National Park Service
U.S. Department of the Interior

Denali National Park and Preserve
Long-Range Transportation Plan

Appendix B: Denali Long-Range Transportation Planning and Acoustic Resources

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Research Sets the Stage

Author Eli Seigel wrote in 1970, "*all the opposites are two freedoms which question each other and complete each other*." Transportation and solitude likely represent such a pair of mutually-exclusive freedoms. In Denali and other Alaskan parks we can immediately recognize a tradeoff between the ability to be easily and quickly transported to a location and the ability to participate in the tranquility of wilderness beyond the reach of modern technology and crowds.

This recognition is a fundamental drive behind the work of the NPS Natural Sounds and Night Skies Division, whose vision statement is to ensure that, "*National parks are enduring sanctuaries for natural sounds and dark environments, where current and future generations have the opportunity to experience undisturbed soundscapes and an unimpeded view of the cosmos, and where the ecological roles and cultural values of acoustics and photics are understood and appreciated.*" (NPS 2014)

For the purposes of acoustic planning and research, the NPS has developed an autonomous system that can provide both American National Standards Institute (ANSI) certified acoustic levels (i.e., numeric measurements of sound pressure level in decibel units,) and audio recordings (i.e., sound that one can listen back to in headphones.) ANSI also recommends the collection of meteorological data concurrent with measurements of sound pressure level. Thus, a simple weather station incorporating wind speed, wind direction, temperature, and relative humidity is also part of the acoustic monitoring station. The photo below shows an external photograph of a typical station.

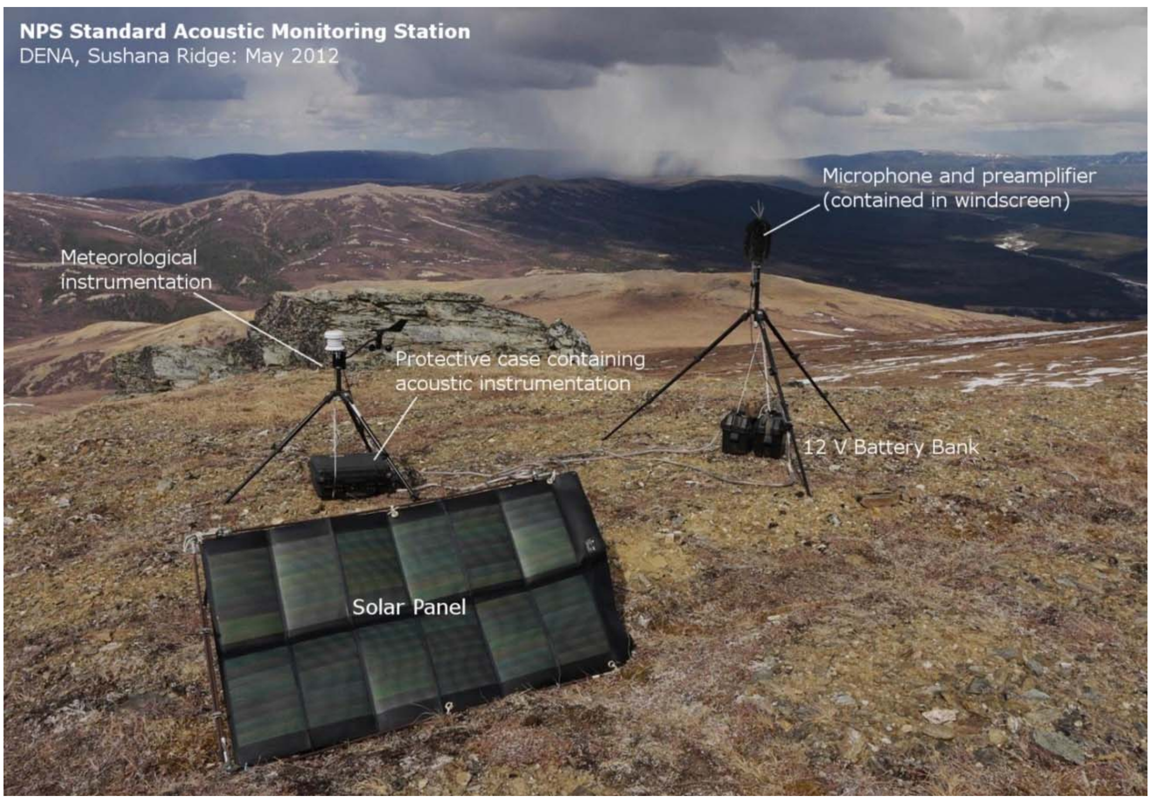


Figure 1. NPS Standard Acoustic Monitoring Station – equipment is composed of a microphone, meteorological instruments, sound level meter, digital audio recorder, battery bank and solar paneling.

Scientific work to understand Denali's acoustic environment began in 1999 in response to a large increase in aviation and snowmobile noise in the mid-1990s. (Morgan 2001) Early data were incorporated into the Backcountry Management Plan (BCMP) EIS, a supplement to Denali's General Management Plan. (NPS 2006e) After the BCMP was published, the park embarked on a decade-long inventory of the acoustic environment. The project was completed in 2015, and as of 2016 the park has moved into a monitoring phase. A basic timeline of acoustic resource management in Denali is shown below:

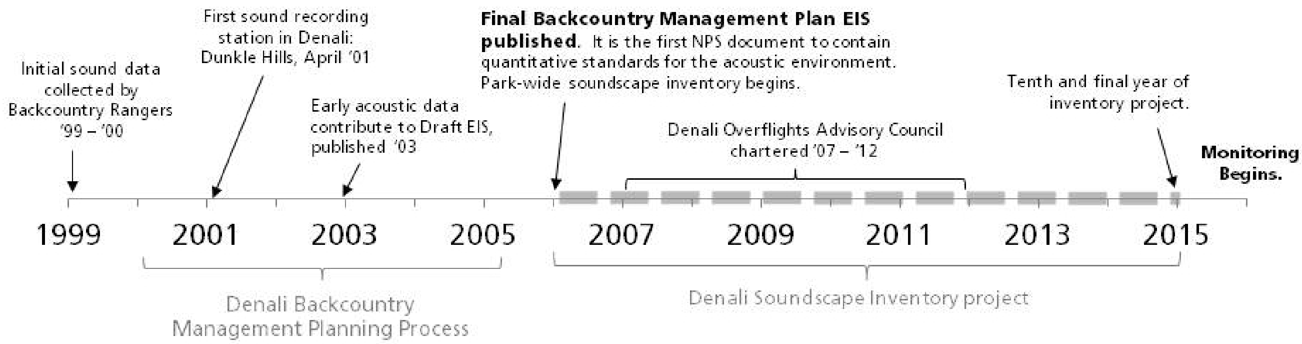


Figure 2. Timeline of acoustic resource management in Denali, 1999 – 2016.

Denali's acoustic inventory project is unique among park service units in that it was designed as a spatially random sample on a 20 by 20 kilometer grid. This allows inference beyond the local detection radius of each microphone. For example, consider the following map that depicts the acoustic metric '*daily average noise free interval*' – a measure of how long a typical quiet period is before it is broken by motorized noise. Noise free intervals in Denali are largely determined by the frequency of air traffic. Aircraft are very acoustically powerful sources that are audible at distances similar to the scale of the sampling grid, thus mapped measurements of noise free interval immediately form a discernable pattern to the human eye:

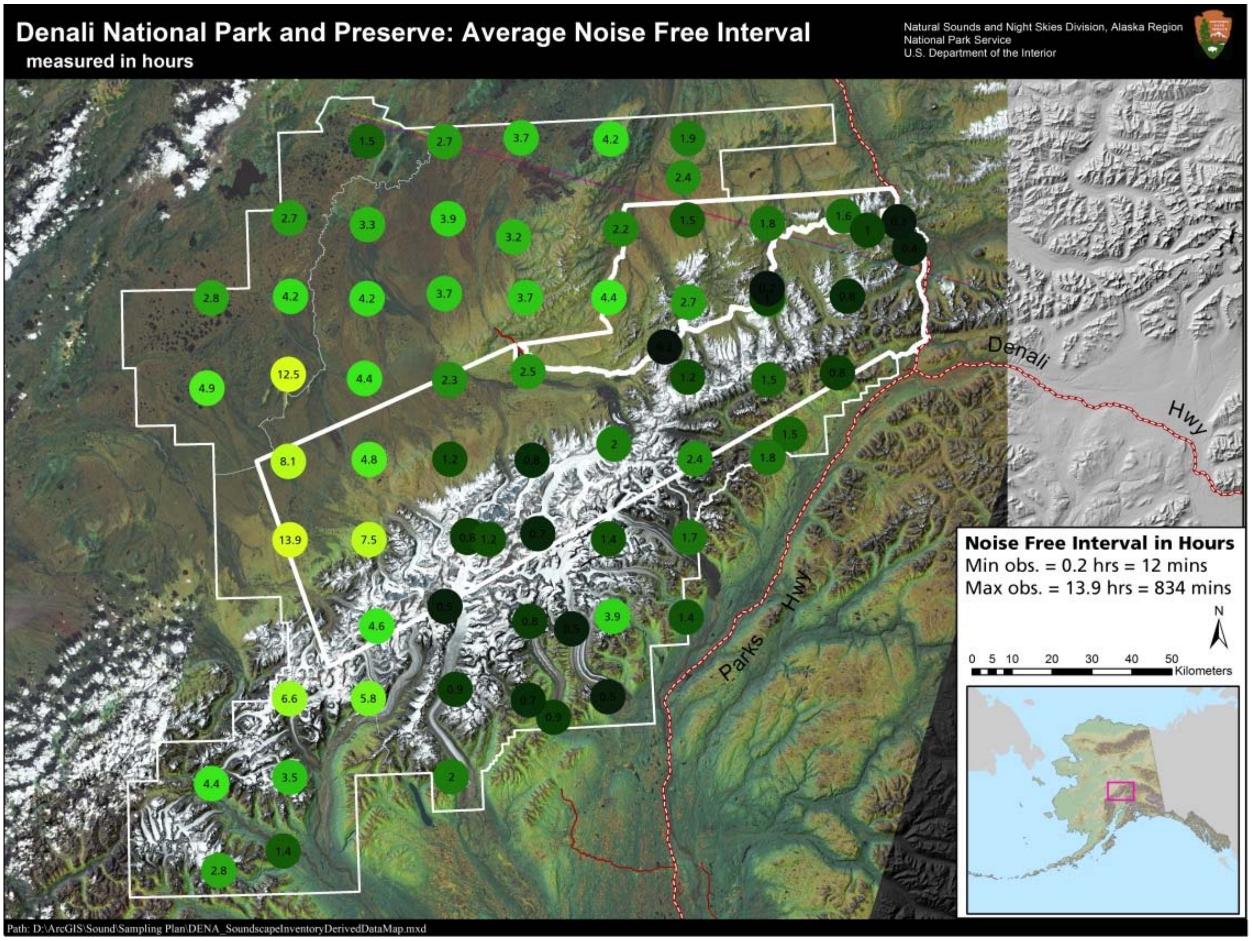


Figure 3. Daily average noise free intervals, measured in hours. Data were collected as part of Denali's Soundscape Inventory project, 2006 – 2015. Noise free interval is a measure of how long a typical quiet period is before it is broken by motorized noise.

Entering the realm of inference, the following map uses observations at specific soundscape inventory points to estimate the noise free interval at a park-wide scale. It uses a spatial smoothing technique called *"inverse distance weighting"* to construct new data points between the known values - a method known as *interpolation*. Again, because the scale of the phenomena (aircraft traffic) and the scale of the sample (20 km^2 resolution) are comparable, noise free interval is a metric well-suited to interpolation techniques. (Peterson 1998, Gergel 2006) Continuous change in the metric is physically sensible and approximate the visual effect of looking at the original point data. Denali's soundscape inventory was important for understanding which acoustic metrics are best suited to monitoring change at a landscape scale.

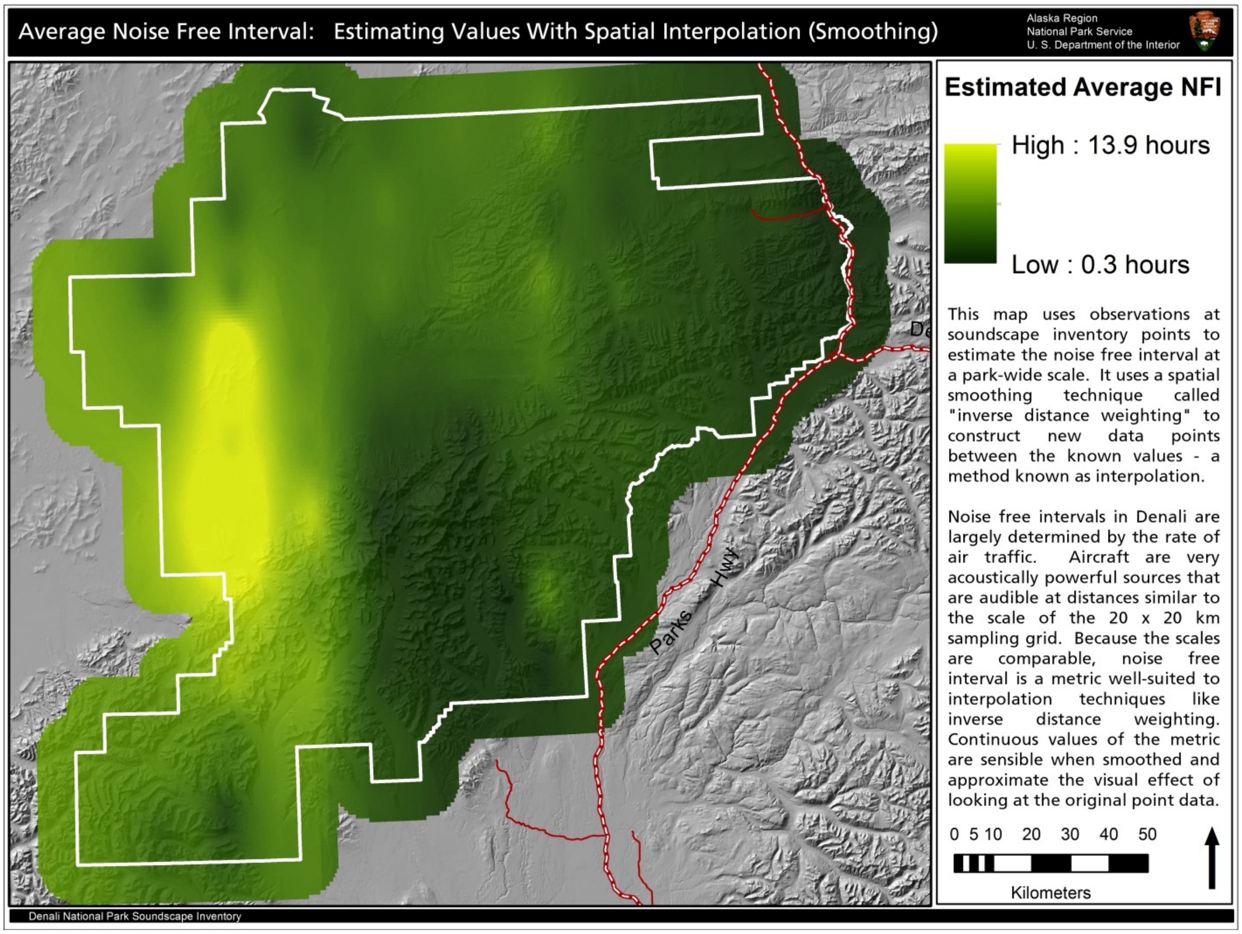


Figure 4. Average noise free interval: values estimated by spatial interpolation. Units are in hours. This map uses observations at soundscape inventory points to estimate the average noise free interval at a park-wide scale. It uses a smoothing technique called inverse distance weighting to construct new data points between the known values – a method known as interpolation.

The Denali soundscape inventory supplies spatially-rich information about the current state of the acoustic environment. It also clarifies the choices available to quiet the park, as per NPS policy. Inventory data have been:

(1) Inventory data have been used to review the indicators and standards of the BCMP:

- They explain how indicators change in response to the acoustic ambience.
- They explain the relationship between indicators (for example, NFI and event rate are inversely related, thus one can be estimated from the other.)
- They provide an understanding as to which indicators are best suited to the scale of the park.

(2) Inventory data have been used as input to the voluntary aviation best practice development process of the Denali Overflights Advisory Council (2007 – 2012):

- They provided the basis from which to monitor the effects of aviation best practices.
- They provided updates to the council directing attention to areas most in need of mitigation.
- They transcend anecdote as the sole basis for making decisions.

(3) Inventory data have been used in predictive acoustic modelling:

- They provide a means to *validate* noise models of aircraft takeoffs or overflights, road noise, or other sources.
- Data such as event rates or hourly distributions can also be used as *inputs* to models.

Aviation, Transportation, and NPS Policy

There are currently several types of aviation transport in the park. Section 1110(a) of the Alaska National Interest Lands Conservation Act (ANILCA) provides for aviation access for traditional activities and for travel to and from homesites, which will not be discussed in this document. Nor will high-altitude commercial aviation – which does impact the park, but would involve participation of the Federal Aviation Administration in the revision of Victor Airways or Jet Routes within the National Airspace System, a process well beyond the scope of this plan.

Instead, this document seeks to build on discussions of the Denali Overflights Advisory Council (https://www.nps.gov/articles/denali-aircraft-overflights.htm),a federal advisory committee chartered by the Secretary of the Interior from 2007 – 2012. The group developed a suite of voluntary aviation best practices that were adopted by both commercial and government aviators. It is fitting that these best practices were broadly adopted because NPS policy does not distinguish the obligations of governmental and Concessionaire operations with respect to resource protection. NPS Management Policies 2006 § 10.2.4.9 states:

> *Concessioners are required to comply with applicable provisions of all laws, regulations, and policies that apply to natural and cultural resource protection.*

It is relevant, then, to provide a brief policy review. NPS Management Policies 2006 § 8.2.3 addresses impacts to natural sounds directly, stating:

> *The Service will strive to preserve or restore the natural quiet and natural sounds associated with the physical and biological resources of parks. To do this, superintendents will carefully evaluate and manage how, when, and where motorized equipment is used by all who operate equipment in the parks, including park staff . Uses and impacts associated with the use of motorized equipment will be addressed in park planning processes. Where such use is necessary and appropriate, the least impacting equipment, vehicles, and transportation systems should be used, consistent with public and employee safety. The natural ambient sound level—that is, the environment of sound that exists in the absence of human-caused noise—is the baseline condition, and the standard against which current conditions in a soundscape will be measured and evaluated.*

Further guidance related to aircraft is articulated in § 6.3.4.3:

> *Managers contemplating the use of aircraft or other motorized equipment or mechanical transportation within wilderness must consider impacts to the character, esthetics, and traditions of wilderness before considering the costs and efficiency of the equipment.*
>
> *In evaluating environmental impacts, the National Park Service will take into account (1) wilderness characteristics and values, including the primeval character and influence of the wilderness; (2) the preservation of natural conditions (including the lack of man-made noise); and (3) assurances that there will be outstanding opportunities for solitude, that the public will be provided with a primitive and unconfined type of recreational experience, and that wilderness will be preserved and used in an unimpaired condition.*

Furthermore, § 6.3.7 offers and important reminder that in wilderness areas:

> *The principle of nondegradation will be applied to wilderness management, and each wilderness area's condition will be measured and assessed against its own unimpaired standard. Natural processes will be allowed, insofar as possible, to shape and control wilderness ecosystems. Management should seek to sustain the natural distribution, numbers, population composition, and interaction of indigenous species. Management intervention should only be undertaken to the extent necessary to correct past mistakes, the impacts of human use, and influences originating outside of wilderness boundaries.*

Envisioning a (Flight) Route Forward

Denali's Backcountry Management Plan (BCMP) remains the overarching unit-level policy document on the management of the natural acoustic environment. Data collection during the implementation of the BCMP has provided a robust baseline description of the resource. Transportation planning directly benefits from a synthesis of these inventory data.

One way to approach the protection of acoustic resources is through a cost-distance analysis. Cost-distance analysis balances the costs associated with travelling a certain distance (in this case, the cost of aviation fuel,) with resistances to travel. Resistances to travel can take many forms – the increased difficulty in crossing a major river or mountain range, or the difficulty of moving over muskeg as opposed to alpine tundra. In this case, we describe resistances to noise – areas sensitive to the acoustic disturbance created by mechanical transport.

What is meant by resistance? Synonymous with 'noise sensitivity' for the purposes of this discussion, the word resistance more accurately conveys the interlocked relationship between isolation and transportation. The following two definitions are applicable to the Long Range Transportation Plan:

Resistance *(noun):*

1. Resistance is the degree to which a substance prevents flow through it.
2. Resistance is the ability to prevent something from having an effect.

In this case, the *"ability to prevent something from having an effect"* describes the human ability to make choices about how to conserve the acoustic environment. In other words, we conceptualize a resistance when we answer the question, *"How do we mitigate the effects of motorized transport on the acoustic environment?"* We will later see how the *resistive* analogy between traffic flows and electrical flows can be used to the benefit of managing acoustic resources.

Resistances to noise typically fall into three basic categories:

1) Those defined by NPS policy or aviation best practices.
2) Those related to the acoustic or ecological properties of the landscape.
3) Those related to avoiding interactions between motorized and non-motorized experiences.

Resistances to noise can be assigned based on a number of different rationales. For instance, consider the following raster dataset that depicts the amount of use by backcountry unit. One long-standing approach to describing which areas should be protected from noise is to separate backcountry user groups from aviation user groups in space. Lighter areas on the map indicate more backcountry use – and thus suggest that aircraft avoid units along the Denali park road corridor.

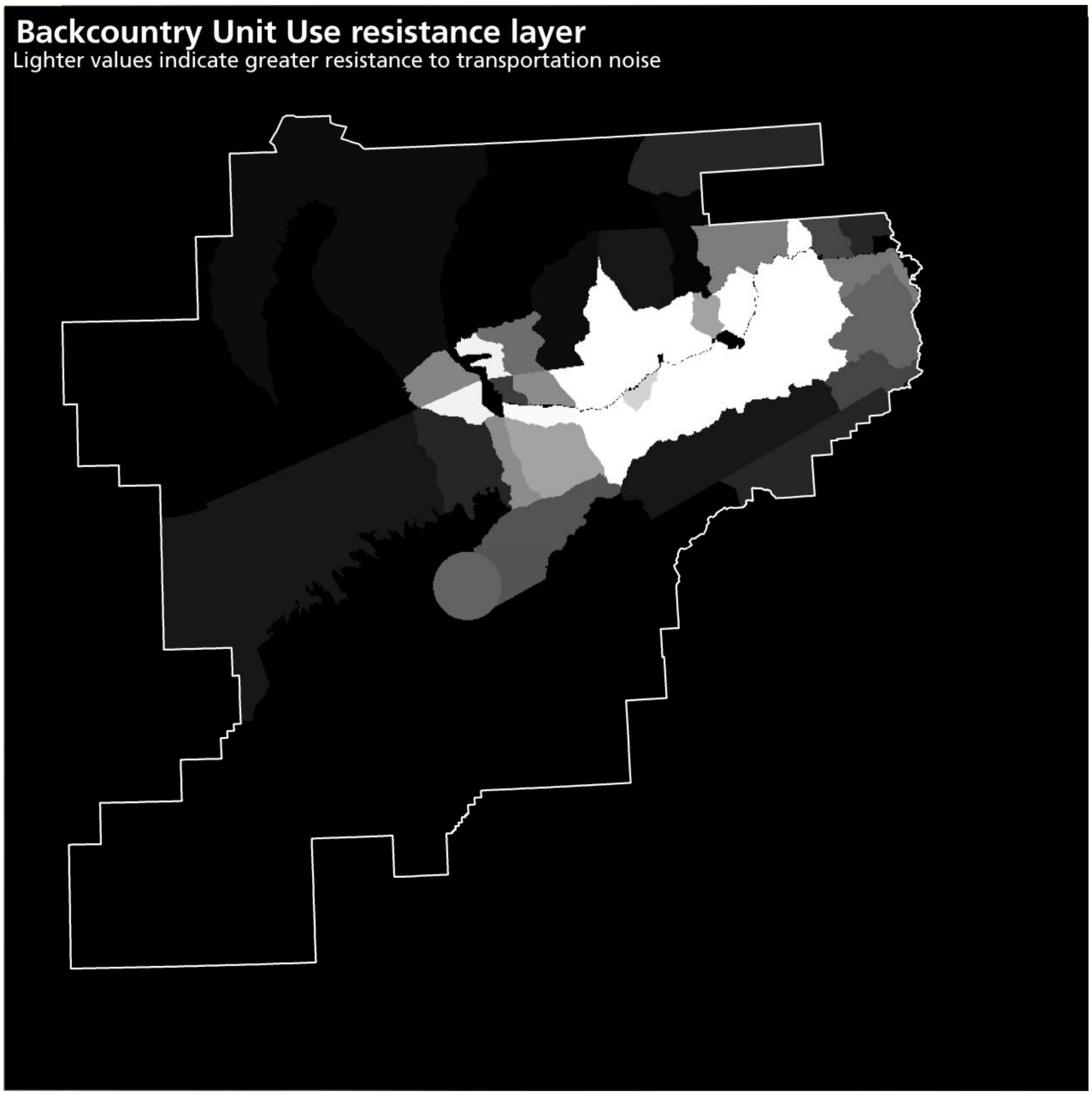


Figure 4. Backcountry Unit Use resistance layer. Lighter values indicate a greater resistance to transportation noise. This suggests that aviation routes should avoid core units around the road corridor.

Contrast this with data which show the average noise free interval across the park. The layer is normalized to the same brightness as the backcountry use layer, with lighter areas representing a greater resistance to noise and thus higher resource costs for transportation over the area.

The rationale behind the noise free interval map produces different optimal routes than the backcountry user map. This is because resistance is based on the fact that areas with long noise free intervals are sensitive to minor changes in air traffic, and thus traffic should be routed over areas that are already highly fractured. In this case, areas that already have air traffic would continue to bear the brunt of resource damage, allowing the most pristine acoustic environments of the park to remain intact.

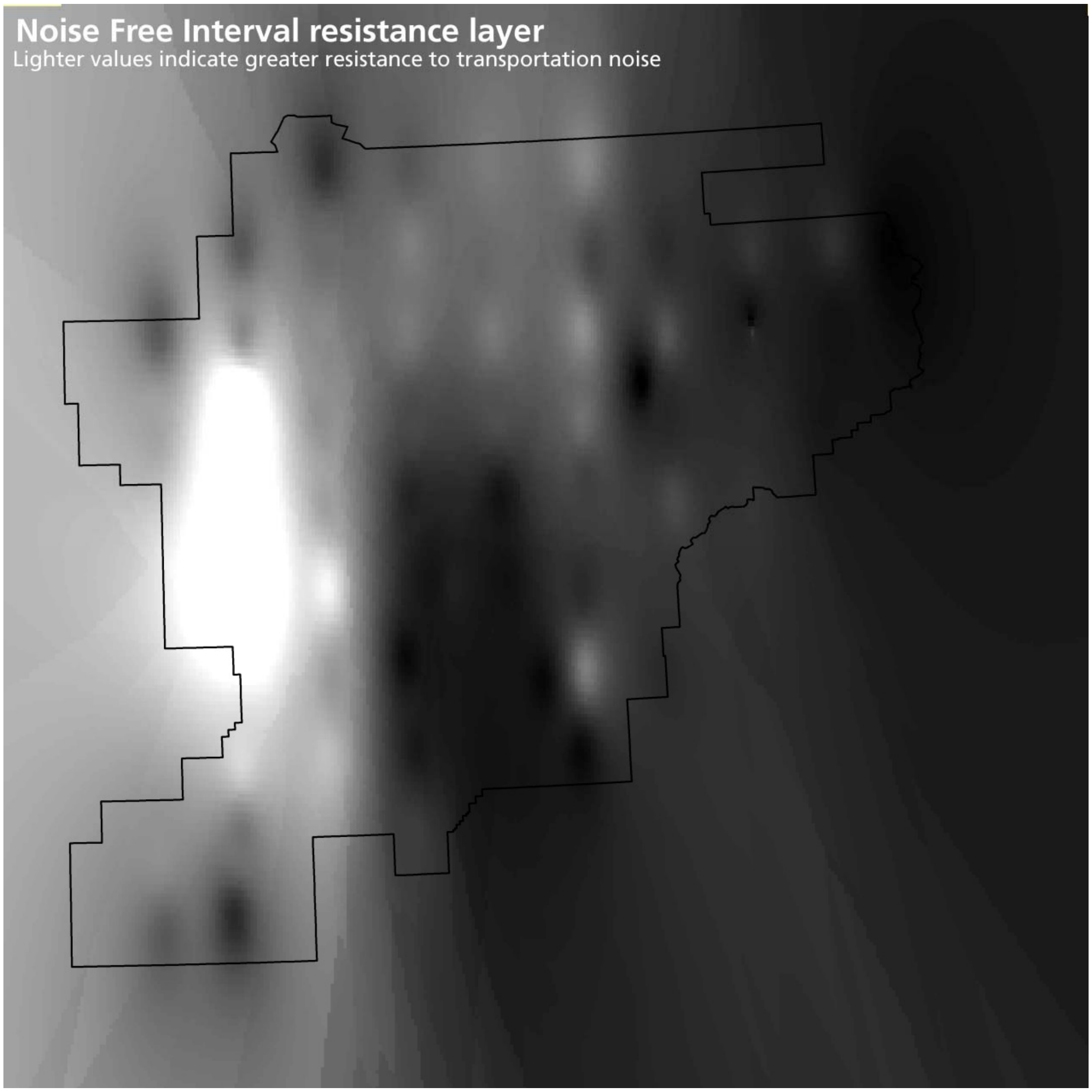


Figure 5. Noise Free Interval resistance layer: lighter values indicate greater resistance to transportation noise. This would suggest that aircraft routing remain largely the same, especially in the areas between the Kahiltna and Ruth glaciers.

Backcountry use statistics and noise free intervals are just two of many different ways of assigning resistances to aviation transport. Which strategy is best? That depends entirely on the basis of each claim. After reviewing both layers, it should be apparent that a wide range of conflicting rationales can be applied to mitigating impacts from Denali's aviation transportation network. Deciding which should be prioritized is a complex decision.

Unless the overall aviation traffic volume over the park is reduced, displacement in free space is the primary mitigation technique available to park stewards. The most substantial mitigations enacted for the park thus far – the Denali Overflights Advisory Council aviation best practices – required the council to weigh certain routing displacements over others. (DOAC 2012)

Once a weighting network of resistance layers has been distilled from public and expert opinion, it is possible to use them to envision idealized flight corridors. One useful tool for this purpose is the cost-distance modelling software *Circuitscape* (www.circuitscape.org,) which uses electrical theory to describe the travel of electrons over a semiconductor. This is analogous to a pilot with knowledge of areas resistant to noise who utilizes this knowledge while conducting their flight operations. Results of a *Circuitscape* analysis include all the possible routes a pilot might fly, but highlight stewardship-friendly corridors. It allows us to see the conclusions that follow from our rationale.

The following is an example weighting network that can be used as an input for *Circuitscape*. The weights are chosen in this case to produce a result that is realistic while avoiding the influence of hard, discrete edges. It balances nine data sets with widely varying rationales to produce a final summation that can be used to visualize flight corridors.

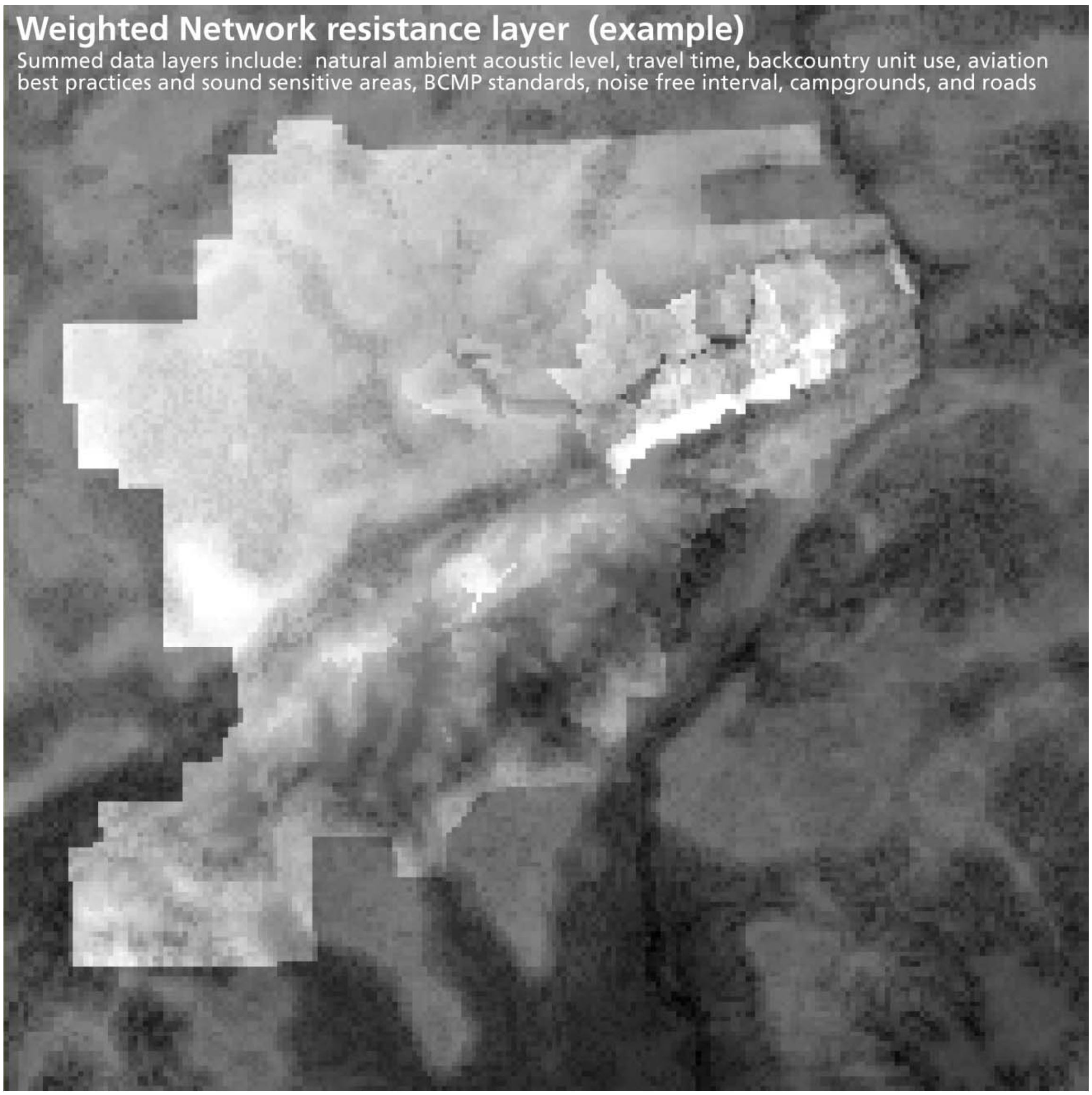


Figure 6. Example of a weighted network resistance layer. Summed data layers include: natural ambient acoustic level, travel time, backcountry unit use, Denali Overflights Advisory Committee aviation best practices and sound

sensitive areas, BCMP standards, noise free interval, campgrounds, and road corridors. The hard edges of polygon features are especially prominent in the final sum.

Dataset Name	Description of Dataset	Rationale Statement for Noise Resistance	Weight
Natural Sound Pressure Level (Median, L50)	Typical ambience of the natural acoustic environment. (Modelled)	"Listening area is reduced in more energetic acoustic environments, reducing the impact of human activities." *Less natural energy = higher resistance.*	50%
Travel Time	Estimated travel time on foot from portal areas. (Modelled)	"Backcountry users travelling in more remote areas of the park have a greater motivation to find solitude." *Greater travel time = higher resistance.*	25%
Backcountry User Days	Utilization of backcountry units of the park. (Empirical)	"Areas with a greater amount of backcountry users should be preferrentially avoided." *More users = higher resistance.*	15%
Denali Overflights Advisory Council: Aviation Best Practices	Best-practices for mitigating acoustic impacts from aviation. (Federal Advisory Committee)	"Best-practices identified by the Denali Overflights Advisory Council should be fully implemented." *Areas affected by best-practices = high resistance.*	10%
Backcountry Management Plan Soundscape Standards	Soundscape standards by spatial region of the park. (GMP)	"Adherence to NPS policy should be prioritzed." *Lower impact management zone = Higher resistance.*	5%
Noise Free Interval	Average amount of time before experiencing the next noise disturbance. (Empirical, interpolated)	"Areas with longer noise-free intervals are more sensitive to fracturing due to increases in air traffic." *Greater noise-free interval = higher resistance.*	5%
Campground Locations	Buffered campground areas. (Empirical)	"Campgrounds are places where many people spend time resting, and should be preferrentially avoided." *Closer to campground = higher resistance.*	5%
Roads	Buffered road network. (Empirical)	"Roads are already impacted by noise, so aviation noise will have a lesser impact in proximity to roads." *Beyond road noise footprint = high resistance.*	3%
Denali Overflights Advisory Council: sound sensitive areas	Areas identified by the Denali Overflights Advisory Council as noise sensitive, banded into three categories: low, medium, high. (Federal Advisory Committee)	"Sound sensitive areas should be preferrentially avoided." *Higher sensitivity band = higher resistance.*	2%

Table 1. Description of noise resistance rasters that were used to show how varying rationales can be balanced to produce an overall weighted noise resistance layer.

Once the weighted resistance layer has been created, *Circuitscape* is used to recognize ideal flight corridors. Airports with commercial use represent sources of electrical potential, and include: Talkeetna, Healy, McKinley Public / ERA helipad, McKinley Private, Cantwell, and Kantishna. The sink (ground) of electrical potential is the Denali massif. For the example weighting network in this document, the following map was produced:

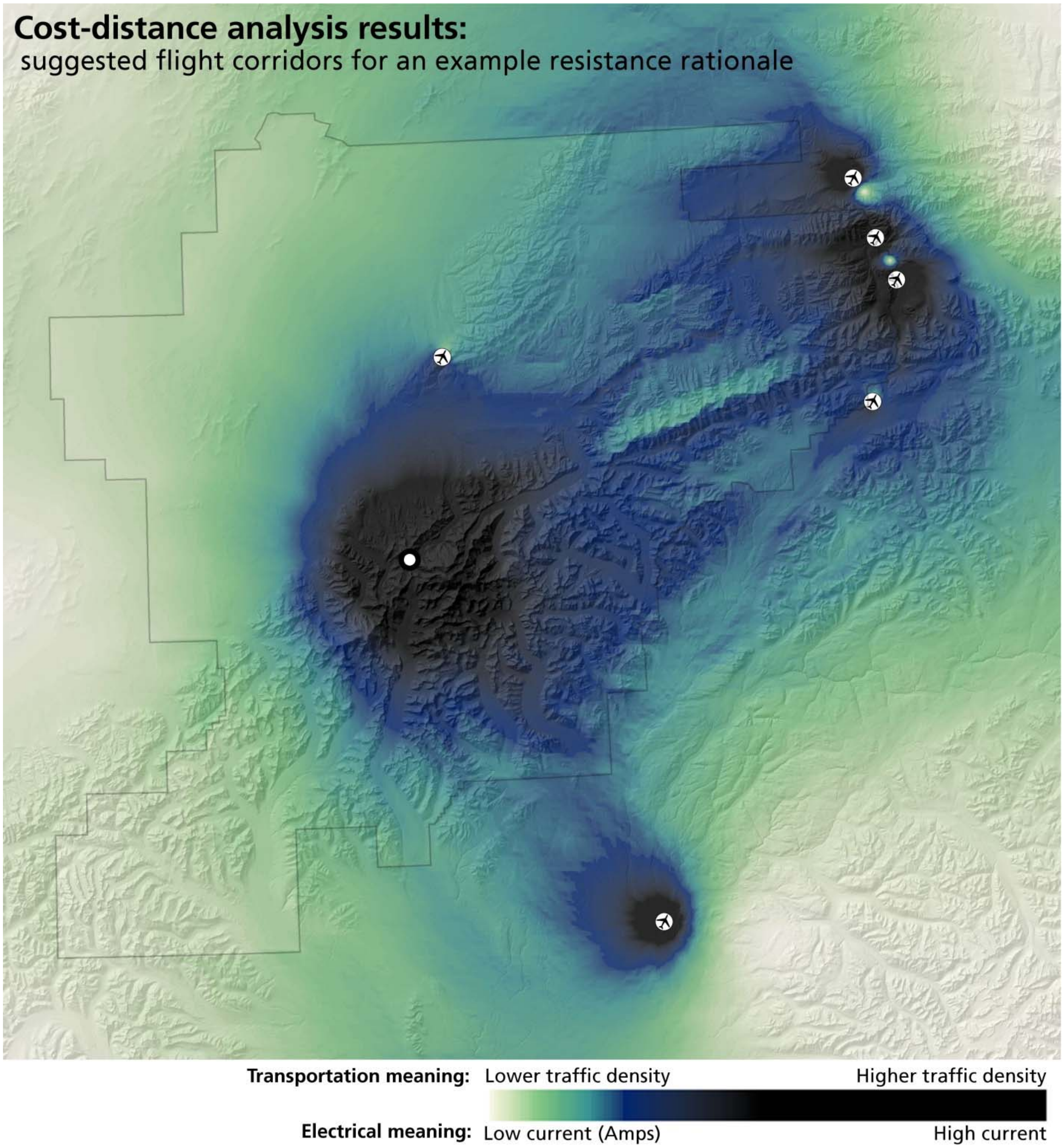


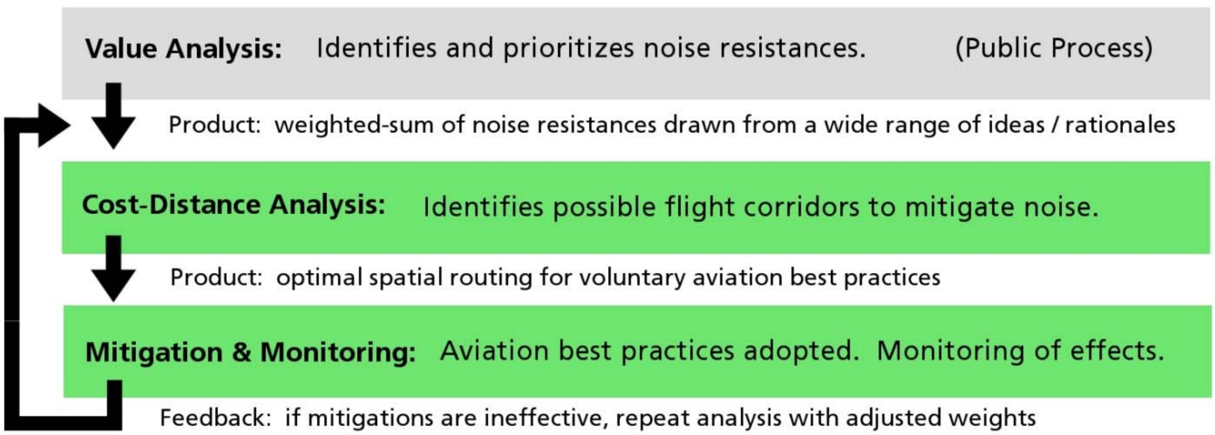
Figure 7. Cost-distance analysis results. This graphic shows current flow from electrical sources (airports) to an electrical sink (the Denali massif.) This is analogous to air traffic density.

What does the model show? It represents air traffic density as an analogy to electrical current – the greater the current, the greater the air traffic density. As a model, it is an imperfect representation of reality, but this example representation does identify flight corridors that follow from the input rationale. (These corridors include: the Denali park road corridor, the Denali Fault, a route along the outer range, and one that connects Broad Pass to the Eldridge Glacier.) Obviously the map in Figure 7 fails to capture public opinion, and for that reason it is incomplete, but the technique stands as a meaningful strategy to approach these complex decisions.

Conclusion

Data from the Denali Soundscape Inventory describe the park's acoustic environment at a landscape scale. These data can be used for many purposes but their most critical is to provide a baseline from which to monitor the effects of future noise mitigation efforts.

In the preceding section we described a cost-distance analysis technique that could be utilized to identify the most beneficial long-term mitigations for the acoustic environment. Such corridors represent opportunities for park management and the aviation community to work together as stewards. What has not been identified in this document is the "value analysis" process by which public and expert opinion can be synthesized into an appropriate weighted resistance layer for cost-distance analysis. The overall strategy may follow a form similar to this:



An informal version of this same process was used to by the twelve members of the Denali Overflights Advisory Council to develop an initial suite of aviation best practices from 2007 – 2012. Some of these best practices have produced substantial positive changes for the park, but others have failed to be acoustically effective due to their extent or timing. The strategy described in this document could be used to open the doors of conversation and improve the effectiveness of the mitigations to protect Denali's acoustic environment.

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