Health Consultation

Evaluation of Hydrogen Sulfide Migration at Twin Lakes Beach
And Adjacent to the Santa Cruz Harbor

Santa Cruz Harbor, Santa Cruz County, California

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U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Agency for Toxic Substances and Disease Registry
Division of Health Assessment and Consultation
Atlanta, Georgia 30333

Health Consultation: A Note of Explanation

An ATSDR health consultation is a verbal or written response from ATSDR to a specific request for information about health risks related to a specific site, a chemical release, or the presence of hazardous material. In order to prevent or mitigate exposures, a consultation may lead to specific actions, such as restricting use of or replacing water supplies; intensifying environmental sampling; restricting site access; or removing the contaminated material.

In addition, consultations may recommend additional public health actions, such as conducting health surveillance activities to evaluate exposure or trends in adverse health outcomes; conducting biological indicators of exposure studies to assess exposure; and providing health education for health care providers and community members. This concludes the health consultation process for this site, unless additional information is obtained by ATSDR which, in the Agency's opinion, indicates a need to revise or append the conclusions previously issued.

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HEALTH CONSULTATION

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Santa Cruz Harbor, Santa Cruz County, California

Prepared By:

California Department of Health Services
under Cooperative Agreement with the
Agency for Toxic Substances and Disease Registry

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Background and Statement of Issue

The California Department of Health Services (CDHS), under the cooperative agreement with the federal Agency for Toxic Substances and Disease Registry (ATSDR), was asked by the Environmental Health Services of the Santa Cruz County Health Services Agency (county health department), to assist the Monterey Bay Unified Air Pollution Control District (air district) in responding to neighborhood exposure and health concerns regarding the Santa Cruz port district's dredging activities. In this health consultation, CDHS will (1) review the environmental data, specifically the hydrogen sulfide (H_2S) monitoring conducted during the dredging operations for adherence to the dredging protocols and for public health impact and (2) review epidemiological research suggesting health impacts from H_2S at low levels. The health consultation also includes a summary of the health concerns CDHS staff heard as a part of their outreach effort and a thorough review of the available information such as complaint logs.

The agencies involved in the project and their responsibilities are listed below:

- Santa Cruz Port District (port district): the public authority that oversees the operation of the port.
- U.S. Army Corps of Engineers: beginning in 1982, they handled the dredging operations jointly with the harbor. They issue the permits needed to conduct the harbor dredging and beach rejuvenation.
- California Coastal Commission: the regulatory authority for issuing coastal permits and permit reviews.
- Monterey Bay National Sanctuary: provides consultation to the U.S. Army Corps of Engineers to avoid biological impacts from the dredging. Due to trout spawning habits, dredging can not occur in certain months.
- Regional Water Quality Control Board: the regulatory authority for issuing the dredging permits to the port district.
- Air district: the regulatory authority for air quality related to the dredging barge (combustion engine).
- California Air Resources Board (CARB): the regulatory authority for air quality for the State of California.
- County health department: the local authority for public health in Santa Cruz County.

The Santa Cruz Harbor is located near Murray-Eaton Bridge in the City and County of Santa Cruz, California (Appendix B, Figure 1). The dredging areas include the upper harbor and the lower harbor, and the discharge occurs on Twin Lakes Beach to Black's Point for about ½ mile (Appendix B, Figure 1). Twin Lakes Beach and Black's Point are both popular destinations for beach visitors (Appendix D, Photos 1 and 2). The Santa Cruz harbor contains a popular restaurant, several stores that cater to the beach crowd, as well as a boat launch and marina. The Coast Guard has a permanent dock in the harbor from which they patrol and perform rescue operations along the coast from Moss Landing to Half Moon Bay. The harbor is one of several harbors along the West Coast considered a safe haven for distressed boats. The harbor has space for approximately 1,000 wet-berthed and 275 dry-stored vessels. Roughly 15% of these vessels are commercial fishing boats, 35% are recreational power boats, and 50% are recreational sailboats (8).

East Cliff Drive is the street that divides the beaches from the nearby residential community (Appendix D, Photo 3). Some of the houses along East Cliff Drive are owner occupied while others are rentals. A lift station for the sewer line is located on the corner of Twin Lakes Beach where East Cliff Drive bends (Appendix D, Photo 4). As you travel south along East Cliff Drive, a stagnant lake (Schwan Lake) occupies a low lying area between Twin Lakes Beach and Black's Point (Appendix B, Figure 1). Approximately 350 people live within 3 miles of the beaches (9). The residential community's boundary is North from East Cliff Drive to Carmel Street and East from Ninth Avenue to Lake Avenue.

Dredging Operations

The dredging program has been in existence since the harbor's dedication in 1964. In the early years, dredging was accomplished by the U.S. Army Corps of Engineers through contracts with private dredging operators. Beginning in 1982, a joint venture between the U.S. Army Corps of Engineers and the port district acquired the dredge "Seabright" for 3.2 million dollars (Appendix D, Photo 5). The port district now operates the dredging program (10). The material from the upper harbor is deposited on the near shore; the lower harbor material is used as a source of beach replenishment at Twin Lakes Beach (Appendix B, Figure 2). If beach replenishment did not occur; East Cliff Drive, the underground utilities, and even nearby homes may be in danger of being lost (Appendix D, Photo 6).

The dredging activity is conducted annually. It usually begins in early October and continues through the storm months and into April. In order for the harbor to operate, the dredging program maintains a designed depth of 20 feet in the harbor entrance at low tide. According to the port district, if the dredging program failed to operate for just two days during a strong storm and coupled with the sand's littoral drift, the entrance could be closed and would prevent the safe passage of all vessels (10) (Appendix D, Photo 7). The littoral drift includes the process of moving eroding bluffs or streams to shorelines miles away.

The dredged material is a combination of sand, natural organic plant life, and seawater. During a typical year, the port district will remove as much as 206,000 cubic yards of dredge material (11). The dredging process works much the same as a vacuum cleaner. An 18-inch diameter nozzle containing one of two mechanisms (rotating cutter head or snorkel head) is used to suck up the material from the harbor's bottom. When the cutter head attachment is used, the rotating cutter head will act like an excavator and the material is then sent up through the nozzle. The snorkel head employs the use of water jets and a chopper component. The water jets will disturb the debris and the chopper reduces the material down to a slurry consistency. In both cases, the dredged material will pass through the suction head and is discharged via the dredge discharge line. When the dredge material is disposed on the beach (Appendix B, Figure 2), the area around the discharge is demarcated to keep visitors away from getting too close to the dredging activities (Appendix D, Photos 8, 9, and 10). In 2005, a permanent sign was placed at the edge of the beach along East Cliff Drive to inform beach visitors of the dredging activities (Appendix D, Photo 11).

According to the Santa Cruz port district's website, the dredging process could result in odors from the dredged material in the immediate proximity of the discharge point. These odors are

created by the natural decay of aquatic plant life and are principally due to the "minute" presence of Hydrogen Sulfide (H_2S) gas, a natural byproduct of the decay process (12).

Community Concerns

Since the mid-1990s, some tourists and residents in the neighborhood adjacent to the Santa Cruz Harbor have voiced concerns about the odor released as a result of the on-shore disposal of dredged material. Some community members are concerned about possible adverse health effects resulting from H_2S exposure related to the dredging operations. Some community members stated that they have been concerned for several years; while other community members stated that they do not have health or exposure concerns related to H_2S.

CDHS sought to understand the nature of community health concerns by communicating with residents in the area. CDHS reached out to the community members in August and September 2006 by telephone, e-mail, and in person.

In addition, CDHS reviewed some complaint logs that captured complaints received by the port district and air district. It was brought to CDHS' attention the air district kept a working logbook of the community health concerns regarding the dredging. However, CDHS did not compare the logbook against the sampling data because the number of concerns could not be verified or considered complete. The air district mentioned to CDHS that they did not have a complete set of the community's concerns for various reasons. CDHS felt if an analysis was performed, looking for a correlation between health concerns and the H_2S monitoring data, the results would not show a true correlation between the two data sets because the health concerns are incomplete. CDHS reviewed the complaint logs in order to understand the overall nature of the community's health concerns. The

Hydrogen Sulfide (H_2S)

H_2S is a colorless gas with the characteristic odor of rotten eggs. It can occur naturally, such as in volcanoes, swamps, stagnant bodies of water, and in crude petroleum and natural gas. It can also occur as a result of manmade processes such as municipal sewer and sewage treatment plants (1). Releases of H_2S from these facilities often affect the surrounding communities.

Acute Toxicity

Exposure to very high concentrations of hydrogen sulfide (H_2S) (above or equal to 500,000 parts per billion (ppb)), even briefly, can result in cessation of breathing, pulmonary edema (fluid filling the lungs instead of air), loss of consciousness, and death (1). Most lethal cases have occurred in confined spaces (such as sewers, tanks, sludge plants, and animal processing plants), which facilitated the buildup of concentrations.

Health Effects of Hydrogen Sulfide

- A review of 26 studies found the average odor detection threshold ranged between 0.007 ppb and 1,400 ppb. The geometric mean of these studies was 8 ppb (2).
- Acute H_2S exposure has been found to cause nausea, headaches, disturbed equilibrium, poor memory, fatigue, dizziness, neurobehavioral changes, olfactory paralysis, loss of consciousness, and convulsions (1).
- There may be permanent or persistent neurological effects following high exposures such as cognitive and motor impairments, including vision and memory impairment, rigid movements, tremor, ataxia, psychosis, abnormal learning, and motor function (1).
- H_2S is a known eye irritant (1).
- Cardiovascular effects have been noted after high level H_2S exposures, including blood pressure increases and tachycardia (abnormal beating of the heart) (1).
- Gastrointestinal, hematological, musculoskeletal, hepatic, and dermal effects have been noted at varying exposure levels.
- No human data was available on endocrine, body weight, immunological effects, or developmental effects.

logs of health complaints reviewed by CDHS covered the time periods for dredging seasons 2003-2004 and 2004-2005, and the months of January and May 2006.

Community concerns related to H_2S were reported by a variety of individuals, including residents, visitors to the beach, and some who made anonymous complaints. Community members reported health concerns such as red and burning eyes, blurry vision, conjunctivitis, headaches, agitation and shakiness, heart palpitations, dizziness, nausea, vomiting, bloody nose, sinus infections, worsening asthma, and being mentally "foggy." One person reported having a metallic taste in their mouth. Some were concerned that infants and children (i.e., sensitive populations) who play on the beach might be exposed to H_2S or other chemicals related to the dredging. Some community members were concerned when they saw "clay balls" on the beach near the discharge pipe. They were concerned that exposure to H_2S was affecting their health in the short and long term.

Some residents stated that although the smell "is not pleasant," they had no health concerns. One resident classified the odor as a nuisance and typically dealt with it by shutting her doors and windows, but had no health concerns.

Some community members were concerned about the effect of exposure to H_2S on their quality of life. Community members stated that the odor is "like rotten celery or lettuce" and "like an outhouse." Some community members who reside near the dredging operation report that once the odor enters their home it remains there, even after dredging has stopped for the day. In past dredging seasons, some community members have had to adjust their living habits such as remaining indoors with their windows and doors shut to avoid the odor, making arrangements to leave their homes during dredging operations for hours or days at a time, and selling their homes. Some community members were concerned about the impact of H_2S odors on recreation at Twin Lakes Beach.

Some of the community members indicated that they had been examined by Dr. Kaye Kilburn of the University of Southern California. As part of the examination they were given a battery of neurological examinations. They said that Dr. Kilburn had told them that they had permanent damage to their neurological system due to the exposure to H_2S (Community Resident, Santa Cruz, personal communication August, 16, 2006). Dr. Kilburn indicated to his patients that by continuing to live near the dredging activities there, they would be putting themselves at a greater risk.

Community members were concerned about the contents of the dredging when it originates from the upper harbor. They say this dredged material is black, and they are concerned about exposure to chemicals such as pesticides, heavy metals, and chlordane. Community members were also concerned about being exposed to the burning of diesel fuel from the dredging boat.

Some environmental concerns were not related to dredging operations. Some community members were concerned about H_2S exposure as a result of the sewer pump station, which they believe is operating beyond maximum capacity and may be leaking. Community members were also concerned about exposure to arsenic in soot generated from the burning of chemically-treated wood at the beach. One community member was concerned about the lack of a barrier

separating the beach from East Cliff Drive, stating that it represented a physical injury hazard. Finally, one community member expressed concerns about exposure to diesel coming from trucks making deliveries to the harbor.

Actions to Address the Community Concerns

Over the years a number of activities have been undertaken by various agencies to address community concerns and in some cases, were conducted under order.

- In April 1997, the port district conducted air sampling (42 samples) for 23 sulfur-containing compounds, and only H_2S was detected. Since the sampling event, the port district has focused on H_2S as the primary contaminant of concern (13).

- In April 2004, environmental samples consisting of sand, water, and air were taken at the discharge point on Twin Lakes Beach and 200 yards upcoast at Seabright Beach. The air district took an air sample the day after the discharge was discontinued and a sand sample was taken from the area of discharge on the beach one week after the discharge was stopped. The county health department sampled the sand and water. Metals were found elevated in one of the two dredge (sand) samples but below EPA soil screening levels. No organics were found elevated. The sand sample taken one week later did not contain elevated metals. Two water samples were taken from the discharge pipe at one hour intervals. The first sample had similar characteristics to the reference sample (ocean water); the second sample contained elevated metals. In both samples, organic compounds were very low to non-detect. Air samples were analyzed for arsenic, copper, chromium, sodium, and chloride. Arsenic was not detected in the samples. Metals were not elevated and were well below the recommended California Environmental Protection Agency's screening levels (14).

- In July 2004, the county health department compared the levels of contaminants in the upper harbor sediment with EPA soil screening levels. None of the chemicals measured in the sediment exceeded the soil screening value which is established based on incidental ingestion of soil while playing/working around it (15).

- In July 2004, the air district sampled fire rings and pits at seven Santa Cruz beaches and one inland state park. Most of the samples (soil/sand) showed levels of arsenic below the detection limit. The concentrations for chrome and copper were above the laboratory detection limits. In August 2006, the air district sampled the fire pits to look for signs of chemically treated wood being used in the bonfires. Chrome, copper, and arsenic are components used in the process to chemically treated wood. This treated wood is still used in construction materials and is readily available for bonfires (16).

- In April 2005, the county health department analyzed the "clay balls" found on the beach. They determined the three samples to be native soil based on the level of five metals detected in the material (17).

- In October 2005, the air district took air and sediment samples during the dredging of material from the upper harbor. The air samples were analyzed for metals, and the sediment

samples were sampled for metals, polycyclic aromatic hydrocarbons (PAHs), and pesticides. The air district's evaluation of the analytical data concluded that there was no indication of sediment contaminants from the upper harbor dredge discharge becoming airborne and traveling downwind toward the residential community (15).

- February 2, 2006, the Santa Cruz Public Works (SCPW) department performed hydrogen sulfide monitoring at the lift station (wet well hatch) and at eight manholes along the East Cliff Street Drive sewer line. This effort was undertaken to assist the air district's efforts to respond to nearby residents' odor and health concerns. The hydrogen sulfide concentration decreased from 21 ppb to 0 ppb as the distance increased away from the lift station (wet well hatch). The concentrations outside the manholes ranged from 0 ppb to 139 ppb; concentrations taken inside the manholes ranged between 2 ppb to 2,100 ppb. In an effort to lower the manholes' outside concentrations, SCPW staff installed a bioteg biofilter in one of the manholes on March 5, 2006. After one year of service, SCPW staff determined the bioteg biofilter could not adequately lower the concentrations; as a result, they stopped using the biofilter (18). More recently, the SCPW in coordination with the harbor district began treating the lift station located on the harbor's property with an agent called Bioxide. Bioxide is a non-hazardous biological process that both removes dissolved hydrogen sulfide and prevents its formation through the addition of nitrate oxygen (19). Due to lift station's up-gradient position, the Bioxide would be able to effectively treat the odor at the lift station as well as the manholes along East Cliff Drive. SCPW picked Bioxide because they have been using it at the lift station located on East Cliff Drive with success for the past least five years. SCPW is also using Bioxide in sewer lines throughout the Santa Cruz County. (Amy Gross and Dan Chua, County of Santa Cruz, Public Works Department, personal communication May 2007).

- In May 2006, CARB conducted air monitoring for H_2S and air sampling for 23 volatile organic compounds (VOCs) at various outside locations and one indoor location. CDHS reviewed this data for human health implications. CDHS found the H_2S levels to be low and posed no health hazard for that air monitoring event. The VOCs levels measured in indoor and outdoor air were within typical levels (20).

Summary of the Air Monitoring Dredging Protocols

During the last three dredging seasons, under the direction and orders of the air district, the port district performed H_2S monitoring. A protocol for responding to the H_2S readings was developed in October 2003 with the assistance of the air district as well as the community (Appendix C, Table 1) (21). The protocol was revised on October 18, 2005 for the 2005-2006 season. The protocol includes language stating beach zone discharge will terminate whenever the H_2S meter is not functioning properly. After such termination, beach zone discharge may continue once the monitor is placed back in service. The protocol includes levels of H_2S that will trigger a work stoppage and typical "emergency conditions" days. The emergency conditions occur when the harbor has to deposit dredge sediments onto the beach zone because 1) dredging is necessary in order to ensure sufficient depth at the harbor's entrance, thus allowing a safe passage for the boats entering the harbor channel, and 2) the offshore outfall is incapacitated. The field crew must notify the air district of the intention to conduct emergency beach discharge as soon as the

decision is made (see Appendix C, Table 1 for action levels during emergency conditions days). Also shown in Table 1 are the distances from the air monitoring station to the end of the discharge pipe. The protocols state that the H_2S monitoring should take place downwind; however, an optimal distance is not mentioned. The H_2S protocols also state that if the action levels are exceeded the dredging must stop. The action levels that were used for the three dredging seasons are described in greater detail below.

2003-2004 Dredging Season

The protocol for the 2003-2004 dredging season was created in October 2003. The protocol states that the beach discharge will terminate whenever two consecutive 2-minute readings of 10 parts per billion (ppb) over background or 15 ppb absolute are recorded. If an observer detects the presence of H_2S odor, the harbor will switch the termination to four 1-minute readings of 10 ppb over background, and if 15 ppb absolute is reached, the dredging team will have to shut down the operation (21). The protocol did not state that dredging was to stop for the day.

There were no emergency condition days during the 2003-2004 dredging season.

CDHS observed the following sampling trends for monitoring periodicity during the 2003-2004 dredging season (Appendix B, Figure 4):

- One sample per minute was taken on the following dates: all sampling days from October 28-November 6, 2003, and April 27-May 6, 2004.
- One sample every 2 minutes was taken on the following dates: all sampling days from November 7-December 18, 2003; January 7, 8, 20, and 21, 2004; and February 3-April 1, 2004.
- On January 22, 2004, the port took one sample every 5 minutes. This was the only day during the year that samples were taken at this interval.
- On April 19-22 and 26, 2004, the sampling intervals varied between one sample per minute and one every 2 minutes.

(CDHS did not try to confirm that the protocol was followed vis-à-vis the monitoring periodicity.)

2004-2005 Dredging Season

The port district used the protocol that was created in October 2003 for the 2004-2005 dredging season (21). The protocol's action level can be located in the paragraph on the previous page or in Appendix C, Table 1.

There were no emergency condition days during the 2004-2005 dredging season.

CDHS observed the following trends for the monitoring periodicity during the 2004-2005 dredging season (Appendix B, Figure 5):

- One sample per minute was taken on the following date: December 7, 2004.

- One sample every two minutes was taken on the following dates: all sampling days from November 17-December 6, 2004; December 13, 14, 21, 29 and 30, 2004; January 20, 26 and 30, 2005; March 15, 17, 28, and 29, 2005; and April 4, 6, 18, 20, and 25-28, 2005.
- On January 5, 2005, one sample (3:55 p.m. to 4:01 p.m.) lasted for 6 minutes.
- The sampling intervals taken in 2005 varied between one sample per minute and one sample per 2 minutes on January 18, 19, 24, 25, and 27; on March 3, 9, and 10; and on April 15 and 19.

(CDHS did not try to confirm that the protocol was followed vis-à-vis the monitoring periodicity.)

2005-2006 Dredging Season

The protocol for the 2005-2006 dredging season was created on October 18, 2005 (21). The protocol states the field crew must stop all dredging activities when they encounter four consecutive one-minute readings of 15 ppb or more, any single reading of 60 ppb or if the H_2S monitor is removed from the service (Appendix C, Table 1); a shutdown can also occur if the monitor exceeds the rolling one-hour average of 30 ppb. According to the protocol, if the meter encounters four consecutive readings above or equal to 15 ppb or a single reading of 60 ppb, the crew must discontinue beach dredging and may resume the dredging activities the following day once the operation is modified, to reduce H_2S limits to allowable limits. If the beach zone discharge is stopped as a result of either of the two situations mentioned earlier, the monitor shall continue to take readings until the readings are below 15 ppb and stay there for at least 10 minutes. If the beach discharge is terminated due to exceeding the H_2S levels, the port district must contact the air district by fax, informing them of the termination, and include the following details: the readings that trigged the termination, the times the levels were exceeded, the time when beach discharge flow actually stopped, and all readings occurring until they returned to below 15 ppb.

Guidelines

Various agencies have established specifications for guidance to help protect the public and workers from excess exposure to chemicals, including hydrogen sulfide (H_2S).

These guidelines are estimates of daily exposure to the human population (including sensitive subgroups), below which noncancer adverse health effects are unlikely to occur.

- The California Office of Environmental Health Hazard Assessment (OEHHA) acute reference exposure level (REL) for H_2S is 30 parts per billion (ppb) (2). The acute REL is set based a one hour exposure on an intermittent basis.
- The ATSDR Minimal Risk Level (MRL) for intermediate duration exposure to H_2S is 20 ppb (1). This is designed for contact that is at least 14 days in length and less than 1 year.
- The OEHHA chronic REL for H_2S is 8 ppb (4). The chronic REL is based on a lifetime exposure.
- The U.S. Environmental Protection Agency has set a chronic inhalation reference concentration (RfC) for chronic exposure to H_2S of 1 ppb (6). The RfC is set based on continuous exposure for a lifetime.
- The World Health Organization recommends a more stringent ceiling of 5 ppb, 30-minute average as to avoid an odor nuisance (7).

As mentioned in the 2003-2004 and 2004-2005 protocols, the emergency conditions days take place when the port district has to dispose of the dredge material into the beach zone and the

wind direction is onshore (21). In the 2005-2006 protocol, it states that when an emergency beach discharge is needed, "the port district must contact the air district by fax as soon as the decision has been made explaining the intention and rationale to conduct the beach discharge and the anticipated period of said discharge (21)." The port district must also notify the public of the intention to conduct emergency beach discharge as soon as the decision is made. They must "post the information on their website and they are required to give individual notice to any member who requests such a notice" (21). During emergency condition days, the H_2S measurements should not exceed a one hour average of 30 ppb. Emergency conditions days occurred 13 times during the 2005-2006 dredging season: December 21 and 22, 2005; January 3, 4, 5, 6, 7, and 8, 2006, and April 20, 24, 25, 26, and 27, 2006.

During the 2005-2006 dredging season, the port district operated under a new protocol that called for sampling once a minute. CDHS observed the following trend for the monitoring periodicity during the 2005-2006 dredging season (Appendix B, Figure 6):

- In the 2005-2006 dredging season, samples were taken once per minute during the sampling days with the exception of the following dates: December 1, 2005; January 11 and 17, 2006; March 16, 2006; and May 10, 2006.
- During the days mentioned above, the samples were a mixture of one sample per minute and two samples per minute.

In January 2006, the port district asked the air district board to allow them to continue dredging under the emergency variance with "relief from the protocol's downwind emission limit" of an average hourly H_2S reading of 30 ppb. The reason for the need for the variance was given as "the depositing of sand on the beach is necessary to adequately prevent damage to East Cliff Drive." A hearing board of the air district approved the "emergency variance" on January 9, 2006 (22). The variance was effective from January 4-19, 2006. Under this variance, the emissions were to stop for the day if one reading of 1,000 ppb occurred. According to the port district, they operated under "emergency variance" on January 9 and 10, 2006 (22).

Nearest Potentially Impacted Persons

The monitoring occurs on the beach but not at the point of discharge so the emissions have already been diluted to some extent when they are measured by the monitor. A port district employee is constantly monitoring the hydrogen sulfide (H_2S) levels at the monitoring station and thus would be the closest person to the discharge. CDHS talked with the staff person who worked at the monitoring station in 2005-2006 and he reported no ill effects; however, CDHS noted in the field notes some of the workers used words like "mild odor," "smelly odor too strong," "strong odor throughout the day," and "odor is present."

The beach is not closed during these discharges, thus anyone may walk near the discharge area (Appendix B, Photo 2). It is not clear how the emissions measured downwind and some distance from the discharge pipe would reflect H_2S levels that individuals may experience while walking on the beach as they may be walking upwind or sideways to the wind direction of the discharge.

The nearest residents are located several hundred feet farther from the discharge point than is the monitoring location. Depending on the location of the resident, the dilution of the H_2S could be less than a ten fold order of magnitude (3).

There is limited information about exposure where people are located, i.e., on the beach but not at the monitoring station, in their front yards, etc. In May 2006, CARB monitored for H_2S briefly at several places located away from the beach and did not find levels above 9 ppb. The dredging discharge on the beach and the H_2S levels at the monitoring station on the beach were also very low (less than 15 ppb) (5). This implies that if levels are kept low on the beach, the nearest neighbors will not be affected by the discharge.

In April 2006, the port district asked the air district to allow them to continue using the beach for the dredge material even though the offshore disposal location was not incapacitated and the wind was onshore. The port district stated that the request was due to "an unusual current is moving sand from the underwater outfall area into the mouth of the harbor." A hearing board of the district granted the "emergency variance" on April 17, 2006 (23). The variance was effective April 4-19, 2006. Under this variance, the protocol's limit of a 30 ppb hour average was supposed to be followed. According to the port district, they operated under "emergency variance" on April 5, 6, 10, 12, 13, 17, and 18, 2006 (Alan Romeo, Santa Cruz Port District, personal communication, March 13, 2007).

Discussion

In this section, CDHS will evaluate the port district's adherence to the action levels in the protocols and screen the H_2S monitoring data for possible health concerns. Figures 4-6 in Appendix B depict the calendar months when dredging occurred in the past 3 years. For each day when monitoring occurred, the following information is provided:

- the number of air monitoring readings over 30 ppb;
- the number of air monitoring readings that occurred that day;
- the highest concentration of H_2S detected that day;
- the days when the port district operated under discretionary beach discharge;
- the days when the port district operated under emergency conditions; and,
- the days when the port district operated under emergency variance.

Based on a review of the air monitoring data and the protocols, the figures show CDHS' evaluation of the port district's response when exceedances of the applicable action levels occurred. The information presented in the next section, Adherence to Protocols, is also depicted in Appendix B, Figures 4-6.

Adherence to Protocols

Based on current toxicological information about H_2S, CDHS has found the action levels for the discretionary beach discharge days to be protective of public health. CDHS supports the 2005-2006 "emergency beach discharge" action levels as protective of public health for those needed situations. The action level (not to exceed 1,000 ppb) used for the January 2006 emergency variance days is not necessarily protective of public health. It is preferred that the dredging occur in the discretionary discharge mode.

Because CDHS thinks the action levels are protective of public health, CDHS reviewed the H_2S air monitoring data along with the Santa Cruz Port District Dredge Monitor Logs (field notes) to ascertain if the protocol was followed in the field. If the protocol is not followed, it undermines the public agencies overseeing the beach dredging activities and the port district that has the responsibility to adhere to the protocols, and it makes meaningless any review and approval of the action levels by an agency such as CDHS. Additionally, when the protocols are not followed, there is a need to look at the air releases to determine whether a health impact could have occurred.

It should be noted the protocol changed significantly in 2005-2006 to better clarify the actions that were supposed to be taken after an action level was exceeded. For instance, in the first protocol (2003-2004 and 2004-2005), the dredging was supposed to stop after "two consecutive 2-minute readings, or four 1-minute readings of 10 ppb over background or 15 ppb absolute (21)." It was not explicitly stated in the 2003-2004 and 2004-2005 protocols that dredging was supposed to cease for the day. Because of the lack of clarity on this issue, beach disposal did resume on some days in 2003-2004 and 2004-2005 when the action levels were exceeded. In addition, the port district encountered readings that were considered to be anomalies. An anomaly is an unexpected high spike in the data with no accompanying shoulders on either side of the spike. In the 2005-2006 protocol, wording was added to clarify that work was to cease for the day if the action level is exceeded (21). Even when beach disposal was terminated, CDHS recognized that it takes a few minutes for the discharge pipe to empty after the dredging has stopped, and second, once the flow stops, the odorous materials already on the beach continues to off gas for several minutes before the odor is exhausted. Thus in the review of the data for the 2003-2004 and 2004-2005 dredging seasons, CDHS took this lag time into account[1].

CDHS observed that the field notes from the past three dredging seasons did not distinguish when the emergency condition or emergency variance days went into effect. The inclusion of this step would have been helpful in determining how CDHS would examine the data for those days.

2003-2004

According to CDHS' review of the air monitoring data and the field notes, the action levels were exceeded on the following days: January 7 and 8, 2004; February 19, 2004; March 17, 2004; and April 21 and 27, 2004 (Appendix B, Figure 4).

- On March 17, 2004, the action level was exceeded and the beach disposal was discontinued.
- On February 19, 2004; April 21 and 27, 2004, beach disposal did not cease for the day even though the beach discharge action level had been exceeded. However, due to the protocol's lack of clarity on shutting down, the port district followed the protocol.
- On January 7 and 8, 2004, the action level was exceeded, beach disposal stopped but started again. A subsequent exceedance occurred and beach disposal was stopped for the day.

2004-2005

According to CDHS' review of the air monitoring data and the field notes, the action levels were exceeded on the following days: November 22 and 23, 2004; December 6, 14, 21, and 30, 2004; January 5, 6, 10, 12, 13, 18, 19, 24, and 25, 2005; March 3, 9, 10, and 14, 2005; and April 4 and 5, 2005 (Appendix B, Figure 5).

[1] For the first protocol (2003-2004 and 2004-2005 dredging seasons), CDHS determined the port district followed the protocol if it looked like they stopped dredging within 10-20 minutes of exceeding the action level. CDHS determined that the port district followed the protocol if they clearly stopped dredging within 10-20 minutes of exceeding the action level and the emissions went to background, i.e., not spikes, and later restarted. However, if they exceeded the action levels and continued dredging past the 20 minutes, and did not stop, that was determined by CDHS to be a case of "protocol not followed."

- On December 14, 2004, and January 12, 2005, the action level was exceeded and the beach disposal stopped.
- On November 23, 2004; December 6 and 21, 2004; January 5, 6, 10, 19, and 24, 2005; March 9, 10, and 14, 2005; and April 4 and 5, 2005, beach disposal did not cease for the day even though the action level had been exceeded. However, due to the protocol's lack of clarity on shutting down, the port district followed the protocol.
- On November 22, 2004; December 30, 2004; January 13, 18, and 25, 2005; and March 3, 2005, the action level was exceeded, beach disposal stopped, but started again. A subsequent exceedance occurred and beach disposal was stopped for the day.

2005-2006

According to CDHS' review of the air monitoring data and the field notes, the action levels were exceeded on the following days: December 7, 19, 20, and 29, 2005; January 11, 12, 16-18, and 25, 2006; February 1, 6, and 27, 2006; March 1, 2, 6-8, 13-16, 20, 21, and 27-30 2006; April 3, 4, and 19, 2006; and May 2, 3, 16, and 18, 2006.

- On December 7, 2005, offshore dredging stopped for the day when the action level was exceeded.
- December 19, and 20, 2005; January 11, 12, 16-18, and 25, 2006; February 1, 6, and 27, 2006; March 1, 2, 6-8, 13-16, 20, 21, and 27, 28, and 30, 2006; April 3, 4, and 19, 2006; May 2, 3, 10, 16, and 18, 2006, the action levels were exceeded and beach disposal was stopped for the day.
- On December 29, 2005; March 29, 2006 and May 10, 2006, the beach disposal did not cease for the day even though the action level was exceeded.

During the 2005-2006 dredging season, the port district operated under emergency conditions allowing discharge to the beach on the following days: December 21and 22, 2005; January 3-8, 2006; and April 20, and 24-27, 2006.

- On January 8, 2006, the port district exceeded the 1-hour rolling average of 30 ppb and beach disposal ended for the day.
- On December 22, 2005 and January 5 and 7, 2006, the port district exceeded the 1-hour rolling average of 30 ppb and beach disposal was not stopped for the day.
- On December 21, 2005; January 3, 4and 6, 2006; April 20, and 24-27, 2006, the port district did not exceed the 1-hour rolling average of 30 ppb.

During the 2005-2006 dredging season, the port district claimed an emergency variance on the following days: January 9 and 10, 2006; April 5, 6, 10, 12, 13, 17 and 18, 2006.

- On January 9, 2006, there was at least one reading above 1,000 ppb action level and beach disposal was not stopped.
- On January 10, 2006, there were no readings above the 1,000 ppb action level.
- On April 5, 6, 10, 12, 13, 17 and 18, 2006, the readings did not exceed the rolling 1-hour average of 30 ppb.

In summary, the port district and its dredging operators exceeded the action levels while conducting the dredging operations on the beach. When this occurred, they did not always discontinue beach disposal. In the first 2 years of monitoring, the work would sometimes cease when the discretionary action level had been exceeded but work would start again later in the day. Doing this was not a violation of the protocol, because the October 2003 protocol states "after discretionary beach discharge, beach zone discharge may be resumed when either the dredge operation is modified so that emission limits will be complied with …" The protocol did not state that the beach disposal needed to stop for the day.

During the 2003-2005 dredging seasons, the air district indicated to CDHS that they were unaware of the aggressive dredging tactics that were employed during that time (Ed Kendig, personal communication, December 4, 2006). According to the 2003-2004 and 2004-2005 protocol, the air district received the H_2S data one month after the monitoring has passed. Thus, the air district did not have real-time understanding of the emissions happening at the beach. According to the air district supervisor, "It was common practice during those first 2 years, for the beach observer [air monitoring person] to phone the air district's inspector whenever they shut down, and the inspector noted those occasions" (Ed Kendig, personal communication, December 8, 2006). As indicated by the air district's Compliance Manager, the air district's inspectors reviewed the following information in order to determine compliance: "the monitor data logs and the beach observer logs [field notes], and their own notes from their nearly continuous presence during the dredging."

For the 2003-2004 and 2004-2005 dredging seasons, the air district reached the conclusion that during those 2 years, the harbor had in fact shut down when they were supposed to under the protocol and that there were no violations of that requirement (Ed Kendig, personal communication, December 8, 2006). It should be noted the inspector notes for dredging seasons 2003-2004 and 2004-2005 were not available for CDHS review. CDHS has learned it is standard procedure for the air district to discard the inspector's notes when the particular job assignment is completed.

The protocol was modified for the 2005-2006 season to clarify that work was to cease for the day and immediate notification for the air district is required when the protocol is exceeded. According to the CDHS' review, the port district followed the protocols except for December 29, 2005; March 29, 2006 and May 10, 2006. On these days, the beach disposal did not stop even though the port district exceeded the action level; violating the protocol.

The port district under emergency conditions did not follow the protocol on December 22, 2005 and January 5 and 7, 2006. One these days, the port district exceeded the 1-hour rolling average 30 ppb and beach disposal did not stop for the day.

The port district under emergency variances did not follow the protocol on January 9, 2006. On this day, the port district had at least one reading above 1,000 ppb and beach disposal did not stop for the day.

In the next section, CDHS examines the H_2S levels for health impact.

Screening of Hydrogen Sulfide Monitoring Data for Health Impact

CDHS screened the dredging data using the OEHHA acute reference exposure level (REL) of 30 ppb (see text box on page 8). The acute REL was established for a 1-hour exposure (2). CDHS chose the acute REL screening level as the exposure scenario occurring at the beach. Given the periodicity of the discharge to the beach and the pattern of emissions (see below for more detail), CDHS analyzed the H_2S dredging data for the past 3 years. For each year, CDHS searched for trends in the data. In Appendix C, Table 2, the air monitoring data is shown for the days when concentration's exceeded the acute REL. In Appendix E, the air monitoring data is shown in graph form for each day when the acute REL was exceeded for an individual monitoring point.

2003-2004 Dredging Season

The 2003-2004 dredging season lasted 7 months, from October 2003 to April 2004. Reviewing the 2003-2004 dredging calendar (Appendix B, Figure 4), there was a total of 47 calendar days when dredging occurred. During the dredging season, a total of 9,214 samples were taken; 41 of those samples exceeded the 30 ppb screening value. The H_2S levels measured on the beach exceeded the acute REL 0.4% of the samples during the 7-month sampling season. Depending on the length of the measurement being either 1-sample every minute or every 2 minutes, H_2S concentrations exceeded the acute REL for a total of 34 to 68 minutes during the 2003-2004 dredging season.

2004-2005 Dredging Season

The 2004-2005 dredging season lasted 5 months, from November 2004 to April 2005. Reviewing the 2004-2005 dredging calendar (Appendix B, Figure 5), there was a total of 45 calendar days when any dredging occurred. A total of 6,935 samples were taken; 303 of those samples were above the 30 ppb screening value. H_2S levels measured at the beach exceeded the acute reference exposure level (REL) 4.4% of the samples during the 5-month period. Depending on the length of the measurement being either 1-sample every minute or every 2 minutes, H_2S concentrations exceeded the acute REL for a total of 294 to 588 minutes dredging 2004-2005 dredging season.

2005-2006 Dredging Season

The 2005-2006 dredging season lasted 6 months, from December 2005 to May 2006. Reviewing the 2005-2006 dredging calendar (Appendix B, Figure 6), there was a total of 91 calendar days when dredging occurred. In the 2005-2006 dredging season, there was a total of 13 emergency condition days and six emergency variance days. These days were due to an unusually heavy rainy season that occurred during the dredging season. The port district collected a total of 25,303 samples; 552 of those samples exceeded the 30 ppb screening value. The H_2S levels measured at the beach exceeded the acute REL 2.2% of the samples during the 6-month sampling period. Depending on the measurement taken, H_2S concentrations exceeded the acute REL for a total of 549 to 1,098 minutes during the 2005-2006 dredging season.

Overview of the Santa Cruz Harbor Hydrogen Sulfide Monitoring, 2003-2006

As described above, emissions generated from the dredged material are usually very low. For instance 96.7% of the sampling points for the three years of dredging with discharge on the beach fell below 20 ppb (Appendix B, Figure 3). And 97.7% fell below the screening level of 30 ppb. Based on state and federal governmental standards, H_2S levels below 30 ppb would not be expected to cause adverse health effects.

It has been reported that some individuals can smell H_2S as low as 8.1 ppb. Smelling offensive odors is known to elicit health effects such as nausea and headaches. In fact, as a way to avoid the nuisance the WHO recommends a more stringent ceiling of 5ppm over a 30 minute average (7). In Amoore's 1985 report, he indicated that the odor perception threshold decreases with age. Recent studies suggest that 9 year olds may not be as sensitive as 15 year olds in odor identification (24); however, this may be partly explained by the results of another study in which children aged 8-14 had an odor sensitivity similar to that of young adults, but appeared not to have the capability of identifying the odors by name (25).

On several occasions, the levels averaged above the acute REL for periods of time greater than an hour: December 22, 2005 and January 5, 7, and 8, 2006. The acute REL was established based on a combination of odor objection and headaches that could occur around 30 ppb.

On certain instances the levels exceeded the screening value of 30 pbb for short periods of time. For example, there were three sampling points above 3,000 ppb. Also shown in Figure 3, there are 67 readings have occurred greater than 500 ppb.

Looking at the government standards it is not clear if levels between 30 ppb and 5,000 ppb for short periods of time may have an affect on an individual. For example, the American Industrial Hygiene Association established a level that could pose life threatening conditions at 100,000 ppb based on conjunctivitis, respiratory irritation, and unconsciousness in humans exposed to estimated concentrations of 200,000 to 300,000 ppb for 20 minutes to 1 hour.

Short-term exposures to high levels of H_2S have been associated with the following adverse health effects including:

- airway constriction in individuals who have asthma (26);
- decreased lung function (27);
- inability to smell gas (olfactory fatigue) (28, 29);
- eye irritation (keratoconjunctivitis, punctate corneal erosion, blepharospasm, lacrimation, and photophobia) (6, 30); and
- pulmonary edema and central nervous system effects including dizziness, nausea, headache, and physical collapse (31-33).

However, the length of time and the amount of H_2S that causes these adverse health impacts is not well documented. Many of these health effects were reported with occupational to near-lethal levels. The occupational exposure standard for H_2S for an 8-hour shift is 10,000 ppb (34).

The symptoms reportedly associated with the short-term high levels of exposure typically resolve after the exposure ceases. However, the neurological effects have been described as permanent or persistent. Thus, at this time, it is not possible to understand the neurological effects, if any, that may have resulted from the levels above 30 ppb that occasionally occurred with discharge to the beach. In addition to not-having a clear dose-response understanding for the emissions measured on the beach, it is unclear what the levels might have been for beach visitors or nearest neighbors. Dose-response is the idea that a chemical can be harmless in small quantities, but it can cause illness in large amounts. The scientific literature describing low-level H_2S exposures is further described in the next section.

Community Health Studies

Preliminary Studies of the Effects of Hydrogen Sulfide on Communities/People Exposed to Low Levels of Hydrogen Sulfide

Though there is some understanding of the effects (even without a dose-response understanding) of acute exposures to H_2S, relatively little is known about the health effects of intermittent and long-term, low-level exposures to communities residing next to sources of H_2S. The following section describes a few research studies of communities/people exposed to low-level H_2S. The findings of research studies such as these may lead to a confirmation or a reevaluation of the current standards and guidelines for occupational and environmental exposures to H_2S.

Respiratory Effects

A series of studies in Finland examined persons living downwind from pulp and paper mills that release H_2S and related compounds (methyl mercaptan and dimethyl sulfides), often referred to as total reduced sulfur (TRS) compounds. Rates of eye, nasal and respiratory symptoms and headache in adults in two exposed communities compared with an unexposed community found elevated odds ratios for nasal symptoms and cough. Breathlessness or wheezing was also elevated, although not significantly. All three of the symptoms showed a dose-related trend, with greater occurrence of the symptoms in the more highly exposed areas. The mean and maximum exposures for H_2S, respectively, in the high exposure community were 2.9 ppb and 40 ppb, and 1.4 ppb and 16 ppb in the moderate exposure community. A study of children in these communities similarly found increases in nasal symptoms, eye symptoms, cough, and headache, although not at levels of statistical significance (35).

In a Finnish community with sulfur compound exposure close to a maximum 4-hour H_2S concentration of nearly 100 ppb, investigators found increases in ocular, respiratory, and neuropsychological symptoms (36). Subsequent investigation of daily exposure and symptom reporting in this community found dose-related increases in nasal and pharyngeal irritation across exposure levels of less than 7.2 ppb and more than 21.5 ppb (37).

Another Finnish study found significantly higher rates of cough, headache, and respiratory infections in a community with exposures to pulp mills compared to a reference community (38). Using total reduced sulfur as the exposure, of which two-thirds was estimated to be H_2S, investigators found intensity of respiratory symptoms to be higher on days of medium and high

exposure. The 24-hour average H_2S concentrations varied between 0 ppb and 40.2 ppb in the exposed community.

Another study using total reduced sulfur investigated the association between ambient H_2S exposure and respiratory-related hospitalizations in two Nebraska cities. Exposures were from a beef-slaughtering and leather tanning facility. An association was found between children's hospital visits for all respiratory disease (including asthma) and H_2S levels and total reduced sulfur levels the previous day. A similar association was noted between previous day's H_2S and asthma among adults. A high H_2S or TRS level was defined as a 30-minute rolling average of greater than or equal to 30 ppb (39).

A Canadian community with H_2S exposures from natural gas refineries was compared in a health survey with a demographically similar but unexposed community. Increased reported respiratory symptoms were found in the exposed group (28% vs.18% of children), although no differences in spirometric (the volume of air entering and leaving the lungs) values were found (40).

In 2001, Legator et al. compared two communities with chronic low-level exposure to H_2S to three reference communities with no known sources of H_2S. The two exposed communities were Odessa, Texas, with H_2S from wastewater in solar ponds, and Puna, Hawaii, with exposure from geothermal electricity generation. In Texas, air modeling found maximum 8-hour measurements of H_2S levels of 335-503 ppb a mile from the ponds, and annual average measurements of 7-27 ppb. In Hawaii, most hourly measurements were less than 1 ppb, although periodic releases of H_2S in the range of 200-500 ppb had been reported at times. Rates of respiratory symptoms were much higher in the exposed communities. However, results may have been affected by community concern, particularly among Odessa participants who were involved in a lawsuit.

A series of investigations in a New Zealand community with naturally-occurring geothermal H_2S examined hospitalization rates for respiratory illnesses within exposure zones of high, medium, and low H_2S exposure areas. Significant dose-response trends were found for diseases of the respiratory system generally, as well as for subgroupings of this category, including upper respiratory tract diseases and chronic obstructive pulmonary disease (41).

Neurological Effects

In the Finnish studies discussed earlier under the Respiratory Effects heading, all reports found increases in headaches or migraines among exposed compared to unexposed communities, although only a more recent study found the effect to reach statistical significance. In that study, exposed persons had 1.8 times the risk of headaches compared to the unexposed population over the preceding 12 months, after adjusting for differences in age, gender, smoking habit, history of allergic diseases, education, and marital status (38).

In the two Nebraska towns studied, H_2S did not appear to adversely affect performance on most neurobehavioral tests and the exposed community outperformed the referent community on a majority of tests. For two tests out of 21, a memory test and a test of grip strength, the exposed group scored lower, but not statistically significantly lower. According to the U.S.

Environmental Protection Agency (EPA), measured outdoor H_2S levels exceeded 1,000 ppb, 275 times over a 4-year period in the exposed Nebraska town (42).

The New Zealand investigation using data on hospitalizations found neurological outcomes to be the target organ grouping to be most highly affected by H_2S exposure (43). For diseases classified as of the nervous system and sense organs, significant elevations in incidence were noted in the exposed community compared to rates for the rest of New Zealand. For subcategories of neurological groupings and individual diseases, highly significant elevations were found for disorders of the central nervous system, peripheral nervous system, migraine, infant cerebral palsy, other conditions of the brain, mononeuritis (nerve inflammation) of the limbs, and mononeuritis multiplex (loss of sensory and motor function of peripheral nerves). A follow-up study of this population which divided the exposed community into low, medium, and high exposures found dose-related trends for diseases of the nervous system and sense organs; specifically central nervous system, disorders of the eye, and disorders of the ear (41).

Exposures in the New Zealand study were estimated in the low area as between 0 ppb - 30 ppb generally; the moderate area would be variable depending on whether the wind from the more highly exposed area blows in this direction, in which cases there may be concentrations of around 500 ppb; and in the high exposure area, H_2S samplers gave the highest concentrations of 320 ppb and 800 ppb, with one “hot spot” estimated to be 2500 ppb (44).

A series of investigations conducted in the United States, used a neurological battery of tests have been performed on patients with exposure to H_2S, led by Dr. Kaye Kilburn. In order to evaluate neurological abnormalities in patients with environmental or occupational exposures to chemicals that could cause neurological effects, Dr. Kilburn and another investigator created an equation by which to predict expected individual scores based on factors such as a person’s age, sex, and educational level (45). In particular, as damage to nervous system by many chemicals can result in effects similar to aging, accounting for age is critical in estimating expected test performance. The comparison group of persons was recruited from voter registration rolls from three areas in the United States with no evidence of chemical contamination in different states and matched for sex, age, and years of education with the exposed persons. A screening questionnaire was used to exclude persons with chemical exposures and/or medical conditions that were considered to possibly affect the tests. Tests of central nervous system functioning were chosen to measure: balance, reaction time, blink reflex latency, color discrimination, visual fields, hearing, and neuropsychological recall tests. Investigators used this group’s data to create prediction equations based on the results of the regression. In this way, specific predictions can be made per individual based on these demographic characteristics. The regression equations were validated using a separate group of similarly screened persons from another unexposed area (24).

In the first investigation, 16 subjects had been referred for evaluation of effects of exposure to reduced sulfur gases, including H_2S (46). Four of the subjects had been overcome with to the point of unconsciousness by H_2S; six of the subjects had smelled the “rotten egg” odor, with exposures generally estimated between 1,000 and 10,000 ppb for several hours, possibly at times as high as 50,000 ppb; another six had exposure over several years in different settings, including living downwind from a crude oil collection tank, work in a sewage treatment facility, and

spending time downwind from two oil refineries. Tests were conducted on patients, and then the actual score was compared to the predicted score, and the percentage of the predicted was calculated for the patient group and the referent group. The author concluded neurological impairment was apparent in all 16 subjects. For those who had chronic low-dose exposure, the most sensitive tests were those of impaired balance, simple reaction time, left visual field, and verbal recall. Those with intermediate exposures (in hours duration) had additional impairments, and those who had experienced unconsciousness had deficits in all areas tested.

In another investigation, 13 former workers and 22 neighbors of a crude oil refinery were compared to controls based on age, gender, and educational level who were friends or relatives of the participants (47). Air monitoring for H_2S at street level near residents' homes showed H_2S at 10 ppb, with peaks at 100 ppb. For several years, the refinery's 24-hour emissions averaged non-detect to 8,800 ppb for H_2S and 1,100 to 70,700 ppb for total reduced sulfur gases. The regional air pollution monitoring station located near the facilities often had the nation's highest ambient air sulfur dioxide levels. There were greater discrepancies in the percent of the actual compared to the expected scores for exposed compared to the unexposed group for reaction time, balance, color discrimination, immediate story recall, and other areas.

The neurological battery of tests was also conducted on a group of patients exposed to H_2S from a variety of sources and with different durations, ten occupational and nine environmental (48). Exposures were transient and no measurements were available; sources included work at oil and natural gas sites, exposure to a natural gas storage site, building sewers, paper mill, and chemical explosions, and others. For nearly all tests, differences were found between the exposed subjects' percent of predicted and the referents' percent of predicted scores, reflecting deficits among the exposed compared to referents.

Ocular Effects

The New Zealand study found an increase in ocular effects among the exposed vs. the rest of the population, and dose-related increases within exposure groupings. Among a group of 19 previously exposed subjects, exposed persons had worse performance on color vision and visual field tests, compared with a control population (48).

Cardiovascular Effects

The New Zealand investigation found highly significant increases in diseases of the circulatory system among residents compared to the rest of New Zealand, and again a dose-related trend across exposure groupings.

Other Effects

Nausea has been found in high exposure situations (H_2S poisoning), but also among exposed community members in the Finnish studies (36, 37). Evaluations of possible cancer effects have been limited. In Canada, persons living downwind from natural gas refineries did not have increased cancer (49). In the New Zealand exposed community, nasal cancers were elevated, and

an analysis by race and sex found an increased risk for trachea, bronchus, and lung cancer among exposed females of an ethnic minority, the Maori (43).

Evaluation of Studies of Health Effects

Judgment and interpretation of study results must always be made in the context of possible alternative explanations of findings. Besides the issue of whether the exposure information is precise enough, various forms of possible bias, such as selection bias (who is chosen to participate in the study) or reporting bias (whether health outcomes are reported with the same accuracy between the exposed and unexposed), could affect the study results. Study design can influence the likelihood of bias.

For example, controlled laboratory studies are less likely to be influenced by bias than other design types. The studies that were conducted in New Zealand are also less likely to be affected by bias, as the population is accustomed to living there, and furthermore the studies described used existing data (e.g., cancer, mortality, and hospital discharge). In community health studies based on a local exposure source, residents may be aware of and concerned about their exposure, which could influence their choice to participate. Those with health problems, due to their worry about the exposures or interest in studying their health, may be more likely to participate in a health study than those without problems. This can create bias in a study. However, selection of the study populations based strictly on exposure criteria will minimize the possibility of this type of selection bias, particularly if the two populations can be shown to be comparable other than in the exposure. The Nebraska investigation using hospitalization data would not be affected by selection bias, and the community study applied methods to randomly select participants. However, for example, in the Finnish studies, it may be that residents' concerns about the paper/pulp mill could have influenced reporting. Similarly, the participation of subjects in lawsuits, such as in the Kilburn and Legator studies, raises the question of bias. Dr. Kilburn concluded bias from conscious altering of the tests was unlikely, citing factors such as subjects' naïveté regarding the tests and the robustness of the measurements to manipulation (46).

Methodologically, the use of prediction equations may confer an advantage in that it is individual-specific in adjusting for known influences on test performance. However, the test standard was developed to measure performance among "normal" persons unaffected by illness, chemically caused or otherwise. Thus it measures deviations from "normality." In real life, neurological deficits exist in the population, some of which may, in certain circumstances, be caused by H_2S, and others existing for many other reasons. The tests do not distinguish between potential causes of deficits. Thus, although deficits may be detected, attribution to H_2S is a matter of context and judgment.

Another issue particularly relevant to assessing potential health effects of H_2S is whether anxiety from smelling a noxious odor could be causing the symptoms. This is especially true for subjective symptoms, such as headache. Determining the effects of H_2S separately from anxiety is best addressed in a population which is not experiencing stress from worry over exposure. The Roturua population in New Zealand, which resides in an area of naturally occurring H_2S, is generally unconcerned about exposures (Dr. Michael Bates, personal communication, November

13, 2006). Thus the findings of an association in that population supports the hypothesis that the health outcomes found represent actual biological effects rather than stress-induced reactions.

In general, research suggests it is reasonable to conclude that respiratory, neurological, and ocular symptoms may be caused by low-level exposure to total reduced sulfur and/or H_2S. However, current knowledge is limited by lack of specific exposure levels, small study populations, and exposures that include other compounds that may also be biologically active.

Community Health Concerns Evaluation

As mentioned previously, CDHS communicated with community members in August and September 2006 by telephone, e-mail, and in-person. CDHS also reviewed several complaint letters sent to the air district, as well as two logbooks consisting of health complaints prepared by the air district for dredging seasons 2003-2004 and 2004-2005. The following section discusses some of the community's concerns that were brought to up to CDHS.

Are the hydrogen sulfide nuisance prevention protocols protective of beach visitors and nearby residents?

CDHS has reviewed the port district's protocols and have found the discretionary beach action level (15 ppb for four consecutive readings) and the "emergency condition" level (the acute REL, a "rolling average" of 30 ppb) to be adequate in protecting the residents and beach visitors during the dredging seasons. Based on state and federal governmental standards, H_2S levels below 30 ppb would not be expected to cause adverse health effects.

Could the hydrogen sulfide that is released during the beach discharge cause health impacts to beach visitors and nearby residents?

CDHS found that 97.7% of the time when dredging occurred on the beach over the past three years, the levels of H_2S were below the screening level of 30 ppb. Levels at this range would not be expected to cause health concerns.

However, H_2S does have an odor and studies have shown that smelling offensive odors at concentration as low as 8.1 ppb could elicit health effects such as nausea and headaches. As a way to avoid odor nuisances associated with H_2S, the WHO recommends a more stringent ceiling of 5 ppm over a 30 minute average (7).

On several occasions, the levels averaged above the acute REL for periods of time greater than an hour: December 22, 2005; January 5, 7, and 8, 2006. The acute REL was established based on a combination of odor objection and headaches that could occur around 30 ppb.

During certain periods of time the levels get very high for short periods of time, greatly exceeding the screening value of 30 ppb. CDHS has also reviewed the current scientific literature concerning the correlation between H_2S contamination and health effects. Case studies have shown that people can experience symptoms if they experience high H_2S concentrations for a short period of time. And there is research underway that suggests respiratory, neurological and

even cardiac effects may be possible from lower levels of H_2S over intermittent or longer exposure periods. However given the limited time that these high emissions occurred and a dilution that would occur from the monitoring station to the nearest beach visitor or neighbor, it is not possible to connect health effects to the observed H_2S emissions at the Santa Cruz Harbor site.

Are the health effects the nearby neighbors experiencing caused by hydrogen sulfide emitted from the lift station and manholes along Sea Cliff Drive?

Due to the levels recorded by the Santa Cruz County's Public Works Department, it is possible the lift station and manholes along Sea Cliff Drive could act as a possible source of H_2S. However, it does not seem to be the primary source because the hydrogen sulfide levels will drop off when the distance from the source is increased.

Are the health effects that the nearby neighbors (and beach visitors) are experiencing caused by hydrogen sulfide?

While it's possible the health effects the nearby neighbors and beach visitors are experiencing could be related to the H_2S from the dredge material, it would be difficult to make this determination without a more complete understanding of the chemical's toxicity. It should be stated that CDHS did not medically evaluate anyone as a part of this health consultation. Based on our analysis of the H_2S monitoring data, CDHS can not conclude that the health effects were caused by the releases of H_2S from beach discharge of the dredged material.

ATSDR Child Health Considerations

ATSDR recognizes that infants and children may be more sensitive to exposures, depending on substance and the exposure situation, than adults in communities with contamination of their water, soil, air, and/or food. This sensitivity is a result of several factors: 1) children may have greater exposures to environmental toxicants than adults because pound for pound of body weight, children drink more water, eat more food, and breathe more air than adults; 2) children play outdoors close to the ground which increases their exposure to toxicants in dust, soil, surface water, and in the ambient air; 3) children have a tendency to stick their hands in their mouths while playing without washing their hands, thus, they may come into contact with, and ingest, potentially contaminated soil particles at higher rates than adults (also, some children possess a behavior trait known as "pica" which causes them to ingest non-food items, such as soil); 4) children are shorter than adults, which means they can breathe dust, soil, and any vapors close to the ground; 5) children's bodies are rapidly growing and developing; thus, they can sustain permanent damage if toxic exposures occur during critical growth stages; and 6) children and teenagers may disregard no trespassing signs and wander onto restricted locations. Because children depend completely on adults for risk identification and management decisions, ATSDR is committed to evaluating their special interests at sites such as the Santa Cruz site.

CDHS identified places (e.g., the beaches) in the vicinity of the Santa Cruz site where children spend time (i.e., live and play). The location closest to the Santa Cruz site where children may spend time is at Twin Lakes Beach and Black's Point where the deposition of the dredging

material often occurs. There is a barrier that identifies the exclusion zone but kids are still able to play on the beach (Appendix D, Photo 9). It should be noted that children also have the tendency to ignore warning/exclusion signs and zones. For the reasons described previously, CDHS recognizes that the beach dredging is posing a public nuisance but the exposures are not at levels likely to cause adverse health effects to adults or children.

Limitations of the Evaluation

The identification and analysis of environmental exposure is difficult and inexact. This health consultation was prepared using different sources. There are varying degrees of uncertainty associated with each source of information. The following describes areas where uncertainties may be found and provides examples of some of these uncertainties.

Environmental Data

CDHS assumes that adequate quality control measures were followed with regard to chain of custody, laboratory procedures, and data reporting. The validity of the analyses and conclusions reported in this health consultation depends on the completeness and reliability of the referenced information. Since, the port district only has three years of air monitoring data; it is difficult for CDHS to determine long-term exposure levels. Additionally, during the 3 years of air monitoring there were gaps in the data that CDHS received. It is not clear if air monitoring occurred and CDHS did not get the data, or if no air monitoring occurred during those times, a violation of the protocol.

Sampling Instrument Limitations

The port district has been using a hand held Jerome 631-X H_2S analyzer. When the instrument operates correctly, it is meant to take a sample once every 2 minutes. For the past 3 years, the port district has been pushing the instrument's limitations by consistently taking samples once every minute. This aggressive approach to sampling has lead to a number of "anomalies" in the sampling data—an anomaly is an unexpected high spike in the data with no accompanying shoulders on either side of the spike. CDHS reviewed the data and found anomalies to have occurred on the following days: January 7, February 13, and March 16, 2004; December 7, 13, 20, 21, and 22, 2005; January 5, 19, and 26, 2006; February 1, 15 and 28, 2006; March 8, and 22, 2006; April 6, 2006; and May 3, 4 and 5, 2006.

Health Studies Limitations

Judgment and interpretation of study results must always be made in the context of possible alternative explanations of findings. Besides the issue of whether the exposure information is precise enough, various forms of possible bias, such as selection bias (who is chosen to participate in the study) or reporting bias (whether health outcomes are reported with the same accuracy between the exposed and unexposed), could affect the study results. Study design can influence the likelihood of bias.

Conclusions

CDHS talked with community members in August and September 2006, who expressed concern about the possible adverse health effects resulting from exposure to H_2S related to the dredging operations. Community members reported health concerns such as red and burning eyes, blurry vision, conjunctivitis, headaches, and nausea. Some residents described the smell as a nuisance and dealt with the problem by shutting their doors and windows. Other community members had to adjust their living habits such as leaving their homes for an extended period of time or moving out of the neighborhood. It should be noted that some on the residents indicated they had been examined by Dr. Kaye Kilburn. Based on a battery of neurological examinations, Dr. Kilburn reportedly told these nearby residents that they had been permanently damaged from H_2S exposure arising from the dredging operations.

For the past three dredging seasons, the Santa Cruz harbor has worked under two protocols that set forth H_2S levels which when detected would call for the termination of dredging operations. CDHS reviewed the port district's protocols and found the action levels (15 ppb and the acute REL's "rolling average" of 30 ppb) to be adequate in the protecting the residents and beach visitors while the beach disposal is occurring. During the first two dredging seasons, there were days when the port district would shutdown and restart during the same day, this was not considered a "violation" because the protocol did not specifically state the dredging activities must stop for the day. According to the CDHS' review of the 2005-2006 dredging data, the port district followed the protocols except for December 29, 2005; March 29, 2006 and May 10, 2006. On these days, the beach disposal did not stop even though the port district exceeded the action level; thus, violating the protocol.

However, the port district did fail to stop the dredging activities during the following emergency condition days: December 22, 2005, and January 5 and 7, 2006. On January 9, 2006, while operating under emergency variance conditions, the port district had at least one sample greater than or equal to 1,000 ppb, and they did not stop beach disposal for the day. It is imperative the harbor continues to follow its protocol as to ensure the health of beach visitors or nearby residents will not be compromised. Adhering to the protocols also establishes a sense of trust between the community and the port district.

CDHS found that 97.7% of the time when dredging occurred on the beach over the past three years, the levels of H_2S were below the screening level of 30 ppb. Levels within this range would not be expected to cause health concerns.

Smelling any offensive odor can cause health effects. H_2S does have an odor and studies have shown that smelling offensive odors at concentration as low as 8.1 ppb could elicit health effects such as nausea and headaches. Amoore indicated that the odor perception threshold decreases with age. Recent studies suggest that 9 year olds may not be as sensitive as 15 year olds in odor identification; however, this may be partly explained by the results of another study in which children aged 8-14 had an odor sensitivity similar to that of young adults, but appeared not to possess the capability to identity the odors by name.

On several occasions, the levels averaged above the acute REL for periods of time greater than an hour: December 22, 2005 and January 5, 7, and 8, 2006. The acute REL was established based on a combination of odor objection and headaches that could occur around 30 ppb.

During certain monitoring periods, H_2S levels were very high for short periods of time, greatly exceeding the screening value of 30 ppb. CDHS has reviewed the current scientific literature concerning the correlation between H_2S exposure and health effects. Case studies have shown that people can experience symptoms if they experience high H_2S concentrations for a short period of time. And there is research underway that suggests respiratory, neurological and even cardiac effects may be possible from lower levels of H_2S over intermittent or longer exposure periods. However given the limited time that these high emissions occurred and a dilution that would occur from the monitoring station to the nearest beach visitor or neighbor, it is not possible to connect health effects to the observed H_2S emissions with the Santa Cruz harbor beach disposal site.

In conclusion, on the basis of the available data, CDHS and ATSDR classify the Santa Cruz Harbor site as posing no apparent public health hazard due to the harbor's dredging activities.

Recommendations for Further Actions

On the basis of available data, CDHS and ATSDR recommend that:

- the port district should comply with the H_2S protocol and establish a clear understanding with their dredging contractors that the dredging should stop for the day when the action levels are exceeded;

- the port district should continue the H_2S sampling for the upcoming dredging seasons;

- the port district, with the assistance of the other regulatory agencies, ensure the dredging is performed off shore and under water as much as possible to dissipate the H_2S;

- the harbor should post additional signs on the beaches, warning of possible health implications during dredging;

- the port district should create a better delineation around the discharge area;

- the air district should start a policy where they archive their inspector notes; and

- the dredging crew should indicate on their field notes when the operations on the beach are being conducted under emergency conditions or emergency variance.

Public Health Recommendations and Actions

The Public Health Recommendations and Action Plan (PHRAP) for this site contains a description of the action taken, to be taken or under consideration by ATSDR and CDHS, at and near the site. The purpose of the PHRAP is to ensure that these actions are designed to mitigate

and prevent adverse human health effects resulting from exposure to hazardous substances in the environment. CDHS and ATSDR will follow up on this plan to ensure that actions are carried out.

Actions Completed

- In April 1997, the port district conducted air sampling for 23 sulfur-containing compounds.
- In April 2004, the air district sampled the air; the county health department sampled water and sand at the discharge point on Twin Lakes Beach and 200 yards upcoast at Seabright.
- In July 2004, a risk assessment compared the levels for contaminants in the upper harbor sediment to the U.S. Environmental Protection Agency (EPA)'s soil screening levels.
- In July 2004, the air district conducted ash sampling from the nearby fire pits to look for chemicals used in production of chemically treated wood.
- In April 2005, the county health department analyzed the "clay balls" found on the beach.
- In October 2005, the air district took air and sediment samples of the dredge material from the upper harbor.
- In February and March 2006, the SCPW performed hydrogen sulfide sampling at the lift station (wet well hatch) and eight manholes along East Cliff Street Drive sewer line.
- In May 2006, CARB conducted air monitoring for H_2S and air sampling for 23 VOCs at various outside locations and one indoor location.

Actions Planned

- The port district is proposing to conduct beach discharge during the 2006-2007 dredging season by employing three different underwater discharge locations; each day the discharge pipe will be placed into and beyond the surf line so that the discharge is below 4-5 feet of water, outside the surf break.
- The port district will continue to monitor the H_2S samples during the 2006-2007 dredging season.
- In the 2006-2007 dredging season, the air district will conduct PM-10 air monitoring to see if this is evidence of upper harbor sediments becoming airborne and being transported ashore from the offshore dredge disposal pipe.
- CARB is conducting indoor/outdoor air monitoring for H_2S at a nearby residence.
- CARB is analyzing air samples collected during "stinky" times to see what compounds may be present.

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Certification

The health consultation Evaluation of Hydrogen Sulfide Migration at Twin Lakes Beach and Adjacent to the Santa Cruz Harbor, Santa Cruz County, was prepared by the California Department of Health Services under a cooperative agreement with the federal Agency for Toxic Substances and Disease Registry (ATSDR). It was completed in accordance with approved methodology and procedures existing at the time the public health consultation was initiated. Editorial review was completed by the Cooperative Agreement partner.

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Appendix A. Glossary

Acute Exposure
Contact with a chemical that happens once or only for a limited period of time. ATSDR defines acute exposures as those that might last up to 14 days.

Adverse Health Effect
A change in body function or the structures of cells that can lead to disease or health problems.

ATSDR
The Agency for Toxic Substances and Disease Registry (ATSDR) is a federal public health agency with headquarters in Atlanta, Georgia, and ten regional offices in the United States. ATSDR's mission is to serve the public by using the best science, taking responsive public health actions, and providing trusted health information to prevent harmful exposures and diseases related to toxic substances. ATSDR is not a regulatory agency, unlike the U.S. Environmental Protection Agency, which is the federal agency that develops and enforces environmental laws to protect the environment and human health.

Background Level
An average or expected amount of a chemical in a specific environment or, amounts of chemicals that occur naturally in a specific environment.

Chronic Exposure
A contact with a substance or chemical that happens over a long period of time. ATSDR considers exposures of more than 1 year to be chronic.

Concern
A belief or worry that chemicals in the environment might cause harm to people.

Concentration
How much or the amount of a substance present in a certain amount of soil, water, air, or food.

Contaminant
See Environmental Contaminant.

Dose
The amount of a substance to which a person may be exposed, usually on a daily basis. Dose is often explained as “amount of substance(s) per body weight per day.”

Dose/Response
The relationship between the amount of exposure (dose) and the change in body function or health that result.

Duration
The amount of time (days, months, and years) that a person is exposed to a chemical.

Environmental Contaminant
A substance (chemical) that gets into a system (person, animal, or environment) in amounts higher than that found in Background Level, or what would be expected.

Exposure
Coming into contact with a chemical substance (for the three ways people can come in contact with substances, see Route of Exposure).

Frequency
How often a person is exposed to a chemical over time; for example, every day, once a week, or twice a month.

Health Effect
ATSDR deals only with Adverse Health Effects (see definition in this glossary).

Inhalation
Breathing. It is a way a chemical can enter your body (see Route of Exposure).

Noncancer Evaluation, ATSDR's Minimal Risk Level (MRL) USEPA's Reference Concentration (RfC), and California EPA's Reference Exposure Level (REL)
MRL, RfC, and REL are estimates of daily exposure to the human population (including sensitive subgroups), below which noncancer adverse health effects are unlikely to occur. MRL, RfC, and REL only consider noncancer effects. Because they are based only on information currently available, some uncertainty is always associated with MRL, RfC, and REL. "Safety" factors are used to account for the uncertainty in our knowledge about their danger. The greater the uncertainty, the greater the "safety" factor and the lower MRL, RfC or REL.

When there is adequate information from animal or human studies, MRLs are developed for the ingestion and the inhalation exposure pathway, whereas RELs and RfCs are developed for the inhalation exposure pathway.

Separate noncancer toxicity values are also developed for different durations of exposure. ATSDR develops MRLs for acute exposures (less than 14 days), intermediate exposures (from 15 to 364 days), and for chronic exposures (greater than 1 year). The California EPA develops RELs for acute (less than 14 days) and chronic exposure (greater than 1 year). EPA develops RfCs for acute exposures (less than 14 days), and chronic exposures (greater than 7 years). REL, RfC,and MRL for inhalation are expressed in units of milligrams per cubic meter (mg/m^3).

No Apparent Public Health Hazard
The category is used in ATSDR's public health assessment documents for sites where exposure to site-related chemicals may have occurred in the past or is still occurring, but the exposures are not at levels expected to cause adverse health effects.

Population
A group of people living in a certain area or the number of people in a certain area.

Source (of Contamination)
The place where a chemical comes from, such as a smokestack, landfill, pond, creek, incinerator, tank, or drum. Contaminant source is the first point of an exposure pathway.

Sensitive Populations
People who may be more sensitive to chemical exposures because of certain factors such as age, sex, occupation, a disease they already have, or certain behaviors (cigarette smoking). Children, pregnant women, and older people are often considered special populations.

Toxic
Harmful. Any substance or chemical can be toxic at a certain dose (amount). The dose determines the potential harm of a chemical and whether it would cause someone to get sick.

Toxicology
The study of harmful effects of chemicals on humans or animals.

Volatile Organic Chemical (VOC)
Substances containing carbon and different proportions of other elements such as hydrogen, oxygen, fluorine, chlorine, bromine, sulfur, or nitrogen. These substances easily volatilize (become vapors or gases) into the atmosphere. A significant number of VOCs are commonly used as solvents (paint thinners, lacquer thinner, degreasers, and dry-cleaning fluids).

Appendix B. Figures

Figure 1. Map of Area Around Santa Cruz Harbor Showing Effects of the Littoral Drift, Santa Cruz County, California

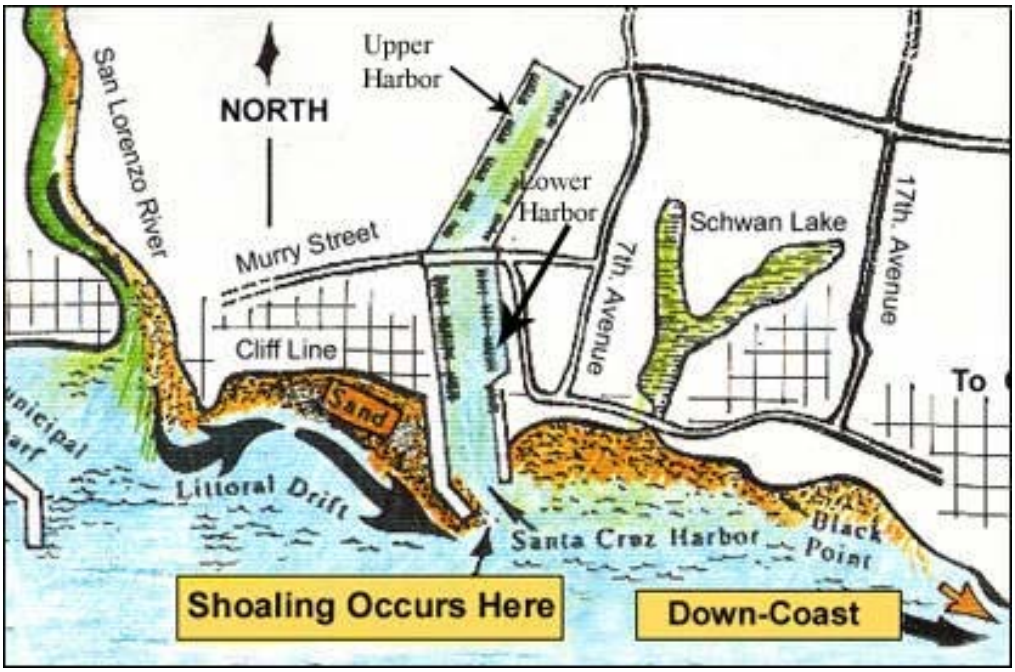


Figure 2. Map of Lower Santa Cruz Harbor and Discharge to Twin Lakes Beach, Santa Cruz County, California

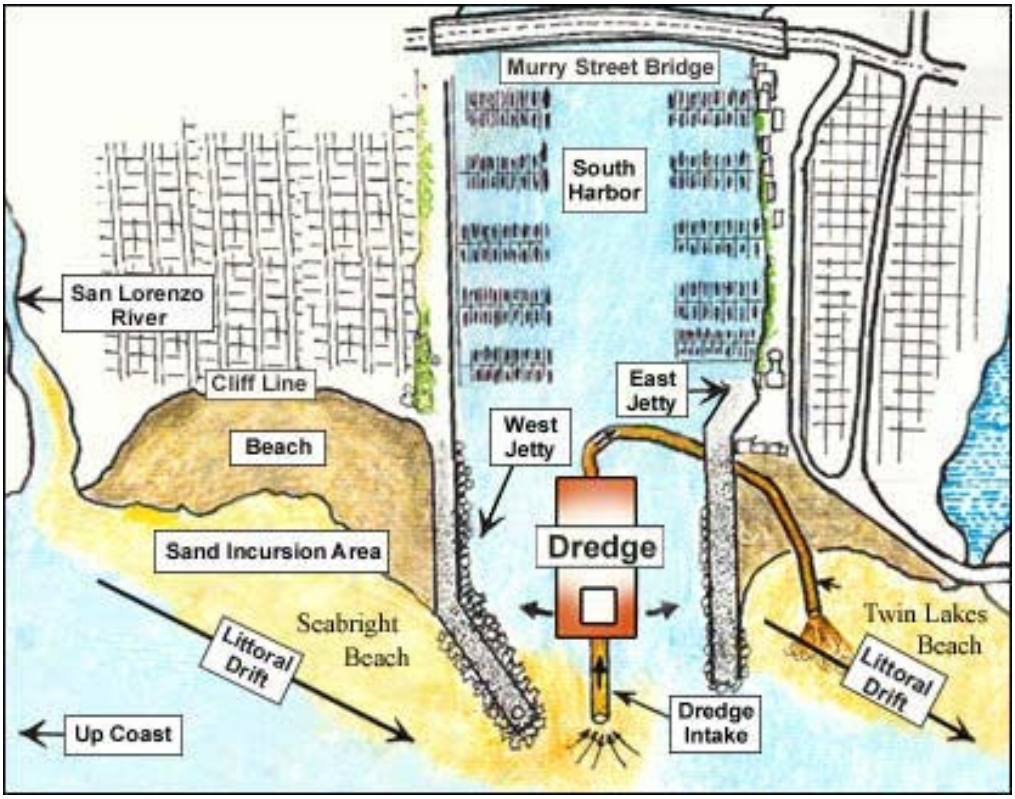
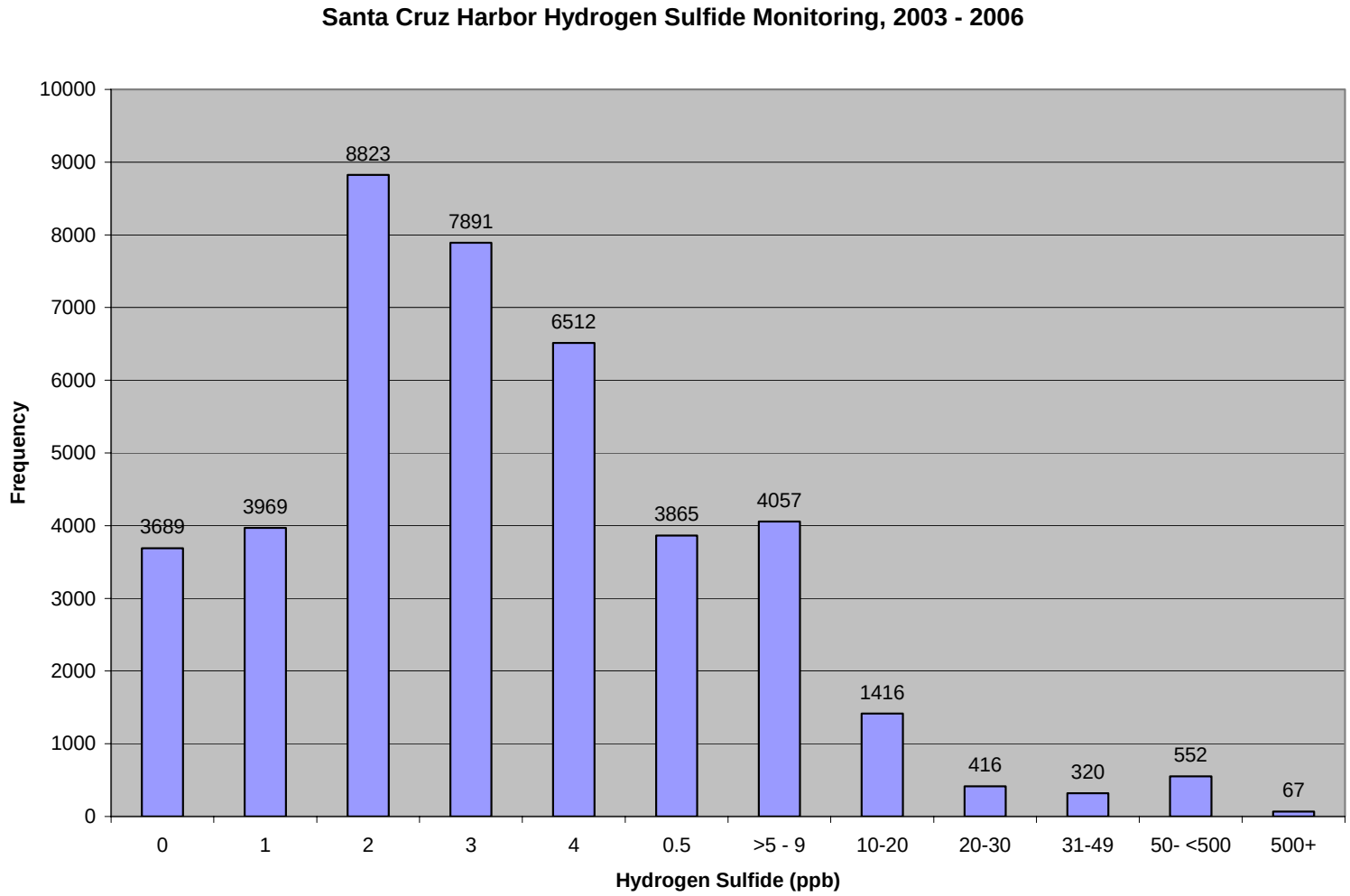


Figure 3. Frequency of Hydrogen Sulfide Levels from 3 Years of Monitoring (2003-2006), Santa Cruz Harbor, Santa Cruz County, California



ppb: parts per billion

Figure 4. Hydrogen Sulfide Dredging Calendar 2003-2004, Santa Cruz Harbor, Santa Cruz County, California

October 2003

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28 0/79	29	30	31	

November 2003

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3	4	5 0/3536	6 0/3696	7 0/1712	8
9	10 0/1478	11	12	13 0/144	14	15
16	17	18 0/1317	19	20 0/112	21	22
23 30	24	25 0/11	26	27	28	29

December 2003

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	1	2	3 0/1064	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18 0/9210	19	20
21	22	23	24	25	26	27
28	29	30	31			

January 2004

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
				1	2	3
4	5	6	7 **6/133 450**	8 **6/88 82**	9	10
11	12	13	14	15	16	17
18	19	20 0/1615	21 0/5624	22 0/295	23	24
25	26	27	28	29	30	31

February 2004

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	2	3 0/1215	4 0/65	5 0/14811	6	7
8	9	10 0/15912	11 0/18311	12	13 1/1682,900	14
15	16	17	18 0/61	19 **1/21548**	20 0/553	21
22	23	24	25 0/34	26 0/166	27	28
29						

March 2004

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16 1/256130	17 **2/17057**	18 0/9913	19	20
21	22 0/2539	23 0/24912	24 0/15212	25	26	27
28	29 0/22711	30 0/2275	31 0/16513			

April 2004

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
				1 0/2139	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19 0/4035	20 0/44616	21 9/49446	22 0/44312	23	24
25	26 **0/21819**	27 **15/396390**	28 0/88010	29 0/14714	30	

May 2004

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3	4	5 0/32010	6 0/50710	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23 30	24 31	25	26	27	28	29

Two consecutive 2-minute readings > 10 ppb background or 15 ppb absolute; work did not stop, dredging deposition continued on the beach

Two consecutive 2-minute readings > 10 ppb background or 15 ppb absolute; beach disposal stopped

The action level was exceeded; beach disposal stopped but restarted again; then a subsequent exceedance occurred and beach disposal was stopped for the day

For each day of dredging for which there are monitoring data the following information is shown:

- Number of points > acute REL / total
- Number of sampling points
- Maximum concentration in parts per billion (ppb)

Anomalies were not removed from data presented in this figure.

Figure 5. Hydrogen Sulfide Dredging Calendar 2004-2005, Santa Cruz Harbor, Santa Cruz County, California

November 2004

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17 1/101 38	18 0/234 19	19	20
21	22 10/209 110	23 2/203 88	24	25	26	27
28	29	30				

December 2004

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			1 0/144 6	2 0/206 25	3	4
5	6 4/220 160	7 1/147 31	8	9	10	11
12	13 0/242 21	14 **10/235** **170**	15	16	17	18
19	20	21 **4/151** **110**	22	23	24	25
26	27	28	29 0/113 19	30 **6/87** **130**	31	

January 2005

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
						1
2	3	4	5 **28/240** **250**	6 **1/143** **43**	7	8
9	10 **1/173** **120**	11	12 **30/81** **1,400**	13 **16/183** **550**	14	15
16	17	18 **48/133** **300**	19 **9/132** **480**	20 0/2 0	21	22
23	24 **13/210** **97**	25 **5/163** **49**	26 0/100 6	27 **0/104** **23**	28	29
30	31 0/201 11					

March 2005

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		1	2	3 **32/107** **900**	4	5
6	7	8	9 **37/144** **1,900**	10 **12/136** **350**	11	12
13	14 **9/180** **130**	15 0/3 28	16	17 0/189 6	18	19
20	21	22	23	24	25	26
27	28 0/225 6	29 0/236 11	30	31		

April 2005

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
					1	2
3	4 4/207 520	5 **20/157** **260**	6 0/188 6	7	8	9
10	11	12	13	14	15	16
17	18 0/81 8	19 0/190 14	20 0/229 6	21 0/69 5	22	23
24	25 0/50 5	26 0/164 6	27 0/1 2	28 0/222 7	29	30

Two consecutive 2-minute readings > 10 ppb background or 15 ppb absolute; beach disposal did not stop

Two consecutive 2-minute readings > 10 ppb background or 15 ppb absolute; beach disposal stopped

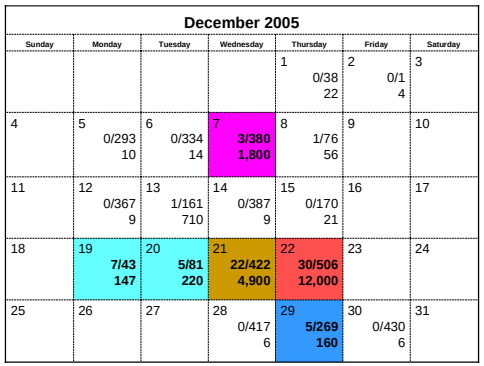
The action level was exceeded; beach disposal stopped but restarted again; then a subsequent exceedance occurred and beach disposal was stopped for the day

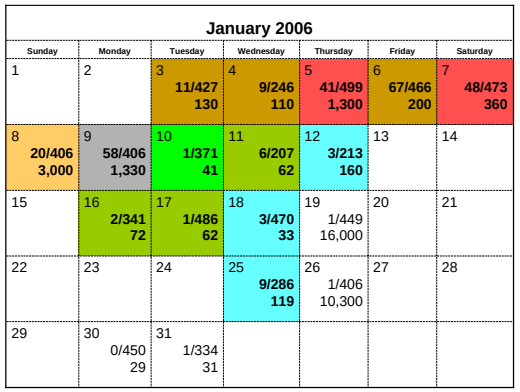
For each day of dredging for which there are monitoring data the following information is shown:

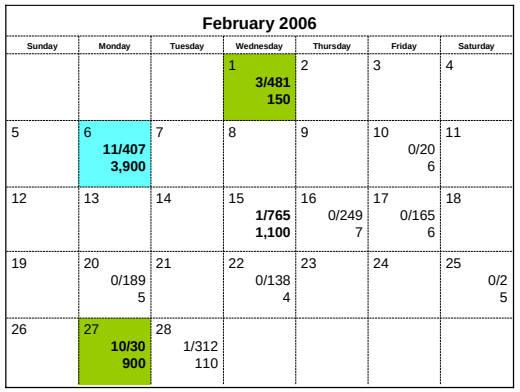
- Number of points > acute REL / total
- Number of sampling points
- Maximum concentration in parts per billion (ppb)

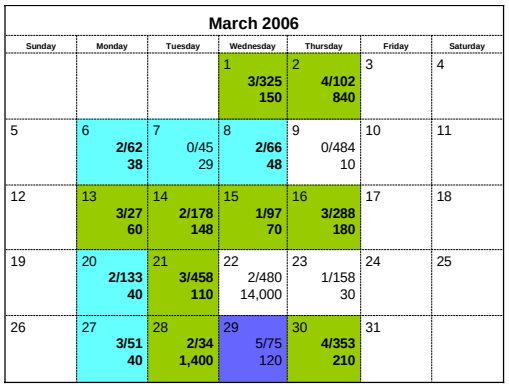
Anomalies were not removed from data presented in this figure.

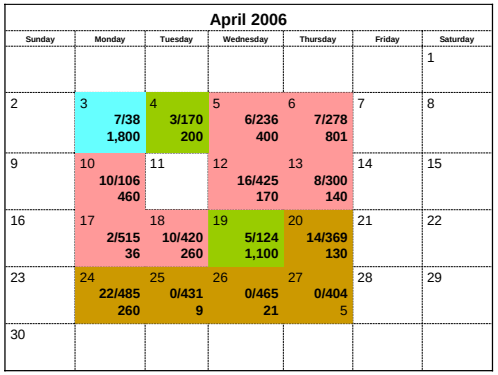
Figure 6. Hydrogen Sulfide Dredging Calendar 2005-2006, Santa Cruz Harbor, Santa Cruz County, California

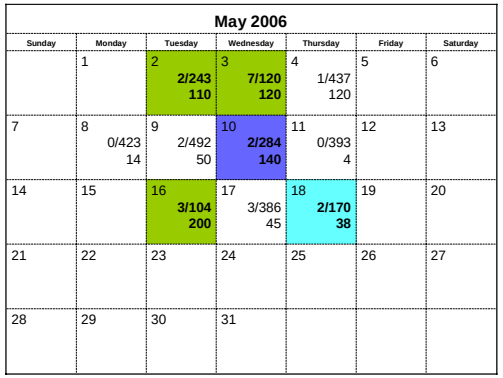












4 readings ≥ 15 ppb; beach disposal stopped for the day; protocol followed

4 readings ≥15 ppb; beach disposal not stopped for the day

At least one reading ≥ 60 ppb; beach disposal stopped; protocol followed

At least 1 reading ≥ 60 ppb; off shore disposal stopped

At least one reading ≥ 60 ppb; beach disposal not stopped; protocol not followed

Emergency condition (exceeded 1 hour average of 30 ppb); beach disposal stopped for the day; protocol followed

Emergency condition (exceeded 1 hour average of 30 ppb); beach disposal did not stop for the day; protocol not followed

Emergency condition (did not exceed 1 hour average of 30 ppb)

Emergency variance; no readings at or above 1,000 ppb

Emergency variance (did not exceed 1 hour average of 30 ppb)

Emergency variance; at least 1 reading ≥ 1,000 ppb; beach disposal did not stop for the day

For each day of dredging for which there are monitoring data the following information is shown:

- Number of points > acute REL / total number of sampling points
- Maximum concentration in parts per billion (ppb)

Anomalies were not removed from data presented in this figure.

Appendix C. Tables

Table 1. Summary of Dredging Protocols for Years 2003-2006, Santa Cruz Harbor, Santa Cruz County, California

Dredge season	Action Taken	Action level in protocol	Distance from end of pipe discharge
2003-2004	Discretionary beach discharge	Terminate discharge into the beach zone whenever: • Two consecutive 2-minute readings or four 1-minute readings of 10 ppb over background or 15 ppb absolute	50-100 feet
	Emergency conditions	Terminate beach discharge within 15 minutes, if the monitor records a 45-minute average level of 30 ppb or more	
2004-2005	Discretionary beach discharge	Terminate discharge into the beach zone whenever: • Two consecutive 2-minute readings or four 1-minute readings of 10 ppb over background or 15 ppb absolute	Less than 50 feet
	Emergency conditions	Terminate beach discharge within 15 minutes, if the monitor records a 45-minute average level of 30 ppb or more	
2005-2006	Discretionary beach discharge	Terminate discharge into the beach zone whenever: • Four consecutive readings of 15 ppb gauge or more, or any single reading of 60 ppb gauge or more	100-150 feet
	Emergency conditions	Terminate beach discharge, if the monitor records a 60 minute rolling average exceeding 30 ppb	

ppb: parts per billion
Source (21) (21)

Table 2. Santa Cruz Hydrogen Sulfide Sampling Observations—Summary of Total Sampling Points and Those That Exceed 30 ppb, Santa Cruz Harbor, Santa Cruz County, California

Sampling Dates	Number of Samples	Number that Exceed 30 ppb
10/28/03	7	0
11/5-25/03	1,197	0
12/3-2/18/03	198	0
1/7-22/04	467	12
2/3-26/04	1,080	2
3/16-31/04	1,798	3
4/1-29/04	3,640	24
5/5-6/04	827	0
11/17-/23/04	747	13
12/2-30/04	1,545	25
1/5-31/05	1,865	151
3/3-29/05	1,220	90
4/4-28/05	1,558	24
12/1-28/05	4,375	74
1/3-31/06	6,936	282
2/1-28/06	2,758	26
3/1-31/06	3,416	42
4/6-27/06	4,766	106
5/2-18/06	3,052	22
Totals	**41,450**	**890**

ppb: parts per billion

Appendix D. Photos

Photo 1. Twin Lakes Beach, Santa Cruz Harbor, Santa Cruz County, California

(Photo taken on October 12, 2005)

Photo 2. Recreational Beach Visitors, Santa Cruz Harbor, Santa Cruz County, California

(Date of photo unknown)

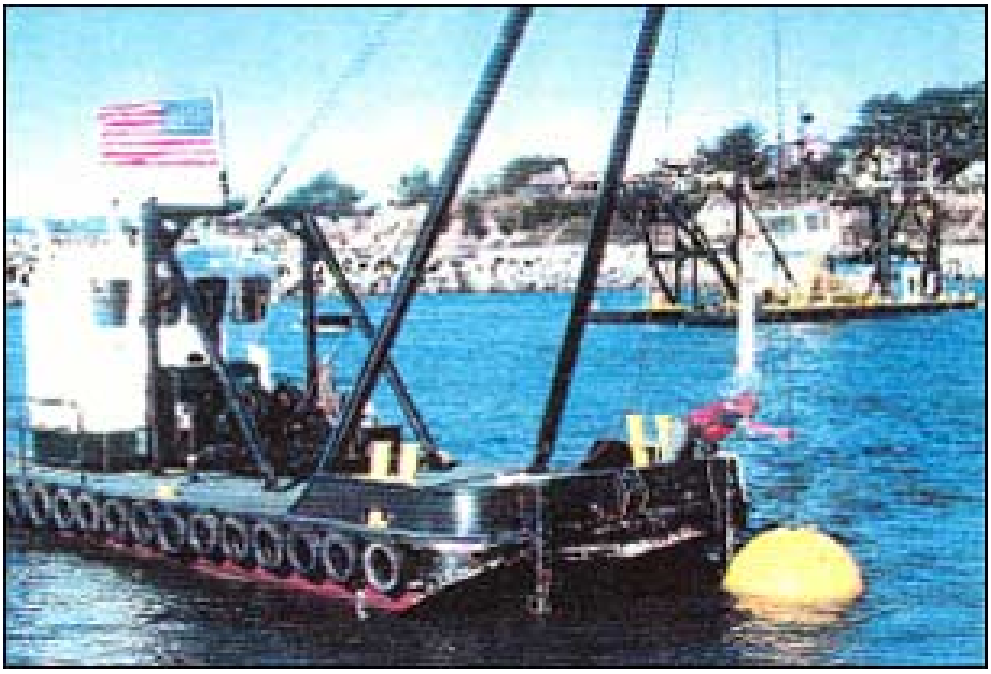
Photo 3. Disposal Onshore with Air Monitoring Occurring in the Vehicle with the Nearest Neighbors in the Background, Santa Cruz Harbor, Santa Cruz County, California

(Date of photo unknown)

Photo 4. Lift Station Along East Cliff Drive, Santa Cruz Harbor, Santa Cruz County, California

(Date of photo unknown)

Photo 5. The Duantless (Tug Boat) in the Foreground, with the Seabright (Dredger) in the Background, Santa Cruz Harbor, Santa Cruz County, California



(Photo taken on October 1986)

Photo 6. Beach Along East Cliff Drive Washed Away During Storm, Santa Cruz County, California

(Photo taken on January 2, 2006)

Photo 7. Shoaling of Harbor, Santa Cruz County, California.

(Photo taken in 1976)

Photo 8. Beach Replenishment Activities, Santa Cruz Harbor, Santa Cruz County, California

(Photo taken in 2006)

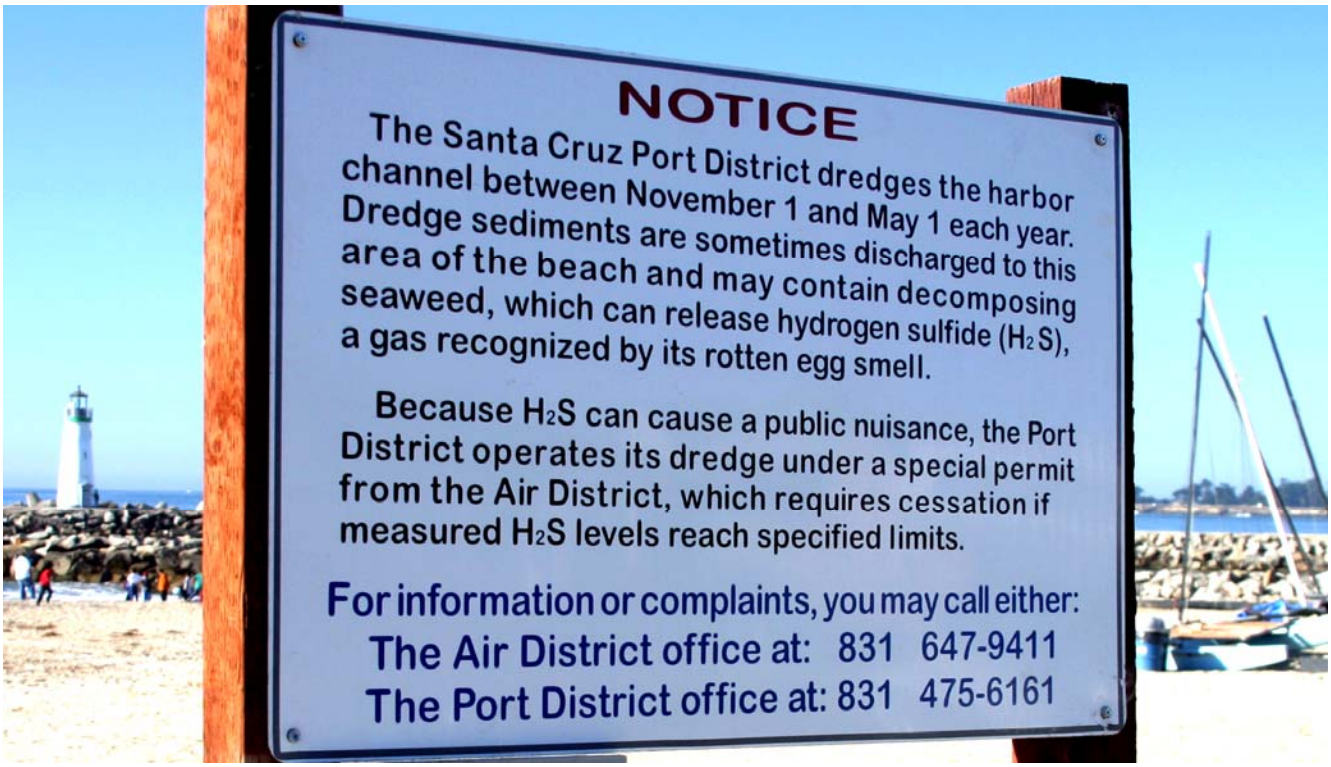
Photo 9. Dredge Operation Demarcated to Beach Visitors, Santa Cruz Harbor, Santa Cruz County, California

(Photo taken on March 28, 2005)

Photo 10. On-Shore Discharge/Point Source Location, Santa Cruz Harbor, Santa Cruz County, California

(Photo taken in December 2005)

Photo 11. Hydrogen Sulfide Public Notice Posting As Displayed in Fall 2005, Santa Cruz Harbor, Santa Cruz County, California.



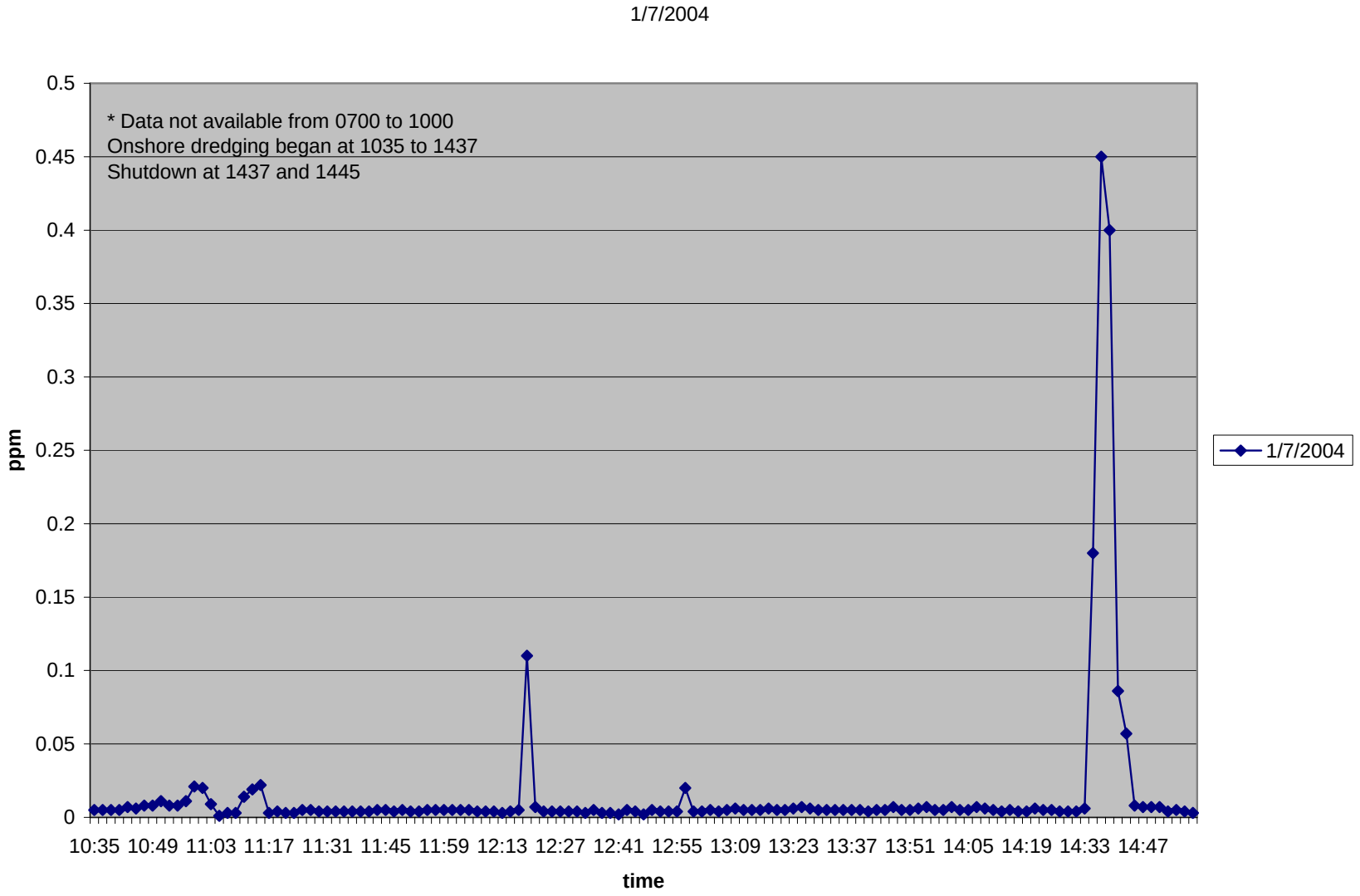
(Photo taken on October 12, 2005)

Appendix E. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day for Those Days When At Least One Reading (Non-Anomaly) ≥ 30 ppb

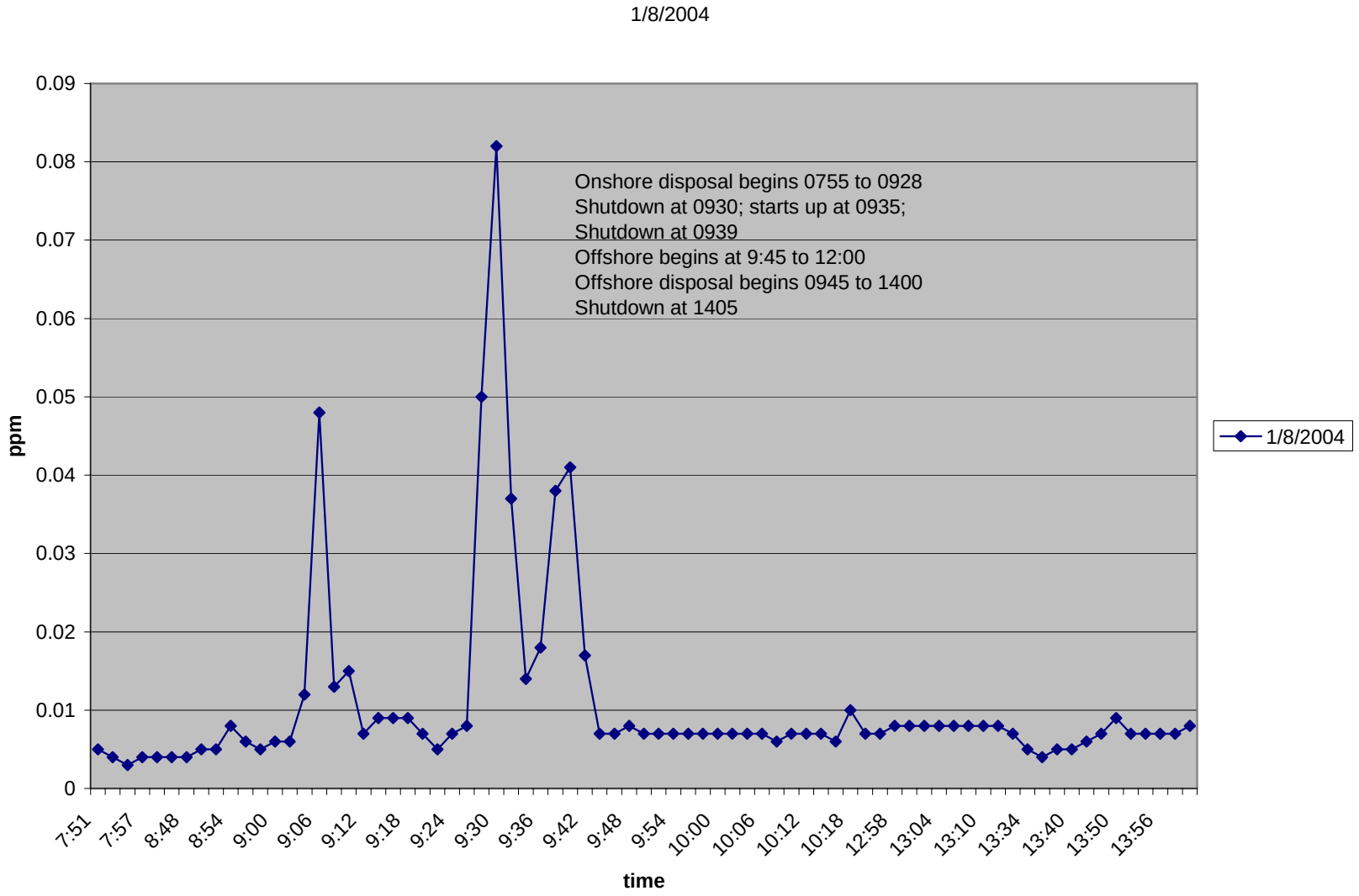
Notes

- The notations on the graphs were taken from Beach Observer Logs (field notes)
- Time is given in military style
- The Y axis values vary on each graph
- Onshore refers to beach disposal
- Offshore refers to underwater disposal

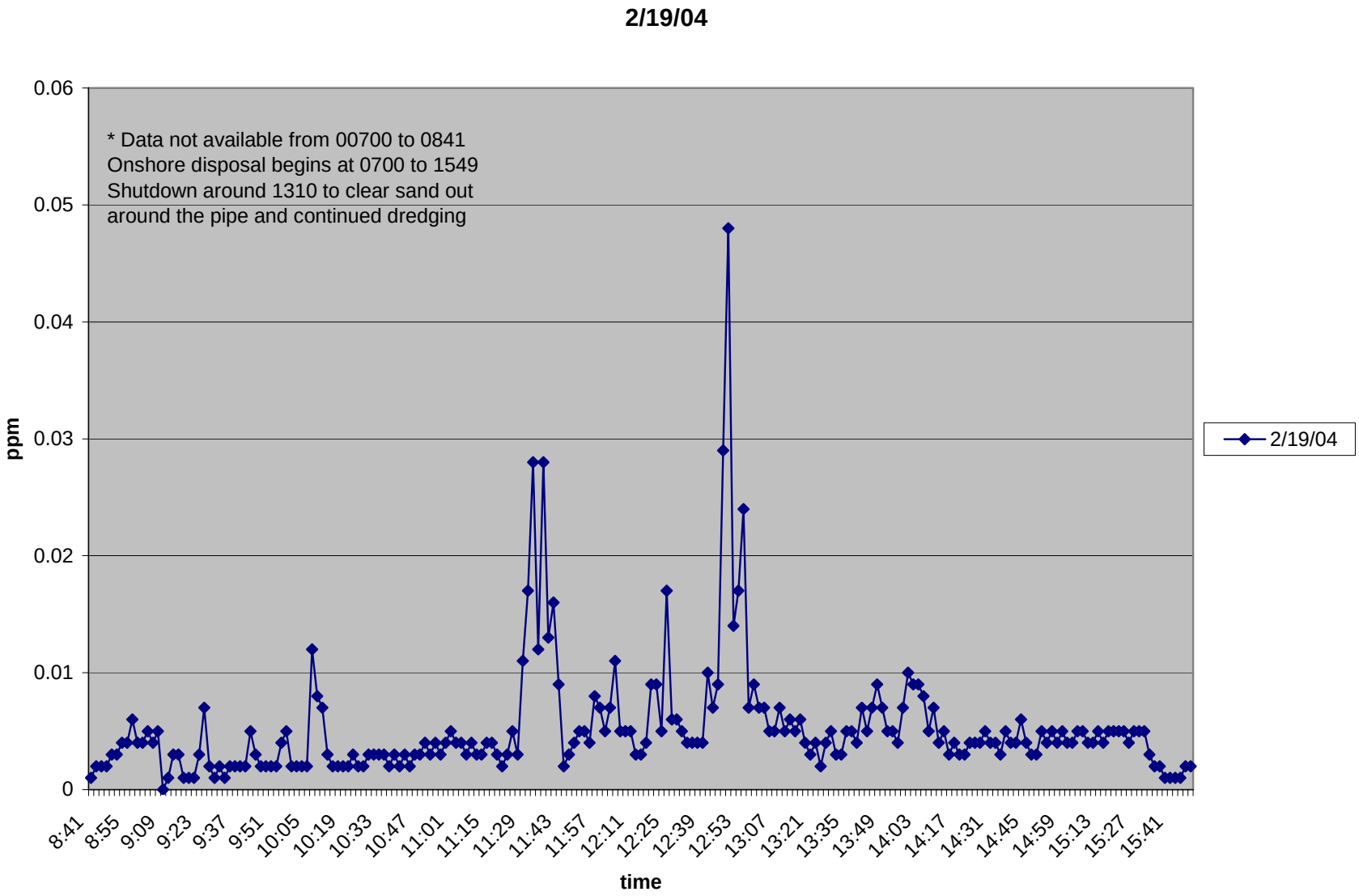
Graph E1. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 7, 2004, Santa Cruz Harbor, Santa Cruz County, California



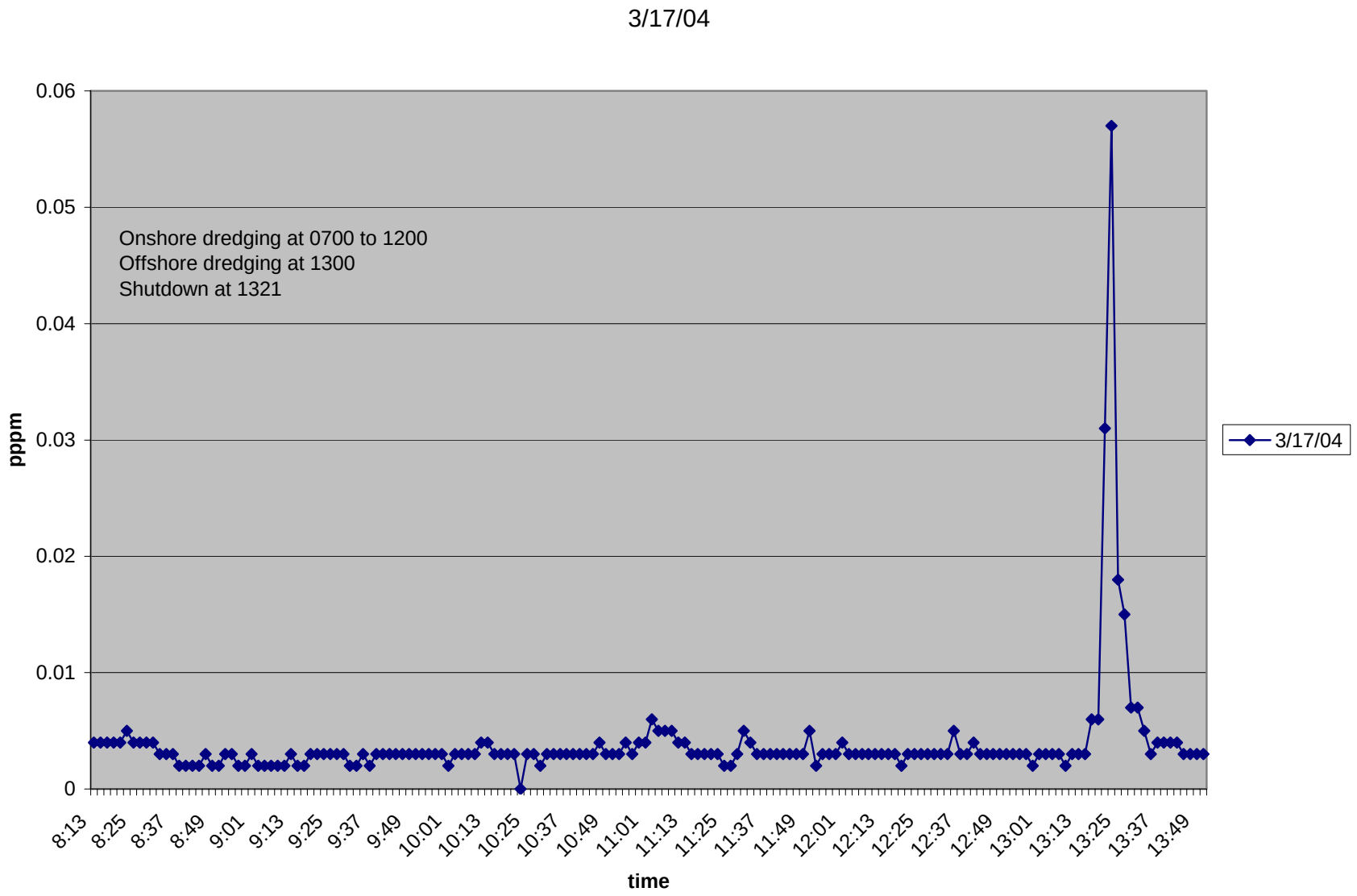
Graph E2. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 8, 2004, Santa Cruz Harbor, Santa Cruz County, California



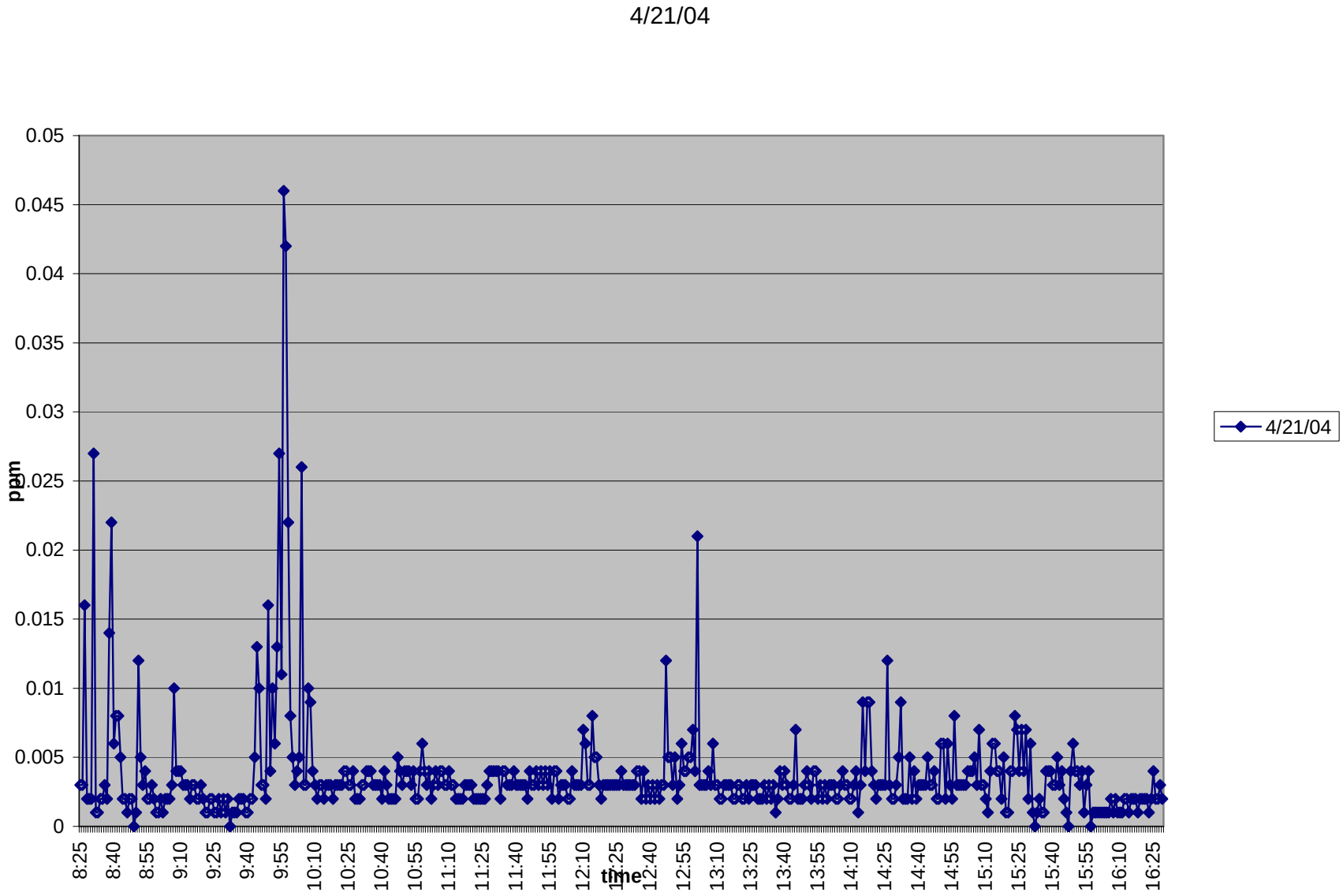
Graph E3. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, February 19, 2004, Santa Cruz Harbor, Santa Cruz County, California



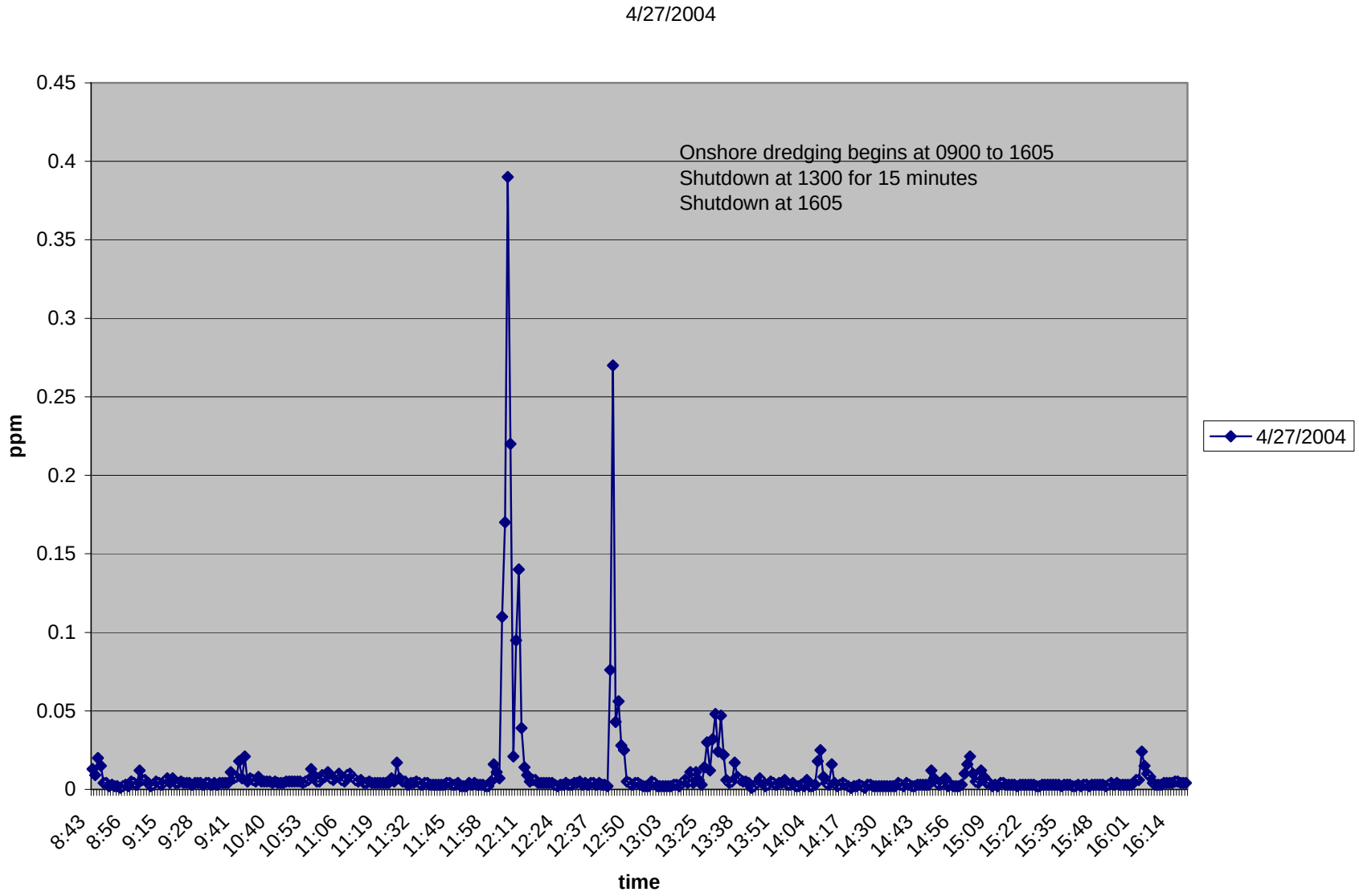
Graph E4. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, March 17, 2004, Santa Cruz Harbor, Santa Cruz County, California



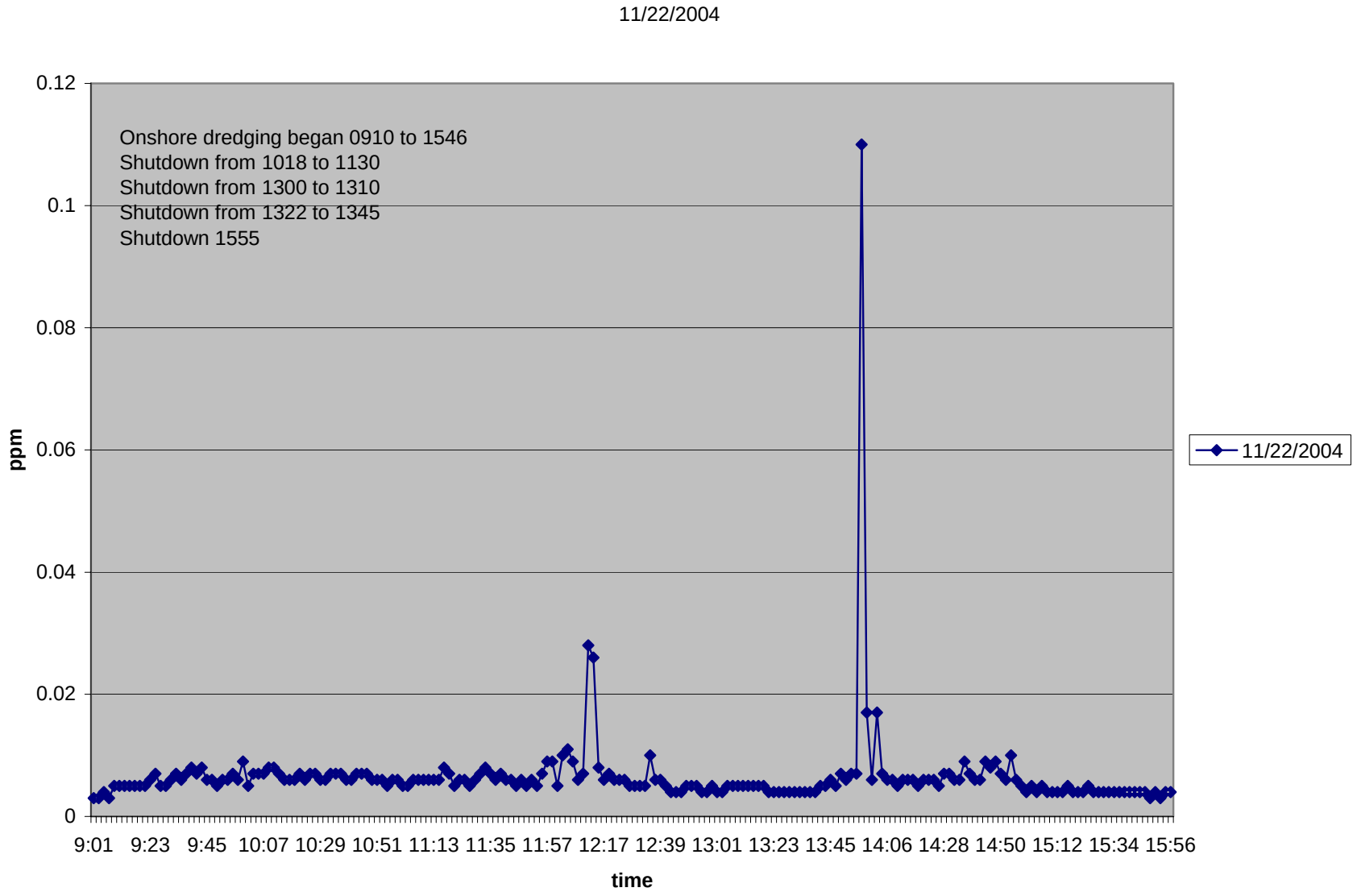
Graph E5. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, April 21, 2004, Santa Cruz Harbor, Santa Cruz County, California



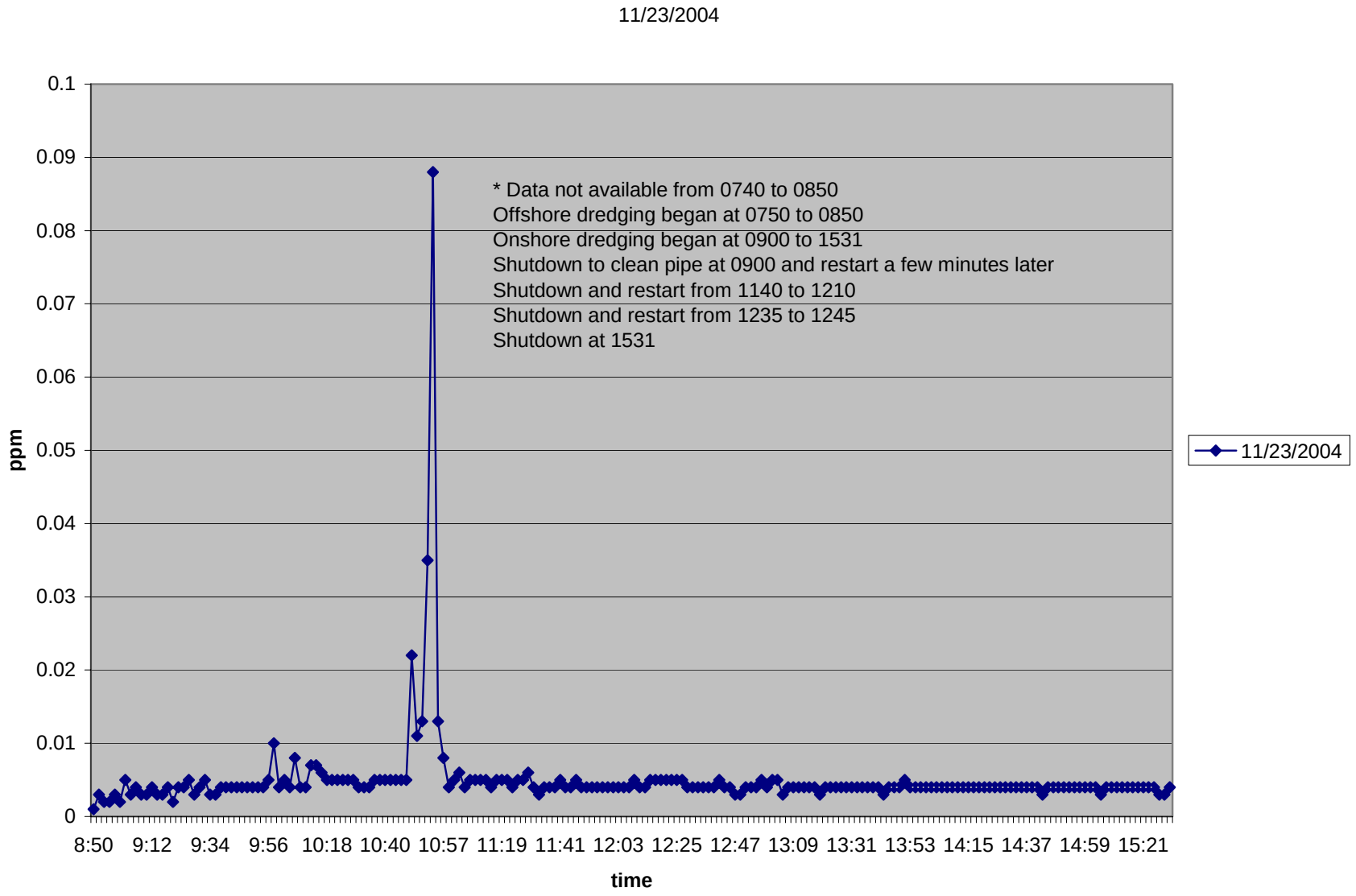
Graph E6. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, April 27, 2004, Santa Cruz Harbor, Santa Cruz County, California



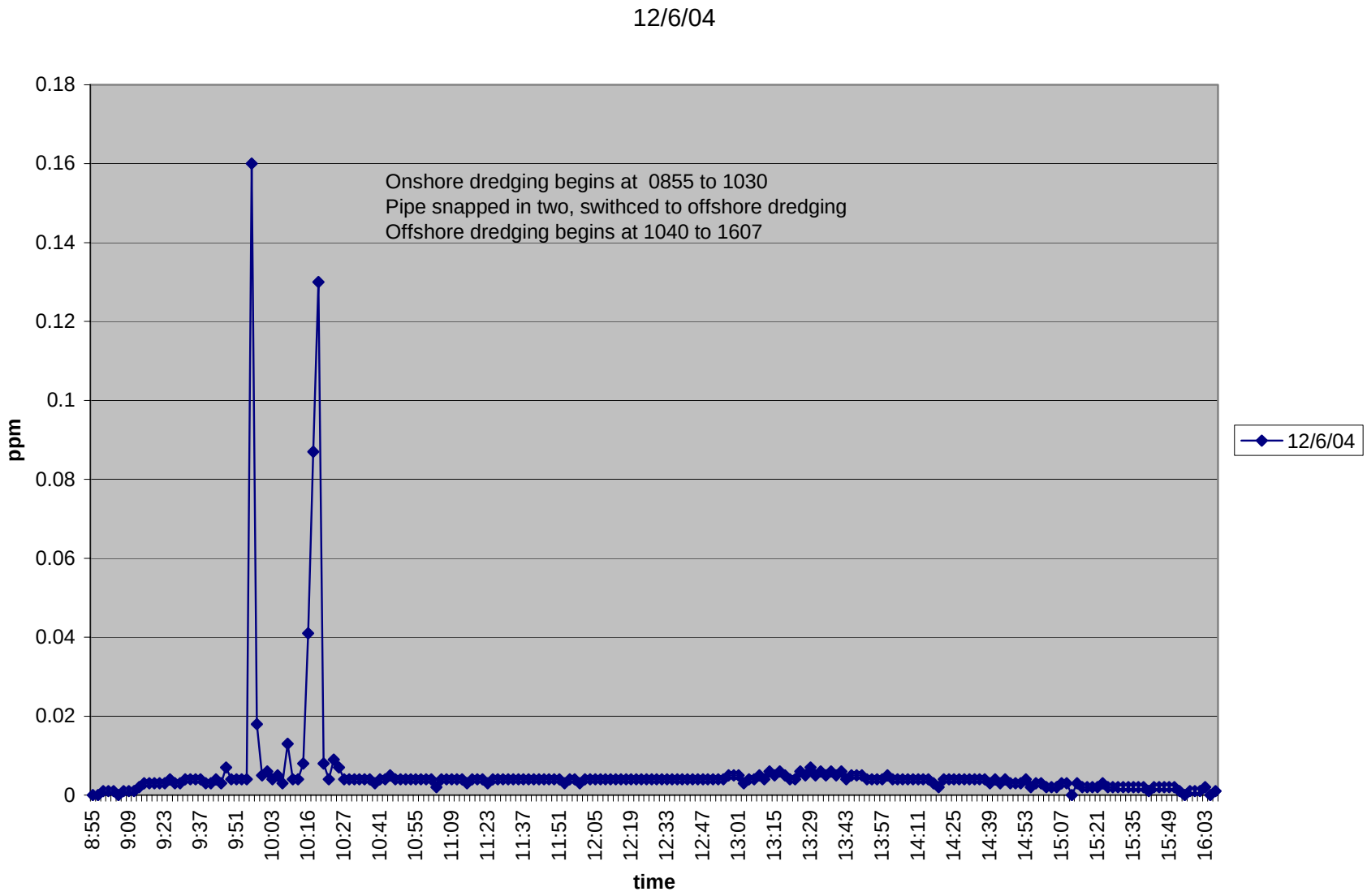
Graph E7. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, November 22, 2004, Santa Cruz Harbor, Santa Cruz County, California



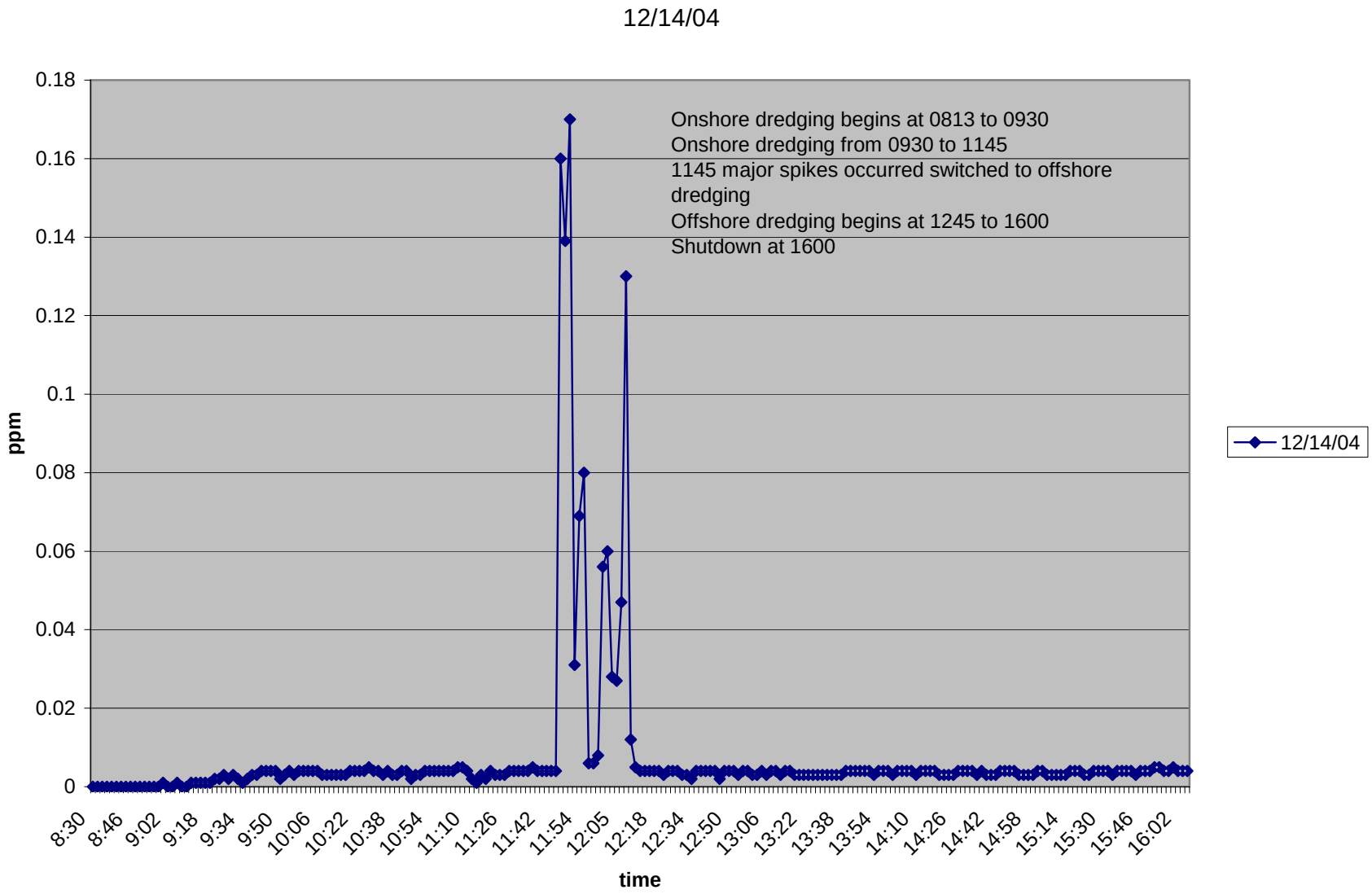
Graph E8. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, November 23, 2004, Santa Cruz Harbor, Santa Cruz County, California



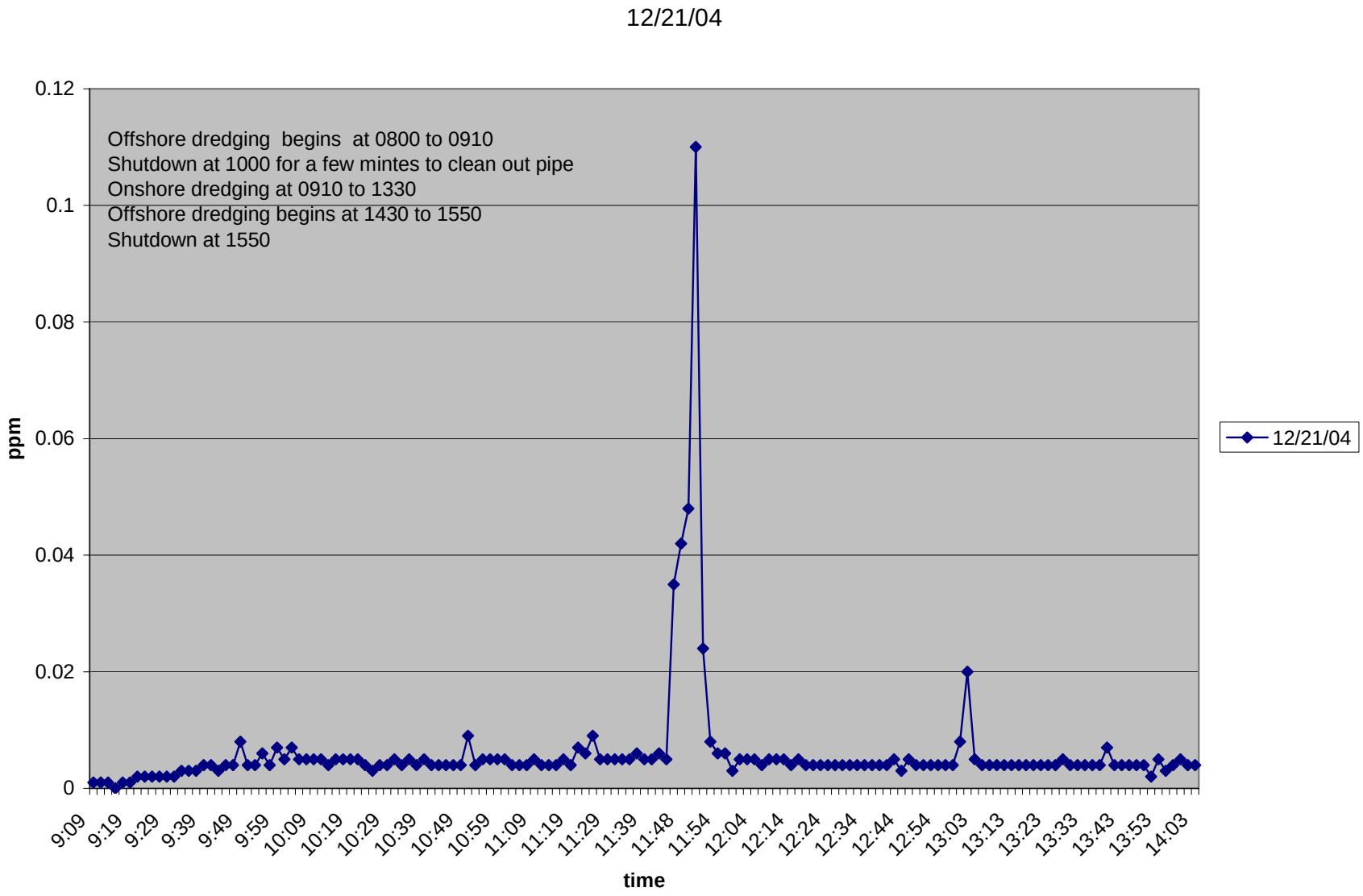
Graph E9. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, December 6, 2004, Santa Cruz Harbor, Santa Cruz County, California



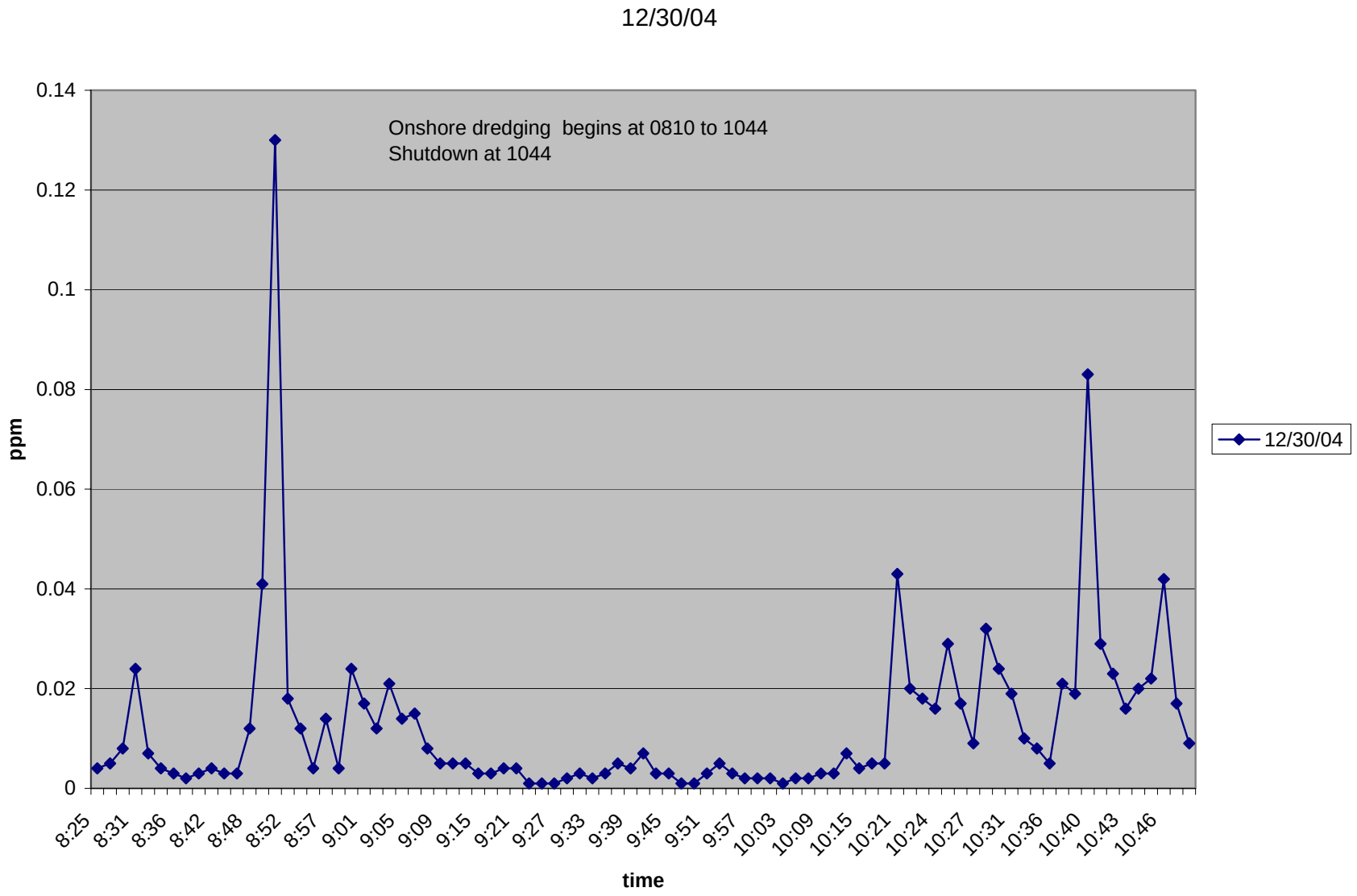
Graph E10. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, December 14, 2004, Santa Cruz Harbor, Santa Cruz County, California



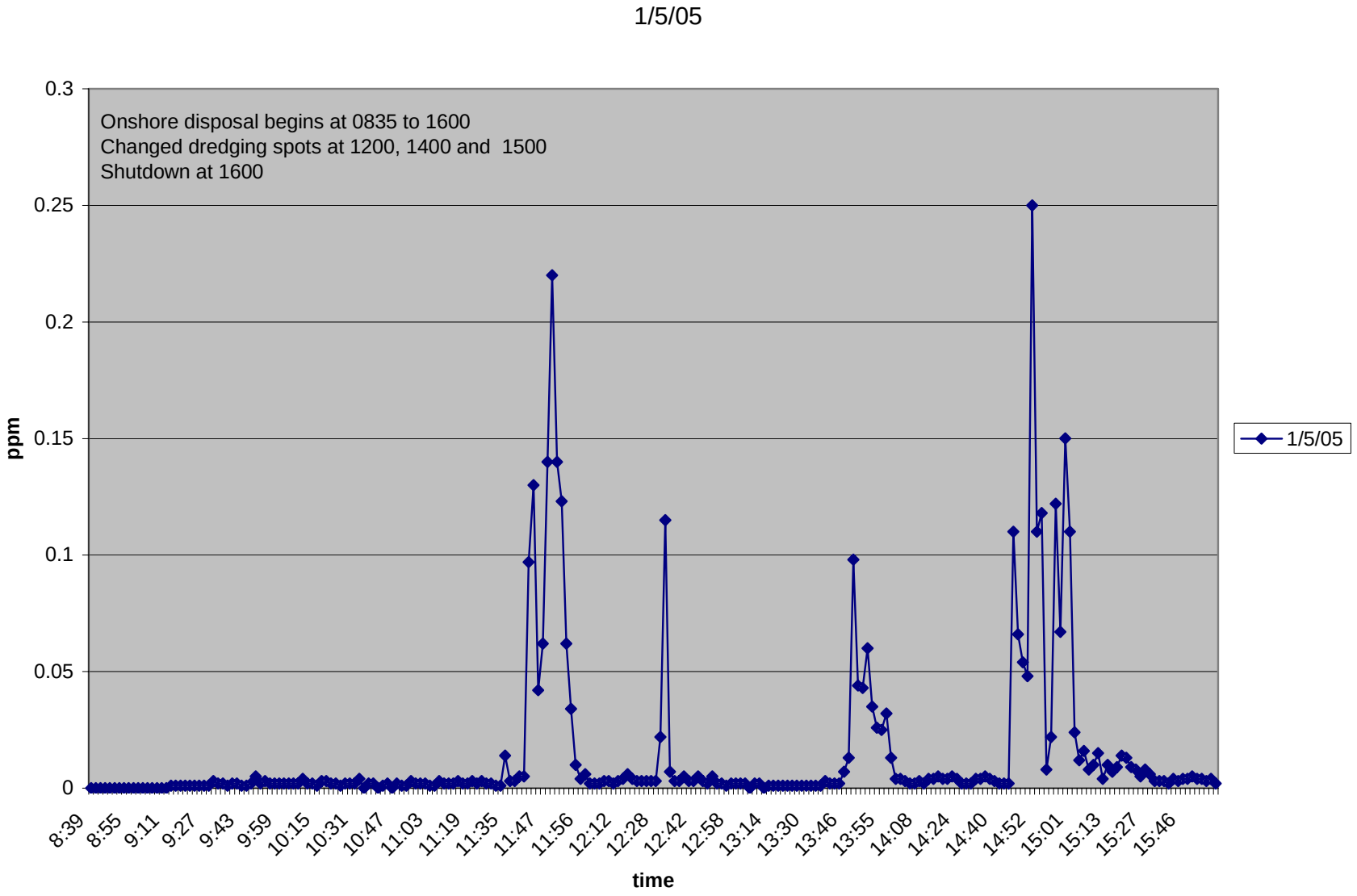
Graph E11. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, December 21, 2004, Santa Cruz Harbor, Santa Cruz County, California



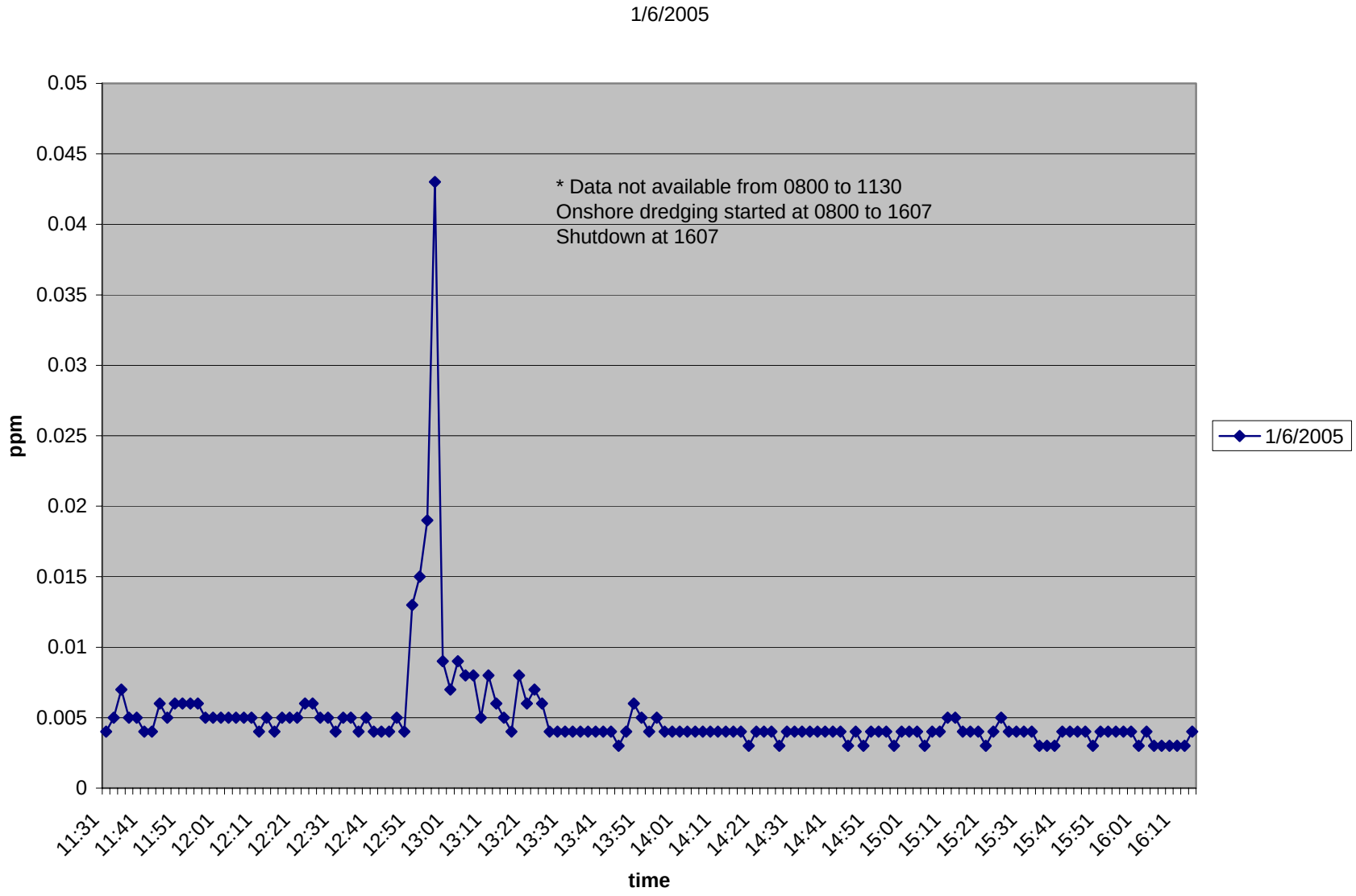
Graph E12. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, December 30, 2004, Santa Cruz Harbor, Santa Cruz County, California



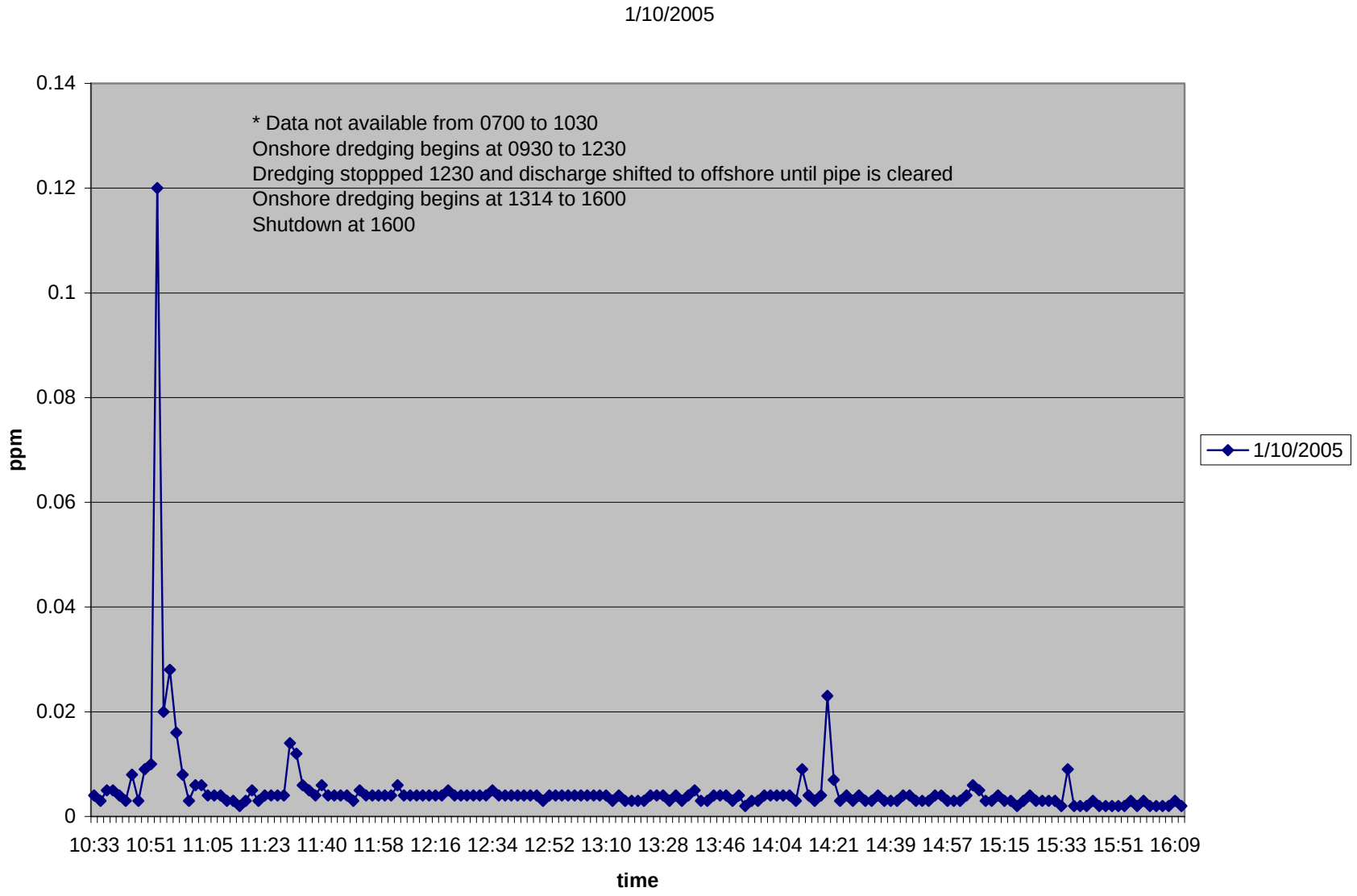
Graph E13. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 5, 2005, Santa Cruz Harbor, Santa Cruz County, California



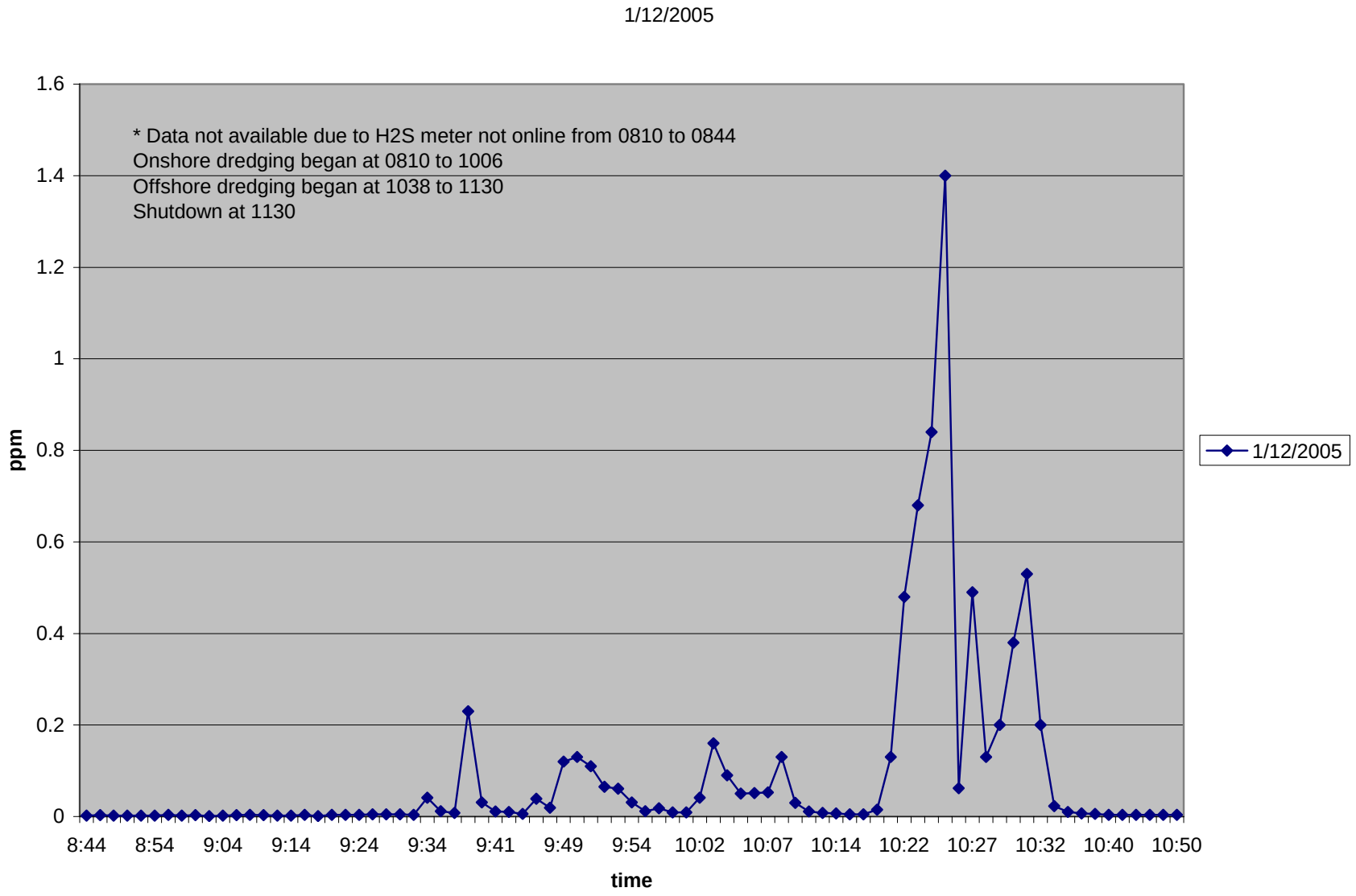
Graph E14. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 6, 2005, Santa Cruz Harbor, Santa Cruz County, California



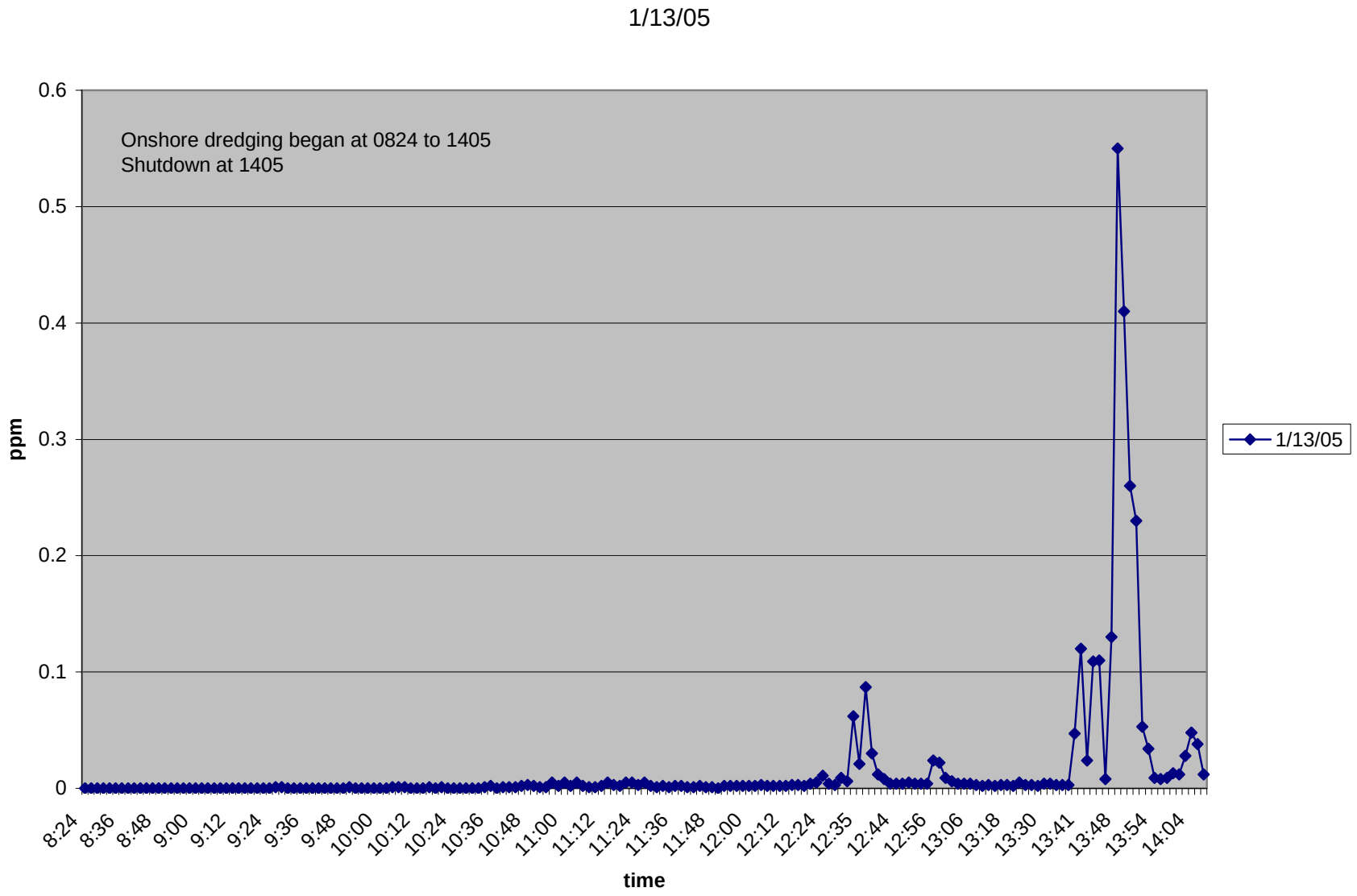
Graph E15. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 10, 2005, Santa Cruz Harbor, Santa Cruz County, California



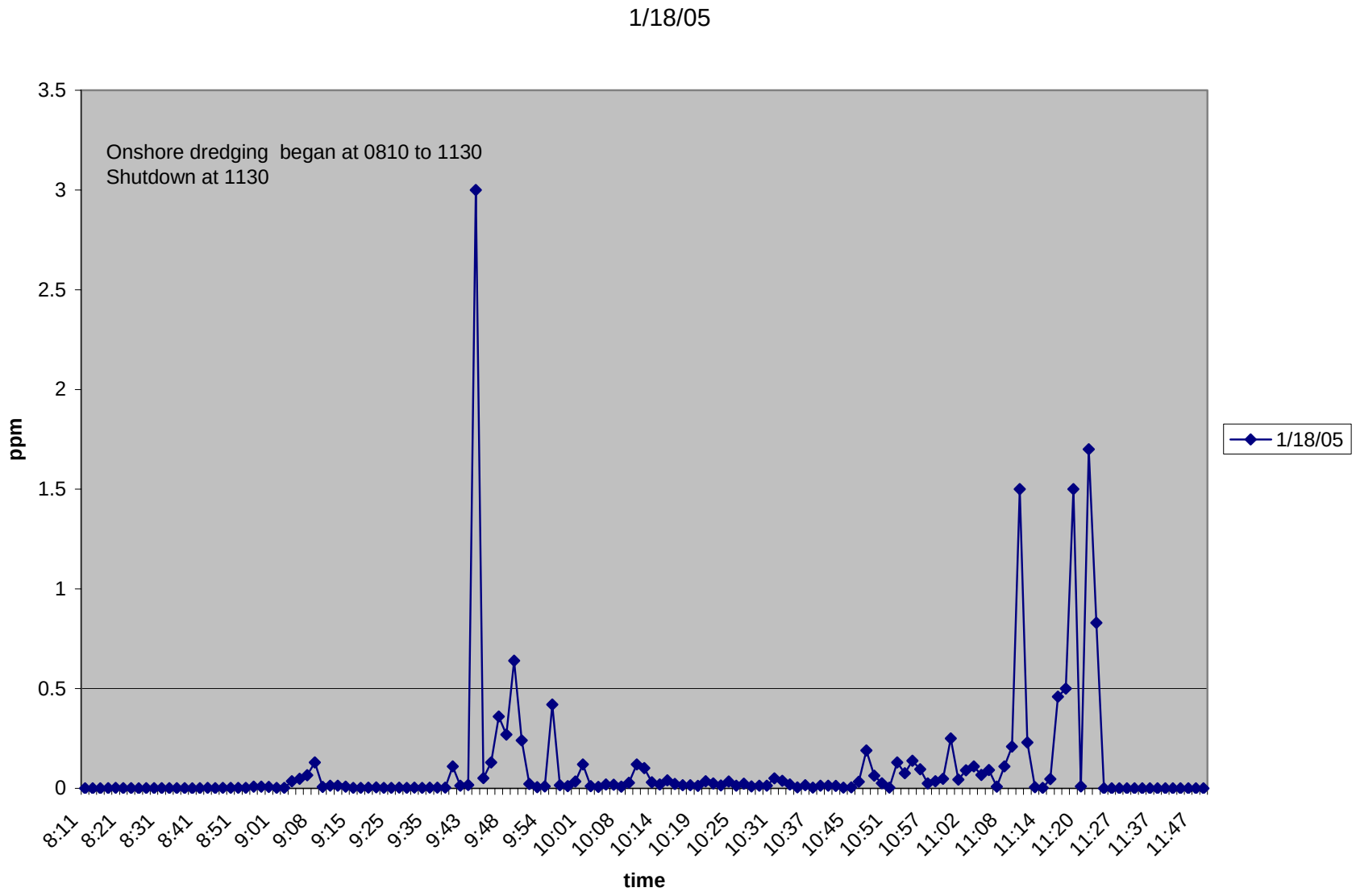
Graph E16. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 10, 2005, Santa Cruz Harbor, Santa Cruz County, California



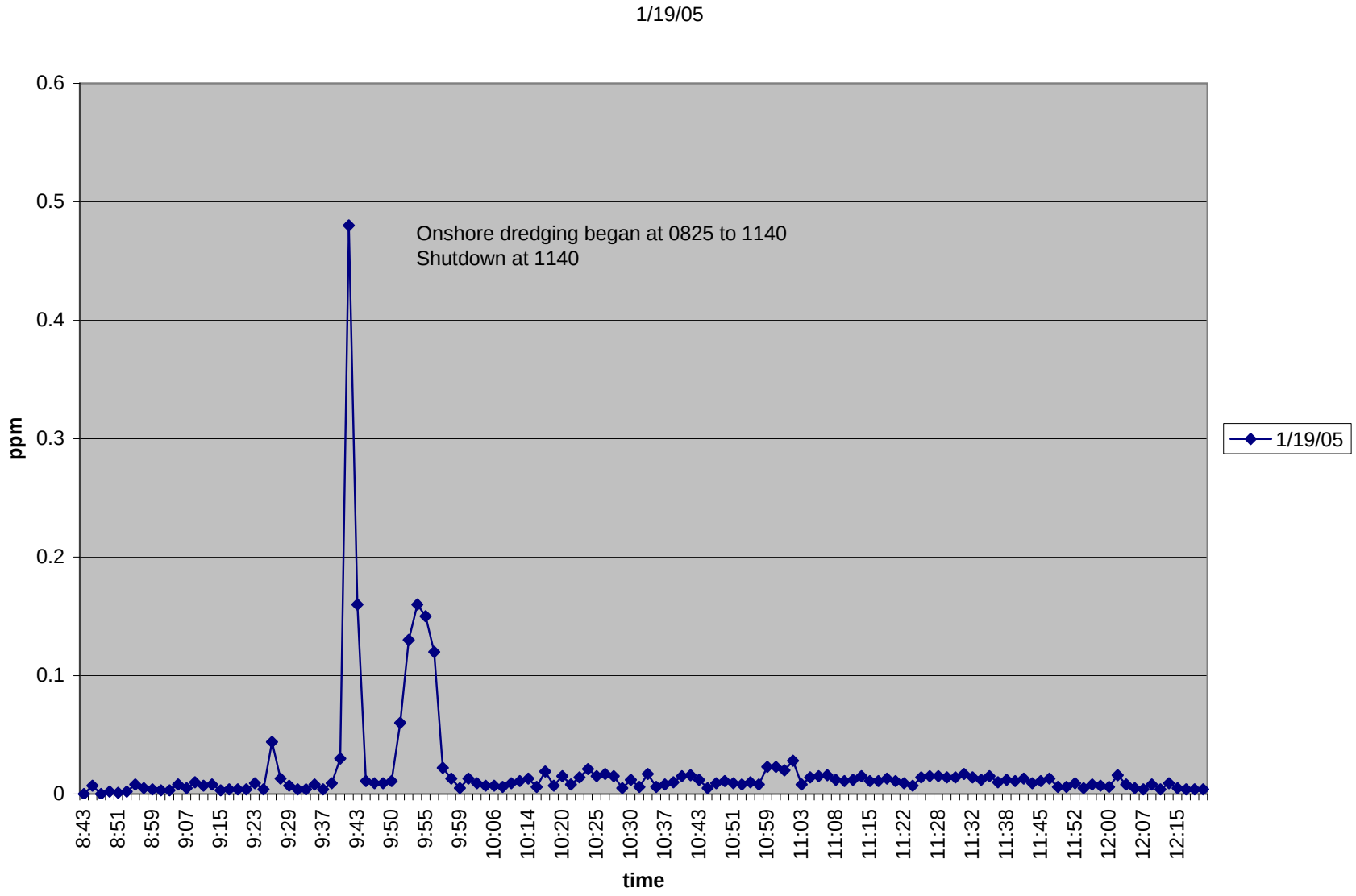
Graph E17. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 13, 2005, Santa Cruz Harbor, Santa Cruz County, California



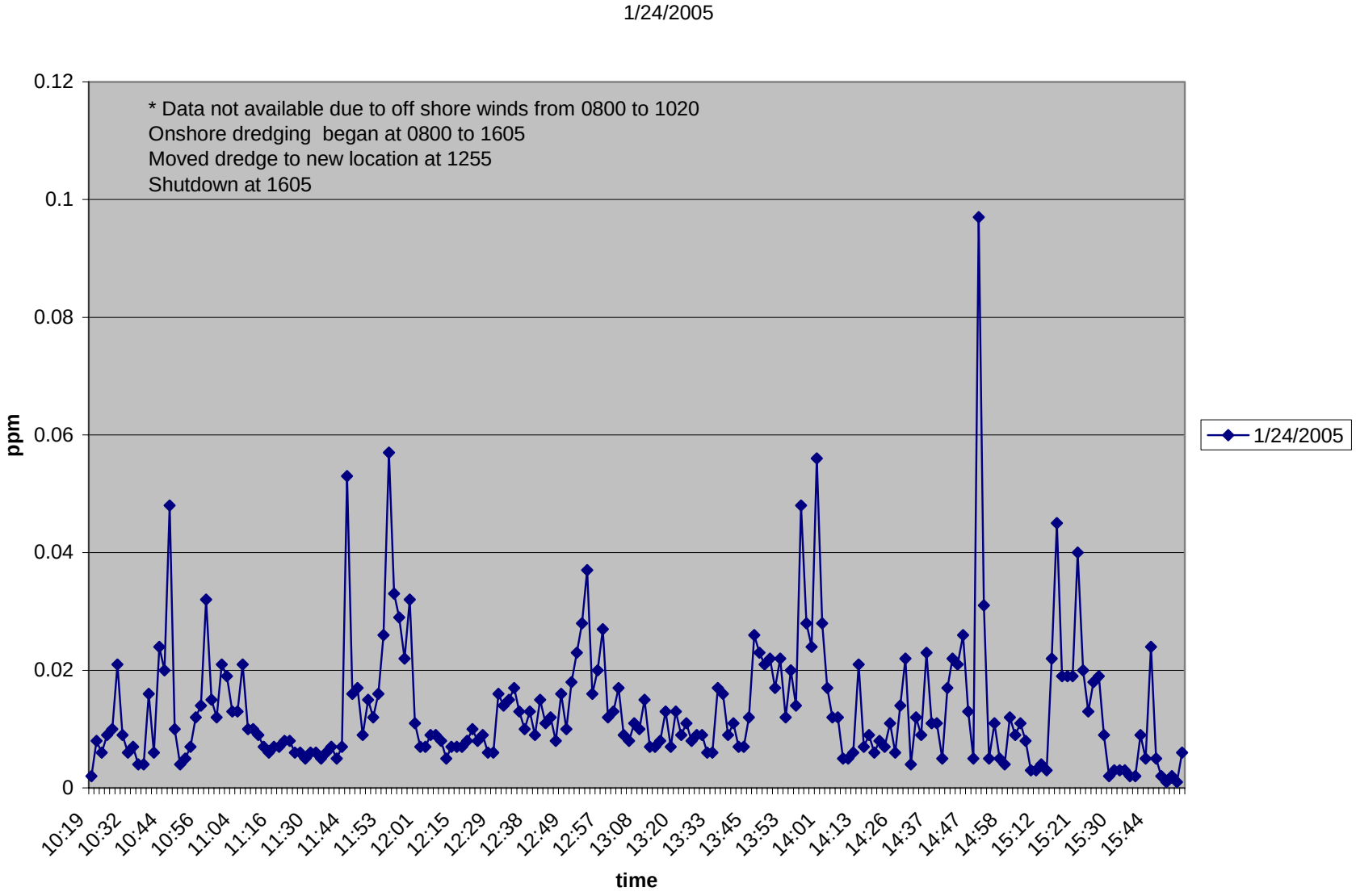
Graph E18. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 18, 2005, Santa Cruz Harbor, Santa Cruz County, California



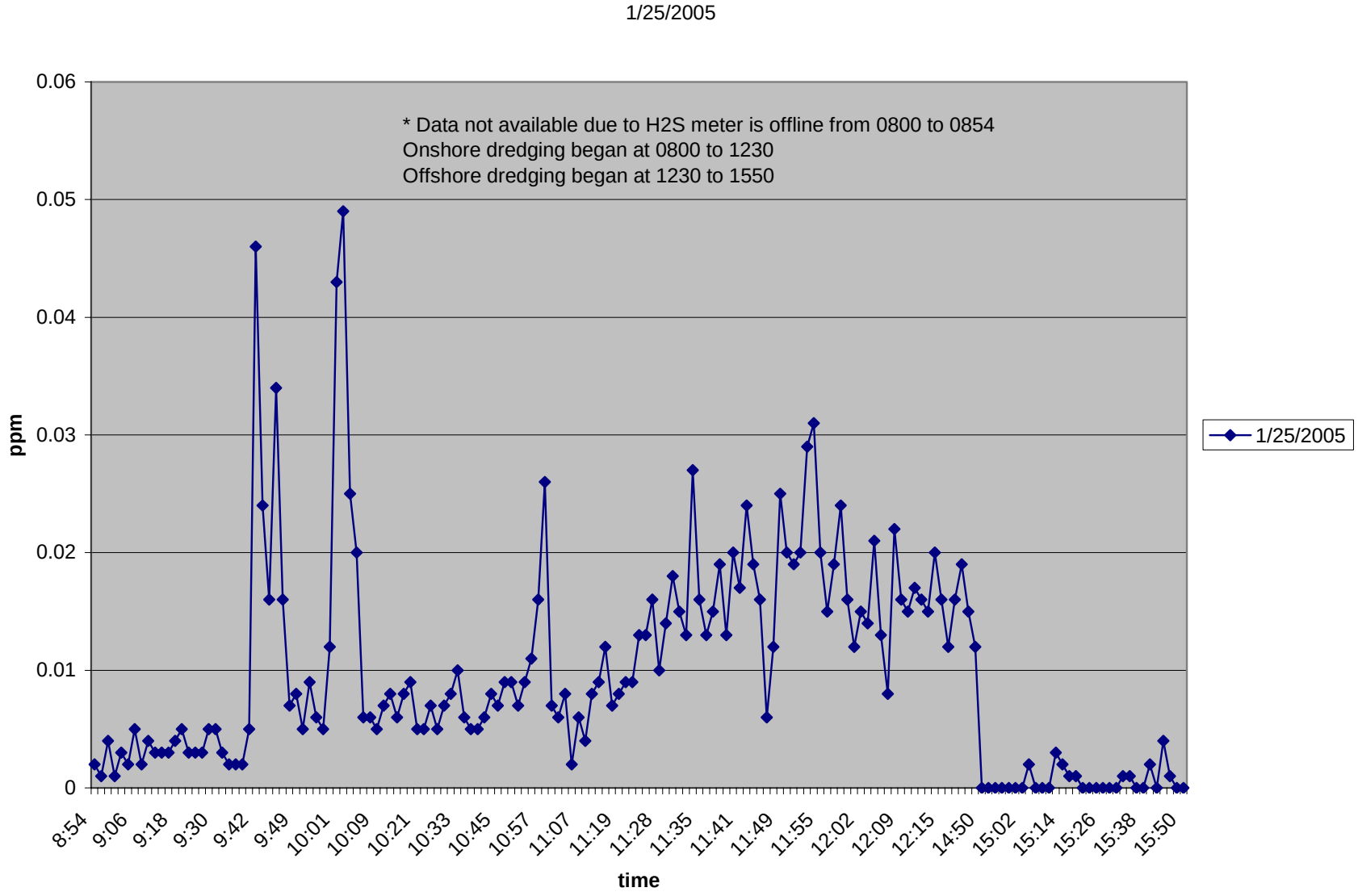
Graph E19. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 19, 2005, Santa Cruz Harbor, Santa Cruz County, California



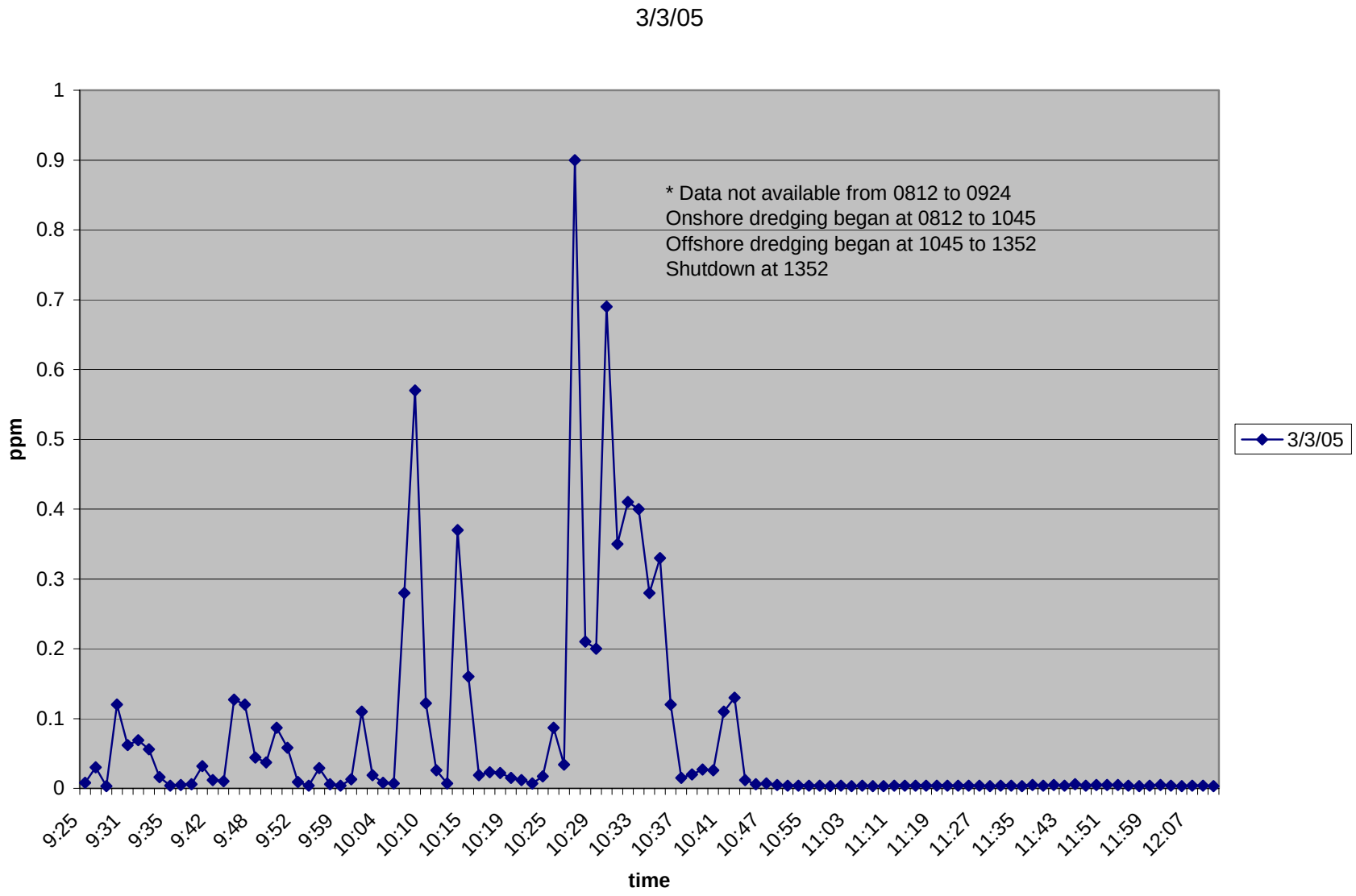
Graph E20. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 24, 2005, Santa Cruz Harbor, Santa Cruz County, California



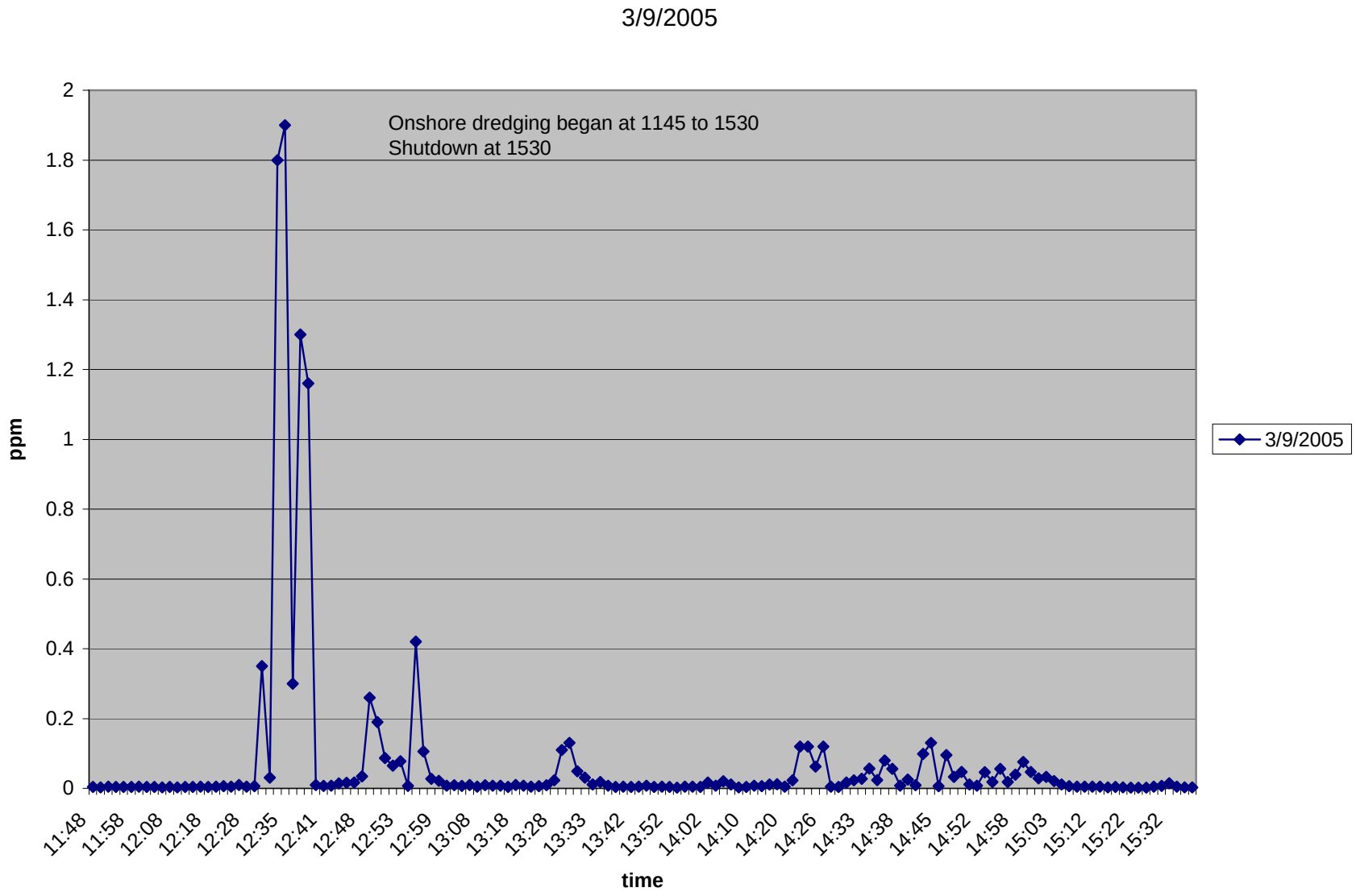
Graph E21. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 25, 2005, Santa Cruz Harbor, Santa Cruz County, California



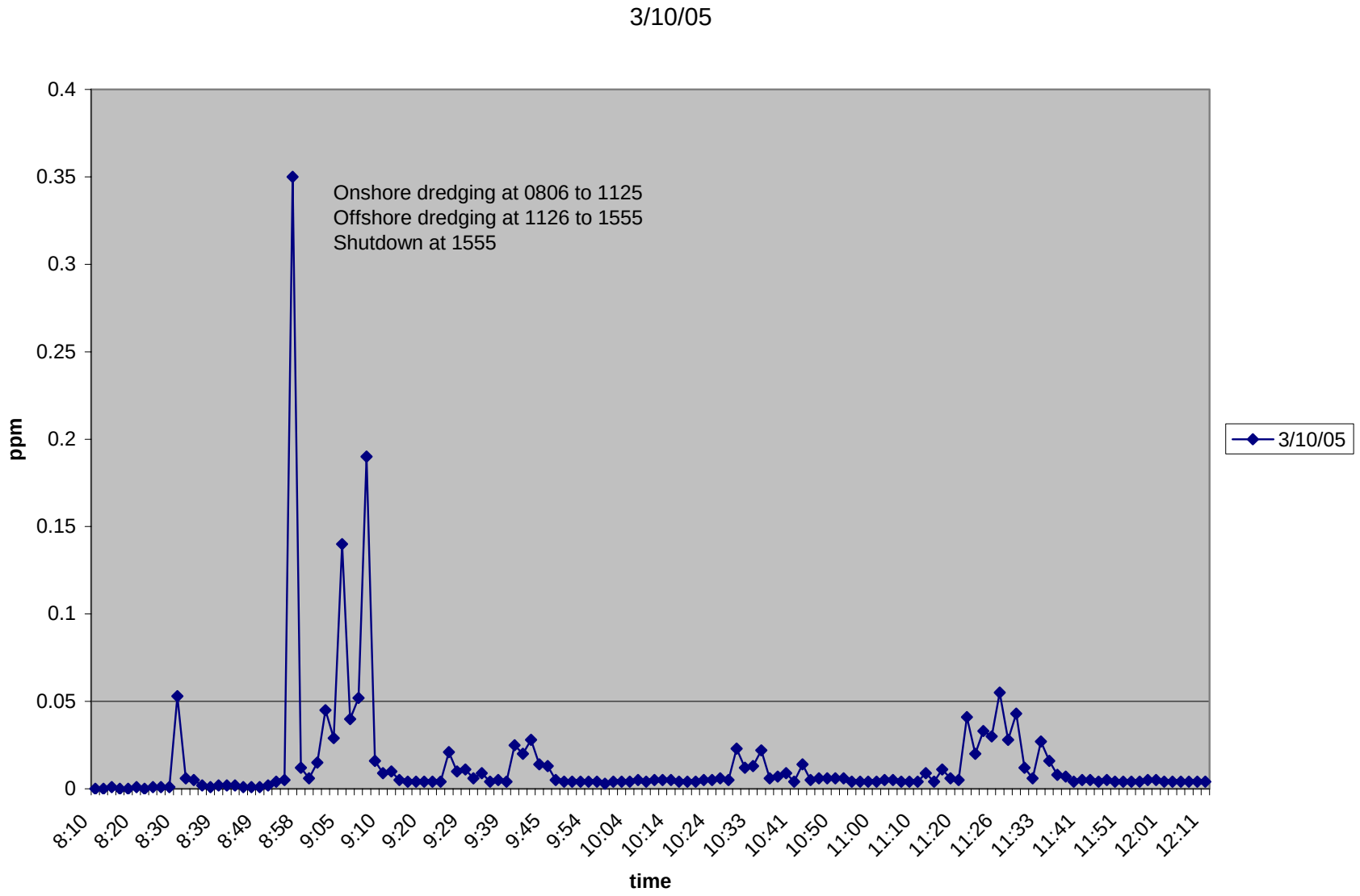
Graph E22. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, March 3, 2005, Santa Cruz Harbor, Santa Cruz County, California



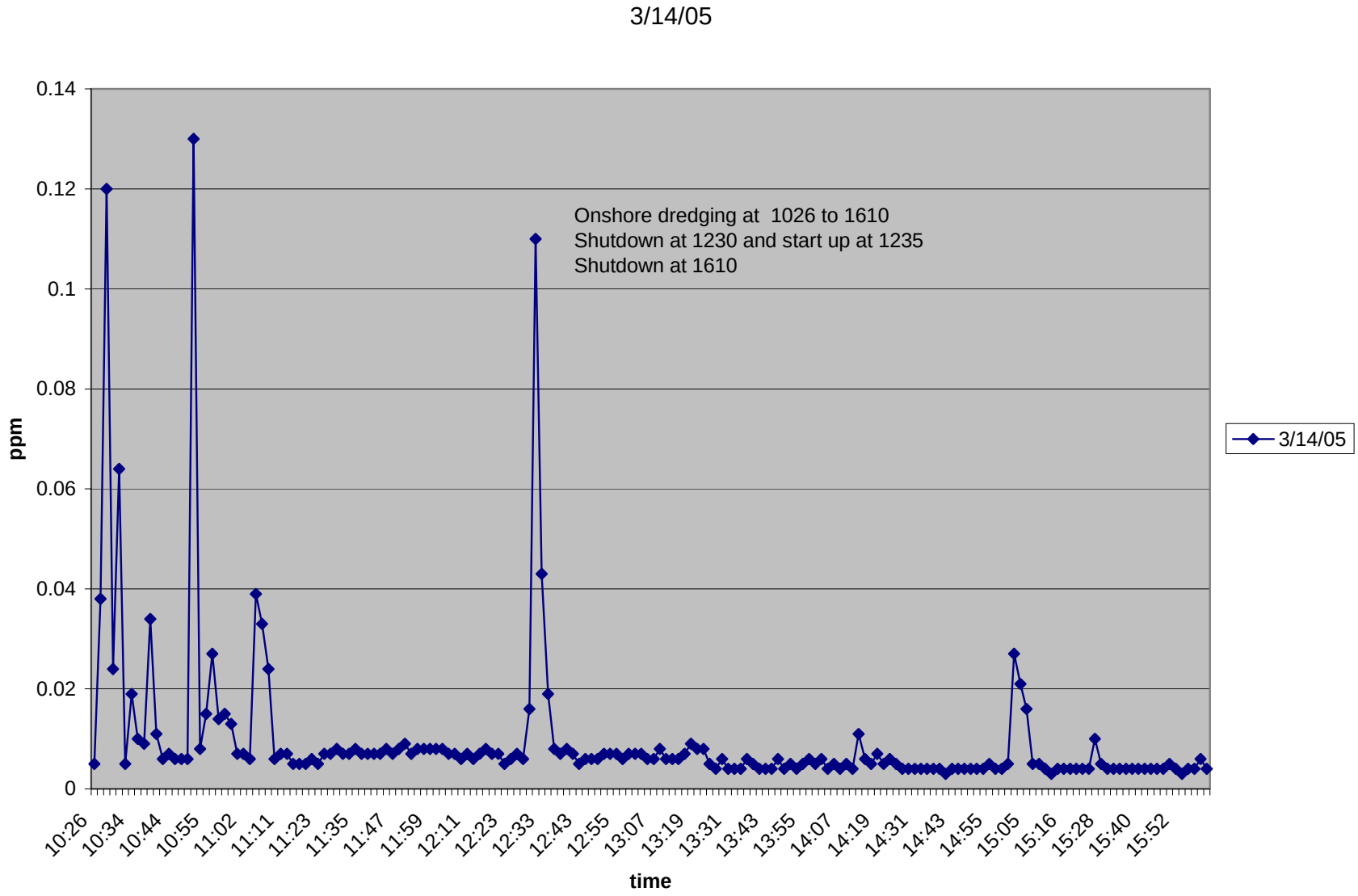
Graph E23. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, March 9, 2005, Santa Cruz Harbor, Santa Cruz County, California



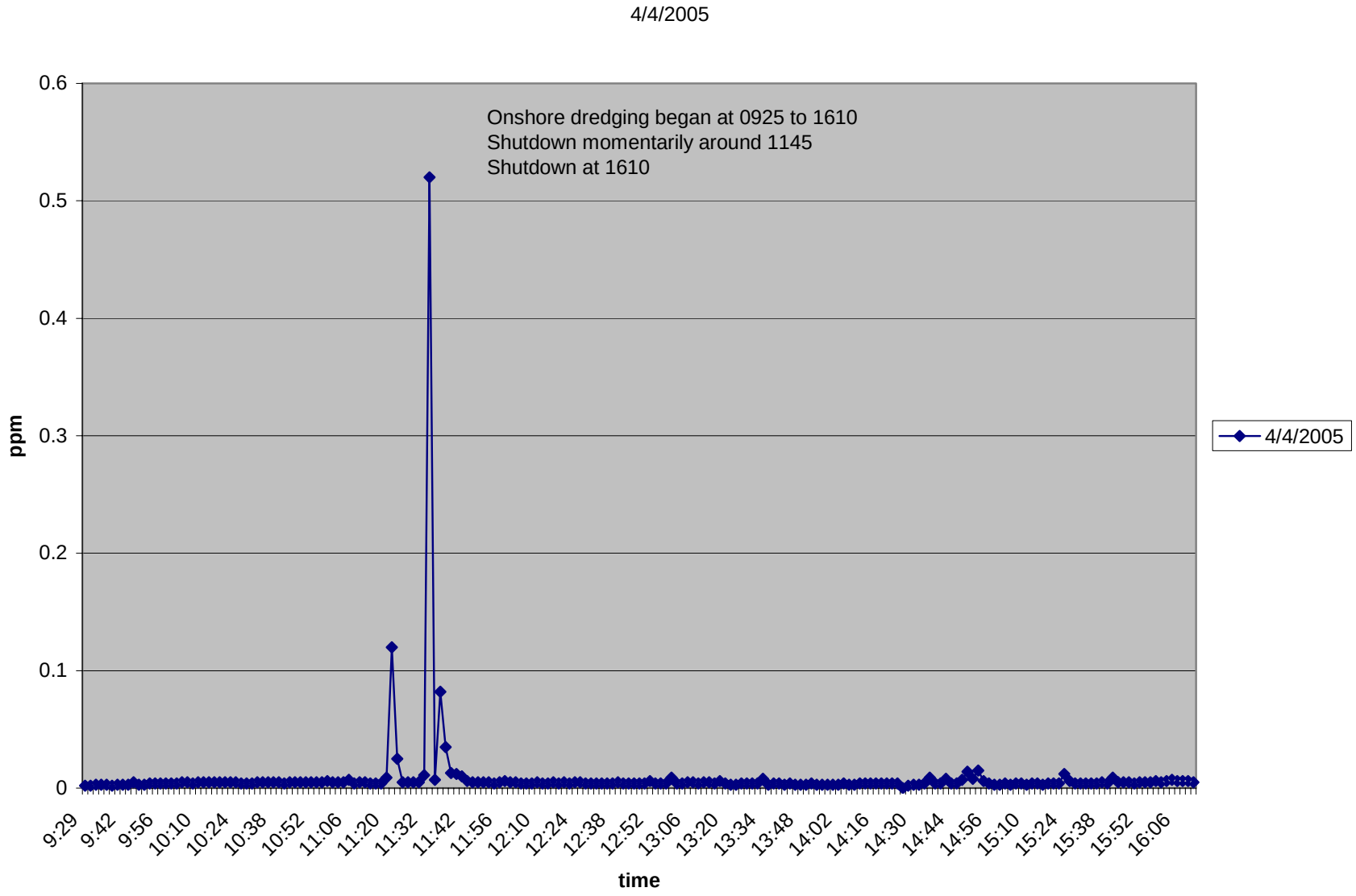
Graph E24. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, March 10, 2005, Santa Cruz Harbor, Santa Cruz County, California



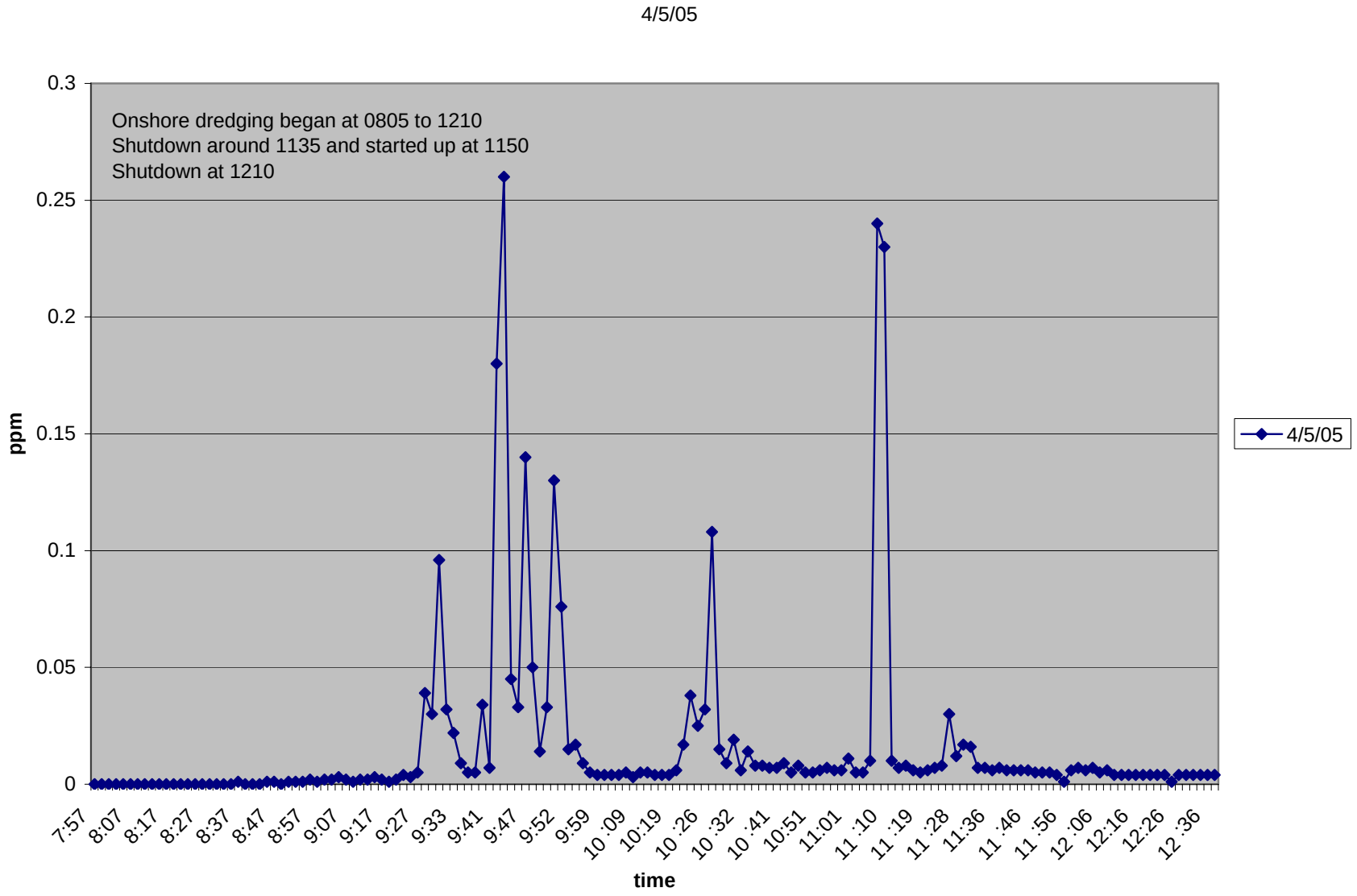
Graph E25. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, March 14, 2005, Santa Cruz Harbor, Santa Cruz County, California



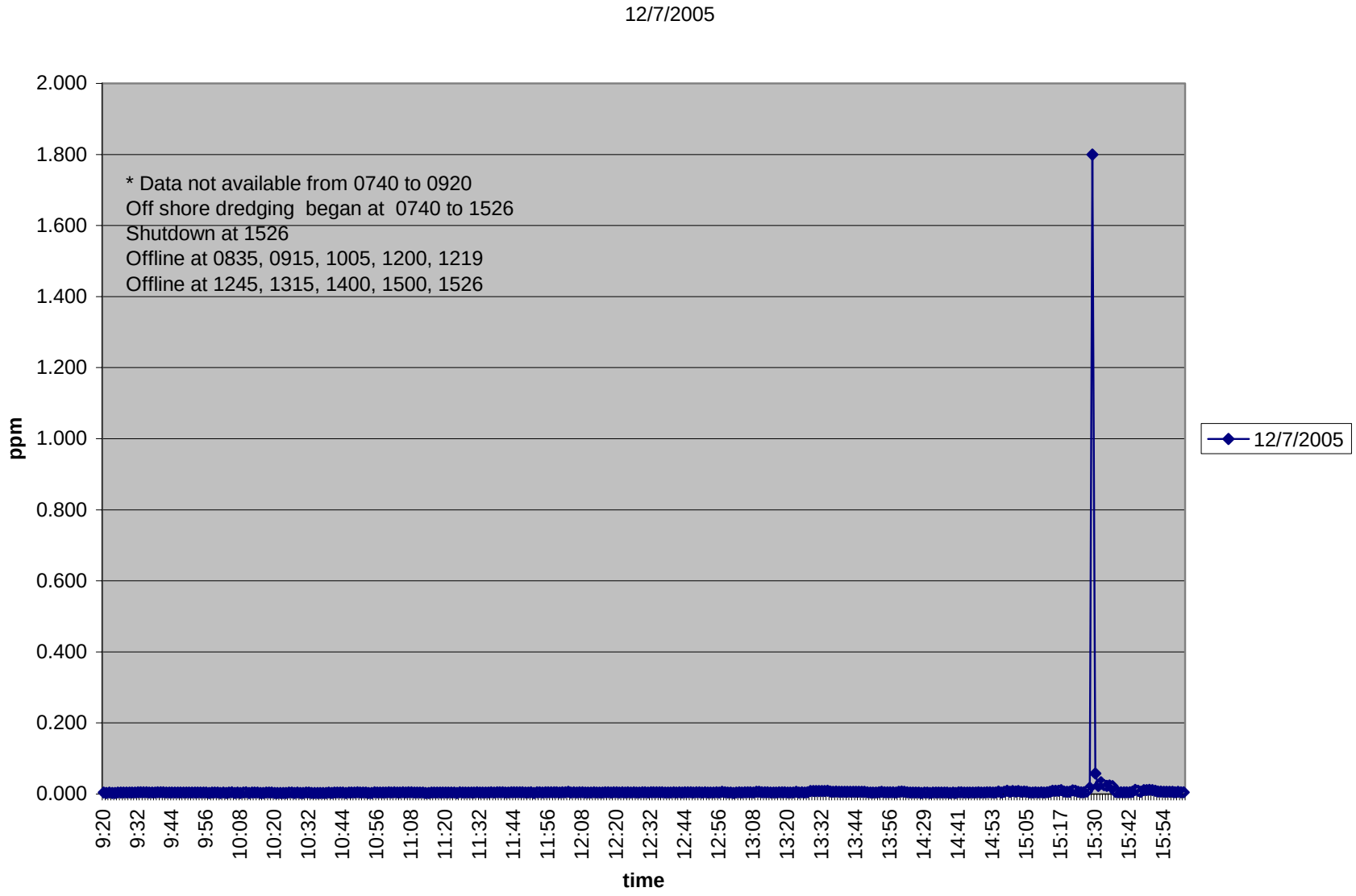
Graph E26. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, April 4, 2005, Santa Cruz Harbor, Santa Cruz County, California



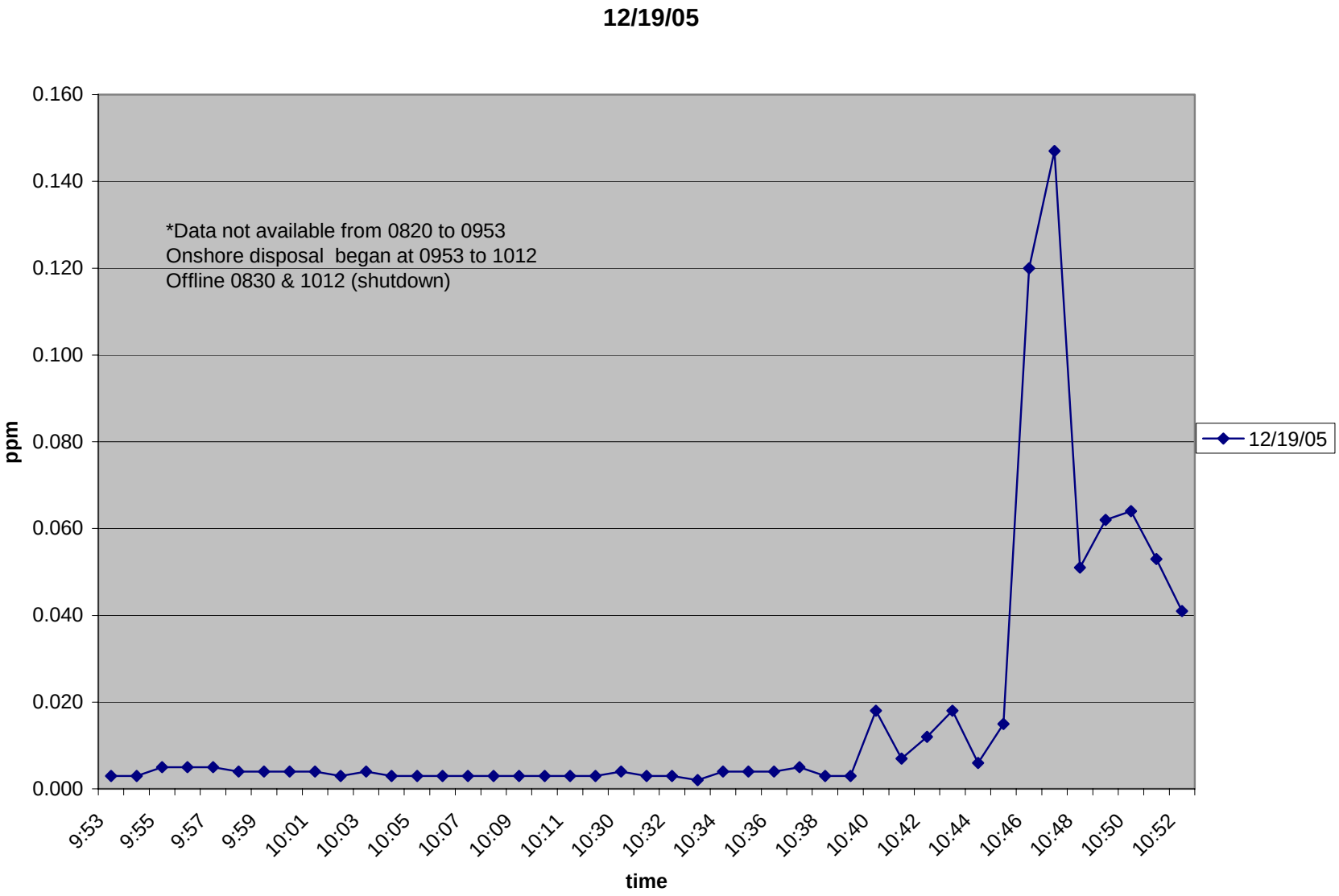
Graph E27. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, March 5, 2005, Santa Cruz Harbor, Santa Cruz County, California



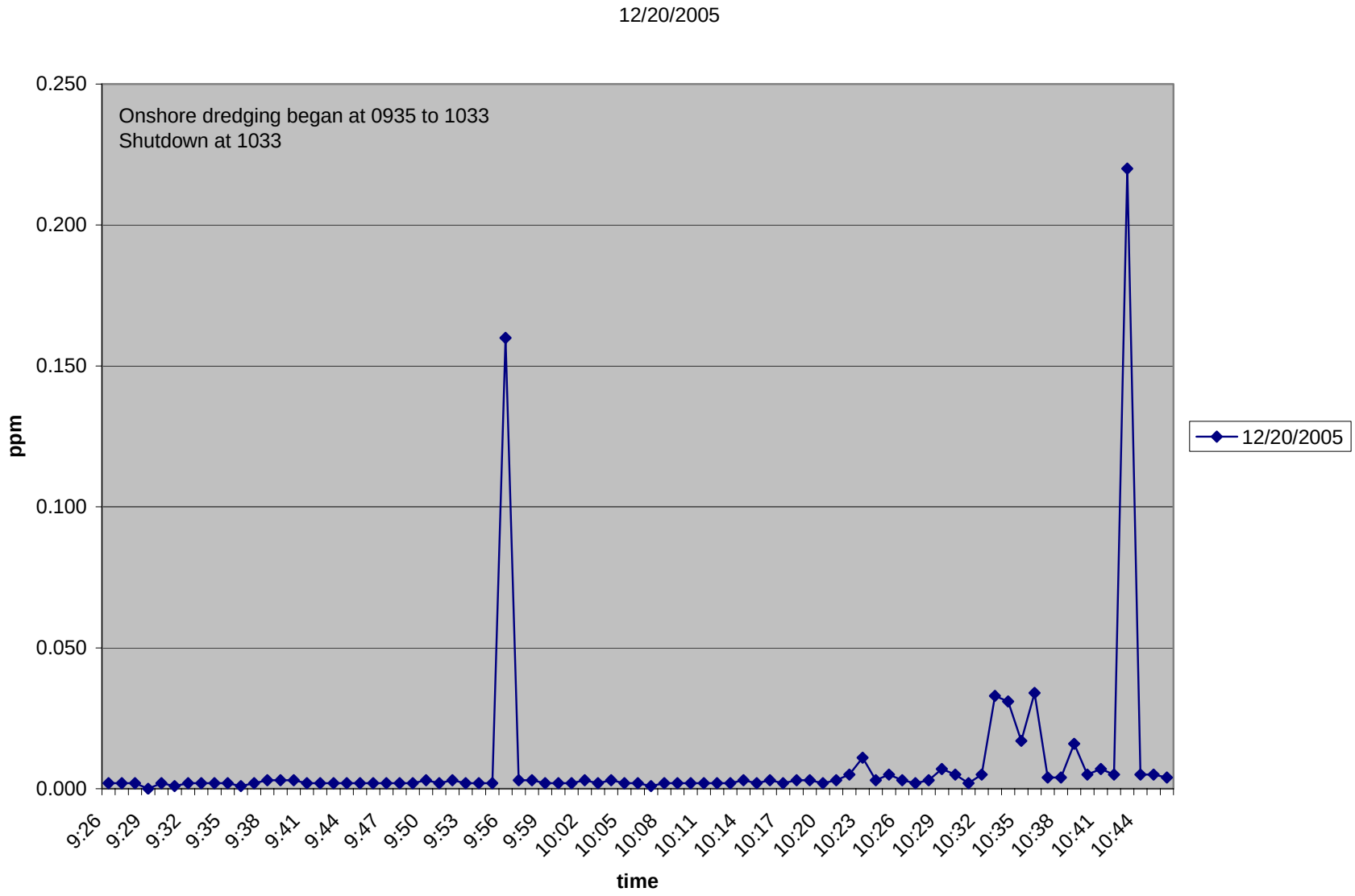
Graph E28. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, December 7, 2005, Santa Cruz Harbor, Santa Cruz County, California



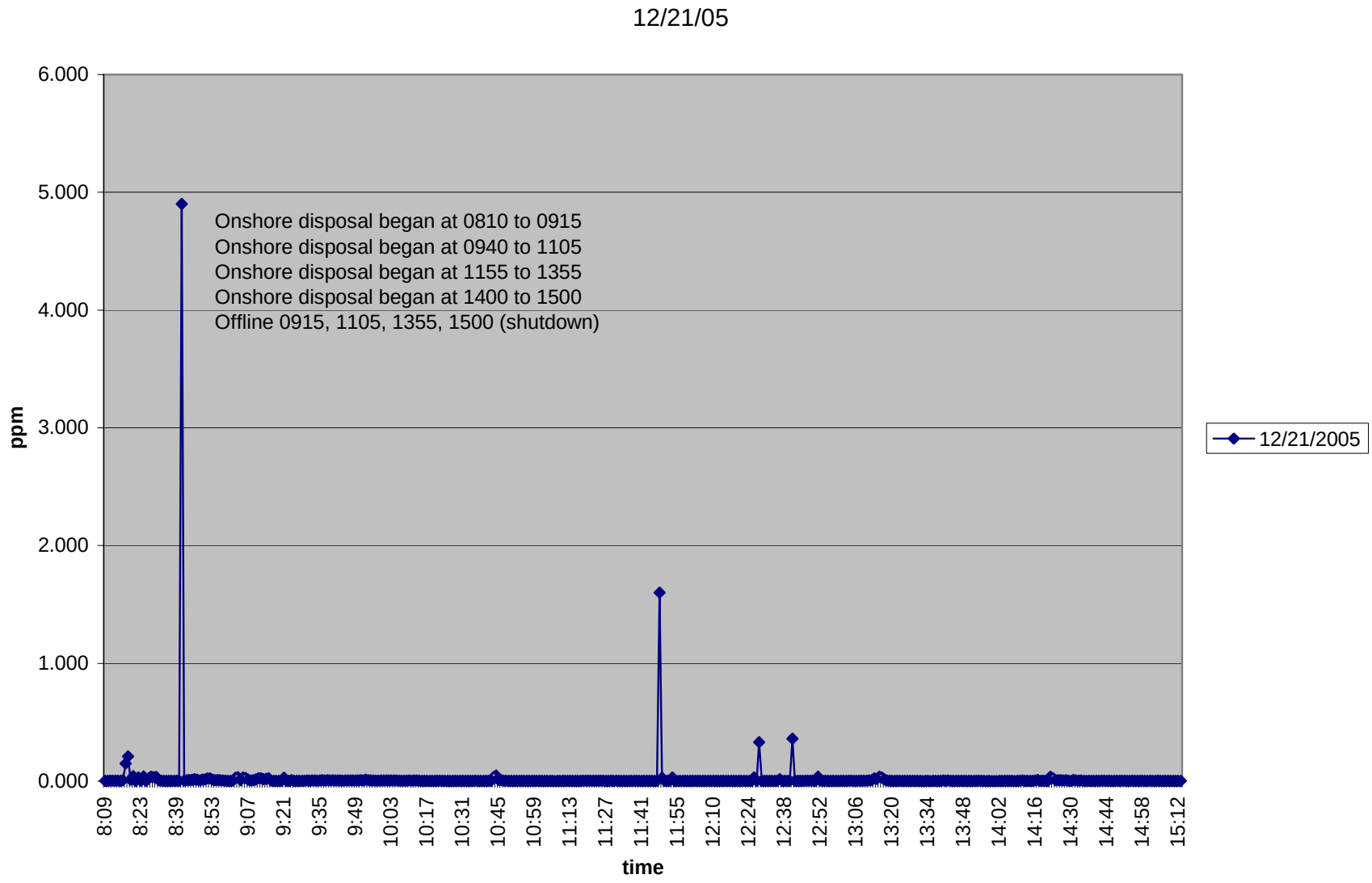
Graph E29. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, December 19, 2005, Santa Cruz Harbor, Santa Cruz County, California



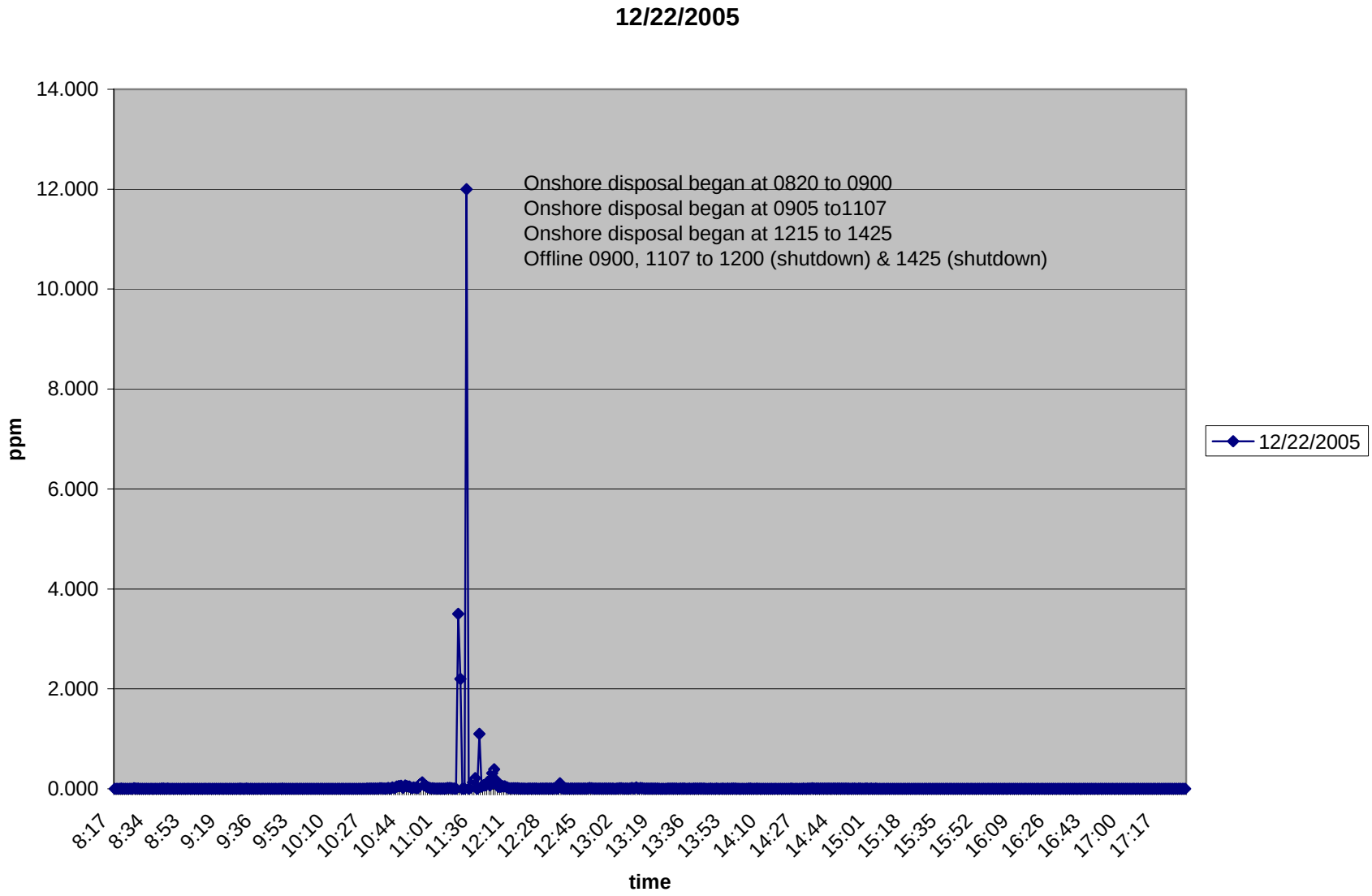
Graph E30. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, December 20, 2005, Santa Cruz Harbor, Santa Cruz County, California



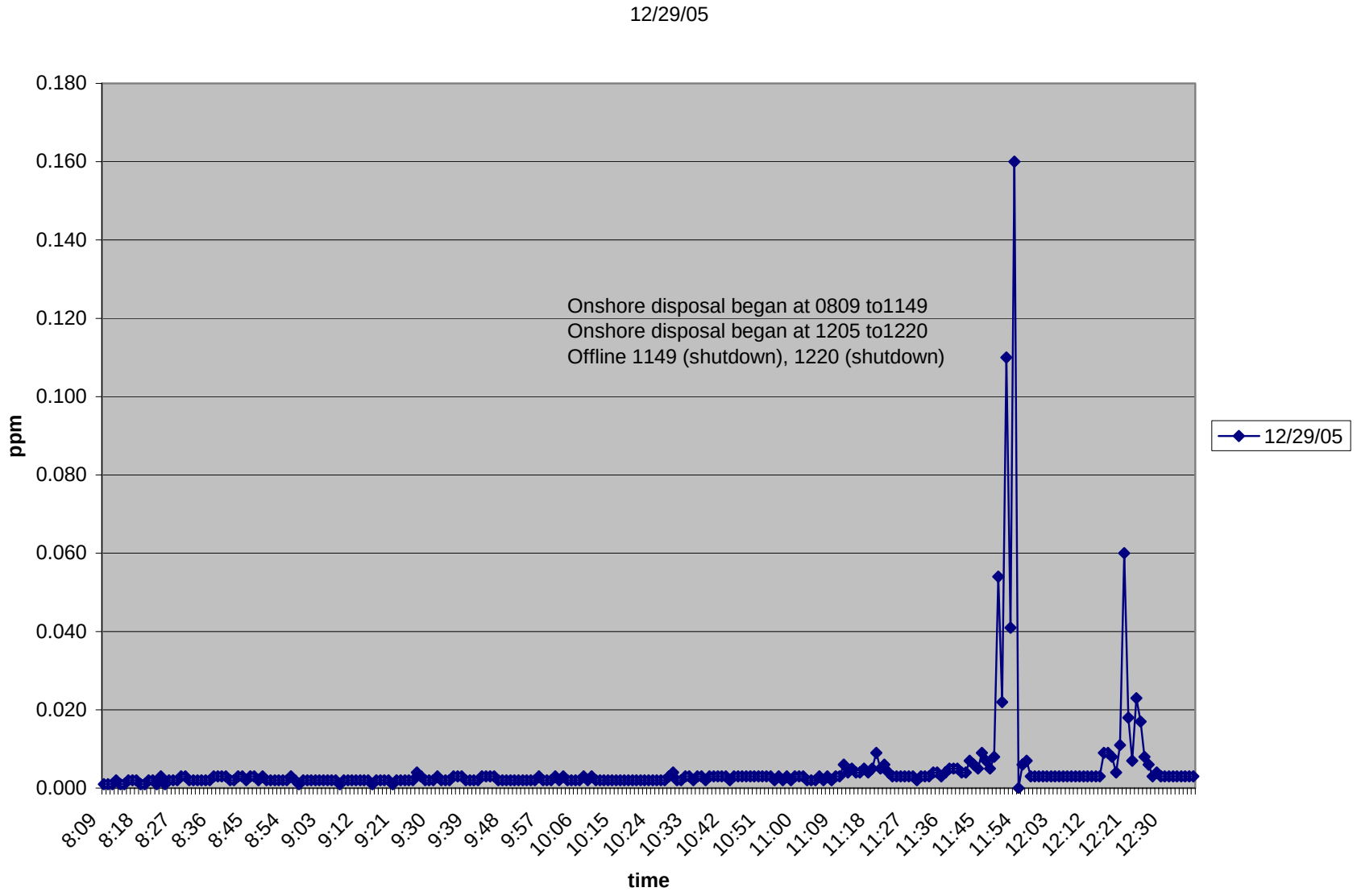
Graph E31. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, December 21, 2005, Santa Cruz Harbor, Santa Cruz County, California



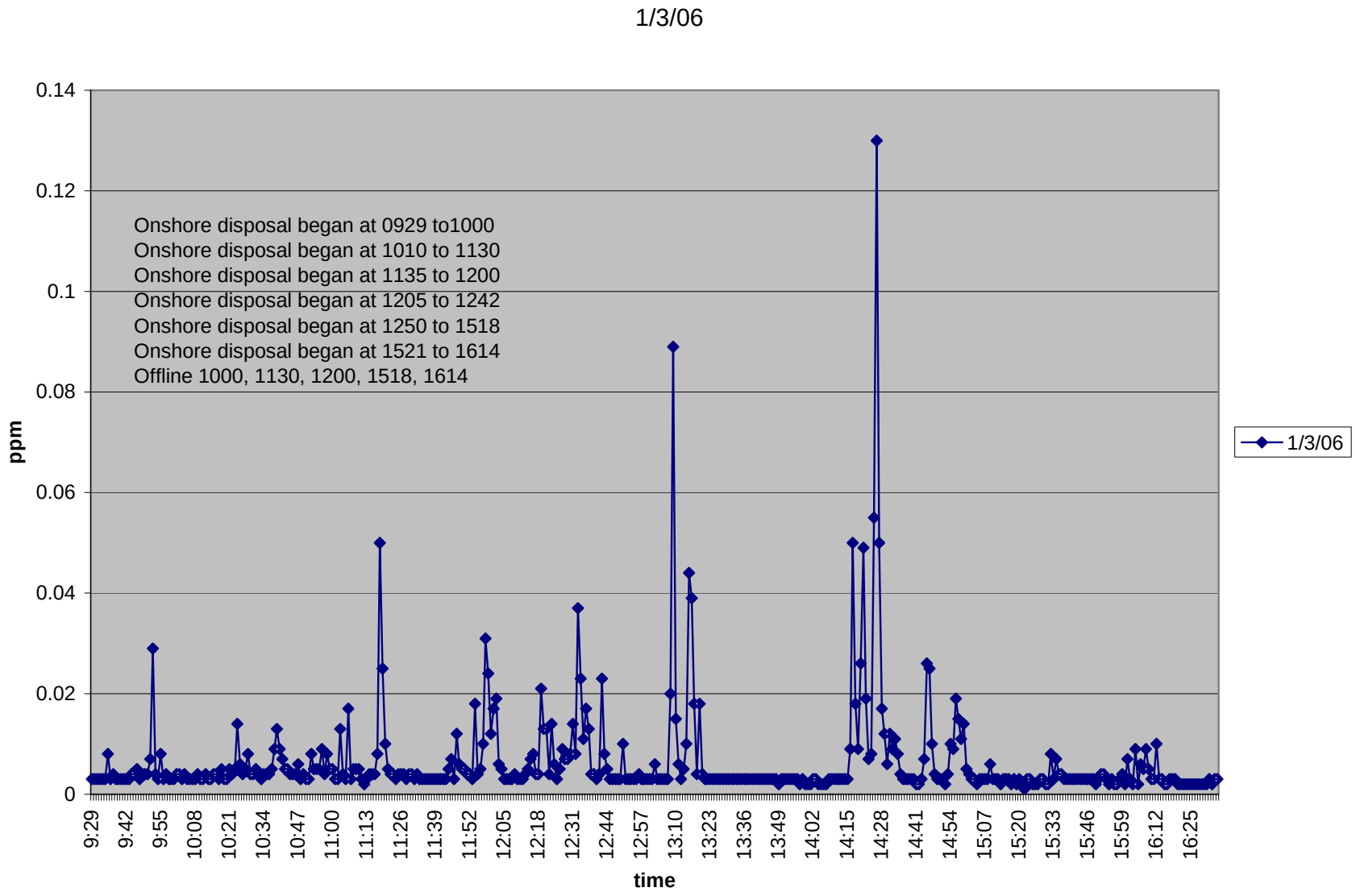
Graph E32. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, December 22, 2005, Santa Cruz Harbor, Santa Cruz County, California



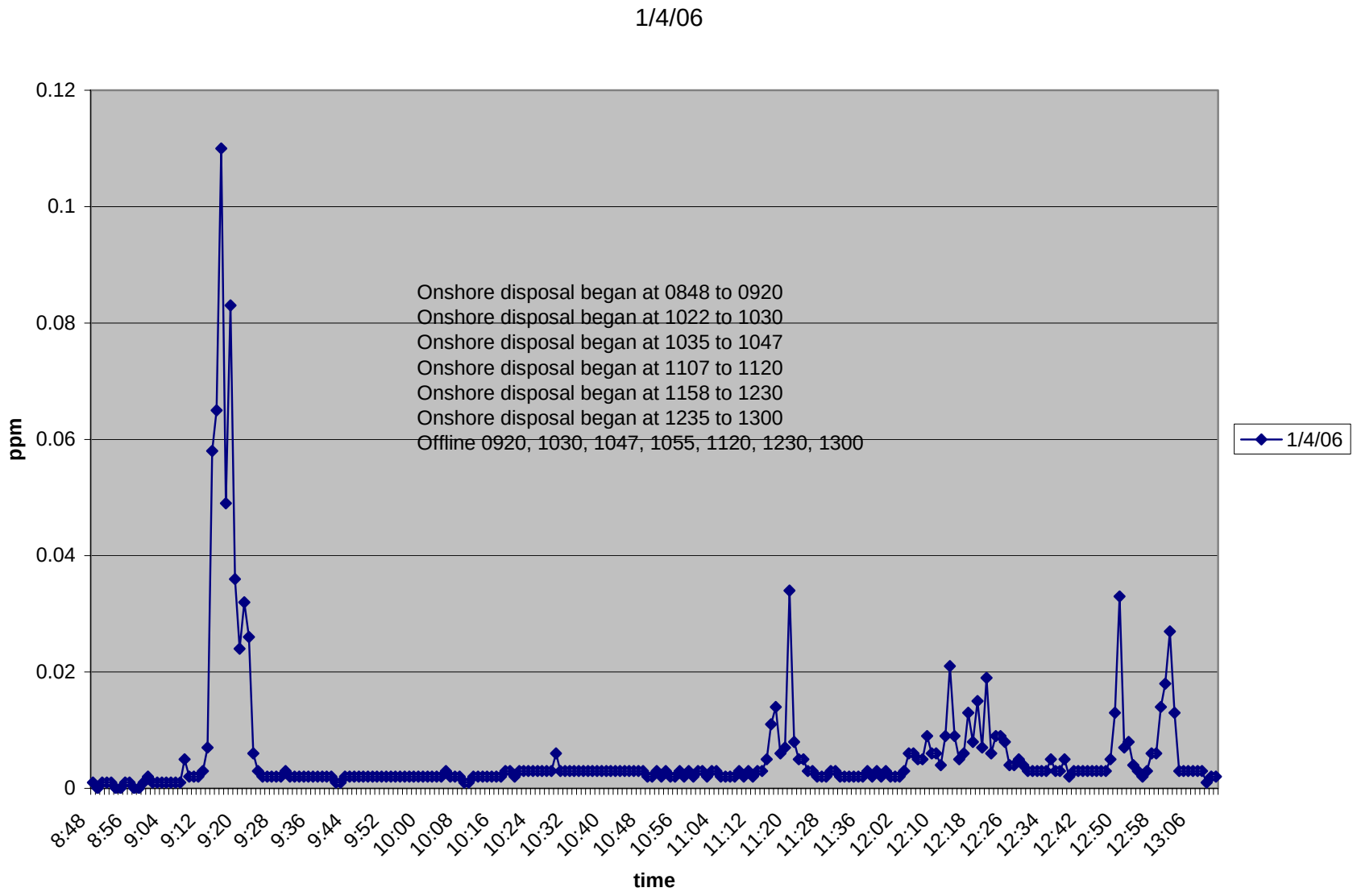
Graph E33. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, December 29, 2005, Santa Cruz Harbor, Santa Cruz County, California



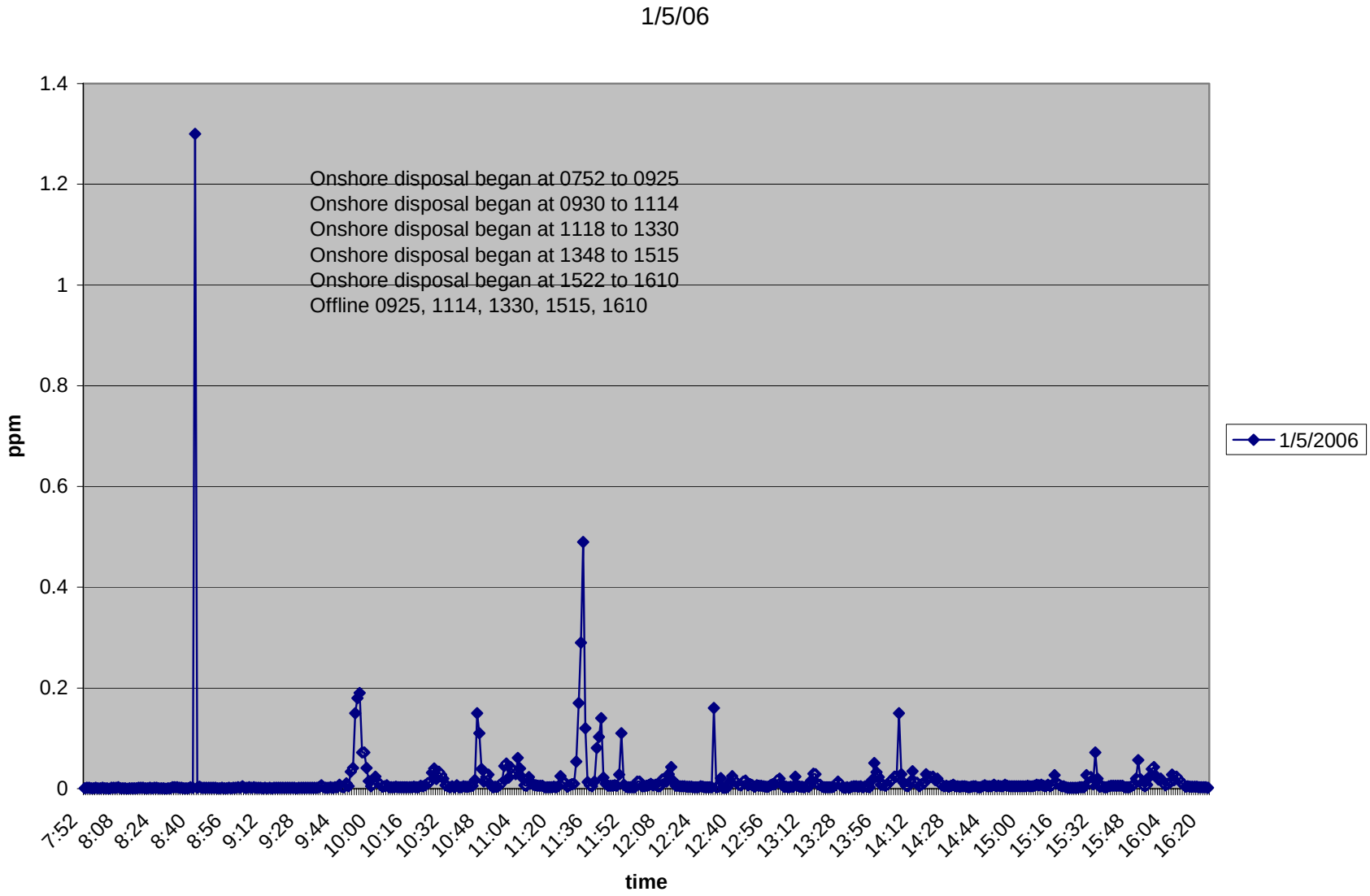
Graph E34. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 3, 2006, Santa Cruz Harbor, Santa Cruz County, California



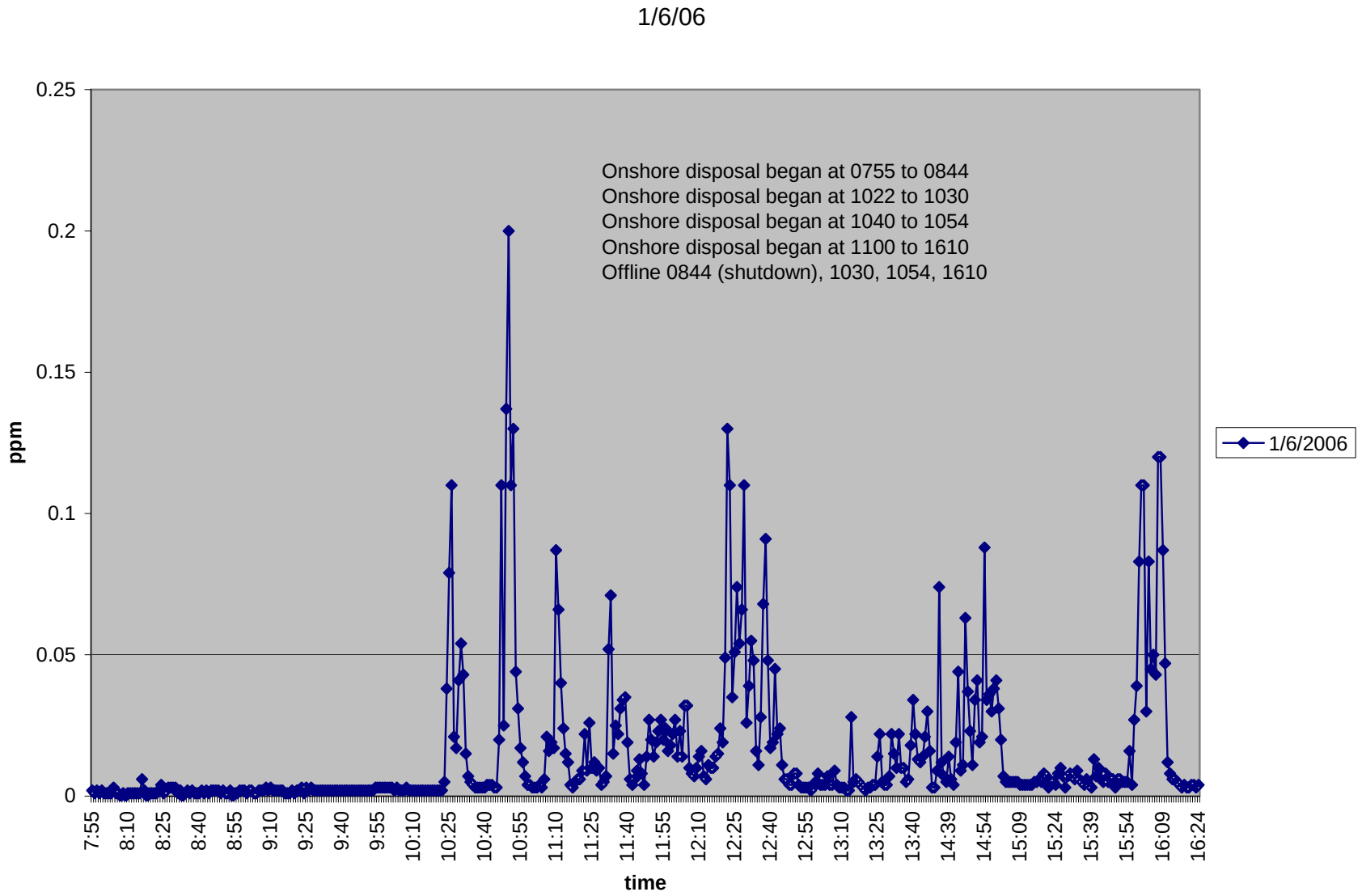
Graph E35. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 4, 2006, Santa Cruz Harbor, Santa Cruz County, California



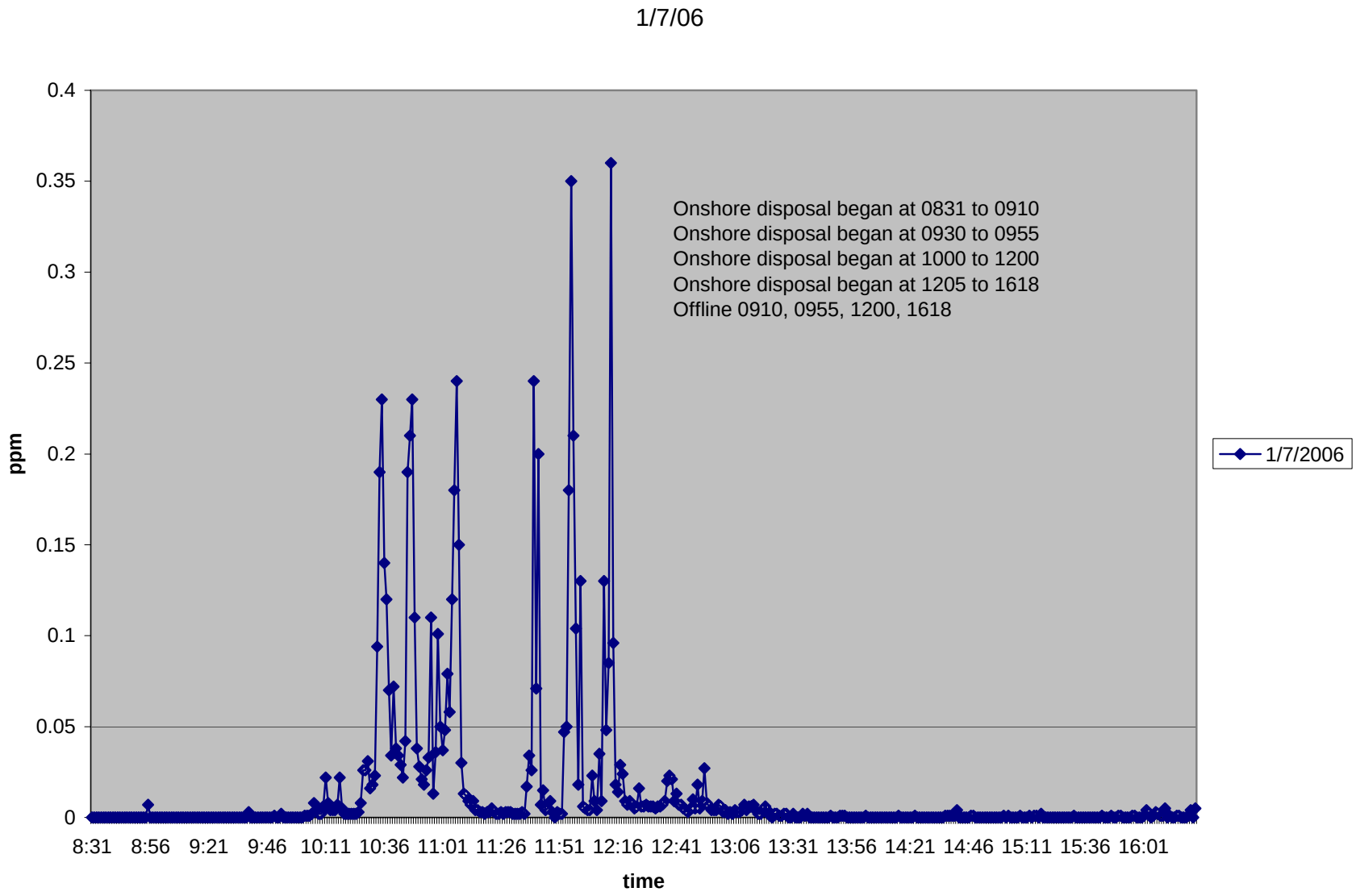
Graph E36. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 5, 2006, Santa Cruz Harbor, Santa Cruz County, California



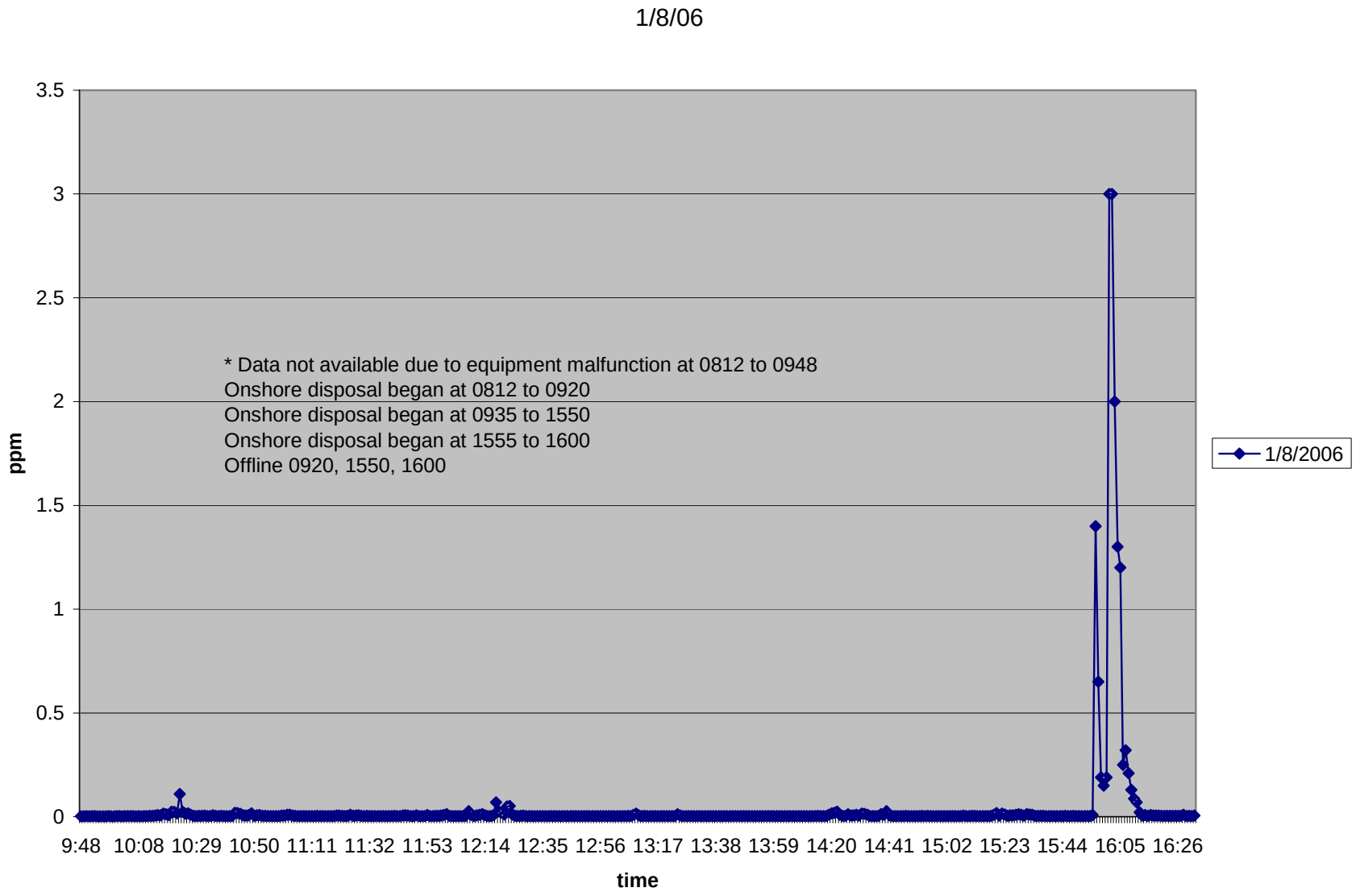
Graph E37. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 6, 2006, Santa Cruz Harbor, Santa Cruz County, California



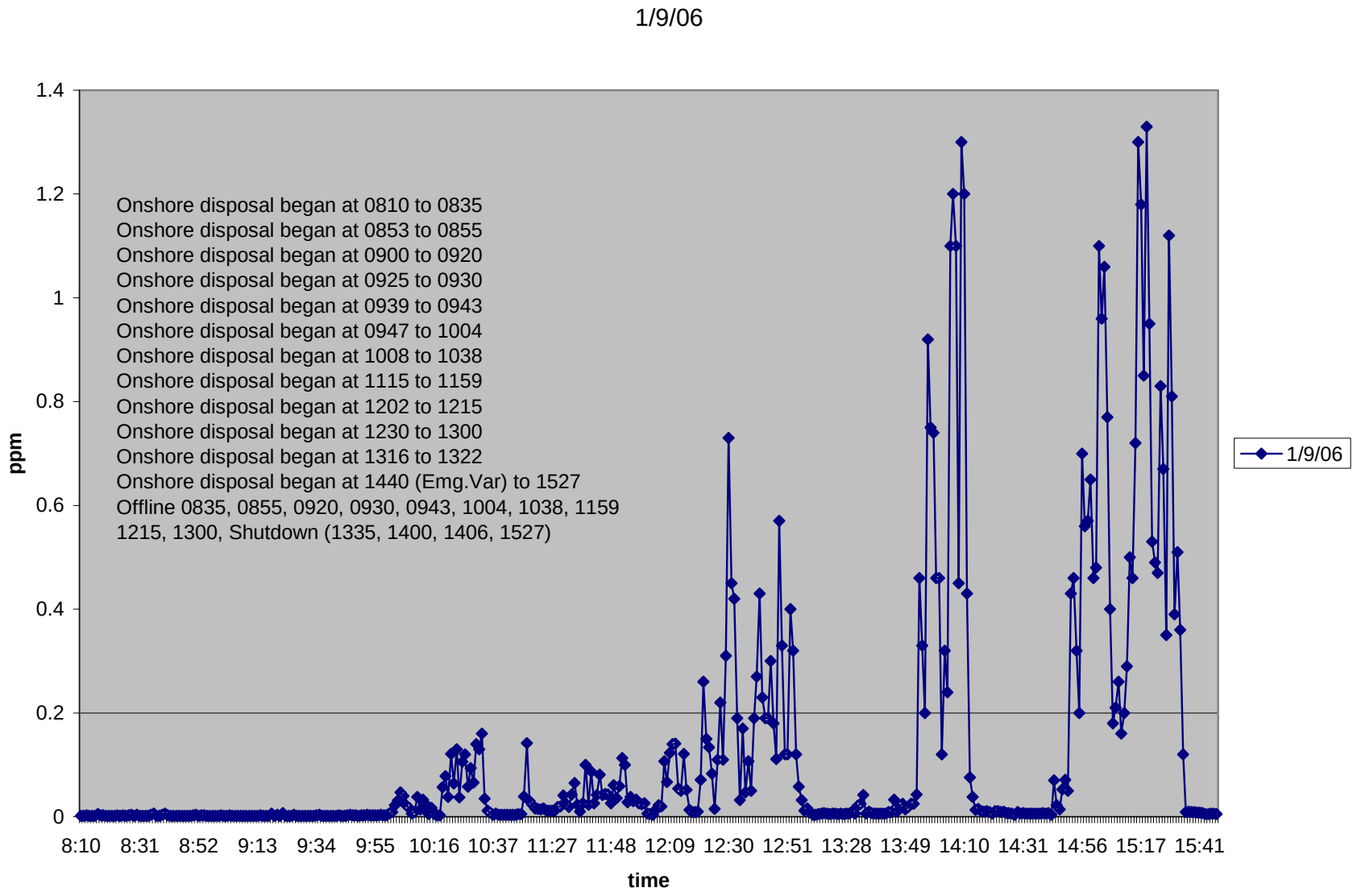
Graph E38. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 7, 2006, Santa Cruz Harbor, Santa Cruz County, California



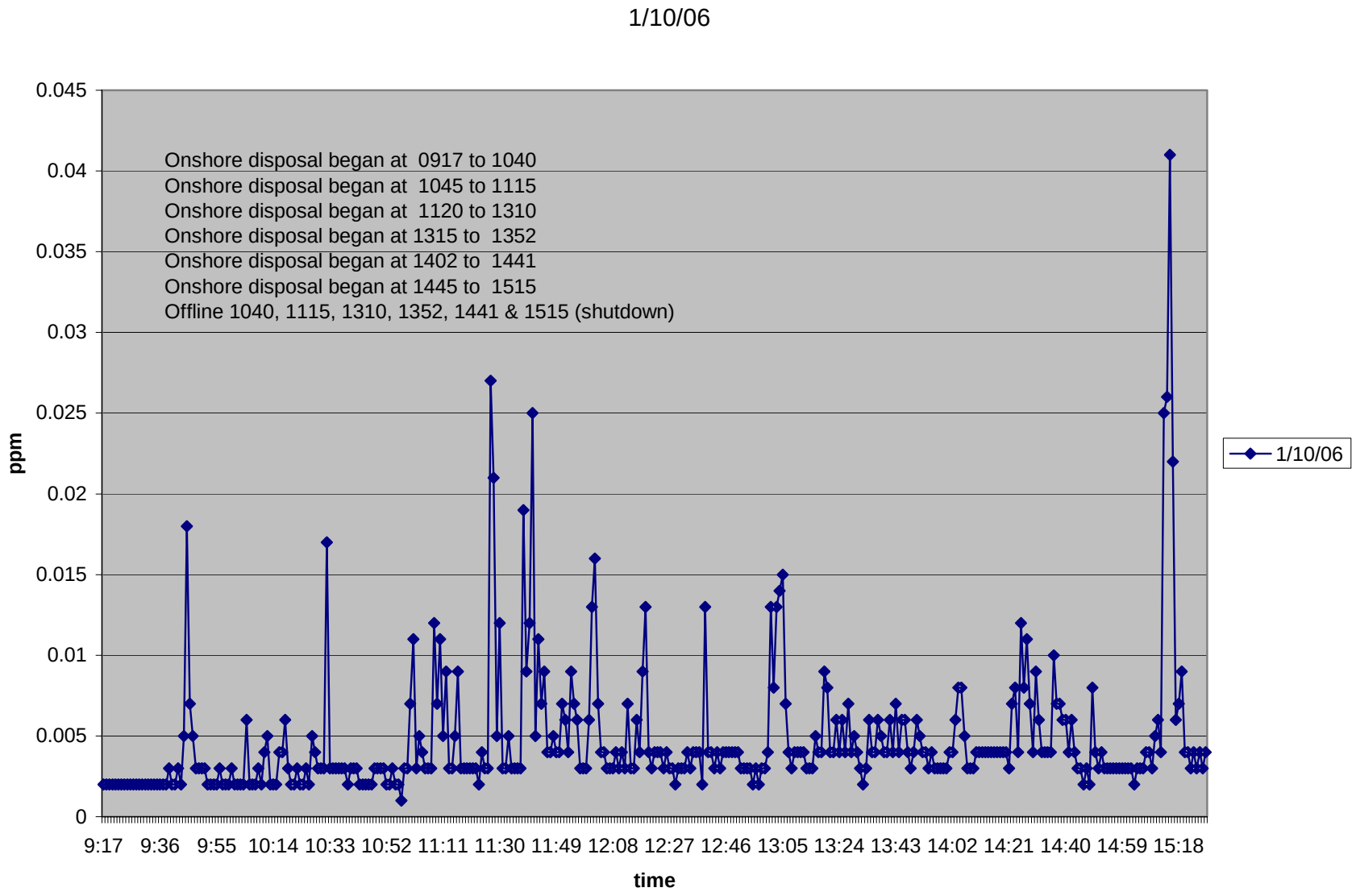
Graph E39. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 8, 2006, Santa Cruz Harbor, Santa Cruz County, California



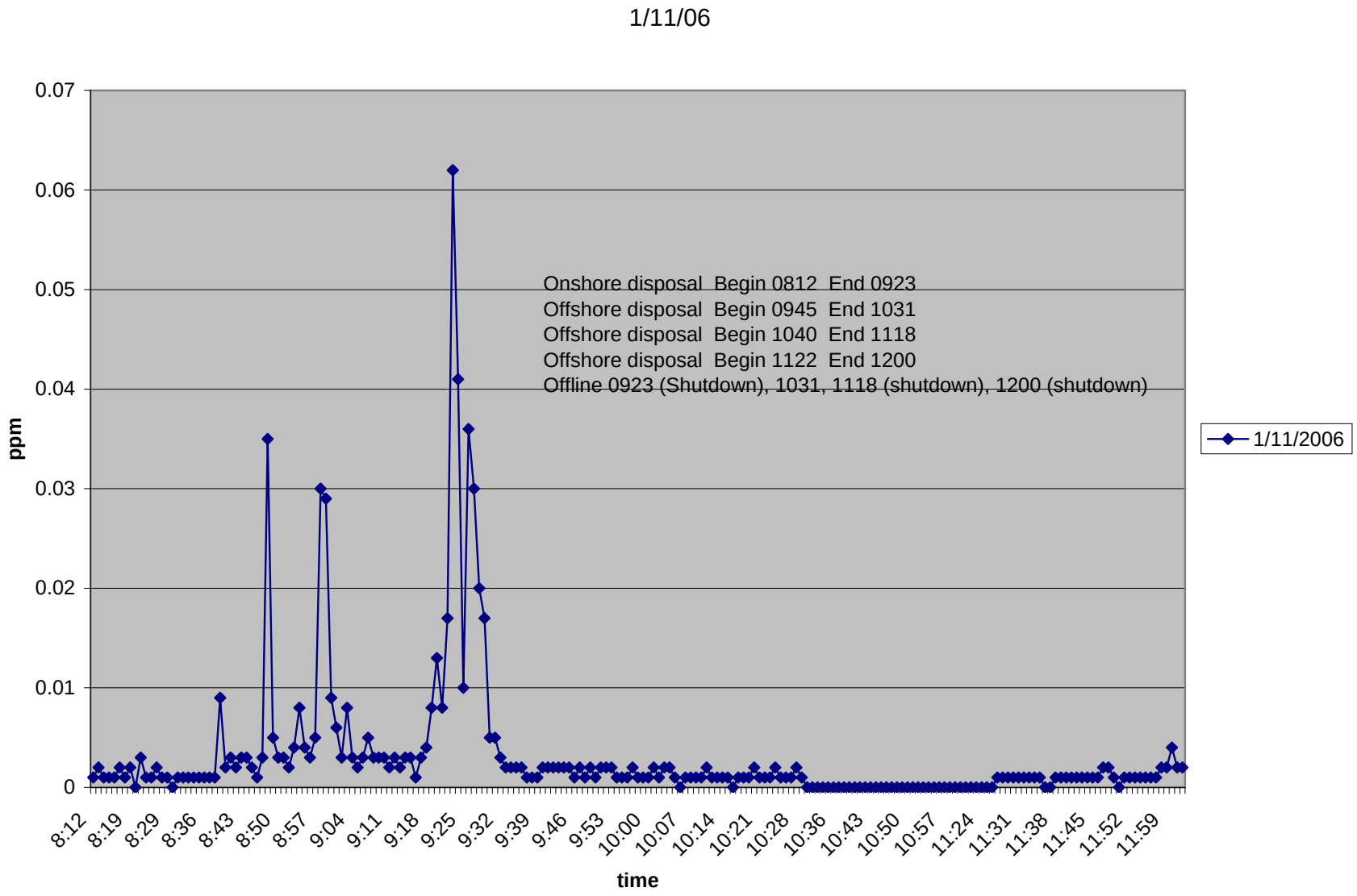
Graph E40. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 9, 2006, Santa Cruz Harbor, Santa Cruz County, California



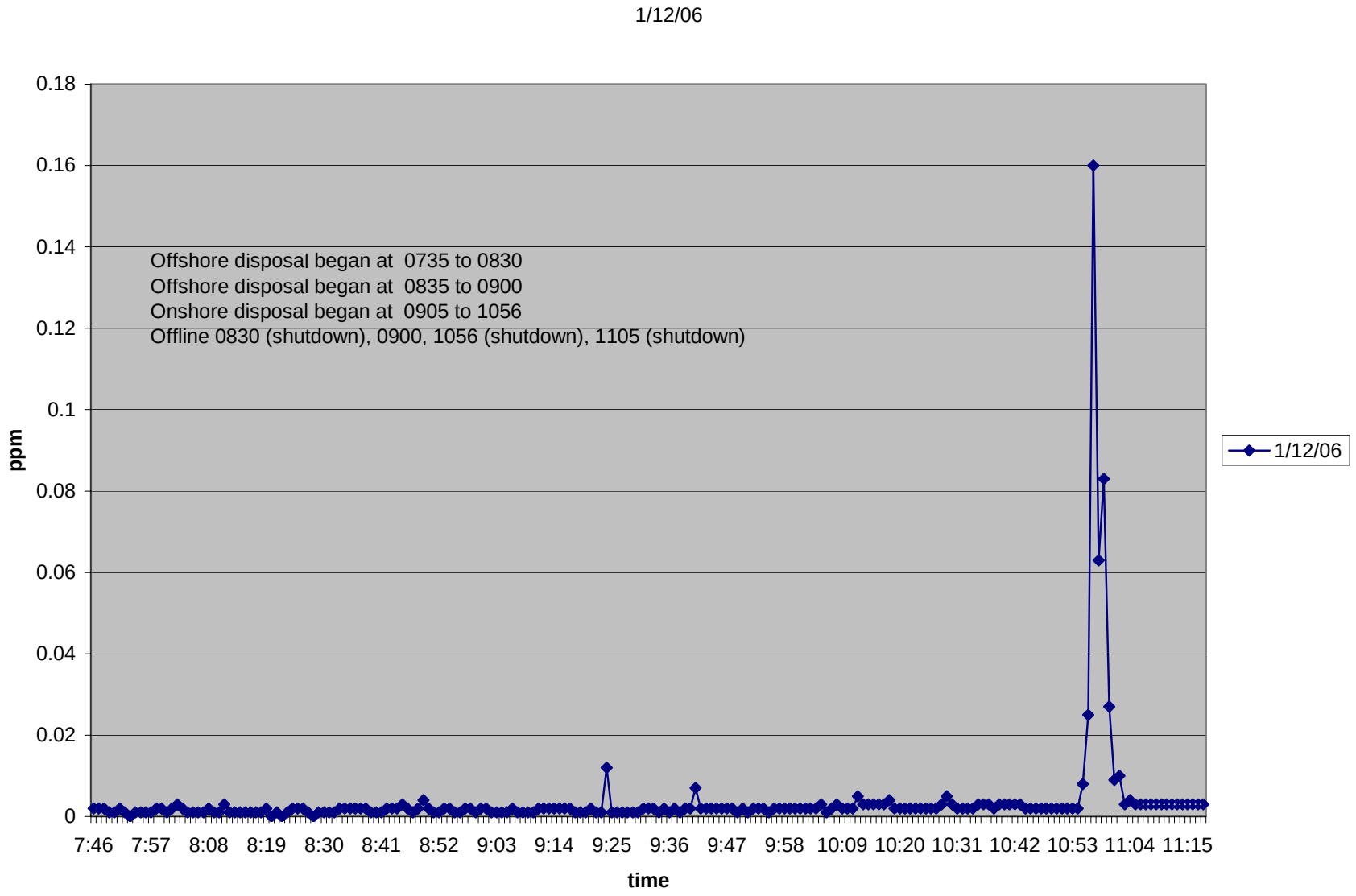
Graph E41. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 10, 2006, Santa Cruz Harbor, Santa Cruz County, California



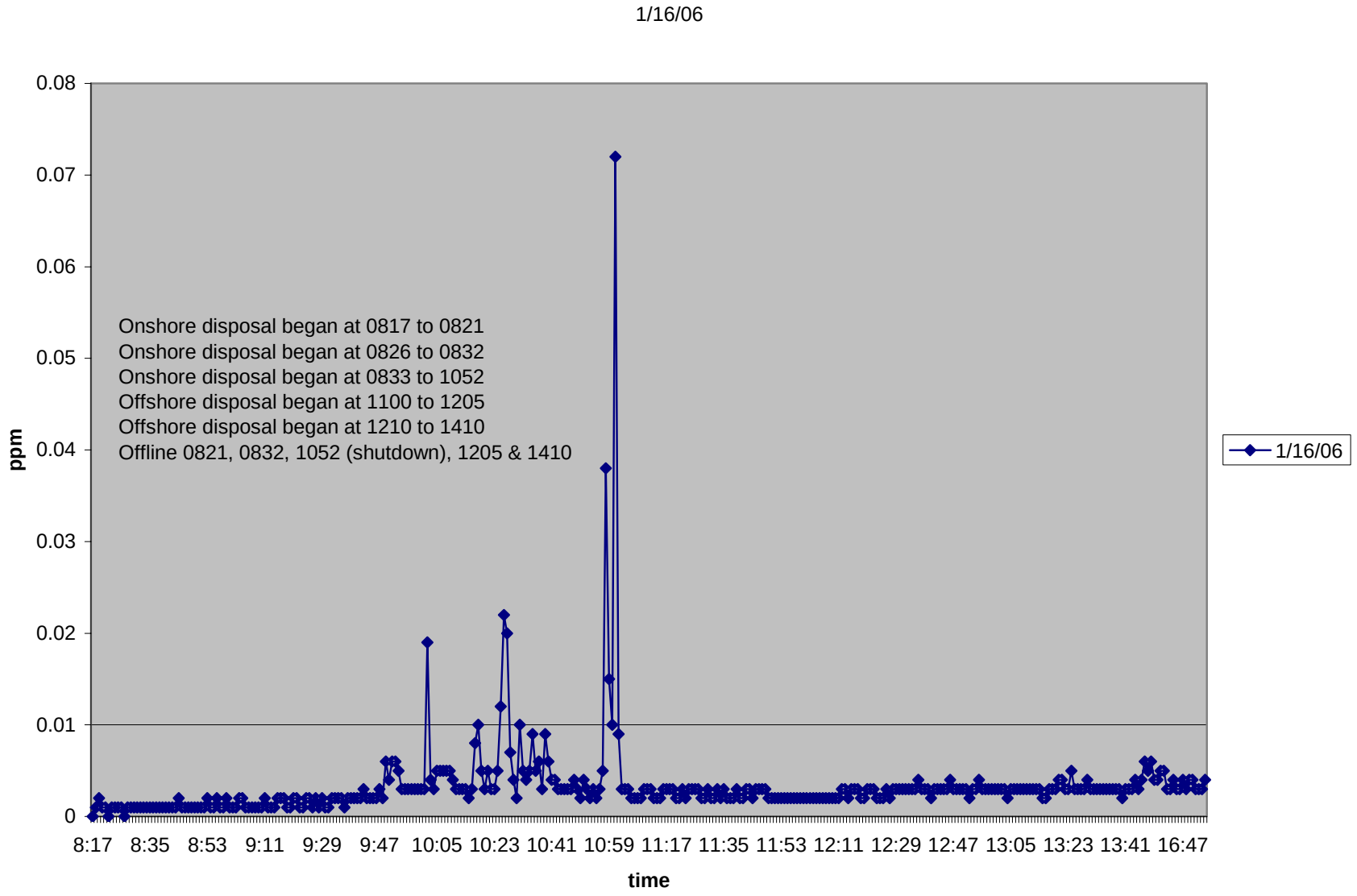
Graph E42. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 11, 2006, Santa Cruz Harbor, Santa Cruz County, California



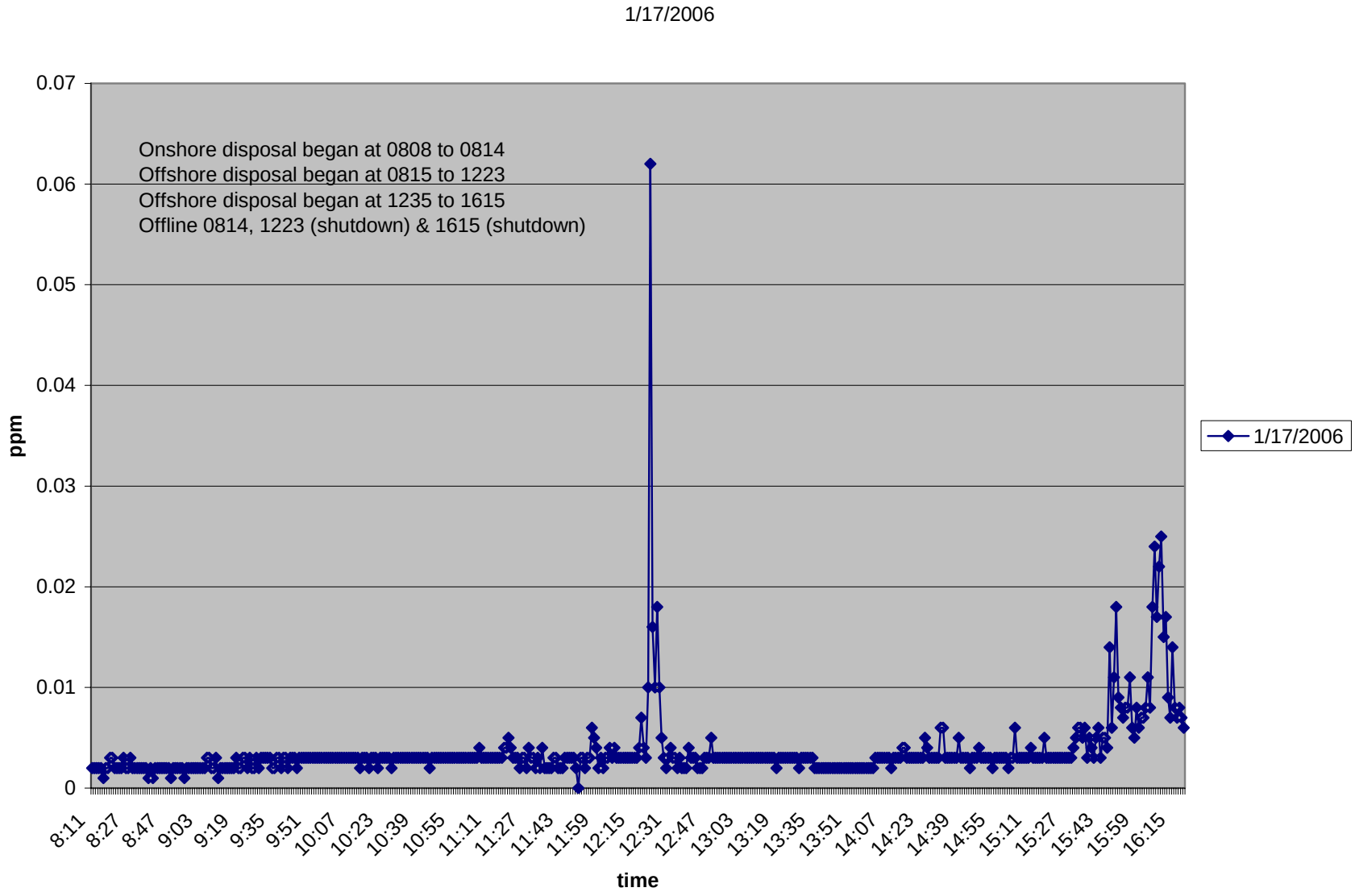
Graph E43. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 12, 2006, Santa Cruz Harbor, Santa Cruz County, California



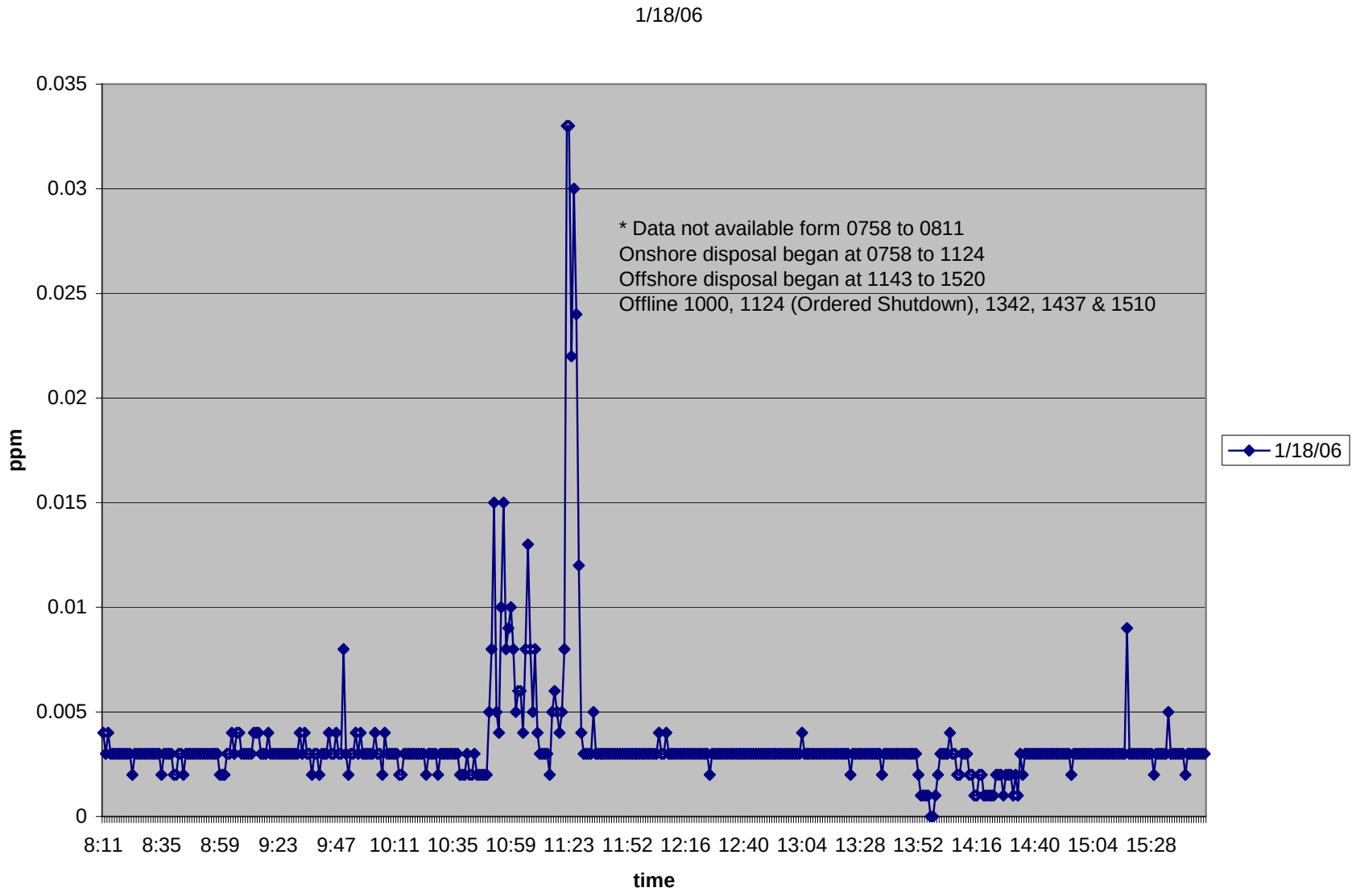
Graph E44. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 16, 2006, Santa Cruz Harbor, Santa Cruz County, California



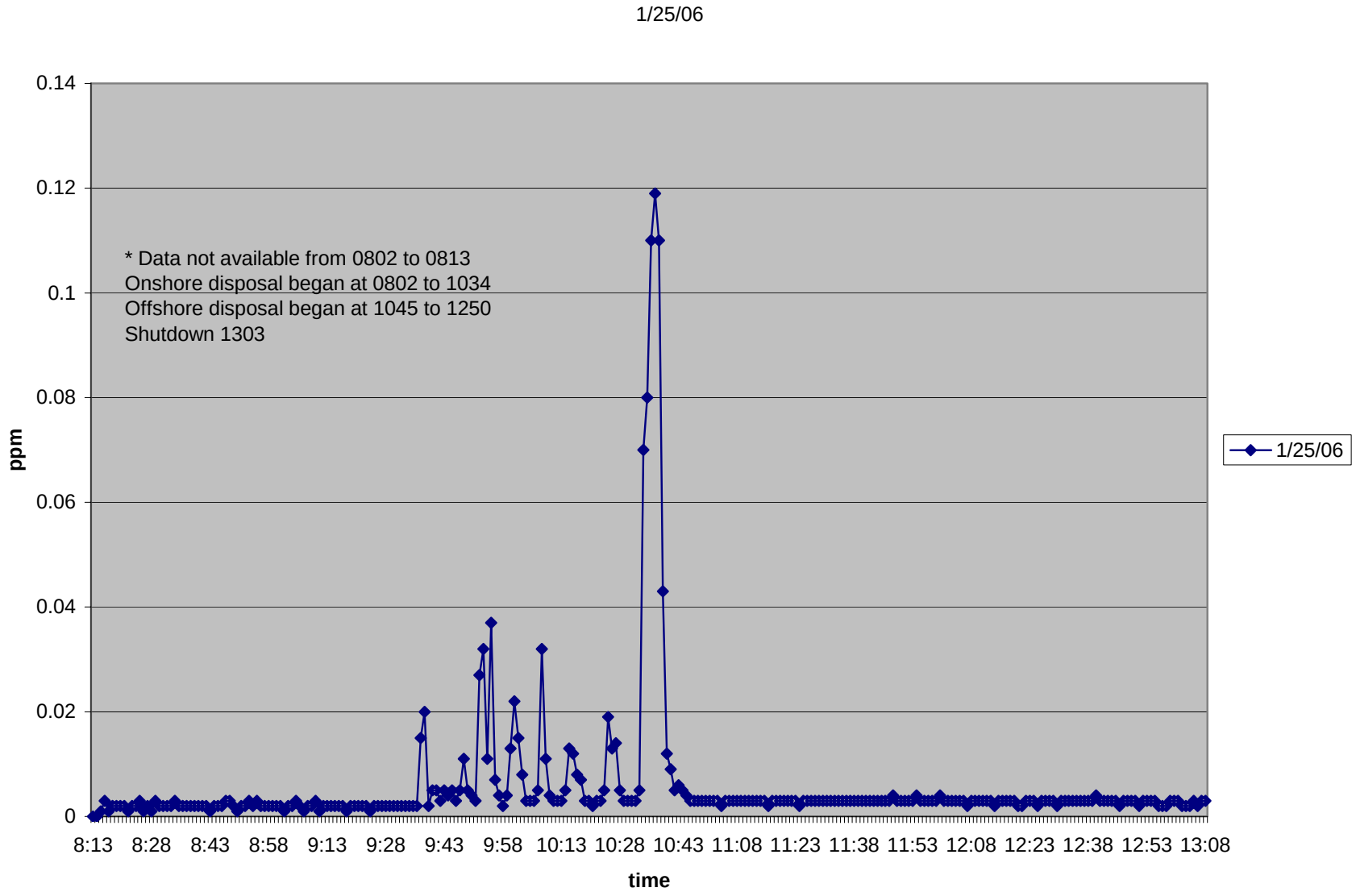
Graph E45. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 17, 2006, Santa Cruz Harbor, Santa Cruz County, California



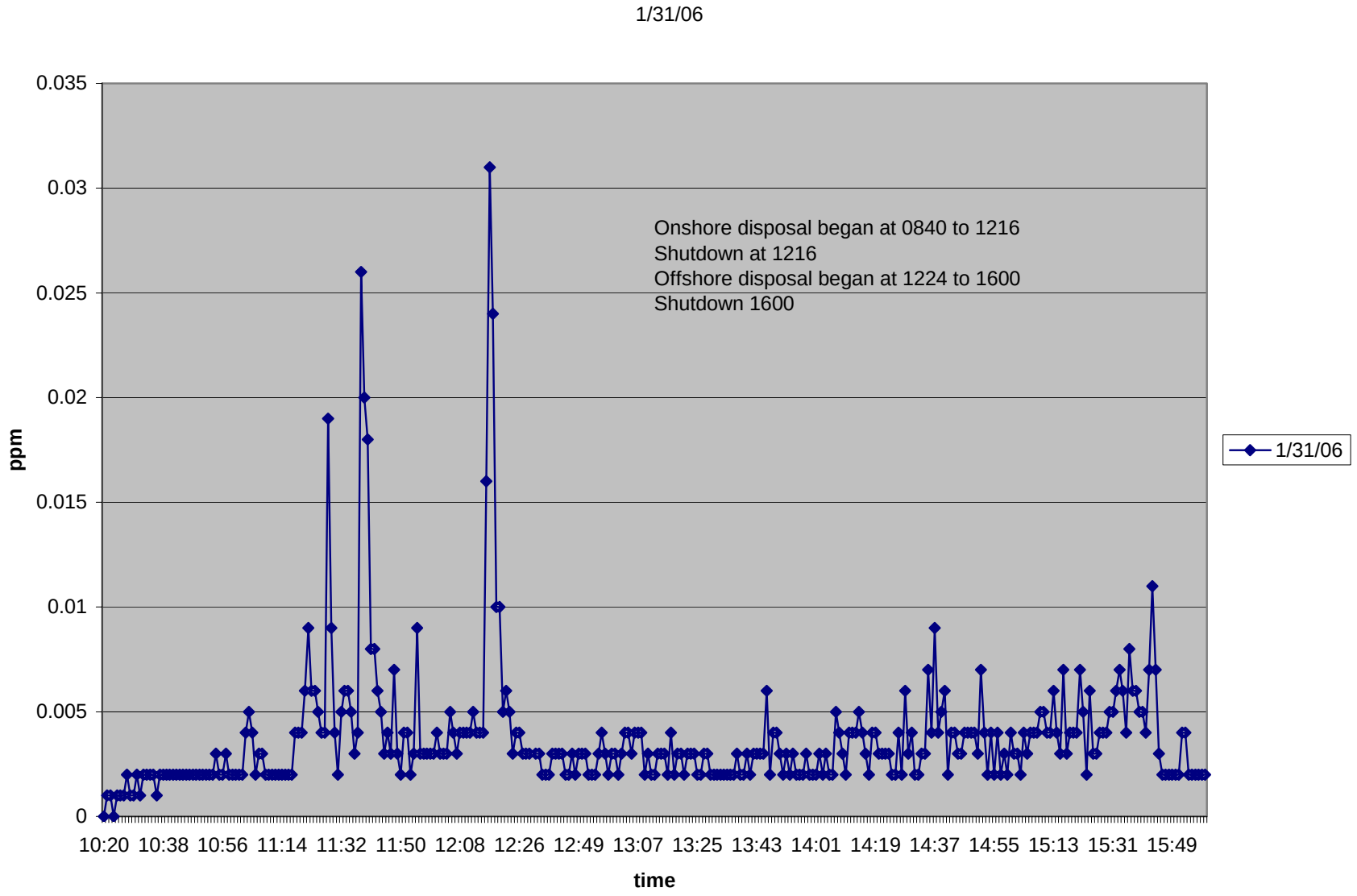
Graph E46. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 18, 2006, Santa Cruz Harbor, Santa Cruz County, California



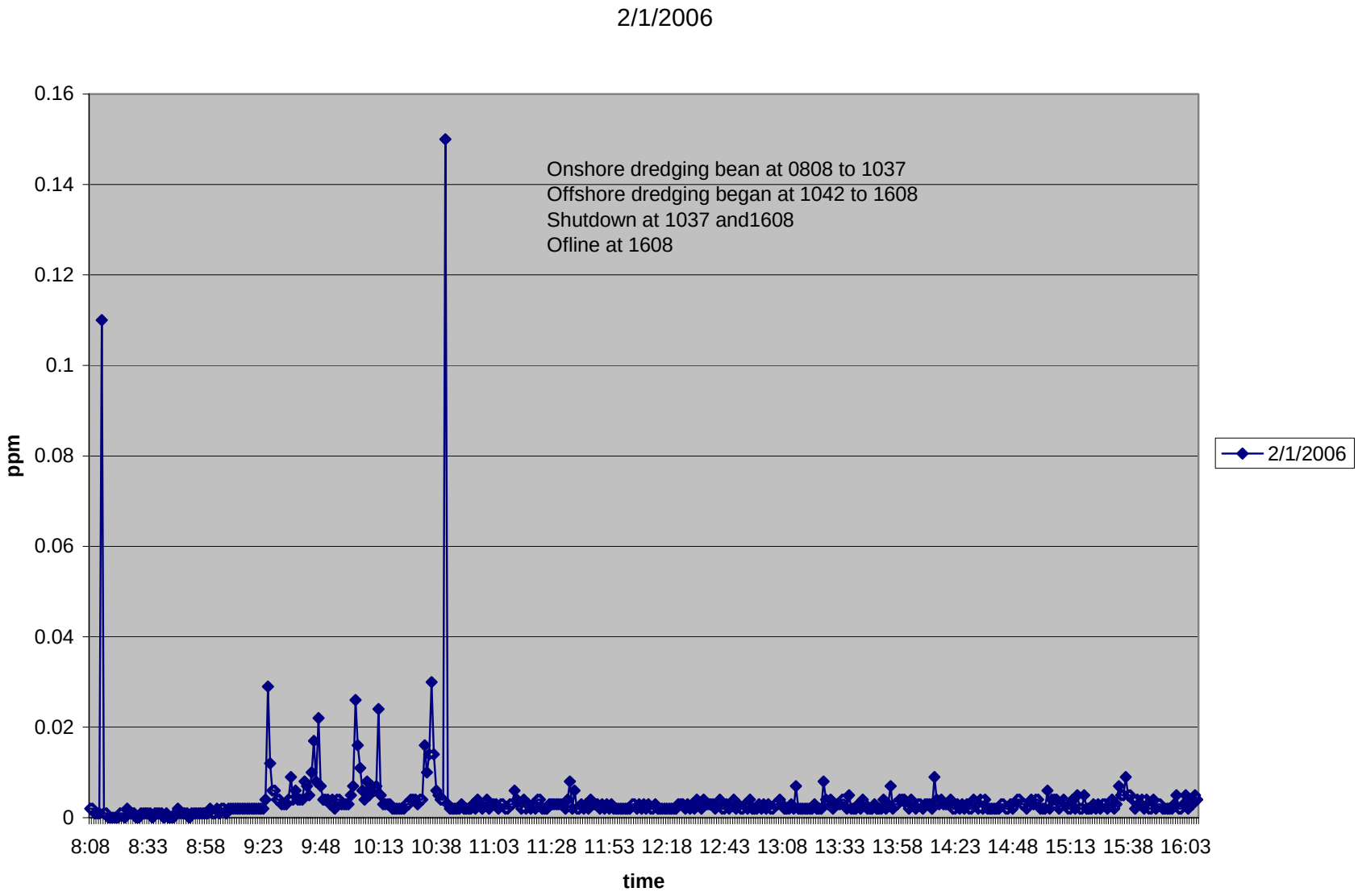
Graph E47. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 25, 2006, Santa Cruz Harbor, Santa Cruz County, California



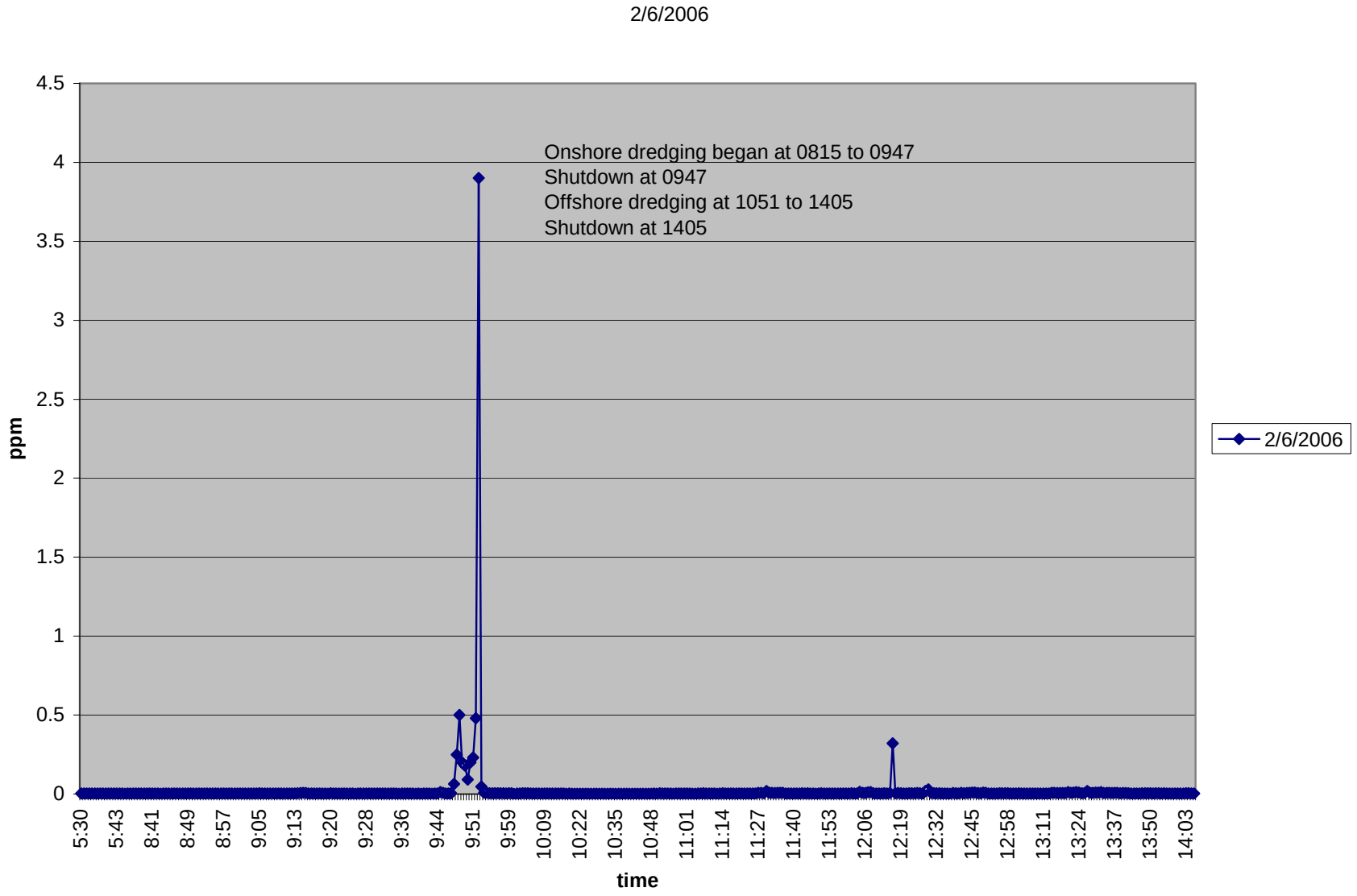
Graph E48. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, January 31, 2006, Santa Cruz Harbor, Santa Cruz County, California



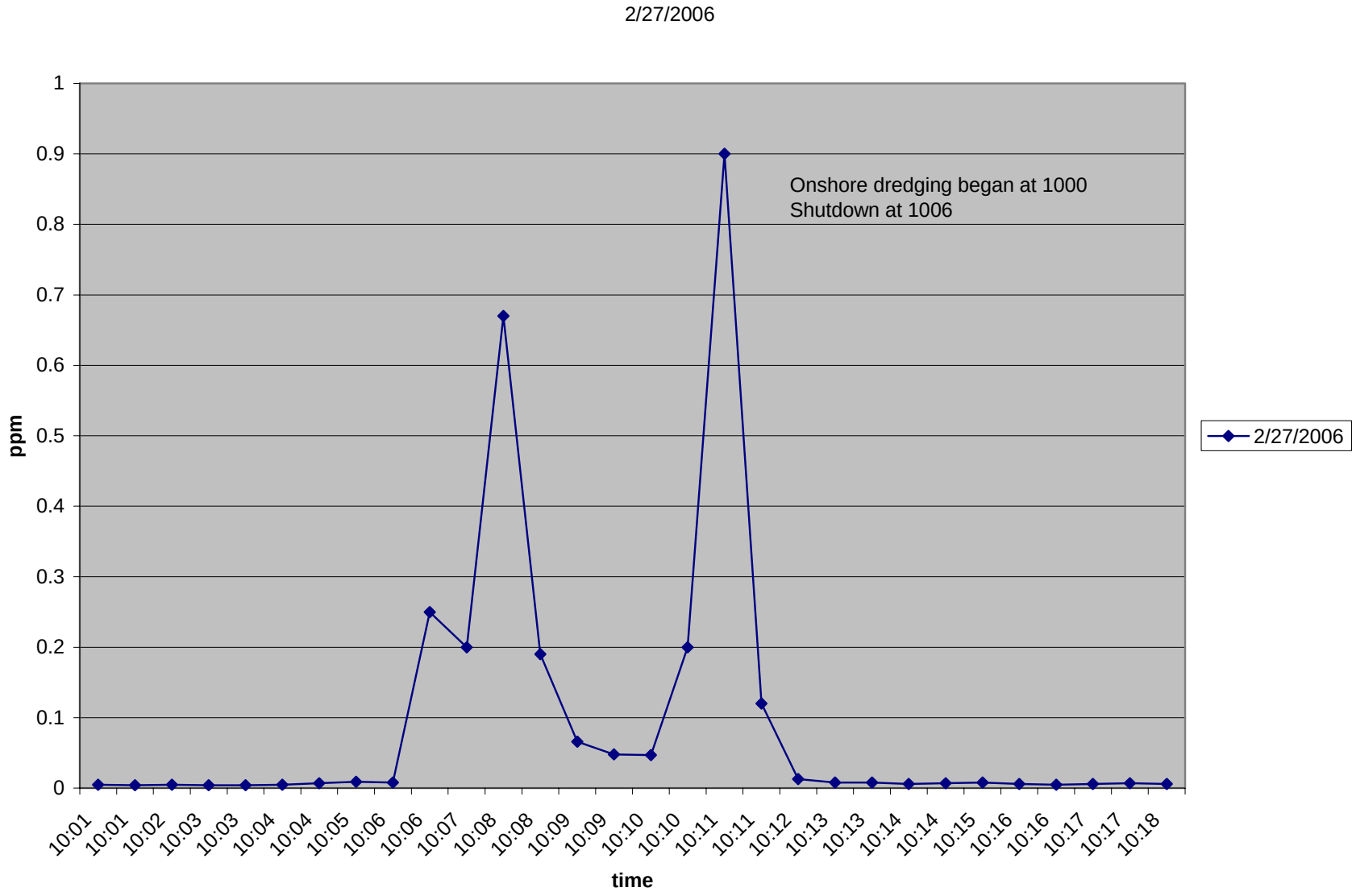
Graph E49. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, February 1, 2006, Santa Cruz Harbor, Santa Cruz County, California



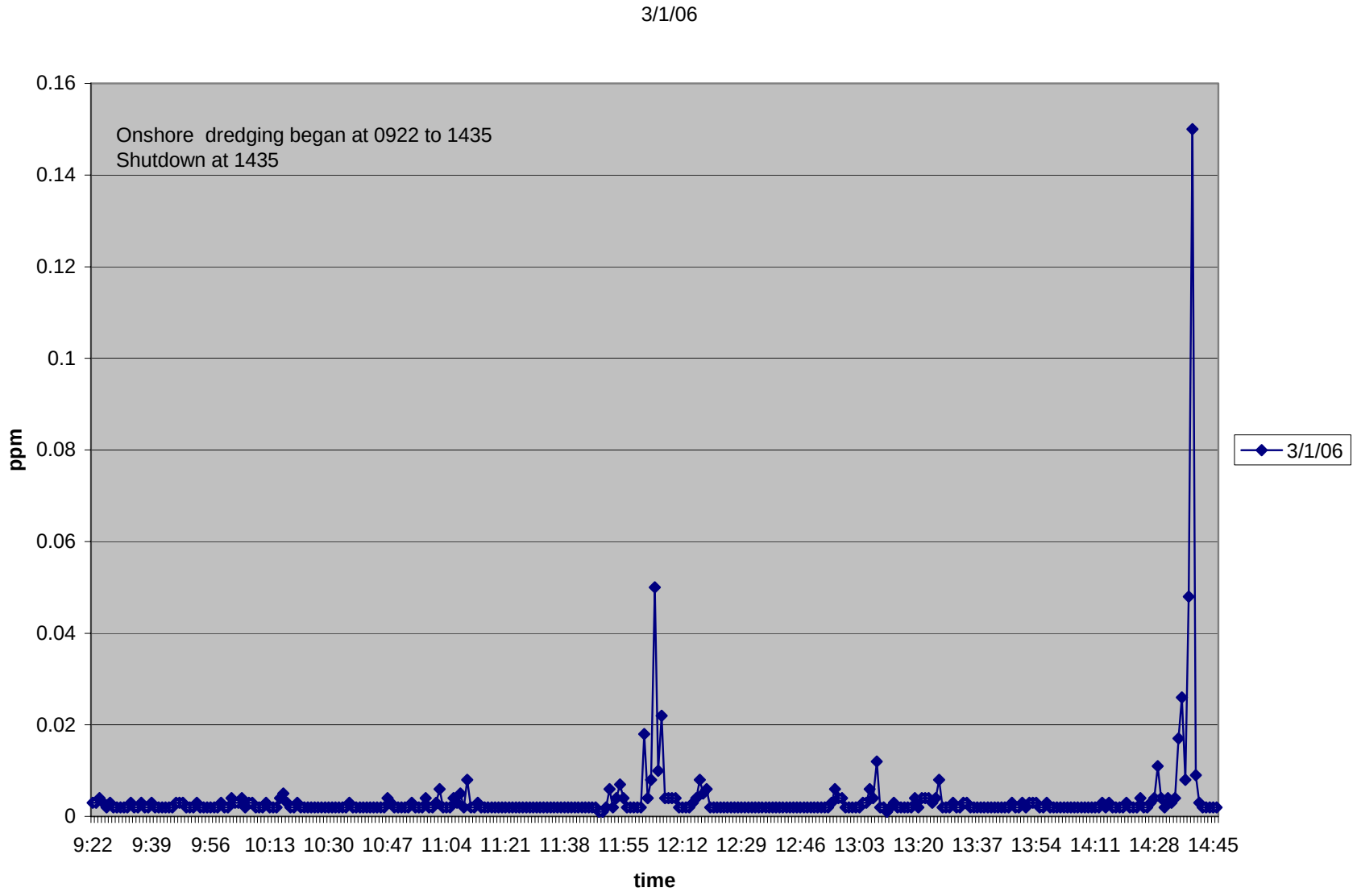
Graph E50. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, February 6, 2006, Santa Cruz Harbor, Santa Cruz County, California



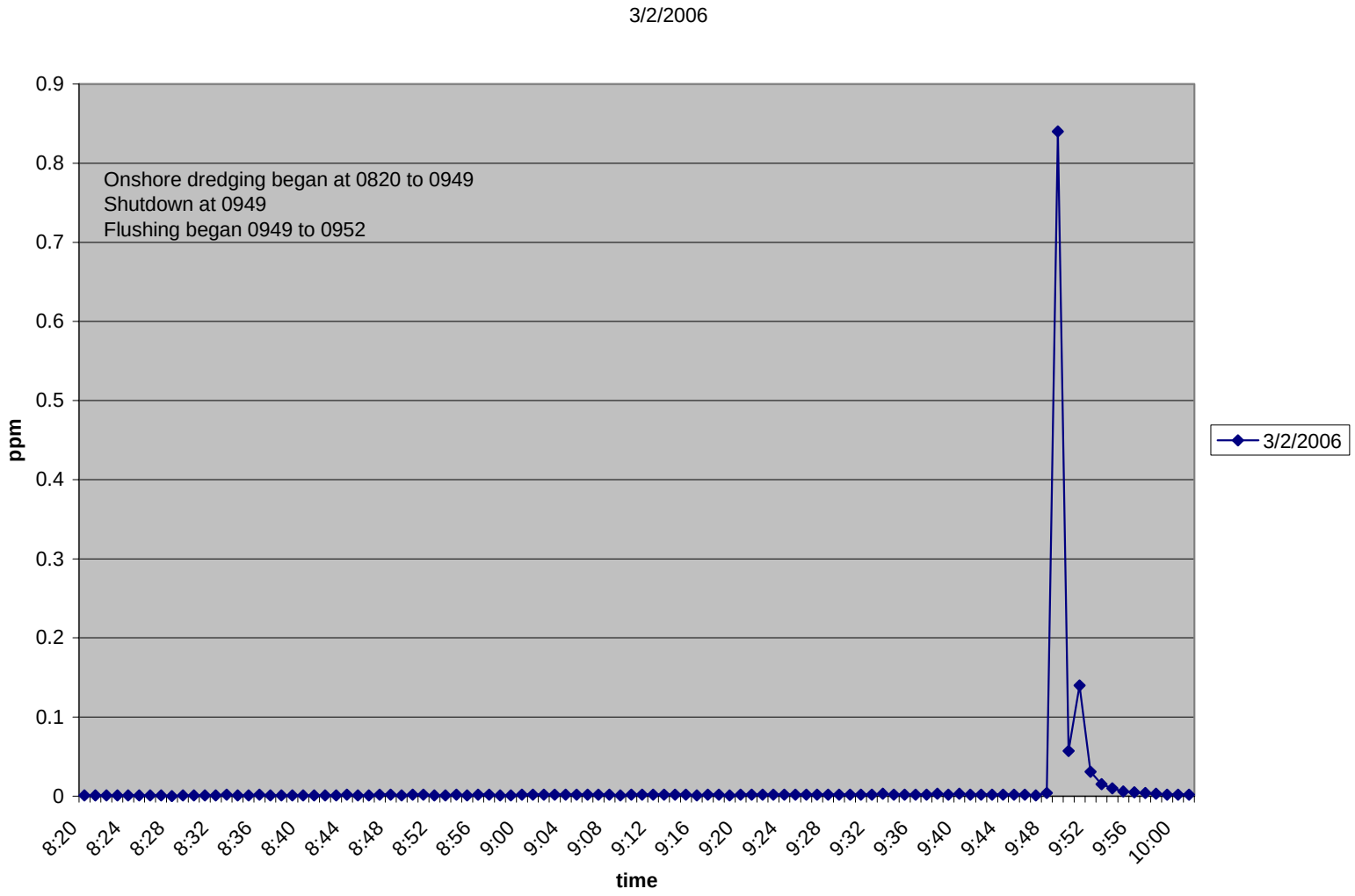
Graph E51. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, February 27, 2006, Santa Cruz Harbor, Santa Cruz County, California



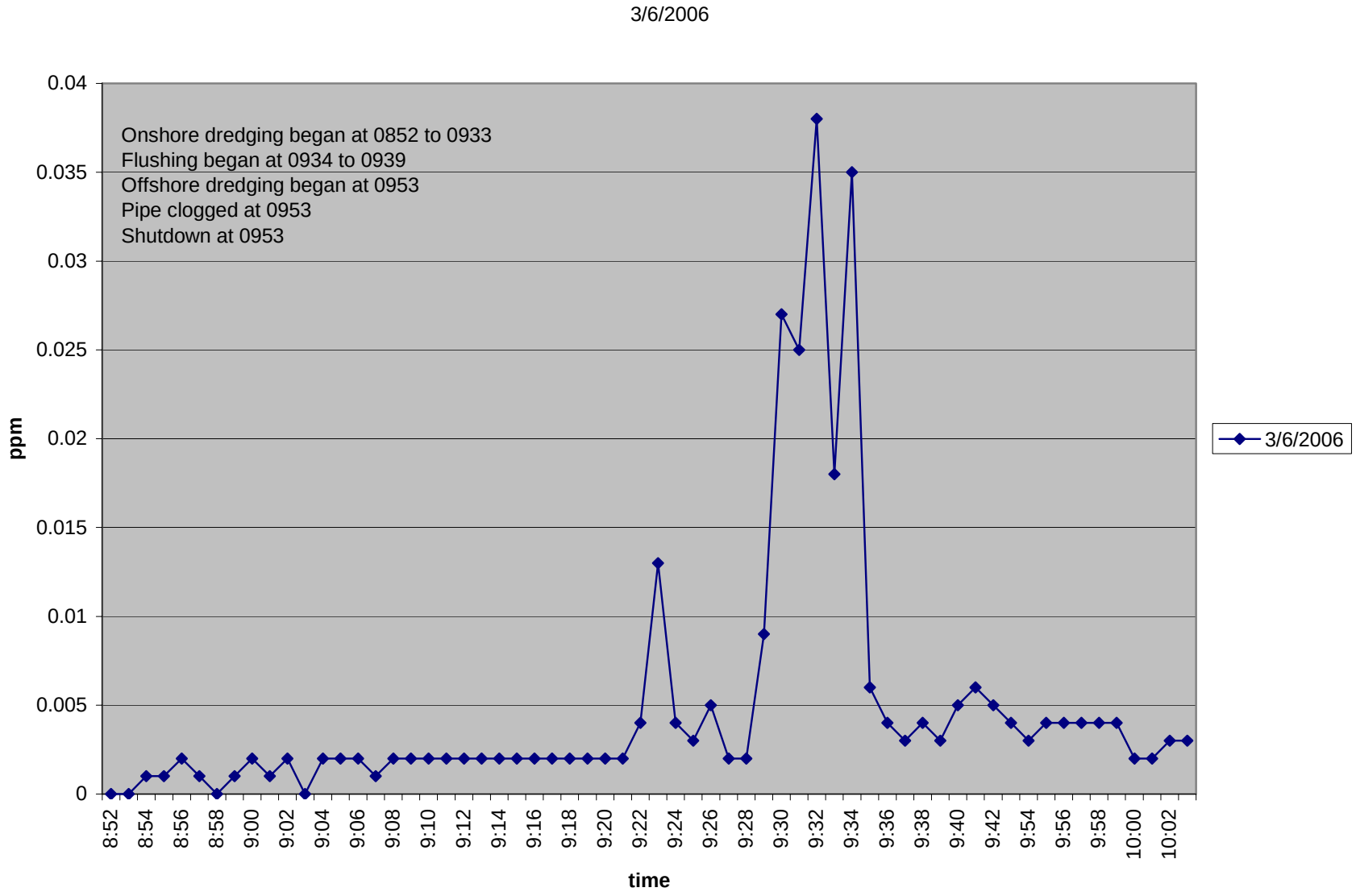
Graph E52. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, March 1, 2006, Santa Cruz Harbor, Santa Cruz County, California



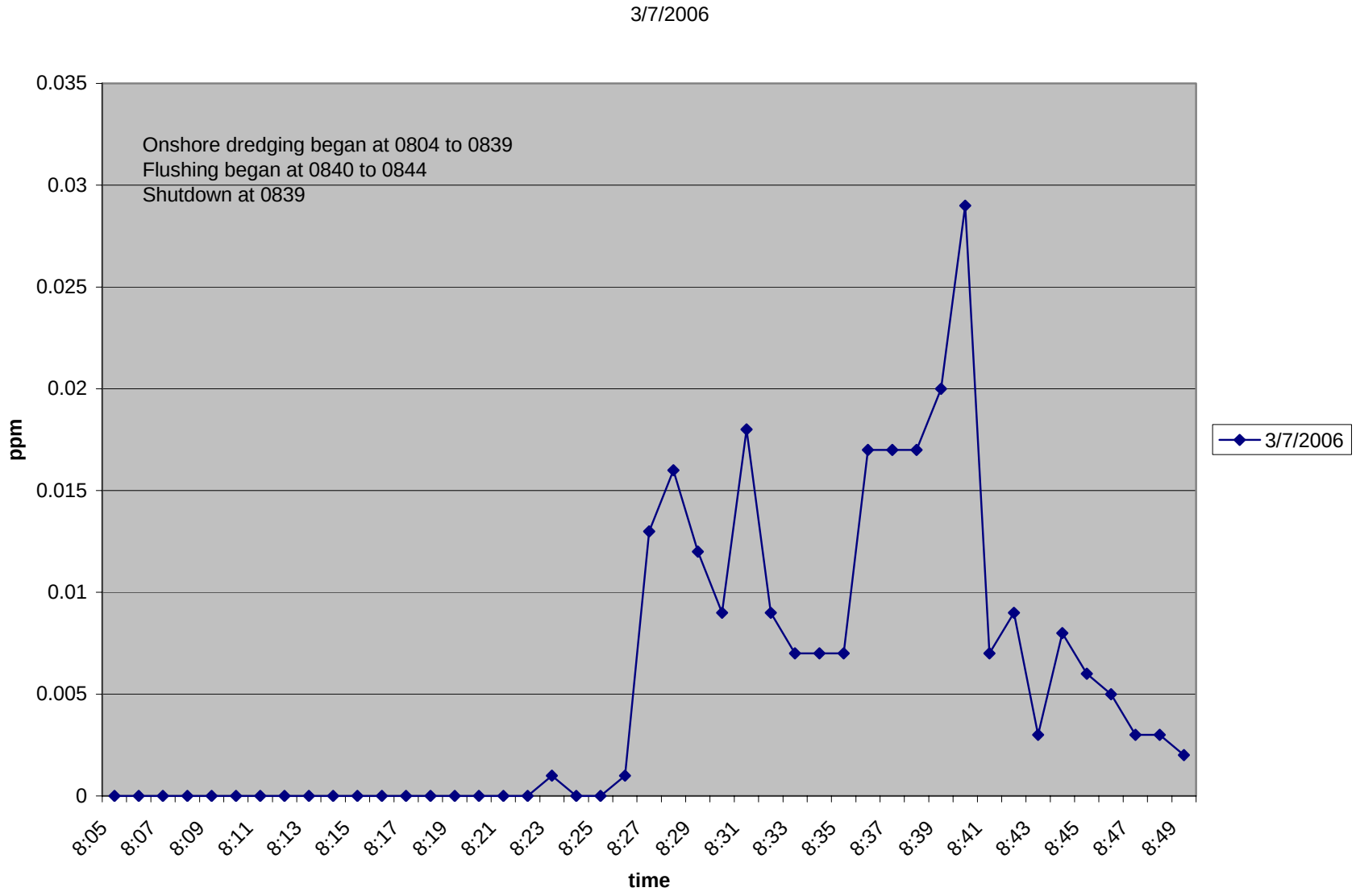
Graph E53. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, March 2, 2006, Santa Cruz Harbor, Santa Cruz County, California



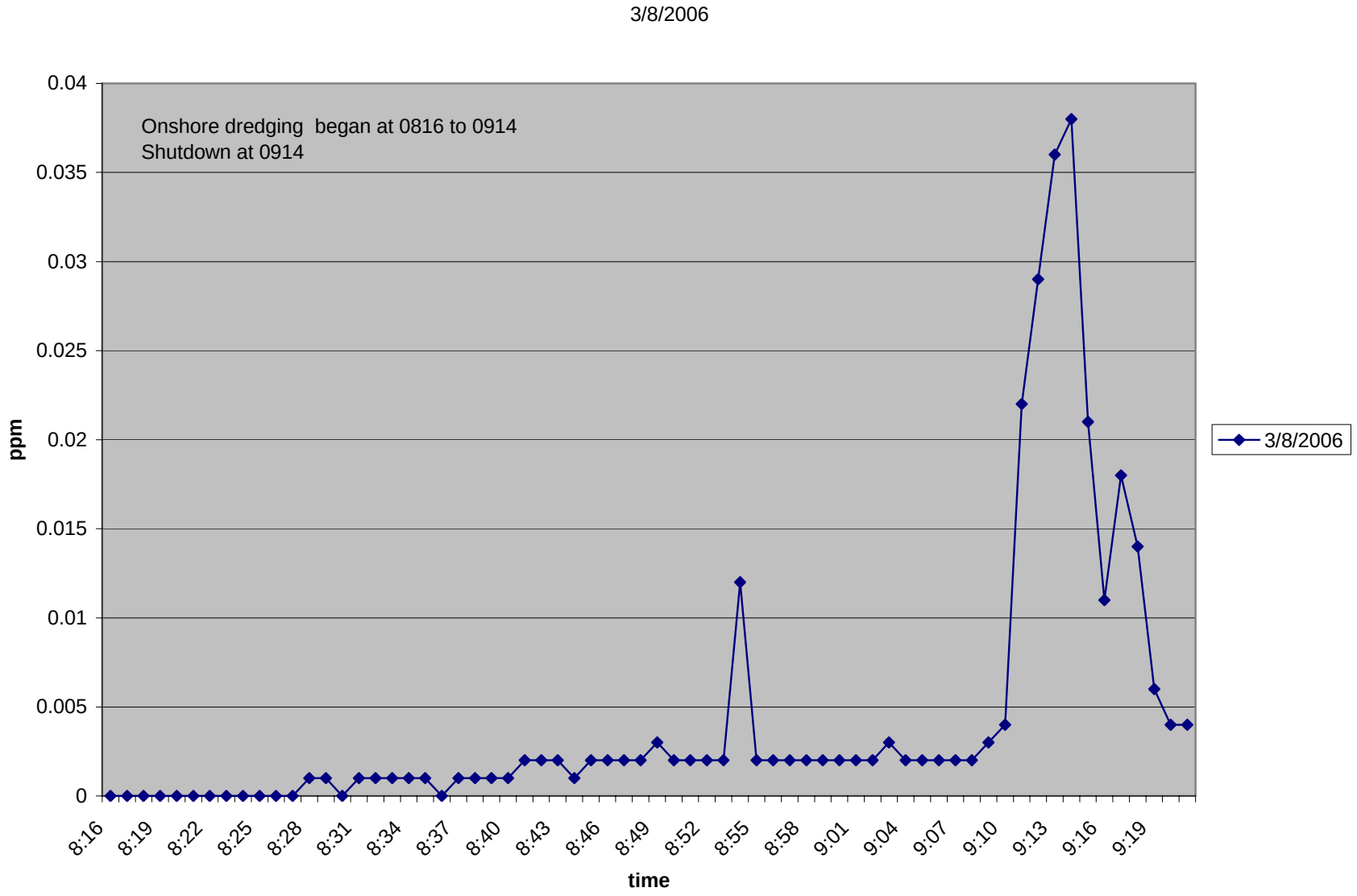
Graph E54. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, March 6, 2006, Santa Cruz Harbor, Santa Cruz County, California



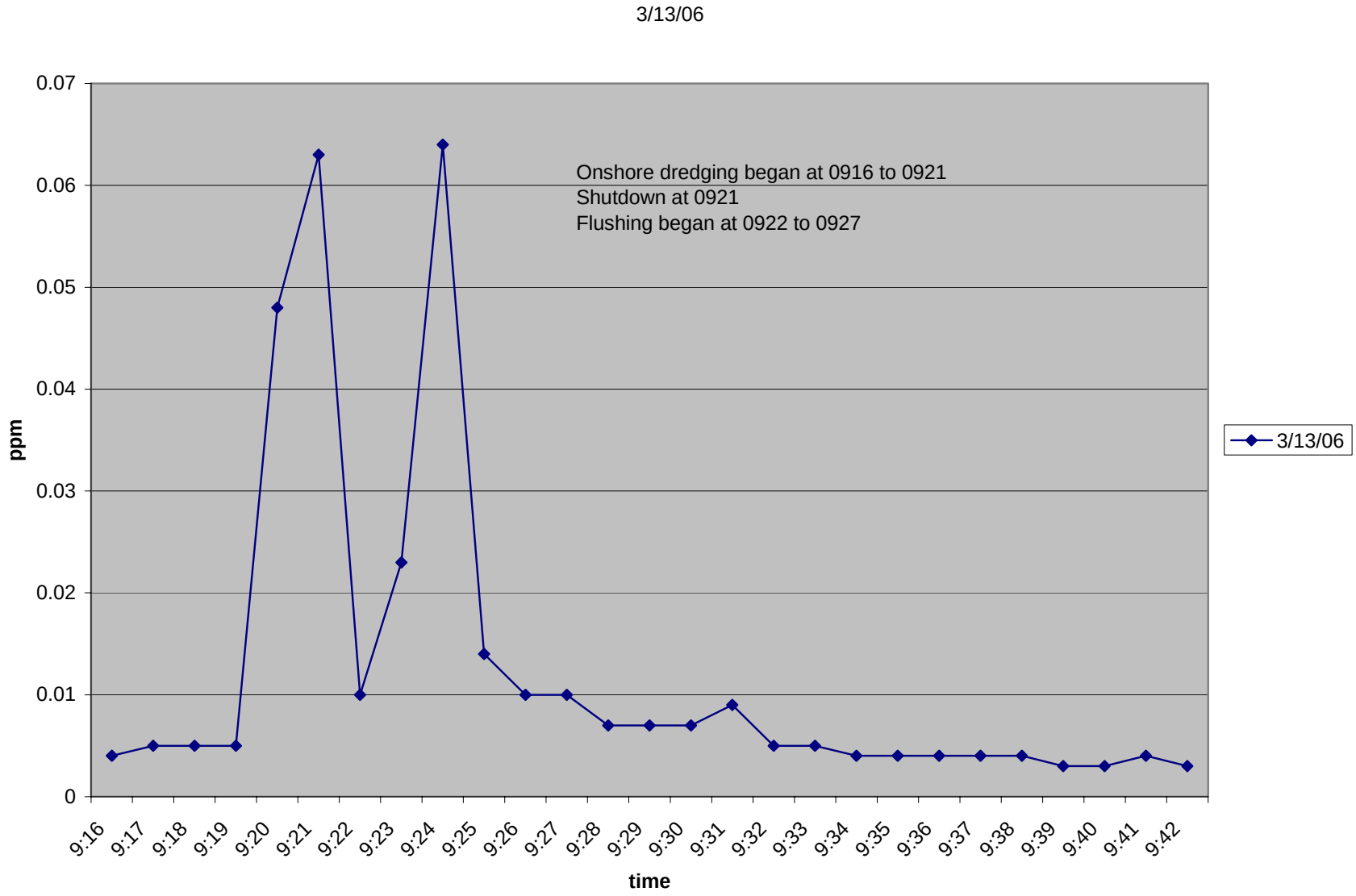
Graph E55. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, March 7, 2006, Santa Cruz Harbor, Santa Cruz County, California



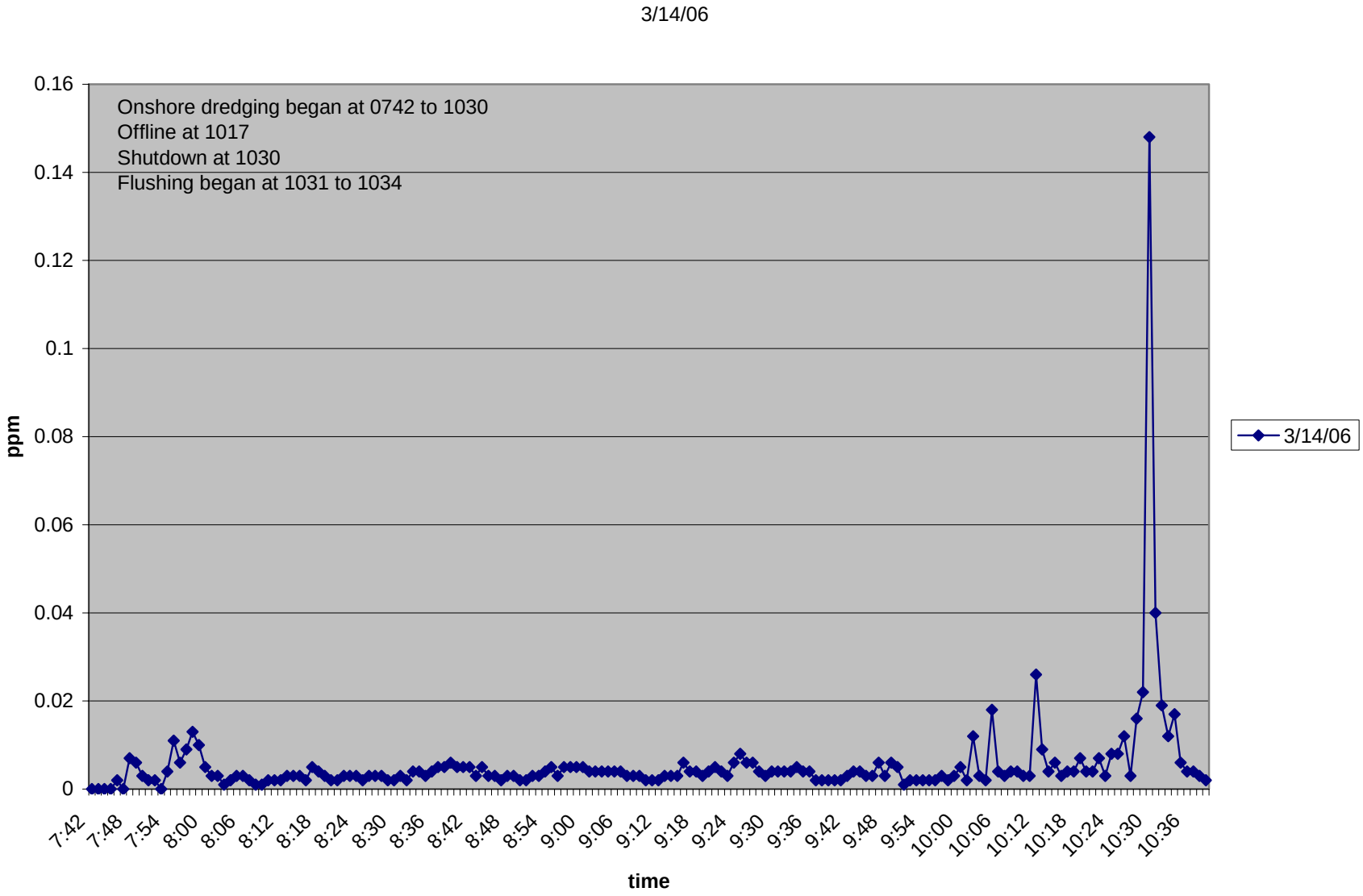
Graph E56. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, March 8, 2006, Santa Cruz Harbor, Santa Cruz County, California



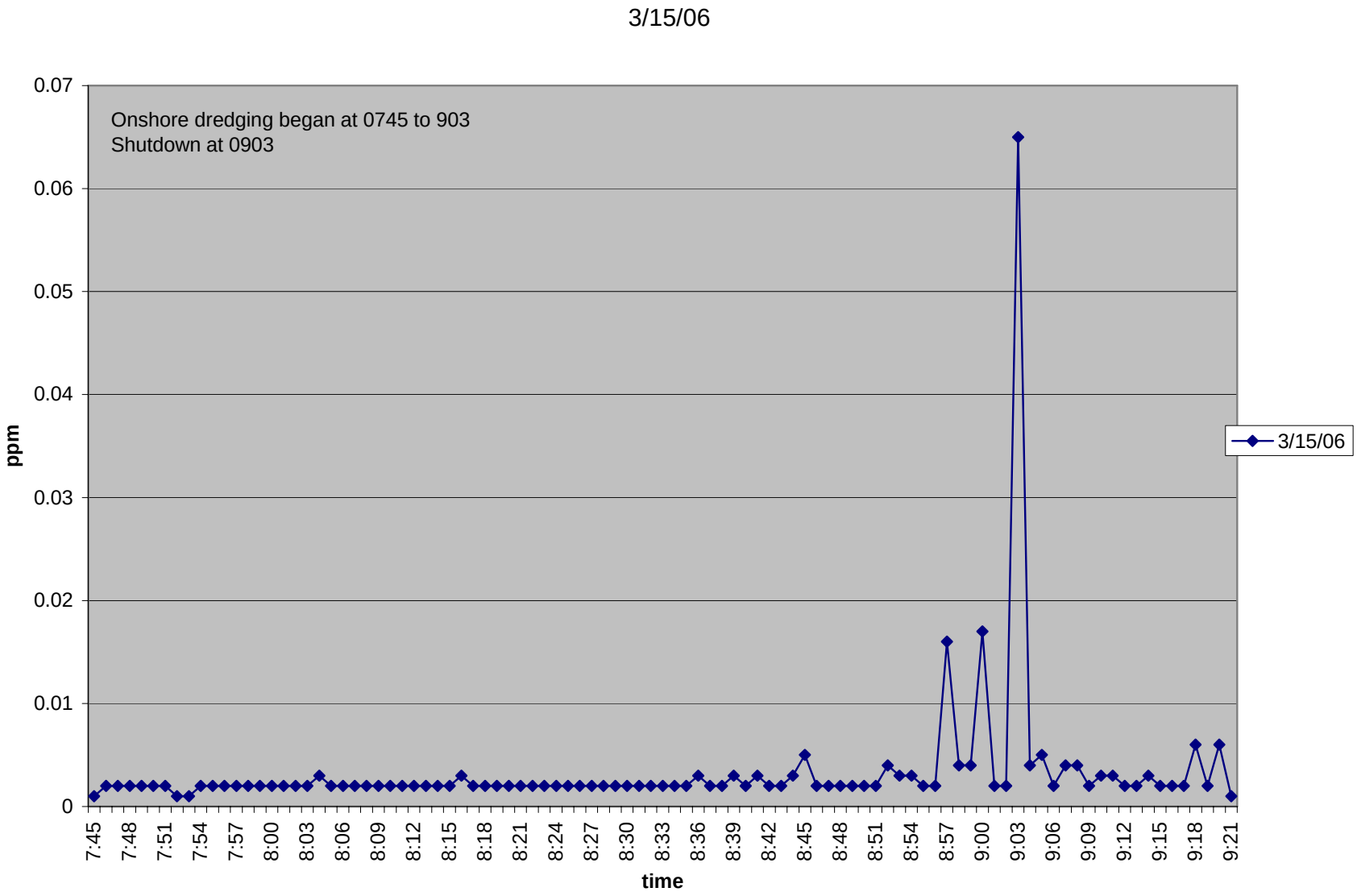
Graph E57. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, March 13, 2006, Santa Cruz Harbor, Santa Cruz County, California



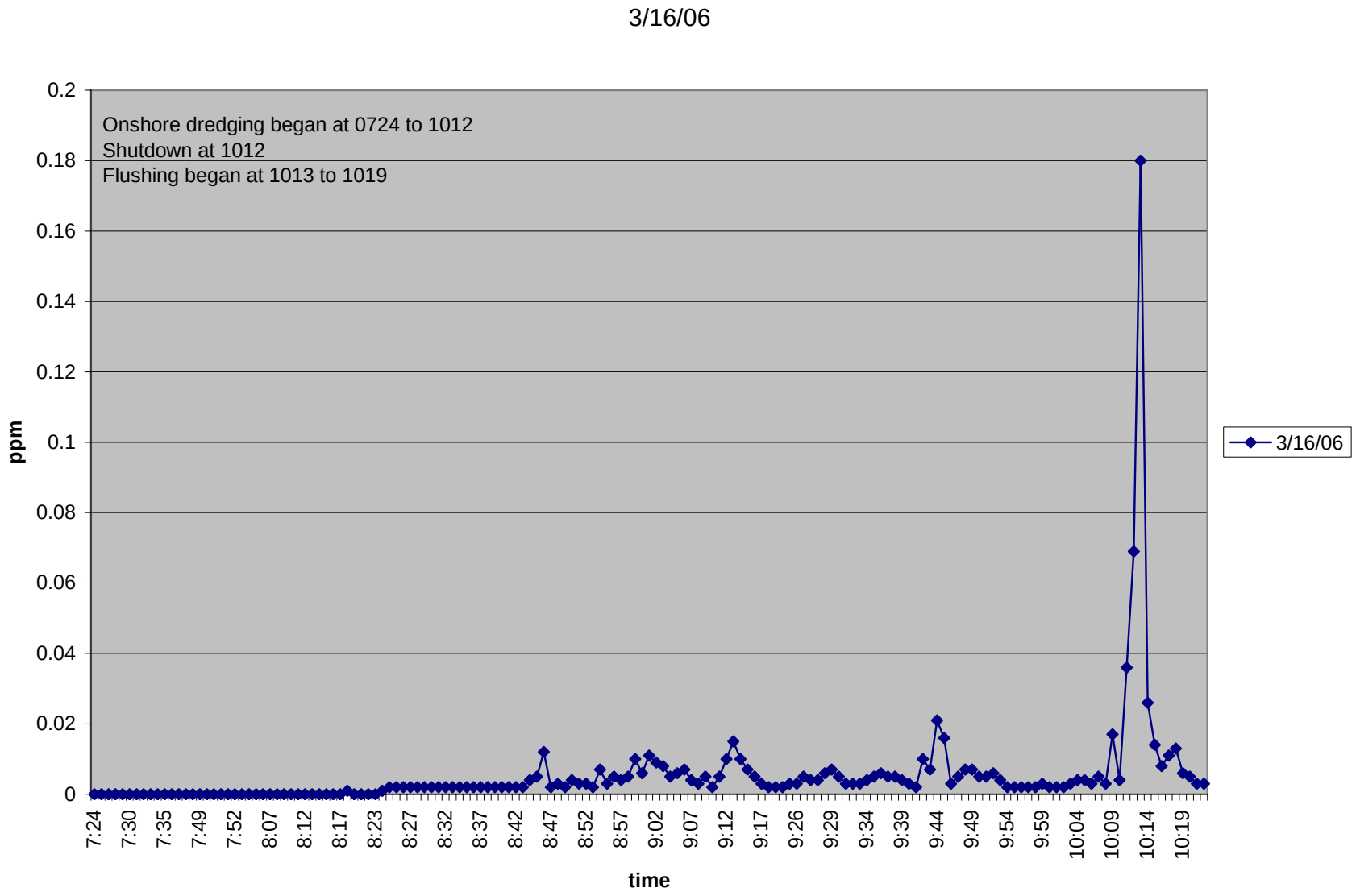
Graph E58. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, March 14, 2006, Santa Cruz Harbor, Santa Cruz County, California



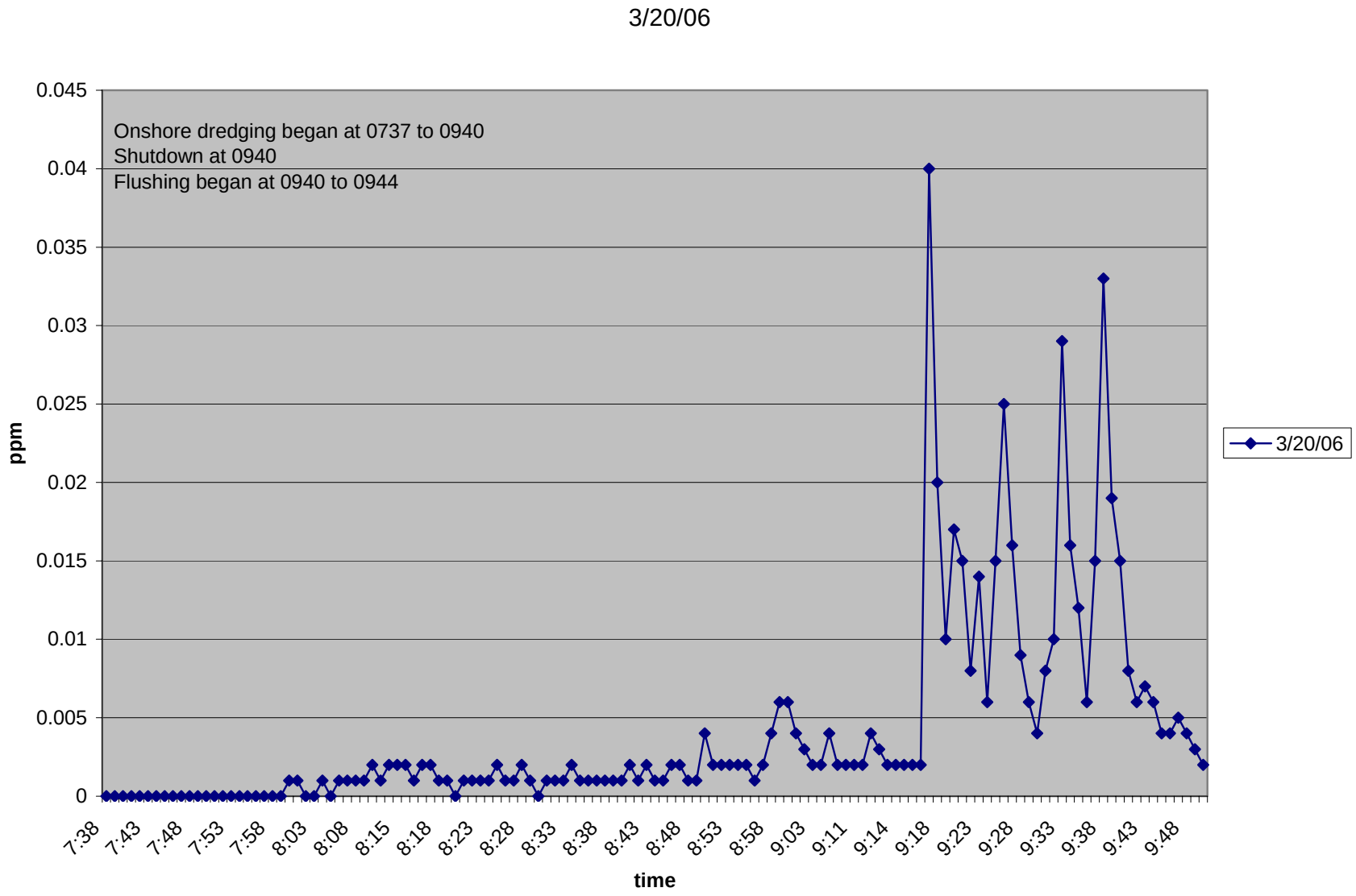
Graph E59. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, March 15, 2006, Santa Cruz Harbor, Santa Cruz County, California



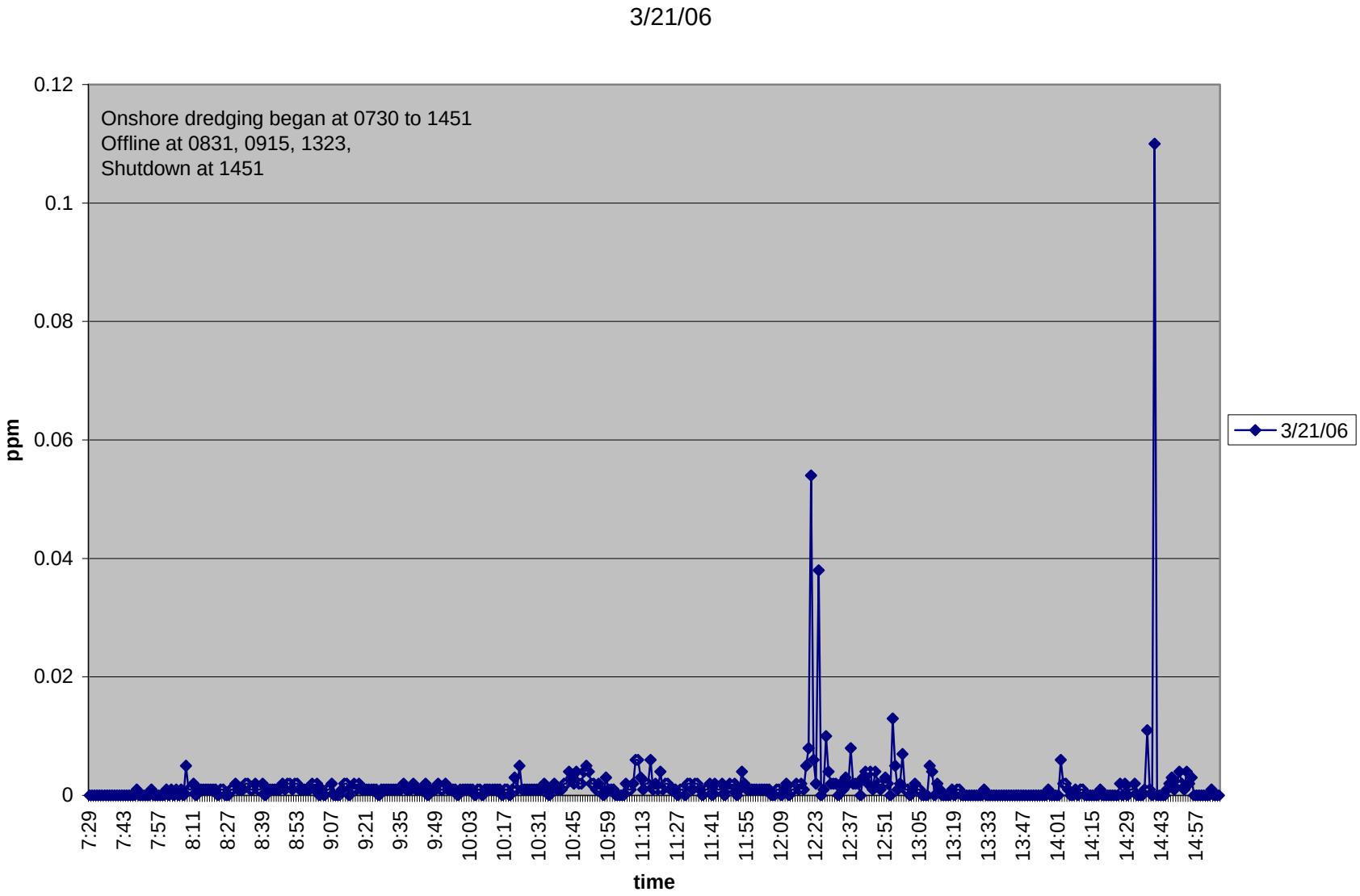
Graph E60. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, March 16, 2006, Santa Cruz Harbor, Santa Cruz County, California



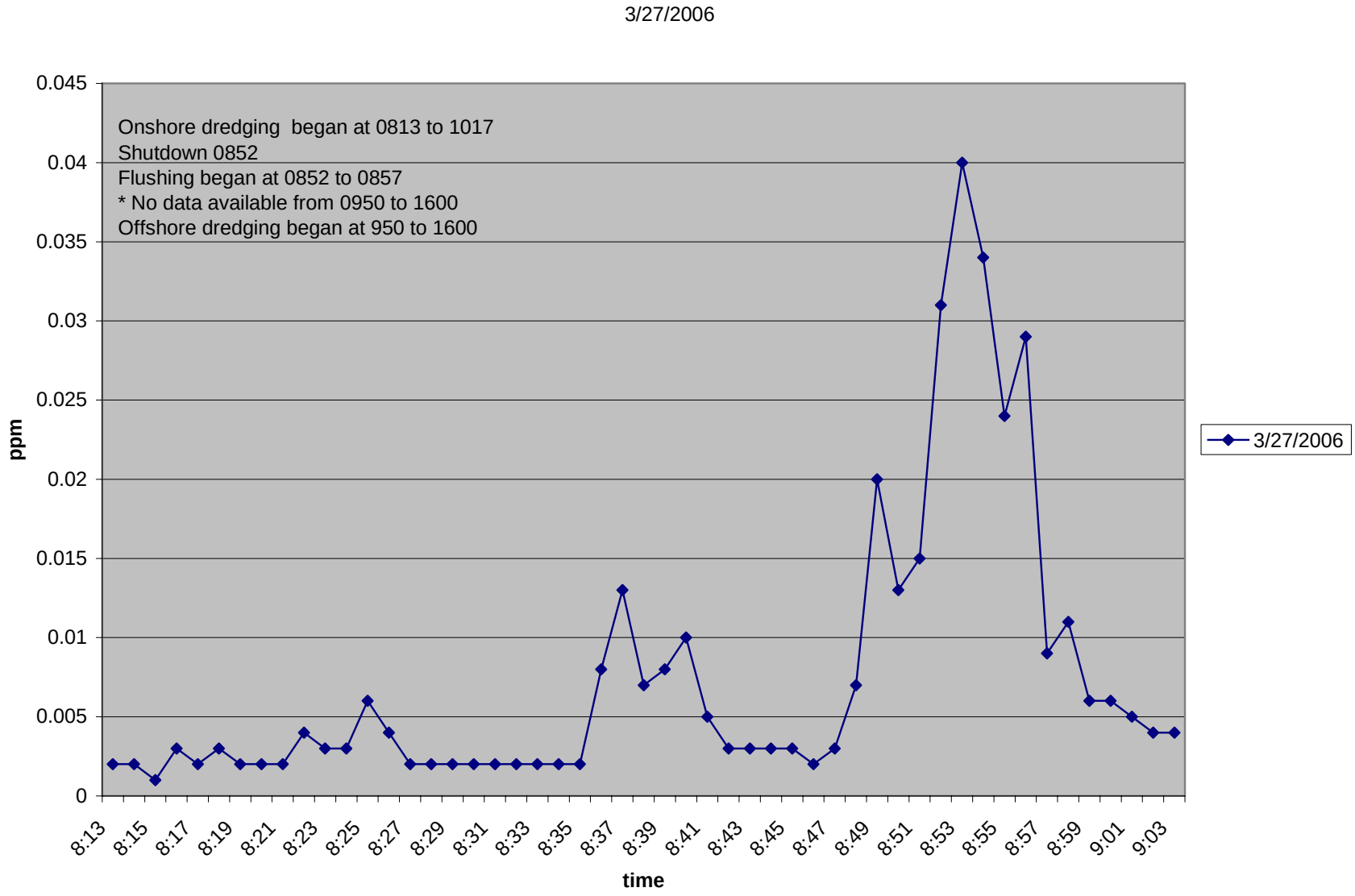
Graph E61. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, March 20, 2006, Santa Cruz Harbor, Santa Cruz County, California



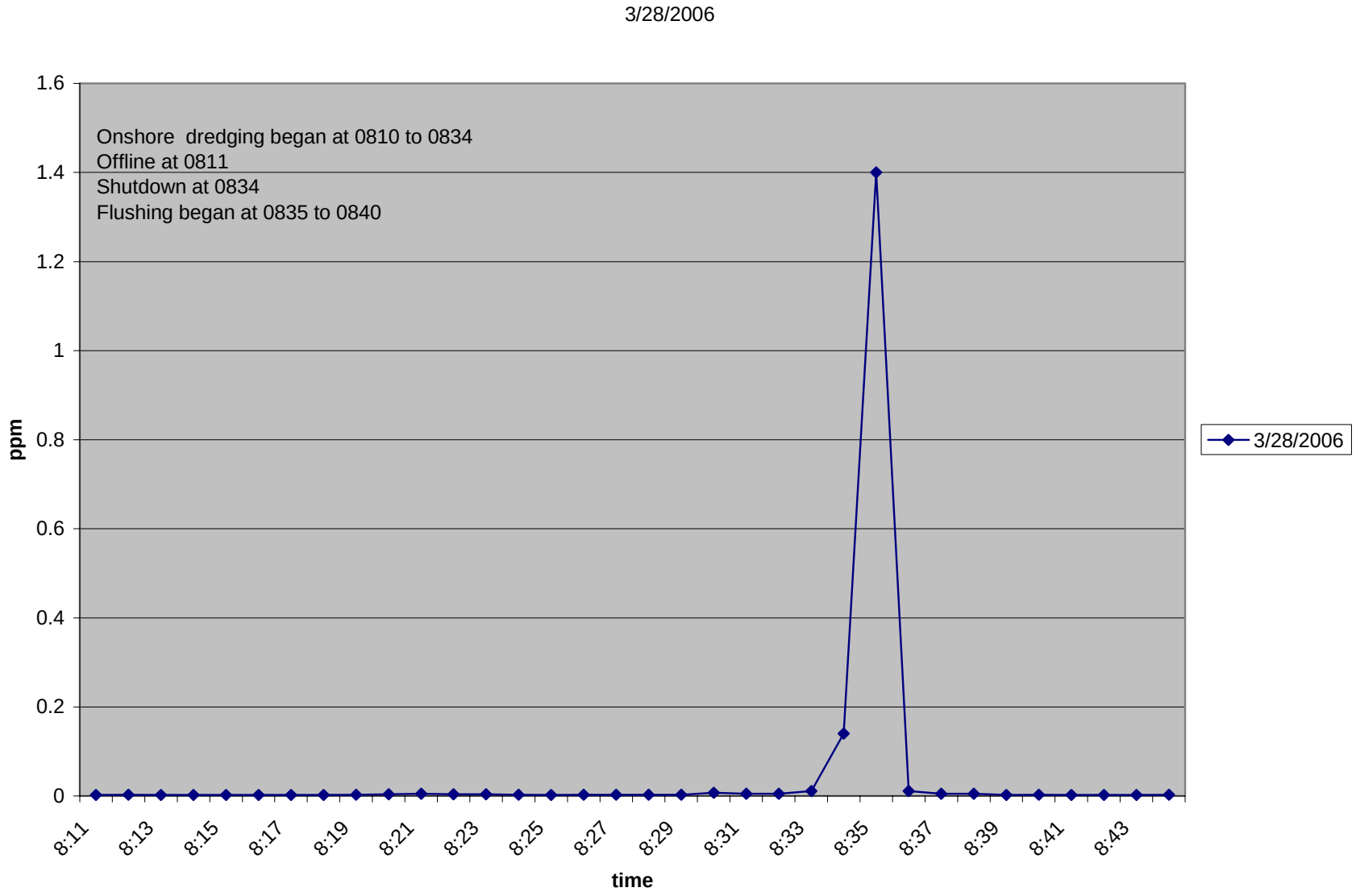
Graph E62. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, March 21, 2006, Santa Cruz Harbor, Santa Cruz County, California



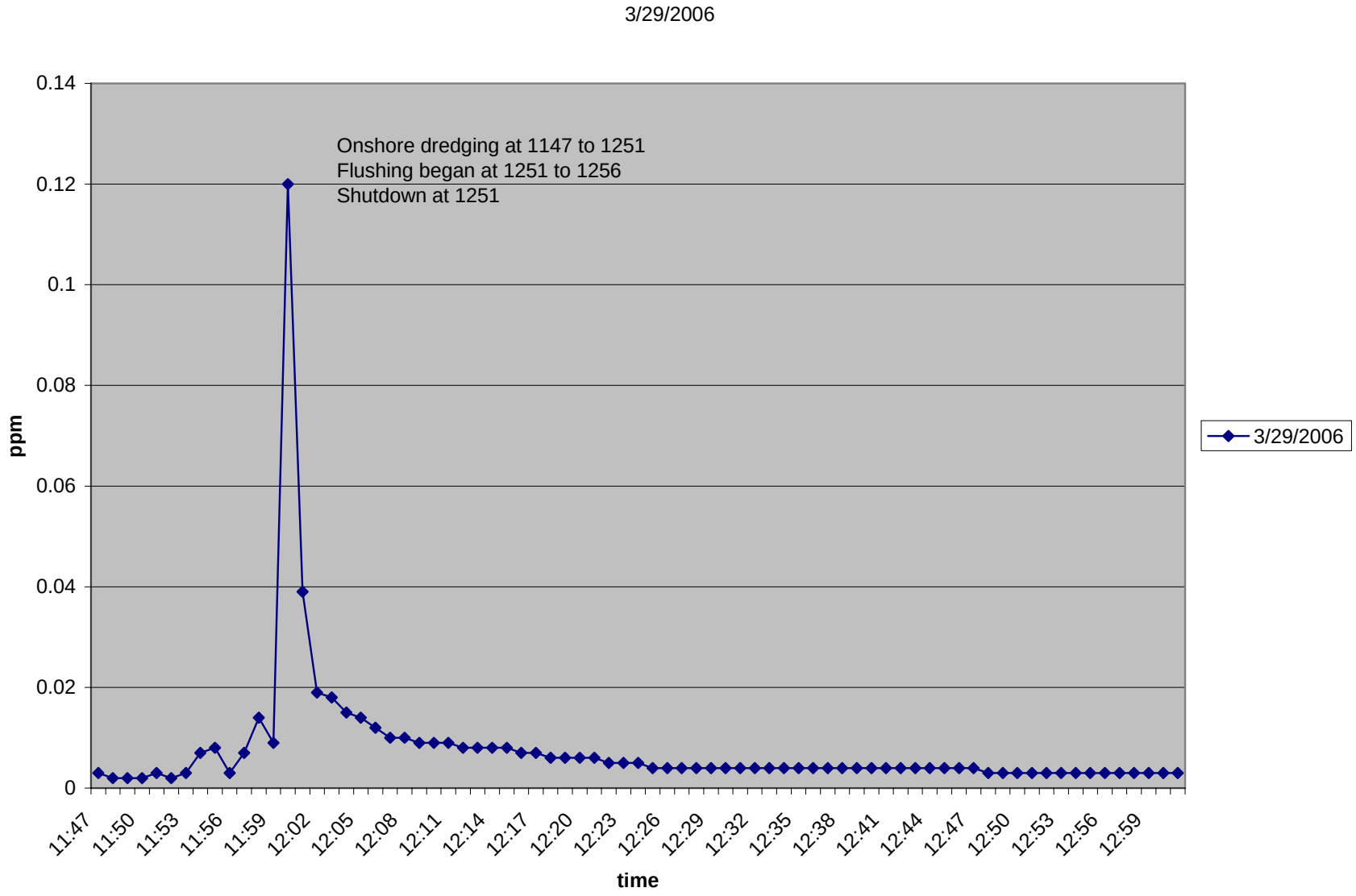
Graph E63. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, March 27, 2006, Santa Cruz Harbor, Santa Cruz County, California



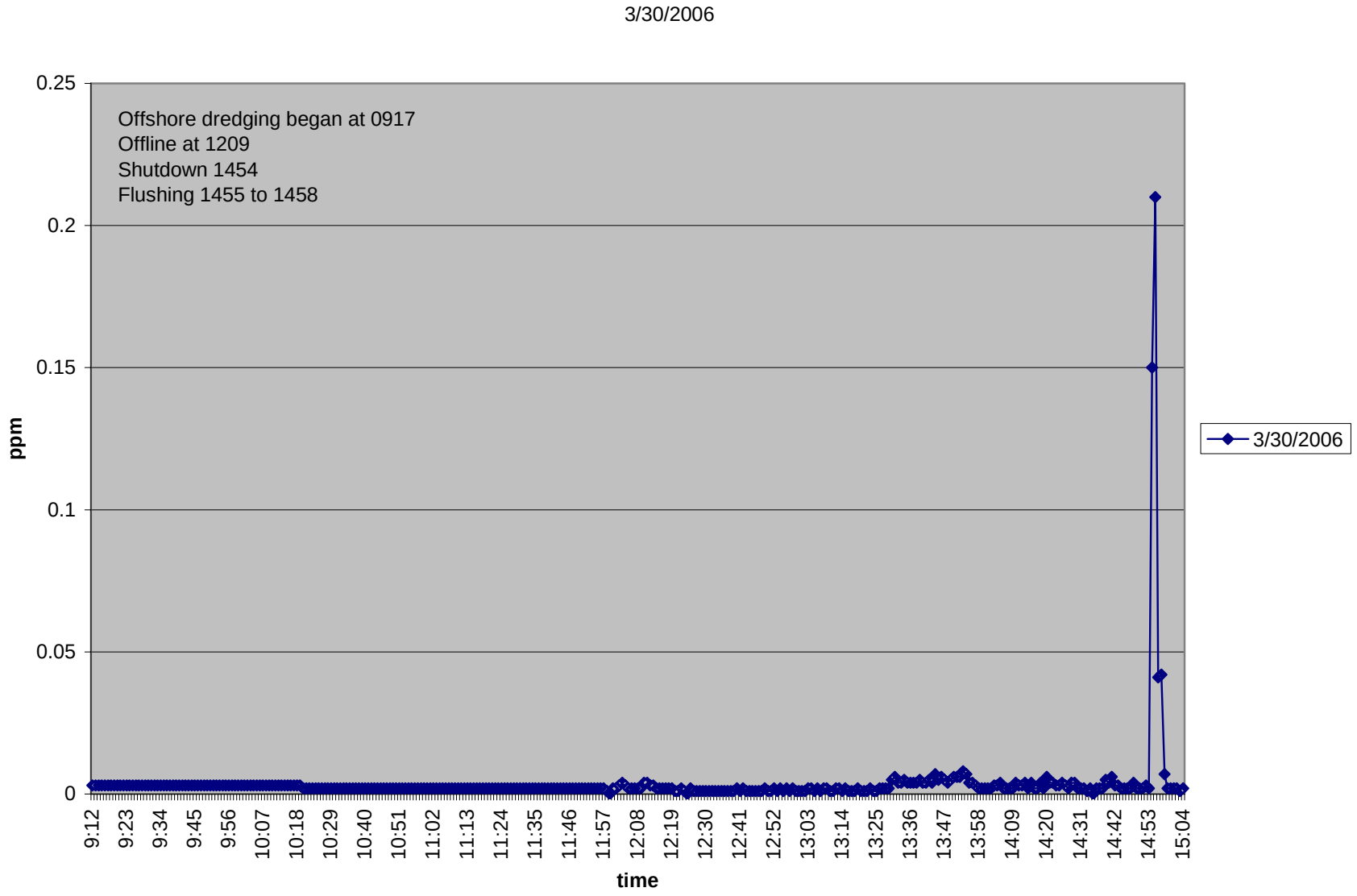
Graph E64. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, March 28, 2006, Santa Cruz Harbor, Santa Cruz County, California



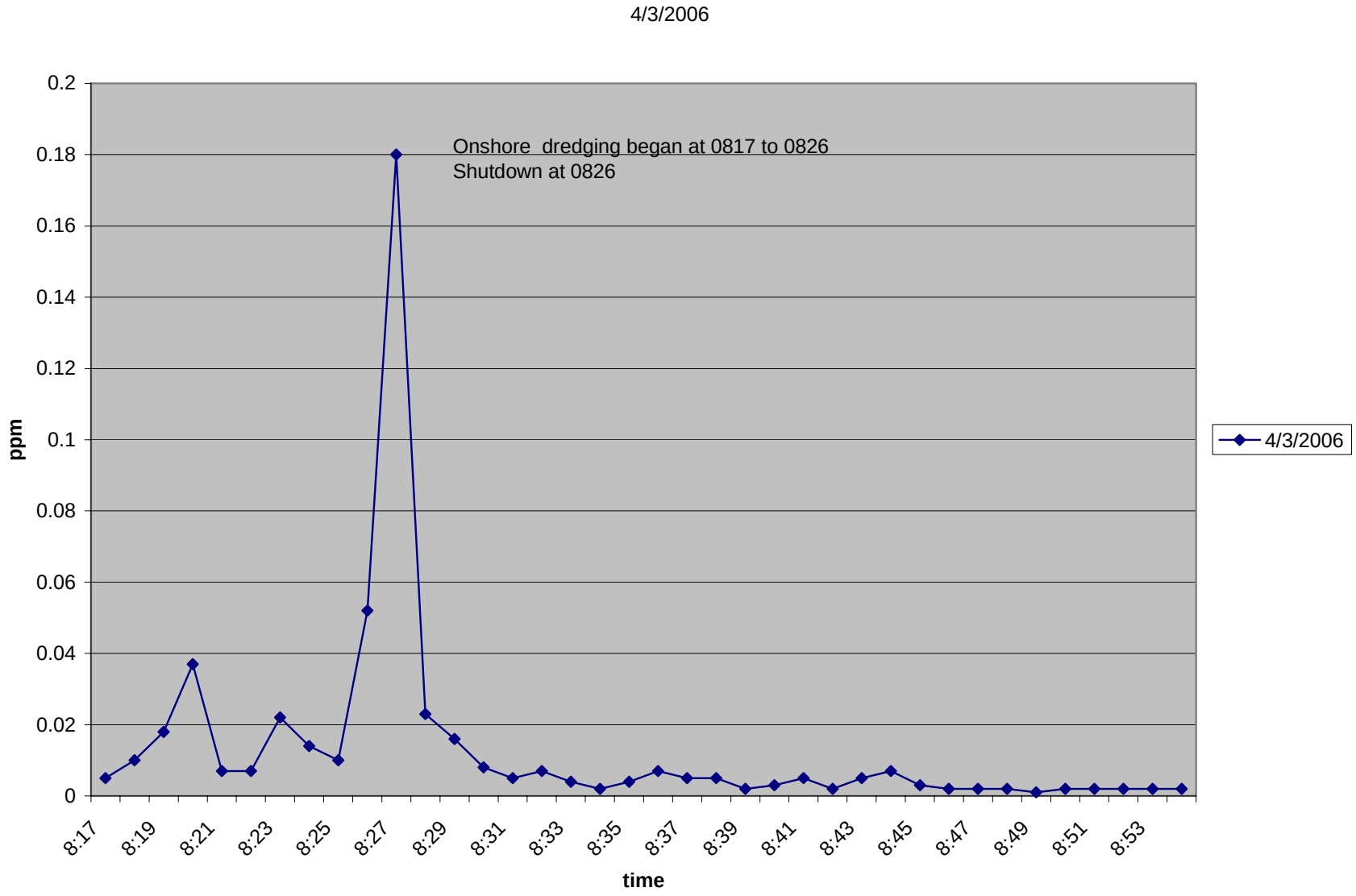
Graph E65. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, March 29, 2006, Santa Cruz Harbor, Santa Cruz County, California



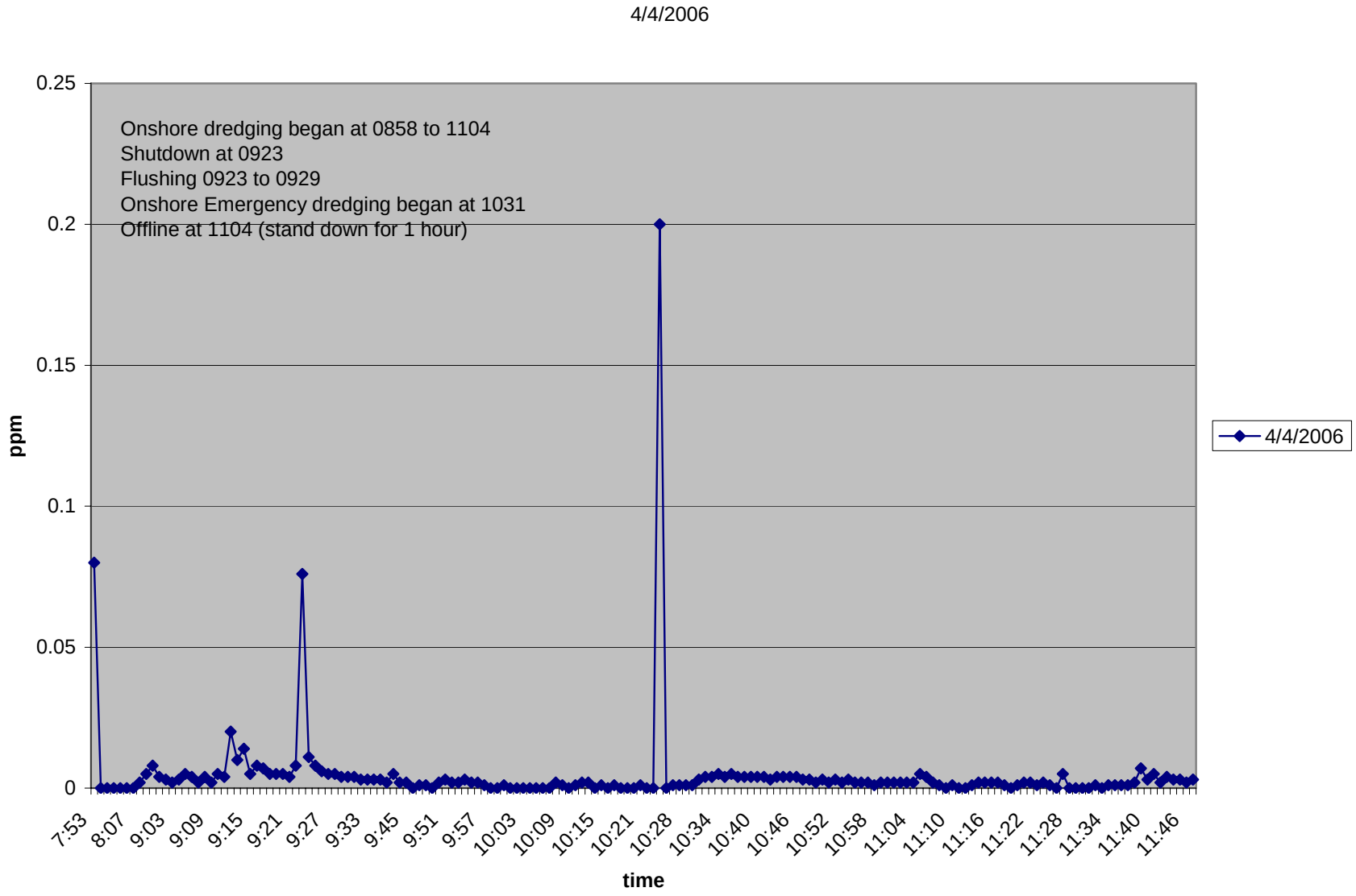
Graph E66. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, March 30, 2006, Santa Cruz Harbor, Santa Cruz County, California



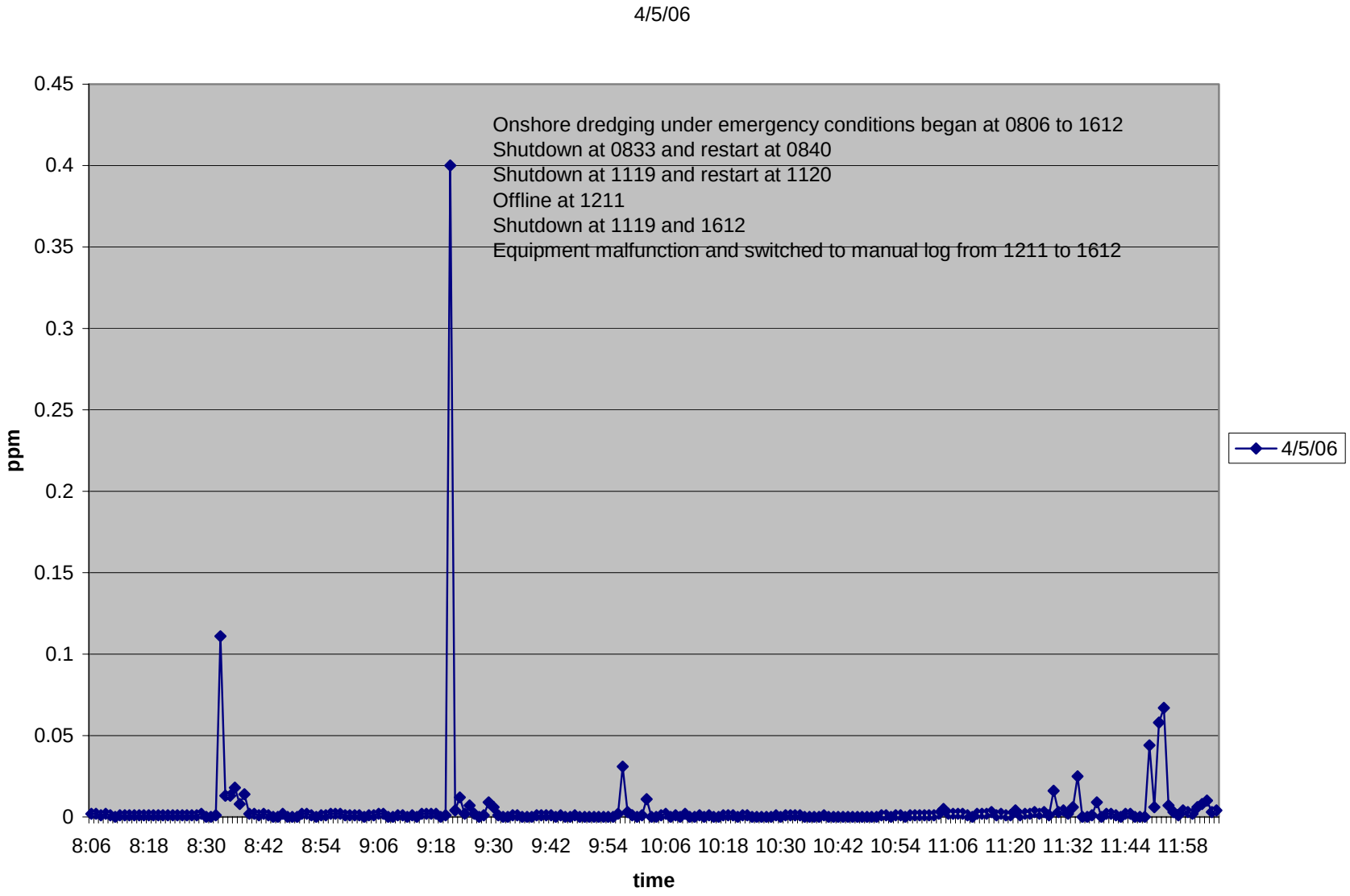
Graph E67. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, April 3, 2006, Santa Cruz Harbor, Santa Cruz County, California



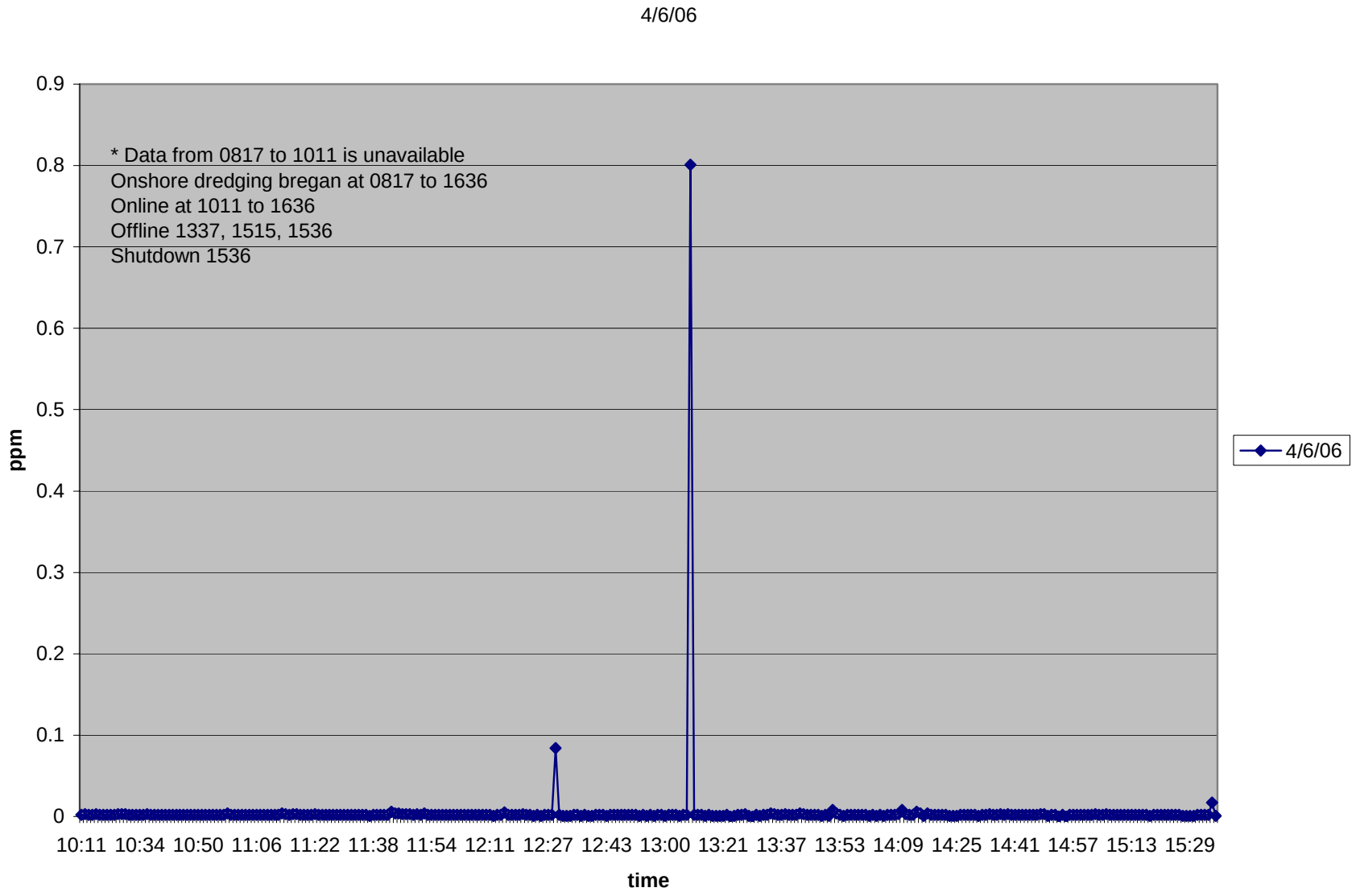
Graph E68. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, April 4, 2006, Santa Cruz Harbor, Santa Cruz County, California



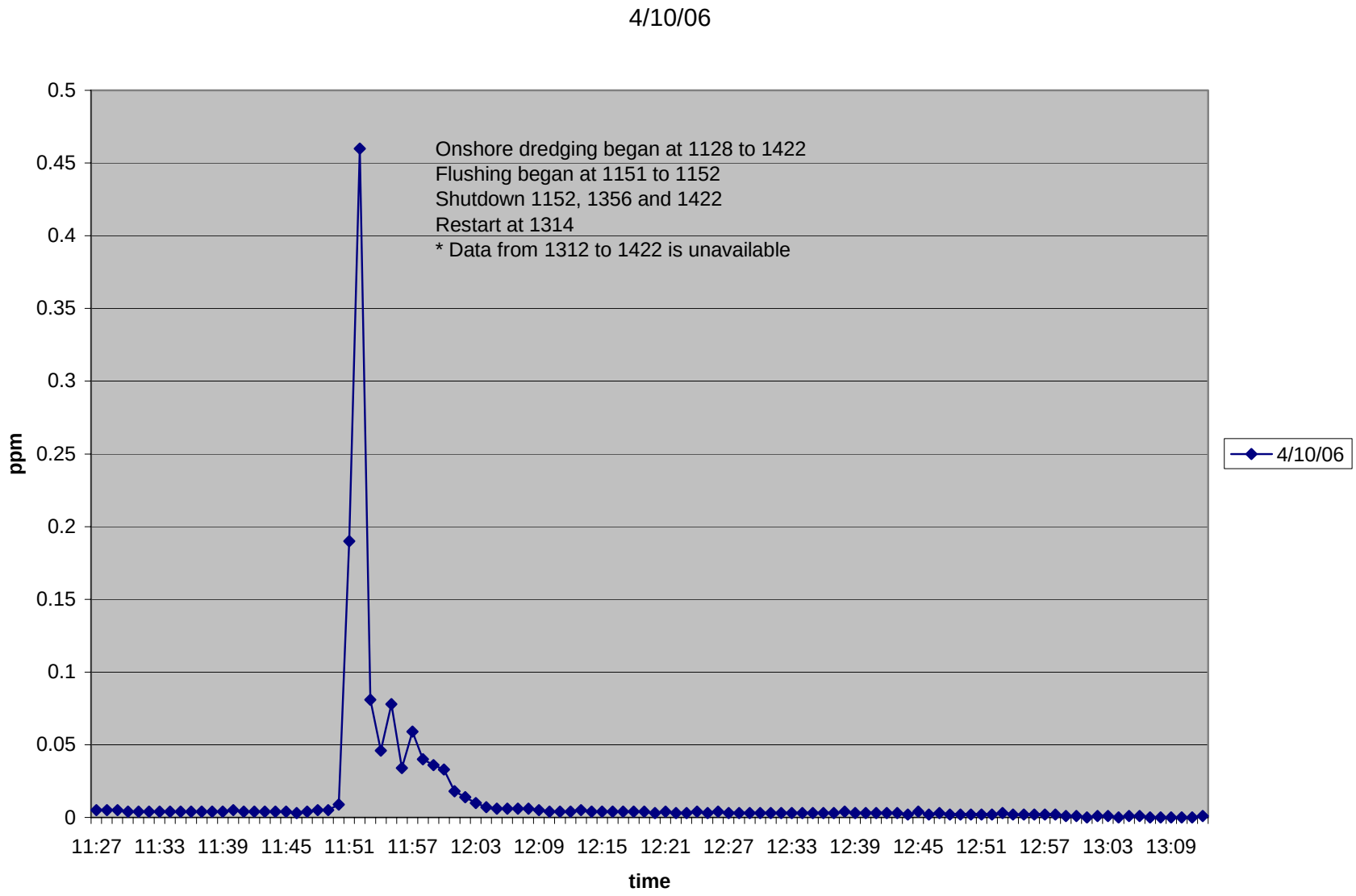
Graph E69. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, April 5, 2006, Santa Cruz Harbor, Santa Cruz County, California



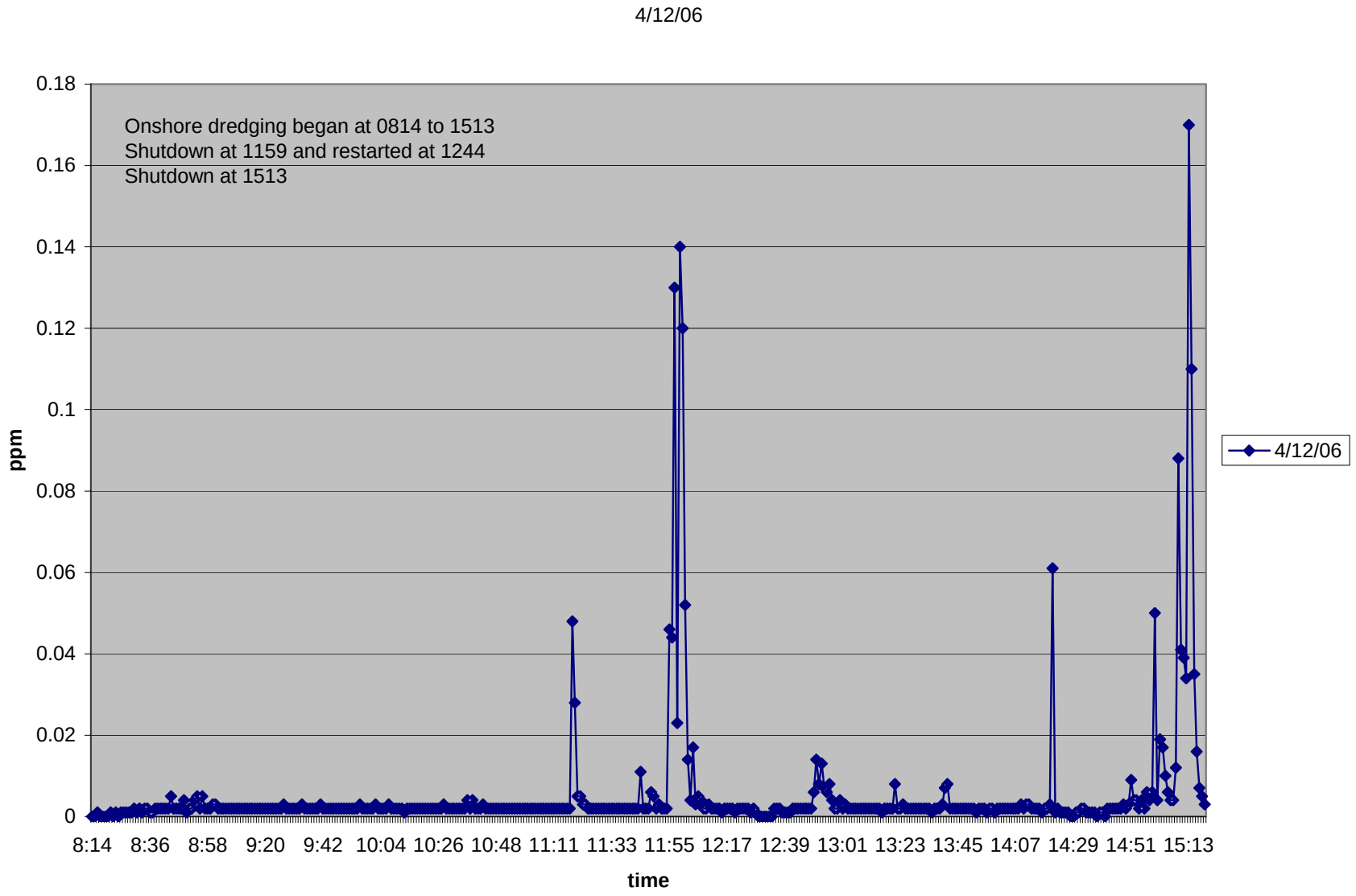
Graph E70. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, April 6, 2006, Santa Cruz Harbor, Santa Cruz County, California



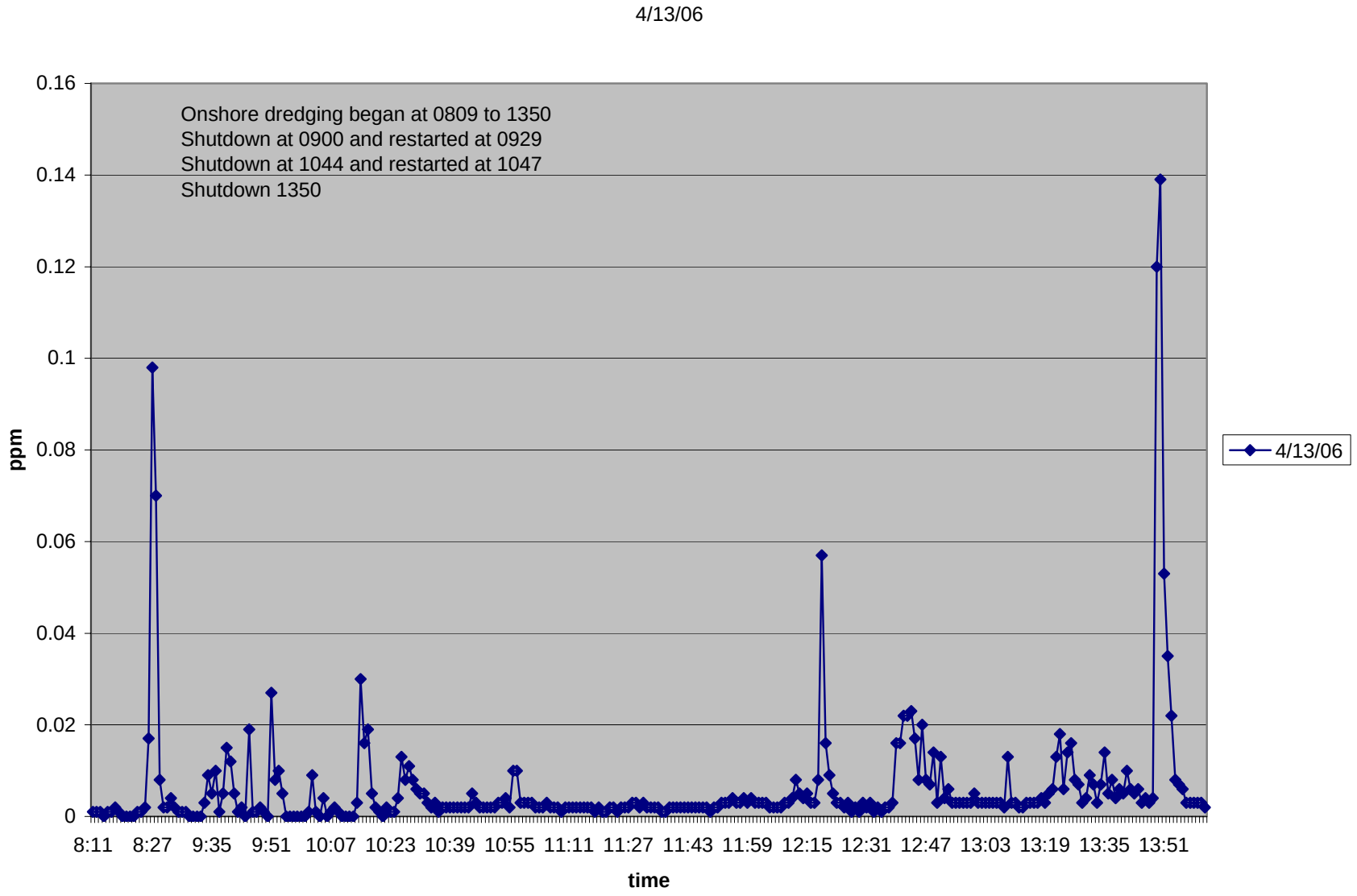
Graph E71. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, April 10, 2006, Santa Cruz Harbor, Santa Cruz County, California



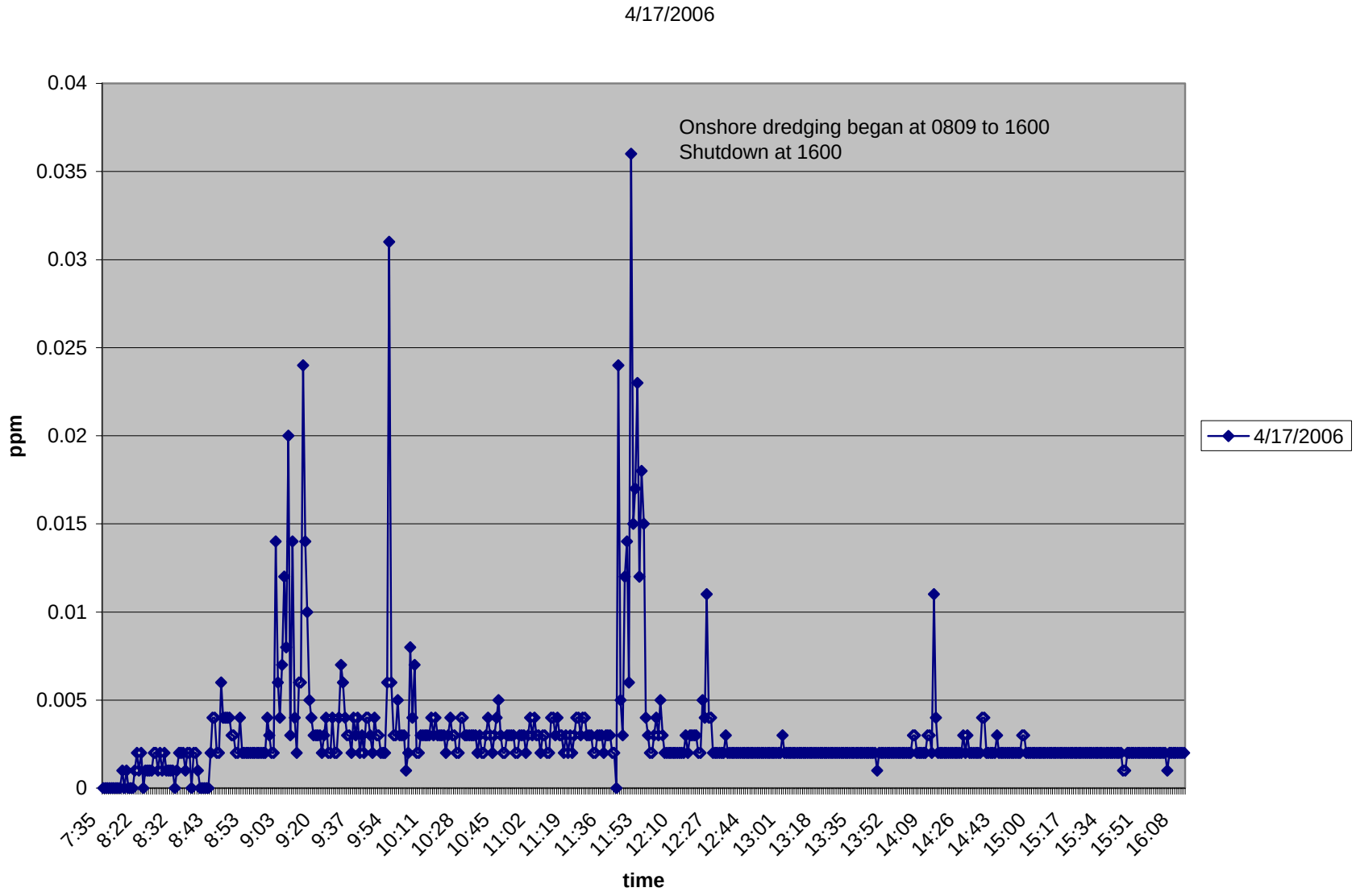
Graph E72. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, April 12, 2006, Santa Cruz Harbor, Santa Cruz County, California



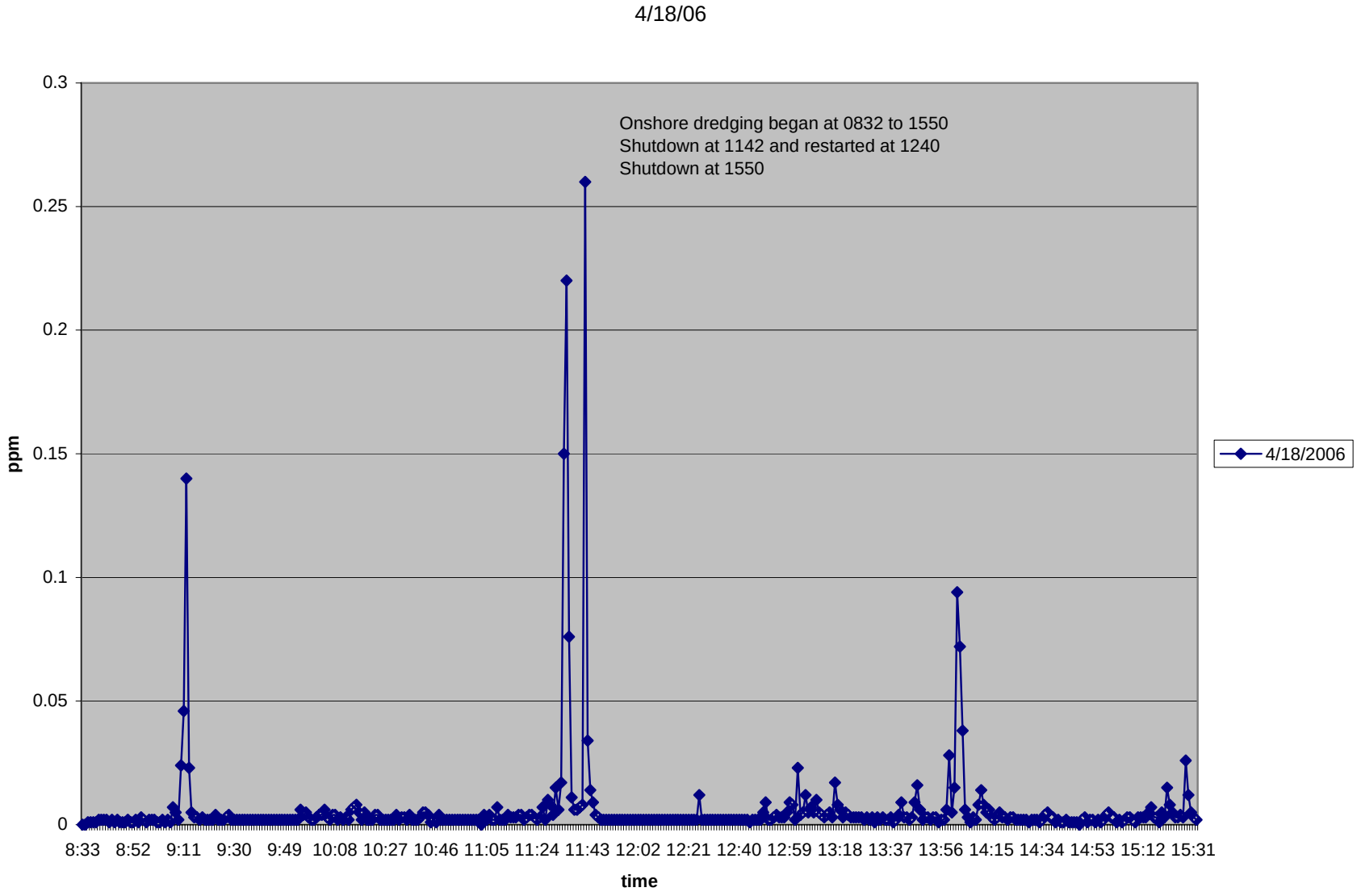
Graph E73. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, April 13, 2006, Santa Cruz Harbor, Santa Cruz County, California



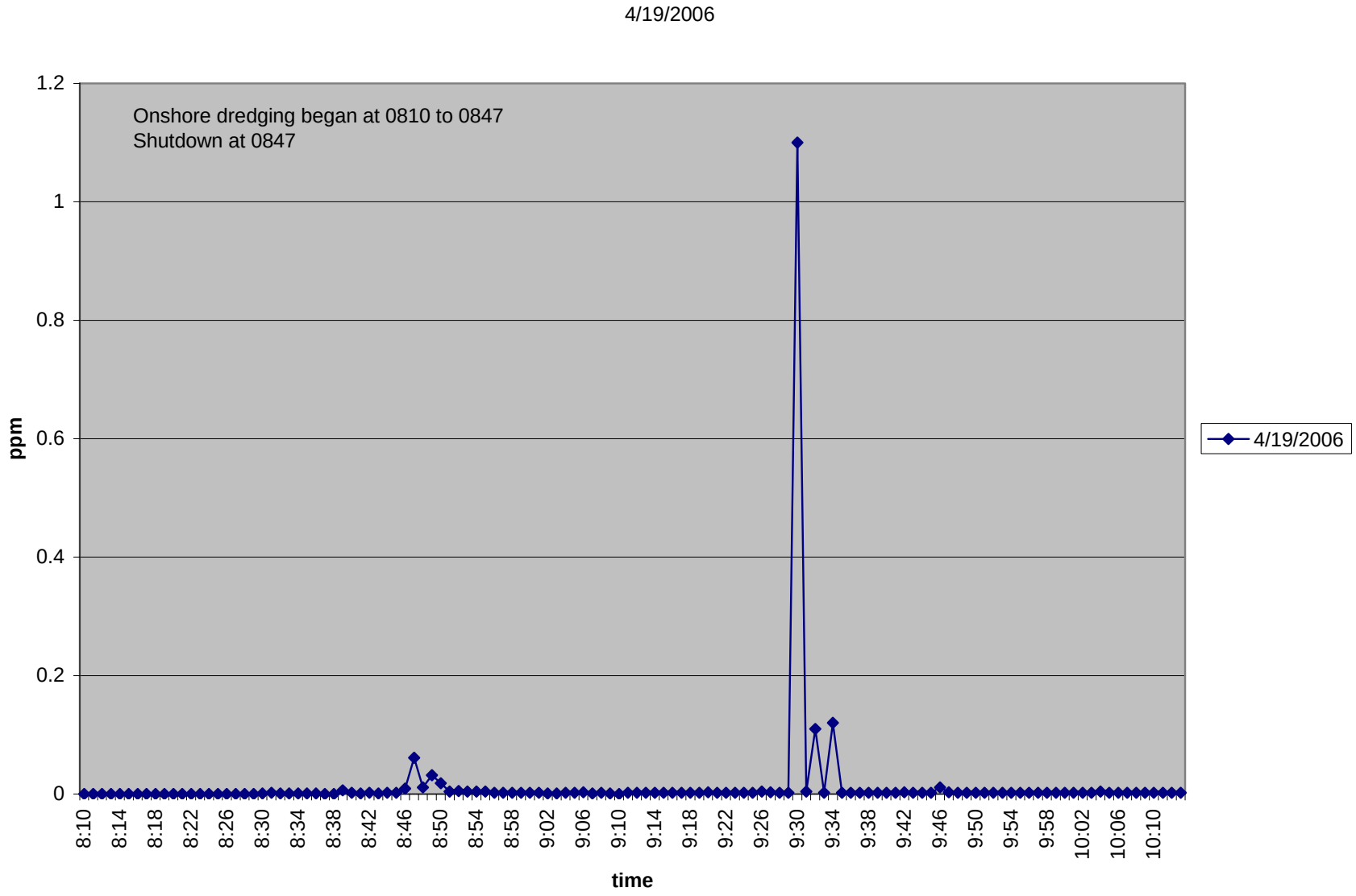
Graph E74. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, April 17, 2006, Santa Cruz Harbor, Santa Cruz County, California



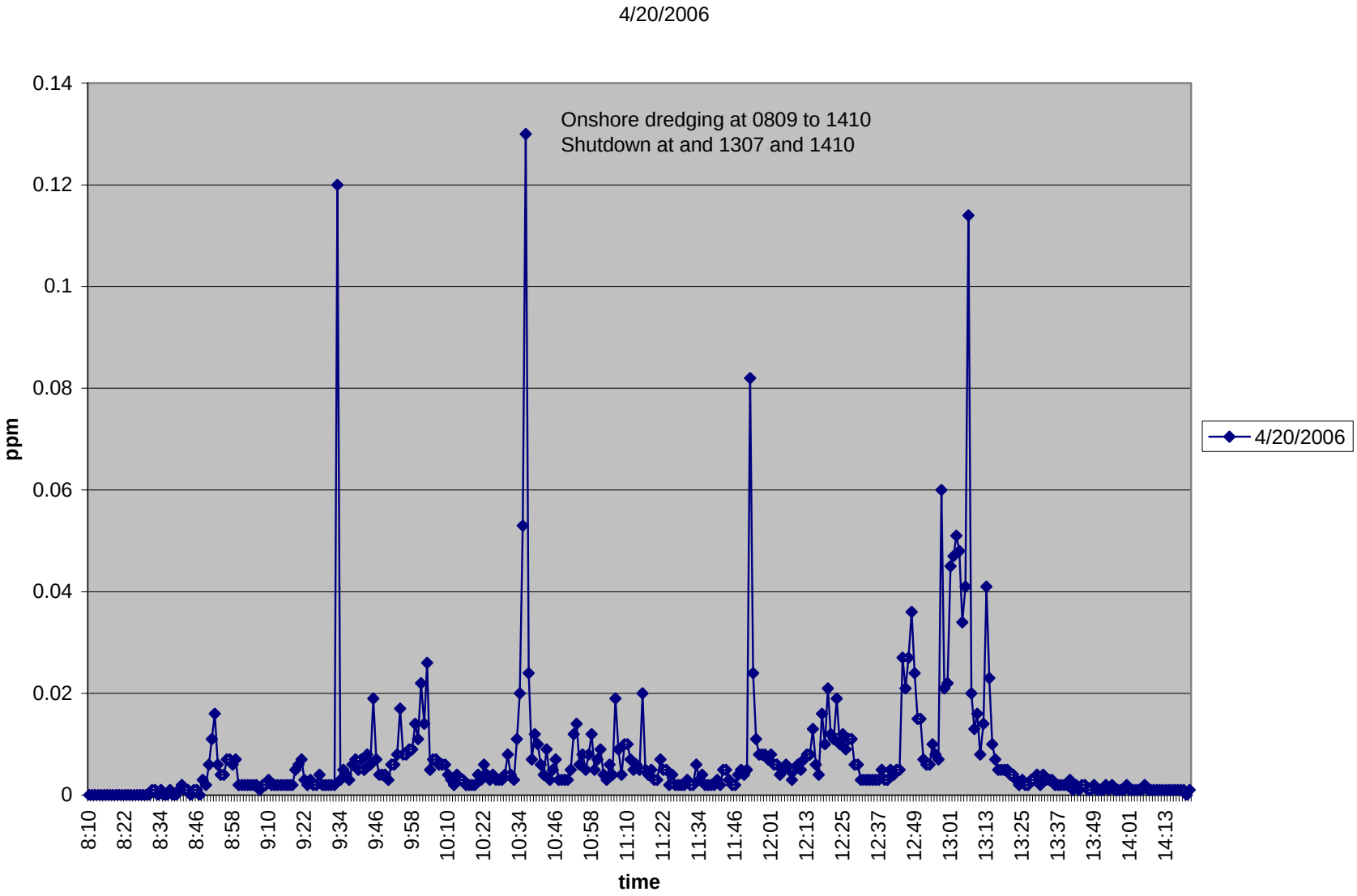
Graph E75. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, April 18, 2006, Santa Cruz Harbor, Santa Cruz County, California



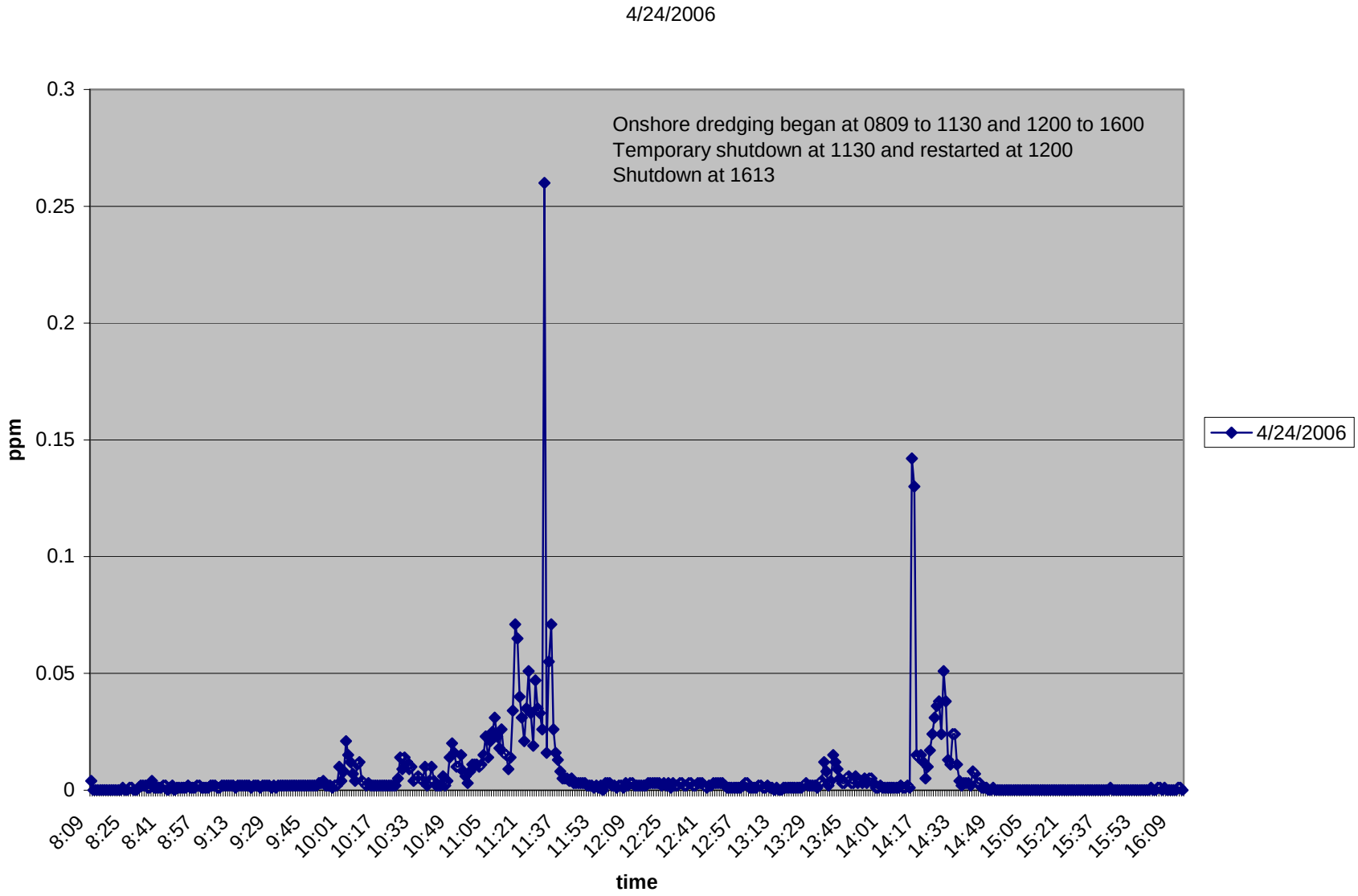
Graph E76. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, April 19, 2006, Santa Cruz Harbor, Santa Cruz County, California



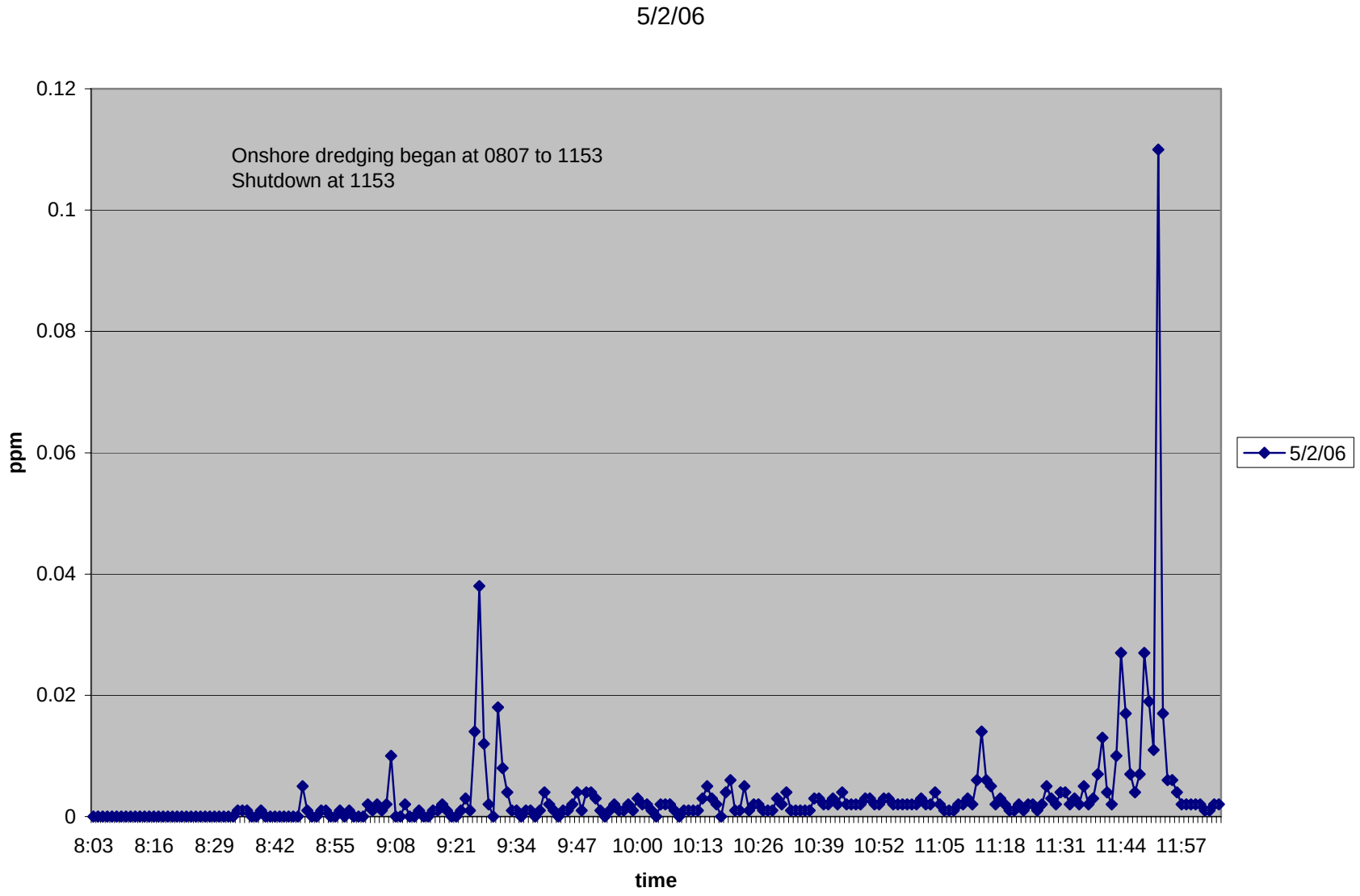
Graph E77. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, April 20, 2006, Santa Cruz Harbor, Santa Cruz County, California



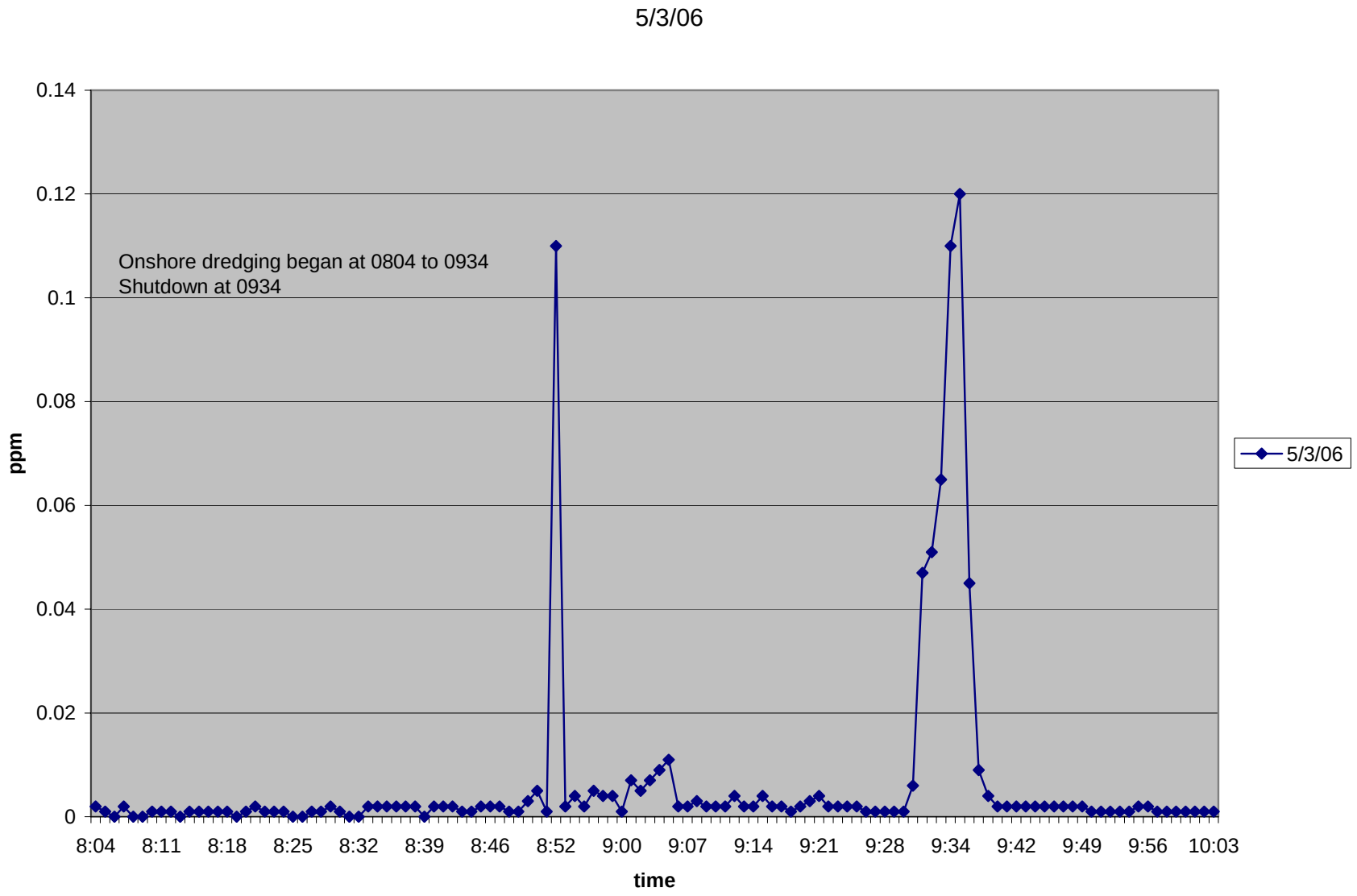
Graph E78. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, April 24, 2006, Santa Cruz Harbor, Santa Cruz County, California



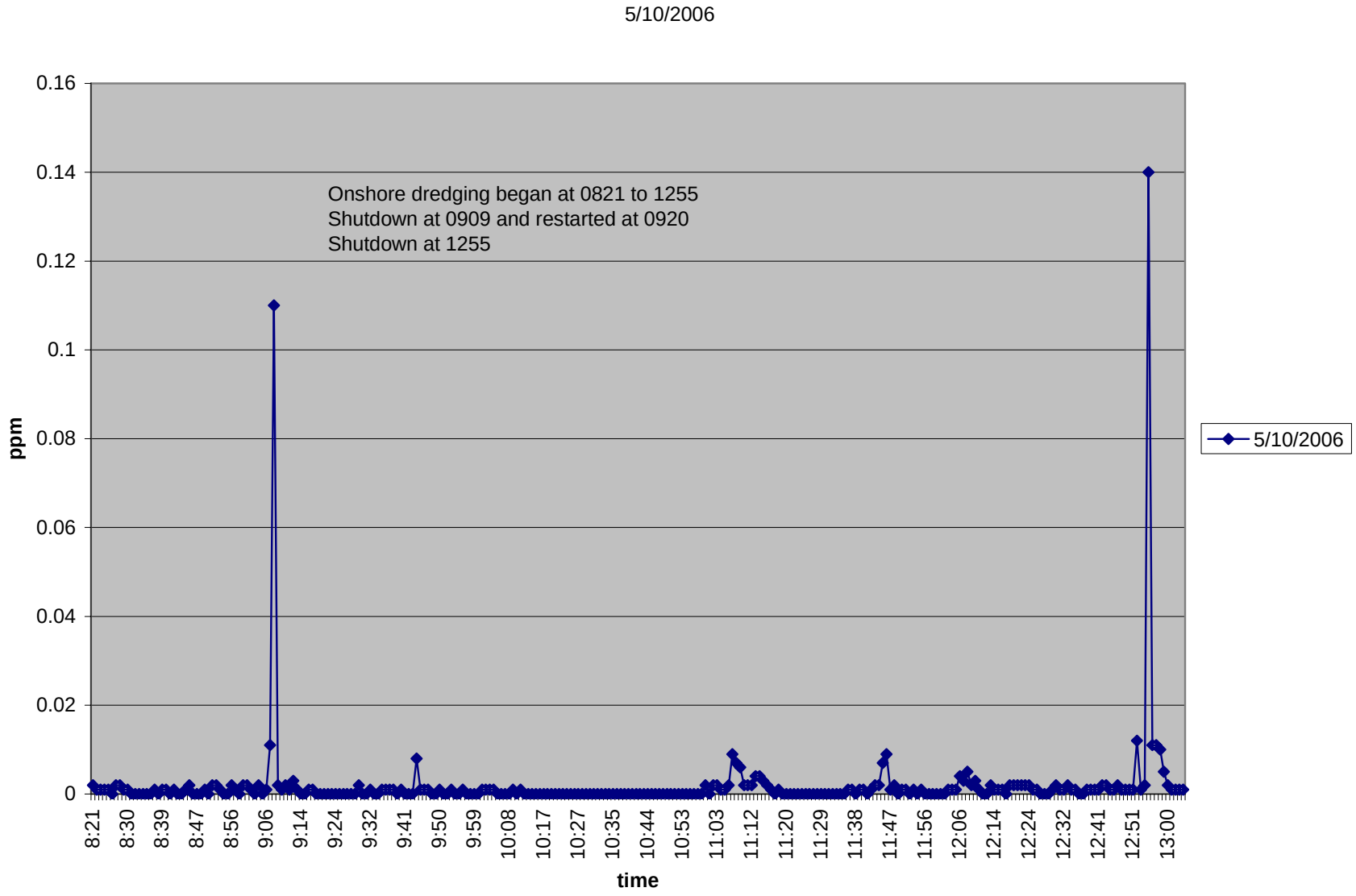
Graph E79. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, May 2, 2006, Santa Cruz Harbor, Santa Cruz County, California



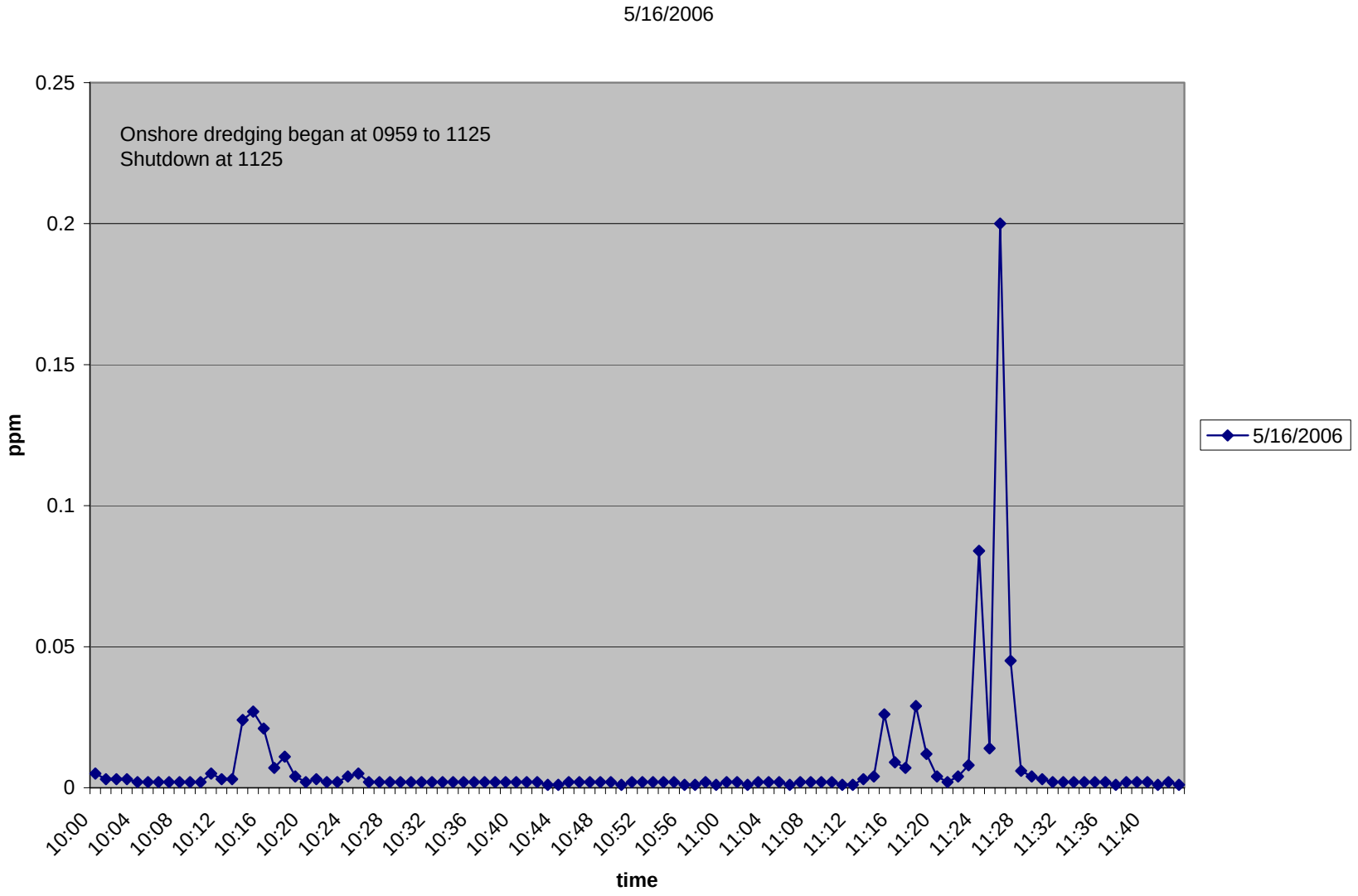
Graph E80. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, May 3, 2006, Santa Cruz Harbor, Santa Cruz County, California



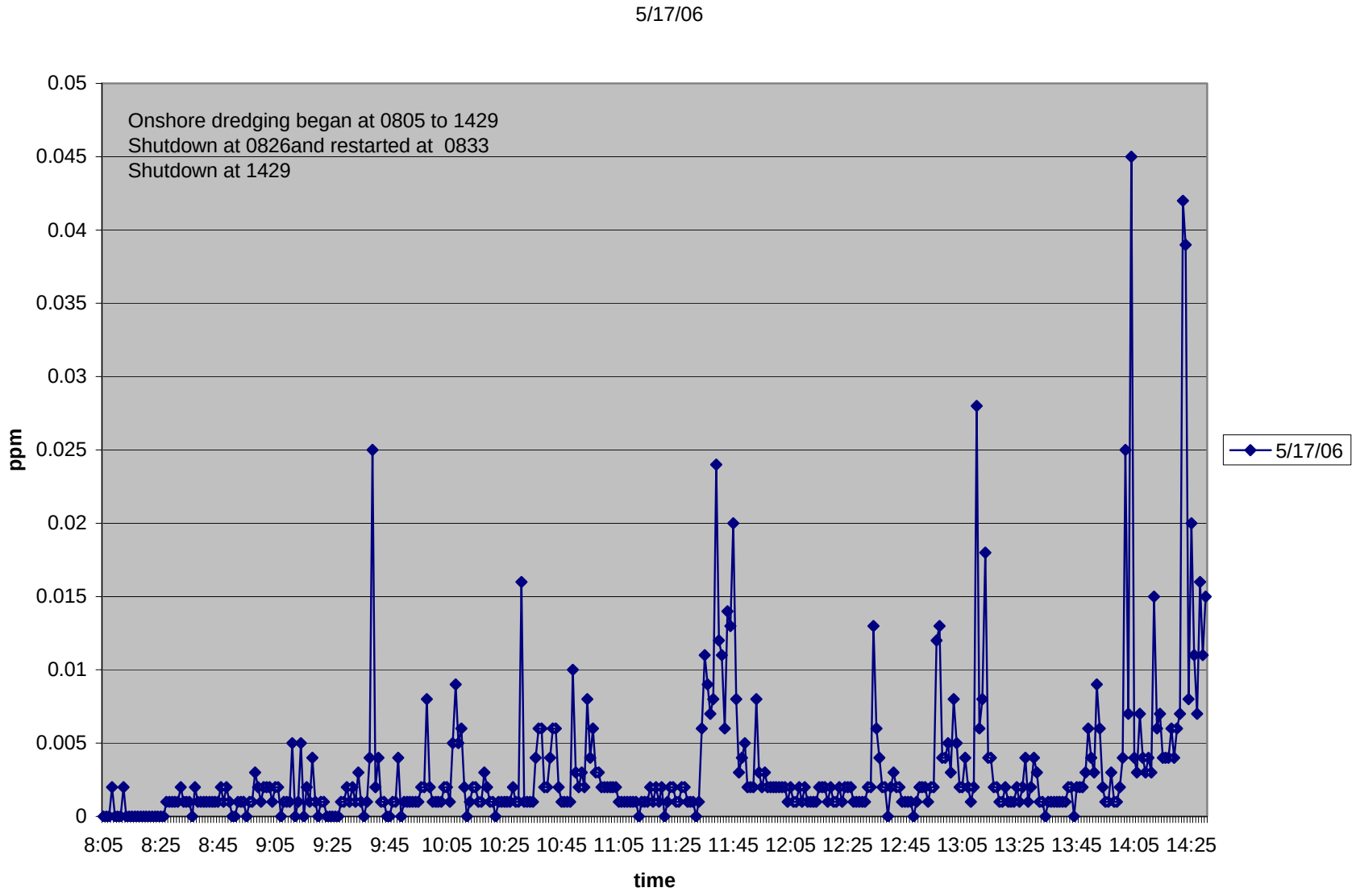
Graph E81. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, May 10, 2006, Santa Cruz Harbor, Santa Cruz County, California



Graph E82. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, May 16, 2006, Santa Cruz Harbor, Santa Cruz County, California



Graph E83. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, May 17, 2006, Santa Cruz Harbor, Santa Cruz County, California



Graph E84. Plots of Hydrogen Sulfide Monitoring Levels Over the Course of a Dredging Day, May 18, 2006, Santa Cruz Harbor, Santa Cruz County, California