Local in Space and Time: Acoustic Environmental Policy in Minnesota and a Fine-Scale Spatiotemporal Representation of Aircraft Noise Impact on Residential Life

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Dudley B. Bonsal

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Dedication

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Abstract

Communities near the Minneapolis-St. Paul International Airport (MSP) have been affected by significant levels of aircraft noise. The ways that residents are sensitive to the noise have been reflected in the conflicts over how best to regulate it, including how to adopt mapping techniques that accurately reflect the degree of their exposure and how to provide the appropriate amount of mitigation.

In this dissertation, a mixed-method approach is adopted to examine how the acoustic environment, and aircraft noise in particular, are configured spatiotemporally in an urban, residential context. First, the legal designation of quietude as an acoustic natural resource in Minnesota is examined in regard to its implications for how aircraft noise exposure is regulated in the vicinity of MSP and how sound research can be reconceived on a broader scale. Next, a geospatial analysis of MSP aircraft departure patterns is adopted so that temporal variations are represented to better reflect the day-to-day noise exposure of local residents. Finally, a methodology is created for representing the cumulative impact of aircraft noise, based on changing departure patterns over time and the use of demographic data for the overall population, as well as sub-populations whose exposure varies based on the time spent at home.

The project is guided throughout by three overarching concerns: the impact of environmental policy on the acoustic landscape, the urban acoustic environment from a residential perspective, and geographic representations of aircraft noise exposure at finer spatial and temporal scales.

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Chapter 1. Objectives of Research

1. Sound and noise in geography

Environmental sound poses a challenge for the geographer who wants to study it, since it proves elusive to representation in space and time. The elusiveness is inherent in its physical composition. Spatially, sound consists of periodic waves, specifically the compression and rarefaction of air molecules. The waves are affected by their environmental surroundings, including variations in air temperature and pressure, and the existence of buildings and topography, all of which affect the loudness and frequency heard by individuals. Temporally, the sound environment is in constant flux. Sounds begin and end, swell and fade, and affect one another by way of synchrony or masking, to name two of a multitude of interactions. When a sound abates, air composition resumes its previous equilibrium-oriented dispersion until new sounds disrupt that equilibrium. The spatial and temporal variations pose a tremendous challenge to any geographer who wants to model the acoustic environment in a manner that attends to atmospheric changes, to the built environment, to human and non-human animal activity, and to the other countless ways in which sound is produced.

Since the sources and settings of sound can vary so greatly, one way to narrow the focus of inquiry is to concentrate on the acoustic environments that have the most bearing on well-being and day-to-day life. While there is no lasting, cumulative effect of sound on air composition itself, sound events can have psychological impact on those who hear them. Sound is a medium by which humans and other animals gather information about their surrounding environment, and by which they contribute their own acoustic information as a means of communication. Often such information is critical to well-being, where for most animals in the wild, it indicates the proximity of predators and prey, or the search for and detection of possible mates. Sounds can also provide pleasure, or they can be a source of annoyance as noise. At an individual level, responses to sound in general or noise in particular can be the impetus for choices about where to live and what activities to undertake.

Given the varying degrees of sensitivity to sound and the multitude of contexts in which it is registered and understood, perceptions of it greatly vary. Often, the spatial and temporal contexts in which sound occurs are critical to any agreed understanding. At a community level, sounds can be promoted by way of organized concerts or the creation of parks that highlight the sounds of nature, and they can be discouraged if they are regarded as noise – that is, if those with the means to create policies agree about what sounds are or are not pleasurable, and what is or is not noise.

2. Research themes

In this dissertation, I address the implications of quietude being legally designated as an acoustic natural resource in the state of Minnesota; an analysis of aircraft noise patterns in the vicinity of the Minneapolis-St. Paul International Airport, so that temporal variations are represented to better reflect the day-to-day experience of local residents; and a methodology for representing the cumulative impact of noise, based on changing flight patterns over time and the use of demographic data for the overall population as well as sub-populations whose exposure varies based on the time spent at home.

Three themes in this dissertation are consistent throughout: the impact of policy on the acoustic landscape; a particularly residential perspective of the sound environment; and the impact of aircraft noise at the community level. All of these themes are addressed with primary emphasis on the spatial and temporal dimensions of the acoustic environment, so that a more accurate portrait is presented of how the acoustic environment in general – and patterns of aircraft noise specifically – are perceived in an urban setting.

3. Sound and noise in policy

Government policies and standards allow for a limited form of agreement about how to characterize the sound environment and how to regulate noise. Conflicts persist over how to characterize noise in a measurable way, how to apply regulations to the appropriate spatial and temporal contexts, and how to determine the most appropriate scale of spatial and temporal representation. While sound has many physical components, such as loudness, resonance, timbre, and frequency, most regulation is limited to restrictions on its loudness when determining whether it constitutes noise. The context in which noise occurs also matters, such as when more activity restrictions and penalties are imposed on sound activity at night or in close proximity to noise sensitive areas like hospitals, schools, and libraries. The scale at which spatial and temporal patterns are measured is also contentious, especially in the regulation of ongoing aircraft departures and arrivals, and depending on whether the yearly averaging of it masks smaller-scale patterns that cause annoyance.

4. Sound and residential life

The residential experience of sound and noise also varies in space and time. The variation depends both on individual differences in perception and cognition, the activities that people engage in every day, and the built environment of the residence. In regard to perception and cognition, the annoyance felt when one is exposed to noise will result not just from loudness but also from the frequency with which noise events occur, and if they occur so as to make someone believe they are the result of someone else's blatant disregard. Noise can also become more annoying based on how it can disrupt activities that someone wishes to engage in, whether talking with neighbors, enjoying the sounds of nature, or listening to music. Finally, the built environment has a significant effect on residential experience, depending on the degree to which indoor and outdoor sounds can be segregated, as well as the extent to which the residence possesses incentives for spending more time inside or outside.

5. Aircraft noise as nexus

Aircraft noise is the topic around which most conceptual and methodological discussions revolve in this work, and the Twin Cities region serves as the ideal study area for considering the policy of quietude and the conflicts over aircraft noise. In both cases, questions are raised about how noise should be measured, the extent to which quietude should be available spatially, and the disparity between the scale of policy-dictated noise measurement and noise perception. The second chapter focuses on quietude, and the third and fourth chapters address spatiotemporal patterns of aircraft noise and their impact on surrounding communities.

6. The chapters

In Chapter 2, I examine how environmental policy contributes to the configuration of the acoustic environment. I focus on quietude, which has been designated under the Minnesota Environmental Rights Act as a natural resource. My analysis aims to compare a resource approach to a pollution approach for the purposes of acoustic environmental policy and management. I draw from existing research in soundscape ecology and urban soundscape studies. My geographical aim is to contextualize the policy regarding quietude in terms of how it has played out spatiotemporally and how judicial decisions have led to restrictions on its spatial distribution.

In the third and fourth chapters, I focus on aircraft noise in the Twin Cities, and I analyze departure patterns for flights out of MSP in 2010 and 2011. The focus on these two years reflects qualitative research into what plays out as a policy mismatch, given the disparities between how the airport measures the noise using the day-night average noise level (DNL) and how residents in south Minneapolis characterize the noise when talking about how it annoys them. Residential descriptions of their exposure to noise often pertain to the relationship between flight patterns over time and daily residential activity.

Chapter 3 focuses on the spatiotemporal patterns of departures, and how patterns for particular times of day compare year to year. The analysis shows how certain neighborhoods in south Minneapolis were more greatly impacted by aircraft noise in 2011 than the DNL metric would indicate. The departure data for each year is separated out into hourly representations, over the extent of two hours, using a fuzzy logic approach. This approach allows for a perceptual representation that accounts for remembrance of events in the near past and ones anticipated in the near future, and it also accounts for the frequency of flights near the turn of the hour. In addition to frequency, the analysis accounts for spatial concentration of departure paths based on raster weighting and loudness of noise based on aircraft altitude.

In Chapter 4, I present a methodology for determining the cumulative impact of aircraft noise on residents at a community scale. It utilizes the noise exposure mapping described in Chapter 3 and also draws from American Community Survey data provided by the United Census. By determining where people live within the block groups and creating a raster representation of density, it provides a composite rendering of the cumulative impact of aircraft departures on residents. The time-weighted maps, being specific to different hours of the day, allow for understanding how temporal patterns of noise match with temporal patterns of residential presence at home, as gleaned from the sub-populations whose profiles are suggestive of time spent at home and time spent outdoors. The spatiotemporal context of noise exposure is thereby enhanced with a finer-scale rendering of both flight patterns and their impact on residents.

Chapter 2. Quietude as a Natural Resource: Noise Management in an Urban Land Use Context

Summary. Sound in general and noise in particular are attracting greater attention in the realms of law, policy, and research. One alternative approach to addressing noise impacts is to consider the acoustic environment within a resource rather than a pollution framework. This chapter explores the ramifications of designating quietude as a natural resource and offers a broader conceptual basis for understanding noise and sound in general. It uses judicial rulings concerning quietude to examine the concept in greater detail, with an emphasis on land use and the manner in which quietude can be obtained depending on its urban or rural context. This chapter then presents a case study based on court cases concerning Minnesota airport noise in order to develop concepts of how noise and sound play out in urban soundscapes, subsequently affecting our perception of them, and influencing how they are configured spatially and temporally. For urban environments especially, quietude as a resource is relegated to the indoors. I draw from literature in soundscape ecology and soundscape studies to address how quietude compares with the soundscape as a natural resource. This comparison provides a means for better understanding how the sound environment becomes differentiated between indoor and outdoor spaces, and for humans and wildlife.

1. Introduction

Noise has long been a focus of research and policy because it is central to the human experience. At its simplest, noise is usually defined as unwanted sound. A number of intellectual streams flow together and intertwine around the concept of noise, including policy and regulation; law and the judiciary; and a broad range of academic research. In keeping with the "unwanted" nature of noise, much of this work stems from policies that treat noise as a pollutant and focus on regulating it as such. More recently, there has been a growing emphasis on regulatory alternatives that place noise within a broader examination of both the negative and positive aspects of the acoustic environment.

One result of this focus on noise within the broader acoustic environment is that researchers and policymakers are treating the sonic components of the landscape as a resource akin to clean water or forests. This change of focus leads to two competing policy-related notions of noise. The first is a noise pollution approach directed toward limiting activity that contributes to noise and reducing the noise itself, while the second is an acoustic resource approach which assumes that some acoustic elements are integral to the make-up of the landscape, and can provide benefits to well-being and the local environment. In particular, the acoustic resource approach attempts to position noise within a broader concept of "sound", wherein certain desirable qualities of it can be treated like other resources – measured, regulated, modeled, used, and conserved.

The growth of the acoustic resource approach to sound, versus the treatment of noise as pollution, offers a number of important research opportunities. First, case studies can help tease apart the strengths and weaknesses of these competing ways of understanding and regulating noise in human and natural environments. Second, better ties can be established with a broader array of sound research, especially recent research on human and ecological soundscapes as aural complements to landscapes (Adams et al., 2006; Smith & Pijanowski, 2014). Of particular interest is the need and potential for bridging a number of gaps in the literature, including nature-focused soundscape ecology vs. human-focused soundscape studies, human- vs. wildlife-centric noise research, and indoor vs. outdoor noise regulations. Third, there is a need to better integrate the many streams of research about sound with broader policy and judicial frameworks.

This chapter addresses these research needs. It aims to advance the acoustic resource discussion, linking policy concerns to the psychological, ecological, and spatiotemporal aspects of sound. I focus on the concept of quietude – which was designated as a natural resource under the Minnesota Environmental Rights Act (1971) – and how it plays out in an urban environment with respect to airplane and airport noise. I examine the subsequent court rulings concerning quietude and consider whether it has been successfully designated as a natural resource or has been compromised by judicial interpretation. The way that legal authority has defined quietude has ramifications for understanding our relationship with the acoustic environment, and it impacts how we are able to manage quietude as a resource. Rather than arguing for or against the validity of quietude itself as a natural resource, I address the impact of its policy designation on how we as humans engineer their environment, how we inhabit the sound environment, and how we contribute to its spatiotemporal configuration. This examination helps us to move toward a broader conceptualization of the natural resource approach – one that is relevant to both human- and wildlife-dominated environments.

In order to conceptualize this approach in the context of quietude's designation, section 2 provides background on the noise pollution issues that have intersected with the resource approach, along with discussion of the concept of soundscape, based on research in soundscape ecology and soundscape studies, in terms of its potential as a natural resource. Having examined these other ways of conceptualizing the sound world, section 3 examines the case of airport noise in Minnesota and how quietude broadens our understanding of the acoustic environment within spatiotemporal and policy-based frameworks. Section 4 develops broader lessons from the case study, particularly in terms of how quietude, despite being conceived of as a generic environmental resource, is in practice relegated to indoor spaces and remains inadequately conceived for an outdoor, urban environment. I also examine how quietude policy has benefited humans but not wildlife, despite mounting research on the importance of noise impacts on wildlife and the ostensible focus on the natural world implicit in the natural resource designation. Section 5 concludes with some more general observations on noise and sound, and it points the way to future research directions.

2. Noise research and policy

The acoustic environment has long been of practical concern. Centuries of architecture and planning, after all, have included considerations of how to best transmit sound, as in the case of a concert hall or cathedral (Thompson, 2002), or block it, as when planning heavily trafficked roads and trails in or near parks or residential areas. Research into sound and noise has a long track record, and spans many fields, including sound mapping (Arana et al., 2009; de Kluijver & Stoter, 2003; King & Rice, 2009; Klæboe, Engelien, & Steinnes, 2006; Lacey & Harvey, 2011; Stoter, de Kluijver, & Kurakula, 2008; Tsai, Lin, & Chen, 2009; Wang & Kang, 2011), psychological response to sound

(Axelsson, Nilsson, & Berglund, 2010; Brooker, 2009, 2010; Lam, Brown, Marafa, & Chau, 2010; Maris, Stallen, Vermunt, & Steensma, H., 2007), and soundscapes (Botteldooren, De Coensel, & De Muer, 2006; Davies et al., 2013; De Coensel & Botteldooren, 2006), among many other topics, as documented in countless articles in journals such as *Journal of the Acoustic Society of America*, *Acta Acustica united with Acustica*, and *Applied Acoustics*. Biologists have focused on the effects of noise on animal communication (Halfwerk et al., 2011; Warren, Katti, Ermann, & Brazel, 2006), efforts to react to environmental signals (Barber, Crooks, & Fristrup, 2010), non-acoustic features of physiology (Kight & Swaddle, 2011), and larger-scale distribution of animals (Barber et al., 2011; Bayne, Habib, & Boutin, 2008).

Geographers have also addressed sound and noise from a number of perspectives. They have examined the broader topic of environmental sound from a humanities perspective (Atkinson, 2007; Pocock, 1989; Rodaway, 1994; Smith, 1994) that incorporates the notion of soundscapes and draws from literature and cultural studies research. Much of the noise research has pertained to its political, social, and economic aspects. This work is interested in the socioeconomic (Feitelson, Hurd, & Mudge, 1996; Harvey, Frazier, & Matulionis, 1979; Ogneva-Himmelberger & Cooperman, 2009; Sobotta, Campbell, & Owens, 2007; Wrigley, 1977) and the sociotheoretical (Bröer, 2007; Oosterlynck & Swyngedouw, 2010) implications of sound and noise, while also critically addressing its cartographic representation (Cidell, 2008).

With respect to sound and noise in the landscape, several streams of research may be brought together to better understand quietude as a resource. First, noise policy research addresses the political and legal aspects of noise. Second, there is growing interest in sound from a resource perspective, and treating the sonic landscape as an acoustic resource. Third, there is fast-growing research into acoustic resources in space and time, particularly regarding how they are treated by soundscape ecology, which has a wildlife and natural landscape focus, and soundscape studies, which is more human-centric and primarily, although not exclusively, urban-focused. When taken together, these separate streams of research and practice provide the conceptual foundation necessary to understand the paired themes of noise regulation and quietude preservation.

2.1 Noise policy

In terms of policy, and in terms of considering how best to regulate the acoustic environment for most day-to-day affairs, noise prevention and reduction have been paramount. The evolution of noise policy has occurred roughly in parallel with research into noise in general. Noise is usually defined in policy as unwanted sound or sound that is annoying, and its prevalence in urban settings in particular is overwhelmingly acknowledged (Berglund & Lindvall, 1995; Kryter, 1985). At an individual level, noise is regarded as annoying and stress-inducing. The annoyance that noise causes is due to the disruption of information access and emotional states. Access to information is limited by the combined noise factors of loudness and frequency bandwidth range, resulting in masked environmental signals and blocked communication. Glass and Singer (1972) presumed noise was sufficiently important to give it primary focus in their book *Urban Stress*. They saw it as an important contributor to the stress of urban living, to the point where it influenced their design of lab experiments to demonstrate the negative impacts of noise. They demonstrated that noise disrupts test subjects' intended behavior and impairs cognitive capacity. They found that these effects were apparent even in tests administered after the noise had ceased, especially when one's ability to control or predict the occurrence of the noise had been limited. As with sound in general, noise leaves its cognitive trace, acting as an individual-level pollutant with a lingering impact.

While concern about noise has persisted for millennia, regulation of it gained traction in the United States in the 1970s with a wave of environmental laws created at the federal and state levels. Although the Noise Control Act of 1972 was meant to provide a nationwide regulatory system for dealing with noise pollution, the regulation and attendant enforcement has been fragmented across different agencies for specific contexts. One of the most well-worked and therefore illustrative bodies of regulation about land use and sound is tied to airplane noise. The topic of land use compatibility is integral to policy applications of airport noise. Federal Aviation Regulation Part 150, Airport Noise Compatibility Planning (2015), specifies the land uses that are compatible with varying levels of outdoor noise. The most desired outcome is the prevention of incompatible land uses within range of the airport. If that is not possible, the next option is the purchasing of incompatible properties to reduce the impact. The last option is to provide mitigation to impacted property owners. In the state of Minnesota, aircraft noise regulation is based on FAA guidelines for standardizing sound measurement using A-weighted decibels (dBA). Houses are insulated so that decibel levels are reduced as sound moves from outdoors to indoors. Homeowners are provided the means to block sound passage at windows and doors, either directly with sound insulation or indirectly with central air conditioning, thereby allowing for doors and windows to remain closed in the summer months. The sound pressure level for indoors, based solely on the contribution of outdoor sounds, should not exceed 45 dBA. Given that the noise level reduction (NLR) for an unmitigated house is assumed to be 20 dBA, an outdoor sound level greater than 65 DNL must be mitigated by providing insulation that increases the NLR.[1]

2.2 Why a resource approach?

In contrast to the noise pollution approach, policy can also address the sound environment in a positive, resource-based manner. Resources are environmental features or states that have ecological and social value. In environmental policy, they are usually deemed as requiring measures for being protected and conserved. Hence, an acoustic resource would refer to environmental conditions in which auditory capacity – the ability to perceive, process, and respond to auditory information – is maintained such that well-being is preserved or enhanced. Situations in which an unimpaired acoustic resource is important include times when auditory information allows someone to register the presence and location of another resource or provides a clear understanding of the degree to which an environment is safe or harbors a threat to well-being (Pijanowski, Farina, Gage, Dumyahn, & Krause, 2011). Impairment inevitably entails a reduction of information – whether it prevents locating a resource, creates an unnecessary sense of vigilance, or blocks awareness of nearby threats (Barber et al., 2010). An environment that has ample acoustic resources entails access to information about one's surroundings, without the presence of noise to mask that access (Barber et al., 2010; Pijanowski et al.,

[1] The DNL calculation methodology temporally varies based on the distinction between acceptable day and night levels, with 10 decibels added to its calculation for flights between 10 PM and 7 AM, which means that residents should expect an even lower sound level indoors at night.

2011). Dumyahn and Pijanowski (2011) find that an acoustic resource has ecological, social, and cultural importance, and it reflects the context in which it is found.

The designation of a resource also implies to some extent physical existence. One challenge in treating sound as a resource is that this physical component is elusive, in the sense that no physical trace in any conventional sense is left once a sound has dissipated. This said, sound is a physical (albeit transient) artifact in that it is composed of differential compressions and rarefactions of air pressure. An insightful footnote regarding acid rain litigation in Minnesota expresses the unusual position of quietude among other resources in the state: “Quietude is the only natural resource not affected by acid rain.” (Johnson, 1983, p. 110). As research in psychology advances, more evidence accumulates of the physical traces left by sound, whether or not sound is regarded as noise, that are becoming more readily recognized. These traces originate in sound’s vibratory impact, and in the case of hearing, they will translate to neurological effects. These traces either fall under the category of information, when the sound signals the availability of environmental or social cues, or emotional resonance, when a sound leads to a state ranging from peacefulness to disturbance. Sound as a resource, and in this physical manifestation, thereby impacts human well-being (Gourévitch, Edeline, Occelli, & Eggermont, 2014).

With the continued legal applicability of quietude in Minnesota, and the developing awareness of soundscapes as measurable resources, soundscapes and quietude stand to be compared on the basis of how they are defined and their range of applicability. As with quietude, soundscapes by definition bridge the environmental and psychological. In a recently released standard by the International Organization for Standardization (ISO)

(2014), whereas the acoustic environment represents the composition of acoustic elements, the soundscape pertains to perception of the acoustic environment. In addressing the issue of soundscapes, I first discuss issues that pertain to wildlife settings, and then urban ones.

2.3 Soundscape ecology

Given that the recently founded discipline of soundscape ecology is well-suited to examine wildlife matters and spatiotemporal dynamics, a recent push by ecologists to legitimize an acoustic-based resource (Dumyahn & Pijanowski, 2011) – namely, the soundscape – makes a comparative analysis with quietude worth pursuing. Landscape ecologists regularly address spatial dynamics (Wiens, Stenseth, Van Horne, & Ims, 1993), and it was only a matter of time before sound became an important component of landscape ecology in general.

Soundscape ecology is a landscape ecology sub-discipline, comprised of knowledge garnered by way of acoustic ecology, bioacoustics, psychoacoustics, and spatial ecology (Pijanowski et al., 2011) for examining soundscapes, with much of it focusing on wildlife environments. Soundscape ecologists investigate the spatial factors pertaining to the relationship between sound patterns and ecological processes (Pijanowski et al., 2011), drawing from pioneering soundscape research (Krause, 1987; Schafer, 1994; Truax, 2001) while also taking advantage of the recording and sound processing technology that has allowed for measurable analysis. By incorporating research concerning individual-level processes by researchers in bioacoustics and psychoacoustics and utilizing their own measurements of community-wide sound patterns, soundscape ecologists focus on how a community of animals creates an overall soundscape. Therefore, much of the initial soundscape ecology work has focused on meso-scale concerns, given the utilization of recording to gauge the health of wildlife communities (Krause, 2012; Villanueva-Rivera, Pijanowski, Doucette, & Pekin, 2011). Soundscape ecology has so far focused primarily on wildlife areas, but it has been beating a path toward a broader conception of soundscapes that integrates human and policy-related dimensions (Smith & Pijanowski, 2014).

Soundscape ecology research has spanned the spectrum from conceptions of the physical soundscape, focusing on time, place, and bandwidth frequency (Pijanowski et al., 2011), to conceptions more focused on meaning and semiotics (Farina, Lattanzi, Malavasi, Pieretti, & Piccioli, 2011). Soundscape ecology classifies the soundscape, based on the dominant sound sources, into three types: geophony, biophony, and anthrophony, pertaining to sounds originating respectively from geologic and climatic phenomena, the non-human animal world, and human activity (Krause, 2012). The methodology for listening to and analyzing the soundscape has its origin in the use of wildlife recordings and analysis (Krause, 2012) for understanding how elements of the soundscape interact with one another. Soundscape ecologists consider the sound environment as an informational medium that wildlife can utilize to locate resources. An examination of the overall sound environment can therefore elucidate how well individuals vocally and aurally inhabit their particular acoustic niche (Farina et al., 2011), a finite and exclusive frequency "space" where other individuals and species cannot interfere (Farina et al., 2011; Krause, 1987), and where conflict would ensue between individuals or species with similar niches.

Given how soundscapes are characterized as resources, we can quickly ascertain that a soundscape represents something that is, in an ideal sense, fully formed – a state in which participants find the niche they seek, and all possible niches are inhabited. In a wildlife setting, it is the acoustic marker of biodiversity. As with biodiversity in its optimal state, soundscapes are therefore constantly vulnerable to degradation. Certain species become no longer viable and leave a gap in the ecological community. This leaves the preservation of soundscapes fraught with hazard, as it leads to repeated frustration at the damage already done and always seemingly on the verge of enduring more damage. The question of how to preserve something so fully formed is perhaps best accomplished by identifying the main participants in the soundscape, and resolving to ensure they remain viable through conservation practices. The lingering question remains, however, about the degree to which the importance of the players identified can be vouched for on the basis of acoustic information. It also raises the question of whether the participants have an exaggerated presence such that they might be masking the sounds of other species that could also be important. In short, with the idea of preserving soundscapes comes the responsibility of accounting for all the other dimensions of effort to preserve ecosystem well-being.

The notion of the soundscape as a natural resource is not a purely theoretical one. In the management policies of the National Park Service, soundscapes are a form of perception-based resource, in addition to lightscapes, chemical information, and odors. To protect soundscapes, *human-derived* sounds, lighting, and scents are regarded as needing to be regulated, given that they are most likely to interfere with the sensory needs of wildlife in the course of detecting prey, avoiding predators, and attracting or finding mates. According to its management report, "In and adjacent to parks, the Service will monitor human activities that generate noise that adversely affects park soundscapes, including noise caused by mechanical or electronic devices." (National Park Service, 2006, p. 56)

2.4 Soundscape studies

Complementing the growth in soundscape ecology has been soundscape studies, with a body of literature pertaining primarily to human perception of sound and largely concerning urban soundscapes. With greater focus on the social and policy dimensions of sound comes a greater focus on the importance of human psychology – including the importance of humans' cognitive, behavioral, and emotional needs (Smith & Pijanowski, 2014). The environmental and psychological dimensions of sound have long been linked, and represent just one subset of inquiry into the relationship between environment and behavior. One particularly important aspect of this relationship, as examined by psychologists, is the degree to which they are "well-matched" to one another (Stokols, 1978). Humans are not just trying to move through and interact with their surroundings – a common point of inquiry among behavioral geographers – but are instead trying to establish the cognitive basis for inhabiting their surroundings. Hence, the ways that humans evaluate and respond to their environment are a primary concern.

The study of soundscapes addresses how the acoustic environment is perceived (International Organization of Standards, 2014). The notion of a soundscape dates back at least to the writings of J. G. Granö. In *Reine Geographie* (1929), translated to English in 1997 as *Pure Geography*, he laid out a framework for examining landscapes that highlighted perceived features, including the auditory. The concept of soundscape was explored comprehensively in the writing of musician R. Murray Schafer, who created a typology of sounds that comprise the acoustic environment – a typology that acknowledges the good sounds as well the noise. An ideal soundscape can be characterized as having high fidelity, such that the different sounds of the soundscape can be heard and are not vulnerable to masking (Schafer, 1994).

While geographical studies of sound have often adopted more spatial analytic and cartographic approaches, soundscape studies has found common ground with the discipline's humanistic approach to human-environment relationships. The writings of Tuan, Porteous, and Rodaway have addressed sound as part of a broader discussion of the sensory realm. Tuan (1990) has identified it as one component of an individual's relationship with the environment and the seeking of one's place in the world. Porteous (1990) has drawn from environment and behavior research and examined soundscapes as one from among many forms of "–scape". Like Porteous, Rodaway (1994) has also focused on all of the senses, drawing from environmental psychology, personal narrative, and critical theory to make sense of the relationship between geography and the senses. Of these three, Porteous focuses most explicitly on the soundscape as conceived of by Schafer.

Sound research has become increasingly inter-disciplinary, comprised of projects that have pooled the expertise of researchers from multiple disciplines (Adams et al., 2006, Davies et al., 2013; Irvine et al., 2009; Liu, Kang, Luo, Behm, & Coppack, 2013). Given geography's inter-disciplinary leanings, papers with this pooled talent and from other disciplines have sometimes been published in geography-based or geographyfriendly journals (Adams et al., 2006; Atkinson, 2007; Irvine et al., 2009; Liu et al., 2013; Raimbault & Dubois 2005; Watts, Miah, & Pheasant, 2013). Acoustic journals have also published articles based on wide-ranging inter-disciplinary studies about soundscapes. The research conducted by the Positive Soundscapes Project, based at the University of Salford, utilized a diverse set of research methods, ranging from the quantitative, including fMRI scans and signal processing and listening tests, to the qualitative, including interviews and focus groups, to the artistic, including field recording and commissioned artwork (Davies et al., 2013).

Some themes are recurring in the urban soundscape research. First, soundscapes, more than noise alone, are better addressed in policy and planning, since a noise-reduction approach can lead to homogenization of the acoustic environment and eliminate desirable unique sounds (Adams et al., 2006; Jennings & Cain, 2013; Raimbault & Dubois, 2005). Second, an enrichment of soundscape resources can be made possible by way of protection and restoration of ecological resources (Irvine et al., 2009) – an assumption that the soundscape will first and foremost be an indicator of underlying ecological health rather than the primary conservation aim in and of itself. Urban soundscape research has also addressed the different types of stakeholders invested in soundscapes, roughly classified as planners, acousticians, and city-users (Raimbault & Dubois, 2005) and classified similarly but more broadly by Jennings and Cain (2013) as planners, serious listeners, and users of the space. Overall, studies of urban soundscapes can adopt a wide range of methods and formulate a diverse array of typologies to facilitate inquiry.

3. Case study: quietude and airport noise in Minnesota

Quietude is a particularly human-based resource, since it has come to depend on embedded assumptions about human behavior. The word “quietude” bridges environmental and psychological states, and is therefore often used to apply either to places or people. Quietude can just as easily be evoked as an environmental value and amenity, and it has been examined as one (Thorne & Shepherd, 2013). The degree to which it is accessible varies in space and time. Given its initial designation and subsequent judicial interpretation, urban quietude in practice ends up being preserved by way of policy on the assumption that much of its human access requires access to indoor living.

The designation of quietude in Minnesota as a natural resource provides an opportunity to consider how well it is protected, specifically in terms of its spatiotemporal distribution and its land use relevance. As first defined in the Minnesota Environmental Rights Act (MERA), passed by the Minnesota legislature in 1971, “natural resources” include “all mineral, animal, botanical, air, water, land, timber, soil, quietude, recreational and historical resources” (MERA, 2014 Minn. Stat. 116B.02, §4). Every citizen therefore “is entitled by right to the protection, preservation, and enhancement” of these resources, and “it is in the public interest to provide an adequate civil remedy to protect” the resources from “pollution, impairment, or destruction” (MERA, 2014 Minn. Stat. 116B.01).

MERA is derived from a model ordinance created by law professor Joseph Sax and first adopted in Michigan as the Michigan Environmental Policy Act (Klass, 2006).

Sax had formulated the public trust doctrine, which he cited as "a tool of general application for citizens seeking to develop a comprehensive legal approach to resource management problems" (Sax, 1970, p. 474). Sax outlined his support of the doctrine, and by extension, his reasons for creating the ordinance, in his book *Defending the Environment* (1971). First, he was motivated by a desire that environmental matters not be overwhelmingly decided through back-door administrative dealings and the whims of individual regulators. He argued that there should be a judicial means for citizens to assert environmental rights. Second, citizens should be able to act for the protection of publicly available resources, and not just when their own private property was affected. Therefore, unlike with nuisance law, MERA stated that plaintiffs would not have to prove that a specific injury occurred; rather, a *prima facie* case could be made that a defendant's actions would pollute, impair, or destroy the resource in the public sphere.

In Minnesota, the word "quietude" was not inserted into the MERA bill until midway through the lawmaking process, after an air pollution control law enacted in 1969 was amended in late 1971 (Act of June 4, 1971, ch. 727) to address noise pollution, thus bringing the issue of noise to the forefront of legislative concern (Note, 56 Minn. L. Rev., 1972). Given that MERA was created to reflect Sax's proposition that the courts are where the citizen's pursuit of environmental quality should be exercised, the subsequent judicial rulings that interpreted the law help us understand the impact of quietude as a resource to be enjoyed and offer insight into how much the environmental and the psychological can be intertwined in the management of resources. Two themes are important here: the issue of how well quietude qualifies as a resource given its land use context and given the type of conduct that threatens it.

MERA has nothing explicit to state regarding land use context. It does not designate a greater degree of protection for one land use compared to another, or one part of the state compared to another. Implicitly, however, land use is addressed in the guise of conduct, such that a potential violator could demonstrate “that there is no feasible or prudent alternative” (MERA, 2014 Minn. Stat. 116B.04) to the actions leading to impairment. A pollution control statute, in contrast, does address the land use context. It notes that “due to variable factors no single standard of sound pressure is applicable to all areas of the state” (MERA, 2014 Minn. Stat. 116.07 § 2c). Regulations that followed have adopted this context-based view by creating four land use classes, each of which are subject to different limits on sound pressure level. The land use context, as the statute makes clear, is premised on the partial impact of zoning classifications and “the fact that a standard which may be proper in an essentially residential area of the state, may not be proper as to a highly developed industrial area of the state” (MERA, 2014 Minn. Stat. 116.07 § 2c).

The airport noise case of *Alevizos v. Metropolitan Airports Commission*, brought before the court in 1970, illustrates how an appeal to nuisance-based pollution law can fail where MERA might have succeeded. (However, as we shall see, the success of applying MERA in a subsequent aircraft noise case comes at the cost of diminishing quietude’s value as a resource.) The *Alevizos* case involved an effort by residents to seek redress for the loss of housing market values. The argument made by residents was one of inverse condemnation – that the noise, in addition to air pollution and the residue of oil and grime, constituted a taking of their properties such that financial compensation was deserved (*Alevizos v. MAC*, 1974). The argument echoed the U. S. Supreme Court’s

Causby vs. United States case of 1944, in which Justice William Douglas argued that military planes flying low enough over a chicken farm constituted a taking of the property (Banner, 2008). With *Alevizos*, however, the Minnesota Supreme Court ruled that a class action suit could not be undertaken, and it upheld the trial court's opinion that the case involved "a multitude of individual issues and an absence of common issues" (*Alevizos v. MAC*, 1974, p. 654), a legal obstacle that would later be sidestepped, courtesy of MERA's *prima facie* suitability.

MERA was addressed in two Minnesota cases regarding noise from gun ranges. In *Minnesota Public Interest Research Group v. White Bear Gun Club*, MERA allowed for the Minnesota Public Interest Research Group (MNPIRG) to seek relief from noise despite the lack of pollution control standards for "impulsive sounds" (*MNPIRG v. White Bear*, 1977, p. 791). The court ruled that the plaintiffs had established that the "noise from gun club operation [sic] would substantially disturb and degrade quietude of area [sic]" (*MNPIRG v. White Bear*, 1977, p. 766). On the basis of acoustic tests conducted by an official from the Minnesota Pollution Control Agency (MPCA), the presence of a gun club made impossible the maintaining of quietude in what was characterized by one expert witness as a "very quiet neighborhood" (*MNPIRG v. White Bear*, 1977, p. 772). The ruling affirmed that MERA allowed "case-by-case determination by use of balancing test" (*MNPIRG v. White Bear*, 1977, p. 782) that weighed the reason for the defendant's conduct against the harm imposed.

Although the issue of the defendant's conduct was inherently a land use issue, the two dissenting opinions in the *White Bear* case stressed that land use context had not been given due consideration. One dissenter argued that quietude be assessed "in relation to the surroundings in which it was measured" (*MNPIRG v. White Bear*, 1977, p. 788) while a second dissenter argued that there should be a "balancing of carefully weighed interests" (*MNPIRG v. White Bear*, 1977, p. 791) such as when neighboring land uses are predicated on conflicting values. The ruling contributed to concerns about the viability of gun clubs like White Bear to the extent that subsequent Minnesota legislation made them exempt from MPCA regulation. MERA, however, proved its durability in an appeals case for the subsequent *Citizens for a Safe Grant v. Lone Oak Sportsmen's Club* decision. Regardless of the gun club exemption, the degradation of quietude as a natural resource, as "caused by 'impulsive sound'" (*Citizens v. Lone Oak*, 2001, p. 806), was similarly sufficient for ruling against the Lone Oak club.

With a 2007 airport noise ruling for *Minnesota v. Metropolitan Airports Commission*, the designation of quietude as a resource took an interesting turn in the context of urban land use and the built environment. As a practical matter, the court case hinged on a claim that the airport had reneged on a commitment. In 1996, the state legislature had advised the Metropolitan Airports Commission (MAC), the operating agency of the Minneapolis-St. Paul International Airport (MSP), to review options for extending mitigation to the 60 DNL contour, beyond what the FAA mandates for 65 DNL – in order to keep the airport at its location while also approving an expansion project.

MAC, in return for keeping the airport at the same location and building a new runway (U.S. Department of Transportation, 1998), committed to mitigation, in the form of sound insulation and central air-conditioning, for residents living in the 60-65 DNL areas. After MAC backed off from their commitment, citing a drop in air traffic after the

World Trade Center and Pentagon attacks on September 11, 2001, the cities of Minneapolis, Richfield, and Eagan sued the MAC and Northwest Airlines so that these residents could receive mitigation (Complaint, *Minnesota v. MAC*, Apr. 20, 2005).

In addition to requiring that MAC and Northwest honor its commitments, the cities cited MERA, arguing that noise from the airport "destroyed the quietude of otherwise quiet neighborhoods" (Plaintiff's Memorandum, *Minnesota v. MAC*, June 27, 2005, at 1). The complaint emphasized the importance of quietude as a resource in its own right, stating that the "low ambient noise levels constitute a unique and important resource in an urbanized area like the Twin Cities" (Complaint, *Minnesota v. MAC*, Apr. 20, 2005, ¶ 12). The complaint also emphasized the contribution of quietude to well-being: "Quietude in neighborhoods in the Cities and on properties owned by MPHA [Minneapolis Public Housing Authority] is important for residents' health, welfare, quality of life and property values" (Complaint, *Minnesota v. MAC*, Apr. 20, 2005, ¶ 13).

MAC and Northwest argued that the plaintiffs had applied MERA in a manner that had proven unsuccessful in *Alevizos*, specifically that the complaint brought forth by the cities "would convert the statute from an environmental protection law to an economic regulation" (Memorandum, *Minnesota v. MAC*, May 19, 2005, at 12 (quoting *Stansell v. Northfield*, 618 N.W.2d 814, 820 (2000))) and that "their true cause of action arises from alleged impaired use of property, diminution in value, and damages" (Memorandum, *Minnesota v. MAC*, May 19, 2005, at 11) based on MAC's backing away from the mitigation. They also argued on the basis of context, specifically in terms of land use and the socioeconomic value of the defendants' activities. MERA, MAC claimed, was being applied to "areas where its use was not clearly intended"

(Memorandum, *Minnesota v. MAC,* May 19, 2005, at 12 (quoting *Skeie v. Minnkota Power Cooperative*, 281 N.W.2d 372, 374 (1979))). Specifically, "MERA is not intended to allow city residents to secure a level of quietude equivalent to that experienced in less developed areas" (Memorandum, *Minnesota v. MAC*, May 19, 2005, at 11). MAC also emphasized the socioeconomic role the airport played for the region and included a quote directly from the Minnesota Supreme Court's *Alevizos* decision, that "[e]very landowner must continue to endure that level of inconvenience, discomfort, and loss of peace and quiet which can be reasonably anticipated by any average member of a vibrant and progressive society" (Memorandum, *Minnesota v. MAC*, May 19, 2005, at 12 (quoting *Alevizos v. MAC*, 216 N.W.2d 651, 662 (1974))).

Interestingly, the plaintiffs' argument for preserving quietude, while practical for the sake of negotiating with an airport that was not going anywhere, had significant ramifications for the spatial reach of quietude as a resource – that as far as being a natural resource in an urban area, space for it would have to be allocated in order to be accessed, and that indoors was sufficient for quietude to be protected. "At least one feasible and prudent alternative is apparent: the MAC can implement a complete mitigation program in the 60-65 DNL to preserve the quietude protected by MERA as to interior spaces, without in any way effecting air operations" (Complaint, *Minnesota v. MAC*, Apr. 20, 2005, ¶ 86).

As noted in the order for partial summary judgment, the defendants argued that that MERA did not pertain to *indoor* environments (*Minnesota v. MAC*, Order, 2007, at 3). Northwest stated that "the alleged failure to insulate houses in the 60-64 dB DNL contour does not cause pollution, impairment or destruction of a protected natural resource as required by the statute" (Answer, *Minnesota v. MAC*, May 20, 2005, at 11). With such reasoning, Northwest thereby framed the issue of preserving quietude as necessarily addressing the source of the noise and its persistence at a larger spatial scale than represented at house level. Consequently, in ISO parlance, Northwest was arguing on hypothetical behalf of the acoustic environment while devaluing its perceptual component, i.e. the soundscape. An argument that quietude was being impaired, Northwest claimed, required legally addressing the *conduct* that led to impairment, not compensation that only allowed for the plaintiffs to protect their own property. By protecting only their own property, the plaintiffs were effectually seeking a financial compensation that did nothing to protect quietude as a publicly available resource.

The judge in the case ordered that indoor quietude was indeed a resource under MERA (*Minnesota v. MAC*, Order, 2007, at 18). With the ruling, a distinction was implied between how accessible quietude should be in an urban setting versus a rural one, given that the "proper measure for outdoor quietude in this case is the average quietude in an urban area" (*Minnesota v. MAC*, Order, Jan. 25, 2007, ¶ 2). The urban setting led to a need for indoor relief from the noise, and the mitigation would provide the quietude that could serve as "a haven from airport noise for residents" (*Minnesota v. MAC*, Order, 2007, ¶ 3).

4. Discussion

Both soundscape ecology and soundscape studies are able to cover a wide range of issues pertaining to wildlife, urban landscapes, and human psychology, with each having their own contribution to a wider discussion of the acoustic environment. With the designation of quietude as a resource, consideration of how successfully it has taken on that role, supported by the insights of soundscape research, bears examination. The particular strengths of soundscape ecology, soundscape studies, and quietude, as summarized in Table 2.1, all contribute to a richer understanding of how soundscapes can be more effectively addressed in policy.

Soundscape ecology	***Soundscape studies***	***Quietude***
• Methodologies for measuring extent of space, time, and bandwidth, particularly well-suited for wildlife environments • Applicable to acoustic environments with shared spaces by way of acoustic niches • Typology of different soundscape types, spanning urban and rural environments	• Well-suited for planning applications and human perception • Extends beyond noise concerns to address the positive role of sounds • Tied to concerns about humans' sense of place, including meaning and attachment	• Has legal basis in court cases regarding residential areas in both rural and urban settings • Ties in with noise pollution measures to address soundscape protection in a high-noise setting • As a publicly available resource, has potential, although not yet realized, as a wildlife protection instrument

Table 2.1: Contributions of soundscape ecology, soundscape studies, and quietude

The contributions of treating quietude as a resource, however, are guided in part by the way in which judicial decisions have made its applicability yet to be fully realized. The airport case leads to two seeming paradoxes about the spatial and temporal dimensions of quietude. First, despite being treated as an environmental resource, quietude can end up being relegated to indoor spaces. It remains to be seen whether the airport noise court decision hampers our ability to recover outdoor quietude in an urban environment, and if recoverable, determine which urban settings have a place for it. Second, despite being considered a natural resource, quietude ends up being primarily designated for the benefit of humans and not wildlife. The contributions of soundscape ecology and soundscape studies offer ways to think about these paradoxes. The airport case, with its legal interpretation of quietude, helps to underscore which tools and insights of this research are most relevant, and leads toward a better understanding of the spatiotemporal dimensions of soundscapes.

4.1 Indoors and outdoors

The MAC/NWA ruling led to a residential landscape defined by sharp contrasts in how sound is measured and understood, namely by way of an indoor/outdoor divide. The commonly adopted mitigation practices such as insulation and air conditioning and the court ruling emphasize a key role for the built environment by making the indoors an urban refuge for attaining quietude. The resulting soundscape is therefore highly segregated between indoors and outdoors. From a property rights perspective, the protection of indoor quietude seems to be a decision tailored to be a rough compromise – a decision that gives everyone some access to quietude without making that access ubiquitous in space. The airport case requires residents, when looking to protect the acoustic environment as a public good, to make allowances at a neighborhood and household level. The interpretation of quietude in the MAC/NWA case transforms Sax's vision of citizens arguing for the public interest into one that offers limited protection – one that reserves the ambient resource for the indoors.

When quietude requires indoor refuge, the exaggerated segregation of the indoors from outdoor environments can have undesirable physical effects by disrupting air and sound circulation. Some mitigated houses have been found to be so well-insulated that further measures must be taken to minimize the potential for indoor air quality hazards when housing exteriors get tightened (Metropolitan Airports Commission, 2010). With the insulation barrier set up between inside and outside, sound from the outside world, and the information embedded in that sound, becomes hard to access. Of course, residents create their own indoor soundscapes and therefore their own meaning. Sometimes indoor soundscapes are created by way of music and media entertainment with minimal disruption by planes, cars, trains, or neighbors. Central air conditioning is often part of the mitigation package, and the history of air-conditioning use itself shows how the technology not only allowed for the closing of windows and doors for a cooled temperature, but also, in the early days of its use, helped the cinemagoer to foster the illusion of being in another world of sight and sound (Cooper, 1998). Despite these potentially off-setting features of creating an indoor space, the net result of having mitigation depend on an indoors-outdoors divide is a very limited access to quietude for residents.

In addition to the physical effects of the segregation of indoors from outdoors, any given residential sense of place also becomes limited due to a lack of exposure to the outdoors. The airport noise and the resulting indoor/outdoor segregation restrict a resident’s acoustic horizon, diminishing the ability to enjoy the natural world. More specifically, any preferences that spring from biophilia (Kahn, 1999; Wilson, 1984) also become acoustically limited, as the sounds of nature can be less frequently enjoyed. Kaplan’s attention restoration theory (ART) addresses the beneficial psychological effects of interacting with nature, such that natural environments not only promote the ability to enable attention by making information available, but by also restoring attention. A failure to restore attention leads to stress (Kaplan, 1995, 2001). Mental fatigue is common in neighborhoods with fewer accessible natural landscapes (Herzog, Hayes, Applin, & Weatherly, 2011; Kuo, 2001), even when accounting for other characteristics like poverty (Kuo, 2001).

Since this ruling led to more houses receiving sound insulation and central air conditioning, it begs the question of how an environmental resource came, in practice, to be available for indoor but not outdoor use. Has quietude been successfully designated as a natural resource, or has it been compromised by judicial ruling? The airport court decision demonstrates that we make allowances for the quality of quietude the more urban the setting, and we focus more on the indoor quality of that resource. While on first glance, this outcome might seem to make quietude an anomalous case, an equivalent situation with other resources becomes evident. Rivers, lakes, and the outdoor air can be expected to be less pristine in an urban setting, so we often settle for the resource being best preserved indoors. What makes these resources directly tied to human well-being in urban settings is that they require infrastructure in order to be enjoyed. Filtrated water is piped into houses by way of pipes, air is cooled and dehumidified by way of air conditioning, and the National Weather Service warns citizens to stay inside on days of bad air quality. With quietude entered into the mix, resources continue to have a tenuous place in the urban outdoors. This observation is not meant to discourage attempts to realize the outdoor restoration of quietude or other resources. In urban areas, citizens and government officials often strive to protect air and water resources outdoors, in order to improve public health and to increase the enjoyment of parks and other public venues. As for quietude, if it can be gradually be better protected outdoors, resource-worthy soundscapes have a better opportunity to establish a firm foundation for long-term sustainability.

4.2 Humans and wildlife

Given soundscape ecology's early emphasis on wildlife environments, with the accompanying notion that soundscapes can be seen as benchmarks for the success of environmental biodiversity (Krause, 2012), the call for a resource approach to soundscape management by Dumyahn and Pijanowski (2011) is striking for its extension to other environments. Their typology includes not only soundscapes associated with wildlife (natural quiet, sensitive), but also ones that have value for both wildlife and humans (threatened, unique, recreational, representative) and ones that are distinctly human-oriented (cultural, everyday). A soundscape resource paradigm that is beneficial to both wildlife and humans is worth pursuing. The evolution of quietude's resource designation bears examination in terms of how well it contributes to a paradigm suitable for both humans and wildlife.

Dumyahn and Pijanowski (2011) propose that soundscape protection be contingent on aspiring to the following values: human well-being, wildlife well-being, sense of place, landscape interactions, and ecological integrity. The preservation of indoor quietude in an aircraft-dominant acoustic environment really only meets the requirements for human well-being at best. This is evident on the basis of the judicial ruling that preservation of indoor quietude is manifested when abiding with an accepted relationship between human exposure to noise and annoyance. Other values, such as sense of place and landscape interactions, are of greater or lesser importance to every resident, and ecological integrity is maintained only to the extent that urban ecology operates by a set of values different from those of rural ecology. Wildlife well-being, meanwhile, does not get addressed in *Minneapolis v. MAC* or in the previous gun club cases. The implicit planning decision embedded in the airport decision only pertains to wildlife that can adapt to such a compromised outdoor environment.

Although the issue of quietude in the case did not end up pertaining to wildlife, MAC did attend to wildlife concerns given the airport's proximity to the Minnesota Valley National Wildlife Refuge (MVNWR). Due to the expected effects of airport expansion – including the creation of the new north-south (4/22) runway – MAC, the FAA, and the US Fish and Wildlife Service signed a Memorandum of Understanding for a mitigation package, including a settlement of $26,090,000, the planned acquisition of 4000 additional acres to the refuge, a visitor and recreation center, and the building of several facilities designated for visitors, education, and wildlife interpretation (U.S. Fish & Wildlife Service, 2004).

The settlement provision was discussed in an oversight hearing of the House Committee on Resources (*The Impact of the Expansion*, 1999). The committee chair, Rep. Don Young of Alaska, brought up an issue concerning the Izembek National Wildlife Refuge in his own state. Namely, allowances made for human activities in Minnesota Valley had been rejected for a proposed road-building project in Izembek. He argued that the Minnesota Valley mitigation package did not directly address the concerns of wildlife which, he stated, "deserve every bit as much protection as do the species that live in other national refuges" (*The Impact of the Expansion*, 1999, p. 2).

Young regarded the lack of evidence for wildlife protection via the mitigation package as an instance of the federal government favoring urban interests relative to rural ones.

In August 2000, MAC, along with five “supporting organizations” – including Friends of the Minnesota Valley, the Minnesota River Basin Joint Powers Board, the Minnesota Department of Natural Resources, the Minnesota Waterfowl Association, and the National Audubon Society – created the Minnesota Valley Trust (Minnesota Valley Trust, 2016). The Comprehensive Conservation Plan for the refuge states that the trust was designated to act as the mitigation agent and “administer the $26,090,000” (U.S. Fish and Wildlife Service, 2004, p. 234). In addition to the human-oriented amenities addressed in the MOU, wildlife protection is directly addressed such that 25% of the money should be dedicated to the acquisition of up to 2000 acres of Wildlife Protection Areas (WPA). To qualify, the WPA land “must have a direct linkage to the Minnesota River and serve to enhance and benefit wildlife species that inhabit the river” (U.S. Fish and Wildlife Service, 2004, p. 234).

Notably, the wildlife-based remedy is not one that actually reduces noise at the source or exposure to the noise in a given location. The solution is instead directed toward increasing access to habitat in areas more distant from the overflights, while maintaining or even enhancing the contiguity of the refuge. Given the importance of biodiversity to ecosystem function (Chapin, 1997; Tilman, Isbell, & Cowles, 2014), the known effects of noise on animals (Barber et al., 2010; Kight & Swaddle, 2011), and the methods employed by soundscape ecologists to capture the effects of increasing anthropogenic noise on biodiversity (Krause, 2012; Pijanowski et al., 2011), one can therefore ask whether designating quietude as a resource is sufficient for providing soundscape protection for wildlife-dominated areas as much as for urban neighborhoods.

Key to this discussion are the significant differences between domesticated and wildlife behavior and the degree to which humans manipulate their sound environment. One way of exploring the differences is to consider a key concept in soundscape ecology as it has been applied to wildlife perception and livelihood: the acoustic niche (Krause, 1987; Pijanowski et al., 2011). Wildlife must adapt to shared living space with other individuals and species. In order to access acoustic information and satisfy communication needs, they must inhabit their own acoustic niche, which is characterized by restricted ranges of space, time, and bandwidth frequency (Krause, 1987, 2012). While this environment is always subject to changes in population structure, it leads to a state where individual utilization of sound is “coordinated” to avoid masking, so that mating and warning calls can be heard. In such a manner, individuals inhabit their acoustic niche.

In contrast to soundscape ecology’s rendering, the acoustic niche in an urban quietude framework implies availability – availability of space, time, and bandwidth for enjoying whatever acoustic environment is preferred. Consider how the niche concept can be applied to human environments. Humans have extra demands for what they would regard as their own acoustic niches. They seek an array of time and bandwidth characteristics to suit their needs, and these characteristics will usually encompass a greater range of both, given the diversity of activities an individual desires to undertake. With most indoor activities – be they reading, conversing, watching a video, or concentrating on a creative project – individuals will likely require a wide bandwidth of low-amplitude environmental sound in order to readily switch from one activity to another. Although space is restricted, time and bandwidth can be expected to be more widely available, given the multiple activities that humans undertake. Quietude as a resource offers more latitude than soundscapes in terms of private life. It provides the context for human choice about desirable urban soundscapes, establishing the ambient foundation upon which a soundscape is created, or, metaphorically speaking, acting as an information basin.

The acoustic niche concept is also pertinent to land use, since the niche functionality can be regarded as one of the land use features. When the niche is not realized, the land use is considered less suitable in light of what the intended activities were to be, even as acoustic suitability is weighed against other locational factors. Because of the airport noise case, the designation of quietude for residential environments has broad implications for the spatiotemporal configurations of a human-based acoustic niche. Since urban quietude is primarily restricted to the indoors, the built structure becomes important to our understanding of human endeavor in the pursuit of a niche. Spatially, the niche is sharply delineated. Temporally, the sharpness of the niche's delineation corresponds to the amount of outdoor noise as activities change throughout the day.

When we consider how our sound environment supports or hinders our intentions, or how it fosters or disrupts our equanimity, we can better comprehend a niche that allows us to follow through with our intentions and that can be clearly identified in terms of space, time, and bandwidth. Granted, individuals vary significantly in terms of preferred niche, given the diverse activities they wish to engage in, and the personal thresholds for the types of sound that constitute noise and disrupt desired activities. Still, we have some means for proceeding with a determination of how well our soundscapes align with our individual needs.

The adoption of quietude as a resource in Minnesota illustrates the difficulties inherent to making it available across a broad spatial extent, since the judicial cases pertaining to quietude have been primarily for the benefit of residential environments. The airport case decision demonstrates that a state of quietude must be available to all, however limited the space is for each person to obtain it, and it has provided residents with access to spaces of relative quiet in the midst of one of the more taxing acoustic environments found in an urban setting. Nevertheless, it also forces us to reconsider which wildlife settings are worthy of quietude protection, and it calls into question how auditory experience can be re-conceptualized so that we can more readily integrate the behavior-related concerns of both people and wildlife.

5. Conclusion

Noise, and sound more broadly, is ubiquitous. Long a topic of study, it has attracted the attention of policy makers and regulatory bodies; of the law and judiciary; and a wide array of academic researchers. Recent debates focus on whether to continue pursuing a noise pollution approach or to adopt regulatory alternatives that see noise within a broader acoustic environment. The growth of the latter approach lends itself to further examination via case studies such as the one offered here. This work also develops better ties with recent advances in sound research, particularly concerning both ecological and human soundscapes. The combination of the case study and recent scholarship also highlights some unresolved concerns pertaining to indoor vs. outdoor acoustics and human vs. wildlife-dominated soundscapes.

Overall, the concept of quietude under MERA offers lessons into how policy designation interacts with human ways of engineering the lived environment and lays the foundation for a broader conceptualization of noise and sound as part of an acoustic natural resource – one that is relevant to both human-dominated and wildlife environments. The topics addressed in this chapter suggest future research directions, including studies of how airport noise concerns contribute to modification of the surrounding urban landscape and built environment, and how residents strive to promote well-being in areas where noise is a major concern.

References

Act of June 4, 1971, ch. 727, 1971 Minn. Laws, 1400-1405.

Adams, M., Cox, T., Moore, G., Croxford, B., Refaee, M., & Sharples, S. (2006). Sustainable soundscapes: Noise policy and the urban experience. *Urban Studies*, *43*(13), 2385–2398.

Airport Noise Compatibility Planning, 14 C.F.R. § 150 (2015).

Alevizos v. Metropolitan Airports Commission, 216 N.W.2d 651 (Minn. 1974). Summary retrieved from https://casetext.com/case/alevizos-v-metropolitan-airports-comm

Answer of Intervenor Northwest Airlines, Inc., *Minnesota v. Metropolitan Airports Commission*, No. 27-CV-05-5474 (D. Minn. May 20, 2005).

Arana, M., San Martín, R., Nagore, I., & Pérez, D. (2009). Using noise mapping to evaluate the percentage of people affected by noise. *Acta Acustica United with Acustica*, *95*(3), 550–554. http://doi.org/10.3813/AAA.918180

Atkinson, R. (2007). Ecology of sound: The sonic order of urban space. *Urban Studies*, *44*(10), 1905–1917.

Axelsson, Ö., Nilsson, M. E., & Berglund, B. (2010). A principal components model of soundscape perception. *The Journal of the Acoustical Society of America*, *128*(5), 2836–46. http://doi.org/10.1121/1.3493436

Banner, S. (2008). *Who owns the sky?: The struggle to control airspace from the Wright Brothers on*. Cambridge, MA: Harvard University Press.

Barber, J. R., Burdett, C. L., Reed, S. E., Warner, K. A., Formichella, C., Crooks, K. R., … Fristrup, K. M. (2011). Anthropogenic noise exposure in protected natural areas: Estimating the scale of ecological consequences. *Landscape Ecology*, *26*(9), 1281–1295. http://doi.org/10.1007/s10980-011-9646-7

Barber, J. R., Crooks, K. R., & Fristrup, K. M. (2010). The costs of chronic noise exposure for terrestrial organisms. *Trends in Ecology & Evolution*, *25*(3), 180–9. http://doi.org/10.1016/j.tree.2009.08.002

Bayne, E. M., Habib, L., & Boutin, S. (2008). Impacts of chronic anthropogenic noise from energy-sector activity on abundance of songbirds in the boreal forest. *Conservation Biology*, *22*(5), 1186–93. http://doi.org/10.1111/j.1523-1739.2008.00973.x

Berglund, B., & Lindvall, T. (Eds.). (1995) Community noise. *Archives of the Centre for Sensory Research 2*(1). 1-195. Retrieved from http://www.who.int/docstore/peh/noise/Noiseold.html

Botteldooren, D., De Coensel, B., & De Muer, T. (2006). The temporal structure of urban soundscapes. *Journal of Sound and Vibration*, *292*(1-2), 105–123. http://doi.org/10.1016/j.jsv.2005.07.026

Bröer, C. (2007). Aircraft noise and risk politics. *Health, Risk & Society*, *9*(1), 37–52. http://doi.org/10.1080/13698570601181631

Brooker, P. (2009). Do people react more strongly to aircraft noise today than in the past? *Applied Acoustics*, *70*(5), 747–752. http://doi.org/10.1016/j.apacoust.2008.08.008

Brooker, P. (2010). Aircraft noise annoyance estimation: UK time-pattern effects. *Applied Acoustics*, *71*(7), 661–667. http://doi.org/10.1016/j.apacoust.2010.01.010

Chapin, F. S., III. (1997). Biotic control over the functioning of ecosystems. *Science*, *277*(5325), 500–504. http://doi.org/10.1126/science.277.5325.500

Cidell, J. (2008). Challenging the contours: Critical cartography, local knowledge, and the public. *Environment and Planning A*, *40*(5), 1202–1218.

Citizens for a Safe Grant v. Lone Oak Sportsmen's Club, 624 N.W.2d 796 (Minn. Ct. App. 2001).

Complaint, *Minnesota v. Metropolitan Airports Commission*, No. 27-CV-05-5474 (D. Minn. Apr. 20, 2005).

Cooper, G. (1998). *Air-conditioning America: Engineers and the controlled environment, 1900-1960*. Baltimore, MD: Johns Hopkins University Press.

Davies, W. J., Adams, M. D., Bruce, N. S., Cain, R., Carlyle, A., Cusack, P., … Poxon, J. (2013). Perception of soundscapes: An interdisciplinary approach. *Applied Acoustics*, *74*(2), 224–231. http://doi.org/10.1016/j.apacoust.2012.05.010

De Coensel, B., & Botteldooren, D. (2006). The quiet rural soundscape and how to characterize it. *Acta Acustica United with Acustica*, *92*(6), 887–897.

De Kluijver, H., & Stoter, J. (2003). Noise mapping and GIS: Optimising quality and efficiency of noise effect studies. *Computers, Environment and Urban Systems*, *27*(1), 85–102. http://doi.org/10.1016/S0198-9715(01)00038-2

Dumyahn, S. L., & Pijanowski, B. C. (2011). Soundscape conservation. *Landscape Ecology*, *26*(9), 1327–1344. http://doi.org/10.1007/s10980-011-9635-x

Farina, A., Lattanzi, E., Malavasi, R., Pieretti, N., & Piccioli, L. (2011). Avian soundscapes and cognitive landscapes: Theory, application and ecological perspectives. *Landscape Ecology*, *26*(9), 1257–1267. http://doi.org/10.1007/s10980-011-9617-z

Feitelson, E. I., Hurd, R. E., & Mudge, R. R. (1996). The impact of airport noise on willingness to pay for residences. *Transportation Research Part D: Transport and Environment*, *1*(1), 1–14.

Glass, D. C., & Singer, J. E. (1972). *Urban stress: Experiments on noise and social stressors*. New York, NY: Academic Press.

Gourévitch, B., Edeline, J.-M., Occelli, F., & Eggermont, J. J. (2014). Is the din really harmless? Long-term effects of non-traumatic noise on the adult auditory system. *Nature Reviews. Neuroscience*, *15*(7), 483–91. http://doi.org/10.1038/nrn3744

Granö, J. G. (1929). *Pure geography*. (O. Granö & A. Paasi, Eds.). Baltimore, MD: The Johns Hopkins University Press.

Halfwerk, W., Bot, S., Buikx, J., van der Velde, M., Komdeur, J., ten Cate, C., & Slabbekoorn, H. (2011). Low-frequency songs lose their potency in noisy urban conditions. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(35), 14549–54. http://doi.org/10.1073/pnas.1109091108

Harvey, M. E., Frazier, J. W., & Matulionis, M. (1979). Cognition of a hazardous environment: Reactions to Buffalo airport noise. *Economic Geography*, *55*(4), 263–286. http://doi.org/10.1001/archgenpsychiatry.2010.16

Herzog, T. R., Hayes, L. J., Applin, R. C., & Weatherly, A. M. (2011). Incompatibility and mental fatigue. *Environment and Behavior*, *43*(6), 827–847. http://doi.org/10.1177/0013916510383242

International Organization for Standardization (ISO) (2014). Acoustics – Soundscape – Part 1: Definition and Conceptual Framework (International Standard No. ISO/FDIS 12913-1).

Irvine, K. N., Devine-Wright, P., Payne, S. R., Fuller, R. A., Painter, B., & Gaston, K. J. (2009). Green space, soundscape and urban sustainability: An interdisciplinary, empirical study. *Local Environment*, *14*(2), 155–172. http://doi.org/10.1080/13549830802522061

Jennings, P., & Cain, R. (2013). A framework for improving urban soundscapes. *Applied Acoustics*, *74*(2), 293–299. http://doi.org/10.1016/j.apacoust.2011.12.003

Johnson, J. L. (1983). Acid rain: Minnesota remedies. *William Mitchell Environmental Law Journal*, *1*(1), 82–116.

Kahn, Jr., P. H. (1999). *The human relationship with nature: Development and culture*. Cambridge, MA: The MIT Press.

Kaplan, S. (1995). The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology*, *15*(3), 169–182.

Kaplan, S. (2001). Meditation, restoration, and the management of mental fatigue. *Environment and Behavior*, *33*(4), 480–506.

Kight, C. R., & Swaddle, J. P. (2011). How and why environmental noise impacts animals: An integrative, mechanistic review. *Ecology Letters*, *14*(10), 1052–61. http://doi.org/10.1111/j.1461-0248.2011.01664.x

King, E. A., & Rice, H. J. (2009). The development of a practical framework for strategic noise mapping. *Applied Acoustics*, *70*(8), 1116–1127. http://doi.org/10.1016/j.apacoust.2009.01.005

Klæboe, R., Engelien, E., & Steinnes, M. (2006). Context sensitive noise impact mapping. *Applied Acoustics*, *67*(7), 620–642. http://doi.org/10.1016/j.apacoust.2005.12.002

Klass, A. (2006). Modern public trust principles: Recognizing rights and integrating standards. *Notre Dame Law Review*, *82*(2), 699–754.

Krause, B. L. (1987). Bio-acoustics: Habitat ambience and ecological balance. *Whole Earth Review*, *57*, 14–18.

Krause, B. (2012). *The great animal orchestra: Finding the origins of music in the world's wild places*. New York: Little, Brown and Company.

Kryter, K. D. (1985). *The effects of noise on man* (2nd ed.). Orlando, Florida: Academic Press.

Kuo, F. E. (2001). Coping with poverty: Impacts of environment and attention in the inner city. *Environment and Behavior*, *33*(1), 5–34. http://doi.org/10.1177/00139160121972846

Lacey, J., & Harvey, L. (2011). Sound cartography approaches to urban soundscape research: CitySounds and Sites-of-Respite in the CBD of Melbourne. In S. Caquard, L. Vaughan, and W. Cartwright (Eds.), *Mapping environmental issues in the city: Arts and cartography cross perspectives* (pp. 246–265). Berlin: Springer-Verlag.

Lam, K.-C., Brown, A. L., Marafa, L., & Chau, K.-C. (2010). Human preference for countryside soundscapes. *Acta Acustica United with Acustica*, *96*(3), 463–471. http://doi.org/10.3813/AAA.918299

Liu, J., Kang, J., Luo, T., Behm, H., & Coppack, T. (2013). Spatiotemporal variability of soundscapes in a multiple functional urban area. *Landscape and Urban Planning*, *115*, 1–9. http://doi.org/10.1016/j.landurbplan.2013.03.008

Maris, E., Stallen, P. J., Vermunt, R., & Steensma, H. (2007). Evaluating noise in social context: the effect of procedural unfairness on noise annoyance judgments. *The Journal of the Acoustical Society of America*, *122*(6), 3483–94. http://doi.org/10.1121/1.2799901

Memorandum in Support of Defendant's Motion to Dismiss, *Minnesota v. Metropolitan Airports Commission*, No. 27-CV-05-5474 (D. Minn. May 19, 2005).

Metropolitan Airports Commission (2010). Tips for insulating your home against airport noise. Retrieved from https://www.macnoise.com/sites/macnoise.com/files/pdf /tips.pdf

Minnesota Environmental Rights Act of 1971 (MERA), 2014 Minn. Stat. 116B.01-07 (2014).

Minnesota Public Interest Research Group v. White Bear Gun Club. 257 N.W.2d 762 (Minn. 1977).

Minnesota v. Metropolitan Airports Commission, No. 27-CV-05-5474, (D. Minn., order granting partial summary judgment, Jan. 25, 2007). Retrieved from http://www.ci.minneapolis.mn.us/www/groups/public/@communications/documents /webcontent/convert_254051.pdf

Minnesota Valley Trust (2016). Board & Staff: Minnesota Valley Trust. Retrieved from http://www.mnvalleytrust.org/board_and_staff/

National Park Service (2006). *Management policies 2006*. Washington, DC: U.S. Government Printing Office. Retrieved from http://www.nps.gov/policy /mp2006.pdf

Note: The Minnesota Environmental Rights Act. *Minnesota Law Review 56*(4), 575-639 (1972).

Ogneva-Himmelberger, Y., & Cooperman, B. (2009). Spatio-temporal analysis of noise pollution near Boston Logan Airport: Who carries the cost? *Urban Studies*, *47*(1), 169–182. http://doi.org/10.1177/0042098009346863

Oosterlynck, S., & Swyngedouw, E. (2010). Noise reduction: The postpolitical quandary of night flights at Brussels airport. *Environment and Planning A*, *42*(7), 1577–1594. http://doi.org/10.1068/a42269

Pijanowski, B. C., Farina, A., Gage, S. H., Dumyahn, S. L., & Krause, B. L. (2011). What is soundscape ecology? An introduction and overview of an emerging new science. *Landscape Ecology*, *26*(9), 1213–1232. http://doi.org/10.1007/s10980-011-9600-8

Plaintiffs' Memorandum of Law in Response to Defendant's Motion to Dismiss, *Minnesota v. Metropolitan Airports Commission*, No. 27-CV-05-5474 (D. Minn. June 27, 2005).

Pocock, D. (1989). Sound and the geographer. *Geography*, *324*(3), 193–200.

Porteous, J. D. (1990). *Landscapes of the mind: Worlds of sense and metaphor*. Toronto, CA: University of Toronto Press.

Raimbault, M., & Dubois, D. (2005). Urban soundscapes: Experiences and knowledge. *Cities*, *22*(5), 339–350. http://doi.org/10.1016/j.cities.2005.05.003

Rodaway, P. (1994). Sensuous geographies: Body, sense and place. New York: Routledge.

Sax, J. L. (1970). The public trust doctrine in natural resource law: Effective judicial intervention. *Michigan Law Review, 68*(3), 471–566.

Sax, J. L. (1971). *Defending the environment: A strategy for citizen action*. New York: Alfred A. Knopf.

Schafer, R. M. (1994). *The soundscape: Our sonic environment and the tuning of the world*. Rochester, VT: Destiny Books.

Skeie v. Minnkota Power Cooperative, 281 N.W.2d 372, 374 (Minn. 1979)

Smith, J. W., & Pijanowski, B. C. (2014). Human and policy dimensions of soundscape ecology. *Global Environmental Change*, *28*, 63–74. http://doi.org/10.1016/j.gloenvcha.2014.05.007

Smith, S. J. (1994). Soundscape. *Area*, *26*(3), 232–240.

Sobotta, R. R., Campbell, H. E., & Owens, B. J. (2007). Aviation noise and environmental justice: The barrio barrier. *Journal of Regional Science*, *47*(1), 125–154. http://doi.org/10.1111/j.1467-9787.2007.00503.x

Stansell v. Northfield, 618 N.W.2d 814 (Minn. Ct. App. 2000).

Stokols, D. (1978). Environmental psychology. *Annual Review of Psychology*, *29*, 253–95.

Stoter, J., de Kluijver, H., & Kurakula, V. (2008). 3D noise mapping in urban areas. *International Journal of Geographical Information Science*, *22*(8), 907–924. http://doi.org/10.1080/13658810701739039

The Impact of the Expansion of the Minneapolis-St. Paul International Airport of the Minnesota Valley National Wildlife Refuge: Oversight Hearing before the Committee on Resources, House of Representatives, 106th Cong. 1 (1999).

Thompson, E. (2002). *The soundscape of modernity: Architectural acoustics and the culture of listening in America*. Cambridge, MA: The MIT Press.

Thorne, R., & Shepherd, D. (2013). Quiet as an environmental value: A contrast between two legislative approaches. *International Journal of Environmental Research and Public Health*, *10*(7), 2741–2759. http://doi.org/10.3390/ijerph10072741

Tilman, D., Isbell, F., & Cowles, J. M. (2014). Biodiversity and ecosystem functioning. *Annual Review of Ecology, Evolution, and Systematics*, *45*, 471–493. http://doi.org/10.1126/science.1064088

Truax, B. (2001). *Acoustic communication* (2nd ed.). Westport, CT: Ablex Publishing.

Tsai, K.-T., Lin, M.-D., & Chen, Y.-H. (2009). Noise mapping in urban environments: A Taiwan study. *Applied Acoustics*, *70*(7), 964–972. http://doi.org/10.1016/j.apacoust.2008.11.001

Tuan, Y.-F. (1990). *Topophilia: A study of environmental perception, attitudes, and values* (Morningside ed.). Columbia University Press: New York, NY.

U.S. Department of Transportation, Federal Aviation Administration, Great Lakes Region (1998). *Minneapolis-St. Paul International Airport planning process: New runway 17/35 and airport layout plan approval*. Retrieved from https://www.faa.gov/airports/environmental/records_decision/media/rod_minneapolis.pdf

U.S. Fish & Wildlife Service (2004). Minnesota Valley National Wildlife Refuge and Wetland Management District: Comprehensive Conservation Plan and Environmental Assessment. Retrieved from http://www.fws.gov/Midwest/planning/MinnesotaValley/index.html

Villanueva-Rivera, L. J., Pijanowski, B. C., Doucette, J., & Pekin, B. (2011). A primer of acoustic analysis for landscape ecologists. *Landscape Ecology*, *26*(9), 1233–1246. http://doi.org/10.1007/s10980-011-9636-9

Wang, B., & Kang, J. (2011). Effects of urban morphology on the traffic noise distribution through noise mapping: A comparative study between UK and China. *Applied Acoustics*, *72*(8), 556–568. http://doi.org/10.1016/j.apacoust.2011.01.011

Warren, P. S., Katti, M., Ermann, M., & Brazel, A. (2006). Urban bioacoustics: It's not just noise. *Animal Behaviour*, *71*(3), 491–502. http://doi.org/10.1016/j.anbehav.2005.07.014

Watts, G., Miah, A., & Pheasant, R. (2013). Tranquillity and soundscapes in urban green spaces—predicted and actual assessments from a questionnaire survey. *Environment and Planning B: Planning and Design*, *40*(1), 170–181. http://doi.org/10.1068/b38061

Wiens, J. A., Stenseth, N. C., Van Horne, B., & Ims, R. A. (1993). Ecological mechanisms and landscape ecology. *OIKOS*, *66*(3), 369–380.

Wilson, E. O. (1984). *Biophilia*. Cambridge, MA: Harvard University Press.

Wrigley, N. (1977). Probability surface mapping: a new approach to trend surface mapping. *Transactions of the Institute of British Geographers, New Series, 2*(2), 129–140.

Chapter 3. Mapping Spatiotemporal Variability of Aircraft Departure Noise Impacts

Summary. This article offers new ways to represent and understand the spatiotemporal nature of airport noise and impacts. It presents an analysis of flight departure data that can identify spatial resolutions of a hundred meters and minute-by-minute temporal differences for the case study of the Minneapolis-St. Paul International Airport (MSP). In addition to advancing the use of large amounts of flight data, it fulfills the larger goal of creating a representation of aircraft exposure that reflects the spatial and temporal variation in residential experience of noise, providing a much-needed alternative to the standard portrayal of flight noise via day-night average sound level mapping. To give greater consideration to the correspondence between noise and daily life, this study adopts a fine-grained approach to analyzing flight departures from the airport, highlighting three attributes: paths of departures, times of departure, and altitude.

1. Introduction

Concerns about residential well-being are inherently spatial and temporal. Where we live or desire to live based on our means depends on the housing quality and the accessibility of amenities so that we can better enjoy how we live day-to-day. When a problem arises, however, residents benefit from being able to refer to it in a way that is well-understood by local authorities.

An emphasis on the temporal dimension of GIS allows for moving beyond geographical representations that mask shorter-term trends. Aircraft noise pollution provides an ideal scenario for studying daily and hourly patterns extracted from large sets of data. While average metrics of noise can be informative in regard to how areas close to airports are generally affected, a study of how patterns are revealed cyclically can better reflect understandings of personal exposure to noise, based on the days and times when residents can expect to be at home, when they desire to engage in activities that are less vulnerable to noise interference, and when they are less likely to be annoyed.

Large datasets of flight departures and arrivals can be examined for patterns that better reflect both residential and flight-based daily routines. This chapter focuses on the temporal patterns of departures. The breakdown of patterns to day of the week and hour of the day allows for greater understanding of how noise can affect residents at times that most concern them. The analysis incorporates the characteristics of temporal frequency and altitude in order to provide weighting to the significance of individual departure events. One of the advantages of the methodology presented here is its focus on a few key dimensions that reflect the concerns of residents, as expressed in interviews. By aiming for simplicity of inputs, the analysis can better highlight the strengths of the fine-grained temporal approach to representing the distribution of noise.

2. Mapping airport noise

Over the course of decades of decision-making about how airport noise should be measured, averaged, and mapped, certain methodologies become the standard for how spatial and temporal flight patterns should be represented. These standards, however, are sometimes subject to challenges because they do not measure or represent many features of interest to policymakers, residents, and other stakeholders (Cidell 2008). At the heart of this analysis, therefore, is an inquiry into the effectiveness of existing policy-based standards of mapping. In light of a government-sanctioned mapping methodology that aims to accurately capture aircraft noise impacts on residents who live below, this chapter presents an alternative way of mapping noise patterns that can better reflect residential experience.

2.1 Airport noise regulatory environment

Airport noise mapping is driven by noise regulation. Because the effects of airport noise were so pressing on communities from the very beginning of commercial jet aviation, the goal of studying noise effects in pursuit of crafting effective regulation has been prevalent since the 1950s (Beranek, 2008). In the United States, the Noise Control Act was established in 1972, but initial efforts to address noise by way of the Environmental Protection Agency switched to oversight by the agencies that regulated the sources of noise. Hence, the Federal Aviation Administration (FAA) would come to largely oversee how noise should be measured, averaged, and mapped for the purposes of achieving land use compatibility in the vicinity of airports.

In the 1970s, aircraft noise pollution was addressed as a national concern and prompted numerous Congressional hearings. In 1984, the federal regulation of Airport Noise Compatibility Planning (2015), also known as “Part 150”, initiated development of noise measurement and mapping standards, in addition to determining which land use types were compatible with varying noise levels. Airports could voluntarily create noise contour maps for the surrounding region, with the understanding that the use of the maps for adopting land use compatibility measures – including the removal of noise-sensitive land uses or the provision of mitigation to residences in the form of sound insulation or centralized air-conditioning – would restrict lawsuits by neighboring landowners (Pearson & Riley, 2015).

The determination of proper measurement standards was based on both government-sponsored and independent research into noise reaction. In 1974, the U. S. Environmental Protection Agency published what became commonly known as the "Levels Document" (U.S. Environmental Protection Agency, 1974), establishing an understanding that a day-night average sound level (DNL) of 55 outdoors and 45 indoors represented the thresholds above which annoyance or activity interference was common. Schultz (1978) reviewed the noise response studies to date, and focused on the response of annoyance, especially for determining what percentage of people would be highly annoyed by a certain level of average noise. A 1992 report by the Federal Interagency Committee on Noise would reaffirm DNL-based methodologies for the calculation of noise impacts, the primacy of the highly-annoyed threshold, and a fitting function developed for the U.S. Air Force as giving the best representation of the relationship between the DNL and the percentage of the population that would be highly annoyed (Federal Interagency Committee on Noise, 1992; Fidell, 2003). The FAA decreed the 65-DNL measure as the federal outdoor standard for airports to use in their mapping of areas that would need to be mitigated with sound insulation, centralized air conditioning, or both.

To determine how the DNL contours map out, Part 150 called for the use of the Integrated Noise Model[2] (INM), a model that takes into account inputs such as the airport layout, climatic variables, runway use, fleet mix, and maintenance-related aircraft engine “run-ups” (Federal Aviation Administration, 2007). (See Figure 3.1 for an example of DNL contours.) The model relies on data for one year of actual fleet operations and the projected operations for the following five years. The issue of time is significant to the use of DNL because a 10-decibel penalty is assigned to planes that depart or arrive between 10 PM and 7 AM. The use of time-based inputs for noise metrics is not unique to the DNL. In fact, the European Union and California use the day-evening-night sound

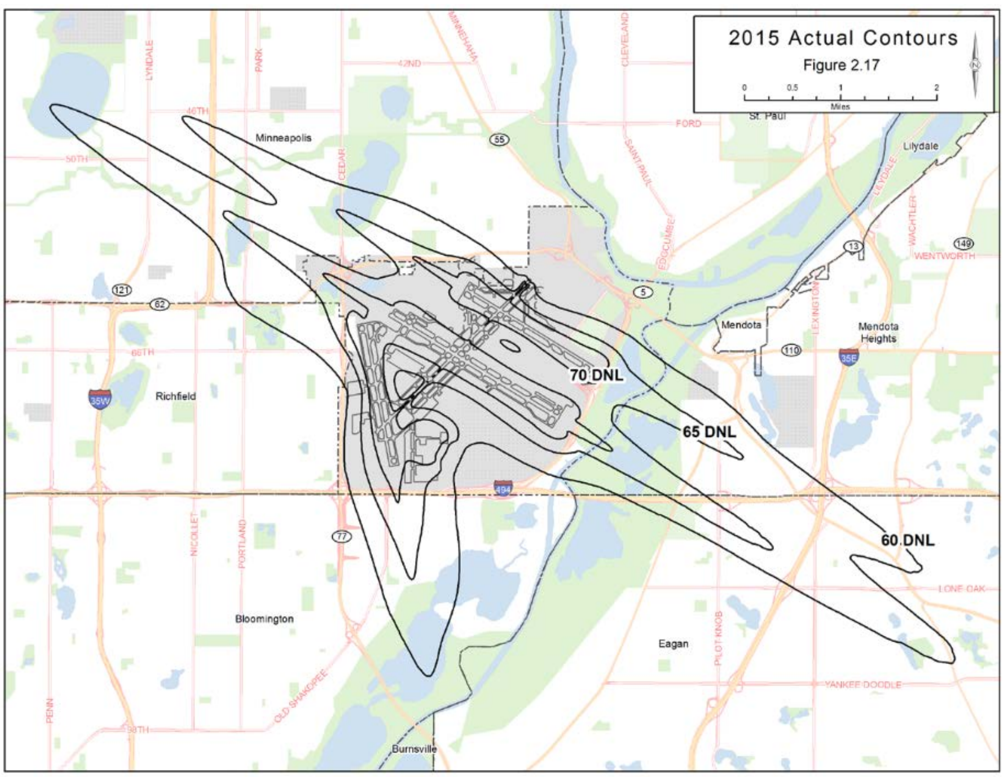

Figure 3.1: 2015 MSP DNL contours
(Metropolitan Airports Commission, n.d., p. 38)

[2] In May 2015, the FAA replaced the INM with the Aviation Environmental Design Tool (AEDT).

level (known in California as the Community Noise Equivalent Level) which adds a 5-decibel penalty to flights from 7 PM to 10 PM. (Bütikofer, 2013; Murphy & King, 2010).

2.2 Developing a noise mapping alternative

Geographers and other spatially-informed scientists offer several avenues forward in the mapping of airport noise. The DNL maps incorporate space and time but in many respects subordinate these to other features of aircraft and the broader aviation system. It is certainly possible to gain higher fidelity in the representation of the airport system by adding even more variables and complexity to the INM. The work of the research organization PARTNER (Partnership for AiR Transportation Noise and Emissions Reduction), with sponsorship provided by several agencies including the FAA, the U.S. Environmental Protection Agency, and Transport Canada, among others, has been exemplary in this regard with its focus on several more fine-grained dimensions of the issue, including low-frequency noise, night-time noise, and health effects resulting from exposure. Foertsch and Davies (2013), for example, examine how annoyance models can be formulated to assess the relative impacts of sound level and number-of-events. Importantly, the problem is not with the INM but with the simplicity of the end product, the DNL contour maps that broadly generalize the time dimension to produce a very simple spatial rendering of airport noise.

Another way forward, and the one explored here, is to simplify the representation of flight patterns while substantially increasing the spatial and temporal resolution of the end product, namely the noise map. Space matters in the straightforward sense that the noise impact on any given household will be affected by how close the aircraft is to a person's residence, which is a function of horizontal and vertical (altitude) displacement.

Time matters just as much, and sometimes more, than space. With the increasing incorporation of time into GIS, a growing number of conceptions and representations of spatiotemporal phenomena are available for analysis and visualization. Psychological understandings of time have been examined in conjunction with their geospatial rendering (Peuquet, 2002). The choice of temporal representation should follow a similar psychologically sound line of reasoning as offered by Couclelis (1992) regarding spatial representation, namely that it should reflect human cognition of the geographic world. This is especially the case for such a perception-based concern as the trajectory of aircraft over residential areas.

Time in GIS can be conceptualized in multiple ways. Frank (1998) characterized several types, including ordinal, interval, continuous, and cyclical. The first three of these measurement scales, so common in spatial analysis, reasonably apply to a linear time flow (e.g., a spatial interval is conceptually similar to a temporal interval or time period, while continuous space maps well onto continuous time). Cyclical time goes a step further by incorporating periodicity. Psychologists and sociologists have addressed the human experience of time (Friedman, 1990; Werner, Altman, & Oxley, 1985; Young, 1988) as conceived both linearly and cyclically, due to habit-making, work life, and circadian rhythms, to name just a few factors (Young, 1988). The temporality of home life itself has been noted for its linear and cyclical components (Werner et al., 1985), each of which also apply to the experience of airport noise. Along a linear time scale, home life is subject to change and flow from one state to another, without recurrence. Backyard decks get built. Kitchens get remodeled. Household members get older. Some members leave home while others join the household. In terms of cycles, behavior at home is dominated by regularly occurring activities. Annually, events and activities will be set up around the celebration of holidays or the carrying out of seasonal yardwork (e.g., planting or raking, dusting off the snow blower). Weekly, time at home can revolve around spending time gardening, watching particular TV shows, and setting aside time for family activities. Daily cyclical activities include eating, sleeping, relaxing after returning from work, and so on.

Concern about how time is cognitively regarded in both its linear and cyclical aspects leads to concerns about how to represent it effectively in GIS. Time has been visually represented in numerous ways throughout history (Aigner, Miksch, Schumann, & Tominski, 2011). Questions about handling time in GIS have addressed not only the visual ways of representing time but also the computational aspects of encoding it (Langran, 1992; Langran & Chrisman, 1988; Peuquet, 1994; Worboys & Duckham, 2004). Goodchild (2013) has grouped the main representations of space and time into several types, among which are object tracking, snapshot sequences, polygon coverage sequences, event- and transaction-based records, and cellular automata. More simply, traditional spatiotemporal ontologies distinguish between two non-overlapping categories: instants of time and gradual change, or what Galton (2004) has referred to respectively as the snapshot and the chronicle. For example, the snapshot representation alone can lead to error when used for change detection (Chrisman, 1998). Grenon and Smith (2004) argue for a combining of these ontologies to better reflect the dynamic characteristics of real-world phenomena.

Ultimately, it is important to create explicitly spatiotemporal representations of airport noise. Conversion of movement data to point representation offers a useful way to store dimensional attributes, including altitude, that can change along the course of the path, and facilitate subsequent spatial analysis. Downs (2010) acquires sample point locations along a travel path to be used for conducting a kernel density estimation of the point locations, using a geo-ellipse between each two consecutive points for computing density estimates. Similar kernel density analysis has been conducted for 3-dimensional data (Demšar, Buchin, van Loon, & Shamoun-Baranes, 2015; Demšar & Virrantaus, 2010). In addition to methods for creating static two- and three-dimensional representations of movement, geovisualization of these spatiotemporal data is also being improved and used for flight paths. Andrienko, Andrienko, Hurter, Rinzivillo, and Wrobel (2013) have undertaken spatiotemporal visualization of flight arrivals and departures, including cluster analysis based on both position and movement direction within a three-dimensional graphic interface. GIS and spatial analysis have much to offer in exploring the spatiotemporal nature of flight paths and their attendant noise impacts.

Existing research points to how mapping of flight trajectories poses special challenges. The multi-dimensionality of the flight data – three spatial dimensions and time – requires that any representation be subject to generalization. The volume of data also requires filtering so that time-based patterns can be more readily seen. Three-dimensional rendering can facilitate data exploration, but large-scale patterns can be hidden in large volumes of data, with the result that cluttered images may hide interesting patterns (Shepherd, 2008). Transects provide a way to gain more insight, but the range of choice regarding where those transects should be placed is wide, and there may be issues with making meaningful comparisons between transects that are at varying distances and directions from the airport itself. As explored below, this analysis builds on existing research by forgoing many of the difficulties posed by 3-d visualization. Instead, it embeds time and altitude in a two-dimensional analysis – first, by way of partitioning the flights based on hour of day and day of week, and second, by the weighting of both time and altitude in flight trajectory points in order to conduct a field-based analysis that shows how they vary over longer time periods – specifically for the summer seasons year to year.

This analysis limits the number of model inputs in order to highlight the influence of variables most reflective of perceived operational choice – the variables that residents will regard as most related to decisions made by air traffic controllers and pilots, including how quickly planes will ascend, how soon they will turn toward the direction of their destination, and how much time elapses between departures. Granted, the perception of choice is sometimes illusory, given that many decisions are constrained by overriding concerns for safety and the need to match patterns of traffic with the overall network. Nevertheless, on-the-ground perception overwhelmingly drives the classification of sound as noise, and these operational matters contribute to a more salient representation of the factors most directly tied to perceptions of malfeasance or misfeasance should flights, either alone or in aggregate, be considered too noisy.

3. Study site and methods

By way of overview, my analysis uses the flight track data from MSP to determine how flight patterns vary by hour of the day and by day of the week. In order to understand how the frequency, concentration, and altitude of flights are distributed in space and time, the analysis disaggregates these data to segments that exhibit day-to-day patterns reflective of the spatial and temporal impacts on residential experience. First, I describe the Twin Cities study area, which offers a great setting in which to understand many issues surrounding airport noise. Second, I discuss qualitative approaches – archival research, public meetings, and in-person interviews – conducted in order to understand the spatial and temporal nature of noise impacts from a resident's perspective. Third, I describe the development of a very large dataset comprising hundreds of thousands of flight trajectories per year that were converted into points and then converted to rasters via kernel density estimation. Fourth, I present a time-based weighting of departures to capture sub-daily variation in noise. Fifth, I detail the calculation of an altitude-based exposure index that translates flight data into noise measures. Finally, I describe how I combine these time-weighted departure data and noise exposure data to develop a single raster representation of noise exposure within the study site. These raster layers offer a straightforward means to represent and understand how patterns play out cyclically and at particular times of day.

3.1 Twin Cities study area

The Minneapolis-St. Paul International Airport (MSP) has been at its current location since it was converted from a short-lived racetrack to having its first hangar and landing strip in 1920 (Allard & Sandvick, 1993; Harper, 1971). In the early 1940s, this location was designated as the primary metropolitan airport for the Twin Cities, since it was situated equidistant from downtown Minneapolis and downtown St. Paul (Harper, 1971). The airport has remained in its original location ever since, enhanced by the construction of the main Lindbergh Terminal in 1962 and the construction of the Humphrey Terminal in 2001. Ever since the 1958 introduction of commercial jets led to much greater airplane noise in the airport's surrounding neighborhoods, waves of protest and complaint have waxed and waned (Cidell, 2008).

For residences near MSP, eligibility for mitigation depends on the house's block falling at least partially within specific DNL contours. Mitigation was extended to all residences between 60 and 64 DNL due to a commitment made by MSP in an environmental impact statement to expand the airport while remaining at its location (U.S. Department of Transportation, 1998), and a subsequent judicial ruling in a lawsuit that forced MAC to honor that commitment (*Minnesota v. Metropolitan Airports Commission*, Order, 2007, ¶12).

The summer of 2011 saw a renewed wave of protests against aircraft noise, with many residents voicing their concerns to the Metropolitan Airports Commission (MAC), policymakers, and local media. Places directly north of the airport – including neighborhoods located in the vicinity of Lake Hiawatha and due north – and to the west, near the shared border of the cities of Minneapolis, Edina, and Richfield – were home to some of the most vocal protestors. (See Figure 3.2 for map of area northwest of MSP.) The concern was due to the perception of an increased amount of air traffic, mostly

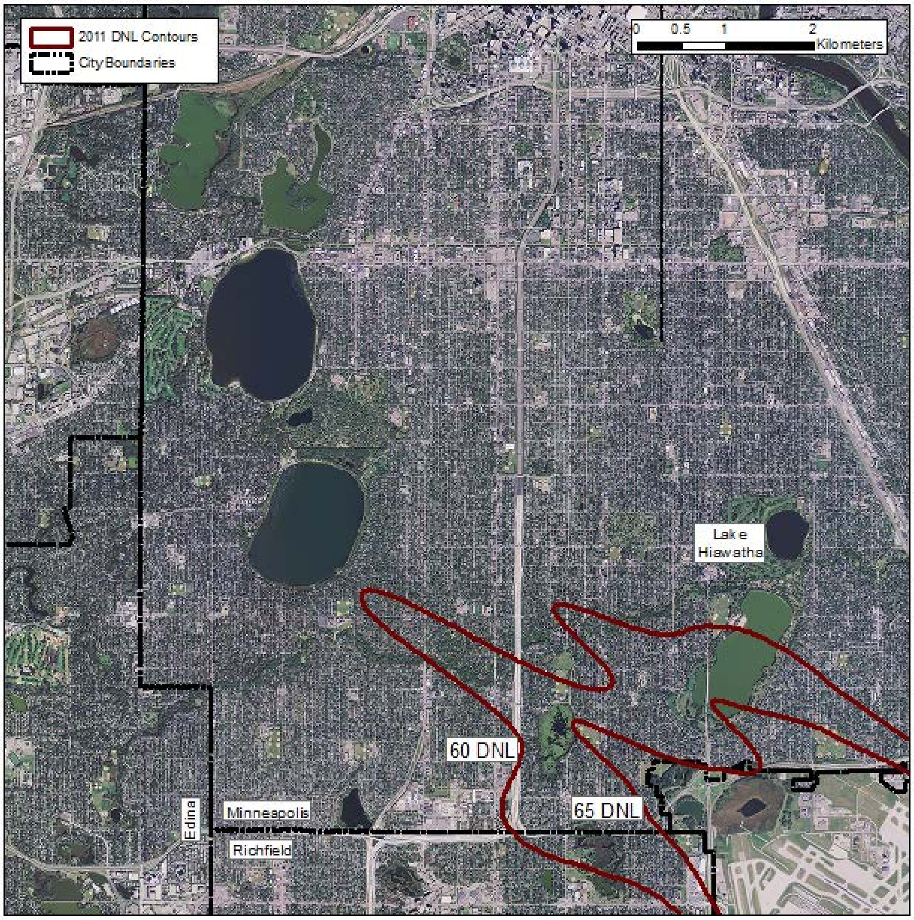

Figure 3.2: Detail of area northwest of MSP

because of departures from runways 35L and especially 35R (shown in runway diagram as Figure 3.3). This noise was considered far beyond what was commonly experienced. Over 150 people, along with local news reporters, attended a Public Input Meeting at MAC on October 25, 2011. Residents at the meeting typically grounded their noise experience in the context of how they desired to spend their lives day to day, and spoke of how the noise disrupted desired ways of residential living specific to time and place (Metropolitan Airports Commission, 2011b).

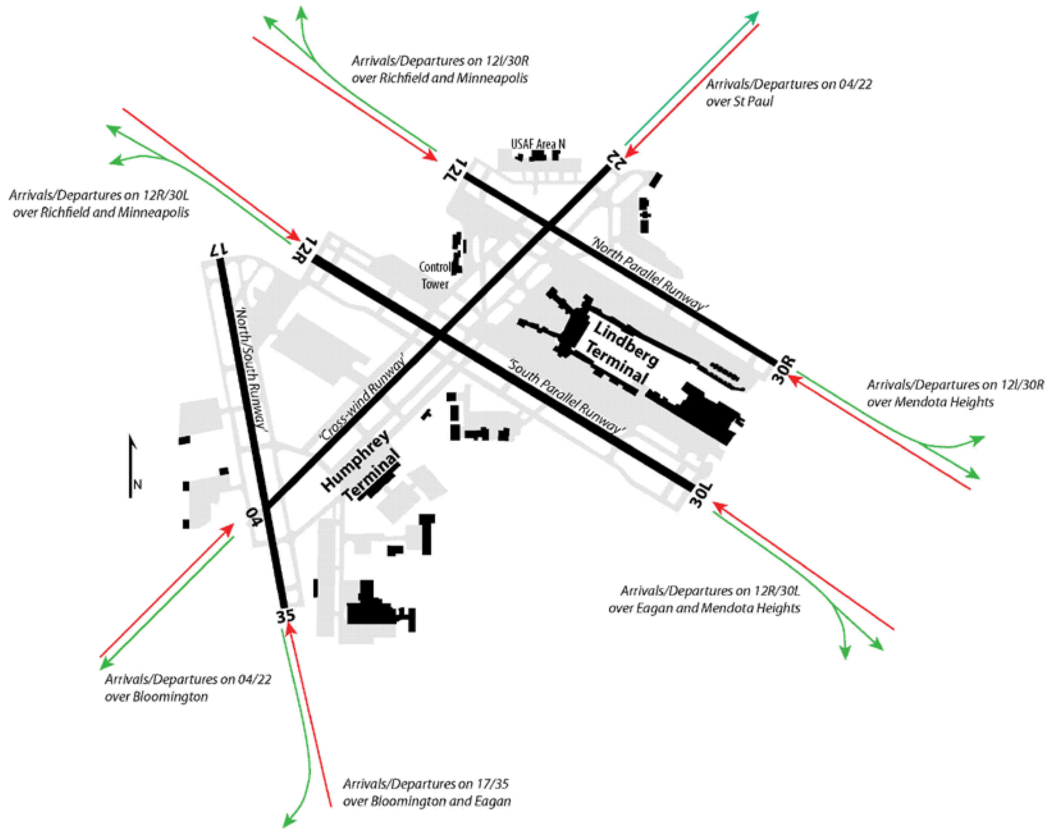

Figure 3.3: MSP runway diagram
(Metropolitan Airports Commission, 2013)

Three possible causes of the change in patterns were addressed in the summer and the months following – specifically, wind direction, a near collision, and fewer small jets in the aircraft mix. First, wind direction influences decisions concerning departure and arrival direction, since headwind helps to generate lift, and the airport will typically change its operations to better accommodate prevailing wind conditions (Metropolitan Airports Commission, 2014). Second, there was a near collision on September 16, 2010 between two planes, in which a commercial jet and a small aircraft departed on parallel runways and then crossed paths, passing within one hundred feet of each other (National Transportation Safety Board, 2010). The incident led to FAA-implemented changes in departure protocol (Doyle, 2011a) that likely brought about a heavier concentration of departures over more northerly neighborhoods. Third, the FAA conducted a study of departure patterns and concluded that as the number of propeller (prop) planes had been declining over the course of the previous few years, more jets were departing from MSP at a faster rate and along a more consistent northward course (Shelerud, 2012). The fact that each of these trends can be reasonably expected to have a noticeable impact on departure patterns invites the question of why the 2010 contour map (Figure 3.4) and the 2011 map (Figure 3.5) show almost no noticeable difference in contour extent.

The core issue raised by airplane noise conflict in the Twin Cities, and by extension many other regions, is the fundamental mismatch between the policy-based DNL maps and a spatiotemporal distribution of noise that confounds expectations of who should be highly annoyed. MAC's contour maps showed the contours situated far from the locations of many residents expressing their annoyance. (Refer back to Figure 3.2 for distance from contours.) This lack of correspondence between maps and perception prompted the Minneapolis city council member John Quincy to remark to the local newspaper, the *Star Tribune*, that "the human ear does not hear in averages" (Doyle, 2011b). The dramatically heightened reaction in 2011 compared to 2010, and the disconnect between this change and similarities of the contour maps for those two years is indicative of a deeper problem, that the contour maps fail to capture the ways that the noise can be annoying (Cidell, 2008). The mismatch raises questions regarding how to create maps that are just as well-attuned to smaller-scale temporal changes in noise exposure. How can maps best capture the daily and hourly variation of the flight patterns in a manner that reflects the experience of residents?

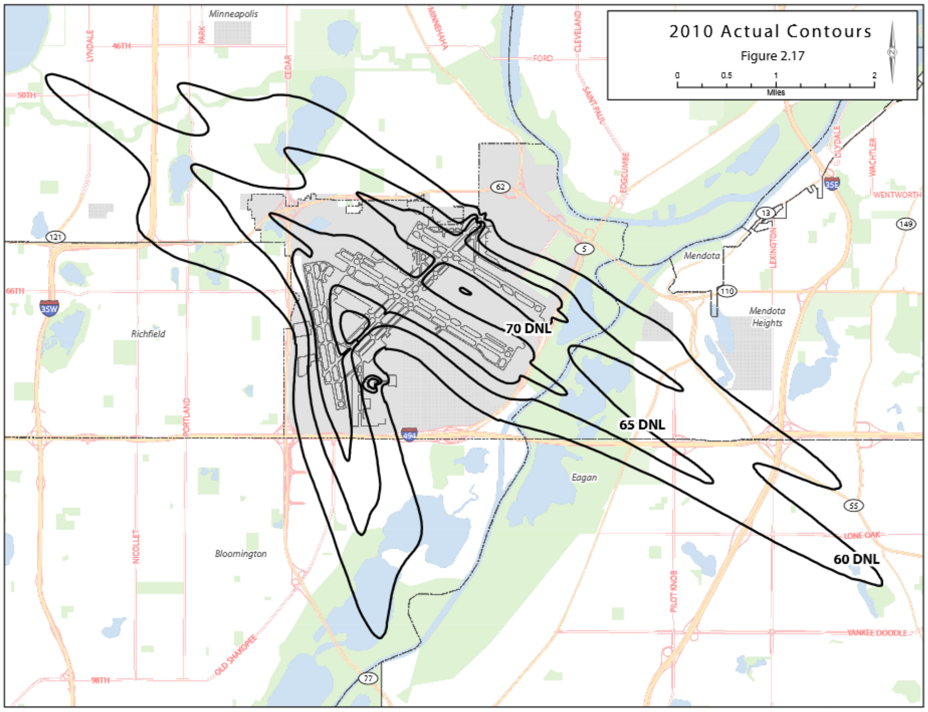

Figure 3.4: MAC noise contour map for 2010
(Metropolitan Airports Commission, 2012b, following p. 15)

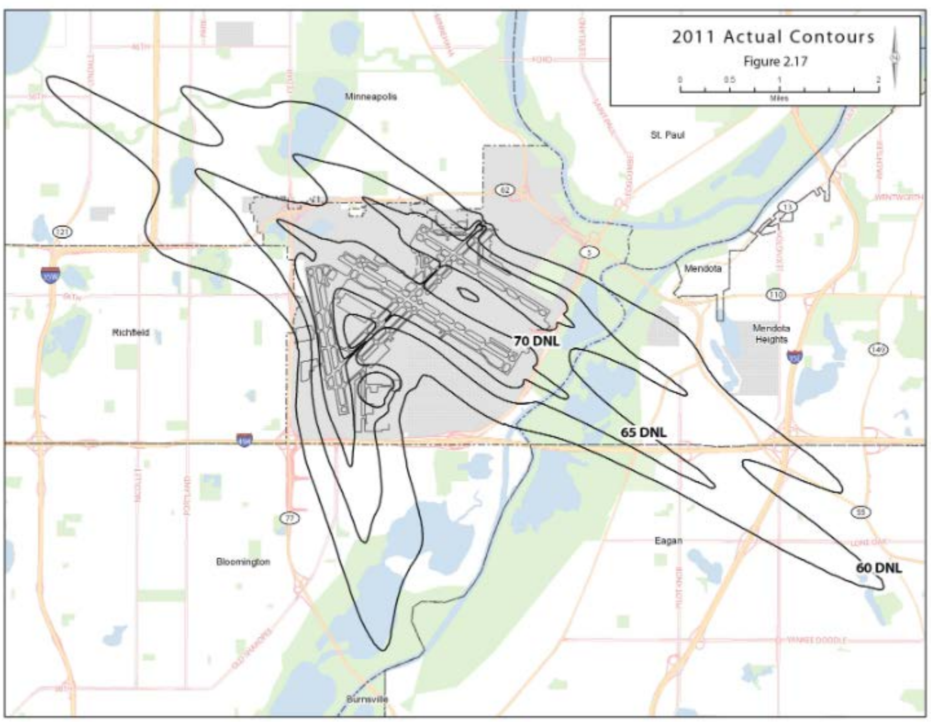

Figure 3.5: MAC noise contour map for 2011
(Metropolitan Airports Commission, 2012c, following p. 14)

3.2 Archival research, public meetings, and interviews

The first step in creating airport noise maps that better reflect the spatiotemporal nature of this noise was to use archival research, public meetings, and interviews to develop a deeper understanding of its human dimensions. First, I conducted historical research in the Minnesota Historical Society archives to develop a history of airport noise politics in the Twin Cities. I also examined transcripts of congressional hearings from the 1970s onward to understand how policymakers, scientists, and residential activists were describing their perspective on airport noise, and how legislators sought a consensus regarding how to measure and map the noise. Second, I attended public meetings sponsored by MAC and examined transcripts of these and other meetings. Third, I conducted interviews with fifteen residents of south Minneapolis to understand the nature of residential concerns. Interviewees were recruited by posting fliers around south Minneapolis in community centers, libraries, and cafes, placing classified notices in neighborhood newspapers, and following up on conversations at public meetings. Interview questions focused on the flight patterns and their relationship to the residents' day-to-day lives. I used a combination of scripted questions and open-ended discussion in order to understand residents' perception of noise, including discussing specific characteristics of flights and flight patterns that were regarded as disruptive, such as low-altitude flights and the high temporal frequency of flights. In addition to speaking to a variety of residents, I spoke with staff members of institutions dealing with airport noise and sound more generally, including a GIS analyst at MAC, a Minneapolis city council member that also sat on MAC's Noise Oversight Committee, and an acoustic consultant based in south Minneapolis. Note that for what follows, the primary aim of the qualitative inquiry is to explore individual perspectives – drawn from the residential interview transcripts – concerning the spatiotemporal dimensions that directly pertain to the GIS analysis, rather than to provide a fully grounded and exhaustive analysis of this data.

The spatial analysis of airplane noise in this chapter adopts methodological steps that are guided by residents' account of their noise experience having distinct spatial and temporal components. Three flight pattern characteristics were commonly mentioned in interviews: frequency in time, concentration in space, and altitude.

> There's three main factors that affect the neighborhood, in my mind. Frequency. Um, what do they call it? Spreading out. Fanning or spreading out of the flight patterns… Spread out the overflight pattern and then the third thing is altitude. We've got to get these planes to go higher, and we know they can.

Spatial displacement, particularly altitude, is a primary concern for residents. Barring more nuanced or extreme concerns related to altitude – that it seems like a property trespass or that it creates fears of possible crashes – the most general concern is that aircraft flying at closer proximity are simply louder. Residents encounter planes by seeing and hearing them, and noise mapping should capture proximity to residence:

> But no, right over the house, it's - it's a little bit much. Sometimes I wonder if the pilots can see me. (Laughs.)

Also important is aircraft altitude, and because aircraft altitude is more often detected by ear than by eye, it should be incorporated into the analysis to reflect auditory experience.

> And sometimes they fly so low that it actually shakes your body, and, and - I mean, not visibly, but you can just feel it. And, the urge is to go like th- is to cover your ears, but that doesn't really do it because it's inside you and, uh, that, that is when it's really unbearable.

> Get - get higher. And they just don't anymore…They just go - It's just straight. You swear sometimes you could touch 'em.

Time joins space as an important determinant of noise impacts. Residents often expressed concern that airplane noise affected their capacity to enjoy the use of house and property. Assessing how the noise can disrupt that enjoyment often reflects an understanding of time being cyclical. Residential annoyance corresponds with noise exposure via a series of conflicting cyclical patterns: airplane noise has its own cycles, and people’s residentially-focused activities also have their own cycles. Hence, residents respond to the noise based on times of the day, of the week, and of the year when they will most likely be at home and most often outdoors. Flights exhibit cyclical trends based on flights scheduled at consistent times each day to particular cities, the daily arrival and departure of overnight delivery planes, and weekly patterns that reflect tendencies of businesses to schedule trips on some days more often than others, and vacationers to embark or return on particular days as well. By representing flights based on time patterns, the residential experience on particular days of the week at particular times can be better understood. Flight patterns are dominated by multiple cycles that are embedded within one another, from the daily to the weekly to the yearly.

The cyclical patterns of flight noise thus intersect with the cyclical patterns of residents who spend time at home. Over multi-year cycles, some long-term change occurs by way of the appearance or disappearance of regularly scheduled flights, airlines, connecting hubs, and the upswing or decline of passenger demand with the economy or (hopefully) one-off events such as the World Trade Center attacks. There is also a yearly cycle to the residential experience of airport noise in that planes seem more annoying in spring, summer, and fall, simply because windows are open more often and people spend more time outside.

At daily time scales, based on how domestic life and flight patterns can operate in conjunction, the temporal dimension becomes a vital component for understanding how plane noise affects residents. If enjoyment of property hinges primarily on being home, for example, in the early morning and the early evening, little concern would be raised if flights occurred only at other times during the day.

> If it's - If it's the odd, you know, one in the afternoon, two in the afternoon one, I notice but I don't worry about it so much, because I know it's not a predictor of another one coming… If we're in the landing or takeoff pattern, hearing one - all that means is that there's another one coming right behind it. You know? So I guess it would have to be two or three going across before I start going, "Ohhhh, here we go."

At hourly and sub-hourly cycles, the importance of airport noise can be tied to a psychological experience of planes having recently flown over and the anticipation of more flying over soon. In terms of the temporal perception of flights, there are certainly ways that flights in the recent past, the present, and the near future contribute to psychological impact. In terms of flights that have recently passed, people have lingering emotions about what has happened. The stress of noise does not go away instantly. In the present, they hear what is presently flying over, and it disrupts their ability to carry out conversation, watch TV, or enjoy the sounds of the outdoors. Regarding future events, people have premonitions of what lies ahead and are tentative to be fully relaxed when a plane might go over soon.

> I think it's the frequency of it, and the predictability that kind of makes you nuts. Cause you can hear it coming from far away and just kind of wait for it to pass…the whole sequence of being able to hear it fly overhead, go over that way, wait ten seconds, and then another one.

Beyond capturing specific cycles or frequencies of airplanes passing overhead, there is also temporal overlap at sub-minute cycles. A crisp, instantaneous temporal snapshot will capture a noise event or it will not, and the more temporally localized we make the representation, the more the value of the output is prone to random chance (e.g., it is one thing to ask if a plane passes over exactly at 7pm, another to ask if a plane passes at about that time). This suggests a role for employing a “fuzzy” snapshot of flights that is better suited for asking basic, colloquial questions about noise impacts on particular days at particular times, and to reflect perceptual experience as guided in the present both by memory of recent events and the anticipation of upcoming ones. Residents do not interpret a question like “What are the flights typically like at 7 PM on a Thursday?” in a literal sense, but instead regard “7 PM” as accounting for events that have also happened shortly before or after. Including flights before and after a given time addresses not only the experience of someone being exposed at that instant, but also the memory of planes that have flown just before and the expectation that there could soon be more to come. A fuzzy membership approach also has the advantage of capturing patterns of high temporal frequency. Flights that occur within a short time span of one another often have a greater impact on residents than when they occur on an infrequent basis.

> And it's what happens when - you know there's another one coming. And every nerve ending in your body gets like this. And then you get quiet and you think “Where's the planes?” I'm waiting for them to come and irritate my day again.

> And it takes about - I know I'm talking like a crazy woman. It takes like about 40 to 50 seconds for these planes to clear my house. So then there will be like 10 seconds where there won't be any noise, and then you'll hear it again. You know. And it's like living in a war zone. And it really is - It's really intense.

By focusing on how people are affected by patterns of noise events at certain times of year, times of day, and patterns of altitude, alternative representations of flight patterns provide a way to represent spatiotemporal patterns that stand out and to understand how they relate to the experiences of residents. This suggests that mapping both the spatial nature of flights along with their cyclical patterns will illuminate how residents are most impacted by noise exposure.

3.3 Importing and cleaning spatial data

The clear message of the archival work, attending public meetings, and interviews is that the spatial and temporal nature of flights is a major determinant of noise impacts. In order to discover the spatiotemporal patterns, I obtained 3-d polyline flight data from MAC that includes the trajectories of all departure and arrival flights within a 40 nautical-mile (or 74-kilometer) radius of MSP for 2010 (Metropolitan Airports Commission, 2011a) and 2011 (Metropolitan Airports Commission, 2012a). I restricted the analysis extent, as shown in Figure 3.6, to an area within a 15-kilometer radius of the airport center – an area large enough to completely cover areas where residents have voiced complaints.

A year's worth of flight data consists of approximately 750,000 polylines with 3-d encoding. Data preparation involved selecting for the departures and putting aside the arrivals for separate analysis. The decision to focus on departures is partly based on a desire to highlight patterns that are more varied and more reflective of perceived decision-making by pilots and air traffic control. While height and temporal frequency are worth considering, the issue of spatial concentration for arrivals shows little change year to year within the radius considered for this airport. The analysis algorithms for measuring the noise impact would need to be adjusted as well. Because the trajectories are so consistent per arrival, a slight systematic error in a given year for geolocating the trajectories incorrectly leads to an increase in the calculated difference across years. This error requires either correction of the vector data or smoothing out of the rasterized data.

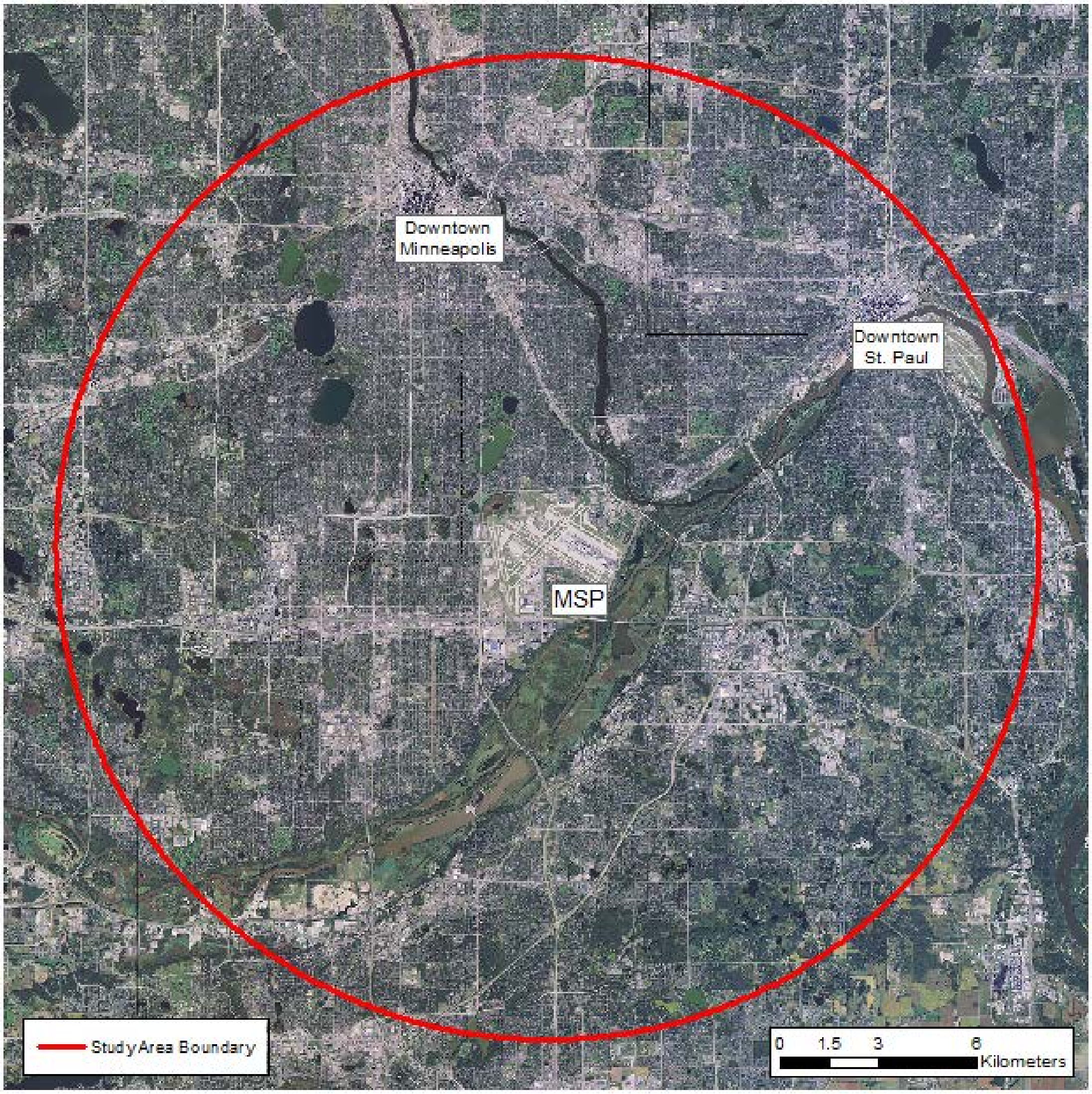

Figure 3.6: Study area

Certain departures were removed from the analysis: those that took highly irregular paths and those which indicated that the flight path line was incompletely recorded. The former characteristic was found in flights that both departed from and returned to MSP along with flights whose polyline length was greater than 150,000 meters before exiting the 40 nautical mile radius. The latter characteristic was identified for any flight path lines that simply ended before exiting the 15-km radius. One year of departures consists of approximately 210,000 polylines. The flight data was then clipped to be within a 15-km radius of the airport, in order to focus on departure trends whose range reaches just beyond the downtowns of Minneapolis and St. Paul, and which defines an area encompassing almost all noise complaints made to MAC.

These 3-d points were then converted via kernel density estimation into raster layers. Points were extracted every 50 meters along the path polylines and had the altitude encoded, thus avoiding computing difficulties with interpolating altitude along the line. Fifty meters is well within the turning radius of any plane flying from MSP and therefore is more than adequate to capture flight path information. To handle the sheer volume of points created by the conversion, the points were separated into daily feature classes. Then a kernel density estimation was performed on these point datasets. Because flight velocities are not computationally represented by rapid change between neighboring points, each point – rather than consecutive point pair – serves as a kernel center. The initial conversion of flight lines to points turns continuous flight trajectories into instantaneous, discrete events, while the subsequent field-based analysis of the flight points reinstates the continuity of the flight paths and the noise that they bring about.

3.4 Time-based weighting of departures

As indicated by the resident interviews and other sources described above, it is critical to capture the temporal element of noise impacts. In order to represent aircraft noise so that experiences at different hours or different days are differentiated, numerous choices exist about how to divide up flight events over time. One possible representation, for example, would be to group flight events into one- or two-hour segments, so that each flight in that set would be of equal importance. However, as noted above, temporal snapshots or use of crisp boundaries poses problems. An arbitrary segment length, like one hour, can be limiting in terms of the amount of time a resident might put aside for a particular activity that could be disrupted. In addition, crisp boundaries at the end of each segment in which departures occur makes the segment even more arbitrary (e.g., why an hour and not 1.67 hours?). In addition, the representation of planes flying overhead becomes exaggerated if the majority of those planes occur close to the start or the end of the segment, so perhaps a relatively long period of time passes within that segment that is free of the disruption.

The analysis adopts a fuzzy logic approach centered around the turn of each hour so that departure flights are inversely valued based on their distance from the center time. As a temporal representation, the weighting system provides a field-based approach to time that blends linear and cyclical notions of time designed to reflect human perception. Perceptually, it addresses how a flight might be less significant the farther it occurs from the present time, while its impact still contributes to the present experience. Precedents of the fuzzy snapshot approach include the work of Dragicevic and Marceau (2000), who adopt the approach to record nominal values in a land use change study, where the membership of an area belongs to one or another land use type during a transitional period of change. Prats, Puig, Quevedo, and Nejjari (2010), for a study that seeks an optimized trajectory for airport departures, adopt a temporal fuzzy membership scheme for departure data. While the methodology is similar to this chapter’s in terms of a membership rule based on temporal distance, classification is restricted to nominal categories of morning, afternoon, and night. In this analysis, time-based departure data are given membership values for an extensive dataset and a more fine-grained resolution of time intervals. Fuzzy membership pertains to the departure's importance relative to the experience of flights overhead at the "kernel" time (i.e. the "present" turn of the hour).

The degree to which flights cluster near the kernel time can be addressed by way of this fuzzy membership, where the value of a point is based on time difference from the center, as long as it occurs within an hour before or after. In order to analyze the flight patterns based on time cycles, two-hour periods were selected out of the data to be centered on every hour. By selecting two-hour segments, the analysis represents what the spatiotemporal distribution of departures is like "at about" that central hour – a way of reflecting the colloquial concerns of residents. Hence, an inquiry into what departures are like at about 8 PM would require accounting for departures between 7 PM and 9 PM, giving the center time – in this case, 8 PM – the highest value. A linear 0 to 1 scale is used based on how close the departure time is to the center time, with a departure at exactly 7 PM or 9 PM being worth 0 and at exactly 8 PM being worth 1. A point exactly forty-five minutes before or after the center time would have a weight of 0.25, a half hour before or after with a weight of 0.5, fifteen minutes before or after with a weight of 0.75, and so on.

In Figure 3.7, the clustering of flights around 8 PM in the right-hand scenario will be valued higher than the flights in the scenario on the left. This weighting system allows for a two-hour segment to represent a brief experience with departure patterns in which frequency of departures could be represented at a particular time, with planes having

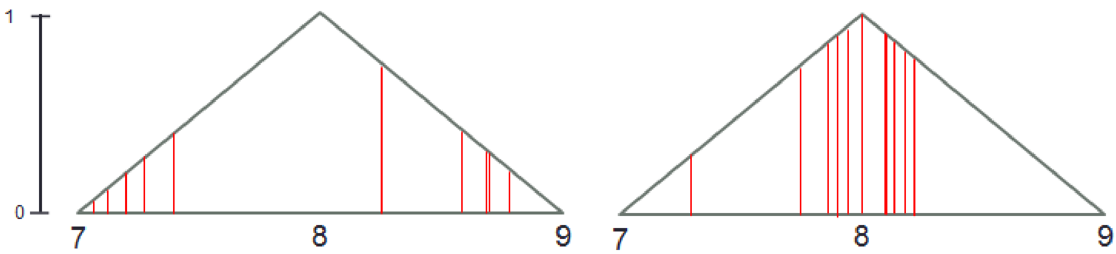

Figure 3.7: Time-weighted clustering scenarios

more of an impact on residents the closer they occur to that time. By assigning these temporal proximity weights to the points, the weights can be incorporated into point statistic analysis and subsequent raster representation.

3.5 Altitude-based exposure index

The representation of altitude in this dataset is based on a simplification: that loudness is proportional to altitude. In this case, the altitude of a plane is directly tied to a distance decay factor in which the sound level drops by 6 decibels with doubling of distance. The quasi-decibel value is then converted to a non-logarithmic quantity that is roughly akin to loudness perception.

Hence, when modeling the flight impacts on the basis of time and altitude alone, many critical attributes are ignored, including plane type, meteorological conditions, land cover, and so on – essentially, many of the factors used in calculating the DNL using INM. The altitude data is assumed to be directly related to the sound pressure level (*SPL*) and to loudness perception (*L*). Assumptions include: 1) a typical plane (with an Airbus A320 considered representative) as having an SPL of 85 dBA at 300 meters above ground (Dresden International Airport, n.d.), 2) SPL reduced by 6 dBA with each doubling of altitude (*alt*) (Sinha & Labi, 2007), and 3) loudness perceived as doubling for every 10 dBA increase. Converting altitude to sound pressure level, which is then converted to loudness perception, requires the following two calculations:

$$SPL = 85 - 6\log_2 alt/300$$

$$L = 2^{(SPL-40)/10}$$

The conversion of sound pressure level to loudness perception in this analysis is based on equating decibels with phons, which refers to the loudness perceived at a 1000-hertz frequency. Although this relationship would be modified for higher or lower frequencies, the generalized relationship is assumed as adequate for this study in order to compare different flight patterns over time.

3.6 Raster analysis

The aim of the raster map output is not to create datasets that focus on one residential experience over another, but to provide a data bank that allows for an understanding of what patterns of overhead departures have occurred on any day of the week and any hour of day. Certain regularities can be expected to occur over time, but discrepancies will also be found year to year. The output is the product of the time-weighted flights and the loudness perception value. The grid images are created using kernel density estimation, wherein point statistics are calculated with 100-meter resolution in a 3-by-3 cell neighborhood. The time weight raster layer represents the sum of the weighted values of the points within the neighborhood. The altitude-based loudness layer represents the point of the aircraft with the median altitude in the neighborhood. The means for making a composite time-weighted exposure output based on the time-weighting and the altitude rasters can be varied, so that the importance of the former versus the latter can be adjusted. For example, in the Thursday 11 AM representation in Figure 3.8, the flight that veers off to the east ends up with a negligible value in the time-weighted exposure despite its low altitude. The time-weighted value of 0.49 (given its 10:29 departure) plays a part in its minor importance, but its trajectory being unique to that flight plays a larger one.

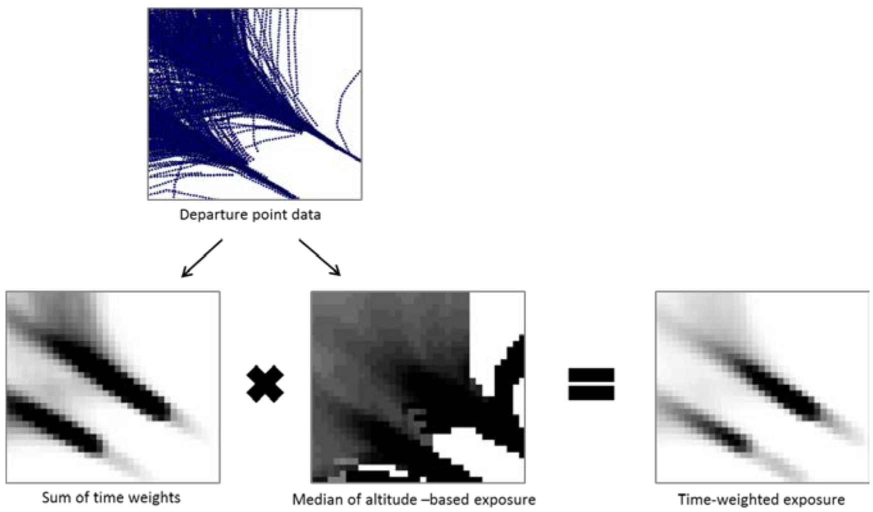

Figure 3.8: Conversion of departure points to time-weighted exposure raster dataset (Sample area for Thursday, 11 AM, 2010)

4. Results

The approach to mapping airport noise described above is flexible in that it can explore temporality in many ways. To simplify matters and draw out general trends, a raster based on both day of week and hour of day represents the "grid unit" for this study (e.g., a single raster layer can illustrate what flight noise is like for Fridays at 7 PM). In addition, we can create an average composite per hour in order to not differentiate days (e.g., a single raster can describe noise at 7 PM regardless of day). Note that the representations here are for flights in what could be informally referred to as the summer season – the Friday before Memorial Day to Labor Day – for the study area because this period is of peak interest to residents spending their time outdoors or having their windows open. These composites, still restricted to the warm months and consolidated by year, allow for some daily variation to be minimized, so that some more general comparisons can be made between years. Using these composites, change between years is represented by simple image differencing – where $year_x$ is subtracted by $year_{x-1}$.

4.1 Hour-by-hour comparisons

The maps shown in Figure 3.9 represent the varying impact of cumulative flights on Fridays in the summer season of 2011. Hour by hour, they indicate the varying requency of flights throughout the day, and how departure direction and pathways upon ascent will vary. Importantly, when understanding how residents below might be affected by these flights, the concentration and intensity of pathways is considered. The maps show how nighttime flights have a tendency to depart heading southeast off of the 12L and 12R runways, while flights departing off of 30L and 30R to the northwest and over south Minneapolis are proportionally more common during the day. Variations hour-to-hour also show that after a high frequency of planes at 8 PM, departure traffic begins to dwindle with fewer at 9 PM before traffic around 10 PM temporarily rebounds and becomes more commonly directed southeast.

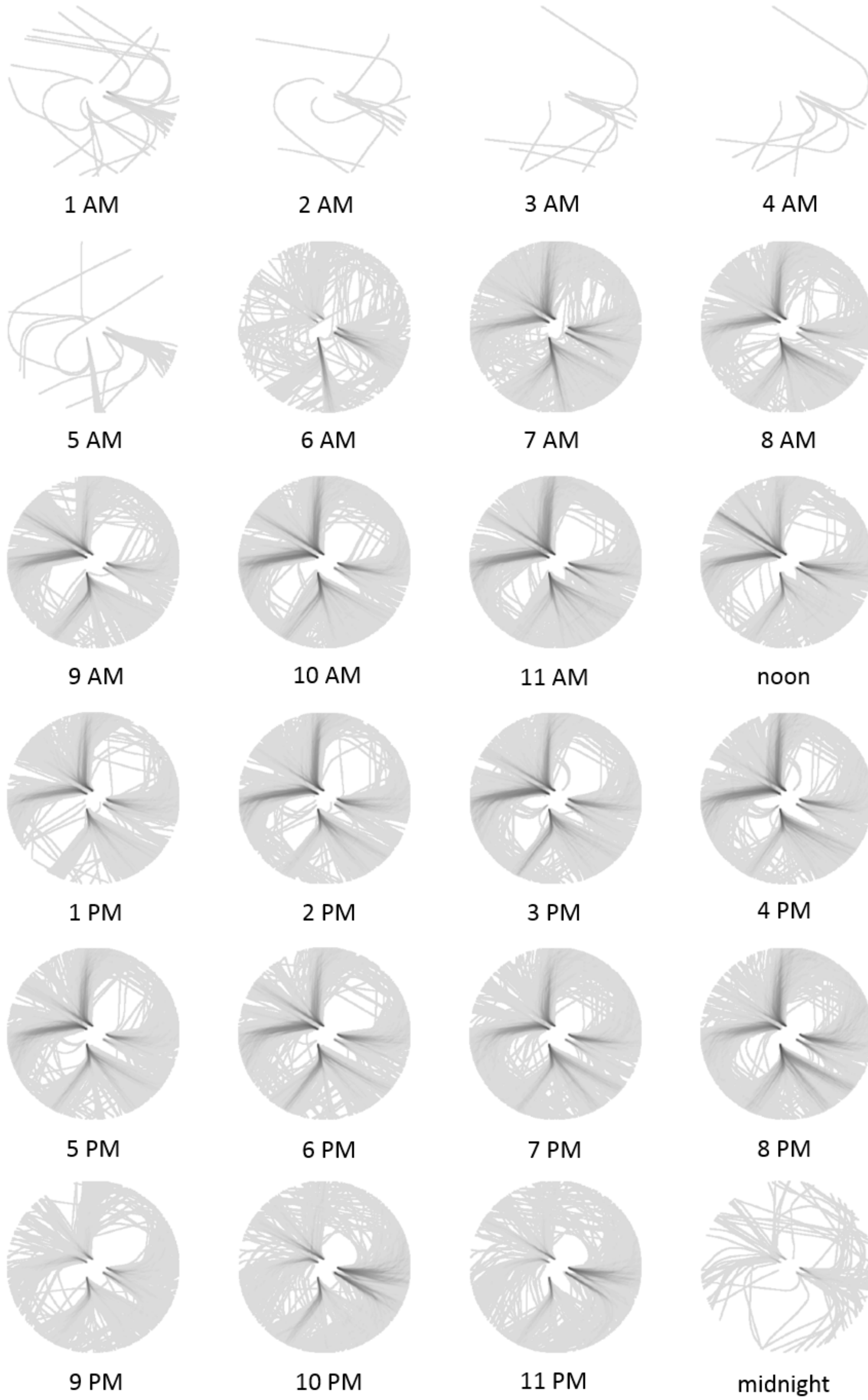

Figure 3.9: Friday by the hour, 2011

4.2 Yearly comparisons of summer flights

Figure 3.10 shows composites of the 8 AM, 12 PM, 4 PM, and 8 PM flights for the entire study area in 2010 and 2011, plus the difference of the two years. The images

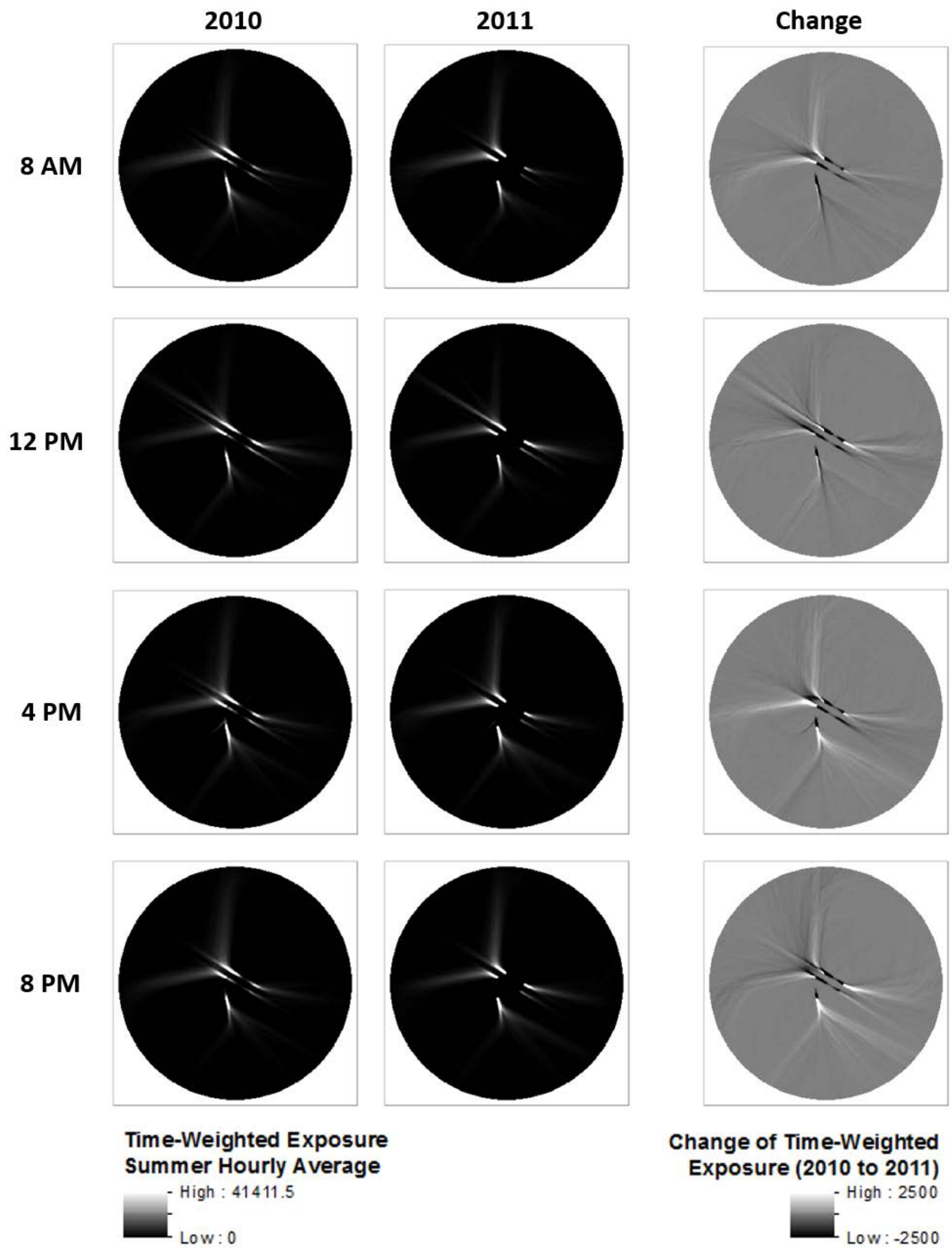

Figure 3.10: Comparison of raster output for 2010 and 2011 for entire study area

show that for departures heading due north, 2011 departures tend to be more concentrated and on average, slightly shifted eastward, compared to their 2010 counterparts.

A closer look at South Minneapolis, as seen in Figure 3.11, shows that 2010 flights heading north tend to be more spread out and less concentrated. Flights in 2011

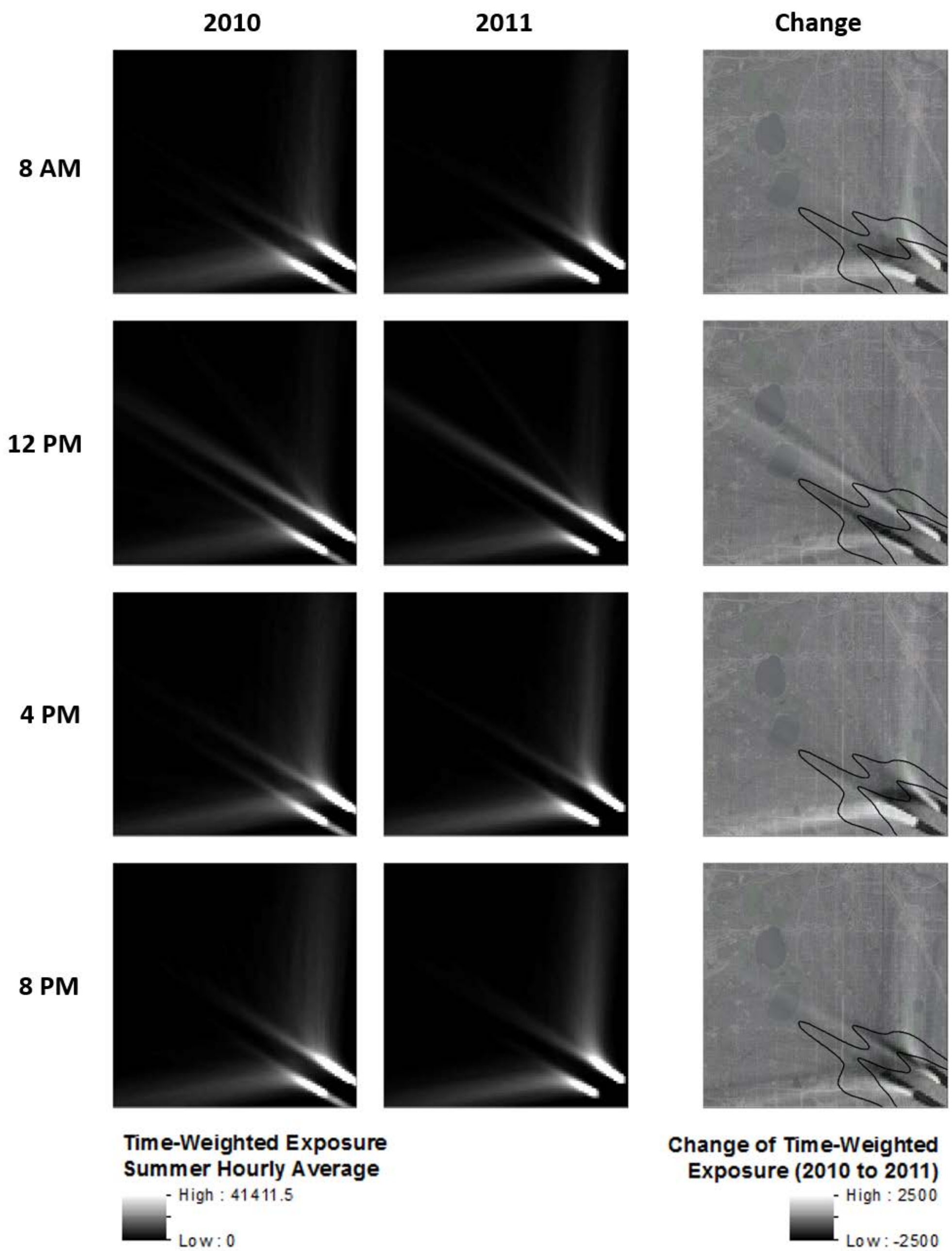

Figure 3.11: Comparison of raster output for 2010 to 2011, northwest detail (with 2011 DNL contours for reference)

are condensed into a narrower corridor for flights that head due north, over neighborhoods where residents spoke out about increased noise. Flights in 2010 tend to be somewhat greater most often to the west, but sometimes to the east as well, of the 2011 corridor. Another fairly consistent pattern – one which can be seen as resulting from FAA protocol change following the September 2010 near-collision – is the greater 2010 traffic just due northwest of the area between runways 30L and 30R, showing that 2010 departures tend to include more flights crossing the runway lines after taking off – hence, more flights off of 30L heading northeast and more flights off of 30R heading west.

5. Discussion and conclusions

The analysis presented here is purposely simpler than the FAA-sanctioned INM. It forgoes incorporation of numerous variables such as aircraft type, wind and weather patterns, and terrain. With this simplicity comes power, however, in that this work offers a straightforward way of using existing data to grant greater insight into the spatiotemporal nature of airport noise and its impacts on real-world residents, who could use it in several ways. First, this approach gives a more vivid understanding of what a particular time period might have in store than is provided by a simple annual DNL map. Second, this approach can give spatiotemporally specific snapshots of time that can be personalized to a variety of schedules. A common problem for the prospective home buyer or renter, for example, is the inability to have any certainty about what the noise environment in a neighborhood will be. The times when they get to visit a house of interest might be during one of the quieter moments to be experienced in that location.

Maps that break down the flight paths by time of day, while also accounting for spatial concentration and altitude, offer a means for residents to get a better grasp on what types of patterns to expect. Third, at the policy level that concerns itself with issues ranging from conservation hotspot mapping to land-use zoning, mapmaking can have a direct impact on how regulations are carried out, which in turn can affect outcomes regarding the environment and human well-being. Contour maps created for airport noise regulation have had, and continue to have, direct impact on the landscape via land-use planning and in terms of who is eligible for mitigation. Mitigation, including sound insulation and central air-conditioning, adds thousands of dollars to the value of a home, while land-use zoning can shift millions of dollars in development and economic activity.

This analysis of airport noise suggests several future research directions. First, the approach could include more characteristics used in the INM to create DNL maps, at the cost of adding complexity. Second, the spatial analysis employed here does not address such issues as actual exposure of people to noise based on spending time outside. Considerations such as the degree to which weather patterns allow for comfortable nights spent outside – given sunny skies, mild temperatures, and low humidity – can significantly affect how much noise disrupts outdoor activities. Therefore, one future model enhancement to consider is the amount of time people actually spent outside one summer relative to the next based on how much comfort was afforded by temperature and humidity level. The more that good weather tempts residents to get outdoors, the more annoyed they can be when aircraft noise thwarts their appreciation. Third, the point representation of flight data also has simplifications, given that flight path times are not estimated per point along the line trajectory. Estimating the times along these paths is possible given that we know the aircraft type and the time stamps of the line endpoints. Fourth, we can better estimate altitude-derived loudness by considering differences among aircraft. It is not clear how much improvement the time- and aircraft-related enhancements would add to the analysis, given, respectively, the short time period elapsed before aircraft leave the 15-km boundary and the overall volume and concentration of flights that could overwhelm the contributions of different aircraft types.

In sum, this chapter has offered a means of representing residential exposure to aircraft, based on altitude as calibrated to correspond to loudness, and broken down to segments at the turn of the hour with departures weighted according to proximity to that hour. One of the notable characteristics of airport noise contour mapping is the high degree of temporal generalization. Even with a 10-decibel penalty for night-time flights, the metric used to average the noise level does not provide insight into *changes* over time. Discrepancies between residential accounts of experience with aircraft noise and the policy-dictated mapping of average noise contours suggest that measurement of noise impact should put greater emphasis on temporal and event-based characteristics of noise. Visualization and analysis of characteristics like spatiotemporal frequency and altitude provide the opportunity to investigate the types of flight patterns that residents cite as disruptive but which do not get explicitly incorporated in the DNL.

References

Aigner, W., Miksch, S., Schumann, H., & Tominski, C. (2011). *Visualization of time-oriented data*. London, UK: Springer.

Airport Noise Compatibility Planning, 14 C.F.R. § 150 (2015).

Allard, N. E., & Sandvick, G. N. (1993). *Minnesota aviation history 1857-1945*. Chaska, MN: MAHB Publishing, Inc.

Andrienko, G., Andrienko, N., Hurter, C., Rinzivillo, S., & Wrobel, S. (2013). Scalable analysis of movement data for extracting and exploring significant places. *IEEE Transactions on Visualization and Computer Graphics*, *19*(7), 1078–94. http://doi.org/10.1109/TVCG.2012.311

Beranek, L. (2008). *Riding the waves: A life in sound, science, and industry*. Cambridge, MA: MIT Press.

Bütikofer, R. (2013). Airport noise. In G. Licitra (Ed.), *Noise mapping in the EU: Models and procedures* (pp. 129–158). Boca Raton, FL: CRC Press.

Chrisman, N. R. (1998). Beyond the snapshot: Changing the approach to change, error, and process. In M. J. Egenhofer & R. G. Golledge (Eds.), *Spatial and temporal reasoning in geographic information systems* (pp. 85–93). Oxford, UK: Oxford University Press.

Cidell, J. (2008). Challenging the contours: Critical cartography, local knowledge, and the public. *Environment and Planning A*, *40*(5), 1202–1218.

Couclelis, H. (1992). People manipulate objects (but cultivate fields): Beyond the raster-vector debate in GIS. In A. U. Frank, I. Campari, & U. Formentini (Eds.), *Theories and methods of spatio-temporal reasoning in geographic space: International conference GIS – From space to territory: Theories and methods of spatio-temporal reasoning* (pp. 65–77). Berlin: Springer-Verlag.

Demšar, U., Buchin, K., van Loon, E. E., & Shamoun-Baranes, J. (2015). Stacked space-time densities: A geovisualisation approach to explore dynamics of space use over time. *GeoInformatica*, *19*(1), 85–115. http://doi.org/10.1007/s10707-014-0207-5

Demšar, U., & Virrantaus, K. (2010). Space–time density of trajectories: exploring spatio-temporal patterns in movement data. *International Journal of Geographical Information Science*, *24*(10), 1527–1542. http://doi.org/10.1080/13658816.2010.511223

Downs, J. A. (2010). Time-geographic density estimation for moving point objects. In S. I. Fabrikant, T. Reichenbacher, M. van Kreveld, & C. Schlieder (Eds.), *Lecture notes in computer science (Geographic information science)* (Vol. 6292, pp. 16–26). Berlin: Springer. http://doi.org/10.1007/978-3-642-15300-6_2

Doyle, P. (2011a, September 22). Near-collision over MSP means more noise for some. *Star Tribune*. Retrieved from http://www.startribune.com

Doyle, P. (2011b, November 17). FAA reconsiders rise in airport noise. *Star Tribune*. Retrieved from http://search.proquest.com/newsstand/docview/904415618 /625EDF11C3B546BBPQ/1?accountid=14586

Dragicevic, S., & Marceau, D. J. (2000). A fuzzy set approach for modelling time in GIS. *International Journal of Geographical Information Science*, *14*(3), 225–245. http://doi.org/10.1080/136588100240822

Dresden International Airport (n.d.). Noise monitoring. Retrieved from http://www.dresden-airport.de/company/noise-and-environment/noise-protection/noise-monitoring.html.

Federal Aviation Administration (2007). *Environmental desk reference for airport actions*. Retrieved from https://www.faa.gov/airports/environmental /environmental_desk_ref/media/desk-ref.pdf

Federal Interagency Committee on Noise. (1992). *Federal agency review of selected airport noise analysis issues*. Retrieved from ftp://public-ftp.agl.faa.gov /Materials%20Released%20Related%20to%20the%20OM%20EIS/3-31-2005%20World%20Gateway%20Related%20Documents/787_122.pdf

Fidell, S. (2003). The Schultz curve 25 years later: A research perspective. *The Journal of the Acoustical Society of America*, *114*(6), 3007–3015. http://doi.org/10.1121/1.1628246

Foertsch, K., & Davies, P. (2013). *The number-of-events as a predictor variable in aircraft noise annoyance models* (Report No. PARTNER-COE-2013-002). A PARTNER Project 24 Report. Cambridge, MA. Retrieved from PARTNER website: http://web.mit.edu/aeroastro/partner/reports/proj24/proj24-2013-002.pdf

Frank, A. U. (1998). Different types of “times” in GIS. In M. J. Egenhofer & R. G. Golledge (Eds.), *Spatial and temporal reasoning in geographic information systems* (pp. 40–62). New York: Oxford University Press.

Friedman, W. (1990). *About time*. Cambridge, MA: MIT Press.

Galton, A. (2004). Fields and objects in space, time, and space-time. *Spatial Cognition & Computation*, *4*(1), 39–68. http://doi.org/10.1207/s15427633scc0401

Goodchild, M. F. (2013). Prospects for a space–time GIS. *Annals of the Association of American Geographers*, *103*(5), 1072–1077. http://doi.org/10.1080/00045608.2013.792175

Grenon, P., & Smith, B. (2004). SNAP and SPAN: Towards dynamic spatial ontology. *Spatial Cognition and Computation*, *4*(1), 69–103. http://doi.org/10.1207/s15427633scc0401_5

Harper, D. V. (1971). The Minneapolis-St. Paul Metropolitan Airports Commission. *Minnesota Law Review*, *55*(3), 363–459.

Langran, G. (1992). *Time in geographic information systems*. Bristol, PA: Taylor & Francis.

Langran, G., & Chrisman, N. R. (1988). A framework for temporal geographic information. *Cartographica: The International Journal for Geographic Information and Geovisualization*, *25*(3), 1–14. http://doi.org/10.3138/K877-7273-2238-5Q6V

Metropolitan Airports Commission (2011a). 2010 MACNOMS Flight Track Data [Data file, SFTA download]. Minneapolis, MN: MAC.

Metropolitan Airports Commission (2011b). Public input meeting comments/responses. October 25, 2011. Retrieved from https://www.macnoise.com/pdf /pim_responses_web_10-25-11.pdf

Metropolitan Airports Commission (2012a). 2011 MACNOMS Flight Track Data [Data file, CD-ROM]. Minneapolis, MN: MAC.

Metropolitan Airports Commission (2012b). Annual Noise Contour Analysis: Comparison of 2010 Actual Noise Contour and the 2007 Forecast Noise Contour, February 2011 (Rev. April 2012). Retrieved from https://www.macnoise.com/pdf /msp_annual_contour_report_2010.pdf

Metropolitan Airports Commission (2012c). Annual Noise Contour Analysis: Comparison of 2011 Actual Noise Contour and the 2007 Forecast Noise Contour, February 2012. Retrieved from https://www.macnoise.com/pdf/2011-MSP-Annual-Noise-Contour-Report-2-29-12.pdf

Metropolitan Airports Commission (2013). Examining runway use at MSP. Retrieved from https://www.macnoise.com/news/examining-runway-use-msp

Metropolitan Airports Commission (2014). Wind factors at MSP. Retrieved from https://www.macnoise.com/news/wind-factors-msp

Metropolitan Airports Commission (n.d.). Minneapolis-St. Paul International Airport (MSP) Annual Noise Contour Analysis: Comparison of 2015 Actual Noise Contour and the 2007 Forecast Noise Contour. Retrieved from https://www.macnoise.com /pdf /msp-2015-annual-noise-contour-report-web.pdf

Minnesota v. Metropolitan Airports Commission, No. 27-CV-05-5474, (D. Minn., order granting partial summary judgment, Jan. 25, 2007). Retrieved from http://www.ci.minneapolis.mn.us/www/groups/public/@communications/documents/webcontent/convert_254051.pdf

Murphy, E., & King, E. A. (2010). Strategic environmental noise mapping: Methodological issues concerning the implementation of the EU Environmental Noise Directive and their policy implications. *Environment International*, *36*(3), 290–298. http://doi.org/10.1016/j.envint.2009.11.006

National Transportation Safety Board. (2010). NTSB investigating near midair collision over Minneapolis involving commercial jetliner and small cargo aircraft [Press release]. Retrieved from http://www.ntsb.gov/news/press-releases/Pages/NTSB_Investigating_Near_Midair_Collision_over_Minneapolis_Involving_Commercial_Jetliner_and_Small_Cargo_Aircraft.aspx

Pearson, M. W., & Riley, D. S. (2015). *Foundations of aviation law*. Surrey, UK: Ashgate Publishing.

Peuquet, D. J. (1994). It's about time: a conceptual framework for the representation of temporal dynamics in geographic information systems. *Annals of the Association of American Geographers*, *84*(3), 441–461.

Peuquet, D. J. (2002). *Representations of space and time*. New York: The Guilford Press.

Prats, X., Puig, V., Quevedo, J., & Nejjari, F. (2010). Multi-objective optimisation for aircraft departure trajectories minimising noise annoyance. *Transportation Research Part C: Emerging Technologies*, *18*(6), 975–989. http://doi.org/10.1016/j.trc.2010.03.001

Schultz, T. J. (1978). Synthesis of social surveys on noise annoyance. *The Journal of the Acoustical Society of America*, *64*(2), 377–405. http://doi.org/10.1121/1.382013

Shelerud, S. (2012). *Departures analysis: What has changed?* [PDF document]. Minneapolis, MN: Federal Aviation Administration. Retrieved from Metropolitan Airports Commission website https://www.macnoise.com/sites/macnoise.com/files/pdf/noc_presentation-1-18-12x.pdf

Shepherd, I. D. H. (2008). Travails in the third dimension: A critical evaluation of three-dimensional geographical visualization. In M. Dodge, M. McDerby, & M. Turner (Eds.), *Geographic visualization: Concepts, tools and applications* (pp. 199–222). West Sussex, UK: John Wiley & Sons.

Sinha, K. C., & Labi, S. (2007). *Transportation decision making: Principles of project evaluation and programming*. Hoboken, NJ: John Wiley & Sons, Inc.

U.S. Department of Transportation, Federal Aviation Administration, Great Lakes Region (1998). *Minneapolis-St. Paul International Airport planning process: New runway 17/35 and airport layout plan approval*. Retrieved from https://www.faa.gov/airports/environmental/records_decision/media /rod_minneapolis.pdf

U.S. Environmental Protection Agency (1974). *Information on levels of environmental noise requisite to protect public health and welfare with an adequate margin of safety* (Report No. 550/9-74-004). Washington, DC. Retrieved from http://nepis.epa.gov/Exe/ZyPDF.cgi /2000L3LN.PDF?Dockey=2000L3LN.PDF

Werner, C. M., Altman, I., & Oxley, D. (1985). Temporal aspects of homes: A transactional perspective. In I. Altman & C. M. Werner (Eds.), *Home Environments* (pp. 1–32). New York: Plenum Press.

Worboys, M., & Duckham, M. (2004). *GIS: A computing perspective* (2nd ed.). Boca Raton, FL: CRC Press.

Young, M. (1988). The metronomic society: Natural rhythms and human timetables. Cambridge, MA: Harvard University Press

Chapter 4. Time-Weighted Aircraft Noise Exposure Mapping: A Cumulative Population-Based Approach

Summary. This chapter applies a new way of mapping airport noise to determine its differential impacts on human populations. It employs a model of the spatiotemporal patterns of departures from the Minneapolis-St. Paul International Airport in order to develop a fine-scaled portrayal of how noise intersects with social and economic variation in residents. The value of this analysis lies in the provision of spatiotemporal flight data that reflects patterns of time that can correspond with the day-to-day variation in residential activity and behavior, and that in turn maps onto specific variations in socioeconomic characteristics. In addition to offering greater spatiotemporal specificity concerning which populations are affected by noise at any given time, it can also be used to understand how changes in airport noise over longer time spans will affect new populations.

1. Introduction

Aircraft noise has a significant impact on residential life. Since noise, defined as unwanted sound, is a perceptual phenomenon, the manner in which aircraft noise varies in time greatly depends on spatiotemporal patterns of residence. While noise perception is guided to greater or lesser degrees by environmental context (Gidlöf-Gunnarsson & Öhrström, 2007; van Praag & Baarsma, 2005), differences in sensitivity (Miedema, 2007), and by social factors (Maris et al., 2007; van Praag & Baarsma, 2005), the issue of physical exposure is paramount. Regardless of the varying individual influences on perception, noise is generally more disruptive when residents are at home and when they are either outside or have their windows and doors open. Indeed, as explored below, standard policy responses to airport noise are comprised of controlling when flights occur (e.g., scheduling fewer at night), managing where they occur through routing and via land use compatibility planning, and mitigating the impact of noise on residences (e.g., installing sound insulation and air-conditioning).

In general, these noise policies are effective for the population as a whole, but they ignore specific subpopulations because the metrics are defined in very broad spatial and temporal terms. There is a great deal of diversity on the ground in terms of how behavior and lifestyle preferences lead an individual to places of increased or decreased noise exposure and annoyance. At a very broad scale, land use compatibility planning accounts for noise by striving to send planes over agricultural, industrial, or commercial areas instead of over residences or noise-sensitive areas like hospitals, libraries, and schools. Such measures result in fewer people being exposed, and therefore less annoyed in aggregate, but they make no accommodations beyond these general categories. Nor do these rules account for hourly cadences of residential living, but instead only recognize general day-versus-night distinctions.

Of the planes that pass over residential areas, our understanding of noise's impact does not consider spatial and temporal differences in the daily behavior, activities, and perceptions of those who live below and who have ears to hear. Since sound is deemed noise based on residential perception, and noise brought about by urban airports overwhelmingly affects residential environments, how do we arrive at a mapping system that shows not just potential exposure, but exposure that actually *matters* given where people live? If noise policies aim to minimize the number of people who are exposed, there is need for improved methodologies that offer greater spatial and temporal specificity of noise impacts, not only in terms of what causes noise – airplanes – but also in terms of who is affected when and where.

This article offers a new approach for understanding the spatiotemporal nature of noise impacts by combining finer spatiotemporal resolution of flight paths and greater specificity in the identification of affected populations. Drawing on a method for determining the spatiotemporal variation of departures presented in Chapter 3, this chapter presents a methodology for examining the *cumulative* impact of departures on human populations. Section 2 offers background on airport noise and how it affects residential life. Section 3 then details the study site and methods, focusing on developing high resolution population maps and then combining them with noise maps that incorporate frequency, concentration, and altitude. Section 4 describes how these methods illustrate which residents are most impacted by airplane noise and how certain sub-groups could be more adversely affected than others based on where they live. Section 5 wraps up with a broader discussion of results and consideration of future research directions.

2. Airport noise and measurement of who is affected by noise

Aircraft noise has long been a major annoyance for residents who live near airports. While the use of the standard mapping approaches based on DNL for determining how to measure noise exposure has been broadly accepted by regulatory agencies (Fidell, 2003; Mestre, 2008), strong community response to the noise in the Twin Cities has sometimes originated from locations not considered unduly affected by noise based on the DNL mapping methodology. Despite standards of measurement and mapping that have been arrived at by consensus, many factors are not accounted for in understanding who is affected by noise. These factors include who will be at home the most often, who will be home at the times that aircraft are most likely to fly overhead, who enjoys spending time outdoors the most, who desires fresh air and the sounds of nature by way of open windows, and so on. In turn, these factors can play a significant role in terms of determining who is most affected by airport noise.

2.1 Annoyance and the DNL

Annoyance is regarded as the human response most appropriate for gauging noise impact (Mestre, 2008). The relationship of DNL to annoyance has set the standard for how noise should be measured and mapped. Schultz (1978) compared various studies of noise and annoyance, and proposed a dose-response function that would determine the proportion of people who were “highly annoyed” by a given level of noise. In 1992, the Federal Interagency Committee on Noise (FICON) (1992) adopted an updated fitting function proposed by Fidell (1991) when declaring the use of DNL and the 65-DNL threshold as standards for addressing noise problems. Many studies were subsequently conducted that implicitly assumed the DNL to be the best available metric for measuring effect on annoyance (Mestre, 2008). Concerns about the DNL have subsequently been raised, however, based on doubts about whether a single measure can adequately capture many physical components of noise over time – including number of events, duration, and loudness – as well as the vagaries of human response (Fidell, 2003). Concern has also been raised about the fitting curve used by FICON for the 65-DNL threshold as over-simplified (Fidell, 2003; Mestre, 2008).

Based solely on DNL-based measurements of noise exposure, strategies for reducing exposure can be regarded as successful, given that the number of people in the USA exposed to aircraft noise above the 65 DNL threshold has dramatically decreased. The Federal Aviation Administration (2014b) estimates that this number declined from 498,000 in 2005 to 321,000 in 2012. The long-term decline over the past three decades is primarily attributed to the use of noise reduction technologies applied to existing aircraft and the phasing out of older and noisier Stage 1 and Stage 2 aircraft[3] (Federal Aviation Administration, 2014b). The mapping of noise contours based on the DNL, however, does not account for differential schedules and preferences in residential living. Instead, the noise contours are based on a year-long average plus the projected airport traffic for the coming five years.

2.2 Impacts on people

The literature on exposure to aircraft noise addresses three dimensions – the economic (especially housing values), the psychological (relationship to home and landscape), and the political (policy, environmental justice). In addition to questions about exposure, the issue of how people respond to the noise through behavior

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[3] Stages represent noise compliance standards that planes must meet in order to fly. At this time, civil jets that weigh more than 75,000 pounds must be Stage 3 or 4, while planes that are lighter can be Stage 2, 3, or 4 (Federal Aviation Administration 2014a).

adjustment, including political engagement, has given nuance to our understanding of the social and psychological factors that can influence a correlation-based framework of investigation.

Much research on the human dimensions of noise impacts addresses how residents bear a cost when exposed to noise. This cost can be determined either monetarily, in terms of the effect of the noise on housing values or willingness to move, or comparatively, in which case the burden of noise is measured in relation to amenities that could serve as compensation. Early on, Flowerdew (1972) brought up questions about the economic cost of airport noise, a cost that would be borne by manufacturers and homeowners in terms of the disruptive quality of the noise, thereby affecting activity performance and causing a decline in property values, and a cost for planners who must take into account the narrowing of options brought on by the noise. Numerous articles more recently have examined the relationship of aircraft noise and airport proximity to housing values (Cohen & Coughlin, 2008, 2009; Espey & Lopez, 2000; Tomkins, Topham, Twomey, & Ward, 1998), wherein noise is negatively correlated to prices. (In the Cohen and Tomkins papers, proximity is seen as an amenity, while Espey finds that it is not.) The cost of the noise has also been addressed in willingness-to-pay studies (Feitelson, Hurd, & Mudge, 1996).

Importantly, most studies on the cost of aircraft noise adopt the DNL as the measure of noise exposure, despite the controversies that linger about its regulatory use (Cidell, 2008). Feitelson et al. (1996), however, address how use of the DNL, as well as other peak average metrics, leads to an underestimate of the cost, citing the DNL's failure to incorporate frequency of overhead flights. While use of the DNL is understandable given its primacy in the noise regulatory environment in the United States, the degree to which the noise has caused rancor in neighborhoods outside the DNL contours (Cidell, 2008) suggests that alternatives would increase our understanding of who is exposed and when, and perhaps determine which factors, including frequency, need to be better accounted for in order to determine the actual cost.

Beyond cost, the issue of *who* gets affected *where* is a matter of environmental justice, especially when addressed in terms of income, economic status, or ethnicity. Certain sub-populations are sometimes more greatly affected by environmental degradation than others. Aircraft noise has also been addressed as a matter of environmental justice. Sobotta et al. (2007) show that Hispanic residents were more greatly affected by noise exposure than others in the vicinity of the Phoenix Sky Harbor International Airport. Ogneva-Himmelberger and Cooperman (2009) focus on both environmental justice and cost, first by exploring the relationship between noise exposure with household income, housing value, and the presence of blacks and Hispanics, and then examining the clustering effects of high and low correlations of these variables. The study finds that more prevalent noise is correlated with higher percentages of minorities, lower incomes, and lower housing values. Unjust distribution of the noise is likely to be compounded when it leads to psychological impact. Maris et al. (2007) find, in a laboratory study, that annoyance increases when the conditions under which simulated airport noise occur are designed to be “unfair” (subjected to aircraft sound despite requesting another background sound) rather than neutral (not getting a choice). More directly related to distributional concerns is a feeling harbored by annoyed residents of possible misfeasance by the airport operators, which in turn aggravates the annoyance (Borsky, 1977).

Psychologically, airport noise has also been cited as decreasing residential sense of well-being. Van Praag and Baarsma (2005) explore some residential characteristics pertaining to life satisfaction and find that several are positively related to aircraft noise annoyance. Included among them are economic traits, including personal wealth and value of house. The size of family is also positively correlated, such that more children translates to more annoyance. Two other variables are also cited, and more relevant to the concerns expressed here – namely, the amount of time spent home during the day on weekdays and the presence of a garden. While the former applies directly to the increased exposure due to spending more time at home, the latter relates to the amplified exposure that comes with spending time outside and engaging with the natural world.

2.3 Incorporating time

This research addresses the question of which residents and how many residents in the airport region are affected by the noise in a comparative sense both spatially and temporally. To what degree might people, based on where they live, be exposed to aircraft noise as it changes throughout the day, hour to hour? How does noise exposure change year-to-year in a way that is not reflected by the DNL? How did the noise exposure change for Twin Cities residents between 2010 and 2011, a period in which protests against noise reached new heights? There is a need to make explicit the exposure of people based on where they live and take into account daily and hourly variations in mobility and residence to give insight into who might be most affected by the spatial and temporal vagaries of flights.

While much geographical literature about time and behavior has focused on human mobility, this analysis is less concerned about human mobility that occurs over time than it is about how the environment can change over time and affect how people live their lives as residents. Since most people do move around throughout the day, the question becomes one of the degree to which their quality of life is affected when they are back at their residence. Some airport noise studies have examined the temporal issue. One empirical approach to understanding who is annoyed focuses on the use of complaint data. Airports often provide the means for residents to complain about particularly loud flights or disruptive traffic patterns. Hume, Gregg, Thomas, and Terranova (2003) examine how the time-of-day of noise complaints is related to aircraft operations. While this data raises interesting questions about the temporal dimensions of response, patterns of airport noise complaint can entail relatively few complainers with a relatively high frequency of complaints. In a manner that goes beyond accounting for only those who are vocal about their annoyance, GIS and spatial analysis can determine the cumulative impact of aircraft noise, how particular subsets of population might be affected, and how these impacts change spatiotemporally. Addressing impacts of the overall population and its various segments requires a methodology that captures the extent to which they are affected.

3. Study site and methods

The region within a 15-kilometer radius surrounding MSP, as shown in Figure 3.6 and which includes the Twin Cities, offers an excellent setting in which to study noise impacts. The heightened reaction to the aircraft noise in 2011 compared with the year before, as discussed in Chapter 3, prompts a series of pressing questions regarding the mismatch between the DNL contours and the neighborhoods affected that year, especially north of Lake Hiawatha in south Minneapolis and in locations near the shared border of Minneapolis, Richfield, and Edina (shown in Figure 3.2). Given the ability to tease out noise differences over time – day to day and hour to hour – how should these spatiotemporally specific noise data be linked to human well-being in specific populations? This section describes a method for matching spatiotemporal noise data to socioeconomic data for the study, and then examining what the cumulative impact of it would be.

3.1 Representing residential location

This analysis utilizes 5-year data from the American Community Survey (ACS) for 2009 to 2013. Although the analysis here is restricted to the years 2010 and 2011, the dataset provides fine-grained attribute data not available with the 2010 census. The ACS is produced by the United States Census Bureau. It differs from the official census in two ways pertinent to this study: frequency of data collection and question detail. While the official census is conducted once every ten years, the ACS produces estimates based on samples acquired monthly. Datasets for small areas are rendered on the basis of five years' worth of data, while three-year and one-year extents are created for larger areas (U.S. Census Bureau, 2015). Compared with the official census, question detail is greatly increased in the ACS. Aside from documenting who lives at a given residence at the time of data collection, and general questions regarding age, race, ethnicity, family size, and number of household residents, questions in the ACS address the same themes but in much greater detail. Numerous additional themes are also addressed, including time and means of commute, status of household ownership or rental, age of house, health insurance coverage, and so on (U.S. Census Bureau, 2015).

In terms of analysis, the ACS provides three useful population measures. First, it provides overall population counts. Second, it provides sub-population variables that capture the presence of people of whom we can infer certain trends regarding their day-to-day presence at their home. Residents who will be at home most often will likely include people who are older and more likely to be retired, or who are not in the labor force. For the former category, males and females who are in the age-related categories of 65 and older (65 and 66 years, 67 to 69 years, …, 85 years and over) were aggregated into one category. Of those who are in the labor force, a field for that group in its entirety, and who must be at least 16 years old to be included, is available. Third, we can develop measures of residents who have a more daily, cyclical pattern away at work and back at home. These include people who commute to a conventional nine-to-five existence, and who are more likely to be back home from work in the early evening. Out of the larger category of workers at least 16 years old who work away from home, this analysis captures this subset of commuters by aggregating the fields of "time leaving home to go to work" for the half-hour spans of 6:30 to 6:59, 7:00 to 7:29, 7:30 to 7:59, and 8:00 to

8:29. The morning commute variable is also based on some simple assumptions – that leaving home between those times is most likely to account for variability in commute time while also corresponding best with jobs in which daily work hours would span between 8 AM and 6 PM. The possibility that these commutes could be for part-time jobs or that the evening activities might not involve an immediate return home cannot be ascertained. In addition to sample error, there are certainly a number of people either retired or without a job that still might spend time either volunteering or traveling. The overlap of people between the three subgroups – namely the 65 and older either with commuters or with the non-employed – is to be expected.

ACS data are among the best to use for this analysis but caveats apply. Most importantly, the ACS is a sample, and it is therefore subject to degrees of error nowhere nearly as significant in the ten-year census. With the more numerous and detailed questions of the ACS comes a greater margin of error in the results. The data collection for ACS can also be marked by non-response bias, wherein particular subgroups might be less likely to respond fully and accurately to the survey questions. The Census Bureau aims to minimize the occurrence of bias by numerous follow-up letters to encourage completion, and phone interviews to correct for omissions (U.S. Census Bureau, 2014).

3.2 Location-based aggregation of residential data

To geographically render ACS block group data so that it accurately represents where people live within the block group, residential categories (including single family detached, single family attached, multifamily, and mixed-use residential) were selected from the 2010 Generalized Land Use Data (Metropolitan Council, 2011). The categories were then dissolved so that they represent residential as a general category. The vector-based residential dataset was then intersected with the block groups, and dissolved once again in order to aggregate multiple, discrete residential polygons into one data record per block group. (See Figure 4.1 for block group and Figure 4.2 for final vector-based residential data per block group in the northwest portion of the study area.)

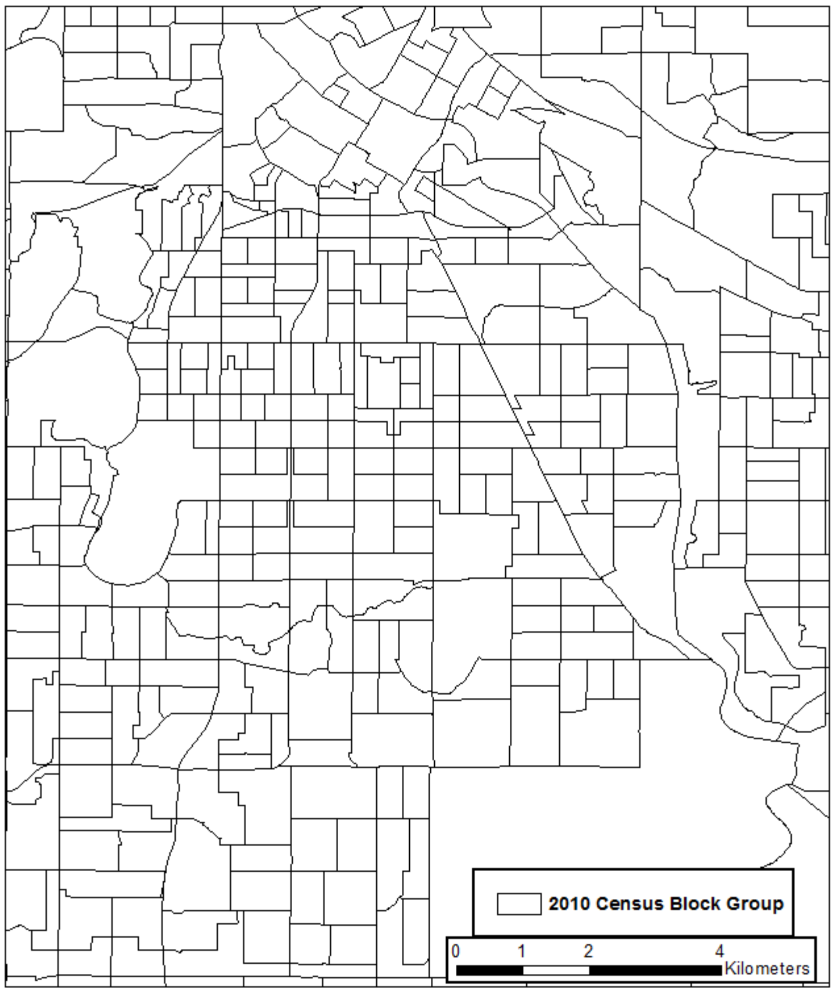

Figure 4.1: Census block groups: Areas west and north of airport

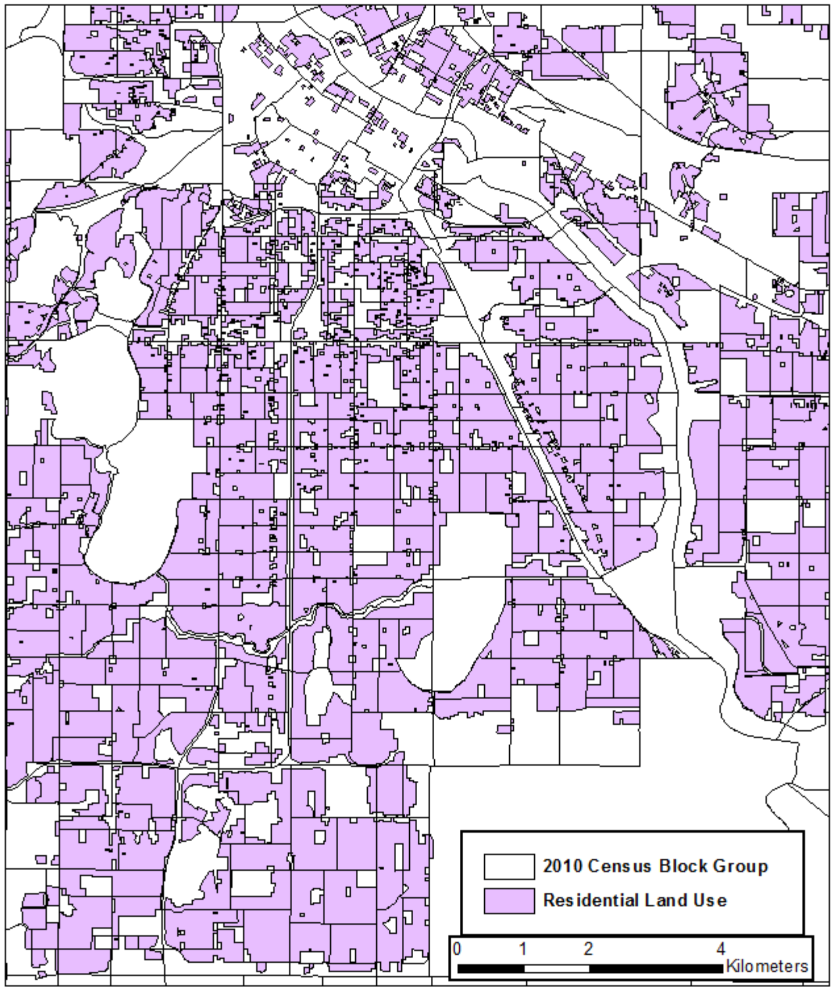

Figure 4.2: Residential land use dissolved per block group: Areas west and north of airport

3.3 Rasterization of population

Raster representation allows for a one-to-one cell correspondence between the time-weighted aircraft exposure grid and the population grid. Early creation of population raster datasets relied on interpolation from point data, including an inverse distance weighting method using census unit centroids (Bracken & Martin, 1989) or on the basis of other data points defined by the user (Martin & Bracken, 1991). More sophisticated ways of converting to raster have been achieved with dasymetric mapping (Holt, Lo, &

Hodler, 2004; Langford & Unwin, 1994; Mennis, 2002), where values can be more smoothly distributed cell by cell near enumeration boundaries.

In this analysis, a simpler, non-dasymetric conversion approach is taken. The availability of high-resolution land use datasets allows for the conversion to grid format by allowing for the census block group population data to be allocated to residential locations within the block group. With block group and residential land use fields in the same dataset, the block group's population totals are then standardized to 10,000-square-meter areas in anticipation of being distributed among the residentially located 100-meter cells that will be created when the data is converted to raster. For block group fields that represent population counts, the cumulative value per block group is divided by the area of residential land use in that block group. This quotient – the fractional "person" that would reside on one square meter of land – is multiplied by 10,000 to obtain a vector field of the estimated number of people living in each 100-meter cell per block group.

$$Cell\ value = 10{,}000\ x\ \frac{block\ group\ population}{residential\ area\ within\ block\ group}$$

The polygons for block-group-based residential land are then converted to raster data, with the standardized population values encoded in each cell. (See Figure 4.3 for the block group vector data and Figure 4.4 for the residential-based raster output.) Martin and Bracken (1991) have pointed out that both location and attribute errors are bound to occur with the creation of raster-based population data. In terms of location error, accuracy will decline with increased cell size. As for attribute values, accuracy will decrease with a greater mismatch between polygon shape and the resulting aggregation of contiguous cells that inherit the desired field value from the polygon (Congalton, 1997). This mismatch typically arises because of poor alignment between polygon boundaries and the cells that overlap them (Fisher, 1997).

To obtain a raster dataset with minimum error, a maximum-area algorithm was chosen for this conversion. Given a vector space that is composed only of residential or non-residential land, the maximum-area algorithm requires that a cell area have greater

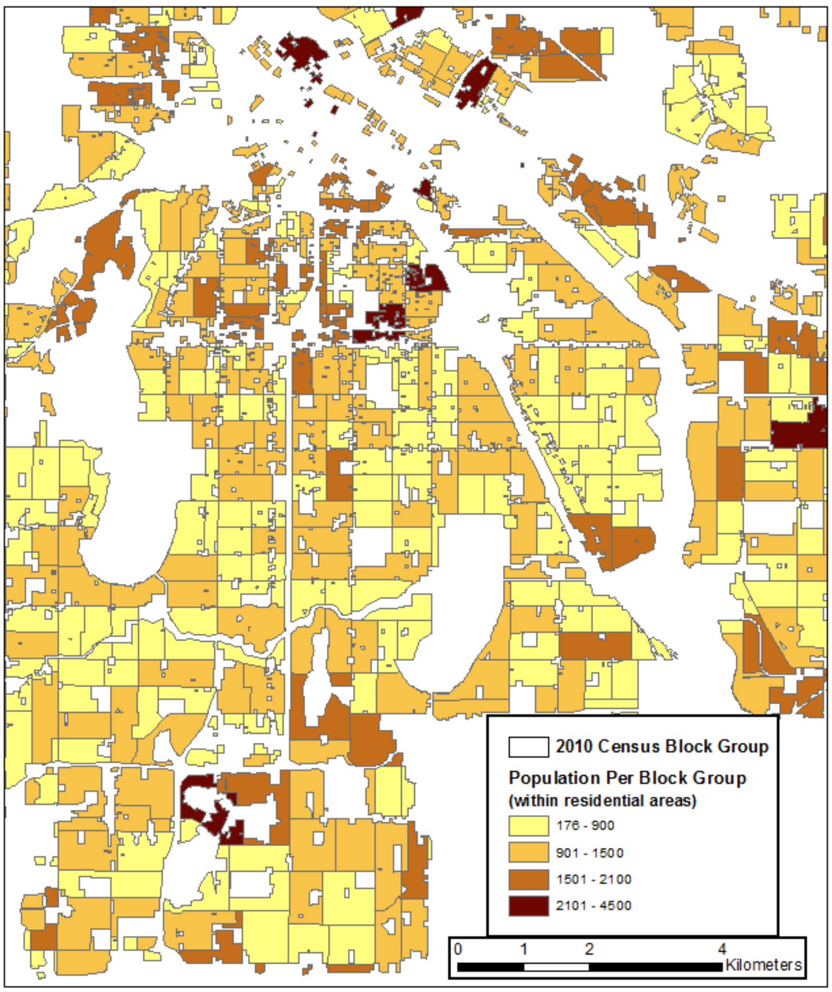

Figure 4.3: Population by vector (per block group): Areas west and north of airport

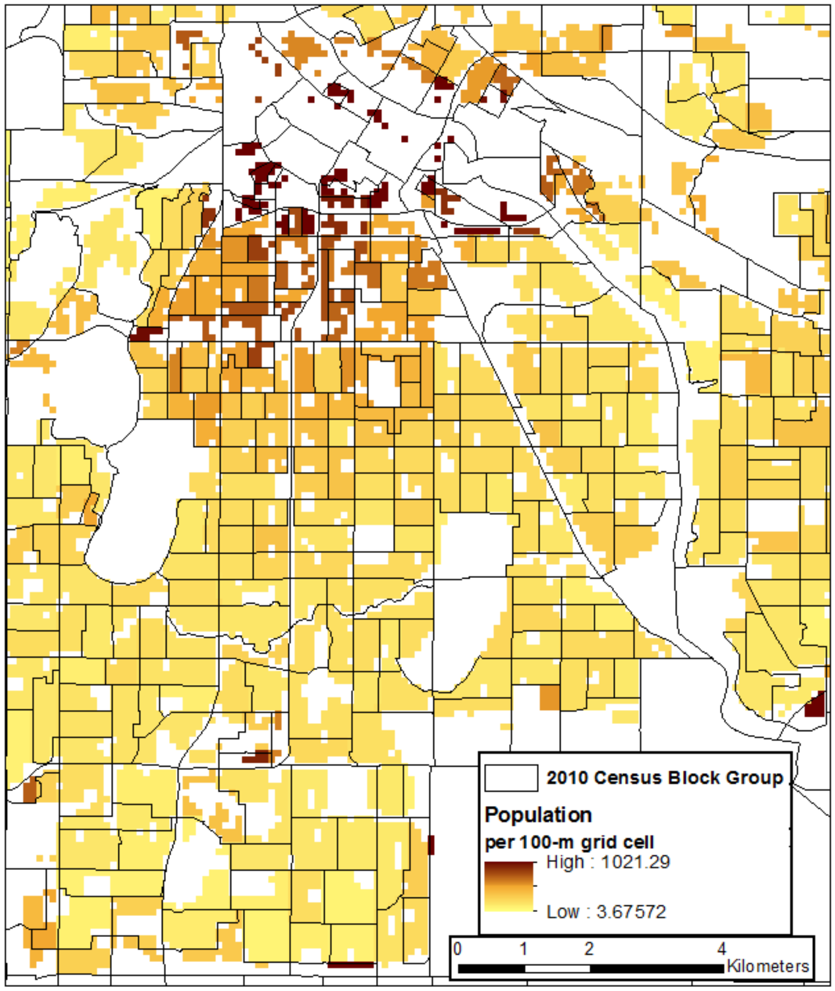

Figure 4.4: Population by raster (per 1000-m cell): Areas west and north of airport

than fifty percent residential coverage to be rendered as residential. Compared to a cell center algorithm, in which the polygon must simply intersect with the center of a grid cell, maximum area tends to provide better coverage for larger, contiguous areas of residential land, which are common in the areas of single-housing tracts indicative of the south Minneapolis neighborhoods near the airport. It does worse at capturing small, discrete polygons. However, these polygons are found more often in downtown apartment buildings that are farther from the airport and structurally less likely to provide the resident the same degree of noise exposure.

The raster-based representation of population density results in maps that show the approximate number of people living in equal-sized 10,000-square-meter areas, as shown in Figure 4.5. The figure shows how mapping based on population raises several issues regarding representation early on. The highest population densities of residents reveal themselves in areas close to downtown Minneapolis. Simple population densities

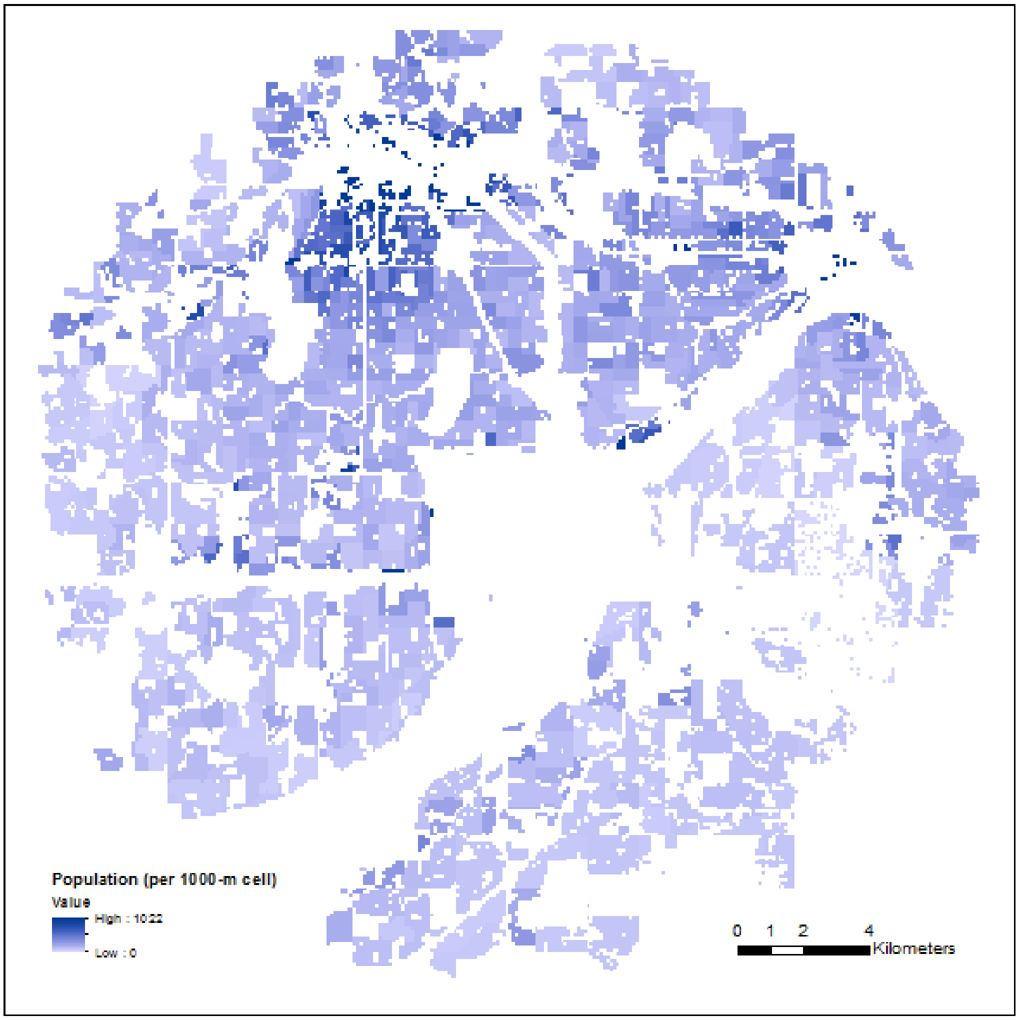

Figure 4.5: Raster-based population in study area

do not account for the various types of building structure, and how they can inherently increase or reduce noise exposure, based on local scenarios such as the side of the building that an apartment-dweller lives on, the floor of residence in relation to the overall number of floors, and the presence of other traffic noise that would override the occasional plane overhead.

Alternative representations are also worth considering that would minimize the influence of downtown density, short of removing multi-family residential from the residential land use aggregation. Households alone might be represented, since they are the unit at which mitigation is provided. The ACS data, however, can allow one to investigate other factors pertaining to noise response. For example, the variable of owner-occupied housing units, with the raster representation shown in Figure 4.6, would highlight the homeowners who actually live there, are exposed to the noise regularly, and have a greater stake in remaining for a long time. Without taking on the inconvenience of having to move, or lacking the recourse to move, they will probably be more inclined to voice their displeasure about noise that invades their property. While this study does not fully explore this alternative, it does suggest how a greater emphasis on ownership shifts some of the density from the downtown Minneapolis to south Minneapolis neighborhoods northwest of the airport.

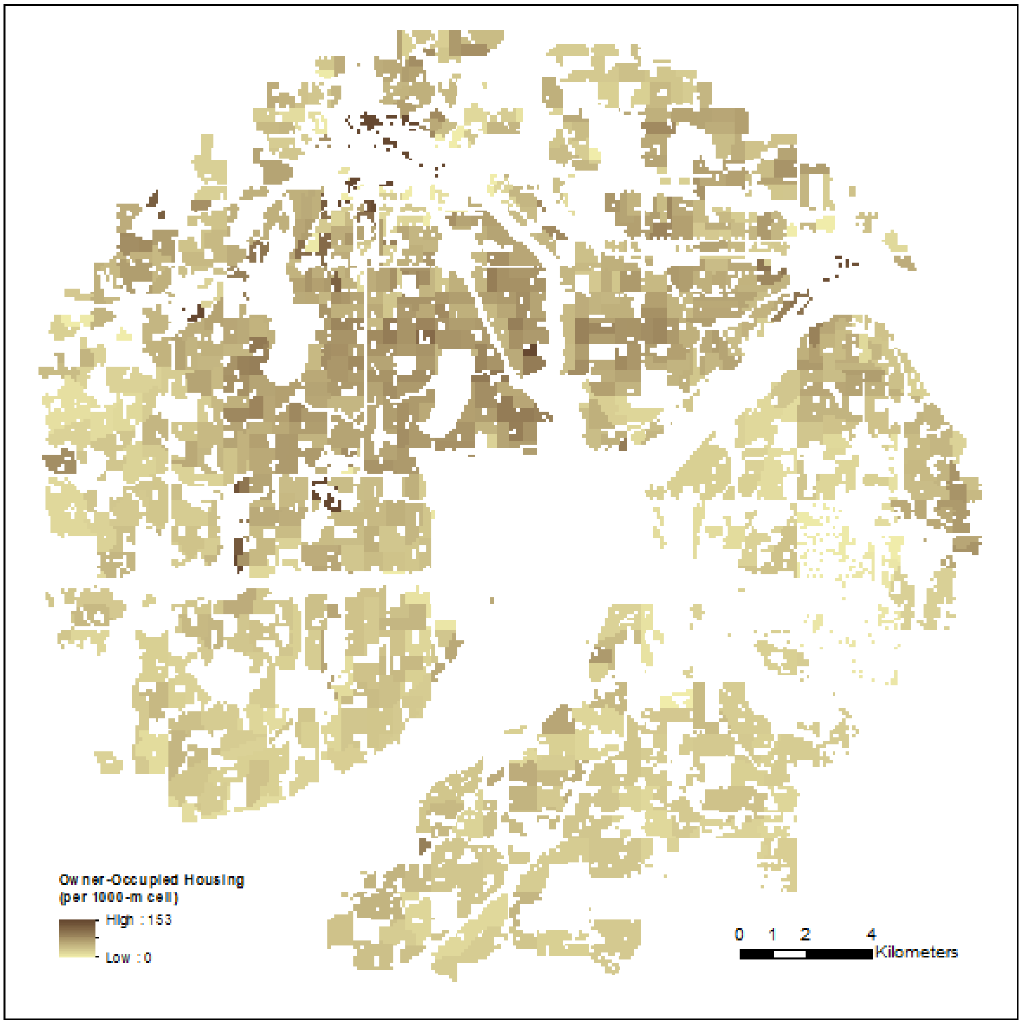

Figure 4.6: Raster-based number of housing units in study area

3.4 Combining noise impact with population

In order to obtain a one-to-one match between time-weighted noise and population raster cells, the ACS data has been processed to correspond in terms of both cell size – at 100 meters – and positioning. Noise-based pixels therefore line up exactly with every population-based pixel. The cumulative impact of the noise on population is determined with simple map algebra. Given that the impact on one individual is the exposure value for the cell of residence, the number of people in the cell determines the cumulative impact of that noise. In other words, the noise exposure level is multiplied by the number of people in the cell. The time-weighted maps described in Chapter 3 provide a readymade way to analyze relationships between noise level and socioeconomic indicators. In this analysis, the ability to focus on time-weighted flight paths and determine how neighborhoods are affected at different hours of the day offers a more nuanced approach.

4. Results

The composite of noise and population datasets provides for time-weighted output that shows cumulative population-based noise exposure. The raster layer is retained as the primary vehicle of analysis, with the grid cell being the highest unit of resolution. Here, the results show the spatial distribution of the impacted residential population for a given time. The day-to-day images are averaged by hour to ascertain the impact on a daily cycle. The differential impact between 2010 and 2011 is also once again highlighted.

4.1 Population-based exposure

The exposure maps represented below in Figure 4.7 to 4.10 show the difference between 2010 and 2011 for cumulative population-based noise exposure, at four different times during the day, for the period between the Friday before Memorial Day and Labor Day. Output that weights the noise exposure change based on the number of people living in specific locations provides an obvious indicator of the overall impact for those locations. Negative values, symbolized by lighter gray, indicate greater exposure in 2010, while darker-gray positive values indicate greater exposure in 2011. The DNL contours are symbolized in black to provide comparison with where the DNL shows areas between 60 and 64 DNL (outer contour) and 65 DNL or greater (the inner contour).

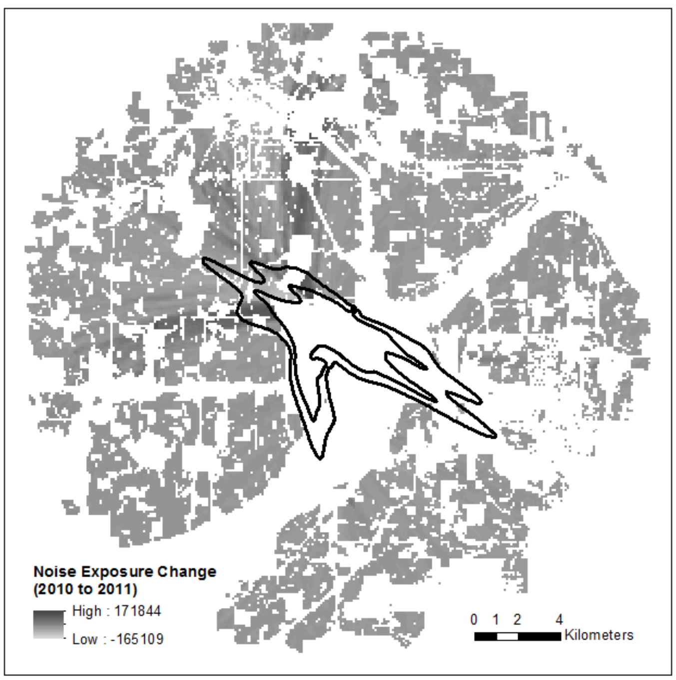

Figure 4.7: Noise exposure change, 8 AM from 2010 to 2011, weighted by population

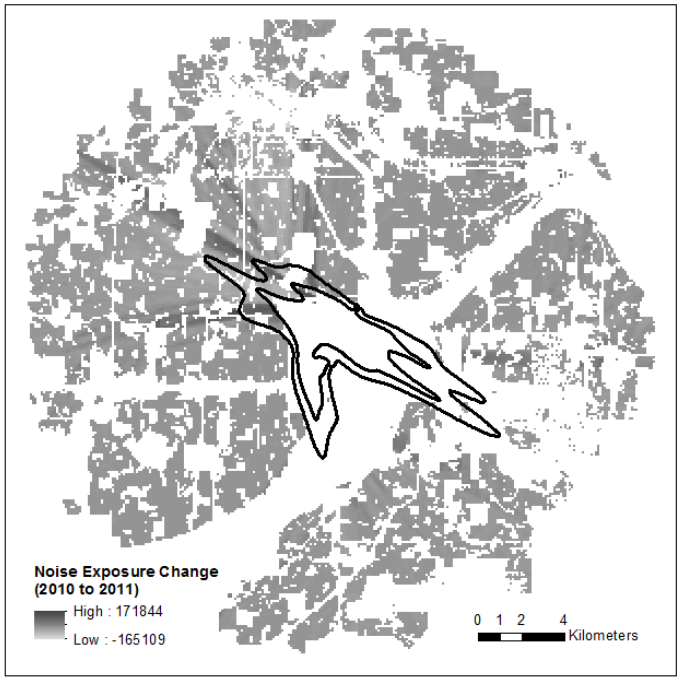

Figure 4.8: Noise exposure change, noon from 2010 to 2011, weighted by population

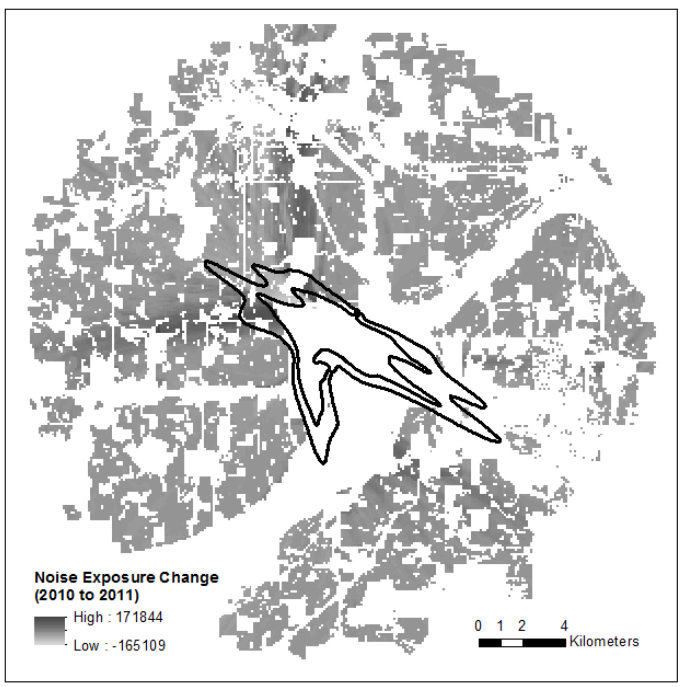

Figure 4.9: Noise exposure change, 4 PM from 2010 to 2011, weighted by population

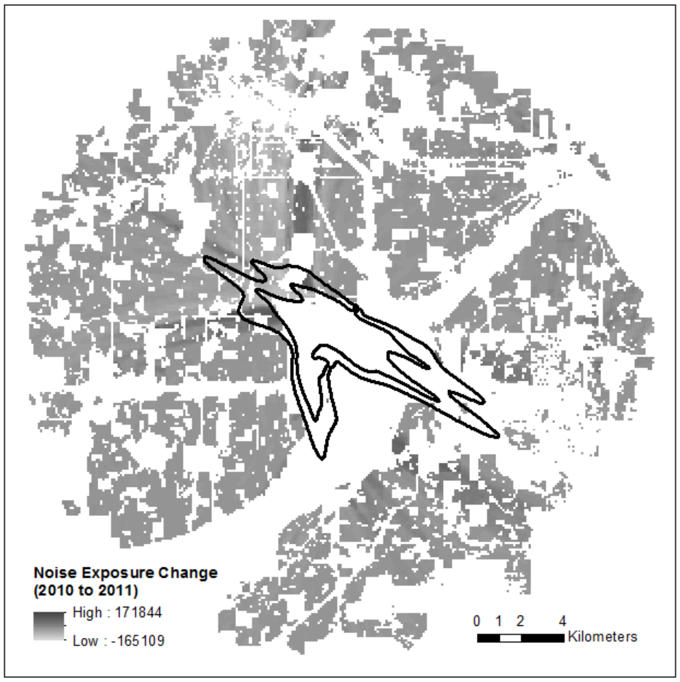

Figure 4.10: Noise exposure change, 8 PM from 2010 to 2011, weighted by population

The maps show consistency in terms of the larger-scale pattern changes, with increased exposure for populations directly west and directly north of the airport. The noontime map shows a more subdued difference, likely due to the increased number of flights that depart in a direct northwest trajectory, typically en route to destinations in the northwest United States. The comparative representation also shows how starkly the spatial distribution changes in the course of moving along an east-west transect, particularly at 8 PM. Although the magnitude of the extremes is subdued relative to the other times, the rapid change from negatively to positively valued areas between the two years illuminates how tighter departure patterns could lead to dramatic changes in perception at that time almost everywhere north of the airport, for better or worse.

The raster noise maps paint a stark picture of the mismatch between the standard DNL maps and actual noise exposure. For areas within the contours, the impact will be less, given that many of the households within the contours will have some form of mitigation provided by the airport. The response of the residents to any pattern changes will likely be tempered, and variation in residential experience could depend primarily on how they allocate their time between indoors and outdoors. For areas outside of the contours, however, there are marked changes, and those areas with positive values will experience more noise. The change maps show, when looked at from a residential perspective, that there is not a significant tradeoff between planes that depart to the southeast, via 12L and 12R, versus to the northwest, via 30L and 30R, at these four times. The time-weighted change maps that are not population-based (see Figure 3.11 in Chapter 3), do reveal a tradeoff, but given the spatial buffer southeast of the airport, consisting of Ft. Snelling State Park as well as commercial and industrial land, much of the impact of 2010 dissipates before departures extend to residential areas. The switch between these departure directions would be most reflective of wind direction concerns – given that aircraft gain stability when flying into a headwind – so as a distributional concern for residents, the influence of wind matters less. The tradeoff instead is largely contained within south Minneapolis with the shift of departures from west to east.

4.2 Sub-populations

An examination of the time-weighted noise impact on population subgroups helps to illuminate implicit issues pertaining to the timing of daily activities and the expected amount of time spent at home. The composites of time weighting and population density, as they change from 2010 to 2011, elucidate the degree to which groups with particular time-relevant concerns can be affected, and consequently the degree to which they might be more vocal about exposure changes. Such composites therefore reveal the changes that can leave certain sub-populations feeling newly exposed in ways that others might not be.

The maps in Figures 4.11 to 4.16 show the distribution of the sub-populations described in Section 3.1 (ages 65 and older in Figure 4.11, morning commuters in Figure 4.13, and not in labor force in Figure 4.15) and how they are cumulatively affected by changes in noise exposure from one year to the next (respectively in Figures 4.12, 4.14, and 4.16), assuming that they were typically home at the given times. The yearly difference maps show changes in noise exposure when comparing across subpopulations, although the difference tends to be in degree rather than in kind. The figures show that similarities are more evident than differences when the study area is viewed as a unit. With the focus on 8 PM, the sizes of each sub-population greatly influence the magnitude of the noise exposure changes. This is especially evident when comparing the 65-and-older and the morning commuter subgroups (with ranges similar enough that their legends share the same value scale), indicating that greater cumulative impact is due to a larger number of commuters than senior citizens.

The similarities here do not limit the effectiveness of these maps for examining these and other subgroups for differential impacts. The potential for this method extends beyond looking at subgroups that vary in their daily schedules, as it also shows promise for examining more traditional environmental justice concerns pertaining to socioeconomic status and race.

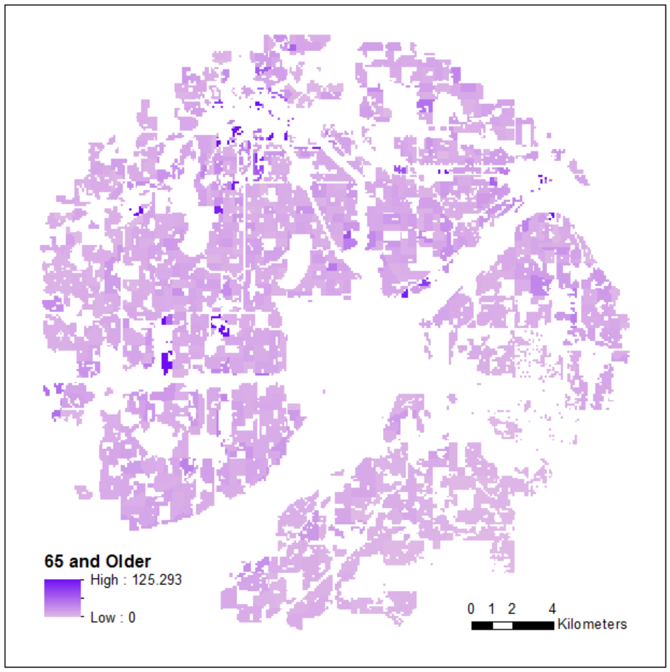

Figure 4.11: Raster distribution of 65-and-older subgroup

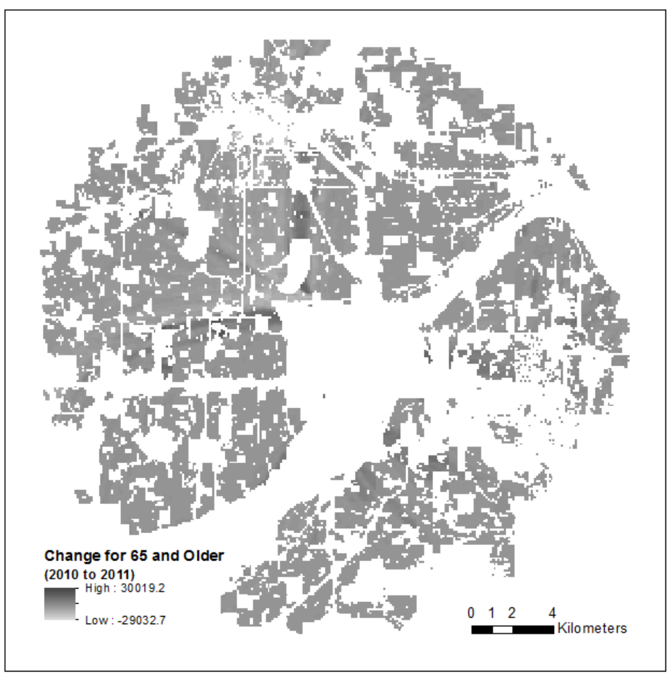

Figure 4.12: Change in cumulative noise exposure for 65-and-older subgroup, 8 PM from 2010 to 2011

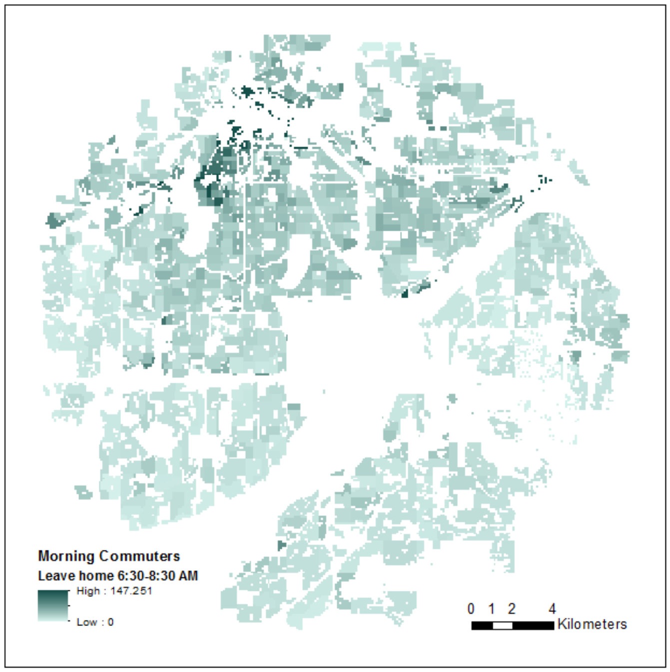

Figure 4.13: Raster distribution of morning commuter subgroup

Figure 4.14: Change in cumulative noise exposure for morning commuter subgroup, 8 PM from 2010 to 2011

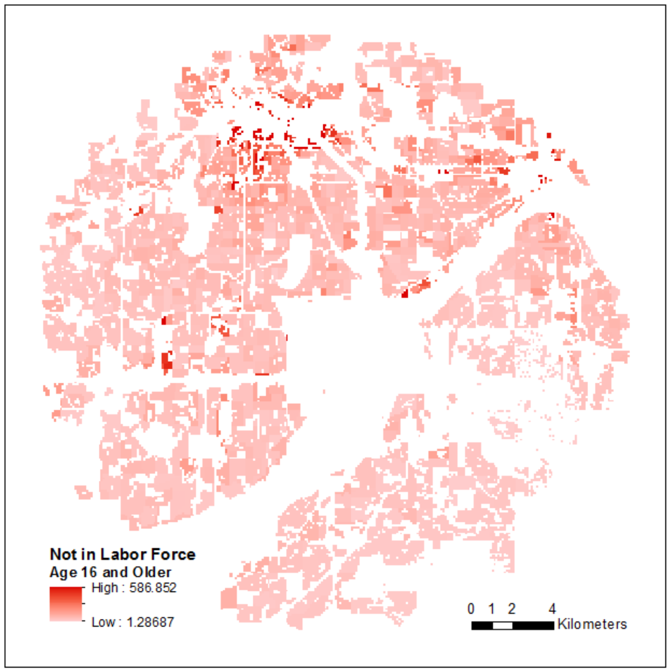

Figure 4.15: Raster distribution of not-in-labor-force subgroup, age 16 and older

Figure 4.16: Change in cumulative noise exposure for not-in-labor-force subgroup, 8 PM from 2010 to 2011

5. Discussion and conclusions

The analysis in this chapter serves to show the impact of noise on the population as a whole, and on specific sub-populations. It presents a way to link time-weighted flight data to their large-scale impact on regional populations, both in sum and as represented by subgroups that will have their own characteristic daily schedules of time spent at home. Focusing on cumulative impact for the population as a whole and for certain segments of the population grants insights that are valuable from a policy and planning perspective.

This population-based model of time-weighted noise exposure aims for simplicity. First, it assumes that greater cumulative impact results from each individual’s experience having equal impact. Hence, ten people exposed to a certain level of noise is ten times as bad as one person exposed to that same level, although it would be straightforward to attach an alternative weighting (e.g., each person equates to a small multiplier, or there could be a set number above which impacts do not count). Second, it focuses solely on the residential experience, and there is room for incorporating quiet zones such as schools, libraries, and hospitals. (For a related example on airport operations timing, see Prats, Puig, & Quevedo (2011).) For this study, however, restricting inquiry to the residential experience allows for a deeper investigation of how that particular experience plays out, at a fine temporal scale, in relationship to the noise environment.

The methodology presented in this chapter will increase in its effectiveness as population data better captures the location- and time-specific activity of residents. Data that more comprehensively captures, for example, the degree to which people enjoy the outdoors, and the consequent disruption of that enjoyment, would be worth incorporating in this analysis. Van Praag and Baarsma's (2005) research finding that a positive correlation between having a garden and reacting with annoyance suggests in a vivid way the importance of outdoor activity. The incorporation of weather patterns can also provide a better understanding of how people's attitudes might be affected differently by noise when comfortable conditions beckon them outdoors, all other things being equal. Proxy indicators embedded in the ACS data are harder to confirm for reliability. Perhaps riding a bike or walking to work or simply not owning a car can be indicative of people who are more conscientious about environmental behavior and who simply like to spend more time outside, but it could also simply indicate unwillingness to bear the costs of car ownership and gasoline purchases.

Overall, the method offered here provides high spatiotemporal resolution with minimal data demands, but it can also accommodate new socioeconomic data readily. In particular, the ACS is not the only data provider that can be useful for such studies. Geodemographic databases such as Esri Demographics (Esri, 2015) could provide another dimension of attribute data to improve our understanding of how and when residents are most disruptively exposed to noise. As the ability to glean insight into survey data like that of the ACS improves and as more categories are created that directly address the amount of time spent home and outside, the better our understanding of what the community response will be.

References

Borsky, P. N. (1977). *A comparison of a laboratory and field study of annoyance and acceptability of aircraft noise exposures* (NASA CR-2772). Washington, DC: NASA. Retrieved from http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19770010664.pdf

Bracken, I., & Martin, D. (1989). The generation of spatial population distributions from census centroid data. *Environment and Planning A*, *21*(4), 537–543.

Cidell, J. (2008). Challenging the contours: Critical cartography, local knowledge, and the public. *Environment and Planning A*, *40*(5), 1202–1218.

Cohen, J. P., & Coughlin, C. C. (2008). Spatial hedonic models of airport noise, proximity, and housing prices. *Journal of Regional Science*, *48*(5), 859–878. http://doi.org/10.1111/j.1467-9787.2008.00569.x

Cohen, J. P., & Coughlin, C. C. (2009). Changing noise levels and housing prices near the Atlanta airport. *Growth and Change*, *40*(2), 287–313.

Congalton, R. G. (1997). Exploring and evaluating the consequences of vector-to-raster and raster-to-vector conversion. *Photogrammetric Engineering & Remote Sensing*, *63*(4), 425–434.

Espey, M., & Lopez, H. (2000). The impact of airport noise and proximity on residential property values. *Growth and Change*, *31*, 408–419.

Esri (2015). Esri data: Current year demographic & business data. Retrieved from http://www.esri.com/data/esri_data

Federal Aviation Administration. (2014a). Aircraft noise issues. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/apl/noise_emissions/airport_aircraft_noise_issues/

Federal Aviation Administration. (2014b). Report to Congress: National Plan of Integrated Airport Systems (NPIAS) 2015-2019. Washington, DC.

Federal Interagency Committee on Noise. (1992). *Federal agency review of selected airport noise analysis issues*. Retrieved from ftp://public-ftp.agl.faa.gov/Materials%20Released%20Related%20to%20the%20OM%20EIS/3-31-2005%20World%20Gateway%20Related%20Documents/787_122.pdf

Feitelson, E. I., Hurd, R. E., & Mudge, R. R. (1996). The impact of airport noise on willingness to pay for residences. *Transportation Research Part D: Transport and Environment*, *1*(1), 1–14.

Fidell, S. (1991). Updating a dosage–effect relationship for the prevalence of annoyance due to general transportation noise. *The Journal of the Acoustical Society of America*, *89*(1), 221–233. http://doi.org/10.1121/1.400504

Fidell, S. (2003). The Schultz curve 25 years later: A research perspective. *The Journal of the Acoustical Society of America*, *114*(6), 3007–3015. http://doi.org/10.1121/1.1628246

Fisher, P. (1997). The pixel: A snare and a delusion. *International Journal of Remote Sensing*, *18*(3), 679–685.

Flowerdew, A. D. J. (1972). The cost of airport noise. *The Statistician*, *21*(1), 31–46.

Gidlöf-Gunnarsson, A., & Öhrström, E. (2007). Noise and well-being in urban residential environments: The potential role of perceived availability to nearby green areas. *Landscape and Urban Planning*, *83*(2-3), 115–126.

Holt, J. B., Lo, C. P., & Hodler, T. W. (2004). Dasymetric estimation of population density and areal interpolation of census data. *Cartography and Geographic Information Science*, *31*(2), 103–121. http://doi.org/10.1559/1523040041649407

Hume, K., Gregg, M., Thomas, C., & Terranova, D. (2003). Complaints caused by aircraft operations: An assessment of annoyance by noise level and time of day. *Journal of Air Transport Management*, *9*(3), 153–160. http://doi.org/10.1016/S0969-6997(02)00079-0

Langford, M., & Unwin, D. J. (1994). Generating and mapping population density surfaces within a geographical information system. *The Cartographic Journal*, *31*(1), 21–26. http://doi.org/10.1179/000870494787073718

Maris, E., Stallen, P. J., Vermunt, R., & Steensma, H. (2007). Evaluating noise in social context: the effect of procedural unfairness on noise annoyance judgments. *The Journal of the Acoustical Society of America*, *122*(6), 3483–94. http://doi.org/10.1121/1.2799901

Martin, D. (1996). An assessment of surface and zonal models of population. *International Journal of Geographical Information Systems*, *10*(8), 973–989.

Martin, D., & Bracken, I. (1991). Techniques for modelling population-related raster databases. *Environment and Planning A*, *23*(7), 1069–1075. http://doi.org/10.1068/a231069

Mennis, J. (2002). Using geographic information systems to create and analyze statistical surfaces of population and risk for environmental justice analysis. *Social Science Quarterly*, *83*(1), 281–297. http://doi.org/10.1111/1540-6237.00083

Mestre, V. (2008). *Effects of aircraft noise: Research update on selected topics*. Washington, DC: Transportation Research Board.

Metropolitan Council (2011). Metadata: Generalized land use – historical 1984, 1990, 1997, 2000, 2005 and 2010, for the Twin Cities Metropolitan Area. Retrieved from http://metrocouncil.org/METC/files/6d/6db8637a-fe3f-4f06-954b-581b680de527.html

Miedema, H. M. E. (2007). Annoyance caused by environmental noise: Elements for evidence-based noise policies. *Journal of Social Issues*, *63*(1), 41–57. http://doi.org/10.1111/j.1540-4560.2007.00495.x

Ogneva-Himmelberger, Y., & Cooperman, B. (2009). Spatio-temporal analysis of noise pollution near Boston Logan Airport: Who carries the cost? *Urban Studies*, *47*(1), 169–182. http://doi.org/10.1177/0042098009346863

Prats, X., Puig, V., & Quevedo, J. (2011). Equitable aircraft noise-abatement departure procedures. *Journal of Guidance, Control, and Dynamics*, *34*(1), 192–203. http://doi.org/10.2514/1.49530

Schultz, T. J. (1978). Synthesis of social surveys on noise annoyance. *The Journal of the Acoustical Society of America*, *64*(2), 377–405. http://doi.org/10.1121/1.382013

Sobotta, R. R., Campbell, H. E., & Owens, B. J. (2007). Aviation noise and environmental justice: The barrio barrier. *Journal of Regional Science*, *47*(1), 125–154. http://doi.org/10.1111/j.1467-9787.2007.00503.x

Tomkins, J., Topham, N., Twomey, J., & Ward, R. (1998). Noise versus access: The impact of an airport in an urban property market. *Urban Studies*, *35*(2), 243–258. http://doi.org/10.1080/0042098984961

U.S. Census Bureau (2014). American Community Survey: Multiyear accuracy of the data (3-year 2011-2013 and 5-year 2009-2013). Retrieved from http://www2.census.gov/programs-surveys/acs/tech_docs/accuracy/MultiyearACSAccuracyofData2013.pdf

U.S. Census Bureau (2015). American Community Survey: Design and methodology report. Retrieved from https://www.census.gov/programs-surveys/acs/methodology/design-and-methodology.html

Van Praag, M. S., & Baarsma, B. E. (2005). Using happiness surveys to value intangibles: The case of airport noise. *The Economic Journal*, *115*(500), 224–246.

Chapter 5. Research Conclusions and Future Directions

1. The geographic dimensions of sound

Sound is an important, if underexamined, area of inquiry for geography and other social, natural, and information sciences. The work presented here advances our understanding of sound and noise by examining the science and policy issues around airport noise and well-being. This work is significant for furthering our understanding of how science and policy have co-evolved around competing ideas centered on sound, noise, and shared conceptions of the acoustic landscape. By adopting a residential perspective of the sound environment, it also increases our understanding of how we experience sound at scales ranging from the individual to the community level and beyond. Additionally, this research demonstrates how spatial analysis and mapping, when combined with approaches like in-person interviews, can grant insight into the spatial and temporal dimensions of how patterns of noise and lived experience are intertwined.

This work also points the way to future lines of inquiry. With the analysis of a subject not inherently suited or historically tied to a discipline – in this case, the study of sound within the context of geography – several avenues of inquiry become more feasible for future research endeavors. For geographers and GIScientists to most effectively examine the dynamics of the acoustic environment, research requires a close examination of 1) how sound is perceived by various parties, 2) how geographic and cartographic representation of sound should reflect these varying perceptions, and 3) how GIScientists can best utilize the computational technology and large datasets required to capture the spatial and temporal variation. More broadly, GIS and spatial analysis serve as entry points into broader engagements with other disciplines.

2. Perception of sound

For a perceptual-based topic like sound, geographic inquiry should be grounded in understanding the variety of ways that people inhabit the sound environment, both in the perceiving and contributing to it. The gathering of qualitative background data, in terms of interviewing stakeholders and reviewing the psychological literature, provides a good starting point. The accounts of people who have experience with noise problems invariably tell of inherently geographic concerns, invoking concepts ranging from spatial displacement to neighborhood-related quality of life. Their stories reveal that their exposure to noise and the ways that they aspire to live, are grounded in space and time.

Consideration of where the natural resource of quietude is located in space and time also enhances our understanding of when and where quietude can and should be accessed. The primary investigation work for this research was policy-based, and the statutes and judicial documents provided much insight into its spatial and temporal dimensions. That said, a fruitful extension of this work would involve inquiring with residents about their notions of what quietude is and where and when they should expect to find it. As with the aircraft noise debates of 2011, there remains the possibility that many residents have an understanding of noise and quietude that is in conflict with what the judicial rulings have rendered for the resource, and that urban quietude, in certain places at certain times, should perhaps be available outdoors as well as indoors.

3. Representation of sound

An examination of the sound environment should also aim for a representation within GIS that reflects how it is perceived. Despite some moves toward acoustic and psychological understanding serving as the basis for noise mapping, the work presented here is primarily geographical, and therefore the ways that sound and noise play out in space and time matter most. As such, the raster representation is appropriate for capturing both the ubiquitousness and spatiotemporal variation of noise. The interpolation approach to representing variation in noise results from developing an understanding of how residents have described their exposure to it. The challenge of addressing a phenomenon like sound, which varies so greatly in space and time, is to arrive at an understanding of the appropriate scale of measurement. Importantly, this scale often does not match up with the scales invoked by policymaking, whether in the judicial rulings about the extent of quietude or in the choice of the DNL and its attendant contour maps that fail to capture the spatial and temporal nature of aircraft noise as actually experienced by people on the ground. Just as cognitive understandings of geographical phenomena should guide choice of vector or raster representation (Couclelis, 1992), an explicitly cognitive understanding should apply to scale concerns as well. The scale of this inquiry, and the chosen units of study, are matched most closely with traditional inquiries in the geography discipline – scales that allow for detecting patterns at the neighborhood and regional levels, account for land use, and allow for identifying detectable changes over time that can be represented cartographically.

4. Temporal-based computation of sound

The increasing computational power and large sets of data that are available for analysis require programs that can quickly process spatiotemporal data. One of the lessons of this research pertains to how the organizing of data based on time can best reflect how time might be perceived by residents. Therefore, if a cyclical model of time effectively captures residential experience of noise, then the manner in which the data is processed and ordered in the computer should reflect that model over more traditional snapshot-based or linear ones. In particular, the organization of data by days of the week or by hours of the day can make for a quicker search and analysis of time-based inquiries about noise tied to overflights.

The ability to process large datasets for such analysis points the way to a web-based means for anyone to query for particular days and hours of departure data during a requested span of time. While not undertaken here, this research lays the foundation for a publicly accessible web-based service. By making requests based on the intersection of hourly, daily, and even yearly cycles, a resident or a prospective homeowner can effectively scout out the likely patterns of noise exposure.

In arriving full circle back to the issue of perception, the representation of the noise environment on the basis of a few simple dimensions – in this case, based on frequency in time, concentration in space, and loudness derived from altitude – corresponds to how residents talk about their experiences with aircraft noise. Most residents realize that there are a multitude of factors that contribute to a sound's loudness and its ability to annoy. A program, however, that can analyze noise exposure based on the few components that matter most to residents will prevent the frustrations that come with a “black box” model, and instead relate directly to those experiences that are most perceptually vivid and psychologically resonant.

References

Couclelis, H. (1992). People manipulate objects (but cultivate fields): Beyond the raster-vector debate in GIS. In A. U. Frank, I. Campari, & U. Formentini (Eds.), *Theories and methods of spatio-temporal reasoning in geographic space: International conference GIS – From space to territory: Theories and methods of spatio-temporal reasoning* (pp. 65–77). Berlin: Springer-Verlag.

Complete Dissertation References

Act of June 4, 1971, ch. 727, 1971 Minn. Laws, 1400-1405.

Adams, M., Cox, T., Moore, G., Croxford, B., Refaee, M., & Sharples, S. (2006). Sustainable soundscapes: Noise policy and the urban experience. *Urban Studies, 43*(13), 2385–2398.

Aigner, W., Miksch, S., Schumann, H., & Tominski, C. (2011). *Visualization of time-oriented data*. London, UK: Springer.

Airport Noise Compatibility Planning, 14 C.F.R. § 150 (2015).

Alevizos v. Metropolitan Airports Commission, 216 N.W.2d 651 (Minn. 1974). Summary retrieved from https://casetext.com/case/alevizos-v-metropolitan-airports-comm

Allard, N. E., & Sandvick, G. N. (1993). *Minnesota aviation history 1857-1945*. Chaska, MN: MAHB Publishing, Inc.

Andrienko, G., Andrienko, N., Hurter, C., Rinzivillo, S., & Wrobel, S. (2013). Scalable analysis of movement data for extracting and exploring significant places. *IEEE Transactions on Visualization and Computer Graphics*, *19*(7), 1078–94. http://doi.org/10.1109/TVCG.2012.311

Answer of Intervenor Northwest Airlines, Inc., *Minnesota v. Metropolitan Airports Commission*, No. 27-CV-05-5474 (D. Minn. May 20, 2005).

Arana, M., San Martín, R., Nagore, I., & Pérez, D. (2009). Using noise mapping to evaluate the percentage of people affected by noise. *Acta Acustica United with Acustica*, *95*(3), 550–554. http://doi.org/10.3813/AAA.918180

Atkinson, R. (2007). Ecology of sound: The sonic order of urban space. *Urban Studies, 44*(10), 1905–1917.

Axelsson, Ö., Nilsson, M. E., & Berglund, B. (2010). A principal components model of soundscape perception. *The Journal of the Acoustical Society of America*, *128*(5), 2836–46. http://doi.org/10.1121/1.3493436

Banner, S. (2008). *Who owns the sky?: The struggle to control airspace from the Wright Brothers on*. Cambridge, MA: Harvard University Press.

Barber, J. R., Burdett, C. L., Reed, S. E., Warner, K. A., Formichella, C., Crooks, K. R., … Fristrup, K. M. (2011). Anthropogenic noise exposure in protected natural areas: Estimating the scale of ecological consequences. *Landscape Ecology*, *26*(9), 1281–1295. http://doi.org/10.1007/s10980-011-9646-7

Barber, J. R., Crooks, K. R., & Fristrup, K. M. (2010). The costs of chronic noise exposure for terrestrial organisms. *Trends in Ecology & Evolution*, *25*(3), 180–9. http://doi.org/10.1016/j.tree.2009.08.002

Bayne, E. M., Habib, L., & Boutin, S. (2008). Impacts of chronic anthropogenic noise from energy-sector activity on abundance of songbirds in the boreal forest. *Conservation Biology*, *22*(5), 1186–93. http://doi.org/10.1111/j.1523-1739.2008.00973.x

Beranek, L. (2008). *Riding the waves: A life in sound, science, and industry*. Cambridge, MA: MIT Press.

Berglund, B., & Lindvall, T. (Eds.). (1995) Community noise. *Archives of the Centre for Sensory Research 2*(1). 1-195. Retrieved from http://www.who.int/docstore/peh /noise/Noiseold.html

Borsky, P. N. (1977). *A comparison of a laboratory and field study of annoyance and acceptability of aircraft noise exposures* (NASA CR-2772). Washington, DC: NASA. Retrieved from http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov /19770010664.pdf

Botteldooren, D., De Coensel, B., & De Muer, T. (2006). The temporal structure of urban soundscapes. *Journal of Sound and Vibration*, *292*(1-2), 105–123. http://doi.org/10.1016/j.jsv.2005.07.026

Bracken, I., & Martin, D. (1989). The generation of spatial population distributions from census centroid data. *Environment and Planning A*, *21*(4), 537–543.

Bröer, C. (2007). Aircraft noise and risk politics. *Health, Risk & Society*, *9*(1), 37–52. http://doi.org/10.1080/13698570601181631

Brooker, P. (2009). Do people react more strongly to aircraft noise today than in the past? *Applied Acoustics*, *70*(5), 747–752. http://doi.org/10.1016/j.apacoust.2008.08.008

Brooker, P. (2010). Aircraft noise annoyance estimation: UK time-pattern effects. *Applied Acoustics*, *71*(7), 661–667. http://doi.org/10.1016/j.apacoust.2010.01.010

Bütikofer, R. (2013). Airport noise. In G. Licitra (Ed.), *Noise mapping in the EU: Models and procedures* (pp. 129–158). Boca Raton, FL: CRC Press.

Chapin, F. S., III. (1997). Biotic control over the functioning of ecosystems. *Science*, *277*(5325), 500–504. http://doi.org/10.1126/science.277.5325.500

Chrisman, N. R. (1998). Beyond the snapshot: Changing the approach to change, error, and process. In M. J. Egenhofer & R. G. Golledge (Eds.), *Spatial and temporal reasoning in geographic information systems* (pp. 85–93). Oxford, UK: Oxford University Press.

Cidell, J. (2008). Challenging the contours: Critical cartography, local knowledge, and the public. *Environment and Planning A*, *40*(5), 1202–1218.

Citizens for a Safe Grant v. Lone Oak Sportsmen's Club, 624 N.W.2d 796 (Minn. Ct. App. 2001).

Cohen, J. P., & Coughlin, C. C. (2008). Spatial hedonic models of airport noise, proximity, and housing prices. *Journal of Regional Science*, *48*(5), 859–878. http://doi.org/10.1111/j.1467-9787.2008.00569.x

Cohen, J. P., & Coughlin, C. C. (2009). Changing noise levels and housing prices near the Atlanta airport. *Growth and Change*, *40*(2), 287–313.

Complaint, *Minnesota v. Metropolitan Airports Commission*, No. 27-CV-05-5474 (D. Minn. Apr. 20, 2005).

Congalton, R. G. (1997). Exploring and evaluating the consequences of vector-to-raster and raster-to-vector conversion. *Photogrammetric Engineering & Remote Sensing*, *63*(4), 425–434.

Cooper, G. (1998). *Air-conditioning America: Engineers and the controlled environment, 1900-1960*. Baltimore, MD: Johns Hopkins University Press.

Couclelis, H. (1992). People manipulate objects (but cultivate fields): Beyond the raster-vector debate in GIS. In A. U. Frank, I. Campari, & U. Formentini (Eds.), *Theories and methods of spatio-temporal reasoning in geographic space: International conference GIS – From space to territory: Theories and methods of spatio-temporal reasoning* (pp. 65–77). Berlin: Springer-Verlag.

Davies, W. J., Adams, M. D., Bruce, N. S., Cain, R., Carlyle, A., Cusack, P., … Poxon, J. (2013). Perception of soundscapes: An interdisciplinary approach. *Applied Acoustics*, *74*(2), 224–231. http://doi.org/10.1016/j.apacoust.2012.05.010

De Coensel, B., & Botteldooren, D. (2006). The quiet rural soundscape and how to characterize it. *Acta Acustica United with Acustica*, *92*(6), 887–897.

De Kluijver, H., & Stoter, J. (2003). Noise mapping and GIS: Optimising quality and efficiency of noise effect studies. *Computers, Environment and Urban Systems*, *27*(1), 85–102. http://doi.org/10.1016/S0198-9715(01)00038-2

Demšar, U., Buchin, K., van Loon, E. E., & Shamoun-Baranes, J. (2015). Stacked space-time densities: A geovisualisation approach to explore dynamics of space use over time. *GeoInformatica*, *19*(1), 85–115. http://doi.org/10.1007/s10707-014-0207-5

Demšar, U., & Virrantaus, K. (2010). Space–time density of trajectories: exploring spatio-temporal patterns in movement data. *International Journal of Geographical Information Science*, *24*(10), 1527–1542. http://doi.org/10.1080/13658816.2010.511223

Downs, J. A. (2010). Time-geographic density estimation for moving point objects. In S. I. Fabrikant, T. Reichenbacher, M. van Kreveld, & C. Schlieder (Eds.), *Lecture notes in computer science (Geographic information science)* (Vol. 6292, pp. 16–26). Berlin: Springer. http://doi.org/10.1007/978-3-642-15300-6_2

Doyle, P. (2011a, September 22). Near-collision over MSP means more noise for some. *Star Tribune*. Retrieved from http://www.startribune.com

Doyle, P. (2011b, November 17). FAA reconsiders rise in airport noise. *Star Tribune*. Retrieved from http://search.proquest.com/newsstand/docview/904415618 /625EDF11C3B546BBPQ/1?accountid=14586

Dragicevic, S., & Marceau, D. J. (2000). A fuzzy set approach for modelling time in GIS. *International Journal of Geographical Information Science*, *14*(3), 225–245. http://doi.org/10.1080/136588100240822

Dresden International Airport (n.d.). Noise monitoring. Retrieved from http://www.dresden-airport.de/company/noise-and-environment/noise-protection/noise-monitoring.html

Dumyahn, S. L., & Pijanowski, B. C. (2011). Soundscape conservation. *Landscape Ecology*, *26*(9), 1327–1344. http://doi.org/10.1007/s10980-011-9635-x

Espey, M., & Lopez, H. (2000). The impact of airport noise and proximity on residential property values. *Growth and Change*, *31*, 408–419.

Esri (2015). Esri data: Current year demographic & business data. Retrieved from http://www.esri.com/data/esri_data

Farina, A., Lattanzi, E., Malavasi, R., Pieretti, N., & Piccioli, L. (2011). Avian soundscapes and cognitive landscapes: Theory, application and ecological perspectives. *Landscape Ecology*, *26*(9), 1257–1267. http://doi.org/10.1007/s10980-011-9617-z

Federal Aviation Administration (2007). *Environmental desk reference for airport actions*. Retrieved from https://www.faa.gov/airports/environmental /environmental_desk_ref/media/desk-ref.pdf

Federal Aviation Administration. (2014a). Aircraft noise issues. Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/apl/noise_emissions /airport_aircraft_noise_issues/

Federal Aviation Administration. (2014b). Report to Congress: National Plan of Integrated Airport Systems (NPIAS) 2015-2019. Washington, DC.

Federal Interagency Committee on Noise. (1992). *Federal agency review of selected airport noise analysis issues*. Retrieved from ftp://public-ftp.agl.faa.gov/ Materials%20Released%20Related%20to%20the%20OM%20EIS/3-31-2005%20World%20Gateway%20Related%20Documents/787_122.pdf

Feitelson, E. I., Hurd, R. E., & Mudge, R. R. (1996). The impact of airport noise on willingness to pay for residences. *Transportation Research Part D: Transport and Environment*, *1*(1), 1–14.

Fidell, S. (1991). Updating a dosage–effect relationship for the prevalence of annoyance due to general transportation noise. *The Journal of the Acoustical Society of America*, *89*(1), 221–233. http://doi.org/10.1121/1.400504

Fidell, S. (2003). The Schultz curve 25 years later: A research perspective. *The Journal of the Acoustical Society of America*, *114*(6), 3007–3015. http://doi.org/10.1121/1.1628246

Fisher, P. (1997). The pixel: A snare and a delusion. *International Journal of Remote Sensing*, *18*(3), 679–685.

Flowerdew, A. D. J. (1972). The cost of airport noise. *The Statistician*, *21*(1), 31–46.

Foertsch, K., & Davies, P. (2013). *The number-of-events as a predictor variable in aircraft noise annoyance models* (Report No. PARTNER-COE-2013-002). A PARTNER Project 24 Report. Cambridge, MA. Retrieved from PARTNER website: http://web.mit.edu/aeroastro/partner/reports/proj24/proj24-2013-002.pdf

Frank, A. U. (1998). Different types of “times” in GIS. In M. J. Egenhofer & R. G. Golledge (Eds.), *Spatial and temporal reasoning in geographic information systems* (pp. 40–62). New York: Oxford University Press.

Friedman, W. (1990). *About time*. Cambridge, MA: MIT Press.

Galton, A. (2004). Fields and objects in space, time, and space-time. *Spatial Cognition & Computation*, *4*(1), 39–68. http://doi.org/10.1207/s15427633scc0401

Gidlöf-Gunnarsson, A., & Öhrström, E. (2007). Noise and well-being in urban residential environments: The potential role of perceived availability to nearby green areas. *Landscape and Urban Planning*, *83*(2-3), 115–126.

Glass, D. C., & Singer, J. E. (1972). *Urban stress: Experiments on noise and social stressors*. New York, NY: Academic Press.

Goodchild, M. F. (2013). Prospects for a space–time GIS. *Annals of the Association of American Geographers*, *103*(5), 1072–1077. http://doi.org/10.1080/00045608.2013.792175

Gourévitch, B., Edeline, J.-M., Occelli, F., & Eggermont, J. J. (2014). Is the din really harmless? Long-term effects of non-traumatic noise on the adult auditory system. *Nature Reviews. Neuroscience*, *15*(7), 483–91. http://doi.org/10.1038/nrn3744

Granö, J. G. (1929). *Pure geography*. (O. Granö and A. Paasi, Eds.). Baltimore, MD: The Johns Hopkins University Press.

Grenon, P., & Smith, B. (2004). SNAP and SPAN: Towards dynamic spatial ontology. *Spatial Cognition and Computation*, *4*(1), 69–103. http://doi.org/10.1207/s15427633scc0401_5

Halfwerk, W., Bot, S., Buikx, J., van der Velde, M., Komdeur, J., ten Cate, C., & Slabbekoorn, H. (2011). Low-frequency songs lose their potency in noisy urban conditions. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(35), 14549–54. http://doi.org/10.1073/pnas.1109091108

Harper, D. V. (1971). The Minneapolis-St. Paul Metropolitan Airports Commission. *Minnesota Law Review*, *55*(3), 363–459.

Harvey, M. E., Frazier, J. W., & Matulionis, M. (1979). Cognition of a hazardous environment: Reactions to Buffalo airport noise. *Economic Geography, 55*(4), 263–286. http://doi.org/10.1001/archgenpsychiatry.2010.16

Herzog, T. R., Hayes, L. J., Applin, R. C., & Weatherly, A. M. (2011). Incompatibility and mental fatigue. *Environment and Behavior*, *43*(6), 827–847. http://doi.org/10.1177/0013916510383242

Holt, J. B., Lo, C. P., & Hodler, T. W. (2004). Dasymetric estimation of population density and areal interpolation of census data. *Cartography and Geographic Information Science*, *31*(2), 103–121. http://doi.org/10.1559/1523040041649407

Hume, K., Gregg, M., Thomas, C., & Terranova, D. (2003). Complaints caused by aircraft operations: An assessment of annoyance by noise level and time of day. *Journal of Air Transport Management, 9*(3), 153–160. http://doi.org/10.1016/S0969-6997(02)00079-0

International Organization for Standardization (ISO) (2014). Acoustics – Soundscape – Part 1: Definition and Conceptual Framework (International Standard No. ISO/FDIS 12913-1).

Irvine, K. N., Devine-Wright, P., Payne, S. R., Fuller, R. A., Painter, B., & Gaston, K. J. (2009). Green space, soundscape and urban sustainability: An interdisciplinary, empirical study. *Local Environment*, *14*(2), 155–172. http://doi.org/10.1080/13549830802522061

Jennings, P., & Cain, R. (2013). A framework for improving urban soundscapes. *Applied Acoustics*, *74*(2), 293–299. http://doi.org/10.1016/j.apacoust.2011.12.003

Johnson, J. L. (1983). Acid rain: Minnesota remedies. *William Mitchell Environmental Law Journal*, *1*(1), 82–116.

Kahn, Jr., P. H. (1999). *The human relationship with nature: Development and culture*. Cambridge, MA: The MIT Press.

Kaplan, S. (1995). The restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology*, *15*(3), 169–182.

Kaplan, S. (2001). Meditation, restoration, and the management of mental fatigue. *Environment and Behavior*, *33*(4), 480–506.

Kight, C. R., & Swaddle, J. P. (2011). How and why environmental noise impacts animals: An integrative, mechanistic review. *Ecology Letters*, *14*(10), 1052–61. http://doi.org/10.1111/j.1461-0248.2011.01664.x

King, E. A., & Rice, H. J. (2009). The development of a practical framework for strategic noise mapping. *Applied Acoustics*, *70*(8), 1116–1127. http://doi.org/10.1016/j.apacoust.2009.01.005

Klæboe, R., Engelien, E., & Steinnes, M. (2006). Context sensitive noise impact mapping. *Applied Acoustics*, *67*(7), 620–642. http://doi.org/10.1016/j.apacoust.2005.12.002

Klass, A. (2006). Modern public trust principles: Recognizing rights and integrating standards. *Notre Dame Law Review*, *82*(2), 699–754.

Krause, B. L. (1987). Bio-acoustics: Habitat ambience and ecological balance. *Whole Earth Review*, *57*, 14–18.

Krause, B. (2012). *The great animal orchestra: Finding the origins of music in the world's wild places*. New York: Little, Brown and Company.

Kryter, K. D. (1985). *The effects of noise on man* (2nd ed.). Orlando, Florida: Academic Press.

Kuo, F. E. (2001). Coping with poverty: Impacts of environment and attention in the inner city. *Environment and Behavior*, *33*(1), 5–34. http://doi.org/10.1177/00139160121972846

Lacey, J., & Harvey, L. (2011). Sound cartography approaches to urban soundscape research: CitySounds and Sites-of-Respite in the CBD of Melbourne. In S. Caquard, L. Vaughan, & W. Cartwright (Eds.), *Mapping environmental issues in the city: Arts and cartography cross perspectives* (pp. 246–265). Berlin: Springer-Verlag.

Lam, K.-C., Brown, A. L., Marafa, L., & Chau, K.-C. (2010). Human preference for countryside soundscapes. *Acta Acustica United with Acustica*, *96*(3), 463–471. http://doi.org/10.3813/AAA.918299

Langford, M., & Unwin, D. J. (1994). Generating and mapping population density surfaces within a geographical information system. *The Cartographic Journal*, *31*(1), 21–26. http://doi.org/10.1179/000870494787073718

Langran, G. (1992). *Time in geographic information systems*. Bristol, PA: Taylor & Francis.

Langran, G., & Chrisman, N. R. (1988). A framework for temporal geographic information. *Cartographica: The International Journal for Geographic Information and Geovisualization*, *25*(3), 1–14. http://doi.org/10.3138/K877-7273-2238-5Q6V

Liu, J., Kang, J., Luo, T., Behm, H., & Coppack, T. (2013). Spatiotemporal variability of soundscapes in a multiple functional urban area. *Landscape and Urban Planning*, *115*, 1–9. http://doi.org/10.1016/j.landurbplan.2013.03.008

Maris, E., Stallen, P. J., Vermunt, R., & Steensma, H. (2007). Evaluating noise in social context: the effect of procedural unfairness on noise annoyance judgments. *The Journal of the Acoustical Society of America*, *122*(6), 3483–94. http://doi.org/10.1121/1.2799901

Martin, D. (1996). An assessment of surface and zonal models of population. *International Journal of Geographical Information Systems*, *10*(8), 973–989.

Martin, D., & Bracken, I. (1991). Techniques for modelling population-related raster databases. *Environment and Planning A*, *23*(7), 1069–1075. http://doi.org/10.1068/a231069

Memorandum in Support of Defendant's Motion to Dismiss, *Minnesota v. Metropolitan Airports Commission*, No. 27-CV-05-5474 (D. Minn. May 19, 2005).

Mennis, J. (2002). Using geographic information systems to create and analyze statistical surfaces of population and risk for environmental justice analysis. *Social Science Quarterly*, *83*(1), 281–297. http://doi.org/10.1111/1540-6237.00083

Mestre, V. (2008). *Effects of aircraft noise: Research update on selected topics*. Washington, DC: Transportation Research Board.

Metropolitan Airports Commission (2010). Tips for insulating your home against airport noise. Retrieved from https://www.macnoise.com/sites/macnoise.com/files/pdf/tips.pdf

Metropolitan Airports Commission (2011a). 2010 MACNOMS Flight Track Data [Data file, SFTA download]. Minneapolis, MN: MAC.

Metropolitan Airports Commission (2011b). Public input meeting comments/responses. October 25, 2011. Retrieved from https://www.macnoise.com/pdf/pim_responses_web_10-25-11.pdf

Metropolitan Airports Commission (2012a). 2011 MACNOMS Flight Track Data [Data file, CD-ROM]. Minneapolis, MN: MAC.

Metropolitan Airports Commission (2012b). Annual Noise Contour Analysis: Comparison of 2010 Actual Noise Contour and the 2007 Forecast Noise Contour, February 2011 (Rev. April 2012). Retrieved from https://www.macnoise.com/pdf /msp_annual_contour_report_2010.pdf

Metropolitan Airports Commission (2012c). Annual Noise Contour Analysis: Comparison of 2011 Actual Noise Contour and the 2007 Forecast Noise Contour, February 2012. Retrieved from https://www.macnoise.com/pdf/2011-MSP-Annual-Noise-Contour-Report-2-29-12.pdf

Metropolitan Airports Commission (2013). Examining runway use at MSP. Retrieved from https://www.macnoise.com/news/examining-runway-use-msp

Metropolitan Airports Commission (2014). Wind factors at MSP. Retrieved from https://www.macnoise.com/news/wind-factors-msp

Metropolitan Airports Commission (n.d.). Minneapolis-St. Paul International Airport (MSP) Annual Noise Contour Analysis: Comparison of 2015 Actual Noise Contour and the 2007 Forecast Noise Contour. Retrieved from https://www.macnoise.com /pdf /msp-2015-annual-noise-contour-report-web.pdf

Metropolitan Council (2011). Metadata: Generalized land use – historical 1984, 1990, 1997, 2000, 2005 and 2010, for the Twin Cities Metropolitan Area. Retrieved from http://metrocouncil.org/METC/files/6d/6db8637a-fe3f-4f06-954b-581b680de527.html

Miedema, H. M. E. (2007). Annoyance caused by environmental noise: Elements for evidence-based noise policies. *Journal of Social Issues*, *63*(1), 41–57. http://doi.org/10.1111/j.1540-4560.2007.00495.x

Minnesota Environmental Rights Act of 1971 (MERA), 2014 Minn. Stat. 116B.01-07 (2014).

Minnesota Public Interest Research Group v. White Bear Gun Club. 257 N.W.2d 762 (Minn. 1977).

Minnesota v. Metropolitan Airports Commission, No. 27-CV-05-5474, (D. Minn., order granting partial summary judgment, Jan. 25, 2007). Retrieved from http://www.ci.minneapolis.mn.us/www/groups/public/@communications/documents /webcontent/convert_254051.pdf

Minnesota Valley Trust (2016). Board & Staff: Minnesota Valley Trust. Retrieved from http://www.mnvalleytrust.org/board_and_staff/

Murphy, E., & King, E. A. (2010). Strategic environmental noise mapping: Methodological issues concerning the implementation of the EU Environmental Noise Directive and their policy implications. *Environment International*, *36*(3), 290–298. http://doi.org/10.1016/j.envint.2009.11.006

National Park Service (2006). *Management policies 2006*. Washington, DC: U.S. Government Printing Office. Retrieved from http://www.nps.gov/policy/mp2006.pdf

National Transportation Safety Board. (2010). NTSB investigating near midair collision over Minneapolis involving commercial jetliner and small cargo aircraft [Press release]. Retrieved from http://www.ntsb.gov/news/press-releases/Pages/NTSB_Investigating_Near_Midair_Collision_over_Minneapolis_Involving_Commercial_Jetliner_and_Small_Cargo_Aircraft.aspx

Note: The Minnesota Environmental Rights Act. *Minnesota Law Review 56*(4), 575-639 (1972).

Ogneva-Himmelberger, Y., & Cooperman, B. (2009). Spatio-temporal analysis of noise pollution near Boston Logan Airport: Who carries the cost? *Urban Studies*, *47*(1), 169–182. http://doi.org/10.1177/0042098009346863

Oosterlynck, S., & Swyngedouw, E. (2010). Noise reduction: The postpolitical quandary of night flights at Brussels airport. *Environment and Planning A*, *42*(7), 1577–1594. http://doi.org/10.1068/a42269

Pearson, M. W., & Riley, D. S. (2015). *Foundations of aviation law*. Surrey, UK: Ashgate Publishing.

Peuquet, D. J. (1994). It’s about time: a conceptual framework for the representation of temporal dynamics in geographic information systems. *Annals of the Association of American Geographers*, *84*(3), 441–461.

Peuquet, D. J. (2002). *Representations of space and time*. New York: The Guilford Press.

Pijanowski, B. C., Farina, A., Gage, S. H., Dumyahn, S. L., & Krause, B. L. (2011). What is soundscape ecology? An introduction and overview of an emerging new science. *Landscape Ecology*, *26*(9), 1213–1232. http://doi.org/10.1007/s10980-011-9600-8

Plaintiffs’ Memorandum of Law in Response to Defendant’s Motion to Dismiss, *Minnesota v. Metropolitan Airports Commission*, No. 27-CV-05-5474 (D. Minn. June 27, 2005).

Pocock, D. (1989). Sound and the geographer. *Geography*, *324*(3), 193–200.

Porteous, J. D. (1990). *Landscapes of the mind: Worlds of sense and metaphor*. Toronto, CA: University of Toronto Press.

Prats, X., Puig, V., & Quevedo, J. (2011). Equitable aircraft noise-abatement departure procedures. *Journal of Guidance, Control, and Dynamics*, *34*(1), 192–203. http://doi.org/10.2514/1.49530

Prats, X., Puig, V., Quevedo, J., & Nejjari, F. (2010). Multi-objective optimisation for aircraft departure trajectories minimising noise annoyance. *Transportation Research Part C: Emerging Technologies*, *18*(6), 975–989. http://doi.org/10.1016/j.trc.2010.03.001

Raimbault, M., & Dubois, D. (2005). Urban soundscapes: Experiences and knowledge. *Cities*, *22*(5), 339–350. http://doi.org/10.1016/j.cities.2005.05.003

Rodaway, P. (1994). Sensuous geographies: Body, sense and place. New York: Routledge.

Sax, J. L. (1970). The public trust doctrine in natural resource law: Effective judicial intervention. *Michigan Law Review, 68*(3), 471–566.

Sax, J. L. (1971). *Defending the environment: A strategy for citizen action*. New York: Alfred A. Knopf.

Schafer, R. M. (1994). *The soundscape: Our sonic environment and the tuning of the world*. Rochester, VT: Destiny Books.

Schultz, T. J. (1978). Synthesis of social surveys on noise annoyance. *The Journal of the Acoustical Society of America*, *64*(2), 377–405. http://doi.org/10.1121/1.382013

Shelerud, S. (2012). *Departures analysis: What has changed?* [PDF document]. Minneapolis, MN: Federal Aviation Administration. Retrieved from Metropolitan Airports Commission website https://www.macnoise.com/sites/macnoise.com /files/pdf/noc_presentation-1-18-12x.pdf

Shepherd, I. D. H. (2008). Travails in the third dimension: A critical evaluation of three-dimensional geographical visualization. In M. Dodge, M. McDerby, & M. Turner (Eds.), *Geographic visualization: Concepts, tools and applications* (pp. 199–222). West Sussex, UK: John Wiley & Sons.

Sinha, K. C., & Labi, S. (2007). *Transportation decision making: Principles of project evaluation and programming*. Hoboken, NJ: John Wiley & Sons, Inc.

Skeie v. Minnkota Power Cooperative, 281 N.W.2d 372, 374 (Minn. 1979)

Smith, J. W., & Pijanowski, B. C. (2014). Human and policy dimensions of soundscape ecology. *Global Environmental Change*, *28*, 63–74. http://doi.org/10.1016/j.gloenvcha.2014.05.007

Smith, S. J. (1994). Soundscape. *Area*, *26*(3), 232–240.

Sobotta, R. R., Campbell, H. E., & Owens, B. J. (2007). Aviation noise and environmental justice: The barrio barrier. *Journal of Regional Science*, *47*(1), 125–154. http://doi.org/10.1111/j.1467-9787.2007.00503.x

Stansell v. Northfield, 618 N.W.2d 814 (Minn. Ct. App. 2000).

Stokols, D. (1978). Environmental psychology. *Annual Review of Psychology*, *29*, 253–95.

Stoter, J., de Kluijver, H., & Kurakula, V. (2008). 3D noise mapping in urban areas. *International Journal of Geographical Information Science*, *22*(8), 907–924. http://doi.org/10.1080/13658810701739039

The Impact of the Expansion of the Minneapolis-St. Paul International Airport of the Minnesota Valley National Wildlife Refuge: Oversight Hearing before the Committee on Resources, House of Representatives, 106th Cong. 1 (1999).

Thompson, E. (2002). *The soundscape of modernity: Architectural acoustics and the culture of listening in America*. Cambridge, MA: The MIT Press.

Thorne, R., & Shepherd, D. (2013). Quiet as an environmental value: A contrast between two legislative approaches. *International Journal of Environmental Research and Public Health*, *10*(7), 2741–2759. http://doi.org/10.3390/ijerph10072741

Tilman, D., Isbell, F., & Cowles, J. M. (2014). Biodiversity and ecosystem functioning. *Annual Review of Ecology, Evolution, and Systematics*, *45*, 471–493. http://doi.org/10.1126/science.1064088

Tomkins, J., Topham, N., Twomey, J., & Ward, R. (1998). Noise versus access: The impact of an airport in an urban property market. *Urban Studies*, *35*(2), 243–258. http://doi.org/10.1080/0042098984961

Truax, B. (2001). *Acoustic communication* (2nd ed.). Westport, CT: Ablex Publishing.

Tsai, K.-T., Lin, M.-D., & Chen, Y.-H. (2009). Noise mapping in urban environments: A Taiwan study. *Applied Acoustics*, *70*(7), 964–972. http://doi.org/10.1016/j.apacoust.2008.11.001

Tuan, Y.-F. (1990). *Topophilia: A study of environmental perception, attitudes, and values* (Morningside ed.). Columbia University Press: New York, NY.

U.S. Census Bureau (2014). American Community Survey: Multiyear accuracy of the data (3-year 2011-2013 and 5-year 2009-2013). Retrieved from http://www2.census.gov/programs-surveys/acs/tech_docs/accuracy/MultiyearACSAccuracyofData2013.pdf

U.S. Census Bureau (2015). American Community Survey: Design and methodology report. Retrieved from https://www.census.gov/programs-surveys /acs/methodology/design-and-methodology.html

U.S. Department of Transportation, Federal Aviation Administration, Great Lakes Region (1998). *Minneapolis-St. Paul International Airport planning process: New runway 17/35 and airport layout plan approval*. Retrieved from https://www.faa.gov/airports/environmental/records_decision/media /rod_minneapolis.pdf

U.S. Environmental Protection Agency (1974). *Information on levels of environmental noise requisite to protect public health and welfare with an adequate margin of safety* (Report No. 550/9-74-004). Washington, DC. Retrieved from http://nepis.epa.gov/Exe/ZyPDF.cgi /2000L3LN.PDF?Dockey=2000L3LN.PDF

U.S. Fish & Wildlife Service (2004). Minnesota Valley National Wildlife Refuge and Wetland Management District: Comprehensive Conservation Plan and Environmental Assessment. Retrieved from http://www.fws.gov/Midwest/planning /MinnesotaValley/index.html

Van Praag, M. S., & Baarsma, B. E. (2005). Using happiness surveys to value intangibles: The case of airport noise. *The Economic Journal*, *115*(500), 224–246.

Villanueva-Rivera, L. J., Pijanowski, B. C., Doucette, J., & Pekin, B. (2011). A primer of acoustic analysis for landscape ecologists. *Landscape Ecology*, *26*(9), 1233–1246. http://doi.org/10.1007/s10980-011-9636-9

Wang, B., & Kang, J. (2011). Effects of urban morphology on the traffic noise distribution through noise mapping: A comparative study between UK and China. *Applied Acoustics*, *72*(8), 556–568. http://doi.org/10.1016/j.apacoust.2011.01.011

Warren, P. S., Katti, M., Ermann, M., & Brazel, A. (2006). Urban bioacoustics: It's not just noise. *Animal Behaviour*, *71*(3), 491–502. http://doi.org/10.1016/j.anbehav.2005.07.014

Watts, G., Miah, A., & Pheasant, R. (2013). Tranquillity and soundscapes in urban green spaces—predicted and actual assessments from a questionnaire survey. *Environment and Planning B: Planning and Design*, *40*(1), 170–181. http://doi.org/10.1068/b38061

Werner, C. M., Altman, I., & Oxley, D. (1985). Temporal aspects of homes: A transactional perspective. In I. Altman & C. M. Werner (Eds.), *Home Environments* (pp. 1–32). New York: Plenum Press.

Wiens, J. A., Stenseth, N. C., Van Horne, B., & Ims, R. A. (1993). Ecological mechanisms and landscape ecology. *OIKOS*, *66*(3), 369–380.

Wilson, E. O. (1984). *Biophilia*. Cambridge, MA: Harvard University Press.

Worboys, M., and Duckham, M. (2004). *GIS: A computing perspective* (2nd ed.). Boca Raton, FL: CRC Press.

Wrigley, N. (1977). Probability surface mapping: a new approach to trend surface mapping. *Transactions of the Institute of British Geographers, New Series*, *2*(2), 129–140.

Young, M. (1988). The metronomic society: Natural rhythms and human timetables. Cambridge, MA: Harvard University Press.