NEXTNAV

October 21, 2024

Ms. Marlene H. Dortch
Secretary
Federal Communications Commission
45 L Street NE
Washington, DC 20054

Re: WTB and OET Seek Comment on NextNav Petition for Rulemaking
WT Docket No. 24-240 & RM-11989

Dear Ms. Dortch:

NextNav Inc. ("NextNav") recently filed a petition for rulemaking to allow it to use its licensed Lower 900 MHz spectrum to leverage 5G-network infrastructure to power a terrestrial, 3GPP-standard positioning, navigation, and timing ("PNT") backup and complement to the U.S. Global Positioning System ("GPS").[1] With this letter, NextNav supplements the record with a report from two leading economists, Coleman Bazelon and Paroma Sanyal of the Brattle Group. Their report (the "Brattle Report") provides an initial assessment of the economic value to the United States of the NextNav proposal, with a total quantified value of $14.6 billion, and the potential to save the American economy $663 million for one day of a global GPS outage.

The Brattle Report demonstrates the value of a terrestrial PNT backup and complement to GPS. To quantify the value of the terrestrial PNT approach enabled by reconfiguration of the Lower 900 MHz band, the Brattle Report focuses on two broad groups of benefits: (i) the value to specific segments of the economy, and (ii) the value to the military. The Brattle Group's economic analysis finds that a 1-day global GPS outage could cost the American economy $1.6 billion, and NextNav's proposal could prevent a loss of **$663 million** to the American economy.[2] For a 30-day outage, the loss could be as large as $58.2 billion, and the NextNav proposal could prevent **$31.9 billion** of that loss. Given the probability of outage events, the value to the American economy of the proposed terrestrial

[1] Petition for Rulemaking of NextNav Inc., WT Docket No. 24-240 & RM-11989 (filed Apr. 16, 2024).
[2] A report prepared for the National Institute of Standards and Technology estimates that a loss of GPS service would cost the U.S. economy $1 billion per day in 2017 dollars. $1.6 billion reflects Brattle Group's estimate of a 1-day value after adjusting for inflation. *See* Economic Benefits of the Global Positioning System (GPS), National Institute of Standards and Technology, RTI Project Number 0215471 (published June 2019).

PNT approach would be $10.8 billion. Thus, the NextNav proposal is the equivalent of offering the American economy a **$10.8 billion insurance policy** to protect against GPS outages. The Brattle Report found that the value of added resiliency to the military is **$3.8 billion**, based on the military's willingness to pay for GPS resilience and anti-jamming capabilities. The total quantified value of a GPS backup is **$14.6 billion** based on The Brattle Group's analysis.

<u>*Value to Private Sector.*</u> To calculate the value of a robust terrestrial PNT backup for critical segments of the economy, the Brattle Report treats the backup terrestrial PNT solution as an insurance policy for GPS outages. To calculate the cost to insure, the Brattle Report considers a sub-set of space events that could likely cause a global GPS outage (*e.g.*, solar storms of varying severity), the segments of the economy most heavily affected, the associated probabilities of such events occurring, and the duration of an outage. After adjusting for expected terrestrial PNT coverage, technical capabilities, and other factors, the aggregate losses in the United States that may be prevented by the existence of a backup to GPS for a 1-day, 7-day, and 30-day GPS outage are $663 million, $6.0 billion, and $31.9 billion, respectively. The Brattle Report then calculates the insurance premium to avoid these losses, which represents the value to these segments of the economy of having a backup to GPS. The Brattle Report calculates that the net present value of 20 years of insurance premiums equals $10.8 billion.

<u>*Value to Military.*</u> To calculate the value to the U.S. military of a terrestrial PNT back-up, the Brattle Report assesses the potential use cases (*i.e.*, PNT resiliency) and the military's willingness to pay for them. The Brattle Report notes that the military has explored using a more jamming-resistant signal, referred to as military code ("M-code"). M-code-capable GPS requires a space segment (M-code satellites), ground segment (an operational control center, or "OCX"), and user equipment. The Brattle Report focuses solely on the costs of OCX. Based on Government Accountability Office cost estimates, the Brattle Report estimates the cost of OCX for a global M-code system to be $7.7 billion, of which it attributes $3.8 billion to resiliency for the United States. The Brattle Report finds that this $3.8 billion would be the lower bound for what the U.S. military would be willing to pay for a robust backup to GPS.

<u>*Value to Public Safety.*</u> Finally, the Brattle Report examines a partial set of benefits from having a terrestrial PNT system that complements GPS. For example, first responders would benefit from more accurate location information, which would improve emergency services and save lives. The Brattle Report notes that in a related context, the Commission stated that reducing emergency response times by one minute via improved location accuracy for emergency services could be valued at $97 billion annually.[3]

In summary, the Brattle Report demonstrates that NextNav's proposal would result in substantial economic benefits to the United States, with no cost to taxpayers.

[3] *See Wireless E911 Location Accuracy Requirements*, Sixth Report and Order and Order on Reconsideration, 35 FCC Rcd 7752, ¶ 72 (2020).

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Please contact me with any questions about this submission.

/s/ Robert Lantz
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Public Benefits of Reconfiguring the Lower 900 MHz Band to Support a Backup and Complement to GPS

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Prepared For

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OCTOBER 18, 2024

Brattle

This report was prepared for NextNav, in accordance with The Brattle Group's engagement terms, and is intended to be read and used as a whole and not in parts.

The report reflects the analyses and opinions of the authors and does not necessarily reflect those of The Brattle Group's clients or other consultants.

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Executive Summary

NextNav is proposing to reconfigure the Lower 900 MHz band, which – when integrated into a 5G network – will allow NextNav to provide a cost-effective Positioning, Navigation, Timing (PNT) system designed to complement and back up current Global Positioning System (GPS) capabilities. The Lower 900 MHz band has a mix of incumbents comprising federal users, site-based operations in distinct geographic areas and Part 15 devices. This analysis focuses on benefits of reconfiguring this band. Those benefits would ultimately be weighed against the costs of the reconfiguration in evaluating the net benefits of the proposal to society.

NextNav's proposal to reconfigure the Lower 900 MHz band offers a significant opportunity to enhance the existing PNT infrastructure of the U.S. The integration of NextNav's technology with 5G networks promises to provide not only a robust backup for GPS but also to expand and enhance PNT services essential for various critical sectors. Having a GPS backup ensures that the economic benefits from the various sectors will not be lost in case of a GPS outage. To quantify this value, we focus on two broad segments – civilian or non-military value and a military-related value.

For the civilian value, our valuation approach recognizes that deploying a terrestrial GPS backup is similar to the nation obtaining an insurance policy for an adverse event that may or may not happen. To calculate the insurance premium, we first consider a subset of space events (such as solar storms and satellite debris) that could lead to a global GPS outage and the associated probabilities of such events occurring. These events are not meant to be exhaustive but are examples of commonly considered events that can cause GPS outages. The sub-set of space-related events under consideration can impact GPS services for varying durations. To make the analysis tractable, we categorize events into three mutually exclusive outage events – events that can cause a short-term (1 day) outage, events that can cause a medium-term (7 day) outage, and events that can cause a long-term (30 day) outage.

Next, we identify the sectors that are expected to be significantly affected by a GPS outage. We then quantify the total expected losses for each GPS-reliant sector by referencing existing studies that detail the potential economic impact of GPS disruptions on these industries. The aggregate loss that may be suffered by the U.S. for a 1-day, 7-day and 30-day GPS outage is $1.6 billion, $12.2 billion, and $58.2 billion, respectively. We then adjust these aggregate loss estimates by NextNav's coverage footprint (*i.e.*, where it would be available, which is the 5G footprint at the time it is deployed), technical capabilities, and other sector-specific factors. The aggregate loss addressable by NextNav, for a 1-day, 7-day and 30-day outage is $663 million, $6.0 billion, and $31.9 billion, respectively. We then calculate the insurance premium associated with various space events that can cause a GPS outage. This represents the value of having a backup to GPS. Based on a 20-year NPV, this value is $10.8 billion.

Next, we estimate the value of this technology for military use. Here we focus on the specific use case of resiliency functions, such as anti-jamming. This value is not well captured in an insurance framework. Thus, we use the military's willingness to pay for resiliency and anti-jamming technology for GPS as a proxy for the value of NextNav's technology for military purposes. This functionality is valued at $3.8 billion. Thus, combined with the civilian value, the total quantifiable value of the GPS complement and backup is $14.6 billion.

We also discuss the value of the additional positioning services that NextNav can provide, such as greater location precision in the x/y plane and relatedly better accuracy for vertical positioning (z-axis). Enhanced location accuracy across the x, y, and z axes can improve situational awareness for first responders and help PSAPs locate wireless 911 callers more rapidly. Enabling the deployment of NextNav's next-generation PNT service will provide incremental x/y and z axis positioning-related benefits through more accurate x/y positioning, which would lead to better z-axis positioning. Additionally, these functionalities would be integrated into the 5G network and would be available to PSAPs and first responders. We do not quantify the value of NextNav's enhanced location technology specifically with respect to emergency services. However, the Commission found that if emergency response times decrease by just one minute due to better location services, the nation could save $97 billion annually.

The strategic implications of creating a reliable backup to GPS extend beyond economic benefits; they encapsulate national security, public safety, and technological advancement. Ultimately, the integration of NextNav's functionalities into the existing PNT framework presents a unique, timely and actionable response to the vulnerabilities posed by our current reliance on satellite systems. As the demand for precise and reliable positioning, navigation, and timing services continues to grow, the strategic implementation of this terrestrial backup solution will be pivotal in ensuring the U.S. remains a leader in PNT capabilities well into the future.

I. Introduction

NextNav is proposing to reconfigure the Lower 900 MHz band, which, when integrated into a 5G network, will allow NextNav to provide a cost-effective Positioning, Navigation, and Timing (PNT) system designed to complement and back up current Global Positioning System (GPS) capabilities.[1] NextNav currently holds spectrum licenses in the 902-928 MHz band which it employs for its positioning technology.[2] It has petitioned the Federal Communications Commission ("FCC" or "Commission") for a reconfiguration of the band that will enable the establishment of a widespread, high-quality terrestrial PNT complement and backup for GPS.[3] The petition requests rule changes to allow 15 megahertz of low-band spectrum (5 megahertz uplink at 902-907 MHz and 10 megahertz downlink at 918-928 MHz) to be used for 5G mobile broadband, which is a prerequisite for NextNav's PNT deployment.[4]

The Lower 900 MHz band has a mix of incumbents. For instance, these include federal users, site-based operations in distinct geographic areas primarily supporting electronic highway tolling, railroad car tracking, and restricted area vehicle access.[5] Additionally, amateur radio operators use the band, and Part 15 devices utilize the Lower 900 MHz Band for various applications,

1 NextNav, "NextNav Lays Out New Vision for Complement and Backup to GPS with Additional Spectrum for Broadband Services," April 16, 2024, accessed September 15, 2024, https://nextnav.com/lays-out-new-vision/ ("NextNav Lays Out New Vision for Complement and Backup to GPS with Additional Spectrum for Broadband Services").

2 NextNav Lays Out New Vision for Complement and Backup to GPS with Additional Spectrum for Broadband Services.

3 *See*, Federal Communications Commission (FCC), "In the Matter of Enabling Next-Generation Terrestrial Positioning, Navigation, and Timing and 5G: A Plan for the Lower 900 MHz Band (902-928 MHz)," Petition for Rulemaking of NextNav Inc., April 16, 2024, accessed September 10, 2024, https://nextnav.com/wp-content/uploads/2024/04/Petition-for-Rulemaking-of-NextNav-Inc.pdf, ("NextNav Petition").

4 We understand that Federal and incumbent operations will be appropriately protected. The costs of doing so are not addressed in this report. *See*, NextNav Petition, pp. iv, 28-32.

5 *See*, NextNav Petition, p. 20. *See also*, NTIA, "902-928 MHz 1. Band Introduction 2. Allocations ," last accessed September 20, 2024, https://www.ntia.doc.gov/files/ntia/publications/compendium/0902.00-0928.00_01MAR14.pdf.

including RFID readers, utility and meter reading devices, and telemetry and security systems.[6] Given that cellular networks face significant increases in data demand, reconfiguring the 900 MHz band to provide more spectrum for low-band terrestrial mobile use will be valuable to consumers of wireless services. The FCC is seeking comments on all the associated costs and benefits of NextNav's proposal.[7]

We were asked to quantify the economic benefits of the terrestrial backup and complement to GPS that would result from NextNav's suggested modernization of the band to make it useable for 5G. Having a GPS backup ensures that the economic benefits from the various sectors will not be lost in case of a GPS outage. As discussed in detail in Section II, our primary valuation approach is in recognizing that deploying a terrestrial GPS backup is similar to the nation obtaining an insurance policy for an adverse event that may or may not happen. This is akin to buying an insurance policy for your house in the event of a flood or fire, in which the insurer calculates the probabilities of a fire happening within a certain time span, calculates the value of your house, and then calculates the expected value of a loss from a fire (its cost times the probability of a fire). As a homeowner, you pay an insurance premium for sure to avoid the risk of having to pay the full cost of rebuilding your house if there is a fire. In this case, we estimate both the cost of a GPS outage (the equivalent of the value of your house) and the probability of such an outage (the equivalent of the chance of a fire). We then calculate the insurance premium pursuant to a standard methodology. In this application, the U.S. government stands in for the homeowner and the insurance is for various space events that can cause a GPS outage. This then represents the insurance value of having a backup to GPS.

It is difficult to capture the back-up value of a terrestrial PNT service for military purposes using an insurance framework, in part because the value of the military use for national security is difficult to quantify and in part because the probabilities needed to calculate an insurance premium are not independent of the military use that would be insured. Consequently, in section III, we take an alternative approach to valuing the back-up value of NextNav's terrestrial PNT service for the military. Here we estimate the value of such a terrestrial GPS backup for the

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6 *See*, NextNav Petition, pp. 19-20. For a review of Part 15 devices see, "Code of Federal Regulations," Title 47, Chapter 1, Subchapter A – Part 15. https://www.ecfr.gov/current/title-47/chapter-I/subchapter-A/part-15.

7 FCC, "Wireless Telecommunications Bureau and Office of Engineering and Technology Seek Comment on NextNav Petition for Rulemaking," Public Notice, WT Docket No. 24-240, released August 6, 2024, https://docs.fcc.gov/public/attachments/DA-24-776A1.pdf.

Department of Defense (DoD) for military resiliency purposes, specifically resiliency functions such as anti-jamming. We use a willingness-to-pay approach and estimate the value of the terrestrial GPS backup based on how much the DoD is willing to pay to address the resiliency issue.

In Section IV, we bring together the estimates from the previous sections and briefly discuss the benefits that can accrue from additional complementary PNT services that NextNav can provide, such as enhanced indoor location accuracy (horizontal and vertical) for emergency services and first responders, often referred to as XYZ axis services.[8] Section V concludes.

II. Estimating the Value of a Terrestrial GPS Backup for Sectors of the U.S. Economy that Rely on GPS

A. Background

The U.S. GPS system offers precise PNT services and, globally, over six billion people use it. Currently there are 32 satellites that provide GPS signals.[9] The constellation needs 24 operational satellites to provide global coverage.[10] The constellation is constantly updated as older satellites come out of service and newer ones go into service.[11]

8 "In a series of orders in PS Docket No. 07-114, the Commission has adopted requirements for indoor location accuracy (horizontal and vertical) with 911 calls delivered by Commercial Mobile Radio Service (CMRS) providers. Links to these orders can be found in the resources section below." See FCC, "Indoor Location Accuracy Timeline and Live Call Data Reporting Template," accessed September 17, 2024, https://www.fcc.gov/public-safety-and-homeland-security/policy-and-licensing-division/911-services/general/location-accuracy-indoor-benchmarks.

9 Diana Furchtgott-Roth, "America Needs GPS Backup," Forbes, March 11, 2022, accessed September 16, 2024, https://www.forbes.com/sites/dianafurchtgott-roth/2022/03/10/america-needs-gps-backup/

10 GPS.GOV, "Space Segment," June 28, 2022, accessed September 16, 2024, https://www.gps.gov/systems/gps/space/, ("Space Segment").

11 Space Segment.

In the U.S., this service is crucial for the economy, with the number of GPS receivers increasing for 600 million to 900 million between 2015 and 2019.[12] In the last five years GPS has become even more ubiquitous, with GPS receivers supporting a wide range of applications, including vehicle navigation, general aviation, financial transactions, the electrical grid, precision agriculture, surveying, and construction.[13] Due to the critical role of GPS, several laws, including the National Timing Resilience and Security Act of 2018 (NTRS Act), mandate that the Department of Transportation (DoT), which is responsible for civilian GPS, develop a backup system.[14] The NTRS Act required this backup to be established by the end of 2020, but Congress has yet to provide the necessary appropriations.[15] The DOT has conducted field studies of "candidate PNT technologies that could offer complementary service in the event GPS disruptions," to assess the effectiveness of these technologies.[16] These demonstrations assessed technologies along 14 Measures of Effectiveness (MoEs) which also included assessing which technologies have a high Technology Readiness Level (TRL) and can function effectively as a GPS backup.[17] NextNav was the only company that was able to demonstrate a service capability across 4 timing and 4 positioning use cases.[18] NextNav's response also received the highest possible TRL score across 8 categories, including static and dynamic indoor and outdoor timing.[19] Thus, NextNav has the technical ability to provide terrestrial PNT that is part of a "system of systems" approach.[20]

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12 Space-Based Positioning Navigation and Timing, "National Space-Based Positioning, Navigation and Timing Advisory Board," p. 14, November 20-21, 2019, accessed October 14, 2024, https://www.gps.gov/governance/advisory/meetings/2019-11/minutes.pdf.

13 Directions 2023: Advancing GPS to Meet the Future.

14 U.S. DOT, "GPS Backup/Complementary PNT Demonstration," accessed September 16, 2024, https://www.transportation.gov/pnt/gps-backupcomplementary-pnt-demonstration ("GPS Backup/Complementary PNT Demonstration").

15 GPS Backup/Complementary PNT Demonstration.

16 Andrew Hansen, *et. al*, "Complementary PNT and GPS Backup Technologies Demonstration Report," DOT-Volpe Center, DOT-VNTSC-20-07. January 2021, accessed September 16, 2024, https://www.transportation.gov/sites/dot.gov/files/2021-01/FY%2718%20NDAA%20Section%201606%20DOT%20Report%20to%20Congress_Combinedv2_January%202021.pdf ("Complementary PNT and GPS Backup Technologies Demonstration Report").

17 Complementary PNT and GPS Backup Technologies Demonstration Report, p. 9.

18 The 9th category was specific to only one technology and was "N/A" for all other technologies. Also, NextNav received TRL9 for the network category. For the receivers, NextNav received TRL 8 for timing, and TRL 9 for positioning. See, Complementary PNT and GPS Backup Technologies Demonstration Report, Figure ES.1.MoE-1.

19 Complementary PNT and GPS Backup Technologies Demonstration Report, Figure ES.1. MoE-1; Figure ES.1. MOE-3.

20 Complementary PNT and GPS Backup Technologies Demonstration Report, Figure ES.2.

However, neither the 2021 Infrastructure Investment and Jobs Act, nor the 2022 Consolidated Appropriations Act have funding to support a backup to GPS.[21]

Industry analysts have identified several scenarios that can cause GPS failures. Among these, geo-magnetic storms and space-debris appear to be some of the greatest threats that can cause widespread outages.[22] Additionally, information corruption or signal jamming by criminals or nation states, and unintentional terrestrial failures can potentially have a significant impact on sectors that rely on GPS.[23] For instance, in 2014, the GLONASS system was completely unusable for 11 hours due to corrupt data issues.[24] In 2019, GALILEO, Europe's Global Navigation Satellite System (GNSS), was out for a full week from unknown causes.[25] In 2022, the U.S. experienced two significant GPS disruptions that involved interference with GPS signals at Denver International Airport and Dallas-Fort Worth International Airport.[26] In Denver, the incident lasted for 33 hours and impacted flights in the affected region at altitudes up to 36,000 feet.[27] In 2024, Estonia's second-largest airport experienced a temporary suspension of its only international route to Finland due to GPS interference and the absence of backup ground-based systems.[28] Such examples can be found in various sectors that depend on GPS, underscoring the importance of having a widespread GPS backup in the U.S..

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[21] H.R.3684 - Infrastructure Investment and Jobs Act, 117th Congress (2021-2022), accessed September 17, 2024, https://www.congress.gov/bill/117th-congress/house-bill/3684/text, H.R.2471 - Consolidated Appropriations Act, 2022, https://www.congress.gov/bill/117th-congress/house-bill/2471

[22] David Piesse, "Solar Storms and Cybersecurity," June 6, 2024, https://www.internationalinsurance.org/insights_solar_storms_and_cybersecurity.

[23] The combined effect of thousands of low-power jammers used daily across the nation can interfere with GPS signals, as can jamming by other domestic and foreign threat actors. However, in general, these are local.

[24] GPS World, "The System: GLONASS Fumbles Forward," May 1, 2014, last accessed September 25, 2024, https://www.gpsworld.com/the-system-glonass-fumbles-forward/#:~:text=In%20an%20unprecedented%20total%20disruption%20of%20a%20fully,to%204%20a.m.%20April%202%2C%20U.S.%20Eastern%20time%29.

[25] Lily Hay Newman, "Europe's Weeklong Satellite Outage Is Over—But Still Serves as a Warning," Wired, May 18, 2019, last accessed September 25, 2024, https://www.wired.com/story/galileo-satellite-outage-gps/.

[26] Lauren Miller, "Staying on Course: The Vital Role of GPS Backup Systems," The Space Review, July 22, 2024, accessed September 17, 2024, https://www.thespacereview.com/article/4832/1,"(Staying on Course: The Vital Role of GPS Backup Systems") Note: The event was caused "by a source unintentionally emitting an L1 frequency signal that interfered with GPS."

[27] Staying on Course: The Vital Role of GPS Backup Systems.

[28] Staying on Course: The Vital Role of GPS Backup Systems.

A *terrestrial* PNT system is a crucial component of a GPS backup because it ensures continued access to PNT services if space-based systems are disrupted or disabled. This redundancy helps maintain critical functions like navigation and infrastructure operations, protecting against the impacts of potential vulnerabilities and threats to satellite systems. Recognizing this need, the DoD and the Space Force have recently launched a grant program to research GPS-independent PNT services.[29]

The sub-sections that follow explain how we estimate the value of deploying a terrestrial GPS backup. As outlined earlier, this value is calculated as an insurance premium to insure the U.S. against the possibility of a GPS outage. Sub-section II.B lays out the insurance valuation framework. Next, we estimate the cost of a GPS outage to various sectors, and the probability of such an outage. Sub-section II.C discusses the various sectors that reply on GPS. Sub-section II.D discusses the events that can cause a GPS outage, the probability of such events, and the length of time that GPS can be disabled due to these events. Sub-section II.E discusses the loss that various sectors can potentially experience if GPS capabilities are affected for differing lengths of times. Given the technological parameters of NextNav's technology, Sub-section II.F estimates the portion of the aggregate losses that NextNav's terrestrial GPS backup system can likely address. In sub-section II.G, we calculate the insurance premium required to insure against various space events that can cause varying lengths of GPS outages. This then represents the value of having a backup to GPS.

B. Valuation for Civilian Sectors Using an Insurance Framework

This section lays out the insurance-based valuation framework. One way to conceptualize the valuation of a GPS backup system for civilian sectors is to view it as a form of insurance. Insurance is a way of managing risk. Most individuals would prefer to pay a small amount with certainty of

[29] Theresa Hitchens, "Space Force Agencies Pile on to Find 'Alternate PNT' Capabilities," Breaking Defense, March 5, 2024, accessed September 17, 2024, https://breakingdefense.com/2024/03/space-force-agencies-pile-on-to-find-alternate-pnt-capabilities/. *See also*, GAO "GPS Alternatives - DOD Is Developing Navigation Systems But Is Not Measuring Overall Progress," August 2022, last accessed September 2020, GAO-22-106010, https://www.gao.gov/assets/d22106010.pdf, ("GPS Alternatives - DOD Is Developing Navigation Systems But Is Not Measuring Overall Progress").

a safety net against a large potential financial loss.[30] This small amount, called the insurance premium, allows individuals to effectively redistribute their wealth across different possible outcomes. In other words, the premium reduces their overall wealth uniformly across all possible scenarios, but ensures they avoid catastrophic outcomes. Insurance mitigates such risks by protecting against these severe outcomes. In essence, insurance involves transferring wealth from favorable scenarios to adverse ones, providing a safety net against significant losses.

In a risky situation, one can ask, "What insurance premium would someone willingly pay to safeguard against catastrophic outcomes?" Here, the risky situation is to have a GPS system that is susceptible to outages. The cost of a GPS backup system can be viewed as an "insurance premium" against the risk of a GPS outage. By investing in this terrestrial backup system, a country incurs an upfront cost to ensure stability and reliability in its critical infrastructure. The insurance premium represents the amount one would be willing to pay for a GPS backup system to avoid the uncertainty and potential losses of GPS disruptions. Essentially, it provides a benchmark for assessing the value of investing in a backup system, ensuring that the cost of the backup aligns with the perceived risk and potential economic impact of GPS outages. Moreover, this perspective helps in understanding the value of a GPS backup system not just as a technological upgrade but as a strategic investment in risk management.

For a country, this insurance can be viewed under a public goods framework. The traditional definition of a public good in economics, rooted in Paul Samuelson's work from 1954, describes

[30] For instance, "loss aversion coupled with risk seeking on losses, make individuals eager to avoid small losses." *See*, David M. Cutler and Richard Zeckhauser, "Extending the Theory to Meet the Practice of Insurance," Harvard University and NBER, April 2004, accessed September 18, 2024, https://scholar.harvard.edu/files/cutler/files/cutler_zeckhauser_theory_and_practice_of_insurance.pdf, pp. 7, 10, pp. 22-25 ("Extending the Theory to Meet the Practice of Insurance"). *See also*, George A. Akerlof, "The Market for "Lemons": And Market Mechanism," The Quarterly Journal of Economics, Volume 84, Issue 3, August 1970 (488-500), accessed September 18, 2024, https://www.sfu.ca/~wainwrig/Econ400/akerlof.pdf. *See also*, Georges Dionne and Scott E. Harrington, "Insurance and Insurance Markets," Handbook of the Economics of Risk and Uncertainty, 1st Edition, W.K. Viscusi and M. Machina (Eds.), North Holland, Amsterdam, 203-261, 2014, accessed September 18, 2024, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2943685. Georges Dionne and Scott Harrington, "Insurance and Insurance Markets" (March 30, 2017). Handbook of the Economics of Risk and Uncertainty, 1st Edition, W.K. Viscusi and M. Machina (Eds.), North Holland, Amsterdam, 203-261, 2014.

it as a good that is both non-excludable and non-rival.[31] This means that individuals cannot be excluded from using it, and one person's consumption of the good does not reduce its availability for others. The production of public goods can result in market failure, which happens when the private market fails to produce outcomes that are efficient for society as a whole.[32] This failure is primarily due to the free rider problem, where individuals benefit from a public good without contributing to the costs of providing it.[33] Consequently, public goods are typically provided by governments rather than private entities.[34] GPS is a classic example of a public good and is therefore provided by the government. Thus, if the government wanted to provide a backup for GPS or insure against the risk of an outage, those too would be public goods. Thus, one can view the insurance premium itself as a public good, that suffers from a free-rider problem and has externalities associated with its service provision.[35] Due to the free-rider problem, individual entities who would benefit from the GPS backup do not have an incentive to pay for it, and hence will not fund the insurance premium. Additionally, there are significant positive externalities associated with GPS, such as military resiliency, which will not be captured by the private market.

In our analysis, we value NextNav's proposed terrestrial GPS backup based on the insurance premium for the catastrophic outcomes from which it can shield. We do this in five steps.

- First, we assess the potential loss that would occur if GPS functionality were lost for a period. We identify the sectors that are expected to be significantly affected by a GPS outage. This involves analyzing which industries heavily depend on GPS for their operations and currently lack backups and alternatives. We then quantify the expected losses for each sector reliant on GPS by referencing existing studies that detail the economic impact of GPS disruptions on these industries. Additionally, since the loss depends on the duration of the GPS outage, we

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31 June Sekera, "Public Goods in Everyday Life," Global Development And Environment Institute, Tufts University, pp. 4-5, 29, last accessed September 17, 2024, https://www.bu.edu/eci/files/2019/10/PublicGoods.pdf, ("Public Goods in Everyday Life").

31 Holcombe, Randall. "Public Goods Theory and Public Policy", 2000, The Journal of Value Inquiry. 34. 273-286. 10.1023/A:1004730424324.

32 Public Goods in Everyday Life, p. 29. Insurance and Insurance Markets.

33 Hardin, Russell and Garrett Cullity, "The Free Rider Problem", The Stanford Encyclopedia of Philosophy (Winter 2020 Edition), Edward N. Zalta (ed.), last accessed September 17, 2024, https://plato.stanford.edu/archives/win2020/entries/free-rider/, ("The Free Rider Problem").

34 Public Goods in Everyday Life, pp. 4-5.

35 The Free Rider Problem. *See also*, Econlib, "Market Failures, Public Goods, and Externalities," accessed September 17, 2024, https://www.econlib.org/library/Topics/College/marketfailures.html

estimate the impact for outage scenarios of 1 day, 7 days and 30 days. This provides an estimate of the total losses that sectors could experience from GPS outages.[36]

- Second, we consider various events that could lead to a global GPS outage, and the associated probabilities of such events occurring. There are many possible scenarios that can lead to a widespread GPS outage. We focus on a subset of these scenarios based on the severity of the risk and the availability of objective information to support our likelihood estimates. Moreover, by not including every possible scenario, we ensure that our estimates remain conservative. In our insurance framework, we focus on the likelihood of the extreme space weather affecting the GPS constellation. We also qualitatively discuss the risk of space debris harming the satellites in the GPS constellation. We do not include this type of event in our quantitative insurance framework, as the probability of a space debris collision event disabling a significant number of satellites and disrupting al GPS services is small. This exclusion makes our estimates conservative.
- Third, once we have identified these potential outage events, we assess the likelihood of each scenario by focusing on the probability of each event occurring. We rely on probability estimates derived by field experts.
- Fourth, since various space-related events can impact GPS services for varying durations, we combine the probability of each harmful space event with the expected length of the GPS outage. To make the analysis tractable, we categorize potential outages into three types of space events - those that can cause a short-term (1 day) outage, those that can cause a medium-term (7 day) outage, and those that can cause a long-term (30 day) outage.[37]

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36 We do not include any sub-1-day outage events as the at-risk value is likely unaffected by these events. Additionally, there could be some tail scenarios where a GPS outage may last more than 30 days. Limiting our estimates to our three scenarios makes our estimates conservative.

37 The RTI International Report focuses on a 30-day outage scenario. *See*, RTI International, "Economic Benefits of the Global Positioning System (GPS)", June 2019, accessed October 18, 2024, https://www.rti.org/sites/default/files/gps_finalreport618.pdf?utm_campaign=SSES_SSES_ALL_Aware2019&utm_source=Press%20Release&utm_medium=Website&utm_content=GPSreport, ("Economic Benefits of the Global Positioning System (GPS)". However, the probability of smaller solar storms causing shorter and medium-term outages is higher than a more severe solar storm causing a 30-day outage. Thus, we chose two additional scenarios (1-day and 7-day outage) that would reflect the effect of solar storms of varying severity on GPS outages. We do not address a scenario beyond 30-days as it is difficult to predict.

- Fifth, with probabilities and potential losses determined, the valuation of a GPS backup system is conducted using an insurance framework.[38] The insurance framework calculates the anticipated benefit of a GPS backup by multiplying the probability of each outage event by the estimated loss for each sector, then aggregating these values. This estimation is done at a sector level, as the impact of varying lengths of GPS outage is different for each sector. This provides a measure of the expected losses of not having a backup system, which in turn provides the value of a terrestrial GPS backup.

C. GPS Usage in Various Sectors

In this section, we identify the sectors that heavily rely on GPS, summarize the applications of GPS technology across these sectors, and summarize the potential effects of a widespread GPS outage on each sector. Details of each of the sectors we include in our analysis are provided in Table 1. Based on the applications and potential effects in each sector, we calculate estimates of potential losses incurred by each sector.

GPS technology serves three major functions: positioning, navigation, and timing. Positioning refers to the ability of GPS to determine the precise location of an object or individual relative to the Earth's surface. Navigation refers to the ability to determine current and desired position and apply corrections to course leading to the desired position. Timing refers to the ability to provide extremely precise time references. The applications of these functionalities vary by sector. Table 1 summarizes the applications of GPS for each sector.

[38] *See*, Extending the Theory to Meet the Practice of Insurance. *See also*, Richard Zeckhauser, "Insurance," Econlib, accessed September 18, 2024, https://www.econlib.org/library/Enc/Insurance.html.

TABLE 1: A SUMMARY OF SECTOR-BASED GPS APPLICATIONS

Sector	Applications of GPS [A]
Finance	GPS timing signal is used to time stamp financial transactions.
Electricity	GPS timing signal is used for synchronizing electrical waves in the power grid and detect faults in the infrastructure.
Surveying	GPS location signal is used for lowering the costs of surveying tasks.
Mining	GPS location signal is used for exploring promising ore bodies and support mine-site processes.
Oil and gas	GPS location signal is used in exploration and production operations.
Location-based services	GPS location signal is used for location information and turn-by-turn navigation services.
Telematics	GPS location signal is used for increasing operational efficiency.
Telecommunications	GPS timing signal is used for synchronizing the network.
Maritime	GPS location signal is used in commercial shipping, fishing and recreational boating for navigation and tracking.
Agriculture	GPS location signal is used in precision farming, which enables farmers to efficiently monitor and manage crops.

Sources and Notes:
[A]: RTI International, "Economic Benefits of the Global Positioning System (GPS)," June 2019, https://www.rti.org/sites/default/files/gps_finalreport618.pdf?utm_campaign=SSES_SSES_ALL_Aware2019&utm_source=Press%20Release&utm_medium=Website&utm_content=GPSreport. For specific examples and industry wide summaries of GPS applications, *see*, Tables ES-1 and 1-2, in addition, *see*, Finances: 7-1, Electricity 6-1, Surveying 12-1, Mining 10-1, 11-1, Location-based services 8-1 and 13-2, Telematics 13-1, Telecommunications 4-1, Maritime 9-1, and Agriculture 5-1.

As seen from Table 1, the finance, electricity and telecommunications sectors rely on GPS for timing applications, where precise time synchronization is crucial for financial transactions, network operations, and power grid stability. In contrast, the surveying, mining, oil and gas, location-based services, telematics, maritime, and agriculture sectors leverage GPS primarily for positioning. Accurate location data is used for tasks such as land surveying, resource extraction, navigation, and precision farming.

Table 2, we provide an overview of potential effects that can be suffered by each sector due to a widespread GPS outage.

TABLE 2: SECTOR-BASED IMPACTS OF A WIDESPREAD GPS OUTAGE

Sector	Effects of a GPS Outage [A]
Finance	The effects would be minimal as there are existing alternatives to GPS in place.
Electricity	The probability of outages would increase. But a widespread failure is unlikely as there are already safeguards in place.
Surveying	There would be delays, higher costs and productivity losses in activities.
Mining	The efficiency of mining work practices would decrease.
Oil and gas	Offshore exploration, development, and construction operations would be disrupted.
Location-based services	Some location services use additional sources such as Wi-Fi and cell towers for location information. However, some of the technologies use the GPS as critical input and thus, the accuracy of these location services would decrease significantly. Other non-GPS loaction signals are not as accurate.
Telematics	There would be losses in labor and fuel savings benefits.
Telecommunications	The quality of services would degrade.
Maritime	The largest impacts would be interruptions in port operations leading to supply-chain disruptions.
Agriculture	The efficiency of farm management would decrease, which can cause lower yields. The effects are negligible if the outage happens outside of the crop planting season.

Sources and Notes:
[A]: RTI International, "Economic Benefits of the Global Positioning System (GPS)," June 2019, https://www.rti.org/sites/default/files/gps_finalreport618.pdf?utm_campaign=SSES_SSES_ALL_Aware2019&utm_source=Press%20Release&utm_medium=Website&utm_content=GPSreport, Table 3-2.

D. Estimating the Expected Probabilities of Space-Related Events That Can Impact GPS Functionality

In this section, we consider events that could lead to a significant GPS outage, focusing on varying degrees of extreme space weather as the primary type of threat.[39] We chose to focus on this type of event because they have the potential to cause more extensive outages due to their broader impact on satellite systems.[40] For instance, NOAA explains that when geomagnetic storms occur, they "create large disturbances in the ionosphere. GPS systems cannot correctly model this

39 "GPS radio signals travel from the satellite to the receiver on the ground, passing through the Earth's ionosphere. …..In the absence of space weather, GPS systems compensate for the "average" or "quiet" ionosphere, using a model to calculate its effect on the accuracy of the positioning information. But when the ionosphere is disturbed by a space weather event, the models are no longer accurate and the receivers are unable to calculate an accurate position based on the satellites overhead." *See*, NOAA Space Weather Prediction Center, "Space Weather and GPS Systems," accessed October 14, 2024, https://www.swpc.noaa.gov/impacts/space-weather-and-gps-systems, ("Space Weather and GPS Systems").

40 Robert Wells, "New NASA-funded Study Hopes to Put Risks of Space Junk on People's Radar," UCF Today, October 13, 2022, accessed September 17, 2024, https://www.ucf.edu/news/new-nasa-funded-study-hopes-to-put-risks-of-space-junk-on-peoples-radar/. *See also*, Space Weather and GPS Systems.

dynamic enhancement and errors are introduced into the position calculations."[41] We estimate the probabilities of these events using existing risk analyses by field experts. For the insurance-based model, we do not focus on events such as jamming and spoofing, as these typically result in localized disruptions to GPS signals, affecting specific regions or users rather than causing more widespread outages.

1. Harm Due to Extreme Space Weather

Extreme space weather can significantly impact GPS functionality. As GPS signals travel from satellites to ground receivers, they pass through the Earth's ionosphere, which can distort the signals. Under normal conditions, GPS systems can correct this distortion. However, during space weather events, such as geomagnetic storms, these safeguards fail, leading to large errors in the transmitted positioning and timing data.[42] The likelihood of space weather affecting GPS systems depends on the severity of the event. More extreme space weather is more likely to affect the GPS system and cause an outage. However, more extreme space weather events are also less likely to occur.

We base our estimates on a 2020 research paper that characterizes the likelihood of geomagnetic storms of varying intensities, using data that dates to 1868.[43] The severity of the geomagnetic storms is categorized in three levels, (i) a "Severe" storm that can potentially cause a short-term GPS outage, (ii) a super-storm than can cause a medium-term outage; and (iii) a "Carrington-class" storm that can cause a longer term outage.[44] Table 3 summarizes the probabilities of different categories of geomagnetic storms.

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[41] Space Weather and GPS Systems.

[42] Space Weather and GPS Systems. *See also*, Civilian applications of GPS – Timing.

[43] S.C. Chapman, R.B. Horne and N.W. Watkins, "Using the AA Index Over the Last 14 Solar Cycles to Characterize Extreme Geomagnetic Activity,'' Geophysical Research Letters, January 22, 2022, accessed September 17, 2024, https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019GL086524 ("Using the AA Index Over the Last 14 Solar Cycles to Characterize Extreme Geomagnetic Activity"). The significance of this research paper is that they can estimate the likelihood of a Carrington-class superstorm occurring, which "can be used for planning the level of mitigation needed to protect critical national infrastructure."

[44] The Carrington Event was a massive solar storm in 1859 that caused widespread damage to telegraph systems, which were the primary means of long-distance communication at the time. Because of the superstorm, telegraph lines sparked fires and operators received electric shocks, leading to significant operational losses. See Using the AA Index Over the Last 14 Solar Cycles to Characterize Extreme Geomagnetic Activity.

2. Qualitative Discussion of Harm Due to Space Debris Impacting the GPS Infrastructure

Collision with space debris is a serious risk for any space mission and the mitigation of collision risk is an ongoing effort.[45] NASA estimates that over 100 million objects with a size of 1 mm and smaller are in Earth's orbit.[46] Even though these objects are very small, they can cause damage when traveling at extreme orbital speeds.[47] The space environment is monitored to prevent possible collisions, but very small objects are challenging to track. Analysts have estimated that 19% of tracked space objects threaten the GPS constellation.[48] Additionally, a substantial number of untracked debris objects measuring less than 10 cm in size can be found in or passing through the medium earth orbit (MEO).[49] NASA states that objects with diameters between 1 cm and 10 cm pose the greatest risk because they lack tracking data, rendering them essentially invisible.[50] Moreover, debris in Low Earth Orbit (LEO) can eventually drift to higher orbits or interact with MEO debris.[51] Also, as the number of space missions increases, the space debris problem is expected to worsen in the future.[52]

A recent event involving one of the satellites in the Galileo global navigation satellite constellation shows how imminent this risk can be.[53] In March 2021, the Galileo satellite GSAT0219 had to perform a collision-avoidance maneuver to avoid space debris.[54] The satellite was taken out of service on March 5 shortly before the collision-avoidance maneuver was performed, and wasn't reintroduced into service until March 19.[55] Although the maneuver was

45 NASA, "The Orbital Debris Issue," accessed September 17, 2024, https://orbitaldebris.jsc.nasa.gov/ ("The Orbital Debris Issue").

46 The Orbital Debris Issue.

47 The Orbital Debris Issue.

48 Ken Eppens, "Space Debris Endangers GPS," GPS World, May 25, 2021, accessed September 17, 2024, https://www.gpsworld.com/space-debris-endangers-gps ("Space Debris Endangers GPS").

49 Space Debris Endangers GPS.

50 Space Debris Endangers GPS.

51 Space Debris Endangers GPS.

52 Space Debris Endangers GPS.

53 Tracy Cozzens, "Galileo Satellite Performs Collision Avoidance Maneuver," GPS World, March 25, 2021,accessed September 17, 2024, https://www.gpsworld.com/galileo-satellite-performs-collision-avoidance-maneuver/ ("Galileo Satellite Performs Collision Avoidance Maneuver ").

54 Galileo Satellite Performs Collision Avoidance Maneuver.

55 Galileo Satellite Performs Collision Avoidance Maneuver.

successfully executed, the satellite was not operational for 14 days, showing that space debris can indeed threaten the GPS system.[56]

However, we do not include this type of event in our quantitative insurance framework, as the probability of a space debris collision event disabling a significant number of satellites and disrupting all GPS services is small. This non-inclusion makes our estimates conservative.

3. Summary of the Probability Estimates

As discussed briefly earlier, various space-related events can impact GPS service differently. For instance, different events can potentially cause outages of varying durations.[57] Each event's specific characteristics, such as the severity and extent of the event, can result in different lengths of disruption. While we recognize that these categorizations are a simplification of the continuous nature of potential outages, they are helpful in managing the complexity of potential disruptions. By defining these discrete levels, we aim to capture a range of possible scenarios with varying levels of impact. We group these space events into three outage levels: 1 day, 7 days and 30 days. Table 3 summarizes this information below.

TABLE 3: ESTIMATED PROBABILITIES FOR SPACE EVENTS THAT CAN CAUSE A NATIONWIDE GPS OUTAGE

Event		Estimated Probability of Causing an Outage in a Given Year	Outage length
		[A]	[B]
Severe Geomagnetic Storm	[1]	0.2800	1-day
Great Geomagnetic Storm	[2]	0.0400	7-day
Carrington-Class Geomagnetic Storm	[3]	0.0070	30-day

Sources and Notes:

[56] Galileo Satellite Performs Collision Avoidance Maneuver.

[57] *See* Section II.A for a discussion of recent major outages. These space events, such as geomagnetic storms, are not uncommon. As recently this month, there were warnings for a severe geomagnetic storm that could potentially affect GPS operations. *See*, Brittany Kriegstein, "NYC Officials Warn 'Potential Severe Geomagnetic Storm' Could Disrupt Critical Systems," Gothamist, October 9, 2024, accessed October 15, 2024, https://gothamist.com/news/nyc-officials-warn-potential-severe-geomagnetic-storm-could-disrupt-critical-systems.

[A][1],[A][2],[A][3]: Using the AA Index Over the Last 14 Solar Cycles to Characterize Extreme Geomagnetic Activity. S.C. Chapgam, R.B. Horne, and N.W., Watkins," Using the aa Index Over the Last 14 Solar Cycles to Characterize Extreme Geomagnetic Activity," Geophysical Research Letters, January 22, 2020, accessed September 17, 2024, https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019GL086524.
[B]: Assumed GPS outage length conditional on the event occurring.

While we recognize that an event causing a longer outage could also result in shorter-term outages (*e.g.*, a great geomagnetic storm, which is grouped under 7-day outage events can also cause a 1-day outage) dividing each event into all these potential durations would necessitate making *ad hoc* assumptions due to a lack of data on these intricacies. To avoid the complexities and uncertainties associated with such assumptions, we have opted for this simplification.

E. Impact of a GPS Outage on Various Sectors

In this section, we discuss the loss that various sectors can potentially experience if GPS capabilities are affected for various time periods. The starting point of our estimates is the 2019 report by RTI International, commissioned by National Institute of Standards and Technology (NIST), that studies the economic benefits of the GPS and calculates the potential impact of a 30-day GPS outage.[58] We describe the effect on the telecommunications sector in detail and then summarize the other sectors.

Based on the RTI International report and our calculation for the telecommunications sector, Table 4 below shows the total estimated sector-specific losses (adjusted for inflation) that would be potentially incurred for a 1-day and 7-day outage scenario for sectors reliant on GPS. We observe that just a 1-day outage can lead to a $1.6 billion loss, while a 30-day outage can cost the U.S. economy as much as $58.2 billion.[59] Additionally, for a 30-day outage, the largest impact is on agriculture, maritime, telecommunications and telematics.

58 Economic Benefits of the Global Positioning System (GPS).

59 The RTI Report estimates that a loss of GPS service would cost the U.S. economy $1 billion per-day in 2019 2017 dollars. $1.6 billion reflects Brattle's estimate of the value lost with a 1-day GPS outage based on adjusting the RTI report's estimates for inflation and industry-specific impact. *See*, Economic Benefits of the Global Positioning System (GPS), p. 17.

TABLE 4: POTENTIAL LOSSES FROM A 1-DAY, 7-DAY, AND 30-DAY GPS OUTAGE

Sector		Potential Losses ($ million)		
		1-day Outage [A]	7-day Outage [B]	30-day Outage [C]
Agriculture (soil mapping)	[1]	$650	$4,552	$19,507
Maritime	[2]	$448	$3,134	$13,430
Telecommunications	[3]	$48	$1,563	$12,663
Telematics	[4]	$178	$1,245	$5,337
Location-based services	[5]	$123	$861	$3,688
Oil and gas	[6]	$65	$458	$1,961
Mining	[7]	$41	$286	$1,224
Surveying	[8]	$14	$100	$427
Electricity	[9]	$12	$83	$355
Finance	[10]	Negligible	Negligible	Negligible
Total		**$1,567**	**$12,197**	**$58,237**

Sources and Notes:

We adjust 2017 values to 2024 dollars by multiplying values by 1.29. *See*, U.S. Inflation Calculation, "Inflation Calculator," accessed October 13, 2024, https://www.usinflationcalculator.com/.

[A]: [C]/[30] except for Telecommunications.

[B]: [A]*[7] except for Telecommunications.

[C]: *See*, RTI International, "Economic Benefits of the Global Positioning System (GPS)", Table 14-2, June 2019, accessed September 17, 2024 https://www.rti.org/sites/default/files/gps_finalreport618.pdf?utm_campaign=SSES_SSES_ALL_Aware2019&utm_source=Press%20Release&utm_medium=Website&utm_content=GPSreport.

[3]: Note, the losses incurred by the telecommunication sector is non-linear. The loss for a GPS outage depends on the decrease in the wireless network functionality, which decreases in a nonlinear way. Thus, a 1-day outage is not equal to the 30-day outage divided by 30 for the telecommunications sector. For other sectors, the effect is assumed to be linear. *See*, Table 4-9 in RTI International, "Economic Benefits of the Global Positioning System (GPS)." We obtain the 1-day value by only looking at the damages in day 1, and we obtain 7-day value by summing up the damages for the first 7 days.

F. Estimating Sector-Specific Losses Addressable by NextNav's GPS Backup System

In the previous sub-section, we discussed the impact of a GPS outage on various sectors of the economy. However, we recognize that even if NextNav deploys a GPS backup technology, it will not be able to mitigate the entire loss. This is because, amongst other things, the NextNav technology is going to be deployed via a partner's 5G network. This implies that the 5G coverage area imposes a limit on where the backup GPS will be available.[60] To account for this and other adjustments, we use the initial estimates of lost revenues provided by an RTI International study (Table 4), (except for telecommunications) and adjust these for NextNav specific adjustments, such as geographic availability. Below, we provide our estimate of aggregate losses for a 1-day, 7-day and 30-day outage for the telecommunications sector and then summarize the losses for other sectors.

1. Telecommunications

In this section, we estimate the value of a GPS backup for the telecommunications sector. We focus on the telecommunications sector to demonstrate the calculations because the sector is highly dependent on GPS, so a significant portion of the economic value for a GPS backup system is generated from it. The calculations for other sectors follow similar steps.

We begin with describing the effects of a 30-day outage in the telecommunications sector. The telecommunications sector uses GPS as the primary source of precise timing information that synchronizes their networks. In the event of a GPS outage, telecommunications networks must rely on secondary sources for their precise timing information. One example of these secondary sources are atomic clocks, which can keep precise time for a few days to over a month.[61] It is assumed that wireline networks, which have sophisticated atomic clocks that can keep precise time for a time duration, would remain unaffected by a 30-day outage.[62] However, wireless networks are generally not well-equipped with these atomic clocks to keep precise time for a long period in the event of a GPS outage.[63] Most base stations are equipped with relatively basic and cheaper clocks with short holdover capabilities, which makes them more susceptible to disruptions in GPS service.[64] Thus, in the event of a 30-day outage, the quality of service would

60 In our model we use the footprint of the entire 4G/LTE area to proxy for the 5G coverage in the near future. Currently two of the national providers have 4G/LTE footprints that are generally comparable and well approximated by the national 4G/LTE footprint. We recognize however, that if the NextNav technology is deployed on a partner network that is more limited than the national 5G footprint, our estimates will need to be adjusted.

61 Economic Benefits of the Global Positioning System (GPS), p. 4-11.

62 Economic Benefits of the Global Positioning System (GPS). p. 4-15.

63 Economic Benefits of the Global Positioning System (GPS). p. 4-17.

64 Economic Benefits of the Global Positioning System (GPS). pp. 4-5.

start to degrade, as less sophisticated clocks will begin to show errors after a few minutes to hours without GPS. The degradation of the service is characterized by “failure of handovers from one base station to another,” “increased call drops and lost frames in video,” and “a general slowdown in data speeds.”[65]

The lost revenue due to a 30-day GPS outage is calculated as a percentage of the total revenue that telecom service providers would lose from wireless users during such an outage. The wireless revenue in 2023 for the top three wireless telecommunication carriers was approximately $270 billion, implying a daily value of $739 million.[66] To obtain the percentage of revenues lost from a GPS outage, we rely on the RTI International estimates of the impact of a GPS outage on the telecommunications sector. RTI International conducted interviews with telecom experts to qualitatively describe what might happen in the next 30 days following a GPS outage. These qualitative estimates were then converted into quantitative estimates of the percentage of wireless network functionality lost for each of the 30 days following a GPS outage. The report shows that for telecommunications, the impact on wireless functionality would be minimal for the first 48 hours. After this period, service quality would decline rapidly, as handovers become less dependable and data speeds start to drop. Around day 4, the rate of service degradation would slow down, but continue to degrade.[67] Note that the impact on the wireless functionality is nonlinear, *i.e*., the rate at which service quality drops is not constant over time. This means that the initial drop in service quality is much more pronounced than the decline expected to see in the later days. Finally, these percentages are multiplied by the average daily revenue to get an estimate for value lost with a 1-day, 7-day and 30-day outage.[68]

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[65] Economic Benefits of the Global Positioning System (GPS). p. 4-16

[66] Verizon reported the highest wireless revenue of any major U.S. telecommunications provider in 2023, generating $107.22 billion followed by AT&T and T-Mobile with $83.98 billion and $78.56 billion respectively. *See*, Statista, “Wireless Revenue Generated by Major U.S. Telecommunication Providers from 2011 to 2023,” accessed September 27, 2024, https://www.statista.com/statistics/199796/wireless-operating-revenues-of-us-telecommunication-providers/.

[67] Economic Benefits of the Global Positioning System (GPS) *See,* Figure 4-4.

[68] Economic Benefits of the Global Positioning System (GPS) *See,* Table 4-9 in “for the damages estimate for each day.

2. Adjustments Made to Address NextNav's Technology and Coverage Boundaries

We make two types of adjustments to the RTI International estimates. The first is a geospatial overlap adjustment. Since NextNav's technology is going to be deployed on a partner's 5G network, it will benefit various sectors only in the areas where the 5G network is available. We use current 4G network coverage to proxy the reach of 5G networks in the near future. For agriculture we adjust the value by the overlap between farmland and the 4G LTE network (98.8%), for maritime the value is adjusted by the percentage overlap between the navigable waterways and the 4G/LTE network 49.3%, for telematics, we adjust it with a 4G LTE coverage of road miles 92.1%, and for the rest of the sectors, the value is adjusted by the 4G LTE coverage of total U.S. square miles 72.7%.[69] Second, we account for the fact that each sector is impacted differently by a potential GPS outage, both in terms of how the length of outage affects activities in the sector and how it is affected. This is primarily implemented for agriculture, where we adjust for the cropping season and the fact that NextNav's backup GPS service will not address some enhanced GPS services used by precision agriculture.[70] The final adjustment for agriculture brings down the total adjustment to 6.39%. All these three types of adjustments are described in Appendix B.

We then calculate potential losses for 1-day and 7-day outage scenarios, based on the potential losses calculated for the 30-day outage scenario. Potential losses incurred by each sector for each outage scenario are summarized in Table 5. We find that the losses that can potentially be prevented if NextNav's GPS backup is deployed is $663 million if there is a 1-day GPS outage, $5.9 billion if there is a 7-day GPS outage and $31.9 billion if there is a 30-day GPS outage.[71]

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[69] For further details on these adjustments, *see*, Appendix B.

[70] The cropping season adjustment is done because, GPS failure during this season has a significant negative impact, whereas outside this season, the impact is far more limited. Enhanced GPS is primarily used for soil mapping which requires high precision levels.

[71] A report by the Homeland Security and Operational Analysis Center estimates that an aggregate loss of $804 million – $987 million (2018 dollars) for a 3-day loss of GPS due to a solar storm. *See*, "Analyzing a More Resilient National Positioning, Navigation, and Timing Capability, Table 6.6, p. 127.

TABLE 5: POTENTIAL LOSSES BY SECTOR DUE TO A GPS OUTAGE ADDRESSABLE BY NEXTNAV

Sector		Potential Losses ($ million)		
		1-day Outage [A]	7-day Outage [B]	30-day Outage [C]
Telecommunications*	[1]	$51	$1,670	$13,528
Maritime	[2]	$221	$1,545	$6,620
Telematics	[3]	$164	$1,147	$4,915
Location-based services	[4]	$89	$626	$2,681
Oil and gas	[5]	$48	$333	$1,426
Agriculture (soil mapping)	[6]	$42	$291	$1,247
Mining	[7]	$30	$208	$890
Surveying	[8]	$10	$72	$310
Electricity	[9]	$9	$60	$258
Finance	[10]	Negligible	Negligible	Negligible
Total		**$663**	**$5,951**	**$31,875**

Sources and Notes:

[A]: [C]/30 (except for telecommunications)

[B]: [A]*7 (except for telecommunications)

[C]: *See,* Table 4 column [C]. For telecom, *see* notes below. Since the estimates are not from 2024, we multiply them according to the values for the year in which the data is available, 1.29 for the RTI 2017 values, and 1.03 for the 2023 telecom estimation. *See*, U.S. Inflation Calculation, "Inflation Calculator," accessed September 16, 2024, https://www.usinflationcalculator.com/.

We multiply Table 4 column [C] by assumed coverage as follows: [1]: 100%. [2]: 49.3%, [3]: 92.1%, [4]: 98.8%, [5]-[9]: 72.7%.

For telecommunications, we assume a 100% adjustment based on 4G LTE coverage in 2024. https://www.statista.com/outlook/co/digital-connectivity-indicators/united-states.

For maritime, we assume a 49.3% adjustment based on our mapping exercise overlaying 4G coverage over the U.S. marine highways (excluding Alaska) and calculating what percentage of waterways is covered by the 4G network.

For telematics, we assume a 92.1% adjustment based on FCC estimates for percentage of road miles covered by the 4G LTE network. *See*, FCC, "In the Matter of Communications Marketplace Report: 2022 Communications Marketplace Report," FCC 22-103, GN Docket No. 22-203, adopted December 30, 2022, accessed September 19, 2024, https://docs.fcc.gov/public/attachments/FCC-22-103A1.pdf, Appx. D-5.xxxiii., p. 312 ("FCC 2022 Communications Marketplace Report").

For agriculture, we assume a 98.8% adjustment based on our mapping exercise overlaying 4G coverage over farmland, and calculating what percentage of farmland is covered by the 5G network.

For location-based services, oil and gas, mining, surveying, electricity we assume a 72.7% adjustment based on FCC estimates for percentage of total U.S. square miles covered by the 4G LTE network. *See*, FCC 2022 Communications Marketplace Report, Appx. D-5.xxxiii, p. 312.

Telecom estimation methodology:

[C][1]: Verizon reported the highest wireless revenue of any major U.S. telecommunications provider in 2023, generating $107.22 billion followed by AT&T and T-Mobile with $83.98 billion and $78.56 billion, respectively. We take the 2023 total telecom revenue and divide it by 365 to get an average daily revenue of $739 million. To calculate losses over 30 days, we apply the daily percentage of losses based on 2018 values in the RTI report to the daily revenue total. This allows us to estimate damages on days 1 through 30 of a month. *See*, Statista, "Wireless Revenue Generated by Major U.S. Telecommunication Providers from 2011 to 2023 (in billion U.S. dollars)," February 2024, accessed September 17, 2024, https://www.statista.com/statistics/199796/wireless-operating-revenues-of-us-telecommunication-providers/. *See also*, Economic Benefits of the Global Positioning System (GPS), Table 4-9.

[B][1]: The losses incurred by the telecommunication sector depends on the decrease in the wireless network functionality, which decreases in a nonlinear way. Thus, a 1-day outage is not equal to the 30-day outage divided by 30 for the telecommunications sector. *See*, Table 4-9 in RTI International, "Economic Benefits of the Global Positioning System (GPS)", June 2019, https://www.rti.org/sites/default/files/gps_finalreport618.pdf?utm_campaign=SSES_SSES_ALL_Aware2019&utm_source=Press%20Release&utm_medium=Website&utm_content=GPSreport

[A][1]: Given the trend in telecom losses is non-linear, we take the value of losses reported by taking the sum of losses from days 1 through 7.

Agricultural estimation methodology:

[C][6]: Agricultural 30-day outage equals, Table 4, column ([C][1], *(2.33/12)*98.8%)/3.

[C][6]: Note we make 3 adjustments to estimate the impact of precision agriculture within agricultural activities with reported losses from a GPS outage.

1. Months in which precision agriculture technologies for soil mapping is used (weighted average of crops planting time and weighting of crops using PA). Planting season varies from crop to crop. We assume it is on average 2.33 months. We calculate this by weighting the monthly time to grow crops requiring PA, by the percentage of these crops that utilize PA planting processes as reported in the RTI report. Thus, we adjust by 2.33/12 to capture the likelihood of the GPS outage happening during the 2.33-month average-long planting season within a year. For crop month planting times, *see*, USDA, "Crop Calendars for United States," accessed September 19, 2024, https://ipad.fas.usda.gov/rssiws/al/crop_calendar/us.aspx. For the percentage of crops that utilize PA, *see*, Economic Benefits of the Global Positioning System (GPS), p. 5-14 at Table 5-9: Revenue Loss if GPS Failed During the Spring Planting Season.

2. Percentage of Cropland covered by 4G. We calculate this value in ArcGIS using an overlay of USDA cropland and FCC data to determine 98.79% of cropland is covered by 4G. NextNav's PNT services utilize the 5G network, a portion of the farmland is not covered by the 5G network. We adjusted the numbers in "Economic Benefits of the Global Positioning System (GPS)" by 98.79% to capture this distinction.

3. We assume 1/3 of agricultural activities use soil mapping (while the other 2 agricultural activities listed in the source compose the remaining 2/3 of GPS use cases).

G. Determining the Insurance Premium for Civilian Sectors

Next, we combine the probability estimates with the potential losses to calculate the insurance premium. In particular, we calculate the *actuarially fair* insurance premium, which equals the expected value of potential monetary losses.[72] Under actuarially fair insurance, premiums just cover expected risks, and the insurer would make zero expected profits. In our application, "the insurer" is the policymaker deciding on a GPS backup system. The expected value of losses is calculated by multiplying the probability of each outage scenario with the potential losses incurred from that scenario and then summing these values across all outage scenarios. Table 6 shows this calculation. Thus, the actuarially fair annual insurance premium, and the annual value of the GPS backup, is equal to **$647 million**. To understand the value over a longer time horizon we calculate the net present value (NPV) of annual insurance premium over a 20-year periods. The NPV of insurance premiums equals **$10.8 billion**.[73]

TABLE 6: EXPECTED VALUE FROM NEXTNAV'S GPS BACKUP SERVICES FOR CIVILIAN SECTORS

		$ millions			*$ billions*
Event (Outage Length)		**Outage Probability** [A]	**Potential Losses** [B]	**Expected Losses** [C]	**NPV 20-year** [D]
Severe Geomagnetic Storm (1 Day Outage)	[1]	0.2800	$663	$186	
Greeat Geomagnetic Storm (7 Day Outage)	[2]	0.0400	$5,951	$238	
Carrington Class Geomagnetic Storm (30 Day Outage)	[3]	0.0070	$31,875	$223	
Value of the GPS Backup	[4]			**$647**	**$10.79**

Sources and Notes:
[A]: Brattle analysis. See, Table 3.
[B]: Brattle analysis. See, Table 5.
[C]: [A]x[B]
[C][4]=[C][1]+[C][2]+[C][3]
[D][4]: Assuming an insurance premium equal to [C][4] is paid each year for the next 20 years with a discount rate of 0.02. The discount rate is based on the social rate of time preference, *see*, The White House, "Circular No. A-4," November 9, 2023, https://www.whitehouse.gov/wp-content/uploads/2023/11/CircularA-4.pdf. Net present value of this stream is given by $\sum_{i=0}^{19}([C][4])/(1.02)^\wedge i$.

[72] David Autor, "Lecture Note 17: The Market for Risk," Fall 2016, accessed September 15, 2024, https://ocw.mit.edu/courses/14-03-microeconomic-theory-and-public-policy-fall-2016/52fb22da4549f122296baafbf35a512d_MIT14_03F16_lec17.pdf.

[73] Assuming an insurance premium equal to $647 million is paid each year for the next 20 years with a discount rate of 0.02. The discount rate is based on the social rate of time preference, *see*, The White House, "Circular No. A-4," November 9, 2023, https://www.whitehouse.gov/wp-content/uploads/2023/11/CircularA-4.pdf. Net present value of this stream is given by $\sum_{i=0}^{19}(\$647)/(1.02)^\wedge i$.

III. Estimating the Value of Resiliency for the Military Using a Willingness-To-Pay Approach

GPS remains the principal source of PNT information for the U.S. military.[74] As part of the efforts to make GPS more resilient, the Air Force launched the first GPS satellite capable of broadcasting the more jamming-resistant, military-specific signal, referred to as military code (M-code) in 2005.[75] Efforts led by the U.S. Space Force to improve the M-code are ongoing. M-code satellites transmit a new type of signal that is designed to be more resistant to jamming and interference compared to the standard GPS signals used for civilian purposes.[76] Thus, the DoD's budget for this technology can be used as a proxy for the military's willingness to pay for a more resilient GPS backup system, such as the one offered by NextNav.

The amount budgeted for M-code represents a significant investment that could have been used for other defense priorities. This reflects the value placed on avoiding disruptions and maintaining operational capability in the face of potential jamming threats. Of course, the value of a successful M-code is likely much larger; the DoD's willingness to pay for the initial development provides a minimum bound.

M-Code equipped GPS consists of three segments: space (*i.e.,* satellites), a command-and-control system (called the Next Generation Operational Control Segment or OCX), and user equipment. Upgrading the GPS constellation to accommodate the M-code signal requires more powerful

74 GAO, ''GPS Modernization: Space Force Should Reassess Requirements for Satellites and Handheld Devices,'' June 2023, accessed September 10, 2024, https://www.gao.gov/assets/d23106018.pdf. Note that the U.S. military is pursuing other technologies such as Assured PNT as a backup for GPS. We do not use this in our estimation as it is difficult to disaggregate the value of the technology development between its resiliency function and other enhanced features such as precision, security in communication and so on. *See*, PNI, "Assured PNT: Military's Solution to GPS-Denied Navigation," accessed October 12, 2024, https://www.pnisensor.com/the-importance-of-assured-pnt-to-the-us-military/.

75 Matteo Luccio, "First Fix: Still Waiting for M-Code," GPS World, July 10, 2023, accessed September 10, 2024, https://www.gpsworld.com/first-fix-still-waiting-for-m-code/.

76 Sandra Erwin, "The Race to Back up Vulnerable GPS," Space News, February 20, 2024, accessed September 10, 2024, https://spacenews.com/the-race-to-back-up-vulnerable-gps/.

satellites, operationalizing the OCX required by the launch, and new user equipment.[77] To measure the cost of the M-Code, we would require costs for all three segments. For the M-Code development cost, we do not have exact estimates of the cost associated with the M-Code technology, but aggregate costs of satellites equipped with M-Code. We find that the M-Code satellite costs are, on average, similar to general GPS satellites. Thus, the incremental cost of M-Code can be proxied by the OCX and use-equipment cost. We have estimates for the OCX development but not for the user-equipment costs. Thus, we use the spending on OCX as a proxy for the value of GPS resiliency to the military.

For estimating the incremental value of a GPS backup to the military, *i.e.,* the willingness to pay for resiliency and anti-jamming functions, we have to estimate the incremental value of an M-code satellite system. We estimate the costs associated with the OCX based on the total program costs calculated as of January 2023 by the Government Accountability Office (GAO).[78] This cost is $7.69 billion.[79] However, the cost of the M-Code satellites provides a global resiliency benefit. NextNav will provide GPS backup to the U.S.. Therefore, we should only consider the cost for the U.S.. This is a difficult figure to estimate, and we assume a 50 percent allocation of the cost to U.S. operations.[80] Thus, our proxy for the military's willingness to pay for resiliency and anti-jamming technology for GPS, and hence the value for NextNav's technology for the military is $3.847 billion.[81] This is likely a lower bound as the M-Code is still under development and the GAO expects that it will cost more than what was budgeted for in terms of money and time.[82]

[77] GAO, ''GPS Modernization: Space Force Should Reassess Requirements for Satellites and Handheld Devices,'' June 2023, accessed September 15, 2024, https://www.gao.gov/assets/d23106018.pdf,("GPS Modernization: Space Force Should Reassess Requirements for Satellites and Handheld Devices")

[78] GPS Modernization: Space Force Should Reassess Requirements for Satellites and Handheld Devices.

[79] GPS Modernization: Space Force Should Reassess Requirements for Satellites and Handheld Devices.

[80] The allocation factor is based on triangulating several estimates for U.S. military related spending domestically and overseas, where the range was approximately between 40% and 60%. For example, *see*, Watson Institute for International Affairs, "U.S. Federal and State Budgets," last accessed October 7, 2024, https://watson.brown.edu/costsofwar/costs/economic/budget.

[81] Note, we round this to $3.8 billion.

[82] GPS Alternatives - DOD Is Developing Navigation Systems But Is Not Measuring Overall Progress, pp. 24, 40. The $2.5 billion mentioned in this article is transition costs and is not included in our estimate. *See also*, GAO, "GPS Modernization: Delays Continue in Delivering More Secure Capability for the Warfighter," September 9, 2024, last accessed September 20, 2024, https://www.gao.gov/products/gao-24-106841.

IV. Summarizing the Value of NextNav's Terrestrial Backup to GPS and Additional Complementary PNT Services

A. Value of the Terrestrial GPS Backup

The value of deploying a terrestrial backup to GPS is calculated as an insurance premium to insure against the possibility of GPS outage. We calculated this for civilian sectors that would be impacted by a GPS outage (Section II), and also estimated the value of such a service for the military (Section III). For the civilian sectors we found that the actuarially fair annual insurance premium – the annual value of the GPS backup – was equal to $647 million. To understand the value over a longer time horizon we calculated the net present value (NPV) of annual insurance premium over a 20-year period. The NPV for 20 years of insurance premiums is $10.79 billion. For the value to the military, we use the military's willingness to pay for resiliency and anti-jamming technology for GPS, as a proxy for the value of NextNav's technology for the military. This functionality is valued at $3.847 billion. Thus, the total value of the GPS complement and backup is $14.63 billion.

TABLE 7: AGGREGATE EXPECTED VALUE FROM NEXTNAV'S GPS BACKUP SERVICES FOR CIVILIAN SECTORS AND RESILIENCY VALUE FOR THE MILITARY

		$ millions		*$ billions*
Sectors		**Annual Value**	**Aggregate Value**	**NPV 20-year**
		[A]	[B]	[c]
Value of the GPS Backup for Civilian Sectors	[1]	**$647**		**$10.79**
Global Security GPS Resiliency Value	[2]		$7,693	
Military GPS Resiliency Value	[3]		**$3,847**	
Total:	[4]			**$14.63**

Sources and Notes:

[A][1]: Brattle analysis. See, Table 6.

[B][2]: Total costs for the Next Generation Operational Control System (OCX) Block 0,1,2,3F as of January 2023. GAO, ''GPS Modernization: Space Force Should Reassess Requirements for Satellites and Handheld Devices,'' June 2023, https://www.gao.gov/assets/d23106018.pdf.

[B][3]: We assume that 50% of the value can be allocated to the U.S.

[C][1]: Brattle Analysis. See, Table 6.

[C][4]: [C][1]+[B][3]

B. Value of Enhanced Location Accuracy

In addition to quantifying the incremental value, we also briefly discuss the value of the additional positioning services that NextNav can provide. The pursuit of an alternative PNT system is not solely motivated by the fear that the GPS constellation might become unusable — though concerns about jamming and spoofing are certainly valid. There are also pressing needs for reliable PNT services in environments where GPS is ineffective or unavailable. This includes scenarios like indoors, in dense urban areas with limited sky visibility or signal multipath issues, and in locations experiencing interference.[83] NextNav's technology offers solutions that can address these challenges.

In this report we primarily focus on how enhanced location accuracy across the x, y, and z axes can improve situational awareness for first responders and also help Public Safety Answering Points (PSAPs) locate wireless 911 callers more rapidly, although the benefits go beyond this use.[84] Responding to emergencies in indoor settings, especially in multi-story buildings, requires awareness of not just the caller's horizontal position in the x/y plane but also their vertical location along the z axis.[85] Enhancing the accuracy of vertical location data will enable first responders to more accurately determine the caller's floor level, thus reducing emergency response times and ultimately saving lives. With this in mind, the FCC introduced a vertical (z) location requirement in 2019 that was aimed at determining the specific building floor from which a wireless 911 call is made.[86] The 2020 Wireless E911 Location Accuracy Requirements Sixth Report and Order required "nationwide CMRS providers to deploy z-axis technology nationwide by April 2025."[87]

Enabling the deployment of NextNav's next-generation PNT service will provide incremental x, y, and z axis positioning-related benefits for E911 services in three ways:

- *The next-generation system will be capable of improving x/y location accuracy,* identifying horizontal location within 10 meters or less wherever the Lower 900 MHz 5G signal is available. Given the superior penetration characteristics of low frequency spectrum, this will include most indoor locations where other positioning alternatives may be challenged.[88]

83 Gavin Schrock, "Non-GPS PNT – NextNav," Gogeomatics, September 2, 2021, accessed October 14, 2024, https://gogeomatics.ca/non-gps-pnt-nextnav/.

84 Wireless E911 Location Accuracy Requirements Sixth R&O, ¶ 1. There are additional benefits

85 Wireless E911 Location Accuracy Requirements Sixth R&O, ¶ 2.

86 FCC, "Wireless E911 Location Accuracy Requirements," Fifth Report and Order and FNPRM, PS Docket No: 07-114, adopted November 22, 2019, https://www.fcc.gov/document/fcc-helps-first-responders-quickly-locate-wireless-911-callers-0, ("Wireless E911 Location Accuracy Requirements Fifth R&O").

87 FCC, "Wireless E911 Location Accuracy Requirements," Sixth Report and Order, PS Docket No: 07-114, adopted July 16, 2020, https://www.fcc.gov/document/fcc-helps-first-responders-find-911-callers-multi-story-buildings-0 ("Wireless E911 Location Accuracy Requirements Sixth R&O").

88 NextNav Comments, September 5, 2024, Appendix at 2.

- *This improved x/y accuracy will lead to improved z-accuracy*. NextNav is one of the few companies able to use Height Above Terrain (HAT) measurements that account for the topography of a location instead of Height Above Ellipsoid (HAE) which simply assumes the earth is a smooth ellipsoid.[89] This is particularly important in for first responders in urban locations where, at the same HAE, one person could be on the third floor of a building, while another individual nearby might be on the first floor.[90] We understand that NextNav can provide more accurate HAT measurements compared to other services, based on increased accuracy of its x/y services.

- *The improved positioning will be widely available to both E911 callers and first responders*. Since NextNav's technology will be available in 5G devices, such as smart phones, it will not require specialized, PNT-related equipment, leading to a relatively rapid adoption.

In this report, we do not quantify the value of NextNav's enhanced location technology specifically with respect to E911. However, the FCC has provided estimates that show it will have significant value as the Commission found that if emergency response times decrease by just one minute due to better location services, the annual benefit could be as high as $97 billion.[91] In addition, it seems likely that there are additional economic benefits from a terrestrial PNT solution, particularly with respect to the benefits of complementary PNT. While we do not quantify those benefits in this report, we may be able to do so in the future.

89 One of the problems with the current z-axis technologies is that the vertical measurement is provided as an HAE, i.e., distance from the earth's surface (HAE is a measure of the distance from a point in space from a mathematical model of the earth's surface as if it were a perfect ellipsoid). But, e.g., due to variations in terrain and floor-to-ceiling heights, receiving HAE alone doesn't provide clear guidance as to the floor on which an E911 caller is located.

90 *See*, e.g., "Life-Saving Z-Axis Data in the Emergency Communication Center," January 31, 2024, accessed September 15, 2024, https://www.geocomm.com/life-saving-z-axis-data/ and NextNav Comments, September 5, 2024, Appendix at pp. 10-11.

91 Wireless E911 Location Accuracy Requirements Sixth R&O, ¶ 72.

V. Conclusion

NextNav is proposing to reconfigure the Lower 900 MHz band, which – when integrated into a 5G network – will allow NextNav to provide a cost-effective PNT system designed to complement and back up current GPS capabilities. The Lower 900 MHz band has a mix of incumbents comprising federal users, site-based operations in distinct geographic areas and Part 15 devices. This analysis focuses on benefits of reconfiguration. Those benefits would ultimately be weighed against the costs of the reconfiguration in evaluating the benefits of the proposal to society.

NextNav's proposal to reconfigure the Lower 900 MHz band offers a significant opportunity to enhance the existing PNT infrastructure in the U.S. The integration of NextNav's technology with the 5G network promises to provide not only a robust backup for GPS but also to expand and enhance PNT services essential for various critical sectors. Having a terrestrial backup to GPS ensures that the economic benefits from the various sectors will not be lost in case of a GPS outage. To quantify this value, we focus on two broad segments – civilian or non-military value and a military use value.

For the civilian value, our valuation approach recognizes that deploying a terrestrial GPS backup is similar to the nation obtaining an insurance policy for an adverse event that may or may not happen. To calculate the insurance premium we first consider various space events (such and solar storms and satellite debris) that could lead to a global GPS outage, and the associated probabilities of such events occurring. Various space-related events can impact GPS services for varying durations. To make the analysis tractable, we categorize events into three mutually exclusive outage events – events that can cause a short-term (1 day) outage, events that can cause a medium-term (7 day) outage, and events that can cause a long-term (30 day) outage.

Next, we identify the sectors that are expected to be significantly affected by a GPS outage. We then quantify the total expected losses for each GPS-reliant sector by referencing existing studies that detail the economic impact of GPS disruptions on these industries. The aggregate loss that may be suffered by the U.S. for a 1-day, 7-day and 30-day GPS outage is $1.6 billion, $12.2 billion, and $58.2 billion, respectively. We then adjust these aggregate loss estimates by NextNav's coverage footprint (*i.e.*, where it would be available, which is the 5G footprint at the time it is deployed), technical capabilities, and other sector specific factors. The aggregate loss addressable by NextNav, for a 1-day, 7-day and 30-day outage is $663 million, $6.0 billion, and $31.9 billion, respectively. We then calculate the insurance premium associated with various space events that can cause a GPS outage. This then represents the value of having a backup to GPS. Based on a 20-year NPV, this value is $10.8 billion.

Next, we estimate the value of this technology for the military, which is not well captured in an insurance framework. Here we focus on a specific use case – resiliency functions such as anti-jamming. We use the military's willingness to pay for resiliency and anti-jamming technology for GPS as a proxy for NextNav's technology for the military. This functionality is valued at $3.9 billion. Thus, the total quantifiable value of the GPS complement and backup is $14.6 billion.

We also discuss the value of the additional positioning services that NextNav can provide, such as greater location precision in the x/y plane and relatedly better accuracy for vertical positioning (z-axis). Enhanced location accuracy across the x, y, and z axes can improve situational awareness for first responders and also help PSAPs locate wireless 911 callers more rapidly. Enabling the deployment of NextNav's next-generation PNT service will provide incremental x/y and z axis positioning-related benefits through more accurate x/y positioning, which would lead to better z-axis positioning. Additionally, these functionalities would be integrated into the 5G network and would be available to PSAPs and first responders. We do not quantify the value of NextNav's enhanced location technology specifically with respect to emergency services. However, the FCC has provided estimates that show it will have significant value as the Commission found that if emergency response times decrease by just one minute due to better location services, the nation could save $97 billion annually.

Appendix A

In this section, we briefly summarize the GPS reliance of each sector and discuss sector-specific GPS backup availability. Throughout the section, we assume that in the event of a GPS outage, other GNSS such as Galileo, GLONASS and BeiDou would also be unavailable throughout the outage period.[92]

a. Agriculture

The positioning signal provided by GPS plays an essential role in precision agriculture technologies.[93] Applications of precision agriculture technologies include guidance systems, which are used to operate tractors with more precision, variable-rate technology, which allows farmers to apply the appropriate amount of seed, fertilizer or pesticides for a particular site, and yield and soil mapping, which assists farmers with their planting and input decisions.[94] Note that all of the applications are assisted and facilitated by GPS. Some of the applications of precision agriculture, such as the guidance systems and the variable-rate technology, require positioning information with centimeter-level accuracy[95] Hence, the agriculture sector frequently uses GPS combined with the Real Time Kinematics (RTK) technology to address these accuracy needs.[96] The RTK technology increases the accuracy of GPS by combining positioning information from GPS satellites with signals from a fixed base station that sends out corrections.[97] This allows for the RTK GPS receiver to provide positioning information with 1-2 centimeters of accuracy.[98]

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92 Note that US systems are authorized to access Galileo but not GLONASS or BeiDou. *See,* NextNav Petition p. 8; NextNav Comments note 1.

93 Economic Benefits of the Global Positioning System (GPS), p. 5-1.

94 Economic Benefits of the Global Positioning System (GPS), p. 5-2.

95 Economic Benefits of the Global Positioning System (GPS), p. 5-2.

96 AgriTech Tomorrow, "RTK Makes Precision Agriculture Simple," September 13, 2024, https://www.agritechtomorrow.com/news/2023/09/13/rtk-makes-precision-agriculture-simple/14836/, accessed September 17, 2024.

97 Global GPS Systems, "What is RTK and what does it stand for?," accessed https://globalgpssystems.com/gnss/what-is-rtk-and-what-does-it-stand-for/ ("What is RTK and what does it stand for?")

98 What is RTK and what does it stand for?

There are no alternatives to the functionality provided by GPS in precision agriculture.[99] In the event of an outage, farmers would have to resort to manually complete the operations facilitated by precision agriculture.[100]

b. Electricity

The electricity sector uses the precision timing signal provided by GPS to monitor the daily operations in the power grid and detect potential problems and faults in the transmission infrastructure.[101] The monitoring is facilitated by phasor measurement units (PMUs), which evaluate electrical waves by time stamping the dynamics of the electrical system.[102] However, the GPS applications for electric utilities are not considered to be critical for the operation of the grid, but are seen as tools that increase the efficiency of system monitoring.[103] The electric utility systems also have additional supervisory control and data acquisition (SCADA) systems that they can fall back to.[104] SCADA systems can also time stamp transactions, but they are significantly slower than the PMUs.[105] Therefore, in the event of an outage, a loss in efficiency is expected but the fundamental operations would not be disrupted.[106]

c. Finance

Financial services sector uses the GPS timing signal to time stamp financial transactions up to the precision required by financial regulations.[107] However, GPS technology is not critical to the daily operations of financial markets, as there are additional safeguards in place such as atomic clocks with sufficient holdover capacity that can keep time in the absence of a GPS timing signal.[108] In the event of a GPS outage, the functioning of financial markets would not be disrupted.[109]

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[99] Economic Benefits of the Global Positioning System (GPS), p. 3-5.
[100] Economic Benefits of the Global Positioning System (GPS), p. 5-2.
[101] Economic Benefits of the Global Positioning System (GPS), p. 6-1.
[102] Economic Benefits of the Global Positioning System (GPS), p. 6-1.
[103] Economic Benefits of the Global Positioning System (GPS), p. 6-17.
[104] Economic Benefits of the Global Positioning System (GPS), p. 6-1.
[105] Economic Benefits of the Global Positioning System (GPS), p. 6-17.
[106] Economic Benefits of the Global Positioning System (GPS), p. 6-17.
[107] Economic Benefits of the Global Positioning System (GPS), p. 7-1.
[108] Economic Benefits of the Global Positioning System (GPS), p. 7-8.
[109] Economic Benefits of the Global Positioning System (GPS), p. 7-8.

d. Location-based Services

GPS chips in smartphones and other devices determine positioning information by receiving signals from satellites.[110] To improve accuracy and reliability, these devices also use data from Wi-Fi hotspots and cell towers, but GPS is the most critical source of the positioning information.[111] By combining signals from these sources, software and apps provide location information to users.[112] In the event of a GPS outage, location-based services can obtain some location information from the additional sources of Wi-Fi hotspots and cell towers, but they would lose precision and some functionality, such as providing turn-by-turn directions.[113]

e. Oil and Gas

GPS positioning information is used extensively in exploration and production operations in the oil and gas sector, both offshore and on land.[114] The impact of a GPS outage would be most significant for offshore operations, as these activities rely heavily on GPS and there are not any backups in place.[115]

f. Surveying

The surveying industry heavily depends on GPS for precise location information to increase productivity and lower the costs of surveying tasks.[116] There aren't sector-wide backups in place to deliver the precise location information provided by GPS and in the event of an outage, surveyors would have to rely on methods used prior to the adoption of GPS.[117]

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[110] Economic Benefits of the Global Positioning System (GPS), p. 8-1.

[111] Economic Benefits of the Global Positioning System (GPS), p. 8-1.

[112] Economic Benefits of the Global Positioning System (GPS), p. 8-1.

[113] Economic Benefits of the Global Positioning System (GPS), p. 8-17.

[114] Economic Benefits of the Global Positioning System (GPS), p. 11-1.

[115] Economic Benefits of the Global Positioning System (GPS), p. 11-11.

[116] Economic Benefits of the Global Positioning System (GPS), p. 12-1.

[117] Economic Benefits of the Global Positioning System (GPS), p. 12-1.

g. Telematics

Telematics technology uses in-vehicle equipment to remotely track and monitor vehicles.[118] There aren't sector-wide backups that can seamlessly replace the positioning information provided by the GPS in the event of an outage.[119] However, the impact of a GPS outage depends on the user and their application of telematics, as the productivity boost provided by the GPS varies across different applications.[120] For example, UPS uses GPS to plan its delivery routes. In the absence of GPS, the drivers would have to rely on local knowledge and maps. Given the large volume of packages delivered every day, this may cause a significant disruption.[121] However, field service operations also use telematics, but because they have a relatively small number of stops in each day, the impact of a GPS outage would be less pronounced.[122]

h. Mining

The mining sector uses the GPS positioning signal to identify and explore ore bodies.[123] Mines typically do not have backup systems for GPS or GPS-enabled technologies, so they would have to resort to practices they employed prior to the adoption of GPS.[124]

i. Maritime

The positioning information from GPS is commonly used in port operations, commercial fishing, recreational fishing and boating, passenger transportation through cruise ships and navigation in seaways.[125] The availability of backup systems for GPS varies across these activities. For example, commercial vessels, such as cruise ships, typically have GPS backup navigation systems in place (*e.g.* radar).[126] Experienced mariners also see GPS as a source of convenience rather than considering it necessary for navigating seaways.[127] However, in commercial fishing, there are no

[118] Economic Benefits of the Global Positioning System (GPS), p. 13-1.
[119] Economic Benefits of the Global Positioning System (GPS), p. 13-13.
[120] Economic Benefits of the Global Positioning System (GPS), p. 13-13.
[121] Economic Benefits of the Global Positioning System (GPS), p. 13-13.
[122] Economic Benefits of the Global Positioning System (GPS), p. 13-13.
[123] Economic Benefits of the Global Positioning System (GPS), p. 10-1.
[124] Economic Benefits of the Global Positioning System (GPS), p. 10-1.
[125] Economic Benefits of the Global Positioning System (GPS), p. 9-1.
[126] Economic Benefits of the Global Positioning System (GPS), p. 9-5.
[127] Economic Benefits of the Global Positioning System (GPS), p. 9-27.

widespread alternative positioning and navigation solutions and the fisherman would have to rely on traditional techniques such as magnetic compasses and paper charts.[128] Similarly, there are no regulations that require recreational boaters and fishers additional navigation equipment and training, so they don't typically have backups and heavily rely on GPS.[129] In port operations, GPS is critical for different activities: It helps container vessels estimate and communicate their arrival times for efficient scheduling, supports container yard operations by tracking the location of containers, and enables GPS-enabled logistics systems to manage truck movements for cargo transport.[130] In the event of a GPS outage, port operators would have to manually track these activities as there aren't any backups in place.[131] Because of the extensive reliance on GPS in port operations, commercial fishing and recreational fishing and boating, an unexpected outage is likely to have significant economic impacts.[132]

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[128] Economic Benefits of the Global Positioning System (GPS), p. 9-13.

[129] Economic Benefits of the Global Positioning System (GPS), p. 9-17.

[130] Economic Benefits of the Global Positioning System (GPS), p. 9-23.

[131] Economic Benefits of the Global Positioning System (GPS), p. 9-23.

[132] Economic Benefits of the Global Positioning System (GPS), p. 9-1.

Appendix B: Adjustments

In this section, we summarize additional adjustments we make in valuating GPS outages. These adjustments account for inflation, the geospatial overlap calculation for all sectors detailed in Table B1, and additional agricultural adjustments.

B.1 Inflation Adjustment

The values in our underlying analyses do not come from 2024. As such, we make an inflation adjustment. The sources and notes of Table 3, Table 4, and Table 5 detail these adjustments. Our estimates in valuing the non-security values of a GPS outage come from a source which reports their values in 2017 dollars.[133] $1 in 2017 dollars, adjusted for inflation, is worth $1.29 in 2024 dollars.[134] Thus, we adjust the numbers by multiplying with 1.29.[135]

B.2 Geospatial Overlap Adjustment

Given the sectors used in our analysis covered vast areas within the U.S., we adjust for the assumed areas that these sectors would utilize and in turn ought to be covered by GPS. Except for the telecommunications, maritime and agriculture sectors, we depend on different FCC estimates for 4G coverage to adjust our outage values. The table below summarizes the geographic adjustments we apply.

133 Economic Benefits of the Global Positioning System (GPS), p. 14-3.

134 *See*, U.S. Inflation Calculation, "Inflation Calculator," accessed September 16, 2024, https://www.usinflationcalculator.com/.

135 Note, in Table 5, the telecommunications estimates are from 2023. As such, we adjust these values based on a 2023 inflation factor, such that $1 in 2023 is equal to $1.03 in 2024.

TABLE B1: ASSUMED 4G COVERAGE OVERLAP ADJUSTMENT BY SECTOR

Sector		Adjustment for Assumed Coverage
Telecommunications*	[1]	100.0%
Maritime	[2]	49.3%
Telematics	[3]	92.1%
Agriculture (soil mapping)	[4]	98.8%
Location-based services	[5]	72.7%
Oil and gas	[6]	72.7%
Mining	[7]	72.7%
Surveying	[8]	72.7%
Electricity	[9]	72.7%
Finance	[10]	N/A

Sources and Notes:
See, discussion in Appendix B.2.

For the agriculture sector, only the portion of the farmlands that are covered by the 5G network will benefit from the NextNav GPS backup. To obtain this overlap, we overlay the 4G network geospatial data obtained from the FCC's Broadband Data Collection as of December 2023 with farmland data from the U.S. Department of Agriculture (USDA) to obtain an estimate of the percentage of farmland covered by 4G.[136] We use current 4G network coverage to proxy the reach of the 5G networks in the near future. We find that 98.8% of farmland is covered by the current 4G network.[137] We use this percentage to adjust the total loss estimates.

[136] National Agricultural Statistics Service and Agricultural Research Service, U.S. Department of Agriculture, "USDA CroplandCROS Cropland Data Layer," data as of 2023, accessed September 17th, 2024, https://croplandcros.scinet.usda.gov/, ("USDA Cropland Data Layer"). *See also*, FCC, "Broadband Map: Mobile," available as of December 31, 2023, accessed September 17, 2024, https://broadbandmap.fcc.gov/area-summary/mobile?version=dec2023&zoom=4&tech=tech4g&env=0 ("FCC: Broadband Map"). For information on the FCC's BDC data, *see*, FCC, "Broadband Data Collection: Specifications for Data Downloads from the National Broadband Map," June 28, 2024, accessed September 19, 2024, https://us-fcc.app.box.com/v/bdc-data-downloads-output.

[137] Brattle analysis. *See*, FCC: Broadband Map for mobile coverage data. *See also*, USDA Cropland Data Layer.

For the maritime sector, we implement a similar adjustment. We overlay the 4G network geospatial data obtained from the FCC's Broadband Data Collection as of December 2023 with waterways mapping data from the U.S. Department of Transportation. We find that 49.3% of waterways are covered by the 4G network.[138] We adjust the maritime sector losses by this percentage to estimate the losses that can potentially be addressed by having a GPS backup.

For telecom, we implement an adjustment based on 4G LTE coverage in 2024, which is 100%.[139]

Telematics technology uses in-vehicle equipment to remotely track and monitor vehicles Therefore, for the telematics sector, we implement an adjustment based on the 4G New Radio coverage of road miles as reported by the FCC. According to the most recent estimate, which is from December 2021, 92.1% of road miles are covered by 4G network. [140]

For electricity, surveying, mining, location-based services, oil, and gas sectors, we implement an adjustment based on the 4G coverage of land area, as reported by FCC. According to the most recent estimate, which is from December 2021, 72.7% of total U.S. square miles are covered by the 4G LTE network.[141]

B.3 Sector-Specific Adjustment in Agriculture

In the agriculture sector, we implement two additional adjustments beyond the standard inflation and geospatial adjustments. These adjustments account for (1) the planting season, in which precision agricultural technology would be in use, and (2) the overall use of precision agriculture in the agriculture sector. These adjustments are detailed in the sources and notes of Table 5.

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[138] Brattle analysis. *See*, FCC: Broadband Map for mobile coverage data. *See also*, U.S. Department of Transportation Maritime Administration, "United States Marine Highway Routes," last updated January 31, 2024, accessed September 19, 2024, https://www.maritime.dot.gov/grants-finances/marine-highways/us-marine-highway-program-routes-map.

[139] Statista, "Digital & Connectivity Indicators - United States," accessed September 19, 2024, https://www.statista.com/outlook/co/digital-connectivity-indicators/united-states.

[140] FCC 2022 Communications Marketplace Report, p. 312.

[141] FCC 2022 Communications Marketplace Report, p. 312.

The agriculture sector is most likely to be impacted by a GPS outage during the planting season.[142] Planting season varies from crop to crop, and different crops have different usage rates of precision agriculture.[143] Using these two inputs, we calculate a weighted average of the time to plant certain crops, based on the percentage of crops that utilize precision agriculture. We assume that, on average, crops have 2.33 months where planting season takes place and that a GPS outage during these months would lead to losses.[144] Thus, we adjust the total loss by the ratio of the planting season to total months to capture lost value from a GPS outage during the planting season. We assume that the impact is zero if the outage happens outside of planting season.

Second, the agriculture sector commonly uses GPS combined with the Real Time Kinematics (RTK) technology.[145] The RTK technology increases the accuracy of GPS by combining positioning information from GPS satellites with signals from a fixed base station that sends out corrections.[146] This allows for the RTK GPS receiver to provide positioning information within 1-2 centimeters of accuracy.[147] Applications of precision agriculture technologies include guidance systems which are used to operate tractors with more precision, and variable-rate technology, which allows farmers to apply the appropriate amount of seed, fertilizer or pesticides for a particular crop's planting site. These two applications rely on RTK GPS and require centimeter-

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[142] Economic Benefits of the Global Positioning System (GPS), p. 14-2.

[143] Foreign Agricultural Service, U.S. Department of Agriculture, "Crop Calendars for United States," accessed September 17, 2024, https://ipad.fas.usda.gov/rssiws/al/crop_calendar/us.aspx.

[144] We calculate this based on a weighted average of the months it takes to plant crops listed in, *see*, Economic Benefits of the Global Positioning System (GPS), Table 5-9. We divide the total estimate by 12: 2.33/12 and use this to adjust the agricultural damages from GPS over 30 days value. Table 5-9 contains the precision agriculture amount applied to specific crops (the weighting used). For the planting season of the specific crops listed (corn, cotton, peanuts, rice, soybeans, and spring wheat), *see*, U.S. Department of Agriculture Foreign Agriculture Service, "Crop Calendars for United States," accessed September 17, 2024, https://ipad.fas.usda.gov/rssiws/al/crop_calendar/us.aspx.

[145] AgriTech Tomorrow, "RTK Makes Precision Agriculture Simple," September 13, 2024, https://www.agritechtomorrow.com/news/2023/09/13/rtk-makes-precision-agriculture-simple/14836/, accessed September 17, 2024.

[146] Global GPS Systems, "What is RTK and what does it stand for?," accessed September 17, 2024, https://globalgpssystems.com/gnss/what-is-rtk-and-what-does-it-stand-for/

[147] What is RTK and what does it stand for?

level accuracy.[148] Other applications, such as yield and soil mapping, which guide farmers in their planting and input decisions, require precision of up to 10 meters.[149] Consequently, these applications do not depend on the centimeter-level accuracy provided by RTK GPS. We assume that NextNav's technology can only provide the yield and soil mapping applications.[150] It is not possible to fully isolate the contribution of yield and soil mapping technologies to annual agriculture revenues. As such, we assume that 1/3 of agriculture gross revenues are due to soil and yield mapping.[151]

Our consideration of planting season and overall uptake in crops using yield and soil mapping results in a 6.39% adjustment.[152]

[148] Economic Benefits of the Global Positioning System (GPS), p. 5-2. *See also*, Anne Effland, Monica Saavoss, Thomas Capehart, William D. McBride, and Amy Boline, "Innovations in Seed and Farming Technologies Drive Productivity Gains and Costs on Corn Farms," April 04, 2022, https://www.ers.usda.gov/amber-waves/2022/april/innovations-in-seed-and-farming-technologies-drive-productivity-gains-and-costs-on-corn-farms.

[149] Economic Benefits of the Global Positioning System (GPS), p. 5-2.

[150] The agriculture sector leverages GPS primarily for positioning and accurate location data is used for precision farming. NextNav's solution is not a replacement for precision GPS applications needed for precision farming.

[151] Estimates from 2016 show that the greatest impact on farmers' net returns comes from soil and yield mapping. David Schimmelpfennig, "Farm Profits and Adoption of Precision Agriculture," USDA, October 2016, https://www.ers.usda.gov/webdocs/publications/80326/err-217.pdf?v=4266, p. 28.

[152] *See*, Table 4 for the RTI reported agricultural losses, and Table 5 for our adjusted calculation. This includes the geospatial adjustment.