APPENDIX A – SECTION 5

NOISE & VIBRATION

A. NOISE

Noise is characterized as unwanted sound, but any noise that is intense enough to damage hearing, interfere with communication, disrupt sleep or is otherwise annoying is undesirable. Even though noise is individually subjective, a causal relationship exists between sound levels and the types of noise that not only cause annoyance, but that also result in a variety of potential adverse effects depending on exposure.

Noise is one of the main adverse effects from airports and aircraft operations and is source of most airport complaints. Because of the flight patterns necessary for plane separation, landings and take-offs, the effects of aircraft noise are spread out over a relatively large area.

This section will address the changes in noise levels generated by Seattle-Tacoma International Airport from 1997 to 2019. Various noise sources originate around and on the airport itself including:

- Aircraft taxiing
- Ground level operations (fuel trucks, food trucks, maintenance equipment, emergency equipment, etc.)
- Road traffic to and from the airport
- Periodic construction activities (although construction has been a relative constant noise source over the past 20 years).

This has created noise at and adjacent to Seattle-Tacoma International Airport that adversely effects the land-uses that are close to it. However, it is apparent that the significant noise events affecting people are related to individual aircraft runups, take-offs, landings and overflights. Therefore, this section focuses on the noise created by aircraft, specifically those with jet engines during air carrier operations.

Sound is created when an object vibrates and radiates part of its energy as acoustic pressure or waves through a medium such as air, water, or a solid object:

> "Whether the sound is interpreted as pleasant (music) or unpleasant (e.g., transportation-related noise) depends on the listener's current activity, past experience, and attitude toward the source of that sound." (Oregon Airspace Initiative 2016)

The human perception of sound involves two characteristics:

- **Intensity** is the measure of the energy of the sound vibrations expressed in terms of sound pressure. The higher the pressure the more that sound energy is carried and the louder the sound is perceived.
- **Frequency** is the number of times per second the air vibrates. Low frequency noise is characterized as rumbles or roars, while high frequency sounds are typified by sirens or screeches (Oregon Airspace Initiative 2016).

Sound levels are expressed as **decibels** (dB) – a logarithmic scale that provides a standard metric considering the large differences in audible sound intensities as heard by humans. Since the human ear does not respond equally to all frequencies (or pitches), measured sound levels (in dB at standard frequency bands) are often adjusted or weighted according to the frequency response of human hearing and the human perception of loudness. The weighted sound level is designated as the A-weighted sound level in decibels, known as dBA.

On the decibel scale, a 10 dB increase represents a perceived doubling of loudness to someone with normal hearing. That means that a 70 dB level will sound twice as loud as a 60 dB sound level. Under ideal listening conditions, people generally cannot detect differences of 1 dB, while differences of 2 or 3 dB can usually be detected by people with normal hearing. In the outside environment, and especially near complex noise sources such as roads or airports, sound level changes of 2 or 3 dB might not be noticeable to some people, while a 5 dB change would likely be perceived as a clear and noticeable change. Figure 5.1 shows some typical sound levels produced by various activities.

Figure 5.1
Sound Levels Produced by Common Noise Sources

Thresholds/ Noise Sources	Sound Level (dBA)	Subjective Evaluations	Possible Effects on Humans
▪ **Human Threshold of Pain** ▪ **Carrier jet take-off at 50 feet**	140	Deafening	Continuous exposure to levels above 70 dBA can cause hearing loss in majority of population
▪ **Siren at 100 feet** ▪ **Loud rock band**	130		
▪ **Jet take-off at 200 feet** ▪ **Auto horn at 3 feet**	120		
▪ **Chain saw** ▪ **Noisy snowmobile**	110		
▪ **Lawn mower at 3 feet** ▪ **Noisy motorcycle at 50 feet**	100	Very Loud	
▪ **Heavy truck at 50 feet, maximum**	90		
▪ **Pneumatic drill at 50 feet** ▪ **Busy urban street, daytime**	80	Loud	
▪ **Normal automobile at 50 mph** ▪ **Vacuum cleaner at 3 feet**	70		
▪ **Air conditioning unit at 20 feet** ▪ **Conversation at 3 feet**	60	Moderate	Speech Interference at 60 dBA and above
▪ **Quiet residential area** ▪ **Light auto traffic at 100 feet**	50	Moderate	Sleep interference at 40 dBA and above
▪ **Library/Quiet home**	40	Faint	
▪ **Soft whisper at 15 feet**	30	Faint	No disruption
▪ **Slight rustling of leaves**	20	Very Faint	
▪ **Broadcast Studio**	10	Very Faint	
▪ **Threshold of Human Hearing**	3	Very Faint	

Source: EPA 1974.

Note that both the subjective evaluations and the physiological responses are continuums without true threshold boundaries. Consequently, there are overlaps among categories of response that depend on the sensitivity of the noise receivers.

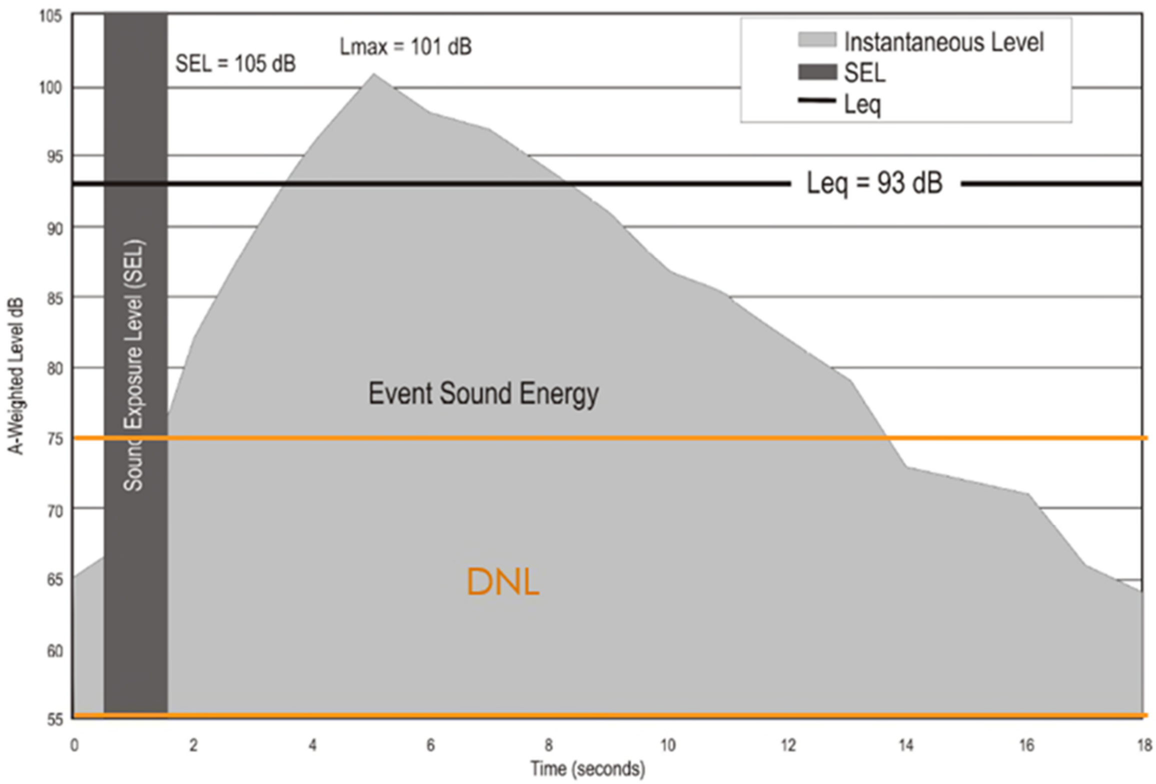
In the past, noise studies have used a variety and confusing number of noise measurements as researchers have attempted to understand and represent noise effects. However, federal agencies such as the Department of Defense, NASA, EPA and the Federal Aviation Administration have specified those to be used for federal noise assessments of aviation noise. The metrics now used by the Federal Aviation Administration include:

- **Maximum Sound Level (Lmax)**
  This is the peak sound level measured during a single noise event, such as an aircraft overflight. Lmax can provide some measure of intrusiveness, but it does not capture the total noise exposure.

- **Sound Exposure Level (SEL)**
  SEL captures total noise exposure and is a combination of the intensity of the sound and its duration. SEL is a logarithmic measure that mathematically represents the sound level of a constant sound that in one second would generate the same acoustic energy as the totality of the sound event. It has been well established in the scientific community that SEL measures noise much more reliably that just dBA.

- **Day-Night Average A-weighted Sound Level (DNL)**
  DNL is a computer model that averages sound levels over a 24-hour period with a 10 dB adjustment added to those noise events occurring between 10 p.m. and 7 a.m. This 10 dB "penalty" accounts for the increased sensitivity to nighttime noise events.

Figure 5.2
Graphic Representation of Sound and Noise Metrics



A sound event is depicted by the shading in the figure and shows how the various metrics represent different aspects of the event. The SEL and DNL are important metrics for aircraft related noise, as the DNL is the regulatory measure that is used for determining noise effects by federal agencies such as the FAA, but the SEL events are typically what are most disturbing to residences and other sensitive land uses in the vicinity of airports, particularly at the runway ends and under the flight paths. Figure 5.2 also shows the large variance between the two metrics, which has been a causal factor in communities pushing for the Federal Aviation Administration to change how it regulates aircraft noise and provides mitigation for areas affected by noise.

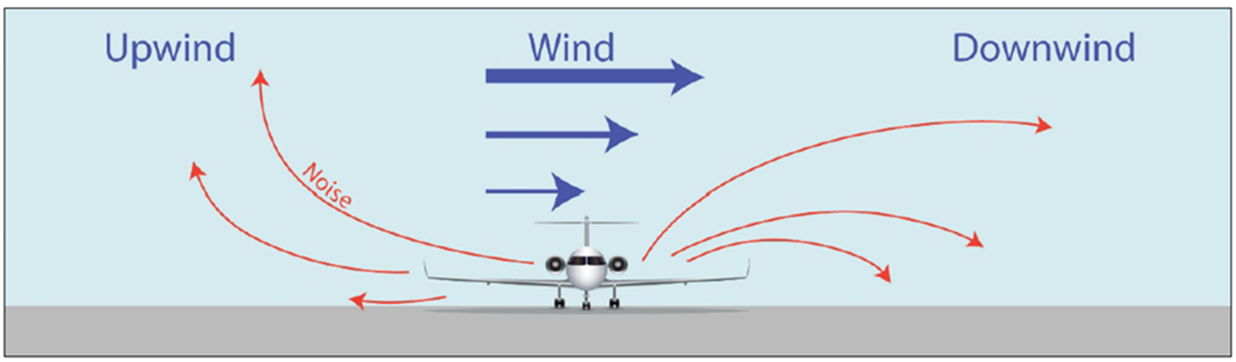
B. CHARACTERISTICS OF AIRCRAFT NOISE

Aircraft noise originates from both the airframe and engines of an aircraft. Noise is generated by the flaps, trailing edges of wings, leading edge devices (slats) and landing gear portions of the airframe, but the engines are, by far, the more significant source of noise (NASA 2004). Jet engines can produce sound levels in excess of 120 decibels (dB).

Meteorological conditions affect the transmission of aircraft noise through the air. Wind speed and direction, and the temperature immediately above ground level, cause diffraction and displacement of sound waves (Figure 5.3).

Humidity and temperature materially affect the transmission of air-to-ground sound through absorption associated with the instability and viscosity of the air (Fort Lauderdale-Hollywood International Airport Part 150 Report 2018). These atmosphere conditions influence noise levels by absorbing and/or reflecting sound. The farther the sound travels, the greater the rate of atmospheric absorption. This typically becomes a factor at distances greater than 1,000 feet.

Figure 5.3
Wind Effects on Aircraft Noise

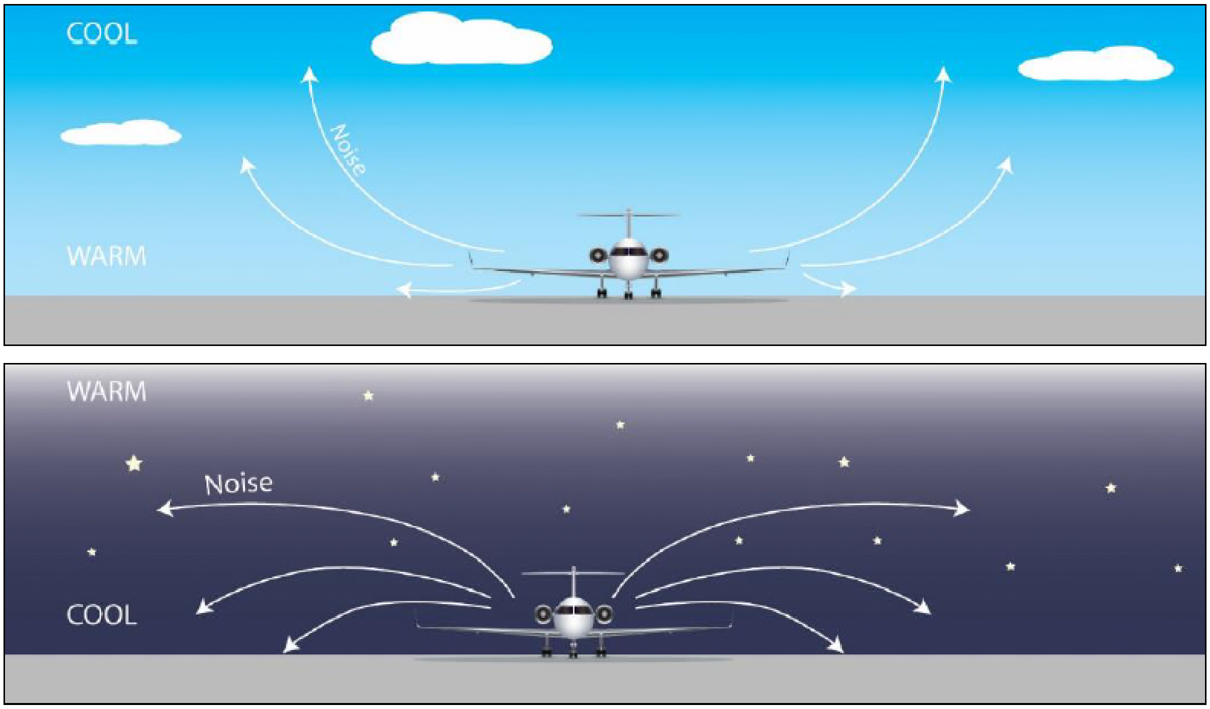


Some atmospheric conditions, such as temperature inversions, can channel or spread the sound resulting in higher sound levels. Without considering the atmosphere, sound levels typically decrease by 6 dB with every doubling of distance from the source.

Noise effects also depend on the frequencies of the generated sound and topography. For example, higher frequencies are more readily absorbed than the lower frequencies, and over distance the lower frequencies become the dominant sound source, as the higher frequencies are attenuated. The lower frequency noise (LFN) is discussed further in the section on vibration.

The effects of ground attenuation on aircraft noise are a function of the height of the sound source and/or receiver and the characteristics of the landscape. The closer the noise source is to the ground, the greater the ground absorption. Soft surfaces, such as vegetation, provide for more ground absorption than hard surfaces, such as paved surfaces.

Figure 5.4
Atmospheric Temperature Effects on Aircraft Noise



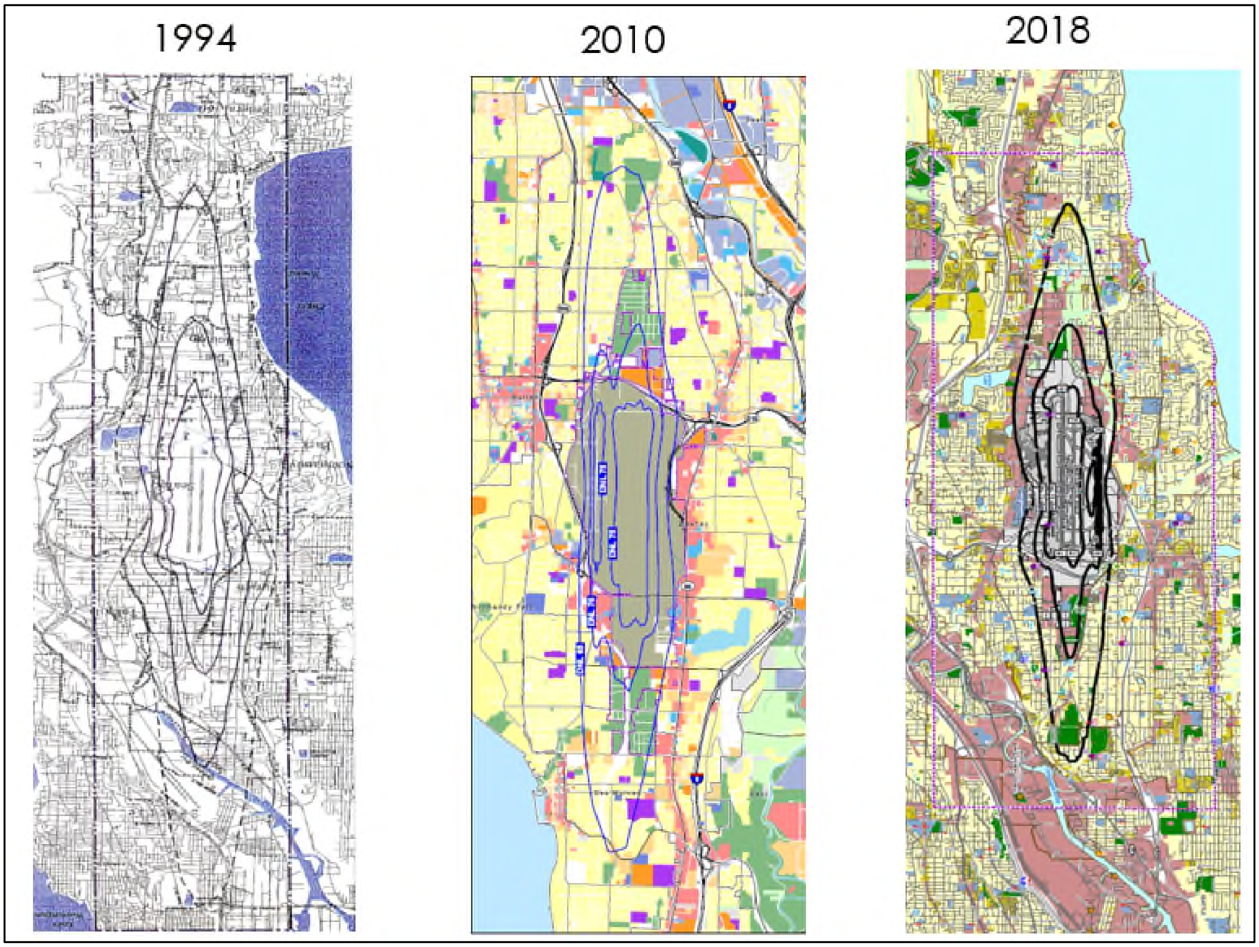
C. REGULATORY TRENDS

The Federal Aviation Administration issued the Aviation Noise Abatement Policy (ASAP) in 1976, which set the levels of significance for exposure from aircraft noise. The policy used the DNL metric and characterized aircraft noise exposures in residential areas with a DNL of 65 to 75 as “significant” and a DNL of 75 and greater as “severe.” This was followed up by the Aviation Safety and Noise Abatement Act (ASNA) in 1979, which encouraged airports to carry out noise abatement programs. Subsequently, the Federal Aviation Administration published Part 150 (14 CFR Part 150), which established a voluntary program for airports to conduct studies to determine ways to reduce noise over residential and other noise sensitive areas. It also defined land use compatibility guidelines for different uses over a range of DNL noise exposure levels. This included adopting the 65 DNL for residential land use compatibility.

These policies and codes are essentially unchanged today, and the 65 DNL noise threshold has been used to make policy assessments in several areas:

- Setting the federal noise goal for reducing the number of people exposed to significant noise around U.S. airports.
- Establishing the level of aircraft noise exposure below which residential land use is compatible, as defined in the ASNA and 14 CFR Part 150.
- Establishing the level of aircraft noise exposure below which Federal Aviation Administration actions in residential areas are not considered “significant” under the National Environmental Policy Act of 1969 (NEPA).

Figure 5.5
Seattle-Tacoma International Airport Noise Contours: 1994, 2010 and 2018

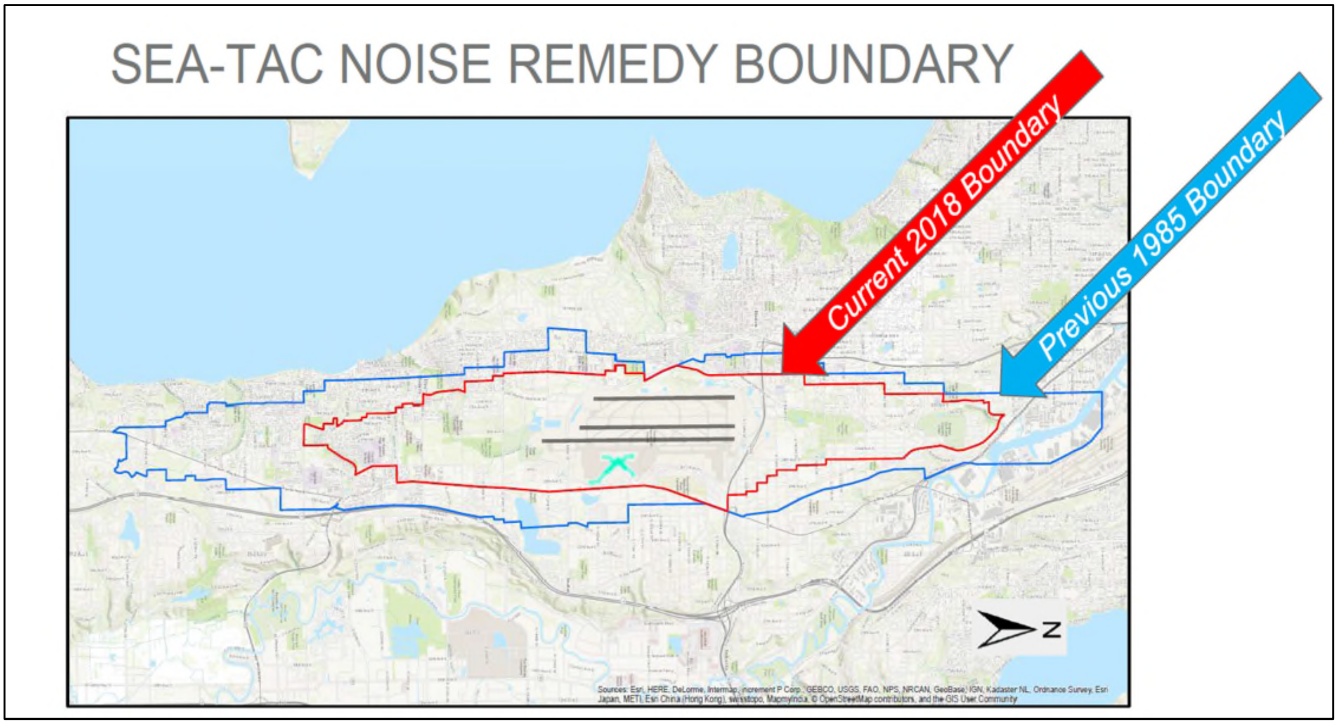


The 65 DNL threshold has also been used to determine the eligibility for noise mitigation funded from Airport Improvement Program grants, passenger facility charges and other airport revenues. Mitigation is in the form of funding for sound insulation for homes, schools, churches, health care facilities and other similar land uses that are within the 65 DNL noise contour surrounding Seattle-Tacoma International Airport.

Figure 5.5 shows how the 65 DNL noise contour has changed over time at Seattle-Tacoma International Airport. In 1994, the area within the 65 DNL contour affected approximately 12.23 square miles, 31,800 people, and 13,620 residences. By 2018, that area shrank and affected approximately 7.3 square miles and 11,389 people and 4,394 residences. This trend has largely been due to phasing out older and louder aircraft.

The use of the DNL metric has been a source of controversy based on perceptions of community annoyance and that people are clearly bothered by individual noise events (SEL). As the number of those events has increased, particularly during the night, so have people's annoyance levels. In addition, the 65 dB significance level does not mean there is no annoyance or other health effects below that noise level (see discussion of negative effects). The figure below shows an overlay how the contour has changed over two time periods.

Figure 5.6
Seattle-Tacoma International Airport Noise Contours: 1985 and 2018



Source: Port of Seattle 2019

D. PUBLIC LAW 115-254

On Oct. 5, 2018, the Federal Aviation Administration Reauthorization Bill was signed into law to cover the years 2018-2023. There are two pertinent sections relating to the ongoing issue of aircraft noise.

- **<u>Section 173 – Alternative Noise Metric Evaluation</u>**

  Section 173 of the Reauthorization Bill states:

  > "Not later than 1 year after the date of enactment of this Act, the Administrator of the Federal Aviation Administration shall complete the ongoing evaluation of alternative metrics to the current Day Night Level (DNL) 65 standard."

  To date there has been no movement from the Federal Aviation Administration on the evaluation of other noise metrics to replace the 65 DNL standard. Other entities have recommended different DNLs for noise exposure. For example, in 2019 the International Civil Aviation Organization (ICAO) recommends a 55 DNL, while the World Health Organization 2018 Guidelines for the European Region recommends that average noise exposure from aircraft should be limited to 45 dB during the day and 40 dB during the night. Although the U.S. Department of Housing and Urban Development, the Department of Defense, and the Federal Aviation Administration consider 65 DNL as the threshold for significance in assessing noise, this threshold does not distinguish between urban, suburban or rural settings. Residents in the study area cities have expressed concerns that the 65 DNL is not an adequate metric for the noise effects from aircraft operations at Seattle-Tacoma International Airport.

- **<u>Section 175 – Addressing Community Noise Concerns</u>**

  Section 175 of the Reauthorization Bill states:

  > "When proposing a new area navigation departure procedure, or amending an existing procedure that would direct aircraft between the surface and 6,000 feet above ground level over noise sensitive areas, the Administrator of the Federal Aviation Administration shall consider the feasibility of dispersal headings or other lateral track variations to address community noise concerns, if:
  >
  > – The affected airport operator, in consultation with the affected community, submits a request to the Administrator for such a consideration.
  >
  > – The airport operator's request would not, in the judgment of the Administrator, conflict with the safe and efficient operation of the national airspace system.
  >
  > – The effect of a modified departure procedure would not significantly increase noise over noise sensitive areas, as determined by the Administrator."

  There have been some flight changes at Seattle-Tacoma International Airport that have not adequately addressed the noise issue. On Nov. 7, 2019, the City of Burien won an appeal relating to the Federal Aviation Administration's change of a flight path over the city. The Ninth Circuit Court of Appeals ruled in Burien's favor that the change came without adequate environmental review.

  The FAA's operational change concentrated the flight path of turboprops over the westerly portion of Burien in a narrow corridor called "the 250 degree heading." This flight path created intolerable noise on the ground below because the noisy turboprop aircraft turned over western Burien at low altitude. Prior to the operational change, the flight paths of turboprop aircraft were distributed citywide, so no single corridor was used. In response to the change, a coalition of residents worked with the city of Burien to mount a legal challenge to the operational change.

  The court's decision does not halt turboprops from flying over Burien, but the decision halts the automation of the turboprops' flight path over the narrow corridor previously used. The court directed the FAA to evaluate the cumulative effects of all of the future actions – including the planned growth addressed by the airport's Sustainable airport Master Plan (SAMP) – in an environmental review process. (As of this study, the environmental documentation and analysis of the SAMP was ongoing. It was hoped that the analysis from that work could be reflected in this study; however, it is uncertain when that analysis will be forthcoming, since it has been delayed several times.)

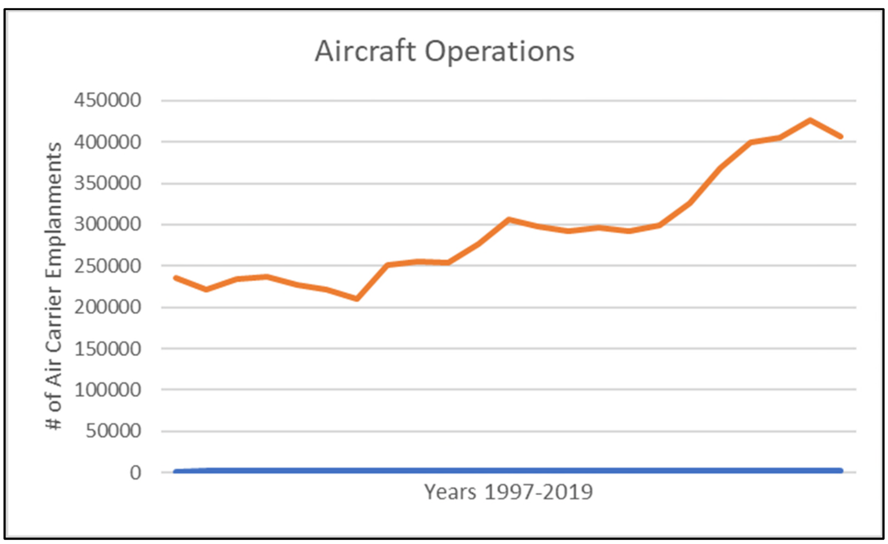
E. CHANGES AT SEATTLE-TACOMA INTERNATIONAL AIRPORT: 1997-2019

The continuing operations or changes over time that have most affected sensitive land uses around the airport due to aircraft noise have included the dramatic increase in air carrier operations, wider range of flight paths, and use of a relatively shallow flight descent path. These effects correspond to the number and type of complaints.

Figure 5.7 shows the annual aircraft operations at the airport by class of aircraft. While there has been a modest increase in total operations, the number of air carrier operations has increased significantly from 1997. Air carrier operations increased by 26% from 1997 to 2009 and 37% from 2009 to 2018. The total change in air carrier operations from 1997 to 2019 was a 73% increase.

Figure 5.7
Seattle-Tacoma International Airport Annual Operations: 1997-2019

YEAR	ITINERANT					LOCAL			TOTAL OPERATIONS
	Air Carrier	Air Taxi	General Aviation	Military	Total	Civil	Military	Total	
1997	235,445	143,034	5,820	80	384,379	103	0	103	**384,482**
1998	221,705	180,563	5,183	126	407,577	20	0	20	**407,597**
1999	233,914	194,352	5,321	59	433,646	14	0	14	**433,660**
2000	236,355	203,723	5,448	95	445,621	56	0	56	**445,677**
2001	227,589	168,322	4,668	66	400,645	16	9	25	**400,670**
2002	220,733	139,793	4,073	59	364,658	13	0	13	**364,671**
2003	210,603	140,777	3,336	54	354,770	49	0	49	**354,819**
2004	250,605	90,521	2,410	106	301,376	93	0	93	**301,469**
2005	254,829	105,377	2,685	121	358,788	103	3	106	**358,894**
2006	253,507	83,928	2,654	59	341,470	284	8	292	**341,762**
2007	277,293	82,147	3,675	95	339,424	621	13	634	**340,058**
2008	306,919	66,056	4,357	96	347,802	883	11	894	**350,983**
2009	297,621	36,869	4,059	120	347,967	0	0	0	**353,088**
2010	292,016	17,133	3,046	73	317,873	0	0	0	**317,873**
2011	295,763	18,562	3,262	114	313,954	0	0	0	**313,954**
2012	291,664	15,324	3,708	149	314,944	0	0	0	**314,944**
2013	299,156	14,196	3,604	133	309,597	0	0	0	**309,597**
2014	325,425	14,440	3,510	80	317,186	0	0	0	**317,186**
2015	368,722	10,813	4,113	127	340,478	0	0	0	**340,478**
2016	399,742	8,401	4,160	125	381,408	0	0	0	**381,408**
2017	405,049	9,513	2,802	93	412,150	20	0	20	**412,170**
2018	427,170	8,651	2,338	86	416,124	12	0	12	**416,136**
2019	406,630	4,1279	2,081	76	412,914	0	0	0	**412,914**



Source: FAA Air Traffic Activity System 2019.

Air carrier jet aircraft create the loudest noise events as compared to general aviation or air taxi service. The 2019 total operations figure means that on average there was approximately 1,131 operations per day or 47 per hour. Since air traffic is heavier during the day, there is a steady occurrence of overflights, particularly during daylight hours. This can vary dramatically depending on the time of day, time of week, etc. However, each operation represents an individual SEL noise event, which have increased by 73% from 1997 to 2019.

Existing Aviation Noise at Seattle-Tacoma International Airport

Figure 5.8 is from the USDOT Noise Map that show the noise from road and aircraft traffic in the Seattle area. The highest sound levels occur at Seattle-Tacoma International Airport and Boeing Field and extend north and south of the airports – both airports show up in purple range at 85 decibels (dB) to 90 dB. While the figure does not solely show aviation noise, it does reflect how much louder it is in the study area cities relative to other urban areas farther from the airports. From this can be inferred that the difference is the location of the airports in proximity to the study area cities.

Figure 5.8
Road and Aviation Noise in the Seattle Area

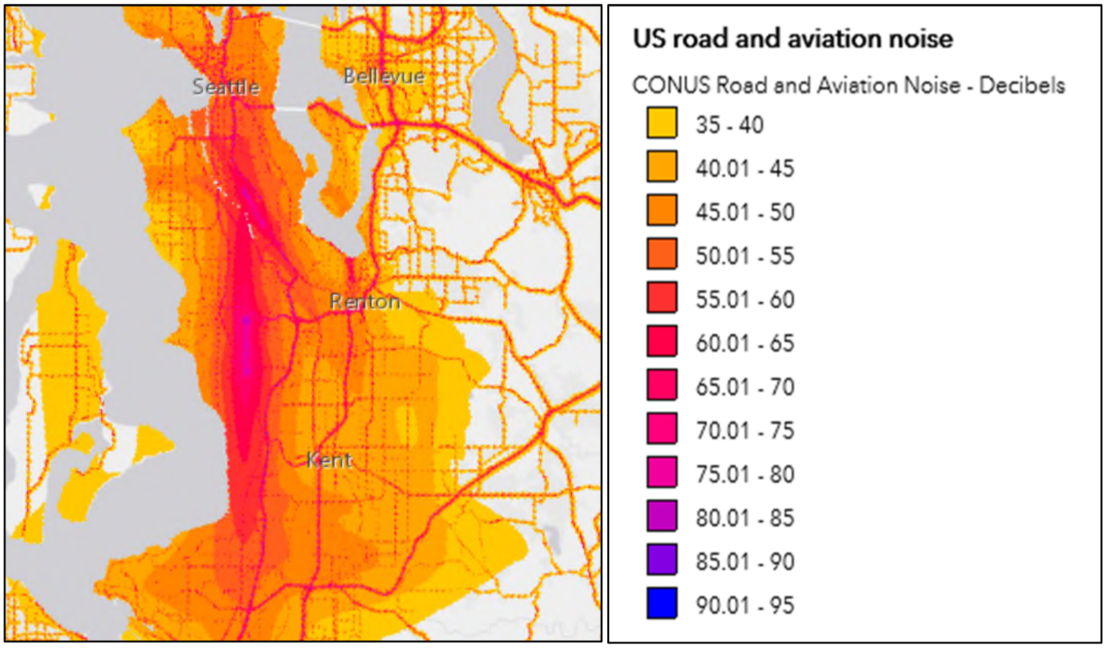
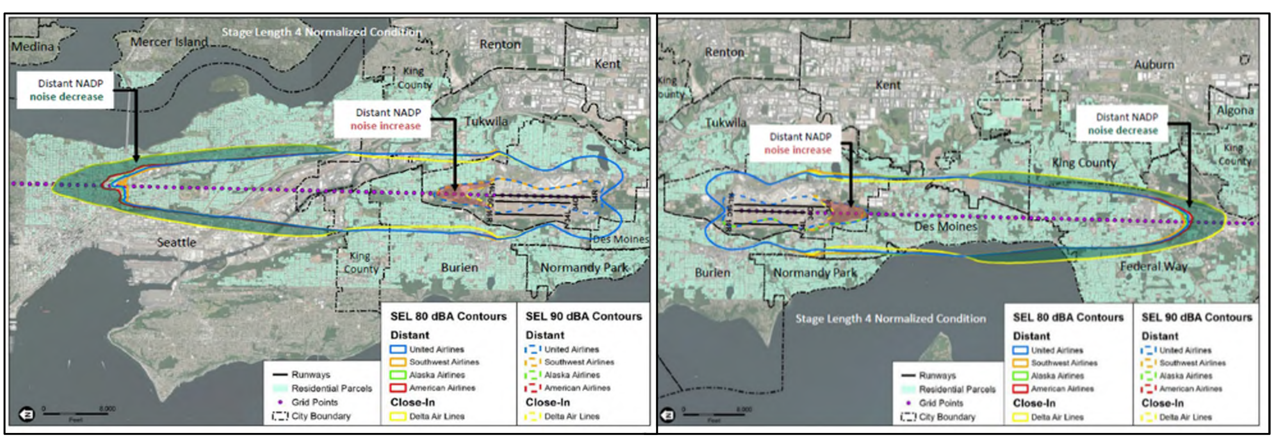


Figure 5.9 shows how extensive an area that is affected by SEL sound events. In this case the figures show the 80 and 90 dB noise contours in 2019, which extend well beyond the 65 dB DNL contour. Even though noise contours have shrunk over time, <u>the SEL 80 and 90 dB contours show that a wider area is affected by overflights</u>. The number of overflight events have increased dramatically since 1997, and the SEL events affect a larger area that is not subject to sound mitigation. The 80 and 90 dB SEL contour extends down through Des Moines and Federal Way to the south and through Burien and Seattle to the north.

Figure 5.9
Northern and Southern Flow 80 and 90 dB SEL Contours

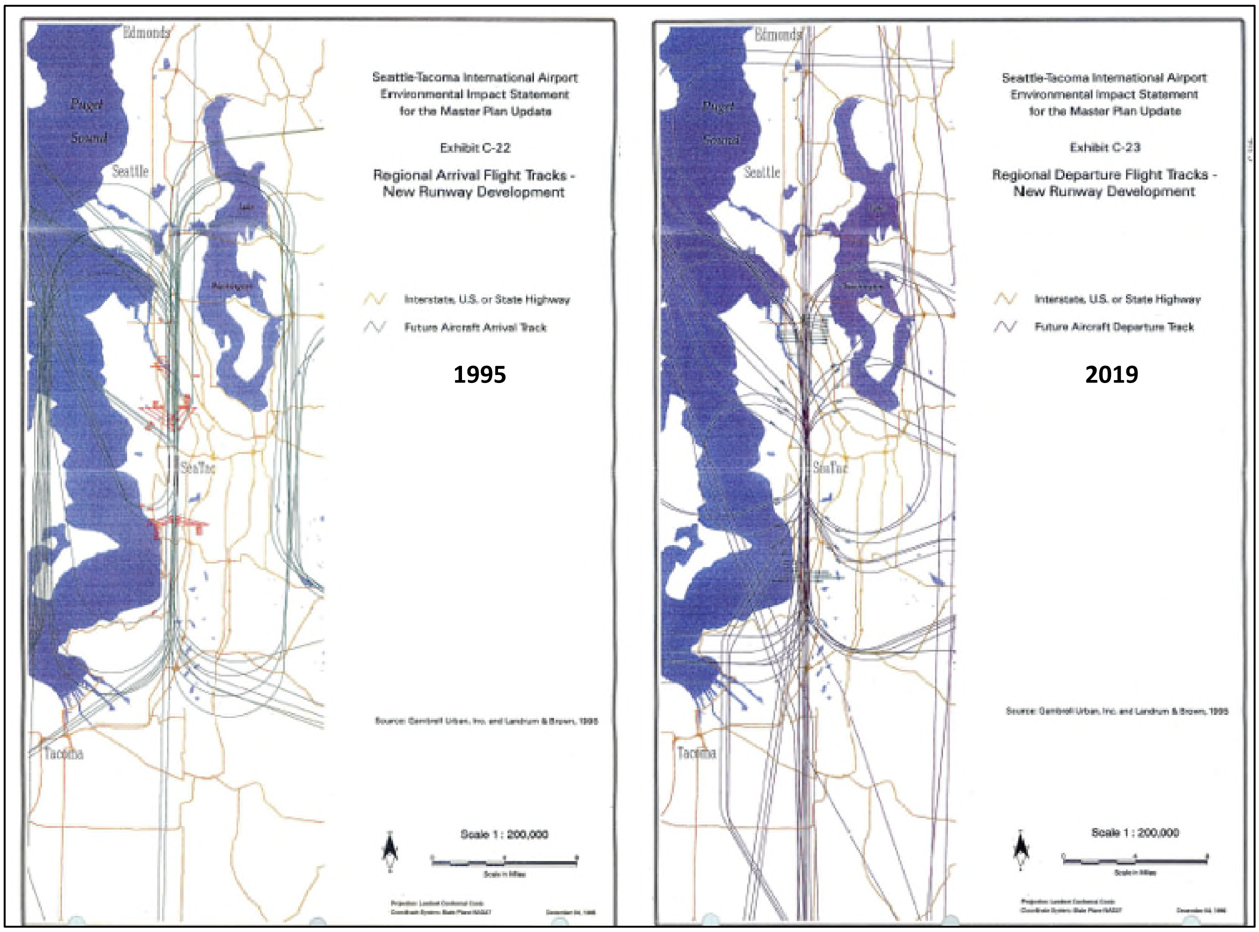


Source: AEDT 2d, 2019; ESA, September 2019.

Flight Track Changes Over Time

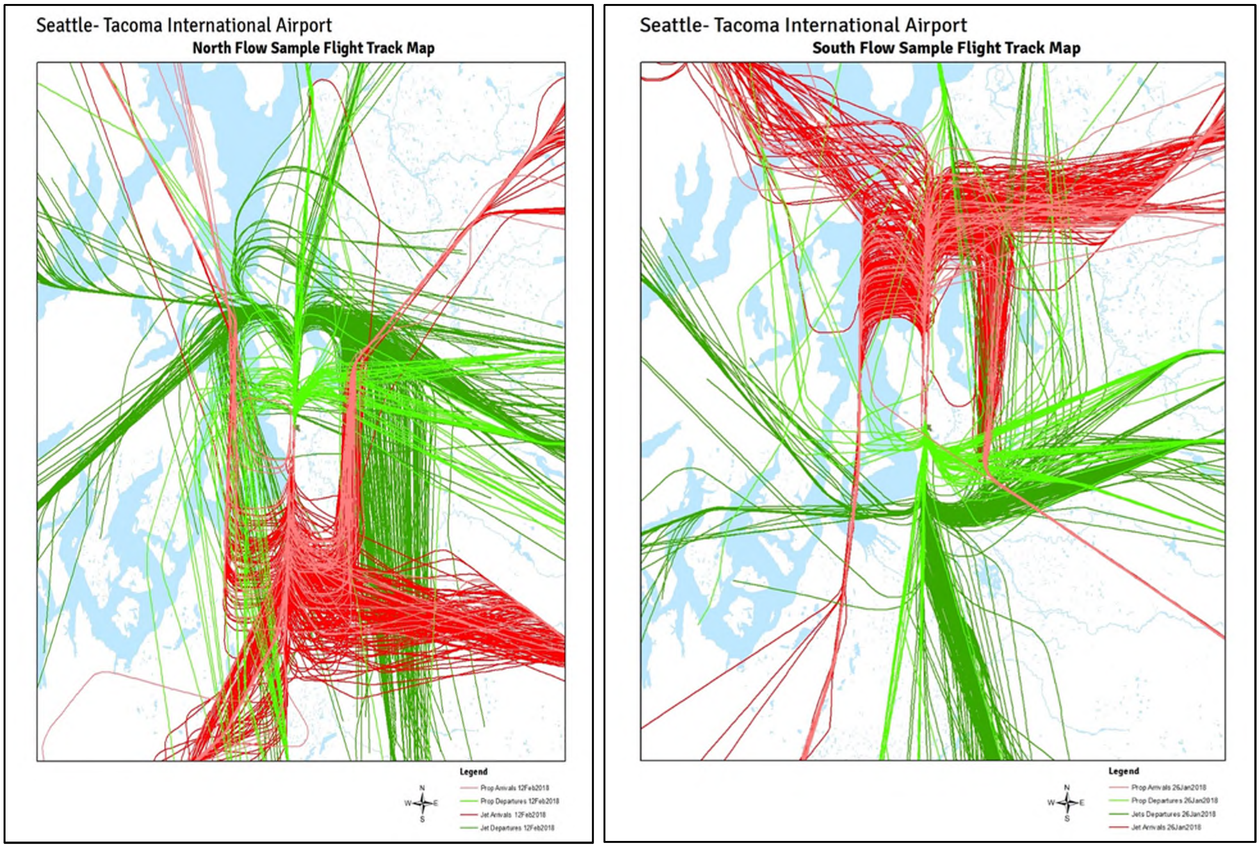
Another aspect of air operations that cause noise issues in the study area cities is how flight paths have changed over time. The Federal Aviation Administration established prescribed flight patterns for jet aircraft in 1990 and these have not changed since that time. However, for a number of reasons these prescribed patterns are not always followed due to missed approaches, weather, onboard emergencies and the need for separation from other aircraft. The sheer change in volume of jet aircraft operations and changes in international airline destinations (particularly the increase in late-night Asian destinations) has resulted in more aircraft deviating from the prescribed flight patterns, thus affecting a wider area. Figure 5.10 demonstrates how aircraft overflight noise is affecting a wide area, corroborated by the location of noise complaints.

Figure 5.10
Flight Patterns: 1995 and 2019



Source: Port of Seattle

Figure 5.11
North and South Flow Flight Track Sample Maps



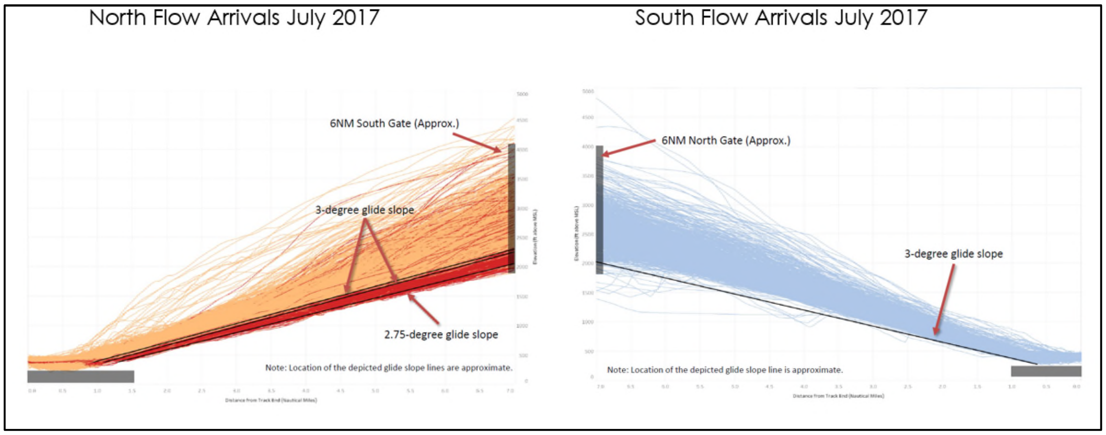
Source: Purcell, 2019.

Altitude Arrivals at Seattle-Tacoma International airport

The Federal Aviation Administration requirement for the glideslope to Runway 34R at Seattle-Tacoma International airport is a 2.75 degree glideslope. Generally, the standard requirements for the maximum glideslope is 3.0 degrees (which varies by airport). Steeper glideslopes result in shorter overflights, limiting the time an aircraft is closer to the ground. This would affect a smaller area on the approach to the runway with less noise due to a greater distance between aircraft and the ground.

Figure 5.12 shows the large number of aircraft using the 2.75 degree glideslope during Northern Flow in particular. Increasing the glideslope would reduce the size of the underlying area affected by aircraft noise. There are other airports where it is necessary to maintain a steeper angle. For example, London City airport (London, UK) has a glideslope of 5.5 degrees – an angle this steep would not be a recommendation for Seattle-Tacoma International airport).

Figure 5.12
Aircraft Arrival Altitudes at Seattle-Tacoma International Airport



Source. ESA Associates, Aircraft Arrival Altitude Analysis Presentation 2019.

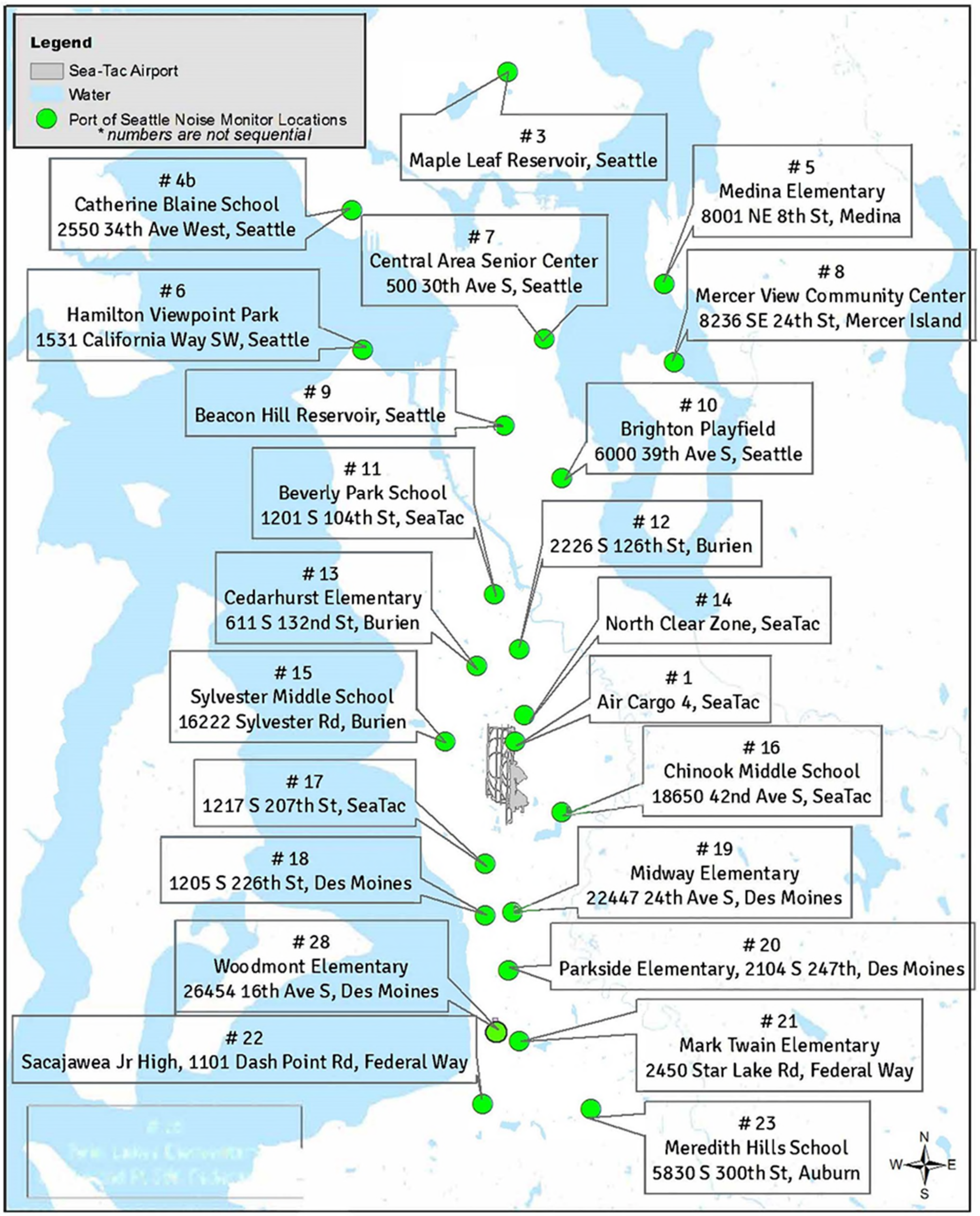
The altitude of flights also plays a significant role in the amount of noise received at ground level. Flights below 3,000 feet tend to produce more SEL noise events that have more significantly adverse effects on residents. Taking a straight line approach of reducing sound by 6 dB for every doubling of distance, a jet producing 120 dB at 200 feet would produce 100 dB at a distance of 3,200 feet (not taking into account atmospheric conditions or ground attenuation). The number of flights below 3,000 feet at the various noise monitoring locations is shown below and the noise monitoring stations in Figure 5.13. Some of the noise monitors are located close to the runway ends, and those flights would be under 3,000 feet. However, Figure 5.14 gives some estimation of how many flights are generating somewhere around or over 100 dB and their location.

Figure 5.13
Number of Flights at Seattle-Tacoma International airport Below 3,000 Feet (Jan-Sept 2019)

Noise Monitor		Flights Below 3,000 Feet Altitude		
#	Location	# of Flights	Percent	Ave/Day
1	Air Cargo 4, Sea-Tac	90,063	100%	334
3	Maple Leaf Reservoir, Seattle	190	4%	1
4b	Catherine Blaine School, Seattle	227	30%	1
5	Medina Elementary, Medina	49	0%	0
6	Hamilton Viewpoint Park, Seattle	136	23%	1
7	Central Area Senior Center, Seattle	649	8%	2
8	Mercer View Community Center, Mercer Island	1	1%	0
9	Beacon Hill Reservoir, Seattle	109,250	75%	405
10	Brighton Playfield, Seattle	3,916	69%	15
11	Beverly Park School, Sea-Tac	140,885	94%	522
12	South 126th, Burien	59,582	99%	221
13	Cedarhurst Middle School, Burien	103,197	100%	382
14	North Clear Zone, Sea-Tac	120,698	100%	447
15	Sylvester Middle School, Burien	5,094	100%	19
16	Chinook Middle School, Sea-Tac	8,528	100%	32
17	S 207th Street, Sea-Tac	152,219	100%	564
18	S 226th Street, Des Moines	142,690	97%	529
19	Midway Elementary, Des Moines	106, 925	96%	396
20	Parkside Elementary, Des Moines	80,339	75%	298
21	Mark Twain Elementary, Federal Way	12,839	13%	48
22	Sacajawea Junior High, Federal Way	44,416	35%	165
23	Meredith Hills School, Auburn	32	2%	0
25	Twin Lakes Elementary, Federal Way	23	1%	0
28	Woodmont Elementary, Des Moines	69,384	49%	257

Source: Port of Seattle, 2019.

Figure 5.14
Seattle-Tacoma International Airport Noise Monitor Locations



Late Night Noise

One of the changes over time has been the increase in late night flights, particularly by air cargo flights between the hours of midnight and 5 a.m. During the third quarter of 2019, there were 3,874 late-night operations. Of those, 239 operations exceeded the recommended SEL noise thresholds (these were established at four noise monitor locations for departures and arrivals), and 62% of those exceedances were cargo operations (Port of Seattle 2019). The SEL thresholds were established at 88 and 91 dB (at monitor #12), 82 dB (at monitor #13), 89 dB (at monitor #18), and 88 and 91 dB (at monitor #19). Any exceedances are tracked by time, airline, flight number and aircraft type, as well as the SEL noise level. Residents in the area have expressed concerns over the noise these late night flights generate and how they disrupt sleep.

Noise Complaints

The most important factor in reducing aircraft noise has been the transition to quieter aircraft and the regulations requiring the phasing out of older louder aircraft. For example, Stage 2 aircraft are now prohibited from use in the U.S. Codified in 14 CFR Part 36, the FAA adopted increasingly restrictive noise certification standards for new aircraft. These requirements have spurred new engine and aircraft technology creating quieter aircraft, and airlines have retired noisier airplanes and invested in these new airplanes.

Other factors in reducing noise effects include working with local communities to reduce the number of people living in areas exposed to significant aircraft noise and use of the Airport Improvement Program grants to provide sound insulation to homes, schools and health care facilities within the 65 DNL noise contour. However, the effect of the increase in air operations and wider flight paths has seen a dramatic increase in noise complaints at Seattle-Tacoma International Airport.

Figure 5.15 details the number of complaints from the period 1997 to 2019. Noise-related complaints were relatively constant from 1997 until 2017. After 2017, the number of complaints dramatically increased to 170,000 in 2018 and 400,000 in 2019. The Port of Seattle indicated that the dramatic increase after 2017 was due in part to the development of an app that allowed for noise complaints to be submitted automatically to the airport with the push of a button. The Port of Seattle also reports that this app is used for airports nationwide, not just Seattle-Tacoma International airport.

Figure 5.15
Seattle-Tacoma International Airport Noise Complaints: 1997-2019

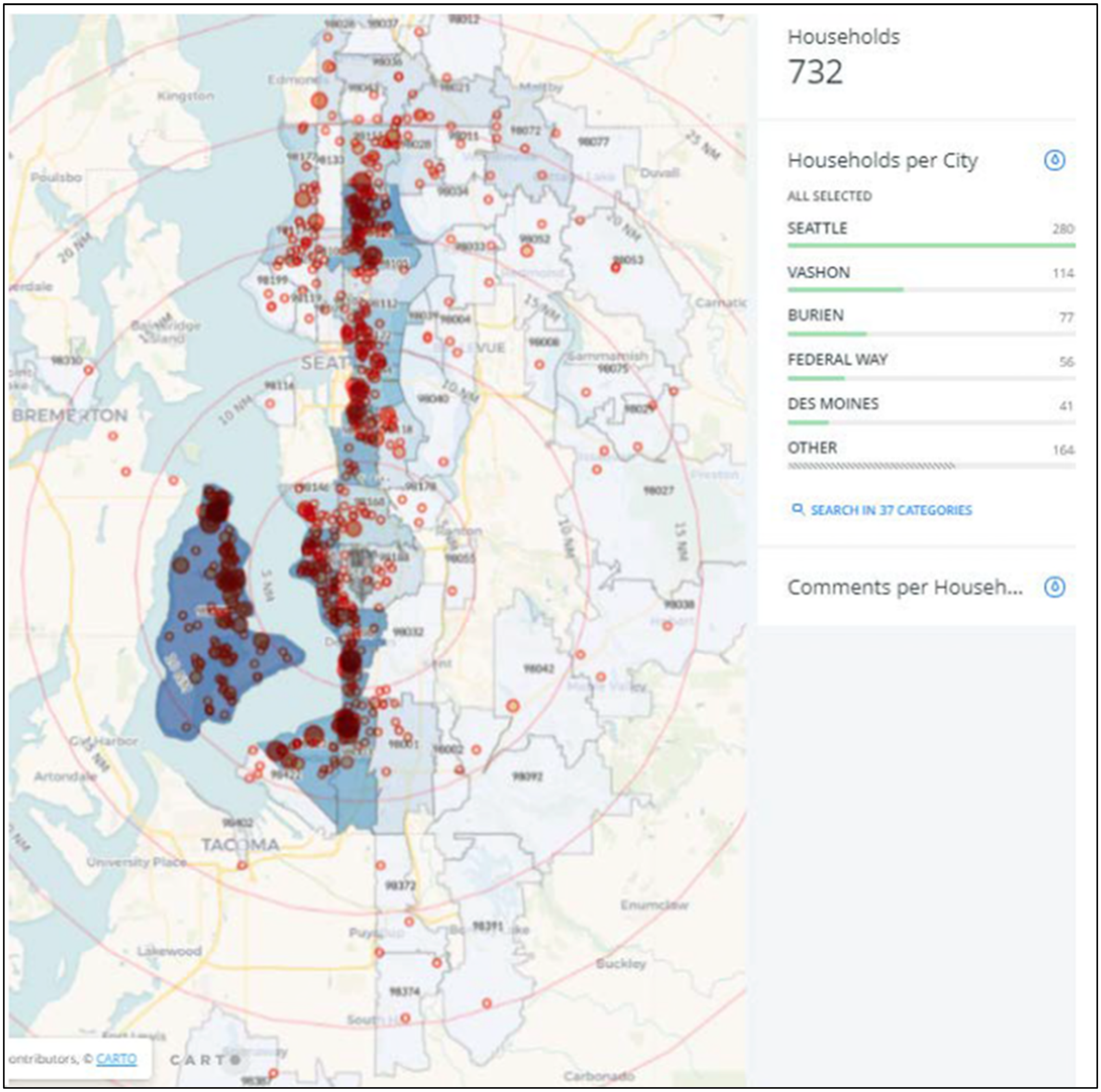
Year	Annual Complaints	Year	Annual Complaints
1997	3,571	**2009**	2,231
1998	4,482	**2010**	2,488
1999	4,968	**2011**	1,786
2000	3,941	**2012**	3,868
2001	3,192	**2013**	2,507
2002	2,050	**2014**	2,172
2003	1,493	**2015**	2,632
2004	1,432	**2016**	2,959
2005	1,442	**2017**	7,929
2006	1,274	**2018**	**170,000**
2007	1,556	**2019**	**400,000 +**
2008	1,927		

Source: Port of Seattle

Figure 5.16 shows where noise complaints have been received over the three-month period from July to September 2019. This demonstrates how widespread the area is that is affected by aircraft overflights.

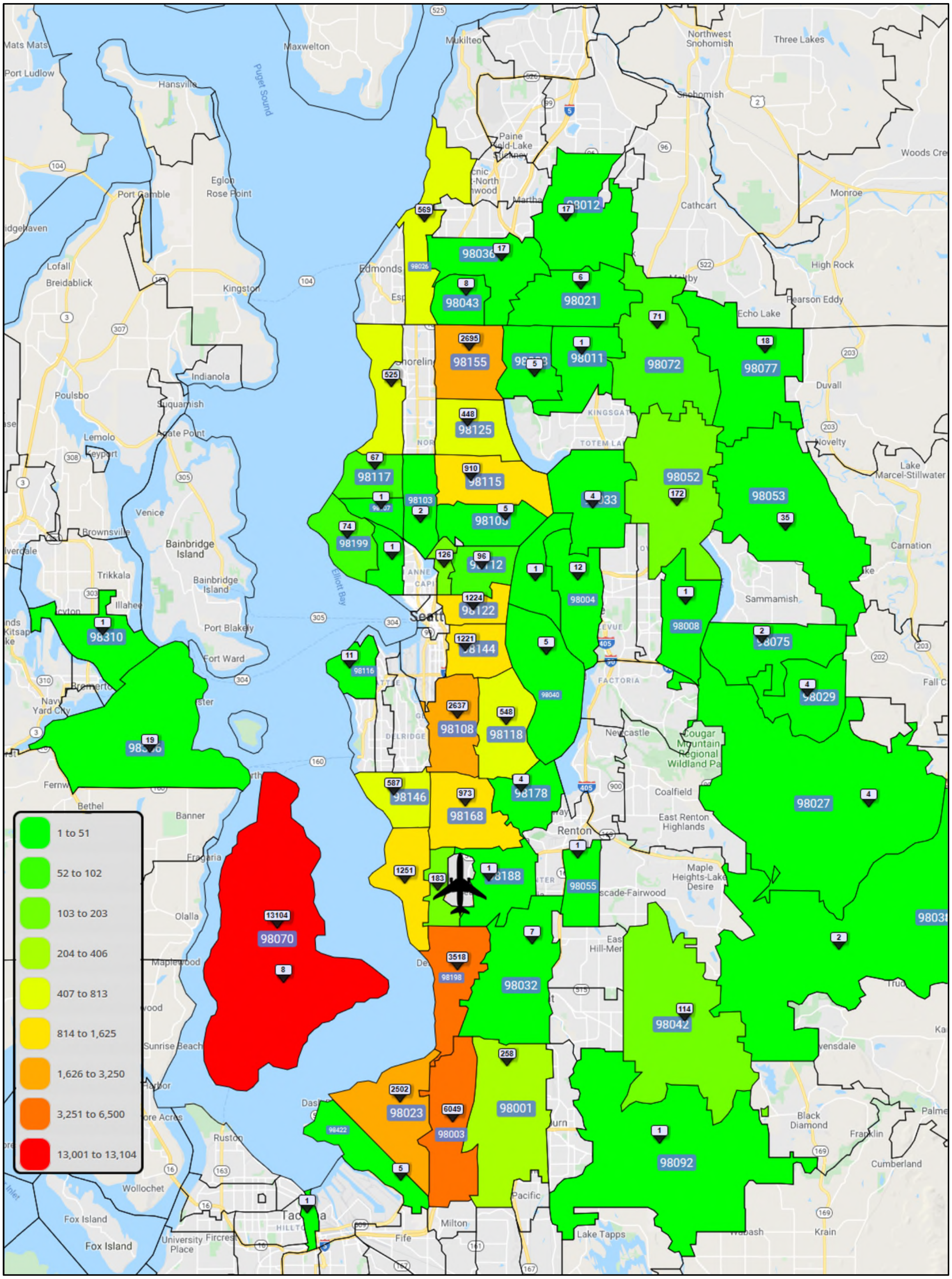
Figure 5.16 shows that the study area cities are affected by noise as are surrounding communities including Shoreline, Kent, Vashon Island, Lynnwood, Woodway, Lake Forest Park, Mountlake Terrace, Seattle (particularly Beacon Hill) and the north and east sides of Lake Washington. A one-month depiction of noise complaints is shown in Figure 5.17 for August 2019.

Figure 5.16
Seattle-Tacoma International Airport Location of Noise Complaints: July-September 2019



Source: Port of Seattle, Purcell 2019.

Figure 5.17
Seattle-Tacoma International Airport Location of Noise Complaints: August 2019



F. NOISE EFFECTS

Positive Effects

There are no known positive results of receiving noise.

In some settings, noise is part of the experience – crowds cheer during air shows such as when the Blue Angels roar overhead, at the Seafair hydroplane races, or at Seattle Seahawks games. Those are isolated events.

There is ongoing technological research and testing to develop quieter aircraft, and this has been a focus of agencies such as NASA and universities including MIT and Penn State. Recent activities include investigation of all-electric and hybrid jet engines, use of all-composite fuselage, and enclosing jet engines within the fuselage of aircraft to shield their noise signature, all of which could reduce the noise from take-offs, landings and overflights. Recent NASA activities include testing technologies related to the use of fairings on landing gear, cavity treatments (a cavity is formed when the landing gear is deployed), and seamless wing flap design (NASA 2018). These design changes remain experimental at present but may have future applications to reduce noise generated by the airframe. MIT has recently developed a futuristic plane with no moving parts that is powered by an ionic wind (MIT News 2018), however it may take years or longer before such technological changes are developed enough to be feasible and implemented throughout the airline industry.

Neutral Effects

There are no known neutral effects of noise.

Negative Effects

The increase in air carrier operations at the airport from 1997 to 2019 has increased the number of noise events and the likelihood of adverse effects. Generally, an average residential structure can provide some sound attenuation – typically 20 dB (Oregon Airspace Initiative, 2018). Aircraft noise events within the 90 dB SEL contour previously would result in an indoor sound level of 70 dB for that event. This level (and lower and higher levels) of noise can result in a variety of negative effects.

- **Annoyance**
  The primary, and perhaps most obtrusive, aspect of aircraft noise is community annoyance. Analyses have shown that the annoyance response is influenced by both acoustic and non-acoustic factors:
  - Acoustic factors being the maximum sound levels, number of flights, and fleet mix distributed over time.
  - Non-acoustic factors include personal noise sensitivity, attitude towards the noise source, mistrust of authorities, a feeling of not being fairly treated, and expectations of property devaluation (ICAO 2019).

  A general trend indicated by some researchers have suggested that at equal noise exposure levels, people today seem to be more annoyed by aircraft noise than they were 30 to 40 years ago (Janssen et al. 2009; Guski et al. 2017).

  The World Health Organization summarized and analyzed data from a dozen studies across airports in Europe and Asia on the association between aircraft noise and annoyance. In comparing the aircraft noise exposures at 50 and 60 dBA, their analyses revealed evidence of a high association between the sound exposure and the percent annoyance for an increase per 10 dB when data on all sound classes were assessed. Figure 5.18 presents the percentage of those annoyed by noise of varying intensities, derived from the systematic review of the studies run through regression analysis in Guski et al. The table shows low annoyance at the 40 to 50 dB level and over 50% annoyance at the 70 dB level. For each 5 dB increase in the sound level, the percent of people annoyed increased by approximately 10%.

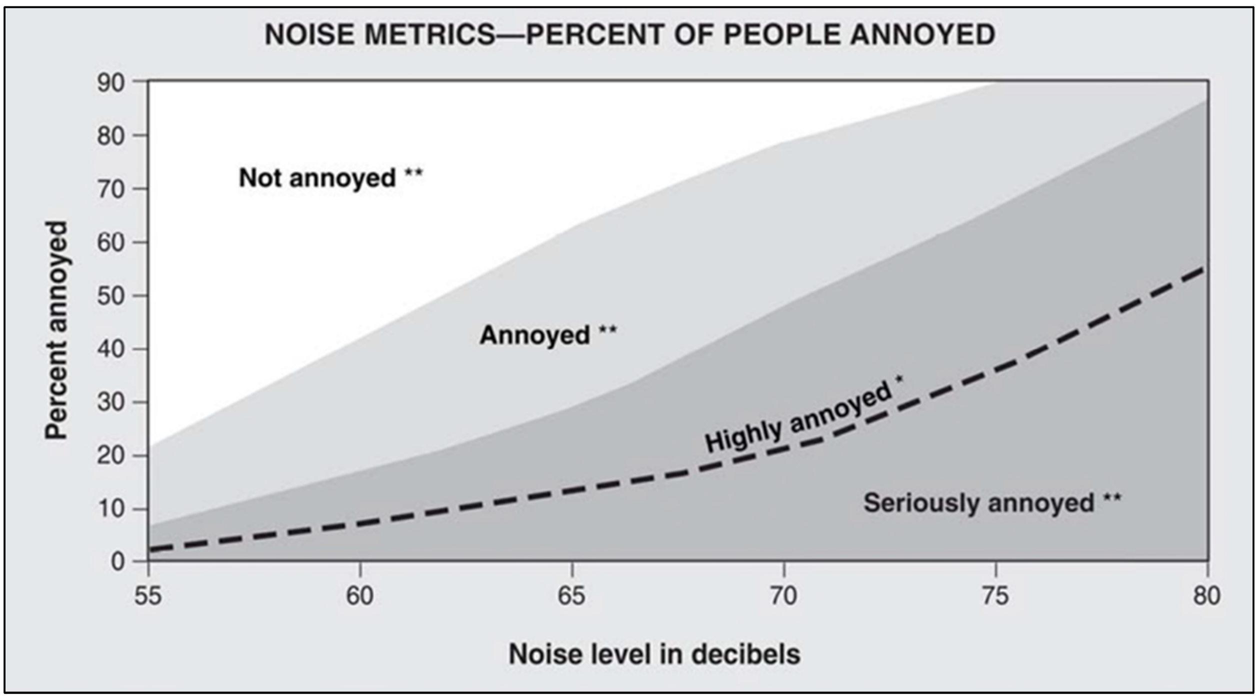
Figure 5.18
Annoyance Associated with Varying Noise Levels

DNL (dB)	% Annoyance
40	1.2%
45	9.4%
50	17.9%
55	26.7%
60	36.0%
65	45.5%
70	55.5%

Source: World Health Organization

Figure 5.19 graphically shows the variability in the degree of annoyance based on people's sensitivity to noise and their perceptions of annoyance. There is a wide variation in people's sensitivity to noise, but what is important to consider is that some people may be "seriously annoyed" even at relatively low levels of noise.

Figure 5.19
Annoyance Perception Graph



Sources:

* Percentage of Residents Annoyed, Richard, E.J. and J.B. Ollerhead; reproduced in "Aviation Noise Effects," FAA Offices of Environment and Energy, March 1985.

** Schultz, T.J. "Synthesis of Social Surveys on Noise Annoyance," *Journal of Acoustical Society of America*, 1978.

- **<u>Sleep Disturbance</u>**
  Undisturbed sleep is a vital function necessary for daytime alertness, quality of life and health. There is ample evidence that chronic disturbance or curtailed sleep is associated with adverse health effects such as obesity, diabetes and high blood pressure. Aircraft noise is intermittent, and whether or not aircraft noise disturbs sleep depends on factors such a sleep depth and noise sensitivity, as well as and the number and acoustical properties of the SEL event(s).

Noise sensitivity plays an important part in sleep disturbance. Research has shown that the elderly, children, shift-workers and those in Ill health are particularly vulnerable to be disturbed (Muzet 2007). Younger children and shift-workers tend to sleep during daytime hours when there are higher air traffic volumes.

Sleep depth also tends to decrease with age, making the elderly more likely to be awakened by noise. It has also been shown that some people (not all) will become habituated to aircraft noise over time, resulting in less sleep disturbance.

For individuals who are sensitive to aircraft-induced noise, they can be affected by changes in sleep structures that affect sleep onset and early awakenings; cause less deep sleep and REM sleep; and more time spent in a superficial sleep stages (Basner et al 2010; Basner et al 2011). Deep and REM (rapid eye movement) sleep are important for recuperation and memory consolidation. Short-term effects from noise disturbance include perceived and actual daytime sleepiness, and impaired mood and cognitive performance (Basner 2008; Elemenhorst et al. 2010).

In 2018, the World Health Organization prepared a systematic review on environmental noise and effects on sleep evaluating exposure-response functions. It was found that significant exposure-response functions were found for aircraft-induced noise affecting sleep stage changes per 10 dB increases and highly sleep disturbed for questions mentioning the noise source. Figure 5.20 shows the association between exposure to aircraft noise and sleep disturbance found in the World Health Organization study. They recommended reducing noise levels produced by aircraft during the nighttime below 40 dB to avoid adverse effects on sleep.

Figure 5.20
Nighttime Noise and Sleep Disturbance

Nighttime Noise Level (dB)	% Sleep Disturbed
40	11.3%
45	15.0%
50	19.7%
55	25.5%
60	32.3%
65	40.0%

Source: World Health Organization, 2018.

- **Cardiovascular Effects**

  Potential health effects related to long-term aircraft noise exposure includes hypertension, ischemic heart disease (IHD), and metabolic effects (diabetes, obesity). Studies of hypertension related to aircraft noise have generally shown a positive association but a non-statistically significant association reflecting inconstancy between studies to date:

  - Nine cross-sectional studies of hypertension found that there was a 5% increase in hypertension per 10 dB of aircraft noise (van Kempen et al. 2018).
  - A cohort study in Sweden did not show an overall association with hypertension incidence but did show an annoyance association (Eriksson et al 2010).
  - A NORAH study found no associations overall but did find an increased risk for the subgroup that went on to develop hypertension-related heart disease (Zeeb et al 2017).
  - A study in Athens found that nighttime aircraft noise produced a 2.6-fold increased risk of hypertension associated with a 10 dB increase (Dimakopoulou et al 2017). The mixed results are due to different methodologies, sample sizes, and variability in the sound sources.

Some researchers have stated that reviews have not been carried out in a systematic way, making them prone to bias. At best there is a weak association between aircraft noise and hypertension, but the results are still inconclusive.

The data on IHD is a bit more conclusive than for hypertension. The SIREN project used data covering 4.4 million people from the Swiss National Cohort and reported associations between aircraft noise and myocardial infarction mortality with an increased risk of 2.6% per 10 dB increase. The highest associations were seen with intermittent nighttime noise exposures.

Another large study in Germany forming part of the NORAH study found associations of aircraft noise with myocardial infarction at higher noise levels (> 55 dB) in the early morning hours. Another part of the NORAH study found a linear exposure-response relationship for heart failure or IHD at a rate of 1.6% percent per 10 dB in 24-hour continuous noise level. No association was found for stroke and aircraft noise in the review of several studies (van Kempen et al. 2018).

Another potential health effect that has been studied in the literature is the association between aircraft noise and metabolic effects. A small number of studies has found a positive but non-statistically significant association. Findings to date are consistent with a hypothesis that noise exposure is related to stress-hormone-mediated deposition of fat centrally and other impacts on metabolic functioning and/or adverse effects of disturbed sleep on metabolic and endocrine function, also with results from a small number of studies considering road traffic noise that also found associations with diabetes, but more studies are needed to strengthen the evidence base for this outcome (ICAO 2018).

- **<u>Children's Learning and Cognitive Impairment</u>**
  Several studies found a correlation between aircraft noise at school and home on children's reading comprehension and memory and standardized test scores (Clark et al 2018; Haines et al 2002; Sharp et al. 2014). A study of 89 schools around airports in London (Heathrow), Amsterdam (Schiphol), and Madrid (Barajas) found exposure-response relationships between aircraft noise and poorer reading comprehension and recognition memory after taking road noise exposure and social position into account (Stansfeld et al 2005). Nighttime aircraft noise at children's homes was also associated with cognitive impairment but did not have an additional effect to that of daytime noise exposure.

  In one study, a 5 dB increase in aircraft noise exposure resulted in a two-month delay in reading age in the UK and one-month delay in the Netherlands (Clark et al 2006). A German study also found a one-month delay in reading age with a 10 dB increase in aircraft noise (Klatte et al. 2017). The effects of aircraft noise on children's learning has been demonstrated across a range of noise metrics.

  Other noise pathways that may also affect children's learning include:
  - Noise levels that may distort a teacher's voice or make it harder to hear teachers
  - Home exposure that may have resulted in sleep disturbance
  - Annoyance from the noise causing frustration, or other physiological or psychological stress responses, which might explain poorer learning in addition to the direct noise exposure-response (Eagen et al. 2017).

  Interventions to reduce aircraft noise exposure at schools have been shown to improve learning. A study of school learning near an airport in Munich that was relocated found that two years after the airport closed, the cognitive impairment that existed when the airport was in operation was no longer present. This suggested that the effects of aircraft noise on learning and memory may be reversible if the noise exposure stops (Hygge et al. 2002).

- **Speech Interference**

  Another factor related to noise related annoyance is speech interference. Aircraft noise can disrupt routine activities such as listening to the television or music, use of the telephone, or family discussions giving rise to irritation and frustration. The quality of speech to communicate is also important in classrooms, offices, hospitals and similar land uses. It has been shown that whenever "intrusive" noise exceeds approximately 60 dB indoors that there will be speech interference (FICON 1992). A steady background sound level of 60 dB will produce 93% intelligibility; a 70 dB level produces 66% intelligibility; and a 75 dB level reduces intelligibility to 2% (USEPA 1974). Locally, residents in the study area have coined the phrase "the Des Moines Pause" when conversations are temporarily halted due to aircraft noise.

- **Depressed Property Values**

  Aviation noise has an indirect effect on property values because noise is a factor considered during the buyer/seller negotiations on the price of a property located near an airport. Studies have researched the influence of aviation noise on property values:

  - Newman and Beattie (1985) found that a 1.0 dB change in the cumulative airport noise resulted in a 0.5% to 2% decrease in property value.
  - A study by Nelson (2004) developed a noise depreciation index and applied it to 23 airports in the U.S. and Canada and found that property values in the U.S. declined by 0.5% to 0.6% per decibel increase at noise exposure levels of 75 dB or less (in Canada the property values declined by 0.8% to 0.9% per decibel increase).

  Surveys of property values and estimates of devaluation near Seattle-Tacoma International Airport have been conducted as part of the Port of Seattle's environmental documentation. In 1997, the State of Washington funded a study through a grant from the former Community, Trade and Economic Development Department for the Port of Seattle to assess, among other effects, the potential changes in land values within the cities of Burien, Des Moines, Federal Way, Normandy Park and Tukwila. The 1997 study showed a relationship between property values and distance from the airport – property values increased with distance from the airport. It also estimated that over time, property values were anticipated to decrease in relation to increased operations.

  An issue of concern represented by several residents that attended the public workshops for this study indicated that they had purchased properties near Seattle-Tacoma International Airport not knowing how loud it would be inside their homes. A study of 200 realtors and 70 appraisers in 35 suburban communities near Chicago O'Hare Airport found that a significant segment of buyers lacked sufficient information about the noise environment. Accordingly, their bid prices for the properties tended to be too high, and their expectations for the amenity levels of their residences were a disappointment to the buyers. The disappointment of some buyers served to exacerbate conflict between homeowners and airport authorities (Frankel 1991).

  In contrast, there was one study in the City of College Park, Georgia that concluded that the noise from nearby Atlanta Hartsfield-Jackson International Airport did not significantly affect the value of residential properties. There were unique demographic and conditions, namely many of the community residents were employed in airport-related employment. Thus, a short commute distance from the airport was given more emphasis (Lipscomb 2003). However, generally the literature indicates that airport noise does have a negative effect on property values.

- **Effects on Wildlife and Domestic Pets**

  Aircraft noise also has an effect on wild animals and domestic pets. Wildlife species differ greatly in their responses to noise. Species have adapted to fill certain ecological niches, and their hearing usually reflects their role. They rely on hearing to communicate with other members of their species, find food and avoid predators. Noise from aircraft can affect their ability to carry out these necessary survival skills. Both wildlife and domestic pets that are exposed to high sound levels can experience stress, hypertension and other nervous disorders similar to humans.

G. RECOMMENDATIONS

This study acknowledges that the Port of Seattle has voluntarily implemented a Part 150 Noise Study and noise mitigation program and has been actively providing sound insulation to schools, residences and others for a number of years. The Port of Seattle has been working with the Federal Aviation Administration to implement a noise reduction program since the early 1980s. The Port of Seattle states that it has spent more than $300 million to provide noise insulation for more than 9,600 homes in the study area.

The Port of Seattle has also implemented a voluntary "Fly Quiet" program for air carriers operating at the airport. In 2018, they created the Stakeholder Advisory Round Table (StART) to engage the neighboring cities to discuss and voice concerns about ongoing activities at the airport including noise reduction measures. However, several cities dropped out of the StART committee in 2019 over various concerns. It is hoped that those concerns may be addressed and a full contingent of the study area cities can rejoin the roundtable and work to address noise issues with the Port.

The following recommendations to positively influence noise mitigation at Seattle-Tacoma International Airport require changing some policies at the federal level and, thus, may require a longer time-frame to accomplish:

- **Noise and Vibration Recommendation #1: Alternative Noise Metrics**
  Encourage the Federal Aviation Administration to complete its study of alternative noise metrics for assessing the effects of noise on residential areas. If the metric is not changed, the Port of Seattle should advocate for an alternate metric. (The Port of Seattle has stated that it and the StART committee have been advocating to the Federal Aviation Administration on this issue, including a multi-signature letter that went to the Federal Aviation Administration and to the Washington congressional delegation. Prior to the COVID-19 pandemic, a group of Port of Seattle and city representatives had planned a trip to Washington, D.C. to advocate on these issues.)

- **Noise and Vibration Recommendation #2: Increase Arrival Glideslope**
  Work with the Federal Aviation Administration to increase the arrival glide slope to a minimum of 3-degrees for all arrival aircraft.

- **Noise and Vibration Recommendation #3: Conduct an Environmental Review for Flight Track Changes**
  Any desired changes in flight tracks should have adequate environmental review and provide opportunities for public involvement.

- **Noise and Vibration Recommendation #4: Institute Noise Abatement Procedures**
  The Port of Seattle should consider noise reduction measures for take-off and landing procedures during low traffic and late-night hours. A limit on late-night flights (between midnight and 7 a.m.) should be considered, including both cargo and passenger flights.

- **Noise and Vibration Recommendation #5: Expand Noise Monitor Locations**
  The Port of Seattle should consider installing additional noise monitoring stations – possibly using mobile stations – to monitor noise in the areas receiving the highest number of complaints. (The Port of Seattle may have already acquired five mobile noise monitors.) This information would be valuable to get a better idea of the extent and how noise is distributed throughout area communities and to possibly use this data to customize the mitigation program.

It is important to note that while the 2020 Study was underway, the Port of Seattle Commission voted on Nov 19, 2019 to adopt Motion 2019-14, which authorized the purchase of five new portable noise monitors. That motion stated that "the determination of the location of the monitors shall be based on community outreach and analysis of coverage of the Port's current noise monitoring system and technical factors and shall include Vashon Island."

- **Noise and Vibration Recommendation #6: Address Existing Mitigation Packages**
  There have been numerous citizen reports of faulty installations of sound insulation features on homes within the 65 DNL contour. These were mostly mitigated during the third runway project. While the 2020 study did not conduct a house-to-house analysis of these failures, it is recommended that the Port of Seattle's mitigation program review reported cases of mitigation failure and consider some accommodation for addressing faulty and failed installations, as well as ensuring that future mitigation installations are properly installed. (Rep. Tina Orwall has proposed draft legislation to address concerns with the mitigation program in its current state).

- **Noise and Vibration Recommendation #7: Direct Representation on the Port Commission**
  The Port of Seattle is governed by a five-member commission. Each commissioner is elected at-large and serves a four-year term. It is recommended that the Port of Seattle designate one commission position to be directly representative of the study area cities. This "district commissioner" would represent the constituents of the study area cities and would be a resident of the city of Burien, Des Moines, Federal Way, Normandy Park, SeaTac, or Tukwila.

H. VIBRATION

In addition to noise, vibration is also a concern associated with noise events. Low-frequency noise (LFN) comprises a spectrum of sound sources including natural (wind) and man-made sources (e.g., aircraft, automobiles, industrial installations, and domestic appliances). LFN has been recognized as a special environmental noise problem, particularly to sensitive people in their homes (Leventhall 2004). LFN is defined as sound frequencies below 250 hertz (Hz) to around 20 Hz and have characteristic long wavelengths that travel farther and last longer, as these frequencies encounter less absorption in the atmosphere than higher frequency noise (HFN) levels. Thus, the higher the sound frequency the quicker it dissipates (Hodgdon et al. 2007). In cases where high levels of noise occur, such as aircraft take-offs, LFN causes a secondary effect resulting in vibration, which can enter nearby residences. LFN more readily travels through structures than HFN, and this movement has focused research and studies on LFN-generated vibration.

The noise resulting from aircraft overflights can travel from the exterior to the interior of a house through the structure itself or through the air. The aircraft sound first hits the exterior wall where some of the energy is reflected away and some it makes the wall vibrate. The wall vibrations radiate the sound to the interior surfaces through the studs and through the airspace and insulation between the studs (Oregon Airspace Initiative 2019). The most susceptible structures to vibration are loose windowpanes. While not normally something that causes major damage to structures, noise-induced vibration from aircraft can rattle windows, doors and objects, such as pictures attached to walls and items on shelves. Persons inside their homes may feel this vibration or hear it as a "rumble" or "hum." Minor damage may also occur or be aggravated by vibration, such as cracked plaster, loosened nails and peeling wall trim (Cant et al. 1973). Only sounds lasting for more than one second above a sound level of 130 dB are potentially damaging to structural components (Von Gierke et al. 1991).

A phenomenon of low-frequency sound is that humans experience a more rapid growth of loudness than when experiencing higher frequencies. This contributes to a low-frequency sound being perceived as "too loud" to be closer to the threshold for detectability, increasing the potential for rapid annoyance with a minimal increase in loudness (Hodgdon et al 2007).

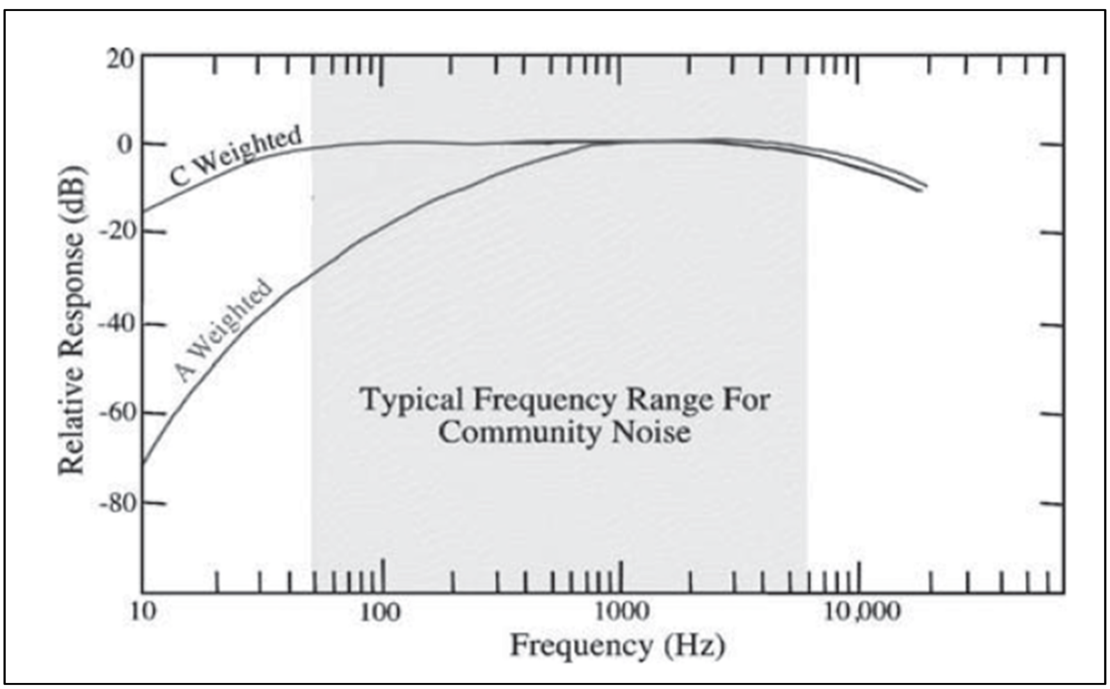
There have been a number of research studies of aircraft-generated LFN in the U.S. and Canada by NASA, the Federal Aviation Administration, Transport Canada, the Federal Interagency Committee on Airport Noise, the American Acoustical Society, and the Journal of Low-Frequency Noise and Vibration, as well as European and Asian studies particularly in the Netherlands and Japan.

LFN has been studied at airports in Los Angeles, San Francisco, Boston, Minneapolis/St. Paul, New York (John F. Kennedy International airport), Baltimore/Washington, and Washington, D.C. (Dulles), to name a few. Some of the first of these studies were initiated due to the Concorde supersonic transport, which generated high noise levels and vibration on take-off.

These studies have shown that jet engines create enough low-frequency noise energy to induce wall and floor vibration and rattling of windows and objects, particularly to the sides of the runway take-off/departure zones in proximity to airports. Generally, the start of take-off rolls, acceleration down a runway, and thrust reversal generate the highest levels of LFN. Measurements of noise to the sides of the take-off roll show that the larger the aircraft the higher the LFN levels, which decrease as the aircraft moves down the runway. Measurements during thrust reversal do not show the same trend with airplane size.

Overall, large jets produce SEL low-frequency events that may be annoying in their own right, as well as calling attention to the aircraft operation (overflights, take-offs and thrust reversals). The DNL measurement is insensitive to these low-frequency events (Fidell et al. 2002) and use of the A-weighted measurement may not adequately reflect the LFN levels causing vibration inside residences. Studies have suggested that using the C-weighted measurement may be more appropriate to measure LFN. Figure 5.21 shows the differences in how the two measurements capture LFN.

Figure 5.21
Noise Frequency Relative to A-Weighted and C-Weighted Decibels



Source: Atchley 2005.

Vibration at Seattle-Tacoma International Airport

Aircraft noise-induced vibration is not monitored or extensively studied at Seattle-Tacoma International Airport. However, there was a vibration study conducted at the airport in 1973 (Cant et al 1973) that measured wall acceleration levels during a 24-hour continuous sampling period at 15 residences (sampling occurred for one 24-hour period at each residence). The homes were located 0.2 to 3.3 miles from the airport, and each structure was wood-frame construction except for one that was composed of a brick veneer. All homes were habituated at the time of the study. Vibration was measured using accelerometers located on an outside bearing wall of the living room of each structure.

Background levels at all the homes were under 0.0018 g rms (g rms = root mean square acceleration, the metric used to measure vibration).

Normal activities such as radio and TV use, street traffic, children playing, appliance and furnace operation, and strong winds can cause vibration levels to fluctuate momentarily up to 0.01 g rms. Opening and closing doors can cause a momentary fluctuation up to 0.02 g rms. These normal activities do not raise the average continuous levels higher than 0.0032 g rms. The study considered average values over 0.01 g rms to be the boundary between normal levels and those temporarily caused by activities such as aircraft flyovers (the study did not determine the noise solely from aircraft).

In the 1973 study, the total number of flyovers ranged from 124 to 172 flights during the 24-hour test periods with recorded measurement values ranging from 0.0025 to 0.22 g rms. The total time spent at or above 0.01 g rms for all structures ranged from 0.05 to 2.2 hours. Floor vibrations were one-tenth the level of the wall acceleration. These measurements were correlated with residents indicating that vibration was detected. The study concluded that the threshold of vibration detection for the homes studied was approximately 62 to 68 dB inside the homes, which corresponded to approximately 100 to 105 dB outside sound pressure (Cant et al. 1973).

Correlating indoor response to an outdoor sound pressure level can be problematic because of the variability in transmission loss through structures due to the different building and insulation materials and the possibility of increasing vibration levels due to normal indoor activities (shutting doors, operating appliances, etc.). However, it has been shown that standard sound insulation does not sufficiently reduce LFN generated vibration (LAX Low-Frequency Aircraft Noise Study, 2010).

A 2002 study at the Los Angeles and Minneapolis-St. Paul airports suggested that using maximum C-weighted sound levels results in perceptible vibration in residences at outside sound pressures of 75 to 85 dB, and this may be a better predictor of when vibration effects may occur inside residences (Fidell et al. 2002). Other factors have also been found to affect perceptions of vibration, including the level, spectral shape, tonal content and modulation rate of the transmissions (Hodgdon et al. 2007).

Vibration Effects

There are no known positive or neutral issues associated with vibration and LFN. Many of the negative effects of LFN are similar to those described previously for noise, but typically the first reaction and primary effect to the vibration caused by LFN is annoyance. This is often accompanied by secondary effects including difficulties in concentration, headaches, problems sleeping, mood effects, increased stress and palpitations (Moller and Lydolf 2003; Leventhall 2004 and 2009; Ising and Ising 2002). According to a study of local environmental health authorities, complaints due to LFN comprised about 35% of the total noise complaints from man-made sources such as aircraft, roads and industrial installations (Bengtsson and Waye 2003).

Previous research suggests that sensitivity also plays a significant role in how individuals biologically respond to low-frequency noise exposure (Recio et al., 2016, Shepherd et al, 2010):

- A 2002 study (Waye et al, 2002) found that with LFN exposure, subjects who were classified as highly noise sensitive maintained higher cortisol levels compared to low-sensitive subjects, suggesting differential stress responses based on an individual's noise sensitivity.
- A 2004 study (Lusk et al, 2004) found that stress levels positively influenced heart rate.
- In 2016, the results of a panel study of cardiovascular and stress responses to short-term noise exposure also found that low-frequency noise caused variability in heart rates (Walker et al. 2016).

However, "there is limited risk-assessment research in the field of LFN and health effects," (this is related to outdoor noise exposure and not occupational noise exposure) and it has been recommended that more research be undertaken, particularly relating to epidemiological effects (Baliatsas et al. 2016). Generally, the epidemiological research on LFN and its health effects is scarce and suffers from methodological shortcomings. The problem is that many of the studies occur in laboratories, are small in scale and evaluate only short-term exposure. Long-term low frequency noise in the everyday environment constitutes an issue that requires more research attention, particularly for people living in the vicinity of loud sound sources (Baliatsas et al. 2016).

Vibration Recommendations

While there is some data on LFN, there is a large data gap related to evaluating vibration effects resulting from operations at Seattle-Tacoma International Airport. Even though monitoring for vibration effects has not occurred at the airport, it is possible to extrapolate that vibration effects have increased in frequency based on the increase in air carrier operations at the airport, as well as the likelihood that older residential units do not have adequate insulation.

If there is a desire to study LFN and vibration effects at Seattle-Tacoma International Airport, the following recommendations should be considered:

- **Noise and Vibration Recommendation #8: Additional Monitoring**
  A number of residences should be identified in the area where SEL events occur that exceed 75 dB and should include monitoring of the windows, walls and floor vibration. The monitoring should occur over a longer timeframe (the previous study only evaluated the effects over a 24-hour period).

- **Noise and Vibration Recommendation #9: Targeted Study Area**
  A panel of subjects living in the vicinity of the airport should be assembled to rate the annoyance of individual aircraft SEL events in their homes and conduct a statistical analysis to establish the best combination of measures to predict annoyance. (In the literature, a possible first measure to evaluate the noise and vibration effects on residential structures is to use the Hubbard Exterior Sound Pressure Level Threshold Criteria, and a measure for predicting annoyance is to use the Tokita and Nakamura Thresholds.)

- **Noise and Vibration Recommendation #10: Sound Insulation Effectiveness**
  The efficiency of the sound insulation in limiting LFN that the Port has been installing in homes under its Part 150 program should be evaluated.

I. NOISE and VIBRATION EFFECTS ATTRIBUTABLE TO AVIATION ACTIVITY

As stated on page 1 of this report, the 2020 study was tasked with looking at historical data between 1997 and roughly 2019 in order to establish a baseline of airport-related performance criteria using a variety of metrics and how they affect the study area cities. Three milestone dates were selected: **1997** (the base year), **2009** (the first full year of operations of the third runway) and **2019** (most recent full year of data).

Positive Effects of Noise and Vibration

There are no known positive results of receiving noise or vibration.

Neutral Effects of Noise and Vibration

There are no known neutral effects of noise or vibration.

A large data gap exists related to evaluating vibration effects resulting from operations at Seattle-Tacoma International Airport. More information and monitoring are required to identify effects that are directly attributable to aviation activity.

Negative Effects of Noise and Vibration

The 2020 study finds that noise has been directly affecting most of the study area since 1997. Some improvements have been as a result of the replacement of older aircraft with newer generation equipment. However, those improvements have been offset by two important factors.

First, Seattle-Tacoma International Airport has grown significantly in both passenger count and annual air carrier operations. Since 2000, the number of passengers increased from 28,408,553 to 49,849,520 in 2019 – a 75.5% increase. During that same period, air carrier operations increased from 236,355 to 427,170 – an 80.7% increase.

Second, the implementation of NextGen procedures has concentrated flight patterns over a tighter airspace, resulting in a higher concentration of flights in a smaller area. As a result, noise complaints received by the Port of Seattle increased from 3,941 (in 2000) to over 400,000 in 2019 (the spike in noise complaints began in 2018 with over 170,000 complaints). This increase may be partially due to the use of a new smartphone app that made submitting noise complaints easier. But it also indicates a dramatic increase in noise-related concerns that can be attributed directly to aircraft activity.

As previously identified in this section, the following negative effects are associated with noise:

- Annoyance
- Sleep disturbance
- Cardiovascular effects
- Children’s learning and cognitive impairment
- Speech interference
- Depressed property values
- Effects on wildlife and domestic pets.

The above issues have resulted in a continuing concern about noise effects in most of the study area cities:

- Burien, Des Moines, Federal Way, and Normandy Park seem to be the most affected. These cities have also been the most vocal about aircraft noise since 1997 (and some have voiced issues prior to 1997). Even within these four cities, some areas/neighborhoods are affected more than others, so the effect is not uniform across each city.
- Anecdotal information from study area residents indicated that the western portions of the city of SeaTac appears to be more affected by noise than other parts of the city.

- Tukwila appears to be the least affected by aviation activity at Seattle-Tacoma International Airport. But it is important to note that Tukwila is also located closer to two other airports (Boeing Field/King County International airport and Renton Municipal airport), which may also be contributing to local noise concerns.

Summary of Noise and Vibration Effects Attributable to Aviation Activity

Noise has been an ongoing community concern in most of the study area, with additional study recommended for the city of Tukwila. Noise is not necessarily confined to the DNL noise contours as calculated by the Port of Seattle, nor is it confined to neighborhoods directly beneath approach/departure paths. How noise is perceived is also influenced by other factors including weather, wind, heat, ambient background noise, etc. Therefore, not all neighborhoods in the study area experience noise equally.

Regarding vibration, there was not enough data available to determine how it may affect the study area or if it is attributed to aviation activity or other sources (such as vehicles, rail, etc.).

The graphs and tables in this section present various aspects of noise and vibration, including magnitude and intensity. However, Figure 5.22 presents a general assessment of noise and vibration effects in the study area attributable to aviation activity, categorized into four effect types:

- Positive effect attributable to aviation activity
- Negative effect attributable to aviation activity
- Neutral or no effect attributable to aviation activity
- Inconclusive data/needs additional study.

Figure 5.22
Summary of Noise and Vibration Effects Attributable to Aviation Activity – 1997 to 2019

🟩	Positive effect attributable to aviation activity	🟨	Neutral/no effect attributable to aviation activity
🟥	Negative effect attributable to aviation activity	○	Inconclusive data/needs additional study

NOISE and VIBRATION METRIC	STUDY AREA CITY																	
	Burien			Des Moines			Federal Way			Normandy Park			SeaTac			Tukwila		
	1997	2009	2019	1997	2009	2019	1997	2009	2019	1997	2009	2019	1997	2009	2019	1997	2009	2019
Noise	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	○	○	○
Vibration	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Noise is categorized as a negative effect in Burien, Des Moines, Federal Way, Normandy Park, and the city of SeaTac. Additional study is recommended to noise effects in Tukwila attributable to Seattle-Tacoma International Airport.

Regarding vibration effects, due to the lack of information and data, additional study is recommended throughout the study area to determine the effects associated with vibration.

Figure 5.22 indicates a causality between noise and various effects, not magnitude or intensity. Further study, monitoring and modelling is recommended to fine-tune the above effects to smaller areas within each study area city (such as census tracts or enumeration districts).

J. THE FUTURE

In addition to the historic and existing issues surrounding noise and vibration, potential future changes in various areas may also influence these concerns:

- **New airport**

  Air passenger service in the Seattle metropolitan region is provided principally by Seattle-Tacoma International Airport, with two smaller airports – Paine Field (served by Alaska Airlines, San Juan Airlines, and United Express), and Boeing Field/King County International Airport (served by JSX and Kenmore Air). Conversations about a new airport to relieve demand at Seattle-Tacoma International airport have been discussed since 1994 when the Puget Sound Regional Council looked at several locations for a new airport. Those locations received significant opposition, and the study ended with no further action.

  In 2005, a proposal was made by Alaska Airlines and Southwest Airlines to use nearby Boeing Field, but that was rejected by King County (although Alaska Airlines does offer passenger service at Paine Field in Everett).

  The concept of a new airport received support again in 2019 when Washington Governor Jay Inslee signed a bill sponsored by State Senator Karen Keiser (Des Moines) to create a commission tasked with locating a new airport. The commission will identify six candidate locations by January 2021, with a preferred site being located by January 2022.

  Building a new "ground-up" airport is a lengthy and complex process. As an example, the most recent brand new airport in the U.S. (not a renovation of an existing facility) is Denver International Airport, which opened in 1995, with its initial studies dating back to 1980. The process of locating, permitting, designing, and constructing a brand new airport for Seattle could be equally as long, meaning that if a suitable site were selected by 2022, it might not be ready for service until 2037 – not accounting for any political or environmental opposition.

  Even if a new airport were in the region's future, given current permitting requirements and aviation technology, it would not sufficiently address the immediate concerns raised by this study. It could, however, have the potential to reduce overflights in the study area cities should a new airport eventually be developed, which might divert some operations currently at Seattle-Tacoma International Airport.

- **Changes in Aviation Technology**

  The airline industry is interested in operating efficiently, lowering capital and operating expenses whenever possible. Aviation technology has constantly changed over the decades to create faster, larger, safer, more fuel efficient, and quieter aircraft. From the first generation of jet airliners to aerodynamic designs, composite materials, and the latest Stage 5 noise standards, there has been ongoing improvement in commercial aircraft.

  – STOL Aircraft – There has been a long-term interest in STOL (short take-off and landing) aircraft for commercial purposes. A STOL aircraft can land or take off on a runway of 1,500 feet or less, reducing the area needed for most airports. And while there are small STOL aircraft today, there is no existing commercial passenger aircraft capable of competing with a Boeing 737 or an Airbus A321. Only the de Havilland Canada Dash 7, which is used for limited passenger service, is a STOL aircraft.

- VTOL Aircraft – Similar to STOL's are VTOL (vertical take-off and landing) aircraft, which can land and take off vertically, requiring little or no runway. The most common application of VTOL design is in helicopters, which are rotor-based aircraft, but there are VTOL jet aircraft for military applications. These include the Lockheed Martin F-35B Lightning II and the Boeing/BAE Systems Harrier "Jump Jet" (the tilt-rotor Bell Boeing V-22 Osprey, is also a VTOL, but not a jet). Any application of military jet VTOL technology on a large commercial scale is currently unknown, or at least many decades in the future.
- Advanced Engines – Aircraft engine technology also continues to change. At the 2019 Paris Air Show, Fortune magazine (July 2019) noted that:

  > "Aviation currently accounts for around 2.5% of global carbon emissions and with the industry has pledged to halve its 2005-level footprint by 2050 through an offsetting program. Therefore, engineering firms were keen to showcase a range of eco-friendly inventions such as hybrid engines, urban mobility vehicles, and autonomous flight systems at the annual event, the largest for the aerospace industry. It's not just environmental considerations driving the research: UBS estimates sales of hybrid engines will be worth $178 billion by 2040, while the electric vertical take-off and landing (eVTOL) market will be a $285 billion business by 2030."

  While the practical application of these hybrid and alternative engines is years in the future, it is worth noting that the first commercial flight of an electrically powered aircraft took place in December 2019 in Vancouver, British Columbia. A 10-minute flight by Harbour Air demonstrated the successful conversion of a de Havilland DCH-2 Beaver to an all-electric aircraft. Harbour Air plans to have full commercial service for its fleet of 14 "eBeavers" by 2022 – each plane is a six-passenger prop-driven seaplane.

  Orville Wright's first flight was airborne for 12 seconds, and the only flight of Howard Hughes' H-4 Hercules (the "Spruce Goose") lasted 26 seconds, so the modest first flight of the "eBeaver" may yet prove the viability of electro-motive aircraft technology (but not likely in the near term).

- **Flying Cars and Taxis**

  The flying car has been a dream of auto and aviation designers for over 100 years – since Glen Curtiss's "Autoplane" (1917) and Henry Ford's "Flivver" (1925). Various stops and starts have occurred, especially after World War II, but nothing beyond a few concept vehicles. More recently, there have been numerous new start-ups and concepts, many associated with the proposal for a flying taxi service.

  Uber and Hyundai are partnering on a working prototype for a flying taxi service (Uber Air), which is slated to start testing in 2020 and roll out commercial service by 2023 in Los Angeles (California), Dallas (Texas), and Melbourne (Australia). These services plan to cruise at between 1,000 and 2,000 feet and would partner with select real estate developers to provide the various landing/take-off "stations."

  It remains to be seen if the flying car and taxi market is viable and affordable. Should the flying taxi service become a viable travel mode, it appears to be mostly for short-haul service – replacing many conventional surface modes. It may not be a realistic mode at this point to compete with long-haul commercial air service.

  Realistic private flying cars for "the masses" is likely decades away at this point. The technology being pursued seems to favor all-electric vehicles as opposed to internal combustion engines, but the start-of-the-art for engines and battery capacity are still limiting factors.

  However, it should be noted that a small division of the U.S. Department of Transportation's Federal Highway Administration is in the early stages of developing performance standards and regulatory language for flying cars and taxis. There may be a time in the future when flying vehicles are a viable and affordable travel mode, but it does not appear to be anytime soon.

- **<u>Autonomous Vehicles</u>**

  Almost all major automobile manufacturers – and many small start-ups – are working on their versions of a self-driving car. Autonomous technology has been building for almost two decades, with the initial introduction of safety systems that controlled self-braking and lane departure warning. While simple, those early systems are paving the way for fully autonomous vehicles.

  In response to this growing field, the Society for Automotive Engineers (SAE) in 2014 developed six levels of autonomy – from 0 to 5:

  - Level 0: No automation (driver is in 100% control of the vehicle)
  - Level 1: Driver Assistance (with hands on the wheel)
  - Level 2: Partial Automation (hands off the wheel, but eyes on the road)
  - Level 3: Conditional Automation (hands off the wheel, but eyes on the road most of the time
  - Level 4: High Automation (car does most of the controlling, but the driver can intervene)
  - Level 5: Full Automation (car is in complete control, no steering wheel, no human needed).

  Even the most advanced new cars do not exceed Level 3 automation. Reaching Level 4 and 5 will require additional reliable high-speed wireless technologies and accepted industry-wide standards (such as vehicle-to-everything communications – V2X – that allows vehicles to communicate with other similarly equipped devices, including other vehicles). Achieving Level 5 automation will also require institutional acceptance at the insurance and regulatory levels nationwide.

  Despite media optimism, Level 5 autonomy is probably farther away than expected. There will surely be early models and early adopters, but significant market penetration may not occur until well into the 2030 decade. This is important because if self-driving vehicles are to be a viable alternative to some air routes, there are considerable hurdles that remain to be cleared. The autonomous car will not address concerns surrounding Seattle-Tacoma International Airport in the near-term.

  In the meantime, manufacturers are pressing forward with advancing and perfecting alternative engine technologies that no longer rely on conventional fuel sources. The trend seems to be toward a new generation of fully electric vehicles with the speed and range of conventional internal combustion engines. That will be a significant step toward improving local air quality, as well as a necessary first step toward developing a practical Level 5 autonomous vehicle.

- **<u>5G Cellular Technology</u>**

  In 2019 and 2020, the next generation of cellular service – 5G – began its rollout in selected markets. It will take some time for the service to be available nationally and for a number of 5G-compatible devices to reach market saturation. 5G promises near fiber optic cable speeds delivered wirelessly, which could usher in a whole new generation of devices for everything from simple communications to telemedicine to widespread adoption of IoT (the Internet of Things) devices to new standards for the workplace.

  5G is also integral to the deployment and operation of autonomous vehicles, which will require a high-speed and secure platform for navigation, communication, and sensing systems.

  If previous upgrades are an indicator, the adoption of 5G should be rapid and comprehensive. While it is necessary for autonomous vehicles, it is not without some concerns. The 5G spectrum is very close to passive remote sensing systems integral to weather satellites and other Earth observation systems. This has direct concerns to the national aviation safety system, including satellite operations that help predict severe weather. Other concerns include health issues from 5G radiation, and security issues associated with IoT devices (the latter which are also part of future "Smart Home" systems).

Similar concerns were raised with previous then-new wireless technologies (such as high-definition television signals). It would be reasonable to presume that these issues may be addressed as the 5G technology improves. However, how much 5G alters business and leisure travel patterns is yet to be determined. Therefore, it is not known what effects, if any, 5G may have on growth and demand at Seattle-Tacoma International Airport.

- **Hyperloop**

  The Hyperloop is an enclosed tunnel or tub that contains a high-speed magnetic levitation (maglev) train promising speeds at or above the speed of sound (hyper-speed). There is also a variation of the Hyperloop wherein individual cars are whisked along a subterranean track.

  The idea was proposed by Elon Musk in 2012 as an alternative to conventional high-speed rail, since the enclosed tube solves the challenges of air resistance at high speeds. But the basis for the Hyperloop concept can be traced as far back as 1799 when the "vactrain" (a train inside a pneumatic tube) was proposed in London.

  In 2020, no viable existing Hyperloop (or tunnel) routes exist, but numerous companies are developing test tracks in various locations. Supporters promote the system's ability to compete with aviation routes, but as of 2020, none of the Hyperloop proposals have demonstrated this ability.

  The Hyperloop is not without its critics. Some note that high-speed rail currently reaches viable speeds that do not require a sealed tube (including Japan's SCMaglev), which raises construction costs. Others cite the physical and psychological effects of riding in a narrow windowless capsule inside a sealed steel tube, subjected to high acceleration forces, buffeting, and high noise levels. Further testing is required to prove if there is market acceptance by the public.

  Another hurdle is the location of many of the proposed Hyperloop stations – usually on the fringes of a metropolitan area. Airports and most conventional trains bring passengers close to their destinations in most cases. But a mode-shift would be required for use the Hyperloop, transferring from the arrival point to local transport modes, which could significantly increase cost and travel time. Other criticisms included visual, financial, and political. This study will not address those further except to say these criticisms need to be addressed for the Hyperloop to be a competitive and successful alternative to driving or flying.

  The Hyperloop is many years away from viability and is not considered to be an alternative travel mode that would reduce demand at Seattle-Tacoma International Airport in the near-term. At some point in the future, a Hyperloop route might be considered when – and if – a new airport is considered for future development (possibly providing high-speed direct access to a new airport).

  At present, the 2020 study does not consider the Hyperloop to be a workable alternative for the study area cities or the region.

K. SUMMARY

Noise is a common complaint by residents in and around airports. Airports nationwide (and internationally) deal with noise complaints daily. Complaints generally are associated with aircraft overflights (especially departures, which are typically much louder than arrivals), ground activity (such as reverse thrust), and late-night maintenance run-ups. So, it was no surprise that noise was noted as one of the main concerns in the study area.

Noise is more than an annoyance. Exposure can contribute to a host of issues, including sleep deprivation/interruption, learning disruptions, property devaluation, and other issues. And while improvements in aviation technology may reduce noise in the future, many residents believe present-day answers are required, as well as addressing concerns that have gone unanswered for many years.

The 2020 study should not be interpreted as being “anti-airport.” There are areas where the Port of Seattle can work with the study area cities to find common ground and realistic answers to concerns of residents and businesses. The 2020 study has noted areas of concern and has offered various recommendations to address noise-related concerns. An improved monitoring program will help the Port of Seattle better understand and quantify these concerns. And using alternative metrics to augment the standard DNL contour approach will help paint a more comprehensive picture of how aviation-related noise influences area communities.

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