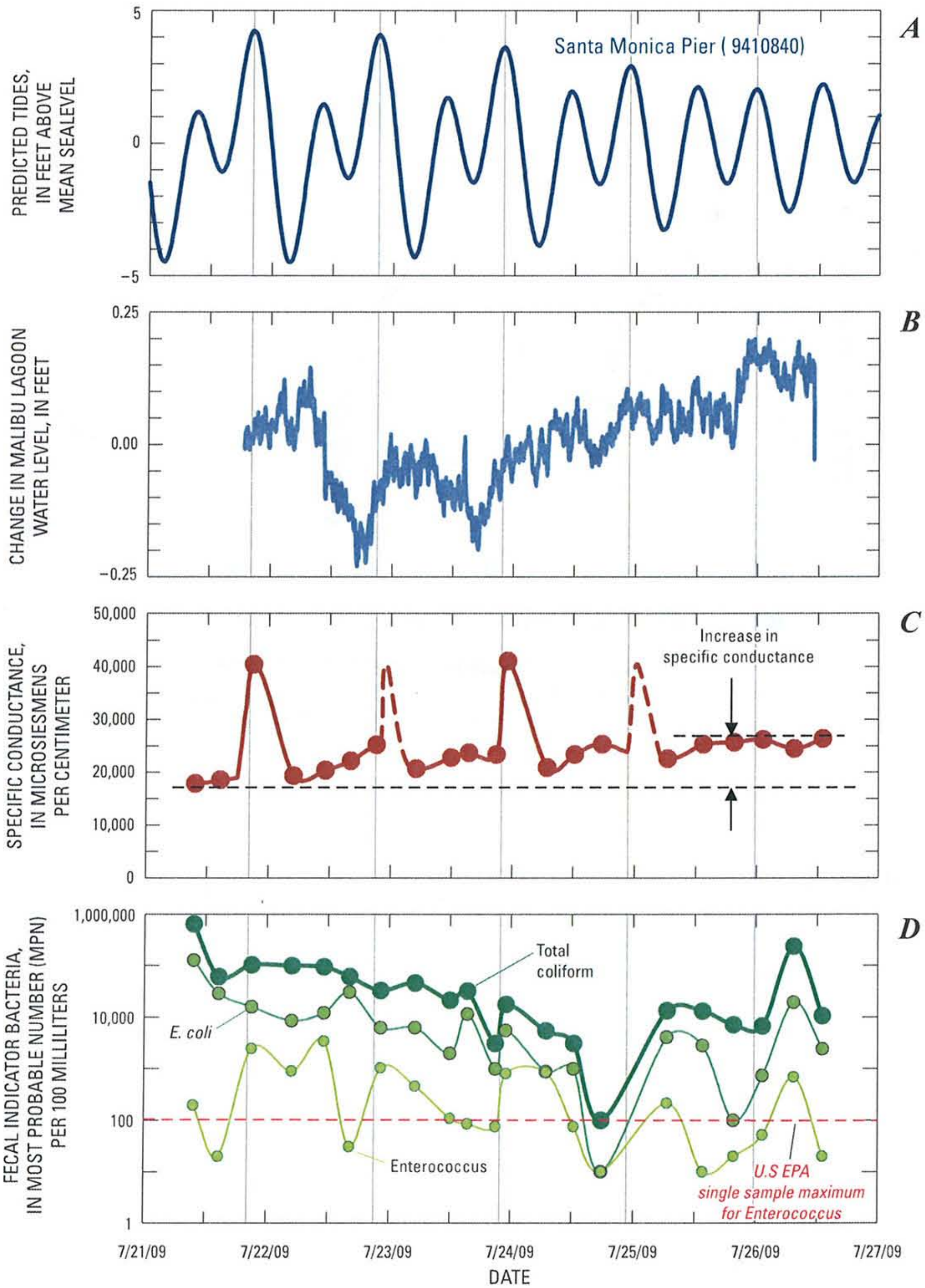

Land surface
WEST
EAST
Saline water
Freshwater lenses
Saline water
Bedrock
DEPTH BELOW MEAN SEALEVEL, IN FEET
0
-25
-50
-75
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360
DISTANCE ALONG SECTION, IN FEET

Figure 06



PREDICTED TIDES, IN FEET ABOVE MEAN SEALEVEL
Santa Monica Pier (9410840)
A
CHANGE IN MALIBU LAGOON WATER LEVEL, IN FEET
B
SPECIFIC CONDUCTANCE, IN MICROSIESMENS PER CENTIMETER
Increase in specific conductance
C
FECAL INDICATOR BACTERIA, IN MOST PROBABLE NUMBER (MPN) PER 100 MILLILITERS
Total coliform
E. coli
Enterococcus
U.S EPA single sample maximum for Enterococcus
D
7/21/09
7/22/09
7/23/09
7/24/09
7/25/09
7/26/09
7/27/09
DATE

Figure 07

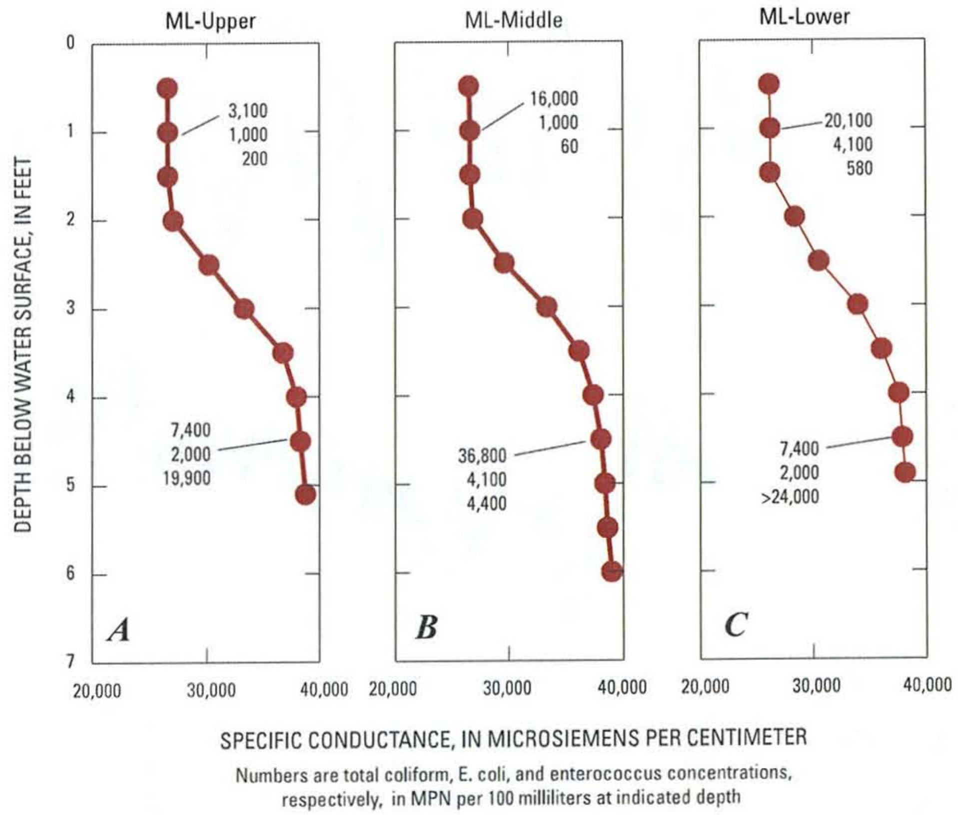

ML-Upper
ML-Middle
ML-Lower
DEPTH BELOW WATER SURFACE, IN FEET
0
1
2
3
4
5
6
7
3,100
1,000
200
7,400
2,000
19,900
16,000
1,000
60
36,800
4,100
4,400
20,100
4,100
580
7,400
2,000
>24,000
A
B
C
20,000
30,000
40,000
SPECIFIC CONDUCTANCE, IN MICROSIEMENS PER CENTIMETER
Numbers are total coliform, E. coli, and enterococcus concentrations, respectively, in MPN per 100 milliliters at indicated depth

Figure 08

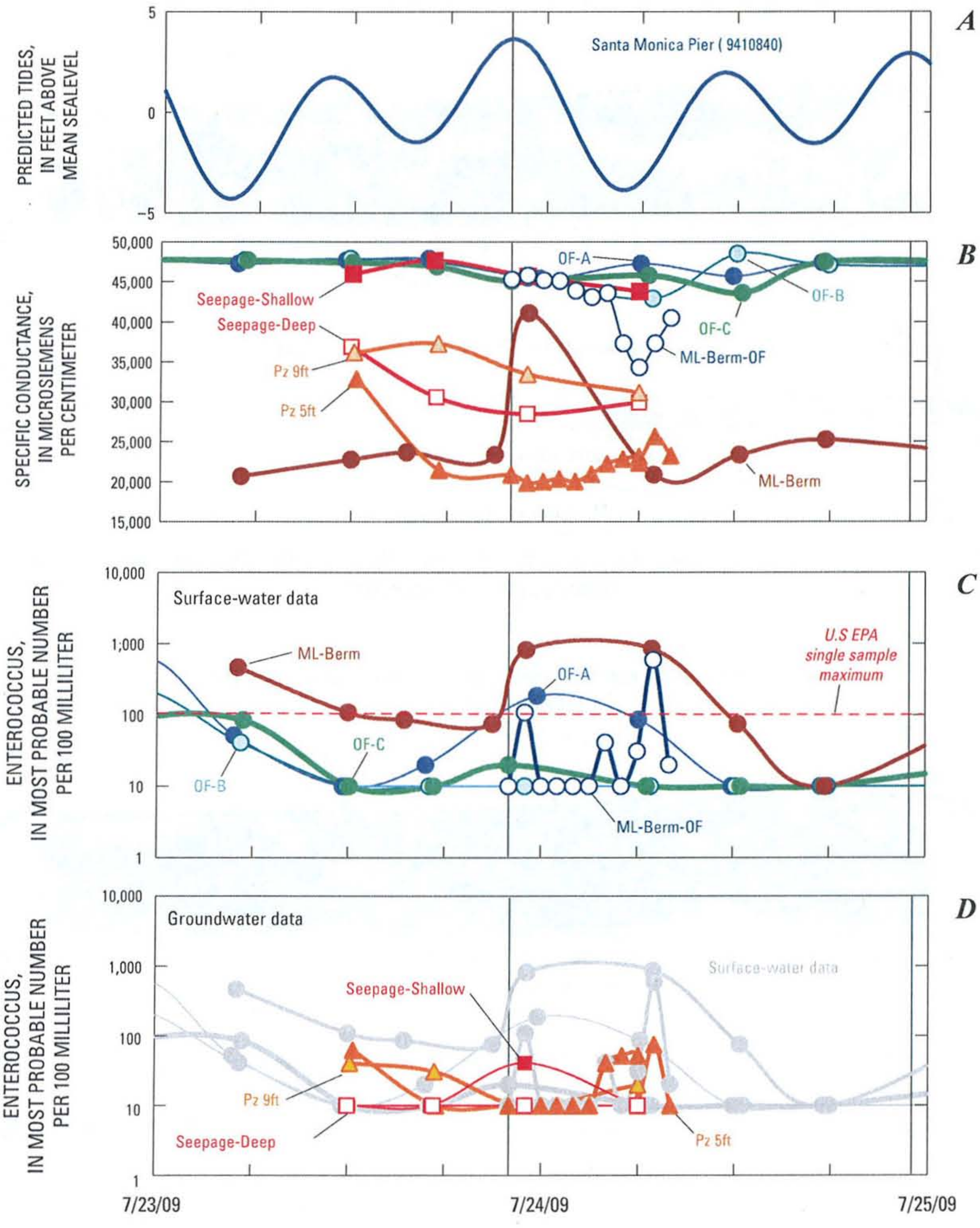
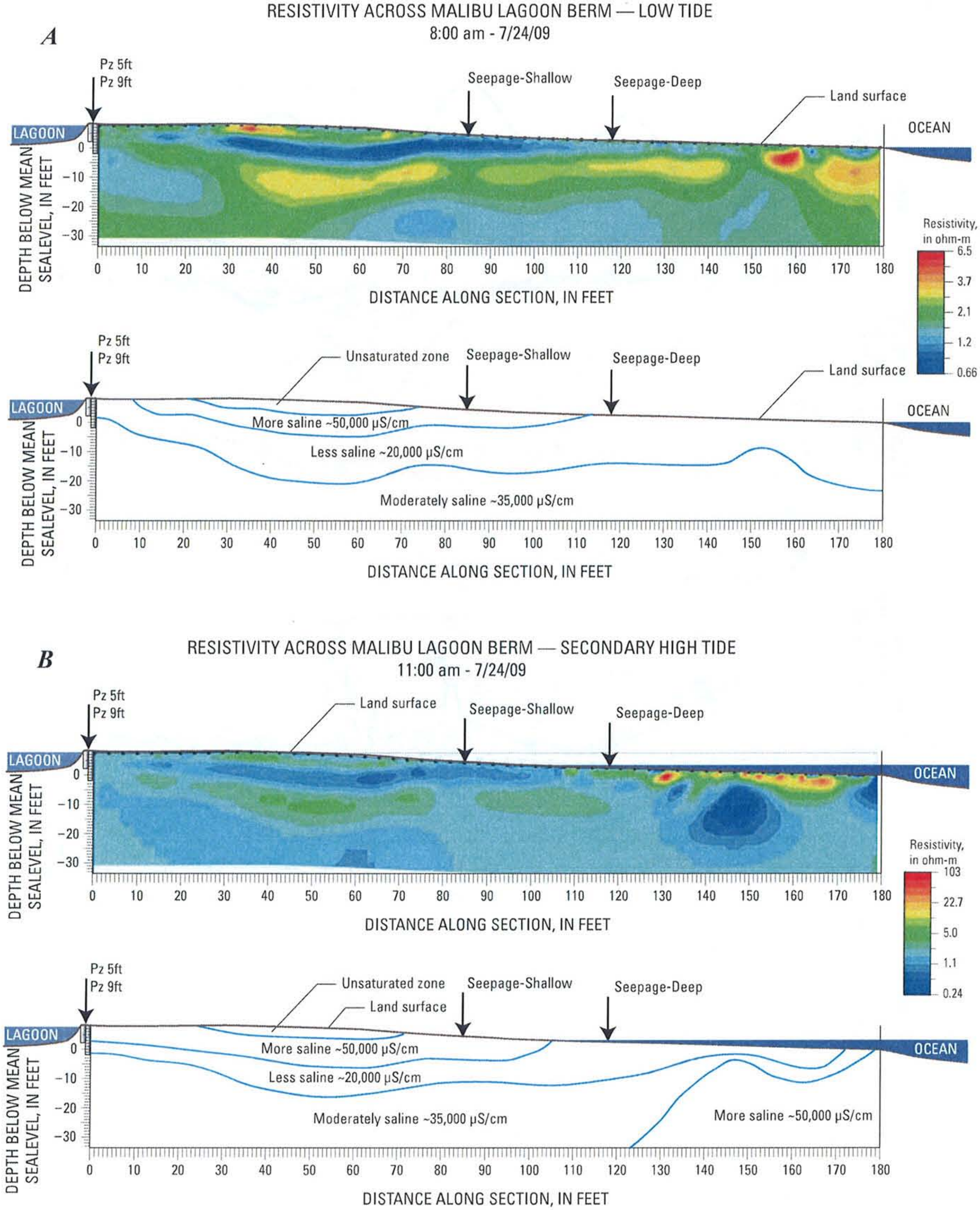

A
B
C
D
PREDICTED TIDES, IN FEET ABOVE MEAN SEALEVEL
Santa Monica Pier (9410840)
5
0
−5
SPECIFIC CONDUCTANCE, IN MICROSIEMENS PER CENTIMETER
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
OF-A
OF-B
OF-C
Seepage-Shallow
Seepage-Deep
Pz 9ft
Pz 5ft
ML-Berm-OF
ML-Berm
ENTEROCOCCUS, IN MOST PROBABLE NUMBER PER 100 MILLILITER
10,000
1,000
100
10
1
Surface-water data
ML-Berm
OF-A
OF-B
OF-C
ML-Berm-OF
U.S EPA single sample maximum
Groundwater data
Surface-water data
Seepage-Shallow
Pz 9ft
Seepage-Deep
Pz 5ft
7/23/09
7/24/09
7/25/09

Figure 09


A
RESISTIVITY ACROSS MALIBU LAGOON BERM — LOW TIDE
8:00 am - 7/24/09
Pz 5ft
Pz 9ft
Seepage-Shallow
Seepage-Deep
Land surface
LAGOON
OCEAN
DEPTH BELOW MEAN SEALEVEL, IN FEET
0
−10
−20
−30
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
DISTANCE ALONG SECTION, IN FEET
Resistivity, in ohm-m
6.5
3.7
2.1
1.2
0.66
Unsaturated zone
More saline ~50,000 µS/cm
Less saline ~20,000 µS/cm
Moderately saline ~35,000 µS/cm
B
RESISTIVITY ACROSS MALIBU LAGOON BERM — SECONDARY HIGH TIDE
11:00 am - 7/24/09
Resistivity, in ohm-m
103
22.7
5.0
1.1
0.24
More saline ~50,000 µS/cm

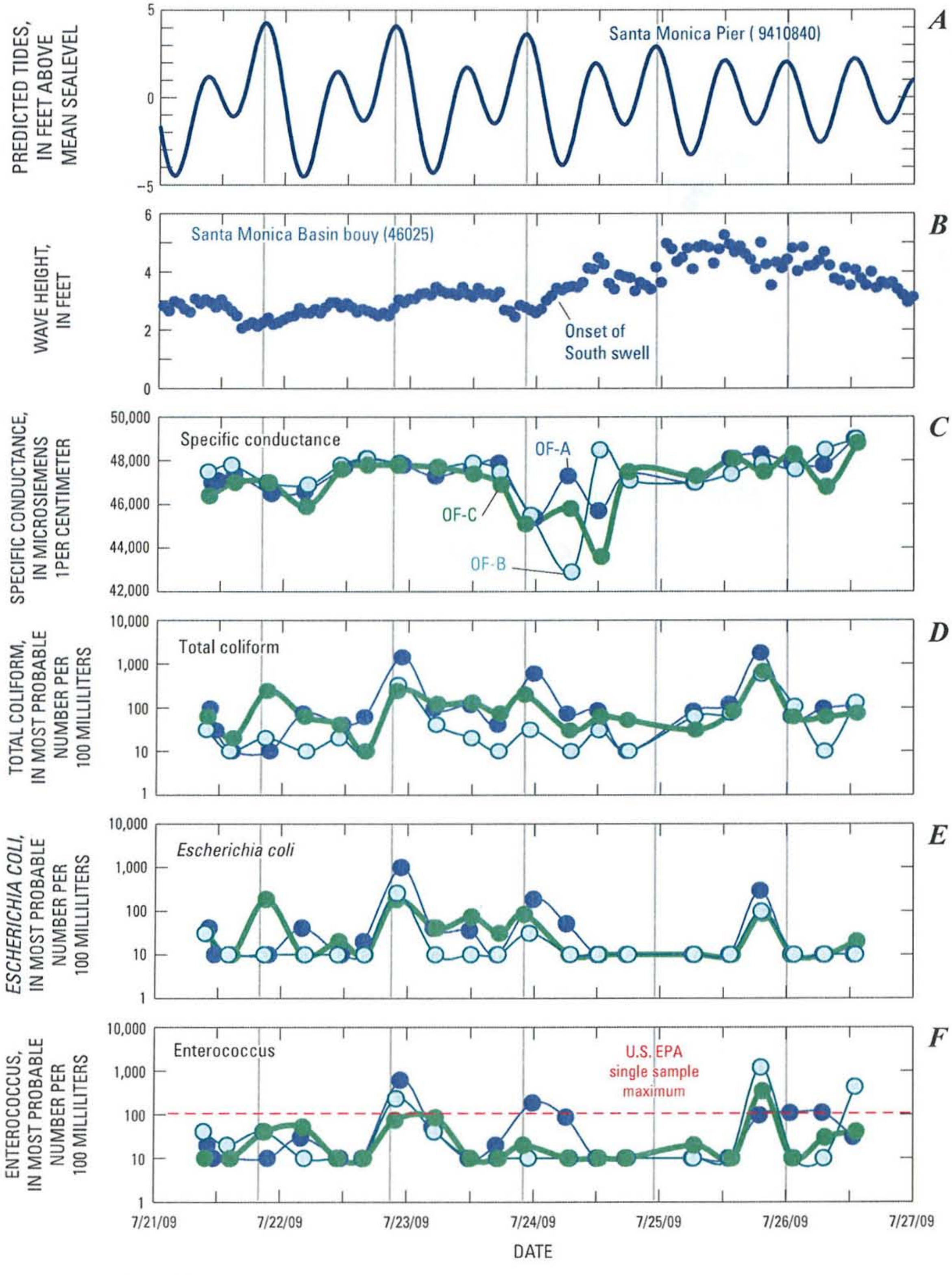

PREDICTED TIDES, IN FEET ABOVE MEAN SEALEVEL
Santa Monica Pier (9410840)
A
WAVE HEIGHT, IN FEET
Santa Monica Basin bouy (46025)
Onset of South swell
B
SPECIFIC CONDUCTANCE, IN MICROSIEMENS 1PER CENTIMETER
Specific conductance
OF-A
OF-C
OF-B
C
TOTAL COLIFORM, IN MOST PROBABLE NUMBER PER 100 MILLILITERS
Total coliform
D
ESCHERICHIA COLI, IN MOST PROBABLE NUMBER PER 100 MILLILITERS
Escherichia coli
E
ENTEROCOCCUS, IN MOST PROBABLE NUMBER PER 100 MILLILITERS
Enterococcus
U.S. EPA single sample maximum
F
7/21/09
7/22/09
7/23/09
7/24/09
7/25/09
7/26/09
7/27/09
DATE

Figure 11

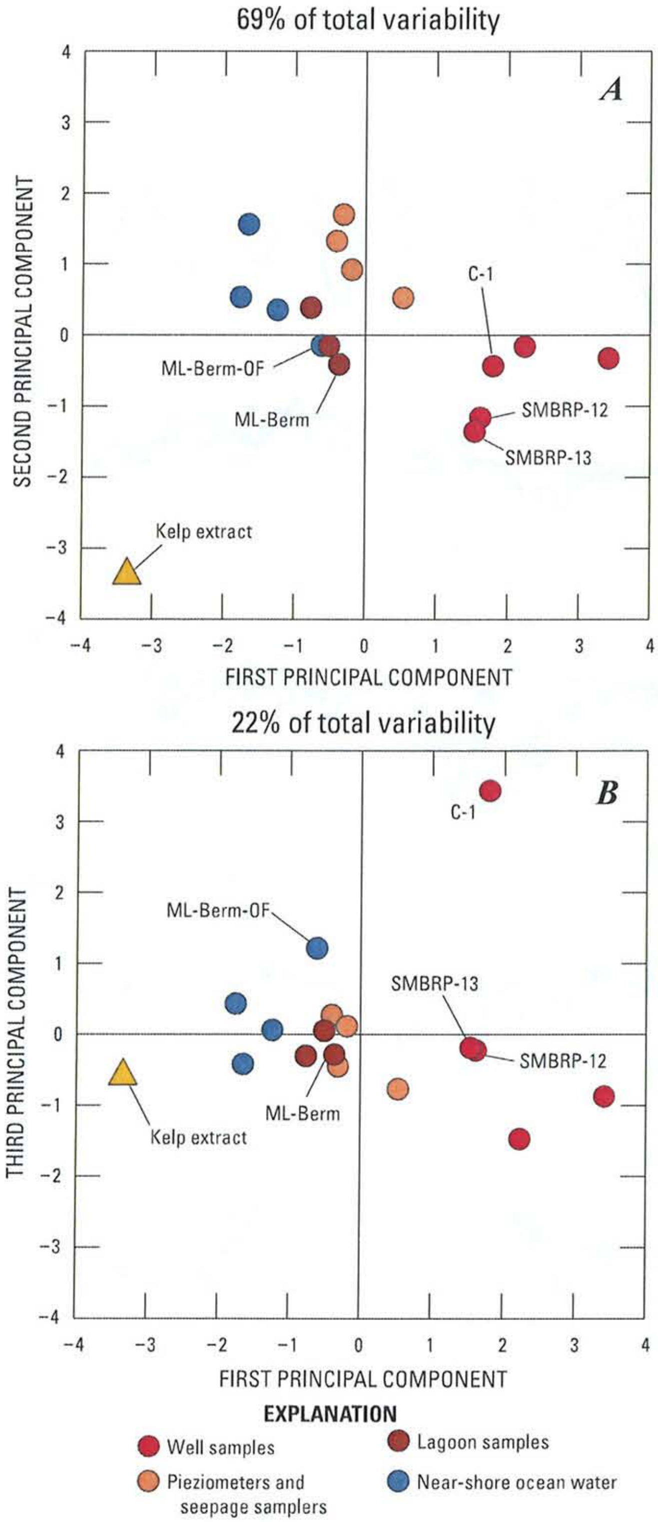

69% of total variability
A
SECOND PRINCIPAL COMPONENT
FIRST PRINCIPAL COMPONENT
C-1
ML-Berm-OF
ML-Berm
SMBRP-12
SMBRP-13
Kelp extract
22% of total variability
B
THIRD PRINCIPAL COMPONENT
FIRST PRINCIPAL COMPONENT
C-1
ML-Berm-OF
SMBRP-13
SMBRP-12
ML-Berm
Kelp extract
EXPLANATION
Well samples
Lagoon samples
Piezometers and seepage samplers
Near-shore ocean water

Figure 12

Table 1. Fecal indicator bacteria (FIB) concentration in water from selected water-table wells, Malibu, California, July 21-26, 2009.

[The five-digit parameter code below the constituent name is used by the U.S. Geological Survey to uniquely identify a specific constituent or property. C, Celsius; dpm/L, disintegrations per minute per liter; ft, feet; LSD, land surface datum; mg/L, milligrams per liter; mL, milliliters; MPN, most probable number; nc, not collected; µS/cm microsiemens per centimeter; <, less than;]

Well Identification No.	Date (m/dd/yyyy)	Time (24 hour)	Water level (ft below LSD)	Well depth (feet)	Dissolved oxygen, (mg/L) (00300)	pH (standard units) (00400)
SMBRP-10C	7/21/2009	14:45	6.12	25	2.9	7.2
SMBRP-11	7/21/2009	11:45	8.40	20	1	6.4
SMBRP-2	7/22/2009	13:15	5.34	11	0.4	7.1
SMBRP-12	7/22/2009	10:30	6.97	25	0.2	7.1
SMBRP-13	7/22/2009	14:30	7.47	20	1.7	7.3
P-9	7/22/2009	10:00	nc	12	0.3	7.1
CCR-1	7/24/2009	9:00	5.69	19	0.1	7.4
CCPE	7/23/2009	14:30	4.97	53	0.2	NR
CCPNE	7/23/2009	9:00	6.03	25	0.2	NR
CCPC	7/23/2009	10:25	5.76	22	0.2	NR
C-1	7/26/2009	11:45	4.47	14	0.1	7.3

Well Identification No.	Specific conductance (µS/cm at 25°C) (00095)	Total coliforms (MPN/100 mL) (50569)	*Escherichia coli* (MPN/100 mL) (50468)	*Enterococci* (MPN/100 mL) (99601)	Radon-222 (dpm/L)
SMBRP-10C	12,700	< 10	< 10	< 10	nc
SMBRP-11	2,960	< 10	< 10	< 10	nc
SMBRP-2	3,360	< 1	< 1	< 1	1,220 ± 189
SMBRP-12	3,820	< 1	< 1	< 1	650 ± 141
SMBRP-13	2,450	< 1	< 1	< 1	850 ± 158
P-9	2,000	< 1	< 1	< 1	1,340 ± 198
CCR-1	2,080	2	< 1	2	1660 ± 163
CCPE	10,800	11	65	1,600	1,050 ± 139
CCPNE	1,960	1	< 1	7.5	1,370 ± 160
CCPC	2,020	< 1	< 1	< 1	950 ± 134
C-1	22,300	< 10	< 10	< 10	nc

Table 2. Fecal indicator bacteria (FIB) concentration in discharge water from a traditional septic system (OLD) and from an advanced septic system (ADV), Malibu, California, October 1, 2009.

[The five-digit parameter code below the constituent name is used by the U.S. Geological Survey to uniquely identify a specific constituent or property. C, Celsius; mL, milliliters; MPN, most probable number; µS/cm, microsiemens per centimeter]

Site Identification No.	Date (mm/dd/yyyy)	Time (24 hour)	pH (standard units) (00400)	Specific conductance (µS/cm at 25°C) (00095)
MC-OLD-Septic	10/1/2009	12:30	6.9	1160
MC-ADV-Septic	10/2/2009	11:00	7.5	990

Site Identification No.	Total coliforms (MPN/ 100 mL) (50569)	*Escherichia coli* (MPN/100 mL) (50468)	Enterococcus (MPN/ 100 mL) (50569)
MC-OLD-Septic	610,000	220,000	7,300
MC-ADV-Septic	16,000	1,400	52