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16. Abstract
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The objective of this study was to identify potential modifications to departure and arrival procedures at Boston Logan International Airport (BOS) which would reduce community noise impact in areas which experience flight track concentration. The potential procedure modifications were separated into two sequential “Blocks”. Block 1 procedures were characterized by clear predicted noise benefits, limited operational/technical barriers and a lack of equity issues. Block 2 procedures exhibit greater complexity due to potential operational and technical barriers as well as equity considerations (defined as noise redistribution between communities for the purposes of this study).

The Block 2 phase included consideration of procedures which would redistribute noise exposure such as approaches to increase flight trajectory dispersion, which have been requested by some communities. It also included new noise reduction opportunities enabled by PBN that were identified during the Block 2 process, as well as a redesigned procedure which resolved technical issues identified with one of the prior Block 1 recommendations.

Candidate approach and departure modifications were first identified based on an analysis of historical flight track densities over the communities surrounding BOS before and after the implementation of new RNAV procedures coupled with noise complaint records and US Census population data. Potential procedure modifications were considered for each identified arrival and departure runway as well as procedure concepts to reintroduce dispersion into flight trajectories.

The noise impact of candidate procedure modifications was modeled and presented to community and operational stakeholder

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Block 2 Procedure Recommendations for Boston Logan Airport Community Noise Reduction

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EXECUTIVE SUMMARY

Recent developments in navigation and surveillance technology have enabled new high-precision departure and arrival procedures using GPS and Performance-Based Navigation (PBN) standards. These procedures have proven effective for reducing fuel consumption and streamlining some aspects of air traffic control. However, flight tracks that were previously dispersed over wide areas due to less precise navigation or ATC vectoring are more concentrated on specific published tracks with effects on underlying communities.

The objective of this study was to identify potential modifications to departure and arrival procedures at Boston Logan International Airport (BOS) which would reduce community noise impact in areas which experience flight track concentration. The potential procedure modifications were separated into two sequential "Blocks". Block 1 procedures were characterized by clear predicted noise benefits, limited operational/technical barriers and a lack of equity issues. Block 2 procedures exhibit greater complexity due to potential operational and technical barriers as well as equity considerations (defined as noise redistribution between communities for the purposes of this study).

The Block 2 phase included consideration of procedures which would redistribute noise exposure such as approaches to increase flight trajectory dispersion, which have been requested by some communities. It also included new noise reduction opportunities enabled by PBN that were identified during the Block 2 process, as well as a redesigned procedure which resolved technical issues identified with one of the prior Block 1 recommendations.

Candidate approach and departure modifications were first identified based on an analysis of historical flight track densities over the communities surrounding BOS before and after the implementation of new RNAV procedures coupled with noise complaint records and US Census population data. Potential procedure modifications were considered for each identified arrival and departure runway as well as procedure concepts to reintroduce dispersion into flight trajectories.

The noise impact of candidate procedure modifications was modeled and presented to community and operational stakeholder groups. Community feedback was used to identify procedures of interest and gather input on improvements or revisions. Operational stakeholder feedback was used to identify and to the extent possible mitigate operational barriers and concerns.

The procedures which were identified for Block 2 and their primary noise benefits are listed below.

BLOCK 2 PROCEDURE RECOMMENDATIONS

Table 1. Block 2 Procedure Recommendations.

Proc. ID D = Departure A = Arrival	Procedure	Primary Benefits
APPROACH PROCEDURES		
2A-1	**Runway 22L** Implement a new overwater RNAV approach for Runway 22L that crosses the Nahant Causeway from the east to join a 4-mile final approach.	Arrival flight paths from the south and east moved overwater instead of overflying populated areas north/northeast of the airport.
2A-2	**Runway 4R** Maintain use of current ILS approach to Runway 4R.	The current straight-in approach was found to have the lowest net population exposure among all RNAV approach candidates evaluated.
DEPARTURE PROCEDURES		
2D-1	**Runway 22L/R** Modify the current RNAV SID with a speed restriction to enable an earlier turn to the east, shifting aircraft tracks north away from Hull.	Departure flight paths moved north away from Hull.
2D-2	**Runway 33L** Modify the current RNAV SIDs to enable the start of flight track dispersion at the earliest point possible (1 NM from the end of the runway).	Increased dispersion of flight tracks and noise distribution.
2D-3	**Runway 27** Modify RNAV SIDs to begin flight track dispersion at the earliest point possible while satisfying the 1996 Environmental Record of Decision.	Increased dispersion of flight tracks and noise distribution; lower net population noise exposure.

Because some Block 2 procedures result in redistribution of noise between communities it will ultimately be the communities which will need to request the implementation of the procedures. This report attempts to document the noise impacts of the proposed Block 2 procedures to support this community decision process.

It should be noted that any Block 2 procedures put forward will be required to go through the formal FAA 7100.41 procedure design review and approval process, where unanticipated issues may arise. During this process, procedures will be further evaluated for potential implementation barriers, a safety analysis will be conducted, and a flight check will be executed prior to procedure publication. In parallel to this process, the FAA will also conduct an environmental review of any requested procedure. Any procedure carrying significant effects (i.e. noise redistribution or increased noise footprint) will be subject to a full environmental review. Final procedure implementation will therefore be contingent on both a successful 7100.41 design process and a positive environmental review.

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Acronyms and Abbreviations

Term	Definition
A4A	Airlines for America
AEDT	Aviation Environmental Design Tool
ASDE-X	Airport Surface Detection Equipment Model X
ATC	Air Traffic Control
BADA-4	Base of Aircraft Data Version 4
BOS	Boston Logan International Airport
DNL	Day-Night Average Level
FAA	Federal Aviation Administration
HMMH	Harris Miller Miller and Hanson, Inc.
IAP	Instrument Approach Procedure
ILS	Instrument Landing System
LMAX	Maximum Sound Pressure Level
Massport	Massachusetts Port Authority
MCAC	Massport Community Advisory Committee
MIT	Massachusetts Institute of Technology
MOU	Memorandum of Understanding
MTOW	Maximum Takeoff Weight
NABOVE	Number of Events Above Set Level
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NATCA	National Air Traffic Controllers Association
NAVAID	Navigation Aid
NM	Nautical Mile
NPD	Noise Power Distance
PBN	Performance Based Navigation
RNAV	Area Navigation
RNP	Required Navigation Performance
RVFP	RNAV Visual Flight Procedure
RWY	Runway
SEL	Sound Exposure Level
SID	Standard Instrument Departures
SPL	Sound Pressure Level
STAR	Standard Terminal Arrival Route
TARGETS	Terminal Area Route Generation, Evaluation, and Traffic Simulation
TASOPT	Transport Aircraft System Optimization

I. Introduction

Aircraft noise is a growing concern for communities near airports around the United States. While modern aircraft are quieter on a flight-by-flight basis than their predecessors[1], aircraft overfly some communities with increasing frequency due to traffic growth and flight track concentration. The precision of aircraft navigation has improved over the past few decades due to the introduction of GPS and other advanced navigation systems. This has led to the introduction of advanced Performance Based Navigation procedures[2], including Area Navigation (RNAV) and Required Navigation Performance (RNP) procedures as illustrated in Figure 1.

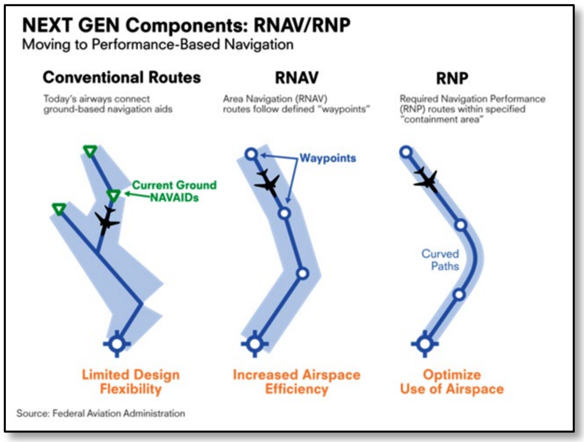


Figure 1. Comparison between Conventional, RNAV, and RNP Navigation (Source: FAA).

Historically, routes were defined by radio navigation aids (NAVAIDs) located at various locations on the ground. Approach and departure procedures consisted of tracks connecting existing NAVAIDs or compass headings issued by air traffic controllers either through published procedures or by radar vectoring. A combination of natural variation in navigational precision and controller instruction timing resulted in a natural dispersion of flight trajectories. This can be seen in the left side of Figure 2 which shows flight tracks of 2010 Runway 33L departures from Boston Logan Airport (BOS) prior to the implementation of RNAV departures.

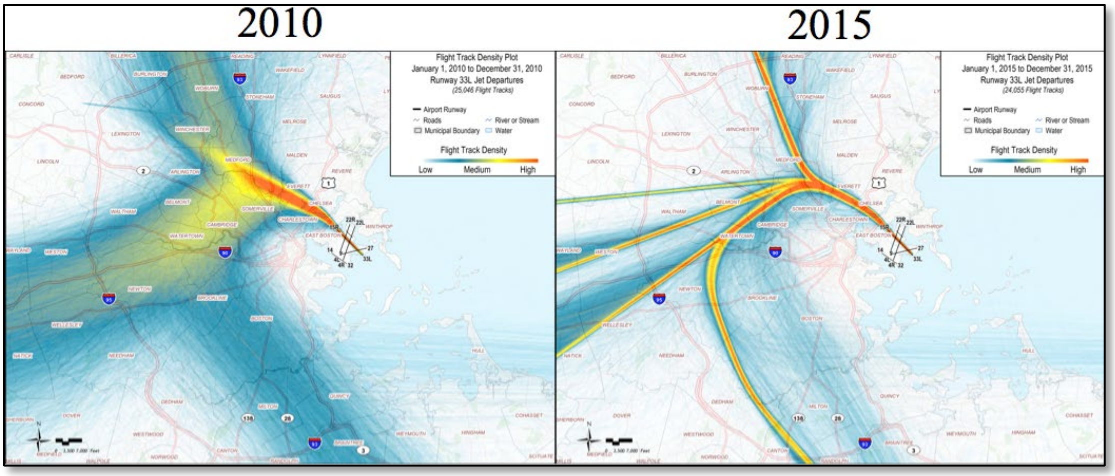


Figure 2. Runway 33L Departure Flight Tracks in 2010 (before) and 2015 (after) RNAV implementation.

Area Navigation (RNAV) provides the ability for aircraft to navigate between waypoints which can be defined at any location. This improves the precision, safety and flexibility in flight procedures. RNAV procedures are generally comprised of an ordered sequence of waypoints with altitude and/or speed constraints at some or all of the waypoints. Required Navigation Performance (RNP) procedures can be designed with tighter tolerances in areas where this is necessary for the purpose of terrain clearance, due to the onboard monitoring and alerting capability of participating aircraft.[3]

In recent years, it has become evident that some PBN procedures have potential unintended consequences in terms of community noise impact.[4] The increased use of Area Navigation (RNAV) and Required Navigation Performance (RNP) procedures has resulted in a concentration of lateral tracks near airports due to the increased precision of these procedures. While this increased precision has enabled operational benefits such as improved safety, reduced ATC workload, higher runway throughput, reduced fuel burn, better terrain avoidance, and lower approach minimums[3], it has also resulted in noise concentration and community opposition as aircraft fly consistent and repetitive tracks over the same communities. The right panel of Figure 2 shows an example of flight track concentration at Boston Logan Airport (BOS) arising from RNAV departure procedure implementation between 2010 and 2015.

Jet departures at BOS are normally assigned to one of nine RNAV departure procedures. These procedures are typically flown by an airplane's autopilot system, although they can also be flown manually with guidance from the aircraft's onboard navigation systems. Each of the procedures ends at a waypoint that serves as a transition into the high-altitude airway system for a particular direction of flight. The purpose of the published procedures is to provide a safe, systematic, and efficient transition for departing aircraft from liftoff through the cruise phase of flight. However, the precision of the new procedures has removed much of the dispersion in flight tracks that existed prior to RNAV implementation.

Arrivals at BOS also use RNAV Standard Terminal Arrival Routes (STARs) for the transition from the high-altitude airway structure to the airport terminal environment. The final approach and landing may also occur with PBN guidance at some runways, although most flights use the conventional radio-based Instrument Landing System (ILS) or visual guidance for the final approach to landing. The observed lateral navigation precision of aircraft flying the ILS is similar to RNAV.

Communities around the US have expressed frustration with flight track concentration and noise arising from PBN implementation.[5] At the same time, operational and safety benefits of PBN and the worldwide implementation of new procedures make it difficult to revert to non-PBN procedures. Ideally, PBN technology and procedures could be used to reduce overflight noise while retaining operational benefits.[6]

This report presents the results of the second phase (Block 2) of an effort to identify opportunities to reduce noise through changes or amendments to PBN procedures at BOS conducted in support of a Memorandum of Understanding (MOU) between Massport and the FAA. The first phase (Block 1) was focused on procedures with clear noise benefits, limited operational or technical barriers and no equity or noise re-distribution issues. Block 1 procedure recommendations were issued in 2017.

The Block 2 phase included consideration of procedures which would redistribute noise exposure such as approaches to increase flight trajectory dispersion which have been requested by some communities. It also included new noise reduction opportunities which were identified during the Block 2 process and a redesigned procedure which resolved technical issues identified with one of the prior Block 1 recommendations.

II. Study Approach

Overall Approach

The approach to develop procedure recommendations in Block 2 is shown in Figure 3. The general approach was similar to the Block 1 process, but an enhanced effort to obtain and respond to operational stakeholder input was included to increase the likelihood that the recommended procedures would be able to pass through the FAA implementation process.

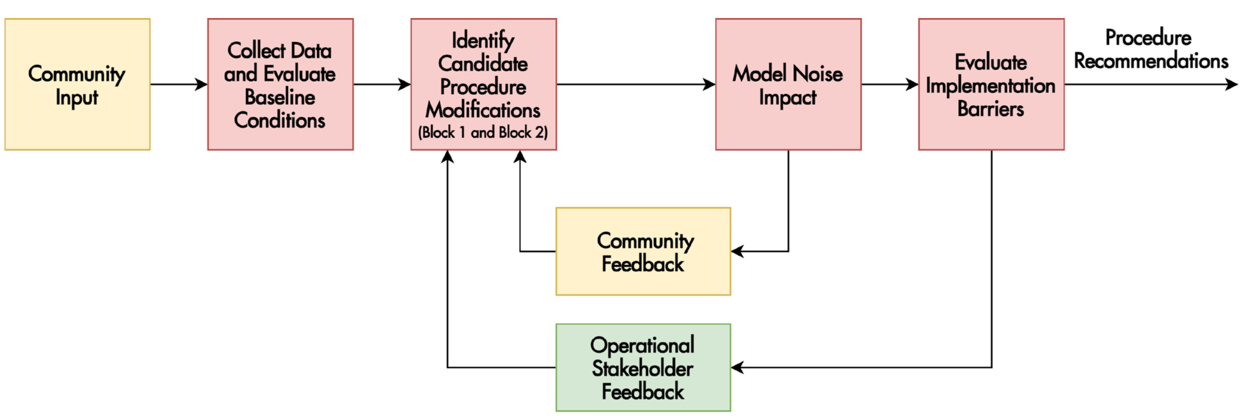


Figure 3. MIT research approach (methodology).

The process shown in Figure 3 began with community input and analysis of complaint data to identify key noise concerns and community objectives for procedure modification. Community input was collected through open-forum public meetings and briefings to the Massport Community Advisory Committee (MCAC) Aviation Subcommittee. Because the concerns and objectives generally were related to specific arrival or departure runway procedures, radar data and current flight procedures before and after RNAV were analyzed to define baseline conditions for the primary overland arrival and departure runways at BOS. Based on the design objectives and a preliminary analysis of technical feasibility, a preliminary set of candidate procedure modifications was then proposed for each arrival and departure runway being evaluated. The noise impact of preliminary procedure modifications was modeled and presented to community and operational stakeholder groups. Community feedback was used during this stage to identify procedures of interest, and to solicit community input on improvements or revisions. Those procedures that were identified as having the potential to provide noise benefit were then evaluated for implementation barriers, which generally included the verification of procedure design criteria, as well as air traffic control and operator acceptance. For verification of procedure design criteria, procedure candidates were modeled using the FAA's procedure design tool (TARGETS), which allowed for the real-time check of design criteria compliance. Several preliminary discussions with both airline and air traffic control stakeholders were held to further verify procedure operational acceptance. Based on feedback from this stakeholder group, the research team attempted to modify procedure proposals to resolve implementation concerns. It should be noted that any Block 2 recommended procedures put forward will be required to go through the formal FAA 7100.41 design process, where unanticipated issues may arise. During this process, procedures will be further evaluated for potential implementation barriers, a safety analysis will be conducted, and a flight check will be executed prior to procedure publication. In parallel to this process, the FAA will also conduct an environmental review of any requested procedure. Any procedure carrying significant effects (i.e. noise redistribution or increased noise footprint) will be subject to a full environmental review. Final procedure implementation will therefore be contingent on both a successful 7100.41 design process and a positive environmental review.

Because some of the Block 2 procedures requested by community groups result in redistribution of noise between communities it will ultimately be the communities which will need to request the implementation of the procedures. This report attempts to document the noise impacts of the proposed Block 2 procedures to support this community decision process.

Each step of the research process, including the modeling of noise impacts and the evaluation of implementation barriers, is further detailed in the sections that follow.

Data Collection and Evaluation of Baseline Conditions

This study used a data-driven approach to identify opportunities where approach and departure procedure modifications would have a significant community noise reduction impact.

1. Flight Track Density Evaluation

Historical radar data from before (2010) and after (2015) RNAV procedures were implemented was evaluated for each of the primary overland arrival and departure runways. This was used to understand current flight trajectories and areas of flight concentration. An example is shown in Figure 2, for Runway 33L jet departures before and after RNAV implementation, clearly illustrating the communities which are impacted by increased track concentration. Visualizations for flight track density were generated by Harris, Miller, Miller and Hanson Inc. (HMMH) and are included in the introduction to the procedure discussions in Section III for each arrival and departure addressed in Block 2.

2. Complaint Analysis

In addition to the radar data analysis, complaint data from the Massport Noise Office were used to identify regions of widespread annoyance arising from specific arrival or departure procedures. Figure 4 shows examples of complaint data from August 2015 to July 2016. Each address where at least one complaint was filed is shown with a red dot. The left side of the figure shows departure radar tracks and the right side shows arrivals, including both jet and propeller aircraft.

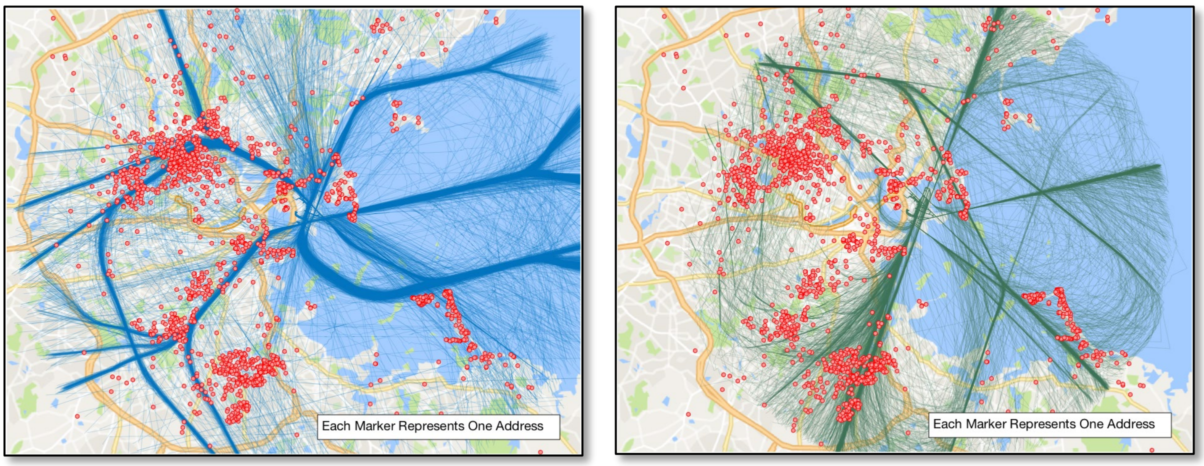


Figure 4. Complaints from August 2015 – July 2016 for BOS, Departures (Left) and Arrivals (Right).

Qualitative assessment of the complaint map shows several areas where complaint clusters were associated with particular arrival or departure corridors. Departures from Runway 33L drive a broad set of complaints in the vicinity of Medford, Somerville, Cambridge, Arlington, and beyond. Departures from Runway 27 are associated with a region of complaints ranging from the South End of Boston to Roxbury, Jamaica Plain, and points beyond. Departures from Runway 22L and 22R drive complaints in South Boston and the Hull peninsula. In terms of arrivals, approaches to runways 4R and 4L drive a region of complaints along the approach path including Braintree, Milton, Dorchester, and South Boston. Approaches to Runway 33L appear to drive additional complaints in the vicinity of Hull. Approaches to runway 22L and 22R appear to drive complaints from Revere, Lynn, Peabody, and other North Shore communities. Complaints outside of these primary clusters (including those outside the geographic bounds of the maps shown in Figure 4) were also evaluated to determine potential annoyance drivers and mitigation strategies further from the airport.

Noise concerns arising from both arrivals and departures in close-in communities surrounding the airport are also evident in the complaint map. However, RNAV technology has a minimal impact on typical flight tracks immediately after takeoff or before landing. RNAV procedure modifications, such as those under investigation in this study, are unlikely to have significant impacts on noise in the immediate vicinity of the airport.

Complaint data is important for identifying high-level annoyance trends but can also be influenced by outside factors such as unequal access to complaint mechanisms. Therefore, direct community engagement and outreach was also a key component of the procedure evaluation process to identify and understand problem areas for overflight noise.

3. Community Input

A number of meetings with community groups, the MCAC and elected representatives were held to understand concerns related to aircraft noise impacts and opportunities for reduced noise procedures. This started during the Block 1 process but continued during the Block 2 development. In some cases, specific candidate procedures were suggested by communities and evaluated for expected noise impact and implementation feasibility by the research team. Community-requested procedures largely focused on methods to re-introduce the flight track dispersion lost with the introduction of RNAV procedures, which was perceived as an equity issue.

Development of Candidate Procedures

Based on community input and analysis of noise complaints, procedure development was done on a runway basis, taking approach and departure procedures that correlated with key areas of complaints. Several approach and departure procedures were addressed in Block 1. The Block 2 design efforts focused on approaches to runways 22L and 4R, and departures from runways 22L/R, 33L and 27.

For each approach and departure procedure, the modification design objective was defined based on community input or noise reduction technical opportunities arising from RNAV/RNP capabilities. In some cases, such as runways for which the re-introduction of flight track dispersion was the objective, several initial concept procedures were developed. In some cases, specific procedures were suggested by community groups. The noise impact of these procedures was modeled and presented to communities and operational stakeholder groups for feedback on noise impact and operational feasibility. This input was then used to refine procedure concepts until arriving at the recommended procedures presented in this report.

Noise Impact Modeling

Candidate procedures were evaluated using the noise modeling methodology shown in Figure 5. Aircraft trajectories used in noise evaluations were generated from radar data for existing procedures, or simulated in the case of new procedures. These trajectories were run through a Flight Profile Generator tool to produce an estimate of aircraft thrust, altitude, and speed throughout each trajectory. This data was used in one of 2 noise models depending on the type of procedure being evaluated. In most cases the FAA Aviation Environmental Design Tool (AEDT) was used. For cases which involved modifying airspeeds or flap and landing gear configuration the NASA Airplane Noise Prediction Program (ANOPP) was used. Although ANOPP was used for some evaluation studies, all results shown in this report use the FAA AEDT noise model. The output from the noise models were tabulated in 0.1 nautical mile square grids for each aircraft trajectory. These grids were overlaid with grids generated from the 2010 Boston Census Data to produce counts of population exposed to various noise levels. Because the grid is smaller than the census tract, the total population in each was distributed uniformly over the tract except for known unpopulated areas such as water, islands or causeways.

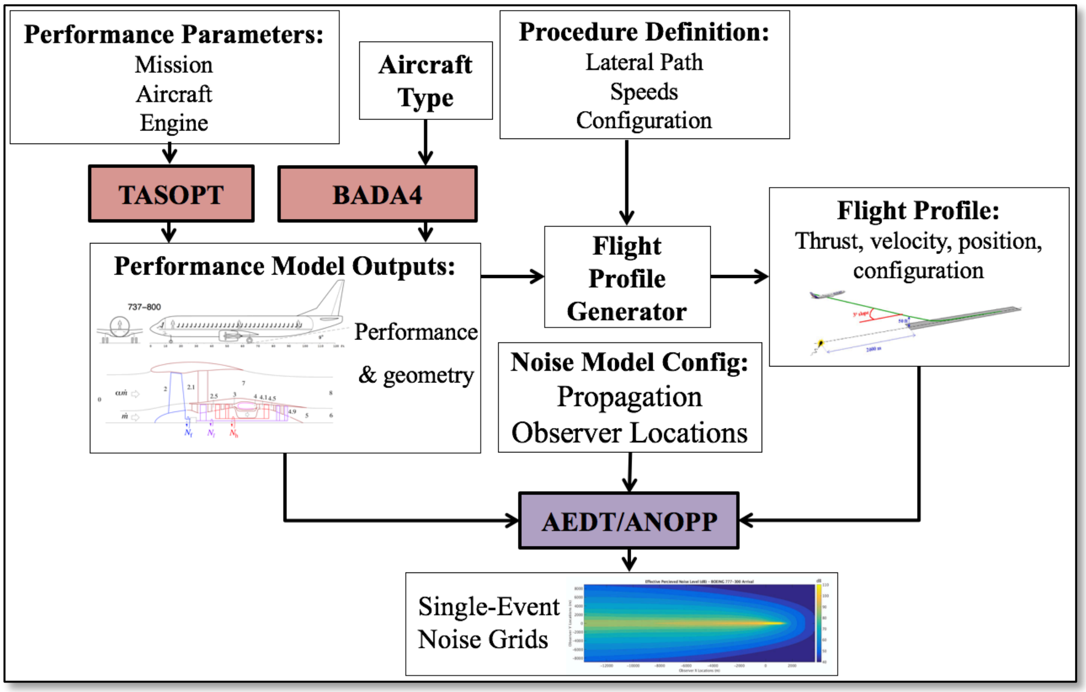


Figure 5. Noise modeling methodology.

Two different metrics were used for procedure evaluation. The first is $L_{A,MAX}$, which describes the loudest absolute sound level to the human ear generated during an overflight, regardless of the duration of the noise event. A second metric, N_{60}, was developed to represent concerns expressed by the communities regarding the short time between overflights during days of specific runway use. For the noise analyses conducted, the N_{60} metric represents the number of noticeable overflights during a peak day of operation on a specific runway. The threshold for a noticeable event was set at $L_{A,MAX} > 60$ dB during daytime (7am – 10pm) and $L_{A,MAX} > 50$ dB during nighttime. These thresholds were determined by a study of noise complaint locations at 4 airports (BOS, LHR, MSP, CLT) which found that more than 50 flights on a peak day of runway use above the N_{60} level correlated with over 80% of the noise complaint locations.[19]

$L_{A,MAX}$ was used when analyzing the impact of a single-track procedure change where all aircraft are moved from one track to another, since all aircraft fly the same procedure. The N_{60} metric was used for multi-track procedures, where the aggregate noise of multiple tracks needs to be considered, such as for efforts to reintroduce dispersion in the procedures.

Single-track procedures were normally evaluated at the 60 dB $L_{A,MAX}$ contour level corresponding to the daytime noticeability threshold (although when relevant 50 dB $L_{A,MAX}$ nighttime noticeability was also conducted). These results were presented in "Red-Green" plots such as the example in Figure 6 below. The 60 dB contours for the current procedure (cyan) and alternative procedure (yellow) are shown. Populations which benefit from the new procedure (within the cyan contour and outside the yellow contour) are represented as green dots, whereas disbenefited populations (outside the cyan contour and inside the yellow contour) are shown in red. Total population impact was calculated from the 2010 census data.

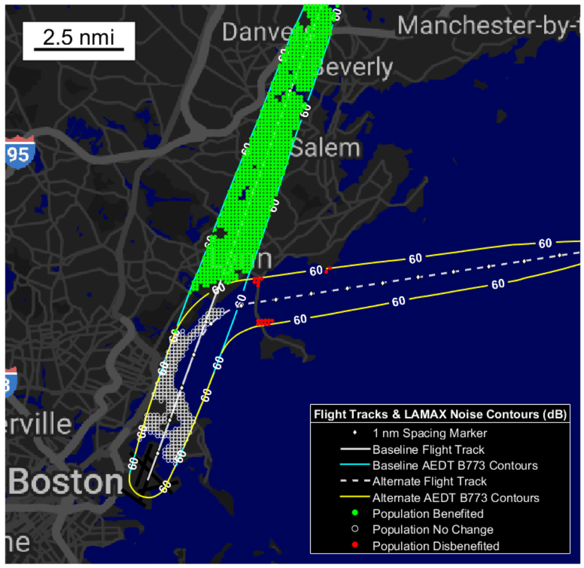


Figure 6. Example single event "Red-Green" plot showing populations benefited by a procedural change (in green) and populations disbenefited (in red).

For procedures where the cumulative impact of multiple tracks is important, such as dispersion-based procedures, the analysis is based on a peak day of operations and uses $N_{60,day}$>50 to compute the affected population count. Populations within the $N_{60,day}$>50 contour experience at least 50 flights that meet a 60 dB threshold during the day or a 50 dB threshold at night (10pm to 7am) on a peak day for that runway.

The peak day used for each runway was derived from 2017 ASDE-X radar data. The peak days for various runways and their associated number of operations are shown in Appendix A. For each peak day, a baseline noise analysis was derived by conducting a noise analysis for every flight within the peak day radar trajectory set. Each aircraft was simulated by the closest of the seven representative aircraft types shown in Table 2. In most cases nominal vertical flight profiles corresponding to representative altitude, thrust and speed profiles were used. In some cases, these profiles were modeled from radar trajectory data for each flight.

Table 2. Representative Aircraft Classes.

Aircraft Type Bin	Representative Aircraft
A320 Family	Airbus A320
B737 Family	Boeing 737-800
B757 Family	Boeing 757-200
Large Regional Jet	Embraer 170
Small Regional Jet	Embraer 145
Twin-Aisle Jet	Boeing 777
Older Jet	MD-88

The noise change from candidate procedures was simulated by taking each flight from the baseline peak day and assigning them to the appropriate flight track in the proposed procedure. For departure procedures with different route options this was done by assigning flights to the track which matched the fix or direction that the original flight left the BOS terminal airspace. For arrival procedures, flights were assigned to tracks that matched the direction or fix that the original flight entered the BOS terminal airspace.

The aggregate change in noise exposure is represented as a change in N_{60} in the "Heat Map" plot, an example of which is shown in Figure 7. In these plots the areas where there is an exposure of more than 50 N_{60} events either in the original or proposed procedure are shown. Locations with an increase of more than 10 overflights at the N_{60} level are shown in hot colors and locations with a decrease of more than 10 overflights are shown as cool colors. Locations for which there is no change (difference lower than 10 overflights) or no population to be impacted (e.g. over water) are shown in white. For reference the N_{60} contours of the original procedure are shown as black lines.

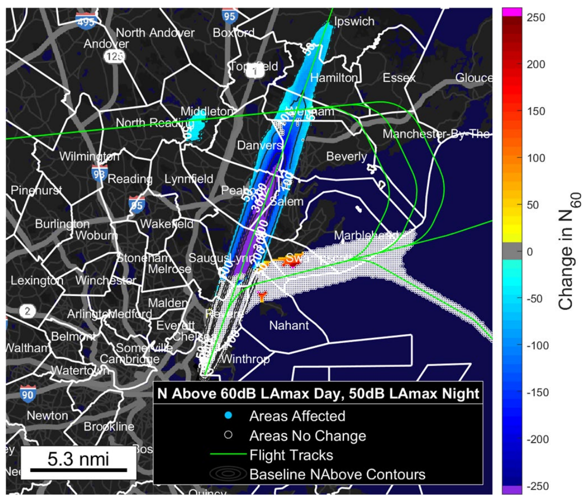


Figure 7. Example peak day change in N_{60} "Heat Map" plot showing the aggregate change in number of overflights for a given procedure.

Evaluation of Implementation Barriers

Candidate procedures that exhibited potential noise benefit or were supported by the communities based on noise analysis results were evaluated for implementation barriers and overall feasibility.

Compliance with standard FAA design criteria, including criteria such as minimum leg lengths, maximum turn angles, and terrain clearance was conducted with the use of the FAA TARGETS procedure design tool. TARGETS allowed for the verification of core design criteria as well as some indication of flyability issues and estimated trajectories.

Identification and mitigation of implementation barriers was also addressed through discussions with operational stakeholders from airlines and air traffic control. Several opportunities for stakeholder input existed during both Block 1 and Block 2. Initial Block 2 concepts were presented to operational stakeholders during the stakeholder meetings for implementation of the Block 1 recommendations required by the FAA 7100.41 implementation process. In addition, an evaluation of potential departure procedure concepts for Runways 33L, 27 and 22L/R was conducted through an informal meeting with key operational stakeholders. Several additional informal opportunities for technical discussion were used to conduct a preliminary evaluation of the complete set of recommended procedures.

Operators were engaged in this project through several meetings with airline technical pilots and the trade association Airlines for America (A4A). These pilots represented air carriers with significant operational footprints at BOS. The meetings provided feedback on potential operational constraints from the airline perspective including safety concerns arising from specific procedure proposals.

Regulators and air traffic controllers were also engaged throughout the process. Representatives from the FAA Air Traffic Organization (ATO) were consulted to gain insight and understanding of air traffic control procedures, airspace layouts, standard operating procedures, and potential ATC-related constraints to procedure modification. Meetings with ATC included representatives from the Boston Tower, Boston Terminal Radar Approach Control, Boston Air Route Traffic Control Center, FAA New England Regional Office, the National Air Traffic Controllers Association (NATCA), and FAA headquarters. In addition to ATC, additional FAA engagement included meetings with the following offices: Environment and Energy, ATO Mission Support Services, Flight Standards, Airport Planning and Programming, NextGen, and Flight Technologies and Procedures.

Based on the input from the operational stakeholders, procedures were modified to address operational constraints if possible. Those procedures for which all known operational issues have been addressed are identified in the procedure recommendation sections. In some cases, known operational issues persist in procedures that some community groups continued to support. These are also identified in the procedure recommendations below and it is unlikely that those procedures would survive the 7100.41 implementation process if recommended by the communities.

III. Block 2 Procedure Recommendations

Procedures recommended under Block 2 are listed in Table ; the remainder of this section expands on each procedure in detail.

Table 1. Block 2 Procedure Recommendations.

Proc. ID D = Departure A = Arrival	Procedure	Primary Benefits
APPROACH PROCEDURES		
2A-1	**Runway 22L** Implement a new overwater RNAV approach for Runway 22L that crosses the Nahant Causeway from the east to join a 4-mile final approach.	Arrival flight paths from the south and east moved overwater instead of overflying populated areas north/northeast of the airport.
2A-2	**Runway 4R** Maintain use of current ILS approach to Runway 4R.	The current straight-in approach was found to have the lowest net population exposure among all RNAV approach candidates evaluated.
DEPARTURE PROCEDURES		
2D-1	**Runway 22L/R** Modify the current RNAV SID with a speed restriction to enable an earlier turn to the east, shifting aircraft tracks north away from Hull.	Departure flight paths moved north away from Hull.
2D-2	**Runway 33L** Modify the current RNAV SIDs to enable the start of flight track dispersion at the earliest point possible (1 NM from the end of the runway).	Increased dispersion of flight tracks and noise distribution.
2D-3	**Runway 27** Modify RNAV SIDs to begin flight track dispersion at the earliest point possible while satisfying the 1996 Environmental Record of Decision.	Increased dispersion of flight tracks and noise distribution; lower net population noise exposure.

2-A1: Runway 22L

Objective: Reduce overall noise exposure on final approach.

1. Introduction

Analysis of radar tracks from 2010 and 2015 indicate that the adoption of RNAV arrivals to Runway 22L caused some flight track concentration on the downwind legs east and west of the airport, although no significant change in track density is noticed on the final approach path (Figure 8). The track concentration on the downwind legs is consistent with three RNAV STARs at Boston Logan shown in Figure 9. For example, the JFUND RNAV arrival (shown in magenta) takes traffic from the west and turns north onto a downwind leg in a concentrated track. From the JFUND RNAV downwind leg aircraft are turned right to the final approach course by ATC vectors at different locations depending on other traffic. Once on the final approach course the aircraft fly the same conventional Instrument Landing System (ILS) final approach procedure which was in place before RNAV. Similarly, traffic from the south fly the ROBUC RNAV arrival to a left turn downwind leg and traffic from the east fly the OOSHN RNAV arrival to the left downwind.

Additional non-RNAV STARs also exist (GARDNER and WOONS), and are used by non-RNAV aircraft and propeller aircraft.

It is important to distinguish the arrival procedures from the approach procedure to Runway 22L. Currently only some of the arrival procedures are RNAV and the approach procedure is the conventional ILS approach which is non-RNAV.

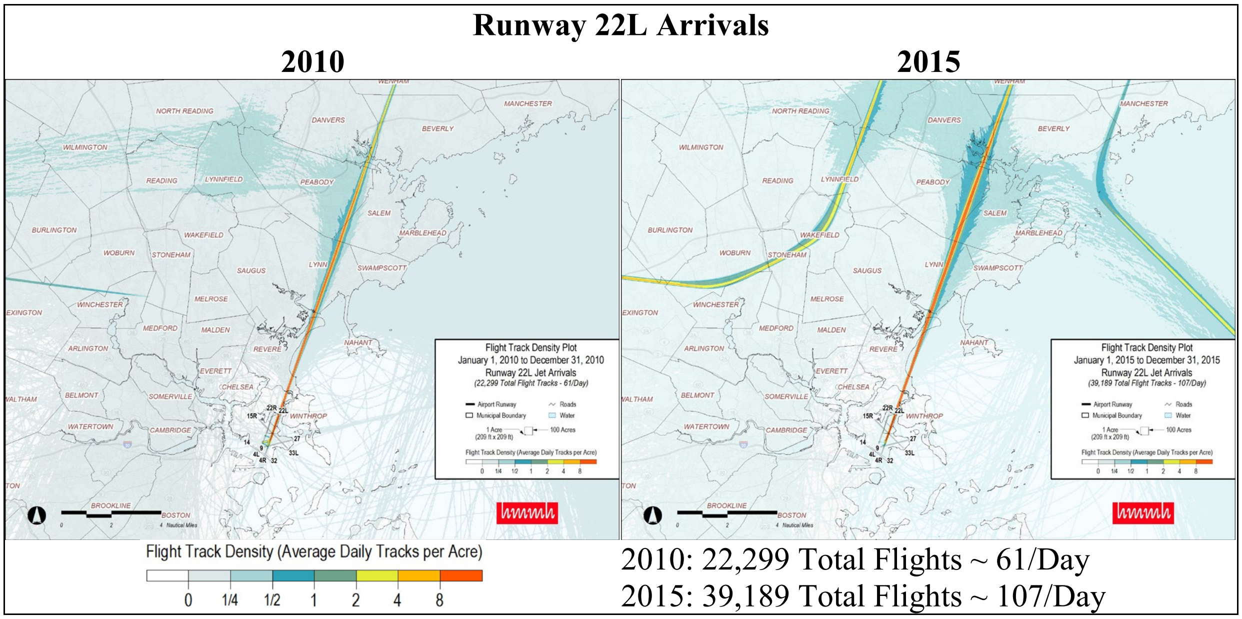


Figure 8. Comparison between flight track density on Runway 22L arrivals between 2010 and 2015.

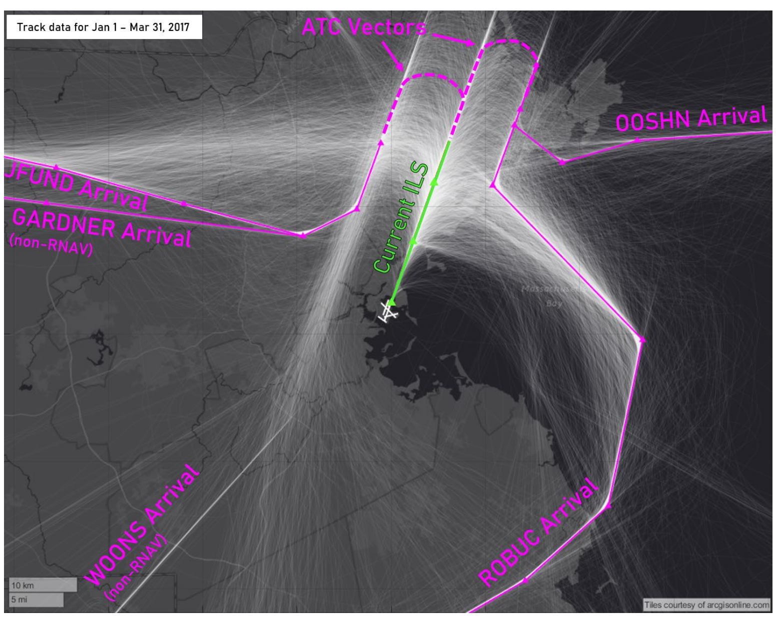


Figure 9. Tracks of aircraft landing on Runway 22L (white) between January 1 and March 31, 2017. Highlighted in magenta are the STARs, and in green the ILS final approach segment.

During the Block 2 study, an opportunity to reduce noise on the approach was identified by taking advantage of RNAV capability to move part of the final approach over the water. This sometimes occurs during visual approaches in good weather conditions. However, because the current ILS approach (used in instrument conditions) is dependent on a ground-installed radio beacon to guide aircraft to the runway, it can only be set up as a straight line. An RNAV approach would use GPS for navigation and can relocate parts of the approach for the purpose of noise abatement. The RNAV approach could be designed to replace the ILS during certain weather and traffic conditions while minimizing noise exposure to communities north and northeast of the airport.

2. Recommended Overwater RNAV Procedure

The recommended procedure is an overwater RNAV approach that shifts aircraft noise away from land and onto the water. This RNAV procedure initially approaches the airport from the northeast in a continuous 3-degree descent, crossing the Nahant Causeway to join a 4-mile final to Runway 22L. The procedure defines an RNAV "line" east of the airport, to which ATC would vector aircraft starting from the current RNAV JFUND, OOSHN or ROBUC STARs, which are not modified as shown in Figure 10.

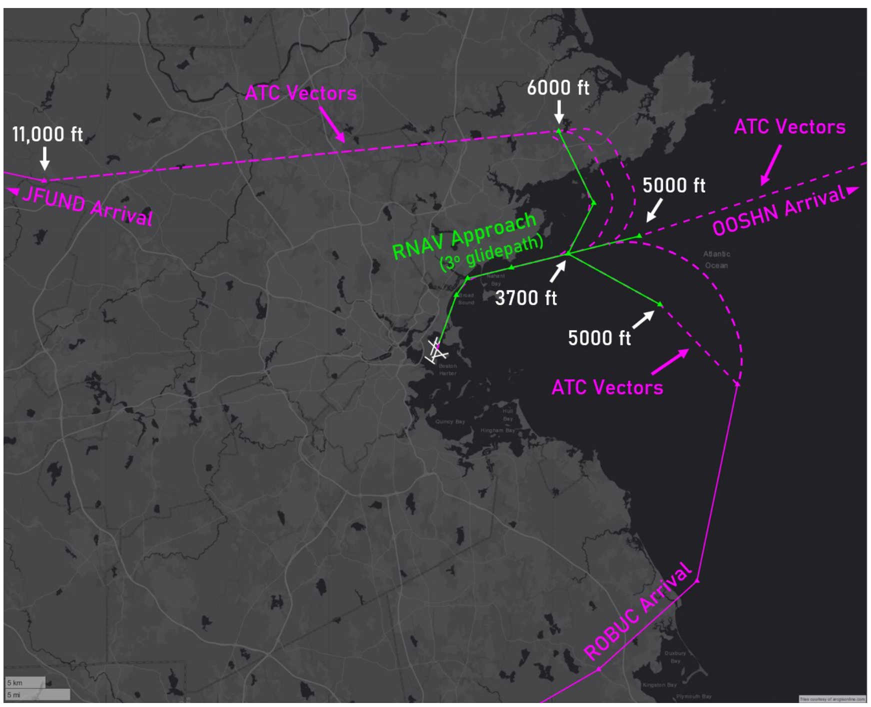


Figure 10. Proposed overwater RNAV approach represented by the green line, RNAV STARs represented by solid mageta lines, and expected ATC vectors represented by dashed magenta lines.

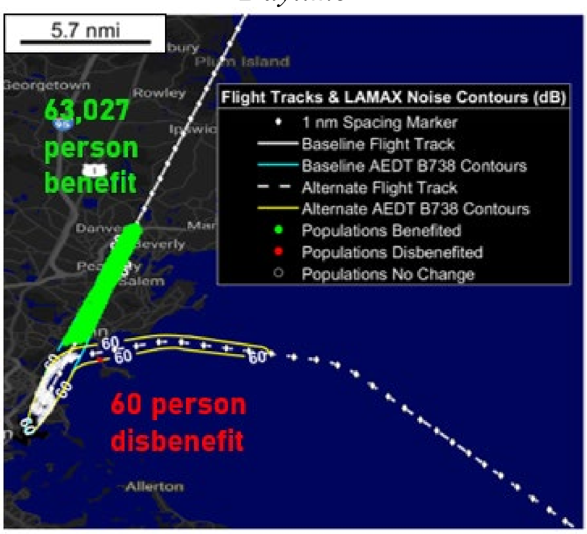
The overwater RNAV approach procedure is expected to be usable whenever Runway 22L is the only active landing runway, and while the meteorological ceiling is higher than 500 ft. Under these conditions, the overwater RNAV procedure could be the primary approach to BOS. The overwater RNAV procedure cannot be used when Runway 27 is used as a second landing runway due to the sharing of airspace between the two runways. During low IFR conditions (500 ft ceilings or 1-mile visibility) the RNAV would not be usable and the ILS approach would be required. Based on 2019 FAA Aviation System Performance Metrics (ASPM) data under these conditions, the proposed procedure would be available for up to 25% of the arrivals at BOS.

The overwater RNAV approach procedure was evaluated in TARGETS and verified to pass design criteria. Air traffic stakeholder feedback was positive and indicated that the procedure would be feasible from an air traffic perspective. As an RNAV approach procedure, it can be used by the vast majority of commercial jet traffic. An RNP AR overlay is also recommended and could be used interchangeably with the RNAV. It should be noted that the RNAV approach and RNP AR procedures would have identical lateral accuracy requirements of 0.3 NM on final approach, so no difference in track accuracy between RNAV and RNP is expected.

3. Noise Results

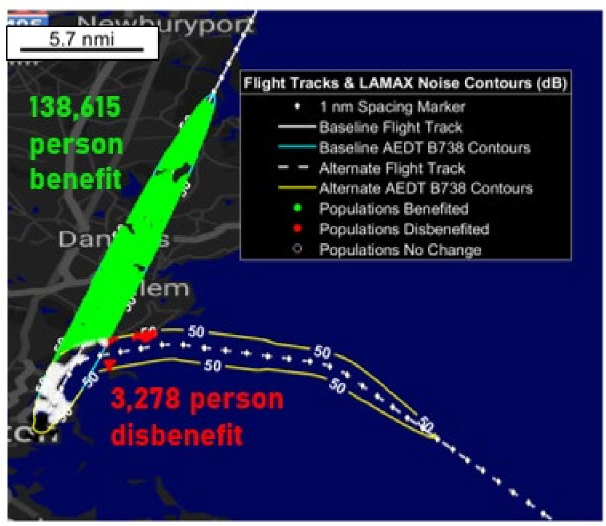
An initial single-overflight noise analysis comparing the overwater RNAV approach with a straight-in ILS was conducted for a number of different aircraft types. An example for a representative narrowbody aircraft (B737-800) is shown in Figure 11, showing the daytime 60 dB $L_{A,MAX}$ noise contours and nighttime 50 dB $L_{A,MAX}$ noise contours. The results show that during the day, the overwater RNAV would benefit 63,027 people on the final approach and disbenefit 60 people. There would be a total of 62,967 fewer people exposed at the daytime noticeable noise level. During the nighttime, the 10 dB lower noticeability threshold widens the impact contour and increases the exposed population. At night the overwater RNAV would benefit 138,615 people and disbenefit 3,278 people, ultimately resulting in 135,337 fewer people being exposed at the nighttime noticeable noise.

Daytime



B737-800 Population Exposure ($L_{A,MAX}$)	$L_{A,MAX}$>60dB (Population Exposed)
Straight-In	82,901
RNAV	19,934
Difference (Straight-In – RNAV)	62,967

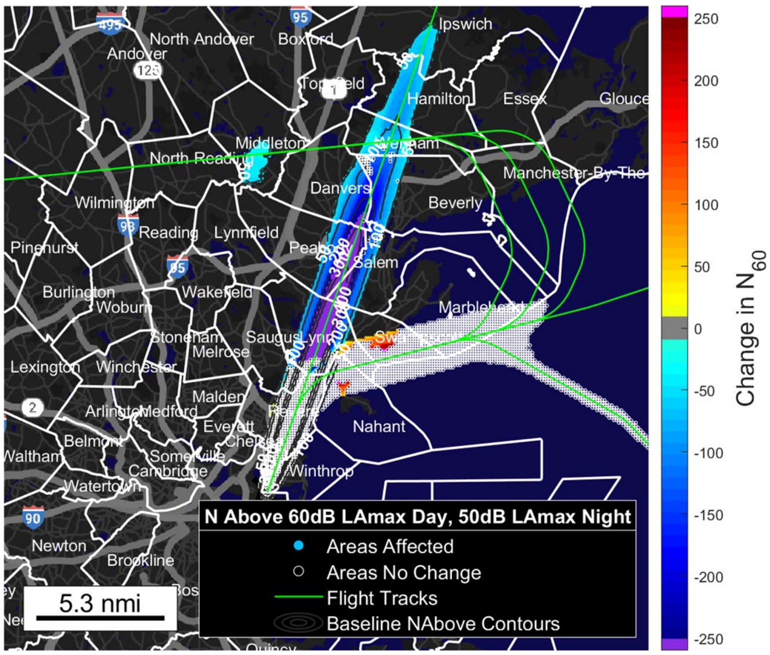
Nighttime



B737-800 Population Exposure ($L_{A,MAX}$)	$L_{A,MAX}$>50dB (Population Exposed)
Straight-In	178,509
RNAV	43,172
Difference (Straight-In – RNAV)	135,337

Figure 11. Single overflight results for B737-800 for both daytime (left; 60 dB) and nighttime (right; 50 dB).

Because the overwater RNAV could be the primary approach when Runway 22L is the only landing runway, an integrated impact analysis was conducted to evaluate the cumulative noise impact during a full peak day of operations on Runway 22L in 2017 using actual aircraft radar tracks. This is shown in Figure 12. Note that areas with no population (e.g over water) are shown in white.

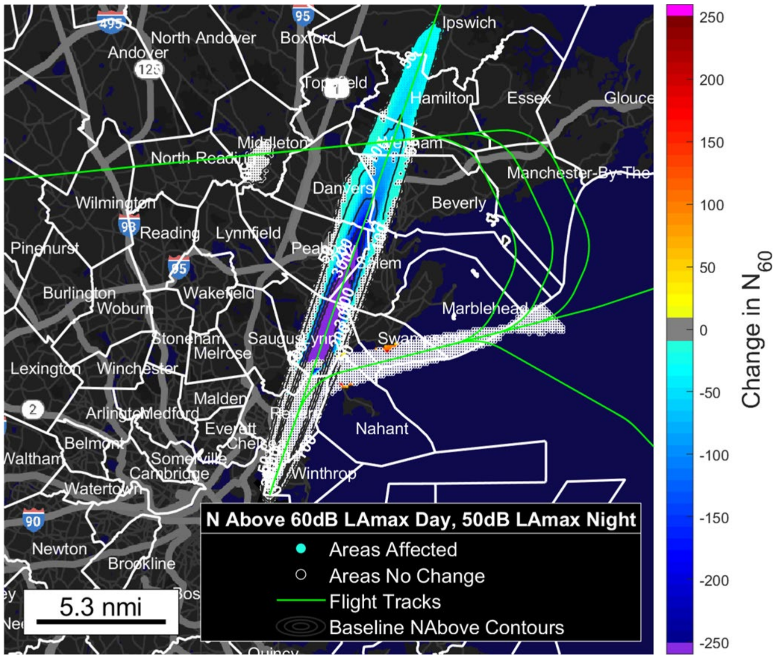


	N_{60}>50 (Population Exposed)
Current procedure	178,831
Proposed procedure	46,939
Difference (Current - Proposed)	131,892

Figure 12. N_{60} results of the aggregate noise analysis for overwater RNAV approach on a peak day of Runway 22L operations.

The results indicate that there would be a large integrated benefit with 131,892 fewer people experiencing more than 50 overflights at the N_{60} level if the proposed RNAV overwater approach was used in place of the ILS for all commercial jet landings. While the integrated benefits are large (particularly for residents of Danvers, Beverly, Peabody, Salem and Lynn), there is some disbenefit noted along the coast in Swampscott and Nahant due to nighttime flights which have a wider noise footprint due to the lower 50 dB $L_{A,MAX}$ impact threshold. More detailed city-by-city analysis of the noise impact is included in Appendix C.1.

One option to limit the impact on coastal communities would be to limit the use of the overwater RNAV approach to daytime which is evaluated in Figure 13 below. The adverse impact in Swampscott and Nahant is reduced at the expense of a significantly lower aggregate benefit of only 9,666-person reduction at the 50 overflight per day level. This is due to the large increase in residents of Danvers, Beverly, Peabody, Salem and Lynn who would receive noticeable nighttime exposure. More detailed city-by-city analysis of this option is also included in Appendix C.2.



	N_{60}>50 (Population Exposed)
Current procedure	178,831
Proposed procedure	169,165
Difference (Current - Proposed)	9,666

Figure 13. N_{60} results of the aggregate noise analysis for an overwater RNAV approach (limited to daytime use only) on a peak day of Runway 22L operations.

4. Recommendation – Overwater RNAV Approach

Due to strong noise benefits, implementation of the overwater RNAV approach procedure with an RNP AR overlay is recommended. No known operational concerns exist for this procedure.

2-A2: Runway 4R

Objective: Reduce exposure to highly impacted communities.

1. Introduction

Analysis of radar tracks from 2010 and 2015 indicate that the adoption of RNAV arrivals to runway 4R caused flight track concentration on the downwind leg east of the airport, although no significant change in track density is noticed on the final approach path as seen in Figure 14. Track concentration on the downwind leg results from the JFUND and OOSHN RNAV arrivals shown in magenta in Figure 15. The ROBUC RNAV arrival from the south merges with the ILS well away from the airport and does not contribute to additional concentration. The JFUND and OOSHN RNAV STARs end at a point where aircraft are flying parallel to the landing runway and away from it (the downwind leg), while the ROBUC arrival ends approximately 20 miles southwest of the airport. It is the task of the air traffic controller to issue the turn (i.e. vector) for an aircraft to join the final approach. Additional non-RNAV STARs also exist (GARDNER and WOONS), and are used by non-RNAV aircraft and propeller aircraft. Furthermore, it should be noted that, because Runway 4R and Runway 4L are closely-spaced parallel runways, approaches to both runways must be handled as a single approach stream for aircraft separation purposes.

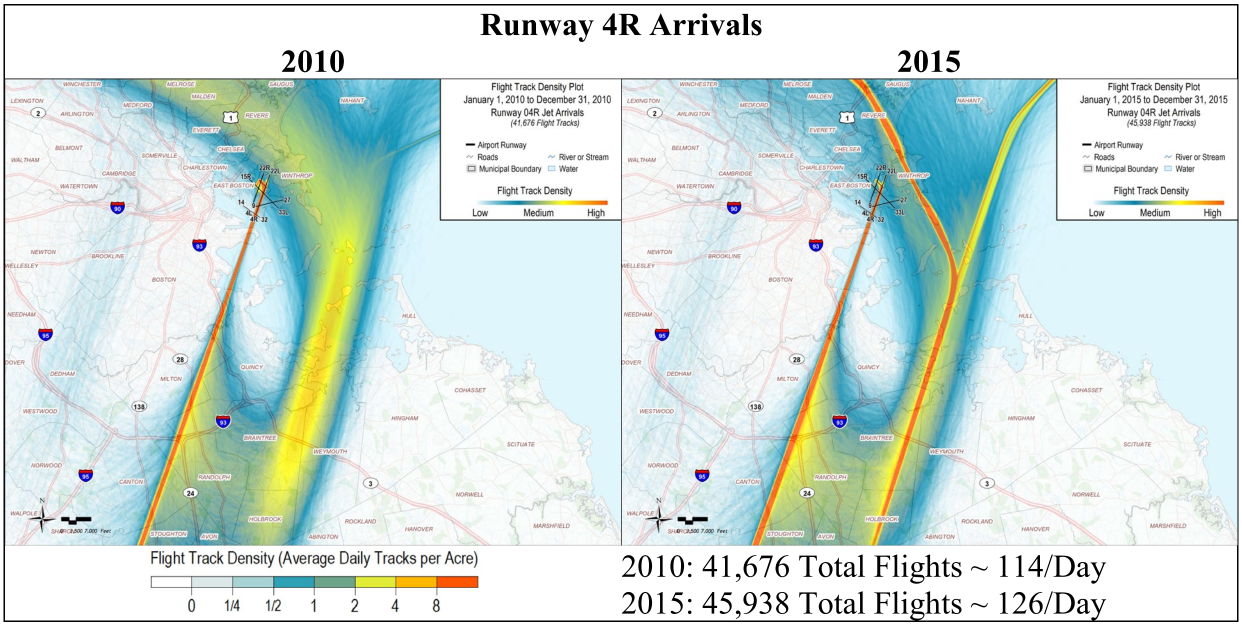


Figure 14. Comparison between flight track density on Runway 4R arrivals between 2010 and 2015.

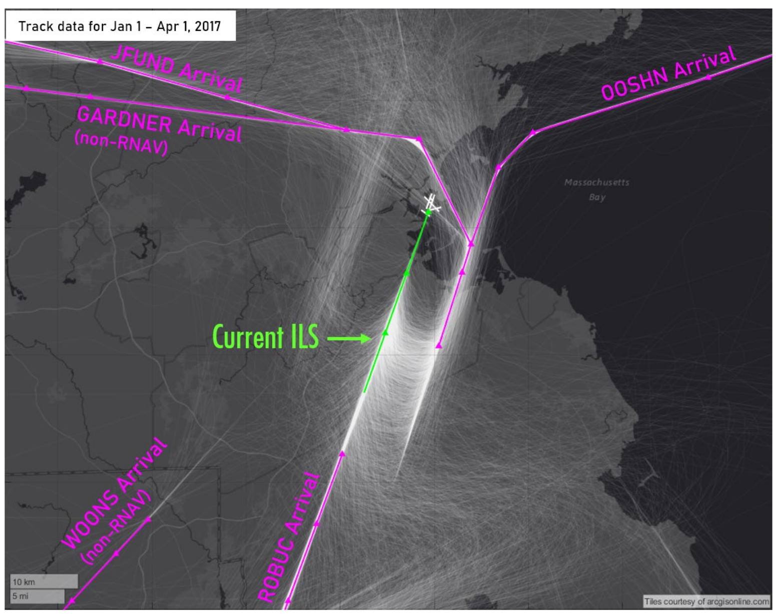


Figure 15. Tracks of aircraft landing on Runway 4R (white) between January 1 and April 1, 2017. Highlighted in magenta are the STARs, and in green the ILS final approach segment.

Communities located on the final approach path of Runway 4R have voiced a strong desire for alternate approach procedures that could reduce the noise exposure to highly impacted areas. To address this request, a series of potential RNAV and RNP approach options for Runway 4R were evaluated, with the objective of finding feasible procedure candidates that reduced noise exposure to highly impacted communities. It must be noted that, unlike departure procedures, approaches require aircraft to merge towards a common final approach course. As a result, many dispersion concepts do not apply to approach procedures, and concepts for noise reduction must instead focus on alternative approach trajectories.

2. Methodology for Evaluating Alternative RNAV and RNP Approaches

A comprehensive set of initial approach concepts were developed for Runway 4R which met the RNAV or RNP approach criteria shown in Figure 16. An approach procedure typically consists of three segments: initial, intermediate, and final. Different approach types have different requirements for how these segments can be constructed, based on capabilities offered by the navigation solution. As the name suggests, the final segment ends just prior to the landing threshold and is typically aligned with the runway.

For an RNAV approach, the final segment must begin at an altitude of at least 500 ft above the tallest ground obstacle in the approach path. Due to the presence of obstacles south of BOS, this altitude value is 1400 ft for an RNAV approach to Runway 4R. In order to descend from 1400 ft to the airport surface on a standard 3-degree glidepath, aircraft need to cover a distance of 4.65 NM. This is therefore the shortest possible length of an RNAV final segment to Runway 4R. In addition, design criteria impose a maximum turn angle of 15 degrees at the beginning of this final segment (i.e. the Final Approach Fix). Although straight approaches to the runway are standard and preferred by operators, FAA design criteria allow for an RNAV approach to be offset by up to 5 degrees with respect to the runway direction.

For an RNP approach, which can have curved segments, a Final Rollout Point (FROP) is specified. This is the point at which the last turn of the RNP procedure must end, and where the aircraft must be flying with wings level just prior to landing. Design criteria specify that aircraft must be no lower than 500 ft at the FROP. Using a standard 3-degree glidepath, this means that the FROP must be no closer than 1.41 NM from the threshold of Runway 4R.

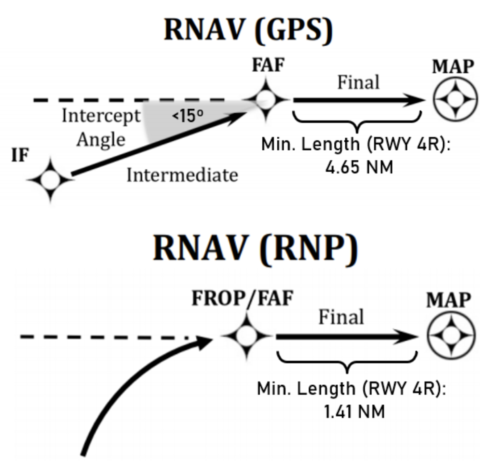


Figure 16. RNAV/RNP design criteria applying to the final approach segment.

Due to the presence of Runway 4L, only approaches from the east to Runway 4R were considered implementable, as the airspace to the west is typically reserved for traffic approaching the left runway.

An initial scan was used to identify the procedures with the lowest overall population exposure which met the RNAV and RNP criteria. Additional procedures were also developed based on suggestions from the communities or to evaluate the impact of specific RNP capabilities. Examples of RNAV and RNP approaches considered are shown in Figure 17.

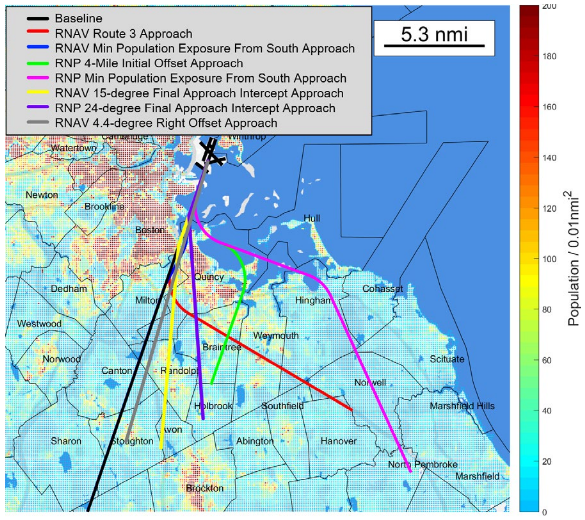
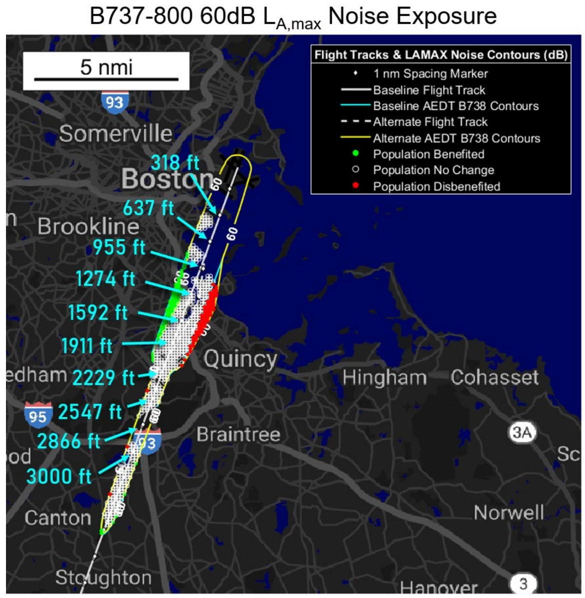


Figure 17. Example RNAV and RNP procedures considered, overlaid on population density grid.

3. Approach Procedures Evaluated in Detail

Each of the procedures evaluated in detail are discussed below along with example noise analysis results for a representative narrowbody aircraft (Boeing 737-800).

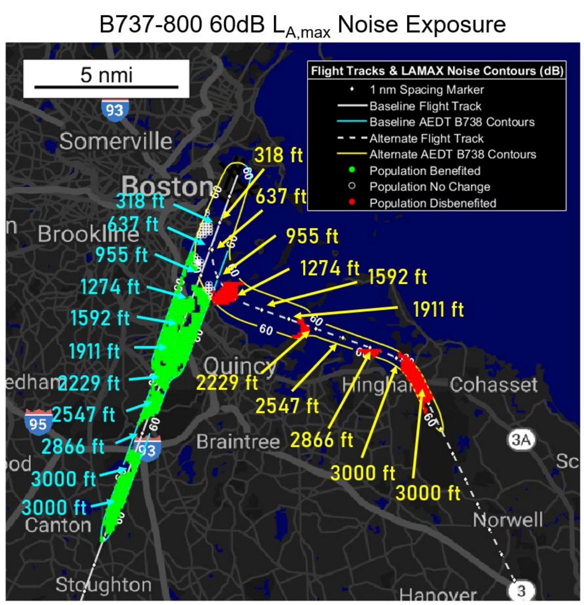
- *RNAV Minimum Population Exposure from South:* Based on the comprehensive review of various RNAV procedures meeting general design criteria, the RNAV approach with an aligned final segment and the lowest total population noise exposure at the 60 dB $L_{A,MAX}$ level is shown in Figure 18. Notably, this approach is very similar to the current ILS with a slight deviation of 0.3 NM to the right of the centerline approximately 5 NM from touchdown, resulting in a reduction of 214 people out of 32,232 (a 0.66% population reduction). This indicates that the current ILS is extremely close to the lowest total noise exposure procedure with an aligned final segment. This concept was also not supported by pilots as it created a more complex and not fully stabilized final approach segment. The concept also failed to pass further criteria checks by not satisfying ground obstacle clearance, which requires the final approach segment to be no shorter than 4.65 NM.



B737-800 Population Exposure ($L_{A,MAX}$)	$L_{A,MAX}$>60dB (Population Exposed)
Straight-In	32,232
RNAV Evaluated	32,018
Difference (Straight-In – RNAV)	214

Figure 18. 4R RNAV Minimum Population Exposure from the South.

- *RNP Minimum Population Exposure from South:* The RNP procedure with the lowest total population noise exposure from the south is shown in Figure 19. The procedure takes advantage RNP capability and has a 90 degree turn to join a 1.5 NM final approach (approximately the closest allowable under RNP criteria) to keep the approach over water in Boston harbor as much as possible crossing the shoreline at Hingham. Based on the $L_{A,MAX}$ 60 dB threshold the procedure would be expected to benefit 20,550 people.



B737-800 Population Exposure ($L_{A,MAX}$)	$L_{A,MAX}$>60dB (Population Exposed)
Straight-In	32,232
RNAV Evaluated	11,682
Difference (Straight-In – RNAV)	20,550

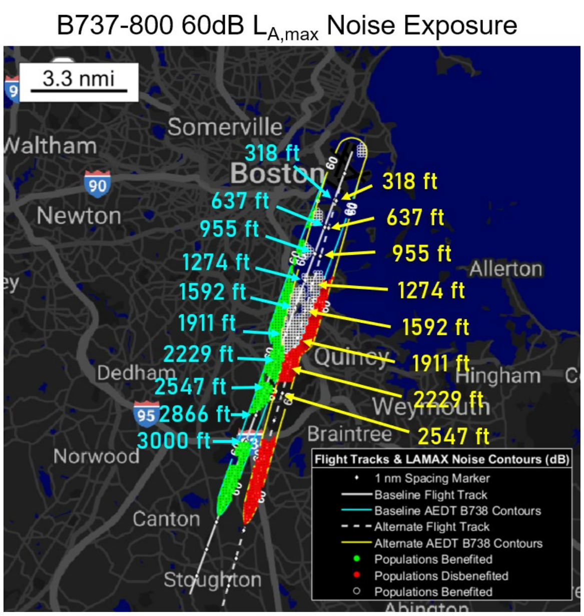
Figure 19. 4R RNP Minimum Population Exposure from the South.

While the procedure demonstrated significant noise benefits, numerous concerns were raised by the operational stakeholders. Because the RNP procedure would only be usable by RNP-equipped aircraft, those that are not equipped would be required to fly the existing

ILS approach. If both the RNP approach and the ILS approach are used at the same time, air traffic must work to ensure that the two approach streams are merging onto the same final approach with adequate separation. This task is commonly referred to as *merging and spacing*. The merging of RNP and ILS traffic so close to the runway (2 NM in this case) is generally recognized as a significant challenge in current operations, and has severely impacted the adoption of RNP approach procedures nationally. Air traffic reported that, in the current operational environment, it would be unable to use the RNP approach whenever the ILS approach is needed by any number of aircraft.

In addition, airline stakeholders reported safety concerns with procedures requiring a turn close to the runway. Airline pilots are typically trained to be fully "stabilized" on final approach as the aircraft crosses 1000 ft (approximately 3 NM from the runway). This means that the aircraft must be flying with wings level and fully configured for landing when crossing the *stabilization gate* at 1000 ft. Procedures that would cause pilots to deviate from this criterion, such as one with a final turn 1.5 NM from the runway, are seen as non-standard and as presenting higher risk.

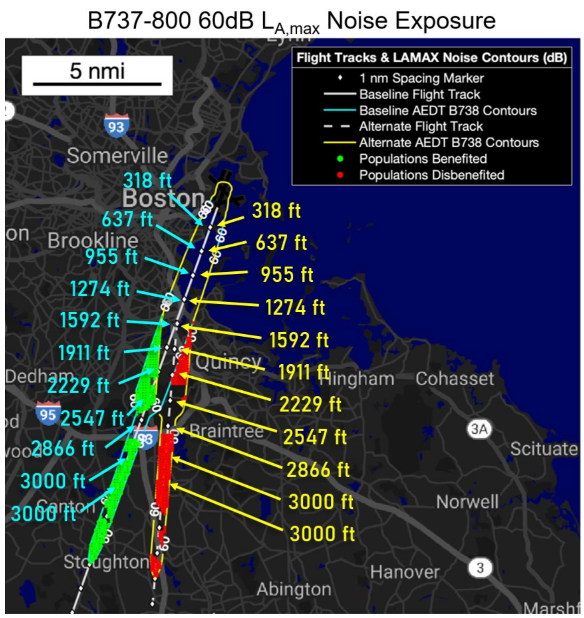
- *RNAV 4.4-degree Right Offset:* Early noise analysis was conducted for 4.4-degree offset/angled approaches from the left and right of the runway threshold, which were requested by the communities for alternating use (referred to as the "Strings of the Harp" concept). In this concept, the entire approach was offset by 4.4 degrees with respect to the runway direction and terminated at the runway threshold. The left offset raised air traffic concerns due to conflicts with approaches to Runway 4L. However, discussions with operational stakeholders have indicated strong resistance from airlines towards approach procedures that are not aligned with the runway due to safety concerns. The right offset procedure noise results in an increase to the overall population noise exposure to the $L_{A,MAX}$ 60 dB threshold by 214, as can be seen in Figure 20.



B737-800 Population Exposure ($L_{A,MAX}$)	$L_{A,MAX}$>60dB (Population Exposed)
Straight-In	32,232
RNAV Evaluated	32,446
Difference (Straight-In – RNAV)	-214

Figure 20. 4R RNAV 4.4 Degree Right Offset.

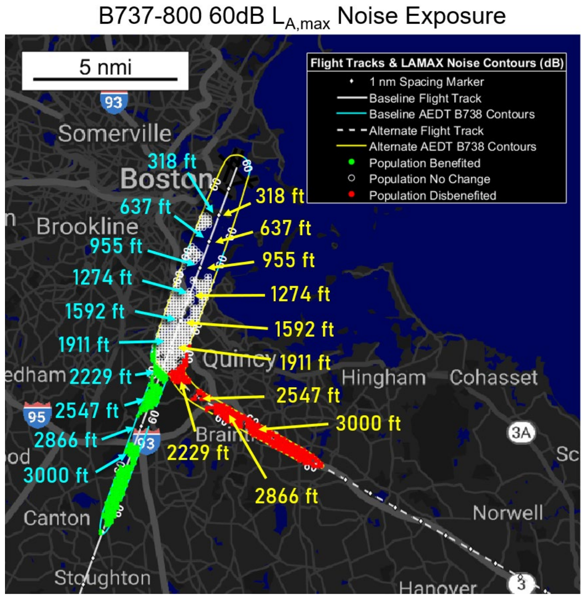
- *RNAV 15-degree Final Approach Intercept:* This procedure was also derived from the community request to establish alternative approach tracks that merge into the final approach from the east. The procedure evaluated here was set up to "mirror" a Jetblue-proposed RNAV Visual approach into Runway 4L, which intercepts the final approach of Runway 4L at an angle of approximately 20 degrees and approximately 4 NM from the runway. Under RNAV design criteria, this procedure to Runway 4R includes an intercept of the final approach at 4.6 NM, at an angle of 15 degrees which is the maximum angle change allowed at the final approach fix for an RNAV approach. The intercept distance of 4.6 NM is the closest RNAV final intercept point for Runway 4L due to ground obstacles on the approach path, which require a longer final approach under RNAV criteria. Community support for the procedure has remained unclear during the Block 2 process, as it relocates noise to communities southeast of the airport and increases the overall population noise exposure to the $L_{A,MAX}$ 60dB threshold by 5892 as can be seen in Figure 21.



B737-800 Population Exposure ($L_{A,MAX}$)	$L_{A,MAX}$>60dB (Population Exposed)
Straight-In	32,232
RNAV Evaluated	40,459
Difference (Straight-In – RNAV)	-5,892

Figure 21. 4R RNAV 15-degree Final Approach Intercept.

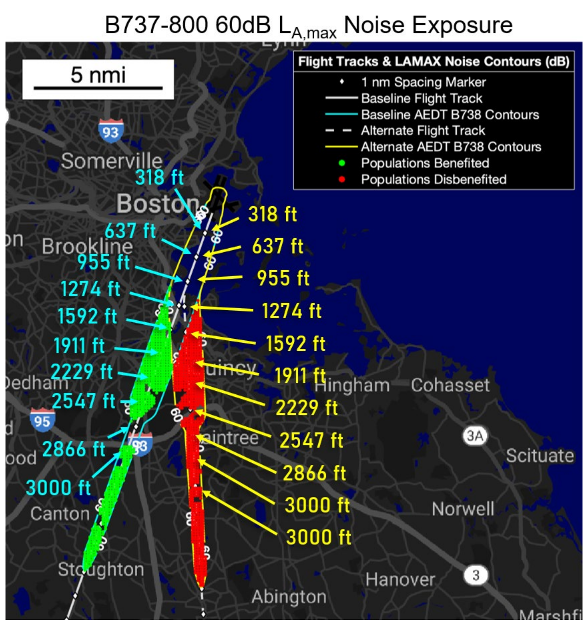
- *RNAV Route 3 Initial Approach:* This procedure explored the potential of flying over a highway to reduce overall noise exposure by moving as much noise over the unpopulated highway as possible, and utilizing noise masking by the current road. In the modeled procedure, aircraft initially approach from the southeast while remaining over the Route 3 highway. From Route 3, aircraft join a 5.5 NM final approach segment. As can be seen in Figure 22, the highway overflight procedure increased the population exposed to the 60 dB $L_{A,MAX}$ threshold by 6,121 compared to the ILS, as the 60 dB contours are wider than the highway and the noise was shifted to high population density areas in Braintree.



B737-800 Population Exposure ($L_{A,MAX}$)	$L_{A,MAX}$>60dB (Population Exposed)
Straight-In	32,232
RNAV Evaluated	38,353
Difference (Straight-In – RNAV)	-6,121

Figure 22. 4R RNAV Route 3 Initial Approach.

- *RNP 24-degree Final Approach Intercept:* This procedure was derived from the community request to establish alternative approach tracks that merge into the final approach from the east. It is similar to the *RNAV 15-degree Final Approach Intercept* described above, but manages to mimic the Jetblue RNAV Visual more closely due to the use of RNP design criteria, which allow for a tighter turn at the final approach fix. In this procedure, aircraft intercept the final approach 3 NM out at an angle of 24 degrees, initially approaching from the southeast. As can be seen in this procedure results in an increase in the population exposed by 18,704 at the $L_{A,MAX}$ 60 dB threshold level.

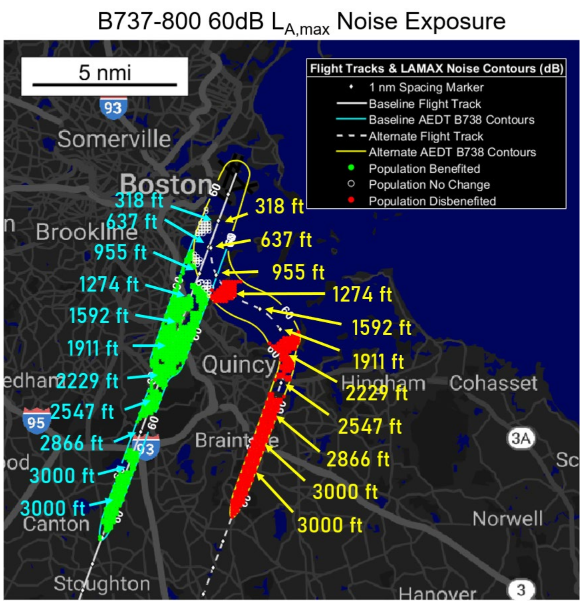


B737-800 Population Exposure ($L_{A,MAX}$)	$L_{A,MAX}$>60dB (Population Exposed)
Straight-In	32,232
RNP Evaluated	53,271
Difference (Straight-In – RNP)	-18,704

Figure 23. 4R RNP approach with 24-degree intercept.

Operational stakeholder concerns related to merging and spacing are again present due to the late merging with the ILS approach. In addition, community support for the procedure has remained unclear during the Block 2 process, as it relocates noise to communities southeast of the airport and increases overall population noise exposure

- *RNP 4-Mile Initial Offset*: In this RNP procedure, aircraft initially approach from the southeast on a course that is parallel to the final approach path but offset to the east by 4 NM. An "S turn" (a sequence of two 90-degree turns) is initiated approximately 5 NM from the runway in order to intercept the final approach 1.5 NM from the runway threshold. As can be seen in Figure 24Figure 25, there is reduction in the population exposed by 7,126 at the $L_{A,MAX}$ 60 dB threshold level. However, while the procedure is within RNP design criteria, the same operational barriers including air traffic merging and spacing concerns and airline late turn to final concerns discussed for the *RNP Minimum Population Exposure from South* would exist for this procedure.



B737-800 Population Exposure ($L_{A,MAX}$)	$L_{A,MAX}$>60dB (Population Exposed)
Straight-In	32,232
RNP Evaluated	25,106
Difference (Straight-In – RNP)	7,126

Figure 24. 4R RNP 4-Mile Initial Offset.

4. Recommendation – Maintain Current ILS to 4R

Because the current ILS approach is effectively the lowest total population exposure approach no RNAV approaches were identified which had significant noise benefit. RNP approaches with total population noise benefit had significant implementation barriers. As such, the ILS remains the trajectory with lowest net population noise exposure that also satisfies operational constraints and no clear alternative emerged from the study.

2-D1: Runway 22L/R

Objective: Move departure tracks north away from the Hull peninsula.

1. Introduction

Figure 25 shows jet track concentration for departures from Runway 22R before and after implementation of RNAV procedures (2010-2015). The departure tracks became more concentrated after RNAV implementation and the centroid of the departure corridor shifted south toward Hull. The initial RNAV turn direction and location of the TJAYY waypoint shown in Figure 26 were constrained by separation criteria from Runway 27 arrivals and minimum path length distance criteria between the first turn and the TJAYY waypoint due to the location of the TJAYY waypoint.

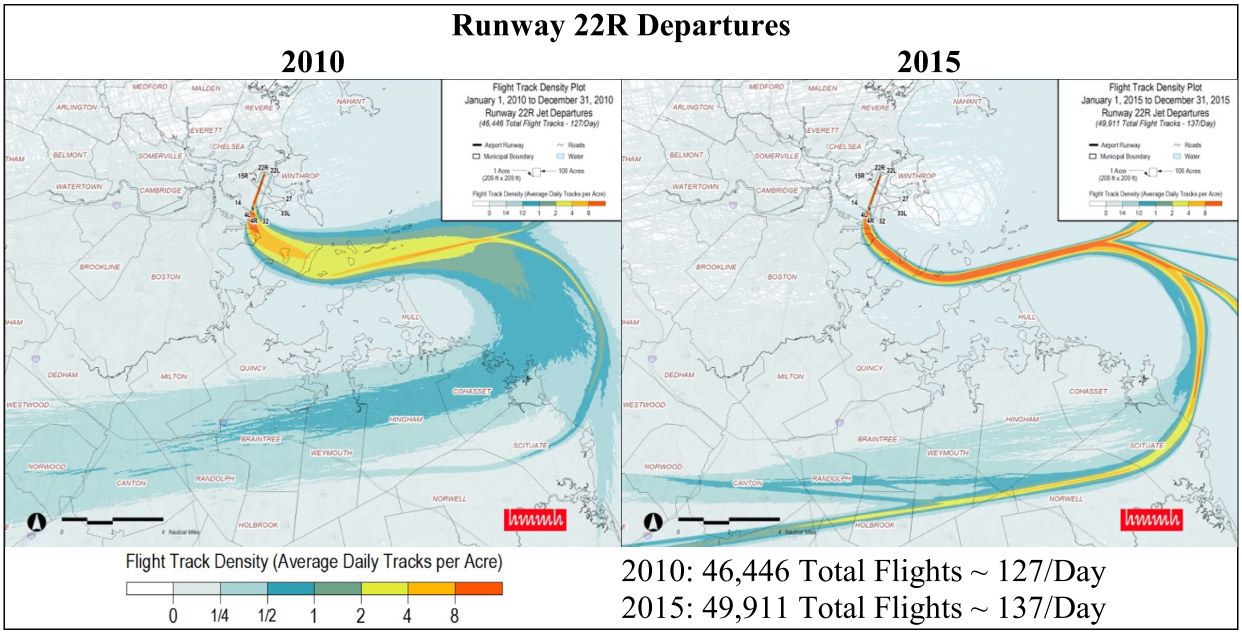


Figure 25. Comparison between flight track density from Runway 22R jet departures between 2010 and 2015.

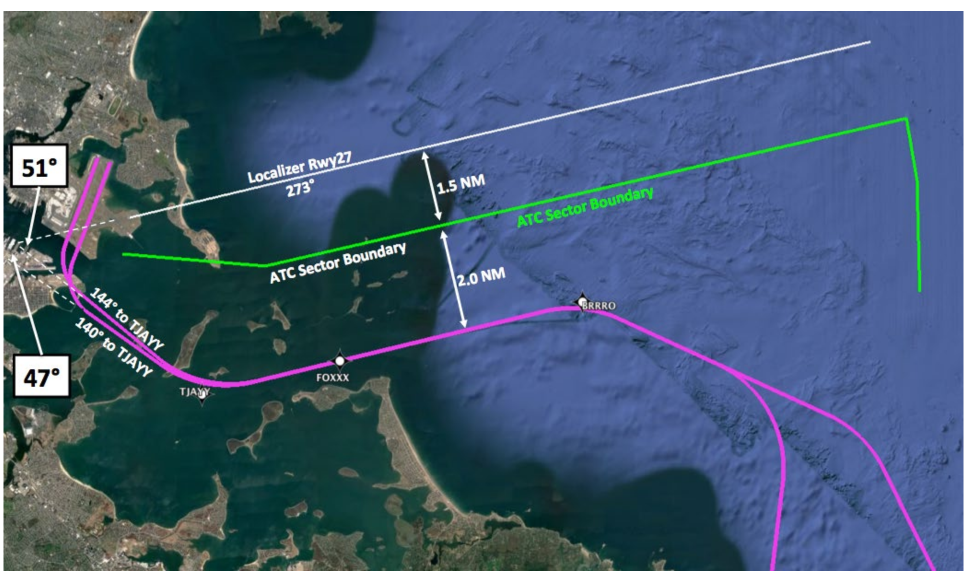


Figure 26. Current RNAV SIDs from Runway 22L and 22R (magenta), ILS Localizer to Runway 27 (white) and the air traffic control sector boundary (green).

The community of Hull voiced a strong desire for a relocation of flight tracks north towards the original pre-RNAV locations over Boston Harbor.

2. Initial Candidate Procedures

Three candidate procedures for Runway 22L/R departures were originally proposed as part of the Block 1 process, but were ultimately rejected during feasibility evaluation by a 7100.41 stakeholder group or due to the need for waivers from criteria.

These candidate procedures included: 1-D3a: *Runway 22L/R RNAV waypoint relocation (climb to intercept course)*; 1-D3b: *Runway 22L/R RNAV waypoint relocation (VI-DF climb to altitude then direct)*: 1-D3c: *Runway 22L/R heading-based departure when Runway 27 arrivals not in use*.

- *1-D3a: Runway 22L/R RNAV waypoint relocation (VI-CF climb to intercept course):* This procedure shown in the white line in Figure 27 uses the same leg types and geometry used in the current published departures. It retains the current turn location after takeoff but shifts the initial turn north from TJAYY to WPONE which would maintain the minimum 1.5 NM spacing form the ATC sector boundary. Evaluation of this procedure by operational stakeholders identified concerns with the minimum path length between the initial turn and WPONE particularly under certain wind conditions and was determined to be infeasible as proposed.

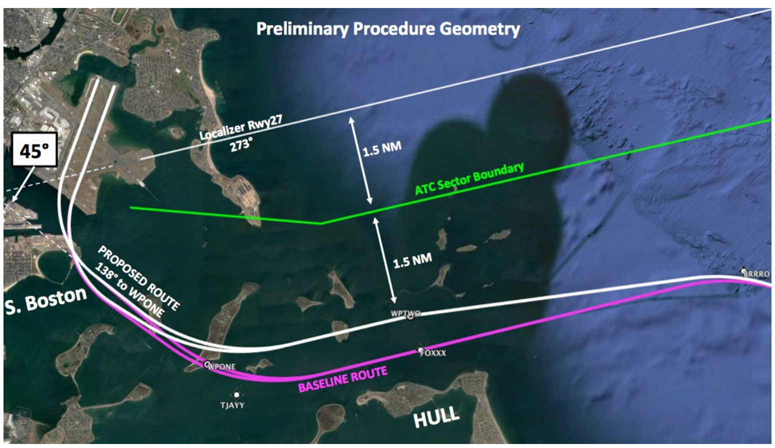


Figure 27. Procedure illustration for a 22L/R departure climbing via the BLZZR4 departure (baseline) compared to procedure 1-D3a.

- *1-D3b: Runway 22L/R RNAV waypoint relocation (VA-DF climb to altitude then direct):* This procedure shown in Figure 28 uses a modified procedure definition that turns to a more northerly waypoint WPTWO at an altitude of 500 ft and allows for earlier turns after takeoff for certain steep-climbing aircraft. Operational stakeholders found this procedure infeasible due to variability in aircraft turn location, which created sequencing problems for ATC and the potential for increased noise exposure in South Boston for some slow-climbing aircraft.

Figure 28. Procedure illustration for a 22R departure climbing via the BLZZR4 departure (baseline) compared to procedure 1-D3b.

- *1-D3c: Runway 22L/R heading-based departure when Runway 27 arrivals not in use:* In this procedure shown in Figure 29, the local tower controller would issue a heading of 100° at the time of takeoff clearance. Aircraft would have the flexibility to commence the turn based on pilot discretion and company policy, likely allowing earlier turns than the current RNAV engagement altitude between 400 and 500 ft above ground level. Once clear of population-sensitive areas, the aircraft may continue on ATC vectors or be cleared to a downstream fix on a published RNAV SID. This procedure is only possible when Runway 27 is not in use for arrivals. The procedure was not supported by operational stakeholders due to increased ATC workload, the potential for late vectors increasing noise exposure and concern of operational errors as well as problems with airline dispatch not being able to predict when the procedure would be available.

Figure 29. Procedure illustration for a 22R departure climbing via the BLZZR4 departure (baseline) compared to procedure 1-D3c.

3. Recommended VI-CF Procedure with Speed Restriction

Based on feedback from the operational stakeholder group as well as input from the FAA Air Traffic Procedures group, a modified version of the *1-D3a VI-CF* procedure with a speed restriction was identified as a procedure that would address the minimum path length concerns identified and is shown in Figure 30.

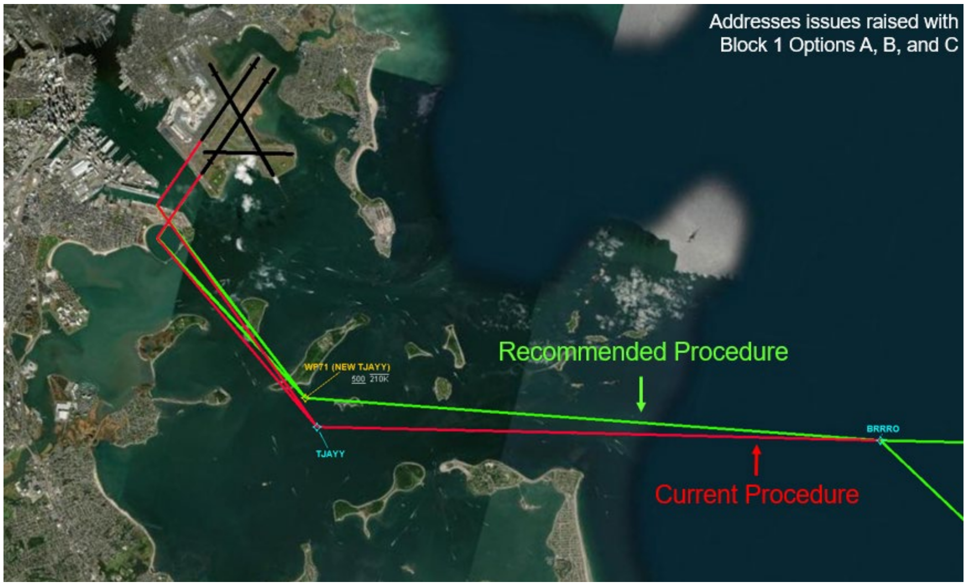


Figure 30. Comparison between recommended (green) and current (red) procedure.

Minimum leg length criteria and operator flyability concerns from Block 1 were addressed by adding a speed restriction to the new initial waypoint. By restricting the speed of aircraft to 210 knots in the first and second segments of the procedure a shorter leg length is possible due to the slower speeds. The new location for the initial waypoint (TJAYY) was chosen as to satisfy the air traffic rule that requires a separation of 1.5 NM from an ATC sector boundary to the north. The final design is an RNAV departure procedure that shifts aircraft tracks north away from Hull while satisfying airspace and procedure design constraints. The entire set of constraints addressed in the procedure design is shown in Figure 31 below.

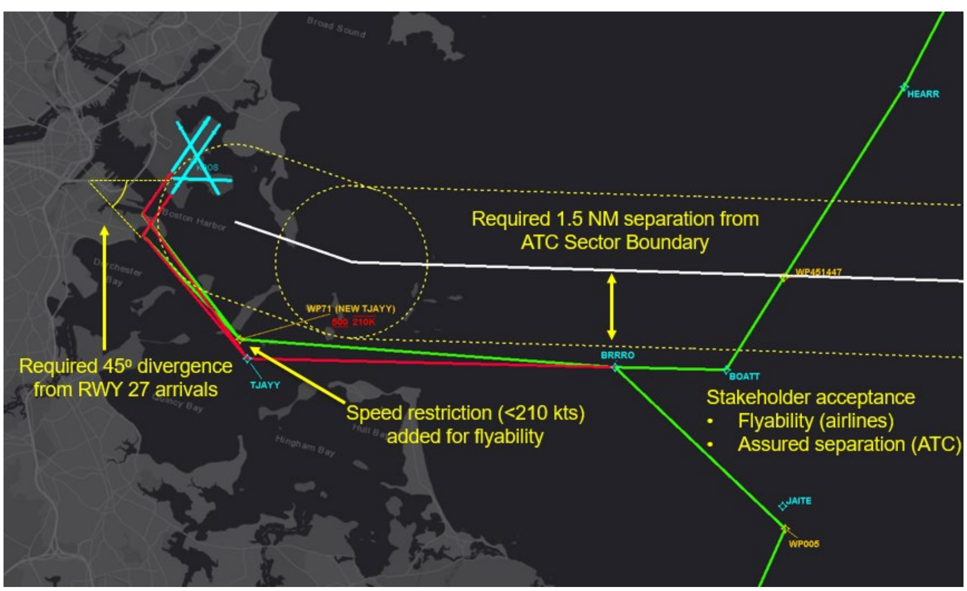
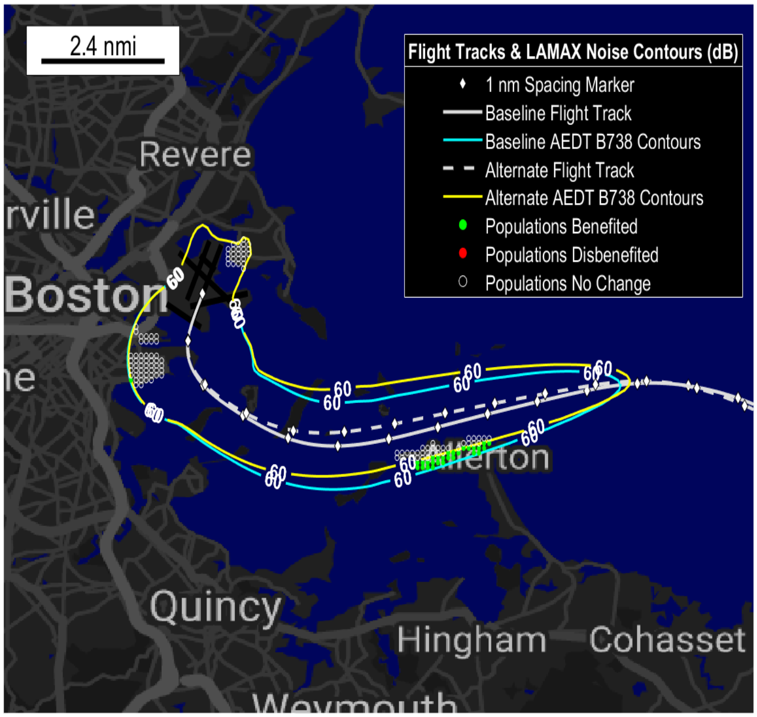


Figure 31. Constraints considered in the design of the proposed procedure.

4. Noise Results

Noise was modeled for the proposed procedure using the single-track analysis framework, using AEDT (Appendix B) to compute noise levels and plotting results in terms of $L_{A,MAX}$. Analysis was performed using the Boeing 737-800 as a representative narrowbody aircraft.



B737-800 Population Exposure ($L_{A,MAX}$)	$L_{A,MAX}$>60dB (Population Exposed)
Current procedure	15,289
Proposed idea	14,342
Difference (Current - Proposed)	947

Figure 32. Single-track noise analysis of proposed procedure.

As illustrated by the green cells in the noise analysis plot, the procedure is expected to benefit 947 people in the Hull peninsula, as measured by exposure to $L_{A,MAX}$ levels greater than 60 dB.

5. Recommendation of Modified VI-CF Procedure with Speed Restriction

The modified VI-CF procedure with speed restriction addresses all known operational concerns and is therefore recommended.

2-D2: Runway 33L

Objective: Increase equity by dispersing flight tracks.

1. Introduction

Analysis of radar tracks for jet aircraft from 2010 and 2015 for Runway 33L in Figure 33 show concentration into 5 departure tracks consistent with the published RNAV departures at BOS. As shown in Figure 34, northbound aircraft use the HYLND and LBSTA departures, westbound aircraft use the REVSS, BLZZR and PATSS departures, and southbound aircraft use the SSOXS, BRUWN and CELTK departures.

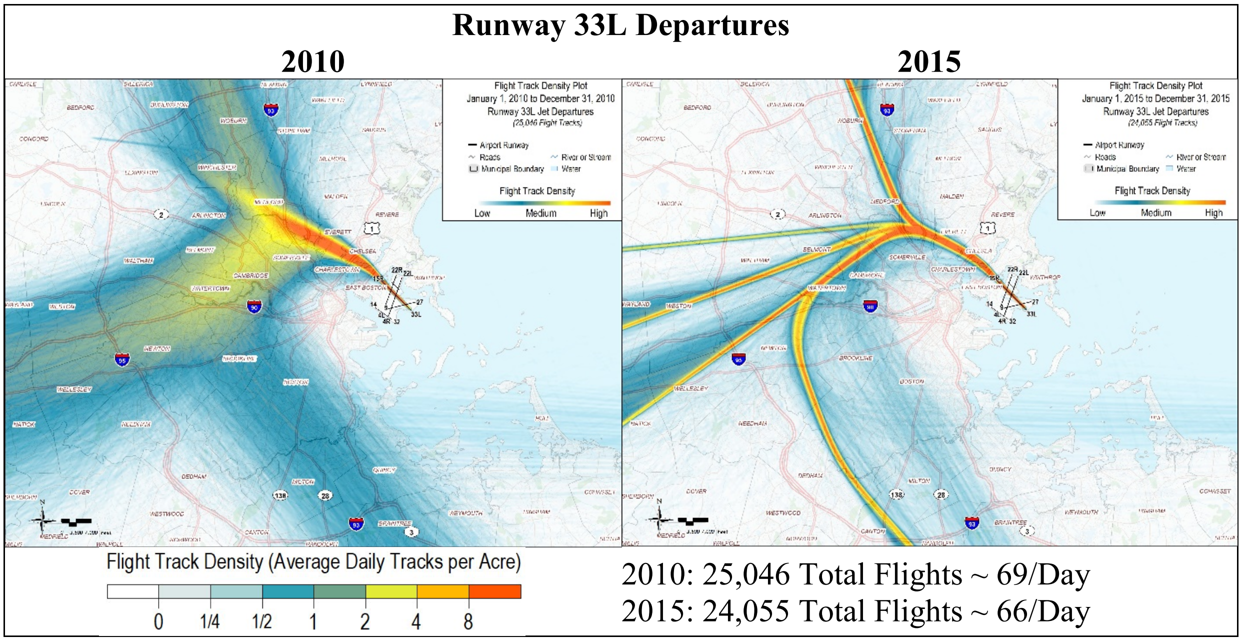


Figure 33. Comparison between flight track density from Runway 33L jet departures between 2010 and 2015.

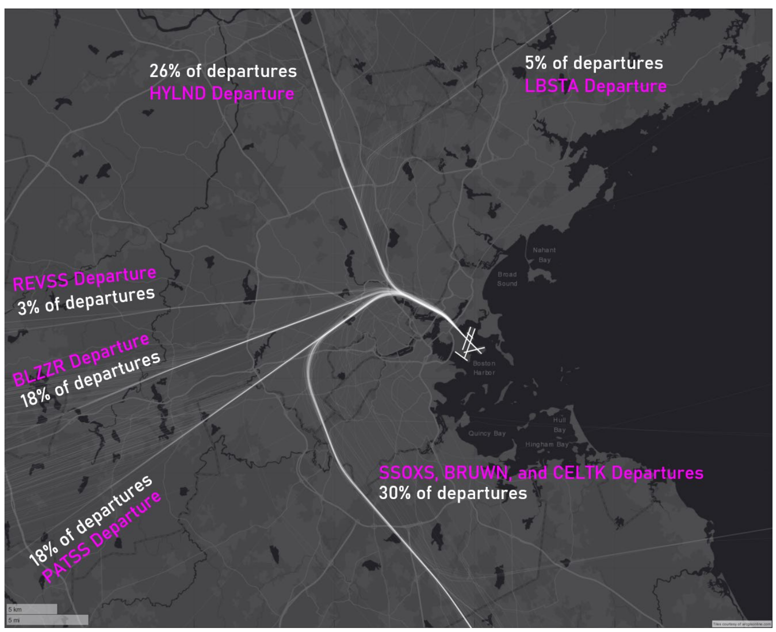


Figure 34. Current RNAV departure procedures from Runway 33L.

Due to the concentration of tracks introduced by RNAV, communities located west and northwest of the airport have requested consideration of procedures which would re-introduce dispersion to the departure flight tracks from Runway 33L.

2. Initial Candidate Procedures

Five concepts for increasing flight track dispersion were initially evaluated as shown in Figure 35. These included Altitude-Based Dispersion, Controller-Based Dispersion through vectoring, Divergent Heading Dispersion, RNAV Waypoint Relocation and a community suggested concept for Variable Rotation Departures.

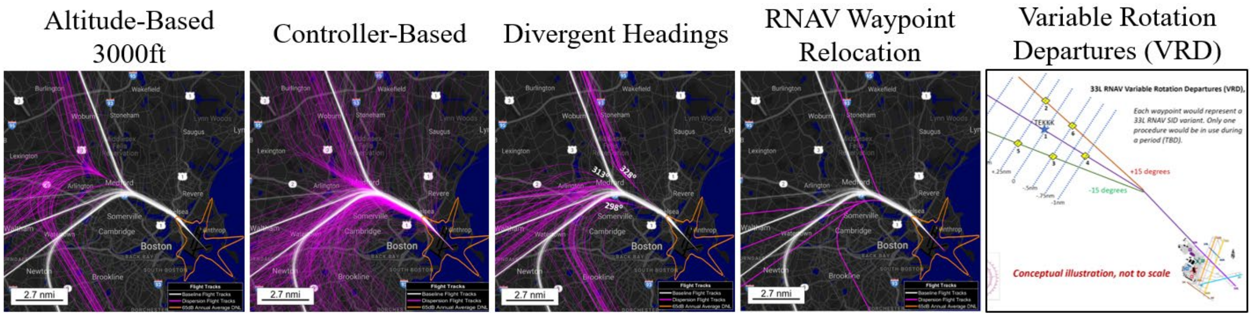
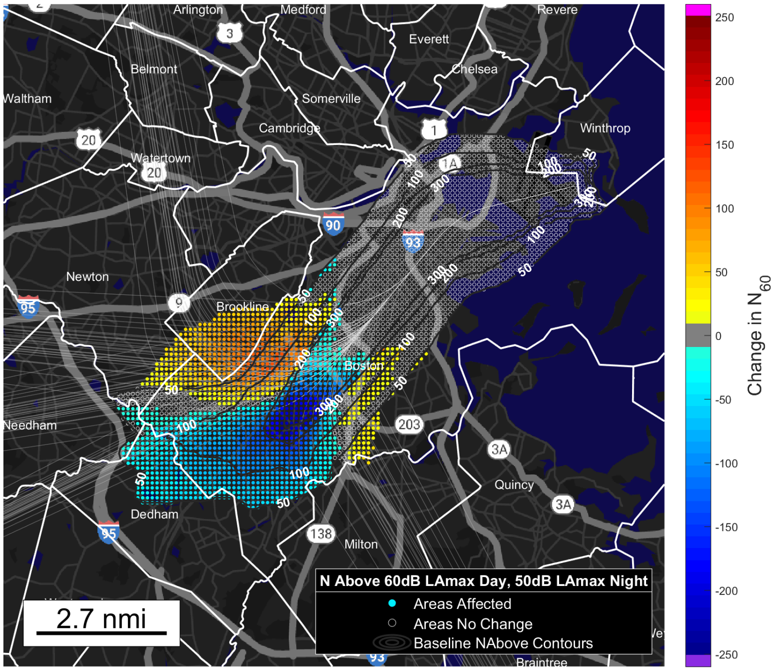


Figure 35. Runway 33L departure procedure candidates evaluated with stakeholder group.

Noise was modeled for the proposed procedures using the multiple-track analysis framework, using the AEDT noise model (Appendix B) to compute noise levels and plotting results in terms of N_{60} heat maps. The analysis conducted considered a peak day of operations in 2017, and used actual radar tracks in order to compute the baseline N_{60} levels. Radar flight tracks were modified to match those of the proposed procedure, keeping aircraft type and track assignment consistent with the new N_{60} levels being computed and compared to baseline values.

The five procedure concepts were presented to a group of key air traffic and airline stakeholders in May 2020, who provided a preliminary assessment of the implementation feasibility for each procedure. Each of these procedures is discussed below, along with the preliminary assessment given by the stakeholder group at that time.

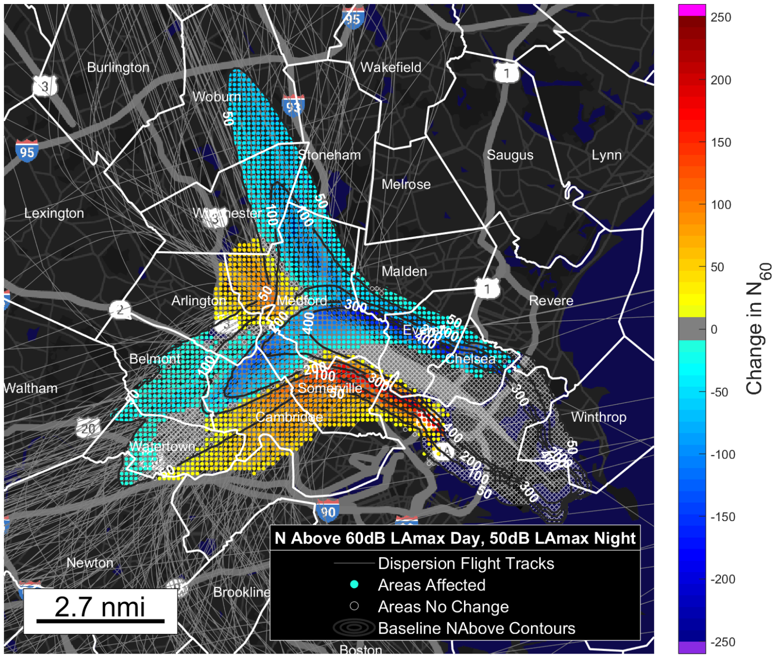
- *Altitude-Based Dispersion:* In this concept, aircraft climb to a common altitude before turning in their respective directions of flight. Due to different aircraft climbing at different rates based on weight and thrust setting, this would result in aircraft reaching the turn altitude at different distances from the runway, therefore creating flight track dispersion around the turn location. This procedure idea was evaluated with stakeholders but ultimately not supported due to the loss of track predictability from an air traffic standpoint. Due to some aircraft to turning early and others to turning late, as well as aircraft later converging at a common point, the procedure would introduce aircraft separation challenges for air traffic control and concerns that the procedure may have a negative impact on safety. Noise results for altitude-based dispersion at 3000 ft are shown in Figure 36.



	N_{60}>50 (Population Exposed)
Current procedure	335,823
Proposed procedure	340,974
Difference (Current - Proposed)	-5,151

Figure 36. Noise results for Runway 33L Altitude-Based Dispersion at 3000 ft.

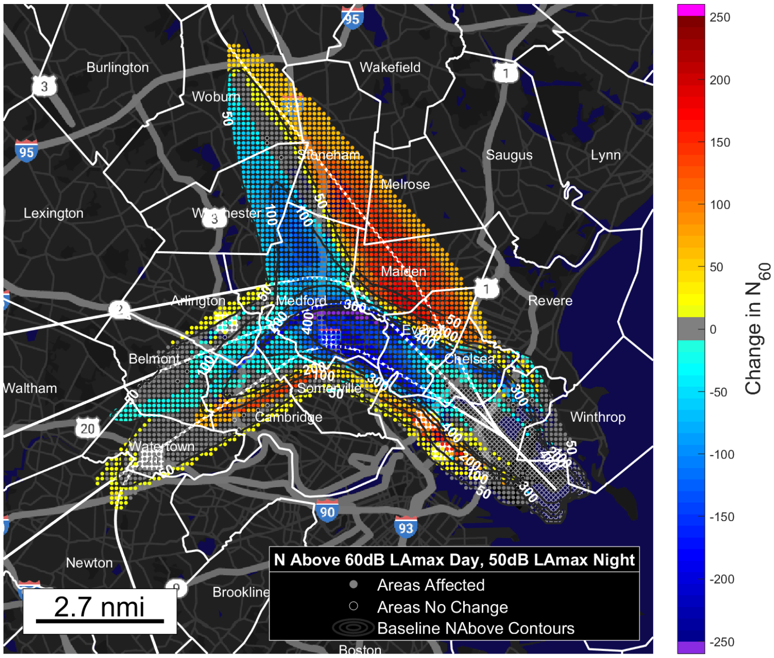
- *Controller-Based Dispersion (Vector Procedure):* This procedure option consisted of using air traffic control (ATC) vectors instead of the existing RNAV departures during times of low traffic. In ATC vectors, turns are issued to aircraft via radio communications by the air traffic controller. Due to the manual nature of vector operations, this procedure would add dispersion to flight tracks due to the variability in turn locations and vector instructions. Operational stakeholders did not support the use of a vector-based procedure due to the higher air traffic control workload it causes. Its use during periods of low traffic was also not supported due to concerns with airline flight planning and dispatching, who may not know what departure procedure to expect ahead of time. In a scenario in which a pilot receives a clearance that is different from the expected one (e.g. issued a vector-based departure procedure instead of the regular RNAV due to low-traffic conditions), cockpit workload would be increased as pilots must reprogram Flight Management Systems (FMS). Noise results for this concept are shown in Figure 37.



	N_{60}>50 (Population Exposed)
Current procedure	335,823
Proposed procedure	356,864
Difference (Current - Proposed)	-21,041

Figure 37. Noise results for Runway 33L Controller-Based Dispersion.

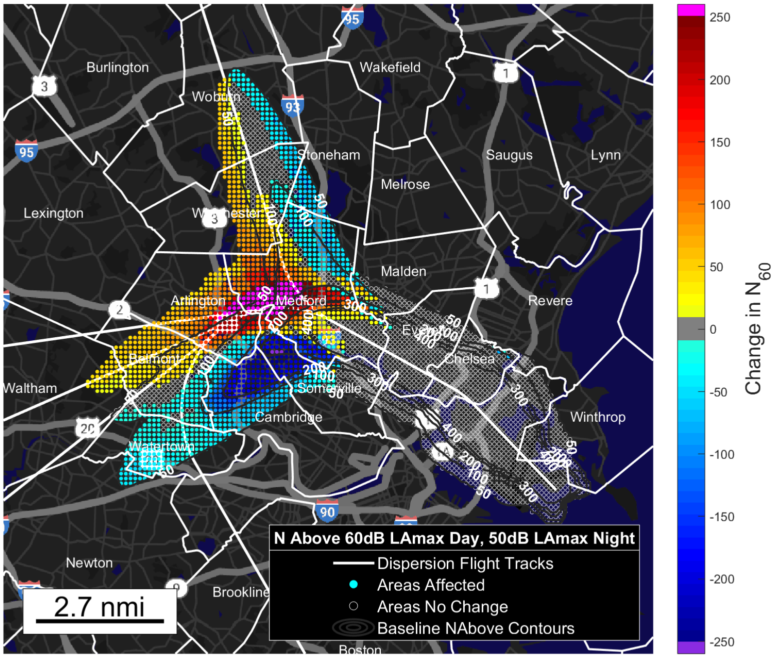
- *Divergent Headings Dispersion:* This procedure consisted of assigning different initial headings to departing aircraft based on their direction of flight. For example, aircraft departing to the north would be given a 15-degree turn to the right after departure before continuing on its RNAV trajectory, while aircraft departing to the south would be given a 15-degree turn to the left. During discussions, the stakeholder group pointed out that right turns after departure from Runway 33L were not feasible due to the airspace northeast of the airport being used for propeller-aircraft departures, as well as an ATC sector boundary being present north of the airport. Concerns were also raised regarding turns to the left, which caused potential violations of minimum leg length later in the procedure. Noise results for this concept are shown in Figure 38.



	N_{60}>50 (Population Exposed)
Current procedure	335,823
Proposed procedure	412,782
Difference (Current - Proposed)	-76,959

Figure 38. Noise results for Runway 33L Divergent Headings Dispersion (off runway).

- *RNAV Waypoint Relocation:* This concept involved a relocation of the initial procedure waypoint (TEKKK), which today is located approximately 4 NM northwest of Runway 33L and shared by all of the eight published RNAV SIDs. By relocating the waypoint, flight tracks could be shifted to areas of lower population density. Several potential options moving the TEKKK waypoint in or out 0.5 NM and 1.0 NM were modeled. One example moving TEKKK out by 1.0 NM is shown in Figure 39. Other locations modeled are shown in Appendix F. Discussion with the stakeholder group raised issues related to proximity to ATC sector boundaries and procedure minimum leg length violations when TEKKK was moved to the new proposed location.



	N_{60}>50 (Population Exposed)
Current procedure	335,823
Proposed procedure	294,419
Difference (Current - Proposed)	41,404

Figure 39. Noise results for Runway 33L RNAV Waypoint Relocation (TEKKK moved out by 1 NM).

- *Variable Rotation Departures:* It was proposed by the communities that multiple versions of the eight published RNAV SIDs be created, with 6 different initial waypoints representing 3 divergent headings with early and late turns shown in Figure 40. The concept was that ATC could "rotate" through the different versions of the procedures on a periodic basis, so that flight tracks were concentrated over different regions during different time periods. An example of the noise impact for one of the waypoint locations is shown in Figure 41 and the complete set of noise impacts for all of the waypoints considered is included in Appendix F.

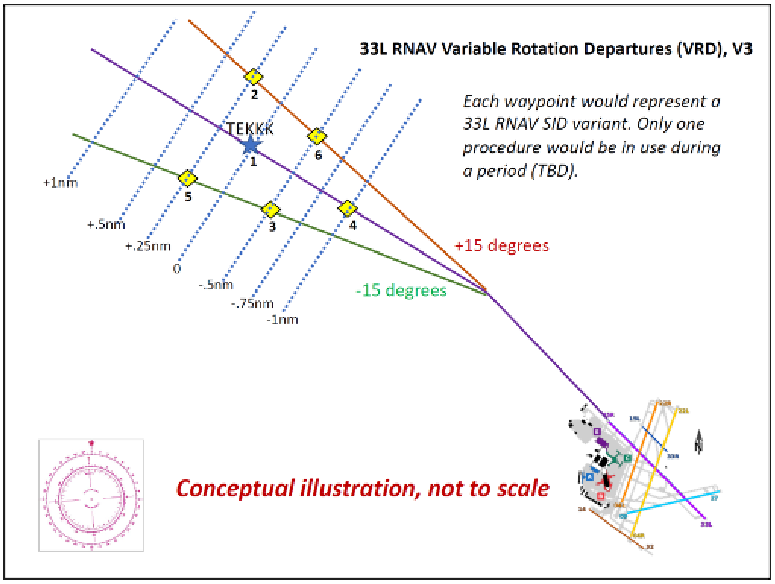
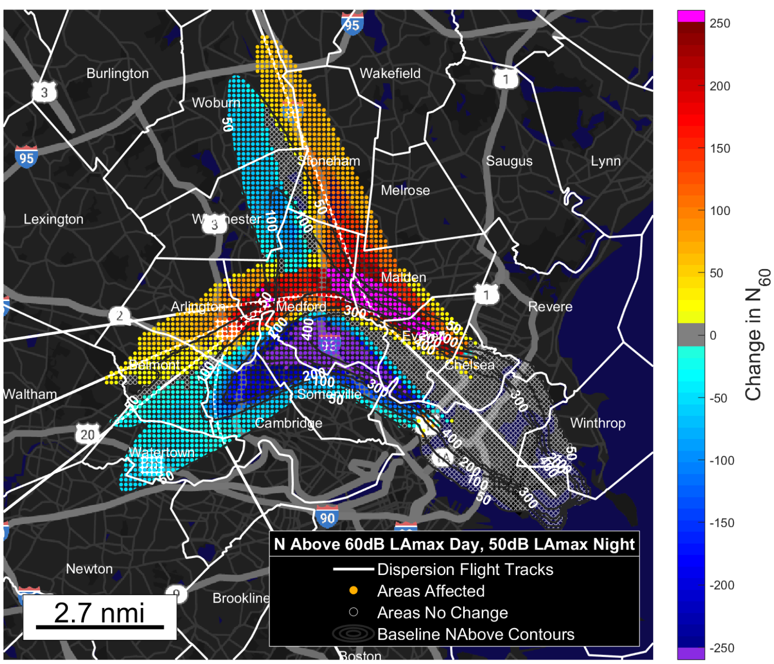


Figure 40. Community Suggested Variable Rotation Departures.



	$N_{60}>50$ (Population Exposed)
Current procedure	335,823
Proposed procedure	269,491
Difference (Current - Proposed)	66,332

Figure 41. Noise Results for Runway 33L Variable Rotation Departures (single waypoint example).

Through discussions with operational stakeholders, the research team concluded that there were significant barriers to the implementation of the *Variable Rotation Departures* procedure. Namely, the creation of multiple versions of each SID would require the charting of a large number of departures. For instance, if six versions of TEKKK existed, six charted procedures would be required per current departure, bringing the total number of charted procedures required to 48 (i.e. 8 current procedures × 6 versions per procedure). Having such a large number of procedures would create problems for aircraft Flight Management Systems (FMS) where the procedures are stored as they have limited data storage. In addition, because the existing departure procedures are named after their respective end fixes (e.g., the BLZZR departure gets its name due to its last waypoint BLZZR), having six versions of a procedure that all end at the same end fix would require a break from this charting convention and could create confusion for air traffic and operators alike. Finally, the concept of a periodic procedure "rotation" was not supported by air traffic, as it could potentially increase the chance of human error in operations (e.g. an air traffic controller issuing the wrong procedure for the current day, or an aircraft flying the wrong version of the procedure that it was issued). These potential errors could lead to a loss of aircraft separation in the airspace, therefore having a negative impact on safety.

3. Modified Waypoint Relocation Procedure

After initial candidate procedures were evaluated with operational stakeholders, a procedure recommendation that addressed all concerns previously was identified. This concept involved a change of the waypoint where the procedure branching first occurs, with the waypoint TEKKK being the current location. The modified waypoint relocation procedure is shown in Figure 42 with the proposed procedure shown in green and present-day aircraft tracks shown in white.

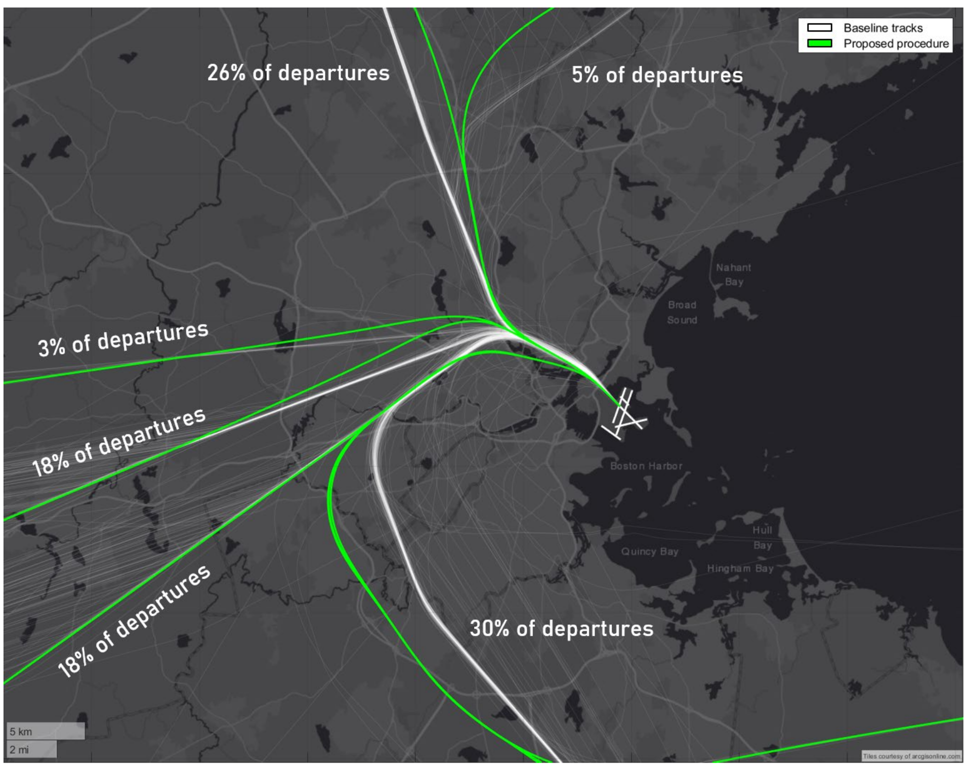


Figure 42. Baseline radar tracks from 2017 (white) are compared to simulated flight tracks of aircraft flying the proposed procedure (green).

The initial divergence point was moved as close to the runway as possible (1 NM) for southbound departures. Right turns at 1 NM for northbound departures were not possible due to conflicts with propeller-aircraft departures. Northbound and westbound departures could not be dispersed earlier than the TEKKK waypoint due to required separation from an ATC sector boundary located north of the airport. Westbound traffic is further split northwest of the TEKKK waypoint. The entire set of constraints that had to be satisfied by the modified procedure is shown in Figure 43.

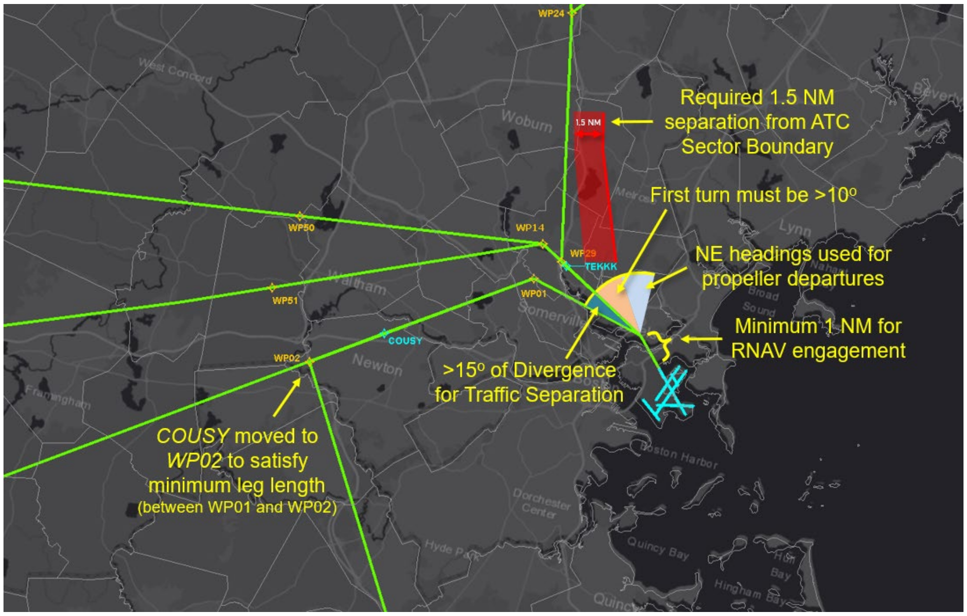
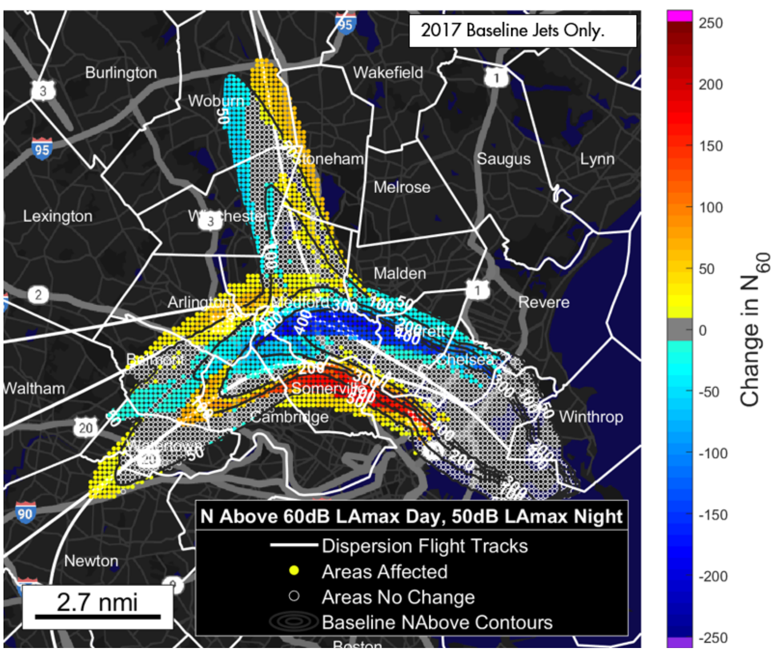


Figure 43. Constraints considered in the design of the proposed procedure.

4. Noise Results

The plot below shows changes in N_{60} that would be expected if the modified waypoint relocation procedure were to be implemented.



	N_{60}>50 (Population Exposed)
Current procedure	335,823
Proposed procedure	352,775
Difference (Current - Proposed)	-16,952

Figure 44. Change in N_{60} introduced by the recommended procedure in comparison to the current procedure.

As shown in the plot above, regions northwest of the airport see a reduction in N_{60} (as illustrated by the dark blue cells), while areas of increase in N_{60} are observed in the southern regions of the noise footprint as well as west and north (as illustrated by the red cells). At a net level, the recommended procedure is expected to expose 16,952 additional people to peak day N_{60} levels greater than 50. While the net impact is negative, this procedure modification was in response to community requests to increase noise dispersion. In the detailed city-by-city analysis of the noise re-distribution available in Appendix D, it was found that the proposed procedure reduced the number of people exposed to more than 300 daily overflights ($N_{60} > 300$) by 26,622 during a peak day of operations. As a result, the proposed procedure was successful in providing relief to highly impacted communities.

5. Recommendation – Waypoint Relocation Dispersion Procedure

The modified waypoint relocation procedure discussed in this section is the only dispersion procedure identified which addresses all known operational concerns. Because it results in a redistribution of noise and an aggregate increase in population exposed to more than 50 daily overflights at the N_{60} level on a peak day of Runway 33L operations, it will ultimately be up to the communities to determine if the redistribution is equitable and merits requested implementation of the procedure.

2-D3: Runway 27

Objective: Increase equity by dispersing flight tracks.

1. Introduction

Analysis of radar tracks for jet aircraft from 2010 and 2015 for Runway 27 in Figure 45 show concentration into 4 tracks consistent with the RNAV departures at BOS. As shown in Figure 46, northbound aircraft use the HYLND and LBSTA departures, westbound aircraft use the REVSS, BLZZR and PATSS departures, and southbound aircraft use the SSOXS, BRUWN and CELTK departures. The current point of dispersion is the KIRAA waypoint, located 7 NM from the runway. This is because all departures are required to follow a 3-mile-long corridor established by an environmental Record of Decision (ROD) signed in 1996.

Due to the fact that the vector-based flight tracks from Runway 27 were already reasonably concentrated in the ROD corridor during initial climb before RNAV implementation there was not a significant change in concentration. However, radar tracks indicate that the adoption of RNAV departure procedures caused significant flight track concentration during later stages of the climb and that the initial point of dispersion is moved out from the pre-RNAV location at the WYLYY waypoint to the KIRRA fly by waypoint.

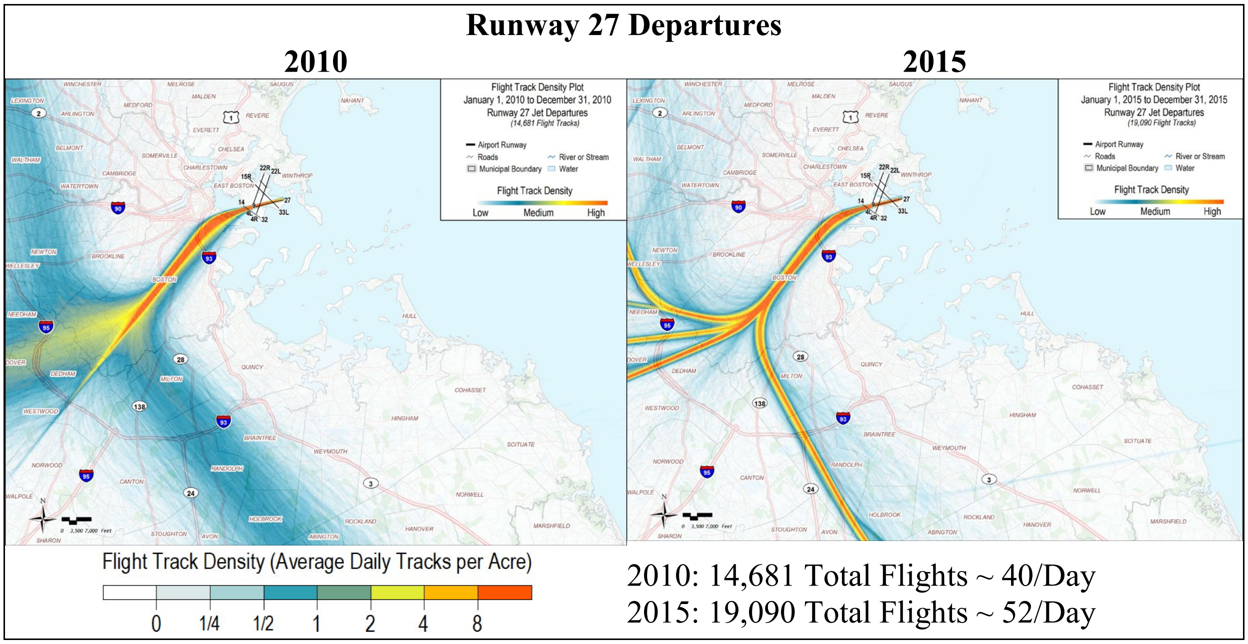


Figure 45. Comparison between flight track density from Runway 27 jet departures between 2010 and 2015.

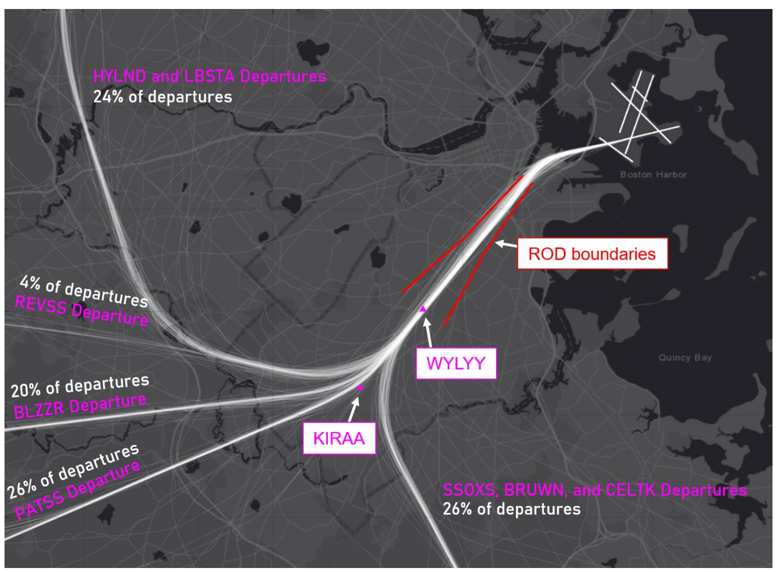


Figure 46. Flight tracks from a single day of departures from Runway 27, showing the boundaries of the 1996 environmental Record of Decision (ROD) as well as the location of the KIRAA branching waypoint.

Communities located southwest of the airport have requested consideration of procedures which would re-introduce dispersion and move the initial dispersion point closer to WYLYY.

2. Initial Candidate Procedures

Four procedure types were initially evaluated as potential solutions for achieving a higher flight track dispersion compared to the baseline RNAV departure. These used the same types of dispersion concepts assessed for Runway 33L departures, with feasibility assessments happening simultaneously for both runways. Because of this, much of the stakeholder input collected for Runway 33L departure ideas applies to those evaluated for Runway 27. The four concepts for increasing flight track dispersion are shown in Figure 47 and included Altitude-Based Dispersion, Controller-Based Dispersion through vectoring, Divergent Heading Dispersion, and RNAV Waypoint Relocation.

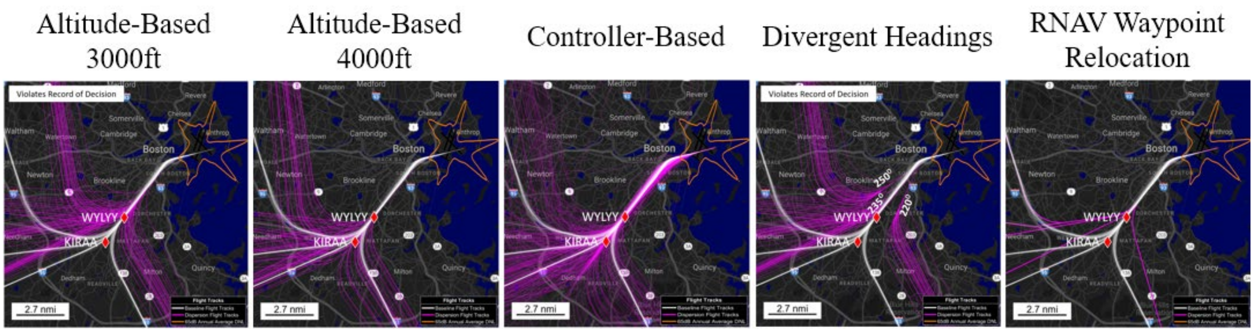
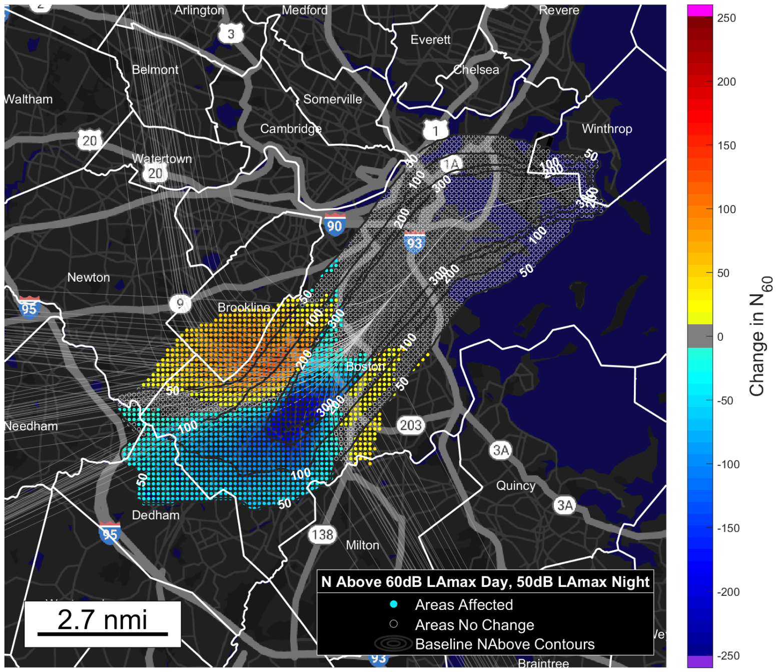


Figure 47. Runway 27 departure procedure initial candidates evaluated with stakeholder input.

Noise was modeled for the proposed procedures using the multiple-track analysis framework, with the AEDT noise model (Appendix B) to compute noise levels and plotting results in terms of N_{60} heat maps. The analysis conducted considered a peak day of operations in 2017, and used actual radar tracks in order to compute the baseline N_{60} levels. Radar flight tracks were modified to match those of the proposed procedure, keeping aircraft type and track assignment consistent with the new N_{60} levels being computed and compared to baseline values.

Each of these procedures is discussed below, along with the peak day noise analysis and preliminary assessment received from operational airline and air traffic stakeholders.

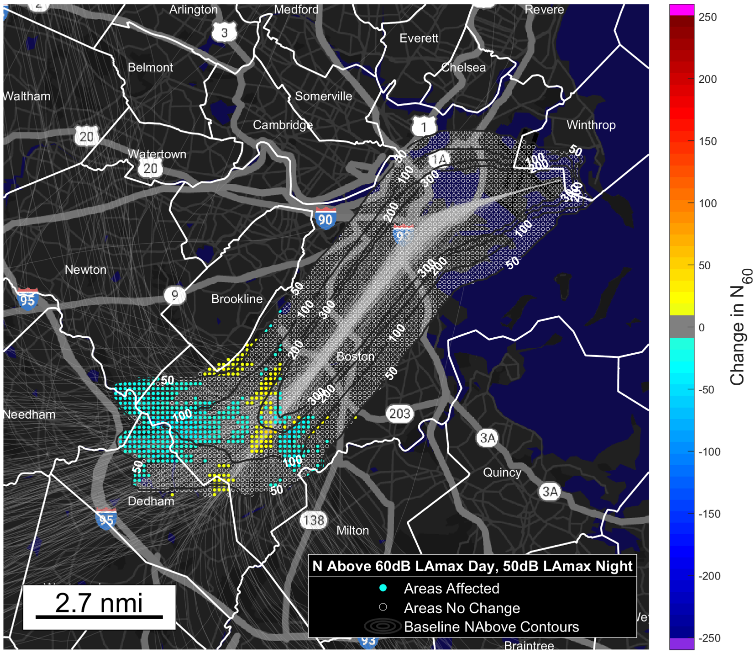
- *Altitude-Based Dispersion:* In this concept, aircraft climb to a common altitude (either 3000 ft or 4000 ft) before turning in their respective directions of flight. Due to different aircraft climbing at different rates based on weight and thrust setting, this would result in aircraft reaching the turn altitude at different distances from the runway, therefore creating flight track dispersion around the turn location. This procedure idea was evaluated with stakeholders but ultimately not supported due to the loss of track predictability from an air traffic standpoint. Due to some aircraft to turning early and others to turning late, as well as aircraft later converging at a common point, the procedure would introduce aircraft separation challenges for air traffic control and concerns that the procedure may have a negative impact on safety. Evaluation of this procedure also identified that it would not be compliant with the 1996 environmental ROD, and it was therefore not considered for further evaluation. Results for the altitude-based dispersion implemented at 3000 ft are shown below, with results for the 4000 ft dispersion available in Appendix F.



	N_{60}>50 (Population Exposed)
Current procedure	407,357
Proposed procedure	384,114
Difference (Current - Proposed)	23,243

Figure 48. Noise Results for Runway 27 Altitude-Based Dispersion at 3000 ft.

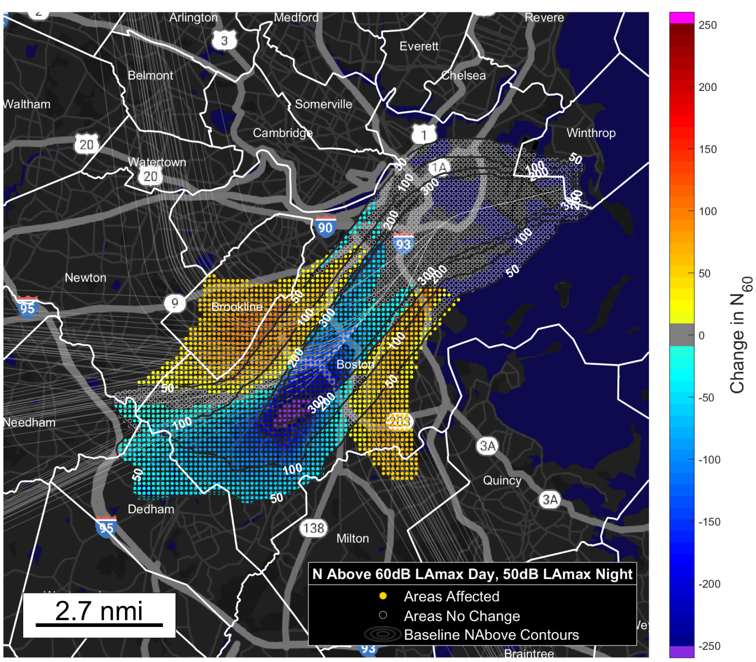
- *Controller-Based Dispersion (vector procedure):* This procedure option consisted of using air traffic control (ATC) vectors instead of the existing RNAV departures during times of low traffic. In ATC vectors, turns are issued to aircraft via radio communications by the air traffic controller. Due to the manual nature of vector operations, this procedure would add dispersion to flight tracks due to the variability in turn locations and vector instructions. Operational stakeholders did not support the use of a vector-based procedure due to higher air traffic control workload. Its use during periods of low traffic was also not supported due to concerns with airline flight planning and dispatching, who may not know what departure procedure to expect ahead of time. Noise results for this concept are shown in Figure 49.



	N_{60}>50 (Population Exposed)
Current procedure	407,357
Proposed procedure	407,001
Difference (Current - Proposed)	356

Figure 49. Noise Results for Runway 27 Controller-Based Dispersion.

- *Divergent Heading Dispersion:* This procedure consisted of assigning different initial headings to departing aircraft based on their direction of flight. For example, aircraft departing to the north would be given a 15-degree turn to the right after departure before continuing on its RNAV trajectory, while aircraft departing to the south would be given a 15-degree turn to the left. Evaluation of this procedure identified that it would not be compliant with the 1996 environmental ROD, and it was therefore not considered for further evaluation. Noise results for this concept are shown in Figure 50.



	N_{60}>50 (Population Exposed)
Current procedure	407,357
Proposed procedure	399,883
Difference (Current - Proposed)	7,474

Figure 50. Noise Results for Runway 27 Divergent Headings Dispersion (off runway).

- *Waypoint Relocation:* This concept involved a change of the waypoint where the procedure branching first occurs, with the waypoint KIRAA being the current location used. By changing the waypoint, flight tracks could be shifted to areas of lower population density as requested by the communities. An initial version of this procedure shifted the branching location to the waypoint WYLYY, located at the *exit gate* of the ROD and the earliest possible point for dispersion. Further noise analysis and community input identified that using WYLYY as the branching waypoint for westbound and northbound tracks and KIRAA for southbound tracks provided both a reduction in noise exposure and an increase in flight track dispersion. The image below shows the final version of this procedure after stakeholder concerns were addressed, with the proposed procedure shown in green and the present-day flight tracks shown in white.

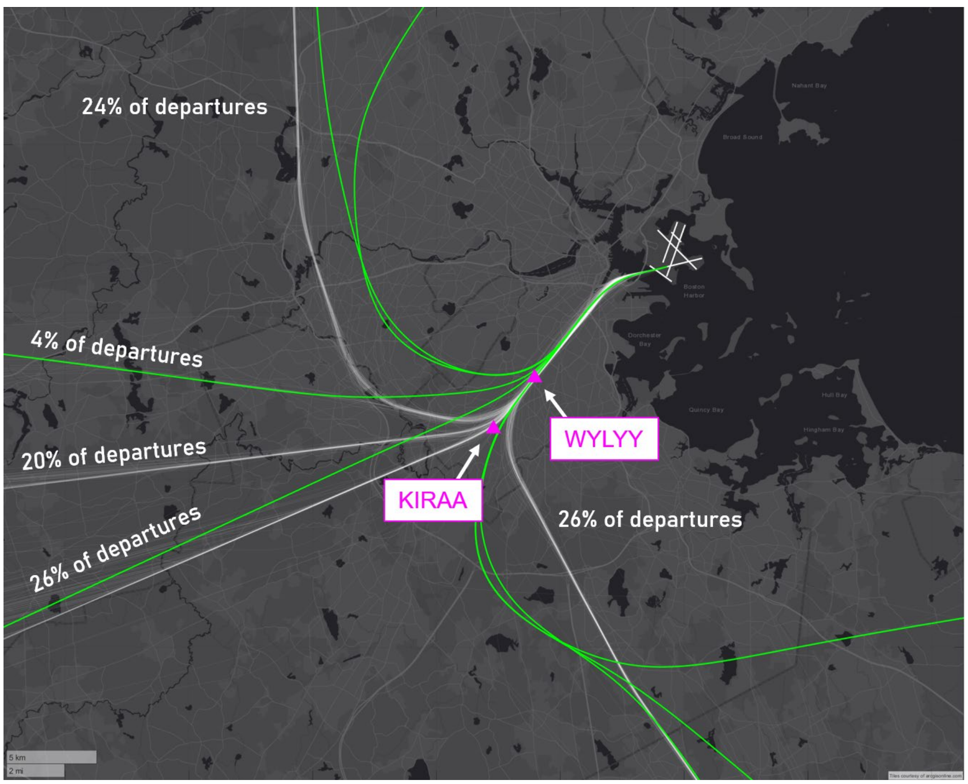


Figure 51. Baseline radar tracks from 2017 (white) are compared to simulated flight tracks of aircraft flying the proposed procedure (green).

To achieve an implementable version of the procedure, specific constraints regarding minimum leg lengths and separation from Runway 33L departures had to be addressed in the design. Here, WYLYY is used as the branching waypoint for westbound and northbound tracks, while KIRAA is used for southbound tracks. This waypoint assignment allows for a higher dispersion of flight tracks compared to the current RNAV departure. The procedure was also verified to comply with the 1996 environmental ROD with the earlier turn at WYLYY through an analysis of historical turn dispersion on the current procedure. In addition to the new branching waypoints, slight modifications were required in later segments located north and south of the airport to satisfy airspace constraints. The entire set of constraints that had to be satisfied by the waypoint relocation procedure is shown in Figure 52.

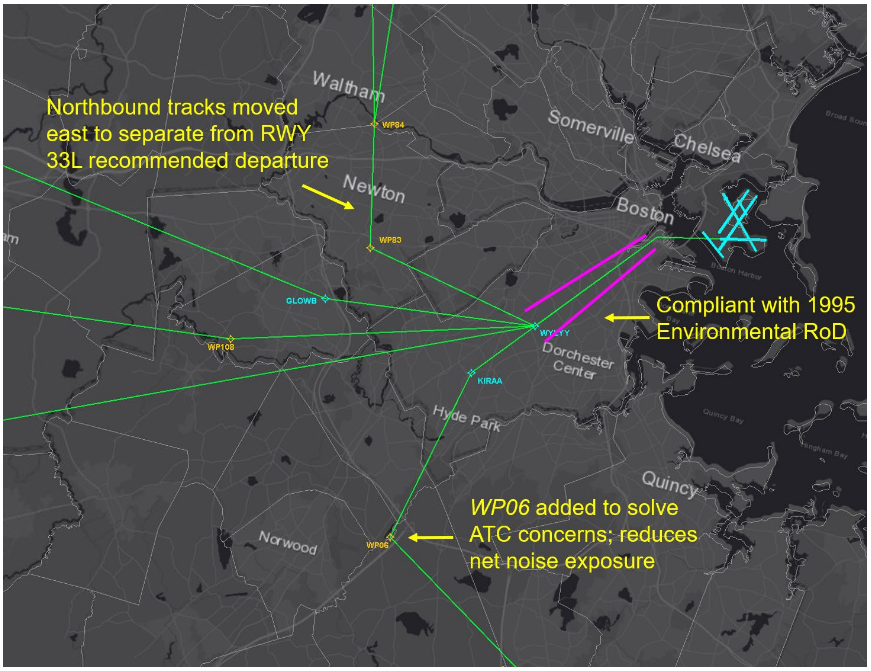
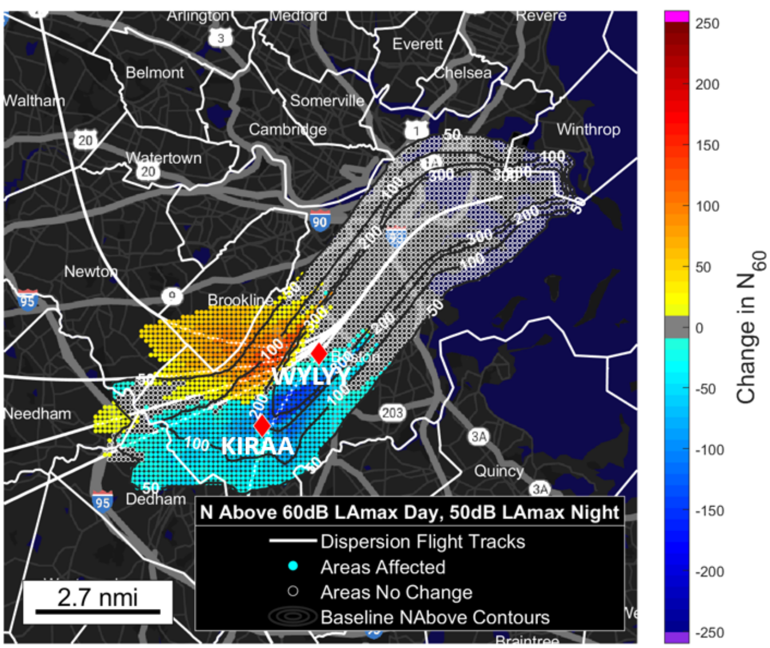


Figure 52. Constraints considered in the design of the proposed procedure.

The plot below shows the changes in N_{60} that would be expected with use of the waypoint relocation procedure on a peak day Runway 27 operation.



	N_{60}>50 (Population Exposed)
Current procedure	407,357
Proposed procedure	386,332
Difference (Current - Proposed)	21,025

Figure 53. Change in N_{60} introduced by the recommended procedure in comparison to the current procedure.

As illustrated in the plot above, regions south and southwest of the WYLYY waypoint see a significant reduction in N_{60} (as illustrated by the blue cells), while an increase in N_{60} is observed in regions west of WYLYY (as illustrated by the red cells). The recommended procedure is expected to benefit 21,025 people by decreasing their peak day N_{60} levels below 50. The procedure was also shown to reduce the number of people exposed to more than 300 daily overflights ($N_{60} > 300$) by 6,944. A detailed analysis of the noise re-distribution, along with noise data on a town/city basis, is available in Appendix E.

3. Recommendation – Waypoint Relocation

The waypoint relocation procedure has an aggregate noise benefit, addresses community requests and has no known operational barriers. Because it does result in noise redistribution, it will ultimately be up to the communities to determine if the redistribution is equitable and merits requested implementation of the procedure.

IV. Conclusion

This report presented the results of the second phase (Block 2) of an effort to identify opportunities to reduce noise through changes or amendments to PBN procedures at BOS conducted in support of a Memorandum of Understanding (MOU) between Massport and the FAA.

BLOCK 2 PROCEDURE RECOMMENDATIONS

Table 1. Block 2 Procedure Recommendations.

Proc. ID D = Departure A = Arrival	Procedure	Primary Benefits
APPROACH PROCEDURES		
2A-1	**Runway 22L** Implement a new overwater RNAV approach for Runway 22L that crosses the Nahant Causeway from the east to join a 4-mile final approach.	Arrival flight paths from the south and east moved overwater instead of overflying populated areas north/northeast of the airport.
2A-2	**Runway 4R** Maintain use of current ILS approach to Runway 4R.	The current straight-in approach was found to have the lowest net population exposure among all RNAV approach candidates evaluated.
DEPARTURE PROCEDURES		
2D-1	**Runway 22L/R** Modify the current RNAV SID with a speed restriction to enable an earlier turn to the east, shifting aircraft tracks north away from Hull.	Departure flight paths moved north away from Hull.
2D-2	**Runway 33L** Modify the current RNAV SIDs to enable the start of flight track dispersion at the earliest point possible (1 NM from the end of the runway).	Increased dispersion of flight tracks and noise distribution.
2D-3	**Runway 27** Modify RNAV SIDs to begin flight track dispersion at the earliest point possible while satisfying the 1996 Environmental Record of Decision.	Increased dispersion of flight tracks and noise distribution; lower net population noise exposure.

Because some Block 2 procedures result in redistribution of noise between geographic areas, it will ultimately be the communities who will need to request the implementation of the procedures. This report attempts to document the noise impacts of the proposed Block 2 procedures to support this community decision process.

It should be noted that any Block 2 procedures put forward will be required to go through the formal FAA 7100.41 design process, where unanticipated issues may arise. During this process, procedures will be further evaluated for potential implementation barriers, a safety analysis will be conducted, and a flight check will be executed prior to procedure publication. In parallel to this process, the FAA will also conduct an environmental review of any requested procedure. Any procedure carrying significant effects (i.e. noise redistribution or increased noise footprint) will be subject to a full environmental review. Final procedure implementation will therefore be contingent on both a successful 7100.41 design process and a positive environmental review.

Appendix A: List of Peak Day Operation Days used for Noise Analysis

Days in the table below correspond to the peak day of operations for individual runways in 2017. Flight tracks from these days were used for analyses of aggregate noise impacts based on N_{60}.

Table 3. List of days used for noise analysis.

Runway / Type of Procedure	**Date**	**Number of large jet operations**
22L / Arrivals	October 24, 2017	431
4R / Arrivals	October 12, 2017	433
4L / Arrivals	October 12, 2017	54
33L / Departures	May 18, 2017	468
27 / Departures	September 18, 2017	341

Appendix B: Noise Analysis Method

Noise Analysis Tools

The analysis framework used to evaluate the noise impact of current and modified arrival and departure procedures is shown in Figure 54.

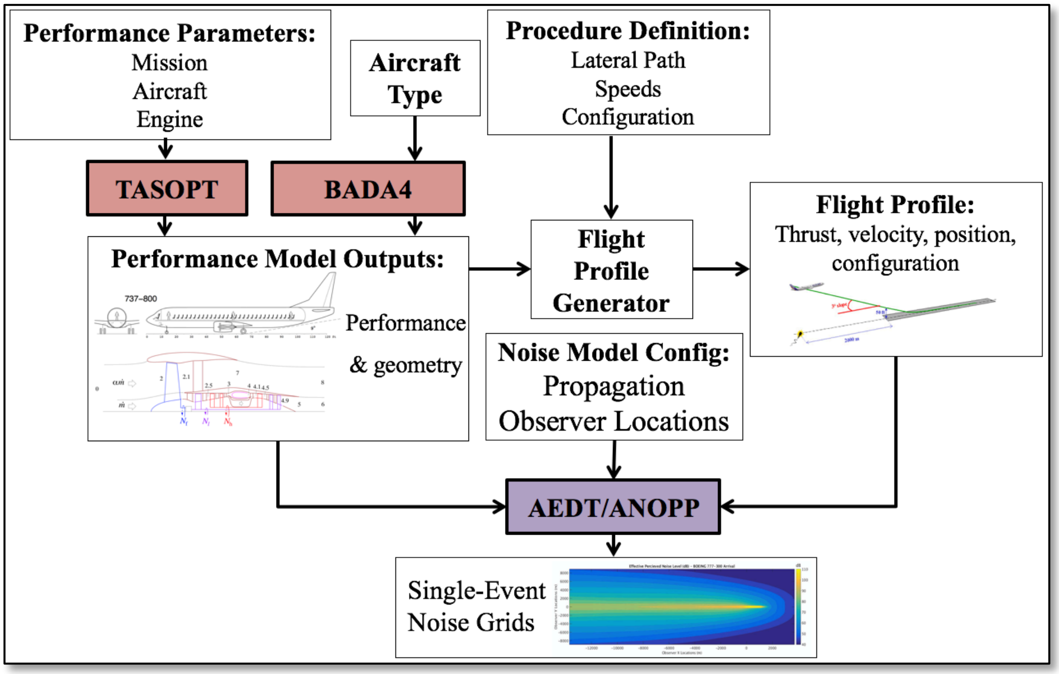


Figure 54. Integrated TASOPT and ANOPP analysis process to generate high fidelity approach and departure noise estimates

For procedures which involved only track modifications, the FAA Aviation Environmental Design Tool (AEDT) was used. AEDT uses Noise-Power-Distance (NPD) lookup tables derived from flight test and certification data and computes noise propagation through the atmosphere for a standard day. AEDT models noise referenced to a fixed airspeed (160 knot) and does not fully capture aerodynamic noise changes away from that speed.[14] For procedures which involved speed or configuration modifications, the NASA Aircraft Noise Prediction Program (ANOPP) was used. Although results from ANOPP analyses are not presented in this report, ANOPP was used in earlier stages of the project.

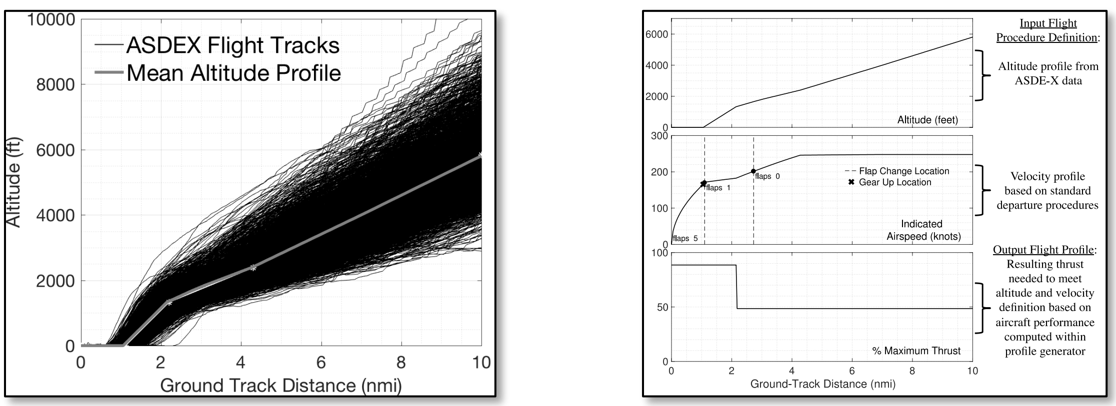
Both the AEDT and ANOPP noise models require aircraft performance models that provide thrust levels that are used for the noise computations. Aerodynamic drag data for each aircraft type in this study were obtained from the Eurocontrol Base of Aircraft Data (BADA-4), a database of aircraft performance parameters obtained from aircraft manufacturers.[16]

Outputs from both the AEDT and ANOPP noise models are single-event noise grids. These models calculate both maximum A-weighted sound pressure level ($L_{A,MAX}$) and the Sound Exposure Level (SEL) metrics. The grids used for AEDT results shown in this report were 30nm square grids with 0.25nm spacing. Results were then re-interpolated to 0.1nm spaced grids.

Flight Trajectory Inputs

The noise computed in both AEDT and ANOPP is dependent on the assumed flight profile, including position, altitude, airspeed and thrust. In order to obtain the flight profile data used for this study, a kinematic force-balance calculation method was used. The method was used to calculate thrust and acceleration estimates using aircraft weight, drag data from BADA-4, and detailed trajectory definitions derived from historical radar data. Fuel burn results were also calculated using BADA-4[18].

Departure profiles (altitude, speed, and thrust) were generated using two methods. The first method used historical radar data from the Airport Surface Detection Equipment Model X (ASDE-X) system to identify mean altitude profiles for each aircraft type. Standard acceleration profiles were assumed from liftoff to a baseline target speed of 250 kts. Thrust levels were calculated assuming a weight of 90% MTOW using the kinematic force-balance method described above. Flap settings were configured according to aircraft-specific speed ranges provided by BADA-4. This method was used to calculate profiles for recommendations 1-D2, 1-D3, and the baseline profile for 1-D1. Figure 55 shows results of this process for the Boeing 737-800. Figure 55(a) shows the distribution of ASDE-X altitude profiles for 20 days of Boeing 737-800 departures at BOS between January 1, 2016 and March 30, 2016. Figure 55(b) shows the velocity profile and resulting thrust profile associated with the median altitude profile from ASDE-X.



(a) (b)

Figure 55. (a) ASDE-X Boeing 737-800 altitude profiles over 20 days in 2015-2016 from all runways at BOS (b) Final profile generator output matching the mean altitude profile

The second method used to derive flight profiles was by defining desired thrust, configuration, and velocity and calculating the resulting altitude profile using the force-balance kinematic method described above. Desired thrust levels can be derived from historical data, maintained at a consistent baseline profile, or modified based on noise abatement objectives. This method was used to calculate modified speed profiles for recommendations 1-D1 and all profiles for 1-A1. Figure 56 shows an example output from this method when used for evaluating recommendation 1-D1 for the Boeing 737-800.

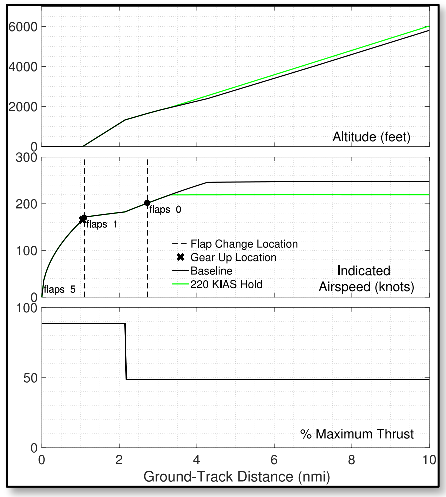


Figure 56. Flight profile generator output for a user-defined 220 kts reduced speed Boeing 737-800 departure profile compared to the standard departure profile derived from ASDE-X data

Population Exposure Calculations

In order to calculate population exposure at various noise levels, both noise results and demographic variables from the 2010 census data were re-gridded and compiled on a consistent 0.1nm square grid. Noise grids and population data were indexed and overlaid such that noise impact metrics can be calculated efficiently. Figure 57 shows an example of a re-gridded population map for the Boston area, allowing for computationally efficient noise impact evaluation in that area.

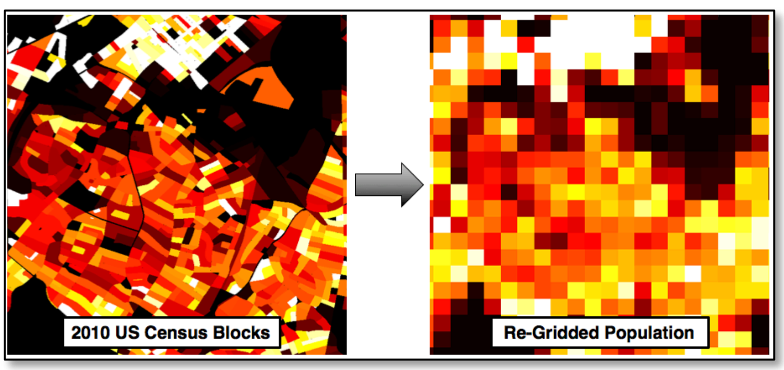


Figure 57. Re-gridded 2010 US Census data provide population data for noise impact calculations

The analysis region was a 60 NM square grid centered on Boston Logan Airport Reference Point.

Appendix C.1: 2-A1 Runway 22L Overwater RNAV Full Day Noise Dispersion Impacts

From a noise re-distribution standpoint, the effects of the Runway 22L recommended procedure operating for a full peak day can be visualized in the bar plots below in Figure 58. The top bar plot depicts the population per N_{60} bin for the current procedure. The middle bar plot depicts the population per N_{60} bin for the recommended procedure. Finally, the last bar plot depicts the change in the population within each N_{60} bin.

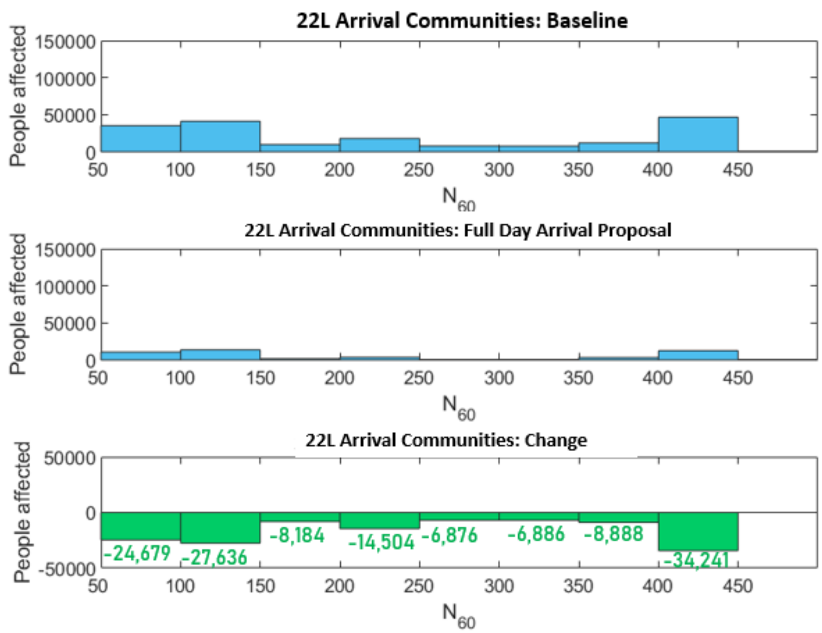


Figure 58. Bar plots showing the population counts in discrete bins of N60 for the current procedure (top) and the proposed procedure (middle). The bottom plot shows the change in population counts per N60 bin.

For each of the town/cities below, the top-left plot includes a map of the town/city for situational awareness, the bottom-left plot shows N_{60} levels with the current baseline procedure, the bottom-right plot shows N_{60} levels with the proposed procedure, and the top-right plot shows the total N_{60} change if the proposed procedure were to be implemented.

A. Beverly 2-A1 Runway 22L Full Day

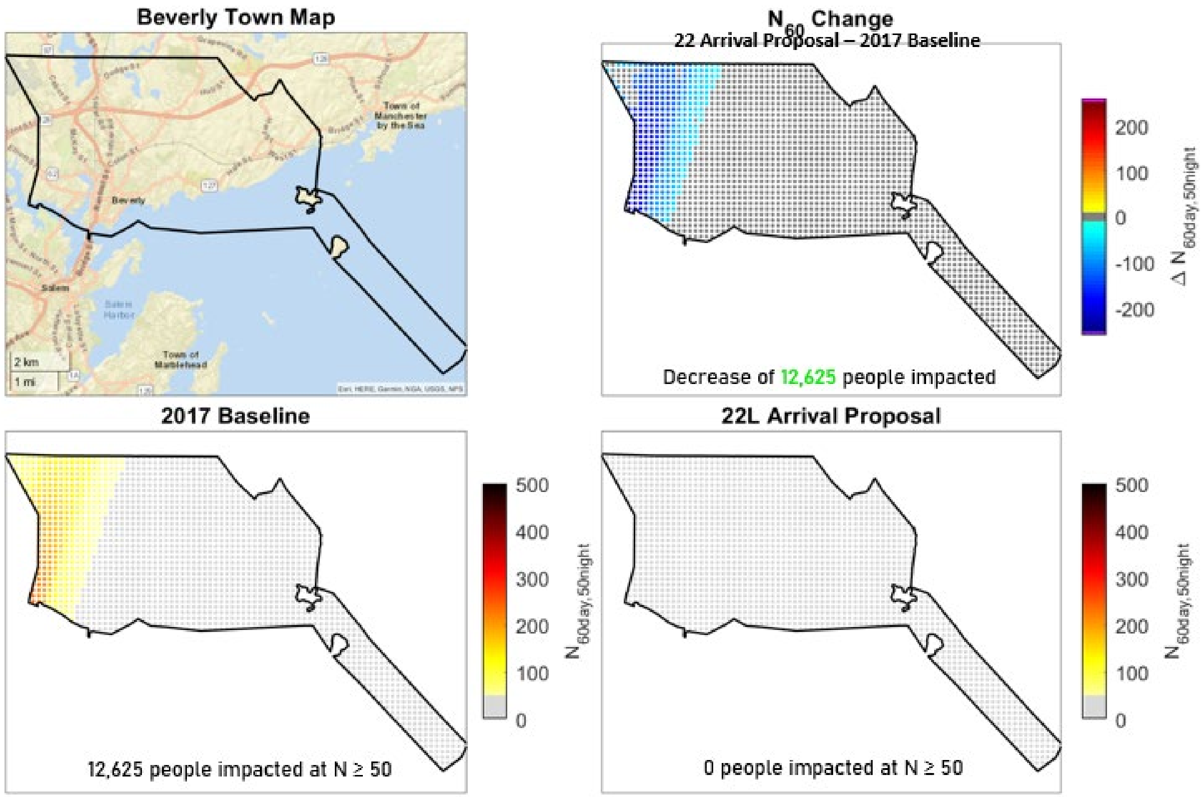


Figure 59. 2-A1 Runway 22L impact in Beverly if the proposed procedure were to be used on a full peak day.

B. Boston 2-A1 Runway 22L Full Day

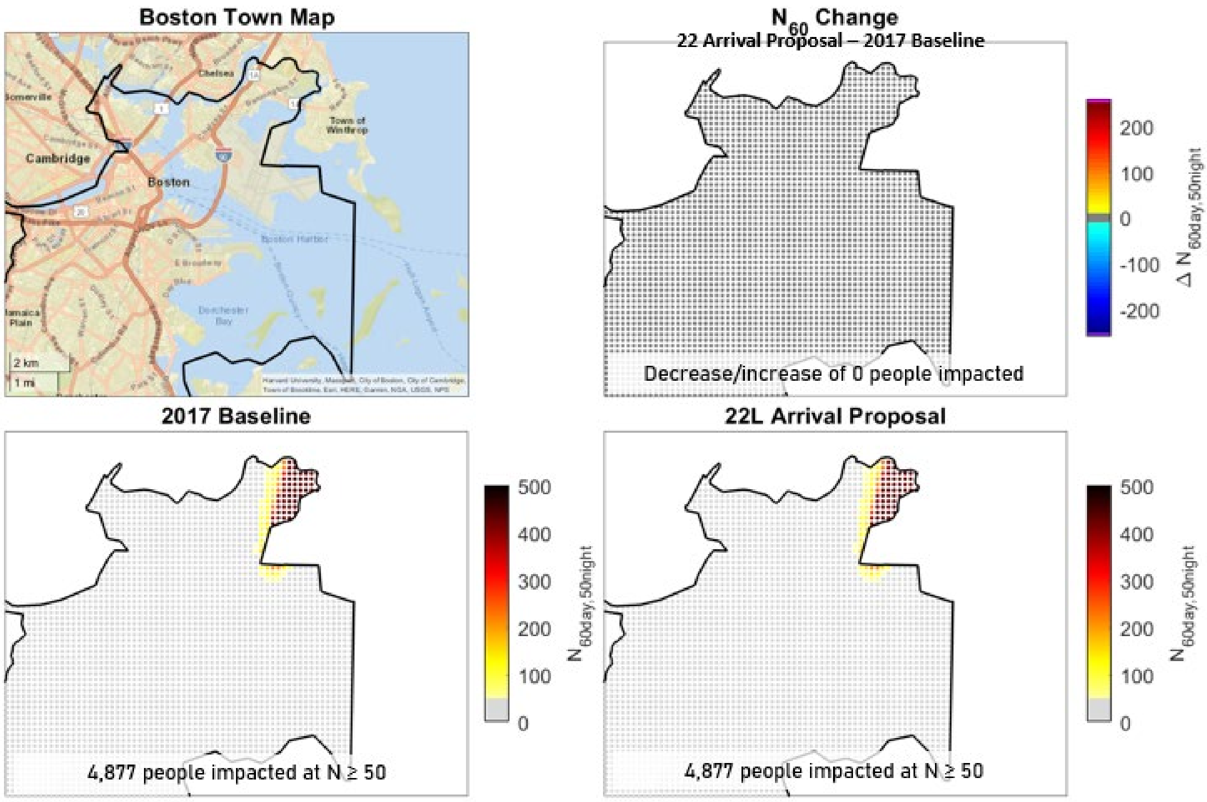


Figure 60. 2-A1 Runway 22L impact in Boston if the proposed procedure were to be used on a full peak day.

C. Danvers 2-A1 Runway 22L Full Day

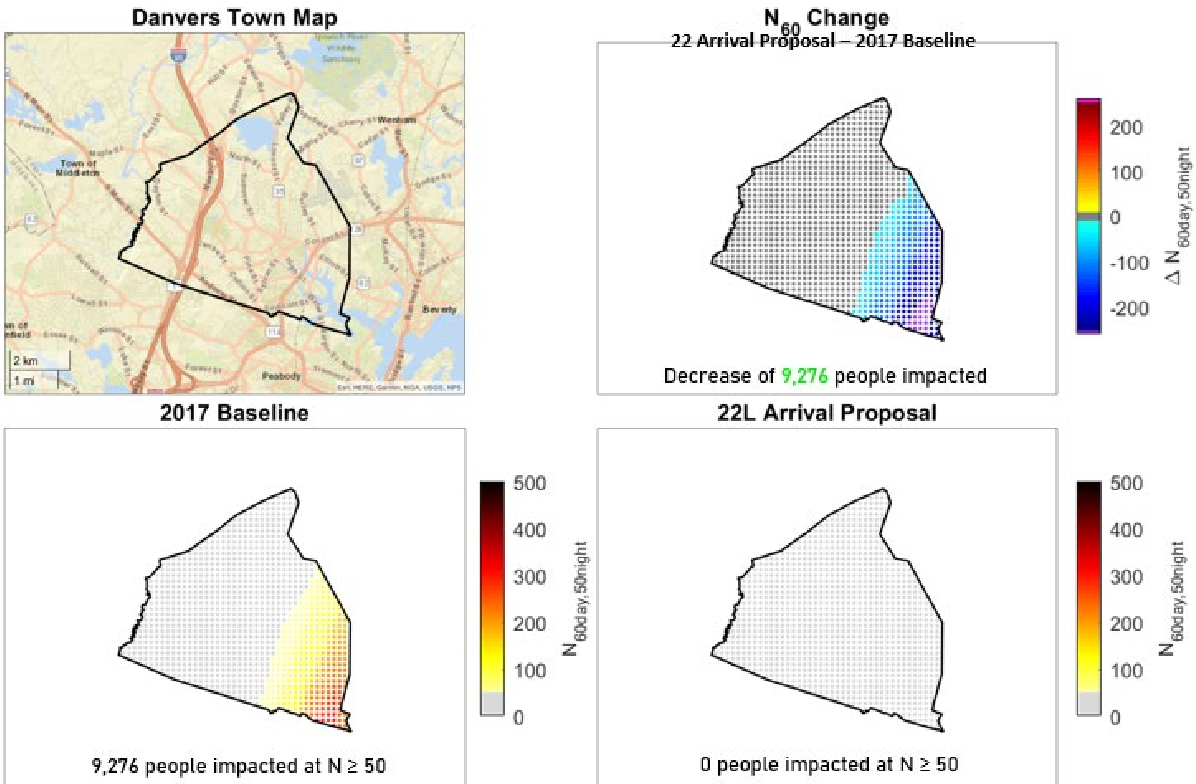


Figure 61. 2-A1 Runway 22L impact in Danvers if the proposed procedure were to be used on a full peak day.

D. Hamilton 2-A1 Runway 22L Full Day

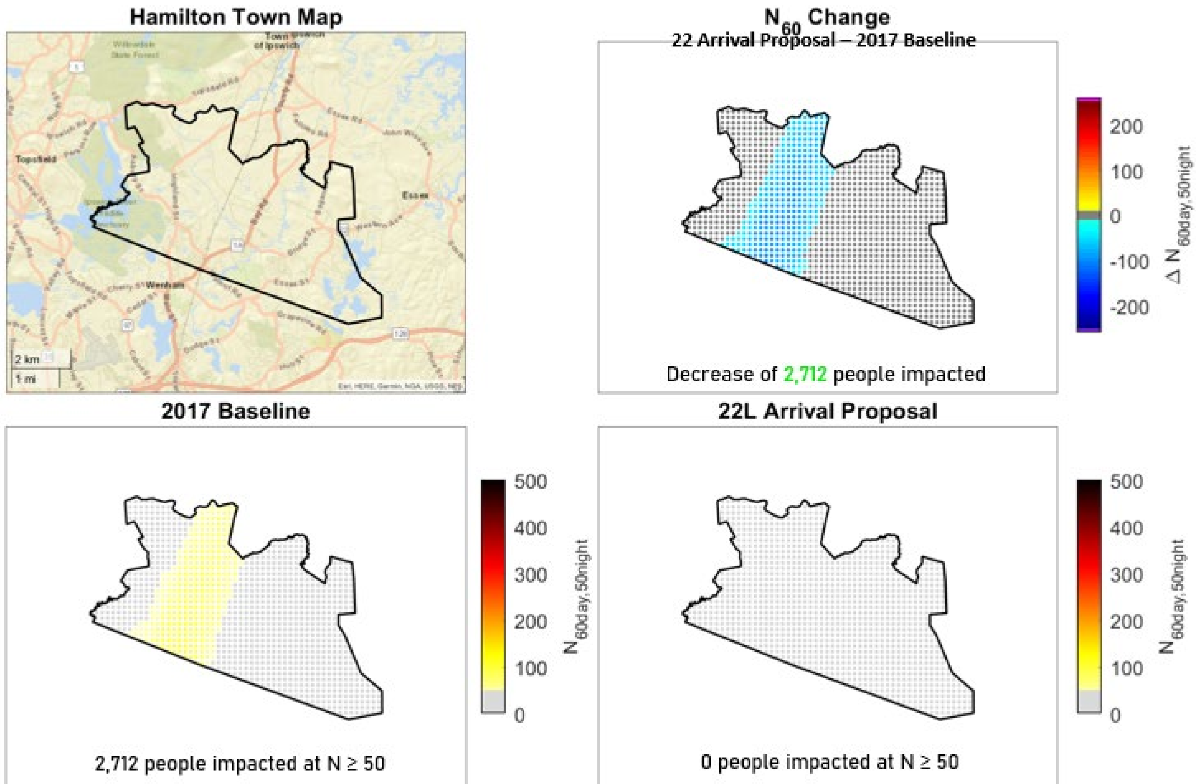


Figure 62. 2-A1 Runway 22L impact in Hamilton if the proposed procedure were to be used on a full peak day.

E. Ipswich 2-A1 Runway 22L Full Day

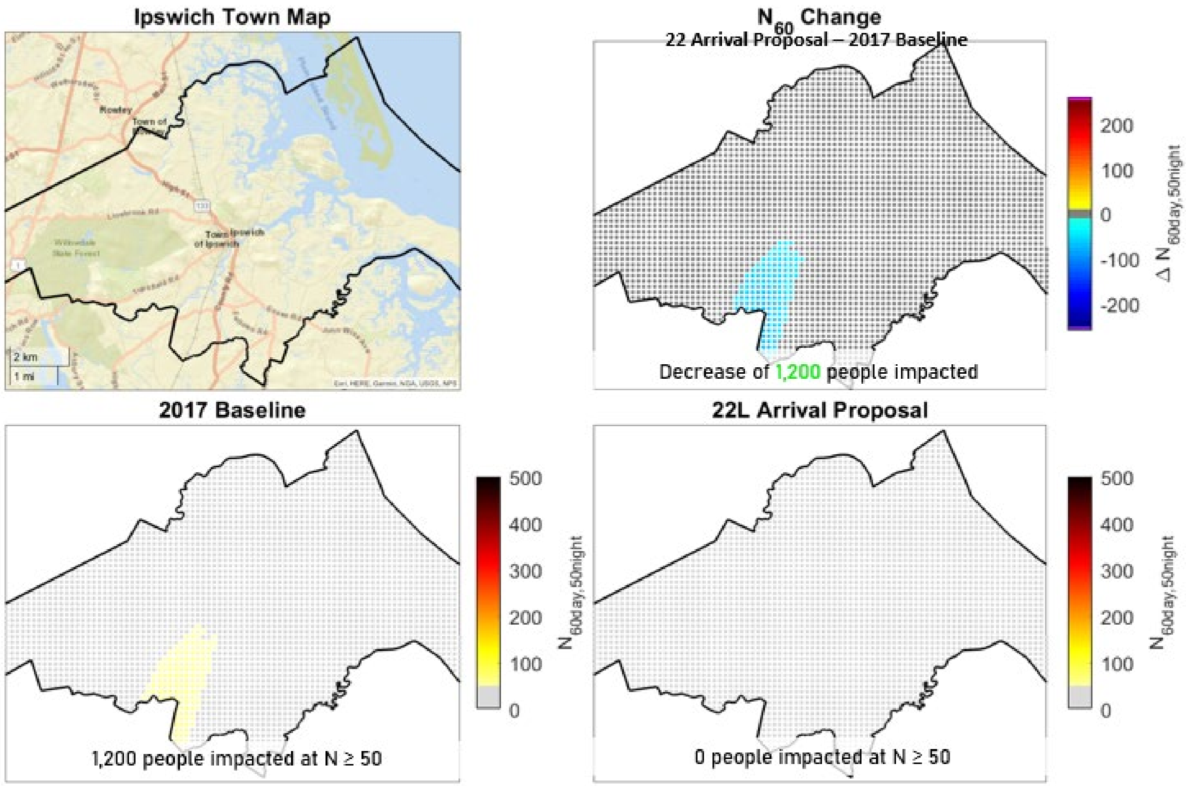


Figure 63. 2-A1 Runway 22L impact in Ipswich if the proposed procedure were to be used on a full peak day.

F. Lynn 2-A1 Runway 22L Full Day

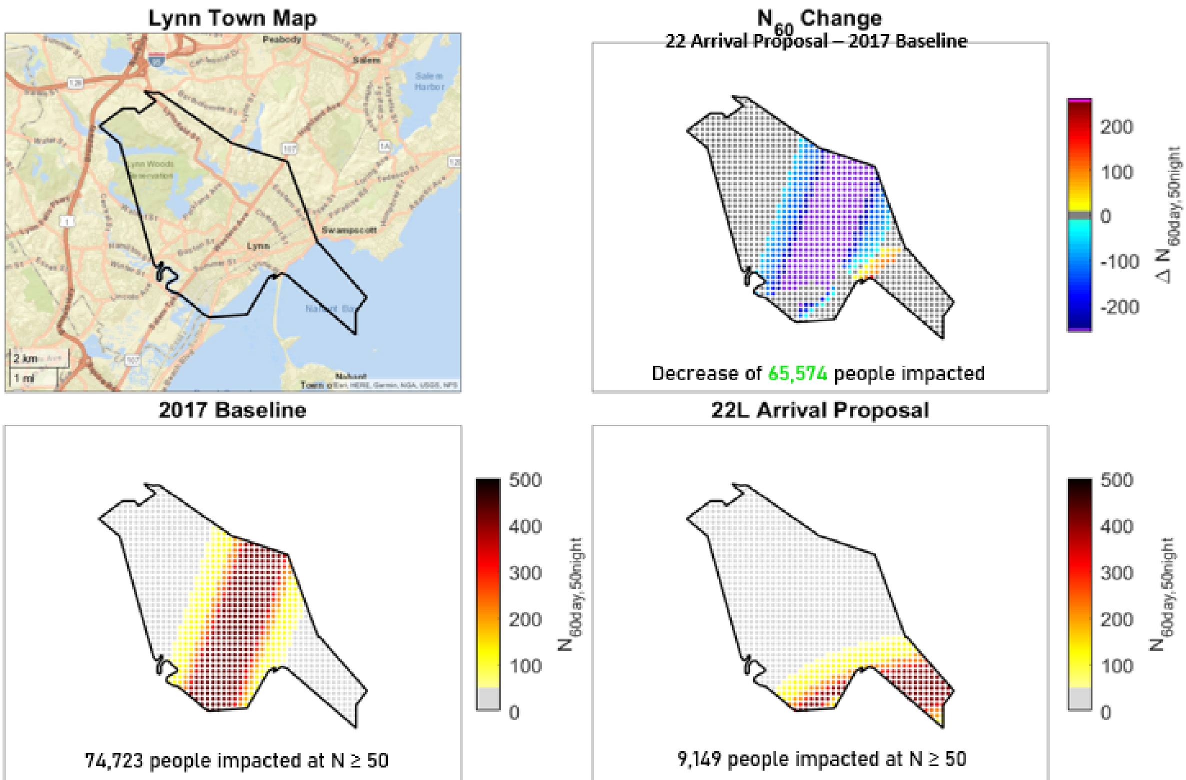


Figure 64. 2-A1 Runway 22L impact in Lynn if the proposed procedure were to be used on a full peak day.

G. Marblehead 2-A1 Runway 22L Full Day

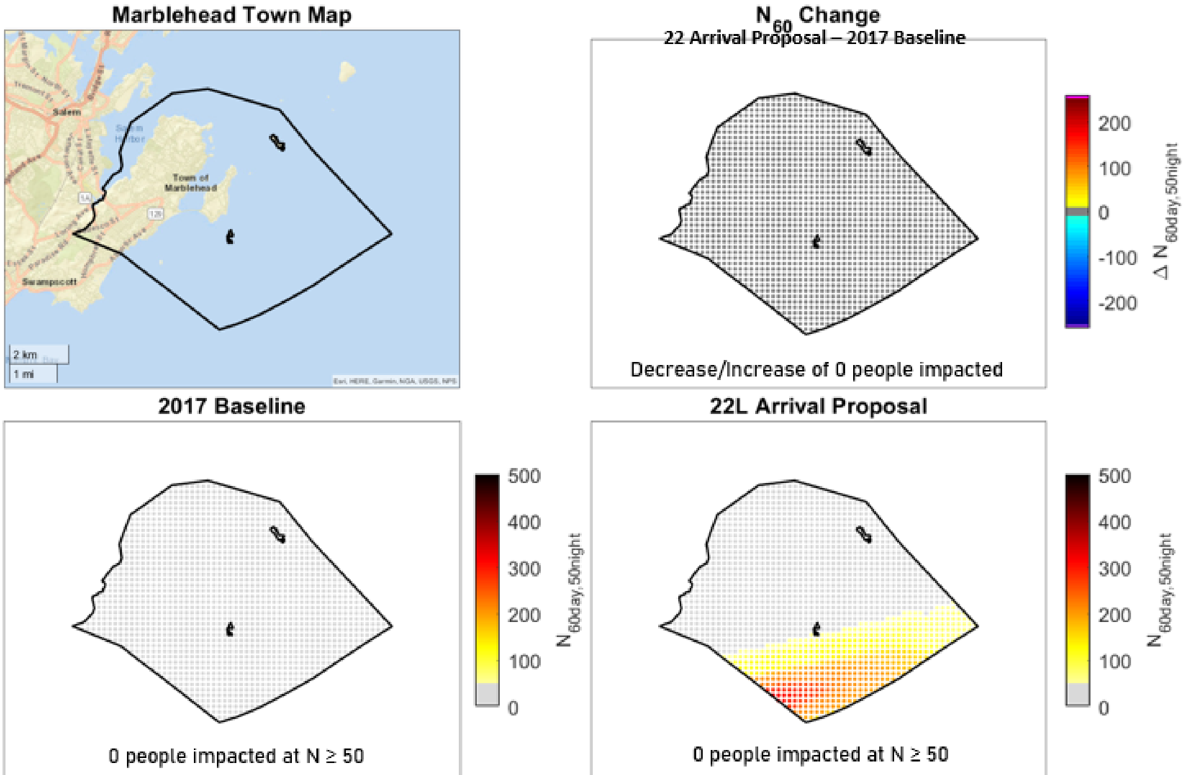


Figure 65. 2-A1 Runway 22L impact in Marblehead if the proposed procedure were to be used on a full peak day.

H. Middleton 2-A1 Runway 22L Full Day

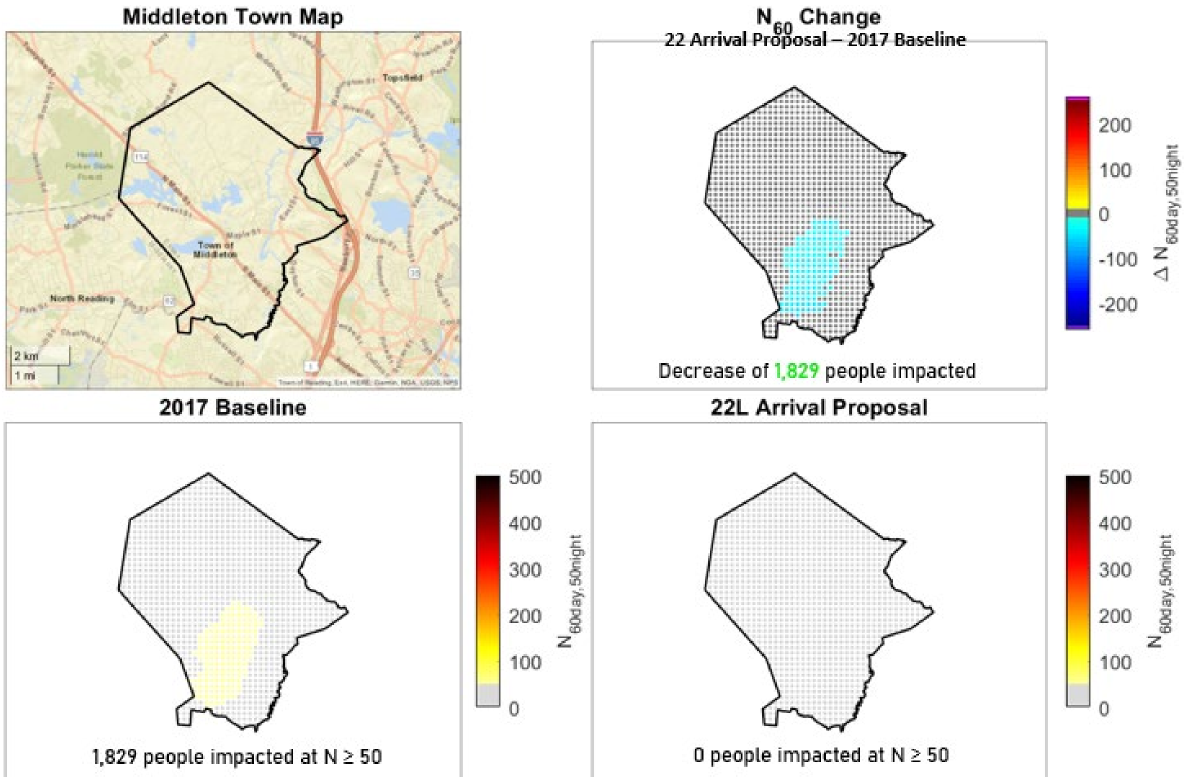


Figure 66. 2-A1 Runway 22L impact in Middleton if the proposed procedure were to be used on a full peak day.

I. Nahant 2-A1 Runway 22L Full Day

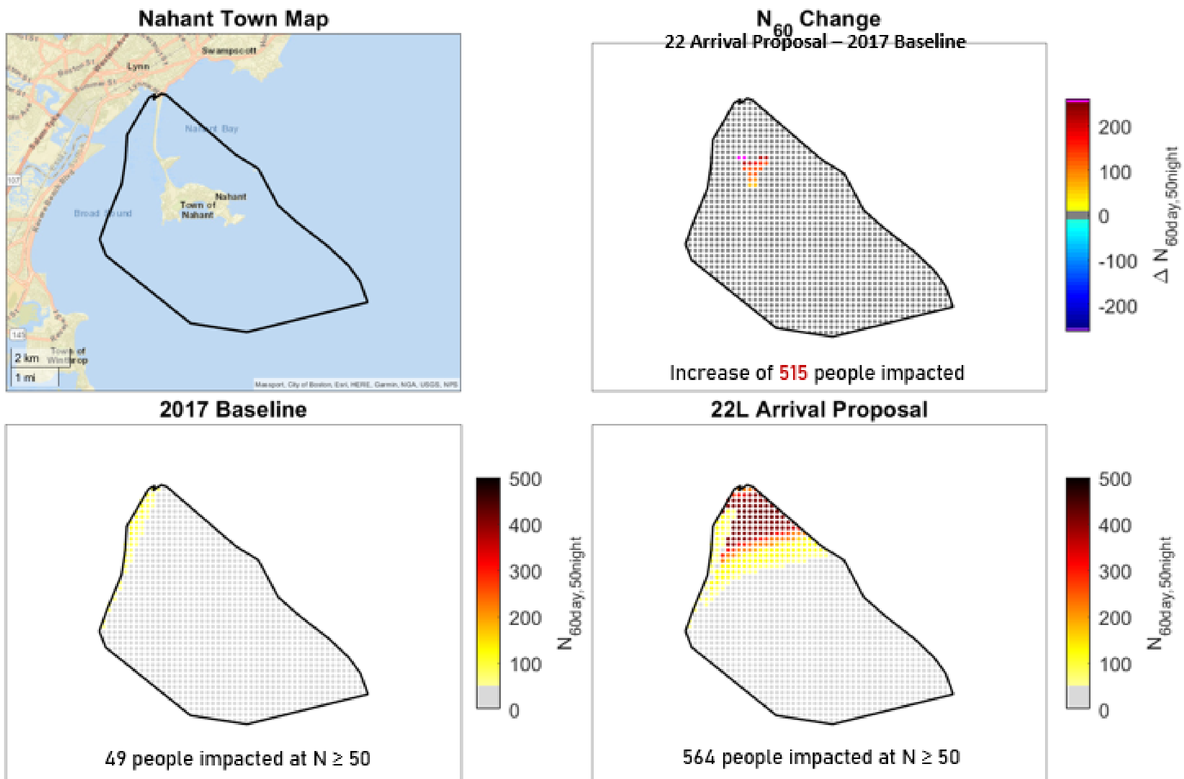


Figure 67. 2-A1 Runway 22L impact in Nahant if the proposed procedure were to be used on a full peak day.

J. Peabody 2-A1 Runway 22L Full Day

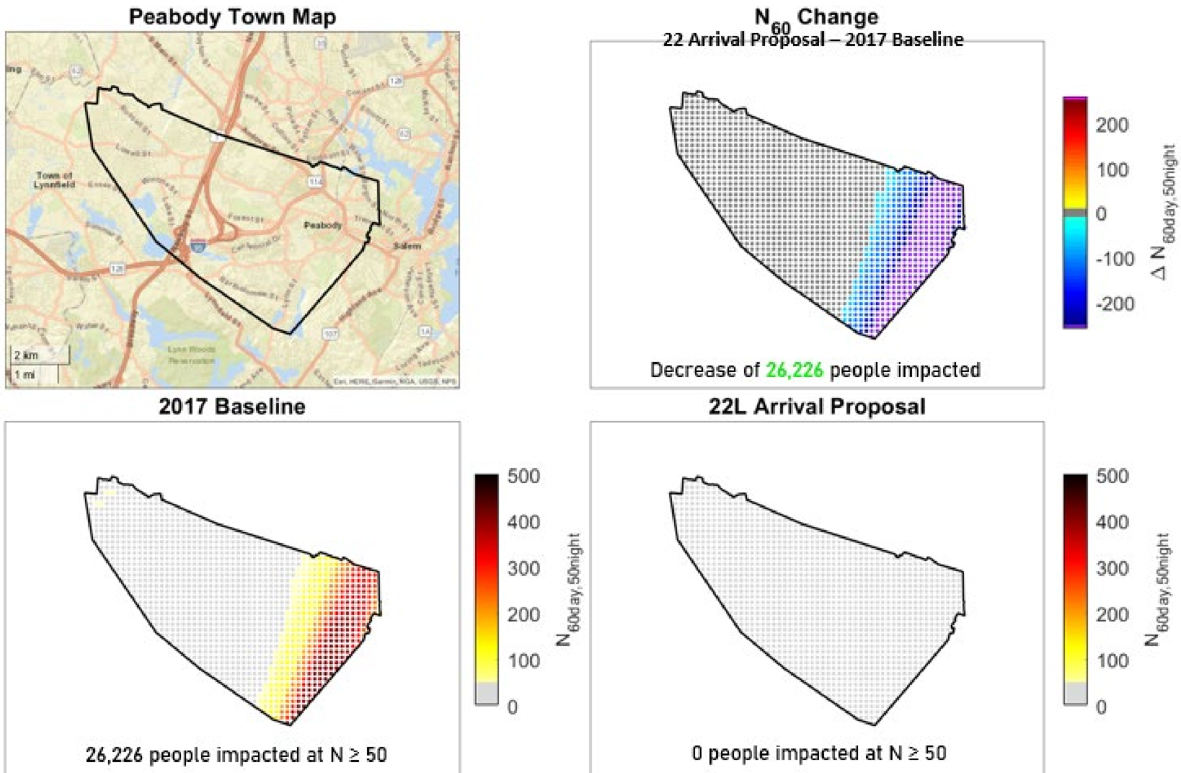


Figure 68. 2-A1 Runway 22L impact in Peabody if the proposed procedure were to be used on a full peak day.

K. Revere 2-A1 Runway 22L Full Day

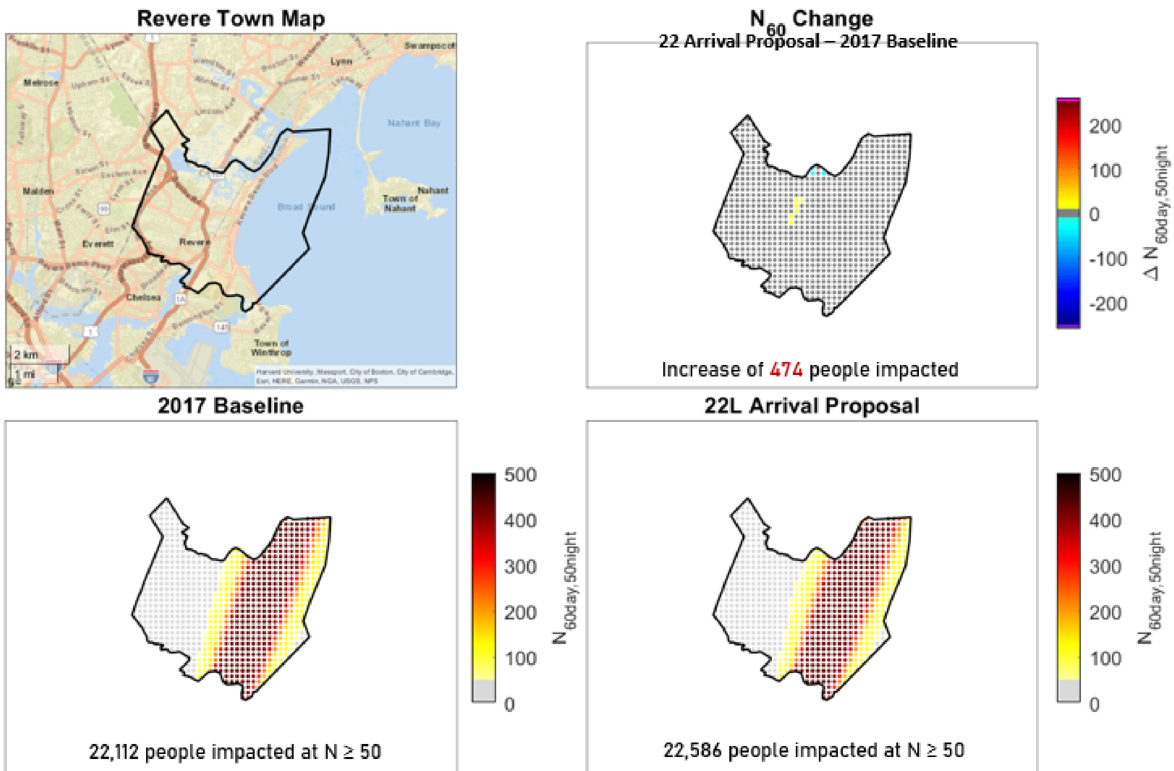


Figure 69. 2-A1 Runway 22L impact in Revere if the proposed procedure were to be used on a full peak day.

L. Salem 2-A1 Runway 22L Full Day

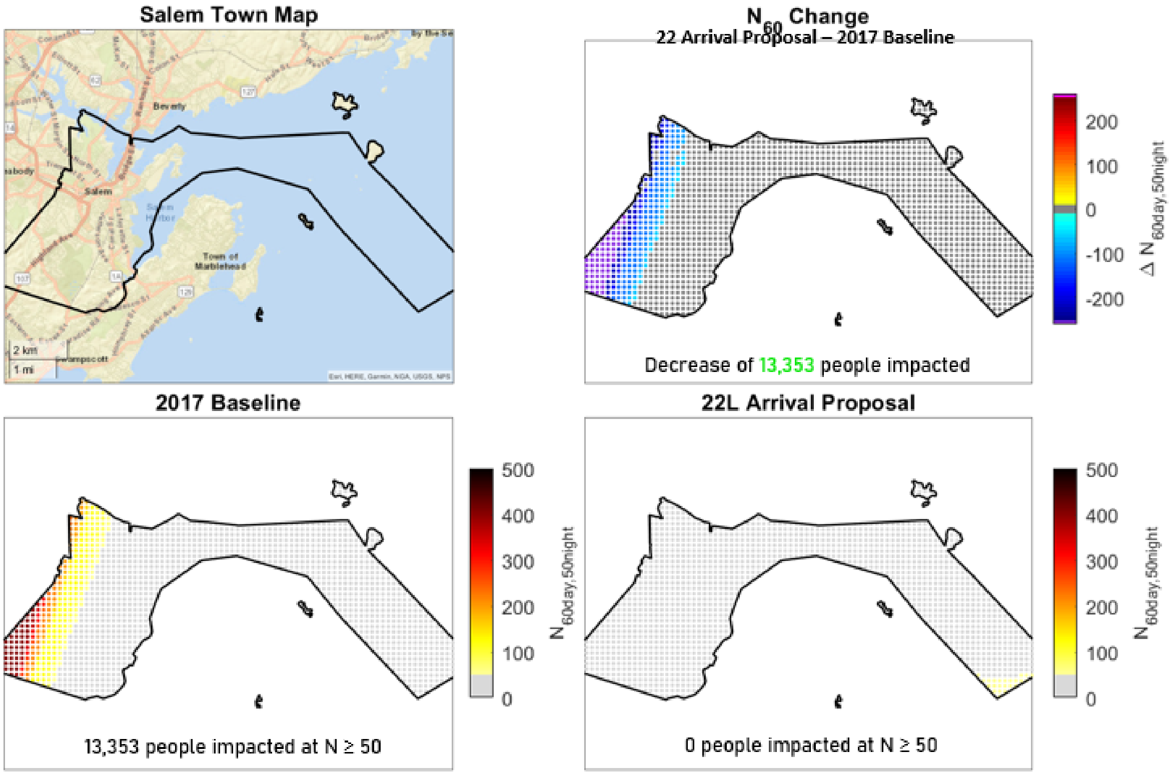


Figure 70. 2-A1 Runway 22L impact in Salem if the proposed procedure were to be used on a full peak day.

M. Saugus 2-A1 Runway 22L Full Day

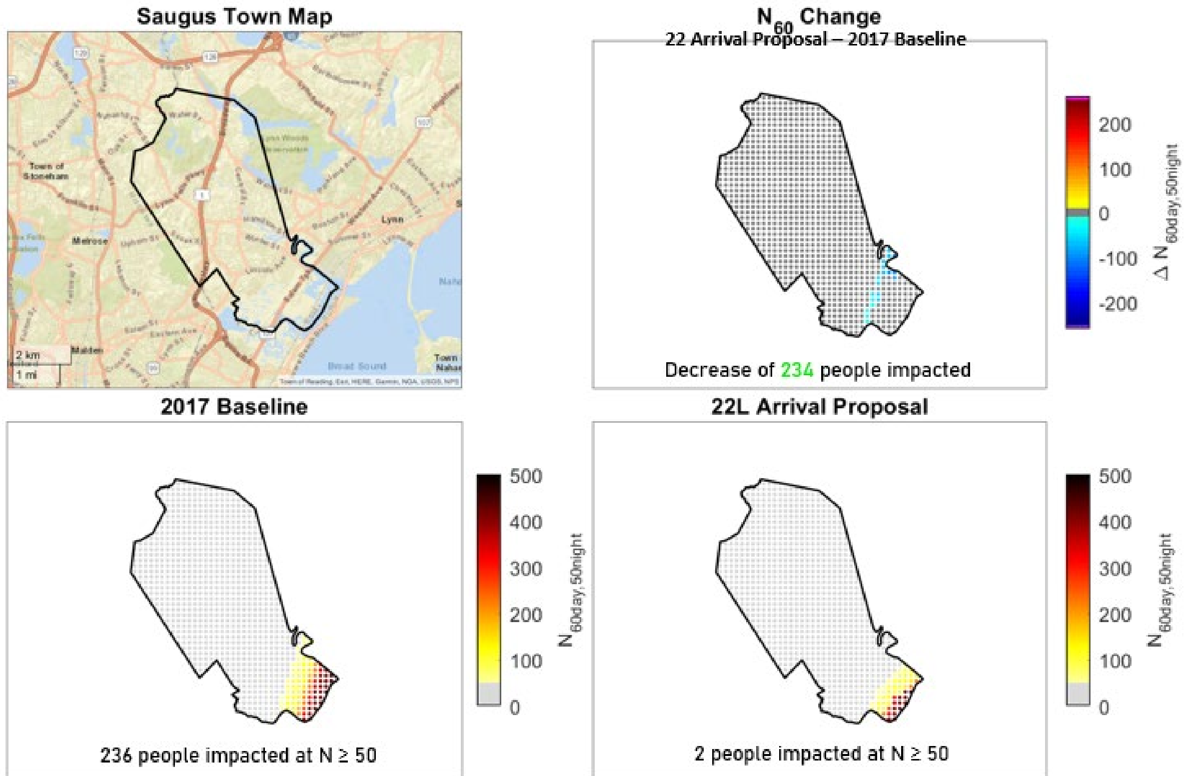


Figure 71. 2-A1 Runway 22L impact in Saugus if the proposed procedure were to be used on a full peak day.

N. Swampscott 2-A1 Runway 22L Full Day

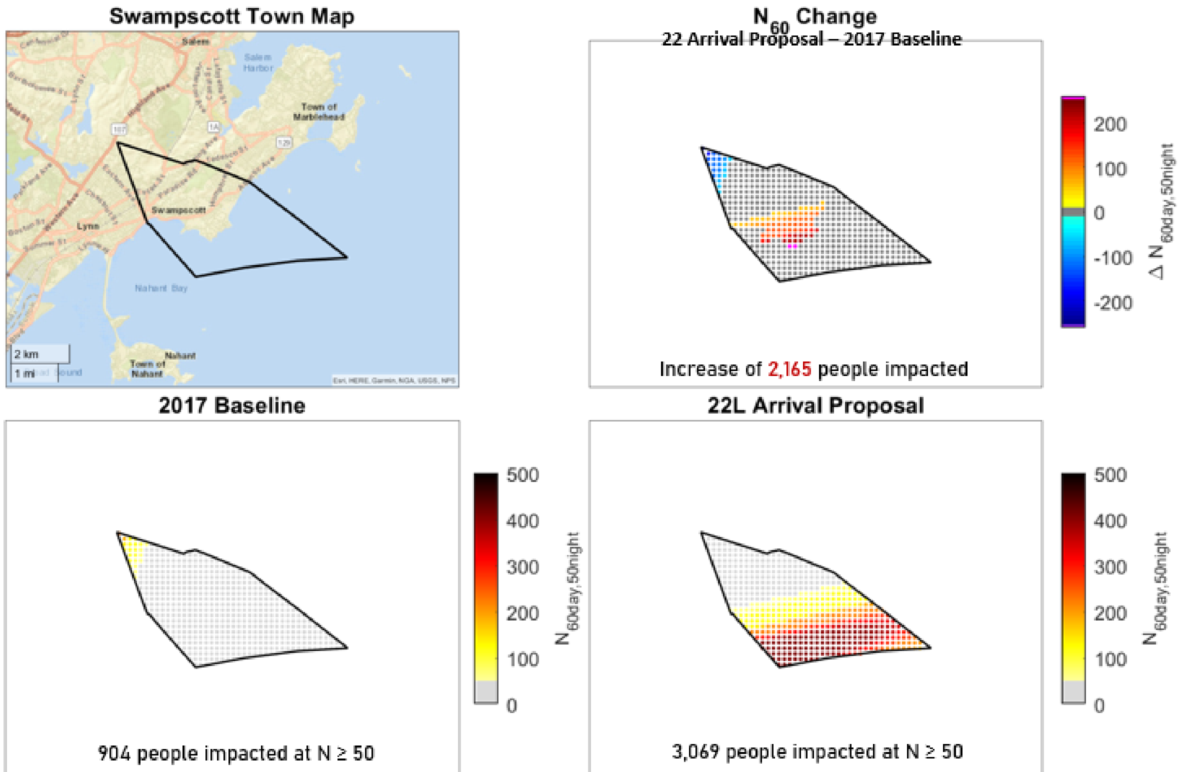


Figure 72. 2-A1 Runway 22L impact in Swampscott if the proposed procedure were to be used on a full peak day.

O. Wenham 2-A1 Runway 22L Full Day

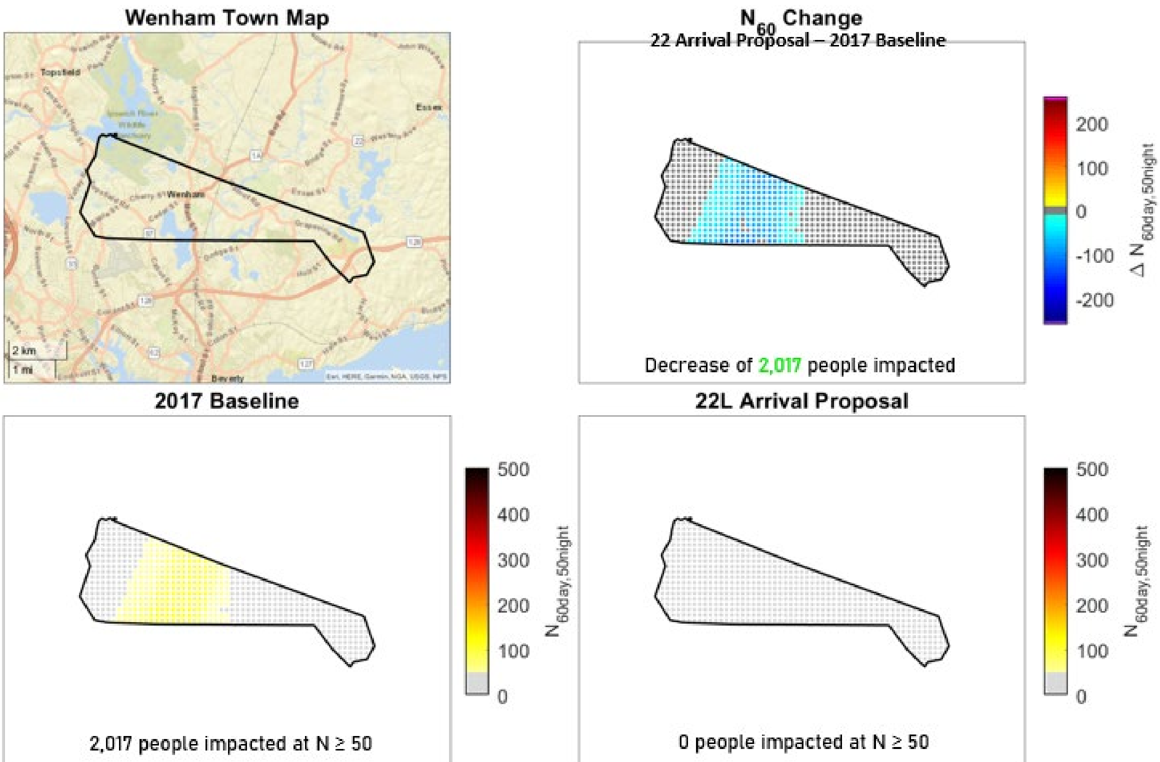


Figure 73. 2-A1 Runway 22L impact in Wenham if the proposed procedure were to be used on a full peak day.

P. Winthrop 2-A1 Runway 22L Full Day

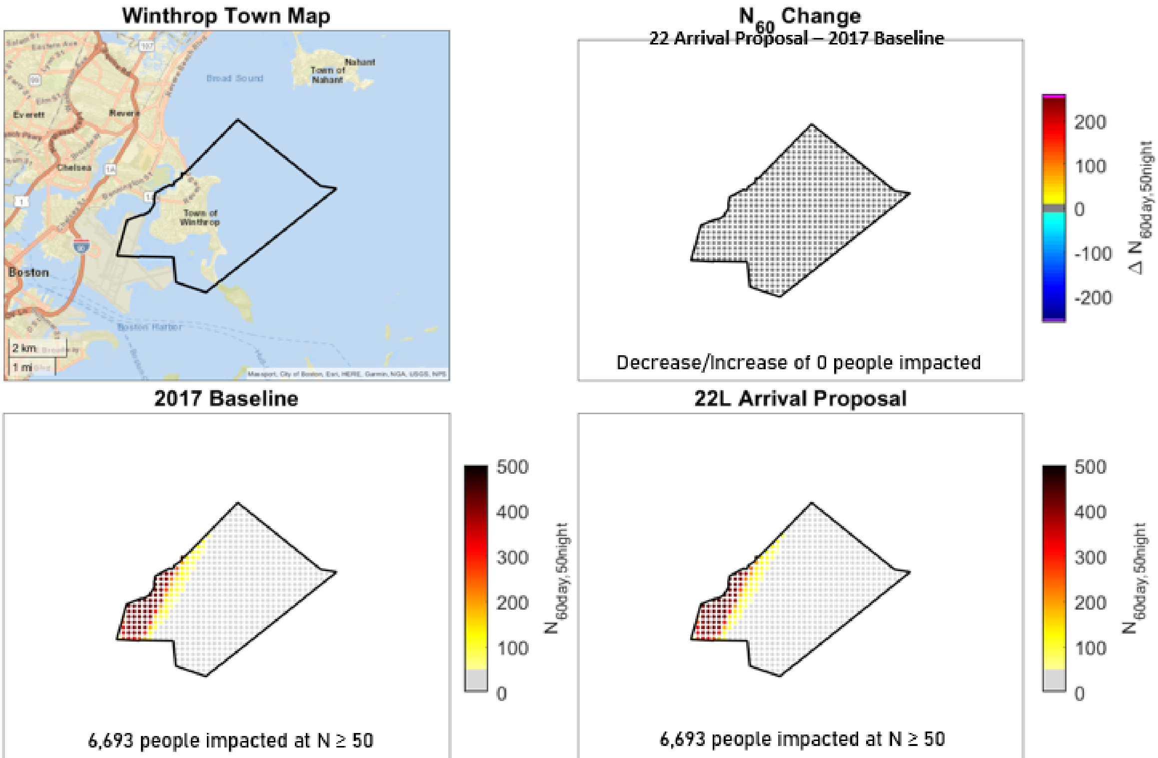


Figure 74. 2-A1 Runway 22L impact in Winthrop if the proposed procedure were to be used on a full peak day.

Appendix C.2: 2-A1 Runway 22L Overwater RNAV Daytime Use Only Noise Dispersion Impacts

From a noise re-distribution standpoint, the effects of the Runway 22L recommended procedure operating during a peak daytime (with the ILS used at night) can be visualized in the bar plots below in Figure 74. The top bar plot depicts the population per N_{60} bin for the current procedure. The middle bar plot depicts the population per N_{60} bin for the recommended procedure. Finally, the last bar plot depicts the change in the population within each N_{60} bin.

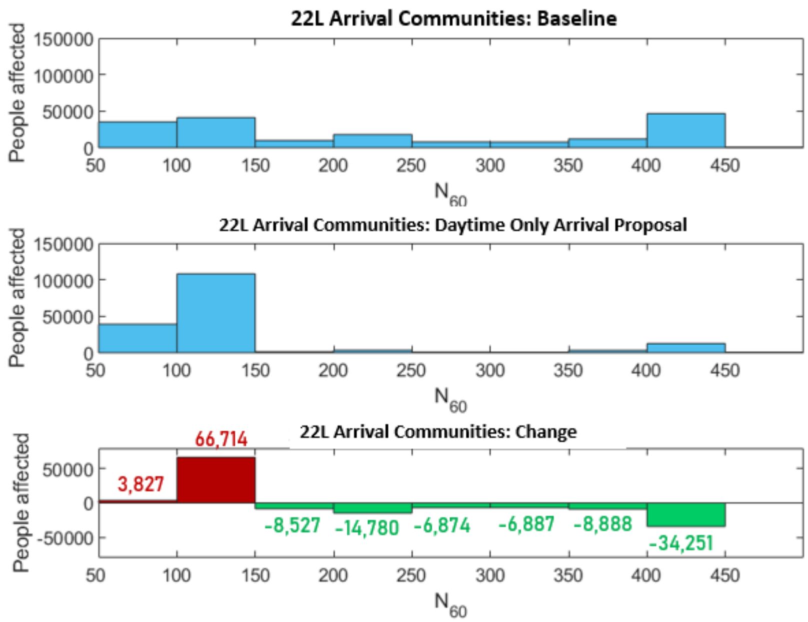


Figure 75. Bar plots showing the population counts in discrete bins of N60 for the current procedure (top) and the proposed procedure (middle). The bottom plot shows the change in population counts per N60 bin.

For each of the town/cities below, the top-left plot includes a map of the town/city for situational awareness, the bottom-left plot shows N_{60} levels with the current baseline procedure, the bottom-right plot shows N_{60} levels with the proposed procedure, and the top-right plot shows the total N_{60} change if the proposed procedure were to be implemented.

A. Beverly 2-A1 Runway 22L Daytime Use Only

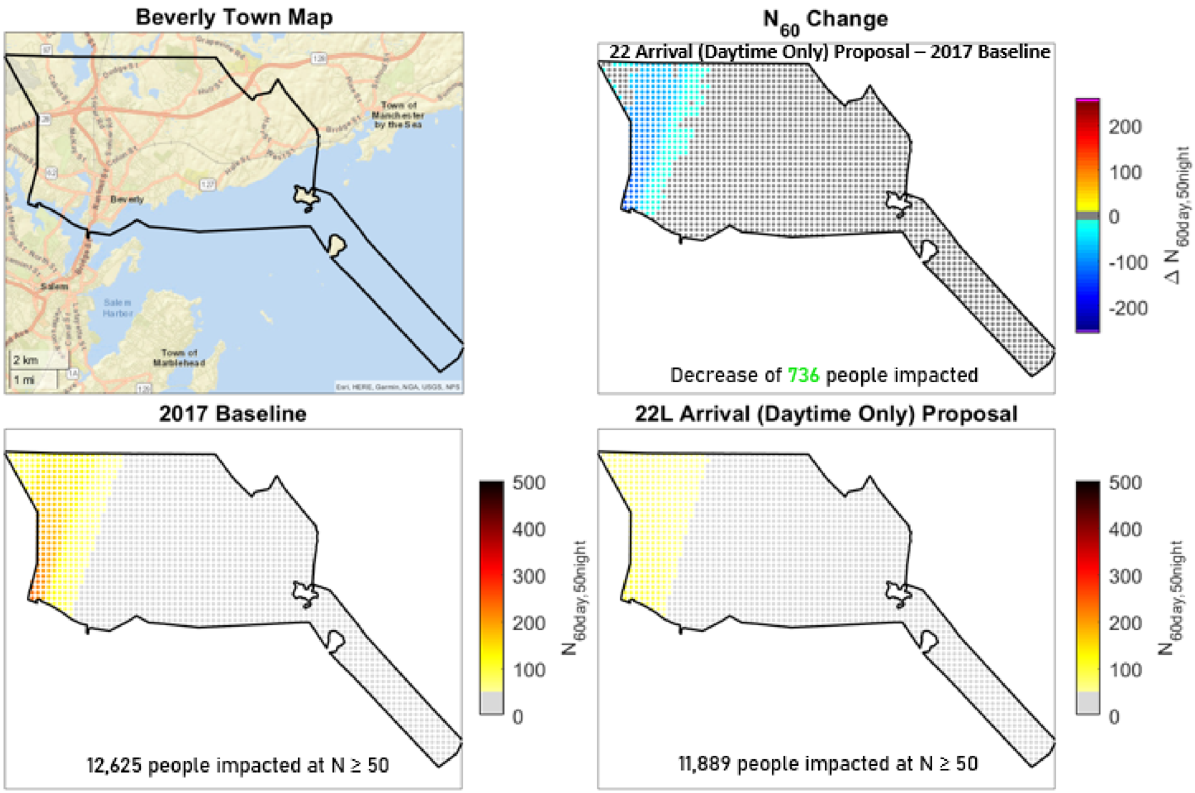


Figure 76. 2-A1 Runway 22L impact in Beverly if the proposed procedure were to be used on a peak day only during the daytime, with the ILS used at night.

B. Boston 2-A1 Runway 22L Daytime Use Only

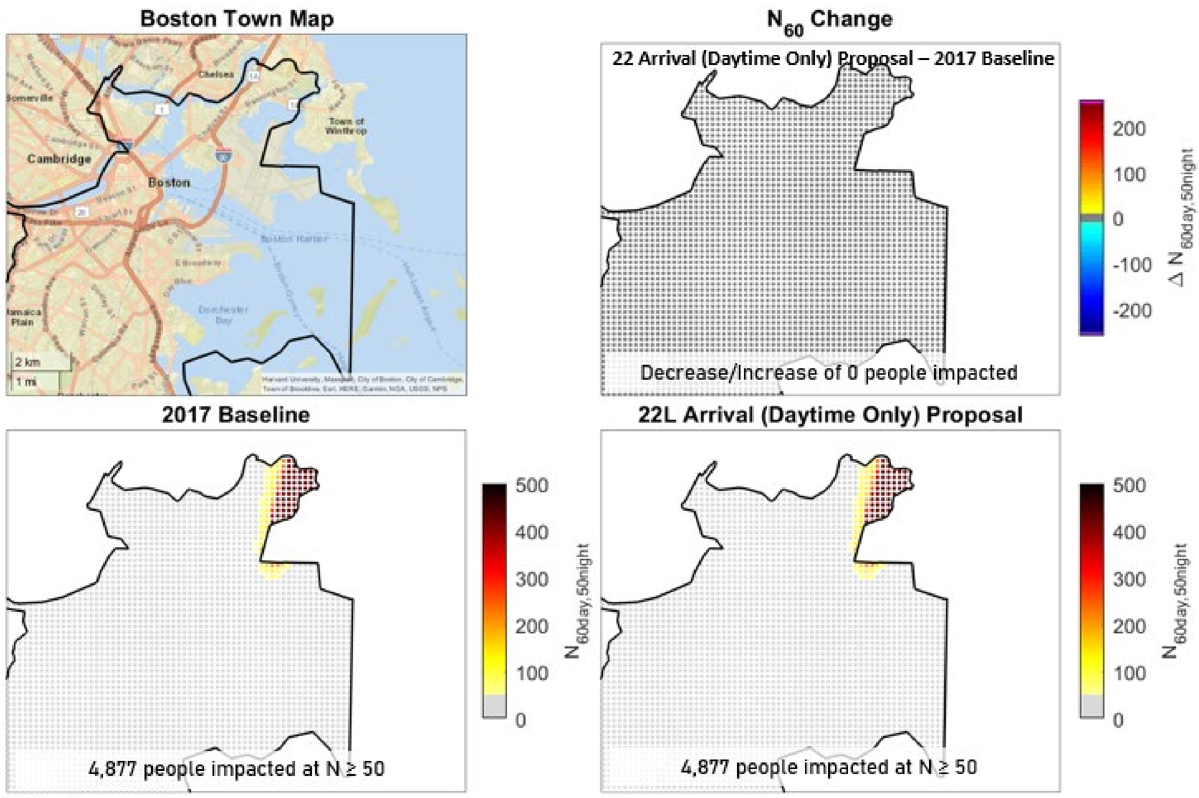


Figure 77. 2-A1 Runway 22L impact in Boston if the proposed procedure were to be used on a peak day only during the daytime, with the ILS used at night.

C. Danvers 2-A1 Runway 22L Daytime Use Only

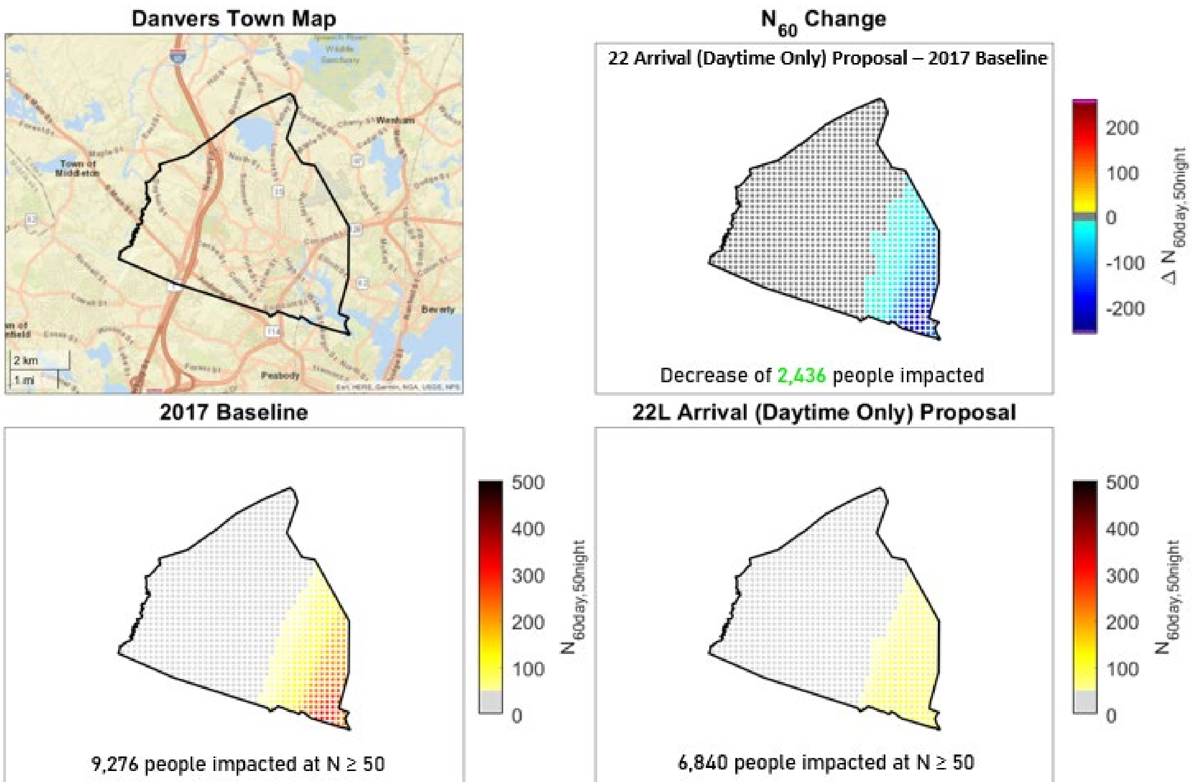


Figure 78. 2-A1 Runway 22L impact in Danvers if the proposed procedure were to be used on a peak day only during the daytime, with the ILS used at night.

D. Hamilton 2-A1 Runway 22L Daytime Use Only

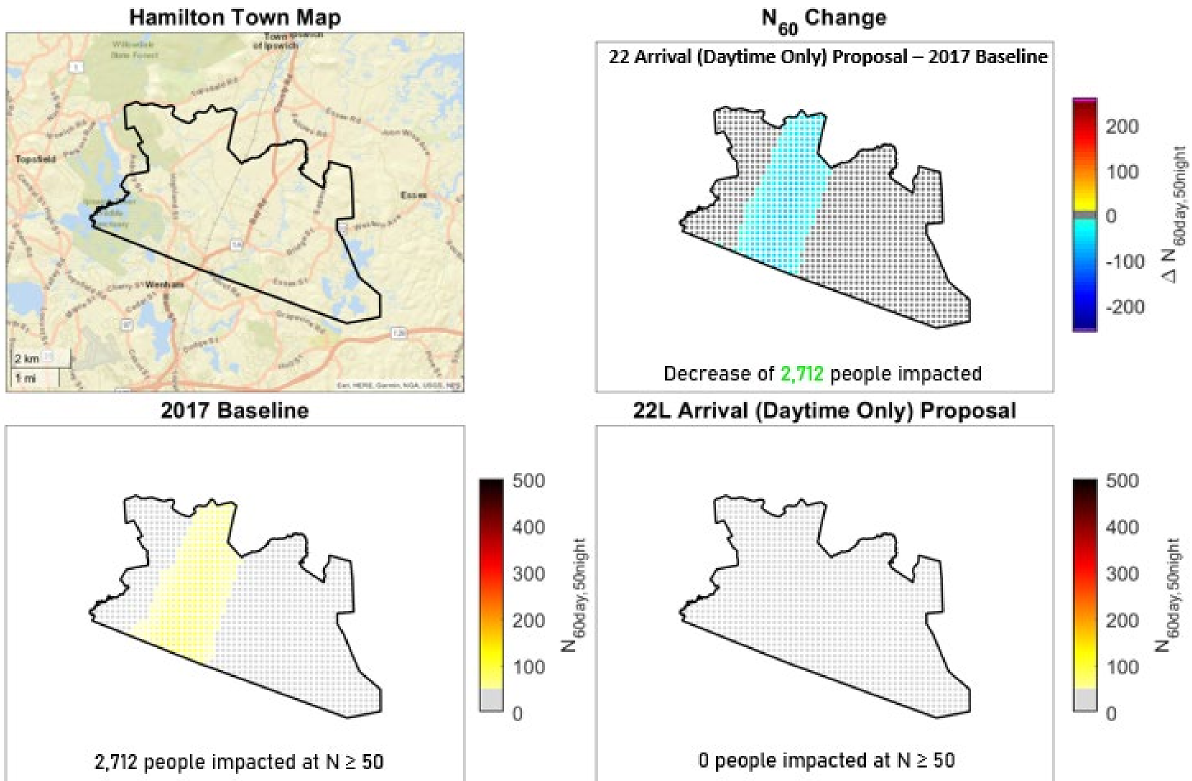


Figure 79. 2-A1 Runway 22L impact in Hamilton if the proposed procedure were to be used on a peak day only during the daytime, with the ILS used at night.

E. Ipswich 2-A1 Runway 22L Daytime Use Only

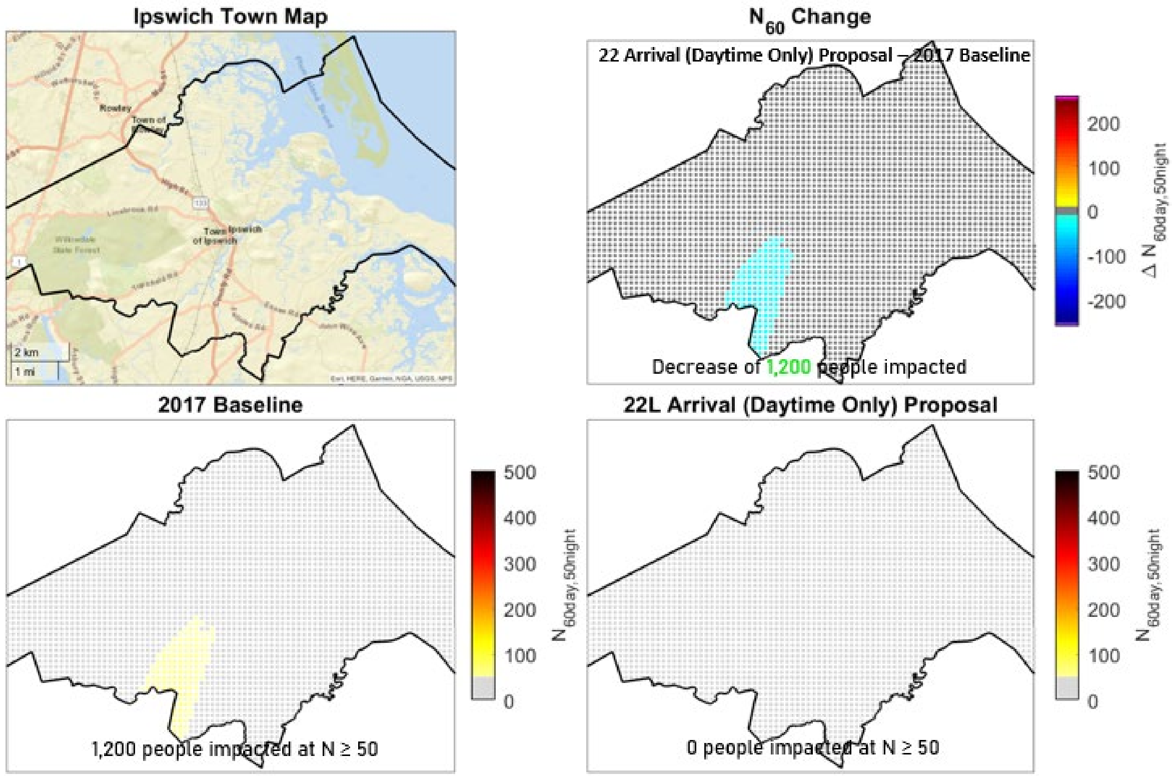


Figure 80. 2-A1 Runway 22L impact in Ipswich if the proposed procedure were to be used on a peak day only during the daytime, with the ILS used at night.

F. Lynn 2-A1 Runway 22L Daytime Use Only

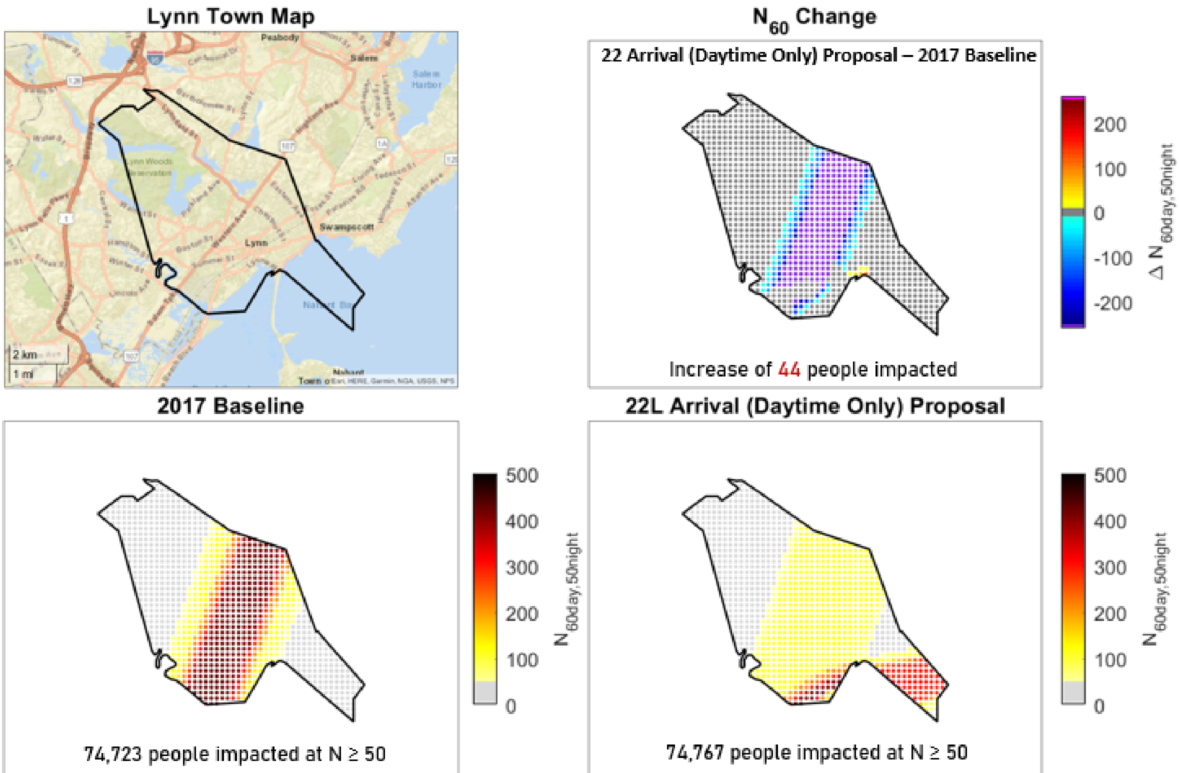


Figure 81. 2-A1 Runway 22L impact in Lynn if the proposed procedure were to be used on a peak day only during the daytime, with the ILS used at night.

G. Marblehead 2-A1 Runway 22L Daytime Use Only

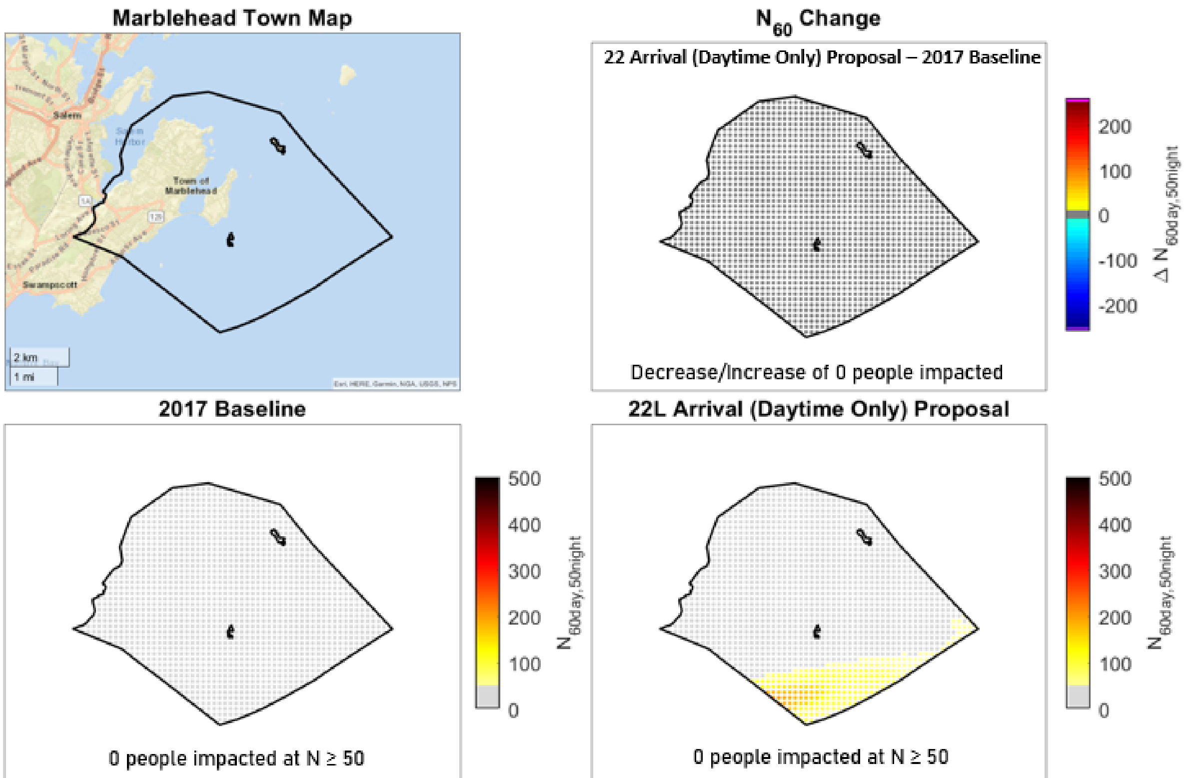


Figure 82. 2-A1 Runway 22L impact in Marblehead if the proposed procedure were to be used on a peak day only during the daytime, with the ILS used at night.

H. Middleton 2-A1 Runway 22L Daytime Use Only

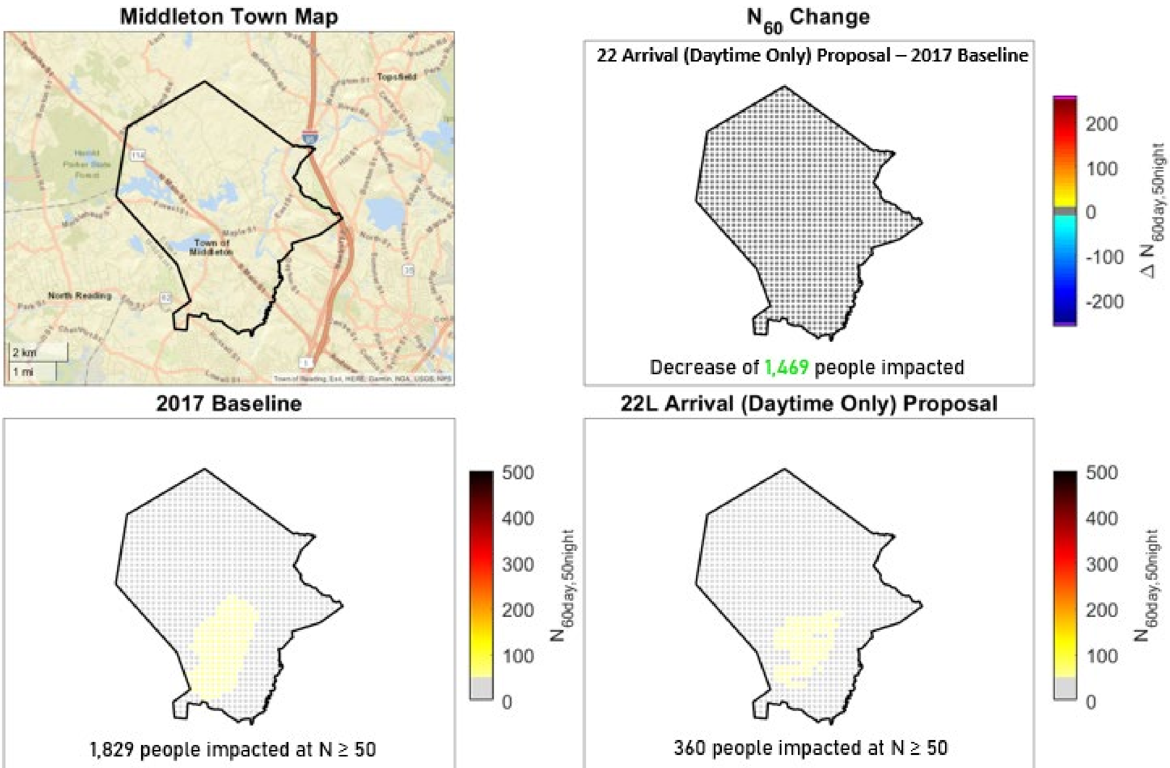


Figure 83. 2-A1 Runway 22L impact in Middleton if the proposed procedure were to be used on a peak day only during the daytime, with the ILS used at night.

I. Nahant 2-A1 Runway 22L Daytime Use Only

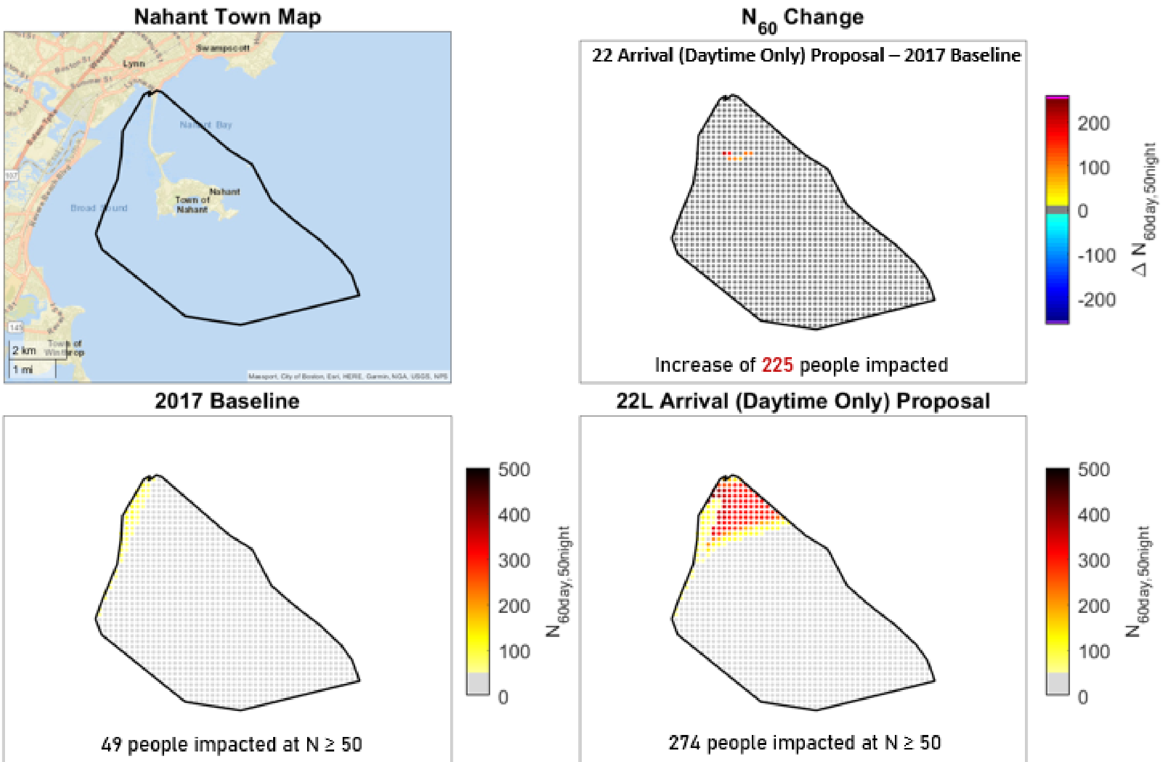


Figure 84. 2-A1 Runway 22L impact in Nahant if the proposed procedure were to be used on a peak day only during the daytime, with the ILS used at night.

J. Peabody 2-A1 Runway 22L Daytime Use Only

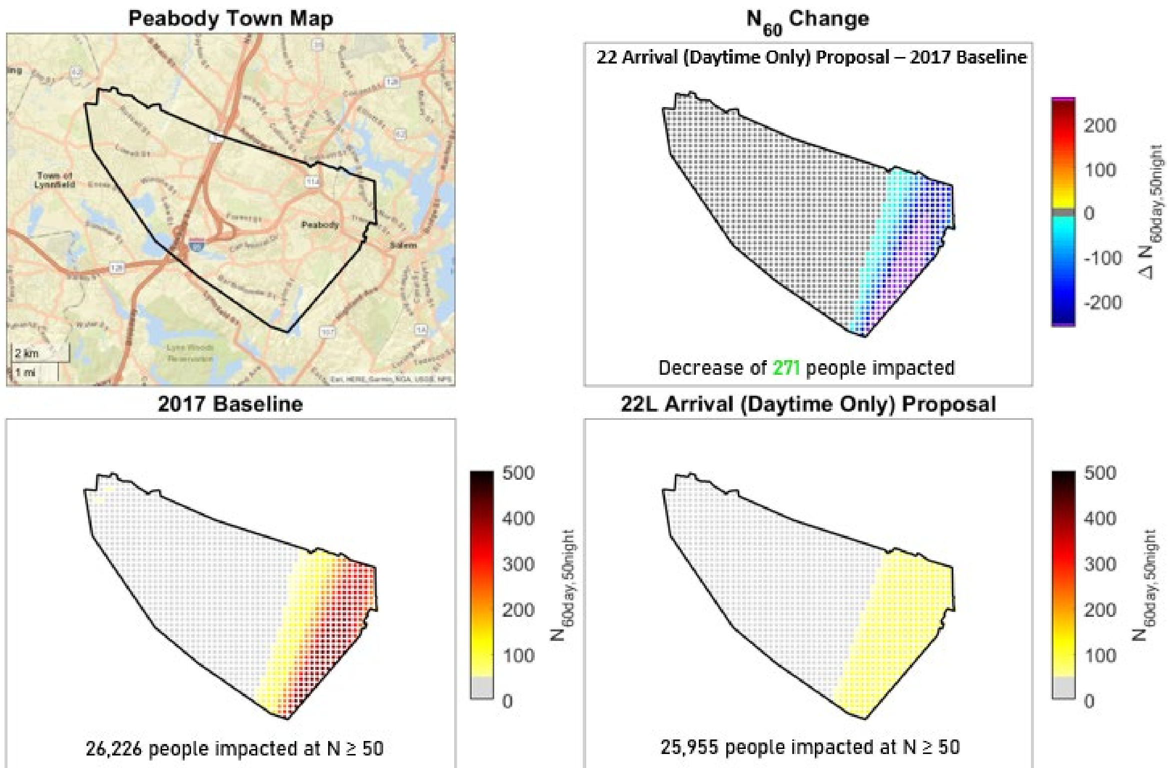


Figure 85. 2-A1 Runway 22L impact in Peabody if the proposed procedure were to be used on a peak day only during the daytime, with the ILS used at night.

K. Revere 2-A1 Runway 22L Daytime Use Only

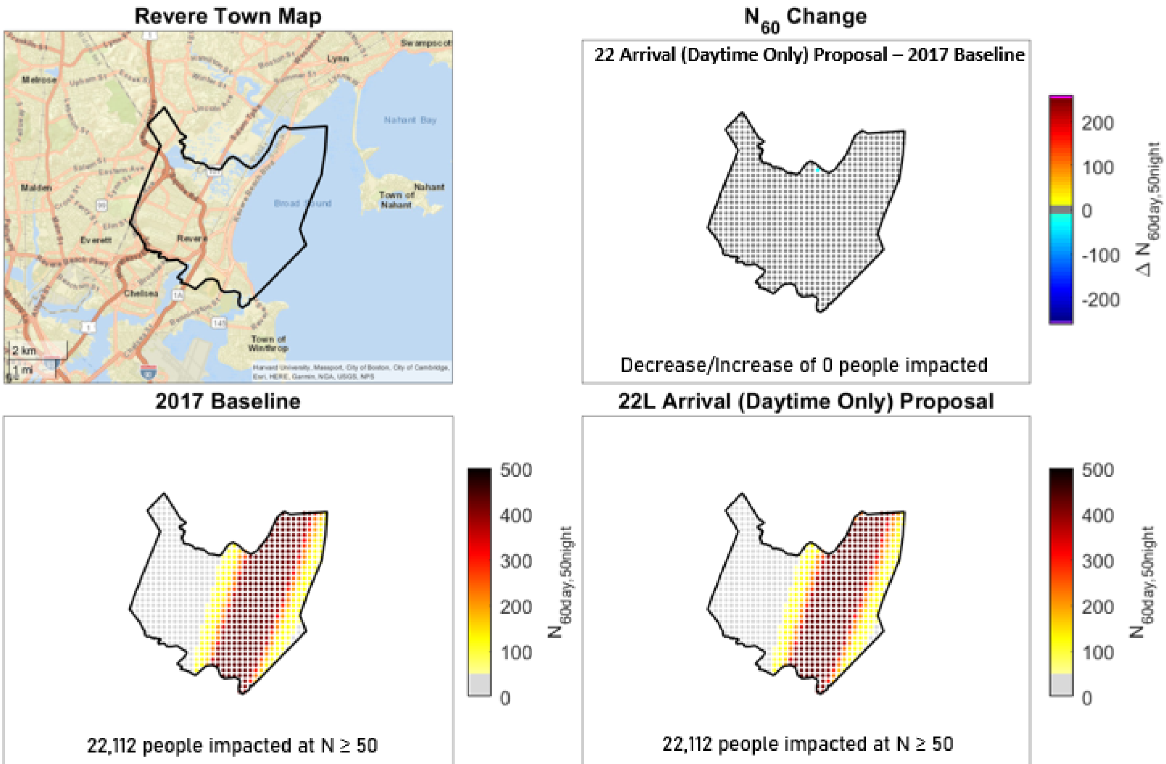


Figure 86. 2-A1 Runway 22L impact in Revere if the proposed procedure were to be used on a peak day only during the daytime, with the ILS used at night.

L. Salem 2-A1 Runway 22L Daytime Use Only

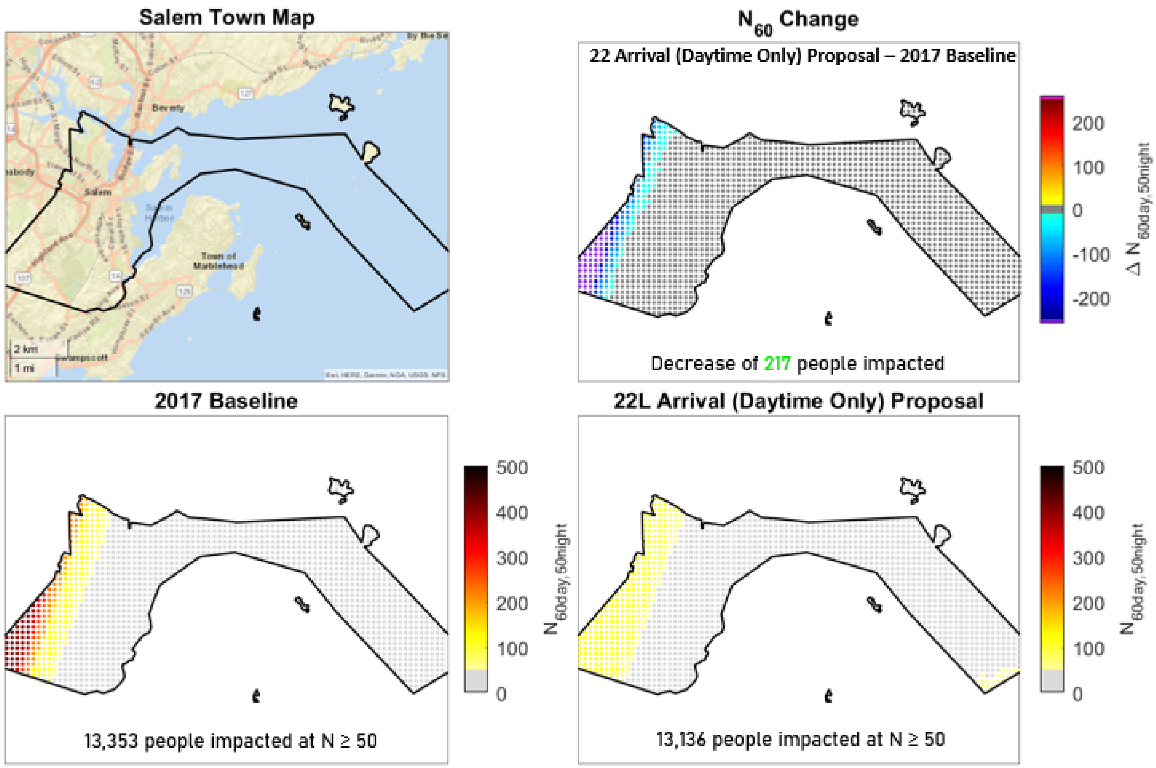


Figure 87. 2-A1 Runway 22L impact in Salem if the proposed procedure were to be used on a peak day only during the daytime, with the ILS used at night.

M. Saugus 2-A1 Runway 22L Daytime Use Only

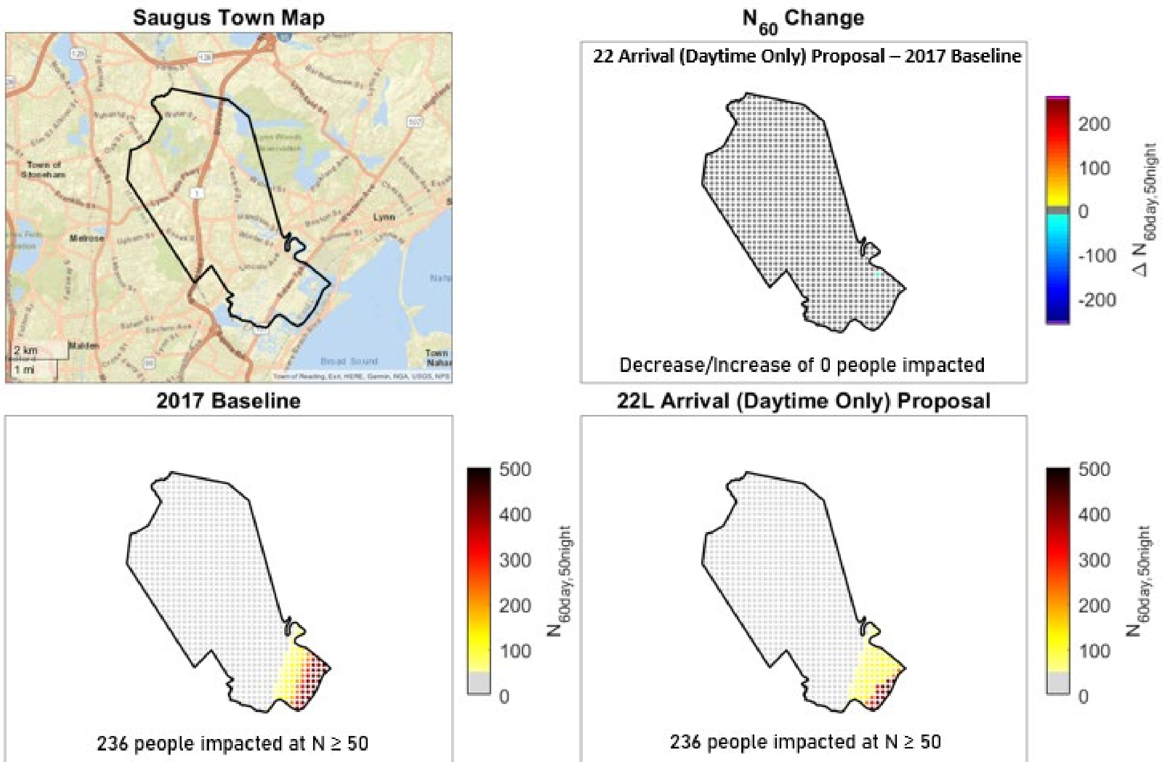


Figure 88. 2-A1 Runway 22L impact in Saugus if the proposed procedure were to be used on a peak day only during the daytime, with the ILS used at night.

N. Swampscott 2-A1 Runway 22L Daytime Use Only

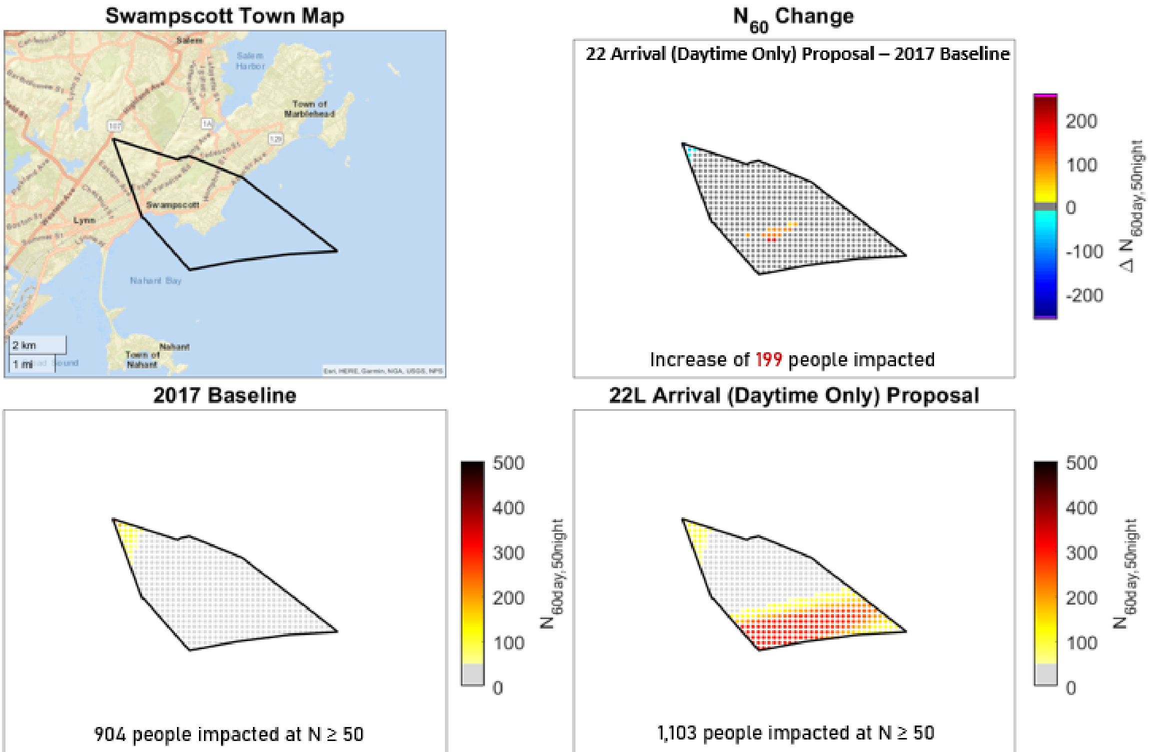


Figure 89. 2-A1 Runway 22L impact in Swampscott if the proposed procedure were to be used on a peak day only during the daytime, with the ILS used at night.

O. Wenham 2-A1 Runway 22L Daytime Use Only

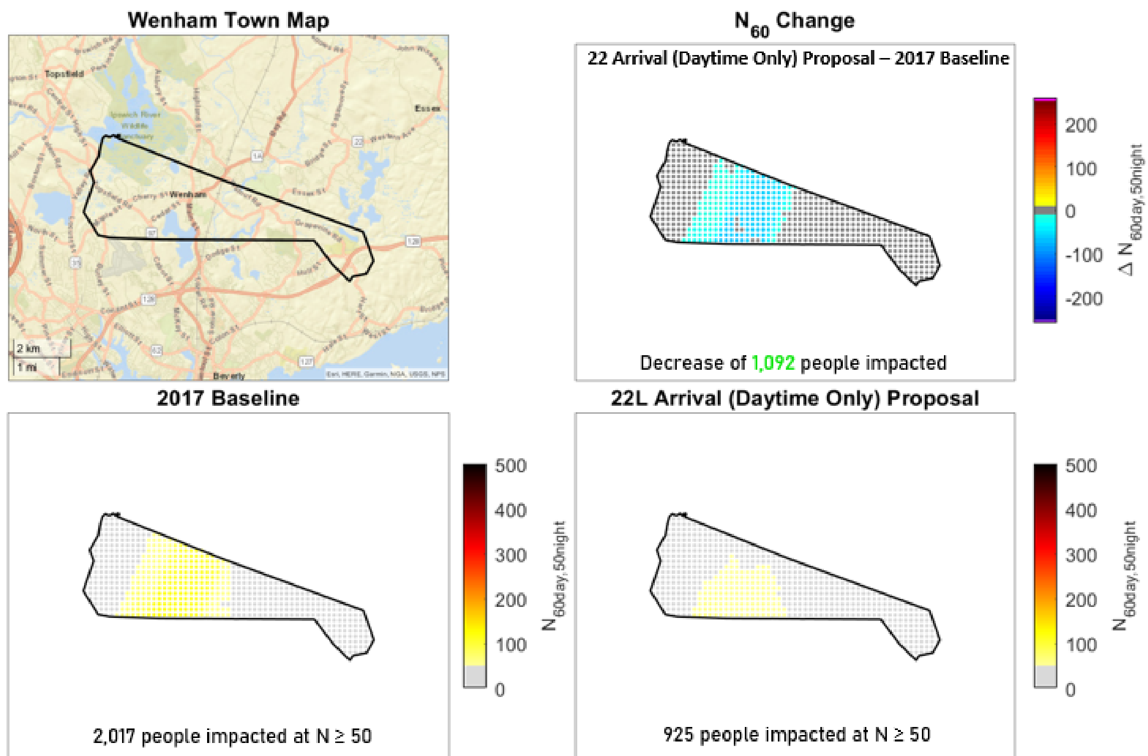


Figure 90. 2-A1 Runway 22L impact in Wenham if the proposed procedure were to be used on a peak day only during the daytime, with the ILS used at night.

P. Winthrop 2-A1 Runway 22L Daytime Use Only

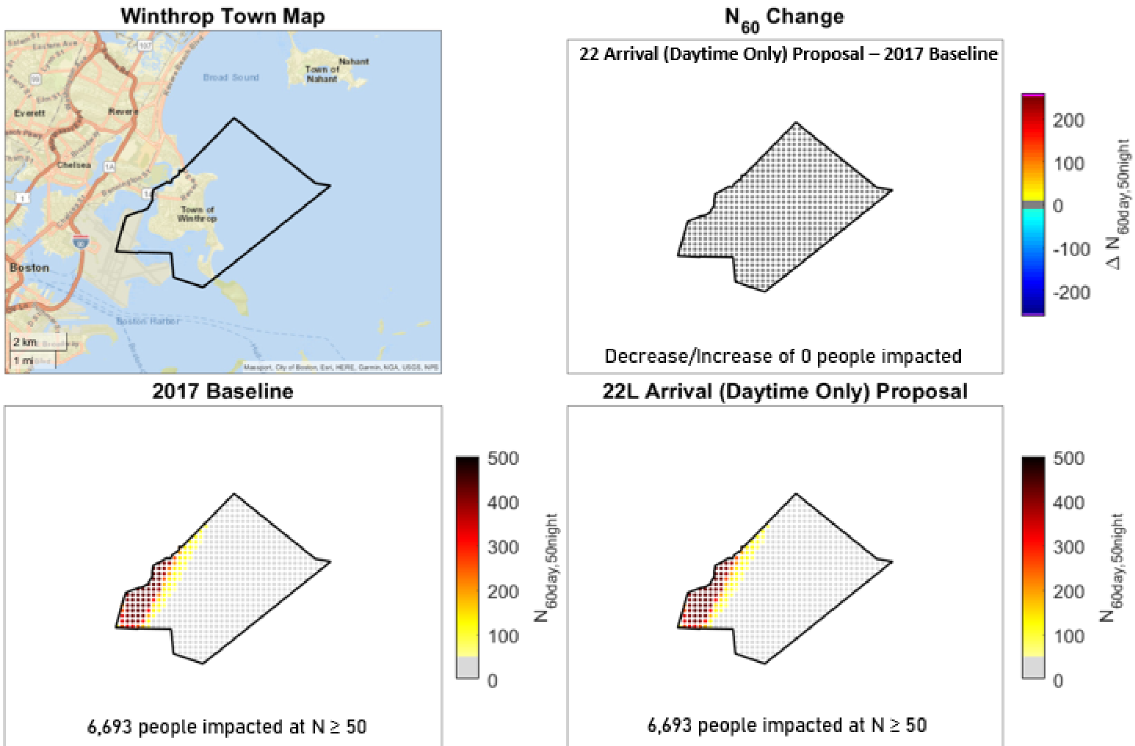


Figure 91. 2-A1 Runway 22L impact in Winthrop if the proposed procedure were to be used on a peak day only during the daytime, with the ILS used at night.

Appendix D: 2-D2 Runway 33L Waypoint Relocation Noise Dispersion Impacts

From a noise re-distribution standpoint, the effects of the RUNWAY 33L recommended procedure can be visualized in the bar plots below in Figure XX. The top bar plot depicts the population per N_{60} bin for the current procedure. The middle bar plot depicts the population per N_{60} bin for the recommended procedure. Finally, the last bar plot depicts the change in the population within each N_{60} bin. The results show that a total of 26,622 fewer people are affected by $N_{60} > 300$ when the recommended procedure is used, while an additional 16,952 people are affected by $N_{60} > 50$.

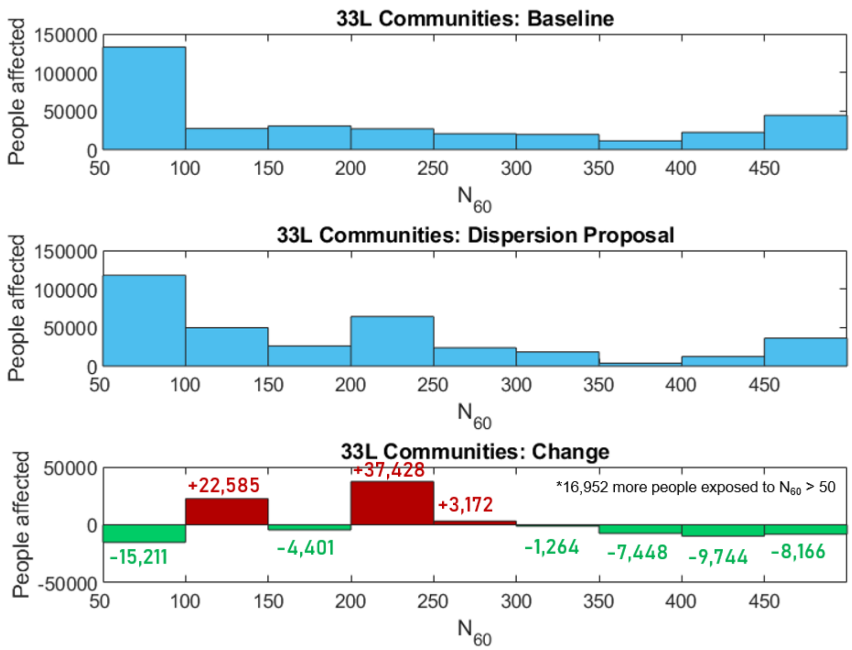


Figure 92. Bar plots showing the population counts in discrete bins of N60 for the current procedure (top) and the proposed procedure (middle). The bottom plot shows the change in population counts per N60 bin.

For each of the town/cities below, the top-left plot includes a map of the town/city for situational awareness, the bottom-left plot shows N_{60} levels with the current baseline procedure, the bottom-right plot shows N_{60} levels with the proposed procedure, and the top-right plot shows the total N_{60} change if the proposed procedure were to be implemented.

A. Arlington 2-D2 Runway 33L Waypoint Relocation

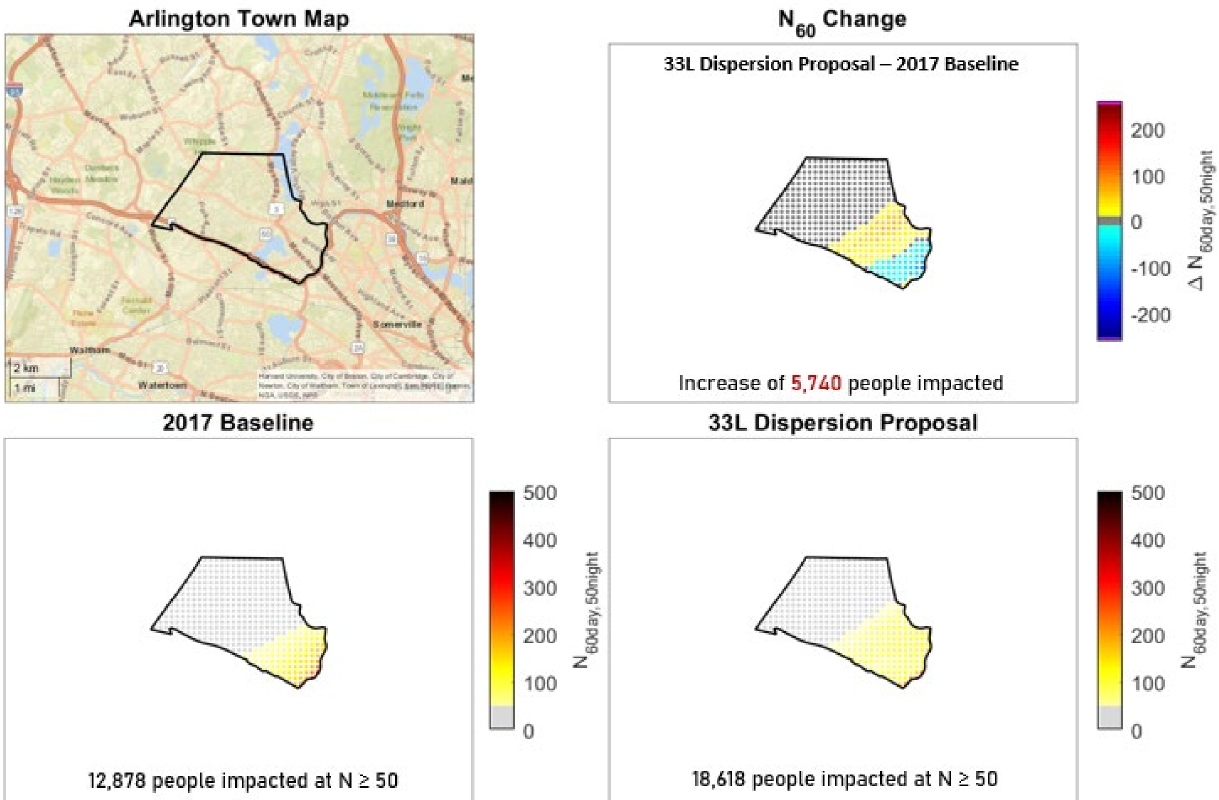


Figure 93. 2-D2 Runway 33L Waypoint Relocation Dispersion Arlington local impact.

B. Belmont 2-D2 Runway 33L Waypoint Relocation

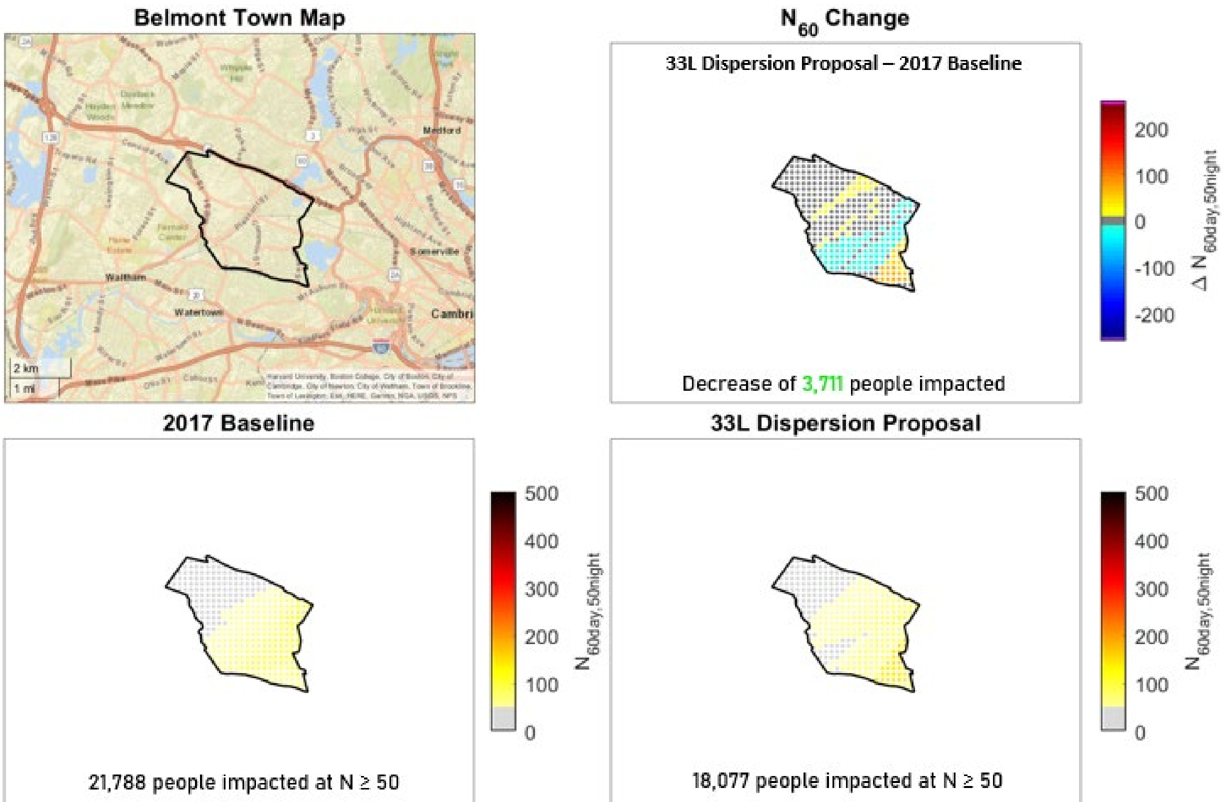


Figure 94. 2-D2 Runway 33L Waypoint Relocation Dispersion Belmont local impact.

C. Boston 2-D2 Runway 33L Waypoint Relocation

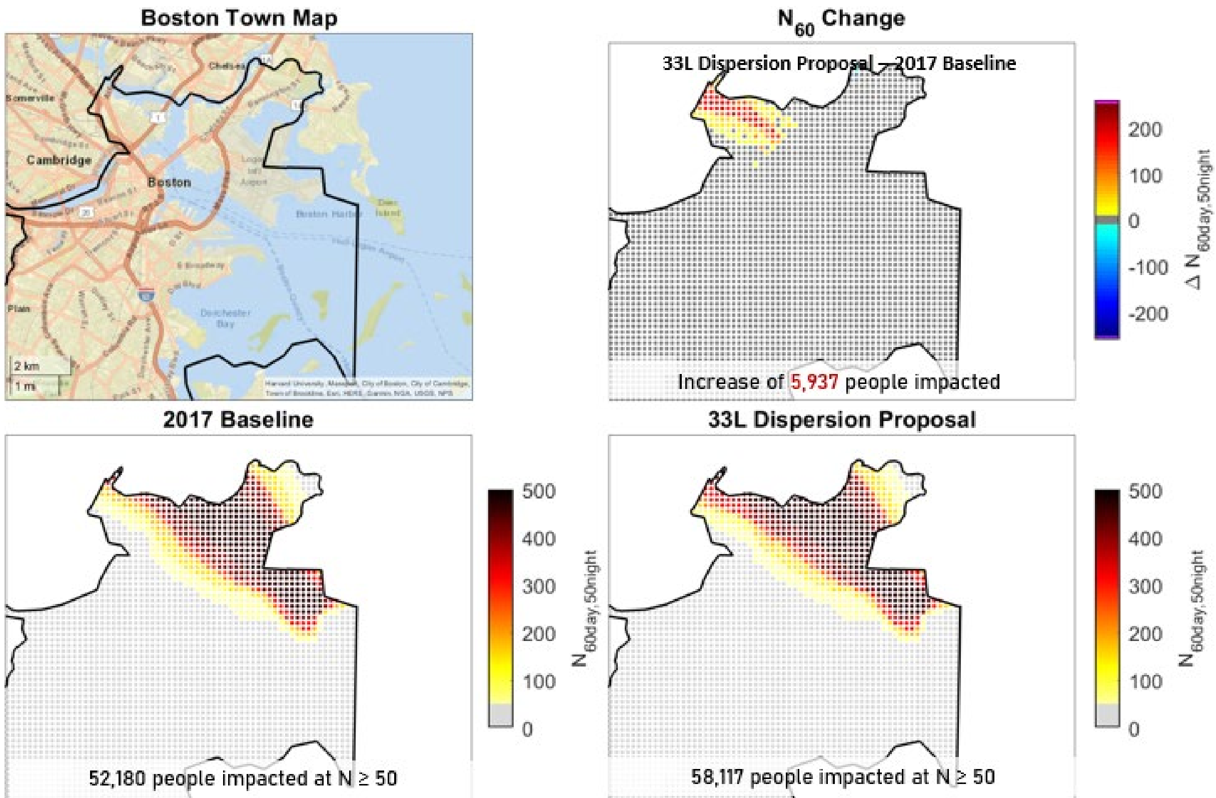


Figure 95. 2-D2 Runway 33L Waypoint Relocation Dispersion Boston local impact.

D. Cambridge 2-D2 Runway 33L Waypoint Relocation

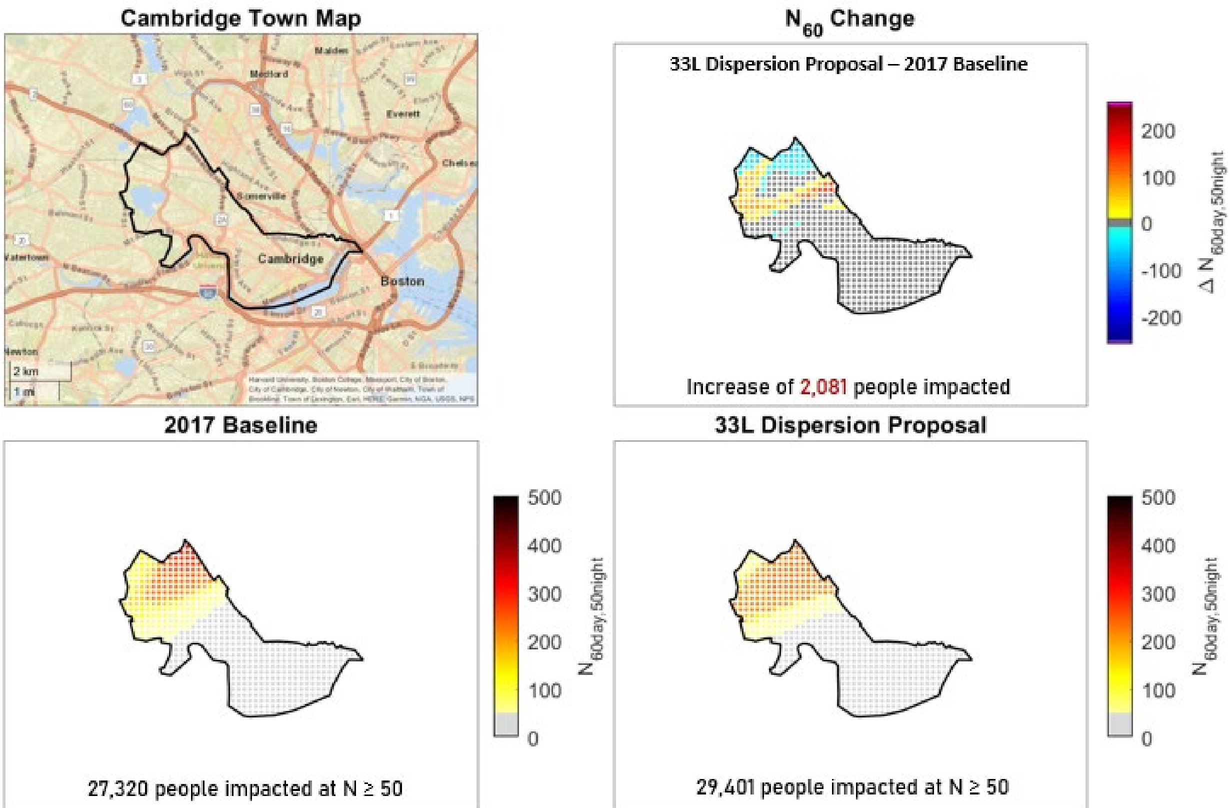


Figure 96. 2-D2 Runway 33L Waypoint Relocation Dispersion Cambridge local impact.

E. Chelsea 2-D2 Runway 33L Waypoint Relocation

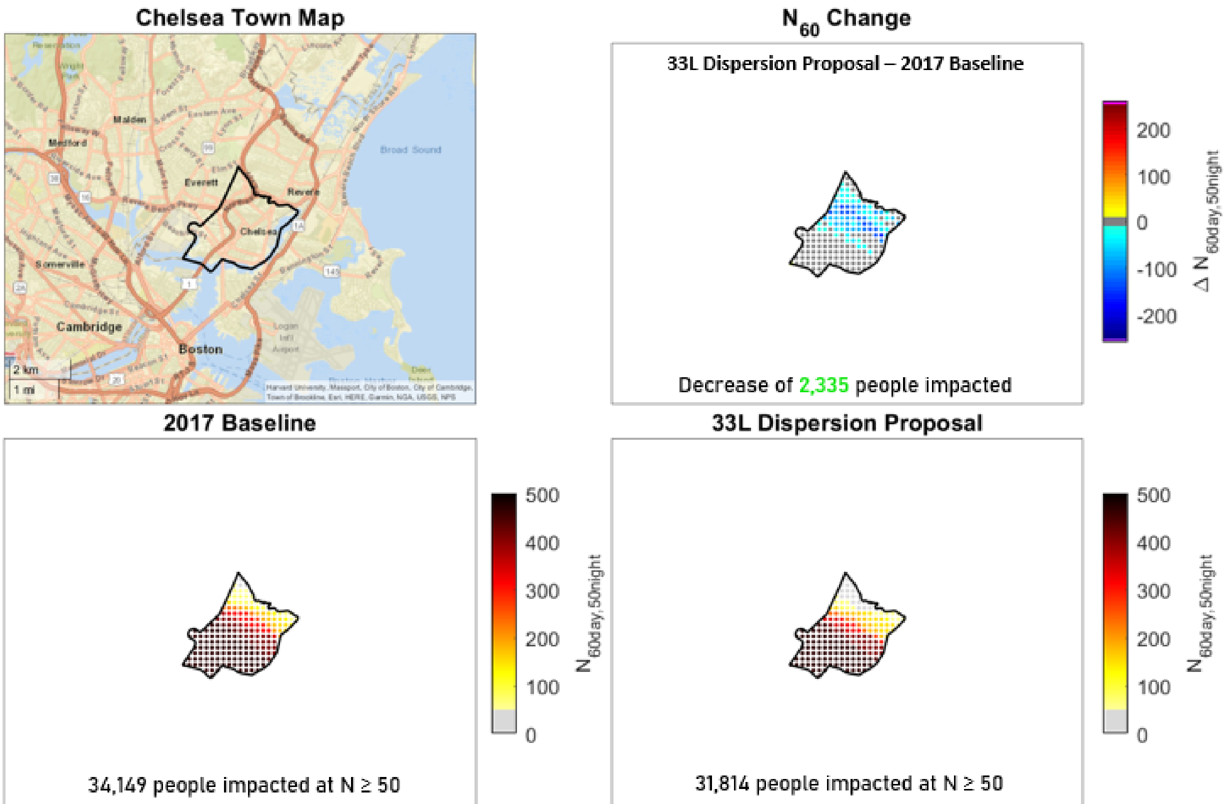


Figure 97. 2-D2 Runway 33L Waypoint Relocation Dispersion Chelsea local impact.

F. Everett 2-D2 Runway 33L Waypoint Relocation

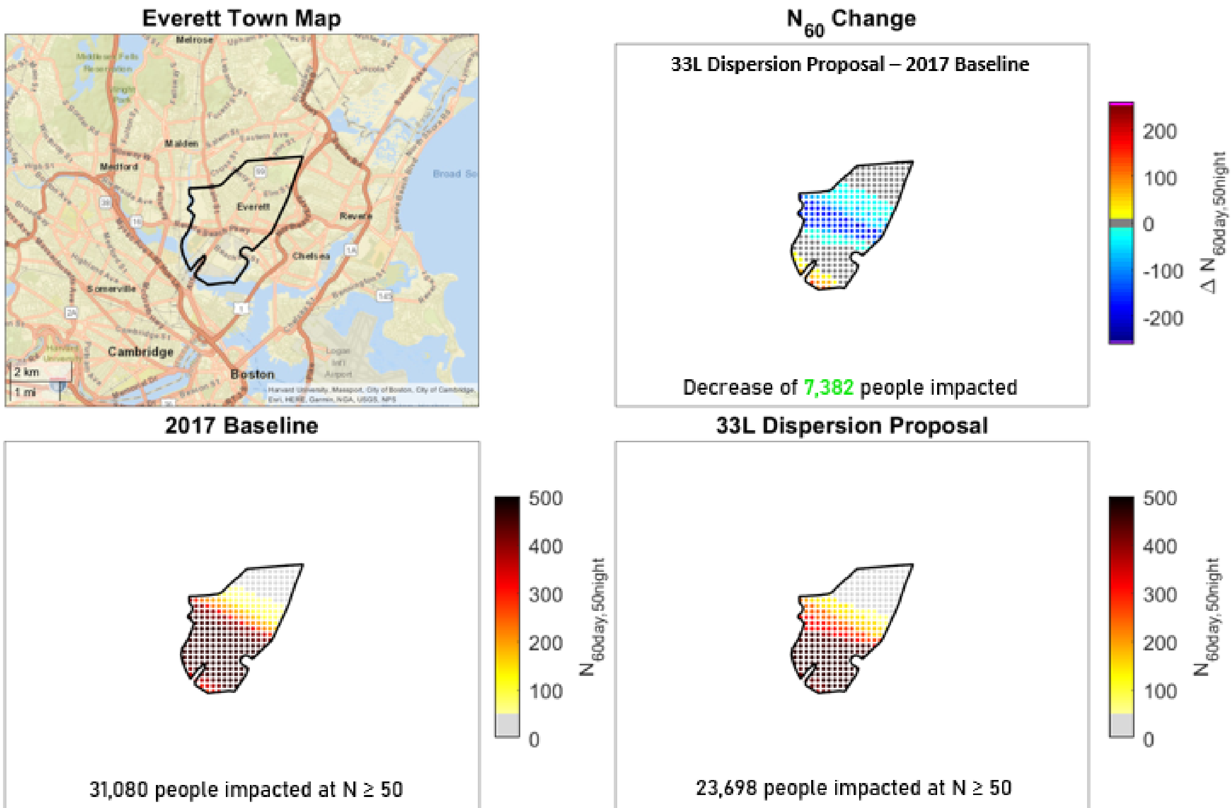


Figure 98. 2-D2 Runway 33L Waypoint Relocation Dispersion Everett local impact.

G. Malden 2-D2 Runway 33L Waypoint Relocation

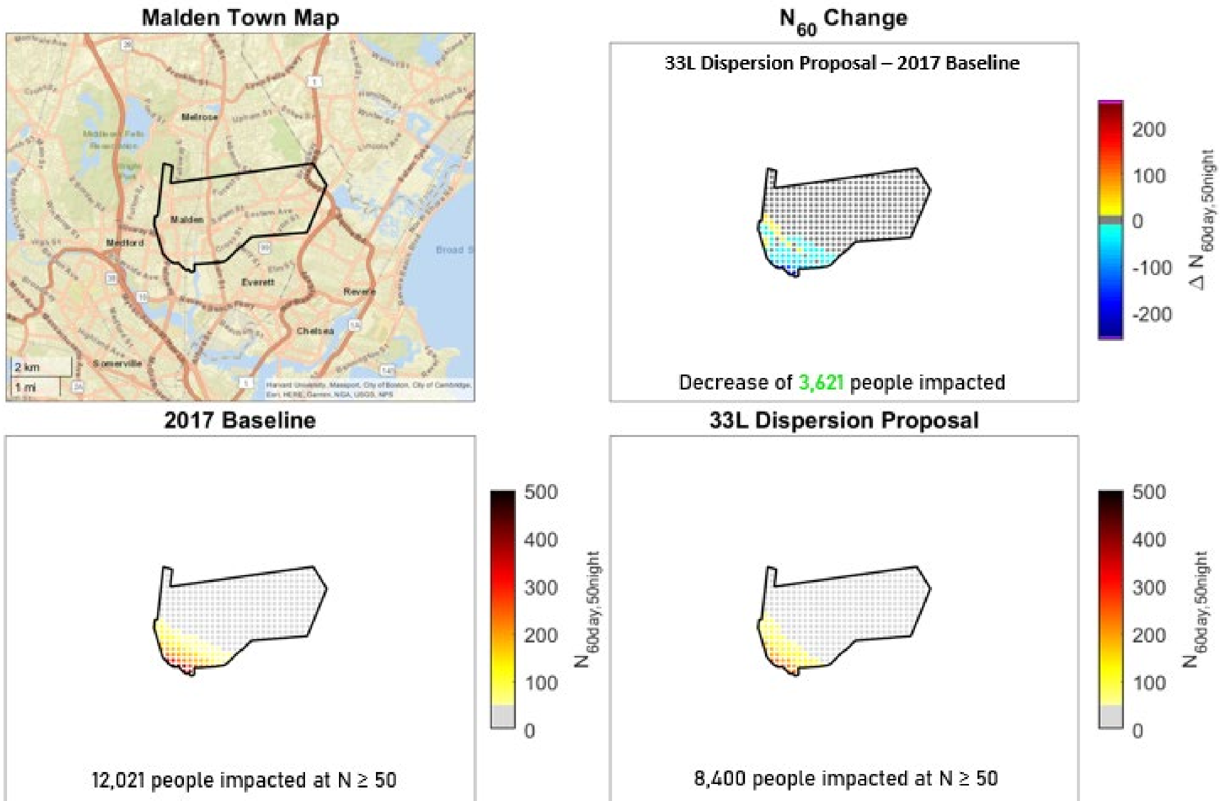


Figure 99. 2-D2 Runway 33L Waypoint Relocation Dispersion Malden local impact.

H. Medford 2-D2 Runway 33L Waypoint Relocation

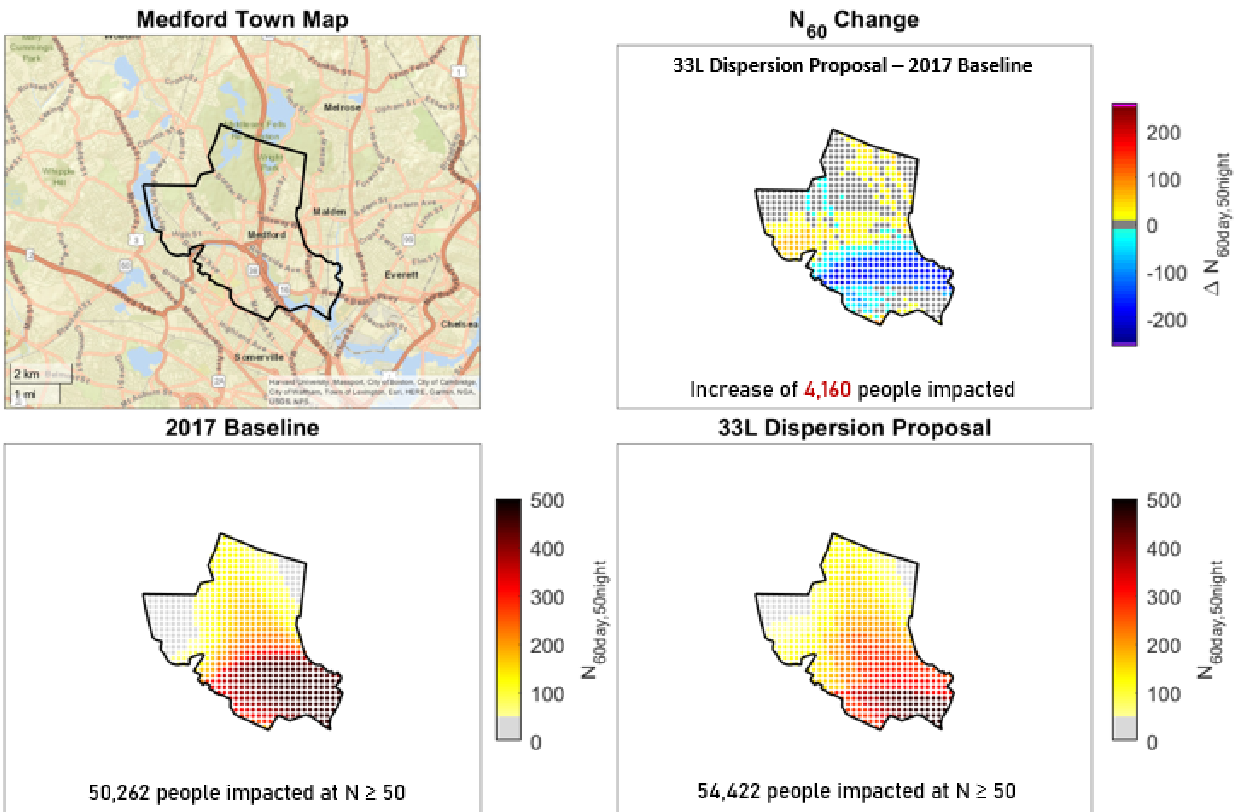


Figure 100. 2-D2 Runway 33L Waypoint Relocation Dispersion Medford local impact.

I. Newton 2-D2 Runway 33L Waypoint Relocation

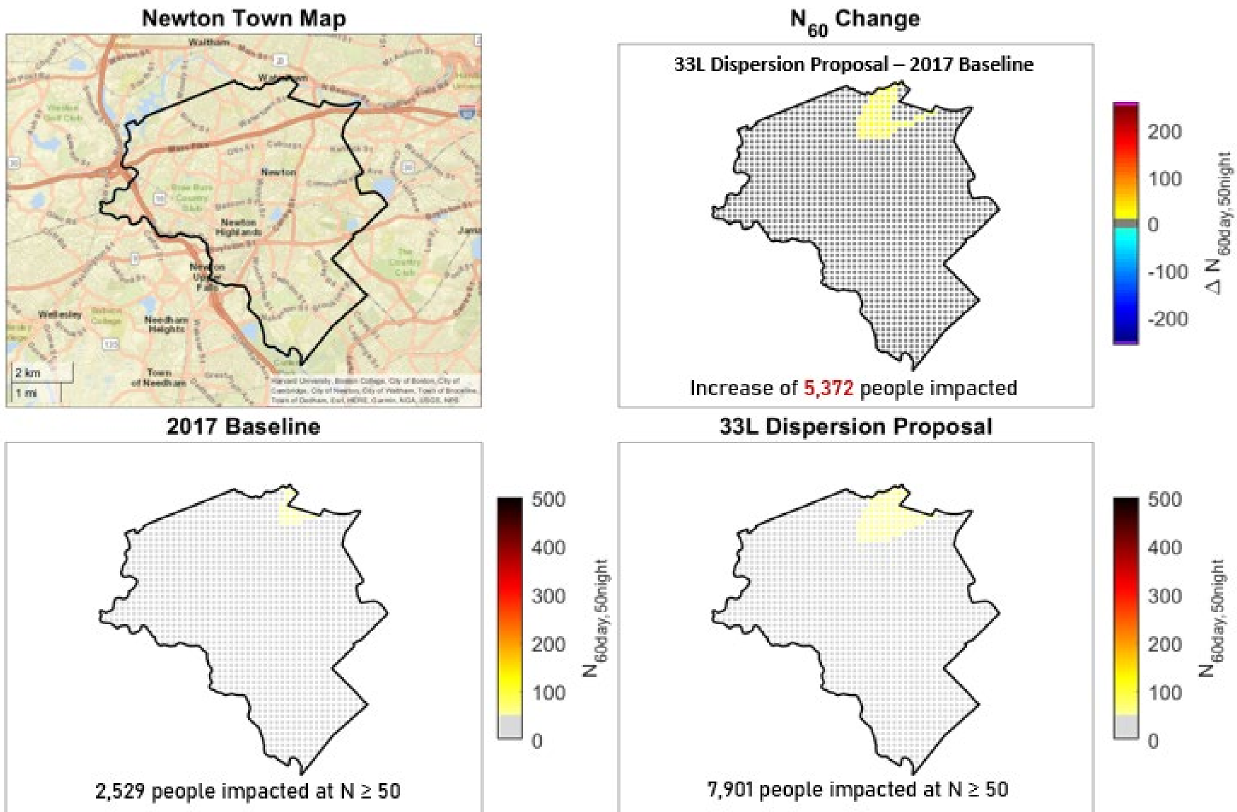


Figure 101. 2-D2 Runway 33L Waypoint Relocation Dispersion Newton local impact.

J. Revere 2-D2 Runway 33L Waypoint Relocation

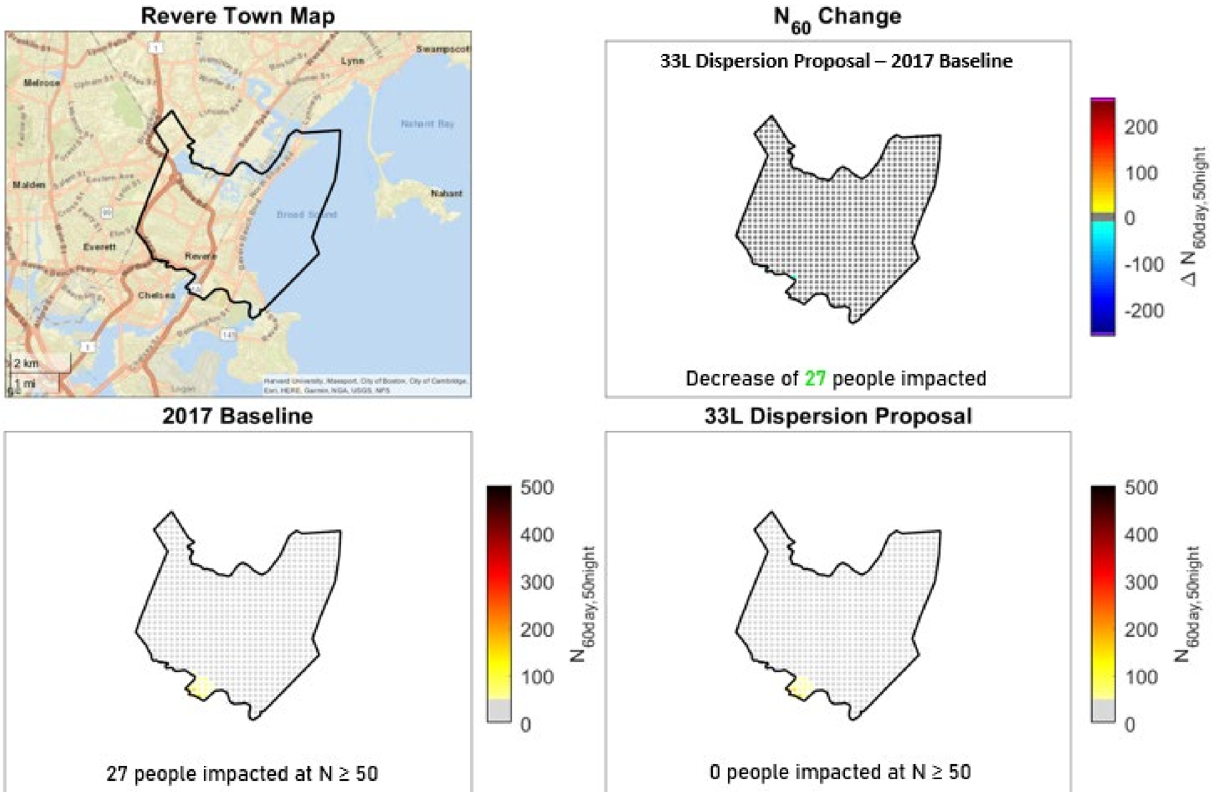


Figure 102. 2-D2 Runway 33L Waypoint Relocation Dispersion Revere local impact.

K. Somerville 2-D2 Runway 33L Waypoint Relocation

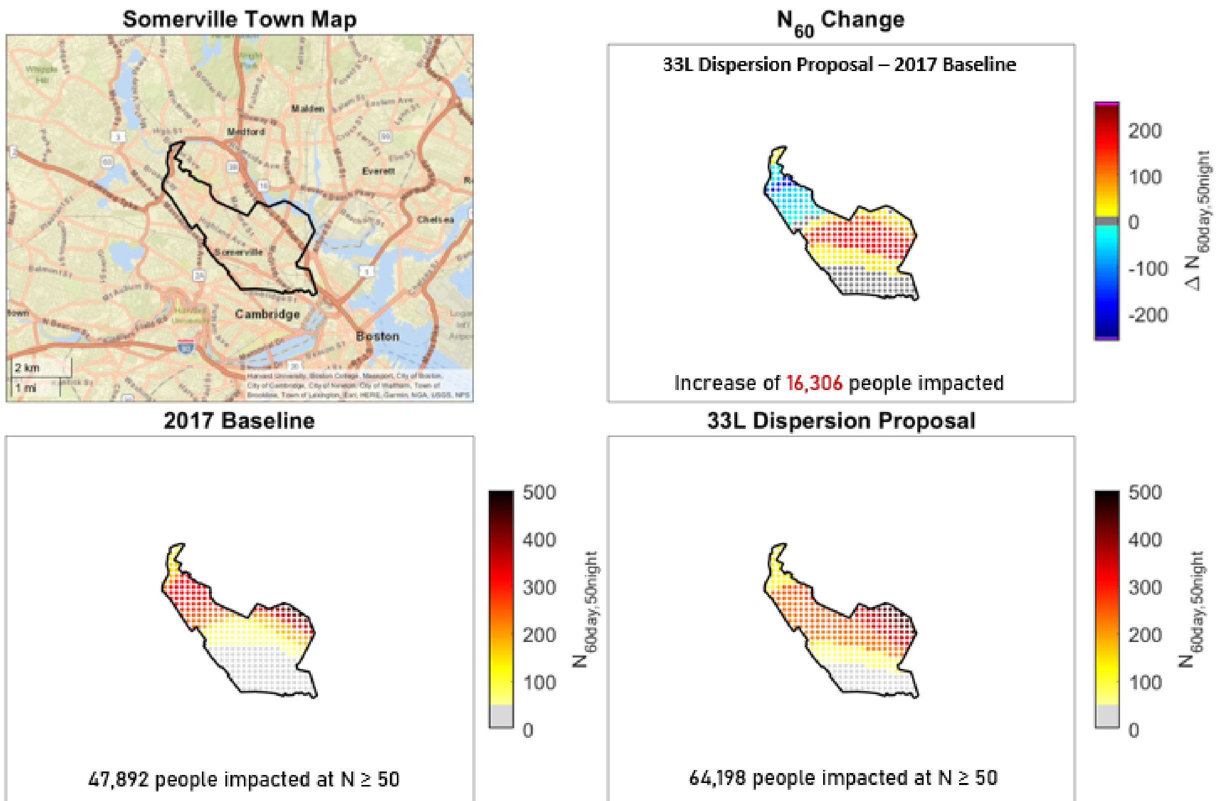


Figure 103. 2-D2 Runway 33L Waypoint Relocation Dispersion Somerville local impact.

L. Stoneham 2-D2 Runway 33L Waypoint Relocation

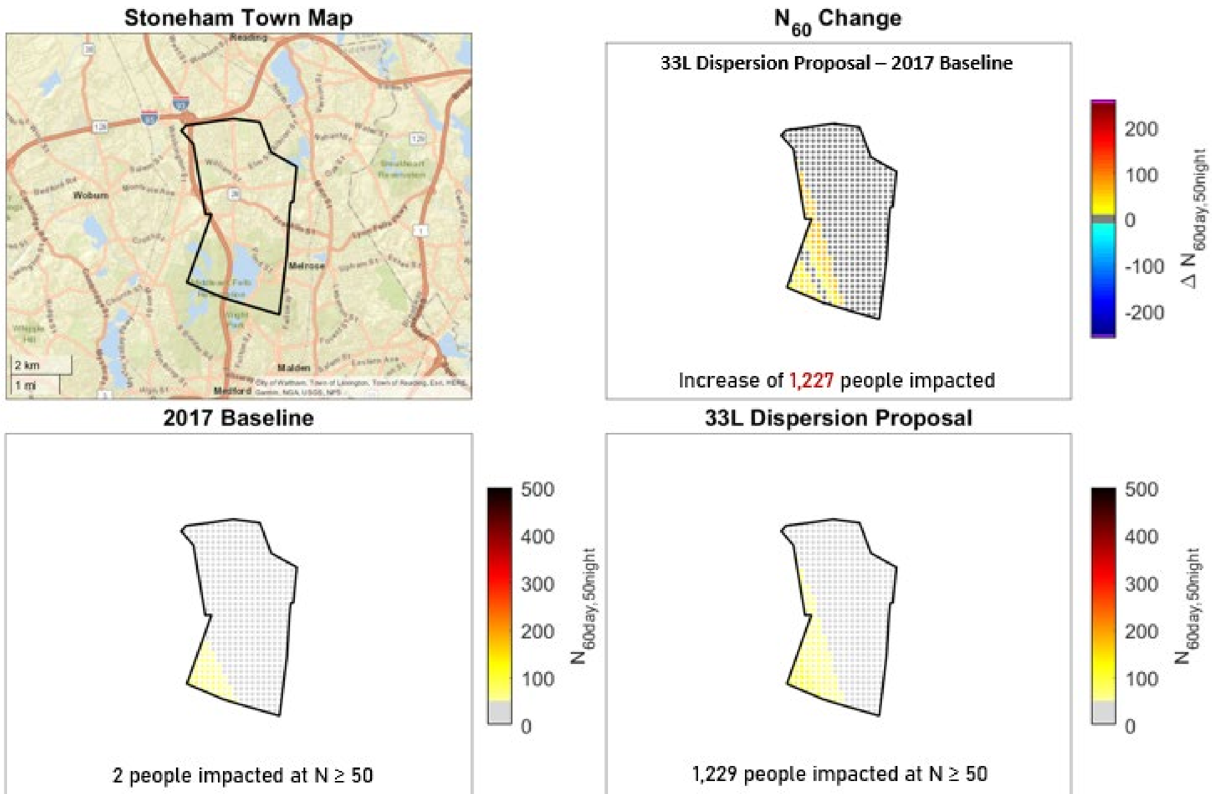


Figure 104. 2-D2 Runway 33L Waypoint Relocation Dispersion Stoneham local impact.

M. Waltham 2-D2 Runway 33L Waypoint Relocation

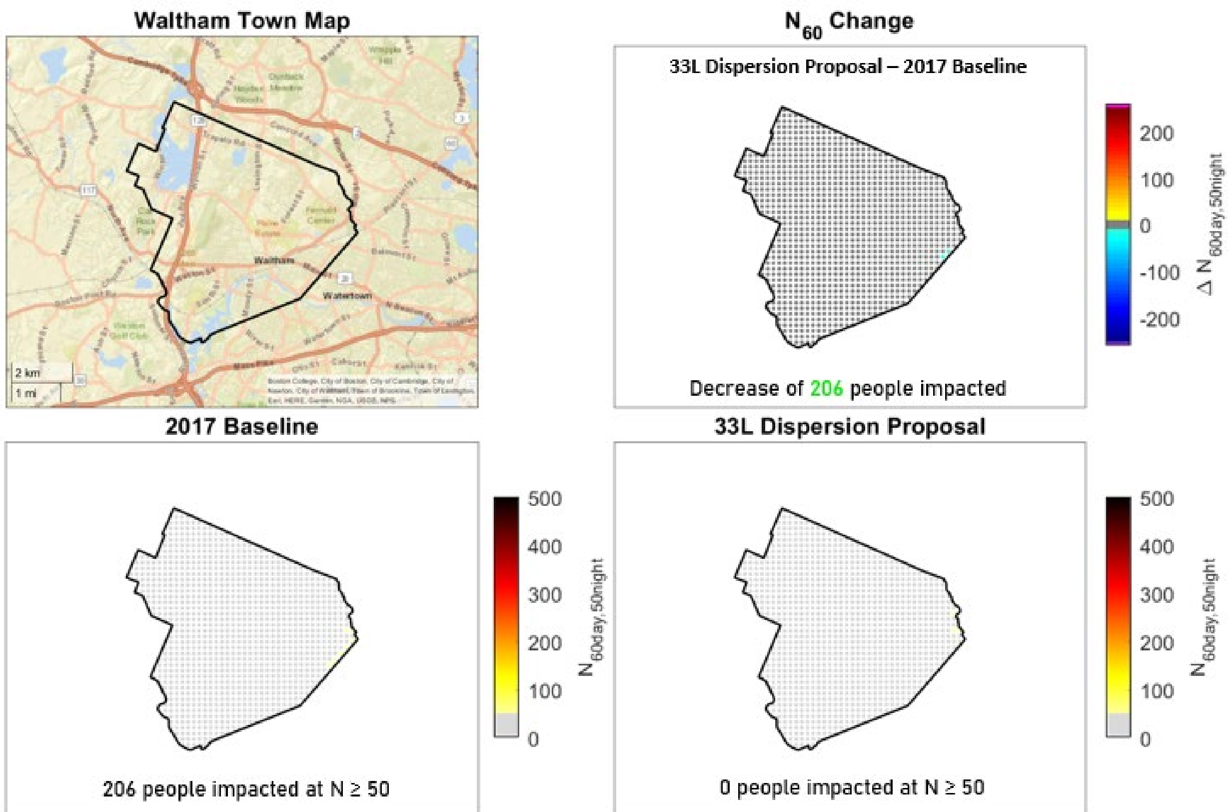


Figure 105. 2-D2 Runway 33L Waypoint Relocation Dispersion Waltham local impact.

N. Watertown 2-D2 Runway 33L Waypoint Relocation

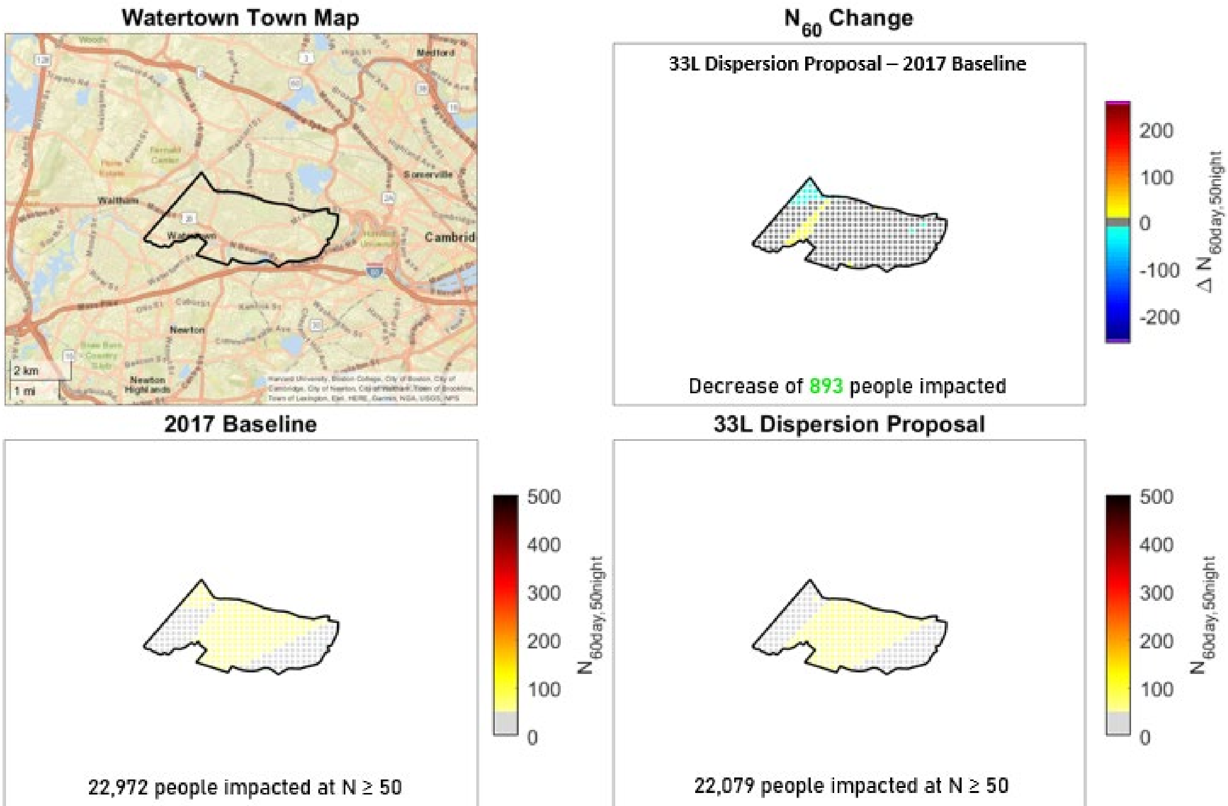


Figure 106. 2-D2 Runway 33L Waypoint Relocation Dispersion Watertown local impact.

O. Winchester 2-D2 Runway 33L Waypoint Relocation

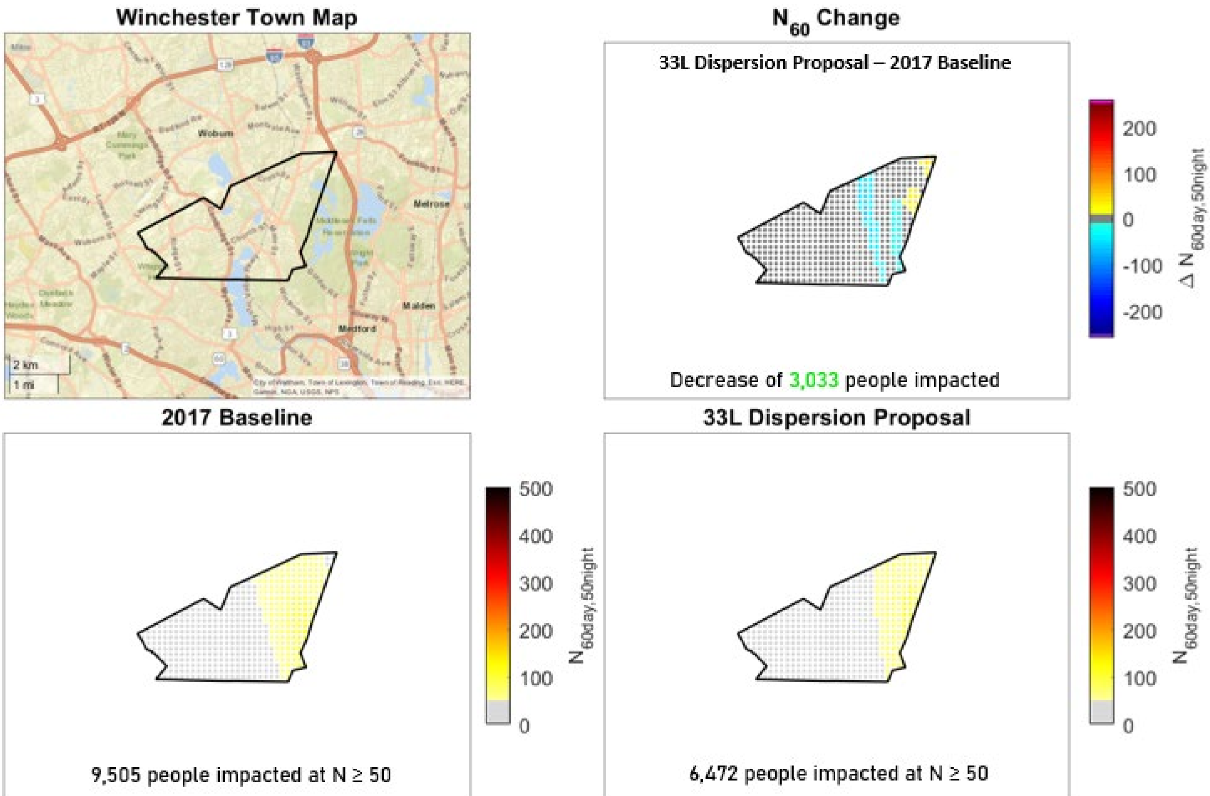


Figure 107. 2-D2 Runway 33L Waypoint Relocation Dispersion Winchester local impact.

P. Winthrop 2-D2 Runway 33L Waypoint Relocation

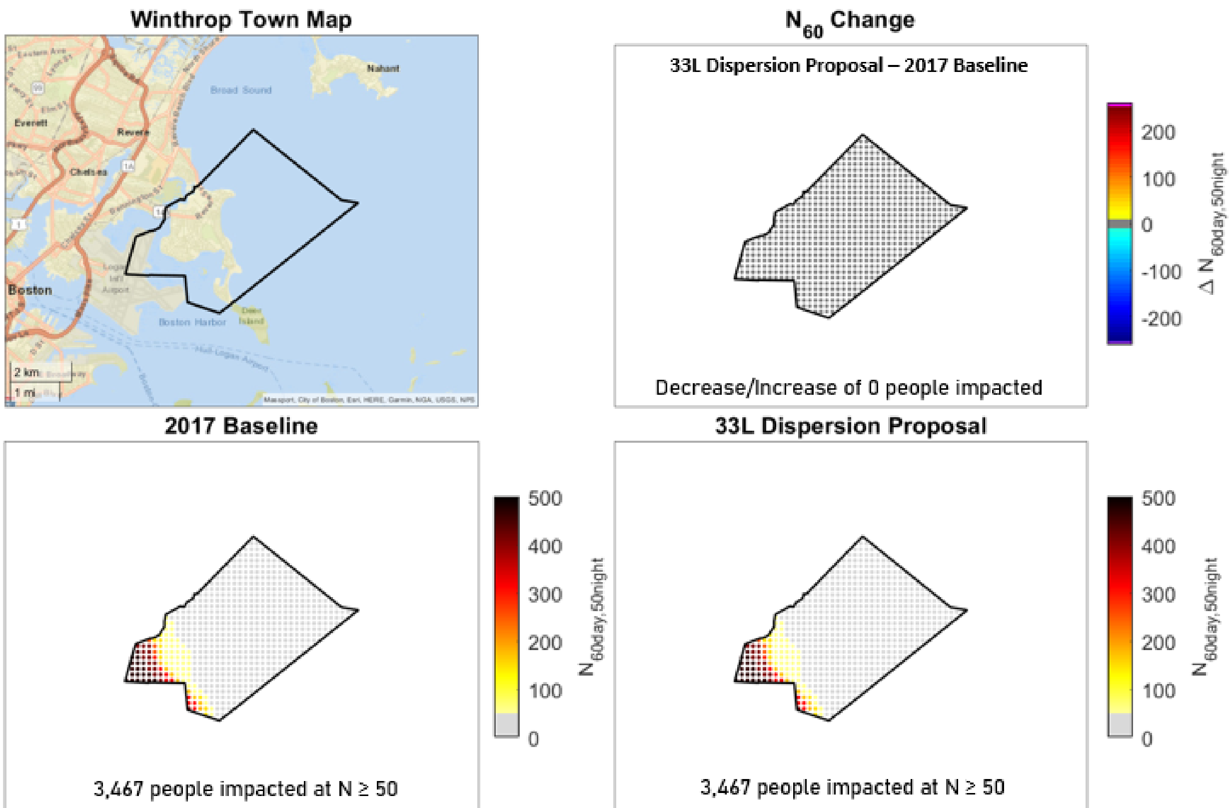


Figure 108. 2-D2 Runway 33L Waypoint Relocation Dispersion Winthrop local impact.

Q. Woburn 2-D2 Runway 33L Waypoint Relocation

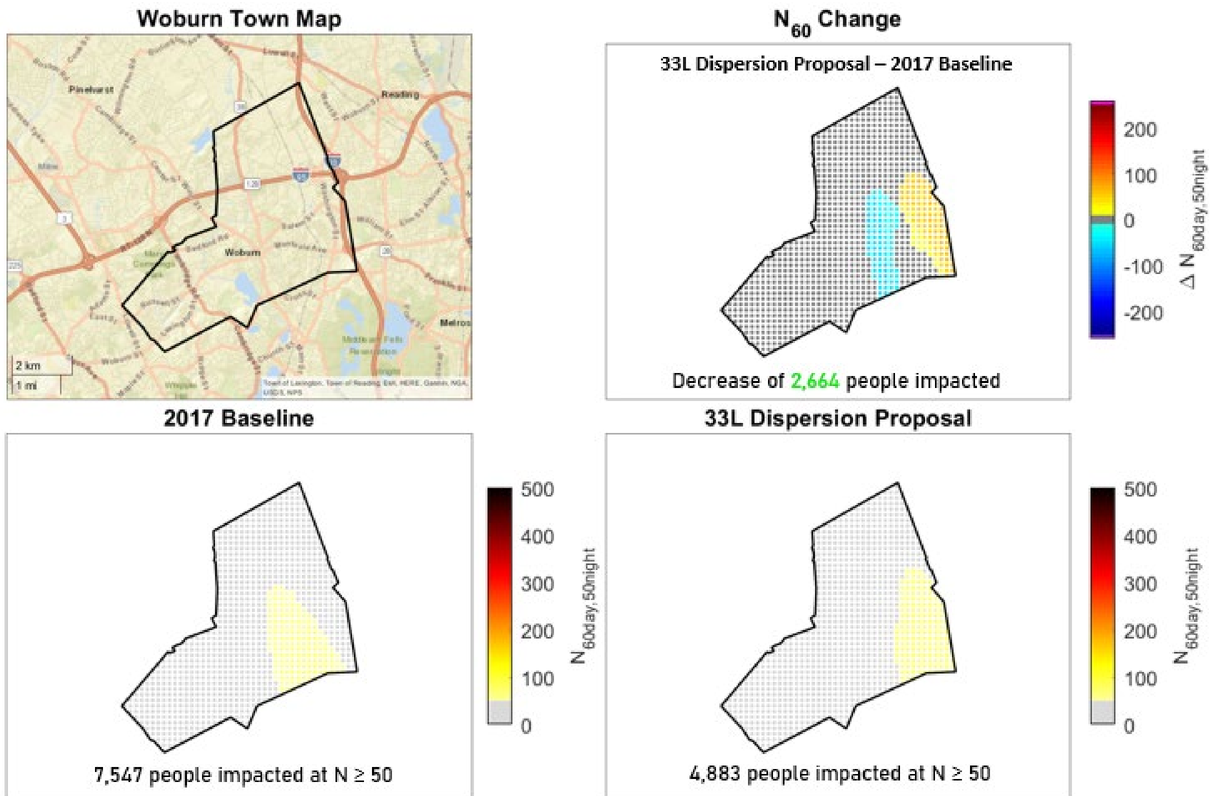


Figure 109. 2-D2 Runway 33L Waypoint Relocation Dispersion Woburn local impact.

Appendix E: 2-D3 Runway 27 Waypoint Relocation Impacts

From a noise re-distribution standpoint, the effects of the Runway 27 recommended procedure can be visualized in the bar plots below. The top bar plot depicts the population per N_{60} bin for the current procedure. The middle bar plot depicts the population per N_{60} bin for the recommended procedure. Finally, the last bar plot depicts the change in the population within each N_{60} bin. The results show that a total of 6,944 fewer people are affected by $N_{60} > 300$ when the recommended procedure is used, and 21,025 fewer people are affected by $N_{60} > 50$.

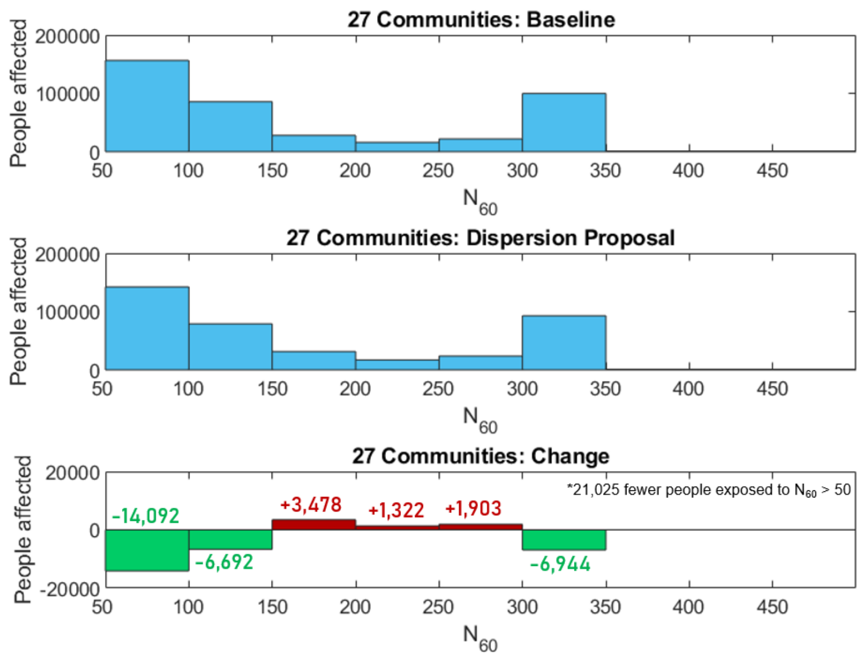


Figure 110. Bar plots showing the population counts in discrete bins of N_{60} for the current procedure (top) and the proposed procedure (middle). The bottom plot shows the change in population counts per N_{60} bin.

For each of the town/cities below, the top-left plot includes a map of the town/city for situational awareness, the bottom-left plot shows N_{60} levels with the current baseline procedure, the bottom-right plot shows N_{60} levels with the proposed procedure, and the top-right plot shows the total N_{60} change if the proposed procedure were to be implemented.

A. Boston 2-D3 Runway 27 Waypoint Relocation

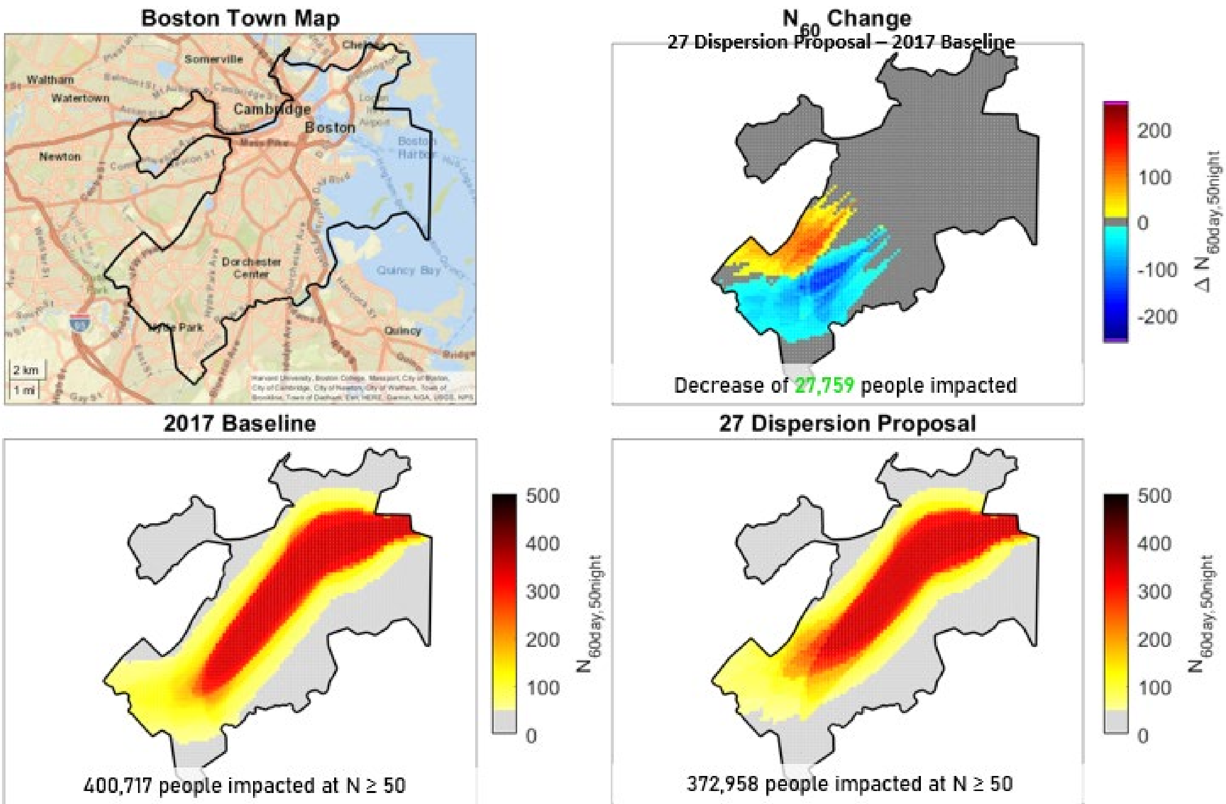


Figure 111. 2-D3 Runway 27 Waypoint Relocation Boston local impact.

B. Brookline 2-D3 Runway 27 Waypoint Relocation

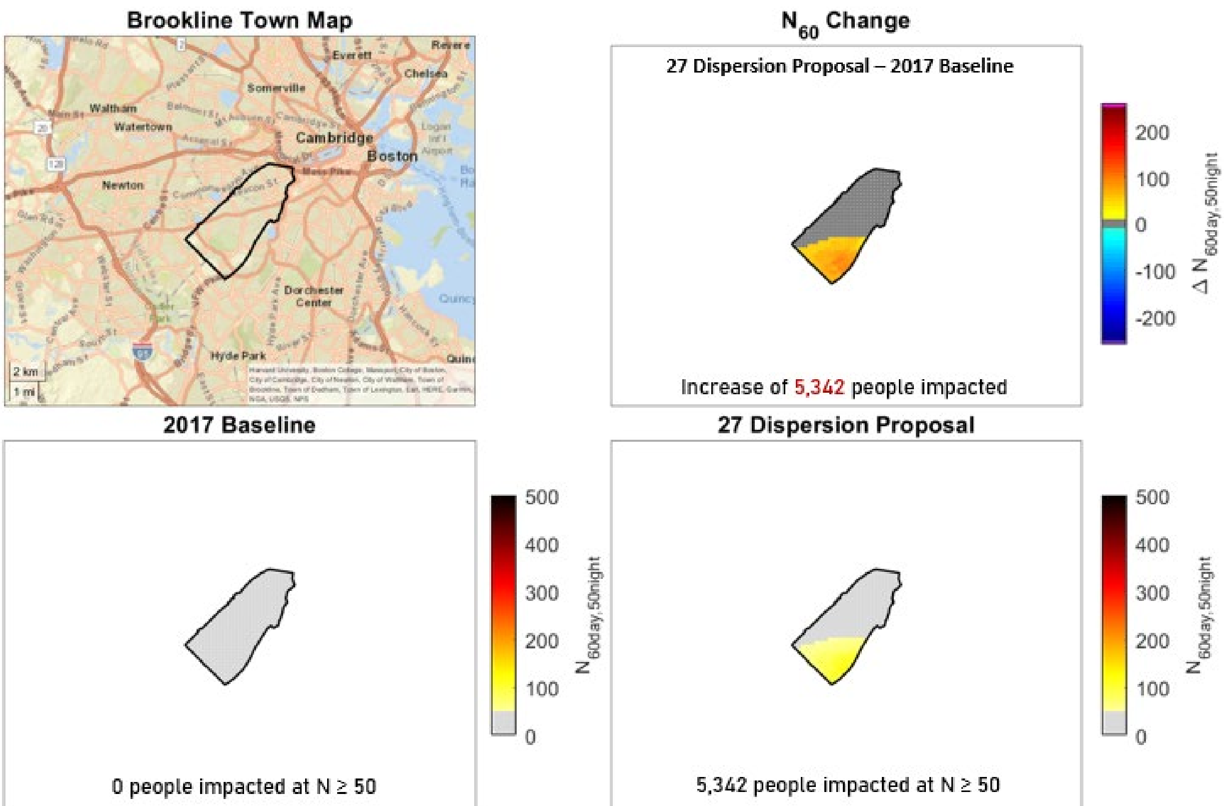


Figure 112. 2-D3 Runway 27 Waypoint Relocation Brookline local impact.

C. Dedham 2-D3 Runway 27 Waypoint Relocation

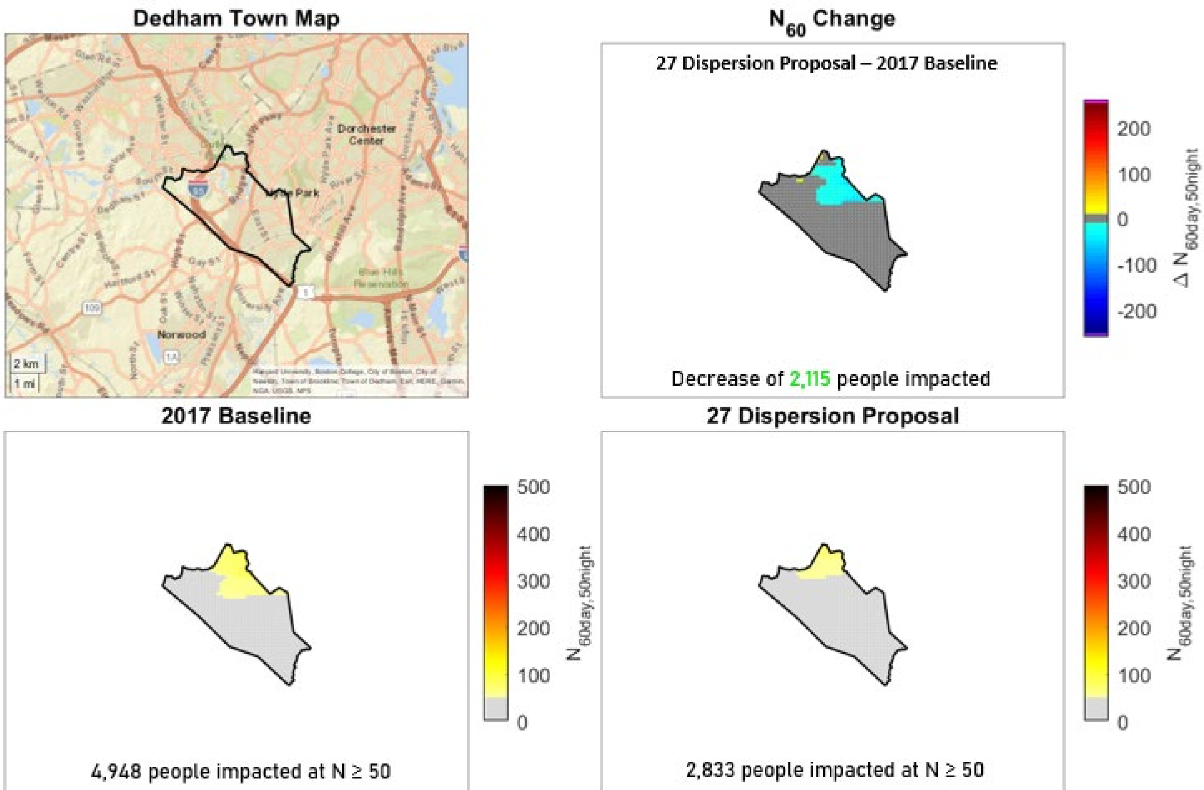


Figure 113. 2-D3 Runway 27 Waypoint Relocation Dedham local impact.

D. Milton 2-D3 Runway 27 Waypoint Relocation

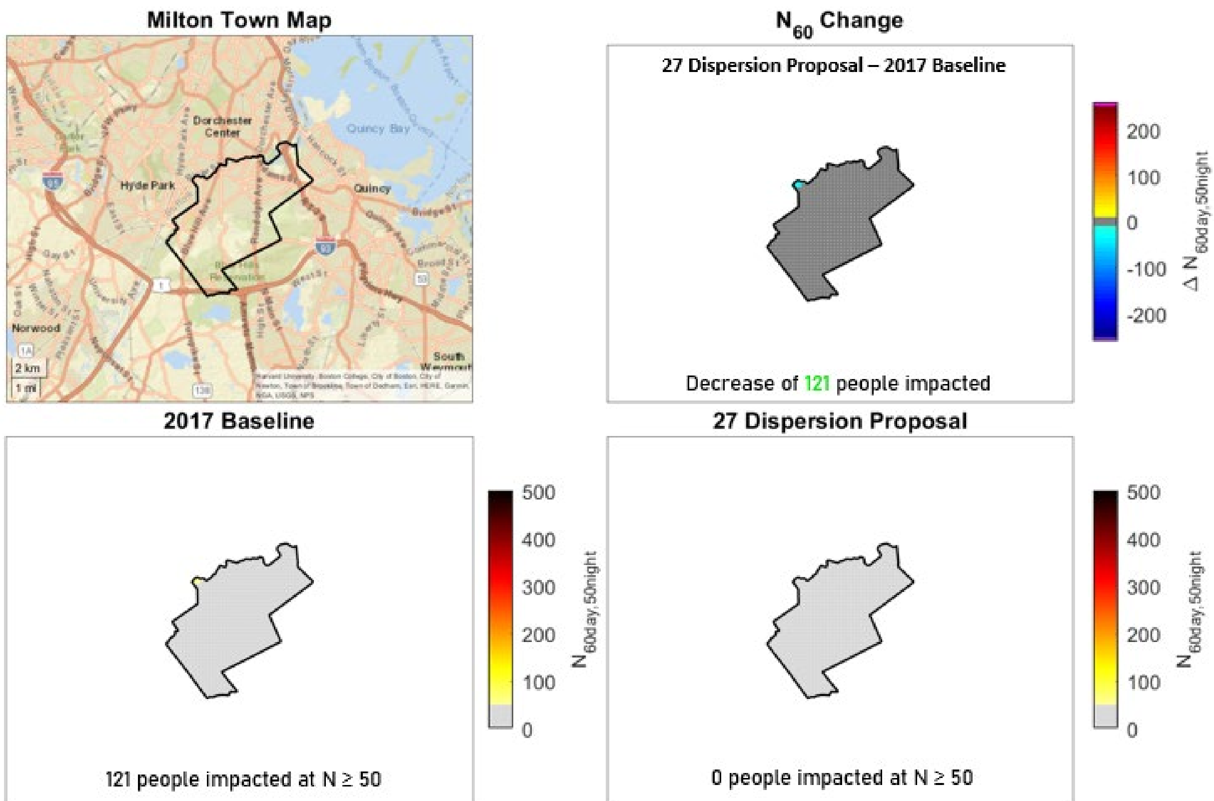


Figure 114. 2-D3 Runway 27 Waypoint Relocation Milton local impact.

E. Needham 2-D3 Runway 27 Waypoint Relocation

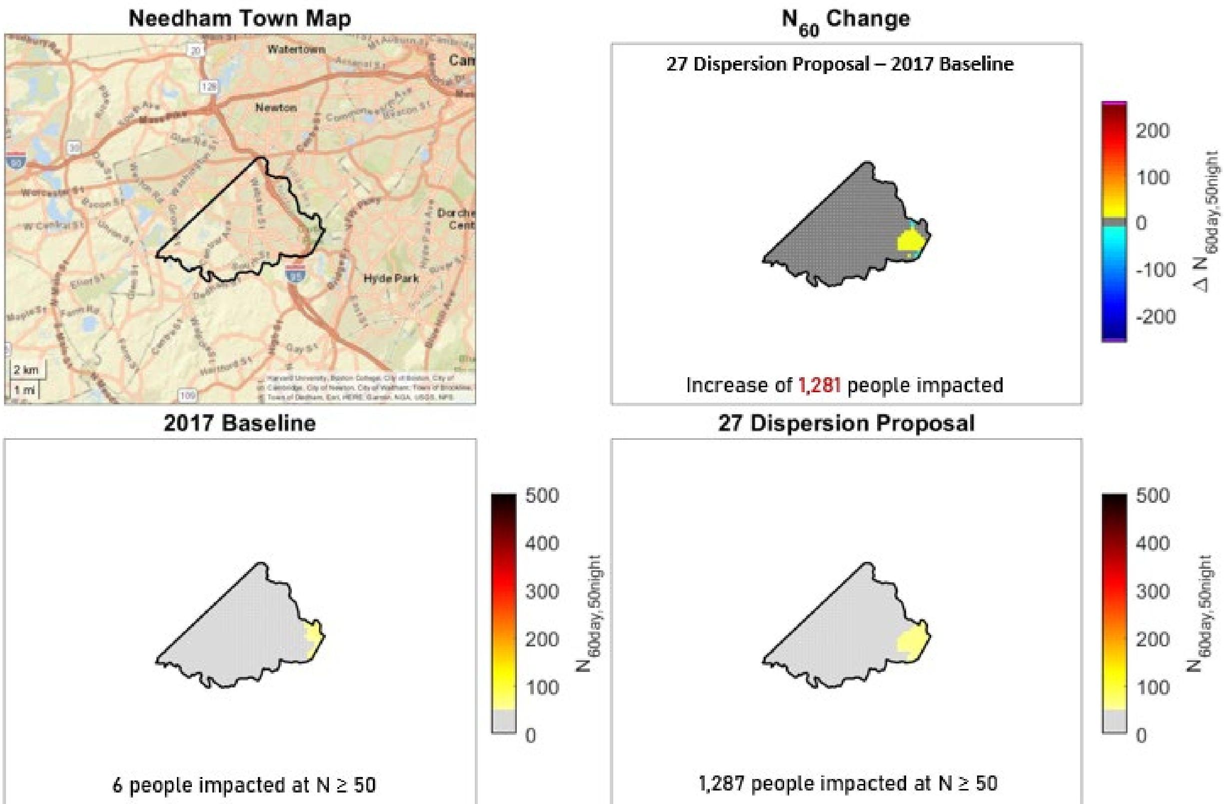


Figure 115. 2-D3 Runway 27 Waypoint Relocation Needham local impact.

F. Newton 2-D3 Runway 27 Waypoint Relocation

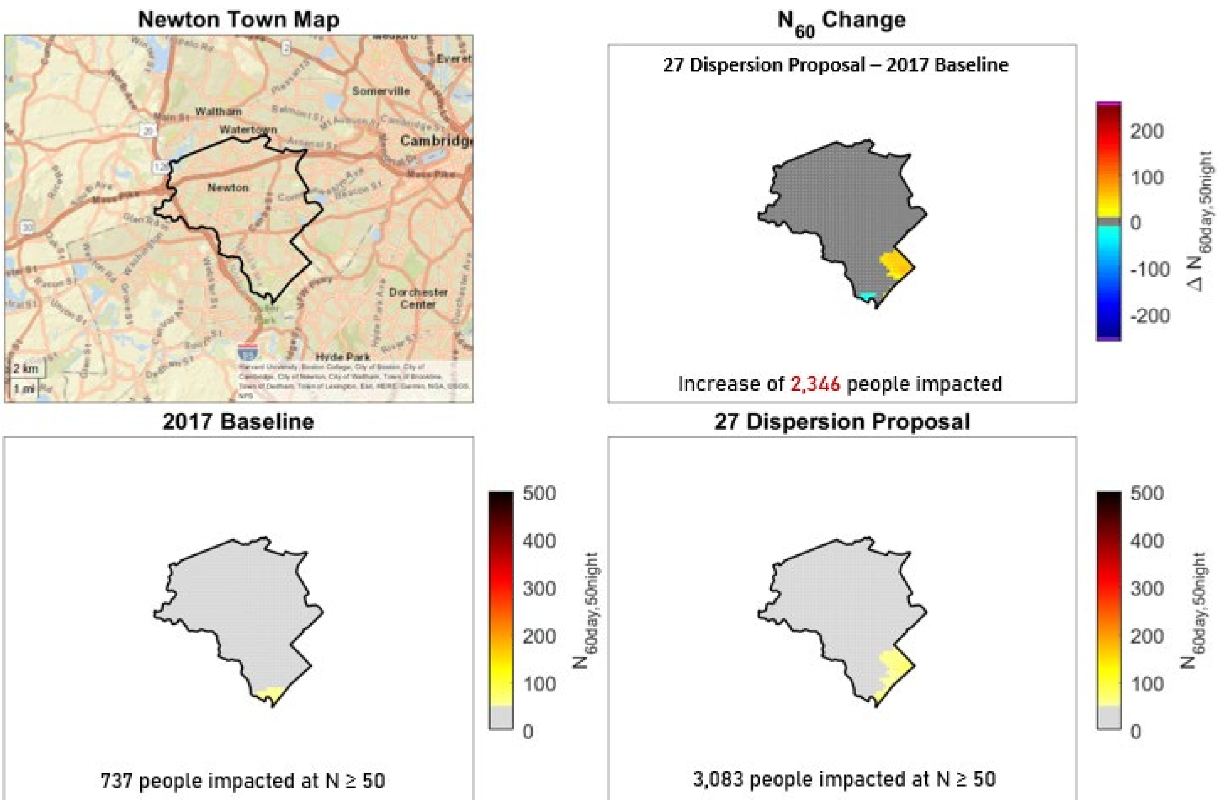


Figure 116. 2-D3 Runway 27 Waypoint Relocation Newton local impact.

G. Winthrop 2-D3 Runway 27 Waypoint Relocation

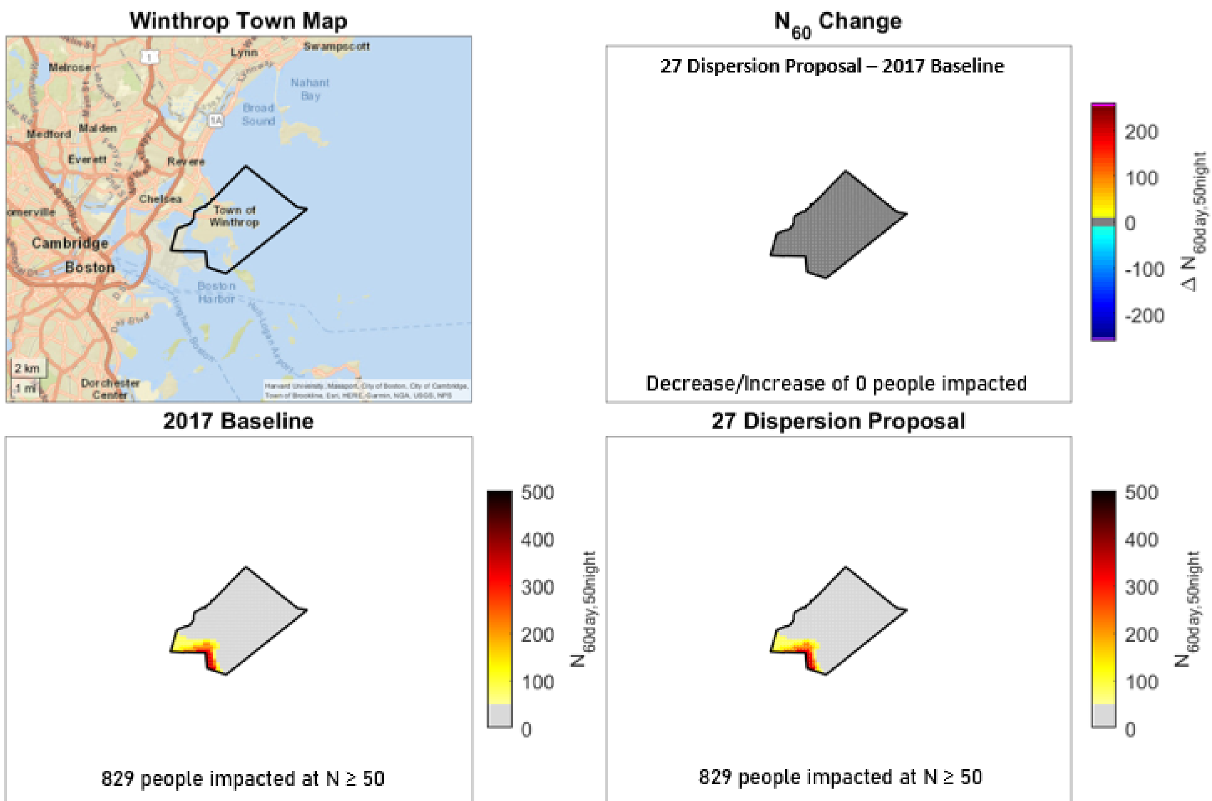
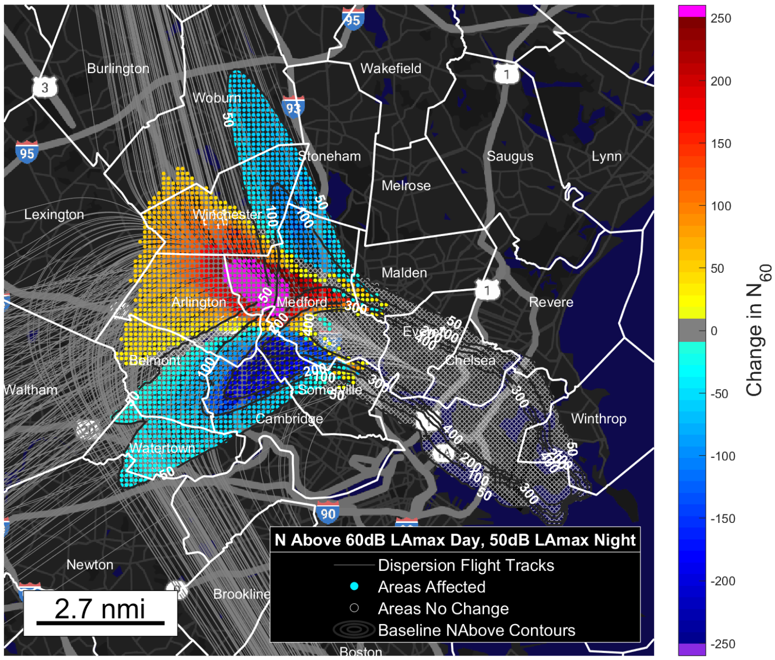


Figure 117. 2-D3 Runway 27 Waypoint Relocation Winthrop local impact.

Appendix F: Additional Noise Analyses for Initial Candidate Procedures

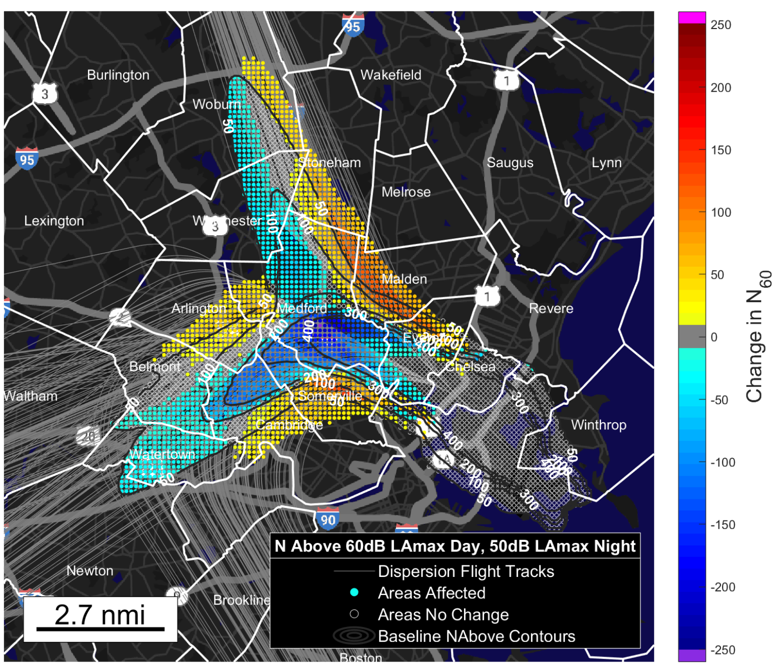
A. RWY 33L Altitude-Based Dispersion



	N_{60}>50 (Population Exposed)
Current procedure	335,823
Proposed procedure	281,319
Difference (Current - Proposed)	54,504

Figure 118. Altitude-based dispersion at 4000 ft.

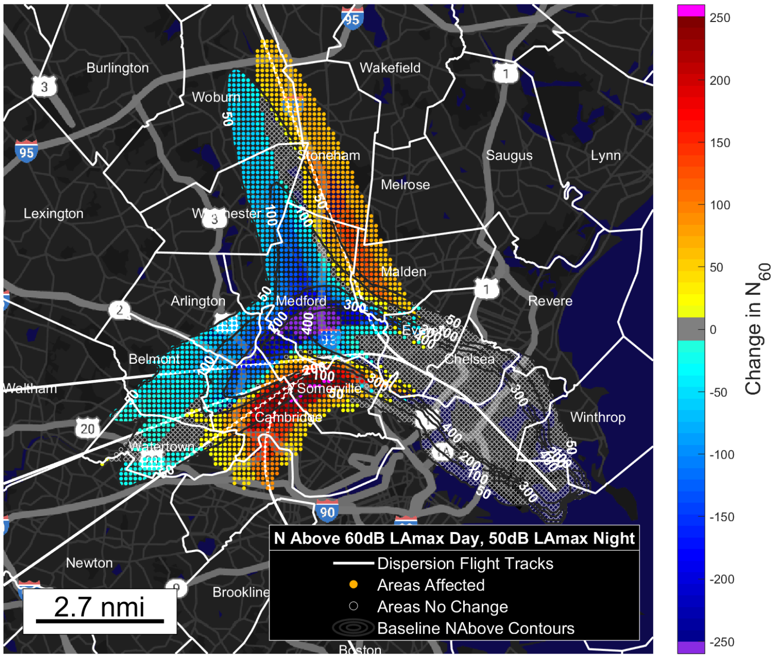
B. RWY 33L Divergent Headings Departure



	N_{60}>50 (Population Exposed)
Current procedure	335,823
Proposed procedure	363,759
Difference (Current - Proposed)	-27,936

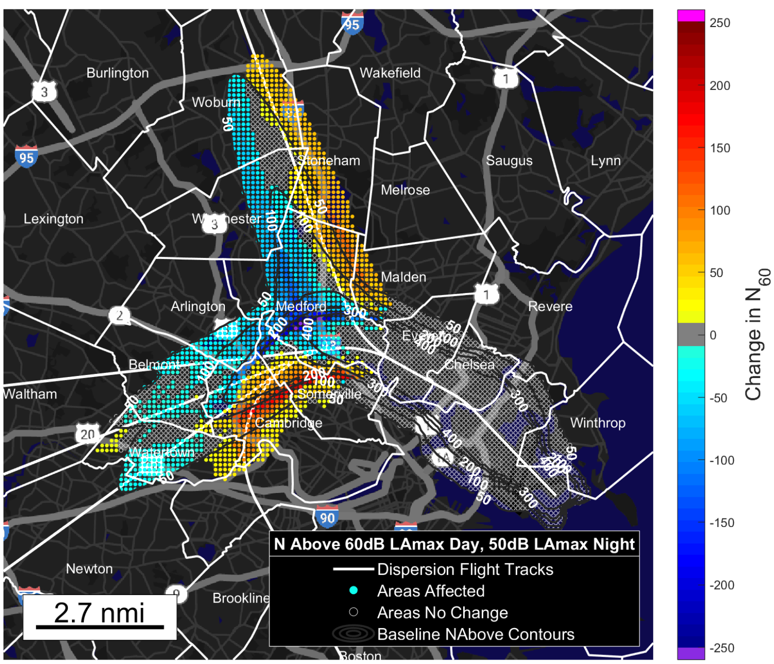
Figure 119. Divergent headings departure with initial heading of 330.

C. RWY 33L Waypoint Relocation



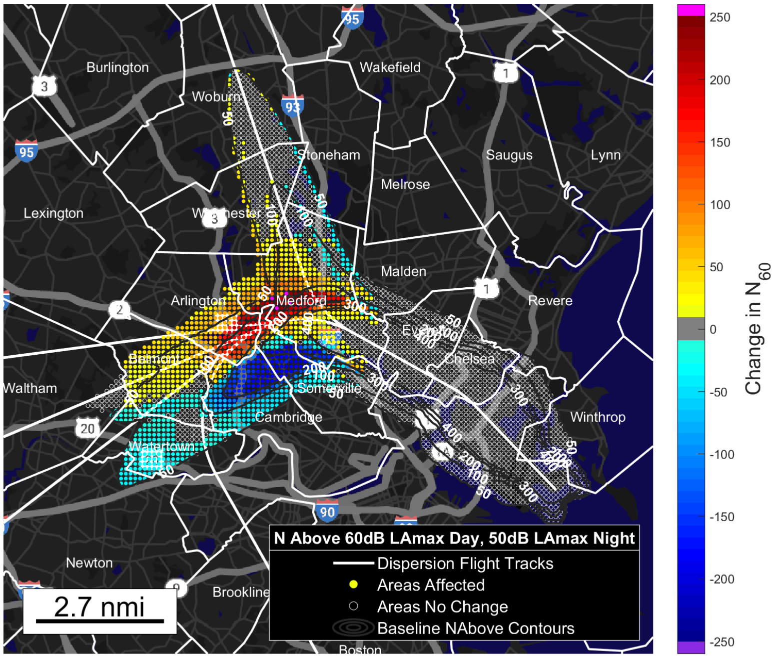
	N_{60}>50 (Population Exposed)
Current procedure	335,823
Proposed procedure	345,368
Difference (Current - Proposed)	-9,545

Figure 120. TEKKK moved "in" by 1 NM.



	N_{60}>50 (Population Exposed)
Current procedure	335,823
Proposed procedure	324,761
Difference (Current - Proposed)	11,062

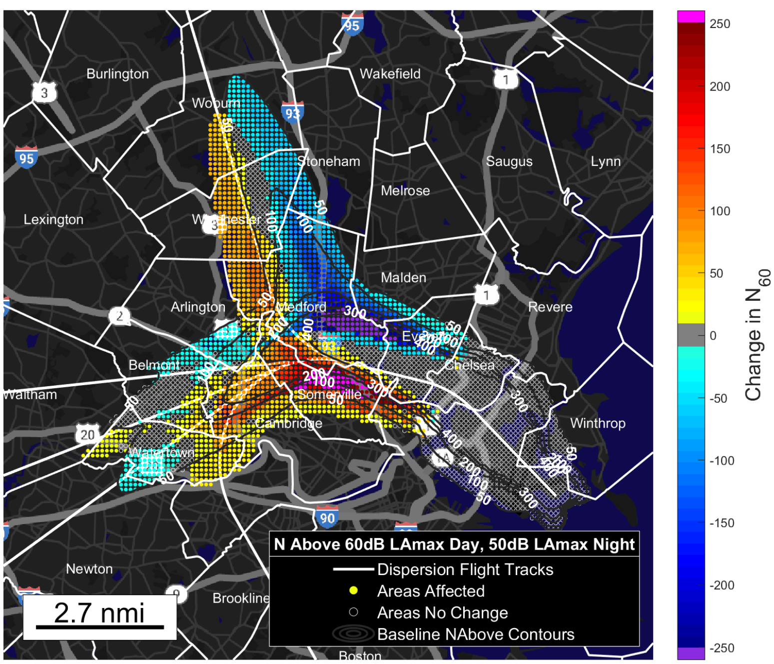
Figure 121. TEKKK moved "in" by 0.5 NM.



	N_{60}>50 (Population Exposed)
Current procedure	335,823
Proposed procedure	302,824
Difference (Current - Proposed)	32,999

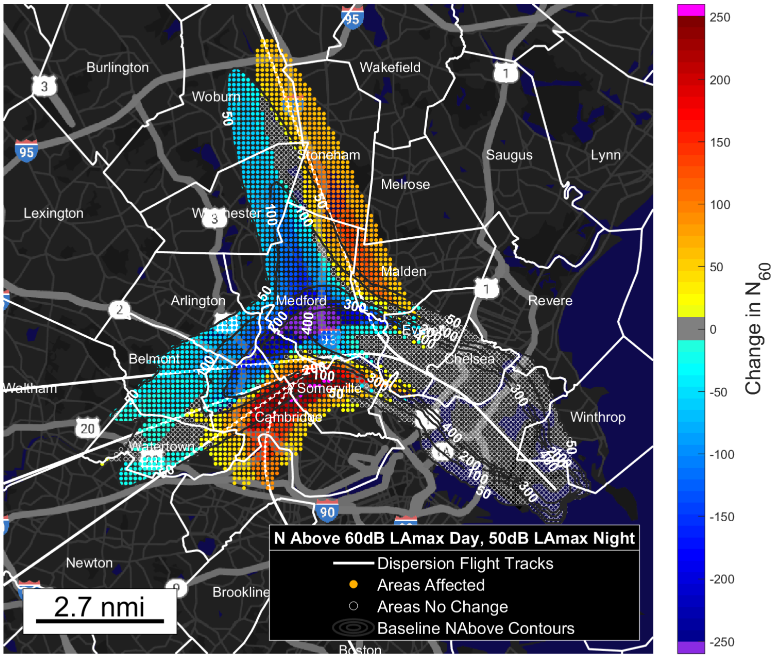
Figure 122. TEKKK moved "out" by 0.5 NM.

D. RWY 33L Variable Rotation Departures



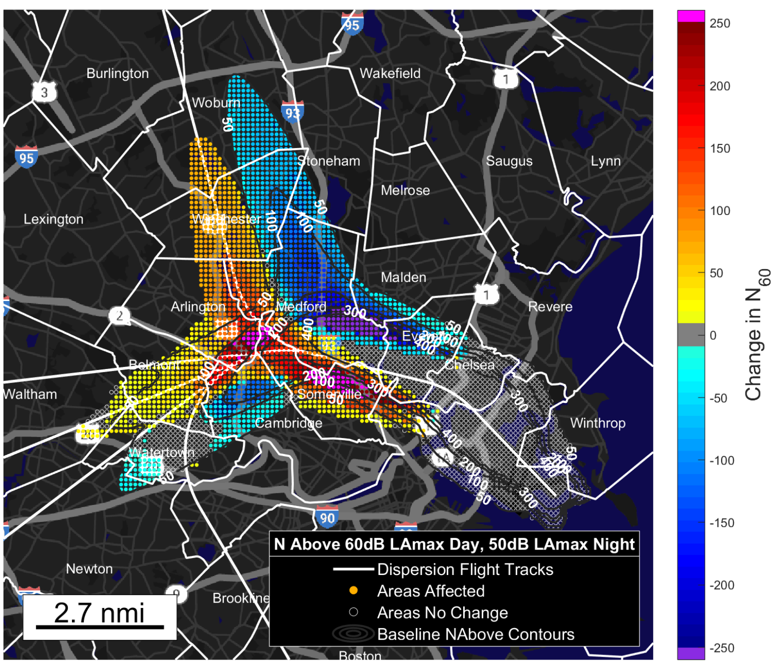
	N_{60}>50 (Population Exposed)
Current procedure	335,823
Proposed procedure	334,570
Difference (Current - Proposed)	1,253

Figure 123. VRD Waypoint 3.



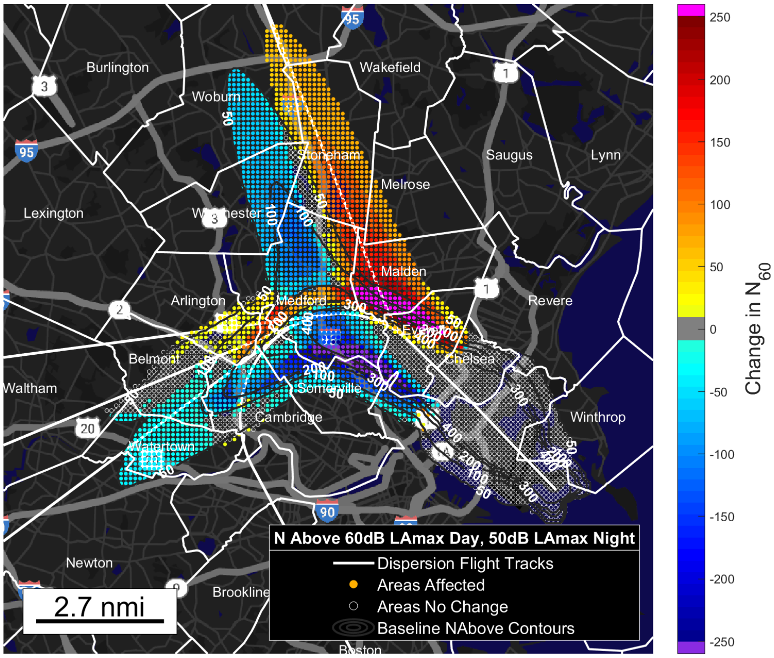
	N₆₀>50 (Population Exposed)
Current procedure	335,823
Proposed procedure	345,368
Difference (Current - Proposed)	-9,545

Figure 124. VRD Waypoint 4.



	N₆₀>50 (Population Exposed)
Current procedure	335,823
Proposed procedure	321,688
Difference (Current - Proposed)	14,135

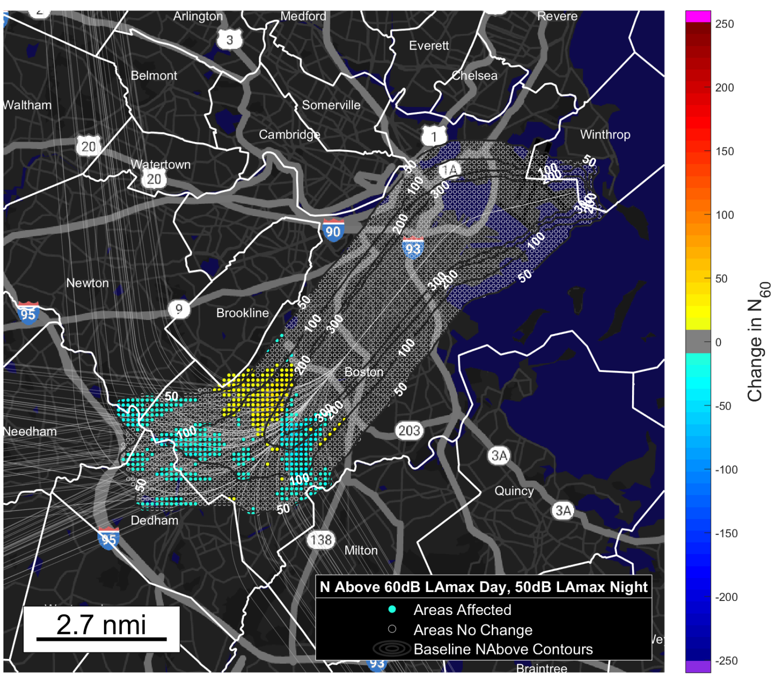
Figure 125. VRD Waypoint 5.



	$N_{60}>50$ (Population Exposed)
Current procedure	335,823
Proposed procedure	319,040
Difference (Current - Proposed)	16,783

Figure 126. VRD Waypoint 6.

E. RWY 27 Altitude-Based Dispersion



	$N_{60}>50$ (Population Exposed)
Current procedure	335,823
Proposed procedure	340,974
Difference (Current - Proposed)	-5,151

Figure 127. Altitude-based dispersion at 4000 ft.

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