Health Consultation

Evaluation of Hydrogen Sulfide Emissions from the New River

Calexico, Imperial County, California

Prepared by the
California Department of Public Health

DECEMBER 3, 2010

Prepared under a Cooperative Agreement with the
U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Agency for Toxic Substances and Disease Registry
Division of Health Assessment and Consultation
Atlanta, Georgia 30333

Health Consultation: A Note of Explanation

A health consultation is a verbal or written response from ATSDR or ATSDR's Cooperative Agreement Partners 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 or ATSDR's Cooperative Agreement Partner which, in the Agency's opinion, indicates a need to revise or append the conclusions previously issued.

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Summary

Introduction

In 2008, Imperial County stakeholders requested assistance from the California Department of Public Health (CDPH) in responding to the community's continuing concern about potential health risks posed by the New River. One of the main concerns voiced by residents living closest to the New River relates to the development of health symptoms when odors from the New River are strongest.

Industrial wastes and raw sewage are dumped into the New River on the Mexican side of the border and they are carried by the river into the United States. The Regional Water Quality Control Board (RWQCB) has been conducting monthly monitoring of water from the New River since 1975. Water from the New River is analyzed for heavy metals, volatile organic chemicals, pesticide-related chemicals, and fecal coliform bacteria. On the basis on current data, the contaminants presenting the greatest potential exposure concern are fecal coliform bacteria and other microbial contaminants associated with sewage discharges, confined animal feeding operations (CAFOs), and trash dumping.

A number of chemicals commonly associated with sewage that can become airborne are known as malodorous (having a bad smell) compounds. Hydrogen sulfide (H_2S) is the most common sulfur-containing malodorous compound associated with sewage; it is usually described as smelling like rotten eggs.

During the winter of 2008 and summer of 2009, CDPH conducted limited air monitoring for H_2S along the banks of the New River in Calexico and in the nearest neighborhood, in order to determine whether emissions of H_2S from the New River were having an effect on the air quality in the neighborhood and on the health of nearby residents.

In 2009, CDPH held two public availability sessions in addition to knocking on doors and meeting with residents in the West Side Neighborhood, to hear their concerns about the New River. Residents reported having an increase in health-related symptoms when odors from the New River were the strongest. They were also concerned that mosquitoes could be breeding along the New River, carrying contaminants from the New River, and infecting them when they are bitten.

A number of the health symptoms (irritated eyes, headaches, and nausea) reported to CDPH staff could be caused by breathing H_2S in ambient air. However, these symptoms are very common and can be caused by a number of other factors.

To address the community's concern about mosquitoes, CDPH contacted Imperial County Vector Control. CDPH was informed that the New River is not considered a primary breeding source for mosquitoes. Unmaintained swimming pools represent one of the main sources of mosquito breeding. Bird baths, fountains, buckets, and old tires are other common sources found in residential neighborhoods. Residents who are concerned about mosquitoes in their neighborhood can contact Imperial County Vector Control for assistance.

Conclusions

The H_2S monitoring conducted by CDPH staff provides limited information on ambient air levels of H_2S along the banks of the New River, in the West Side Neighborhood, and in other areas of Calexico. The data suggest that H_2S levels in Calexico are higher than levels typically found in urban environments, and are likely the result of the emissions from multiple sources, both locally and in Mexicali. The New River does not appear to be the source of the H_2S odors in ambient air in the West Side Neighborhood, because the H_2S levels were higher in other areas of Calexico than at the New River. Additional monitoring would be needed to adequately characterize the range of ambient levels of H_2S in Calexico throughout the year.

The levels of H_2S measured during both monitoring events are consistent with H_2S levels measured in some studies in which people experienced headaches, nausea, and irritation of the nasal cavity and eyes. Therefore, it is possible that residents of Calexico experienced headaches, nausea, and irritation of the nasal cavity and eyes from ambient H_2S on the days that CDPH staff conducted monitoring. These symptoms are considered temporary and should disappear once exposure to H_2S stops. However, without more extensive monitoring, it is not possible to determine if H_2S in ambient air is regularly affecting the health of Calexico residents.

Recommendations

CDPH and ATSDR recommend that local, state, and federal agencies (Imperial County Air Pollution Control District, California Air Resources Board, US Environmental Protection Agency, respectively), in collaboration with their counterparts in Mexico, consider implementing an air monitoring study defining the ambient level of H_2S in Calexico and Mexicali at different times of the year and identify sources. This information would aid in determining the need for mitigation measures to reduce H_2S in ambient air.

Purpose

The California Department of Public Health (CDPH), Site Assessment Section (SAS), evaluates the public health significance of environmental contamination sources through a cooperative agreement with the federal Agency for Toxic Substances and Disease Registry (ATSDR). The CDPH staff conducted air monitoring for hydrogen sulfide (H_2S) along the banks of the New River in Calexico and in the nearest neighborhood, in order to determine whether emissions of H_2S from the New River were having an effect on the air quality in the neighborhood and on the health of nearby residents. This health consultation presents and evaluates the results of H_2S air monitoring conducted during the winter of 2008 and summer of 2009.

Background and Statement of Issue

The New River, which flows north, has been a problem discussed at federal, state, and local levels for nearly 50 years. The underlying problem is that the river carries heavy loads of residential, industrial, and agricultural waste from Mexicali, Mexico, through Calexico, California. The pollution in the New River increases health risks and health-related concerns for the nearby community.

In 1993, the Imperial County Board of Supervisors petitioned ATSDR to evaluate the public health impact of the New River. In response, ATSDR prepared a health consultation evaluating environmental data collected for the New River from 1969 to 1994. However, the relevance of some of the data dating back 20 years was questioned by some members of the public[1].

In 1995 and 1996, data were collected from the New River as part of a U.S.-Mexico Binational Environmental Monitoring Program. CDPH reviewed these data to evaluate the potential health effects from exposure to the New River water, sediments, and fish [2-4]. In late 1999 and early 2000, CDPH released the following health consultations under a cooperative agreement with ATSDR:

- Evaluation of contamination in the water column of the New River.
- Evaluation of contamination in suspended and bottom sediment of the New River.
- Evaluation of contamination in fish of the New River at Westmorland.

Based on the findings of these health consultations, CDPH concluded that the following activities posed a public health risk: 1) consumption of fish from the New River; 2) exposure to the contamination in the New River from ingestion of suspended sediments and through dermal absorption of contaminants from bottom sediments; and 3) ingestion and dermal exposure to the New River water.

In mid-2008, Imperial County stakeholders requested assistance from CDPH in responding to the community's continuing concern about the odors and health risks posed by the New River. Community members had indicated an increase in health-related symptoms when odors are the strongest.

Regulatory Involvement

In 1998, the New River was placed on the federal Clean Water Act (CWA) 303(d) list of impaired water bodies because it did not meet water quality standards for pathogens. The CWA requires the establishment of a TMDL (total maximum daily load)[1] to address the "impairment" and ensure that water quality standards will be achieved.

In October 2001, the RWQCB adopted a pathogen (disease-causing agent such as bacteria, virus, or other living microorganism) TMDL for the New River; the TMDL was approved by the U.S. Environmental Protection Agency (EPA) on August 14, 2002 [5].

The International Boundary and Water Commission (IBWC) is a U.S.-Mexican federal agency responsible for applying International Boundary and water treaties (such as the Mexican-American Water Treaty) and settling issues that may arise. The Mexican-American Water Treaty, ratified by Congress in 1945, specifically charges the IBWC with solving border sanitation problems and other border water quality issues [5]. The IBWC and the EPA have primary responsibility for ensuring that discharges of wastes from Mexico do not cause or contribute to a violation of the TMDL.

The New River Pathogen TMDL Implementation Plan states that "the IBWC has been working with its Mexican Counterpart (CILA) and other federal and state agencies on both sides of the border, including the Regional Board, to address New River water quality problems at the International Boundary. Short-term measures, dubbed the 'Quick Fixes,' were completed in 1999, and designed for compatibility with long-term solutions, and were funded through a cost-sharing agreement between both countries. The U.S. and Mexico have contributed 55% and 45%, respectively, of the total cost of $7.5 million for the Quick Fixes, which were implemented by a Binational Technical Advisory Committee (BTAC)" [5]. The Quick Fixes, as summarized by the RWQCB, include: "improvements to the collection system, either by lining or replacing existing sewer pipes and acquiring modern sewer cleaning equipment; rehabilitation and upgrades to pumping facilities that lift and deliver wastewater to the treatment facilities, including installation of standby power equipment; and improvements to the existing lagoons at the Ignacio Zaragoza (Mexicali I) and Gonzalez Ortega wastewater treatment facilities in Mexicali to increase their reliability and capacity" [6].

During that same time period, the IBWC identified a number of sewage infrastructure projects for Mexicali, aimed at addressing the New River pollution. Many of these projects have been completed, with costs exceeding $50 million dollars [5]. In 2007, the Las Arenitas waste water treatment plant (WWTP) went on-line, resulting in the elimination of approximately 15-20 million gallons per day of sewage that had been routinely discharged into the New River at the U.S.-Mexico border [6]. The process for contaminant removal at the Las Arenitas WWTP is

[1] A TMDL specifies load allocations for nonpoint sources and waste load allocations for point sources that, when implemented, are expected to result in attainment of applicable water quality standards. State law requires an implementation plan and schedule to ensure that the TMDL will be accomplished. Monitoring actions include the development and implementation of a monitoring plan and Quality Assurance Project Plan to monitor water quality and trash in the New River and at the International Boundary.

considered equivalent to secondary treatment (D. Liden, EPA Environmental Engineer, email communication, June 2, 2010). Secondary treatment refers to the biological process involved in the breakdown of organics, designed to degrade the content of sewage derived from human waste, food waste, soaps and detergent.

In 2002, the New River was again placed on the federal CWA's 303(d) list because it did not meet water quality standards for discharges of trash [5]. In June 2006, the RWQCB adopted a trash TMDL for the New River; the TMDL was approved by the EPA on September 24, 2007 [5].

The RWQCB does not have the authority to require Mexico or the U.S. government to reduce trash that crosses the International Boundary. Successful implementation of the New River Trash TMDL will require cooperation and coordination between numerous agencies on both sides of the border. In the TMDL document, the RWQCB "requests, but does not require, that the U.S. government (i.e., the EPA - U.S. section of the IBWC): (a) specifies and implements measures to ensure that trash discharges from Mexico do not violate or contribute to a violation of this TMDL, (b) removes trash from Mexico that has accumulated at Imperial County Calexico Landfill culverts, and (c) conducts water quality and trash monitoring in the New River at the International Boundary" [5].

Site Visit

In December 2008, CDPH staff traveled to Imperial County and toured the New River from the Mexico border to the Salton Sea. Staff met with community stakeholders to ascertain what types of public health activities could be carried out that would be beneficial to the community. CDPH also met with the Imperial County Office of Education to discuss re-implementing a curriculum model developed by CDPH in 1999 concerning the New River. During that visit, staff also collected H_2S readings along the banks of the New River in Calexico.

In July 2009, staff returned to Calexico and collected additional H_2S measurements along the banks of the New River, in the West Side Neighborhood, and in East Calexico. During that visit, CDPH also held two public availability meetings in the West Side Neighborhood to speak with residents about their concerns.

Land Use

The New River enters the United States at the City of Calexico, less than $^1/_8$ of a mile from businesses in the downtown area. The West Side Neighborhood is the closest residential area to the New River, located less than ¼ of a mile to the east. The river continues its flow north through agricultural fields and neighboring cities, collecting urban and agricultural runoff along its 60-mile course to the Salton Sea.

Demographics

The City of Calexico has a population of 38,150; it is contiguous with the Mexican city of Mexicali, which has approximately one million inhabitants. The vast majority (94.6%) of the

population in Calexico are residents of Hispanic origin, of whom 51% are foreign-born (U.S. Census 2000). The median age is 29.3 years and the average family size is 4.18. Only 47% of Calexico's population has graduated from high school, as opposed to 80.4% of the rest of the U.S. population. The median family income in Calexico is $34,250 versus $60,374 for the rest of the United States [7].

Environmental Contamination/Pathway Analysis/Toxicological Evaluation

Industrial wastes and raw sewage are dumped into the New River on the Mexican side of the border and are carried by the river into the United States. The RWQCB has been conducting monthly monitoring of water from the New River since 1975. The water is analyzed for heavy metals, volatile organic chemicals, pesticide-related chemicals, and fecal coliform bacteria. Fecal coliform bacteria are used as an indicator of fecal contamination; other pathogens are probably present as well.

Prior to the Las Arenitas WWTP going on-line in 2007, the RWQCB routinely reported concentrations of fecal coliform bacteria ranging from a most probable number (MPN) of 300,000 to well over 1,000,000 [8]. Since 2007, fecal coliform levels in the New River have decreased, but the levels are still high, ranging from 1,600 to over 300,000 MPN. These levels greatly exceed California's legally mandated intervention level of 200 MPN [9]. While some industrial chemicals have been reported to be present in water from the New River, the contaminants that, on the basis on current data, present the greatest potential exposure concern are fecal coliform and other microbial organisms associated with sewage discharges, concentrated animal feeding operations (CAFOs), and trash dumping [10].

A number of chemicals commonly associated with sewage that can become airborne are known as malodorous (having a bad smell) compounds. These chemicals include sulfur-containing compounds such as H_2S, methanethiol, and dimethylsulfide, which are often characterized as having a "rotten egg" smell [11]. These chemicals are not typically monitored in the water. A study looking at the composition and quantity of sulfur-containing compounds released from wastewater treatment plants in Baton Rouge, Louisiana, found H_2S as the primary sulfur-containing compound emitted [12].

H_2S is a colorless gas released into the air as a product of the decomposition of dead plant and animal material, particularly in swamps or stagnant water bodies with limited oxygen. Volcanoes, hot springs, crude petroleum and natural gas also emit H_2S. Roughly 90% of the sources that emit H_2S are natural.

H_2S can also be released as a result of many industrial processes. Populations living in areas of geothermal activity or near industries such as natural gas plants, petroleum refineries, food processing plants, coke oven plants, CAFOs, rayon manufacturing plants, manure handling plants, tanneries, landfills, and wastewater treatment plants, are more likely to be exposed to higher levels of H_2S [3].

The California Air Resources Board (CARB) has established health-based ambient air quality standards to identify outdoor pollutant levels considered safe for the public. CARB adopted an

ambient air quality standard for H_2S of 30 parts per billion (ppb) for a 1-hour average [13]. H_2S emissions are monitored at 12 sites in California. The monitoring sites are located in five counties (Inyo, Lake, San Bernardino, Contra Costa and San Bernardino), near a variety of industrial sources, including a geothermal plant, a chemical processing plant, an oil refinery, and an oil and gas processing facility.

To determine whether community members in the West Side Neighborhood and other areas of Calexico are being exposed to H_2S emitted from the New River at levels that could harm their health, we compared the levels measured by CDPH (discussed in the next section) to guidelines established by various agencies to help protect the public and workers from excess exposure to chemicals, including H_2S. These guidelines (see text box on next page) are estimates of daily exposure to the human population (including sensitive groups), below which noncancer adverse health effects are unlikely to occur.

The EPA has determined that studies on potential cancer health effects are inadequate to make a determination as to whether H_2S causes cancer [16]. Additional toxicological information on H_2S is provided in Appendix C.

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 [14]. Smelling offensive odors is known to elicit health effects such as nausea and headaches.

Evaluation of Hydrogen Sulfide Air Measurements

On December 9, 2008 (winter), and July 21-22, 2009 (summer), CDPH took 73 measurements of H_2S along the banks of the New River, near the City of Calexico's WWTP in the West Side Neighborhood, and in East Calexico (Appendix A, Figure 1 and Appendix B, Table 1). A background (typical or expected) sample was also taken in North Calexico, approximately two miles from the New River, where we would not expect the results to be influenced by the New River. (Appendix A, Figure 1 and Appendix B, Table 1). H_2S was measured using a Jerome 631-X Hydrogen Sulfide Analyzer with a detection capability down to 3 ppb.

The typical background level of H_2S in urban areas is less than 1 ppb [12]. H_2S levels measured during the winter and summer monitoring events were higher than the typical background levels, ranging from 3 ppb to 24 ppb (Appendix B, Table 1). H_2S levels were lower during the winter monitoring compared to the summer monitoring.

On December 9, 2008, the highest level of H_2S (21 ppb) was measured at the City of Calexico's WWTP (Appendix A, Figure 2 and Appendix B, Table 1). On that day, the winds were blowing at high wind speed predominantly from the north towards the south (Mexicali) (Appendix A, Figure 3).

On July 21, 2009, during the first day of the summer monitoring event, the highest level of H_2S (21 ppb) was measured at the City of Calexico's WWTP (Appendix B, Table 1). During the first 2 hours (1PM-3PM) of monitoring, the winds were blowing from the northwest towards the southeast. The winds shifted during the last hour of monitoring, blowing from the southwest

towards the northeast (Appendix A, Figure 4). The winds were blowing at medium wind speed during the monitoring.

On July 22, 2009, during the second day of the summer monitoring event, the highest level of H_2S (24 ppb) was measured in East Calexico (Appendix B, Table 1). At that time the winds were calm, blowing from Mexicali towards Calexico (Appendix B, Figure 5). CDPH staff noticed a strong rotten egg like odor throughout Calexico that morning, which became less pervasive as the day progressed. The monitoring data indicated decreasing levels of H_2S as the morning progressed and the winds began to change (Appendix A, Figure 6 and Figure 7). By the end of the monitoring event (~11AM), the wind speed increased and the winds shifted, blowing from Calexico towards Mexicali (Appendix A, Figure 5).

The monitoring and meteorological data (wind patterns) indicate that sources south of the border (H_2S emitting industries in Mexicali), as well as local sources of air pollution such as Calexico's WWTP, the city's landfill, CAFOs, and geothermal plants, are likely the main contributors to the higher-than-typical levels of H_2S measured in Calexico. If the New River were the source of elevated levels of H_2S, we would have expected to see higher levels along the banks of the New River, not in East Calexico. The data indicate that H_2S levels measured along the banks of the New River and in the West Calexico Neighborhood during the winter and summer are consistent with ambient levels measured throughout Calexico.

Comparison to Health-based Guidelines

CDPH compared the H_2S levels to both acute (1 hour) and chronic health guidelines. H_2S levels did not exceed the acute REL (42 ppb) during any of the days when monitoring occurred. Thus, we would not expect residents to have experienced acute effects from H_2S exposure during the days in which monitoring was conducted.

Health-based Guidelines for H_2S

- The California Office of Environmental Health Hazard Assessment (OEHHA) acute reference exposure level (REL) for H_2S is 42 ppb, based on headache, nausea and physiological responses to odor (acquiring symptoms from the smell) [14]. The acute REL is set based on a 1-hour exposure on an intermittent basis.
- The ATSDR Minimal Risk Level (MRL) for intermediate duration exposure to H_2S is 20 ppb, based on nasal lesions in the lining of the nose [12]. 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, based on inflammatory changes in the lining of the nose [15]. The chronic REL is based on a lifetime of exposure.
- The EPA has set a chronic inhalation reference concentration (RfC) for chronic exposure to H_2S of 1 ppb, based on nasal lesions of the olfactory mucosa [16]. The RfC is set based on continuous exposure over a lifetime.
- The World Health Organization (WHO) has an air quality guideline of 10.6 ppb, averaged over a 24-hour period, based on eye irritation. WHO also recommends that H_2S not exceed 5 ppb over a 30-minute period to avoid odor nuisance [17].

H_2S levels at all of the points measured during the winter and summer monitoring events exceed the EPA chronic RfC of 1 ppb. The RfC was set with a safety factor of 300 to account for uncertainties in the science. The RfC is based on a sub-chronic animal (rat) study that looked at inflammation of the nasal mucosa (mucous membrane inside the nose). In the study, no pathological effects were seen at 459 ppb of H_2S. The researchers reported seeing lesions in the nasal cavity at levels that

exceeded 1,300 ppb. The highest concentration CDPH measured (24 ppb) would not likely result in nasal lesions. However, it is possible for residents of Calexico to experience some inflammation and/or irritation of the nasal membrane, due to elevated levels of H_2S in ambient air.

In conclusion, the H_2S monitoring conducted by CDPH in the winter and summer provide limited information on ambient air levels of H_2S in the Calexico area. These data suggest that H_2S levels in Calexico are higher than levels typically found in urban environments and are likely the result of multiple sources, both locally and in Mexicali. Additional monitoring would be needed to adequately determine the range of ambient levels of H_2S in Calexico throughout the year. The levels of H_2S measured during both monitoring events exceed health-based guidelines. Thus, it is possible for residents of Calexico to have experienced headaches, nausea, and irritation of the nasal cavity and eyes from H_2S in ambient air on the days CDPH staff conducted monitoring. These symptoms are considered temporary and should disappear once exposure to H_2S stops. However, without more extensive monitoring, it is not possible to determine if H_2S in ambient air is regularly affecting the health of Calexico residents.

Community Health Concerns and Evaluation

CDPH conducted two public availability meetings in the Calexico West Side Neighborhood on July 21 and 22, 2009. The purpose of these public meetings was to collect concerns about the New River from the community members living near the New River.

CDPH announced these meetings through a mailing notice sent to residents of the Calexico West Side Neighborhood living within a ½ mile radius of the New River. The meetings were also advertised in a local newspaper, *El Sol Del Valle*, serving the cities of Calexico, El Centro, Imperial, Brawley, Holtville, Calipatria, Heber, and Westmorland. The newspaper has an approximate audience of 30,000 readers. CDPH also sent an announcement to community stakeholders, and city, county, and local officials.

During the public availability meetings and while canvassing through the West Side Neighborhood, CDPH staff spoke with 20 community members who shared exposure and health concerns about the New River.

Community Exposure Concerns

The primary exposure concern reported by the community members related to dust from the area around the New River. Residents were concerned about neighborhood exposure to dust that they felt contained contaminants from the river. A community member stated that during the rainy season, the river overflows in some areas; then the mud dries out and dust is carried by the wind to the neighborhood. A teenager was concerned about kids riding bikes along the banks of the New River and being exposed to contaminants from the river via airborne dust.

Some of the community members mentioned hearing through the local media that the New River carries fecal coliform bacteria that produce gases that people who live by the river are breathing.

Most people believe the contaminants of the New River are volatile. As one woman expressed during one of the public availability meetings, “whatever bad things there are in the water, go into the air somehow.”

The majority of the people CDPH staff talked to during the public availability meeting, as well as those visited during the neighborhood canvass, shared the concern that mosquitoes could be breeding along the New River, carrying contaminants from the New River and infecting them when they are bitten.

Evaluation of Exposure Concerns

As described earlier in the *Background* and *Environmental Contamination* sections, data from monthly sampling conducted by the RWQCB suggest that fecal coliform bacteria (sewage-related) are the main contaminant of concern in the New River. However, fecal coliform bacteria are not volatile and do not become a gas; therefore, the most common way people become ill from fecal coliform bacteria is by eating contaminated food or drinking water. If the New River overflowed its banks during the rainy season, any fecal coliform bacteria that may be deposited on soil will die in the presence of sunlight[18].

CDPH contacted staff at the Imperial County Vector Control Program to discuss the concern that mosquitoes are breeding along the New River. Mosquitoes do not breed in running water. The New River is not considered a primary breeding source (“mosquitoes don’t like it”), although when the river rises and overflows its banks, it leaves puddles where some breeding does occur. The river overflowing is primarily due to a rise in the water level in the Colorado River, which feeds into the New River. We were informed that the New River is primarily a concern for birds, since they are hosts for the West Nile Virus. According to staff with Imperial County’s Vector Control Program, “mosquitoes go to the New River to feed on the bird’s bloodmeal”, which is being studied at the New River in Brawley (Tim Hodgkin, Imperial County Vector Control Program, personal communication, July 23, 2009). In 2009, there were no confirmed cases of the West Nile Virus in birds or humans in Imperial County [19].

The vector control staff noted that one of the main sources of mosquito breeding is unmaintained swimming pools, which have increased as a result of foreclosures (Tim Hodgkin, Imperial County Vector Control Program, personal communication, July 23, 2009). One swimming pool can attract hundreds of mosquitoes in a neighborhood. Agricultural drainage ditches are another source for mosquito breeding. Bird baths, fountains, buckets, and old tires are other common sources found in residential neighborhoods. We were told that residents who are concerned about mosquitoes are encouraged to contact the Imperial County Vector Control Program and they will receive assistance in identifying and eliminating breeding sources of mosquitoes in their neighborhood (Tim Hodgkin, Imperial County Vector Control Program, personal communication, July 23, 2009).

Community Health Concerns

CDPH collected a variety of health concerns believed to be caused by airborne exposure from the New River. Community members reported suffering from symptoms such as “allergies,

watery and dry eyes, swollen eyes, headaches, welts or skin bumps, fever, pain in the throat, difficulty speaking, and nausea" when odors from the New River are the strongest. All of the residents agreed that no one from the neighborhood comes into contact or drinks water from the river.

CDPH also heard concerns from community members who attended the public availability meetings about specific diseases and/or health conditions such as asthma, ovarian cysts, diabetes, polio, lung damage, heart failure, tumors, and cancer.

Evaluation of Health Concerns

Several health symptoms (irritated eyes, headaches, and nausea) reported to CDPH could be caused by breathing H_2S present in ambient air. However, these symptoms are very common and can be caused by a number of other factors. With the exception of asthma, the diseases (ovarian cysts, polio, lung damage, heart failure, tumors, and diabetes) reported to CDPH are not associated with exposure to H_2S. Studies have found that some people with asthma may have a worsening of their condition upon exposure to odors (not specific to H_2S). Limited data suggests that people with asthma may experience increased airway resistance from exposure to high levels (2,000 ppb) of H_2S [12].

Health Outcome Data

Health outcome data (HOD) record certain health conditions that occur in populations. These data can provide information on the general health of communities living near a hazardous waste site. They also can provide information on patterns of specified health conditions. Some examples of health outcome databases include the California Cancer Registry, birth defects registries, and vital statistics. Information from local hospitals and other health care providers also can be used to investigate patterns of disease in a specific population. A HOD review would not provide information reflective of H_2S exposure since the primary health implications associated with H_2S are not tracked in these databases.

Children's Health Considerations

CDPH and ATSDR recognize that, in communities with contaminated water, soil, air, or food (or all of these combined, depending on the substance and the exposure situation), infants and children can be more sensitive than adults to chemical exposures. This sensitivity results from several factors: 1) children might have higher exposures to environmental toxins 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 indoors and outdoors close to the ground, which increases their exposure to toxins in dust, soil, surface water, and ambient air; 3) children have a tendency to put their hands in their mouths, thus potentially ingesting contaminated soil particles at higher rates than adults; some children even exhibit an abnormal behavior trait known as "pica," that causes them to ingest non-food items, such as soil; 4) children's bodies are rapidly growing and developing; thus, they can sustain permanent damage if toxic exposures occur during critical

growth stages; and 5) children and teenagers more readily than adults can disregard “no trespassing” signs and wander onto restricted property.

Children exposed to the same levels of H_2S as adults may receive larger doses because they have greater lung surface area: body weight ratios and increased minute volume weight ratios. In addition, children may be exposed to higher levels than adults in the same location because of their short stature and the higher levels of H_2S found nearer to the ground. Children may be more vulnerable to irritants than adults because of the relatively smaller diameter of their airways. CDPH considered children in the pathway evaluated in this health consultation to the extent possible.

Conclusions

The H_2S monitoring conducted by CDPH provides limited information on ambient air levels of H_2S along the banks of the New River, in the West Side Neighborhood, and in other areas in Calexico. These data suggest that H_2S levels in Calexico are higher than levels typically found in urban environments and are likely the result of multiple sources, both locally and in Mexicali. The New River does not appear to be the source of H_2S odors (rotten egg smell) in ambient air in the West Side Neighborhood because H_2S levels were higher in other areas of Calexico than levels measured next to the New River. Additional monitoring would be needed to adequately characterize the range of ambient levels of H_2S in Calexico throughout the year.

The levels of H_2S measured during both monitoring events exceed health-based guidelines. Thus, it is possible for residents of Calexico to have experienced headaches, nausea, and irritation of the nasal cavity and eyes from H_2S in ambient air on the days that CDPH conducted monitoring. These symptoms are considered temporary and should disappear once exposure to H_2S stops. However, without more extensive monitoring, it is not possible to determine if H_2S in ambient air is regularly affecting the health of Calexico residents.

CDPH held two public availability sessions, in addition to knocking on doors and meeting with residents in the West Side Neighborhood, to hear their concerns about the New River. Residents reported having an increase in health-related symptoms (irritated eyes, headaches, and nausea) when odors from the New River were the strongest; they also expressed concern that mosquitoes could be breeding along the New River, carrying contaminants from the New River, and infecting them when they are bitten.

A number of the health symptoms (irritated eyes, headaches, and nausea) reported to CDPH could be caused by breathing H_2S that in ambient air. However, these symptoms are very common and can be caused by a number of other factors.

To address the community’s concern about mosquitoes, CDPH contacted Imperial County Vector Control. CDPH was informed that the New River is not considered a primary breeding source for mosquitoes. Unmaintained swimming pools represent one of the main sources of mosquito breeding. Bird baths, fountains, buckets, and old tires are other common sources found in residential neighborhoods. Residents who are concerned about mosquitoes in their neighborhood are encouraged to contact Imperial County Vector Control for assistance.

Recommendations

CDPH and ATSDR recommend that local, state, and federal agencies (Imperial County Air Pollution Control District, California Air Resources Board, US Environmental Protection Agency, respectively), in collaboration with their counterparts in Mexico, consider implementing an air monitoring study defining the ambient level of H_2S in Calexico and Mexicali at different times of the year and identify sources. This information would aid in determining the need for mitigation measures to reduce H_2S in ambient air.

Public Health Action Plan

The Public Health Action Plan (PHAP) for this site contains a description of actions taken, to be taken, or under consideration by ATSDR and CDPH or others at and near the site. The purpose of the PHAP is to ensure that this health consultation not only identifies public health hazards, but also provides a plan of action designed to mitigate and prevent adverse human health effects resulting from exposure to hazardous substances in the environment. The first section of the PHAP contains a description of actions completed and ongoing. The second section is a list of additional public health actions that are planned for the future.

Actions Completed

- CDPH responded to community stakeholders' request to evaluate potential health risk from exposure to odors originating from the New River.

- CDPH conducted two public availability sessions in the West Side Neighborhood to gather community concerns.

- CDPH contacted the Calexico Unified School District about updating and re-implementing a curriculum developed by CDPH that focuses on environmental issues related to the New River.

Actions Planned

- CDPH will share the findings of this health consultation with the community and other stakeholders at a public meeting

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Certification

This Public Health Consultation, **Evaluation of Hydrogen Sulfide Emissions from the New River, Calexico, California** was prepared by the California Department of Public Health under a cooperative agreement with the Agency for Toxic Substances and Disease Registry (ATSDR). It is in accordance with approved methodology and procedures existing at the time the health consultation was initiated. Editorial review was completed by the Cooperative Agreement partner.

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The Division of Public Health Assessment and Consultation, ATSDR, has reviewed this health consultation and concurs with the findings

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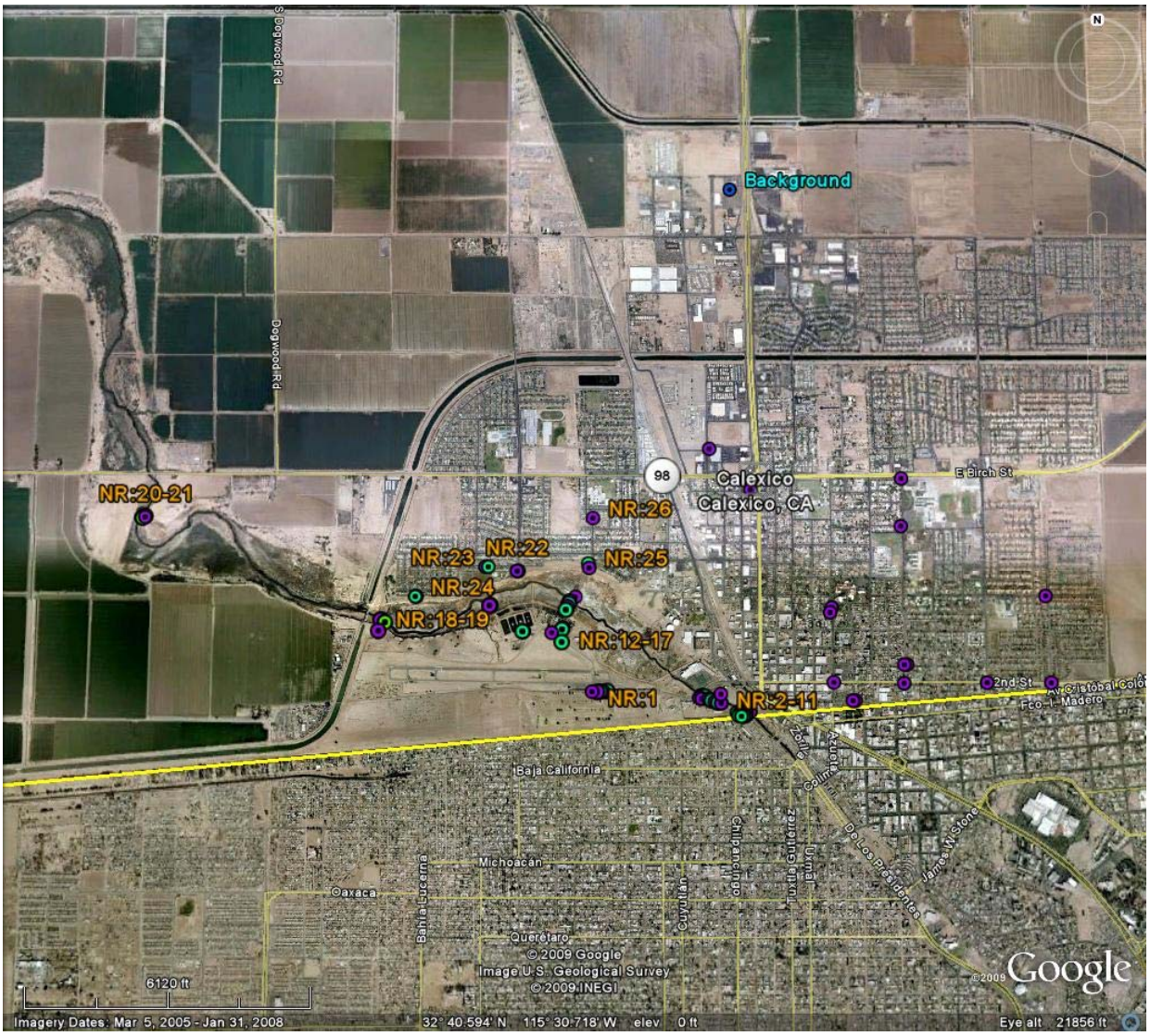
Appendix A. Figures

Figure 1. Approximate Locations of Hydrogen Sulfide Measurements Collected in Winter 2008 and Summer 2009, Calexico, California



⊙: Approximate location of hydrogen sulfide levels measured in December 2008
⊙: Approximate location of hydrogen sulfide levels measured in July 2009
⊙: Approximate location of background level of hydrogen sulfide measured December 2008
NR:1-26: Indicates sample identification numbers for areas sampled along the New River and in the West Side Neighborhood

Figure 2. Hydrogen Sulfide Levels Measured Along the New River (Mexico Border to Highway 98), Calexico's Waste Water Treatment Plant and the West Side Neighborhood During the Winter and Summer, Calexico, California

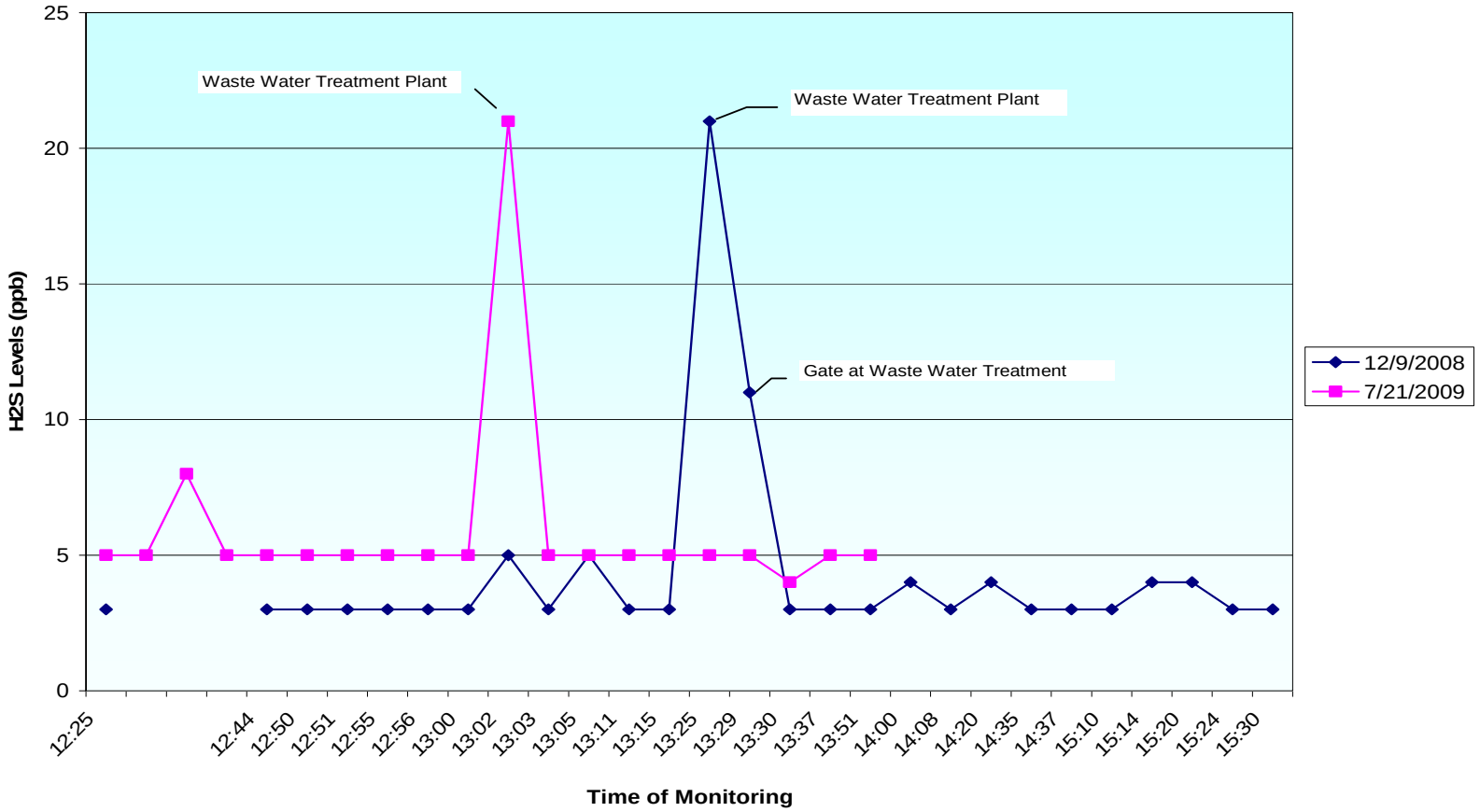
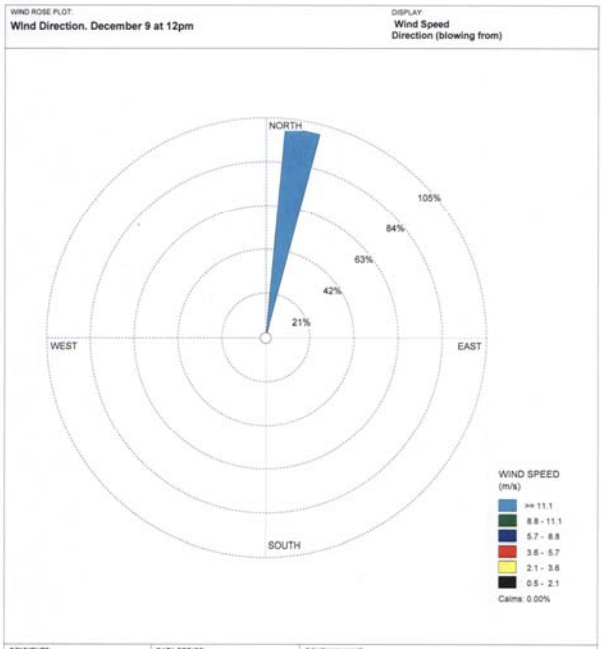
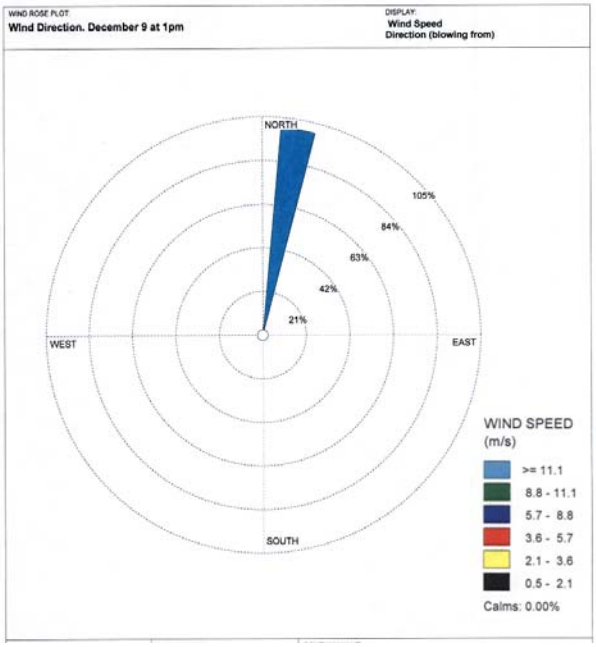


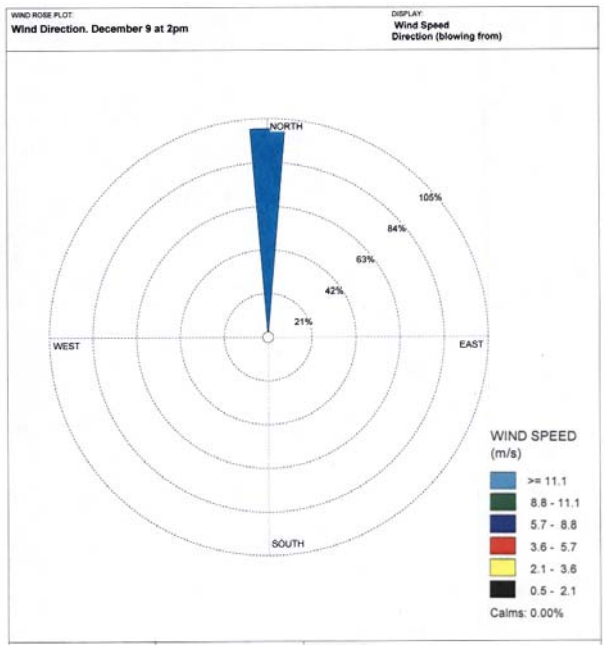
Figure 3. Wind Rose Showing Predominant Wind Direction and Wind Speed During Hydrogen Sulfide Monitoring Conducted on December 9, 2008, Calexico, California



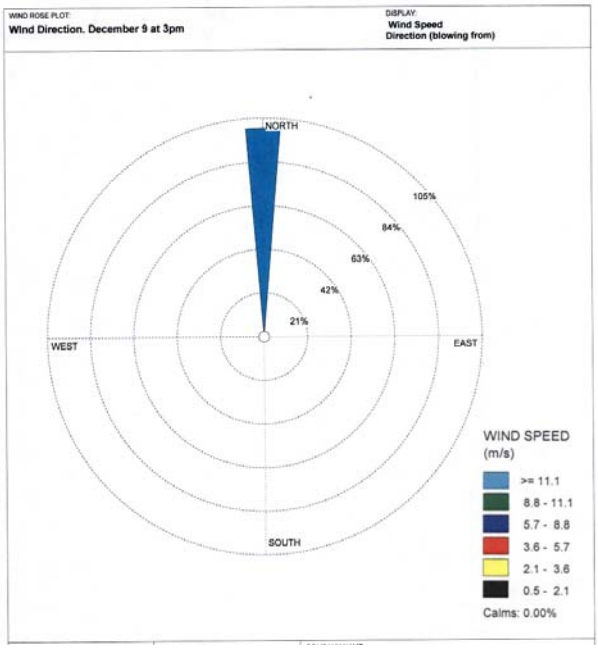
12pm-1pm, Wind Direction: N
Average Wind Speed: 13.30 m/s



1pm-2pm, Wind Direction: N
Average Wind Speed: 13.00 m/s



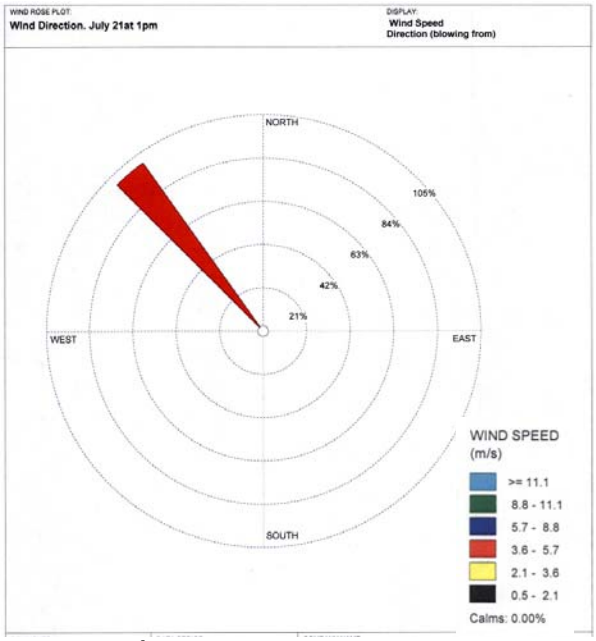
2pm-3pm, Wind Direction: N
Average Wind Speed: 13.20 m/s



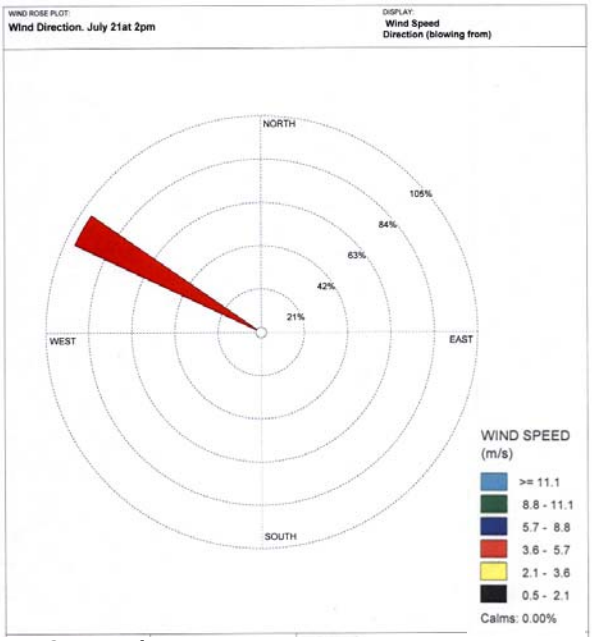
3pm-4pm, Wind Direction: N
Average Wind Speed: 11.20 m/s

Data source: Western Regional Climate Center: meteorological station located in Meloland, CA.

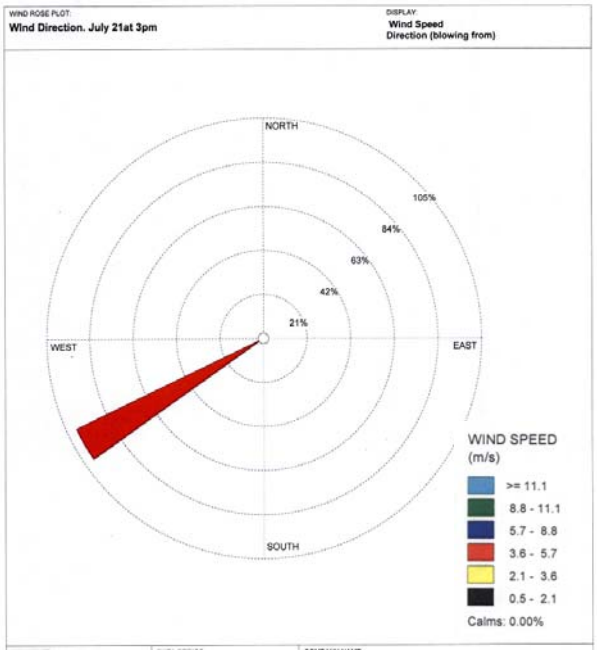
Figure 4. Wind Rose Showing Predominant Wind Direction and Wind Speed During Hydrogen Sulfide Monitoring Conducted on July 21, 2009, Calexico, California



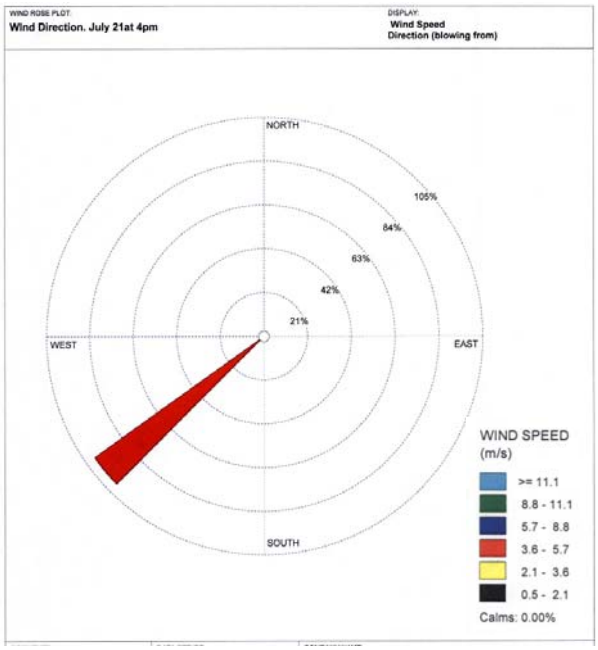
1pm-2pm, Wind Direction: NW
Average Wind Speed: 4.10 m/s



2pm-3pm, Wind Direction: NW
Average Wind Speed: 5.30 m/s



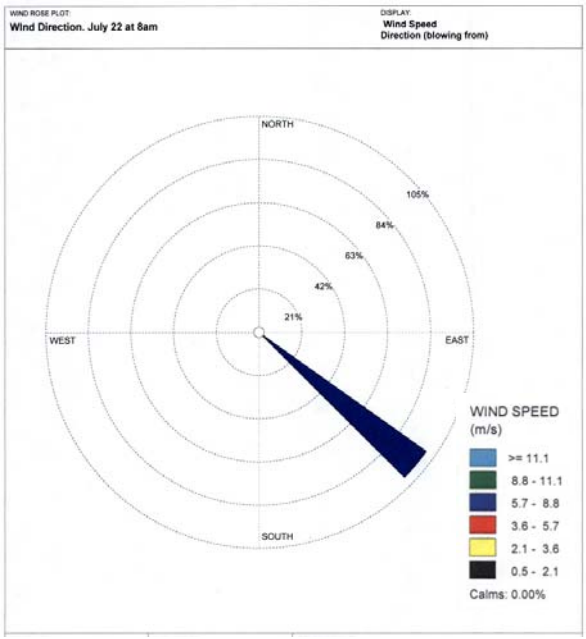
3pm-4pm, Wind Direction: SW
Average Wind Speed: 4.70 m/s



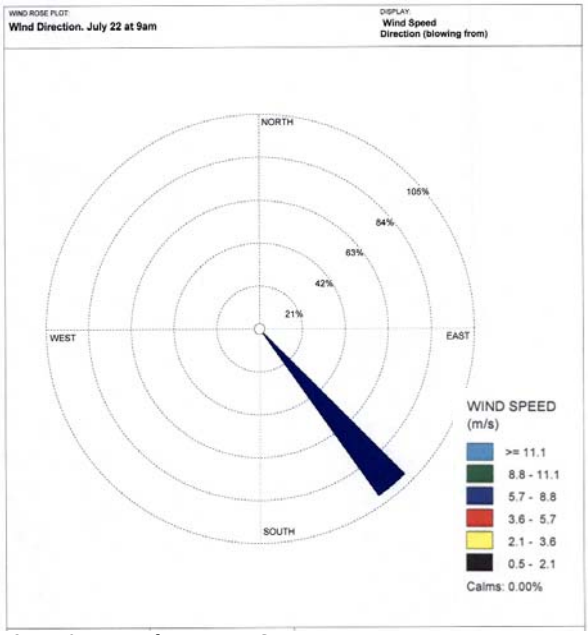
4pm-5pm, Wind Direction: SW
Average Wind Speed: 4.90 m/s

Data source: Western Regional Climate Center: meteorological station located in Meloland, CA.

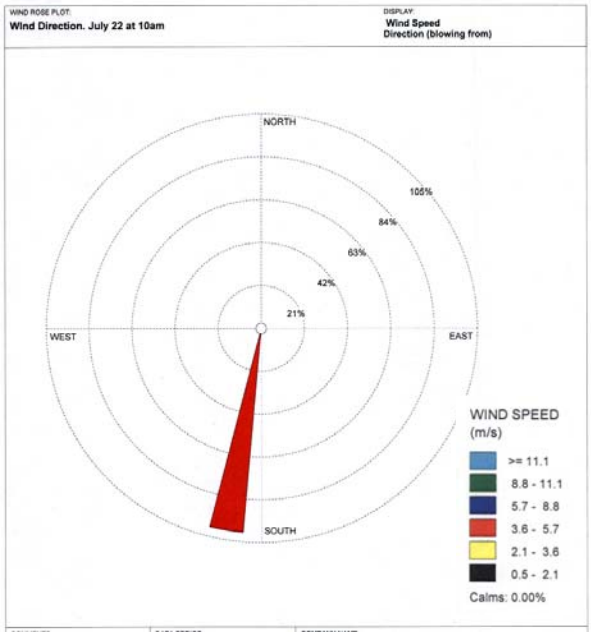
Figure 5. Wind Rose Showing Predominant Wind Direction and Wind Speed During Hydrogen Sulfide Monitoring Conducted on July 22, 2009, Calexico, California



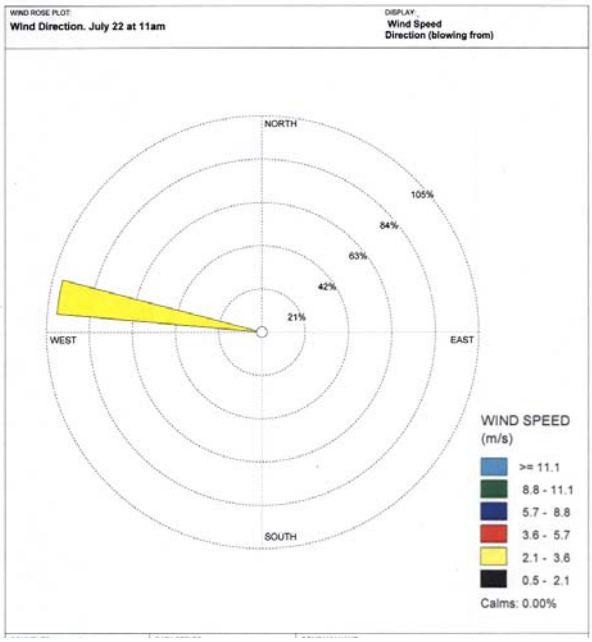
8am-9am, Wind Direction: SE
Average Wind Speed: 7.20 m/s



9am-10am, Wind Direction: SE
Average Wind Speed: 6.80 m/s



10am-11am, Wind Direction: S
Average Wind Speed: 3.70 m/s



11am-12pm, Wind Direction: W
Average Wind Speed: 2.70 m/s

Data source: Western Regional Climate Center: meteorological station located in Meloland, CA.

Figure 6. Hydrogen Sulfide Levels Measured in East Calexico, July 22, 2009

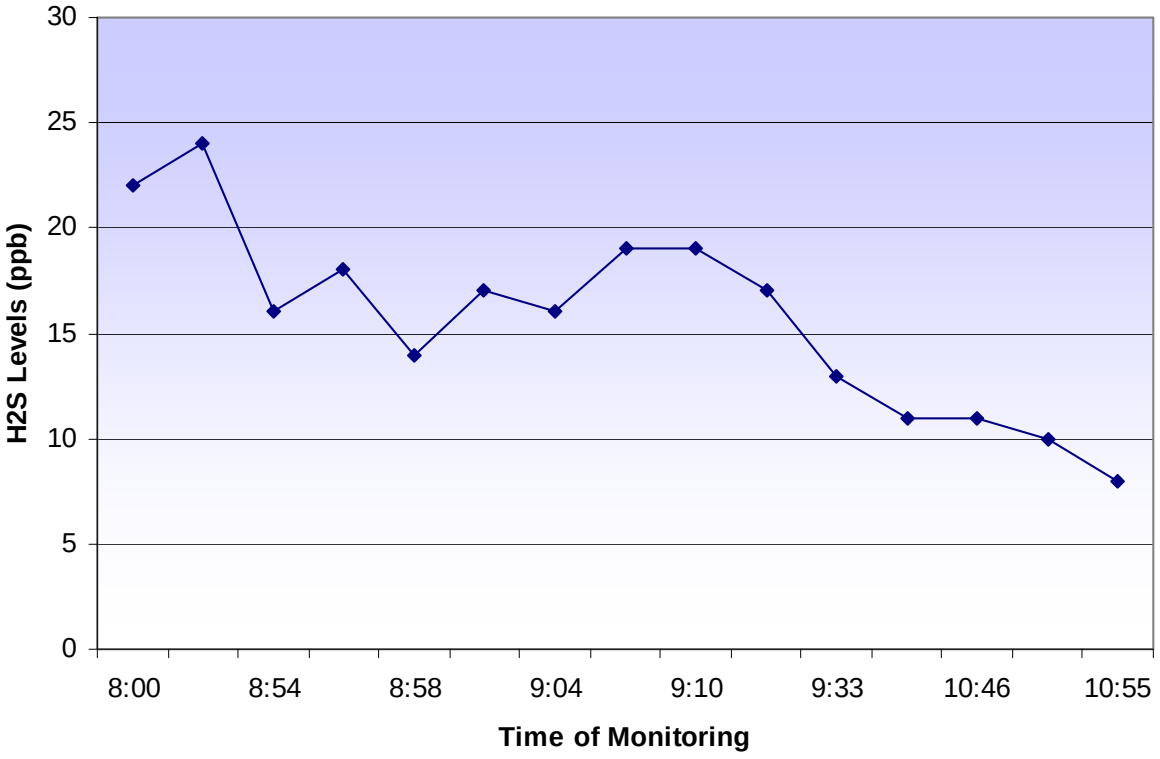
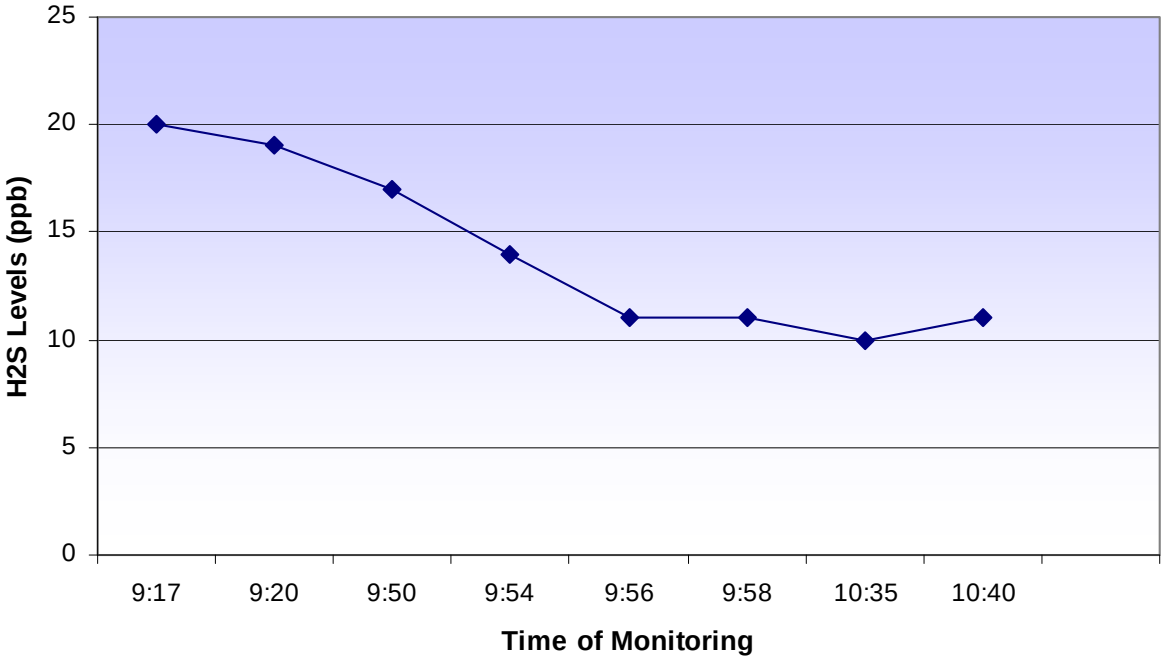


Figure 7. Hydrogen Sulfide Levels Measured in West Calexico Near the New River (2nd Street Bridge, Airport, West Side Neighborhood), July 22, 2009



Note: H_2S = Hydrogen Sulfide; ppb = parts per billion

Appendix B. Tables

Table 1. Hydrogen Sulfide (H_2S) Levels Measured in Winter 2008 and Summer 2009, Calexico, California

Sample ID Number	Monitoring Location	Monitoring Date	Monitoring Time	H_2S (ppb)	Comments
New River and West Calexico					
BKGD	Best Western: Scaroni Road at Highway 111	12/9/08	12:25	3	Background sample
NR-1	Airport (office)	12/9/08	12:44	3	
		12/9/08	15:30	3	
		7/21/09	13:35	5	
		7/21/09	13:52	6	
		7/22/09	9:20	19	
NR-2	2nd Street	12/9/08	12:50	3	Approximately 4 feet from the river bank
		7/21/09	13:09	5	
NR-3	2nd Street bridge	12/9/08	12:51	3	
		7/21/09	13:06	8, 5	
		7/22/09	9:17	20	
		7/22/09	10:40	11	
NR-4	Border on bridge	12/9/08	12:55	3	
		7/21/09	13:11	5	
NR-5	Border, east side of bridge, downwind	12/9/08	12:56	3	
		7/21/09	13:14	5	
NR-6	Border, west side	12/9/08	13:00	3	Culvert mix approximately 80% foam; ammonia odor
		7/21/09	13:20	5	
NR-7	Border, west side	12/9/08	13:02	5	
		7/21/09	13:22	5	
NR-8	Border, west side	12/9/08	13:03	3	
		7/21/09	13:24	5	
NR-9	Border, breathing zone	12/9/08	13:05	5	
		7/21/09	13:16	5	
NR-10	Border at bridge, east side, downwind	12/9/08	13:11	3	No measurements taken due to the presence of a pack of stray dogs
		7/21/09	-	-	

Table 1. Hydrogen Sulfide (H_2S) Levels Measured in Winter 2008 and Summer 2009, Calexico, California

Sample ID Number	Monitoring Location	Monitoring Date	Monitoring Time	H_2S (ppb)	Comments
NR-11	Second Street, east side, downwind	12/9/08	13:15	3	
		7/21/09	13:25	5	
NR-12	Waste Water Treatment Plant, settling pond	12/9/08	13:25	21	
		7/21/09	13:40	21	
NR-13	Waste Water Treatment Plant, airport gate	12/9/08	13:29	11	
		7/21/09	13:39	5	
NR-14	Waste Water Treatment Plant, aeration pond	12/9/08	13:30	3	
		7/21/09	13:42	5	
NR-15	River below Waste Water Treatment Plant, flood zone	12/9/08	13:37	3	
		7/21/09	13:45	5	
NR-16	Waste Water Treatment Plant, effluent	12/9/08	13:51	3	
		7/21/09	13:47	5	
NR-17	Waste Water Treatment Plant, riverbank	12/9/08	14:00	4	
		7/21/09	13:52	5	
NR-18	Below American Canal piping at concrete rapids	12/9/08	14:08	3	Earthy odor
		7/21/09	14:02	5	
NR-19	South of American Canal piping	12/9/08	14:20	4	
		7/21/09	14:04	4	
NR-20	Trash pile	12/9/08	14:35	3	
		7/21/09	16:00	5	
NR-21	Trash pile, below pile	12/9/08	14:37	3	
		7/21/09	16:02	5	
NR-22	Nosotros Park, above river	12/9/08	15:10	3	
		7/22/09	9:56	11	
NR-23	Calexico Street, West Side Neighborhood	12/9/08	15:14	4	
		7/22/09	9:54	14	
NR-24	Wozencraft Street and Thielmen Avenue, West Side Neighborhood	12/9/08	15:20	4	
		7/22/09	9:50	17	

Table 1. Hydrogen Sulfide (H_2S) Levels Measured in Winter 2008 and Summer 2009, Calexico, California

Sample ID Number	Monitoring Location	Monitoring Date	Monitoring Time	H_2S (ppb)	Comments
NR-25	Emilia Drive and Eady Avenue, West Side Neighborhood	12/9/08	15:24	3	
		7/22/09	9:58	11	Grey smoke plume to southeast in Mexicali, Mexico
	Near river	7/22/09	10:35	10	
NR-26	McKinley Street and Eady Avenue	7/22/09	10:25	9	Parking lot
East Calexico					
	City Hall (Heber Avenue and East 6th Street)	7/22/09	8:00	22	Strong rotten egg odor
	3rd Street and Encinas Avenue	7/22/09	8:50	24	
	2nd Street and Andrade Avenue	7/22/09	8:54	16	Approximately 75 yards from the border; strong rotten egg odor
	2nd Street and G. Anaya Avenue	7/22/09	8:56	18	Strong rotten egg odor
	7th Street and G. Anaya Avenue	7/22/09	8:58	14	
	Ethel Street and Encinas Avenue	7/22/09	9:02	17	Calexico High School; strong rotten egg odor
	Birch Street and Encinas Avenue	7/22/09	9:04	16	Calexico High School; strong rotten egg odor
	2nd Street and Encinas Avenue	7/22/09	9:08	19	
	1st Street and Mary Avenue	7/22/09	9:10	19	Heavy traffic at border; strong rotten egg odor
	City Hall (East 6th Street and Heber Avenue)	7/22/09	9:27	17	
	Highway 98/111	7/22/09	9:33	13	Shopping center; strong rotten egg odor
	2nd Street and Heber Avenue	7/22/09	10:45	11	Strong rotten egg odor
	1st Street and Mary Avenue	7/22/09	10:46	11	
	3rd Street and Encinas Avenue	7/22/09	10:50	10	
	Post Office – Ollie Avenue	7/22/09	10:55	8	

Appendix C. Toxicological Information for Hydrogen Sulfide

This appendix provides additional information from the toxicological profile for hydrogen sulfide (H_2S) published by the Agency for Toxic Substances and Disease Registry (ATSDR), as well as from the U.S. Environmental Protection Agency (EPA), and information in the peer reviewed literature.

Acute Toxicity

Exposure to very high concentrations (above or equal to 500,000 ppb) of H_2S, even briefly, can result in cessation of breathing, pulmonary edema (fluid filling the lungs), loss of consciousness, and death [12]. Most lethal cases have occurred in confined spaces (such as sewers, tanks, sludge plants, and animal processing plants), which facilitated the buildup of concentrations.

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

- Airway constriction in individuals who have asthma [20].
- Decreased lung function [21].
- Inability to smell gas (olfactory fatigue) [22].
- Eye irritation (keratoconjunctivitis, punctate corneal erosion, blepharospasm, lacrimation, and photophobia [23].
- Pulmonary edema and central nervous system effects, including dizziness, nausea, headache, and physical collapse [24].

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. The symptoms reportedly associated with the short-term high levels of exposure typically resolve after the exposure ceases.

Studies of the Effects of Hydrogen Sulfide on Communities/People Exposed to Low Levels of Hydrogen Sulfide (H_2S)

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 residents of communities located near sources of H_2S. The following section describes a few research studies of communities/people exposed to low-level of 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 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 and eye symptoms, cough, and headache, although not at levels of statistical significance [25].

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 [26]. 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 [27].

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. 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 [28].

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 self-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 [28].

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 H_2S exposure from geothermal electricity generation. In Texas, air modeling found maximum 8-hour measurements of H_2S levels of 335-503 ppb one 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. Rates of self-reported 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 [29].

A series of investigations in a New Zealand community with naturally occurring geothermal H_2S examined hospitalization rates for respiratory illnesses within high, medium, and low H_2S exposure zones. Significant dose-response trends were found for respiratory hospitalizations, as well as for sub-groupings of this category, including upper respiratory tract diseases and chronic obstructive pulmonary disease [30].

Exposures in the New Zealand study were estimated in the low area as between 0 ppb - 30 ppb generally; the moderate area varied depending on whether the wind from the more highly exposed area blew in this direction, in which cases there could be concentrations of around 500 ppb; and in the high-exposure area, H_2S samplers gave maximum concentrations of 320 ppb and 800 ppb, with one “hot spot” estimated to be 2500 ppb [31].

Neurological Effects

All Finnish studies discussed above 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 [32].

Nausea has been found in high-exposure situations (H_2S poisoning), but also among exposed community members in the Finnish studies [27].

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 (memory and grip strength) out of 21, the exposed group scored lower, but the results were not statistically significant [33].

The New Zealand investigation using data on hospitalizations found neurological outcomes to be the target organ grouping most highly affected by H_2S exposure [34]. 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 hospitalizations 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 hospitalizations due to diseases of the nervous system and sense organs; specifically central nervous system, disorders of the eye, and disorders of the ear [30].

A series of investigations, conducted by Dr. Kaye Kilburn in the United States, used a battery of neurological tests that were performed on patients with exposure to H_2S. 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 to predict expected individual scores based on factors such as a person's age, sex, and educational level [35]. In particular, as nervous system damage by many chemicals can result in effects similar to those of aging, accounting for age is critical in estimating expected test performance. The comparison group was recruited from voter registration rolls in three areas in the United States with no evidence of chemical contamination and was matched on sex, age, and years of education. A screening questionnaire was used to exclude persons with chemical exposures and/or medical conditions that could 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 for individuals based on their demographic characteristics. The regression equations were validated using a separate group of similarly screened persons from another unexposed area [36].

In the first investigation, 16 subjects had been referred for evaluation of effects of exposure to reduced sulfur gases, including H_2S [37]. Four of the subjects had been overcome to the point of unconsciousness by H_2S; six of the subjects had smelled a "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, working 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 who were friends or relatives of the participants [38]. Air monitoring for H_2S at street level near residents' homes showed H_2S at 10 ppb, with peaks of 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. Researchers found that the exposed group did not do as well as the unexposed group in tests of reaction time, balance, color discrimination, immediate story recall, and other areas.

The battery of neurological tests were 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 [39]. 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

As described above, the New Zealand hospitalization study found an increase in ocular effects among the exposed versus the rest of the population, and dose-related increases within exposure groupings [30]. In a study of a Finnish community investigators found increases in ocular symptoms [26]. In the study conducted by Dr. Kaye Kilburn, a group of 19 previously exposed subjects were found to have performed worse on color vision and visual field tests, compared with a control population [39].

Cardiovascular Effects

The New Zealand investigation found highly significant increases in circulatory disease hospitalizations among H_2S-exposed residents compared to the rest of New Zealand, and again a dose-related trend across exposure groupings [30].

Other Effects

Evaluations of possible carcinogenic effects have been limited. In Canada, persons living downwind from natural gas refineries did not have increased rates of cancer incidence [40,41]. 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 [34].