Memo

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cc: John Rehill, Commissioner & Fire Chief, Halton Hills Fire Department

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Subject: Literature Review: Potential Effects of Fireworks on Domestic Animals and Wildlife, the Environment, and Human Health

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1.0 Introduction

Dillon Consulting Limited (Dillon) has conducted a literature review for the Halton Hills Fire Department to review the researched and documented effects of fireworks on animals, the environment, and human health. Fireworks have long had significant cultural importance, thought to have been originally developed over 1000 years ago in China alongside the advent of gunpowder. Since, they have been used across the globe for various purposes including, but not limited to, religious festivals, public entertainment, celebrations of tradition, and sporting events. More recently, however, the potential effects of fireworks have become a relevant discussion.

This literature review consisted of a comprehensive background review of peer-reviewed journal articles, primarily from the last 15 years, as well as articles from reputable news and government sources. Search terms included: fireworks and wildlife; human health; post-traumatic stress disorder (PTSD); the environment; domestic animals/livestock; and wildfires. In total, 30 peer-reviewed journal articles were reviewed, along with seven secondary articles to provide supporting information during the background review. Information was gathered from sources across the globe, with many articles focusing on large festivals or celebratory events where fireworks are commonly observed, such as New Year's Eve.

Five reoccurring topics of study were commonly identified in the articles that were reviewed as part of this literature review: domestic animals, wildlife, environmental effects, human health, and alternative firework options and mitigative actions. These five reoccurring topics have been outlined in this literature review under the following sections and summarize the documented effects of fireworks based on public response/survey input, monitoring, observational and statistical data. Where applicable, sub-topics are addressed in these sections due to the various effects of fireworks identified, the types of analysis conducted, and the consideration for differences between animals and humans.

The intent of this memo is to summarize the findings of the literature review, to provide an overview of the impacts (direct and indirect) of fireworks, and to discuss alternatives and mitigation measures that are being introduced and implemented.

2.0 Potential Effects and Impacts

2.1 Domestic Animals

2.1.1 Companion Animals

The available literature investigating the effects of fireworks on domestic companion animals focused mostly on dogs and cats. Companion animals were a highly studied group due to the controlled environment they could be studied, and the intimate knowledge pet owners had of their domestic animals and what a triggered (stress) response would look like for them. It is common knowledge that many animals, such as cats and dogs, have heightened auditory sensitivities in comparison to humans (Strain, 2021). Due to the unpredictable nature of firework sounds and visual effects, and the unfamiliarity of fireworks in general, companion animals have an increased likelihood to respond to firework displays in a panicked state (Gates et al., 2019).

The primary method of data collection on the effects of fireworks on domestic companion animals was through surveys (postal, online, and face to face interviews). One such study by Blackwell, Bradshaw, and Casey in 2013, had nearly half of the survey respondents report a negative response observed in their pet (dogs) when exposed to abrupt, loud noises, with a greater proportion of dogs showing a fear response to fireworks than any other noise. These experiences are echoed in other, similar studies surveying companion animal owners. One study documented approximately 50% of cats and dogs showing obvious signs of distress when exposed (auditory) to fireworks (Dale et al., 2010). Further, 6% of animals were reported to have received injuries following the exposure to fireworks, including: accidental firing, resulting in direct contact with the animal (21%); deliberate contact through intentional firing at the animal (13%); and, injuries elicited from a fear-based response caused by panicked reactions to the fireworks (66%), such as running into traffic (Dale et al., 2010). In a more recent study released in 2019, approximately 75% of survey respondents reported that their companion animal(s) showed visual (behavioural) fear to fireworks (Gates et al., 2019). The most common behavioural responses reported in this study were hiding (71%), shivering (54%), and cowering (45%). However, a common observation in all surveys was that many owners (up to 75%) have not sought help or treatment for their animal's noise related phobia, though treatments do exist such as chemotherapeutic agents, pheromone products, and behavioural therapy (Dale et al., 2010; Blackwell et al., 2013; and Gates et al., 2019). Lastly, there is evidence to support that fireworks can be a primary stressor leading to PTSD in canines, and a primary trigger mechanism for those experiencing PTSD (Alupo, 2017).

Overall, the findings related to visual stressors for companion animals suggest that fireworks have a documented negative response and effect, leading to heightened stress and fear-based behavioural responses, which can result in PTSD, injuries, and even death.

2.1.2 Domestic Horses

Like companion animals (**Section 2.1.1**), literature methodology investigating the negative effects of fireworks on domestic horses is primarily through surveys of horse owners. Horse anxiety was documented as a very common reaction, with 79% of owners reporting some level of anxiety during and following exposure to fireworks (Gronqvist et al., 2016). Running (82%) was the most common behavioural response, followed by 35% of reported horses breaking through fences, and with 26% reporting injuries associated with firework anxiety behaviours (increased kicking, bucking, head throwing, running, etc.). In this survey, the vast majority (90%) of survey participants were against sale of fireworks for private use (Gronqvist et al., 2016). In comparison, a more recent survey (2022) documented a lower percent of survey participants observing noticeable anxiety in their horses due to noise events (22%); however, where anxious behaviours were recorded, a wider variety of behaviours (appetite loss, trembling, and fever, to name a few) were noted (Riva et al., 2022). In one case, these anxious behaviours were responsible for the death of a horse in Nova Scotia, Canada, on New Year's Eve of 2021; a horse exhibiting anxious behaviours due to a firework event responded with a fear-based flight response. This response resulted in the horse bolting from the owner, and ultimately, the horse suffered a compound fracture injury, and had to be euthanized (CBC, 2022).

Based on the reported cases summarized above, a high percentage of domestic horse owners have documented the effects of fireworks causing varying levels of anxiousness, which can lead to behaviours that can cause injuries and even death in domestic horses. Through this literature review, an intentional search focused on literature documenting potential effects on other domestic animals, such as livestock. Overall, there was a notable lack of supporting studies on other categories of livestock in either peer-reviewed journal articles, or articles from reputable news and government sources. Due to the overwhelming documented effects of fireworks on domestic horses, there is potential for other livestock to experience similar responses.

2.2 Wildlife

2.2.1 Mammals

While it is much more difficult to document the effect of fireworks on mammals in the wild, some observational studies have been conducted for a select few species. One such study documents the observed effect of a fireworks display on a colony of sea lions at a known rookery (breeding and nesting location) (Pedreros et al., 2016). The observed behavioural response to fireworks included the immediate cessation of vocalization following the start of the fireworks, and a significant decrease in sea lions occupying the rookery during their breeding period following the display. This indicates that the sea lions are negatively responding to the firework display, potentially interrupting breeding activities. Another study at the Ekfurt Zoo in Germany observed the effect of fireworks on a variety of zoo animals, most of which would not commonly experience fireworks in their natural habitat or setting (Rodewald et al., 2014). Some animals (rhino, cheetah, and maras) showed panic and anxiety, while many others (llamas, lemurs, and elephants) showed signs of nervousness and attentiveness.

Although no documented studies on resident or migratory wildlife in Canada were found during Dillon's review of available literature, the studies and research summarized above for the potential effects and impacts to mammals indicate that a wide range of wildlife could be affected by fireworks. Wildlife species overlapping with the Ontario geography were not identified during this literature review, which is likely due to the difficulty in isolating a documented study in a controlled natural setting.

2.2.2 Birds

Of the animal groups encountered during this literature review, the effects of fireworks on birds are the most extensively studied. This includes several bird groups, including migratory species, waterbirds, urban birds, as well as disturbance-tolerant species (i.e., higher threshold to human disturbances, such as noise, pollution, infrastructure etc.). The study of fireworks and the potential effects on birds was applied through various study methodologies, such as observational studies, use of radar technologies, and physiological studies.

It is understood that fireworks during important life-cycle periods (breeding, molting, migration) could impact birds by disrupting their breeding (mating, rearing young) or causing physiological stress (Bernat-Ponce et al., 2021; and Wascher et al., 2022). For instance, it is known that breeding failures can occur when young are separated from their parents due to disturbance events, with studies linking fireworks directly to decreased juvenile productivity (Bernat-Ponce et al., 2021). A physiological study assessing heart rate and body temperature of Graylag Geese on New Year's Eve determined that there was a significant increase in heart rate and body temperature during and after the fireworks display (Wascher et al., 2022).

A case study published in 2015 studied the effects of fireworks on wintering waterbirds. This study captured several events in different geographic regions. One study documented the effects over multiple observational counts, specifically, over two separate annual New Year's Eve celebrations (2013 and 2014) at Lake Zurich (Weggler, 2015). The number of waterbirds present dropped by 25% to 35% overnight from the pre-New Year's Eve count, with individual numbers returning to normal levels after three to ten days of the fireworks event. Many of the species recorded during the New Year's Eve study (Weggler, 2015) were described as disturbance-tolerant species, and to be species conditioned to human presence and activity in a highly urbanized setting; however, these individuals displayed mass exodus following the immediate firework displays. A similar observational count study was completed on the Island of Mainau at Lake Constance during a September 2010 fireworks display (Werner, 2015). The firework display caused severe flight reactions in all waterbirds present, with over 4000 birds disappearing from the area within a few minutes of the firework display. The Island of Mainau is a known area of significance for waterbirds; due to the importance of the area for several waterbird species to carry out their life-cycle, firework displays were stopped in this area following the release of findings of this study in 2010. Since then, the number of waterbirds recorded in the area during key life-cycle periods have increased in the general area (Werner, 2015).

Firework disturbances have been observed for bird communities across various habitats, with a distance-dependence relationship between flight-response and the area the fireworks are displayed (Hoekstra et al., 2023; Shamoun-Baranes et al., 2011); the farther the avian individuals are located from the fireworks, the less likely the fireworks will elicit a flight response. On average, approximately 1000 times as many birds were in flight during New Year's Eve fireworks. The number of birds in flight decreased with distance from the fireworks; however, flight activity remained elevated tenfold up to distances of about 10 km from the firework display. Elevated flight activity seemed to be greatest for large-bodied, disturbance intolerant species. This disturbance has also been quantified using more advanced techniques, like L-band[1] radar to track urban bird activity in Birmingham, United Kingdom (Wayman et al., 2023). Flight tracks during firework displays were compared to baseline tracks on normal days, which indicated that the birds flew at significantly higher elevations and in greater numbers during firework periods. Therefore, bird activity was elevated during fireworks at a time of night when many would be roosting. The disturbance to diurnal birds, especially at night (when they have a hard time seeing), can have fatal affect. In one instance, over 3000 birds fell (mortalities) from the sky between 11:30 pm and midnight on New Years Eve, likely due to the induced flight response caused by the fireworks during this period (CTV, 2011).

Overall, fireworks have a documented significant impact on bird activity and survival, which can lead to physiological stress, impacts to breeding, and even mass mortality events.

2.3 Environmental Effects

2.3.1 Air Quality

Use of fireworks can be an important short-term anthropogenic source of air pollutants with significant impacts on local air quality (Singh et al., 2019; Yao et al., 2019; Seidel and Birnbaum, 2015; Cao et al., 2017). Fireworks can release a range of pollutants (gases and particulates) which negatively affect human health. On average, PM_{10} (Particulate Matter 10 microns or less), $PM_{2.5}$ and NO_x (Nitrogen oxides) concentrations increase by 2 to 8 times of what is considered "normal levels" during firework events (Singh et al., 2019). In the United States of America (USA), $PM_{2.5}$ was assessed country wide at 315 monitoring stations during 4th of July celebrations (Seidel and Birnbaum, 2015). The national average $PM_{2.5}$ concentrations were approximately 42% greater than normal concentrations, while monitoring stations in closer proximity to the fireworks showed up to 370% increase in concentration. One of the pollutants released by fireworks is perchlorate, and inorganic anion, with the pollution from fireworks being a primary contributor to increasing perchlorate contamination in the environment (Sijimol and Mohan, 2014). Perchlorate is a potent thyroid disruptor (See **Section 2.4.1**) and has an impact on the ecological environment, as it is a bioaccumulate (i.e., accumulates in waters and soil, passing along the food chain). Perchlorate has also been found in drinking water, milk, and even human blood samples

[1] L-band is the designation for a range of radar frequencies in the radio spectrum from 1 to 2 gigahertz (GHz), falling at the top end of the ultra high frequency band, at the low end of the microwave range. Typical characteristics of L-Band radar are large antennae and long ranges. It is a very common radar frequency, used for applications like GPS and telecommunications.

(Sijimol and Mohan, 2014). Many studies have shown that regulation of firework use, either through controlling sales or outright banning fireworks, has a significant outcome on the release of contaminant concentrations. Cao et al. (2017) provides a review of the effectiveness of these regulatory preventive measures, and how these can reduce environmental contamination, and associated human health risks, by limiting the number of fireworks used which reduces the pollutant concentrations.

It has been documented that environmental pollution from fireworks can pose a serious concern to human health and the ecosystem. Further, regulations of the sales, or outright banning of fireworks, has been shown to effectively reduce pollutant concentrations. These measures, along with firework alternatives, as discussed in **Section 3.0**, could be utilized to mitigate the documented negative effects of fireworks on air quality and human health (**Section 2.4**).

2.3.2 Fire

The application of controlled and uncontrolled use of fireworks has been documented to directly contribute to a significant portion of anthropogenic wildlife ignitions. One study examined the surge in wildfire ignitions following 4th of July celebrations in the USA over a 37-year period. The findings of this study documented a total of 11,294 wildland fires attributed to fireworks over this 37-year period during the week (7 days) before and after the 4th of July (Vachula et al., 2023). The number of wildfires up to and following the 4th of July eclipses the daily number by any other causes throughout the year, with nearly two-thirds of the fires over this period occurring between June 28th and July 11th. The contribution of fireworks to fire ignitions has a substantial affect economically, environmentally, and for human health. While no direct evidence for fireworks exists in the literature, a 2017 report estimated a total economic burden between $71.1 billion and $347.8 billion USD, as well as many injuries and even deaths, caused by wildfires (Thomas et al., 2017). Further, in a report by the National Fire Protection Association, it was determined that in 2018, an estimated 19,500 urban fires were started by fireworks, leading to multiple civilian injuries, five deaths and approximately $105 million USD in direct property damage (NFPA Research Division, 2019).

The evidence presented suggests that fire ignitions caused by fireworks can be impactful to the environment, economy, and human health, and should be considered when implementing mitigation and regulation strategies for fireworks.

2.4 Human Health

2.4.1 Indirect

Human health concerns related to fireworks can be direct (explosion and fire related injuries, PTSD) and indirect (environmental pollution). Common health issues associated with environmental pollution from fireworks are mainly respiratory, such as exacerbation of asthma, respiratory illnesses, and decreased lung function (Singh et al., 2019). The known health issues are mostly acute, as it is unclear what the long-term exposure affects may be due to a lack of relevant studies. Hospital admissions and mortality linked to acute $PM_{2.5}$ exposure (as discussed in **Section 2.3.1**) during festivals with fireworks range from

1.4% to 3.8% of total yearly admissions and mortality in Shanghai, China (Yao et al., 2019). Further, perchlorate competitively inhibits iodide uptake in the thyroid gland (as discussed in **Section 2.3.1**), which results in the decrease of thyroid hormones that are essential for many bodily functions and can affect fetal and neonatal development (Sijimol and Mohan, 2014).

It is important to continually monitor the environmental pollutant impacts to human health to determine if there are long-term exposure related health issues, and to mitigate some of the acute affects causing firework related illnesses.

2.4.2 Direct

The most common injuries associated with fireworks are related to explosion and fire, and include burns, hearing loss, ocular damage, and explosive trauma injuries to hands, legs, and body (Cao et al., 2017; Tu and Ng, 2019). These injuries are most prevalent in young males. For example, worldwide over 80% of ocular injury patients were male, and 70% were under the age of 18 (Cao et al., 2017). The 2019 consumer report for fireworks found that 64% of all injury patients were males, and children younger than 15 years of age accounted for 36% of patients in the USA (Tu and Ng, 2019). This report includes five deaths related to direct impacts from fireworks, all associated with reloadable aerial devices, with two (40%) being teenage males between 15 and 18 years of age.

Less obvious direct effects and impacts are the potential mental health impacts of fireworks on people suffering from PTSD, or people with autism and other related disabilities. Some studies suggest that fireworks, specifically the loud explosions and intense lights, can be a trigger for war veterans with PTSD (Gersons and Carlier, 1992; Bartoszek et al., 2017). So much so, that the Veterans Association of the United States has guidelines for veterans for managing PTSD during firework displays (U.S. Department of Veterans Affairs, 2022). Sudden, sharp noises were also associated with the highest percent of trauma reminders (22%) in people experiencing PTSD from a terrorist attack, a category which included fireworks (Glad et al., 2016). Further, people with autism may have hypersensitive hearing, which could lead to negative reaction to fireworks, specifically increased panic, or anxiety (Valentinuzzi, 2018).

Evidently, fireworks have a documented direct, measurable effect on human physical and mental health, and are a prevalent concern for their association with injuries and even death of young males.

3.0 Suggested Alternatives and Mitigative Actions

In recent years, mitigation and regulation of fireworks have been a relevant discussion worldwide. Certain places have banned the use of fireworks to protect sensitive wildlife and environments, like in the Galapagos Islands, which implemented their ban in 2017 (BBC, 2018). Banff, Alberta, had a similar firework ban in 2018, switching to a pyrotechnic display that minimizes the noise impact of normal firework shows (The Globe and Mail, 2018). Many other places like the Calgary Zoo are making the switch from traditional fireworks to “low noise” displays using new technologies in firework

manufacturing (The Globe and Mail, 2018). Other alternatives are also being considered, such as drone light shows in Niagara Falls, Canada, to supplement their weekly firework displays (Niagara Gazette, 2023). While there is an overall benefit to reducing the use of traditional fireworks, it is also important to consider the potential impact that these alternatives may have on the environment.

In a study assessing of the benefit of "green" fireworks regarding pollution, it was found that these fireworks can reduce ambient $PM_{2.5}$ by approximately 50% compared to traditional fireworks. However, large numbers of fireworks, even "green" options, can still pollute the air, and can produce similar levels of pollutants as traditional fireworks. Therefore, it is beneficial and environmentally conscious to restrict the total number of fireworks used overall, as this will result in the most substantial decrease in air pollutants (Fan et al., 2021). Another common alternative is the use of drone light shows, which substantially eliminates both pollution and noise when compared to traditional fireworks. These drone shows are a more sustainable option when it comes to reducing waste and resources and are far less dangerous to human health both physically and mentally. Additionally, drone shows are a more economically viable option as well as these drones can be recycled and reused multiple times (Zerlenga et al., 2021).

As noise associated with fireworks is the primary disruptor of wildlife (**Section 2.1** and **2.2**), drone light shows are anticipated to have a reduced impact on wildlife in comparison to traditional fireworks. However, there is still potential for wildlife to have direct interactions with drones. A study published in 2019 (Rebelo-Ifran et al., 2019) reviewed interactions of drones with wildlife through a literature review of relevant studies, and various publicly available videos posted online (primarily, YouTube), documenting various taxonomic groups and their individual behavioural response to drone activity. Specifically, when a drone was: physically present or in the vicinity of the wildlife; when a drone was following or chasing the wildlife; and, when wildlife curiously approached or attacked the drone. The type of wildlife that were observed exhibiting a behavioural response ranged from marine and terrestrial mammals, avian species, reptiles, fish, and insects. The behavioural responses observed were escapes, alert observation, attacks, curious approaches, and accidental collision with the drone (only for avian species). Individuals ranged from commonly encountered and disturbance tolerant species, species with reduced disturbance tolerance thresholds, as well as those of locally, regionally, or globally rare status. The findings of this study summarized that although drones are considered a more "cleaner and greener" alternative to fireworks, there are still documented effects and stress-based responses to wildlife. It is also important to note that studies on firework alternatives are limited due to these alternatives being newly introduced to mainstream society.

While alternatives, such as drone light shows, are growing in popularity, it is evident that people still have a strong preference (whether it be culturally, habitually, or nostalgia) for traditional firework displays due to the ongoing purchasing of fireworks, as well as the demand and attendance of large firework displays.

4.0 Summary

Fireworks have a long history and association with celebration, and only recently (within the past several decades) have the effects of fireworks been studied and documented. This literature review identified multiple factors and documented effects fireworks has had on animals, the environment and human health. These effects have been documented in varying degrees including psychological, physical, and compounded effects.

Domestic animals have a range of documented effects, including heightened stress and fear-based behavioural responses that can result in PTSD, injuries and even death. It is understood that fireworks have the ability to disrupt and impact important life-cycles for wildlife, which can result in the abandonment of young, increased physiological stress, and in some cases, causing mass fatalities. Air pollutants associated with fireworks have had a documented impact on local air quality, as they can release a range of pollutants (gases and particulates); these pollutants are also bioaccumulates, which can impact human health and fetal and neonatal development. Common health issues associated with environmental pollution from fireworks are mainly respiratory (asthma, respiratory illness, decreased lung function). More directly, the use of fireworks has documented common injuries related to explosion and fire (burns, hearing loss, ocular damage, explosive trauma injuries to hands, legs, and body). Less obvious direct effects and impacts to human health are the potential mental health impacts of fireworks on people suffering from PTSD, or people with autism and other related disabilities. The application of fireworks are also linked to increased property damage and increased wildfires, contributing to firework related injuries and deaths as a result of wildfires instigated by firework activity.

Studies have shown that regulation of firework use, either through controlling sales or outright banning fireworks, can reduce the documented impacts fireworks have had on human health as well as the environment. Alternatives such as pyrotechnic displays, and drone light shows, referred to as “green” fireworks have been used for their reduced impacts on wildlife, the environment and human health effects. Additionally, these “green” fireworks and can present a more sustainable and economically feasible option, as they minimize the noise impact, reduce air pollutants, and can be recycled for future use, when compared to traditional firework shows.

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