Synthetic Turf Study: Assessment of Health Risks from Exposure to Chemicals in Crumb Rubber Infill

Final Report

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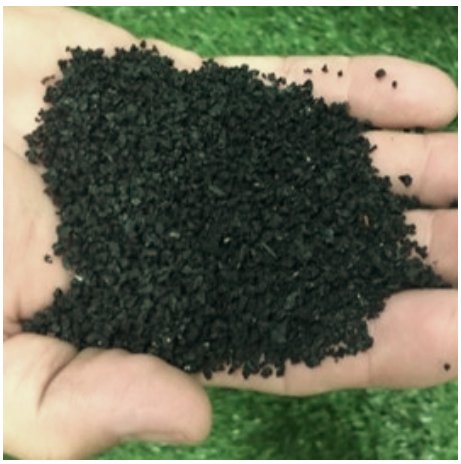

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List Of Abbreviations

ABR	Average daily breathing rate
$AD_{(inh\ or\ der\ or\ ing)\text{-}DART\text{-}field}$	Average one-day exposure dose for a DART (for inhalation, dermal, or ingestion exposure) for an individual field
$ADD_{(inh\ or\ der\ or\ ing)}$	Average daily exposure dose for a general chemical or carcinogen (for inhalation, dermal, or ingestion exposure)
AET	Annual event time
$AF_{inh\ (inh\text{-}DART\ or\ inh\text{-}sensory)}$	Adjustment factor for inhalation exposure or a general chemical (or a DART or sensory irritant)
ALD	Aldehyde
ANOVA	Analysis of variance
ASF	Age sensitivity factor
ASTM	American Society for Testing and Materials
AT	Averaging time
ATSDR	Agency for Toxic Substances and Disease Registry
BaP	Benzo[a]pyrene
BR_{TW}	One-hour time weighted breathing rate
BW	Bodyweight
CA	California
CalRecycle	California Department of Resources Recycling and Recovery
$C_{air\text{-}avg}$	Average concentration of a chemical in air across 35 fields
$C_{air\text{-}field}$	Average concentration of a chemical in air for an individual field
$C_{air\text{-}max}$	Maximum one-hour concentration of a chemical in air
CASRN	Chemical Abstracts Service Registry Number
$C_{(der\ or\ GI)\text{-}crumb\ rubber}$	Average dermal or GI bioaccessible concentration in crumb rubber across 35 fields of a general chemical
$C_{(der\ or\ GI)\text{-}crumb\ rubber\text{-}field}$	Average dermal or GI bioaccessible concentration in crumb rubber for an individual field of a DART
CEC	California Energy Commission
CERCH	Center for Environmental Research and Children's Health
CF	Conversion factor
$C_{inh\ (inh\text{-}DART\text{-}field\ or\ inh\text{-}sensory)}$	Exposure concentration for a general chemical (or a DART or a sensory irritant)
CPSC	Consumer Product Safety Commission
$CSF_{animal\ (or\ human)}$	Cancer slope factor for animal (or human)
$CSF_{inh\ (or\ oral)}$	Cancer slope factor for inhalation or (oral) exposure
DART	Developmental and reproductive toxicant

DL	Dermal load
DNPH	2,4-dinitrophenylhydrazine
DPPD	N,N'-diphenyl-1,4-benzenediamine
ED	Exposure duration
EG	Ethylene glycol
EPDM	Ethylene propylene diene monomer
ESI	Electrospray ionization
$EV_{(DART)}$	Event frequency (for DARTS)
GC-MS	Gas chromatography mass spectrometry
GF	Glass fiber
GI	Gastrointestinal
HES-GC-MS	High efficiency source gas chromatography mass spectrometry
HI	High impact area
$HI_{(DART\ or\ sensory)}$	Hazard index for general chemicals (or for DARTs or sensory irritants)
HPLC	High performance liquid chromatography
$HQ_{der\ (or\ ing\ or\ inh)}$	Hazard quotient for a general chemical for dermal (or ingestion or inhalation) exposure
$HQ_{der\ (or\ ing\ of\ inh)\text{-}DART}$	Hazard quotient for dermal (or ingestion or inhalation) exposure for a DART
$HQ_{inh\text{-}sensory}$	Hazard quotient for inhalation exposure to a sensory irritant
$HQ_{der\ (or\ ing\ or\ inh)\text{-}sum}$	Hazard quotient for the dermal (or ingestion or inhalation) route for all chemicals
$HQ_{der\ (or\ ing\ or\ inh)\text{-}DART\text{-}sum}$	Hazard quotient for the dermal (or ingestion or inhalation) route for all DARTs
$HQ_{inh\text{-}sensory\text{-}sum}$	Hazard quotient for the inhalation exposure route for all sensory irritants
HRAM LC-MS	High resolution accurate mass liquid chromatography mass spectrometry
HTM	Hand-to-mouth
HTOTM	Hand-to-object-to-mouth
IARC	International Agency for Research on Cancer
ICP-MS	Inductively coupled plasma mass spectrometry
IR_{daily}	Daily crumb rubber ingestion rate for a general chemical
IR_{DART}	One-day crumb rubber ingestion rate for a DART
IRIS	Integrated Risk Information System
IUR	Inhalation unit risk

$LADD_{der\ (or\ ing\ or\ inh)}$	Lifetime average daily exposure dose of a chemical for dermal (or ingestion or inhalation) exposure)
LBNL	Lawrence Berkeley National Laboratory
LC-MS	Liquid chromatography mass spectrometry
LOQ	Limit of quantification
MADL	Maximum Allowable Dose Level
MATES	Multiple Air Toxics Exposure Study
$MDL_{(b\ or\ s)}$	Method detection limit (derived from blank sample or from spike sample)
MLATS	Micro-level activity time series
MRL	Minimal risk level
NTP	National Toxicology Program
OEHHA	Office of Environmental Health Hazard Assessment
OTM	Object-to-mouth
PAH	Polycyclic aromatic hydrocarbon
PDMS	Polydimethylsiloxane
PEF	Potency equivalent factor
$PM_{2.5}$	Particulate matter of or less than 2.5 micrometers in diameter
POD	Point of departure
PPRTV	Provisional Peer-Reviewed Toxicity Value
PUF	Polyurethane foam
REL	Reference exposure level
RfC	Reference concentration
RfD	Reference dose
ROF	Rest of field
SAP	Scientific Advisory Panel
SBSE	Stir bar sorptive extraction
SOP	Standard operation procedure
South Coast AQMD	South Coast Air Quality Management District
SVOC	Semi-volatile organic chemical
TAS	Time Activity Study
$TC_{der\ (or\ ing\ or\ inh)}$	Toxicity criteria for dermal (or ingestion or inhalation) toxicity
TD	ThermoDesorption
TMBs	Trimethylbenzenes
TPE	Thermoplastic elastomer
TXIB	2,2,4-trimethyl-1,3-pentanediol diisobutyrate
UA	University of Arizona
UCB	University of California Berkeley

USEPA	United States Environmental Protection Agency
VOC	Volatile organic chemical
VSC	Volatile sulfur chemical

Executive Summary

Introduction

CalEPA's Office of Environmental Health Hazard Assessment (OEHHA) conducted this study of potential health risks associated with the use of synthetic turf fields containing crumb rubber by athletes, referees, coaches and spectators. The California Department of Resources Recycling and Recovery (CalRecycle) contracted with OEHHA in 2015 to conduct this study.

Concerns about possible health risks from exposure to chemicals in crumb rubber infills made of waste tires used in synthetic turf fields prompted this study. There were more than 320,000 active players on affiliated soccer teams and clubs in California in 2013-14, the last year prior to the initiation of this study for which data were available. The California Legislature between 2014 and 2016 considered but did not enact a ban on synthetic turf fields containing crumb rubber. These fields were popular because they reduce the use of water and maintenance otherwise needed for natural grass fields. The use of crumb rubber also reduces injuries from slips and falls and allows for productive reuse of crumb rubber from used motor vehicle tires.

In 2015, CalRecycle compiled a database of 907 synthetic turf fields of various ages in California. A single field can contain more than 200,000 pounds of crumb rubber infill produced from automotive tires made in the United States as well as other countries. The specific chemical content of crumb rubber varies greatly, and this variation is reflected not only in crumb rubber used across different fields, but also within a field.

OEHHA planned this study beginning in 2015 by engaging in extensive consultation with scientific experts from federal agencies and entities in other states. OEHHA conducted three public workshops in Northern and Southern California in late 2015 to seek input from the public and stakeholders. OEHHA formed a Scientific Advisory Panel consisting of seven experts in exposure and biomedical sciences that held annual public meetings between 2016 and 2019 to provide input.

Based on the comments and suggestions from these meetings, OEHHA's turf study consists of the following:

- Investigating 35 synthetic turf fields of various ages and in areas of different climate across California, by collecting data on environmental conditions of each field.
- Conducting "non-targeted analyses" to identify the different kinds of chemicals that are present in crumb rubber, and measuring the extent to which users of the synthetic turf fields could be exposed to these chemicals.
- Conducting "time-activity" studies of youth soccer players to obtain data on the contact with the crumb rubber that users of the fields typically incur.
- Refining models that OEHHA has used to assess potential exposure and health risks.

Field Characterization

A key task in the study was to characterize the release of chemicals from crumb rubber infill on synthetic turf fields. OEHHA accomplished this task by recording environmental conditions and examining chemicals in samples collected at selected fields in California. OEHHA contracted with Lawrence Berkeley National Laboratory (LBNL) to provide technical assistance in this effort.

OEHHA first narrowed down its database of 907 California synthetic turf fields to obtain a representative sampling of the fields across California that could feasibly be monitored and sampled. Fields were categorized by their locations in five climate regions (Southern Coastal Areas, Northern and Central Coastal Areas, Southern California Interior Valleys and Northern California's Central Valley, Southern California High and Low Deserts, and Mountainous Area), and by their age (fields less than nine years old and fields nine years old or greater) based on communications with field owners indicating that warranties for the fields generally expired after eight years. OEHHA selected 35 fields covering these categories. After securing consent from owners of the fields, OEHHA conducted field work at these locations in 2016 and 2017.

Field work consisted of monitoring the 35 fields for environmental conditions and concentrations of airborne volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and fine particulate ($PM_{2.5}$) during times when the fields were idle and when soccer activities on the fields were occurring. Off-field air samples were also taken for comparison to on-field samples. OEHHA also collected crumb rubber samples from six (6) to 10 locations at each field. LBNL analyzed the air samples to identify the organic chemicals that were present for inhalation and used the crumb rubber samples to calculate the gastrointestinal (GI) and dermal bioaccessible concentrations of organic chemicals, metals, and metalloids in the crumb rubber.

The study detected 119 organic chemicals in the air at on-field locations. LBNL's crumb-rubber analyses involved the use of artificial sweat and gastric juices to evaluate the potential for these bodily fluids to take up the chemicals. The study detected 75 organic chemicals in artificial sweat extracts and 76 organic chemicals in artificial gastrointestinal extracts as well as 35 metals and metalloids potentially accessible to uptake through dermal contact and oral ingestion.

The chemicals detected were then assessed for their toxicity and exposure, to characterize the health risks to the turf field users and spectators, as explained in the next three subsections.

Toxicity Evaluation

Toxicity is defined as the degree to which a chemical or mixture of chemicals can impair function or cause damage to a tissue or organ system. Toxicity information for a chemical comes from studies of laboratory animals, studies of the effects of chemicals on workers and other human populations, and studies using tissues, cells or cell

components from humans or animals.

A chemical's toxic effects depend on how much is taken up into the body, also referred to as the dose. For purposes of this study, the intake of a chemical depends on the level of the chemical in the air or crumb rubber; the amount of chemical absorbed into the body from the air, through the skin, or through the gut in case of ingestion; and the frequency or duration of exposure, such as once, several times a month, or daily. For instance, a particular chemical can be a respiratory irritant after inhalation of a high concentration in the air for a few hours. The same chemical may also pose a significant cancer risk through inhalation at much lower concentration in the air after many years of exposure.

OEHHA compiled toxicity criteria for the various chemicals identified in the study. Toxicity criteria for a specific chemical typically identifies a level of long-term exposure above which there may be a risk of cancer, or a level of short- or long-term exposure above which there may be a possibility of a health effect other than cancer ("non-cancer effect"). OEHHA used toxicity criteria it has developed for its other programs, as well as criteria developed by other entities such as the US Environmental Protection Agency and the US Agency for Toxic Substances and Disease Registry.

Toxicity criteria covered health effects ranging from cancer to sensory irritation, reproductive and/or developmental toxicity, and other effects, including effects on the nervous system, respiratory system, kidneys and blood.

Exposure Characterization

The study focused on examining the exposure of soccer players (athletes) and other soccer-related participants (e.g., coaches, referees, and spectators), due to the popularity of soccer in California among all genders, and close and frequent contacts of players with the field surfaces. Since soccer can be a life-long sport for some participants, exposure duration of players on synthetic turf fields can span from a few years to decades. In fact, one-half of the respondents from the survey indicated playing more than eight years. Taken together, OEHHA determined soccer to be an appropriate surrogate for athletic activities on synthetic turf fields.

Synthetic turf fields often contain three major structural parts: synthetic grass blades, backing materials, and crumb rubber infill. Inhalation exposures can occur when chemicals (of various volatility) evaporate from the synthetic turf parts or adsorb to airborne fine particles in the air above the field. This study also accounted for dermal and oral exposures that can arise from the crumb rubber infill.

Athletes, coaches, referees, and spectators are the primary categories of individuals who may experience chemical exposures from synthetic turf fields. OEHHA adopted the following age groups to represent the individuals in these categories: third trimester fetus in pregnant women, newborns to children under age 2, children age 2 to under 6, children age 6 to under 11, children age 11 to under 16, teenagers age 16 to young

adults under 30, adults age 30 to under 40, adults age 40 to under 50, and adults age 50 to under 70 years. We chose these age groupings based on the rapidly changing physiology of young children, differences in activity and behavior patterns between children and adults, and the lifestyle patterns of individuals. These factors may affect an individual's exposure level on a field.

In this study, athletes are soccer players, from ages 2 to 70 years, who take part in soccer practices and games in a seasonal or year-round schedule. There are different activity characteristics among these soccer positions, leading to different levels of exposure. Coaches are late teen and adult (16+ years of age) soccer team leaders and trainers. They share similar exposure parameters with the athletes. Referees are late teen and adult (16+ years of age) game officials, who are present on fields during soccer games. Spectators are the family or friends of athletes, who observe soccer activities from near or off the field, including pregnant people, newborns and adults aged up to 70 years.

The main pathways of human exposure to chemicals from synthetic turf fields are:

- The inhalation pathway: inhaling chemical vapors and airborne fine particulate matter (e.g., $PM_{2.5}$) while on the field.
- The dermal pathway: direct skin contact with synthetic turf components.
- The ingestion pathways: direct intentional and unintentional ("incidental") ingestion of synthetic turf components or indirect ingestion through hand-to-mouth, hand-to-object-to-mouth, or object-to-mouth behaviors.

Breathing of air on the field that contains chemical vapors or airborne fine particulate matter released from the field results in inhalation exposure and athletes are expected to have the highest exposure through this pathway. Running on the field may stir up particles into the air and cause athletes, who have elevated breathing rates, to inhale increased amount of chemical vapor and particulates. Falling or sliding of athletes on the field may also re-suspend particles into the air in the breathing zone of the athletes. Goalkeepers may have high exposures through constant diving onto the field surface, especially during practices, as they inhale particles and chemical vapor in the air just above the field surface.

Due to their higher activity levels on the field, athletes, coaches, and referees can have correspondingly higher inhalation rates and thus higher inhalation exposures than spectators. Spectators have low- to moderate-activity levels associated with sitting, standing, and cheering.

Direct dermal exposure refers to the scenario when there is direct skin contact with the field surface. Crumb rubber particles may adhere to the skin during contact. Chemicals can migrate from the adhered particles onto the skin, where they become available for dermal uptake. Moisture or personal care products on the skin surface, like sweat and sun block, respectively, may enhance adhesion of crumb rubber particles onto the skin

and facilitate transfer of chemicals across the skin.

While coaches routinely spend time on the field, they have less skin contact with the field compared to athletes. Similarly, referees have less direct dermal contact with the field surface. However, some levels of dermal exposure occur in the coaches and referees, as crumb rubber can get into the shoes and under the socks during walking or running on the field.

Spectators may sit directly on the field surface to watch the practices or games. Toddlers and young children may play, crawl around, or roll on the field. They may also play with the crumb rubber. As a result, the spectators' hands, legs, and other body parts can be in frequent or continual contact with the field surface during a soccer event.

Ingestion exposure occurs when particles of any size get in the mouth and are swallowed. Ingestion of particles while engaging in activities on synthetic turf fields can happen either by direct or indirect pathways. OEHHA did not anticipate ingestion behaviors to be a significant exposure pathway for adult spectators, athletes, coaches, and referees. However, toddlers and young child spectators may crawl around on and play with the crumb rubber on the sidelines of the field during sport events. Some young children may ingest varied amounts of crumb rubber in a sport event.

Incidental ingestion of crumb rubber occurs for athletes when particles accidently enter the mouth and are swallowed. Falling onto the field or diving onto the field surface while playing soccer agitates the field and disperses particles of various sizes into the air. Athletes may incidentally ingest these airborne particles. This may be an especially important exposure pathway for goalkeepers, who often lunge across the goal to block the ball and frequently land face-down onto the field surface.

Indirect incidental ingestion occurs when chemicals or particles move from the field into the mouth. Hands or fingers may come into direct contact with the field, or indirectly via objects that have contacted with the field, and then the hands or fingers touch the mouth. To take their gloves off, some goalkeepers grab their gloves with their teeth. Athletes use their clothes to wipe away sweat on their face. Athletes or spectators leave their water bottles on the field and drink through the drinking spouts that have come into contact with the field. Toddlers or young children may touch the field or crumb rubber and use their unwashed hands to pick up an object, such as a pacifier or a toy, and ultimately put the objects into their mouth.

OEHHA, in collaboration with the University of California, Berkeley (UCB) and the University of Arizona (UA), conducted three Time-Activity Studies (TAS) to characterize the activities and exposure patterns of soccer players on synthetic turf fields in California.

In the first TAS, OEHHA and UCB conducted a survey of soccer players in California. Each participant (aged 7 through 71) responded to a questionnaire during an in-person interview or through an on-line platform. We gathered information on soccer activities of players engaged in during practices and games, and the types of direct contact they

had with the field. Activities of interest included on- and off-field activities such as soccer drills, dive or fall on the field, snacking or drinking, and other activities on the sidelines that might result in exposure. In addition, UCB researchers recruited soccer players for in-person interviews through contacting soccer coaches and team managers in the Sacramento and San Francisco Bay areas. Additionally, they solicited players and parents of players to participate in the online survey through contacting coaches and team managers of soccer clubs in California. Overall, we received 40 completed in-person questionnaires and 1,029 on-line questionnaires.

In the second TAS, OEHHA and the collaborators videotaped soccer events to obtain data on events occurring on and off the fields. OEHHA and UCB videotaped 40 consenting soccer players (who also participated in the in-person interviews described above) during five practices and five games. On average, we videotaped four participants per event, one for each of the four soccer positions: forward, defender, midfielder, and goalkeeper. For each event, we continuously videotaped the participants from the time they entered the field until they left the field at the conclusion of a soccer event. In the third TAS, UA reviewed and obtained data from video footages from previous studies.

OEHHA estimated the potential levels of exposure on the fields by incorporating data from the TAS and the chemical results from the field characterization study.

Risk Characterization

This study characterized health risks to artificial turf field users, by focusing on the following health outcomes: acute inhalation toxicity, developmental and reproductive toxicity, sensory irritation, general chronic toxicity, and lifetime cancer risk.

The non-cancer hazards and cancer risks from i) inhalation exposure to organic chemicals in air over synthetic turf fields and ii) oral and dermal exposures to chemicals from crumb rubber samples were assessed. OEHHA confirmed identity of 179 unique chemicals in air and crumb rubber samples, and assessed 148 of them based on availability of toxicity criteria (57 VOCs, 71 SVOCs, 20 metals and metalloids).

Concentrations and average daily dose for the oral and dermal route exceeding the non-cancer toxicity criteria demonstrate some level of hazard, while air concentrations and doses below the toxicity criteria demonstrate the lack of a significant non-cancer hazard.

For cancer risk assessment, the lifetime average daily dose for each chemical was calculated for each route of exposure (inhalation, dermal and oral), and multiplied with the cancer toxicity criteria, with adjustment for age sensitivity to account for the greater sensitivity of children to carcinogens.

OEHHA derived total non-cancer hazards and total lifetime cancer risks for each chemical for all three routes of exposure (inhalation, dermal and oral). The non-cancer hazards and cancer risks for individual chemicals were then summed to calculate

hazard and risk posed by exposure to all the chemicals in the crumb rubber used on the artificial turf.

Results and Findings

Overall, this study found no significant health risks to players, coaches, referees and spectators from on-field or off-field exposure to chemicals in crumb rubber infill from synthetic turf fields based on the assessment method and available data. More specifically:

- The study did not find any chemical exposures associated with the turf fields that would pose immediate (acute) health hazards.
- The study found that use of synthetic turf fields does not pose hazardous levels of exposure to sensory irritants (chemicals that can cause irritation of the eyes or airways). Most exposure to sensory irritants while on the fields comes from chemicals in the ambient air that originate elsewhere.
- The study found that, on average, people using the fields were not exposed to levels of chemicals that can cause harm to childhood development or the male or female reproductive systems. The highest of the 35 fields was associated with moderately elevated exposures to athletes of 11-70 years old under a “worst case” scenario. The likelihood of exposures actually occurring at that level is low and therefore of low concern.
- On average, long-term use of the fields does not result in exposures to chemicals that pose significant non-cancer health hazards. The maximum of the individual field values was associated with slightly elevated exposures, of low concern, for spectators 0-2 years old. For children less than two years old, the exposure is primarily via ingestion of crumb rubber which was assumed to be 153 milligram (mg) per day of event during 161 games and practices per year in this study. The odds of such exposures actually occurring is low. As the actual amount of crumb rubber ingested by the infant spectators decreases, the associated hazards also decrease and would be of low to no concern.
- Cancer risks from the crumb rubber infill used in the artificial turf fields, on average, are insignificant for athletes, coaches and referees, i.e., less than one additional cancer case in a population of 1 million people playing or spending time on the fields during a 70-year lifetime. Average cancer risks for infant spectators 0-2 years were just above this level, at 1.1 additional cancer case in one million during lifetime. The individual fields posing the highest lifetime risks to athletes and infant spectators ranged up to 1.2 and 2.7 in a million, respectively, with the high-end values being slightly about the benchmark of 1 in a million lifetime risk. As with the non-cancer assessment, the cancer assessment for athletes and infant spectators was based on “worst-case” combination of exposure assumptions and parameters, and the odds of these

exposures actually occurring is low. For infant spectators, the lower the actual exposure via ingestion of crumb rubber infill, the lower the corresponding health risk.

- The study did not assess the health risks due to physical or microbiological hazards associated with crumb rubber infills. It found similar ambient temperatures on- and off-field, as well as elevated surface temperatures on synthetic turf fields in line with previous studies. However, no differences between on- and off-field $PM_{2.5}$ concentrations were observed, and field activity did not increase $PM_{2.5}$ concentrations.

Chapter 1. Introduction

1.1. Purpose of Study

The use of synthetic turf on outdoor sport fields has become popular because of their lower maintenance, lower cost and to conserve water use compared to traditional grass playing fields. In California over 900 synthetic turf fields have been installed in the state. However, concerns have been raised about the potential adverse health effects and risks for athletes and children playing on synthetic turf fields that use crumb rubber infill made from recycled waste tires. In response to this concern, the Department of Resources Recycling and Recovery (CalRecycle), which regulates the uses of waste tires in California, contracted with the Office of Environmental Health Hazard Assessment (OEHHA) to perform a risk assessment addressing the health risks for players and other users exposed to chemicals in crumb rubber infill from synthetic turf fields.

The OEHHA study provides a comprehensive and detailed evaluation of these human health risks. It does not however address ecological risk, for example associated with zinc from leachate reaching aquatic environments where it affects wildlife. Nor does it evaluate the risks of the other components of synthetic turf described below. It does however use state-of-the-art science in accomplishing its tasks of determining whether chemicals in crumb rubber infill pose significant health risks.

1.2. Composition of Synthetic Turf Fields and Crumb Rubber

Compared to natural grass, synthetic turf provides the benefits of low maintenance, reduced water usage, improved water drainage, improved playability (requires no field resting between events), and customizable appearance (multiple-colored blades allows built-in designs like team logos). With such advantages, the use of synthetic turf on indoor and outdoor sport fields for football, soccer, and baseball has become common.

First used in 1964 when it was installed on a recreational area at the Moses Brown School (Providence, Rhode Island) and in 1966 when it was installed in the Astrodome (Houston, Texas), synthetic turf (e.g., artificial turf, ChemGrass, or AstroTurf) describes a surface of synthetic fibers designed to resemble natural grass. The first-generation synthetic turf fields were comprised only of turf carpeting and backing without any infill material. To reduce the field hardness and injuries from slips and falls, starting in the 1990s turf systems were redesigned with longer blades and to contain infill materials. Currently, synthetic turf systems generally consist of the following components (NYDOH, 2018; STC) as shown in Figure 1-1:

- Carpet backing and synthetic grass blades: A carpet backing, usually weaved polyester fabric, is a structure that holds the synthetic turf blades. The multiple colored synthetic grass blades are made of nylon, polypropylene, or polyethylene. These blades do not just serve the aesthetics purposes of the fields, but also provide structure to keep the infill materials in place.

- Shock pad: Depending on the types of sports to be played on a field, a shock pad (made of layers of polyethylene) may be placed underneath the turf carpet to absorb the energy from physical impacts during sport activities and reduce or prevent injuries of athletes.
- Infill: Crumb rubber (uncoated or coated), virgin rubbers (synthetic and non-recycled such as ethylene propylene diene monomer (EPDM), polymer elastomer and thermoplastic elastomer (TPE)), or organic materials (cork and coconut husk), used as a single material or as a mixture with sand, are marketed as infill materials. The infill is used to weigh down the synthetic turf carpet and level the field surface for stability, keep the blades up, improve water drainage of the fields, and absorb impacts and provide traction during sport activities. The infill can also prevent or reduce injuries.

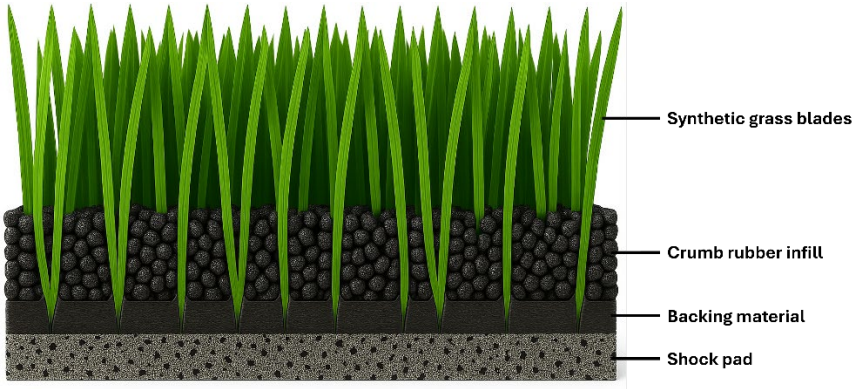

Figure 1-1. Figure of synthetic turf field composition. This image was created with generative AI, Microsoft Copilot.

This study focuses on the risks from crumb rubber, the most commonly used infill on synthetic turf sport fields. A single field can contain over 200,000 pounds of crumb rubber infill (NYDOH, 2018). Particles sized between one-sixteenth and one-quarter inch in diameter are used as infill on turf fields (NYDOH, 2018). In California, crumb rubber particles are made from waste passenger and light truck tires. The main raw materials used in the manufacturing of tires, and the function they serve in tires, are given below (ICBA, 2016; USTMA, 2020):

- Natural rubber and synthetic rubber (butadiene rubber, and styrene-butadiene rubber): The use of natural rubber and synthetic rubber polymers in combination improves tire performance.
- Antioxidants and antiozonants: These additives prevent degradation of the tires. Antioxidants reduce or prevent the oxidation that breaks down the rubber polymers and crosslinks. Antiozonants, which bloom at the tire surface, prevent cracking of the tire by the ozone in ambient air.
- Accelerators or vulcanizing agents: The rubber undergoes high temperature and pressure curing process, which is called vulcanization. The vulcanization process

permanently links the hydrocarbon chains of the rubber to strengthen and solidify the tires. Accelerators are added to reduce the vulcanization time and control the length and number of crosslinks between the hydrocarbon chains.

- Steel wires and textiles (fabric cords): Steel wires reinforce the rubber to improve tire performance and anchor the tires onto the wheels. Fabric cords made of various materials reinforce the tire casing and maintain the shape of tires. During the recycling processes, steel and fabric fibers are separated from the rubber and recycled.
- Fillers: Carbon black and silica are added to the tires to strengthen and improve the longevity of the tires. Silica is covalently coupled to the rubber polymer to reduce the rolling resistance of the tires. Carbon black, acting as a reinforcing and coloring agent, is mixed with the tire rubber. The substance enhances the tear strength and improves the modulus of elasticity (resistance from deformation upon exertion of force) and wear characteristics of tires.
- Extender oils: Extender oils are added during the tire manufacturing process to improve the processability and performance characteristics of tires (Gomes *et al.*, 2021; STRO, 2004).

Tires are made to different specifications and differ in composition due to varying proprietary chemicals and bulk raw material used to manufacture them. Also, manufacturing processes change over time.

The crumb rubber infill is produced from recycled automotive tires made in the United States and imported from other countries. The variety of tires this covers results in the heterogeneity of the infill both within a field, and across different fields. Chemical composition of crumb rubber infill is also affected by the age of the used tires being recycled, aging of crumb rubber on synthetic turf fields, and environmental deposition of pollutants (e.g., PAHs) onto synthetic turf fields.

The next section discusses our approach to designing a study that captures the range of potential chemicals that may result in potentially harmful exposure for users of synthetic turf fields in California.

1.3. Design of the OEHHA Synthetic Turf Study

In this discussion of study design, we first describe our approach to identifying chemicals of concern in crumb rubber, and then our general approach to the design of the study.

1.3.1. Approach to Identifying Chemicals of Concern

OEHHA took a multipronged approach to identify potential chemicals that might be released from crumb rubber - into the air and inhaled, inadvertently consumed by field users, or penetrating the skin with direct skin contact.

- **Literature search:** OEHHA searched the literature to identify tire-related

chemicals, including studies of synthetic fields and crumb rubber.

- **Outreach:** OEHHA received information of the chemicals used in the tire manufacturing processes from the U.S. Rubber Manufacturers Association and the International Carbon Black Association, as well as in its consultations with agencies and academics (see below).
- **Laboratory experiments:** Lawrence Berkeley National Laboratory (LBNL), in collaboration with OEHHA, analyzed samples of crumb rubber both before it was installed on the field ("pre-installed") and from actual fields. LBNL performed chamber emission studies to simulate the release of volatile organic chemicals to the air on synthetic turf fields. LBNL also extracted the pre-installed and composited field crumb rubber samples with solvents of various polarities. They conducted non-targeted chemical analyses of these extracts to identify other chemicals not previously identified in the literature or from our outreach efforts.

Based on these sources, we compiled a list of tentatively identified tire-related chemicals ("Tire-Related Chemical Database"). OEHHA selected and verified chemical targets from this list using high purity reference standards. The targets were prioritized for confirmation based on potential toxicity and the commercial availability of standards. These analyses provided lists of chemicals to be characterized in crumb rubber samples.

1.3.2. General approach to study design

The study design emerged from extensive consultations, literature reviews and work with our research partners, as described here.

Outreach. OEHHA has sought advice from entities that had or were in the process of conducting assessments of synthetic turf fields or were involved in assessing health effects in players or evaluating the toxicity of synthetic turf chemicals. This included several states (Connecticut, New Jersey, New York, and Washington); federal agencies (National Institute for Occupational Safety and Health, US Environmental Protection Agency (USEPA), the National Toxicology Program (NTP), the Agency for Toxic Substances and Disease Registry (ATSDR), and the Consumer Product Safety Commission (CPSC); and the European Chemicals Agency (ECHA). Academics at the University of California, Davis and the Pennsylvania State University were also consulted early in the study.

OEHHA sought advice from players, parents, coaches, and others that had direct experience with exposures to crumb rubber and heard input on concerns most important to them. The general public was also engaged and at an early stage. In 2015 OEHHA held three public workshops using a world café format in communities in Northern and Southern California and convened a statewide virtual workshop to seek input on study design.

Research Partners. OEHHA designed and performed the work in collaboration with

researchers at the following institutions:

- Lawrence Berkeley National Laboratory (LBNL): sample collection, emission testing, biofluid extractions, laboratory analysis of air and crumb rubber samples.
- California Institute of Quantitative Sciences at the University of California Berkeley (UCB): analysis of sample extracts with LC/MS and identification of unknown chemical peaks advanced software.
- UCB Center for Environmental Research and Children's Health (CERCH): activity studies to assess the exposure patterns soccer players and other field users.
- University of Arizona: transcription of video data from UCB CERCH and coding for assessment of parameters for use in the exposure assessment.

Scientific Peer Review and Advice. The academic community was also formally engaged and advised OEHHA in the design and conduct of this complex, and necessarily groundbreaking scientific effort. OEHHA formed a Scientific Advisory Panel ("Panel") of seven scientific experts in exposure, laboratory work and the biomedical sciences. In open public meetings, the Panel advised OEHHA on study plans, data analysis, and methodologies of exposure and risk assessment. At these meetings, the public provided comments and suggestions on the design of the study.

Literature Search. In 2015, OEHHA searched the literature for studies on the chemical composition of automotive tires and crumb rubber, and on studies of synthetic turf fields. We identified 30 studies and reports published by researchers in the United States and 15 by international researchers Appendix Section A.1 highlights the designs and results of these studies. In addition OEHHA had earlier conducted two pilot studies of recycled waste tires (OEHHA, 2007; OEHHA, 2010).

OEHHA used the learnings and insights from all these efforts to guide our study design[1]. We focused on enhancing the knowledge of identification of chemicals in rubber, approaches to understanding bioaccessibility and other components of assessing exposure to crumb rubber-related chemicals. This was for the purpose of evaluating the human health risks from the multiple routes and exposure pathways to players and spectators.

Special Design Features. Based on our literature review, and the consultation and advice from the players described above, the synthetic turf study includes unique features to enhance our understanding of chemical exposures resulting from use of

[1] Since the completion of the literature search in 2015, several entities have conducted field investigations, risk assessments, and a cancer cluster investigation on the use of synthetic turf fields for sport activities. A chemical study on tire-derived consumer products and crumb rubber used for field installation was also published. (Benoit and Demars, 2018). The designs and findings of these studies are relevant to the OEHHA Synthetic Turf Study. We summarized these studies in Appendix Section A.2.

crumb rubber infill on turf fields:

- the collection of chemical vapors and airborne particles on active fields to simulate the environment of exposures for athletes during soccer activities,
- non-targeted chemical analyses using advanced instruments and cheminformatic algorithms to better characterize the chemical composition (both known and unknown chemicals) of crumb rubber and to overcome the limitation of standard analytical methods which are tailored for common environmental chemicals,
- the bioaccessibility measurements of chemicals in crumb rubber samples using dynamic extraction systems to enhance the accessibility of chemicals with low water solubility and to mimic the physiological conditions on the skin surfaces and at the gut linings,
- time-activity studies of soccer players in California and the development of soccer-specific exposure parameters to provide California-specific activity data and more accurate exposure data for risk assessment, instead of using default assumptions to estimate exposures, the literature showed a lack of a comprehensive study on the activity of athletes and children playing on synthetic turf fields.
- the development of toxicity criteria of tire-related chemicals to enhance the assessment of human health risks from exposure to chemicals from crumb rubber on the fields, and
- the assessment of health risks of four receptor categories of synthetic turf field users – players, coaches, referees, spectators - in order to provide a comprehensive understanding of the risks of exposure for each field user category and in various age groups.
- the investigation of 35 synthetic turf fields of various ages and in different climate zones across California

1.4. Components of Study and Organization of the Report

The OEHHA Synthetic Turf Study focuses on assessing the human exposures and health risks from the use of synthetic turf fields constructed with crumb rubber infill. The study consisted of several inter-related components, summarized below.

1.4.1. Collection of Crumb Rubber Infill and Air Samples from Fields Across California

Chapter 2 describes the statewide sampling effort and protocols. Briefly, OEHHA and LBNL collected crumb rubber samples from 35 synthetic turf fields across California and monitored the air during sport or simulated sport activities at these fields. The 35 fields ranged widely in age (years since field was installed) and were in areas of different climate at locations across California. Crumb rubber samples were collected at seven

(7) to 10 locations on each field, which were generally composited into four samples per field.

Since the agitation of field materials by soccer activities might enhance the release of chemicals and particulates, LBNL collected air samples over time at multiple locations adjacent to and during soccer activities. In addition, samples were collected at a single location off each field, and at four different heights at a single location on each field ("vertical chemical data"). For certain air pollutants, the vertical chemical data provided spatial information that could be used to differentiate between chemicals being released into the air from crumb rubber infill and ambient air pollutants being released from sources such as traffic and industrial facilities. Finally, because synthetic turf fields can absorb heat and this can affect health, temperature data for the fields was also collected.

1.4.2. Analysis of Air, Crumb Rubber and Environmental Samples

Chapter 3 presents the approach for the laboratory analyses to determine the presence and concentrations of chemicals in the collected crumb and air samples.

A considerable effort by LBNL in collaboration with OEHHA went into the development of standard operating procedures ("SOPs") for the laboratory analysis samples. SOPs were developed for:

- handling and preparing the samples for chemical analyses,
- conducting the emission chamber study on the pre-installed samples obtained from tire recyclers,
- conducting targeted and non-targeted chemical analyses to determine chemical presence and concentration,
- measuring bioaccessibility, and
- establishing quality assurance and quality control of approaches for handling samples and data.

The SOPs developed are provided in Appendix D.

As noted above (Section 1.3.1) pilot studies were performed using targeted and non-targeted methods to determine chemicals for analysis. This involved chamber emission studies and extracting chemicals from crumb rubber in biological fluid simulants and analyzing the extracts. Chapter 3 covers these studies. It also covers the subsequent analyses of samples and analytical results from the statewide sample collection effort. Using the composite samples of crumb rubber collected on the 35 fields, LBNL conducted bioaccessibility measurements using dynamic extraction systems that mimicked the physiological conditions on skin and in the gastrointestinal tract. The fluids were artificial sweat, artificial gastric fluid, and a set of artificial gastrointestinal biofluids. The artificial gastric bioaccessibility data is used to estimate the amount of chemical released into the body when crumb rubber in inadvertently eaten. The data for the

artificial sweat is used to estimate the amount of exposure from skin contact with the field crumb during play and practice.

Chapter 3 also discusses the approaches used to characterize chemicals detected as field-related (synthetic turf field is the assumed source) or non-field related (assumed to come from other environmental sources) for the purposes of assessing non-cancer hazards and cancer risks in the study.

Results from the analysis of temperature, ozone and particle data are also briefly discussed in Chapter 3.

1.4.3. Compilation and Development of Toxicity Criteria for Tire-Related Chemicals

Chapter 4 describes approaches to evaluate toxicity data and derive toxicity criteria (TC), numerical values which quantitatively characterizes the potential for a chemical to cause toxicity in humans. Criteria are presented for different exposures routes and durations. It provides values for 1-hour, 1-day and chronic exposures and cover general types of toxicity (e.g., effects on liver), developmental and reproductive effects, sensory irritation, and cancer. Values are compiled from established sources such as OEHHA and EPA. It also presents new screening values developed by OEHHA for this study.

1.4.4. Determination of Activity Patterns and Parameters for Estimating Exposure

Chapter 5 details the methods, studies and approaches used to characterize exposure. The mild climate in most parts of the California allows year-round outdoor sport activities like soccer. Since there are no time-activity data for soccer in the literature, OEHHA contracted with the University of California, Berkeley and the University of Arizona to collect time-activity data of soccer players in California. Two studies were performed:

- a field observational study that videotaped activities of soccer players on and off synthetic turf fields. The UA researchers translated the video footage into micro-level activity time series (MLATS) data— type and frequency of activities and behaviors occurring on and off the soccer fields.
- a survey study (in-person or on-line) to collect self-reported personal information, soccer activity data, soccer playing history, and personal hygiene of athletes in California.

OEHHA developed parameters and equations to calculate for four different types of users of soccer fields: athletes, coaches, referees, and spectators (see Appendix B). For each of these groups, OEHHA estimated exposure parameters such as the frequency of play, the amount of time spent on the field during a practice session, breathing rates, and body weights. We applied these exposure parameters and established exposure models to evaluate exposures via inhalation, dermal, and ingestion pathways. For players and spectators different age groups were also

characterized.

1.4.5. Risk Characterization

Chapter 6 presents a health risk assessment associated with exposure to chemicals in crumb rubber from using synthetic turf fields. The presented hazard and risk estimates represent information for users who confine their play to a local field.

1.4.6. Discussion

Chapter 7 discusses the unique features and limitations of the study. This section also characterizes specific areas within the chemical, toxicity, and exposure characterization aspects of the study that introduce variability and uncertainty into our health assessment and how they may affect our final hazard and risk estimates.

1.4.7. Appendices

The report also includes several appendices that the reader can use to reference details on different aspects of the study, as follows:

- Appendix A contains the results of OEHHA's 2015 literature search to identify chemicals that may be released from crumb rubber. It also presents summaries of synthetic turf and crumb rubber assessments published after 2015.
- Appendix B contains the OEHHA Synthetic Turf Technical Support Document (TSD). The TSD defines and describes the development of exposure parameters and outlines the methodologies used to estimate and assess the exposure, non-cancer hazard, and cancer risk of chemicals detected on synthetic turfs field in California.
- Appendix C contains the field recruitment protocols, including the telephone script to contact field owners and managers, and the questionnaire and consent form for participating field owners to complete.
- Appendix D contains the standard operating procedures (SOPs) for sample collection and analysis (including instrument descriptions), and the resulting chemical concentrations from that analysis. An analysis of heterogeneity within sample, within field, and between fields is discussed and the justification for the use of composite samples in this study. The analysis for the source designation of VOCs is also presented in this appendix.
- Appendix E provides detailed information about the derivation of the toxicity criterion (TC) for chemicals detected on synthetic turf fields.
- Appendix F contains the results of the collaborative exposure studies between OEHHA, University of California Berkeley, and University of Arizona. It also contains the calculated exposure doses for all the chemicals that were detected on synthetic turf fields.
- Appendix G provides example non-cancer hazard and cancer risk calculations for

selected chemicals. It also contains the hazard quotient, hazard indexes and risk of all detected chemicals on synthetic turf fields for the inhalation, dermal, and ingestions routes of exposure.

Throughout the report chapters, OEHHA has included in-text references to the appendices, where appropriate, to provide more detailed information on methods, analyses, and data.

1.5. References

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Chapter 2. Collecting Samples from Synthetic Turf Fields Across California

2.1. Introduction

One of the Synthetic Turf Study (the study) tasks is to characterize the release of chemicals from crumb rubber infill from fields in California. OEHHA accomplished this task by visiting synthetic turf fields, collecting samples, recording environmental conditions and examining in the laboratory, chemicals in the samples collected. OEHHA contracted with Lawrence Berkeley National Laboratory (LBNL or the Laboratory) to provide technical assistance in this effort. The Field Team consisted of scientists from OEHHA and LBNL.

There were two major parts to the synthetic turf field characterization study: field work and laboratory work. The laboratory work is covered in Chapter 3. This chapter describes the field work that was done. It included soliciting field owners' or managers' participation for the study, collecting field samples, and recording environmental conditions on and near the fields.

The field work proceeded in three phases.

> **Phase 1:** Samples of freshly manufactured crumb rubber were collected from tire recycling facilities; samples were also collected from six fields of different ages. These samples were used to develop standard operation protocols (SOPs) for sample preparation and to optimize methods for analyzing chemicals in the laboratory. These crumb samples were also used in experiments with non-targeted analysis to identify chemicals to analyze in the statewide study. Phase 1 sample collection is discussed in Section 2.2.1.
>
> **Phase 2:** Field work during Phase 2 tested the sampling SOPs on two pilot fields and provided preliminary information to improve or modify the Field Sampling Plan to be used in the statewide sampling. Phase 2 data collection is discussed in Section 2.2.2.
>
> **Phase 3:** The statewide field sampling in Phase 3 generated field samples for laboratory analyses that were used to characterize chemical exposures on and off the synthetic turf fields across California. Phase 3 data collection is discussed in Section 2.3.

2.2. Sampling for Protocol Development

2.2.1. Sampling Freshly Manufactured and Field Aged Crumb Rubber (Phase 1)

OEHHA collected crumb rubber samples from waste tire recycling facilities (pre-installed samples) and from selected fields of various ages. The goal was to develop SOPs for preparation and chemical analysis of the field samples collected in the main study. Fields were selected to provide crumb rubber samples of different ages and weathered

under different environmental conditions for non-targeted chemical analyses.

Between February and July 2016, OEHHA collected pre-installed crumb rubber samples from four waste tire recycling facilities located in Northern and Southern California. Between September and November 2016, OEHHA also sampled crumb rubber from six synthetic turf fields, half of the fields were in Northern California (aged 3, 7, and 14 years) and half were in Southern California (aged 4, 5, and 10 years).

The pre-installed crumb rubber samples and six field samples were used to develop Field Sampling Protocols for testing in Phase 2 and protocols for analyses of field samples collected in Phase 3. Chapter 3 describes in detail the uses of these samples in the chemical analytical work.

2.2.2. Testing of Field Sampling Protocols on Pilot Fields (Phase 2)

LBNL developed draft Field Sampling Protocols to collect air and crumb rubber samples on synthetic turf fields. The protocol was based on chemical data obtained from samples collected in the Phase 1 and literature search results from previous studies (details in Chapter 1 and Appendix A). In February and April 2017, the Field Team of LBNL and OEHHA staff tested the draft protocols on two pilot fields in Northern California and collected samples for chemical analyses. Based on preliminary data from laboratory analyses of the pilot field samples, the Field Team finalized the Field Sampling Protocols (Appendix section D.1). This covered set up of sampling equipment, collecting locations of samples, types of samples collected, and number of samples collected.

The Field Team collected air samples of volatile organic chemicals (VOCs) vapor, carbonyls of low molecular weight (aldehydes and ketones, ALDs), and volatile sulfur chemicals (VSCs) on the two pilot fields. At nearby locations, but off the two pilot fields (off-field), samples for VOCs were collected.

The Field Team collected hourly VOC and VSC samples using multibed glass thermal desorption (TD) tubes (Supelco, P/N 28286-U, see Appendix section D.2.1 for more specifics). We used computer-controlled air pumps and SKC air pumps to control the rate of airflow through the VOC sampling tubes and the VSC sampling tubes, respectively. We sampled the VOC vapor at two locations adjacent to the monitoring unit (goal box) on-field and at a nearby location off-field for each field (Positions A and C in Figure 2-1). We mounted the VSC samplers on a tripod located behind the net (Position B in Figure 2-1 and set up on Figure 2-2).

For ALD samples, we used special cartridges (2,4-dinitrophenylhydrazine coated silica gel) to capture the low molecular weight and reactive carbonyls, such as formaldehyde and acetaldehyde, in the air. We collected a three-hour ALD sample at each of the two VOC sampling locations on each field by using SKC air pumps to control the rate of airflow.

Figure 2-1. Volatile Compound Sampling Packages A: Cart 1, on field at the right side of the monitoring unit (white goal box). B: Cart 2, on field at the back of the monitoring unit. C: Cart 3, on field at the left side of the monitoring unit. Each package was positioned 1 meter above the field surface.

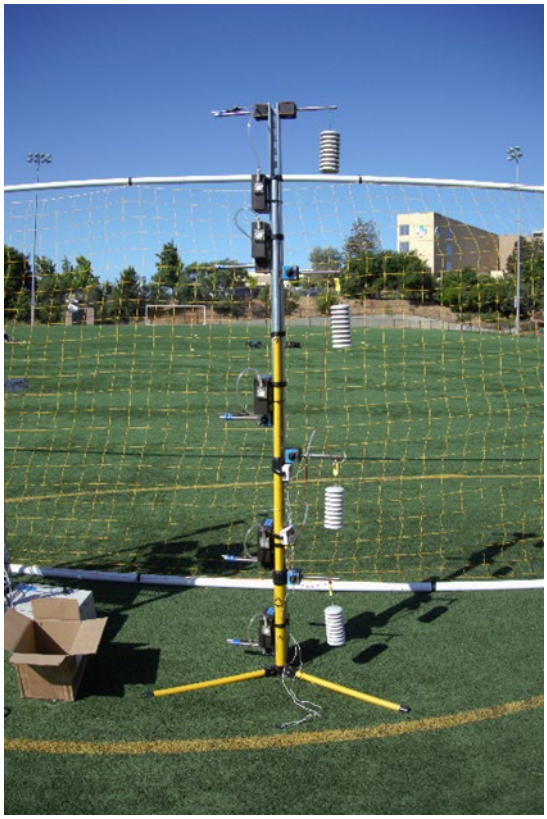

Figure 2-2. A Photograph of the Stratification Sampling Tower Located Behind the Monitoring Unit. VOC or VSC samplers mounted on the tower at designated heights (0.1, 0.5, 1.07, and 1.63 meters above field surface) were connected to SKC air pumps to control the rate of airflow.

LBNL analyzed the VSC samples from the pilot fields using a gas chromatography (GC) coupled with a TD injector and a sulfur chemiluminescence detector. They detected only one VSC, benzothiazole. This chemical was also detected in the VOC samples with an instrument that had higher sensitivity - a TD coupled gas chromatography mass spectrometry (TD-GC-MS). As a result, sulfur chemiluminescence detection was not utilized in Phase 3 sample analysis. Analyses of the ALD samples, using a high-

performance liquid chromatography (HPLC), revealed the presence of only formaldehyde and acetaldehyde.

Given the preliminary analytical results of the VSC and ALD samples collected on the pilot fields, the Field Team determined that collection of VSCs in the air from on- and off-field locations, and ALD in the air from off-field locations were unnecessary in the Phase 3 Field Work. We modified the Field Sampling Protocols accordingly.

2.3. Sampling of Fields Across California (Phase 3)

The Field Team applied the Field Sampling Protocols (Appendix section D.1) to collect samples and monitor environmental conditions on selected synthetic turf fields across California. The primary goal in field selection was to collect a representative sample of fields in California. OEHHA selected these fields by adopting a stratified random sampling method that was reviewed and approved by the OEHHA's Synthetic Turf Scientific Advisory Panel (SAP). The following subsections describe the field selection method in detail.

2.3.1. Selecting Fields: Stratified Random Sampling Technique

OEHHA used installation information furnished by field installers to the California Department of Resources Recycling and Recovery (CalRecycle) to compile a database of synthetic turf fields in California (OEHHA Field Database or Field Database). The Field Database contains 907 fields, of which 688 have installation date or year recorded. We estimated the age of fields based on the time differences between the reported installation dates and January 1, 2017. The full range of field age in the Field Database was 1 to less than 19 years old; over 90 percent were between greater than 3 and less than 14 years old. More than 80 percent of the fields in California are located in three metropolitan areas—the San Francisco Bay Area, the Greater Los Angeles Area, and San Diego County.

A simple random sampling technique with a limited sampling size to select from the 907 fields would probably lead to a collection of fields mainly located within these metropolitan areas. OEHHA therefore used a stratified random sampling method to select the study fields. This sampling technique is particularly effective in collecting random and representative samples from a skewed dataset, even with a limited sampling size. We performed the method as follows: First, we identified and selected the most critical factors (stratification factors) that might affect the release of chemicals or determine the environmental conditions of fields. Second, we divided the fields in the Field Database into strata or subgroups according to the stratification factors. Finally, we randomly selected a pre-determined number of fields from each subgroup. By adopting this sampling technique, the Field Team collected samples from the randomly selected fields in each subgroup, which also were representative of synthetic turf field conditions across California.

OEHHA initially considered three stratification factors--local climate, age of a field, and

ozone level in the ambient air--that might affect degradation of crumb rubber in synthetic turf fields. These factors in turn might influence the chemical and environmental exposures on the fields. After discussing these factors at the SAP Meeting on March 10, 2017, OEHHA followed the recommendations from the SAP and chose the local climate at a field's location and the age of a field as the stratification factors in the field selection process.

2.3.1.1. Stratification Factor: Local Climate

The local climate (e.g., rainfall, humidity, temperature range, and solar insolation) at a field likely affects the weathering or aging of crumb rubber. California has the most diverse climate among all the states in the United States (CEC, 1995). The California Energy Commission (CEC) divides California into 16 distinct climate zones based on the mean temperatures in the summers and winters (CEC, 1995; CEC, 2015). Figure 2-3 outlines the boundary of the 16 climate zones and Table 2-1 lists the California counties covered by each of these climate zones. Some counties fall within multiple climate zones.

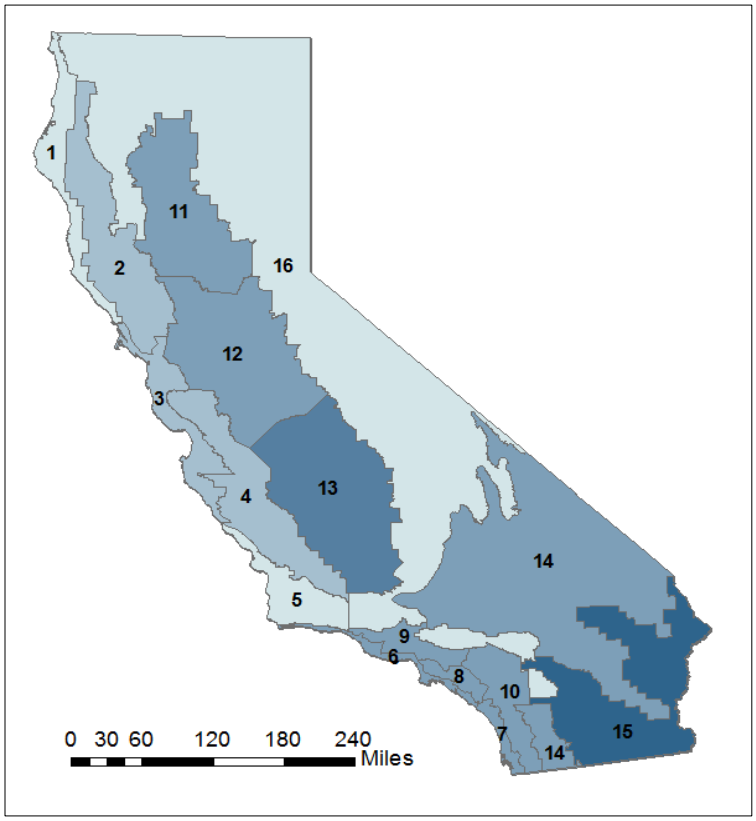

Figure 2-3. Map Showing the 16 Climate Zones Designated by the California Energy Commission (CEC, 2015)

Table 2-1. List of Counties Covered in the 16 Climate Zones (CEC, 2015)

Climate Zone	Counties Covered by Climate Zone
1	Del Norte, Humboldt, Mendocino
2	Humboldt, Lake, Marin, Mendocino, Napa, Sonoma, Trinity
3	Contra Costa, Marin, Monterey, Mendocino, Santa Cruz, San Francisco, San Mateo, Solano, Sonoma
4	Monterey, San Benito, San Luis Obispo, Santa Barbara, Santa Clara
5	San Luis Obispo, Santa Barbara
6	Los Angeles, Orange, Santa Barbara, Ventura
7	San Diego
8	Los Angeles, Orange
9	Los Angeles, Ventura
10	Riverside, San Bernardino, San Diego
11	Butte, Colusa, Glenn, Nevada, Placer, Shasta, Sutter, Tehama, Trinity, Yuba
12	Alameda, Amador, Calaveras, Contra Costa, El Dorado, Mariposa, Merced, Sacramento, San Joaquin, Solano, Stanislaus, Tuolumne, Yolo
13	Fresno, Kern, Kings, Madera, Tulare
14	Imperial, Kern, Los Angeles, Riverside, San Diego, San Bernardino
15	Imperial, Inyo, Riverside, San Diego, San Bernardino
16	Alpine, Amador, Butte, Calaveras, Del Norte, El Dorado, Fresno, Glenn, Inyo, Kern, Lassen, Los Angeles, Madera, Mariposa, Mendocino, Modoc, Mono, Nevada, Placer, Riverside, San Bernardino, Shasta, Sierra, Plumas, Siskiyou, Tehama, Trinity, Tulare, Tuolumne, Ventura, Yuba

OEHHA consolidated the 16 climate zones into 5 climate regions based on the mean temperatures in the warm seasons (defined as the months from May to October, using the data for 2011-2015 from Weather Underground, https://www.wunderground.com) and other climate considerations described below:

> **Region 1: Southern Coastal Areas (Climate Zones 6 to 9).** This region consists of the Southern California coast. The warm ocean water keeps the climate mild throughout the year. Rain occurs mostly in the winters. During the warm seasons, the mean of the average temperatures ranged from 69 to 72° Fahrenheit (F) and the mean of the maximum temperatures ranged from 84 to 89°F.

Region 2: Northern and Central Coastal Areas (Climate Zones 1 to 5). This region is situated along the Northern and Central California coast, where the weather is greatly influenced by the Pacific Ocean. Generally, the summers are cool and winters are mild and wet. Strong wind and fog are common. During the warm seasons, the mean of the average temperatures ranged from 57 to 67°F and the mean of the maximum temperatures ranged from 64 to 80°F.

Region 3: Southern California Interior Valleys (Climate Zone 10) and Northern California Central Valley (Climate Zones 11 to 13). These valleys are surrounded by mountain ranges. In these valleys, the summers are dry and hot, while the winters are wet and relatively cold. During the warm seasons, the mean of the average temperatures ranged from 72 to 78°F and the mean of the maximum temperatures ranged from 88 to 93°F.

Region 4: Southern California High and Low Deserts (Climate Zones 14 and 15). This region is the desert area located at the southeastern border of California. Extremely hot and dry summers but moderately cold winters are the characteristics of this region. During the warm seasons, the mean of the average temperatures ranged from 82 to 86°F and the mean of the maximum temperatures ranged from 97 to 102°F.

Region 5: Mountainous Area (Climate Zone 16). This region contains California's high-altitude and mountainous areas. Climate in the region is mild in the summers but cold and snowy in the winters. The mean of the average temperature was 69°F and the mean of the maximum temperature was 85°F in the warm seasons.

Figure 2-4 displays the five climate regions on a California map and approximate locations of synthetic turf fields. Table 2-2 summarizes the number of synthetic turf fields in each climate region. As shown in this figure and table, there are more fields in or near metropolitan areas (e.g., the San Francisco Bay Area, the Greater Los Angeles Area, and the City of San Diego).

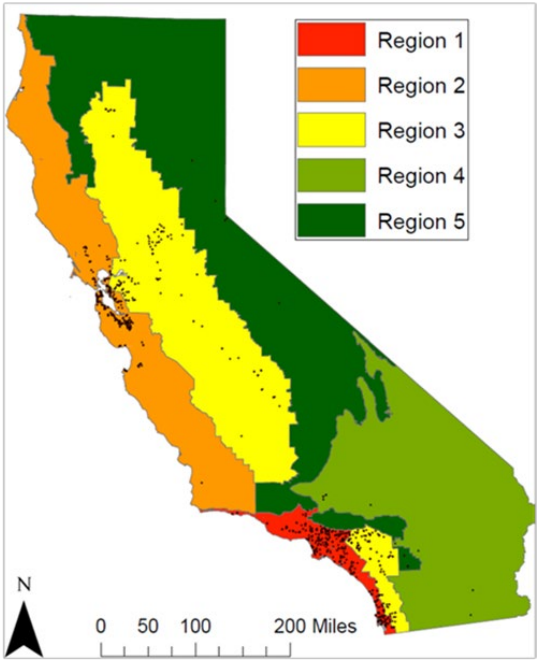

Figure 2-4. California Map Illustrating the Five Climate Regions and the Approximate Location of Synthetic Turf Fields (the black dots on the map represent the 907 synthetic turf fields)

Table 2-2. The Climate Regions in California and Number of Fields in Each Region

Climate Region	Climate Zones Covered	Number of Fields
1	Zones 6 – 9: southern coastal areas	376
2	Zones 1 – 5: northern and central coastal areas	272
3	Zones 10 – 13: southern interior valleys and northern Central Valley	233
4	Zones 14 – 15: southern high and low deserts	16
5	Zone 16: mountainous area	10
All	Zones 1 – 16	907

2.3.1.2. Stratification Factor: Age of a Field

Aging is another important factor effecting the degradation of crumb rubber on synthetic turf fields. Figure 2-5 shows the cumulative frequency of age for 688 fields, of which OEHHA determined the field ages based on their installation dates available in the Field Database. Figure 2-6 shows the cumulative frequency of field age in each climate region. Overall, the median field age was 8.4 years and 54 percent of the fields (371 fields) were less than 9 years old. Communications with several field owners or managers suggested that warranties of synthetic turf fields usually expired after eight years of field installation. Some of the field owners or managers stated that they reduced field maintenance efforts after the warranties expired.

For field selection purposes, OEHHA chose nine years as the age cut-off to subcategorize fields into two age groups for each region: fewer than nine years old (new

fields) and nine years old or older (old fields).

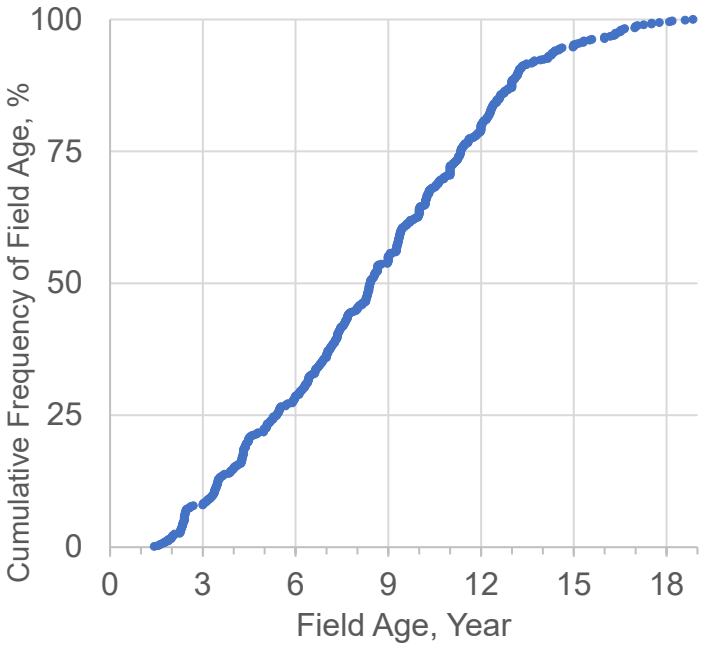

Figure 2-5. Cumulative Frequency of the Age for 688 California Synthetic Turf Fields (as of January 1, 2017) in the OEHHA Field Database

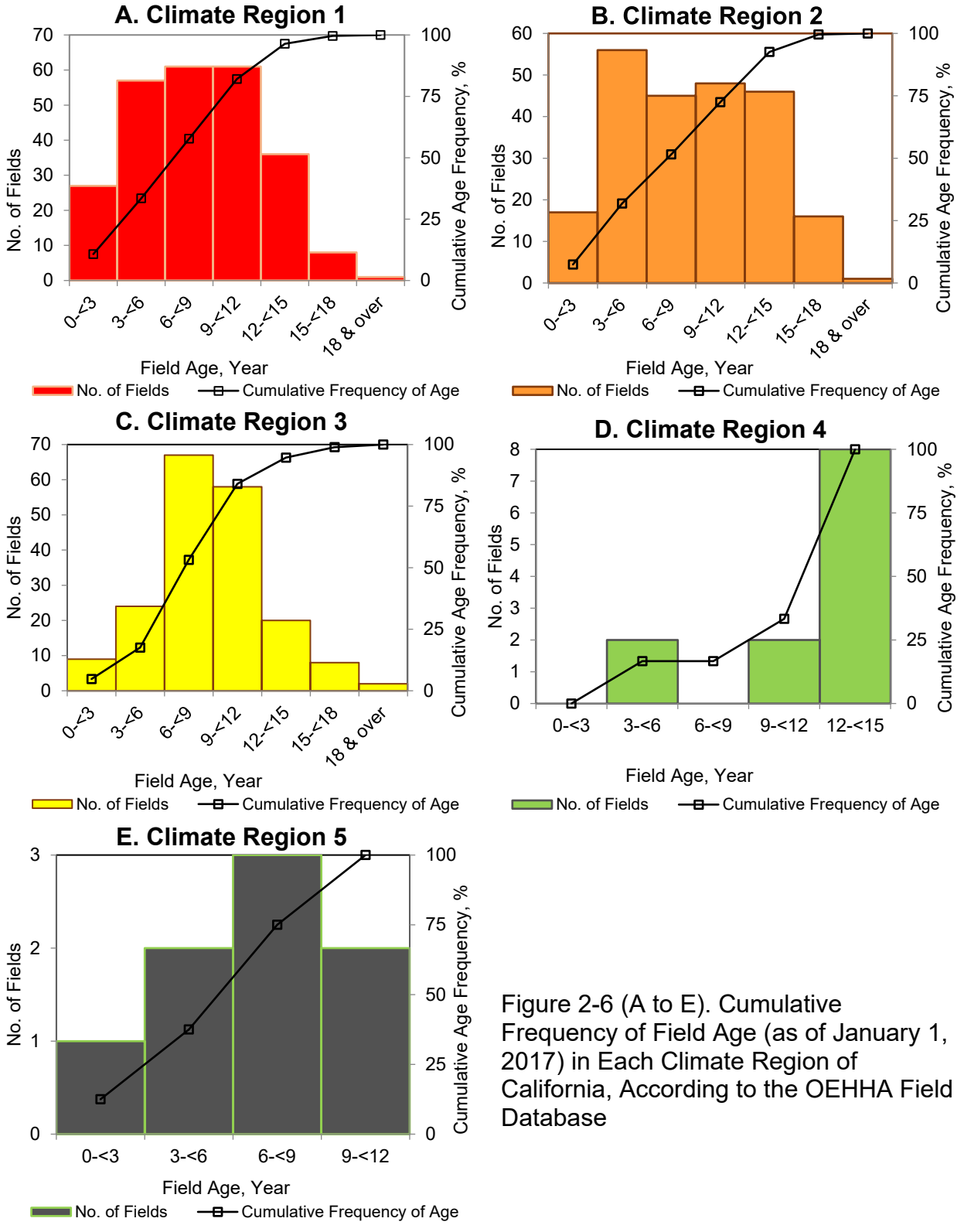

Figure 2-6 (A to E). Cumulative Frequency of Field Age (as of January 1, 2017) in Each Climate Region of California, According to the OEHHA Field Database

Table 2-3 summarizes the number of fields in each climate region and field age subcategory. The Climate Regions 1 to 3, which contain the major metropolitan areas in California, have higher numbers of fields compared to the Climate Regions 4 and 5. The Climate Regions 4 and 5, respectively, cover the desert and mountainous areas in California. There are small numbers of fields in these two climate regions, especially when these two climate regions are further divided into the two field age subgroups. OEHHA, therefore, consolidated the Climate Regions 4 and 5 into a Combined Climate Region 4/5 for the field selection purposes.

Table 2-3. Stratification of Fields into Climate Regions and Field Age Subgroups

Climate Region	Number of New Fields (0 to <9 years old)	Number of Old Fields (≥9 years old)	Total
1	145	106	251
2	118	111	229
3	100	88	188
4/5	8	12	20
Total	371	317	688

2.3.1.3. Field Selection Process Steps

Applying the stratified random sampling method, OEHHA categorized the 688 fields into 8 subgroups: four climate regions and two field age groups per climate region.

Initially, OEHHA planned to randomly select five fields from each subcategory of the Climate Regions 1 to 3 (a total of 30 fields) and two to three fields per field age group in the combined 4/5 Climate Region (a total of five fields). The total number would be 35 fields. However, the plan regarding the number of fields per climate region had to be modified as discussed in Section 2.3.2.1.

OEHHA selected 35 synthetic turf fields in the Phase 3 Field Work. In the field selection process, OEHHA performed the following steps:

1. Randomly ordered fields in each subcategory
2. Searched the internet to gather field owners' or managers' contact information
3. Contacted field owners or managers following the randomly assigned order and used a developed phone script (Appendix section C.1) to solicit their participation in the study
4. Interviewed each participating field owner or manager to complete a field questionnaire (Appendix section C.2) and a consent to participating form (Appendix section C.3)
5. Visited each participating field to confirm that it met the study criteria (e.g., age, region, and field materials)

6. Updated field information in the Field Database, if needed
7. Followed the Field Sampling Protocols (Appendix section D.1) to sample the fields and document the procedures and findings

2.3.2. Conduct of the Statewide Sampling

In early 2016, the Field Team began to contact field owners and managers to secure their consent to participate in the study. The consent form and questionnaire answers were maintained in a confidential manner by OEHHA. As per the consent form (Appendix C.3), OEHHA did not include name or other identifying information of the fields in this report but used a unique identification number in its analysis. By the end of 2017, we completed the field work. The following subsections summarize the field work that was done.

2.3.2.1. Fields Sampled Statewide

From June to December 2017, the Field Team sampled 35 selected synthetic turf fields across California. Thirty-three were crumb rubber infilled fields and 2 were new synthetic turf fields containing a mixture of crumb rubber and cork infill.

Although OEHHA planned to sample 10 fields in each of the Climate Regions 1 to 3 and 5 fields in the Combined Climate Region 4/5, several issues necessitated modifications to this sampling plan:

- Inadequate responses in the Climate Regions 4/5**:** After contacting all 26 field owners or managers in this region, OEHHA was able to sample only two fields.
- Field age discrepancies**:** Two fields in the Climate Region 1 originally were identified as old (according to the OEHHA Field Database). Upon interviewing the owners or managers, we discovered discrepancies between the installation dates provided by the owners or managers and the dates recorded in our database. OEHHA recategorized these fields as new fields (details in Section 2.3.2.2).
- New infill materials used**:** In Climate Region 1, OEHHA found that two synthetic turf fields originally labelled as crumb rubber only were recently replaced with cork and crumb rubber mixed infill. According to the field owners or managers, field manufacturers developed the new infill mixture to reduce the heat exposures on the synthetic turf fields. OEHHA decided to sample these fields.

To address the low number of fields participating in the Combined Climate Region 4/5, OEHHA added an extra old field in the hot and dry Climate Region 3 and an extra new field in the Climate Region 1 at a location bordering the Combined Climate Region 4/5. In addition, we oversampled new fields in the Climate Region 1 because of field age discrepancies and use of new infill materials in field replacements described above. To keep the total number of fields at 35, we reduced the number of new fields in the Climate Region 2 to four fields.

Overall, the 35 fields investigated in the study covered approximately four percent of the California fields on the OEHHA Field Database (35 out of 907 fields). The final sampling percentages of fields in Climate Regions 1 to 3 ranged from three to five percent. Despite the low number of fields sampled in the Combined Climate Region 4/5, they represented eight percent of the fields in this region. Table 2-4 shows the number of fields sampled in each region by general age category.

Table 2-4. Number of Fields Sampled by Climate Region and Age, in Statewide Field Work (Phase 3)

Category of Fields Sampled[a]	Region 1	Region 2	Region 3	Combined Region 4/5	Total
Cork/Crumb Rubber Mixed Fields (≤1 year-old)	2	0	0	0	2
New Crumb Rubber Fields (0 to <9 year-old)	8	4	5	1	18
Old Crumb Rubber Fields (≥9 year-old)	3	5	6	1	15
Number of Fields Sampled (percentage of total fields in region)	13 (3.5%)	9 (3.3%)	11 (4.7%)	2 (7.7%)	35 (3.9%)

[a] Age of fields as of January 1, 2017, according to the updated OEHHA Field Database and supplemented with information provided by participating field owners or managers

2.3.2.2. Age of Fields Sampled

OEHHA interviewed the participating field owners or managers to collect detailed field information. We noticed discrepancies between the owner- or manager-reported field installation dates and the corresponding data in the OEHHA Field Database for some fields, especially those in the Climate Region 1. For example, the ages of some fields in the database were older if the fields had been replaced more recently. For other fields, some field owners or managers indicated that their fields were older than the ages determined by OEHHA (according to data in the OEHHA Field Database). We suspected that this might be due to the lengthy field installation planning processes, long delays in field installation, or memory bias of field owners or managers. We did not have additional information to reconcile these discrepancies. For these fields, OEHHA decided to agree with the field age data provided by the owners or managers. Upon re-confirming the age of these fields with the owners or managers, OEHHA updated the Field Database and re-categorized the corresponding fields as needed.

Figure 2-7 shows cumulative frequency data for the age of fields sampled in the Phase 3 Field Work and the field ages according to the updated OEHHA Field Database.

Overall, there is a slight left shift of the age data for the sampled fields (i.e., younger in field age) compared to the curve for all fields in the database. Despite the shift, these data and the curve share a similar shape. OEHHA was unable to verify the field age data of the entire database and therefore could not affirm that the pool of fields sampled in this study was actually younger than the overall field population in California.

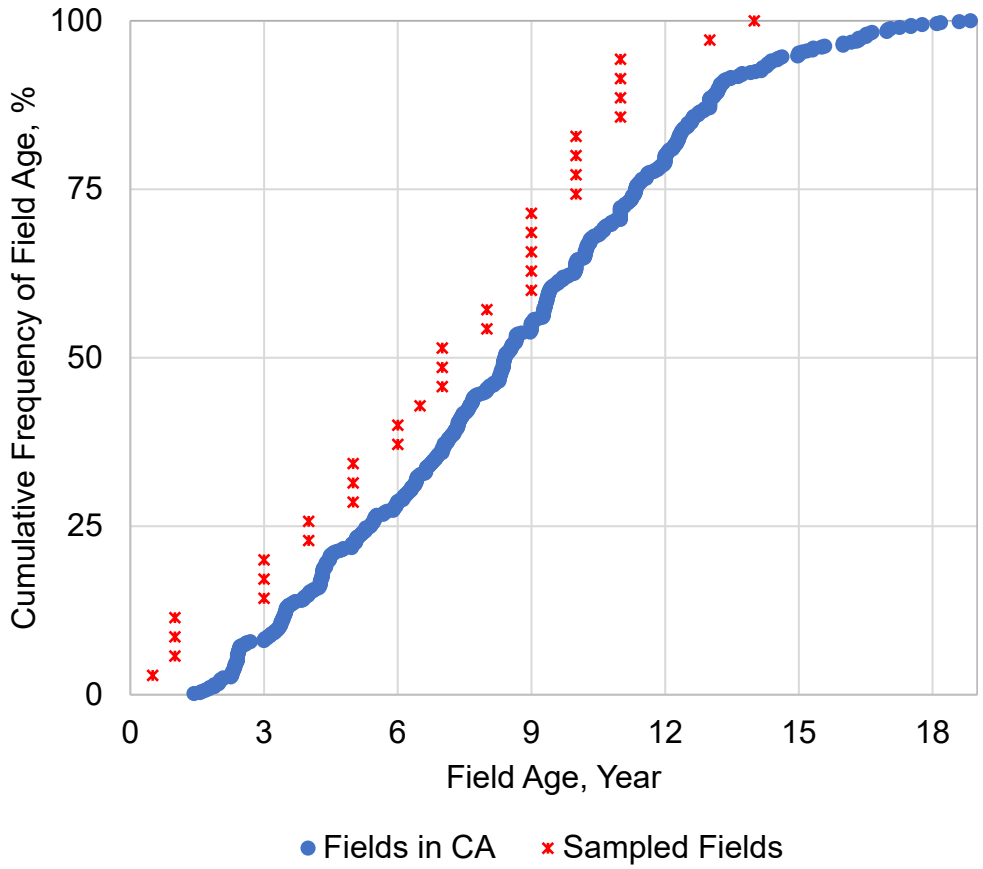

Figure 2-7. Cumulative Frequencies of Field Age of the 35 Fields Sampled in the Phase 3 Compared to the 688 Fields in the Updated OEHHA Field Database (updated with information furnished by the participating field owners or managers)

Among the fields sampled in the Phase 3 Field Work, only a cork and crumb rubber mixed field was less than one year old (Figure 2-7). The age distribution of fields sampled in the New Field Group spread evenly between one to eight years old, whereas most of the fields sampled in the Old Field Group were between 9 and 11 years old. The median age of all the fields sampled was 7 years old, with 57 percent of the fields (20 out of 35) being less than 9 years old. The oldest field sampled was 14 years old.

Communications with some of the field owners or managers revealed that facilities often initiated field replacement plans when fields were approximately 10 years old, and the planning process might take a few years to complete. Field replacements then occurred when the fields became close to 14 years old. As a result, less than eight percent of the

fields in the OEHHA Field Database were 14 years or older (53 out of the 688 fields).

2.3.2.3. Air Samples Collected and Sampling Methods and Conditions

VOCs and Carbonyls. The Field Team collected vapor samples from the air under static (without soccer activity) and active conditions (with soccer activities). To simulate the active field conditions, we recruited volunteer soccer players from local communities to agitate the surface within the monitoring unit (around a goal box set up in the middle of a field, see Figure 2-1) on the field. They conducted vigorous soccer drills (e.g., catching, dribbling, kicking, and diving) by responding to balls released by an automatic ball-kicking machine, which set the pace of the activities.

To measure the VOCs and ALDs in the air on the 35 selected fields, the Field Team followed the Field Sampling Protocols (Appendix section D.1) to set up the instrument packages at several locations of each field, as follows (see also Table 2-5):

- VOC sampling packages on three carts and one tripod. Two carts were located on the field locations next to the monitoring unit and one was located off-field. The samplers were positioned one meter above the field surface to represent the breathing zone of a child. The tripod was a stratification sampling tower located on-field behind the monitoring unit. Samplers were positioned on the tripod at heights of 0.1, 0.5, 1.07, and 1.63 meters above field surface.
- ALD samplers on carts. Two carts were located on-field next to the monitoring unit. The sampler was positioned at a height of one meter above the field surface.

Integrated VOC and ALD samples were collected. In integrated sampling, the air is continuously sampled over the sampling period; the hourly integrated samples absorb chemicals from the air as it is pumped through the samplers. Air concentration can then be determined by:

- The amount of a chemical (e.g., nanograms) collected over a sampling period, determined in the laboratory analysis described in Chapter 3.
- Flow rates of air passing through a sampling device (cubic meter per hour) monitored during the sampling period.
- Period of time over which the sample was collected.

Table 2-5. VOCs and Carbonyls Sampling Instrument Packages for Phase 3 Statewide Field Work

Targeted Chemicals	Instrument, Method, or Device	Location (refer to Figure 2-1)
VOCs	Hourly integrated samples collected on thermal desorption sorbent tubes	on field: right and left of the monitoring unit – Carts 1 and 3 off field; Cart 4 (not shown on Figure 2-1)
Stratified VOCs	One-hour integrated samples collected at four levels above field surface using thermal desorption sorbent tubes	on field: back of the monitoring unit - Cart 2
Carbonyls	Three hour integrated samples collected using 2,4-dinitrophenylhydrazine-cartiridges	on field: right and left of the monitoring unit - Carts 1 and 3

The Field Team used a computer-controlled air pump to collect one VOC sample per hour for five consecutive hours. Each sample was separately analyzed. The first and fifth hours under static field condition on the fields and the second to fourth hours under active field conditions on the fields. Simultaneously, we collected five consecutive hourly VOC samples at an off-field location, where no simulated soccer activity occurred.

On the sampling tower on the tripod, we collected four VOC samples at various vertical levels (0.1 meter, 0.5 meter, 1.07 meter, and 1.63 meter above the field surface, stratified VOC samples) using SKC pumps to regulate the rate of airflow. These samples enabled us to examine the vertical concentration profile of VOCs in the air and in some cases distinguish field related chemicals from non-field related chemicals (See Chapter 3, section 3.5).

Additionally, the Field Team collected a three-hour ALD sample under active field conditions at each of the two on-field locations for each field (see Table 2-5 and Figure 2-1) for the sampling locations on the fields).

At the end of each field sampling day, we shipped the VOC and ALD samples overnight to LBNL for analyses upon arrival.

Semi-Volatile Organic Chemicals in Air. The Field Team followed the Field Sampling Protocols (Appendix section D.1) to collect semi-volatile organic chemicals (SVOCs) in the air (vapor and particulate matters with diameters 2.5 µm and below, $PM_{2.5}$) at the 35 selected synthetic turf fields. The SVOC sample train, in the order of airflow, consisted of a 47mm glass fiber (GF) filter connected to a $PM_{2.5}$ cyclone (opening at a height of 1 meter above the field surface), a polyurethane foam (PUF) sampler, and an XAD®-2

cartridge[1]. Briefly, we placed three SVOC sample trains at the same locations as the VOC samplers (details in Table 2-5 and Figure 2-1)—two on-field and one off-field locations at each field. At each of the on-field locations, we collected a three-hour high-volume SVOC sample from the air under active field conditions. Simultaneously, we collected a three-hour high-volume SVOC sample at the off-field location.

At the end of each field sampling day, we shipped the SVOC samples overnight to LBNL for archiving and storing in refrigerators until they were analyzed. OEHHA applied the analytical results to calculate the SVOC concentrations in the air on and off the fields.

2.3.2.4. Crumb Rubber Samples Collected and Sampling Methods and Conditions

For metals and metalloids analysis, OEHHA followed the Field Sampling Protocols (Appendix section D.1) to collect crumb rubber samples at six (6) to 10 pre-selected locations on each synthetic turf field using single-use plastic sampling scoops and stored in high-density polyethylene bottles. The number and location of samples collected on field depended on the field orientation and uses (see field sample location map in the Appendix section D.1.7.4). Samples were shipped to LBNL overnight for storage at room temperature.

For organic chemicals analyses, OEHHA collected the crumb rubber samples using clean metal scoops and stored in airtight amber glass jars. The samples were shipped to LBNL overnight for storing in refrigerators.

2.3.2.5. Other Data Collected

The Field Team monitored the following environmental conditions at the on-field and off-field locations of each field: ambient and field surface temperatures, relative humidity, solar insolation, wind speed and direction, and airborne particle size distribution and counts in the air.

2.4. Summary: Types and Number of Samples Collected in the Statewide Field Work

Unexpected incidents occurring during the Phase 3 Field Work included instrument failure, insufficient power supply at the field, power failure during sample collection, and loss of samples during shipment. This resulted in one or two fields having fewer samples than planned. For example, we had VOC samples off-field for 34 instead of 35 fields. Table 2-6 and Table 2-7 summarizes the numbers and types of field samples collected in the Phase 3 Field Work.

[1] XAD is a sorbent material registered by the Dow Chemical Company or an affiliated company of Dow

Table 2-6. Samples Resulting from the Statewide Field Work

Type of Sample	Number of Fields Captured		Number of Samples for Analysis			Blank Samples[a]
	On Field	Off Field	On Field	Off Field	Total	
VOC vapor	35	34	481	170	651	68
Carbonyl vapor	34	0	68	0	68	14
SVOC train[b]	34	33	64	33	97	11

[a] Refer to Appendix section D.1.6 for the types of blank samples and the use of analytical data from blank samples
[b] For collection of SVOC vapor and particulate matter with diameter 2.5 µm and below ($PM_{2.5}$)

Table 2-7. Number of Infill Samples Collected During the Statewide Sampling

Infill Type	Fields Sampled	Number of Samples Collected		
		Organic	Inorganic	Total
Crumb	33	308	308	618
Cork and crumb mix	2	20	20	40

2.5. References

CEC (1995). California Climate Zone Descriptions for New Buildings, California Energy Commission.

CEC (2015). California Buildling Climate Zones, California Energy Commission.

Chapter 3. Laboratory Analyses and Resulting Chemical Concentrations

3.1. Introduction

This chapter describes the laboratory work conducted over the course of the Synthetic Turf Study (the study) and provides an overview of the results of that work. The chapter is divided into sections covering the analyses and results of:

- Organic chemicals in artificial gastrointestinal (GI) fluids and artificial sweat extracts of crumb rubber
- Metals and metalloids in acid extracts of crumb rubber simulating gastric conditions
- Organic chemical in air samples and airborne particulate matter samples

Each of the sections begins by summarizing the experiments and analyses conducted to identify and select chemicals for study. This generally involved conducting studies to release chemicals from crumb rubber samples obtained from recycling facilities (e.g., through extractions or chamber emission studies), and performing non-targeted analyses[3] on the chemicals released. The section describes how this work was enriched by the literature research, findings from prior studies (see Appendix A), and discussions with government and academic experts. Each section presents the resulting list of “targeted chemicals” for analysis of samples collected from the 35 fields.

Each section then gives an overview of the approach to the extraction of samples and analysis conducted to measure “targeted chemicals”, and refers to where the details on these methods can be found in Appendix D. The sections conclude with an overview of the results for each of the “targeted chemicals”. This includes indicating the number of fields the chemicals were detected in, and the average and upper bound concentrations detected across the fields sampled.

The sections also provide tabulations of mean, minimum and maximum values for the concentrations measured in air and crumb rubber infill samples. Further statistics are provided in Appendix Sections D.4.1 and D.4.2. For cases where there was not a detection at or above the method detection limit (MDL) the concentration was assumed to be zero. If a chemical was detected, that is it was above MDL, but its concentration could not be reliability quantified because it fell below the limit of quantification (LOQ), its concentration was set to half of the LOQ. Concentrations measured above the LOQ are assumed to correct and are used without modification.

[3] In non-targeted analyses, the data streams from high resolution mass spectrometry (HRMS) are analyzed to identify known and suspected chemicals present. The suspected chemicals are later confirmed with highly pure standards (Place *et al.*, 2021).

Regarding the results of the analyses of artificial biofluids, we define the bioaccessible concentration of a chemical as the releasable amount (e.g., in micrograms per gram of crumb rubber) from crumb rubber into artificial biofluid and available for absorption via the GI tract or skin.

The synthetic turf field environment is subject to sources of pollution, such as from industrial facilities and traffic, so that not all measured levels are directly attributable to the field, especially for chemicals in air. The Chapter concludes with a section on how OEHHA made the determination that a chemical in an air sample or crumb rubber extract was field related.

3.2. Analysis of Crumb Rubber – Organic Chemicals in GI and Dermal Biofluid Extracts

3.2.1. Identifying Chemicals for Analysis

LBNL conducted solvent extractions and analyzed the composite samples of crumb rubber samples collected from tire recycling facilities (Phase 1) and 35 fields using non-targeted chemical analyses to identify chemicals of potential concern (or suspected chemicals):

- Organic solvent comprised of a one-to-one volume ratio of acetone and hexanes was used to extract chemicals for the analysis using high efficiency source gas chromatography mass spectrometry (HES-GC-MS) (see Appendix Section D.3.3).

  The algorithms and procedures used to analyze the GC-MS data and confirm chemical identities are described in Appendix Section D.3.3.4.

- A polar solvent, made up of 10 percent methanol in water, was used to extract polar organic chemicals for analysis with high resolution accurate mass liquid chromatography mass spectrometry (HRAM LC-MS) (see Appendix Section D.3.4).

  The algorithms and procedures used to analyze the LC-MS data and confirm chemical identities are described in Appendix Section D.3.4.4. This included matching LC-MS data to that for chemicals on OEHHA's Tire-Related Chemical List, among other information sources, computer software search to available chemical databases (e.g., ChemSpider and mzVault), and application of cheminformatic algorithms to deduce the unknown chemical structures.

- Suspected chemicals from the GC-MS and LC-MS analyses were then confirmed against commercially available high purity reference chemicals.

The resulting compiled list of chemicals to be targeted in the analysis of organic extracts from crumb rubber is shown in Table 3-1. LBNL looked for the presence of and quantified these chemicals in the artificial GI biofluids and artificial sweat extracts.

These are referred to as the “bioaccessibility measurements”. These were done for the crumb rubber samples collected from the 35 fields in the Phase 3 Field Work described in Section 2.3.2.4.

Table 3-1. Targeted Organic Chemicals for Gastrointestinal and Dermal Bio-accessibility Measurements

Targeted Chemical	CASRN	Analysis[a]
Acenaphthylene	208-96-8	GC
Aniline	62-53-3	GC
Anthracene	120-12-7	GC
Anthracene, 2-methyl-	613-12-7	GC
Anthracene, 9,10-dimethyl	781-43-1	GC
Anthracene, 9,10-diphenyl-	1499-10-1	GC
Anthracene, 9-phenyl	602-55-1	GC
2-Azacyclotridecanone	947-04-6	LC
Benzene, n-butyl-	104-51-8	GC
1,4-Benzenediamine, N-(1,3-dimethylbutyl)-N’-phenyl-	793-24-8	GC
1,4-Benzenediamine, N,N’-diphenyl-	74-31-7	GC and LC
1,4-Benzenediol, 2,5-bis(1,1-dimethylethyl)-	88-58-4	GC
Benz[a]anthracene	56-55-3	GC
Benzo[a]pyrene	50-32-8	GC
Benzo[b]fluoranthene	205-99-2	GC
7H-Benzo[c]fluorene	205-12-9	GC
Benzo[e]pyrene	192-97-2	GC
Benzo[g,h,i]perylene	191-24-2	GC
Benzo[k]fluoranthene	207-08-9	GC
Benzothiazole	95-16-9	GC and LC
Benzothiazole, 2-phenyl-	883-93-2	GC
1,3-Benzothiazole-2-thiol	149-30-4	LC
2-Benzothiazolone	934-34-9	GC and LC
Benzyl butyl phthalate	85-68-7	GC
Bis(2-Ethylhexyl)adipate	103-23-1	GC
Bis(2,2,6,6-tetramethyl-4-piperidyl)sebacate	52829-07-9	GC
Butylated Hydroxytoluene	128-37-0	GC
n-Caproic acid vinyl ester	3050-69-9	GC
Chrysene	218-01-9	GC
Coronene	191-07-1	GC
Cyclohexylamine	108-91-8	GC
Cyclohexyl isothiocyanate	1122-82-3	GC
Cyclopenta[cd]pyrene	27208-37-3	GC
Demecolcine	477-30-5	GC
Dibenz[a,h]anthracene	53-70-3	GC
Dibenzothiophene	132-65-0	GC
Dibutyl phthalate	84-74-2	GC
Cyclohexanamine, N-cyclohexyl-	101-83-7	GC and LC
N,N-Dicyclohexyl-methylamine	7560-83-0	GC and LC
N,N’-Dicyclohexylurea	2387-23-7	LC
Diethyl Phthalate	84-66-2	GC
Diisobutyl Phthalate	84-69-5	GC
Diisooctylphthalate	27554-26-3	GC
Dimethyl phthalate	131-11-3	GC
Di-n-octyl phthalate	117-84-0	GC
1,3-Diphenylguanidine	102-06-7	LC
Diphenylurea	102-07-8	LC
2,5-di-tert-Butyl-1,4-benzoquinone	2460-77-7	GC
3,5-di-tert-Butyl-4-hydroxybenzaldehyde	1620-98-0	GC and LC
Fluoranthene	206-44-0	GC
Fluorene	86-73-7	GC
Hexadecane	544-76-3	GC
2,5-Hexanedione	110-13-4	GC
Hexanoic Acid, 2-ethyl	149-57-5	GC
1-Hydroxypyrene	5315-79-7	GC
Indeno[1,2,3-cd]pyrene	193-39-5	GC
Limonene	138-86-3	GC
Linoleic acid	60-33-3	LC
Methyl stearate	112-61-8	GC
2-(Methylthio)benzothiazole	615-22-5	LC
Naphthalene	91-20-3	GC
Naphthalene, 1-methyl-	90-12-0	GC
Naphthalene, 1,2-dimethyl-	573-98-8	GC

Targeted Chemical	CASRN	Analysis[a]
Naphthalene, 1,6-dimethyl-	575-43-9	GC
Naphthalene, 2-(bromomethyl)-	939-26-4	GC
Naphthalene, 2,3-dimethyl-	581-40-8	GC
Naphthalene, 2-methyl	91-57-6	GC
1-Octadecene	112-88-9	GC
4-tert-Octylphenol	140-66-9	GC
Oleic acid	112-80-1	LC
17-Pentatriacontene	6971-40-0	GC
Phenanthrene	85-01-8	GC
Phenanthrene, 1-methyl	832-69-9	GC
Phenanthrene, 2-methyl-	2531-84-2	GC
Phenanthrene, 3-methyl	832-71-3	GC

Targeted Chemical	CASRN	Analysis[a]
Phenol, 2,4-bis(1-methyl-1-phenylethyl)-	2772-45-4	GC
Phenol, 4-(1-phenylethyl)-	1988-89-2	GC
Phenoxazine	135-67-1	LC
N-Phenylbenzamide	93-98-1	GC
Phthalimide	85-41-6	GC
Pyrene	129-00-0	GC
Pyridine, 2-(4-methylphenyl)-	4467-06-5	GC
Resorcinol	108-46-3	GC
Ricinoleic acid	141-22-0	LC
Triethylene glycol monobutyl ether	143-22-6	LC
5,9-Undecadien-2-one, 6,10-dimethyl-	689-67-8	GC

[a]GC: gas chromatography; LC: liquid chromatography

3.2.2. Sample Extraction and Analysis

LBNL extracted chemicals from crumb rubber into artificial sweat to simulate conditions leading to dermal exposure. The artificial sweat preparation is described in Appendix Section D.4.1.3.1.

Similarly, three different types of artificial GI fluids were used during chemical extraction to simulate conditions leading to oral exposure: saliva, gastric, and intestinal biofluids. These three artificial GI fluid preparations are described in Appendix Section D.4.1.4.1.

The extraction systems used specially coated stir bars to enhance the accessibility or solubility of chemicals from crumb rubber into the artificial fluids. When coupled with GC-MS or LC-MS analyses, this stir bar sorptive extraction (SBSE) method provides a simple sample preparation that supports simultaneous, trace analyses of a large number of chemicals (Telgheder *et al.*, 2018) without the need of an extensive cleanup.

The conventional approach to simulating dermal and GI physiological conditions is to include lipids and milk in the artificial biofluids to model the skin surface and GI linings, respectively. Milk is often included in GI biofluids to simulate the fed state. Lipids or milk enhance the extractability of lipophilic chemicals from samples. However, the resulting extracts require extensive cleanup prior to instrumental analyses. This would not be practical and feasible for analyzing the large number of organic chemicals, which have a wide range of physical properties (e.g., polarity and solubility) and ranges of concentrations in our study. Loss of chemicals during the cleanup processes would be hard to control.

Nonetheless, LBNL tested feasibility of the SBSE extraction system for GI bioaccessibility measurements under different conditions, which included the addition of milk. They used commercially available artificial gastric and intestinal biofluids (See

Appendix Section D.4.1.4.1 for artificial gastric biofluid compositions). Ultra-heat treated milk was added to the artificial gastric fluid to simulate the presence of food in the fed state.

After extracting crumb rubber samples using the SBSE system, LBNL conducted GC-MS analysis of the organic chemicals adsorbed on the polydimethylsiloxane (PDMS) stir bars. Preliminary GC-MS analytical data showed that the presence of milk reduced the GC signals. This could be due to the binding of the crumb rubber chemicals to lipids and proteins in the milk, which interfered with their adsorption onto the PDMS stir bars. Alternatively, the adhesion of lipids and proteins could have saturated the adsorption capacity of the stir bars for crumb rubber chemicals. The Team, therefore, adopted crumb rubber extraction systems without added lipids or milk.

Below we provide an overview of the approaches used to create the artificial biofluid extracts and analyze them for the presence and levels of chemicals in the fluids. For details on the procedures and instruments used, see Appendix Section D.4.1.3 for the artificial sweat extraction and analyses and Appendix Section D.4.1.4 for the artificial GI fluids extractions and their analyses.

Lipophilic chemicals: A PDMS coated Gerstel stir bar was magnetically affixed on the wall of a test tube that contained the crumb rubber and artificial fluid mixture (Figure 3-1). LBNL incubated the mixtures at 37°C under constant stirring with an inert (Telfon-coated) stir bar at the bottom of the tube, for various time durations. At the end of the incubations, LBNL removed and gently rinsed the Gerstel stir bars.

The PDMS coated stir bar acted as a chemical sink which sequestered lipophilic chemicals from the aqueous artificial fluid and enhanced the extractability and accessibility of these chemicals from crumb rubber, simulating human physiological conditions in the gut linings or lipid layer on skin surfaces.

Figure 3-1. Bioaccessibility Measurement Setup. A Gerstel stir bar is magnetically fixed on the side of an incubation tube. The solution in the tube is an artificial biofluid. The inert stir bar in the bottom of the tube constantly stirs the mixture.

The Laboratory analyzed the chemicals adsorbed on the stir bar using a HES-GC-MS system (Series 7890 Plus; Agilent Technologies) equipped with a thermal desorption injection system (ThermoDesorption Autosampler – Gerstel Model TDSA2 and a thermal desorption oven – Gerstel Model TDS3). See Appendix Sections D.4.1.3.2 and D.4.1.4.2.

Hydrophilic Chemicals: Hydrophilic chemicals generally dissolve or extract well into aqueous artificial biofluids. However, inorganic salts in the biofluids interfered with the analysis of organic chemicals using the HRAM LC-MS. Instead of processing the extracts for desalting and cleanup, LBNL used ethylene glycol-PDMS copolymer coated Gerstel stir bars (EG stir bars) to adsorb the accessible hydrophilic chemicals from the aqueous artificial fluids during extraction. The setup was similar to the extraction system used for lipophilic chemicals (Figure 3-1), with the EG stir bar used instead of the PDMS stir bar. At the end of the incubation, LBNL removed and gently rinsed the EG stir bars. They reconstituted the chemicals adsorbed on the EG stir bars into acetonitrile and analyzed the acetonitrile extract using the HRAM LC-MS system: a 1200 series LC system (Agilent Technologies) connected in line with an (linear ion trap) LTQ-Orbitrap-XL® mass spectrometer equipped with an electrospray ionization (ESI) source (ThermoFisher Scientific). See Appendix Section D.3.4.3 for details.

Limits of Detection: LBNL determined the MDL and LOQ of each chemical targeted in the bioaccessibility measurements using the USEPA protocols (USEPA, 2016).

Appendix Section 3.6.1.5 details the methods and provides the limits of detection for the chemicals analyzed by HES GC-MS. LBNL was unable to determine the limits of detection using the HRAM LC-MS due to its limited availability. However, the sensitivity of this instrument has been reported to be at the sub-femtomole level[4] (UWPR, 2007).

3.2.3. Results of Analyses of Artificial GI Fluids

The results of the analyses of the GI fluid extracts of the 35 sampled fields (Phase 3) are summarized in Table 3-2. As described in Appendix Section D.1.8, two composite samples were prepared in the Laboratory using crumb rubber sampled from each field, one from samples collected in areas of high impact ("HI"), such as in the two goal areas in a soccer field, the second from samples collected in the rest of the field ("ROF"). A discussion of the differences between HI and ROF samples is provided in Appendix Section D.4.1.4.3, along with a discussion of sample variation. Variations in chemical composition within a sample, within a field, and between pairs of composite samples from the 35 individual fields were found to be low, thus OEHHA found the use of composite samples to be appropriate for the study. For the presentation here, a single value was calculated for each field by averaging analytical data for the HI and ROF composite samples for each field.

The mean value shown for each chemical is the arithmetic mean of the 35 individual field average GI bioaccessible concentrations. The table also shows the minimum and maximum values of the 35 fields. Further statistics on these chemical results are presented in Appendix Section D.4.1.4.6, Table D-41.

Table 3-2. Gastrointestinal (GI) Bioaccessible Concentrations of Organic Chemicals in Crumb Rubber Sampled from 35 Synthetic Turf Fields in California*

Chemical	CASRN	Detections (# of fields)	GI Bioaccessible Concentration (nanograms per gram crumb rubber)		
			Minimum	Mean	Maximum
1,4-Benzenediamine, N-(1,3-dimethylbutyl)-N'-phenyl-	793-24-8	20	0	48	230
1,4-Benzenediamine, N,N'-diphenyl-	74-31-7	7	0	5.5	120
17-Pentatriacontene	6971-40-0	9	0	4	42
1-Hydroxypyrene	5315-79-7	1	0	1.1	40
1-Octadecene	112-88-9	32	0	4.7	14
2-(Methylthio)benzothiazole	615-22-5	5	0	15	300
2,5-di-tert-Butyl-1,4-benzoquinone	2460-77-7	4	0	0.082	1.2
3,5-di-tert-Butyl-4-hydroxybenzaldehyde	1620-98-0	35	0.049	18	180

[4] For example, the molecular weight of benzothiazole is 135 grams per mole, thus, 1 femtomole of benzothiazole equals to 0.1 picogram.

Chemical	CASRN	Detections (# of fields)	GI Bioaccessible Concentration (nanograms per gram crumb rubber)		
			Minimum	Mean	Maximum
4-tert-Octylphenol	140-66-9	35	5.3	69	430
5,9-Undecadien-2-one, 6,10-dimethyl-	689-67-8	35	2	3.4	6.5
7H-Benzo[c]fluorene	205-12-9	31	0	0.77	6.2
Acenaphthylene	208-96-8	35	0.041	0.32	1.2
Aniline	62-53-3	12	0	1.8	18
Anthracene	120-12-7	28	0	0.83	6.8
Anthracene, 2-methyl-	613-12-7	35	0.48	3.3	15
Anthracene, 9,10-dimethyl	781-43-1	2	0	0.027	0.88
Anthracene, 9,10-diphenyl-	1499-10-1	2	0	0.21	5.3
Anthracene, 9-phenyl	602-55-1	30	0	0.31	1.4
Benz[a]anthracene	56-55-3	35	0.19	2.9	13
Benzene, n-butyl-	104-51-8	29	0	0.18	2.7
Benzo[a]pyrene	50-32-8	35	0.47	2.4	7
Benzo[b]fluoranthene	205-99-2	35	0.81	4	12
Benzo[e]pyrene	192-97-2	35	2.1	7.1	16
Benzo[g,h,i]perylene	191-24-2	35	0.33	4.8	13
Benzo[k]fluoranthene	207-08-9	35	0.11	1.3	4.8
Benzothiazole	95-16-9	35	110	490	1200
Benzothiazole, 2-phenyl-	883-93-2	35	15	53	280
Benzothiazolone	934-34-9	35	790	1200	1700
Benzyl butyl phthalate	85-68-7	35	1.3	25	100
Bis(2,2,6,6-tetramethyl-4-piperidyl)sebacate	52829-07-9	4	0	12	130
Bis(2-Ethylhexyl)adipate	103-23-1	33	0	16	57
Butylated Hydroxytoluene	128-37-0	19	0	0.67	5.6
Chrysene	218-01-9	35	3.2	13	35
Coronene	191-07-1	7	0	1.8	28
Cyclohexyl isothiocyanate	1122-82-3	29	0	160	410
Cyclopenta[cd]pyrene	27208-37-3	35	0.49	2.8	13
Dibenz[a,h]anthracene	53-70-3	7	0	0.17	2.1
Dibenzothiophene	132-65-0	27	0	0.67	4.1
Dibutyl phthalate	84-74-2	31	0	48	140
Dicyclohexylamine	101-83-7	25	0	41	110
Diethyl Phthalate	84-66-2	23	0	4	12
Diisobutyl Phthalate	84-69-5	32	0	4.8	73
Diisooctylphthalate	27554-26-3	33	0	100	270
Dimethyl phthalate	131-11-3	9	0	0.93	15
Di-n-octyl phthalate	117-84-0	26	0	9.9	110
Diphenylurea	102-07-8	35	5.6	130	770

Chemical	CASRN	Detections (# of fields)	GI Bioaccessible Concentration (nanograms per gram crumb rubber)		
			Minimum	Mean	Maximum
Fluoranthene	206-44-0	35	3.1	22	110
Fluorene	86-73-7	11	0	0.29	3.5
Hexadecane	544-76-3	28	0	2.1	8.2
Indeno[1,2,3-cd]pyrene	193-39-5	12	0	0.48	3.3
Limonene	138-86-3	34	0	4.2	76
Linoleic acid	60-33-3	35	630	1000	1300
Methyl stearate	112-61-8	35	2.5	10	47
N,N'-Dicyclohexylurea	2387-23-7	17	0	23	220
Naphthalene	91-20-3	1	0	0.053	1.8
Naphthalene, 1,2-dimethyl-	573-98-8	12	0	0.032	0.36
Naphthalene, 1,6-dimethyl-	575-43-9	35	0.083	0.21	0.59
Naphthalene, 1-methyl-	90-12-0	31	0	0.14	2.8
Naphthalene, 2-(bromomethyl)-	939-26-4	35	0.19	5.5	12
Naphthalene, 2,3-dimethyl-	581-40-8	35	0.041	1.6	7
Naphthalene, 2-methyl	91-57-6	19	0	0.12	3
n-Caproic acid vinyl ester	3050-69-9	1	0	0.13	4.7
N-Phenylbenzamide	93-98-1	22	0	22	150
Oleic acid	112-80-1	3	0	54	760
Phenanthrene	85-01-8	35	1.7	9.8	63
Phenanthrene, 1-methyl	832-69-9	35	0.23	2.6	11
Phenanthrene, 2-methyl-	2531-84-2	35	0.071	3.4	18
Phenanthrene, 3-methyl	832-71-3	35	0.43	5.6	28
Phenol, 2,4-bis(1-methyl-1-phenylethyl)-	2772-45-4	35	3.1	26	70
Phenol, 4-(1-phenylethyl)-	1988-89-2	34	0	14	94
Phenoxazine	135-67-1	3	0	13	250
Phthalimide	85-41-6	16	0	3.9	42
Pyrene	129-00-0	35	8.8	47	140
Pyridine, 2-(4-methylphenyl)-	4467-06-5	2	0	0.1	3.4
Ricinoleic acid	141-22-0	33	0	25	110
Triethylene glycol monobutyl ether	143-22-6	3	0	1.2	26

**Detections*: Number of fields out of 35 with concentrations above method detection limits.
Mean: Arithmetic mean of the concentrations of the individual field average concentrations.
0: A value of 0 means the chemical is not detected or is detected below the method detection limit.

Among the 86 GI bioaccessible organic chemicals targeted (Table 3-1), the study confirmed the presence of and quantified 76 chemicals as having concentrations above the method detection limits.

Two chemicals were determined invalid due to matrix interference or that the reference

standard was not detected in calibration:

- Cyclohexylamine (CASRN 108-91-8) due to matrix interference
- Demecolcine (CASRN 477-30-5) reference standard not detected in the calibration.

Eight chemicals were not detected in the GI extracts:

- 1,3-Benzothiazole-2-thiol (CASRN 149-30-4)
- 1,3-Diphenylguanidine (CASRN 102-06-7)
- Resorcinol (CASRN 108-46-3)
- 2,5-Bis(1,1-dimethylethyl)-1,4-benzenediol (CASRN 88-58-4)
- 2-Azacyclotridecanone (CASRN 947-04-6)
- 2,5-Hexanedione (CASRN 110-13-4)
- Hexanoic acid, 2-ethyl (CASRN 149-57-5)
- N,N-dicyclohexylmethylamine (CASRN 7560-83-0)

3.2.4. Results of Analyses of Artificial Sweat Extracts

The results of the analyses of the dermal fluid extracts of the 35 sampled fields (Phase 3) are summarized in Table 3-3. For each field the average of the concentrations for the HI and ROF composite samples were calculated. The mean value in Table 3-3 is the arithmetic average of the concentrations for the 35 individual fields. The table also shows the minimum and maximum concentration values for the 35 fields. Further details on these results are provided in Appendix Section D.4.1.3.3, Table D-32.

Table 3-3. Dermal Bioaccessible Concentrations of Organic Chemicals in Crumb Rubber from 35 Synthetic Turf Fields in California*

Chemical	CASRN	Detections	Dermal Bioaccessibile Concentration (nanograms per gram crumb rubber)		
			Minimum	Mean	Maximum
Acenaphthylene	208-96-8	10	0	0.0056	0.035
Aniline	62-53-3	4	0	0.18	2.7
Anthracene	120-12-7	20	0	0.062	0.41
Anthracene, 2-methyl-	613-12-7	35	0.022	0.089	0.35
Anthracene, 9,10-diphenyl-	1499-10-1	5	0	0.012	0.17
Anthracene, 9-phenyl	602-55-1	9	0	0.03	0.3
2-Azacyclotridecanone	947-04-6	2	0	0.24	6
Benzene, n-butyl-	104-51-8	1	0	0.00037	0.013
1,4-Benzenediamine, N-(1,3-dimethylbutyl)-N'-phenyl-	793-24-8	32	0	17	140
1,4-Benzenediamine, N,N'-diphenyl-	74-31-7	9	0	3.5	86
Benz[a]anthracene	56-55-3	31	0	0.25	1.3
Benzo[a]pyrene	50-32-8	32	0	0.19	0.76

Chemical	CASRN	Detections	Dermal Bioaccessibile Concentration (nanograms per gram crumb rubber)		
			Minimum	Mean	Maximum
Benzo[b]fluoranthene	205-99-2	34	0	0.35	1.4
7H-Benzo[c]fluorene	205-12-9	26	0	0.03	0.16
Benzo[e]pyrene	192-97-2	35	0.053	0.55	1.5
Benzo[g,h,i]perylene	191-24-2	35	0.051	0.42	1.1
Benzo[k]fluoranthene	207-08-9	29	0	0.15	0.62
Benzothiazole	95-16-9	35	46	200	450
Benzothiazole, 2-phenyl-	883-93-2	35	1.4	4.8	19
1,3-Benzothiazole-2-thiol	149-30-4	1	0	1.3	46
2-Benzothiazolone	934-34-9	35	120	560	790
Benzyl butyl phthalate	85-68-7	35	0.15	2.3	6.5
Bis(2-Ethylhexyl)adipate	103-23-1	35	0.18	2.5	23
Bis(2,2,6,6-tetramethyl-4-piperidyl)sebacate	52829-07-9	1	0	0.52	18
Chrysene	218-01-9	35	0.17	1.6	3.6
Coronene	191-07-1	1	0	0.13	4.4
Cyclohexyl isothiocyanate	1122-82-3	1	0	0.0084	0.29
Cyclopenta[cd]pyrene	27208-37-3	35	0.029	0.28	0.65
Dibenz[a,h]anthracene	53-70-3	14	0	0.091	0.69
Dibenzothiophene	132-65-0	20	0	0.054	0.32
Cyclohexanamine, N-cyclohexyl-	101-83-7	30	0	48	480
N,N-Dicyclohexylmethylamine	7560-83-0	28	0	0.084	0.88
N,N'-Dicyclohexylurea	2387-23-7	18	0	25	360
Diethyl Phthalate	84-66-2	5	0	0.41	6.2
Diisobutyl Phthalate	84-69-5	28	0	0.35	3.4
Diisooctylphthalate	27554-26-3	35	0.098	11	33
Dimethyl phthalate	131-11-3	3	0	0.25	3.2
Di-n-octyl phthalate	117-84-0	33	0	2.4	16
1,3-Diphenylguanidine	102-06-7	2	0	0.72	18
Diphenylurea	102-07-8	32	0	61	220
2,5-di-tert-Butyl-1,4-benzoquinone	2460-77-7	4	0	0.0021	0.028
3,5-Di-tert-butyl-4-hydroxybenzaldehyde	1620-98-0	25	0	11	160
Fluoranthene	206-44-0	35	0.31	1.9	5.2
Fluorene	86-73-7	6	0	0.008	0.14
Hexanoic Acid, 2-ethyl	149-57-5	1	0	0.0092	0.32
1-Hydroxypyrene	5315-79-7	1	0	0.53	19
Indeno[1,2,3-cd]pyrene	193-39-5	28	0	0.18	0.66
Limonene	138-86-3	35	0.077	0.34	1.8

Chemical	CASRN	Detections	Dermal Bioaccessibile Concentration (nanograms per gram crumb rubber)		
			Minimum	Mean	Maximum
Linoleic acid	60-33-3	1	0	1.1	37
Methyl stearate	112-61-8	28	0	1.1	8.1
2-(Methylthio)benzothiazole	615-22-5	9	0	7.3	73
Naphthalene	91-20-3	2	0	0.012	0.21
Naphthalene, 1-methyl-	90-12-0	1	0	0.0019	0.065
Naphthalene, 1,2-dimethyl-	573-98-8	1	0	0.00083	0.029
Naphthalene, 1,6-dimethyl-	575-43-9	6	0	0.0087	0.065
Naphthalene, 2-(bromomethyl)-	939-26-4	33	0	0.34	1.1
Naphthalene, 2,3-dimethyl-	581-40-8	33	0	0.1	0.41
Naphthalene, 2-methyl	91-57-6	1	0	0.0018	0.063
1-Octadecene	112-88-9	27	0	0.59	9.7
4-tert-Octylphenol	140-66-9	34	0	4.6	43
Oleic acid	112-80-1	3	0	5.5	110
Phenanthrene	85-01-8	29	0	0.4	2.5
Phenanthrene, 1-methyl	832-69-9	35	0.04	0.21	0.65
Phenanthrene, 2-methyl-	2531-84-2	34	0	0.26	0.96
Phenanthrene, 3-methyl	832-71-3	3	0	0.093	1.9
Phenol, 2,4-bis(1-methyl-1-phenylethyl)-	2772-45-4	35	0.11	1.4	5.2
Phenol, 4-(1-phenylethyl)-	1988-89-2	35	0.13	1.5	7.3
Phenoxazine	135-67-1	2	0	4.3	100
N-Phenylbenzamide	93-98-1	8	0	0.58	4.2
Phthalimide	85-41-6	26	0	3.8	38
Pyrene	129-00-0	35	0.94	5.1	14
Pyridine, 2-(4-methylphenyl)-	6/5/4467	14	0	0.19	1.6
Ricinoleic acid	141-22-0	3	0	3.8	67
Triethylene glycol monobutyl ether	143-22-6	7	0	0.98	11
5,9-Undecadien-2-one, 6,10-dimethyl-	689-67-8	32	0	0.13	0.63

**Detections*: Number of fields out of 35 fields with concentrations above method detection limits.
Mean: Arithmetic mean of the concentrations of the individual field average concentrations.
0: A value of 0 means the chemical is not detected or is detected below the method detection limit.

Among the 86 chemicals targeted (Table 3-1), the study confirmed the presence of and quantified 75 organic chemicals with dermal bioaccessible concentrations above the method of detection limits.

The analyses of three targeted chemicals were invalidated due to matrix interference or reference standards not detected in the calibration:

- Cyclohexylamine (CASRN 108-91-8) - matrix interference
- Demecolcine (CASRN 477-30-5) – reference standard not detected

- Resorcinol (CASRN 108-46-3) – reference standard not detected

Eight chemicals were not detected in the extracts of artificial sweat:

- 2,5-Bis(1,1-dimethylethyl)- 1,4-benzenediol (CASRN 88-58-4)
- 2,5-Hexanedione (CASRN 110-13-4)
- 17-Pentatriacontene (CASRN 6971-40-0)
- 9,10-Dimethylanthracene (CASRN 781-43-1)
- Butylated hydroxytoluene (CASRN 128-37-0)
- Dibutyl phthalate (CASRN 84-74-2)
- Hexadecane (CASRN 544-76-3)
- n-Caproic acid vinyl ester (CASRN 3050-69-9)

3.2.5. Chemicals Found in GI vs Dermal Extracts

Of the 81 chemicals detected in either the extracts of artificial sweat or artificial GI fluids, 70 chemicals were found in both types of fluids. The chemicals detected are of diverse structure and lipophilicity, from water soluble amines to polycyclic aromatic hydrocarbons (PAHs), and can be generally categorized as follows:

- sulfur-containing chemicals (5 in GI extracts, 6 in artificial sweat)
- alkanes and alkenes (6 in GI extracts, 4 in artificial sweat)
- oxygen-containing (phenols, a quinone, a polyglycol ester) (6 in GI extracts, 5 in artificial sweat)
- fatty acids and esters (7 chemicals in both types)
- phthalates (7 in GI extracts, 6 in artificial sweat)
- nitrogen-containing chemicals (amines, amides, ureas, and a pyridine) (10 in GI extracts, 13 in artificial sweat)
- PAHs and derivatives (32 in GI extracts, 31 in artificial sweat)
- brominated-PAH (one in both types of extracts)
- sulfur-containing PAH (one in both types of extracts)
- an aldehyde (one in both types of extracts)

Five chemicals were detected only in artificial sweat extracts:

- 1,3-Benzothiazole-2-thiol (CASRN 149-30-4)
- 1,3-Diphenylguanidine (CASRN 102-06-7)
- 2-Azacyclotridecanone (CASRN 947-04-6)
- Hexanoic acid, 2-ethyl (CASRN 149-57-5)
- N,N-dicyclohexylmethylamine (CASRN 7560-83-0)

Six chemicals were detected only in GI biofluids extracts:

- 1,4-Benzenediamine, N-(1,3-dimethylbutyl)-N'-phenyl- (CASRN 793-24-8)
- Anthracene, 9,10-dimethyl (CASRN 781-43-1)

- Butylated hydroxytoluene (CASRN 128-37-0)
- Hexadecane (CASRN 544-76-3)
- Dibutyl phthalate (CASRN 84-74-2)
- n-Caproic acid vinyl ester (CASRN 3050-69-9)

3.3. Analysis of Crumb Rubber - Metals and Metalloids in Acid Extracts

Exposure to metals and metalloids from crumb rubber is assumed to mainly occur via the oral route. Measurements were undertaken using simulated gastrointestinal acids to evaluate the degree that metals and metalloids would be released from crumb rubber when ingested. “Bioaccessible concentrations” of metals and metalloids represents the amount of metal released in the GI tract per amount of crumb rubber consumed.

This section presents bioaccessible concentrations measured for the metals and metalloids. In addition, it reports on the full digestion of crumb rubber in acid that enabled calculations of bioaccessible fractions – expressed as the percent of metal/metalloids in crumb rubber that is released into the biofluid.

3.3.1. Selection of Metals and Metalloids for Study and Analytical Method

LBNL analyzed the crumb rubber samples collected from the 35 fields (Phase 3) using inductively coupled plasma mass spectrometry (ICP-MS) for development of sample preparations and extraction SOPs. Originally, we planned to use the crumb rubber collected from manufacturers and pilot fields, as discussed in Phase 1, but were unable to do the analyses until after the Statewide fields were sampled. We therefore amended the project plan to use the statewide field samples instead.

ICP-MS allows a direct and highly sensitive quantitative measurement in a sample of almost all the elements in the periodic table[5]. It provides a nearly complete elemental profile of each sample run. No sample cleanup is required before analyses with the ICP-MS instrument. The method detection limit is at the parts per trillion level.

We decided to use this highly sensitive method to focus on a predetermined list of 31 potentially hazardous metals and metalloids for the targeted elemental analysis of the crumb rubber acid extracts. This was based on preliminary results and input received at the 2018 OEHHA SAP Meeting (OEHHA, 2018). Also, rather than trying to speciate detected metals, as a screening approach, we assumed the detected metals and metalloids were in their most toxic forms in assessing the hazards and risks. Had high risks been seen we could follow-up with additional analysis.

Two different acid digestion methods were used to extract metals and metalloids from

[5] Hydrogen, helium, argon, nitrogen, oxygen, fluorine, and neon are the only elements that cannot be measured.

the crumb rubber samples:

- American Society for Testing and Materials (ASTM) F3188-16 was used to simulate gastric fluid - to obtain extracts for the bioaccessibility measurement of metals and metalloids in the crumb rubber samples.
- USEPA 3051A (USEPA, 2007) is a microwave-assisted method that provides a full acid digestion of the sample. This enables the determination of total extractable metals and metalloids in crumb rubber samples.

The details on how the extractions were performed are presented in Appendix Sections D.4.1.1 and D.4.1.2.

The ASTM method is established for simulating gastric digestion of crumb rubber using mild acid (0.8 Molarity hydrochloric acid or 0.8 M HCl). The amounts metals and metalloids detected in this assay are applied to calculate the oral bioaccessible concentrations of crumb rubber. On the other hand, the USEPA method fully extracted crumb rubber by microwave digestion at 175 °C in a concentrated acid mixture (3:1 concentrated nitric acid and concentrated hydrochloric acid). This provides the basis estimating the amount of a given metal or metalloid in a crumb rubber sample.

A decision was made to deviate from the initially established list of 31 metals and metalloids to be analyzed - to exclude mercury. The analysis for mercury had to be conducted separately from the other metals (see Appendix Section D.2.7). Preliminary analysis of the ASTM extracts found that the bioaccessible concentrations of mercury in most of the crumb rubber extracts were below the MDL (OEHHA, 2018). Less than 6% of samples (5 of 84) had concentrations above the MDL of 0.15 part per billion (ppb). Since mercury was uncommon, as reported in previous studies on crumb rubber and synthetic turf fields, the SAP recommended excluding mercury in the final analysis of the crumb rubber extracts (OEHHA, 2018).

3.3.2. Preparation, Extraction and Analysis of Field Samples

ICP-MS measurements showed minimal variation of metal and metalloid concentrations among samples collected from a selected field. The SAP suggested the preparation of two composite samples per field. One composite sample was from the high impact area of the field - goal areas on a soccer field, end zones on a football field, and four bases on a softball field. The second composite sample was from the rest of the field areas. The procedures for preparing the composite samples is discussed in Appendix Section D.1.8)

LBNL extracted the composite field samples from the statewide sampling using ASTM F3188-16. They quantified the concentrations of metals and metalloids in these acid extracts by ICP-MS, as described in Appendix Section D.4.1.1.4. OEHHA applied the results to assess the gastric bioaccessible concentrations of metals and metalloids from crumb rubber. OEHHA assumes these concentrations represent the amount of crumb

rubber exposure, for example in micrograms, per gram of crumb rubber ingested. These concentrations were used to calculate exposures of field users by the oral route in Chapter 5.

The procedure LBNL used to determine the MDL and LOQ of each metal or metalloid is described in Appendix Sections D.3.7.1.7 and D.3.7.2.

3.3.3. Results of Analysis of GI Extracts for Metals and Metalloids

The results of the analysis of the 30 metals and metalloids quantified by LBNL applying ICP-MS to the GI biofluid extracts are summarized in Table 3-4. Metals and metalloids are generally more soluble in the acidic pH in gastric fluid than the alkali pH in intestinal fluids. OEHHA therefore assumed that the concentrations measured in the artificial gastric fluid (0.8 M hydrochloric acid) represented the gastrointestinal (GI) bioaccessible concentration following the inadvertent ingestion of crumb rubber by field users.

The values shown in Table 3-4 are the arithmetic mean, minimum, and maximum of the 35 individual field averages of GI bioaccessible concentrations. In making these calculations, a single field is represented by the average of the concentration for the samples of the high impact area and of the “rest of field”. Additional statistics for this analysis are provided in Appendix Section D.4.1.1.5, Table D-27.

Table 3-4. Gastrointestinal (GI) Bioaccessible Concentrations of Metals and Metalloids in Crumb Rubber from 35 Synthetic Turf Fields in California*

Metal or Metalloid	Symbol	Detection (# of fields)	GI Bioaccessible Concentration (micrograms per gram of crumb rubber)		
			Minimum	Mean	Maximum
Aluminum	Al	35	7	22	52
Antimony	Sb	35	0.0015	0.024	0.1
Arsenic	As	35	0.0012	0.01	0.039
Barium	Ba	35	0.4	1.5	5.7
Beryllium	Be	11	0	0.00063	0.0035
Boron	B	25	0	0.45	1.8
Cadmium	Cd	34	0	0.017	0.04
Calcium	Ca	35	13	460	7900
Chromium	Cr	35	0.0088	0.047	0.26
Cobalt	Co	35	0.2	1.1	3.8
Copper	Cu	35	0.84	2.1	6.7
Iron	Fe	35	8.1	23	38
Lead	Pb	35	0.19	1	4.5
Lithium	Li	3	0	0.0033	0.047
Magnesium	Mg	35	3.2	19	130
Manganese	Mn	35	0.18	0.99	3.1
Molybdenum	Mo	14	0	0.0018	0.009
Nickel	Ni	35	0.021	0.097	0.37

Metal or Metalloid	Symbol	Detection (# of fields)	GI Bioaccessible Concentration (micrograms per gram of crumb rubber)		
			Minimum	Mean	Maximum
Potassium	K	35	2.9	13	40
Rubidium	Rb	35	0.016	0.05	0.17
Selenium	Se	4	0	0.006	0.088
Silicon	Si	35	5.3	16	50
Silver	Ag	2	0	0.0006	0.014
Sodium	Na	35	0.9	21	110
Strontium	Sr	35	0.081	0.85	9.6
Thallium	Tl	21	0	0.00024	0.0022
Tin	Sn	30	0	0.0093	0.037
Titanium	Ti	35	0.16	0.36	0.69
Vanadium	V	2	0	0.0048	0.085
Zinc	Zn	35	46	210	600

* A value of 0 means the chemical is not detected or is detected below the detection limit. Concentrations below the MDL are set to equal zero. Detections above MDL, but below the LOQ are set to half of the LOQ. Concentrations above the LOQ are presented without modification.
Detections: Number of fields out of 35 total with concentrations above detection limits.
Mean: Arithmetic mean of the concentrations of the individual field average concentrations.

Table 3-5 shows the results of analysis of the full digestion of the crumb rubber samples from the 35 fields - using USEPA 3051A. The values shown in Table 3-5 are the arithmetic mean, minimum, and maximum of the 35 individual field averages of the strong acid digestions. These values represent the concentration of metal in the crumb rubber sample. These values are used to calculate the bioaccessibility percent.

Table 3-5. Total Concentrations of Metals and Metalloids in Crumb Rubber from 35 Synthetic Turf Fields in California[a]

Metal or Metalloid	Symbol	Detections (# of fields)	Total Concentration[b] (micrograms per gram of crumb rubber)		
			Minimum	Mean	Maximum
Aluminum	Al	35	380	860	2300
Antimony	Sb	35	0.18	0.82	2.5
Arsenic	As	35	0.25	0.75	2.1
Barium	Ba	35	4	11	75
Beryllium	Be	4	0.0046	0.018	0.045
Boron	B	31	1.7	5.9	39
Cadmium	Cd	35	0.22	0.96	4.5
Calcium	Ca	35	920	8300	120000
Chromium	Cr	35	0.72	5.2	120
Cobalt	Co	35	48	150	360
Copper	Cu	35	8.3	21	35
Iron	Fe	35	270	720	2600
Lead	Pb	35	3.6	23	91

Metal or Metalloid	Symbol	Detections (# of fields)	Total Concentration[b] (micrograms per gram of crumb rubber)		
			Minimum	Mean	Maximum
Lithium	Li	35	0.76	1.7	3.1
Magnesium	Mg	35	170	430	4600
Manganese	Mn	35	4.5	8.8	25
Molybdenum	Mo	35	0.0059	0.15	0.51
Nickel	Ni	35	1.1	3.7	17
Potassium	K	35	250	490	1700
Rubidium	Rb	35	1	2	9.4
Selenium	Se	35	1.4	2.6	4.4
Silicon	Si	35	61	600	1100
Silver	Ag	11	0.014	2.1	11
Sodium	Na	35	140	370	650
Strontium	Sr	35	1.9	6.8	49
Thallium	Tl	35	0.026	0.046	0.1
Tin	Sn	35	0.44	1.9	9.8
Titanium	Ti	35	20	57	220
Vanadium	V	35	0.51	2.3	6.9
Zinc	Zn	35	7600	16000	25000

[a] Full digestion of crumb rubber using U.S. EPA, 2007.
[b] Minmium, mean, and maximum are the corresponding values for the 35 individual field average concentrations.

The bioaccessibility percent of each metal or metalloid was calculated as the ratio of average GI bioaccessibility concentration for an individual field to the average total concentration of the same field multiplied by 100 percent. Table 3-6 shows the value arithmetic mean of GI bioaccessibility percent of metals and metalloids in crumb rubber for the 35 fields. The values range from 0.2 for vanadium to 18 percent for boron among the 30 metals and metalloids. Fields with no detected total concentration a metal or metalloid above the MDL are excluded in the calculation of bioaccessibility percent.

Table 3-6. Estimates of Gastric Bioaccessibility for Metals and Metalloids in Crumb Rubber from 35 Synthetic Turf Fields in California

Metal or Metalloid	Number of fields with detections by		Mean Gastric Bioaccessibility
	ASTM Method	USEPA 3051A	
Aluminum	35	35	2.9%
Antimony	35	35	3.6%
Arsenic	35	35	1.6%
Barium	35	35	17.4%
Beryllium	11	4	10.3%
Boron	25	31	18.3%

Metal or Metalloid	Number of fields with detections by		Mean Gastric Bioaccessibility
	ASTM Method	USEPA 3051A	
Aluminum	35	35	2.9%
Cadmium	34	35	2.4%
Calcium	35	35	7.3%
Chromium	35	35	2.2%
Cobalt	35	35	0.8%
Copper	35	35	10.6%
Iron	35	35	3.9%
Lead	35	35	7.5%
Lithium	3	35	0.2%
Magnesium	35	35	5.5%
Manganese	35	35	12.0%
Molybdenum	14	35	1.3%
Nickel	35	35	2.9%
Potassium	35	35	2.8%
Rubidium	35	35	2.7%
Selenium	4	35	0.3%
Silicon	35	35	4.6%
Silver	2	11	0.5%
Sodium	35	35	5.7%
Strontium	35	35	12.9%
Thallium	21	35	0.7%
Tin	30	35	0.7%
Titanium	35	35	0.8%
Vanadium	2	35	0.2%
Zinc	35	35	1.4%

3.4. Analysis of Air Samples – for Evaluating Inhalation Exposures

3.4.1. Identifying Chemicals to Analyze in Air Samples

OEHHA also conducted literature research, outreach and consulted experts at federal agencies to identify chemicals for targeted analyses of air samples (see section 3.1 and 1.3.1). In addition, LBNL conducted preliminary laboratory measurements to determine chemical targets for the analysis of samples collected in the air during the statewide

field sampling efforts. This included “non-targeted analysis” to look for chemicals not previously known to be released from crumb rubber, or those suspected of being present. Non-targeted analyses were also performed in the following studies:

- Chamber emission studies where the vapors emitted were analyzed. This produced volatile organic chemicals (VOCs) for analysis by GC-MS and low molecular weight carbonyls for analysis by high performance liquid chromatography (HPLC).
- Direct thermal desorption into the GC-MS. This was used to provide mid-range VOCs for analysis.
- The crumb rubber solvent extracts (one-to-one parts acetone and hexane) used to identify chemicals for oral and dermal routes (see Section 3.2.1) were also used to identify the semi-volatile organic chemicals (SVOCs) in air.

These studies were conducted by LBNL using crumb rubber obtained from waste tire recycling facilities. The chamber and thermal desorption studies are described in in the Appendix D sections, as follows:

- D.3.1 Environmental Chamber and Emissions Testing of Crumb Rubber: Describes how the material was prepared for the emission studies, the material was tested in the chamber, the chamber air was sampled and analyzed for volatile organic chemicals and low molecular weight carbonyls, chamber emissions studies were conducted, how the samples were analyzed for VOCs and low molecular weight carbonyls.
- D.3.2 Direct Thermal Desorption Measurements of Crumb Rubber: Describes the desorption experiment
- D.3.3.4 Non-Targeted Analysis of GC-MS Data: Describes the steps taken to identify and confirm chemicals suspected from the GC-MS data stream.

This work identified chemical targets for analysis that fall in the following groups:

- VOCs: Samples were collected onto multibed glass thermal desorption tubes, hereto after referred to as “sorbent tubes”.
- Low molecular weight carbonyls (aldehydes and ketones): Samples were collected on silica gel cartridges coated with 2,4-dinitrophenylhydrazine (DNPH).
- SVOCs: Samples were collected on an apparatus called a sample train.

3.4.2. VOCs Analyzed

The Team selected the 20 potential tire-related VOCs for analyses based on information from literature review, described in Appendix A. Data obtained in the controlled emission chamber study and the direct thermal desorption measurements of crumb rubber discussed above supported the selection of these chemicals. LBNL also selected

40 common VOC air pollutants including 4 low molecular weight carbonyls (additional discussion on carbonyls in Section 3.4.3). The result is the Table 3-7 list of VOCs targeted for analyses.

Table 3-7. VOCs Targeted in the Analyses of Air Samples from 35 Synthetic Turf Fields

Targeted Chemical	CASRN
Azulene	275-51-4
Benzaldehyde*	100-52-7
Benzene	71-43-2
Benzene, 1,2,3-trimethyl-	526-73-8
Benzene, 1,2,4,5-tetramethyl-	95-93-2
Benzene, 1,2,4-trimethyl-	95-63-6
Benzene, 1,4-dichloro	106-46-7
Benzene, 1-chloro-4-(trifluoromethyl)-	98-56-6
Benzene, 1-ethyl-2,4-dimethyl-	874-41-9
Benzene, 2-ethyl-1,4-dimethyl-	1758-88-9
Benzene, n-butyl-	104-51-8
Benzothiazole	95-16-9
Benzothiazole, 2-mercapto	149-30-4
Benzothiazole, 2-methylthio-	615-22-5
Biphenyl	92-52-4
Butanal*	123-72-8
Butylated Hydroxytoluene	128-37-0
2-Butoxyethanol	111-76-2
3-Carene	13466-78-9
Cyclohexanone	108-94-1
Cyclopentasiloxane, decamethyl-	541-02-6
Cyclotetrasiloxane, octamethyl-	556-67-2
Cyclotrisiloxane, hexamethyl-	541-05-9
Decanal	112-31-2
Decane	124-18-5
D-Limonene	5989-27-5
Dodecane	112-40-3
Ethylbenzene	100-41-4
2-Ethyl-1-Hexanol	104-76-7
Formamide, N-(1,1-dimethylethyl)-	2425-74-3

Targeted Chemical	CASRN
Furan, 2-methyl	534-22-5
Heptanal	111-71-7
Heptane	142-82-5
Hexanal*	66-25-1
Hexane	110-54-3
Indan	496-11-7
m/p-Xylene	106-42-3
Mesitylene	108-67-8
Methacrolein*	78-85-3
5-Methyl 2-hexanone	110-12-3
Methyl Isobutyl Ketone	108-10-1
Naphthalene	91-20-3
Nonanal	124-19-6
Octanal	124-13-0
Octane	111-65-9
o-Xylene	95-47-6
p-Cymene	99-87-6
Phenol	108-95-2
a-Pinene	7785-70-8
Styrene	100-42-5
g-Terpinene	99-85-4
a-Terpineol	98-55-5
Tetrachloroethylene	127-18-4
Tetradecane	629-59-4
Texanol, TXIB (mono-isomer)	25265-77-4
Toluene	108-88-3
Trichloroethylene	79-01-6
Trichloromethane	67-66-3
TXIB "Kodaflex"	6846-50-0
Undecane	1120-21-4

* Also analyzed as a low molecular weight carbonyl (“ALD”, see next section)

The VOCs for analysis were collected in sorbent tube samples at each of the 35 selected fields. Upon arrival at the laboratory after shipping, LBNL analyzed the sorbent tube samples for VOCs by a GC-MS system—equipped with a ThermoDesorption (TD) injection system comprised of the following:

- a TD Autosampler (Model TDSA2; Gerstel),
- a TD oven (Model TDS3, Gerstel),
- a cryogenically cooled injection system (Model CIS4; Gerstel) and
- a GC (Series 6890 Plus; Agilent Technologies) connected to an electron impact MS (Series 5973; Agilent Technologies)—operated in total ion current mode with target and qualifier ions specified for each targeted chemical.

LBNL quantified the response for each analyte (normalized to response of the internal standard) using multipoint calibrations prepared from high purity reference standards. Details on the analysis and instrumentation are provided in Appendix Section D.2.1.

OEHHA used the data from the stratified VOC samples (Section 2.2.2) to evaluate whether chemicals were field related but did not employ the data to assess exposure levels for the purpose of estimating risk, since the sampling and analyses described in the paragraphs above are more accurate and better suited for that purpose.

Established procedures (USEPA, 2016) were used to determine MDL and LOQ for each VOC analyzed. The MDL value was selected to be the higher value between the MDL derived from the blank samples (MDL_b) and MDL derived from the spike sample (MDL_s). For VOCs and carbonyls, we used the analytical data of the travel blanks and low-level sample spikes. Appendix Section D.3.7.1.1 details the determination of limits of detection for analyses of the VOC air samples collected.

3.4.3. Low Molecular Weight Carbonyls

LBNL also analyzed 13 carbonyls (aldehydes and ketones) that are common air pollutants, shown in Table 3-8. The samples for this analysis were captured in 2,4-DNPH cartridges. Four of these chemicals were also analyzed in the VOC sample (sorbent tube), described above (Section 3.4.2).

Table 3-8. Aldehydes and Ketones Targeted in the Analyses of Air Samples (ALD cartridges) from 35 Selected Synthetic Turf

Targeted Chemical	CASRN
Acetaldehyde	75-07-0
Acetone	67-64-1
Acrolein	107-02-8
Benzaldehyde*	100-52-7
Butanal*	123-72-8
2-Butanone	78-93-3
Crotonaldehyde	123-73-9

Targeted Chemical	CASRN
Formaldehyde	50-00-0
Hexanal*	66-25-1
Methacrolein*	78-85-3
Propionaldehyde	123-38-6
m-Tolualdehyde	620-23-5
Valeraldehyde	110-62-3

* Also analyzed in the VOC sample (sorbent tube)

The Laboratory analyzed the samples for the targeted carbonyls by HPLC (1200 Series; Agilent Technologies) connected to an ultraviolet detector. LBNL quantified the targeted carbonyls by using multipoint calibration curves for the certified standard the hydrazone derivatives (CRM47651: Sigma-Aldrich). Appendix Section D.2.2 provides the details on the instrumentation and how the analysis was performed.

For a discussion of limits of detection, see Appendix Section D.3.7.2.

3.4.4. SVOCs analyzed (SVOC sample trains)

The Team compiled a list of 70 SVOCs detected in organic solvent extractions of crumb rubber designed to identify crumb rubber chemicals for the analysis in the study (see Section 3.2.1). These chemicals were the SVOCs targeted in the analyses of extracts from the SVOC sample trains. Table 3-9 lists the SVOCs analyzed.

Table 3-9. SVOCs Targeted in the Analyses of Air Samples from the 35 Selected Synthetic Turf Fields

Chemical	CASRN
Acenaphthylene	208-96-8
Aniline	62-53-3
Anthracene	120-12-7
Anthracene, 2-methyl-	613-12-7
Anthracene, 9,10-dimethyl	781-43-1
Anthracene, 9,10-diphenyl-	1499-10-1
Anthracene, 9-phenyl	602-55-1
Benz[a]anthracene	56-55-3
Benzo[a]pyrene	50-32-8
Benzo[b]fluoranthene	205-99-2
7H-Benzo[c]fluorene	205-12-9
Benzo[e]pyrene	192-97-2
Benzo[g,h,i]perylene	191-24-2
Benzo[k]fluoranthene	207-08-9
Benzothiazole, 2-phenyl-	883-93-2
2-Benzothiazolone	934-34-9
Benzyl butyl phthalate	85-68-7
2,5-Bis(1,1-dimethylethyl)-1,4-benzenediol	88-58-4

Chemical	CASRN
Bis(2,2,6,6-tetramethyl-4-piperidyl)sebacate	52829-07-9
Bis(2-Ethylhexyl)adipate	103-23-1
n-Caproic acid vinyl ester	3050-69-9
Chrysene	218-01-9
Coronene	191-07-1
Cyclohexanamine, N-cyclohexyl-	101-83-7
Cyclohexylamine	108-91-8
Cyclopenta[cd]pyrene	27208-37-3
Cyclohexyl isothiocyanate	1122-82-3
Demecolcine	477-30-5
Dibenz[a,h]anthracene	53-70-3
Dibenzothiophene	132-65-0
Dibutyl phthalate	84-74-2
Diethyl Phthalate	84-66-2
Diisobutyl Phthalate	84-69-5
Diisooctylphthalate	27554-26-3
N-(1,3-Dimethylbutyl)-N'-phenyl-1,4-benzenediamine	793-24-8
Dimethyl phthalate	131-11-3

Chemical	CASRN
Di-n-octyl phthalate	117-84-0
N,N'-diphenyl-1,4-benzenediamine	74-31-7
2,5-di-tert-Butyl-1,4-benzoquinone	2460-77-7
3,5-di-tert-Butyl-4-hydroxybenzaldehyde	1620-98-0
Fluoranthene	206-44-0
Fluorene	86-73-7
Hexadecane	544-76-3
2,5-Hexanedione	110-13-4
1-Hydroxypyrene	5315-79-7
Indeno[1,2,3-cd]pyrene	193-39-5
Limonene	138-86-3
Methyl stearate	112-61-8
Naphthalene, 1,2-dimethyl-	573-98-8
Naphthalene, 1,6-dimethyl-	575-43-9
Naphthalene, 1-methyl-	90-12-0
Naphthalene, 2-(bromomethyl)-	939-26-4
N,N-Dicyclohexylmethylamine	7560-83-0
Naphthalene, 2,3-dimethyl-	581-40-8

Chemical	CASRN
Naphthalene, 2-methyl	91-57-6
1-Octadecene	112-88-9
4-tert-Octylphenol	140-66-9
17-Pentatriacontene	6971-40-0
N-Phenylbenzamide	93-98-1
Phenanthrene	85-01-8
Phenanthrene, 1-methyl	832-69-9
Phenanthrene, 2-methyl-	2531-84-2
Phenanthrene, 3-methyl	832-71-3
Phenol, 2,4-bis(1-methyl-1-phenylethyl)-	2772-45-4
Phenol, 4-(1-phenylethyl)-	1988-89-2
Pyrene	129-00-0
Phthalimide	85-41-6
Pyridine, 2-(4-methylphenyl)-	4467-06-5
Resorcinol	108-46-3
5,9-Undecadien-2-one, 6,10-dimethyl-	689-67-8

To analyze the samples, LBNL first followed the procedures for SVOC sample extraction and preparation (Appendix Section D.4.1.2). An accelerated solvent extraction system and two solvent systems were used—PUF filters were extracted with 1:1 hexane and acetone, while the GF filters and XAD® were extracted with dichloromethane—under elevated temperature and pressure. LBNL analyzed the extracts using a HES-GC-MS system (Series 7890 Plus; Agilent Technologies) fitted with a programmed temperature vaporizer inlet (Model CIS4; Gerstel), a septum-less sampling head. The injection system contained a deactivated glass wool injection liner (P/N 23432; Restek) connected to a 30 meter by 0.25-mm diameter DB-UI8270D column with 2.5 micron film thickness (P/N 122-9732, Agilent) (Appendix Section D.2.4).

Established procedures (USEPA, 2016) were used to determine MDL and LOQ for each SVOC. The MDL value for each chemical was selected to be the higher value between the MDL derived from the blank samples (MDL_b) and MDL derived from the spike sample (MDL_s). Due to high background levels of SVOCs in the PUF filters of the sample trains, the MDL_b would have been higher than the MDL_s for the SVOCs. LBNL therefore used analytical data of the travel blanks to determine the MDL of SVOCs. Appendix Section D.3.7.2 details the determination of limits of detection for analyses of the SVOCs.

3.4.5. Particle Monitoring

The Team collected continuous particle data in air on and off the fields during the statewide field work (Phase 3). Instrument setups are described in Appendix Section D.1.2.5. These environmental particle monitoring data include:

- size resolved particle number concentration, size resolved particle mass

distribution,

- particulate matter sizes of or less than 2.5 micrometer in diameter ($PM_{2.5}$) mass concentration profiles,
- particle number concentrations (0.4 to 0.5 micrometer in diameter and 1 to 2.5 micrometer in diameter) at three different heights (18, 35 and 60 inches),
- particle number concentration for particle sizes 0.3, 0.4, 0.5, 0.7, 1, and 2.5 micrometer in diameters,

Overall, the results showed no difference in particle concentrations, particle size distribution between inactive field condition and active field condition, as well as between on-field and off-field locations for the 35 fields. Details of the particle data were presented in the 2018 SAP Meeting (OEHHA, 2018).

3.4.6. Results of Analyses of Air Samples

As provided in more detail in Section 2.3.2.3, the Team collected air samples as follows:

- a set of five hourly sequential VOC vapor integrated samples, at two locations on-field (Figure 2-1), one location off-field. This covered the first and fifth hour when conditions were static and the second, third, and fourth hours when there were vigorous on-field soccer drills.
- a three-hour ALD vapor integrated sample, at two locations on-field, under active field conditions.
- a three-hour high-volume SVOC integrated sample at one location on-field, under active field conditions, and one location off-field.

OEHHA followed the procedure in Appendix Section D.3.7 to validate the analytical data and calculated the chemicals in the air at on- or off-field locations of each field.

Table 3-10 summarizes the results for average air concentrations of the chemicals detected for the statewide field samples (Phase 3 Field Work). The results presented are based on the average air concentrations for the three-hour period under active field conditions. The tabulated mean is the arithmetic mean of the individual field average concentrations. The minimum and maximum values are also included in the table. These values were used to estimate to estimate average daily dose of the chemical via inhalation exposure on the fields in Chapter 5.

Unexpected incidents occurring during the Phase 3 Field Work included instrument failure, insufficient power supply at the field, power failure during sample collection, and loss of samples during shipment. This resulted in one or two fields having fewer samples than planned, with the exception of VOC vapor for which samples for all 35 fields were available. In reporting “detection frequency” in Table 3-10 the number of fields for which air samples for that chemical are available for analysis is given in parenthesis.

Table 3-10. Average Concentrations of Chemicals Detected in Air at the 35 Synthetic Turf Fields in California[a]

Chemical	CASRN	On-Field				Off-Field			
		Detection	Concentration nanograms per cubic meter			Detection	Concentration nanograms per cubic meter		
			Min	Mean	Max		Min	Mean	Max
1,4-Benzenediamine, N-(1,3-dimethylbutyl)-N'-phenyl-	793-24-8	26 (34)	0	3.7	15	19 (33)	0	4.2	16
17-Pentatriacontene	6971-40-0	2 (34)	0	0.73	17	1 (33)	0	0.5	17
1-Hexanol, 2-ethyl-	104-76-7	6 (35)	0	7.8	91	7 (34)	0	18	230
1-Octadecene	112-88-9	16 (34)	0	4.4	18	14 (33)	0	4.1	19
2,5-di-tert-Butyl-1,4-benzoquinone	2460-77-7	26 (34)	0	32	140	26 (33)	0	39	310
2,5-Hexanedione	110-13-4	5 (34)	0	27	260	3 (33)	0	35	640
2-Benzothiazolone	934-34-9	5 (34)	0	4.6	45	3 (33)	0	4.1	45
2-Butanone	78-93-3	30 (34)	0	570	1400	-	-	-	-
2-Butoxyethanol	111-76-2	1 (35)	0	4.9	170	1 (34)	0	4.7	160
3,5-di-tert-Butyl-4-hydroxybenzaldehyde	1620-98-0	8 (34)	0	17	110	3 (33)	0	11	190
3-Carene	13466-78-9	1 (35)	0	0.77	27	1 (34)	0	1.6	54
4-tert-Octylphenol	140-66-9	10 (34)	0	1.8	14	7 (33)	0	0.53	5.8
5,9-Undecadien-2-one, 6,10-dimethyl-	689-67-8	14 (34)	0	3.8	19	13 (33)	0	2.7	15
7H-Benzo[c]fluorene	205-12-9	13 (34)	0	0.054	0.36	6 (33)	0	0.031	0.33
Acenaphthylene	208-96-8	11 (34)	0	1	8.7	8 (33)	0	1.1	9.4
Acetaldehyde	75-07-0	34 (34)	260	2500	9600	-	-	-	-
Acetone	67-64-1	34 (34)	1600	20000	69000	-	-	-	
Aniline	62-53-3	10 (34)	0	6.5	44	8 (33)	0	7.2	60
Anthracene	120-12-7	12 (34)	0	0.33	2.4	4 (33)	0	0.2	2.8
Anthracene, 2-methyl-	613-12-7	15 (34)	0	0.085	0.42	11 (33)	0	0.052	0.37
Anthracene, 9,10-dimethyl	781-43-1	16 (34)	0	0.097	0.94	12 (33)	0	0.084	0.67
Anthracene, 9-phenyl	602-55-1	1 (34)	0	0.009	0.31	2 (33)	0	0.037	0.61
a-Pinene	7785-70-8	12 (35)	0	37	380	9 (34)	0	46	450
Benz[a]anthracene	56-55-3	1 (34)	0	0.0049	0.17	0 (33)	0	0	0
Benzaldehyde	100-52-7	15 (35)	0	89	540	14 (34)	0	97	580
Benzene	71-43-2	35 (35)	90	600	2500	34 (34)	180	640	2700
Benzene, 1,2,3-trimethyl-	526-73-8	6 (35)	0	13	210	6 (34)	0	17	160
Benzene, 1,2,4,5-tetramethyl-	95-93-2	5 (35)	0	2.5	27	5 (34)	0	3.2	41
Benzene, 1,2,4-trimethyl-	95-63-6	13 (35)	0	120	970	12 (34)	0	130	890
Benzene, 1,4-dichloro	106-46-7	7 (35)	0	19	120	6 (34)	0	17	120
Benzene, 1-chloro-4-(trifluoromethyl)-	98-56-6	34 (35)	0	570	2100	33 (34)	0	580	2000
Benzene, 1-ethyl-2,4-dimethyl-	874-41-9	7 (35)	0	5.3	71	7 (34)	0	6	52

Chemical	CASRN	On-Field				Off-Field			
		Detection	Concentration nanograms per cubic meter			Detection	Concentration nanograms per cubic meter		
			Min	Mean	Max		Min	Mean	Max
Benzene, 2-ethyl-1,4-dimethyl-	1758-88-9	12 (35)	0	7.5	68	11 (34)	0	8.4	77
Benzene, butyl-	104-51-8	2 (35)	0	2.6	73	3 (34)	0	4.3	73
Benzo[a]pyrene	50-32-8	28 (34)	0	1.1	4.7	24 (33)	0	1.4	9.9
Benzo[b]fluoranthene	205-99-2	2 (34)	0	0.025	0.42	3 (33)	0	0.038	0.42
Benzo[e]pyrene	192-97-2	6 (34)	0	0.019	0.13	6 (33)	0	0.027	0.26
Benzo[g,h,i]perylene	191-24-2	19 (34)	0	0.13	0.76	16 (33)	0	0.13	0.99
Benzo[k]fluoranthene	207-08-9	4 (34)	0	0.031	0.35	3 (33)	0	0.032	0.35
Benzothiazole	95-16-9	19 (35)	0	37	120	2 (34)	0	4.8	82
Benzothiazole, 2-phenyl-	883-93-2	27 (34)	0	2.9	17	15 (33)	0	0.43	1.8
Benzyl butyl phthalate	85-68-7	7 (34)	0	3.4	23	5 (33)	0	4.4	51
Bis(2-Ethylhexyl)adipate	103-23-1	1 (34)	0	22	730	2 (33)	0	17	280
Butanal	123-72-8	13 (35)	0	310	3800	12 (34)	0	280	3400
Chrysene	218-01-9	13 (34)	0	0.2	1.3	7 (33)	0	0.1	0.93
Coronene	191-07-1	10 (34)	0	0.085	0.73	7 (33)	0	0.068	0.7
Cyclohexanamine, N-cyclohexyl-	101-83-7	19 (34)	0	0.34	3.1	10 (33)	0	0.2	1.2
Cyclohexylamine	108-91-8	4 (34)	0	2.3	31	1 (33)	0	0.94	31
Cyclopenta[cd]pyrene	27208-37-3	28 (34)	0	0.073	0.41	22 (33)	0	0.064	0.26
Cyclopentasiloxane, decamethyl-	541-02-6	18 (35)	0	160	1300	14 (34)	0	150	1200
Cyclotetrasiloxane, octamethyl-	556-67-2	13 (35)	0	58	330	13 (34)	0	52	320
Cyclotrisiloxane, hexamethyl-	541-05-9	1 (35)	0	73	2600	3 (34)	0	77	1600
Decanal	112-31-2	7 (35)	0	28	550	1 (34)	0	17	580
Decane	124-18-5	11 (35)	0	54	310	12 (34)	0	60	350
Dibenz[a,h]anthracene	53-70-3	14 (34)	0	0.14	1.2	9 (33)	0	0.09	0.73
Dibenzothiophene	132-65-0	14 (34)	0	1.2	6.8	12 (33)	0	1.2	8.5
Dibutyl phthalate	84-74-2	7 (34)	0	380	4900	5 (33)	0	300	5800
Diethyl phthalate	84-66-2	1 (34)	0	2.6	89	2 (33)	0	11	180
Diisobutyl phthalate	84-69-5	15 (34)	0	14	150	14 (33)	0	15	91
Diisooctylphthalate	27554-26-3	9 (34)	0	49	950	6 (33)	0	15	81
Dimethyl phthalate	131-11-3	4 (34)	0	3.6	62	3 (33)	0	3.3	60
Di-n-octyl phthalate	117-84-0	5 (34)	0	0.096	1.1	3 (33)	0	0.099	1.1
D-Limonene	5989-27-5	4 (35)	0	7.7	67	5 (34)	0	9.9	67
Dodecane	112-40-3	4 (35)	0	6.7	120	3 (34)	0	8.7	120
Ethylbenzene	100-41-4	13 (35)	0	170	1200	13 (34)	0	180	1300
Fluoranthene	206-44-0	21 (34)	0	3.8	17	14 (33)	0	2.2	19
Fluorene	86-73-7	15 (34)	0	6	61	11 (33)	0	5	53
Formaldehyde	50-00-0	34 (34)	810	3800	16000	-	-	-	-

Chemical	CASRN	On-Field				Off-Field			
		Detection	Concentration nanograms per cubic meter			Detection	Concentration nanograms per cubic meter		
			Min	Mean	Max		Min	Mean	Max
Furan, 2-methyl	534-22-5	34 (35)	0	110	410	21 (34)	0	38	270
Heptanal	111-71-7	7 (35)	0	15	130	5 (34)	0	15	130
Heptane	142-82-5	20 (35)	0	230	1500	17 (34)	0	230	1700
Hexadecane	544-76-3	11 (34)	0	32	230	9 (33)	0	46	420
Hexanal	66-25-1	30 (35)	0	790	4000	27 (34)	0	870	5800
Hexane	110-54-3	26 (35)	0	670	8700	28 (34)	0	460	2000
Indan	496-11-7	12 (35)	0	14	110	12 (34)	0	13	110
Indeno[1,2,3-cd]pyrene	193-39-5	3 (34)	0	0.11	1.2	2 (33)	0	0.074	1.2
Limonene	138-86-3	14 (34)	0	29	160	10 (33)	0	22	240
m/p-Xylene	106-42-3	25 (35)	0	580	3500	24 (34)	0	610	3400
Mesitylene	108-67-8	15 (35)	0	28	230	13 (34)	0	28	200
Methacrolein	78-85-3	20(35)	0	76	430	16(34)	70	0	400
Methyl Isobutyl Ketone	108-10-1	5 (35)	0	16	180	1 (34)	0	3.6	120
Methyl stearate	112-61-8	10 (34)	0	5.5	44	8 (33)	0	5.5	44
m-Tolualdehyde	620-23-5	19 (34)	0	270	900	-	-	-	-
N,N-Dicyclohexylmethylamine	7560-83-0	18 (34)	0	0.33	2	12 (33)	0	0.35	1.8
Naphthalene	91-20-3	9 (35)	0	27	260	9 (34)	0	29	260
Naphthalene, 1,2-dimethyl-	573-98-8	4 (34)	0	0.37	3.6	6 (33)	0	0.78	7.6
Naphthalene, 1,6-dimethyl-	575-43-9	14 (34)	0	2.7	15	12 (33)	0	2.8	20
Naphthalene, 1-methyl-	90-12-0	15 (34)	0	22	150	12 (33)	0	22	120
Naphthalene, 2-(bromomethyl)-	939-26-4	11 (34)	0	0.74	2.5	8 (33)	0	0.77	7.8
Naphthalene, 2,3-dimethyl-	581-40-8	14 (34)	0	2	10	12 (33)	0	2.1	15
Naphthalene, 2-methyl-	91-57-6	10 (34)	0	33	320	12 (33)	0	35	190
n-Caproic acid vinyl ester	3050-69-9	1 (34)	0	6.8	230	3 (33)	0	13	300
Nonanal	124-19-6	2 (35)	0	7.8	140	0 (34)	0	0	0
N-Phenylbenzamide	93-98-1	6 (34)	0	9	55	4 (33)	0	8.9	130
Octanal	124-13-0	24 (35)	0	45	210	16 (34)	0	44	240
Octane	111-65-9	10 (35)	0	60	420	9 (34)	0	73	480
o-Xylene	95-47-6	13 (35)	0	190	1300	11 (34)	0	190	1400
p-Cymene	99-87-6	21 (35)	0	25	120	18 (34)	0	26	120
Phenanthrene	85-01-8	17 (34)	0	13	84	12 (33)	0	11	92
Phenanthrene, 1-methyl	832-69-9	17 (34)	0	0.82	3.4	13 (33)	0	0.49	3.4
Phenanthrene, 2-methyl-	2531-84-2	18 (34)	0	1.5	6.3	13 (33)	0	0.96	6.3
Phenanthrene, 3-methyl	832-71-3	18 (34)	0	1.8	7.5	13 (33)	0	1.1	7.7
Phenol	108-95-2	18 (35)	0	58	210	12 (34)	0	53	210
Phenol, 2,4-bis(1-methyl-1-phenylethyl)-	2772-45-4	2 (34)	0	0.018	0.3	0 (33)	0	0	0
Phenol, 4-(1-phenylethyl)-	1988-89-2	9 (34)	0	0.44	6.3	9 (33)	0	0.64	7

Chemical	CASRN	On-Field				Off-Field			
		Detection	Concentration nanograms per cubic meter			Detection	Concentration nanograms per cubic meter		
			Min	Mean	Max		Min	Mean	Max
Propionaldehyde	123-38-6	12 (34)	0	180	1800	-	-	-	-
Pyrene	129-00-0	20 (34)	0	3.2	14	14 (33)	0	1.6	10
Pyridine, 2-(4-methylphenyl)-	4467-06-5	2 (34)	0	0.035	1	1 (33)	0	0.0054	0.18
Resorcinol	108-46-3	18 (34)	0	19	120	18 (33)	0	32	260
Styrene	100-42-5	17 (35)	0	59	660	13 (34)	0	60	670
Tetrachloroethylene	127-18-4	7 (35)	0	48	420	7 (34)	0	49	420
Tetradecane	629-59-4	3 (35)	0	8.1	140	2 (34)	0	6.3	140
Texanol, TXIB (mono-isomer)	25265-77-4	15 (35)	0	100	1600	11 (34)	0	100	2300
Toluene	108-88-3	35 (35)	200	1400	7700	34 (34)	200	1400	7100
Trichloroethylene	79-01-6	12 (35)	0	9.7	94	11 (34)	0	9.8	84
Trichloromethane	67-66-3	10 (35)	0	38	350	7 (34)	0	37	230
TXIB "Kodaflex"	6846-50-0	1 (35)	0	2	69	2 (34)	0	4.1	69
Undecane	1120-21-4	5 (35)	0	13	130	7 (34)	0	18	160
Valeraldehyde	110-62-3	11 (34)	0	930	4600	-	-	-	-

[a] On-field and off-field: See Appendix Section D.4.2.3 additional statistics on measurements.
Detection: Number of fields with concentrations above method detection limit. Value in parenthesis: total number of fields tested.
Mean: Arithmetic mean of the individual fields average concentrations. Min: minimum of the individual field average concentrations; Max: maximum of the individual field average concentrations;
0: A value of 0 means the chemical is not detected or is detected below the method detection limit.

Overall, the study detected at **on-field** locations, 119 chemicals with levels at or above MDLs:

- 46 VOCs - out of 55 targeted
- 11 carbonyls (9 aldehydes and 2 ketones) – out of 13 targeted
- 62 SVOCs – out of 70 targeted

The 11 carbonyls were detected in the ALD samples with HPLC, and four of these were also detected in the GC-MS analysis of VOCs:

- Benzaldehyde (CASRN 100-52-7)
- Butanal (CASRN 123-72-8)
- Hexanal (CASRN 66-25-1)
- Methacrolein (CASRN 78-85-3)

For these four chemicals OEHHA chose the VOC/GC-MS results over the ALD/HPLC results to calculate the air concentrations because they provided more spatial and temporal information. The VOC samples were taken from two on- and one off-field locations in five hourly consecutive samples per location whereas the ALD sample was taken at one on-field location over a three-hour period.

For the **off-field** locations, 109 chemicals were detected in the air samples with levels at or above MDLs:

- 45 VOCs – out of 55 targeted
- 4 carbonyls (4 aldehydes) – out of 13 targeted
- 60 SVOCs – out of 70 targeted

Several chemicals previously reported as related to tires were detected in the air at on-field locations more frequently and at levels several times higher than off-field: benzothiazole, methyl isobutyl ketone, and 2-methyl furan. This indicates that synthetic turf field was probably the source of these chemicals.

18 chemicals were not detected in air samples collected at locations either on or off the field:

- Acrolein (CASRN 107-02-8)
- Azulene (CASRN 275-51-4)
- Biphenyl (CAS: 92-52-4)
- 2,5-bis(1,1-Dimethylethyl)1,4-benzenediol (CASRN 88-58-4)
- Bis(2,2,6,6-tetramethyl-4-piperidyl)sebacate (CASRN 52829-07-9)
- Butylated hydroxytoluene (CASRN 128-37-0)
- Crotonaldehyde (CASRN 123-73-9)
- Cyclohexanone (CASRN 108-94-1)
- Demecolcine (CASRN 477-30-5)
- N,N'-Diphenyl 1,4-benzenediamine (CASRN 74-31-7)
- 9,10-Diphenylanthracene (CASRN 1499-10-1)
- N-(1,1-Dimethylethyl)formamide (CASRN 2425-74-3)
- 1-Hydroxypyrene (CASRN 5315-79-7)
- 5-Methyl 2-hexanone (CASRN 110-12-3)
- 2-Methylthiobenzothiazole (CASRN 615-22-5)
- 2-Mercaptobenzothiazole (CASRN 149-30-4)
- gamma-Terpinene (CASRN 99-85-4)
- alpha-Terpineol (CASRN 98-55-5)

Three chemicals were present only in air at on-field locations, but each only on one or two fields:

- Benz[a]anthracene (CASRN 56-55-3, detected 1/34)
- Nonanal (CASRN 124-19-6, detected 2/35)
- 2,4-bis(1-methyl-1-phenylethyl)-phenol (CASRN 2772-45-4, detected 2/34)

This may imply synthetic turf field as a source of these chemicals. However, the low detection frequency introduces some uncertainty.

Thirty PAHs and PAH derivatives were detected in both the on- and off-field SVOC or VOC samples. Benz[a]anthracene was the only PAH that was detected on-field and not in an off-field SVOC sample, and the on-field detection was for only one field. Fourteen

of the 30 PAHs measured had slightly elevated mean concentrations for on-field SVOC samples compared to off-field samples, and 25 were detected more frequently on-field compared to off-field, while 16 PAHs had the same or lower mean concentrations on-field compared to off-field. Taken together, these observations might suggest environmental sources besides synthetic turf may also contribute to the on-field levels of PAHs measured.

However, the off-field sample locations were in relatively close proximity to the on-field sample locations, and wind direction changed over time, so off-field samples were not always upwind of the field. Thus, the off-field samples may also be considered to represent a “near field” exposure with ultimately some of the exposure emanating from the crumb rubber in the synthetic turf field. For these reasons, the off-field samples are not considered to represent a true background that could be used to distinguish field-related chemicals from other environmental sources such as industrial facilities and motor vehicles.

3.5. Distinguishing Field-Related Chemicals from Non-Field Related Chemicals

This section discusses our approach to identifying the chemicals detected as synthetic field related, or non-field related and assumed to come from other environmental sources like traffic.

3.5.1. Chemicals Detected in Biofluid Extracts and SVOCs in Air Samples

The targeted chemical lists for the analysis of the biofluid and metal crumb rubber extracts and the SVOC air samples were developed from non-targeted analyses of solvent or acid extractions of crumb rubber itself. We attribute the concentrations measured in the statewide field sampling (Phase 3) to synthetic turf, and not to other environmental sources like industrial facilities and traffic.

3.5.2. VOCs in Air Samples

On the sampling tower located behind the monitoring unit on each field, we collected four VOC samples at four different vertical levels – at 0.1, 0.5, 1.07 and 1.63 meters above the field surface. We call these the stratified VOC samples. For details on the instrumentation and sample collection protocols, see Section 2.2.2, and Appendix Sections D.1.2.5 and D.2.1.

The stratified samples enabled us to examine the vertical concentration profile of VOCs in the air (Figure 3-2). We used these to distinguish field related VOCs from non-field related VOCs. For field-related VOCs, we expect the air concentrations to be highest closer to the field surface. As the VOCs are released from the crumb in the synthetic turf they enter the air and become less concentrated as they rise from the surface and mix with increasing volumes of air with increasing height.

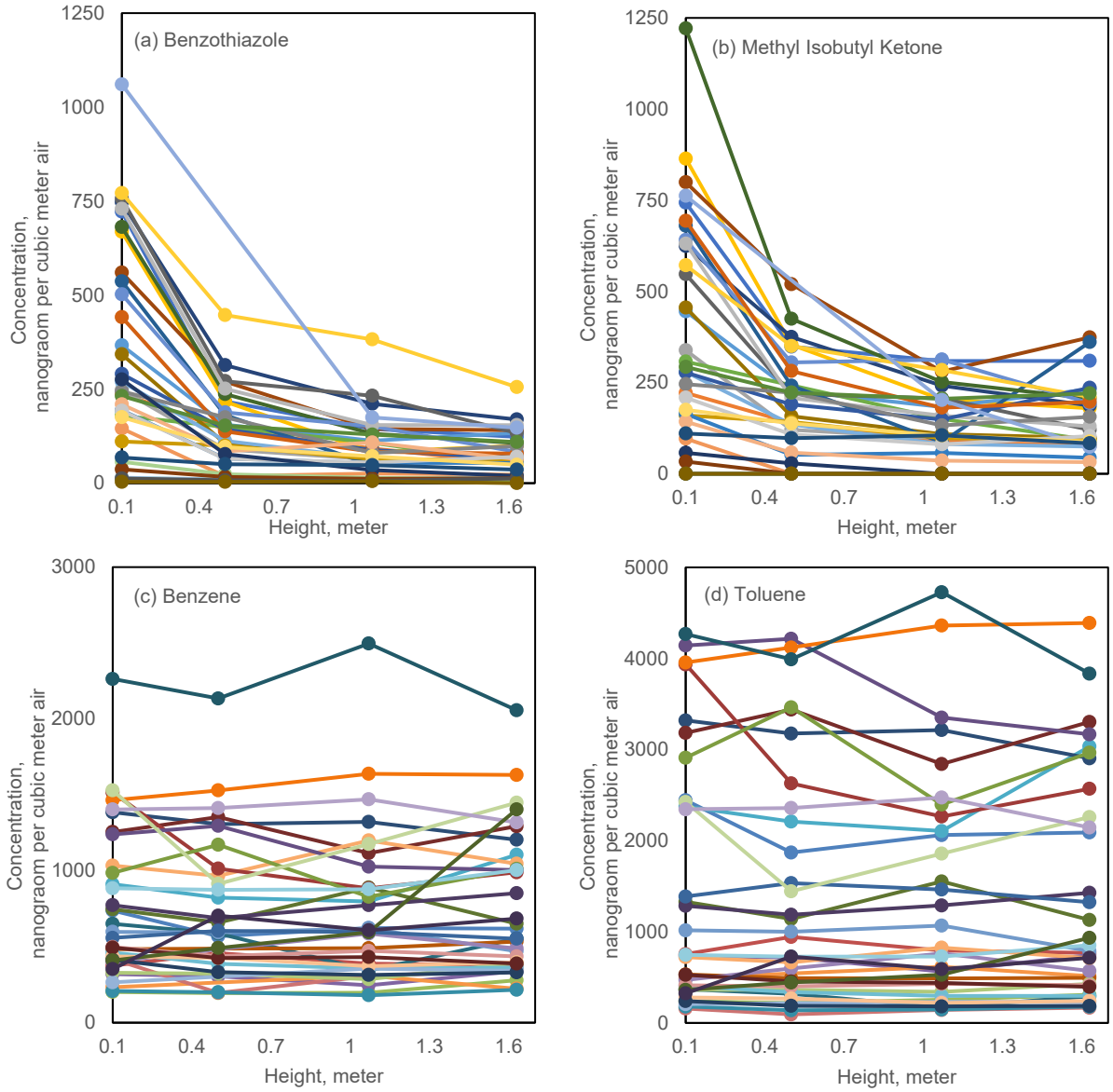

Figure 3-2. Vertical Concentrations of Selected VOCs for 35 Synthetic Turf Fields in California.
Field-Related: (a) Benzothiazole and (b) Methyl Isobutyl Ketone
Non-Field Related: (c) Benzene and (d) Toluene

OEHHA used the chemical concentration data from analysis of stratified VOC samples

to examine the vertical concentration profile of the 50 VOCs. Through statistical analyses we evaluated whether higher concentrations were detected at lower sampling positions, closer to field surface.

Briefly, we employed a linear mixed-effect model to analyze the air concentrations of each VOC in the tower samples using RStudio version 3.6.0 (RStudio Team, 2018) equipped with the lme4 package (Bates *et al.*, 2015). VOCs with concentrations that significantly decreased from low to high positions on the sampling tower (i.e., an inverted concentration gradient) were determined to be field related, with the synthetic field as the predominant source. A statistical significance level of $p < 0.05$ for the linear mixed-effect model with position number ANOVA was used, VOCs lacking this inverted concentration gradient were determined to be non-field related chemicals. Details of the analysis and the results for the 50 chemicals are provided in Appendix Section D.4.3.

Based on results of the statistical analysis, OEHHA designated 29 VOCs as field-related (see List 3-1, for simplicity, we assumed synthetic turf fields as the sources of these chemicals in air on or off the fields):

List 3-1: Field-Related VOCs

3-Carene
alpha-Pinene
Benzaldehyde
Benzene, 1,2,3-trimethyl-
Benzene, 1,2,4,5-tetramethyl-
Benzene, 1,2,4-trimethyl-
Benzene, 1-ethyl-2,4-dimethyl-
Benzene, 2-ethyl-1,4-dimethyl-
Benzene, butyl-
Benzothiazole
Butanal
Cyclopentasiloxane, decamethyl-
Cyclotetrasiloxane, octamethyl-
Decane
D-Limonene
Dodecane
Furan, 2-methyl
Heptanal
Indan
Mesitylene
Methacrolein
Methyl Isobutyl Ketone
Naphthalene
Octanal
Octane
p-Cymene
Styrene
TXIB "Kodaflex"
Undecane

Twenty-one VOCs were determined to be non-field-related (see List 3-2, assumed environmental or other sources of these chemicals detected in air on or off fields):

List 3-2: Non-Field-Related VOCs

1-Hexanol, 2-ethyl-
2-Butoxyethanol
Benzene
Benzene, 1,4-dichloro
Benzene, 1-chloro-4-(trifluoromethyl)-
Cyclotrisiloxane, hexamethyl-
Decanal
Ethylbenzene
Heptane
Hexanal
Hexane
m/p-Xylene

Nonanal
o-Xylene
Phenol
Tetrachloroethylene
Trichloromethane
Tetradecane
Texanol, TXIB (mono-isomer)
Toluene
Trichloroethylene

For each of the field-related VOCs, we cannot determine with reasonable confidence the amounts contributed from environmental sources versus those from field-related sources. Recent studies provide evidence of the presence of tire-related chemicals in the environment (Johannessen *et al.*, 2022; Tian *et al.*, 2021).

3.5.3. Low Molecular Weight Carbonyls

Thirteen carbonyls were analyzed in 2,4-DNPH cartridge sampling of the statewide fields (Phase 3).

Non-Detected Carbonyls. Two aldehydes, acrolein and crotonaldehyde, were not detected in any field samples and a determination of whether these chemicals are field related is therefore unnecessary.

Carbonyls also analyzed in VOC stratified samples. Four aldehydes were analyzed in tower samples. Based on the linear mixed-effects model analysis of the tower data discussed above, OEHHA designated benzaldehyde, butanal, and methacrolein as field-related chemicals, and hexanal as non-field related (see discussion Section 3.5.2).

Other carbonyls analyzed in 2,4-DNPH cartridge samples. South Coast Air Quality Management District (South Coast AQMD) monitored seven of the carbonyls in its Multiple Air Toxics Exposure Study (MATES). The data collected are robust and can be used as a point of comparison with concentration data from our study collected from fields in the District to inform whether the carbonyls should be treated as field-related or non-field related.

The South Coast AQMD has been monitoring environmental levels of air toxics for more than three decades. Their latest MATES study, MATES V (South Coast AQMD, 2021a; South Coast AQMD, 2021b), included monitoring of the following seven carbonyls that are included in this study: 2-butanone; acetaldehyde, acetone, acrolein, benzaldehyde, formaldehyde, and propionaldehyde. Benzaldehyde was designated as a field-related chemical based on statistical analysis of results from the tower samples. Acrolein was not detected in our study.

MATES V used 24-hour integrated samples that were collected once every six (6) days for one (1) year from May 1, 2018, to April 30, 2019, at 10 fixed air sampling stations covering the Greater Los Angeles Area. Seven air stations collected carbonyl samples from the air using DNPH cartridges and analyzed the samples with HPLC. The carbonyls monitoring data from MATES V can be used to characterize background exposures for the six carbonyls detected in our study based on the following considerations:

- MATES V applied the same carbonyl sampling and analytical methods as our study.
- MATES V is a comprehensive environmental monitoring study. The program has a long history of collecting periodic monitoring data of air toxics in the air within the district. Seven of the ten fixed air sampling stations provided validated and continual monitoring data of the carbonyls in air for a whole year.
- MATES covered similar geographical area as the Climate Region 1 and the southern part of the Climate Region 3 of our study. OEHHA detected higher levels of carbonyls in ALD samples collected from fields located in these areas compared to the other Climate Regions. In fact, the four highest concentrations (six percent of total number of samples) for each of the four carbonyls (2-butanone, acetaldehyde, formaldehyde, and propionaldehyde) were collected from fields located within the MATES V monitored area.
- MATES V monitoring occurred between mid-2018 and mid-2019, while our field sample collections were performed August to December 2017 for Climate Region 1, which is in the MATES region. Considering the close time proximity between the sampling periods, the air monitoring data from MATES V provided suitable data to understand the ambient levels of carbonyls in the air for our study.

OEHHA compared the measured air concentrations for six carbonyls in the ALD samples collected in the Climate Region 1 of our study to the monitoring data collected in MATES V (Table 3-11). Based on the regional mean concentrations and maximum concentrations of each carbonyl in the OEHHA study and MATES V for each carbonyl, we identified acetone, benzaldehyde, and propionaldehyde as field-related chemicals, but designated 2-butanone, acetaldehyde, and formaldehyde as non-field-related (details in Table 3-11). The MATES data support the determination of benzaldehyde as a field related chemical based on the tower samples in our study discussed above.

Table 3-11. Concentrations of Six Selected Carbonyls Detected in Climate Region 1 of the Synthetic Turf Study versus MATES V

Chemical	Concentration (nanograms per cubic meter) mean (maximum)		Field-Related?	Rationale
	Turf Study[a]	MATES V[b]		
Acetone	19000 (62000)	5300 (39000)	Yes	Turf mean and maximum are higher
Propionaldehyde	390 (3600)	410 (1500)	Yes	Turf mean similar to MATES V mean but Turf maximum is 2 X higher than MATES V
2-Butanone	750 (1400)	570 (3600)	No	turf mean slightly higher than MATES V, Turf maximum lower than MATES
Acetaldehyde	2700 (5100)	2600 (13000)	No	Turf mean similar to MATES V mean but Turf maximum is lower than MATES V
Benzaldehyde[c]	730 (4600)	260 (2500)	Yes	Turf mean and maximum concentrations higher than MATES V.

Chemical	Concentration (nanograms per cubic meter) mean (maximum)		Field-Related?	Rationale
	Turf Study[a]	MATES V[b]		
Formaldehyde	3900 (6600)	3600 (57000)	No	Turf mean similar to MATES V mean, but turf maximum is lower than MATES maximum.

[a] Mean concentration of individual field average concentrations of the chemical detected in ALD samples collected in climate region 1 of the OEHHA Study.
[b] Mean concentration of a carbonyl is the mean of the 7 individual station average concentrations of the chemical (Table IV-6 in Appendix IV SCAQMD, 2021). Concentration (ng per cubic meter) = molecular weight of a carbonyl (g per mole) × concentration (part per billion) ÷ 24.45 cubic meters per mole × 1000 ng per µg.
[c] Benzaldehyde is also designated as field-related based statistical analysis of vertical concentration profile (see List 3-1, and Appendix D.4.3).

To summarize seven (7) carbonyls were determined to be field-related (see List 3-3).

List 3-3: Field-Related Carbonyls

Acetone
Benzaldehyde
Butanal
m-Tolualdehyde
Methacrolein
Propionaldehyde
Valeraldehyde

Four ALDs were determined to be non-field related (see List 3-4).

List 3-4: Non-Field-Related Carbonyls

2-Butanone
Acetaldehyde
Formaldehyde
Hexanal

3.5.4. Field Related Chemical Determinations

As discussed above, OEHHA applied several strategies to differentiate field-related from non-field-related chemicals. All chemicals, including metals, metalloids, and organic chemicals of low volatility that were found in extracts of crumb rubber using targeted or non-targeted chemical analyses are considered to be field related. Since chemicals targeted in SVOC analysis were identified from non-targeted analyses of solvent extracts of crumb rubber, all SVOCs detected in the air are also considered field-related.

Considering environmental sources, including traffic related, for some of the VOCs and selected carbonyls, OEHHA analyzed their vertical concentration profiles to evaluate whether they should be considered field-related. Low molecular weight carbonyls (e.g., formaldehyde and acetaldehyde), from various environmental and anthropogenic sources, are commonly present in ambient air. OEHHA compared the concentrations of these carbonyls to findings from a well-established air monitoring program (MATES V) conducted by the South Coast AQMD to evaluate the field-related carbonyls in the air. Table 3-12 summarizes these methods and results of these determinations.

Table 3-12. Determination of Field-Related Chemical – Approach, Methods, Result

Chemical Class	Data Source for Determining if Field Related	Field related chemical list
Metals and Metalloids in Crumb Rubber	Assumed to be "field-related"; Chemicals identified from targeted analysis of crumb rubber extracts	Table 3-5
Organic chemicals in Crumb Rubber	Assumed to be "field-related"; Chemicals selected for analysis from non-targeted analysis of crumb rubber extracts	Table 3-1
VOCs in Air	Assumed to be field related if concentrations decreased with increasing vertical height observed for stratified on-field tower data	List 3-1 and List 3-2
Aldehydes and Ketones in Air	• 4 chemicals: Stratified on-field tower data for 4 tested in VOC samples. (3 assumed field related). • 6 chemicals: MATES V (3 assumed field-related) • 2 chemicals: Assumed to be "field-related" since no tower or MATES data available • 2 chemicals not detected	List 3-3 and List 3-4
SVOCs in Air	Assumed to be "field-related"; Chemicals identified from non-targeted analysis of crumb rubber extracts	Table 3-9

3.6. Confirmation of Chemical Identity

OEHHA tentatively identified over 400 organic chemicals in the combined targeted and non-targeted analyses of air and crumb rubber samples. The identities of a total of 179 organic chemicals were confirmed using reference standards by matching the chromatographic (GC retention time) and spectral (MS fragmentation pattern) data (Appendix D.3.6.1, Table D-14). Of these, 30 chemicals were not included in the targeted lists for sample analyses due to limitations in the availability of toxicity data or data showing low toxicity.

The tentative identifications for 260 organic chemicals were not confirmed due to several limitations:

- 79 chemicals (Appendix D.3.6.2, Table D-15), did not have high purity reference standards for a variety of reasons including their unavailability within a reasonable timeline and cost;
- 14 chemicals were only detected in the blank samples (Appendix D.3.6.3, Table D-16);
- 45 chemicals (Appendix D.3.6.4, Table D-17; Appendix D.3.6.5, Table D-18) had available data showing low order of toxicity or that the chemicals are relatively non-toxic such as those commonly found in food or plants (see Chapter 4 for details), or had no toxicity data available; and
- 122 chemicals (Appendix D.3.6.6, Table D-19) could not be confirmed due to limitations of instrument sensitivity and peak resolution among many coeluting chemicals.

3.7. Analysis of Environmental Data

Environmental data were collected on the fields during the study. These data were collected for one hour before any field activity, for three hours during field activity, and for one hour following field activity. The fields studied were distributed throughout California and placed into five climatic regions, as described in Section 2.3: Region 1: Southern Coastal Areas; Region 2: Northern and Central Coastal Areas; Region 3: Southern California Interior Valleys; Region 4: Southern California High and Low Deserts; and Region 5: Mountainous Area. These regions were reduced to four regions when Region 4 and Region 5 were combined into Region 4/5 because of the low number of fields in these regions. The fields were studied from June through December 2017, and divided based on age, with newer fields less than 9 years of age and older fields 9 years to about 14 years of age.

3.7.1. Temperature

Appendix sections D.1.2, D.5.2 and D.5.3 and describe the setup and collection of temperature data during sampling events. Briefly, temperature was monitored for five hours (one hour, for three hours during, and for one hour following field activity) on and off the field. Temperature data were collected at heights of 8, 24, 45, 50, and 65 inches above the field surface. Temperature probes were used to monitor the temperature of deep and shallow crumb rubber for the five-hour sampling period on and off the field. Data were continuously collected and logged every minute at each height and then averaged over the five-hour study period for each height.

The full analysis can be found in Appendix sections D.5.2 and D.5.3. Regardless of location (region) and age of fields, measured air temperatures on the field generally decreased as the height of the measurement increased. Temperature over the fields generally ranged from around 70 °F to almost 100 °F, with the full range of temperatures spanning from below 40 °F to a high of almost 110 °F. No differences in the measured temperature between old and new fields could be determined.

Higher surface temperatures were observed as the ambient temperature increased, with higher surface temperatures observed in the warmer sampling months. The maximum surface temperature was observed at midday for all fields. At the time the maximum surface temperature occurred, it was at least 20 degrees higher than ambient temperature observed at the same time for most of the fields. While ambient temperatures were similar on- and off-field, the off-field surface temperatures (on surfaces including grass, concrete, and dirt) were approximately 20 degrees lower than on-field surface temperatures. No significant differences in the average or maximum surface temperatures were observed based on field region (with the exception of Region 4/5 which had a sampling size of 2 fields) or field age alone.

Average temperatures at the deep, shallow and surface levels on the fields in the four regions studied followed a similar pattern of the deeper the probe, the cooler the

temperature. In general, surface temperatures were the hottest and were more than 20 degrees higher than ambient temperatures. The highest surface temperature measured on a single field was 151 °F.

3.7.2. Ozone

Ozone occurs naturally in the stratosphere above the earth but is also formed troposphere near the ground surface from the photochemical reaction between VOCs and nitrogen oxides. It has been known to affect the aging and degradation of crumb rubber on synthetic turf fields. OEHHA measured ozone on- and off-field with Ozone Dual Beam Monitors and sun light intensity on-field as solar energy in watts per square meter (W/m^2). The dataset and results of the analysis can be found in Appendix section D.5.4. Ozone values were lowest in the morning and tended to peak around midday. Most of the measured concentrations were within the California's ambient ozone air standard of 90 ppb for a 1-hour exposure or the California and the National ambient ozone air standard of 70 ppb for an 8-hour exposure. Only three fields exceeded the 8-hour ozone standard with the highest measured concentration at 87.0 ppb, and these were in areas of the state with higher ambient ozone concentrations.

Our data analysis show ozone levels increasing with light intensity. This suggests that the ozone concentrations measured are related to photochemical reactions to create ozone. The observed high variability in ozone values suggests there are other factors contributing to the formation of ozone, such as the levels of VOCs and oxides of nitrogen that were present in the atmosphere.

3.7.3. Particles

$PM_{2.5}$ was collected on- and off-field. More details can be found in Appendix section D.5.5. Due to several samples being compromised because at least one of the three filters used on each field did not provide useable information, only $PM_{2.5}$ levels from 19 fields were useable and the results of our analysis are uncertain. The calculated average on- and off-field $PM_{2.5}$ concentrations, in micrograms per cubic meter of air, were 13.4 and 14.1 micrograms per cubic meter of air respectively. When the off-field filter $PM_{2.5}$ weight was first subtracted from the on-field $PM_{2.5}$ weight, the average difference seen for the 19 fields was -0.63 micrograms per cubic meter. Based on these results, OEHHA concluded that activity on the fields did not increase $PM_{2.5}$ concentrations.

3.8. References

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Chapter 4. Toxicity Evaluation and Criteria

4.1. Introduction

This Chapter describes how the toxicity of chemicals is evaluated in order to determine if exposure to the chemicals would result in health concerns. The toxicity criterion provide a numeric representation of toxicity, and in this chapter they are provided for most of the detected chemicals in samples of air and crumb rubber. They are presented in summary tables in this chapter. Detailed information about the values and their sources is provided in Appendix E. OEHHA applied these toxicity criteria to assess human health hazards from exposures to chemicals at synthetic turf fields for the OEHHA Synthetic Turf Study (the study).

4.1.1. What is Toxicity?

Toxicity is defined as the degree to which a chemical or mixture of chemicals can impair function or cause damage to a tissue or organ. Toxicity information for a chemical comes from the following sources:

- Human studies: Epidemiological studies of the adverse health effects (for example, in the general population or workers), case reports, and controlled human exposure studies.
- In vivo animal studies: Toxicity studies conducted in laboratory animals (for example, rat and mouse).
- In vitro studies: Toxicity studies using tissues, cells or cell components from animals or humans, as well as studies in yeast, bacteria, and plant cell cultures.

The type of toxicity, or hazard traits, associated with the exposure to a chemical, can be non-cancerous effects to specific organs such as the liver or kidneys, or to systems such as the developmental and/or reproductive systems. They may also be cancerous resulting in tumors in one or more organs, or systemic cancers such as leukemia.

The extent the toxicant causes adverse health effects depends on the chemical's inherent toxicity and how much it is taken up into the body. Factors determining intake include:

- The concentration of the chemical in, for example, the air or crumb rubber.
- The amount of chemicals absorbed into the body, for example, through inhalation of air, or through the gut for ingested crumb rubber.
- The occurrence and exposure duration, for example, acute one-hour, one-day, a few times a month, or daily for a lifetime.

For instance, a particular chemical can be a respiratory irritant after inhalation of a high concentration in the air for a few hours. The same chemical may also pose a significant cancer risk through inhalation, at much lower concentrations in the air after many years of exposure. Among the many possible adverse health effects a particular chemical may

have, human health risk assessment typically focuses on the most sensitive health effects, which are effects that are caused at the lowest exposure levels. Protecting the public health from sensitive health effects also protects them from effects which may occur at higher levels.

4.1.2. What is a Toxicity Criterion?

A toxicity criterion (TC) is a numerical value which quantitatively characterizes the potential for a chemical to cause toxicity in humans for a specific exposure route and duration. In order to facilitate evaluation of adverse health effects posed by chemicals, toxicity criteria are developed by OEHHA, U.S. Environmental Protection Agency (USEPA) and other governmental agencies for their various programs and mandates.

The criteria are broadly grouped separately into criteria for non-cancer and cancer effects, mainly because of differences in the underlying methods to develop and apply the criteria in risk assessment.

For non-cancer effects, a toxicity criterion is the concentration in the air, intake amount, or dose, for a specified exposure route and duration, which is likely to be without an appreciable hazard of deleterious effects to humans, including sensitive subgroups. The assumption is that there is a dose below which the effects are unlikely to occur. An example of a non-cancer toxicity criterion is the exposure dose which does not cause a significant reduction in bodyweight.

Non-cancer toxicity criteria are derived for different exposures routes:

- Criteria for inhalation (TC_{inh}) exposures: These are typically expressed as concentrations in the air (e.g., parts per million in air, ppm; microgram of chemical per cubic meter of air, µg per cubic meter).
- Criteria for oral (TC_{oral}) or dermal (TC_{der}) exposures: These are typically expressed as doses (e.g., as milligram of chemical per kilogram of bodyweight per day, mg per kg per day).

For cancer effects, the criteria can be expressed as a cancer slope factor, or CSF. This is an estimate of increase in cancer risk per unit increase in dose. It reflects the potency of a chemical to cause cancer after a lifetime exposure. Inhalation cancer potencies are also sometimes expressed as a dose or concentration associated with a specific level of risk to the population. The typical assumption in cancer risk estimation is that any level of exposure can result in an additional risk of developing cancer above the background risk of cancer.

Estimated cancer risks ranging from one excess cancer in ten thousand people to one excess cancer in one million people are often used as a reference point in determining what is considered an acceptable exposure level to a cancer-causing chemical. For this study, a risk of one cancer in a million, above the background level of risk, is used as a reference point.

4.2. Toxicity Criteria Compilation

OEHHA has developed work flows to compile and select the most appropriate toxicity criterion for each detected chemical and exposure scenario for the study. A generic workflow is shown in Figure 4-1.

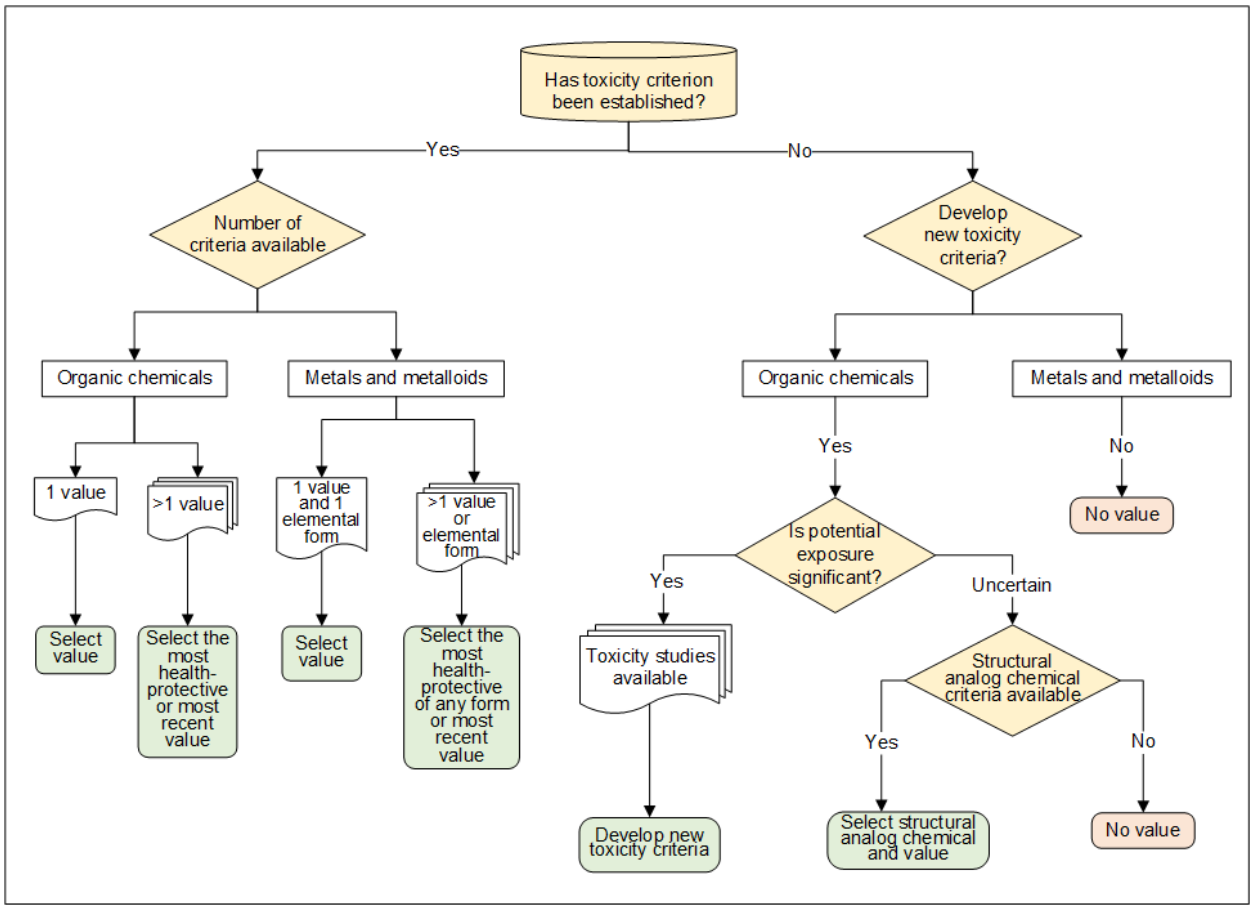


Figure 4-1. Generic Work Flow for Compilation of Toxicity Criteria for the Synthetic Turf Study Chemicals.

The key steps in the workflow are: (1) determine if a toxicity criterion has been established for a relevant chemical, (2) if yes, select the most appropriate value, and (3) if not, do one of three options - derive a new criterion de novo from toxicity studies, use a criterion from an analog chemical, or decline to use a value for the chemical.

Specific toxicity criteria for the following scenarios are needed:

- Inhalation exposures to organic chemicals: non-cancer effects from acute one-hour, one-day, and chronic exposure durations, and cancer from lifetime exposure. These are needed for chemicals detected in samples collected from the air.
- Oral (ingestion) or dermal exposures to organic chemicals: non-cancer effects from one-day and chronic exposures and cancer from lifetime exposure. These

are needed for chemicals detected in artificial gastrointestinal (GI) fluid or artificial sweat extracts of crumb rubber samples collected from fields.

- Oral (ingestion) exposure to metals and metalloids: non-cancer effects from one-day and chronic oral exposures and cancer from lifetime oral exposure. These are needed for metals and metalloids detected in GI acid extracts of crumb rubber samples.

The first step common to all these cases is to survey the four sources of published toxicity criteria:

- OEHHA Chemical Database,
- USEPA Integrated Risk Information System (IRIS),
- USEPA Superfund Provisional Peer-Reviewed Toxicity Value (PPRTV) Program, and
- Toxicological Profiles from Agency for Toxic Substances and Disease Registry (ATSDR).

These sources are used because the toxicity criteria they contain have been established after a comprehensive review of available human and animal toxicity data, relevant *in vitro* testing results, and related information such as absorption, distribution, metabolism, and excretion. In addition, they have undergone extensive internal and external peer reviews and are generally of high quality.

Non-cancer toxicity criteria include:

- reference exposure levels (RELs) or acceptable daily doses (ADDs) by OEHHA,
- reference doses (RfDs) or reference concentrations (RfCs) by USEPA, and
- minimal risk levels (MRLs) by ATSDR.

Cancer toxicity criteria are expressed as cancer slope factors (CSFs), oral slope factors or inhalation unit risk values (IURs).

In this study, CSFs are compiled only for carcinogens classified:

- by the International Agency for Research on Cancer (IARC) in as known (Groups 1), probably (Group 2A), or possibly (Group 2B) carcinogenic to humans,
- by USEPA as known or likely to be carcinogenic to humans, or
- for the cancer endpoint on the California Proposition 65 maintained by OEHHA.

OEHHA developed approaches to select the most appropriate established values for those chemicals that have multiple values and to develop screening toxicity criteria for those chemicals that do not have established values.

For chemicals which have not been identified by IARC, USEPA, or OEHHA as carcinogens, but belong to chemical classes with well-known carcinogens, such as the polycyclic aromatic hydrocarbons (PAHs), OEHHA investigated their potential

carcinogenicity using cancer prediction models within the Virtual Models for Property Evaluation of Chemicals within a Global Architecture (VEGA). The models compared the structure of each chemical of concern with a library of known carcinogenic structure fragments. VEGA model predictions for selected chemicals are presented in Appendix E.

4.2.1. Chemicals with Established Toxicity Criteria

Among the established toxicity criteria of chemicals, there are two characteristics to consider: whether the values are chemical specific and the number of sources with established values.

4.2.1.1. Types of Established Toxicity Criteria

There are two main types of toxicity criteria: chemical-specific and chemical-equivalent. Chemical-specific criteria are those developed using toxicity data for the specified chemical. This is the most common type. Some toxicity criteria are developed for a chemical in the mixture that is assumed to apply to other chemicals in the mixture, for a mixture that is assumed to apply to the chemicals in the mixture, or by using a criterion for a chemical with a similar structure (analogs). We call these types of toxicity criteria "chemical-equivalent".

One example of a chemical equivalent toxicity criterion is the USEPA single chronic inhalation toxicity criterion for the trimethylbenzenes (TMBs), which covers the 1,2,4-, 1,3,5-, and 1,2,3-TMB isomers (USEPA, 2016). These chemicals typically occur as mixtures and the individual isomers are observed to have similar toxicity for the sensitive endpoint, neurotoxicity. EPA elected therefore to assign the same criterion to each of the three isomers.

A different, chemical-equivalent, approach is used for the PAHs. PAHs are structurally related chemicals and are hydrocarbons consisting of multiple conjugated aromatic ring structures. Many PAHs have been found to be carcinogens in studies in animals and one PAH, benzo(a)pyrene (BaP), has been identified as "carcinogenic to humans" by IARC. The carcinogenic potencies for several PAHs were derived from that for BaP. BaP is used as an index chemical for PAHs because it has a relatively large cancer bioassay database. While many PAHs have sufficient toxicity information to identify them as carcinogenic, data on dose-response relationships are limited. Using comparative toxicity and carcinogenicity data, the relative potencies of these PAHs to that of BaP can be determined and expressed numerically as potency equivalent factors (PEFs). For cancer endpoints, the CSFs of these PAHs are then calculated as the product of their respective PEFs and the CSF of BaP. On that basis, OEHHA has developed human CSFs for several PAHs (OEHHA, 2004; OEHHA, 2015).

For metals and metalloids in this study, the toxicity criteria for any oxidation state (referred to as "form") were compiled and the value for the metal or metalloid was set at the most toxic form for the purpose of screening for toxicity concerns. The form of the

metals or metalloids detected in acid extracts of crumb rubber were not examined in this study (see Section 3.3.1), but had a toxicity concern been seen, further follow up would have been undertaken.

4.2.1.2. Selection of Toxicity Criteria from Multiple Sources

For any particular chemical, toxicity criteria are often available from only one source; these values were adopted for this study after a review of the supporting documentation and a determination that the value should be used.

Some chemicals have established toxicity criteria from multiple sources; they are mainly common environmental contaminants. When there are multiple sources, the values can differ because of differences in the data availability, approaches used in hazard identification, dose-response assessment, data extrapolation, or methodology to address uncertainty. In the case of metals or metalloids, the difference can in part be due to the different forms of the element encountered in human studies or administered to laboratory animals in toxicity studies.

OEHHA's selection of toxicity criteria considered the following:

- Magnitude of the value: The lowest non-cancer toxicity criterion and highest CSF represent the most health protective values.
- Quality of the database: Criteria from more recently developed assessments, particularly from the same source (OEHHA or USEPA), are preferred when they are based on higher quality studies, more comprehensive evaluation of the database, or more current methodology.

4.2.2. Chemicals without Established Toxicity Criteria

For organic chemicals with no established non-cancer toxicity criteria, OEHHA either derived new toxicity criteria or used those from structural analogs. OEHHA first conducted a literature search for published toxicology reviews and toxicity studies. The next step was to prioritize developing values for those with greatest potential exposure concern, based on results from published synthetic turf studies and whether they were known to be in tires. OEHHA developed screening toxicity criteria to be used in this study from the published toxicity data. For chemicals without adequate toxicity data, OEHHA identified structural analogs that had toxicity criteria and adopted the TC of the structural analog.

Oral toxicity criteria were available for most of the metals and metalloids detected in the statewide study and of interest because of their toxicity profiles. For metals and metalloids with no established toxicity criteria, we did not derive new toxicity criteria. In addition, we could not use the structural analog approach for metals or metalloids because metals of similar ionic radius and charges can manifest very different effects (e.g., calcium ion and lead ion).

Processes used to derive toxicity values for chemicals without established toxicity

criteria are outlined below.

4.2.2.1. Toxicity Criteria Derived De Novo from Published Toxicity Studies

In developing new toxicity criteria, OEHHA followed its risk assessment guidelines (OEHHA, 2008; OEHHA, 2009b) and documented the studies used and analysis in Appendix section E.3. OEHHA took the following steps in these de novo derivations:

1. Searched the literature for relevant studies.
2. Determined the critical study and critical toxicity endpoints by a hazard identification process using published toxicity studies or reviews.
3. Conducted a dose-response assessment. For non-cancer effects, this step establishes a point of departure. In this study, it was usually the dose at which no adverse effect is observed in an animal study. For cancer, it is to establish an upper bound on the slope of the dose response curve in the low dose region of the curve.
4. Quantified the uncertainty factor and extrapolation of the point of departure (POD), the point on the dose-response curve where below which no effect is expected or the lifetime excess cancer risk is at one in a million.
    - For non-cancer effects, uncertainty factors are used to account for variability in human susceptibility, uncertainty in extrapolation from animals to humans, as well as limitations of the toxicity database. The uncertainty factors are multiplied together. For screening-level non-cancer toxicity criteria, the maximum combined uncertainty factor is 10,000 was used in this study.
    - For cancer, CSFs for humans (CSF_{human}) are developed based on animal CSFs (CSF_{animal}) from chemical-specific animal cancer bioassay data and a scaling factor for animal to human extrapolation.

4.2.2.2. Toxicity Criteria Derived from Structural Analogs

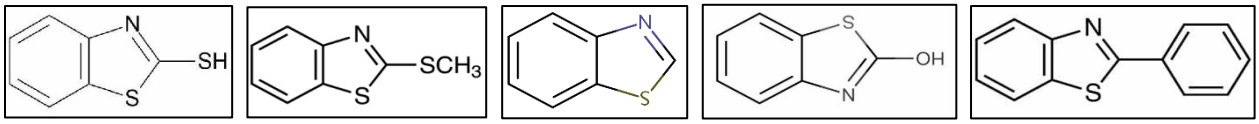
The ideal analog is similar in structure and biological activity in the target organ to the chemical of concern and has an established toxicity criterion for the exposure pathway. However, the ideal case is often not met because many chemicals of concern do not have an adequate toxicity database for comparison to their analogs, or the suitable analogs do not have any established toxicity criterion.

In the interest of public health protection, the study tried to maximize the number of chemicals included in the risk assessment. OEHHA used scientific judgment to identify analogs based on similarities in chemical structure and toxicity, or structure alone. The USEPA CompTox Chemicals Dashboard (Dashboard, (USEPA, 2023)) was queried for structural similarity and Toxicity criteria information. Using the Dashboard, we matched each chemical of potential concern with chemicals in the database using a structural similarity score. However, many of the matched candidates did not have established toxicity criteria. For each of these chemicals, the assignment of an analog was based on

qualitative evaluation of the structure alone.

An example of the structure and toxicity relationship analysis is that for 5 benzothiazoles, shown in Figure 4-2. Two of the chemicals shown have toxicity criteria - benzothiazole (Figure 4-2c) and 2-Mercaptobenzothiazole (Figure 4-2a). The remaining three chemicals do not have toxicity criteria. One important way in which these benzodiazoles differ structurally is that some have a mercapto group while others do not. (Structurally, the mercapto group is represented by R-SH or R_1-S-R_2, where R, R_1 and R_2 represent alkyl groups).

2-Mercaptobenzothiazole is the analog for 2-methythiobenzothiazole (Figure 4-2b), because they both have the mercapto group. Benzothiazole is the analog for 2-hydroxybenzothiazole (Figure 4-2d) and 2-phenylbenzothiazole (Figure 4-2e), as these chemicals do not have the mercapto group.



(a) (b) (c) (d) (e)

Figure 4-2. Chemical Structures of Five Benzothiazoles: (a) 2-mercaptobenzothiazole, CASRN 149-30-4; (b) 2-methylthiobenzothiazole, CASRN 615-22-5; (c) benzothiazole, CASRN 50-32-8; (d) 2-hydroxybenzothiazole, CASRN 934-34-9; and (e) 2-phenylbenzothiazole, CASRN 883-93-2.

4.2.2.3. Criteria Derived From Route- or Duration-Specific Toxicity Criteria for the Same Chemical

When a toxicity criterion is not available for a specific exposure route of a chemical, route-to-route extrapolation is commonly used when a value is available for a different route of exposure. For example, a toxicity criterion for oral exposure based on systemic effects is generally considered appropriate for deriving toxicity criteria for inhalation or dermal exposures. The oral toxicity criterion (TC_{oral}) expressed, for example, as mg per kg per day would be converted to the inhalation criterion (TC_{inh}), expressed, for example, as mg of chemical per cubic meter of air concentration. The oral criterion would be multiplied by the default bodyweight (70 kg) and divided by the inhalation rate (20 cubic meters of air per day). In this case the resulting inhalation criterion would be expressed in units mg per cubic meter. Oral toxicity criteria can be similarly calculated from inhalation toxicity criteria when expressed in these units by multiplying by inhalation rate and dividing by the bodyweight default values. See Appendix Section E.2.3 for examples. An assumption of 100 percent absorption, in the absence of chemical-specific absorption data, is applied in these cases.

For the study, oral criteria (TC_{oral}) are applied in assessing exposure via the dermal route by assuming 100 percent of absorption (both oral and dermal absorptions), in the absence of chemical-specific absorption data. While dermal absorption is rarely 100%,

this assumption is made to screen chemicals for concern. For those chemicals that appear to be concern for dermal exposure this assumption can be examined.

When non-cancer toxicity criterion is available only for subchronic and not for chronic exposure, OEHHA adjusted the subchronic value using a standard uncertainty factor approach (OEHHA, 2008) to derive a value for chronic exposure. An example is using the intermediate-duration oral exposure level (15 to 364 days) for tin to derived a chronic oral value for the compound. The intermediate-duration value available is based on hematological effects observed in a 13-week oral study of animals (ATSDR, Toxicological Profiles). The shorter-term value was divided by an uncertainty factor of 10 to derive the chronic oral exposure toxicity value for tin (see Appendix Section E.2.3.10, Table E-17).

4.3. Grouping of Toxicity Criteria for Risk Assessment

For each general type of toxicity – after acute one-hour, one-day or chronic exposure - the Toxicity criteria are grouped by target organs or specific types of effects, according to the groupings shown in Table 4-2. This allows for the hazard assessment of multiple chemicals that act on the same target systems or produce the same effects. For example, if two chemicals, A and B, both have chronic toxicity criteria based on cardiac effects they would be assessed jointly in evaluating the hazard for cardiac effects. Similarly, chemicals that have sensory irritation as the basis of the toxicity criteria would be jointly assessed in determining the sensory hazard. This comports with the hazard index framework presented in Chapter 6 for making the assessment. The reported toxicity endpoints provided in Appendix E are used group chemicals according to the categories in Table 4-2.

Table 4-1. Groupings of Target Organs or Effects for the Physiological System Basis of the Non-Cancer Toxicity Criteria

Grouping	Target Organs or Effects
Sensory Irritation	
Nervous and sensory system	Brain, sensory or motor effects, ear, eye and nose irritation
Developmental and/or Reproductive Toxicity (DART)	
Developmental system	Effects on the fetus, for example increased gestation period, teratology, and fetal mortality
Reproductive system	Effects on reproductive outcome and organs, for example, litter size, ovulation rate, sex organ weight
All Other Effects	
Alimentary tract	Oral cavity, stomach, forestomach (rodent), liver
Cardiovascular system	Heart, circulatory system

Grouping	Target Organs or Effects
Endocrine system	Thyroid gland, parathyroid gland, pituitary gland, adrenal gland
General toxicity	Clinical signs; change in bodyweight; change in food consumption; effects on bones, teeth, hair, nail, or skin; mortality
Hematological system	Blood cells, spleen, thymus
Immunological system	Antibody levels,
Respiratory system	Nasal cavity, lung
Renal system	Kidney

In calculating the risks from exposures to multiple carcinogens, cancer risks are assumed to be additive, and carcinogens are treated as one large group.

4.4. Toxicity Criteria for Inhalation Exposure to Organic Chemicals

In the following sections, discussion of non-cancer toxicity criteria for inhalation exposures (TC_{inh}) are organized based on exposure duration and effects. The criteria are presented in different sections for:

- acute one-hour exposure
- one-day exposure – developmental and reproductive effects
- chronic exposure – sensory irritation
- chronic exposure
- lifetime exposure – carcinogens

4.4.1. Acute One-Hour Inhalation Exposure

Chemicals with established one-hour non-cancer RELs from OEHHA are provided in Table 4-3. The one-hour RELs are given in units of µg per cubic meter and used as the non-cancer toxicity criteria to evaluate the acute inhalation exposures (Acute TC_{inh}) to these chemicals. Respiratory and sensory are the common target organ systems. For benzene, the one-hour REL was primarily based on respiratory, sensory, and nervous system effects (see Appendix Section E.1 for more details).

In addition to these values, USEPA's tabulation of "Acute Dose-Response Values for Screening Risk Assessments" was an additional point of comparison of concentrations detected on synthetic turf fields to toxicity values (USEPA, 2021).

Table 4-2. Acute One-Hour Inhalation Toxicity Criteria (Acute TC_{inh}) Based on OEHHA

One-Hour Reference Exposure Levels

Chemical	CASRN	Acute TC_{inh} (µg per cubic meter)	Target Organ Systems
Acetaldehyde	75-07-0	470	Eyes; Respiratory System (sensory irritation)
Benzene	71-43-2	27	Reproductive/Developmental; Immune and Hematologic Systems
2-Butanone (methyl ethyl ketone)	78-93-3	13000	Eyes; Respiratory System
2-Butoxyethanol (ethylene glycol monobutyl ether)	111-76-2	4700	Eyes; Respiratory System
Formaldehyde	50-00-0	55	Eyes (sensory irritation)
Phenol	108-95-2	5800	Eyes; Respiratory System
Styrene	100-42-5	21000	Eyes; Respiratory System; Reproductive/Developmental
Tetrachloroethylene	127-18-4	20000	Eyes; Nervous System; Respiratory System
Toluene	108-88-3	5000	Nervous and Respiratory Systems; Eyes; Reproductive/ Developmental
m/p-Xylene	106-42-3	22000	Eyes; Respiratory System; Nervous System
o-Xylene	95-47-6	22000	Eyes; Respiratory System; Nervous System

4.4.2. One-Day Inhalation Exposure: DART

The inhalation toxicity criteria for DART chemicals (DART TC_{inh}) are:

- chemical-specific based on an existing OEHHA or USEPA assessment (6 chemicals),
- chemical-specific - newly developed by OEHHA for this study (2 chemicals), or
- chemical-equivalent based on a structural analog (12 chemicals)

There are six chemical specific values, and these are provided in Table 4-4.

Table 4-3. Chemical-Specific Inhalation Toxicity Criteria for DART Effects (DART TC_{inh})

Chemical	CASRN	DART TC_{inh} (µg per cubic meter)	Source
2-Butanone	78-93-3	5000	USEPA IRIS
Benzo[a]pyrene	50-32-8	0.4 – ages $\leq$ 11	OEHHA derived. See text below
		0.002 – other ages	USEPA IRIS
Bis(2-ethylhexyl) adipate	103-23-1	98	OEHHA

Chemical	CASRN	DART TC_{inh} (µg per cubic meter)	Source
Cyclohexylamine	108-91-8	700	USEPA IRIS
Dimethyl phthalate	131-11-3	400	USEPA PPRTV
4-tert-Octylphenol	140-66-9	140	OEHHA Derived: Appendix E.3.10

In addition, 12 chemicals have values that are chemical-equivalent and based on structural analogy to one of the chemicals in Table 4-4. Table 4-5 summarizes the toxicity criteria for these chemicals and indicates the structural analog used as the basis of the values.

Table 4-4. Chemical-Equivalent Inhalation Toxicity Criteria for DART Effects (DART TC_{inh}) Based on Structural Analog

Chemical	CASRN	Chemical Analog	DART TC_{inh} (µg per cubic meter)
Benzo[e]pyrene	192-97-2	Benzo[a]pyrene	0.4 – ages $\leq$ 11 0.002 – other ages
Benzo[g,h,i]perylene	191-24-2		
Chrysene	218-01-9		
Coronene	191-07-1		
Cyclopenta[cd]pyrene	27208-37-3		
Indeno[1,2,3-cd]pyrene	193-39-5		
Methyl stearate	112-61-8	Bis(2-ethylhexyl) adipate	98
n-Caproic acid vinyl ester	3050-69-9		
N-Cyclohexyl-cyclohexanamine	101-83-7	Cyclohexylamine	700
N,N-Dicyclohexylmethylamine	7560-83-0		
2,4-bis(1-methyl-1-phenylethyl)phenol	2772-45-4	4-tert-Octylphenol	140
4-(1-phenylethyl)-phenol	1988-89-2		

Two values are given in Table 4-4 for benzo(a)pyrene and in Table 4-5 for benzo(a)pyrene analogs. One value is for ages groups <11 years, the second for all

other ages. The value for those greater than 11 years of age is based on a critical study where exposure occurred during pregnancy and offspring were affected. Given the mismatch of this critical study for the young age groups (<11 years, pre-puberty age children), a value more appropriate for application to young children was derived.

No sensitive inhalation studies were available that were relevant to this age period. However, a rat study conducted by the oral route was available where animals were exposed postnatally and neurobehavioral changes were observed, along with effects on ovarian follicles (Chen et al., 2012). The value for young children is based on this study. OEHHA conducted route-to-route-extrapolation to develop the DART TC_{inh} value for children of 0<11 years, shown in Table 4-4. See Appendix Section E.2.1.

4.4.3. Chronic Inhalation Exposure: Sensory Irritation

Inhalation toxicity criteria of chemicals with sensory irritation as the basis (Sensory TC_{inh}) were established by OEHHA as chronic RELs (Table 4-6, see Appendix E for additional details). The effects of concern were eye and respiratory system irritation. To screen for potential effects the study evaluated the average concentrations measured at each field on a single day against these toxicity benchmarks.

Table 4-5. Inhalation Toxicity Criteria for Sensory Irritants (Sensory TC_{inh}) Using Chronic Reference Effect Levels Based on OEHHA Chronic RELs (OEHHA Chemicals Library)

Chemical	CASRN	Chronic REL (µg per cubic meter)
Acetaldehyde	75-07-0	140
Formaldehyde	50-00-0	9
Styrene	100-42-5	900

4.4.4. Chronic Inhalation Exposure

This section presents chemicals with chronic inhalation toxicity criteria (Chronic TC_{inh}) based on chronic reference concentrations for effects other than sensory irritation or DART. The effects can be for general systemic toxicity such as body weight changes, or effects on target organs such as the liver, kidneys, as presented in Table 4-2. For this study, we gave chemicals the term “general chemicals” when their chronic toxicity criteria were based on endpoints other than sensory irritation or DART. Chemicals with chemical-specific inhalation toxicity criteria are listed in Table 4-7 and chemicals with inhalation toxicity criteria from structural analogs are listed in Table 4-8.

Most of the chemicals detected in samples collected from the air, had chronic non-cancer TC_{inh} were available from OEHHA, USEPA, or ATSDR, or could be assigned values using a structural analog. OEHHA newly derived screening TC_{inh} for the following chemicals (details in Appendix Section E.3):

- 2-Methylfuran
- Benzothiazole

- Methacrolein
- Methyl isobutyl ketone
- N-(1,3-dimethylbutyl)-N'-phenyl-p-benzenediamine
- 4-tert-Octylphenol
- 2,2,4-Trimethyl-1,3-pentanediol diisobutyrate (TXIB)

The newly derived value for benzothiazole was used to assign, by structural analogy, toxicity criteria for some of the other benzothiazoles.

Four chemicals do not have established non-cancer TC_{inh}, but were excluded in the development of toxicity criteria because they are relatively non-toxic and commonly found in plants or food: 3-carene, alpha-pinene, D-limonene, and limonene.

Table 4-6. Chemical-specific Chronic Toxicity Criteria for Inhalation (Chronic TC_{inh})
Organic Chemicals

Chemical	CASRN	Chronic TC_{inh}[a] (µg per cubic meter)	Target Organ System	Reference
1,4-Benzene-diamine, N-(1,3-dimethylbutyl)-N'-phenyl-	793-24-8	10.5*	General	Appendix E
1-Hexanol, 2-ethyl-	104-76-7	0.4	Respiratory	USEPA PPRTV
2-Butoxyethanol	111-76-2	80	Respiratory	OEHHA
Acetone	67-64-1	3.15	Renal	USEPA IRIS
Aniline	62-53-3	1	Hematological	USEPA IRIS
Anthracene	120-12-7	1050*	General	USEPA IRIS
Benzaldehyde	100-52-7	350*	Alimentary tract, Renal	USEPA IRIS
Benzene	71-43-2	3	Hematological	OEHHA
Benzene, 1,2,3-trimethyl-	526-73-8	60	Nervous	USEPA IRIS
Benzene, 1,2,4-trimethyl-	95-63-6	60	Nervous	USEPA IRIS
Benzene, 1,3,5-trimethyl	108-67-8	60	Nervous	USEPA IRIS
Benzene, 1,4-dichloro	106-46-7	60	Respiratory	ATSDR
Benzene, 1-chloro-4-(trifluoromethyl)-	98-56-6	300	Alimentary tract	USEPA PPRTV
Benzene, n-butyl-	104-51-8	17500	Alimentary tract	USEPA PPRTV
Benzothiazole	95-16-9	1.75*	General	Appendix E
Benzyl butyl phthalate	85-68-7	700*	Alimentary tract	USEPA IRIS
Cyclopentasiloxane, decamethyl-	541-02-6	700	Alimentary tract, Hematological	OEHHA
Dibenzothiophene	132-65-0	35*	Alimentary tract	USEPA PPRTV
Dibutyl phthalate	84-74-2	350*	General	USEPA IRIS
Diethyl phthalate	84-66-2	2800*	General	USEPA IRIS
Di-n-octyl phthalate	117-84-0	35*	Alimentary tract	USEPA PPRTV
Ethylbenzene	100-41-4	300	Renal	ATSDR
Fluoranthene	206-44-0	140*	Renal, Hematological	USEPA IRIS

Chemical	CASRN	Chronic TC_{inh}[a] (µg per cubic meter)	Target Organ System	Reference
Fluorene	86-73-7	140*	Hematological	USEPA IRIS
Furan, 2-methyl	534-22-5	0.35*	Alimentary tract	Appendix E
Heptane	142-82-5	400	Nervous	USEPA PPRTV
Hexane	110-54-3	700	Nervous	USEPA IRIS
Methacrolein	78-85-3	1.4	Respiratory	Appendix E
Methyl isobutyl ketone	108-10-1	160	Renal	Appendix E
Naphthalene	91-20-3	3	Respiratory	ATSDR
Naphthalene, 1-methyl	90-12-0	24.5*	Respiratory	USEPA PPRTV
Naphthalene, 2-methyl-	91-57-6	14*	Respiratory	USEPA IRIS
Phenol	108-95-2	200	Nervous	OEHHA
Propionaldehyde	123-38-6	8	Respiratory	USEPA IRIS
Pyrene	129-00-0	105*	Renal	USEPA IRIS
Tetrachloroethylene	127-18-4	40	Nervous	USEPA IRIS, ATSDR
Toluene	108-88-3	420	Nervous	OEHHA
Trichloroethylene	79-01-6	2	Hematological	USEPA IRIS, ATSDR
Trichloromethane	67-66-3	300	Alimentary tract, Renal	OEHHA
TXIB, 2,2,4-Trimethyl-1,3-pentanediol diisobutyrate	6846-50-0	10.5*	Alimentary tract	Appendix E
Xylenes mixture: m-Xylene, p-Xylene, and o-Xylene[b]	1330-20-7 108-38-3 106-42-3 95-47-6	100[b]	Impaired motor coordination in rats	USEPA IRIS

[a] Chemicals that are derived from toxicity criteria by the oral route are denoted with an asterisk (*)
[b] There is a Sensory TC_{inh} of 700 microgram per cubic meter for one-day exposure to xylenes (Appendix E.2.3.6), which is less to 10-fold higher than a Chronic TC_{inh} of 100 microgram per cubic meter for other effects. Both effects are evaluated.

Table 4-7. Chemical Equivalent Chronic Toxicity Criteria for Inhalation (Chronic TC_{inh}) for Organic Chemicals Based on Structural Analog

Chemical	CASRN	Analog	Chronic TC_{inh}[a] (µg per cubic meter)	Target Organ System	Reference for Analog
17-Pentatriacontene	6971-40-0	Nonane	20	General	USEPA PPRTV
1-Methyl-4-(1-methylethyl) benzene	99-87-6	Benzene, 1,2,3-trimethyl-	60	Nervous	USEPA
1-Octadecene	112-88-9	Nonane	20	General	USEPA PPRTV
2,5-di-tert-Butyl-1,4-benzoquinone	2460-77-7	Anthraquinone	7*	Alimentary tract, Renal, Hematological	USEPA PPRTV
2,5-Hexanedione	110-13-4	2-Hexanone	30	Nervous	USEPA IRIS
2-Benzothiazolone	934-34-9	Benzothiazole	1.75*	General	Appendix E

Chemical	CASRN	Analog	Chronic TC_{inh}[a] (µg per cubic meter)	Target Organ System	Reference for Analog
3,5-di-tert-Butyl-4-hydroxy-benzaldehyde	1620-98-0	Butylated hydroxyl toluene	1050*	General	USEPA IRIS
5,9-Undecadien-2-one, 6,10-dimethyl-	689-67-8	Methyl isobutyl ketone	160	Renal	OEHHA
7H-Benzo[c]fluorene	205-12-9	Fluorene	140*	Hematological	USEPA IRIS
Acenaphthylene	208-96-8	Acenaphthene	210	Alimentary tract	USEPA IRIS
Anthracene, 2-methyl-	613-12-7	Anthracene	1050*	General	USEPA IRIS
Anthracene, 9,10-dimethyl	781-43-1	Anthracene	1050*	General	USEPA IRIS
Anthracene, 9-phenyl	602-55-1	Anthracene	1050*	General	USEPA IRIS
Benz[a]anthracene	56-55-3	Anthracene	1050*	General	USEPA IRIS
Benzene, 1,2,4,5-tetramethyl-	95-93-2	Benzene, 1,2,3-trimethyl-	60	Nervous	USEPA IRIS
Benzene, 1-ethyl-2,4-dimethyl-	874-41-9	Benzene, 1,2,3-trimethyl-	60	Nervous	USEPA IRIS
Benzene, 2-ethyl-1,4-dimethyl-	1758-88-9	Benzene, 1,2,3-trimethyl-	60	Nervous	USEPA IRIS
Benzo[b]fluoranthene	205-99-2	Fluoranthene	140*	Renal, Hematological	USEPA IRIS
Benzo[k]fluoranthene	207-08-9	Fluoranthene	140*	Urinary, Hematological	USEPA IRIS
Benzothiazole, 2-phenyl-	883-93-2	Benzothiazole	1.75*	General	Appendix E
Butanal	123-72-8	Propionaldehyde	8	Respiratory	USEPA IRIS
Cyclotrisiloxane, hexamethyl- (D3)	541-05-9	Cyclopentasiloxane, decamethyl-	700	Alimentary tract, Hematological	OEHHA
Cyclotetrasiloxane, octamethyl-	556-67-2	Cyclopentasiloxane, decamethyl-	700	Alimentary tract, Hematological	OEHHA
Decanal	112-31-2	Propionaldehyde	8	Respiratory	USEPA IRIS
Decane	124-18-5	Nonane	20	General	USEPA PPRTV
Dibenz[a,h]-anthracene	53-70-3	Anthracene	1050*	General	USEPA IRIS
Diisobutyl phthalate	84-69-5	Di-n-octyl phthalate	35*	Alimentary tract	USEPA PPRTV
Diisooctyl phthalate	27554-26-3	Di-n-octyl phthalate	35*	Alimentary tract	USEPA PPRTV
Dodecane	112-40-3	Nonane	20	General	USEPA PPRTV

Chemical	CASRN	Analog	Chronic TC_{inh}[a] (µg per cubic meter)	Target Organ System	Reference for Analog
Heptanal	111-71-7	Propionaldehyde	8	Respiratory	USEPA IRIS
Hexadecane	544-76-3	Nonane	20	General	USEPA PPRTV
Hexaldehyde (Hexanal)	66-25-1	Propionaldehyde	8	Respiratory	USEPA IRIS
Indan (Benzo-cyclopentane)	496-11-7	Styrene	900	Nervous	OEHHA
m-Tolualdehyde	620-23-5	Benzaldehyde	350*	Alimentary tract, Renal	USEPA IRIS
Naphthalene, 1,2-dimethyl-	573-98-8	Naphthalene	3	Respiratory	ATSDR
Naphthalene, 1,6-dimethyl-	575-43-9	Naphthalene	3	Respiratory	ATSDR
Naphthalene, 2-(bromomethyl)-	939-26-4	Naphthalene	3	Respiratory	ATSDR
Naphthalene, 2,3-dimethyl-	581-40-8	Naphthalene	3	Respiratory	ATSDR
Nonanal	124-19-6	Propionaldehyde	8	Respiratory	USEPA IRIS
N-Phenyl-benzamide	93-98-1	Aniline	1	Hematological	USEPA IRIS
Octanal	124-13-0	Propionaldehyde	8	Respiratory	USEPA IRIS
Octane	111-65-9	Nonane	20	General	USEPA PPRTV
Phenanthrene	85-01-8	Anthracene	1050*	General	USEPA IRIS
Phenanthrene, 1-methyl	832-69-9	Anthracene	1050*	General	USEPA IRIS
Phenanthrene, 2-methyl-	2531-84-2	Anthracene	1050*	General	USEPA IRIS
Phenanthrene, 3-methyl	832-71-3	Anthracene	1050*	General	USEPA IRIS
Pyridine, 2-(4-methylphenyl)-	4467-06-5	Pyridine	3.5*	Alimentary tract	USEPA IRIS
Resorcinol	108-46-3	Phenol	200	Nervous	OEHHA
Tetradecane	629-59-4	Nonane	20	General	USEPA PPRTV
Texanol, 2,2,4-Trimethyl-1,3-pentanediol monoisobutyrate	25265-77-4	TXIB, 2,2,4-Trimethyl-1,3-pentanediol diisobutyrate	10.5*	Alimentary tract	Appendix E
Undecane	1120-21-4	Nonane	20	General	USEPA PPRTV
Valeraldehyde	110-62-3	Propionaldehyde	8	Respiratory	USEPA IRIS

[a] Chemicals that are derived from toxicity criteria by the oral route are denoted with an asterisk (*)

4.4.5. Lifetime Inhalation Exposure: Carcinogens

The cancer slope factors for evaluating inhalation exposure (CSF_{inh}) to carcinogens detected in the study are presented in Table 4-9. They are all based on OEHHA values. Several of them were derived earlier by OEHHA based on potency equivalency factors (PEF) applied to the CSF for benzo(a)pyrene. Two carcinogens did not have established human CSFs - cyclopenta[c,d]pyrene and methyl isobutyl ketone. OEHHA newly derived human CSF_{inh} for these two chemicals. The CSF for methyl isobutyl ketone was chemical-specific and used an inhalation carcinogenicity study for the chemical (See Appendix Section E.3.8.5.2). The CSF for cyclopenta[c,d]pyrene used the CSF_{inh} of BaP and a PEF that was derived by comparing the inhalation toxicity of BaP to cyclopenta[c,d]pyrene (See Appendix Section E.3.9.3).

Table 4-8. Human Cancer Slope Factors for Lifetime Inhalation Exposure to Carcinogens (CSF_{inh})

Chemical	CASRN	Basis	CSF_{inh} (mg per kg per day)$^{-1}$	Tumor Organ System	Reference
Acetaldehyde	75-07-0	Chemical-Specific	0.01	Renal	OEHHA
Aniline	62-53-3	Chemical-Specific	0.0057	Hematological	OEHHA
Benzene	71-43-2	Chemical-Specific	0.1	Hematological	OEHHA
Benzene, 1,4-dichloro	106-46-7	Chemical-Specific	0.04	Alimentary tract	OEHHA
Benzene, 1-chloro-4-(trifluoromethyl)-	98-56-6	Chemical-Specific	0.03	Alimentary tract	OEHHA
Benzo[a]pyrene	50-32-8	Chemical-Specific	3.9	Respiratory	OEHHA
Dibenz[a,h]anthracene	53-70-3	Chemical-Specific	4.1	Respiratory	OEHHA
Ethylbenzene	100-41-4	Chemical-Specific	0.0087	Renal	OEHHA
Formaldehyde	50-00-0	Chemical-Specific	0.021	Respiratory	OEHHA
Methyl isobutyl ketone	108-10-1	Chemical-Specific	0.0039	Alimentary tract	Appendix E.3.8
Naphthalene	91-20-3	Chemical-Specific	0.12	Respiratory	OEHHA
Styrene	100-42-5	Chemical-Specific	0.026	Respiratory	OEHHA
Tetrachloroethylene	127-18-4	Chemical-Specific	0.02	Alimentary tract, Hematological	OEHHA
Trichloroethylene	79-01-6	Chemical-Specific	0.014	Alimentary tract, Hematological, Renal	OEHHA
Trichloromethane	67-66-3	Chemical-Specific	0.014	Alimentary tract, Renal	OEHHA
Benz[a]anthracene	56-55-3	PEF BaP	0.39	Respiratory	OEHHA

Chemical	CASRN	Basis	CSF_{inh} (mg per kg per day)$^{-1}$	Tumor Organ System	Reference
Benzo[b]fluoranthene	205-99-2	PEF BaP	0.39	Respiratory	OEHHA
Benzo[k]fluoranthene	207-08-9	PEF BaP	0.39	Respiratory	OEHHA
Chrysene	218-01-9	PEF BaP	0.039	Respiratory	OEHHA
Cyclopenta[cd]pyrene	27208-37-3	PEF BaP	3.9	Respiratory	Appendix E.3.9
Indeno[1,2,3-cd]pyrene	193-39-5	PEF BaP	0.39	Respiratory	OEHHA

PEF BaP: potency equivalency factor (PEF) with benzo[a]pyrene (BaP) as the index chemical.

4.5. Toxicity Criteria for Oral or Dermal Exposure to Organic Chemicals

There were 81 organic chemicals detected in the artificial biofluid extracts (artificial sweat or artificial GI fluids) of crumb rubber. Four chemicals were excluded from the development of toxicity criteria because they are considered relatively non-toxic or beneficial and commonly found in foods and plants: linoleic acid (an essential fatty acid in diet), oleic acid (an omega-9 fatty acid in olive oil), ricinoleic acid (the main component of castor oil) and limonene (an oil, e.g., in dill, citrus skin and caraway). For the 77 remaining chemicals, criteria were compiled for evaluating oral and dermal exposures for evaluating one-day exposure for DART effects or chronic exposure for other chronic effects. Cancer potency factors were also compiled for the detected carcinogens.

As noted in Section 4.2.2.3, toxicity criteria were typically not available for the dermal route, so oral toxicity criteria were used for the evaluation of the dermal route for this study, using the worst case assumption that dermal absorption was 100%.

Five chemicals did not have established oral chronic toxicity or DART criteria but had suitable toxicity data for derivation of sensitive toxicity criteria. OEHHA derived new screening values for these chemicals as follows:

- 1,3-diphenylguanidine (DART oral, see Appendix Section E.3.4)
- 4-tert-octylphenol (DART oral, see Appendix Section E.3.10)
- Benzothiazole (general chronic toxicity, see Appendix Section E.3.5)
- N-(1,3-dimethylbutyl)-N'-phenyl-1,4-benzenediamine ("6PPD", general chronic toxicity, see Appendix Section E.3.2)
- N,N'-diphenyl-1,4-benzenediamine ("DPPD", DART oral, see Appendix Section E.3.3)

However, there are no toxicity data for derivation of new values, or suitable analogs for three chemicals: phenoxazine, N,N'-dicyclohexylurea, and diphenylurea. We were therefore unable to evaluate these three chemicals in the risk assessment.

4.5.1. One-Day Oral and Dermal Exposures: DART

Toxicity criteria for evaluating developmental and reproductive toxicity (DART TC_{oral}) for oral and dermal exposures to organic chemicals in crumb rubber are presented in Table 4-10. The table also shows the applicable routes for exposure to these chemicals given the detections in biofluid extracts (Chapter 3). Appendix E provides additional details and citations for sources the DART toxicity criteria.

Table 4-9. Chemical-specific Oral Toxicity Criteria for Organic Chemicals for Developmental and Reproductive Effects (DART TC_{oral})

Chemical	CASRN	DART TC_{oral} mg per kg per day	Exposure Route Applied to	Reference
1,4-Benzene-diamine, N,N'-diphenyl-	74-31-7	0.008	Dermal	Appendix E.3.3
1,3-Diphenylguanidine	102-06-7	0.005	Oral, dermal	Appendix E.3.4
4-tert-Octylphenol	140-66-9	0.04	Oral, dermal	Appendix E.3.10
Benzo[a]pyrene	50-32-8	0.0003	Oral, dermal	USEPA IRIS
Bis(2-Ethylhexyl)adipate	103-23-1	0.028	Oral, dermal	OEHHA
Dimethyl phthalate	131-11-3	0.1	Oral, dermal	USEPA PPRTV

For 14 chemicals oral toxicity criteria for the DART endpoint were based on structural analogy, as shown in Table 4-11. The analog used in the assignment of the toxicity value is provided in the table along with the exposure route that the values are being applied to.

Table 4-10. Oral Toxicity Criteria of Organic Chemicals for Reproductive and/or Developmental Effects (DART TC_{oral}) Based on Structural Analogs (OEHHA Chemicals Library; USEPA IRIS)

Chemical	CASRN	Analog	DART TC_{oral} mg per kg per day	Exposure Route Applied to	Reference for Analog
2-Azacyclotridecanone	947-04-6	Caprolactam	0.5	Dermal	USEPA IRIS
Benzo[e]pyrene	192-97-2	Benzo[a]pyrene	0.0003	Oral, dermal	USEPA IRIS
Benzo[g,h,i]perylene	191-24-2	Benzo[a]pyrene	0.0003	Oral, dermal	USEPA IRIS
Bis(2,2,6,6-tetramethyl-4-piperidyl)sebacate	52829-07-9	Bis(2-ethylhexyl) adipate	0.028	Oral, dermal	OEHHA
Chrysene	218-01-9	Benzo[a]pyrene	0.0003	Oral, dermal	USEPA IRIS
Coronene	191-07-1	Benzo[a]pyrene	0.0003	Oral, dermal	USEPA IRIS

Chemical	CASRN	Analog	DART TC_{oral} mg per kg per day	Exposure Route Applied to	Reference for Analog
Cyclopenta[cd]pyrene	27208-37-3	Benzo[a]pyrene	0.0003	Oral, dermal	USEPA IRIS
Cyclohexanamine, N-cyclohexyl-	101-83-7	Cyclohexyl-amine	0.2	Oral, dermal	USEPA IRIS
Indeno[1,2,3-cd]pyrene	193-39-5	Benzo[a]pyrene	0.0003	Oral, dermal	USEPA IRIS
Methyl stearate	112-61-8	Bis(2-ethylhexyl)adipate	0.028	Oral, dermal	OEHHA
N,N-Dicyclohexylmethylamine	7560-83-0	Cyclohexylamine	0.2	Dermal	USEPA IRIS
n-Caproic acid vinyl ester	3050-69-9	Bis(2-ethylhexyl)adipate	0.028	Oral	OEHHA
Phenol, 2,4-bis(1-methyl-1-phenylethyl)-	2772-45-4	4-tert-octylphenol	0.04	Oral, dermal	OEHHA
Phenol, 4-(1-phenylethyl)-	1988-89-2	4-tert-octylphenol	0.04	Oral, dermal	OEHHA

4.5.2. Chronic Oral and Dermal Exposures: General Toxicity Criteria

Toxicity criteria for evaluating general chronic toxicity (Chronic TC_{oral}) for oral and dermal exposures to organic chemicals detected in crumb rubber are presented in Table 4-12. The table also shows the applicable routes for exposure to these chemicals given the detections in biofluid extracts (Chapter 3).

Table 4-11. Chemical-specific Oral Chronic Toxicity Criteria for Organic Chemicals (Chronic TC_{oral})

Chemical	CASRN	Chronic TC_{oral} (mg per kg per day)	Oral Target Organ System	Exposure Route Applied to	Reference
1,4-Benzene-diamine, N-(1,3-dimethylbutyl)-N'-phenyl-	793-24-8	0.003	General	Oral, dermal	Appendix E.3.3.1
1,3-Benzothiazole-2-thiol	149-30-4	0.004	Alimentary tract	Dermal	USEPA PPRTV
Aniline	62-53-3	0.007	Hematological	Oral, dermal	USEPA PPRTV
Anthracene	120-12-7	0.3	General	Oral, dermal	USEPA IRIS
Benzene, n-butyl-	104-51-8	0.05	Alimentary tract	Oral, dermal	USEPA PPRTV
Benzothiazole	95-16-9	0.0005	General	Oral, dermal	Appendix E.3.5

Chemical	CASRN	Chronic TC_{oral} (mg per kg per day)	Oral Target Organ System	Exposure Route Applied to	Reference
Benzyl butyl phthalate	85-68-7	0.2	Alimentary tract	Oral, dermal	USEPA IRIS
Butylated Hydroxytoluene	128-37-0	0.3	General	Oral	USEPA PPRTV
Dibenzothiophene	132-65-0	0.01	Alimentary tract	Oral, dermal	USEPA PPRTV
Dibutyl phthalate	84-74-2	0.1	General	Oral	USEPA IRIS
Diethyl phthalate	84-66-2	0.8	General	Oral, dermal	USEPA IRIS
Di-n-octyl phthalate	117-84-0	0.01	Alimentary tract	Oral, dermal	USEPA PPRTV
Fluoranthene	206-44-0	0.04	Renal, Hematological	Oral, dermal	USEPA IRIS
Fluorene	86-73-7	0.04	Hematological	Oral, dermal	USEPA IRIS
Naphthalene	91-20-3	0.02	General	Oral, dermal	OEHHA
Naphthalene, 1-methyl-	90-12-0	0.007	Respiratory	Oral, dermal	USEPA PPRTV
Naphthalene, 2-methyl	91-57-6	0.004	Respiratory	Oral, dermal	USEPA IRIS
Pyrene	129-00-0	0.03	Renal	Oral, dermal	USEPA IRIS

For 36 chemicals oral toxicity criteria for general chronic toxicity (Chronic TC_{oral}) for oral and dermal exposures were based on structural analogy, as shown in Table 4-13. The analog used in the assignment of the toxicity value is provided in the table along with the exposure route that the values are being applied to.

Table 4-12. Oral Chronic Toxicity Criteria (Chronic TC_{oral},) for Organic Chemicals Based on Structural Analogs

Chemical	CASRN	Analog	Chronic TC_{oral} mg per kg per day	Oral Target Organ System	Applicable Exposure Route	Reference for Analog
17-Penta-triacontene	6971-40-0	Mineral oil	3	Alimentary tract	Oral	USEPA IRIS
1-Hydroxy-pyrene	5315-79-7	Pyrene	0.03	Urinary	Oral, dermal	USEPA IRIS
1-Octadecene	112-88-9	Nonane	0.0003	Alimentary tract	Oral, dermal	USEPA PPRTV
2-(Methylthio)-benzothiazole	615-22-5	1,3-Benzo-thiazole-2-thiol	0.004	Alimentary tract	Oral, dermal	USEPA PPRTV
2,5-di-tert-Butyl-1,4-benzoquinone	2460-77-7	9,10-Anthra-quinone	0.002	Alimentary tract, Urinary, Hematological	Oral, dermal	USEPA PPRTV
2-Benzo-thiazolone	934-34-9	Butylated hydroxy-toluene	0.0005	General	Oral, dermal	Appendix E.3.5

Chemical	CASRN	Analog	Chronic TC_{oral} mg per kg per day	Oral Target Organ System	Applicable Exposure Route	Reference for Analog
3,5-di-tert-Butyl-4-hydroxybenz-aldehyde	1620-98-0	Butylated hydroxy-toluene	0.3	General	Oral, dermal	USEPA IRIS
5,9-Undecadien-2-one, 6,10-dimethyl-	689-67-8	Methyl isobutyl ketone	0.017	Alimentary tract, Urinary	Oral, dermal	OEHHA
7H-Benzo[c]-fluorene	205-12-9	Fluorene	0.04	Hematological	Oral, dermal	USEPA IRIS
Acenaphthylene	208-96-8	Ace-naphthene	0.06	Alimentary tract	Oral, dermal	USEPA IRIS
Anthracene, 2-methyl-	613-12-7	Anthracene	0.3	General	Oral, dermal	USEPA IRIS
Anthracene, 9,10-dimethyl	781-43-1	Anthracene	0.3	General	Oral	USEPA IRIS
Anthracene, 9,10-diphenyl-	1499-10-1	Anthracene	0.3	General	Oral, dermal	USEPA IRIS
Anthracene, 9-phenyl	602-55-1	Anthracene	0.3	General	Oral, dermal	USEPA IRIS
Benz[a]-anthracene	56-55-3	Anthracene	0.3	General	Oral, dermal	USEPA IRIS
Benzo[b]-fluoranthene	205-99-2	Fluoranthene	0.04	Urinary, Hematological	Oral, dermal	USEPA IRIS
Benzo[k]-fluoranthene	207-08-9	Fluoranthene	0.04	Urinary, Hematological	Oral, dermal	USEPA IRIS
Benzothiazole, 2-phenyl-	883-93-2	Benzo-thiazole	0.0005	General	Oral, dermal	Appendix E.3.5
Cyclohexyl isothiocyanate	1122-82-3	Phenyl isothio-cyanate	0.0002	Endocrine	Oral, dermal	USEPA PPRTV
Dibenz[a,h]-anthracene	53-70-3	Anthracene	0.3	General	Oral, dermal	USEPA IRIS
Diisobutyl phthalate	84-69-5	Di-n-octyl phthalate	0.01	Alimentary tract	Oral, dermal	USEPA PPRTV
Diisooctyl phthalate	27554-26-3	Di-n-octyl phthalate	0.01	Alimentary tract	Oral, dermal	USEPA PPRTV
Hexadecane	544-76-3	Nonane	0.0003	Alimentary tract	Oral	USEPA PPRTV
Hexanoic Acid, 2-ethyl	149-57-5	Hexanedioic acid	2	General	Dermal	USEPA PPRTV
Naphthalene, 1,2-dimethyl-	573-98-8	Naphthalene	0.02	General	Oral, dermal	OEHHA
Naphthalene, 1,6-dimethyl-	575-43-9	Naphthalene	0.02	General	Oral, dermal	OEHHA
Naphthalene, 2-(bromomethyl)-	939-26-4	Naphthalene	0.02	General	Oral, dermal	OEHHA
Naphthalene, 2,3-dimethyl-	581-40-8	Naphthalene	0.02	General	Oral, dermal	OEHHA
N-Phenyl-benzamide	93-98-1	Aniline	0.007	Hematological	Oral, dermal	USEPA PPRTV

Chemical	CASRN	Analog	Chronic TC_{oral} mg per kg per day	Oral Target Organ System	Applicable Exposure Route	Reference for Analog
Phenanthrene	85-01-8	Anthracene	0.3	General	Oral, dermal	USEPA IRIS
Phenanthrene, 1-methyl	832-69-9	Anthracene	0.3	General	Oral, dermal	USEPA IRIS
Phenanthrene, 2-methyl-	2531-84-2	Anthracene	0.3	General	Oral, dermal	USEPA IRIS
Phenanthrene, 3-methyl	832-71-3	Anthracene	0.3	General	Oral, dermal	USEPA IRIS
Phthalimide	85-41-6	Folpet	0.1	General	Oral, dermal	USEPA IRIS
Pyridine, 2-(4-methylphenyl)-	4467-06-5	Pyridine	0.001	Alimentary tract	Oral, dermal	USEPA IRIS
Triethylene glycol monobutyl ether	143-22-6	2-butoxy-ethanol	0.1	Alimentary	Oral, dermal	USEPA IRIS

4.5.3. Lifetime Oral or Dermal Exposure to Carcinogens

Oral cancer slope factors (CSF_{oral}) for assessing risks of organic chemicals detected in GI or dermal extracts of crumb rubber are provided in Table 4-14. OEHHA was the source of these values with one exception. The CSF_{oral} for 1,3-benzothiazole-2-thiol was an established value from USEPA IRIS. For cyclopenta[c,d]pyrene, BaP was used by OEHHA as the analog after considering the similarity of the oral toxicity data for the two chemicals (details in Appendix Section E.3.9). The chemical-specific cancer slope factor by the inhalation route (CSF_{inh}) for aniline is based on a systemic effect, thus the inhalation cancer potency is used to derive the values for both the oral and dermal routes for this compound.

Table 4-13. Oral Cancer Slope Factors (CSF_{oral}) for Assessing Lifetime Oral or Dermal Exposure to Carcinogens

Chemical	CASRN	Chemical Basis	CSF_{oral} (mg per kg per day)$^{-1}$	Oral Tumor Organ system	Applicable Exposure Route	Reference
1,3-Benzo-thiazole-2-thiol	149-30-4	Chemical-Specific	0.01	Endocrine	Dermal	USEPA IRIS
Aniline	62-53-3	Chemical-Specific	0.0057	Hemato-logical	Oral, dermal	OEHHA
Benzo[a]pyrene	50-32-8	Chemical-Specific	12	Alimentary tract	Oral, dermal	OEHHA
Benzo[b]-fluoranthene	205-99-2	Chemical-Specific	1.2	Alimentary tract	Oral, dermal	OEHHA
Benzo[k]-fluoranthene	207-08-9	Chemical-Specific	1.2	Alimentary tract	Oral, dermal	OEHHA
Chrysene	218-01-9	Chemical-Specific	0.12	Alimentary tract	Oral, dermal	OEHHA
Dibenz[a,h]-anthracene	53-70-3	Chemical-Specific	4.1	Respiratory	Oral, dermal	OEHHA

Chemical	CASRN	Chemical Basis	CSF_{oral} (mg per kg per day)$^{-1}$	Oral Tumor Organ system	Applicable Exposure Route	Reference
Naphthalene	91-20-3	Chemical-Specific	0.12	Respiratory	Oral, dermal	OEHHA
Benz[a]-anthracene	56-55-3	PEF BaP	1.2	Alimentary tract	Oral, dermal	OEHHA
Cyclopenta[cd]-pyrene	27208-37-3	PEF BaP	12	Alimentary tract	Oral, dermal	Appendix E.3.9
Indeno[1,2,3-cd]-pyrene	193-39-5	PEF BaP	1.2	Alimentary tract	Oral, dermal	OEHHA

PEF BaP: potency equivalency factor (PEF) with benzo[a]pyrene (BaP) as an index chemical.

4.6. Toxicity Criteria for Oral Exposure to Metals and Metalloids

Oral toxicity criteria were compiled for the metals and metalloids detected in the gastric fluid extracts of crumb rubber samples. The metals were not speciated and the health protective approach we took was to select the toxicity criteria for most toxic form for which values were available as representative of toxicity the metal or metalloid in crumb rubber. For example, chromium occurs in the environment in two oxidation states, trivalent chromium (Cr III) and hexavalent chromium (Cr VI) (USEPA, 2000). Cr (III) is known to be much less toxic than Cr (VI) and unlike Cr (VI) has not been found to be carcinogenic in humans. The USEPA oral RfDs are 1.5 mg per kg per day and 0.003 mg per kg per day for Cr (III) and Cr (IV), respectively (USEPA, 1998a; USEPA, 1998b). OEHHA chose to represent chromium with the toxicity value for Cr (VI).

Of the metals and metalloids detected in gastric fluid extracts, the following were excluded in the compilation of toxicity criteria:

- Calcium, iron, magnesium, potassium, and sodium are essential nutrients, are found commonly in food, and are relatively non-toxic.
- Lithium, rubidium, and silver are excluded because the established TC_{oral} are based on side effects from clinical doses, considerably higher than expected from exposures to crumb rubber.
- Silicon and titanium do not have established values and OEHHA did not derive new screening values.

4.6.1. One-Day Oral Exposure to Metal or Metalloids: DART

For a few metals and metalloids the most sensitive endpoints are for DART effects. The chemical-specific DART toxicity criteria for these elements are shown in Table 4-15.

The derivation of the DART toxicity criteria for oral exposure to lead was from dose response data for IQ deficits vs blood lead levels in children (OEHHA (2009b). The dynamic of blood lead level in these children is not a simple dose-response relationship from a one-day oral exposure to lead, but the result from continuous, ongoing exposures to lead. Therefore, despite being a DART, the non-cancer DART toxicity criterion TC_{oral} for lead for children is applied in chronic non-cancer hazard assessment

(see Table 4-15). However, OEHHA's maximum allowable dose level (MADL, 0.5 µg/day) is also compared against the one-day oral exposure dose of lead. MADLs represent safe harbor levels for chemicals that cause reproductive toxicity and are established under Proposition 65. They are defined in regulations (Title 22, Cal. Code of Regs. §12801) and are equal to an exposure 1000-fold lower than a NOEL (No observable effect level), derived from the most sensitive study of sufficient quality, where no observable adverse effects are expected to occur. No threshold for the non-carcinogenic effect of lead to decrease IQ points has been observed (OEHHA, 2009a), thus OEHHA used the MADL and chronic TC value as a tool to assess the level of non-cancer hazard from lead exposure. Appendix E provides additional details and sources of the TC values.

Table 4-14. Oral Toxicity Criteria of Metals and Metalloids for Developmental or Reproductive Effects (DART TC_{oral})

Chemical	Chemical Basis	DART TC_{oral} (mg per kg per day)	Oral Target Organ System	Reference
Arsenic	Unspecified	0.0000035	Developmental	OEHHA
Boron	Boric acid	2.0	Developmental	USEPA PPRTV
Lead*	Unspecified	(MADL = 0.0005 mg per day)	Neuro-developmental	OEHHA
Nickel	NiCl or $NiSO_4$	0.011	Reproductive	OEHHA

*the MADL for lead is compared against the one-day oral dose of the chemical (see text above and Chapter 6 for details).

4.6.2. Chronic Oral Exposure to Metals and Metalloids: General Toxicity

Chronic toxicity criteria (Chronic TC_{oral}) for the metals and metalloids detected in artificial GI and dermal biofluids were available from OEHHA and USEPA and are shown in Table 4-16 below. However, the Chronic TC_{oral} for tin was derived from a subchronic toxicity criterion using a duration uncertainty factor of 10-fold according to OEHHA guidelines (OEHHA, 2008).

Table 4-15. Oral Chronic Non-Cancer Toxicity Criteria of Metals and Metalloids (Chronic TC_{oral})(OEHHA Chemicals Library; USEPA IRIS; USEPA PPRTV)

Chemical (Symbol)	Chemical Basis	Chronic TC_{oral} mg per kg per day	Oral Target Organ System	Reference
Aluminum (Al)	Al lactate	0.018	General	OEHHA
Antimony (Sb)	Sb potassium tartrate	0.00014	Alimentary tract	OEHHA
Barium (Ba)	Unspecified	0.07	Hematological	OEHHA
Beryllium (Be)	Be sulfate tetrahydrate	0.002	Alimentary tract	OEHHA
Cadmium (Cd)	Unspecified	0.00006	Urinary	OEHHA
Chromium (Cr)	$Na_2Cr_2O_7$, Cr VI	0.0002	Alimentary tract	OEHHA
Cobalt (Co)	Unspecified	0.0003	General	USEPA PPRTV

Chemical (Symbol)	Chemical Basis	Chronic TC_{oral} mg per kg per day	Oral Target Organ System	Reference
Copper (Cu)	Unspecified	0.14	Alimentary tract	OEHHA
Lead (Pb)[a]	Unspecified	0.0001	Neurodevelopmental	OEHHA
Manganese (Mn)	Unspecified	0.14	Nervous	USEPA IRIS
Molybdenum (Mo)	Unspecified	0.005	General	USEPA IRIS
Selenium (Se)	Unspecified	0.005	General, Nervous	OEHHA
Strontium (Sr)	$SrCO_3$	0.6	General	USEPA IRIS
Thallium (Tl)	Tl_2SO_4	0.00001	General, Alimentary tract	OEHHA
Tin (Sn)	Stannous chloride	0.03	General	OEHHA
Vanadium (V)	$NaVO_3$	0.00007	Urinary	USEPA PPRTV
Zinc (Zn)	Unspecified	0.3	General	USEPA IRIS

[a] See text above regarding lead toxicity criterion

4.6.3. Lifetime Oral Exposure to Carcinogenic Metals and Metalloids

There were three carcinogenic metals and metalloids for consideration for the oral route: arsenic, chromium (as Cr (VI)), and lead. The oral cancer slope factors (CSF_{oral}) these chemicals were established by OEHHA and are provided below in (Table 4-17). Appendix section E.2.3.11 provides additional details and sources of the values.

Table 4-16. Human Cancer Slope Factors for Lifetime Oral Exposure to Carcinogenic Metals and Metalloids (CSF_{oral})

Chemical (Symbol)	Chemical Basis	CSF_{oral} $(mg\ per\ kg\ per\ day)^{-1}$	Tumor Organ System
Arsenic (As)	Unspecified	9	Respiratory, Urinary
Chromium (Cr)	Chromium VI	0.5	Alimentary tract
Lead (Pb)	Lead	0.0057	Renal

4.7. Summary

OEHHA used available information and health-protective approaches in compiling the toxicity criteria and cancer slope factors to be used in the risk assessment of human exposure to chemicals at synthetic turf fields. Toxicity criteria for many were chemical-specific either established by OEHHA, USEPA, and ATSDR; or derived new as screening values for this study from dose response data in toxicity studies. However, for many chemicals, the toxicity criteria were from structural analogs. Route-to-route extrapolation to estimate inhalation toxicity criteria from oral studies and vice versa was applied in several instances for chemicals when the reference criterion was based on systemic effects.

All the cancer slope factors (CSFs) are chemical-specific, except for three PAHs. For these PAHs, information is available to establish potency equivalency factors (PEFs). These PEFs were applied to derive the CSFs from BaP.

4.8. References

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Chapter 5. Exposure Characterization

5.1. Background

Across California, there are over 900 synthetic turf fields with crumb rubber infill[1]. These fields hold various team sport events like soccer and football. Currently, approximately more than 228,000 soccer athletes are represented by northern and southern California soccer associations[2]. The study focused on examining the exposure of soccer players (athletes) and other soccer-related participants (coaches, referees, and spectators), due to the popularity of soccer in California among all genders, and close and frequent contacts of players with the field surfaces. Since soccer can be a life-long sport for some participants, exposure duration of players on synthetic turf fields can span from a few years to decades. Taken together, OEHHA determined soccer to be an appropriate surrogate for athletic activities on synthetic turf fields.

In order to evaluate the exposure of soccer players and other users of synthetic turf fields, their activities and exposure patterns had to be characterized. To do this, OEHHA collaborated with the University of California, Berkeley (UCB) and the University of Arizona (UA) to conduct three Time-Activity Studies (TAS, referring to all three studies):

- TAS Survey: OEHHA surveyed soccer players' activity patterns, histories, and behaviors at the field (Appendix Section F.2).
- TAS Observation Study: UCB and OEHHA videotaped volunteers during soccer practices or games at selected synthetic turf fields in Northern California. Researchers at UA translated these video footages into micro-level activity time series (MLATS) data— type and frequency of activities and behaviors occurred on and off fields (Appendix Section F.3).
- TAS Archive Study: UA translated video footage into MLATS data of an archived studies of behaviors of young children during play (Appendix Section F.2).

These studies are described in Section 5.3 below.

OEHHA applied the survey and MLATS data to derive model parameters for various exposure scenarios (Appendix Sections B.2 to B.5) such as field play by athletes of various ages. An overview of how these parameters were estimated is also provided in Section 5.3 below. The parameters were used to estimate the levels of chemical exposures in this chapter. Section 5.4 provides an overview of how these parameters

[1] OEHHA compiled our Synthetic Turf Field Database (last updated March 2017) with data collected by the California Department of Resources Recycling and Recovery (CalRecycle). The database does not include sports fields on federal facilities, fields not reported to CalRecycle by installers, or fields that did not receive funding from CalRecycle.

[2] Estimated number of soccer athletes based on data from Cal North (https://www.calnorth.org/parent-guide) and Cal South (https://calsouth.com/what-we-do/).

were integrated with the concentration data measured in air samples and biofluids to estimate exposure to spectators and athletes of various ages, coaches and referees. These exposures were used to assess the associated human health risks for these groups in Chapter 6.

5.2. Synthetic Turf Exposure Model: Exposure Scenarios

OEHHA developed an exposure model describing scenarios of human exposure to chemicals released from crumb rubber infill of synthetic turf fields (Figure 5-1). The model describes the potential exposure pathways by which for athletes, coaches, referees and spectators are exposed through the inhalation, dermal, and ingestion routes. For example, it illustrates how gases from synthetic turf are released into the air and breathed in by all four types of human receptors (athletes, coaches, referees and spectators).

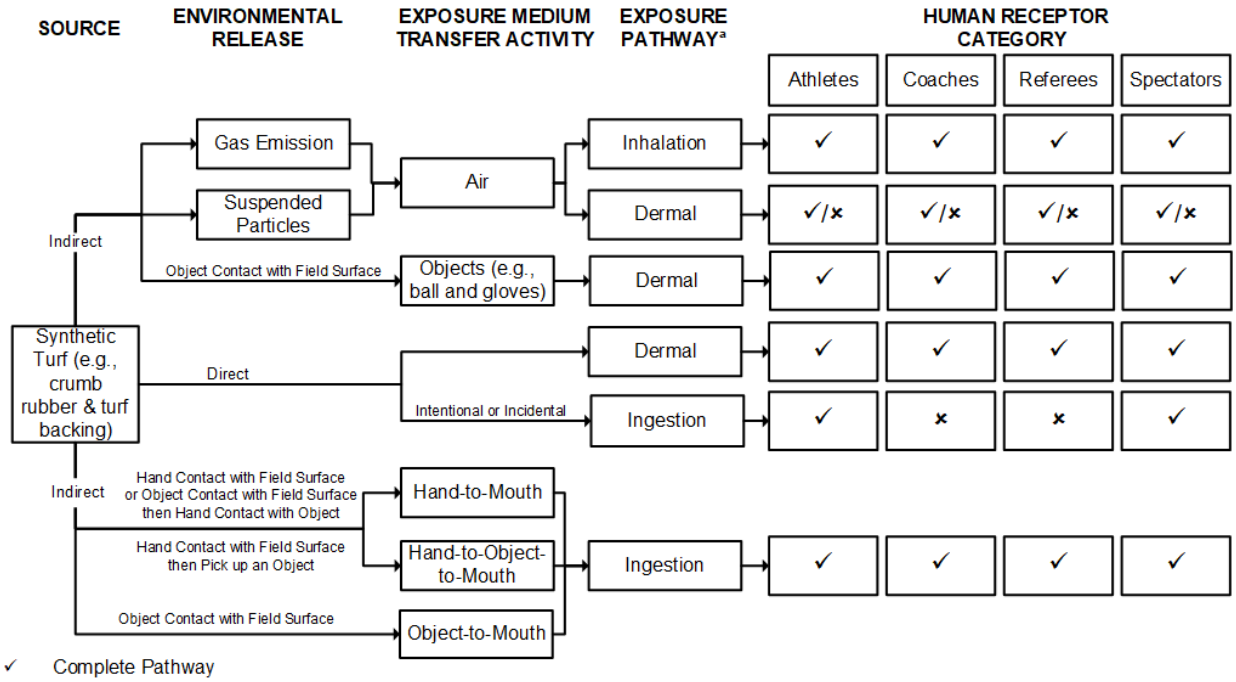

Figure 5-1. Exposure Model: Transfer of Chemicals from Crumb Rubber, via Exposure Pathways, to Human Receptor Categories

5.2.1. Exposure Sources

Synthetic turf fields often contain three major structural parts: synthetic grass blades, backing materials, and crumb rubber infill. This study focuses on the exposure people have to chemicals in crumb rubber infill, for example, when chemicals, which have varying volatility, evaporate from the infill and are breathed in.

Although, windblown dust particles, or surface water runoff from the field may lead to

exposures for off-field spectators, these are expected to be significantly lower than the other exposures scenarios. The model shown in Figure 5-1 and the exposure discussions and evaluations in this report do not cover these off-field exposures. The scope of this study also does not cover ecological receptors, thus did not analyze, for example, runoff to streams potentially resulting in exposure of fish to toxic metals and organic chemicals.

5.2.2. Receptor Categories

Athlete, coach, referee, and spectators are the primary receptor categories on synthetic turf fields. OEHHA adopted the following age groups to represent the individuals in the spectator category: third trimester fetus in pregnant women, 0<2, 2<6, 6<11, 11<16, 16<30, 30<40, 40<50, and 50<70 years. However, all these age groups were not considered for other categories, such as athletes. Table 5-1 shows the age groups considered for each receptor category.

We chose these age groupings based on the rapidly changing physiology of young children, and differences in activity and behavior patterns among children and adults of different ages. These factors may affect a receptor's exposure level, due for example to different breathing rates during playing the game, while watching it or hand to mouth activity. Appendix Section B.2 provides a discussion of the age groupings in the context of exposure parameter selection. Based on the results of the TAS (Appendix Sections F.2 and F.3), we developed age-specific exposure parameters for each receptor category. We also used survey information to inform our exposure framework, such as the age intervals for the assessment. Appendix Section B.2 to Section B.5 describe the development of exposure parameters for each receptor category, age group, and exposure pathway. The following sections briefly discuss the four receptor categories.

Table 5-1. Age Groups Considered for Exposure Assessment for Each Receptor Group

<table>
<tr><th rowspan="2">Age Group</th><th colspan="4">Exposure for age group assessed?</th></tr>
<tr><th>Athletes</th><th>Coaches</th><th>Referees</th><th>Spectators</th></tr>
<tr><td>Third trimester fetus</td><td rowspan="2">No</td><td rowspan="4">No</td><td rowspan="4">No</td><td rowspan="9">Yes</td></tr>
<tr><td>0<2 years</td></tr>
<tr><td>2<6 years</td><td rowspan="7">Yes</td></tr>
<tr><td>6<11 years</td></tr>
<tr><td>11<16 years</td></tr>
<tr><td>16<30 years</td><td rowspan="3">Yes</td><td rowspan="3">Yes</td></tr>
<tr><td>30<40 years</td></tr>
<tr><td>40<50 years</td></tr>
<tr><td>50<70 years</td></tr>
</table>

5.2.2.1. Athletes

Athletes are soccer players, from ages 2 to 70 years, who take part in soccer practices and games in a seasonal or year-round schedule. Athletes on organized soccer teams can play in one or multiple positions (forward, mid-fielder, defense or wingback, and

goalkeeper). There are different activity characteristics among these soccer positions, leading to different levels of exposure. In the TAS Observation Study, scientists at the UA quantified the micro-and macro-activities among the different positions. The TAS Survey also provides self-reported physical data such as bodyweight and soccer activity data for athletes. OEHHA used these TAS results to estimate study-specific exposure parameters for athletes in various age groups (Appendix Sections B.2 through B.5).

5.2.2.2. Coaches and Referees

Coaches are late teen and adult soccer team leaders and trainers, assumed in the study to be 16 years of age or older. In addition to coaching, they often organize and lead team practices, and schedule games. They share similar exposure parameters with the athletes. Referees are game officials, also assumed to be 16 years old or older, who enforce game rules and provide arbitration on field activities. They are present during soccer games. Although the TAS did not collect coach- or referee-specific data, OEHHA used information from the athletes to estimate the values of exposure parameters for these two receptor categories.

5.2.2.3. Spectators

Spectators are typically the family or friends of athletes, who observe soccer activities from near or off the field, ranging in age from ages 0-70 years. The TAS Archive Study provides behavioral data such as hand-to-mouth activity to estimate the values of some exposure parameters for young child spectators. OEHHA used literature values to estimate the exposure parameters for adolescent and adult spectators. Additionally, we applied results from the TAS Survey, such as the number of practices and games they observed each year, to develop soccer-specific exposure data for spectators.

5.2.3. Exposure Pathways

The main pathways of human exposure to chemicals from synthetic turf fields can be grouped by routes of exposure:

- inhalation pathways: inhaling chemical vapors and airborne fine particulate matter (e.g., $PM_{2.5}$) released from crumb while participating in or watching games and practices,
- dermal pathways: direct skin contact with crumb rubber or, to a lesser extent, vapors released into the air and permeating the skin and suspended particles reaching the skin and releasing chemicals,
- ingestion pathways: direct intentional and unintentional (“incidental”) ingestion of crumb rubber or its indirect ingestion through hand-to-mouth, hand-to-object-to-mouth, or object-to-mouth behavior.

OEHHA incorporated the values for activity and behavioral parameters estimated from the TAS and the chemical concentrations measured in samples of crumb rubber and air

taken during the statewide sampling of fields (Phase 3) to derive the exposure doses and exposure concentrations for these exposure pathways (shown in Figure 5-1).

5.2.3.1. Inhalation Exposure Pathway

Inhalation exposure to crumb rubber infill results from the breathing of air that contains chemical vapors or airborne fine particulate matter released from the infill. Among all the receptor categories, OEHHA expects athletes to have the highest exposure through this pathway. Running on the field may stir up particles into the air which athletes, who have elevated breathing rates, inhale. This increased breathing rate also increase their exposures to chemical vapors released from crumb rubber. Falling or sliding of athletes on the field may also re-suspend particles into the air in the breathing zone of the athletes. Goalkeepers may have higher exposures through constant diving onto the field surface, especially during practices, as they inhale particles and chemical vapor in the air just above the field surface. Due to their higher activity levels on the field, coaches and referees also have correspondingly higher inhalation rates and thus higher inhalation exposures than spectators. Spectators have the low- to moderate-activity levels associated with sitting, standing, and cheering.

5.2.3.2. Dermal Exposure Pathways

Dermal exposure to chemicals in crumb rubber infill occurs when the adhered chemical residues permeate the skin and enter the body. This exposure can occur indirectly when the skin comes in contact with chemicals released into the air or onto objects (carriers) and take them up. These different modes of exposure are further described below.

Direct Dermal Exposure Pathway

Direct dermal exposure pathway refers to the scenario when there is direct skin contact with the field surface. Crumb rubber particles may adhere to the skin during the contact. Chemicals can migrate from the adhered particles onto the skin, where they become available for dermal uptake. Moisture or personal care products on the skin surface, like sweat and sun block, respectively, may enhance adhesion of crumb rubber particles onto the skin and facilitate transfer of chemicals across the skin.

Because of the moderate climate in California, athletes often dress lightly (short sleeve shirts and short pants) during outdoor practices and games. Their uncovered arms and legs can come into direct and frequent contact with the field surfaces during warm-up exercises (e.g., sit-ups and push-ups); while pushing off the field with hands to maintain balance or get up after a fall; and when lunging, jumping, and falling repeatedly on the field. Goalkeepers may be especially exposed.

While coaches routinely spend time on the field, they have less skin contact with the field compared to athletes. They seldom fall and do not dive onto the turf like athletes. They typically stand on the sidelines of the field during the entire game. Similarly, referees have less direct dermal contact with the field surface. However, some level of

dermal exposure can occur for the coaches and referees, as crumb rubber can get into the shoes and under the socks during walking or running on the field.

Spectators may sit directly on the field surface to watch the practices or games. Toddlers and young children may play, crawl around, or roll on the field. They may also play with the crumb rubber. As a result, the spectators' hands, legs, and other body parts can be in frequent or continual contact with the field surface during a soccer event.

Indirect Dermal Exposure Pathways

Dermal exposure may also occur indirectly through deposition of chemicals from the air to the skin. On hot days, the temperature can enhance the release of VOCs and SVOCs from the field into the air. Dermal exposure to VOCs and SVOCs is expected to be much smaller by this pathway compared to direct inhalation exposure (OEHHA, 2000). Ball kicking, running, and tackling activities, during soccer practices and games, may also agitate the field surface and disperse crumb rubber particles into the air. The resulting airborne fine particles may also settle onto the skin of players, where the chemicals may be absorbed by the skin and eventually into the body. Athletes, coaches, referees, and spectators may have continuous indirect dermal exposure of chemicals via this mechanism as well. However, the magnitude is expected to be minor compared to that resulting from direct dermal contact with the field. Because the indirect dermal exposure pathways for vapor and deposition of particles on skin were assumed to be minimal in comparison with other pathways, they were not further assessed.

However, indirect dermal exposure may occur through transfer of chemicals or particles to the skin by an object. Objects such as soccer balls, soccer gloves, and shoes are in constant or frequent contact with the field surface. The interactions between these objects and the field surface lead to transfer of chemicals or fine particles onto the objects. Subsequent dermal contact with these objects may transfer the adhered chemicals or particles from the objects to the skin where they can be absorbed into the body. This indirect dermal pathway can occur for all human receptor categories. Hands, lower legs, and forehead of the athletes can in frequent contact with these objects before, during, and after practices or games: athletes head the ball to score, handle or get hit by the balls, put on and take off shoes and gloves. Coaches and referees often have dermal contact as they handle balls and remove and put on their shoes. Spectators can be exposed this way, for example, by assisting in handling soccer equipment, playing with the soccer equipment after the practices or games, or picking up their water bottles left on the field.

5.2.3.3. Ingestion Exposure Pathways

Ingestion exposure occurs when particles of any size get in the mouth and are ingested. Ingestion of particles while engaging in activities on synthetic turf fields can happen either by direct or indirect pathways.

Direct Ingestion Exposure Pathways

Direct ingestion exposure pathways consist of intentional ingestion and unintentional incidental ingestion. OEHHA assumed the direct ingestion exposure pathways to occur for athletes of all ages and young spectators (0 to <2 and 2 to <11 age groups), but not for coaches, referees, or adult spectators.

Intentional ingestion exposure occurs when someone knowingly or purposefully eats crumb rubber. OEHHA did not anticipate intentional ingestion behaviors to be a significant exposure pathway for adult spectators, athletes, coaches, and referees. However, toddlers and young child spectators may crawl around on and play with the crumb rubber on the sidelines of the field during sport events. Some young children may intentionally ingest varied amounts of crumb rubber in a sport event. Uncommonly, this pathway may be important for young children, particularly those who exhibit pica behavior.

Incidental ingestion of crumb rubber occurs when particles accidently enter the mouth and are swallowed. OEHHA assumed that this pathway occurs for athletes of all ages. Falling onto the field or diving onto the field surface while playing soccer agitates the field and disperses particles of various sizes into the air. Athletes may incidentally ingest these airborne particles. This may be an especially important exposure pathway for goalkeepers, who often lunge across the goal to block the ball and often land face-down onto the field surface. OEHHA deemed this direct ingestion pathway unimportant for coaches, referees, and adult spectators, since they seldom fall or dive onto the field.

Indirect Ingestion Exposure Pathway

Indirect incidental ingestion occurs via carriers (e.g., hands or objects): chemicals or particles transferred from the field to carriers eventually enter the mouth via the following mechanisms:

- hand-to-mouth (HTM)
- object-to-mouth (OTM)
- hand-to-object-to-mouth (HTOTM)

OEHHA considered the indirect ingestion exposure pathway to occur for all receptor categories and in all age groups. However, the exposure level may vary greatly among the age groups and individuals.

Hand-to-Mouth Behaviors. Hands or fingers may come into direct contact with the field, or indirectly via objects that have contacted with the field, and then through touching transfer material to the mouth or the peri-buccal area. Hand-to-mouth behaviors can directly or indirectly transfer fine particles and chemical residues from the field and onto the face or into the mouth.

All receptors of all ages may engage in HTM behaviors, although the frequency can vary. Common examples of the HTM behaviors observed on the field are toddler and

young child spectators crawling on the sidelines of the field or playing with crumb rubber and then sucking their fingers. Athletes or spectators may bite their fingernails, touch their mouth (e.g., braces or mouth guard) or face (or teammate's face), or use their hands to wipe away sweat on their face. Coaches and referees may touch their face with their hands after touching the soccer ball and transfer chemical residues or fine particles to the mouth or the peri-buccal area.

Object-to-Mouth Behaviors. Objects may come into contact with the field and then be put into the mouth or they may touch the peri-buccal area. The object acts as a carrier that may transfer fine particles or chemical residues from the field into the mouth. OEHHA considered OTM behaviors to occur for all receptor categories.

There are a number of common examples of OTM behaviors. To take their gloves off, some goalkeepers grab their gloves with their teeth. Athletes use their clothes to wipe away sweat on their face. Athletes or spectators leave their water bottles on the field and drink through the drinking spouts that have come into contact with the field. Mouthing behaviors include touching the face or mouth with objects or putting them into the mouth, as well as licking, sucking, chewing, and biting are common in young children and adolescents (Groot *et al.*, 1998). Coaches and referees accidentally drop their whistles on the field and may blow through the uncleaned whistles.

Hand-to-Object-to-Mouth Behaviors. Hands may come into contact with the field, which then pick up an object and the object may then be put into mouth. Hand-to-object-to-mouth activities involve indirectly transfer of fine particles or chemical residues from the field via the hand, to a carrier object and then into the mouth when the carrier touches to or near the mouth. This exposure pathway involves two carriers, the hand and then the object. OEHHA anticipated the level of exposure from each event of HTOTM to be lower than that of HTM or OTM. Similar to the HTM pathway, we considered the HTOTM exposure pathway to occur for all receptor categories.

Mouthing behaviors are common in toddlers and young children. They may touch the field or crumb rubber and use their unwashed hands to pick up an object, such as a pacifier or a toy, and ultimately put the objects into their mouth. Athletes and spectators may touch the field surface and then handle food with their unwashed hands (OEHHA, 2012), or touch the drinking spout of their water bottles and drink through it. Spectators may put arms of their sunglasses into their month while watching a practice or game.

Coaches or referees may exhibit HTOTM behaviors (e.g., blowing a whistle). Even though coaches and referees rarely have direct dermal contact with the field surface, indirect ingestion exposure may still occur through a sequence of events such as indirect dermal exposure activity (touching an object that had contact with the field surface) followed by a HTOTM activity (coach or referee holds the ball and then picks up the whistle and blows). Depending on the frequency of these event sequences, individuals may have various levels of exposure through the indirect ingestion pathway.

5.3. Development of Exposure Parameters

5.3.1. Time-Activity Studies (TAS) to Estimate Exposure Parameters

This section describes the three Time Activity Studies (TAS) used to characterize the activity patterns and exposure of soccer players, coaches, referees and spectators – the survey of soccer players, field observational study, and study analyzing of the archived video recordings of children playing. These studies focused on soccer activities occurring on synthetic turf fields with crumb rubber infill. These studies enhanced OEHHA's understanding of the models of exposure discussed in Section 5.2, and enabled the derivation of soccer-specific exposure parameters that were incorporated with chemical analysis results to estimate levels of chemical exposures, which in turn were used to derived human health risk for athletes, spectators, coaches and referees of various ages.

OEHHA and its UCB and UA collaborators utilized two approaches to obtain the time-activity data of soccer players:

- a survey of players, which is reported in full in Appendix Section F.2, and
- field observation of games and practices, study reported in full in Appendix Section F.3, and on archived video, study reported in full in Appendix Section F.2.

We received approval from the Institutional Review Boards of the State of California (i.e., Committee for the Protection of Human Subjects) for the UCB, and the UA to conduct these studies according to the authorized human subject protocols.

5.3.1.1. TAS Survey of the Soccer Players

UCB in collaboration with OEHHA conducted an online or in-person survey of soccer players in California that played on synthetic turf fields with crumb rubber infill. The online survey is described at length in Appendix Section F.1.2.3, and the similar in-person survey in Appendix Section F.1.2.4. Participants were aged 4 through 71. The goal was to collect information on roughly 1,000 players to inform parameter estimates related to, for example, duration of exposure and frequency of exposure, breathing rates during play, and the potential for dermal and ingestion exposures. Parents of soccer players under the age of 18 were invited to complete the online survey for their child. For the in-person survey, parent/guardian was asked to complete the questionnaire for participants younger than 14 years.

With these surveys, we gathered information on soccer activities of players engaged in during practices and games, and the types of direct contact they had with the field. Activities of interest included on- and off-field activities such as soccer drills, dive or fall on the field, snacking or drinking, and other activities on the sidelines that might result in exposure. Also, the Survey requested information on the frequency of practices or games, types of uniforms worn, personal hygiene practices, and soccer history of the

participating players.

Researchers at the UCB recruited soccer players for the in-person interviews through contacting soccer coaches and team managers in the Sacramento and San Francisco Bay Areas. Additionally, they solicited players and parents of players to participate in the online survey through contacting coaches and team managers of soccer clubs in California.

Overall, we received 1,029 on-line questionnaires and 40 completed in-person questionnaires. The participants with in-person questionnaires were also videotaped (see next section).

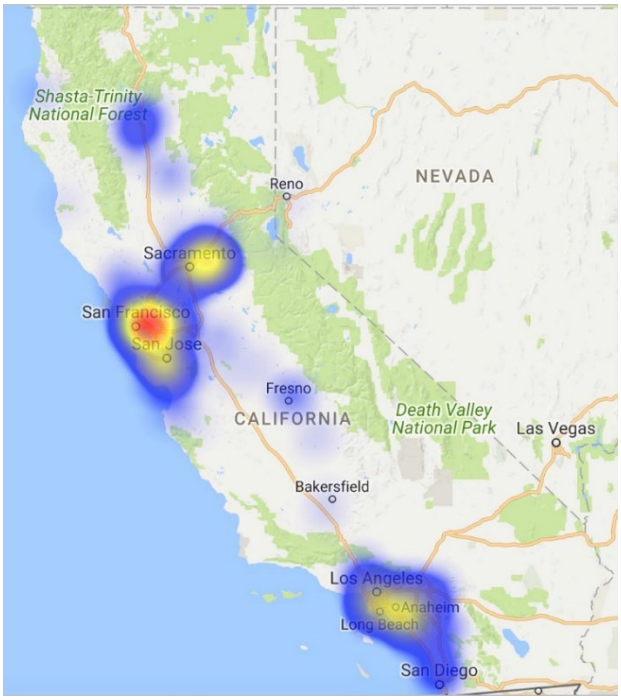

Figure 5-2. Heat Map of Zip Code Reported by Online Survey Participants

Figure 5-2 is a heat map of the residential zip code reported in the online survey. The majority of the survey respondents were located in the San Francisco, Sacramento, Los Angeles, and San Diego metropolitan areas. These are the California regions with the greatest population, and where most of the synthetic turf field with crumb rubber infill are located. See Section 2.3.1.

Results of the online and in-person surveys are presented in Appendix Section F.1.3.

OEHHA compiled and analyzed responses to the questionnaires to estimate several of the exposure parameters. Appendix Sections B.2 to B.5 provide details of parameter development.

5.3.1.2. TAS Field Observation Study of Players during Soccer Games and Practices

UCB and OEHHA videotaped 40 consenting soccer players during events and translated the videos into MLATS data. The players videotaped also completed the in-person surveys discussed above. Activities occurring both on and off field were recorded. Appendix Section F.1.2.4 describes the methods used.

Players were videotaped during five practices and five games. On average, we videotaped four participants per event, one for each of the four soccer positions: forward, defender, midfielder, and goalkeeper. For each event, we continuously videotaped the participants from the time they entered the field until they left the field at the conclusion of a soccer event. Thus, on and off field activities of these players were captured. Table 5-2 summarizes players videotaped, types of event, and positions they played.

Table 5-2. Videotaping Player and Event Summary (Total Players=40)

Event Type	Gender	Age (Years)	Positions Videotaped	Number of Players
Game	Male	9	Defender, Goalie, Variable (2)	4
Game	Female	9	Defender/Goalie, Midfielder (2)	3
Practice	Female	11-12	Defender, Defender/Goalie, Forward, Midfielder	4
Practice	Male	11-12	Forward, Goalie, Midfielder	4
Practice	Female	14	Defender/Midfielder, Forward, Forward/Goalie, Forward/Midfielder	4
Game	Male	14-15	Defender, Forward, Goalie (2), Midfielder	5
Game	Female	16-17	Defender (2), Defender/Forward/Goalie, Forward	4
Game	Male	16-18	Defender (2), Goalie, Midfielder	4
Practice	Male	19-22	Defender, Defender/Midfielder, Goalie, Midfielder	4
Practice	Female	19-21	Defender, Goalie, Midfielder (2)	4

Researchers at the UA translated the video footage using Virtual Timing Device™, videotaping methodologies and video-translation software developed at Stanford University (Beamer *et al.*, 2008; Beamer *et al.*, 2012; Ferguson *et al.*, 2006). In this way we obtained data on the duration and frequency of contacts occurring on and off the field. Briefly, while viewing the video footage on a player, the translator interacted with a video palette to record data (Appendix Section F.1.2.4.4). Every palette contained grids that represented different designations such as location, object, or contact type. The translator activated cells in each grid of the palette that correlated with the activity and contact that occurred in the video. Once the translator activated a cell, the software activated a timer to record the length of each activity and contact. Through this process,

the software captured the activity data and translated video footage into contact frequencies and durations for the types of contacts examined. The translator repeated this recording step to gather data for all the body parts and the types of contact of interest.

OEHHA used the activity data to develop parameters used in the exposure assessment. For example, the dermal contact frequencies with turf fields were used in the assessment of hand-to-mouth ingestion and to evaluate surface area estimates for dermal contact could be derived (Appendix Section B.4.1.1).

5.3.1.3. TAS Archived Video Study of Young Children

UA reviewed and translated video footage from previous studies on children in outdoor settings:

- Outdoor Residential Exposure Task Force Project: 36 children aged 1-12 years were videotaped for 2 hours in a primarily outdoor residential environment to examine mouthing frequency, contact duration, mouthing contacts with hands and non-dietary objects (AuYeung *et al.*, 2006; AuYeung *et al.*, 2004; Ferguson *et al.*, 2006).
- USEPA study from the years 1998-2000: 20 children aged 1- 6 years were videotaped for 2 hours to examine contact activity of the hands and mouth in a primarily outdoor residential environment (Beamer *et al.*, 2012; Ferguson *et al.*, 2006).

The videotapes covering the 56 children playing were watched and footage was analyzed where children were playing on turf or a playground. The same methodologies as used for the TAS Observation Study (Section 5.3.2) were used to gather MLATS data on the hand-to-mouth activity of young children playing outdoors. OEHHA used these data to develop indirect ingestion exposure parameters for child spectators on the synthetic turf field sidelines.

The UA report of this study is reproduced in full in Appendix Section F.2.

5.3.2. Information from the Literature to Estimate Exposure Parameters

Some parameters such as breathing rates were constructed from survey information and values in the published literature. For example, in deriving breathing rates, survey and videotape information on exertion levels was used in concert with published OEHHA guidance values for breathing rates at different levels of exertion (OEHHA (2012), See Table 5-3). This was done to derive overall breathing rates for different receptor groups at different ages.

Table 5-3. Mean One-Hour Breathing Rates for Different Activity Levels[a]

Age Group	Breathing rate (cubic meters per hour)			
	Resting Activity	Light Activity	Moderate Activity	High Activity
0<2 years	0.23[a]	0.58	1.06	Not applicable[b]
2<6 years	0.26	0.68	1.25a	2.24[a]
6<11 years	0.37	1.04	1.49	3.87
11<16 years	0.46	0.96	1.26	5.37
16<70 years	0.41	1.38	2.35	8.43

[a] See Appendix Section B.5.3 for explanation.
[b] Individuals 0<2 years of age were assumed not to engage in high intensity activities (OEHHA, 2012).

Another example of adoption of literature values is OEHHA's use of direct ingestion rates for crumb rubber from assumptions in published risk assessment reports for crumb rubber from the (European Chemical Agency, 2017; National Institute for Public Health and the Environment, 2017).

See Appendix Sections B.2 to B.5 for further examples on how the literature was used to develop parameter values.

5.3.3. Exposure Parameters Estimated

OEHHA analyzed and incorporated data from the literature and the three TAS described above to develop the exposure parameters used in estimating chemical exposures from crumb rubber infill. The approach to parameter estimation is described in Appendix Section B.1.

For athletes, coaches, referees and spectators of different ages, parameter values assigned included the following:

- Bodyweight
- Event frequency: Number of events participated in annually
- Event time: Amount of time spent on or near the field during an event
- Annual event time: Hours per year of exposure
- Route specific factors
    - Breathing rates, dependent on age and exertion level during events
    - Skin surface area of specific parts of the body
    - Adherence factor to skin
    - Absorption factor by inhalation, oral and dermal routes
    - Crumb rubber ingestion rate per hour for hand-to-mouth, object-to-mouth, and hand-to-object-to mouth activities

See Appendix Sections B.2 to B.5 for details.

5.4. Exposure Assessment

The objective of the exposure assessment is to estimate the doses and concentrations

resulting from crumb rubber infill that soccer players, coaches, referees and spectators experience. These estimates are then used in non-cancer and cancer risk calculations for these groups. OEHHA incorporated data from the three Time Activity Studies described above and from the literature to develop exposure parameters to use in the exposure calculations, described in Section 5.3 above. These exposure calculations take into account the variety of pathways by exposure to chemicals from crumb rubber infill can occur to these four receptor groups, described in Section 5.2.

Measurements of chemicals in biofluids, described in Chapter 3, are combined with parameter estimates (e.g., receptor specific ingestion rates) to derive average daily doses (ADD) received by ingestion and dermal routes for receptors of different ages. Similarly, concentrations of chemicals measured in air on the fields are appropriately adjusted using parameters of duration of exposure and other considerations to derive concentrations to represent acute, one-day, and chronic inhalation exposures for the different receptor groups.

Exposure estimates depend on the type of toxicity being assessed. For this study, OEHHA adopted the term “general chemicals” for chemicals with their most sensitive non-cancer effect being neither sensory irritation nor DART. This was necessary because different exposure assumptions (e.g., exposure frequency and exposure duration) were applied in the exposure calculations for general chemicals compared to sensory irritants and DARTs (see Sections 5.4.2 and 5.4.3). Exposures to DARTs are assessed as a one-day exposure, whereas sensory irritants and general chemicals are assessed on a chronic exposure basis (see Section 5.4.4). For each carcinogen, a lifetime average exposure dose is derived, and age sensitivity factors are used to account for enhanced susceptibility to carcinogens early in life (OEHHA, 2012).

For the study, the following groupings were employed:

- one-hour acute exposures for acute toxicity assessment
- one-day exposures to developmental and reproductive toxicants (DART)
- chronic exposures to sensory irritants
- chronic exposure to general chemicals (most sensitive non-cancer endpoint neither sensory irritation nor DART)
- lifetime exposures to carcinogens

This section describes the approaches used to estimate exposure concentrations and doses for each of these exposure classes, for the different pathways of exposures, receptors and age groupings.

5.4.1. One-Hour Acute Exposures

Acute, high exposures to several of the detected chemicals in air can lead to adverse health outcomes on the respiratory and circulatory systems and eyes (see Chapter 4, Table 4-3). To assess the risks of acute inhalation exposure, OEHHA has developed

reference concentrations that apply to chemical exposures for one hour on an intermittent basis (OEHHA, 1999).

In this study, we collected samples sequentially over one-hour periods for VOCs and carbonyls, and over a three-hour period for SVOCs (see Section 2.3.2.3). To represent the acute concentration (Acute C_{inh}) for assessing acute toxicity, we took the maximum concentration of each chemical measured in air at any of the 35 synthetic turf fields during soccer activities ($C_{air\text{-}max}$). Thus, the acute concentration, Acute $C_{inh,}$ that represents an acute exposure to a chemical via inhalation pathway is simply given by:

$$\text{Acute } C_{inh} = C_{air-max} \qquad \text{Equation 5-1}$$

where,

$C_{air\text{-}max}$ = maximum one-hour concentration of a chemical detected in air on- or off-field, among the 35 fields in the study, micrograms per cubic meter

Table 5-4 provides these concentrations (see also Appendix Section B.3.4.1). Samples were collected at on- and off-field locations. The Acute C_{in} in the on-field column in Table 5-4 represents the maximum concentration of the chemical detected in a single sample at any of the 35 fields at on field locations ($C_{air\text{-}max}$) during soccer activities. The off-field Acute C_{inh} is similarly the $C_{air\text{-}max}$ at the off field locations for any of the fields.

Table 5-4. Acute Concentrations of Chemicals in Air (Acute C_{inh})[a] at On- and Off-Field Locations

Chemical[b]	CASRN	Acute C_{inh}, micrograms per cubic meter air	
		On Field	Off Field[c]
Field-Related Chemical			
Styrene	100-42-5	1.6	1.4
Non-Field Related Chemicals			
Acetaldehyde	75-07-0	9.7	not sampled
Benzene	71-43-2	3.7	3.5
2-Butanone	78-93-3	1.9	not sampled
2-Butoxyethanol	111-76-2	1.0	0.48
Formaldehyde	50-00-0	17	not sampled
Phenol	108-95-2	0.21	0.21
Tetrachloroethylene	127-18-4	0.42	0.42
Toluene	108-88-3	12	10
m/p-Xylene	106-42-3	5.2	5.2
o-Xylene	95-47-6	2.1	2.0

[a] Acute C_{inh} is the maximum concentration measured in any of the 35 fields. See text for explanation.
[b] Only chemicals assessed for acute non-cancer hazard are shown in the table.
[c] Selected carbonyls were not sampled at off the field locations. See Section 2.3.2.3,
CASRN: Chemical Abstracts Service Registry Number. Values are rounded to two significant figures.

Acute doses via ingestion and dermal routes are not presented in lieu of the one-day and chronic exposure and risk analyses. See Section 6.2.2 for further explanation.

5.4.2. One-Day Exposures to DART

As a precautionary measure, OEHHA compares one-day exposures to DART reference values in this study, even when the values are taken from chronic reference levels under the EPA IRIS or CA Toxic Hot Spots programs, as discussed in Section 4.2.4. This was done instead of comparing an annual average concentration to the reference concentrations or reference doses. This worse case assumption was used to screen for potential DART hazard. Where hazards are identified, further analyses will be undertaken to consider their significance.

For all exposure pathways, the chemical concentration used to assess one-day DART exposures is the average concentration detected on an individual field which represents a single sampling event. OEHHA chose not to use the average across the 35 fields due to the low likelihood that an individual would travel to all the sampled fields in a single day.

5.4.2.1. One-Day DART Inhalation Concentration: $C_{inh\text{-}DART\text{-}field}$

OEHHA derived field-specific exposure concentrations for one-day inhalation exposure to a DART ($C_{inh\text{-}DART\text{-}field}$, Equation 5-2). This was done by multiplying the measured air concentration of the chemical for the field ($C_{air\text{-}field}$) by an adjustment factor ($AF_{inh\text{-}DART}$) to account for the length of time for the event and other factors such as receptor breathing rates during an event:

$$C_{inh-DART-field} = C_{air-field} \times AF_{inh-DART}$$ Equation 5-2

where

$C_{air\text{-}field}$ = field-specific average concentrations of a DART in air, in nanograms per cubic meter air. Concentrations on- and off- field, are provided Appendix Section D.4.2.3.

$AF_{inh\text{-}DART}$ = adjustment factor that accounts for breathing rate and duration of exposure during the event, for a receptor category in an age group, unitless, provided in Table 5-5.

The above equation provides $C_{inh\text{-}DART\text{-}field}$, in units of nanograms per cubic meter air. It can be expressed in units milligrams per kilogram bodyweight per day by dividing by 1,000,000. For a full discussion on the derivation of the values for $C_{inh\text{-}DART\text{-}field}$ for the different fields see Appendix Section B.3.4.2.

Values for $C_{inh\text{-}DART\text{-}field}$ for the various fields are given in Appendix Section F.4.4.

Table 5-5. $AF_{inh\text{-}DART}$ (unitless) for Different Receptors Categories at Different Ages

Age Group (Years)	Athletes	Spectators	Coaches	Referees
Third trimester fetus	Not applicable	0.049	Not applicable	Not applicable
0<2		0.40		
2<6	0.73	0.21		
6<11	0.55	0.20		
11<16	0.46	0.086		
16<30	0.68	0.057	0.29	0.27
30<40	0.45	0.050	0.25	0.23
40<50	0.45	0.050	0.25	0.24
50<70	0.49	0.050	0.25	0.24

Values are rounded to two significant figures.
Appendix Sections B.3.4.2 and F.XX describe the calculation of $AF_{inh\text{-}DART}$ from the TAS data.

5.4.2.2. One-Day DART Average Dose for Dermal Pathways: $AD_{der\text{-}DART\text{-}field}$

The calculation of the amount of a chemical in crumb rubber that is received by dermal pathways accounts for the amount of crumb rubber adhered on the skin during an event. This is referred to as the dermal loading, or DL, and is discussed at length in Appendix Section B.4.1. Multiplying this amount by the measured concentration of the chemical in simulated sweat – that is the "bioaccessible concentration" ($C_{der\text{-}crumb\ rubber\text{-}field}$, Section 3.2.4) – provides an estimate of the amount of chemical in crumb rubber that is taken up by the body during the event. To express this in terms of a dose, this is then divided by the bodyweight of the receptor coming into dermal contact with the crumb rubber. A factor can also be applied to account for the fraction of the bioaccessible concentration that is absorbed into the body (see Appendix Section B.4.3). However, in this screening assessment absorption it is conservatively assumed to be 100%. Finally, it is assumed that receptors are exposed during one event on any given day.

Thus, $AD_{der\text{-}DART\text{-}field,}$ the average one-day dose of chemicals in crumb rubber infill resulting from dermal contact, is given by Equation 5-3. It is specific to the ages of athletes and spectators.

$$AD_{der-DART-field} = \frac{DL \times C_{der-crumb\ rubber-field}}{BW} \qquad \text{Equation 5-3}$$

where,

DL = mean total loading of crumb rubber particles on the skin in an event, in grams per event, given in Table 5-6 for the various groups

$C_{der\text{-}crumb\ rubber\text{-}field}$ = field-specific average dermal bioaccessible concentration in artificial sweat extracts of crumb rubber, nanograms chemical per gram crumb rubber (tabulated in Section 3.2.4)

BW = bodyweight of an age group, kilograms, given in Table 5-7.

Similar to inhalation exposure, the resulting $AD_{der\text{-}DART\text{-}field}$ is expressed in units nanograms per kilogram bodyweight per day. It can be expressed in units milligrams per kilogram bodyweight per day by dividing by 1,000,000. Values for $AD_{der\text{-}DART\text{-}field}$ are summarized in Appendix Section F.5.2.

Table 5-6. Synthetic Turf Study Mean Dermal Loading (DL), in grams Crumb Rubber per Event

Ages (years)	Athletes	Spectators	Coaches, Referees
Third trimester fetus[a]	Not applicable	0.072	Not applicable
0<2		0.048	
2<6	0.077	0.077	
6<11	0.11	0.11	
11<16	0.14	0.14	
16<30	0.17	0.078	0.083
30<40	0.18	0.084	0.089
40<50	0.18	0.083	0.089
50<70	0.18	0.083	0.089

Appendix Section B.4.1 describes the equation, TAS survey data, and assumptions used to calculate the dermal load for each group. Values are rounded to two significant figures.

Table 5-7. Mean Bodyweight (BW, kilograms)[a] used in the Synthetic Turf Study

Age Group	Mean BW
Third trimester fetus[b]	75.6
0<2 years	9.4
2<6 years[c]	20.5
6<11 years	32.0
11<16 years	48.7
16<30 years	65.8
30<40 years	75.3
40<50 years	74.5
50<70 years	74.3

[a] Appendix Section B.2.2 provides the details on the derivation of bodyweights used in this study.
[b] To evaluate exposure to third trimester fetuses, the BW of third trimester pregnant women is used, as discussed in Appendix Section B.2.2.

5.4.2.3. One-Day DART Average Dose for Ingestion Pathways: $AD_{ing\text{-}DART\text{-}field}$

To calculate the amount of a chemical received by ingesting crumb rubber, the measured bioaccessible concentration for the chemical ($C_{GI\text{-}crumb\ rubber\text{-}field}$) is multiplied by the amount of crumb rubber ingested during the event. To express this in terms of a dose, this is then divided by the bodyweight of the receptor consuming the crumb rubber. A factor can also be applied to account for the fraction of bioaccessible concentration that is absorbed into the body (see Appendix Section B.5.2). However, in this screening assessment absorption is conservatively assumed to be 100%. Finally, it is assumed that receptors are exposed during one event on any given day.

Thus, $AD_{ing\text{-}DART\text{-}field,}$ the average one-day dose for ingestion of chemicals in crumb rubber infill, is given by Equation 5-4, and calculated separately for receptor groups of different ages:

$$AD_{ing-DART-field} = \frac{C_{GI-crumb\ rubber-field} \times IR_{DART}}{BW} \qquad \text{Equation 5-4}$$

where,

$C_{GI\text{-}crumb\ rubber\text{-}field}$ = field-specific average GI bioaccessible concentrations of a DART in crumb rubber, nanograms chemical per gram crumb rubber (see Appendix Section D.4.1.3.3)

IR_{DART} = ingested amount of crumb rubber on the day of the event, in grams. Amounts for different groups are given in Table 5-8.

BW = bodyweight of an age group, kilograms, given in Table 5-7 above

The $AD_{ing\text{-}DART\text{-}field}$ calculated as above is expressed in units nanograms per kilogram bodyweight per day. It can be converted to units milligrams per kilogram bodyweight per day by dividing by 1,000,000.

Table 5-8. Ingestion Rate (IR_{DART}): Grams of Crumb Rubber Ingested on the Day of an Event, for Assessing Exposure to Developmental and Reproductive Toxicants

Age Group	Athletes	Coaches, Referees	Spectators
Third trimester fetus	Not applicable	Not applicable	0.042
0<2 years			0.36
2<6 years	0.30		0.37
6<11 years	0.30		0.40
11<16 years	0.29		0.049
16<30 years	0.32	0.092	0.038
30<40 years	0.31	0.099	0.041
40<50 years	0.30	0.095	0.038
50<70 years	0.30	0.095	0.038

As a weight comparison, a single grain of rice weighs approxiamtely 0.3 grams.
Appendix Section B.5.4 describes the equation, exposure parameters, and assumptions used to calculate the IR_{DART} for each receptor category and age group. Values here are rounded to two significant figures.

5.4.2.4. Example: One Day DART Exposures to Benzo(a)pyrene

Table 5-9 shows the results of the exposure calculations for athletes of different ages to the DART benzo(a)pyrene (CASRN 50-32-8). For each age category, it shows the highest “max” and lowest “min” exposure values for the 35 fields. It also shows the mean value for the 35 fields. Exposure estimates such as these will be used in the assessment of a chemical’s potential to pose a reproductive health risk from crumb rubber infill.

Appendix Section G.1 presents further details on the calculations used in this example. In that case doses are given in units milligram per kilogram. The values in Table 5-9 can be converted to those units by dividing by 1,000,000.

Table 5-9. Exposures of Athletes (Combined Gender) to Benzo(a)pyrene by Different Routes

Age Group, years	Inhalation: $C_{inh\text{-}DART\text{-}field}$, nanograms per cubic meter air			Dermal: $AD_{der\text{-}DART\text{-}field}$, nanograms per kilogram			Oral: $AD_{ing\text{-}DART\text{-}field}$, nanograms per kilogram		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
2<6	0	0.83	3.4	0	0.7	2.8	7.0	35	1.0
6<11	0	0.63	2.6	0	0.63	2.6	4.4	22	66
11<16	0	0.52	2.2	0	0.54	0.22	2.8	14	42
16<30	0	0.77	3.2	0	0.47	1.9	2.2	11	33
30<40	0	0.52	2.1	0	0.44	1.8	1.9	9.8	29
40<50	0	0.52	2.1	0	0.45	1.8	1.9	9.6	28
50<70	0	0.56	2.3	0	0.45	1.8	1.9	9.6	28

Values are rounded to two significant figures.

5.4.3. Chronic Exposure to Sensory Irritants

For this study, chronic inhalation exposure to sensory irritants (Section 4.4.3) was done in precautionary fashion by making no adjustment for a less than 365 days per year and a less than 24 hours per day exposure in estimating the chronic sensory concentration, Chronic $C_{inh\text{-}sensory}$ (Equation 5-5). For each on- and off- field calculation, two values for a chemical, two concentration values were produced to evaluate the sensory hazard: 1) the mean value for the 35 field average concentrations in air during soccer activities for the three hour period under active field conditions ($C_{air\text{-}avg}$, details in Section 3.4.6 and Appendix Section D.4.2.3); and 2) the maximum of the average concentrations of the 35 fields under active field conditions. These are provided in Table 5-10. The assumption in applying these concentrations in the chronic context is that receptors would be exposed repeatedly to the measured levels.

$$\text{Chronic } C_{inh-sensory} = C_{air-avg} \qquad \text{Equation 5-5}$$

where,

$C_{air\text{-}avg}$ = average air concentration measured during active field conditions, in nanograms per cubic meter. See Table 3-10 for mean value and maximum values for the 35 fields, and Appendix Section D.4.2.3 for details.

Table 5-10. Chronic Concentrations of Sensory Irritants in Air (Chronic $C_{inh\text{-}sensory}$) – Detected in the Statewide Study during Active Field Conditions

Chemical[a]	CASRN	Chronic $C_{inh\text{-}sensory}$ nanograms per cubic meter			
		On Field[c]		Off Field[c]	
		Mean	Max	Mean	Max
Field-Related Chemical					
Styrene	100-42-5	59	660	60	670
Non-Field Related Chemicals					
Acetaldehyde	75-07-0	2500	9600	not sampled	
Formaldehyde	50-00-0	3800	16000		

[a] Only sensory irritants with available chronic toxicity criteria are shown in the table.
[b] Mean - average of 35 field average concentrations (active field conditions). Max - maximum of 35 field (active field conditions). Values are rounded to two significant figures. Values also in Table 3-10.
[c] Selected carbonyls, including acetaldehyde and formaldehyde, were not sampled at off the field locations. See Section 3.4 for details.

5.4.4. Chronic Exposures to General Chemicals

General chemicals are toxicants causing adverse health effects upon chronic exposure via one or more pathways. DARTs and sensory irritations are evaluated separately and not included in this group when those endpoints show greater sensitivity than the other toxicities (See Sections 5.4.2 and 5.4.3).

Chronic exposures were estimated from the concentrations measured in air and biofluid extracts in the field sampling described in Chapter 3. OEHHA considered the use of an average concentration of a chemical for an individual field or across the 35 fields to estimate the levels of chronic exposure for athletes at a field. Fields at neighborhood schools and local sport clubs are likely to be the home fields for synthetic turf field users and may be the primary field for many synthetic turf field users. However, soccer players, especially those at the competitive level, often play at fields outside of their local communities and attend multiple local and statewide soccer tournaments during sport seasons. With the potential for widespread travel across the state, soccer players and family spectators most likely have exposures at multiple synthetic turf fields. As such, OEHHA used ADDs and exposure concentrations in air ($C_{air\text{-}avg}$) corresponding to the mean of the individual field averages for each chemical detected in samples collected across 35 fields, as being representative of a chronic or lifetime exposure scenario for the various receptor categories. Before discussing the adjustments made to calculate chronic exposures, OEHHA's approach to selecting representative field concentrations to use in those calculations is discussed.

Averaging of concentrations – individual field. One question for characterizing

concentrations was whether to average concentrations taken at different locations. For example, results are available for GI and dermal biofluid concentrations separately for high impact ("HI") areas, such as in the two goal areas in a soccer field, and in the rest of the field ("ROF"). However, on average HI to ROF sample results were quite similar (Appendix Section D.4.1.4.3). Also, VOCs air samples are available for multiple field locations. One consideration is that during soccer practices, athletes conduct various sport activities, such as warm-up exercise and soccer drills, across the field. During soccer games, the teams are required to switch sides during halftime. The TAS Survey data show that approximately one-third of participants play multiple positions, regardless of categorization based on age, gender, or soccer type. Of those who reported playing multiple positions, approximately 75 percent reported playing two positions, and 25 percent reported playing three positions. The survey was a snapshot in time and over time, players also take up different positions. OEHHA, therefore, used average concentration of a chemical for an individual field to estimate the levels of chronic exposure for athletes for that field.

Integrating concentration information from different fields. Concentration levels measured in air and crumb rubber infill varied for the 35 fields studied. School-aged soccer players conduct sport activities at home fields as they progress in education levels (from elementary to high schools). Generally, fields at neighborhood schools and local sport clubs are their home fields. Soccer players, especially those at competitive level, often attend multiple local and statewide soccer tournaments during sport seasons. Taken together, soccer players and family spectators most likely have exposures at multiple synthetic turf fields—not limited to their neighborhood fields, but also fields across the State. OEHHA therefore evaluated two different exposure scenarios. One derived average daily doses (ADDs) for ingestion and dermal pathways and concentration in air ($C_{air\text{-}avg}$) by averaging values for the 35 individual fields. Under this scenario it is assumed that levels of chemical detected in samples collected across California can be combined to properly represent the exposure levels for the chronic exposures of the various receptor categories. The second scenario assumed that the local field was dominant source of exposure, and so ADDs and air concentrations were evaluated for each individual field. This enabled the consideration of the distributions of exposure across the 35 fields, including maximum levels seen.

Thus, the mean concentrations of chemicals measured in air and in biofluids across the 35 fields, as well as those for the individual fields, underlie the estimates of chronic exposure. The chronic exposure estimates for the different field users were developed from these values by adjusting for

- duration of exposure - less than 365 days per year and a less than 24 hours per day,
- activities on- and off- field by different receptor/age categories such as dermal contact with crumb rubber infill and intentional and unintentional ingestion of the infill, and

- physiological factors such as bodyweights and breathing rates for the different receptor groups.

5.4.4.1. Chronic Exposures to General Chemicals by Inhalation Pathways: Chronic C_{inh}

OEHHA applied a receptor- and age- specific adjustment factor (AF_{inh}) to measured air concentrations to estimate the chronic inhalation exposure, in terms of a chronic concentration (Chronic C_{inh}), to general chemicals for each receptor and age group:

$$\text{Chronic } C_{inh} = C_{air-avg} \times AF_{inh}$$ Equation 5-6

where:

$C_{air-avg}$ = average air concentration measured during active field conditions, in nanograms per cubic meter. See Table 3-10 for mean value and maximum values for the 35 fields, and Appendix Section D.4.2.3 for details.

AF_{inh} = receptor-dependent adjustment factor applied to estimate chronic exposure to a chemical for a receptor category in an age group, unitless, shown in Table 5-11

Table 5-11. Adjustment Factor (AF_{inh}, unitless) Applied to Measured Air Concentrations[a] to Estimate Chronic Inhalation Exposure to General Chemicals

Age Group (years)	Athletes	Spectators	Coaches	Referees
Third Trimester Fetus	Not applicable	0.021	Not applicable	Not applicable
0<2		0.17		
2<6	0.16	0.087		
6<11	0.20	0.083		
11<16	0.20	0.036		
16<30	0.37	0.024	0.15	0.057
30<40	0.24	0.021	0.13	0.050
40<50	0.24	0.021	0.14	0.050
50<70	0.23	0.021	0.14	0.050

[a] Concentrations measured under active field conditions. Appendix Section B.3.4 describes the equation and exposure parameters used to calculate receptor and age-specific values of AF_{inh}. Values are rounded to two significant figures.

The receptor- and age-specific AF_{inh} addresses, among other things, the less than 365 days per year and less than 24 hours per day exposures for events played on synthetic turf fields, for each receptor category and the specific age group. It also covers other pertinent features, such as the increased breathing rates during soccer activities and

Appendix B.3.4.3 provides the details and calculation of AF_{inh} with study-specific exposure parameters derived from the TAS data.

Appendix F.4.6 summarizes values of Chronic C_{inh} for athletes, coaches, referees and spectators of different ages.

5.4.4.2. Chronic Exposures to General Chemicals by Dermal Pathways: Chronic ADD_{der}

Chronic exposures via dermal pathways are expressed as an average daily dose (ADD_{der} for dermal pathway). This is calculated for the general chemicals by considering the dermal loading of crumb rubber infill onto the skin, as discussed in section 5.4.2.2 above, factors related to the length of time of exposure, and the concentration of bioaccessible chemicals. Typically absorption by the dermal route is taken into account; in the current calculations the conservative approach of assuming 100% absorption being used. Thus, the ADD_{der} is calculating using the following equation:

$$\mathrm{ADD_{der}} = \frac{\mathrm{DL} \times \mathrm{C_{der-crumb\ rubber}} \times \mathrm{EV} \times \mathrm{CF}}{\mathrm{BW}} \qquad \text{Equation 5-7}$$

where,

DL = mean total loading of crumb rubber particles on the skin in each event, grams crumb rubber per event, shown in Table 5-6 above.

$C_{der\text{-}crumb\ rubber}$ = the bioaccessible concentration of a general chemical in artificial sweat extracts of crumb rubber, in nanograms chemical per gram crumb rubber. See Table 3-3 for the mean value and maximum values for the 35 fields. See Appendix Section D.4.1.3 for further details.

EV = number of field events per year, shown in Table 5-12 for different receptor and age groups, and discussed in Appendix Section B.2.3.

CF = conversion factor, equal to 1 year per 365 days

BW= bodyweight of an age group, in kilograms, provided in Table 5-7 above

This results in an ADD_{der} expressed in units of nanograms per kilogram bodyweight. It can be expressed in units of milligrams per kilogram bodyweight per day by dividing by 1,000,000. Values for ADD_{der} for the various receptors and ages are provided in Appendix Section F.5.3

Table 5-12. Practice and Game Event Frequency[a] (EV, Events Per Year)

Age Group (years)	Athletes	Spectators	Coaches	Referees
Third trimester fetus[a]	Not applicable	161	Not applicable	Not applicable
0<2				

Age Group (years)	Athletes	Spectators	Coaches	Referees
2<6	139			
6<11	121			
11<16	149			
16<30	215		215	86
30<40	163			
40<50	137			
50<70	138			

[a] Derived from TAS data. Appendix Section B.2.3 provides the details and discussion of EV. Table values are rounded to the nearest whole integer.

5.4.4.3. Chronic Exposures to General Chemicals by Ingestion Pathways: Chronic ADD_{ing}

Similarly, chronic exposure via ingestion pathways is expressed as an average daily dose (ADD_{ing}). This is calculated for general chemicals by considering the rate of intentional and incidental ingestion rate of crumb rubber infill by various groups, as discussed in section xx above, and the concentration of bioaccessible chemicals measured in GI extracts (See Sections 3.2.3 and 3.3.3). The calculations conservatively assume 100% absorption by the oral route. The ADD_{ing} , average daily dose of general chemical via the ingestion pathway, is calculated using the following equation:

$$\mathrm{ADD_{ing}} = \frac{\mathrm{C_{GI-crumb\ rubber}} \times \mathrm{IR_{daily}}}{\mathrm{BW}} \qquad \text{Equation 5-8}$$

where,

$C_{GI\text{-}crumb\ rubber}$ = GI bioaccessible concentrations, in nanograms per gram crumb rubber. Mean and maximum of values for 35 fields is provided in Tables 3-2 and 3-4. Fuller reporting is in Appendix Section D.4.1.

IR_{daily} = daily average amount of crumb rubber ingested per day, in grams per day, shown in Table 5-13.

BW= bodyweight of an age group, in kilograms, provided in Table 5-7 above

Calculations with these parameters results in an ADD_{ing} in units of nanograms per kilogram bodyweight per day. It can be expressed in units of milligrams per bodyweight per day, by dividing by 1,000,000.

Values for ADD_{ing} are summarized in Appendix Section F.5.6.

Table 5-13. Daily Average Ingestion Rate for Crumb Rubber (IR_{daily}), in grams crumb rubber per day

Ages (years)	Athletes	Spectators	Coaches	Referees
Third trimester fetus	Not applicable	0.018[a]	Not applicable	Not applicable

Ages (years)	Athletes	Spectators	Coaches	Referees
0<2		0.15		
2<6	0.095	0.16		
6<11	0.099	0.17		
11<16	0.12	0.021		
16<30	0.18	0.016	0.045	0.020
30<40	0.14	0.017	0.048	0.021
40<50	0.11	0.016	0.046	0.020
50<70	0.12	0.016	0.046	0.020

[a] Value is based on female spectators 16<40 year old estimate exposure to third trimester fetuses via the mother.

For comparison, a single sunflower seed with the shell on weighs approxiamtely 0.1 to 0.2 grams.

Appendix Section B.5.3 describes the equation, exposure parameters, and assumptions used to calculate the IR_{daily} for each receptor category and age group. Values are rounded to two significant figures.

5.4.4.4. Example: Chronic Exposures to Benz[a]anthracene by Different Pathways

Table 5-14 shows the results of the exposure calculations for athletes of different ages to the general chemical benz[a]anthracene. For each age category, it shows the highest "maximum" value for any field and average exposure values across fields in the statewide sampling. Exposure estimates such as these will be used in the assessment of a chemical's potential to pose a general chemical toxicity hazard from crumb rubber infill.

Table 5-14. Chronic Exposure Estimates for Athletes (Combined Genders) to Benz[a]anthracene (CASRN 56-55-3) by Inhalation, Dermal and Ingestion Pathways

Ages (Years)	Inhalation: Chronic C_{inh}[a], nanograms per cubic meter air		Dermal: ADD_{der}[b], nanograms per kilogram bodyweight per day		Ingestion: ADD_{ing}[c], nanograms per kilogram bodyweight per day	
	Average	Maximum	average	maximum	average	maximum
2<6	0.00078	0.27	0.35	1.8	13	58
6<11	0.00098	0.34	0.28	1.5	9.0	40
11<16	0.00098	0.34	0.29	1.5	7.0	31
16<30	0.0018	0.63	0.37	1.9	7.8	35
30<40	0.0012	0.41	0.26	1.4	5.2	23
40<50	0.0012	0.41	0.22	1.1	4.4	20
50<70	0.0011	0.39	0.22	1.1	4.5	20

[a] The average was derived using the On-Field average across fields of 0.0049 nanograms per cubic meter air (Table 3-10). It was only detected for one of 34 fields, at a level of 1.7 nanograms per cubic meter.

[b] Derived using the average across 35 fields of $C_{der\text{-}crumb\ rubber}$ of 0.25 ng per gram and a maximum field with a value of 1.3 nanograms per gram (Table 3-3).

[c] Derived using the average across 35 fields of $C_{GI\text{-}crumb\ rubber}$ = 2.9 ng per gram and the value for the field with the maximum measurement of 13 nanograms per gram (Table 3-2).

Values are rounded to two significant figures.

5.4.5. Carcinogens – Lifetime Average Daily Dose

OEHHA assessed exposures to carcinogens for each receptor category through the

three exposure routes. The approach to identifying a chemical as a carcinogen for the purpose of the study is discussed in Section 4.2. The goal for the exposure assessment is to the estimate lifetime average doses for each carcinogen, that adjusts for the enhanced susceptibility to carcinogens early in life, following OEHHA guidance (OEHHA, 2012). For this study, we defined a lifetime exposure as the period from third-trimester fetus to 70 years old. The fetal exposure was included since under OEHHA guidance there is a presumption of increased sensitivity to carcinogens during this period of pregnancy.

The LADD for carcinogens was calculated for each exposure route and receptor group in steps:

- The average daily doses to the carcinogen for different age groups are estimated by incorporating measured concentrations of chemicals in air and biofluids with exposure parameters.
- For each receptor group (e.g., spectators), the average daily dose for a given age grouping is time-weighted by an age susceptibility factor, and then averaged over a lifetime of 70 years. This produces the lifetime average daily dose, or LADD, for that receptor and age group.

Also, similar to what was done for chronic exposure to general chemicals, calculations were done to create a mean estimate of LADD for each chemical using its mean concentration across the 35 fields. In addition, calculations were done for each of the 35 fields, assuming that was the predominant field of play.

5.4.5.1. Lifetime Average Daily Doses via Inhalation: $LADD_{inh}$

Calculation of the average daily inhalation dose for each receptor age group. For each receptor and for each age group for that receptor, the LADD calculation starts with accounting for the breathing rates for the different receptors of different ages, especially the increased breathing rates of athletes during play. It is assumed that the higher the breathing rate, the higher the exposure to the carcinogen. Table 5-15 shows the one-hour time weighted breathing rates (BR_{TW}) for athletes and different receptors during games, practices and while observing these activities.

Table 5-15. One-Hour Time Weighted Breathing Rates (BR_{TW}) for different activities, in cubic meters air per hour [a]

Ages (years)	Athletes		Coaches		Referees	Spectators
	Practice	Game	Practice	Game	Game	
Third trimester fetus[a]	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	0.4[a]
0<2						0.4
2<6	1.4	1.5				0.5
6<11	2.3	2.3				0.7

Ages (years)	Athletes		Coaches		Referees	Spectators
	Practice	Game	Practice	Game	Game	
11<16	2.8	2.9				0.5
16<30	4.2	4.4	1.9	1.6	1.6	0.4
30<40	3.6	4.0				
40<50	3.9	4.0				
50<70	4.1	4.4				

[a] Appendix Section B.3.2 describes the equation and exposure parameters used to calculate the one hour breathing rates. Values are rounded to one decimal place.
[a] Values are estimated using the breathing rates for 16<40 year old females to evaluate exposure via the mother to the third trimester fetus.

Within an age group these breathing rates for games and practices can then be multiplied by the hours each year spent in these activities each year, that is the "annual event time" (AET) to calculate the cubic meters breathed in a year in these activities. OEHHA derived these values from the TAS survey data (see Appendix Section B.2.5). When divided by the number of days in a year, this produces a daily average breathing rate for the year for the activity. Thus, the average soccer related daily breathing rate (for a given age group and receptor) can be represented as:

$$ABR = \sum_{\text{event type}} (\text{BR}_{\text{TW}} \times \text{AET}) \times \text{CF} \qquad \text{Equation 5-9}$$

where,

BR_{TW} = time-weighted one-hour breathing rate for an event type, cubic meters per hour. Table 5-15 shows these values for receptor category and age groups

AET = annual event time spent on the field, hours per year. Table 5-16 provides values of AET for different receptor categories and age groups for event types, namely games and practices.

CF = conversion factor, equal to 1 year per 365 days. This converts the annual breathing rate to an average daily breathing rate, "ABR".

The resulting average soccer related breathing rate ABR is in units cubic meters per day.

Table 5-16. Synthetic Turf Study Annual Event Time (AET)[a] in Hours Per Year

Ages (years)	Athletes		Coaches		Referees	Spectators	
	Practice	Game	Practice	Game	Game	Practice	Game
Third trimester fetus	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	156	241
0<2							

Ages (years)	Athletes		Coaches		Referees	Spectators	
	Practice	Game	Practice	Game	Game	Practice	Game
2<6	126	104					
6<11	156[b]	137					
11<16	223	129					
16<30	354[c]	241[b]	354	241	241		
30<40	343	167					
40<50	256	214					
50<70	187	239					

[a] Appendix Section B.2.5 describes the equation, TAS survey data, and assumptions used to calculate the annual event time for each receptor category and age group. Values are rounded to nearest whole integer.

Once the breathing rate is estimated for an age and receptor group, the average daily dose by the inhalation route for that group can be calculated. Multiplying the breathing rate by the air concentration breathed in ($C_{air\text{-}avg}$) gives amount breathed in. If the concentration is in nanograms per cubic meter the resulting amount is in nanograms. Dividing this by the bodyweight in kilograms provides the dose estimate for that age group in nanograms per kilogram bodyweight per day. Thus,

$$\mathrm{ADD_{inh}} = \frac{\mathrm{C_{air-avg}} \times ABR}{\mathrm{BW}} \qquad \text{Equation 5-10}$$

where,

$C_{air\text{-}avg}$ = average air concentrations measured during active field condition, in nanograms per cubic meter air. Values may be used for an individual field is provided in Appendix Section 4.2.3, or the mean of 35 individual fields provided in Table 3-10 of Section 3.4.6.

ABR = daily average breathing rate for soccer related activity, as described in text above.

BW= bodyweight of an age group, in kilograms, provided in Table 5-7 above

Appendix Section F.5.1 provides ADD_{inh}, in Tables F-180 to F-184 using the mean values for the 35 fields, and in Tables F-185 to F-217 for individual fields.

Calculation of the LADD for inhalation for each receptor group. This calculation takes the ADD_{inh} for the different age groupings for a given receptor and time-weights it by an age sensitivity factor, or ASF, to account for varying sensitivity to the effects of exposure to a carcinogen with age (OEHHA, 2012's Appendix J). The ASF modifies a chemical's cancer potency. This age group-dependent factor, along with the exposure duration, ED, which is also age-dependent, are included in the calculation of LADD. The equation used is:

$$\mathrm{LADD_{inh}} = \frac{\mathrm{ADD_{inh}} \times \mathrm{ASF} \times \mathrm{ED}}{\mathrm{AT}} \qquad \text{Equation 5-11}$$

where,

ADD_{inh} = the average daily dose of a carcinogen for the inhalation pathway, for an age group within a receptor category, as discussed in the previous subsection.

ASF = the age sensitivity factor for a given age group, unitless, provided in Table 5-17.

ED = exposure duration of an age group, in years. For example, a child spends 4 years of life in the 2<6 years age group. See Table 5-17 for values.

AT = the default number of years of life used in OEHHA cancer risk assessment, 70 years (OEHHA, 2015; Appendix Section B.6.2)

When the ADD_{inh} is expressed in nanograms per kilogram per day, the resulting $LADD_{inh}$ is in those units as well. To convert to milligrams per kilogram per day, the number would be divided by 1,000,000.

Table 5-17. Age Sensitivity Factors (ASF, unitless) and Exposure Duration (years) for Cancer Risk Assessment

Age Group	Exposure Duration, years	ASF
Third trimester fetus	0.25	10
0<2 years	2	
2<6 years	4	3
6<11 years	5	
11<16 years	5	
16<30 years	14	1
30<40 years	10	
40<50 years	10	
50<70 years	20	

Appendix Section B.6.2 provides the details and discussion of ASF.

For an example of this calculation see Appendix section G.1.2.

5.4.5.2. Lifetime Average Daily Doses via dermal pathways: $LADD_{der}$

There are differences across receptor groups and ages in dermal contact with crumb rubber infill that is explicitly accounted for in estimating the average daily dermal dose (ADD_{der}) for these groups. Equation 5-7 above to calculate chronic exposure to general chemicals for the different age groups applies here as well, with the same input parameters, including the dermal loading (DL) values that varied across the receptor age categories. See Section 5.4.4.2. The ADD_{der} results for these different groups are reported in the tables in Appendix Section F.5.4.

The calculation of the lifetime average daily dose for the dermal route $LADD_{der}$ for a receptor and age group takes the same form as for inhalation exposures discussed

above:

$$\mathrm{LADD_{der}} = \frac{\mathrm{ADD_{der}} \times \mathrm{ASF} \times \mathrm{ED}}{\mathrm{AT}} \qquad \text{Equation 5-12}$$

The parameters ASF, ED, and AT are the same and carry the same meaning as in previous section 5.4.5.1. For the $LADD_{der}$ calculation, however, the age and receptor specific dermal average daily dose values ADD_{der} are used. $LADD_{der}$ values are compiled in tables in Appendix Section F.6.2.

5.4.5.3. Lifetime Average Daily Doses via ingestion pathways: $LADD_{ing}$

There are substantial differences in ingestion doses of crumb rubber across the age and receptor groups and these are captured in the ADD_{ing} calculations. The ADD_{ing} calculations are the same as for chronic exposure to general chemicals, following Equation 5-8. Values for the ADD_{inh} can be found in tables in Appendix Section F.5.7.

The calculation of the lifetime average daily dose for the ingestion route ($LADD_{ing}$) for a receptor and age group takes the same form as for inhalation and dermal exposures discussed above:

$$\mathrm{LADD_{ing}} = \frac{\mathrm{ADD_{ing}} \times \mathrm{ASF} \times \mathrm{ED}}{\mathrm{AT}} \qquad \text{Equation 5-13}$$

with the identical meaning for the parameters in the equation with the exception that the ingestion average daily dose (ADD_{ing}) for receptor age groups is used instead those for the other pathways.

The ingestion $LADD_{ing}$ values are compiled in tables in Appendix Section F.6.3.

5.4.5.4. Example of Lifetime Average Daily Dose Result for Receptors for the Three Exposure Routes

Table 5-18 shows the results of the lifetime exposure calculations for each receptor category to the carcinogen benzo[a]pyrene. For each receptor category, it shows the average LADD value for each exposure route. Exposure estimates such as these will be used in the assessment of a chemical's potential to pose a risk from crumb rubber infill.

Table 5-18. Lifetime Average Daily Doses to different groups to Benzo[a]pyrene (CASRN 50-32-8), in units nanogram per kilogram per day

Ages (Years)	Inhalation $LADD_{inh}$		Dermal $LADD_{der}$		Ingestion $LADD_{ing}$	
	Average	Maximum	Average	Maximum	Average	Maximum
2<6	0.0019	0.0056	0.000045	0.00019	0.0019	0.0056
6<11	0.0016	0.0046	0.000045	0.00018	0.0016	0.0046
11<16	0.0012	0.0036	0.000047	0.00019	0.0012	0.0036
16<30	0.0013	0.0037	0.000056	0.00023	0.0013	0.0037
30<40	0.00061	0.0018	0.000028	0.00012	0.00061	0.0018
40<50	0.00052	0.0015	0.000024	0.00010	0.00052	0.0015
50<70	0.0011	0.0031	0.000048	0.00020	0.0011	0.0031

Values are rounded to two significant figures.

5.5. References

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Chapter 6. Risk Characterization

6.1. Background

This study examined non-cancer hazards and cancer risks from exposure to chemicals from crumb rubber infill via multiple routes (inhalation, dermal, and ingestion) on the synthetic turf fields for four receptor categories (athletes, coaches, referees, and spectators) and their appropriate age groups. Off-site data for airborne chemicals was also collected. The study focused on the soccer player exposure scenario (i.e., athletes) in artificial turf fields, as soccer is a popular sport among players of all ages, and based on the nature of play, soccer players were exposed via most of the routes and hence probably had high exposures, hazards and risks. OEHHA assessed there was negligible exposure through: direct ingestion (intentional or incidental as described in Section 5.2.3.3) of crumb rubber for coaches and referees; and dermal or ingestion of airborne chemicals for all receptor categories. Therefore, these exposures were excluded from the evaluation of non-cancer hazards and cancer risks in this study.

Combining the results of the toxicity criteria presented in Chapter 4 and the exposure assessment presented in Chapter 5, OEHHA evaluated acute and chronic non-cancer hazards, as well as lifetime excess cancer risks (OEHHA, 2015; USEPA, 1989) for each receptor category.

Risk characterization was conducted for each chemical exposure in each receptor category (athletes, coaches, referees, and spectators), and for each appropriate age group within the receptor categories (third trimester, 0<2 years, 2<6 years, 6<11 years, 11<16 years, 16<30 years, 30<40 years, 40< 50 years, and 50<70 years). The non-cancer hazards and cancer risk values were obtained for both on-field and off-field exposures to field-related chemicals and non-field-related chemicals.

For non-cancer hazards, a Hazard Quotient (HQ) for the chemical of interest in each category was calculated using the following general equation:

$$\text{Hazard Quotient} = \frac{\text{Exposure Metric}}{\text{Toxicity Criterion}}$$

where:

Exposure Metric refers to the exposure concentration or dose of the chemical. For inhalation exposures, the exposure metric is an airborne concentration, whereas for dermal and ingestions exposures, the exposure metric is an average daily dose. These are presented in Appendix Sections F.4 and F.5

Toxicity Criterion refers to the chemical-specific numerical values that reflect the potency of the chemical, for the specific health (non-cancer) effect and route of exposure. These are available in Chapter 4 and Appendix E.

Once the HQs for all the chemicals were calculated, they were summed together

(HQ_{sum}). The minimum, mean, standard deviation of the mean, 95th percentile, and maximum of HQ_{sum} from the individual 35 fields for all receptor categories and age groups were calculated and provided in Appendix G.

The HQs of individual chemicals were then summed to calculate a Hazard Index (HI) to determine the non-cancer hazard posed by exposure to all the chemicals in the crumb rubber used on the artificial turf. To calculate the HI for each receptor category and age group, the HQ for inhalation, dermal, and ingestion routes were added as follows:

$$\mathrm{HI} = \mathrm{HQ}_{\mathrm{inh-sum}} + \mathrm{HQ}_{\mathrm{der-sum}} + \mathrm{HQ}_{\mathrm{ing-sum}}$$

where:

$HQ_{route\text{-}sum}$ = Summed chemical hazard quotients for an exposure route (inh: inhalation, der: dermal, ing: ingestion)

A HI value up to 1 suggests that the chemical exposures do not present a health hazard. When the HI is above 1, it indicates an increasing but undefined probability of an adverse health impact, particularly in sensitive individuals.

Cancer risk is calculated for lifetime exposure to a carcinogen or multiple carcinogens, in terms of probability of developing cancer in excess of background incidence in a population. The background lifetime cancer risk rate is 0.2 (1 case of cancer out of 5 people) in California (CHPH, 2017). From a public health perspective related to chemical exposures, one excess cancer in a population of one million people over a lifetime of 70 years is considered negligible risk or *de minimis* risk level. Regulatory decisions based on excess lifetime cancer risks generally use an action level between one in ten thousand and one in one million. Cancer Risk in the present study was calculated for each life stage within a receptor category with the following general equation:

$$\text{Cancer Risk} = \mathrm{LADD}_{\mathrm{x}} \times \mathrm{CSF}_{\mathrm{y}}$$

where:

$LADD_x$ = Lifetime Average Daily Dose integrating the age sensitivity factors specific to each age group x, as presented in Section F.6.

CSF_y = Cancer Slope Factor for the route of exposure y. Inhalation and oral CSFs are available in Chapter 4 and Section E. The CSF for dermal exposures is the same as for the oral route.

The cancer risk of individual chemicals were summed to calculate the cancer risk posed by all the chemicals in the crumb rubber for each age and receptor group. Cancer risk for combinations of age and receptor groups can be summed together to estimate the risk to individuals who may participate in multiple roles during specific time periods in their lifetime.

The following sections present the results of HQ and HI calculated for:

- acute toxicity
- developmental and reproductive toxicity
- sensory irritation
- general chronic toxicity, and

risks associated with receptor exposures to carcinogens via multiple routes (inhalation, dermal, and ingestion) on or off the synthetic turf fields.

6.2. Non-Cancer Hazards: Acute Toxicity

6.2.1. Inhalation Exposure

The 11 chemicals detected and evaluated for acute inhalation hazard are listed in Table 6-1. Section 4.4.1 lists the acute TC_{inh} for these chemicals. Using the maximum one-hour measured concentration of a chemical among all the maximal concentrations of these chemicals detected in the air at the 35 individual fields, the acute HQ_{inh} for these chemicals were calculated (see Appendix Sections F.4.1 & G.2.1).

Table 6-1. Chemicals Evaluated for Acute Inhalation Hazard

Field-Related Chemicals	Non-Field-Related Chemicals
Styrene	Acetaldehyde Benzene 2-Butanone 2-Butoxyethanol Formaldehyde Phenol Tetrachloroethylene Toluene m/p-Xylene o-Xylene

The on-field and off-field acute HQ_{inh} for styrene - the only field-related chemical - were 0.000077 and 0.000066, respectively. These values were well below the benchmark HQ of 1 and much lower than the sum of all acute HQ_{inh} for the non-field-related chemicals both on-field (0.47) and off-field (0.13). Acute HI_{inh}, calculated as the sum of the acute HQ_{inh} for the 11 detected chemicals, are summarized in Table 6-2.

Table 6-2. Acute Inhalation Hazard Index[a] for the Inhalation Route

Chemical Group	On-Field Acute HI	Off-Field Acute HI
Field-Related Chemicals	<0.01	<0.01
Non-Field-Related Chemicals	0.47	0.13
All Chemicals Acute HI_{inh}	0.47	0.13

[a]The acute hazard index (Acute HI) equals the sum of acute hazard quotients (Acute $HQ_{inh\text{-}sum}$) assessed.

Given the lack of acute TC_{inh} values for some field-related chemicals, OEHHA made comparisons of the maximum air concentrations of these chemicals with available sub-chronic health guidance values from other peer-reviewed sources (USEPA PPRTV, ATSDR MRL). In all cases, maximum air concentrations on-field and off-field were well below the sub-chronic health guidance values, which indicates that there would be no concern for acute health hazards.

6.2.2. Dermal and Ingestion Exposures

For acute dermal and ingestion exposures to chemicals in crumb rubber, the corresponding toxicity criteria were not available for conducting the assessment. Therefore, single day exposures to field-related chemicals were compared with toxicity criteria developed by ATSDR and USEPA/PPRTV programs for durations ranging from 14 days (ATSDR MRL) to 90 days (USEPA/PPRTV). Even by comparison with such toxicity criteria, there were no cases of exceedance from single day exposure to field-related chemicals in any of the 35 fields, indicating no reason for concern with health hazards associated with acute exposures by the oral or dermal route.

6.3. Non-Cancer Hazards: DART

6.3.1. Inhalation Exposure

Among the 18 DART chemicals detected for inhalation exposure (Table 6-3), 17 were considered field-related chemicals and one was considered non-field-related. The TC_{inh} for these DART chemicals are presented in Section 4.4.3. To assess the reproductive and developmental hazards associated with inhalation of these chemicals, the average concentration ($C_{air\text{-}field}$) of only those chemicals that were detected in air on or off an individual field was used to calculate a field-specific exposure concentration ($C_{inh\text{-}DART\text{-}field}$, see Appendix Section F.4.4). Subsequently, an $HQ_{inh\text{-}DART\text{-}field}$ for the DART endpoint was calculated for each of the individual 35 fields.

Table 6-3. DART Chemicals Evaluated for One-Day Exposure

Chemical	Route Evaluated		
	Inhalation	Dermal	Ingestion
Non-Field Related Chemicals			
2-Butanone	X		

Field-Related Chemicals			
Arsenic			X
2-Azacyclotridecanone		X	
1,4-Benzenediamine, N,N'-diphenyl-		X	X
Benzo[a]pyrene	X	X	X
Benzo[e]pyrene	X	X	X
Benzo[g,h,i]perylene	X	X	X
Bis(2,2,6,6-tetramethyl-4-piperidyl)sebacate		X	X
Bis(2-Ethylhexyl)adipate	X	X	X
Boron			X
n-Caproic acid vinyl ester	X		X
Chrysene	X	X	X
Coronene	X	X	X
Cyclohexylamine	X		
Cyclopenta[cd]pyrene	X	X	X
Dicyclohexylamine	X	X	X
N,N-Dicyclohexylmethylamine	X	X	
Dimethyl phthalate	X	X	X
1,3-Diphenylguanidine		X	
Indeno[1,2,3-cd]pyrene	X	X	X
Methyl stearate	X	X	X
Nickel			X
4-tert-Octylphenol	X	X	X
Phenol, 2,4-bis(1-methyl-1-phenylethyl)-	X	X	X
Phenol, 4-(1-phenylethyl)-	X	X	X

The only non-field-related DART chemical (2-Butanone) had a $HQ_{inh\text{-}DART\text{-}field}$ of less than 0.01 for all the receptor categories and age groups, both on- and off-field exposures; so it is not discussed further. For field-related DART chemicals, most of the mean and maximum HQ values from off-field exposures and many from on-field exposures, were at or less than 0.01. Table 6-4 shows the groups with $HQ_{inh\text{-}DART\text{-}sum\text{-}field}$ of more than 0.01 for field-related DARTs (all $HQ_{inh\text{-}DART\text{-}sum\text{-}field}$ can be found in Appendix Section G.2.2). The $HQ_{inh\text{-}DART\text{-}sum\text{-}field}$ for exposure on-field was above 1 for the athlete groups aged 11 – 70 years only, and it ranged between 1.2 and 1.8.

The $HQ_{inh\text{-}DART\text{-}sum\text{-}field}$ values greater than 1 were driven by PAHs: benzo[a]pyrene (8 fields), indeno[1,2,3-cd]pyrene (3 fields), and chrysene (3 fields). BaP, which was the chemical accounting for 39 to 92% of the value of HQ_{DART}, has a DART TC_{inh} value that is based on toxicological studies of much longer duration than one day.

Table 6-4. Field-Specific[a] Hazard Quotients for Field-Related DARTs

Receptor Category	Age Group	One-Day $HQ_{inh\text{-}DART\text{-}sum\text{-}field}$	
		Mean[b]	Maximum[c]
Athletes	11<16 years	0.39	1.30
	16<30 years	0.58	1.80
	30<40 years	0.39	1.20
	40<50 years	0.39	1.20
	50<70 years	0.42	1.30
Coaches	16<30 years	0.25	0.78
	30<40 years	0.21	0.68
	40<50 years	0.22	0.69
	50<70 years	0.22	0.69
Referees	16<30 years	0.23	0.73
	30<40 years	0.20	0.64
	40<50 years	0.20	0.64
	50<70 years	0.20	0.64
Spectators on-field	11<16 years	0.07	0.23
	16<30 years	0.05	0.15
	30<40 years	0.04	0.13
	40<50 years	0.04	0.14
	50<70 years	0.04	0.14
Spectators off-field	11<16 years	0.08	0.45
	16<30 years	0.05	0.30
	30<40 years	0.05	0.26
	40<50 years	0.05	0.26
	50<70 years	0.05	0.26

[a] 35 field-specific One-Day HQ_{DART} are included in this table.
[b] The mean is the average mean $HQ_{inh\text{-}DART\text{-}sum\text{-}field}$ of the 35 fields sampled
[c] The maximum is the highest $HQ_{inh\text{-}DART\text{-}sum\text{-}field}$ of the 35 fields sampled

6.3.2. Dermal and Oral Exposures

There were 19 DART chemicals evaluated for dermal exposure on-field and 20 DART chemicals evaluated for on-field oral exposure (Table 6-3). Their exposure metrics, $ADD_{der\text{-}DART\text{-}field}$ and $ADD_{ing\text{-}DART\text{-}field}$ are presented in Appendix Sections F.5.2 and F.5.5. The present study did not evaluate off-field dermal and oral exposures to chemicals from crumb rubber as they were not present off the field. The toxicity criteria for these chemicals (DART TC_{oral}) are presented in Chapter Sections 4.5.1 for organic chemicals and 4.6.1 for metals and metalloids.

The $HQ_{der\text{-}DART\text{-}sum\text{-}field}$ for each receptor and age group was calculated by summing the $HQ_{der\text{-}DART\text{-}field}$ for all the chemicals within that group. A similar summation of the $HQ_{ing\text{-}}$

$_{DART\text{-}field}$ for each receptor and age group was done to calculate the $HQ_{ing\text{-}DART\text{-}sum\text{-}field}$. There was no group that had a $HQ_{der\text{-}DART\text{-}sum\text{-}field}$ that was greater than 0.01 (See Appendix Section G.2.5). All receptor categories and age groups also had mean and maximum $HQ_{ing\text{-}DART\text{-}sum\text{-}field}$ of less than 1. Table 6-5 shows only receptor groups with $HQ_{ing\text{-}DART\text{-}sum\text{-}field}$ of more than 0.01 as a mean or maximum value among the 35 individual fields (See Appendix Section G.5.7).

Table 6-5. Field-Specific[a] Hazard Quotients for 1-day exposure to Field-Related DART chemicals

Receptor Category	Age Group	One-Day $HQ_{ing\text{-}DART\text{-}sum\text{-}field}$	
		Mean	Maximum
Athletes	2<6 years	0.05	0.17
	6<11 years	0.03	0.11
	11<16 years	0.02	0.07
	16<30 years	0.02	0.06
	30<40 years	0.01	0.05
	40<50 years	0.01	0.05
	50<70 years	0.01	0.05
Coaches	16<30 years	<0.01	0.02
	30<40 years	<0.01	0.02
	40<50 years	<0.01	0.02
	50<70 years	<0.01	0.02
Referees	16<30 years	<0.01	0.02
	30<40 years	<0.01	0.02
	40<50 years	<0.01	0.02
	50<70 years	<0.01	0.02
Spectators	0<2 years	0.12	0.43
	2<6 years	0.06	0.20
	6<11 years	0.04	0.14
	11<16 years	<0.01	0.01

[a] 35 field-specific One-Day HQ_{DART} are included in this table.

6.3.3. Hazard Index for DART

All the calculated HI_{DART} for each receptor category and age group based on all DART chemicals and multiroute exposures can be found in Appendix Section G.2.9. Most of the calculated mean and maximal values of HI_{DART} were at 0.01 and above for all the receptor categories and age groups on-field. Table 6-6 shows the groups with HI_{DART} above 0.01 as at least the maximum value. The calculated maximum value of HI_{DART} was greater than 1 for on field exposures of athlete groups aged 11 – 70 years, as detailed above in the section on inhalation exposure to DART chemicals (section 6.3.1).

The HI_{DART} for these age groups was based on a TC_{inh} value of 0.002 µg per cubic meter for BaP, while a value of 0.4 µg per cubic meter for BaP was used for children less than 11 years of age (Section 4.2.2).

Table 6-6. Field-Specific[a] One-Day Multi-Route Hazard Index for DARTs

Receptor Category	Age Group	One-Day HI_{DART}	
		Mean	Maximum
Athletes	11<16 years	0.39	1.30
	16<30 years	0.58	1.80
	30<40 years	0.39	1.20
	40<50 years	0.39	1.20
	50<70 years	0.42	1.30
Coaches	16<30 years	0.25	0.78
	30<40 years	0.21	0.68
	40<50 years	0.22	0.69
	50<70 years	0.22	0.69
Referees	16<30 years	0.23	0.73
	30<40 years	0.20	0.64
	40<50 years	0.20	0.64
	50<70 years	0.20	0.64
Spectators on-Field	11<16 years	0.07	0.23
	16<30 years	0.05	0.15
	30<40 years	0.04	0.13
	40<50 years	0.04	0.14
	50<70 years	0.04	0.14
Spectators off-Field	11<16 years	0.08	0.45
	16<30 years	0.05	0.30
	30<40 years	0.05	0.26
	40<50 years	0.05	0.26
	50<70 years	0.05	0.26

[a] 35 field-specific One-Day HI_{DART} are included in this table.

6.4. Non-cancer Hazards: Sensory Irritation

Three chemicals, one field related and two non-field related, were evaluated as sensory irritants (Table 6-7). Each individual field hazard was assessed using each field's average concentrations for sensory irritants (Chronic $C_{inh\text{-}sensory\text{-}field}$, Appendix Section F.4.5) and Sensory TC_{inh} (Section 4.4.2). The mean and maximal hazard quotients, not specific to receptor or age categories, were less than 0.01 for on-field exposures (Table 6-8). The off-field $HI_{sensory\text{-}field}$ were all less than 0.01 and are not shown in the table. Overall, the only field-related chemical, styrene, evaluated as a sensory irritant did not present a hazard on- or off-field. The non-field-related chemicals presented a small concern on-field (no non-field-related sensory irritants were detected off-field) at the

maximal calculated $HI_{sensory\text{-}field}$, as seen in Table 6-8 and Appendix Table G-52, driven by formaldehyde.

Table 6-7. Sensory Irritant Chemicals Evaluated for Inhalation Chronic Hazard

Field-Related Chemicals	Non-Field-Related Chemicals
Styrene	Acetaldehyde Formaldehyde

Table 6-8. Field-Specific[a] Hazard Index for Inhalation Exposure to Sensory Irritants ($HI_{sensory\text{-}field}$) for All Ages and Receptor Groups

Chemical Group	HI Mean	HI Maximum
Field-related Sensory Irritants, On-field	<0.01	<0.01
Non-Field related Sensory Irritants, On-field	0.44	1.90
All Sensory Irritants, On-field	0.44	1.90

[a] 35 field-specific $HI_{sensory\text{-}field}$ are included in this table.

6.5. Non-cancer Hazards: Chronic Effects

This section presents the results of HQ and HI calculated for general chronic toxicity, for multiple routes of exposure (inhalation, dermal, and ingestion) on or off the synthetic turf fields.

6.5.1. Inhalation Exposure

Ninety-four volatile and semi-volatile chemicals were analyzed from on- and off-field sampling. Seventy-three were considered field-related and 21 were considered non-field-related chemicals for inhalation exposure (Table 6-9). Chapter Section 4.4.4 lists the toxicity criteria, Chronic TC_{inh}, for these chemicals. To assess hazards associated with chronic inhalation of these general chemicals, the average concentration for those chemicals detected on an individual field, for on- or off-field, was used to calculate the individual field exposure concentration, $C_{inh\text{-}field}$. These exposure concentrations are in Appendix Section F.4.6.

Table 6-9. General Chemicals Evaluated for Chronic Hazard

Chemical	Route Evaluated		
	Inhalation	Dermal	Ingestion
Field-Related Chemicals			
Acenaphthylene	X	X	X
Acetone	X		
Aluminum			X
Aniline	X	X	X
Anthracene	X	X	X

Chemical	Route Evaluated		
	Inhalation	Dermal	Ingestion
Anthracene, 2-methyl-	X	X	X
Anthracene, 9,10-dimethyl	X		X
Anthracene, 9-phenyl	X	X	X
Anthracene, 9,10-diphenyl-		X	X
Antimony			X
Barium			X
Benz[a]anthracene	X	X	X
Benzaldehyde	X		
Benzene, n-butyl-	X	X	X
1,4-Benzenediamine, N-(1,3-dimethylbutyl)-N'-phenyl-	X	X	X
Benzene, 1,2,3-trimethyl-	X		
Benzene, 1,2,4,5-tetramethyl-	X		
Benzene, 1,2,4-trimethyl-	X		
Benzene, 1-ethyl-2,4-dimethyl-	X		
Benzene, 2-ethyl-1,4-dimethyl-	X		
Benzo[b]fluoranthene	X	X	X
7H-Benzo[c]fluorene	X	X	X
Benzo[k]fluoranthene	X	X	X
Benzothiazole	X	X	X
Benzothiazole, 2-phenyl-	X	X	X
1,3-Benzothiazole-2-thiol		X	
2-Benzothiazolone	X	X	X
Benzyl butyl phthalate	X	X	X
Beryllium			X
Butanal	X		
Butylated Hydroxytoluene			X
Cadmium			X
Chromium			X
Cobalt			X
Copper			X
Cyclohexyl isothiocyanate		X	X
Cyclopentasiloxane, decamethyl-	X		
Cyclotetrasiloxane, octamethyl-	X		
p-Cymene	X		
Decane	X		
Dibenz[a,h]anthracene	X	X	X

Chemical	Route Evaluated		
	Inhalation	Dermal	Ingestion
Dibenzothiophene	X	X	X
Dibutyl phthalate	X		X
Diethyl phthalate	X	X	X
Diisobutyl phthalate	X	X	X
Diisooctylphthalate	X	X	X
Di-n-octyl phthalate	X	X	X
2,5-di-tert-Butyl-1,4-benzoquinone	X	X	X
3,5-di-tert-Butyl-4-hydroxybenzaldehyde	X	X	X
Dodecane	X		
Fluoranthene	X	X	X
Fluorene	X	X	X
Furan, 2-methyl	X		
Heptanal	X		
Hexadecane	X		X
2,5-Hexanedione	X		
1-Hydroxypyrene		X	X
Hexanoic Acid, 2-ethyl		X	
Indan	X		
Lead			X
Manganese			X
Mesitylene	X		
Methacrolein	X		
Methyl Isobutyl Ketone	X		
2-(Methylthio)benzothiazole		X	X
Molybdenum			X
Naphthalene	X	X	X
Naphthalene, 2-(bromomethyl)-	X	X	X
Naphthalene, 1,2-dimethyl-	X	X	X
Naphthalene, 1,6-dimethyl-	X	X	X
Naphthalene, 2,3-dimethyl-	X	X	X
Naphthalene, 1-methyl-	X	X	X
Naphthalene, 2-methyl-	X	X	X
1-Octadecene	X	X	X
Octanal	X		
Octane	X		
17-Pentatriacontene	X		X
Phenanthrene	X	X	X

Chemical	Route Evaluated		
	Inhalation	Dermal	Ingestion
Phenanthrene, 1-methyl	X	X	X
Phenanthrene, 2-methyl-	X	X	X
Phenanthrene, 3-methyl	X	X	X
N-Phenylbenzamide	X	X	X
Phthalimide		X	X
Propionaldehyde	X		
Pyrene	X	X	X
Pyridine, 2-(4-methylphenyl)-	X	X	X
Resorcinol	X		
Selenium			X
Strontium			X
Thallium			X
Tin			X
m-Tolualdehyde	X		
Triethylene glycol monobutyl ether		X	X
TXIB "Kodaflex"	X		
5,9-Undecadien-2-one, 6,10-dimethyl-	X	X	X
Undecane	X		
Valeraldehyde	X		
Vanadium			X
Zinc			X
Non-Field-Related Chemicals			
Benzene	X		
Benzene, 1,4-dichloro	X		
Benzene, 1-chloro-4-(trifluoromethyl)-	X		
2-Butoxyethanol	X		
Cyclotrisiloxane, hexamethyl-	X		
Decanal	X		
Ethylbenzene	X		
Heptane	X		
Hexanal	X		
Hexane	X		
1-Hexanol, 2-ethyl-	X		
Nonanal	X		
Phenol	X		
Tetrachloroethylene	X		
Tetradecane	X		

Chemical	Route Evaluated		
	Inhalation	Dermal	Ingestion
Texanol, TXIB (mono-isomer)	X		
Toluene	X		
Trichloroethylene	X		
Trichloromethane	X		
m/p-Xylene	X		
o-Xylene	X		

For the inhalation route, the on-field $HQ_{inh\text{-}sum\text{-}field}$ for all general (field and non-field) chemicals were below 1 for every receptor category and age group, as can be seen in Table 6-10. Nearly the same results were obtained for the off-field chronic exposures as well. Thus, chronic inhalation exposure to chemicals from crumb rubber infill does not present a significant hazard to participants and spectators. All the HQ values for chronic health hazards associated with general chemicals are presented in Appendix Section G.2.4.

Table 6-10. Field-Specific[a] Chronic Inhalation Route Total Hazard Quotients for **All General Chemicals**

Receptor Category	Age Group	Field-Related General Chemicals		Non-Field-Related General Chemicals		All General Chemicals	
		Chronic $HQ_{inh\text{-}sum\text{-}field}$		Chronic $HQ_{inh\text{-}sum\text{-}field}$		Chronic $HQ_{inh\text{-}sum\text{-}field}$	
		Mean	Maximum	Mean	Maximum	Mean	Maximum
Athletes	2<6 years	0.1	0.23	0.06	0.21	0.15	0.37
	6<11 years	0.13	0.30	0.07	0.28	0.2	0.48
	11<16 years	0.12	0.30	0.07	0.27	0.19	0.47
	16<30 years	0.23	0.56	0.13	0.51	0.36	0.88
	30<40 years	0.15	0.37	0.09	0.33	0.24	0.58
	40<50 years	0.15	0.36	0.09	0.33	0.23	0.57
	50<70 years	0.15	0.35	0.08	0.32	0.23	0.56
Coaches	16<30 years	0.10	0.23	0.05	0.21	0.15	0.36
	30<40 years	0.08	0.2	0.05	0.18	0.13	0.32
	40<50 years	0.08	0.2	0.05	0.19	0.13	0.32
	50<70 years	0.08	0.2	0.05	0.19	0.13	0.32
Referees	16<30 years	0.04	0.09	0.02	0.08	0.06	0.14
	30<40 years	0.03	0.08	0.02	0.07	0.05	0.12
	40<50 years	0.03	0.08	0.02	0.07	0.05	0.12
	50<70 years	0.03	0.08	0.02	0.07	0.05	0.12
Spectators On-field	Third trimester fetus	0.01	0.03	<0.01	0.03	0.02	0.05
	0<2 years	0.10	0.25	0.06	0.23	0.16	0.39

Receptor Category	Age Group	Field-Related General Chemicals		Non-Field-Related General Chemicals		All General Chemicals	
		Chronic $HQ_{inh\text{-}sum\text{-}field}$		Chronic $HQ_{inh\text{-}sum\text{-}field}$		Chronic $HQ_{inh\text{-}sum\text{-}field}$	
		Mean	Maximum	Mean	Maximum	Mean	Maximum
	2<6 years	0.05	0.13	0.03	0.12	0.09	0.21
	6<11 years	0.05	0.13	0.03	0.11	0.08	0.2
	11<16 years	0.02	0.05	0.01	0.05	0.04	0.09
	16<30 years	0.02	0.04	<0.01	0.03	0.02	0.06
	30<40 years	0.01	0.03	<0.01	0.03	0.02	0.05
	40<50 years	0.01	0.03	<0.01	0.03	0.02	0.05
	50<70 years	0.01	0.03	<0.01	0.03	0.02	0.05
Spectators Off-field	Third trimester fetus	<0.01	0.03	<0.01	0.04	0.01	0.06
	0<2 years	0.04	0.20	0.07	0.29	0.11	0.45
	2<6 years	0.02	0.10	0.04	0.15	0.06	0.23
	6<11 years	0.02	0.10	0.03	0.15	0.05	0.22
	11<16 years	<0.01	0.04	0.01	0.06	0.02	0.10
	16<30 years	<0.01	0.03	<0.01	0.04	0.02	0.06
	30<40 years	<0.01	0.03	<0.01	0.04	0.01	0.06
	40<50 years	<0.01	0.03	<0.01	0.04	0.01	0.06
	50<70 years	<0.01	0.03	<0.01	0.04	0.01	0.06

[a] 35 field-specific Chronic $HQ_{inh\text{-}sum\text{-}field}$ are included in this table.

6.5.2. Dermal and Ingestion Exposures

Forty-nine general chemicals were evaluated for chronic dermal on-field exposure and 69 general chemicals were evaluated for chronic ingestion on-field exposure. Dermal and ingestion exposures for off-field exposures to general chemicals were not evaluated as crumb rubber were not present off the fields. The chemicals evaluated are listed in Table 6-9. Chapter Sections 4.5.2 for organic chemicals and 4.6.2 for metals and metalloids list the toxicity criteria for these chemicals. The average daily dose of a general chemical via the dermal and ingestion exposure routes (ADD_{der} and ADD_{ing}, respectively) are shown in Appendix Sections F.5.3 and F.5.6.

The $HQ_{der\text{-}sum\text{-}field}$ was calculated by summing the $HQ_{der\text{-}field}$ for each chemical within the specific category and age group. Similar summations were made to calculate $HQ_{ing\text{-}sum\text{-}field}$ from $HQ_{ing\text{-}field}$. There was no receptor category and age group that had a $HQ_{der\text{-}sum\text{-}field}$ greater than 0.01.

Only the age groups within the receptor categories of athletes and spectators had $HQ_{ing\text{-}sum\text{-}field}$ considerably above 0.01, with the largest at 1 as the maximum calculated value for the spectator category age group 0<2 years, as can be seen in Table 6-11. All HQ_{der}, $HQ_{der\text{-}sum\text{-}field}$, HQ_{ing}, and $HQ_{ing\text{-}sum\text{-}field}$ can be found in Appendix Sections G.2.6 for

dermal exposure and G.2.8 for ingestion exposure. Overall, the calculated HQs were below 1 for chronic dermal and ingestion exposures to the general chemicals in all participant and spectator groups.

Table 6-11. **On-Field** Field-Specific[a] Chronic Ingestion Route Total Hazard Quotients for **All General Chemicals**

Receptor Category	Age Group	Chronic $HQ_{ing\text{-}sum\text{-}field}$	
		Mean	Maximum
Athletes	2<6 years	0.10	0.28
	6<11 years	0.06	0.19
	11<16 years	0.05	0.15
	16<30 years	0.06	0.16
	30<40 years	0.04	0.11
	40<50 years	0.03	0.09
	50<70 years	0.03	0.10
Coaches	16<30 years	0.01	0.04
	30<40 years	0.01	0.04
	40<50 years	0.01	0.04
	50<70 years	0.01	0.04
Referees	16<30 years	<0.01	0.02
	30<40 years	<0.01	0.02
	40<50 years	<0.01	0.02
	50<70 years	<0.01	0.02
Spectators	Third trimester fetus	<0.01	0.01
	0<2 years	0.34	1.00
	2<6 years	0.16	0.47
	6<11 years	0.11	0.33
	11<16 years	<0.01	0.03
	16<30 years	<0.01	0.02
	30<40 years	<0.01	0.01
	40<50 years	<0.01	0.01
	50<70 years	<0.01	0.01

[a] 35 field-specific Chronic $HQ_{ing\text{-}sum\text{-}field}$ are included in this table.

6.5.3. Hazard Index

The hazard indices based on all routes of exposure to all general chemicals are presented in Table 6-12. The mean chronic HI_{field}s for all receptor categories and age groups are below 1 from exposure to field-related, non-field-related and combined chemicals. The maximum individual field chronic HI_{field} calculated for the 16<30 year old athletes group was at 1. The primary reason for this finding comes from the higher maximum chronic $HQ_{inh\text{-}sum\text{-}field}$s for both field-related and non-field-related inhalation

exposures for this group seen in Table 6-10. While the $HQ_{inh\text{-}sum\text{-}field}$s are not above 1, they contribute the most to the final HI_{field}. The primary contributors were the field-related chemical 2-methyl furan and the non-field-related chemicals benzene and hexanal. The maximum individual field chronic HI_{field} calculated for the 0<2 year old spectator group was slightly above 1 for field-related chemical exposure, and this is a consequence of the $HQ_{ing\text{-}sum\text{-}field}$ (=1) for this age group for the ingestion route as seen in Table 6-11, driven by lead. Hand to mouth activity of infants would explain the higher ingestion of crumb rubber from the fields.

Figure 6-1 shows the distribution of HI for field-related chemicals and all chemicals for the 35 individual fields for both the athletes 16<30 years age group and the spectator 0<2 years age group. The off-field chronic HI_{fields} are not shown since they are the same as the chronic $HQ_{inh\text{-}sum\text{-}field}$ in Table 6-10. All on-field and off-field chronic HI_{field} values are presented in Appendix Section G.2.10.

Table 6-12. **On-Field** Field-Specific[a] Chronic Hazard Index (Chronic HI_{field}, unitless) for **General Chemicals**[b]—Combined Gender

Receptor Category	Age Group	On-Field Chronic HI_{field}					
		Field-Related General Chemicals		Non-Field-Related General Chemicals		All General Chemicals	
		Mean	Maximum	Mean	Maximum	Mean	Maximum
Athletes	2<6 years	0.20	0.41	0.06	0.21	0.25	0.59
	6<11 years	0.19	0.42	0.07	0.28	0.26	0.62
	11<16 years	0.17	0.39	0.07	0.27	0.24	0.58
	16<30 years	0.29	0.66	0.13	0.51	0.42	1.00
	30<40 years	0.19	0.43	0.09	0.33	0.28	0.66
	40<50 years	0.18	0.42	0.09	0.33	0.27	0.64
	50<70 years	0.18	0.41	0.08	0.32	0.26	0.63
Coaches	16<30 years	0.11	0.26	0.05	0.21	0.16	0.40
	30<40 years	0.10	0.23	0.05	0.18	0.14	0.35
	40<50 years	0.10	0.23	0.05	0.19	0.15	0.35
	50<70 years	0.10	0.23	0.05	0.19	0.15	0.35
Referees	16<30 years	0.04	0.10	0.02	0.08	0.06	0.15
	30<40 years	0.04	0.09	0.02	0.07	0.06	0.13
	40<50 years	0.04	0.09	0.02	0.07	0.06	0.13
	50<70 years	0.04	0.09	0.02	0.07	0.06	0.13
Spectators On-Field	Third trimester fetus	0.02	0.04	<0.01	0.03	0.03	0.06
	0<2 years	0.44	1.10	0.06	0.23	0.50	1.20
	2<6 years	0.22	0.54	0.03	0.12	0.25	0.58
	6<11 years	0.17	0.39	0.03	0.11	0.20	0.45
	11<16 years	0.03	0.07	0.01	0.05	0.05	0.11

Receptor Category	Age Group	On-Field Chronic HI_{field}					
		Field-Related General Chemicals		Non-Field-Related General Chemicals		All General Chemicals	
		Mean	Maximum	Mean	Maximum	Mean	Maximum
	16<30 years	0.02	0.05	<0.01	0.03	0.03	0.07
	30<40 years	0.02	0.04	<0.01	0.03	0.03	0.06
	40<50 years	0.02	0.04	<0.01	0.03	0.03	0.06
	50<70 years	0.02	0.04	<0.01	0.03	0.03	0.06

[a] 35 field-specific Chronic HI_{field} are included in this table.
[b] Lead is included in Chronic HI_{field} calculation (see Section G.2.2 for details).
[c] Lifetime Average Chronic HI is the 70 year weighted lifetime average of all age groups within a receptor category.

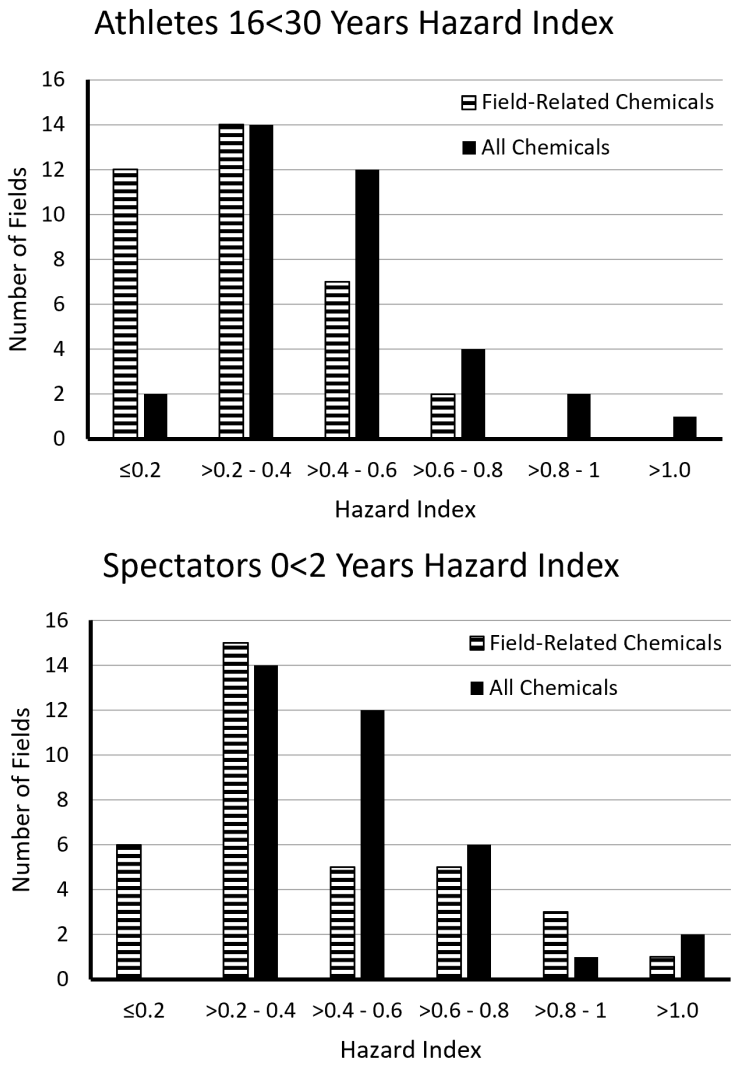

Figure 6-1. Chronic Hazard Index for Field-Related Versus All Chemicals. Top panel is for the Athlete 16<30 years group and the bottom panel is for the Spectator 0<2 years

group.

6.6. Cancer Risk

6.6.1. Inhalation Exposure

OEHHA evaluated the cancer risk from inhalation exposure to 19 carcinogens listed in Table 6-13. Of these, 12 carcinogens were field-related, and 7 carcinogens were non-field-related. The age-sensitivity-weighted lifetime average daily dose and the cancer slope factors for evaluating inhalation cancer risk from exposure to these chemicals are presented in Section F.6.1 and Section 4.4.5, respectively.

Table 6-14 shows the cancer risks for all field-related and non-field-related carcinogens from exposure on-field for all receptor categories as well as off-field for the Spectator category. All inhalation cancer risks can be found in Appendix Section G.3.1.

Table 6-13. Chemicals Evaluated for Cancer Risk

Chemical	Route Evaluated		
	Inhalation	Dermal	Ingestion
Field-Related Chemicals			
Aniline	X	X	X
Arsenic			X
Benz[a]anthracene	X	X	X
Benzo[a]pyrene	X	X	X
Benzo[b]fluoranthene	X	X	X
Benzo[k]fluoranthene	X	X	X
1,3-Benzothiazole-2-thiol		X	
Chromium			X
Chrysene	X	X	X
Cyclopenta[cd]pyrene	X	X	X
Dibenz[a,h]anthracene	X	X	X
Indeno[1,2,3-cd]pyrene	X	X	X
Lead			X
Methyl Isobutyl Ketone	X		
Naphthalene	X	X	X
Styrene	X		
Non-Field-Related Chemicals			
Acetaldehyde	X		
Benzene	X		
Benzene, 1,4-dichloro	X		
Benzene, 1-chloro-4-(trifluoromethyl)-	X		
Ethylbenzene	X		

Formaldehyde	X		
Tetrachloroethylene	X		

Each individual field risk was assessed using the age-sensitivity-weighted lifetime average daily dose, LADD (Appendix Section F.6) and CSF (CSF_{inh}: Section 4.4.5 and CSF_{oral}: Sections 4.5.3 and 4.6.3).

The mean of the sum of cancer risk associated with field-related chemicals was below 1 in a million for all receptor categories. The maximum risk value calculated for the 35 fields ranged up to 1 in a million for athletes while it was below 1 in a million for the other four receptor categories. The mean cancer risk associated with the non-field-related chemicals ranged from 0.02 to 3.7 in a million, with the maximal values ranging from 0.07 to 11 in a million, and it accounted for, in general, 90% or more of the total cancer risks on all fields (Table 6-14).

Table 6-14. Field-Specific[a] Inhalation Cancer Risk ($Risk_{inh\text{-}sum\text{-}field}$)

Receptor Category	Age Group	$Risk_{inh\text{-}sum\text{-}field}$ x 10^{-6}			
		Average of Individual Fields		Range of Individual Fields	
		Field-Related	Non-Field-Related	Field-Related	Non-Field-Related
Athletes	2<6 years	0.08	1.3	0.0004 – 0.4	0.3 – 3.9
	6<11 years	0.1	2.2	0.0007 – 0.6	0.5 – 6.4
	11<16 years	0.1	2.1	0.0006 – 0.6	0.5 – 6.2
	16<30 years	0.2	3.7	0.001 -1.0	0.9 – 11.0
	30<40 years	0.1	1.7	0.0005 – 0.5	0.4 – 5.1
	40<50 years	0.1	1.7	0.0005 – 0.5	0.4 – 5.0
	50<70 years	0.2	3.4	0.001 – 0.9	0.8 – 9.9
Coaches	16<30 years	0.09	1.5	0.0005 – 0.4	0.4 – 4.5
	30<40 years	0.05	1.0	0.0003 – 0.3	0.2 – 2.8
	40<50 years	0.05	1.0	0.0003 – 0.3	0.2 – 2.9
	50<70 years	0.1	1.9	0.0006 – 0.5	0.4 - -5.7
Referees	16<30 years	0.03	0.6	0.0002 – 0.2	0.1 – 1.7
	30<40 years	0.02	0.4	0.0001 – 0.09	0.08 – 1.0
	40<50 years	0.02	0.4	0.0001 – 0.1	0.08 – 1.1
	50<70 years	0.04	0.7	0.0002 – 0.2	0.2 – 2.1
On-Field Spectators	Third trimester fetus	0.002	0.04	0.00001 – 0.01	0.008 – 0.1
	0<2 years	0.1	2.4	0.0007 – 0.6	0.5 -7.0
	2<6 years	0.04	0.7	0.0002 – 0.2	0.2 – 2.2
	6<11 years	0.05	0.9	0.0003 – 0.2	0.2 – 2.6
	11<16 years	0.02	0.4	0.0001 – 0.1	0.09 – 1.1
	16<30 years	0.01	0.2	0.00007 – 0.06	0.05 – 0.7
	30<40 years	0.008	0.1	0.00004 – 0.04	0.03 – 0.4
	40<50 years	0.008	0.1	0.00005 – 0.04	0.03 – 0.4
	50<70 years	0.02	0.3	0.0001 – 0.08	0.07 – 0.9
Off-Field	Third trimester	0.002	0.02	0 - 0.01	0.004 – 0.07

Receptor Category	Age Group	$Risk_{inh\text{-}sum\text{-}field}$ x 10^{-6}			
		Average of Individual Fields		Range of Individual Fields	
		Field-Related	Non-Field-Related	Field-Related	Non-Field-Related
Spectators	fetus				
	0<2 years	0.1	1.1	0 - 0.7	0.3 – 4.7
	2<6 years	0.04	0.4	0 - 0.2	0.08 – 1.5
	6<11 years	0.1	0.4	0 - 0.3	0.1 – 1.8
	11<16 years	0.02	0.2	0 - 0.1	0.04 – 0.8
	16<30 years	0.01	0.1	0 - 0.1	0.03 – 0.5
	30<40 years	0.01	0.07	0 - 0.04	0.02 – 0.3
	40<50 years	0.01	0.07	0 - 0.04	0.02 – 0.3
	50<70 years	0.02	0.1	0 - 0.1	0.03 – 0.6

[a] The mean and maximum values in the table are based on 35 field-specific Riskinh-sum-field.

6.6.2. Dermal and Oral Exposures

Calculations of incremental lifetime cancer risk resulting from the field-related chemicals were conducted for dermal and oral routes. There were 11 carcinogenic chemicals evaluated for dermal exposure and 13 carcinogenic chemicals evaluated for exposure through ingestion of crumb rubber (Table 6-13). The dermal and oral age-sensitivity-weighted lifetime average daily doses for these chemicals are given in the Appendix (Sections F.6.2 and F.6.3), whereas the CSF_{oral} values are presented in Chapter 4 (Sections 4.5.3 and 4.6.3). The CSF_{oral} was used for both dermal and ingestion exposure routes. The mean and maximal cancer risks associated with the dermal route were below one in a million for all receptor categories. Table 6-15 shows the cancer risks for ingestion routes for the receptor categories. The mean and maximal cancer risks were below one in a million for most receptor categories for the ingestion route. However, the mean cancer risk for the spectator category, and the mean and maximal risks calculated for the athletes showed a small excess risk. All dermal and ingestion cancer risk values can be found in Appendix Sections G.3.2 and G.3.3, respectively.

Table 6-15. Field-Specific[a] cancer risk ($Risk_{der\text{-}sum\text{-}field}$) for dermal and ingestion exposures

Receptor Category	Age Group	$Risk_{ing\text{-}sum\text{-}field}$ x 10^{-6}	
		Average of Individual Fields	Range of Individual Fields
Athletes	2<6 years	0.2	0.04 – 0.2
	6<11 years	0.1	0.03 – 0.1
	11<16 years	0.1	0.03 – 0.1
	16<30 years	0.1	0.03 – 0.1
	30<40 years	0.1	0.01 – 0.1
	40<50 years	0.0	0.01 – 0.04
	50<70 years	0.1	0.02 – 0.1

Receptor Category	Age Group	$Risk_{ing\text{-}sum\text{-}field}$ x 10^{-6}	
		Average of Individual Fields	Range of Individual Fields
Coaches	16<30 years	0.03	0.01 – 0.03
	30<40 years	0.02	0.004 – 0.02
	40<50 years	0.02	0.004 – 0.02
	50<70 years	0.03	0.01 – 0.03
Referees	16<30 years	0.01	0.003 – 0.01
	30<40 years	0.01	0.002 – 0.008
	40<50 years	0.01	0.002 – 0.01
	50<70 years	0.02	0.004 – 0.02
Spectators	Third trimester fetus	0.002	0.0004 – 0.002
	0<2 years	0.9	0.2 – 0.9
	2<6 years	0.3	0.07 – 0.3
	6<11 years	0.2	0.06 – 0.2
	11<16 years	0.02	0.004 – 0.02
	16<30 years	0.01	0.002 – 0.01
	30<40 years	0.01	0.002 – 0.01
	40<50 years	0.01	0.002 – 0.01
	50<70 years	0.01	0.003 – 0.01

[a] 35 field-specific $Risk_{der\text{-}sum\text{-}field}$ and $Risk_{ing\text{-}sum\text{-}field}$ are included in the table.

6.6.3. Multiple Routes of Exposure

OEHHA estimated the lifetime cancer risk of multi-route exposure to the field-related and non-field related carcinogens. Table 6-16 lists the lifetime incremental cancer risks from multiple routes of exposures. Overall, the cancer risk associated with field-related exposures was much less than from exposure to non-field-related chemicals (i.e., common air pollutants). Further, the calculated average cancer risk levels across all fields for all age groups of athletes, coaches, referees and spectators (on-field and off-field) were below the *de minimis* risk level of 1 in a million. As seen from Table 6-16, column 3, the field-related cancer risk levels for the 33 receptor groups in the 35 fields ranged from 0.002 to 1.1 in a million.

Examining the individual field-specific cancer risk values for field-related carcinogens (Table 6-16, column 5), one can see that:

- the lifetime excess cancer risk values for coaches were below 1 x 10^{-6} in all cases and ranged between 0.01 to 0.6 in a million.
- the lifetime excess cancer risk values for referees were below 1 x 10^{-6} in all cases and ranged between 0.005 to 0.2 in a million.
- nearly all risk values calculated for the seven groups of athletes were below or very close to 1 x 10^{-6}, with the individual field-specific risk values from 0.03 to 1.2 in a million.

- all risk values calculated for the spectators off-field were below 1 x 10^{-6}, with the individual field-specific risk values ranging up to a maximal value of 0.7 in a million.
- except for infants (0<2 years), for all other groups of spectators on-field, the calculated cancer risk levels were below 1 x 10^{-6}, with individual field-specific values ranging from 0.001 – 0.8 x 10^{-6}. For infants (0<2 years) exposed to the turf-related chemicals on-field during 2 years, the calculated lifetime cancer risk ranges from 0.3 - 2.7 x 10^{-6}. Given the additional application of an age sensitivity factor of 10 to calculate the cancer risk for infants (0<2 years) (OEHHA, 2015), this risk level is low but of possible concern particularly because of the hand-to-mouth activity and ingestion of crumb rubber infill in the turf fields.

Table 6-16. Lifetime Incremental Cancer Risk for Each Age Group and Receptor Category for Multiple Routes of Exposures[a]

Receptor Category	Age Group	Risk x 10^{-6}			
		Average of Individual Fields		Range of Individual Fields	
		Field-Related	Non-Field-Related	Field-Related	Non-Field-Related
Athletes	2<6 years	0.2	1.4	0.06 – 0.7	0.3 – 3.9
	6<11 years	0.3	2.3	0.06 – 0.9	0.5 – 6.4
	11<16 years	0.2	2.2	0.05 – 0.8	0.5 – 6.2
	16<30 years	0.3	3.9	0.06 – 1.2	0.9 – 11
	30<40 years	0.2	1.8	0.03 – 0.6	0.4 – 5.1
	40<50 years	0.1	1.8	0.03 – 0.6	0.4 – 5.0
	50<70 years	0.3	3.5	0.05 – 1.1	0.8 – 9.9
Coaches	16<30 years	0.1	1.6	0.02 – 0.5	0.4 – 4.5
	30<40 years	0.1	1.0	0.01 – 0.3	0.2 – 2.8
	40<50 years	0.1	1.0	0.01 – 0.3	0.2 – 2.9
	50<70 years	0.1	2.0	0.02 – 0.6	0.4 - 5.7
Referees	16<30 years	0.04	0.6	0.01 – 0.2	0.1 – 1.7
	30<40 years	0.03	0.4	0.005 - 0.1	0.08 – 1.0
	40<50 years	0.03	0.4	0.005 – 0.1	0.08 – 1.1
	50<70 years	0.1	0.8	0.01 – 0.2	0.2 – 2.1
Spectators On-field	Third trimester fetus	0.004	0.04	0.001 – 0.014	0.008 – 0.11
	0<2 years	1.1	2.5	0.3 – 2.7	0.5 – 7.0
	2<6 years	0.3	0.8	0.08 – 0.8	0.2 – 2.2
	6<11 years	0.3	0.9	0.07 – 0.8	0.2 – 2.6
	11<16 years	0.04	0.4	0.01 – 0.1	0.09 – 1.1
	16<30 years	0.02	0.2	0.006 -0.09	0.05 – 0.7
	30<40 years	0.02	0.2	0.004 – 0.05	0.03 – 0.4
	40<50 years	0.02	0.2	0.004 – 0.05	0.03 – 0.4

Receptor Category	Age Group	Risk x 10^{-6}			
		Average of Individual Fields		Range of Individual Fields	
		Field-Related	Non-Field-Related	Field-Related	Non-Field-Related
	50<70 years	0.03	0.3	0.01 – 0.1	0.07 – 0.9
Spectators Off-field	Third trimester fetus	0.002	0.02	0.0 – 0.01	0.004 – 0.07
	0<2 years	0.1	1.1	0.0 – 0.7	0.3 – 4.7
	2<6 years	0.05	0.4	0.0 – 0.2	0.08 – 1.5
	6<11 years	0.05	0.4	0.0 – 0.3	0.1 – 1.8
	11<16 years	0.02	0.2	0.0 – 0.1	0.04 – 0.8
	16<30 years	0.01	0.1	0.0 – 0.07	0.03 – 0.5
	30<40 years	0.009	0.07	0.0 – 0.04	0.02 – 0.3
	40<50 years	0.009	0.07	0.0 – 0.04	0.02 – 0.3
	50<70 years	0.02	0.1	0.0 – 0.09	0.03 – 0.6

[a] Based on 35 field-specific $RISK_{field}$ values.

6.7. References

OEHHA (2015). Air Toxics Hot Spots Program Risk Assessment Guidelines: The Air Toxics Hot Spot Program Guidance Manual for Preparation of Health Risk Assessments. Sacramento, CA, Office of Environmental Health Hazard Assessment, California Environmental Protection Agency.

USEPA (1989). Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual (Part A). Washington D.C., Office of Emergency and Remedial Response, U.S. Environmental Protection Agency.

Chapter 7. Discussion

7.1. Introduction

This study assessed the non-cancer hazards and cancer risks for athletes, coaches, referees, and spectators from acute and chronic exposures to chemicals at synthetic turf fields in California. This assessment was based on individual field data on chemical concentrations and the toxicity criteria (TC) for the detected chemicals. OEHHA also derived exposure parameters specific to each receptor category, based on results from three Time-Activity Studies targeting competitive soccer athletes in California.

OEHHA considered the exposure duration, exposure routes, exposure pathways, and toxicity endpoints in conducting the risk assessment. Specifically, this study focused on: (1) acute inhalation exposure to chemicals, (2) one-day inhalation, oral, and dermal exposure to DARTs (developmental and reproductive toxicants), (3) chronic inhalation exposure to sensory irritants, (4) chronic inhalation, oral, and dermal exposure to general toxicants, and (5) lifetime risk from exposure to carcinogens.

This section discusses the limitations and boundaries of the study, while acknowledging areas of variability and uncertainty. It also provides the main conclusions from this assessment.

7.2. Study Design and Unique Features

This OEHHA Study is a cross-sectional study to characterize exposure to chemicals released from crumb rubber on synthetic turf fields and assess the health risks. The study consisted of several core tasks including field characterization, exposure characterization, and risk assessment. Several key elements of the study's protocols allowed OEHHA to obtain accurate and relevant chemical and exposure data for the health risk assessment:

- Use of state-of-the-art analytical instruments and computation algorithms, to identify field-related chemicals and non-field related pollutants, as well as bioaccessible chemicals from crumb rubber.
- Collection of air samples with the setup of a goal box in the middle of each field and scripted soccer activities to measure volatile organic chemicals (VOCs), semivolatile organic chemicals (SVOCs), and particulate matter.
- Measurement of bioaccessible concentrations of chemicals in field crumb rubber samples to assess ingestion and dermal exposures.
- Derivation of exposure parameters for California soccer athletes based on time-activity studies (TAS) and micro-level activity time series (MLATS), and
- Compilation of toxicity criteria for turf-related chemicals through five complementary approaches.

7.3. Study Boundaries and Limitations

The present study focused on the evaluation of human exposure to chemicals that can be released from crumb rubber infill only, and not from alternative infill materials. The backing materials and grass blade components of synthetic turf fields are not included in the scope of this evaluation. This study did not evaluate the field runoff or ecological impact of crumb rubber infill. While the assessment considered combined effect of chemicals emitted or extracted from crumb rubber infill, it did not assess the degradation products including microplastics and particles. Further, the study also did not assess the health risks due to physical or microbiological hazards associated with crumb rubber infills.

The study sampled 35 out of the approximately 907 fields across California. Using a stratified sampling plan (Section 2.3.1) the samples from 35 diverse fields provide representative chemical data for the evaluation of human exposure and assessment of human health risk. About 57% of sampled fields were considered as “new” with a field age of less than nine (9) years. The remaining fields were considered as “old” with a field age of nine (9) years or more. Studies have shown that the rate of chemical volatilization from synthetic turf fields with crumb rubber infill decreases as the fields age (Cheng *et al.*, 2014; Li *et al.*, 2010b). The off-gassing of chemicals is further enhanced due to high ambient and surface temperatures (Gomes *et al.*, 2021; Li *et al.*, 2010b; Lim, 2008). This study sampled each field once, either in the cold or warm season and only sampled four fields with a field age of one year or less. As such, this study did not assess how temperature and field age affect the volatilization of chemicals.

During sample collection for this study, the state experienced a severe drought, resulting in widespread wildfires and subsequent deposition of fire-related chemicals across the State, such as polyaromatic hydrocarbons (PAHs) and metals. These events complicated the characterization of exposures of chemicals present at synthetic turf fields in California.

Recent reports published after the study was initiated revealed the presence in synthetic turf materials, particularly in the grass blades, of chemicals of emerging concern, such as N-(1,3-dimethylbutyl)-N′-phenyl-p-phenylenediamine (6PPD), N-(1,3-dimethylbutyl)-N′-phenyl-p-phenylenediamine quinone, and perfluoroalkyl substances (PFAS) (EWG, 2019; Lowell Center for Sustainable Production, 2024; Murphy and Warner, 2022; Tian *et al.*, 2022; Tian *et al.*, 2021). This study completed a non-targeted chemical analysis of the crumb rubber and did not detect PFAS. The suspected source of PFAS chemicals is not crumb rubber infill or air, the focus of this study, but the artificial turf blades. We did detect 6PPD, a known tire component, though our non-targeted analysis of crumb rubber did not detect or identify its transformation product (N-(1,3-dimethylbutyl)-N′-phenyl-p-phenylenediamine quinone).

The California Department of Toxic Substances Control (DTSC) identified that release

of zinc from tires into water bodies could harm aquatic organisms (DTSC, 2021). Our study was initiated to address concerns about possible effects of crumb rubber materials on human health, and it therefore focused on human exposure and health hazards. Thus, OEHHA did not evaluate migration of chemicals to other environmental matrices and the potential health impacts on ecological receptors exposed through such media.

Other studies (Negev *et al.*, 2022; Van Ulirsch *et al.*, 2010) found lead (at levels exceeding federal statutory limit in synthetic turf fibers and surface dust at synthetic turf fields), trace metals, polycyclic aromatic hydrocarbons, and phthalates (in synthetic turf playground surfaces) in synthetic turf materials. The study measured bioaccessible concentrations of metals (including lead) in crumb rubber for evaluating ingestion exposure, as well as PAHs and phthalates in air (including vapor and fine particulate matters in air) and bioaccessible concentrations in crumb rubber for exposure via multiple routes. Due to logistical reasons, we were unable to collect adequate amounts of fine particulate matter from the air for metal analysis and therefore we did not assess inhalation exposure to lead in air on the fields. However, the California Attorney General has established an enforceable lead standard for synthetic turf (50 ppm) and requires manufacturers to replace fields with levels of lead exceeding the standard (CA DOJ, 2010).

This study measured chemical concentrations in the air and in crumb rubber. No personal or biomonitoring measurements of chemicals in synthetic turf field users were performed. A study plan prepared by UCB presented the feasibility of using personal and/or biological monitoring to assess exposure to chemicals on synthetic turf fields (Appendix F.7). The report identified chemical targets that could be included in a biomonitoring study, and methods and metabolites to monitor and track their exposure. This preliminary study plan highlights the challenges and limitations of monitoring for a small number of VOCs, SVOCs, and metal/metalloids detected on synthetic turf fields. Certain chemicals identified as present on synthetic turf fields, even those designated as field-related, may have multiple uses and other exposure sources which make it difficult to identify synthetic turf fields as the unique chemical exposure or to determine the fraction of measurable chemical biomarkers that are due to synthetic turf field use. In a pilot biomonitoring study on synthetic turf fields (USEPA and CDC/ATSDR, 2024), no differences in blood metal concentrations or urinary PAH levels were found between grass and synthetic turf field users.

7.4. Variability

There are several aspects and sources of variability in any health risk assessment. This OEHHA assessment considered the impact of variability in the chemical content of crumb rubber infills and other input parameters on the exposure of receptors in the synthetic turf fields.

7.4.1. Sample Heterogeneity

Crumb rubber infill is produced from a wide variety of automobile waste tires (different tire types, models, brands, production years, age in traffic). OEHHA considered this heterogeneity in an analysis of crumb rubber variation within a sample and within a field. Each analysis was done on samples from a single field, for only those chemicals detected in the selected field, and the results applied for all individual fields. The full details of the analysis can be found in Appendix D.4.1.4.3. The results suggest that observed small variations present between individual samples and composites of those samples collected on a field have a low impact on the results of the health risk assessment. Therefore, OEHHA applied the assumption of similar variability for all chemicals detected on each of the 35 individual fields.

7.4.2. Time-Activity and Exposure Parameters

The present study conducted California-specific TAS to derive athlete-specific physical parameters and soccer-specific exposure parameters for exposure evaluation of synthetic turf field users.

Overall, OEHHA applied mean values in exposure evaluation. OEHHA considered the potential of using mean, 95th percentile and maximum values for athletes in the study. Uncertainty in the survey results due to response bias, such as differences in interpretation of the terms used in the questions or memory bias, made applying the 95th percentile and maximum values challenging. For example, a very small number of survey participants provided these higher-end responses regarding the number of hours and days spent on the field (i.e., 16 hours a day each of the week). Using this small number of respondents as the most likely scenario on synthetic turf fields would overestimate exposure on synthetic turf fields for most soccer athletes. Additionally, by combining 95th percentile or maximum values for various parameters (i.e. annual event time, AET, Appendix Section B.2.5) that were not provided by the same participant, unrealistic scenarios could be created such as exposure times of 16 hours per event for both practices and games and event frequencies greater than 706 events per year which would indicate more than 2 practices and/or games a day. As a result, OEHHA chose to adopt mean values for soccer-specific activity exposure parameters.

With particular focus on DART endpoint, the time spent on field (exposure time, ET) on tournament days relative to practice days is greater, and there is wide variability in ET among field users. The mean ET varied from 1.5 to 3.1 hours during practice compared to mean ET of 2.1 to 4.3 hours on game days. However, the 95th percentile ET values varied from 2 to 8 hours during practice compared with 4 to 9.2 hours during game days (Appendix B.2.4). As detailed in the preceding paragraph, OEHHA risk assessment is based on mean ET values. Considering the impact of 95th percentile ET values, it will have a direct influence on the resulting exposure calculations and HI_{DART}. Thus, for a hypothetical scenario of tournament day exposure based on the 95th percentile ET values (ET = 4 to 9.2 hours), the resulting HI_{DART} can be greater than the mean values

calculated in this study because of greater ET values (ranging from 1.7 to 4.6).

7.4.3. Athlete Player Position

Within the athlete receptor group, OEHHA received survey responses from players of different positions, including forwards, defenders, midfielders, and goalies. Following public concern of high exposure to chemicals for goalies due to frequent diving activity and potential of ingesting crumb rubber, OEHHA evaluated survey responses for those participants as a separate exposure group. OEHHA's evaluation for goalies did not reveal a large difference from the values derived from all participant data. Based on the small participant number (about 100 participants responded they play in the goalie position) and lack of data for many age groups (the TAS survey only received goalie data for the 11-16 and 16-30 years age groups), this study used a goalie-specific scenario to compute risk values for the all-athlete scenario.

7.4.4. Combined Receptor Scenarios

OEHHA evaluated risk for each receptor category separately and did not assess risk for combined-receptor scenarios. For specific and rare scenarios in which a person acts as multiple receptors during a single event or during a year, the time-adjusted hazard index and combination of cancer risk values can be performed based on the results presented in Chapter 6. Since essentially all age-specific and receptor-specific hazard indices and cancer risk values are well within the acceptable benchmarks, the likelihood of significant health risk during realistic combined-receptor scenarios is low.

7.5. Uncertainty

The following sections discuss the areas of uncertainty in the present study and specifically these relate to uncertainties in source characterization, exposure assessment and dose-response assessment, specifically focusing on toxicity criteria for chemicals detected on synthetical turf fields.

7.5.1. Chemical Characterization and Source Designations

In this study, one critical aspect was the designation of chemicals as field-related or non-field-related. For reasons such as, but not limited to, field location (i.e., next to roads or in industrial areas), the use of power generators on fields where no power inlets were present, and changes in wind direction and speed during sampling events, chemicals detected in air and crumb rubber may have sources other than the synthetic turf field itself. Without the actual background samples to determine background chemical levels at fields, this study (i) examined concentration profiles for chemicals sampled in air on fields and (ii) performed extraction on fresh crumb rubber and field samples to determine the field-related chemicals. Chemicals found to have concentrations that decrease as sampling height increases, and chemicals detected in the crumb rubber extraction, were designated as field-related. For chemicals that were not collected in stratified samples, OEHHA used available regional air monitoring data,

for fields located in that region, to determine the likely source of those chemicals. Any chemicals not determined to be field-related were considered as non-field-related. These assumptions are a source of uncertainty in this risk assessment particularly as to the contribution of hazards and risks from chemicals with field-related sources versus those from non-field related sources.

For chemicals detected on-field, OEHHA applied concentration data collected from the air (Section 3.4.6) to derive acute inhalation exposure concentrations (Acute C_{inh}), chronic inhalation exposure concentrations (Chronic C_{inh}), and average daily doses of chronic inhalation exposure (ADD_{inh}) for each organic chemical detected in the air. Additionally, OEHHA used bioaccessible concentrations of chemicals detected in gastrointestinal fluids extract (Section 3.4.3) and artificial sweat extract (Section 3.2.4) of crumb rubber samples ($C_{der\text{-}crumb\ rubber}$ and $C_{GI\text{-}crumb\ rubber}$, respectively) to derive average daily doses for chronic exposures via dermal and ingestion routes (ADD_{der} and ADD_{ing}). We were unable to confirm all the tentatively identified chemicals in the samples due to limitations on a) availability of high purity reference standards, b) sensitivity of instruments controlled the resolution of peaks among many chemicals in the extracts, and c) coeluted chemicals with highly similar structure like isomers shared very similar behavior in the separation columns (see Section 3.6 for more details). These factors limited the number of chemicals identified for field characterization purposes.

The chemicals off-field were identified following collection of five consecutive hourly samples for VOCs, a three-hour large volume sample for SVOC and particulate matter from air at a nearby, off-field, and upwind location for each field. Ideally, the only difference between on-field and off-field locations would be the presence of synthetic turf materials on the field. Actual field conditions, however, did not always allow for this occurrence. Following the installation of a field, continual migration of chemicals to off-field areas is likely to have occurred through various mechanisms like windblown crumb rubber dusts and migration of SVOCs to surfaces off the field. Also, even though we tried to position the off-field samplers at an upwind location of each field, changes in wind direction during the sampling period sometimes resulted in an off-field sampling location no longer being truly upwind from the field. As a result, the measured off-field chemical concentration data might not reliably reflect background (non-field-related) exposure conditions for athletes, coaches, or referees in the study.

7.5.2. Exposure assessment

The exposure parameters for coaches, referees, or spectators were based on TAS collected in athletes. This approach introduced uncertainty in the exposure and risk assessments for these groups regarding the amount of time each group would spend at the field. However, OEHHA used the highest mean values of the athletes' data for practices and games for the other receptor groups to be health-protective.

Further, the TAS survey data did not collect any information on the amount of crumb

rubber particles that might be directly ingested during the course of soccer activities. However, participants did report it occurring. Without protocols to measure the ingested amount of crumb rubber, OEHHA used data in the literature to estimate the direct ingestion amount. This amount is likely to be a conservative overestimate in the exposure and risk assessments.

For DARTs, OEHHA assumed that a single exposure event may be sufficient to cause developmental and reproductive adverse outcomes. Therefore, for all exposure routes, an event frequency (EV_{DART}) equal to 1 event per day was used. For inhalation exposures, chemical concentration for a less-than-24-hours-per-day exposure was adjusted, using the average volume of air inhaled during a field event (V_{event}) to account for an exposure based on the different exertion levels and breathing volumes during a soccer event.

7.5.3. Dose-Response Assessment

7.5.3.1. Non-carcinogens

To evaluate a health protective non-cancer hazard of multiple route exposures to chemicals at synthetic turf fields, OEHHA used available information and health-protective approaches in developing the toxicity criteria to be used in the hazard and risk assessment of human exposure to chemicals detected in air and crumb rubber samples collected from synthetic turf fields.

For chemicals with established toxicity criteria, the approach was to select the most health-protective value based on the most sensitive toxicity endpoint. Priority was given to recent assessments with higher quality studies, comprehensive review of the studies, and analyses using current risk assessment methodologies. In addition, OEHHA developed new screening level toxicity criteria for several chemicals, which are relevant for synthetic turf exposure scenarios.

For chemicals without established non-cancer toxicity criteria, OEHHA derived new toxicity criteria (either de novo or using route-to-route extrapolation, where appropriate) or identified structural analogs and used their established values. In some cases, no toxicity values could be derived or were available for analogs resulting in no toxicity assessment for those chemicals. The uncertainties associated with these methods is discussed below.

OEHHA applied one-hour toxicity criteria (Acute TC_{inh}) for acute inhalation exposure to 11 volatile organic chemicals and carbonyls detected in air at synthetic turf fields. OEHHA had not established Acute TC_{inh} for the other 108 organic chemicals detected in air. Absence of scientific evidence on toxicities for acute inhalation exposure to these chemicals was one of the reasons for the lack of established acute inhalation toxicity criteria. Further, OEHHA determined that the limited number of chemicals with established 1-hour RELs were not sufficient for use as chemical analogs of these 108 detected chemicals. As a result, for chemicals lacking acute RELs, OEHHA used the

available subchronic health guidance values from other peer-reviewed sources (USEPA PPRTV, ATSDR MRL) and found that exposures were well below even those health guidance values, indicating that there would be no concern for acute health hazards.

The assumption of similar toxicity is a potential source of uncertainty due to the use of analog chemical values. Fourteen chemicals were assigned to the DART group based on the toxicity of analogs. Treating these chemicals as DARTs for exposure calculations introduced uncertainty in the exposure assessment since a single day rather than average exposure is assumed. The interpretation of the resultant hazard should take into consideration this assumption about toxicity. For other endpoints (general chemicals), 66 chemicals had toxicity criteria based on analog values. Using this approach allows the exposure of more chemicals to be included in the risk assessment, however the toxicity could be over- or under-estimated with analog assignment. The use of the route-to-route extrapolation approach for toxicity criteria adds additional uncertainty to the interpretation of the hazard or risk. For this study, toxicity criteria from the oral route were applied to the inhalation exposure of some chemicals and dermal exposure of all chemicals detected. Extrapolation is a conventional practice in risk assessment and in the absence of data, it is reasonable to assume same systemic toxic effects. However, due to lack of pharmacokinetic information to compare the disposition of the chemicals between routes, it is unknown whether this approach leads to over- or underestimation of toxicity.

7.5.3.2. Carcinogens

OEHHA used benzo[a]pyrene (BaP) potency equivalency factors (PEF, see Section 4.4.5) to derive cancer toxicity criteria and assess the risk associated with exposure to carcinogens when established chemical-specific cancer slope factors (CSFs) were not available. PEF_{BaP} are potency factors applied to PAHs for which potency values derived with chemical-specific carcinogenicity data cannot be developed. They are estimated using BaP as the reference chemical. PEF_{BaP} provide a relative estimate that is more likely and better to reflect the specific PAH toxicity than using an assumption of equal toxicity to BaP, which in most cases may overestimate toxicity (OEHHA, 2015). Of the 23 identified carcinogens, 16 chemicals had established chemical-specific CSFs, five chemicals had established PEF BaP, one chemical had a newly derived study specific CSF, and one chemical had a newly derived study-specific PEF BaP.

Thirteen chemicals were assessed in a single pathway with chemical specific CSFs. Ten carcinogens were assessed for risk in all three exposure pathways. Of those assessed in multiple pathways, three had chemical-specific CSF and route-to-route extrapolation was used to apply the CSF for some routes. There is uncertainty with route-to-route extrapolation as differences in deposition, absorption, and metabolism between routes can result in over- or underestimation of the calculated risk.

For metals and metalloids, for either non-cancer or cancer effects, the most health protective value was selected regardless of their oxidation state and anion. For

example, we assumed all chromium in the crumb rubber to be chromium VI instead of the generally less toxic anion chromium III. This approach was used because the actual state and anion in the crumb rubber are unknown. It adds uncertainty in the toxicity assessment and may lead to over-estimation of the risk for some metals and metalloids.

7.6. Cancer and Non-Cancer Risk Characterizations for Artificial Turf Field Users

This study characterized health risks to artificial turf field users, by focusing on the following health outcomes from exposures to chemicals from crumb rubber infill:

- Acute inhalation toxicity
- Developmental and reproductive toxicity
- Sensory irritation
- General chronic toxicity, and
- Lifetime cancer risk

Each assessment was conducted based on detected chemicals that were likely to cause the specific non-cancer hazard or cancer risk, so the chemicals included in each assessment varied and few overlapped in the five outcomes. For non-cancer health hazards, a hazard index (HI) of 1 is considered to not present a health hazard and any exceedance of this value would indicate an increasing but undefined likelihood that adverse health impacts may occur, particularly in sensitive individuals. For cancer risk, a value at or below one excess cancer in a population of one million people over a lifetime of 70 years is considered a negligible risk or *de minimis* risk level.

Four receptor categories, namely, athletes, coaches, referees, and spectators were evaluated in this study and they were further divided into appropriate age groups. The study results indicated that:

- *Acute exposure such as 1-hour intermittent exposure* to artificial turf field-related or non-field related chemicals would not be associated with acute health hazards to any receptor. The acute hazard index from the single field-related and 10 non-field-related acute toxicants evaluated in this study is less than 1.
- *One-Day exposure* to developmental and reproductive toxicants, on average, *was associated with a HI of less than 1 (0.01 to 0.58)* for all receptor and age groups. The calculated maximum HI_{DART} among the 35 fields was above 1 (range of 1.2 to 1.8) for athletes 11-70 years. When HI_{DART} exceeds 1, there is increasing but unquantified probability of health effects. The HI_{DART} of 1.2 – 1.8 in athletes of 11-70 years calculated in this study is the result of combination of "worst-case", health-protective assumptions and parameters used in exposure assessment as detailed below:
    - The exposure assessment assumed a "worst case" summation of chemical doses received through (i) inhalation exposures during 2.3 to 3.1 hours per event (game or practice); (ii) ingestion exposure of 292 to 315 mg crumb rubber per event and (iii) dermal exposure through skin load of

142 – 180 mg crumb rubber per event. The odds of all these actually occurring is very low, thereby indicating low probability of observing HI_{DART} exceedances of 1.2 – 1.8.

While the HQ of each chemical taken individually for each age group of each receptor group was below 1, the sum total of HQs for the 24 chemicals, i.e., HI_{DART}, exceeded 1 in athletes 11-70 years primarily due to inhalation exposures to benzo(a)pyrene. The toxicity criterion for benzo(a)pyrene was calculated using an uncertainty factor of 3000. This means that the reference health guidance value for humans is 3000 times less than the lowest concentration at which adverse effects were observed in animals, to account for data gaps on the health effects of benzo(a)pyrene. As the maximal HI_{DART} of 1.2 – 1.8 calculated in this study for athletes of 11 – 70 years old is very small compared to the factor of 3000, it indicates a low probability of, and concern for, developmental and reproductive health effects.

- *Chronic exposure to sensory irritants*: The mean individual field $HI_{sensory}$ for the single field-related and 2 non-field-related sensory irritants among the 35 individual fields were all below 1. The maximum individual field $HI_{sensory}$ was 1.9, within 2-fold of the level of concern, with 99.9% of the hazard originating from the non-field-related irritants, which are common air pollutants and not coming from the turf infill.

- *Chronic exposure to general chemicals*: The HI method used in this study assumes that the chronic health effects of the various chemicals are additive. This method is a simplification of the HI concept because it only considers the four coarse endpoints (acute, DART, sensory irritants, and general chemicals) and does not consider the specific target organs (liver, kidney…) and toxicity mechanisms of the various chemicals. The mean individual field HI for general chemicals, for combined exposure to field and non-field related chemicals, was below 1 (range of 0.03 to 0.5) for all receptors. While the maximum value of the individual field HI for combined field-related and non-field-related chemicals did not exceed 1 in athletes, referees and coaches, it was 1.2 for on-field spectators 0<2 years of age. Of the 99 field-related chemicals contributing to the HI, lead was the driver, contributing to 66% of the total value through the ingestion of crumb rubber from the fields, particularly by the hand to mouth activity. When the HI exceeds 1, there is increasing but unquantified probability of health effects; the HI was 1.2 in this study for on-field spectators 0-2 years old and it was based on the following “worst-case” combination of health-protective exposure parameters and assumptions:
    - Inhalation of air during 397 hours per year (with the duration of each event ranging from 2.1 to 3.1 hours per day);

- Dermal load of 48 mg of crumb rubber per event during 161 events (games and practices) per year; and
- Ingestion of 153 mg of crumb rubber per day (i.e., during attendance at a game or practice during 161 days per year).

Given that the odds of these exposures actually occurring is low, there is a low probability and concern of health effects in on-field spectators 0-2 years old. The HI in infants will be closer to 1 (i.e., no concern of health effects), if any of these exposure parameters are lower, particularly the amount of crumb rubber ingested per day of event.

- *Lifetime cancer risk*: The cancer risk estimates from this study indicate very low *additional* risk for the synthetic turf field users. The mean individual field risk for combined exposure to field- and non-field-related carcinogens exceeded 1 x 10^{-6} for all receptors, with the cancer risk being driven primarily by the non-field-related carcinogens.

  The calculated average cancer risk levels, associated with the field-related chemicals, across all fields for all age groups of athletes, coaches, referees and spectators (on-field and off-field) were below the *de minimis* risk level of 1 in a million. The range of calculated cancer risk in some but not all fields exceeded 1 x 10^{-6} by a small extent, specifically for athletes (0.03 to 1.2 in a million) and infant spectators on-field (0.3 to 2.7 x 10^{-6}). In these two particular groups, the maximal risk value was slightly above 1 in a million lifetime risk, and it is a result of the "worst-case" combination of health-protective assumptions and parameters used in exposure assessment:
  - Inhalation exposure of infants and athletes during 2.1 to 3.1. hours per event (161 events per year for infants; 138 to 214 events for athletes);
  - Oral exposure of infants to 153 mg crumb rubber per event during 161 events per year, and of athletes to 115 to 176 mg crumb rubber per event day during 138 to 214 events per year; and
  - Dermal exposure to a skin load of 48 mg of crumb rubber per event during 161 events per year in infants, and 168 – 179 mg crumb rubber per event during 138 – 215 outings per year for athletes of 16-30 years and 50-70 years old.

Given the low odds of all these exposure scenarios and parameters actually occurring, the estimated cancer risks do not rise to moderate or significant level of concern.

7.7. Comparison to Other Studies

OEHHA's study of 35 synthetic turf fields with crumb rubber infill adds to the growing literature about exposure to chemicals that may be released from crumb rubber. The OEHHA study is a risk assessment based on detected chemicals with TC values for which exposure assessment was conducted, and it is not a health impact study or an

epidemiological evaluation. The non-cancer hazard and cancer risks to turf field users obtained in this study are comparable to earlier studies summarized in Tables A-1 and A-2 (Beausoleil *et al.*, 2009; Connecticut Academy of Science and Engineering, 2010; Denly *et al.*, 2008; Dye *et al.*, 2006; European Chemical Agency, 2017; European Chemical Agency, 2021; Ginsberg and Toal, 2010; Ginsberg *et al.*, 2011; Li *et al.*, 2010a; Li *et al.*, 2010b; Lim and Walker, 2009; Lioy and Weisel, 2011; Mattina *et al.*, 2007; Menichini *et al.*, 2011; National Institute for Public Health and the Environment, 2017a; National Institute for Public Health and the Environment, 2017b; Pavilonis *et al.*, 2014; Ruffino *et al.*, 2013; Simcox *et al.*, 2010; Simcox *et al.*, 2011; USEPA, 2009; Vetrano, 2009; Zhang *et al.*, 2008). Further, the conclusions of the NTP Toxicology studies on crumb rubber and the ECHA risk assessment are in line with the present study (Appendix A.2). As seen in other studies (Simcox *et al.*, 2010; Simcox *et al.*, 2011; USEPA, 2009; Vetrano, 2009), OEHHA's particle analysis also found that on- and off-field particle levels were similar.

Whereas previous studies used standard or theoretical exposure parameters in their assessments (Denly *et al.*, 2008; Vetrano, 2009), this study estimated exposure to chemicals based on survey and video studies of soccer players in California. Collected data was used to estimate relevant exposure scenarios and characterize variability associated with risk estimates.

Additionally, elevated surface temperatures on synthetic turf fields found in the present study were consistent with the temperature evaluations reported in earlier studies. For example, Lim and Walker (2009) reported that synthetic turf fields had surface temperatures that were on average 26- to 42-degrees Fahrenheit higher than grass and other surfaces. Denly *et al.* (2008) measured surface temperatures ranging from 80 to almost 180 degrees Fahrenheit while the ambient temperatures ranged from around 70 to 100 degrees Fahrenheit.

Apart from the studies included in Appendix Tables A-1 and A.2, a report from the *Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds* (FRAP) study was released (USEPA, 2016; USEPA and CDC/ATSDR, 2024)(US EPA 2024). While the FRAP study is not a risk assessment, it focused on assessing potential human exposure for six chemicals (pyrene, benzo(a)pyrene, benzothioazole, methyl isobutyl ketone, lead and zinc), while the OEHHA study conducted exposure and risk assessments for 148 chemicals associated with crumb rubber infills. Furthermore, in the FRAP study, only 78 of the targeted analytes were found to have any TC values, while the OEHHA study found or developed TC values for 148 chemicals to facilitate a health risk assessment.

Regarding the number of chemicals, OEHHA's study tentatively identified more than 400 organic chemicals initially, and then focused on 149 organic chemicals plus 30 metals and metalloids for targeted analysis. The risk assessment was based on 57 VOCs, 71 SVOCs, and 20 metals and metalloids for which OEHHA had found or developed TCs. These chemicals are comparable to those focused by earlier studies

summarized in Tables A-1 and A-2. The US EPA's FRAP study, in its targeted analysis, identified 31 VOCs, 49 SVOCs and 21 metals (USEPA, 2016). In addition, a literature review of 20 studies on crumb rubber across 6 countries compiled a list of 302 chemicals (from analysis of crumb rubber, air, and leachate), without assigning or identifying chemicals associated with each specific location, study or exposure medium (Perkins *et al.*, 2019).

7.8. Conclusions

Overall, this risk assessment study, focusing on chemicals in crumb rubber infill, found no significant health risks to players, coaches, referees and spectators from on-field or off-field exposure to field-related chemicals in crumb rubber infill from synthetic turf fields based on available data. Specifically, the evaluations of acute toxicity, developmental and reproductive toxicity, sensory irritation, general chronic toxicity and cancer risk in all receptor groups were within acceptable benchmarks with very few exceptions. Considering the health-protective, "worst-case" assumptions and parameters used in the exposure assessment, the small exceedances in the few instances and scenarios associated with turf field-related chemicals are of low probability and of low concern, and would not require further evaluation.

7.9. References

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