NWIRP

Strategic Plan

for the

National Windstorm Impact Reduction Program

Draft for Public Comment

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FEMA

National Institute of Standards and Technology
U.S. Department of Commerce

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Executive Summary

This Draft Strategic Plan for the National Windstorm Impact Reduction Program (NWIRP) is being distributed for a 60-day public comment period. NIST welcomes comments on the draft report, which must be received by the deadline contained in the Federal Register notice once it is published. Comments may be submitted via email to nwirp@nist.gov, by fax to 301-869-6275, or mailed to NWIRP, Attention Marc Levitan, National Institute of Standards and Technology, 100 Bureau Dr., Stop 8611, Gaithersburg, Md. 20899-8611. An electronic copy of this report is available for download at https://www.nist.gov/el/mssd/nwirp.

Once the public comments have been received and considered, the revised Strategic Plan will be submitted to Congress by the Interagency Coordinating Committee of NWIRP, as required by the National Windstorm Impact Reduction Act Reauthorization of 2015 (Public Law 114-52).

This Strategic Plan (Plan) for the National Windstorm Impact Reduction Program (NWIRP or Program) outlines a coordinated program of windstorm research, development, implementation, education, and outreach activities performed by the NWIRP-designated Program agencies, in cooperation with other government agencies and private sector organizations. These Program agencies are:

- the Federal Emergency Management Agency (FEMA);
- the National Institute of Standards and Technology (NIST);
- the National Oceanic and Atmospheric Administration (NOAA); and
- the National Science Foundation (NSF).

The success of NWIRP will require building on the linked roles of the Program agencies and their partners, based on a common vision and shared mission.

The NWIRP Vision is:

A nation that is windstorm-resilient in public safety and economic well-being.

The NWIRP Mission is:

To achieve major measurable reductions in the losses of life and property from windstorms through a coordinated Federal effort, in cooperation with other levels of government, academia, and the private sector, aimed at improving the understanding of windstorms and their impacts and developing and encouraging the implementation of cost-effective mitigation measures to reduce those impacts.

Accomplishing the NWIRP mission requires developing and applying knowledge, data, and science-based tools founded on research in the atmospheric sciences, engineering, and social sciences; educating leaders and the public; and assisting state, local, and private-sector leaders to develop building codes, standards, policies, and practices. The Program agencies have established three overarching, long-term Strategic Goals, with 14 associated objectives, to support this mission:

Goal A. Improve the Understanding of Windstorm Processes and Hazards

Objective 1: Advance understanding of windstorms and associated hazards

Objective 2: Develop tools to improve windstorm data collection and analysis

Objective 3: Understand long term trends in windstorm frequency, intensity, and location

Objective 4: Develop tools to improve windstorm hazard assessment

Goal B. Improve the Understanding of Windstorm Impacts on Communities

Objective 5: Advance understanding of windstorm effects on the built environment

Objective 6: Develop computational tools for use in wind and flood modeling on buildings and infrastructure

Objective 7: Improve understanding of economic and social factors influencing windstorm risk reduction measures

Objective 8: Develop tools to improve post-storm impact data collection, analysis, and archival

Objective 9: Develop advanced risk assessment and loss estimation tools

Goal C. Improve the Windstorm Resilience of Communities Nationwide

Objective 10: Develop tools to improve the performance of buildings and other structures in windstorms

Objective 11: Support the development of windstorm-resilient standards and building codes

Objective 12: Promote the implementation of windstorm-resilient measures

Objective 13: Improve windstorm forecast accuracy and warning time

Objective 14: Improve storm readiness, emergency communications and response

The three Strategic Goals align with the Program Components of NWIRP as identified in statute (42 U.S.C. 15703(c)). Key objectives, implementation strategies, and anticipated outcomes for each goal are provided in Chapter 2. These elements provide the broad and solid foundation for NWIRP. Program agencies are currently implementing many components of these objectives.

The Strategic Plan also identifies seven priority focus areas for new and enhanced efforts. These Strategic Priorities, listed below and detailed in Chapter 3, build upon and support elements of all 14 objectives. Strategic Priorities provide focused areas of foundational research critical to supporting future advances, as well as crosscutting themes and key opportunities for more rapid windstorm impact reduction.

SP-1: Develop Baseline Estimates of Loss of Life and Property due to Windstorms
SP-2: Obtain Measurements of Surface Winds and Storm Surge Current and Waves in Severe Storms
SP-3: Develop Publicly Available Databases of Windstorm Hazards and Impacts
SP-4: Develop Performance-Based Design for Windstorm Hazards

SP-5: Enhance Outreach and Partnerships to Improve Windstorm Preparedness and Hazard Mitigation
SP-6: Enhance and Promote Effective Storm Sheltering Strategies
SP-7: Develop the Nation's Human Resource Base in Windstorm Hazard Mitigation Fields

These goals, objectives, and Strategic Priorities were developed by the Program agencies following review and assessment of prior national research needs and planning documents, and consideration of stakeholder input. Stakeholder input was obtained through the NWIRP Strategic Planning Stakeholder's Workshop, held at the National Science Foundation on June 17, 2016. This Workshop was attended by over 80 participants from the public and private sectors who engaged in a series of 11 breakout sessions and provided ideas to help shape this Plan.

The goals, objectives, Strategic Priorities, and implementation strategies of this Plan will serve as guidelines for NWIRP efforts, but NWIRP will remain adaptable to contingencies and opportunities as they arise. Progress on implementation of this Plan and the rate of Program accomplishment will depend on the level of resources that are available to Program agencies.

NWIRP's success will require partnerships within the windstorm impact reduction stakeholder community, including research and academic institutions, business and industry, professional and technical and other private sector entities, and government. Working together, we can achieve the shared vision of a more windstorm-resilient nation.

Chapter 1: Introduction

The Challenge

Windstorms, and associated flooding, are the largest loss-producing natural hazard in the United States. The greatest of these losses are associated with tornadoes and hurricanes. During the period from 1980 to mid-2016, windstorms caused over $700 billion[1] in economic losses and caused over 4 500 fatalities.[1] Every state in the country is exposed to windstorm hazards from one or more storm types, including tornadoes (see Figure 1), tropical cyclones, thunderstorms, Nor'easters, winter storms, mountain downslope winds, and others.

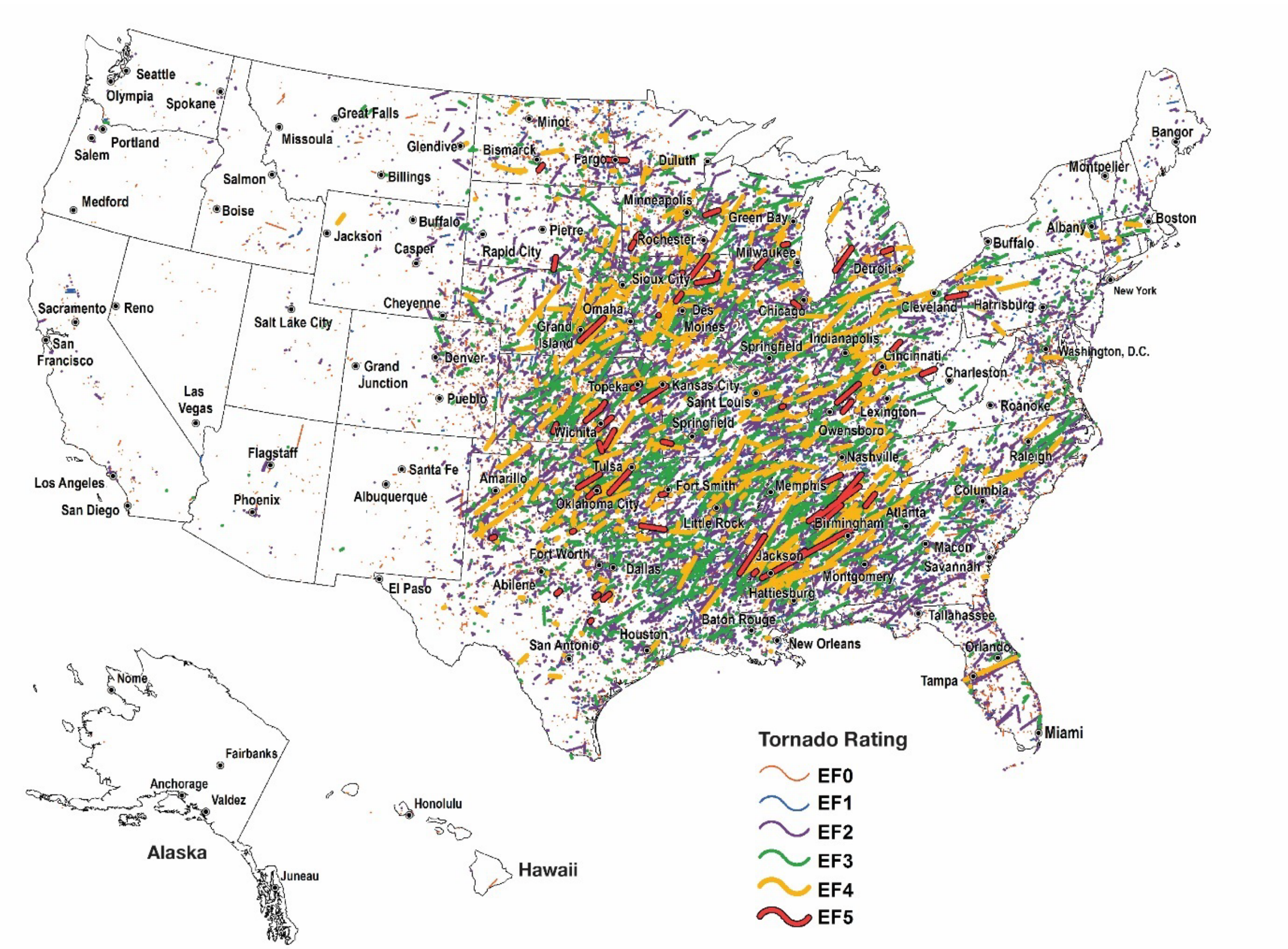

Figure 1. Tornado tracks from 1950-2014 mapped by intensity. Tornadoes occur in all 50 states. (Source: FEMA, using NOAA data)

[1] NOAA National Centers for Environmental Information, U.S. Billion-Dollar Weather and Climate Disasters, 1980-2016 https://www.ncdc.noaa.gov/billions/events.

Over the past 10 years, tornadoes have caused an average loss of over $10 billion per year. In 2011, six different tornado outbreaks affected 16 states and produced a combined damage of $29 billion and 545 fatalities[3]. The 2011 Joplin Missouri tornado alone killed 161 people, injured over a thousand, and resulted in nearly $3 billion in insured losses.[2]

Recent notable hurricane events include Hurricane Sandy, which caused over a $70 billion[1] loss, producing extensive damage in seven states, and Hurricane Katrina, which caused over 1,200 fatalities and a loss in excess of $150 billion, resulting in destructive storm surge along the Louisiana, Mississippi, and Alabama coasts, as well as high winds and damage as far inland as Ohio.[1] Over just a three-week period in the late summer of 1992, the US and its territories were affected by three devastating tropical cyclones, beginning with Hurricane Andrew in South Florida on August 24 ($46.2 billion estimated damage, 25 fatalities[3]), Typhoon Omar on August 28 in Guam ($457 million estimated damage (1992 dollars)), and Hurricane Iniki on September 11 in Kauai, Hawaii ($5.3 billion estimated damage, seven fatalities[3]).

The Pacific Northwest experiences strong winds from low pressure extratropical cyclones that typically cause extensive power outages every few years. Similarly, on the Atlantic coast these low pressure extratropical cyclones, called Nor' Easters, produce wind and storm surge damage, significant power outages and coastal erosion, from the Carolinas up to Maine. In the summer of 2012, a sustained line of strong thunderstorms associated with damaging straight-line winds, known as a derecho, affected 11 states and produced $3.0 billion in estimated damage and 28 fatalities.[3]

The most intense windstorms, hurricanes and tornadoes, have the potential to impact national security by producing devastating damage to critical infrastructure,[3] including, for example, defense facilities, ports, airports, communication and power grids, critical manufacturing, financial services and nuclear facilities. The impact of Hurricane Sandy (2012) on the Financial Center in New York represents a near miss in terms of significant damage to critical infrastructure. In 1992, Hurricane Andrew caused the almost total destruction of Homestead Air Force Base in Florida. The ports of Houston and New Orleans are the top two US ports in terms of tonnage, and both are located in high hurricane hazard areas. Approximately 25% of oil imported into the US is transported by tankers through the Houston Ship Channel for processing by refineries, including the nation's largest, all vulnerable to hurricanes.[4] Tornadoes pose threats to critical infrastructure such as power plants, as well as critical manufacturing and nuclear facilities.

Figure 2 shows the average annual insured and uninsured losses incurred by different hazards (perils) for the 10 year period ending in 2015. Tropical cyclones (including hurricanes and tropical storms) and severe weather (including thunderstorms and tornadoes) contribute the most to the annual losses, collectively making up to 73 % and 75 % of the total and insured losses caused by all hazards, respectively.

[2] Final Report, National Institute of Standards and Technology (NIST) Technical Investigation of the May 22, 2011, Tornado in Joplin, Missouri, NIST NCSTAR-3, March 2014. http://nvlpubs.nist.gov/nistpubs/NCSTAR/NIST.NCSTAR.3.pdf.

[3] The complete list of critical infrastructure sectors is given at https://www.dhs.gov/critical-infrastructure-sectors.

[4] Kramek, Commander Joseph. "The Critical Infrastructure Gap: US Port Facilities and Cyber Vulnerabilities." *Federal Executive Series Policy Papers*, Brookings Institution (2013).

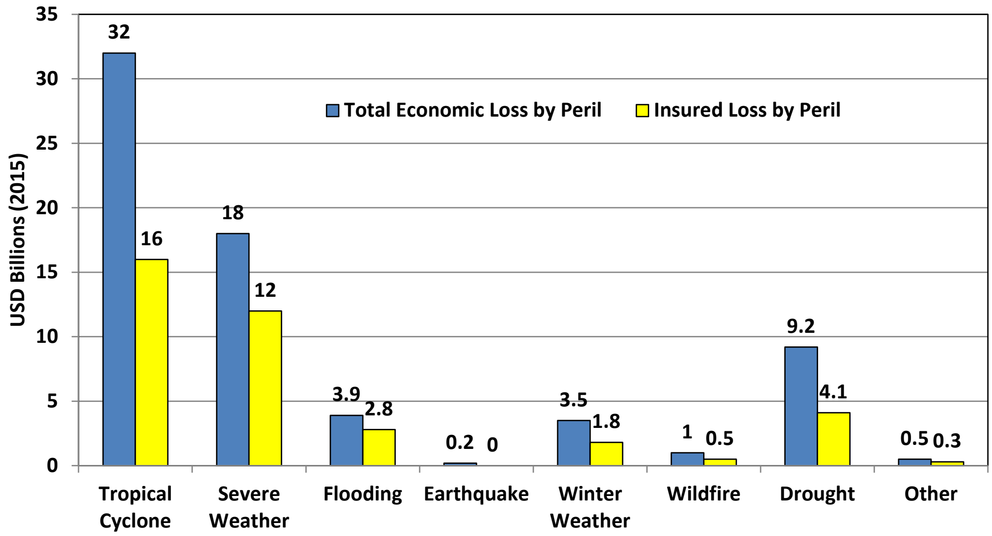

Figure 2. Average annual total and insured U.S. economic losses by peril for the 10-year period ending 2015 [5]

Figure 3 presents the 15 most costly natural disasters in the United States in terms of insured losses (adjusted for inflation but not wealth or population). The data shows that 14 of the 15 costliest natural disasters were due to windstorms (12 hurricanes and 2 tornado outbreaks), which comprised 88 % of the total loss. All but two of these windstorms have occurred since 2004.

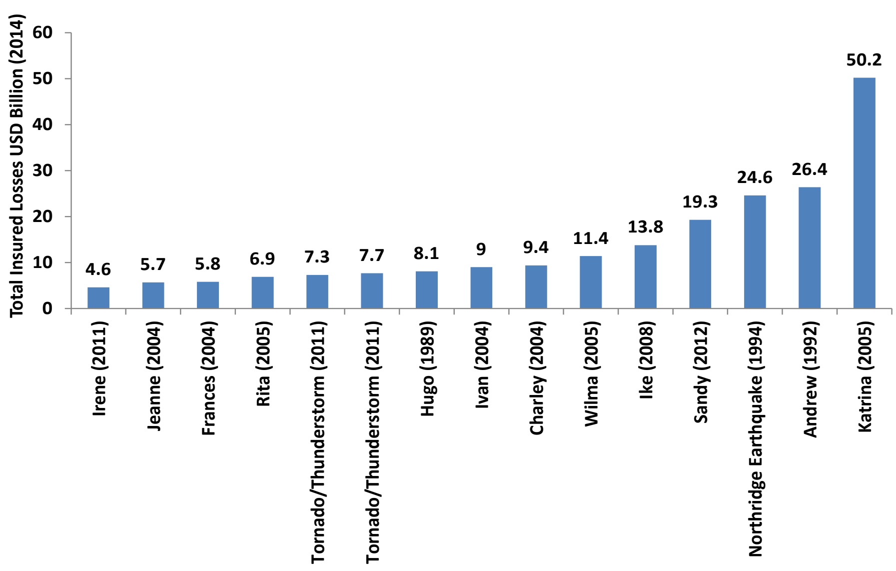

Figure 3. Top 15 most costly U.S. natural disasters (insured losses, 2014 dollars adjusted for inflation but not population or wealth) [6]

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[5] Data source: 2015 Annual Global Climate and Catastrophe Report, Impact Forecasting, Aon-Benfield, 2016 http://thoughtleadership.aonbenfield.com/Documents/20160113-ab-if-annual-climate-catastrophe-report.pdf.

[6] Data source: US Natural Catastrophe Review Webinar, First Half of 2015, Munich Re https://www.munichre.com/site/mram-mobile/get/documents_E336591247/mram/assetpool.mr_america/PDFs/4_Events/MunichRe_III_NatCatWebinar_071415_pdf.pdf.

The Cost of Inaction

The costs associated with hurricanes are forecast to increase more rapidly than the growth of the economy. The Congressional Budget Office (CBO)[7] projects that average annual losses due to hurricanes will increase from 0.16 % of gross domestic product (GDP) to 0.22 % of GDP by 2075. CBO projections include the effects of sea level rise, increased storm activity, population growth, increased coastal development, and increased per capita income in hurricane prone areas. These values do not take into account potential improvements in construction practices, land use practices, and building stock turnover.

Similarly, population growth in tornado alley will likely result in increased loss of life and damage unless cost effective measures are taken to reduce the impact of tornadoes on buildings and infrastructure. Figure 4 shows overall losses due to convective storms for the period 1980 through 2014. The losses are adjusted for inflation but not wealth or population growth. Convective storm losses have increased significantly over the past 35 years, and the rate of increase has accelerated over the last decade.

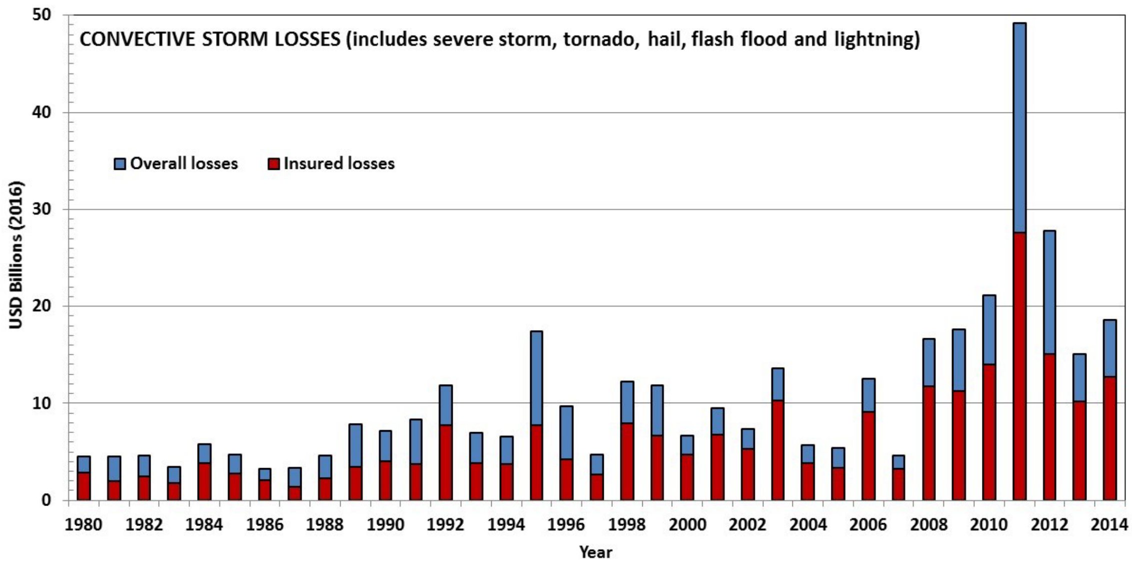

Figure 4. U.S. convective storm losses from 1980–2014 show an increasing trend with time[8]

The causes underlying these massive and rapidly increasing windstorm losses are many, varied, and complex. Some are related to long-term societal changes, such as the movement of population towards coastal areas in hurricane-prone regions of the U.S.[9] Others relate to lack of understanding of the storms and their associated hazards (e.g., extreme winds, windborne debris, atmospheric pressure change, storm surge, and surge-borne debris), interactions of these hazards on the built environment, how to effectively mitigate them, and how to effectively communicate with and educate the public and other stakeholders. Beyond the present limitations of physical science, social science and engineering knowledge, other contributing factors include deficiencies in current engineering design and construction practices, limited

[7] Potential Increases in Hurricane Damage in the United States: Implications for the Federal Budget, CBO, June 2016 https://www.cbo.gov/publication/51518.
[8] Data source: NAT CATS 2014: What's going on with the weather?, Munich Re, January 7, 2015. http://www.iii.org/sites/default/files/docs/pdf/munichre-010715.pdf.
[9] http://www.census.gov/topics/preparedness/about/coastal-areas.html.

code adoption and enforcement in many areas, costs of hazard mitigation, and lack of knowledge and/or prioritization of windstorm hazard mitigation by the public, businesses, and governments.

Advances in recent decades in atmospheric science have led to great improvements in forecasting and warning systems for hurricanes, tornadoes, and other windstorms; however, large knowledge gaps remain in aspects of windstorm climatology and hazards near the surface. This knowledge is critical for risk assessments and engineering design of the built environment to mitigate the impact of these hazards. Similarly, while great progress has been made in understanding earthquake effects on buildings and engineering design to resist those effects, comparatively less progress has been made in engineering for extreme winds, and less still for coastal inundation hazards of wind-driven storm surge and waves.

Without additional actions to mitigate windstorm hazards and thereby reduce windstorm risks, losses due to windstorms will only continue to increase.

Meeting the Challenge

In recognition of the necessary role for the Federal Government and other organizations in supporting windstorm impact reduction, Congress created the NWIRP in 2004 to measurably reduce the loss of life and property from windstorms (National Windstorm Impact Reduction Act of 2004, Public Law 108-360, Title II). On September 30, 2015, the National Windstorm Impact Reduction Act Reauthorization of 2015 (Public Law 114-52) was enacted, which reauthorized the Program, made changes to leadership, oversight, and reporting requirements, modified the roles of the four Program agencies, and updated other Program aspects.

With Public Law 114-52, the lead agency function for NWIRP was moved to NIST. In addition to overall leadership and coordination, NIST responsibilities include:

- Ensuring the Program includes components necessary to promote the implementation of windstorm risk reduction measures;
- Requesting assistance of Federal agencies other than the Program agencies, as necessary;
- Coordinating all Federal post-windstorm investigations to the extent practicable;
- Supporting the development of performance-based engineering tools and working with appropriate groups to promote the commercial application of such tools; and,
- When warranted by research or investigative findings, issuing recommendations to assist in informing the development of model codes, and providing information to Congress on the use of such recommendations.

There are four designated Program agencies: the Federal Emergency Management Agency (FEMA), the National Institute of Standards and Technology (NIST), the National Oceanic and Atmospheric Administration (NOAA), and the National Science Foundation (NSF). Additionally, the Federal Highway Administration (FHWA) has participated in NWIRP since its inception. These agencies work together to implement the Program’s three statutory components:

- Improved understanding of windstorms,
- Windstorm impact assessment, and
- Windstorm impact reduction.

Activities identified in the NWIRP authorization span the full spectrum from research through implementation, including basic physical science, social science, and engineering research; problem-focused research and codes and standards development; information dissemination, public education and outreach; and promotion of the adoption of windstorm preparedness and mitigation measures. NWIRP is instructed to work with other levels of government and private sector entities to develop and promote windstorm preparedness and wind mitigation programs through community outreach and education. NWIRP is tasked to work extensively to improve the performance of the built environment in windstorms. Basic and applied research in science and engineering supports development of methods, tools, and technologies for hazard and risk assessments and for improved design of buildings and infrastructure, which in turn supports changes to national model codes, standards, and practices. Improved construction then follows adoption and enforcement of model codes and standards by the authority having jurisdiction.

An Interagency Coordinating Committee oversees the Program's planning and coordination. The Interagency Coordinating Committee consists of the heads or designees of FEMA, NOAA, NSF, the Office of Science and Technology Policy (OSTP), and the Office of Management and Budget (OMB), and is chaired by the Director of NIST or the Director's designee. A new Windstorm Working Group (WWG) was created in 2016 to provide closer program coordination at the working level. In addition to NIST, FEMA, NOAA, NSF, and FHWA, other Federal agencies are invited to participate in NWIRP activities; among those already involved are the Department of Housing and Urban Development (HUD), the Department of Energy (DoE), and the U.S. Army Corps of Engineers (USACE).

Previous NWIRP activities and accomplishments have been documented in a series of biennial reports to Congress.[10,11,12] There are a number of areas where NWIRP research, development, and actions have reduced the impact of windstorms to lives and property. A few notable successes include:

- Advances in NOAA's satellite-based observations, supercomputers, and data assimilation and modeling have reduced average hurricane forecast track errors significantly—about half of what they were 15 years ago.
- Advances in the use of aircraft data have demonstrated the potential for significant improvements in hurricane intensity forecasts (20 to 40 percent), breaking a 30-year logjam in intensity forecast improvements.
- The introduction of Doppler radar and better understanding of radar indicators for tornado threat, as well as forecasting and prediction have enabled NOAA's National Weather Service (NWS) to double the average warning time for tornadoes over the past two decades to 13 minutes.

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[10] National Windstorm Impact Reduction Program Biennial Report to Congress for Fiscal Years 2013 and 2014, National Science and Technology Council. https://www.nist.gov/sites/default/files/documents/el/nwirp/NWIRP-FY2013-2014-Biennial-Report-to-Congress-2.pdf.

[11] National Windstorm Impact Reduction Program Biennial Report to Congress for Fiscal Years 2011 and 2012, National Science and Technology Council. https://www.nist.gov/sites/default/files/documents/el/nwirp/NWIRP-FY2011-2012-Biennial-Report-to-Congress.pdf. (Note – activities for Fiscal years 2007-2010 are included in appendices).

[12] Windstorm Impact Reduction Program, Biennial Progress Report for Fiscal Years 2005-2006, National Science and Technology Council. https://www.nist.gov/sites/default/files/documents/el/nwirp/NWIRP-FY2005-2006-Biennial-Report-to-Congress.pdf.

- Improvements in tornado intensity estimation (developed jointly by NIST, NOAA, and Texas Tech University) allowed the Enhanced Fujita (EF) tornado scale to be adopted and used for more accurate rating of tornado intensity by the NWS in 2007.
- New knowledge from NSF awards has helped risk communicators improve the effectiveness of warning messages, zoning boards understand opportunities to increase resilience, and emergency managers to address the concerns of evacuees.
- New wind speed maps for the design of buildings and structures developed by NIST have been approved for incorporation in the 2016 edition of the *ASCE 7 Standard for Minimum Design Loads for Buildings and Other Structures*. The new wind speed maps provide more accurate design wind speeds and incorporate regional differences in extreme wind climate across the country.
- FEMA publications presenting design and construction guidance for safe rooms have been available since 1998. Since that time, over one million copies have been distributed and thousands of safe rooms have been built. A growing number of these safe rooms have already saved lives in actual events. There has not been a single reported failure of a safe room constructed to FEMA criteria.
- Successful building code change proposals by FEMA for the 2015 International Building Code (IBC) will result in ICC 500-compliant storm shelters in new schools and first-responder facilities in the areas of the nation with the highest tornado risk. NIST successfully proposed changes to the 2018 IBC and 2018 International Existing Buildings Code (IEBC) to extend the requirements for new schools to also include new buildings and additions to buildings on existing school campuses.
- Results of wind engineering research by FHWA have contributed to a better understanding of bridge cable aerodynamics and effectiveness of associated wind mitigation techniques, improved techniques for physical and computational modeling of wind hazards to transportation structures, and updates of design guides and specifications for wind.

NWIRP Vision, Mission, and Strategic Planning

This section of the report identifies the framework for the NWIRP Strategic Plan, including vision and mission statements, goals and objectives, and a description of the strategic planning process.

The NWIRP Vision is:

A nation that is windstorm-resilient in public safety and economic well-being.

The NWIRP Mission is:

To achieve major measurable reductions in the losses of life and property from windstorms through a coordinated Federal effort, in cooperation with other levels of government, academia, and the private sector, aimed at improving the understanding of windstorms and their impacts and developing and encouraging the implementation of cost-effective mitigation measures to reduce those impacts.

Three overarching, long-term Strategic Goals have been established to accomplish this mission, consistent with identified needs and the statutory requirements of the Program.

- Goal A: Improve the Understanding of Windstorm Processes and Hazards;
- Goal B: Improve the Understanding of Windstorm Impacts on Communities;
- Goal C: Improve the Windstorm Resilience of Communities Nationwide.

The activities of the Program agencies, in collaboration with other Federal agencies, State and local governments, academia and the private sector, are intended to further the ultimate objective, which is to reduce the loss of life and property from windstorms. The extent to which the Program agencies are able to support these outcomes is a function of the resources available. Figure 5 shows the relationships between the goals and how the information, tools, and programs developed by NWIRP will result in products and services that increase community resilience to windstorms.

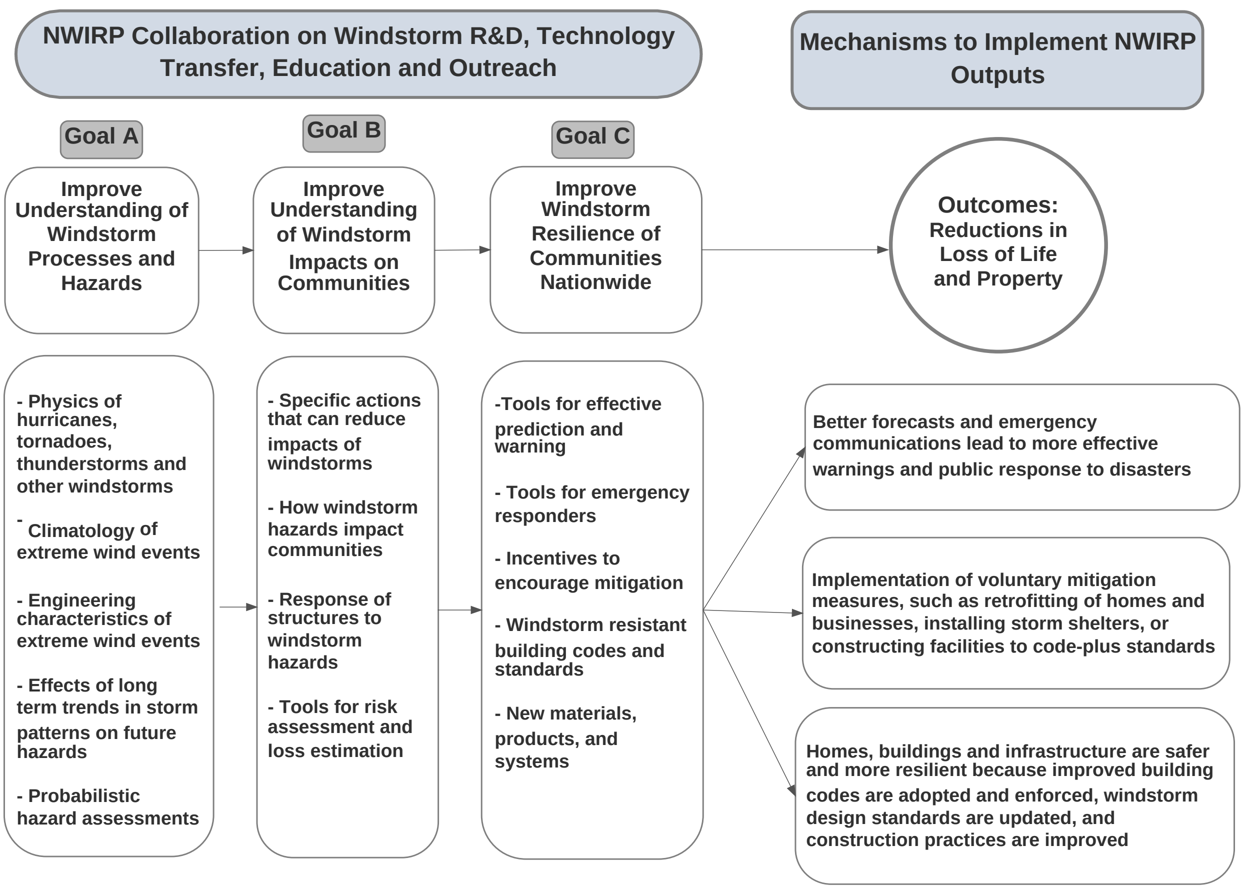


Figure 5. NWIRP Goals and outcomes that reduce loss of life and property

Each Strategic Goal includes several objectives, as listed below. Together, these linked goals and objectives provide a solid foundation for windstorm impact reduction, spanning the range of necessary actions from basic research through implementation. Details on each of the goals and objectives and linkages between them, including implementation strategies and anticipated outcomes, are presented in Chapter 2. Appendix C provides a mapping of each Program agency's statutory responsibilities (42

U.S.C. § 15703(b)) to the Strategic Plan's goals and objectives, and Appendix D maps the required Program Components (42 U.S.C. § 15703(c)) to the goals and objectives. Progress is being made towards a number of elements of these objectives, under NWIRP and other Program agency authorities. These activities are detailed in the most recent NWIRP biennial report to Congress.[13]

Goal A. Improve the Understanding of Windstorm Processes and Hazards

Objective 1: Advance understanding of windstorms and associated hazards

Objective 2: Develop tools to improve windstorm data collection and analysis

Objective 3: Understand long term trends in windstorm frequency, intensity, and location

Objective 4: Develop tools to improve windstorm hazard assessment

Goal B. Improve the Understanding of Windstorm Impacts on Communities

Objective 5: Advance understanding of windstorm effects on the built environment

Objective 6: Develop computational tools for use in wind and flood modeling on buildings and infrastructure

Objective 7: Improve understanding of economic and social factors influencing windstorm risk reduction measures

Objective 8: Develop tools to improve post-storm impact data collection, analysis, and archival

Objective 9: Develop advanced risk assessment and loss estimation tools

Goal C. Improve the Windstorm Resilience of Communities Nationwide

Objective 10: Develop tools to improve the performance of buildings and other structures in windstorms

Objective 11: Support the development of windstorm-resilient standards and building codes

Objective 12: Promote the implementation of windstorm-resilient measures

Objective 13: Improve windstorm forecast accuracy and warning time

Objective 14: Improve storm readiness, emergency communications and response

In addition to these goals and objectives, NWIRP has identified seven priority focus areas for new and enhanced efforts through its strategic planning process. These Strategic Priorities represent a combination of: 1) long-term research efforts to provide foundational windstorm hazard and loss data and models; 2) opportunities for more rapid windstorm impact reduction, building on existing programs; and 3) crosscutting themes to enhance development of the Nation's human resource base in windstorm hazard

[13] National Windstorm Impact Reduction Program Biennial Report to Congress for Fiscal Years 2013 and 2014, National Science and Technology Council. https://www.nist.gov/sites/default/files/documents/el/nwirp/NWIRP-FY2013-2014-Biennial-Report-to-Congress-2.pdf.

mitigation fields. These Priorities, listed below and described in Chapter 3, build on and support elements of all 14 objectives.

SP-1: Develop Baseline Estimates of Loss of Life and Property due to Windstorms
SP-2: Obtain Measurements of Surface Winds and Storm Surge Current and Waves in Severe Storms
SP-3: Develop Publicly Available Databases of Windstorm Hazards and Impacts
SP-4: Develop Performance-Based Design for Windstorm Hazards
SP-5: Enhance Outreach and Partnerships to Improve Windstorm Preparedness and Hazard Mitigation
SP-6: Enhance and Promote Effective Storm Sheltering Strategies
SP-7: Develop the Nation's Human Resource Base in Windstorm Hazard Mitigation Fields

The strategic planning process to develop these goals, objectives, and Strategic Priorities incorporated review of relevant documents, stakeholder input obtained through the NWIRP Strategic Planning Stakeholder's Workshop, and input from NWIRP and other Federal agencies through the WWG. Grand challenge reports, research needs documents, R&D roadmaps, and other relevant information from the technical literature was considered, including from these key documents:

- *Grand Challenges for Disaster Reduction*, National Science and Technology Council, Subcommittee on Disaster Reduction, 2008. http://www.sdr.gov/grandchallenges.html.
- *Hurricane Warning: The Critical Need for a National Hurricane Research Initiative*, National Science Board of the National Science Foundation, 2007. http://www.nsf.gov/nsb/publications/2007/hurricane/initiative.pdf.
- *Final Report*: *Workshop on Weather Ready Nation: Science Imperatives for Severe Thunderstorm Research*, 24-26 April, 2012, Birmingham AL, Sponsored by the National Oceanic and Atmospheric Administration and National Science Foundation, Eds. M. Lindell and H. Brooks, 2012. http://www.nws.noaa.gov/com/weatherreadynation/files/WRN_FinalReport120917.pdf.
- *Measurement Science R&D Roadmap for Windstorm and Coastal Inundation Impact Reduction*, NIST GCR 14-973-13, National Institute of Standards and Technology, 2014. http://www.nist.gov/customcf/get_pdf.cfm?pub_id=915541.
- *Windstorm Impact Reduction Implementation Plan*, National Science and Technology Council, 2006. http://www.sdr.gov/docs/Windstorm%20Impact%20Reduction%20Implementation%20Plan%20FINAL.pdf.

Another key resource document was the *Strategic Plan for the National Earthquake Hazards Reduction Program* (October 2008, http://nehrp.gov/pdf/strategic_plan_2008.pdf). This program, also known as NEHRP, is structured very similarly to NWIRP and has similar goals for earthquake impact reduction. Many elements of the NWIRP Strategic Plan were adapted from the NEHRP Strategic Plan. An NWIRP Strategic Planning Stakeholder's Workshop was held at the National Science Foundation on June 17, 2016, to gather stakeholder input supporting development of the Strategic Plan. The Workshop, including 11 breakout sessions, was attended by over 80 participants, from government, academia, and the private sector, including insurance and reinsurance companies, consultants, building product manufactures and trade associations, professional societies, and standards development organizations. Fourteen Federal agencies participated in the workshop, including all of the agencies in the WWG, as well as the National Aeronautics and Space Administration (NASA), the Nuclear Regulatory Commission (NRC), the United States Geological Survey (USGS), the Department of Homeland Security (DHS), the Veterans Administration (VA), and the General Services Administration (GSA).

NWIRP Participants and Roles

The success of NWIRP depends on a coordinated Federal effort, in cooperation with other levels of government, academia, and the private sector. The roles of all the participating stakeholders are described in this section, beginning with those of the Program agencies.

NSF supports a broad range of basic research in atmospheric sciences and engineering to improve understanding of the behavior of windstorms and their impact on buildings, structures, and lifelines. Recent atmospheric science research includes studies of the physical processes that determine hurricane intensity, tornado genesis, and tornadic vortex structure. Supported engineering research projects include simulation of hurricane and tornado wind fields and the understanding of tornado, hurricane, and wind-driven rain effects on buildings. NSF has supported research to improve coastal modeling capabilities for storm surge simulation. The Natural Hazards Engineering Research Infrastructure (NHERI) program supports two multi-user national facilities for experimental wind engineering. NSF also supports research in economic and social factors influencing windstorm risk reduction measures, as well as education and development of new scientists and engineers.

NOAA also supports atmospheric sciences research to improve understanding of the behavior of windstorms and their impact on the built environment, including study of the physical processes that determine hurricane intensity, tornado genesis, tornadic vortex structure, and other weather phenomena including waves, storm surge, and related impacts. It supports research to improve observations of physical phenomena; development of novel data assimilation and forecasting techniques; and applications of observations, models, and forecasts. NOAA additionally plays a critical role in other component areas of NWIRP not specifically identified in statute (42 U.S.C. § 15703). Such activities include collection and archival of windstorm and post-windstorm data, information dissemination, and education and outreach activities that support windstorm impact reduction, such as through the Weather Ready Nation program.

NIST conducts R&D to improve model building codes, voluntary standards, and best practices for design, construction, and retrofit of buildings, structures, and lifelines. Recent activities include development of procedures for accurate characterization of wind and coastal flood hazards, aerodynamic loading, and structural response to these effects. It has updated design wind speed maps for use in building codes and standards. NIST is currently working to develop new risk-consistent tornado hazard maps to support the development of a performance-based design standard for tornado-resistant design of buildings and infrastructure. NIST is also developing computational wind engineering methods and tools for simulation of wind loads on buildings, supported by aerodynamics testing in the NIST wind tunnel.

FEMA is tasked to support development of risk assessment tools and effective mitigation techniques, such as the Hazus®-MH Hurricane Module. FEMA works closely with national standards and model building code organizations, in conjunction with NIST, to promote implementation of research results and better building practices. FEMA supports windstorm-related data collection and analysis. Their post-storm Mitigation Assessment Team (MAT) reports and other post-disaster investigations translate lessons learned from windstorms into guidance documents and training support for states and multistate regions. FEMA also supports public outreach and information dissemination, and promotion of the adoption of windstorm preparedness and mitigation measures, including for households, businesses, and communities, consistent with the agency's all-hazards approach.

In addition to the four statutory Program agencies, FHWA supports research and development to improve windstorm resilience of transportation facilities and infrastructure.

The roles of the Program agencies and other stakeholder organizations in the windstorm impact reduction process are shown schematically in Figure 6. This figure also identifies the connections among the major components and activities of NWIRP. Basic and applied research in science and engineering supports development of methods, tools, and technologies for hazard and risk assessments and for improved design of the built environment, which in turn supports changes to national model codes, standards, and practices. State and local governments participate by adoption and enforcement of model codes and standards.

Direct windstorm impact reduction takes place in the three fields identified with circles in Figure 6, where 1) risk assessments, planning, training, outreach, and information dissemination trigger risk reduction actions for the full range of end users, and 2) more windstorm-resistant buildings and other facilities are designed, constructed and retrofitted. The latter occurs through two paths, mandatory improvements as regulated through adopted and enforced building codes, and voluntary mitigation through code-plus programs, windstorm retrofits, etc. Examples of risk reduction actions by end users include a homeowner installing hurricane shutters to protect the windows, making a plan for the family of what actions to take in case of a tornado warning, or a homebuyer purchasing a code-plus house instead of one that only meets the minimum requirements. Another type of risk reduction action would be a business or facility owner in a tornado-prone area conducting a windstorm risk assessment, then deciding to either install a storm shelter or at least identify the best available tornado refuge area in the existing facility, followed by developing and practicing operational plans to move building occupants to the shelter or refuge area during a storm. All of these direct windstorm impact reduction actions are informed by the many supporting R&D and codes and standards activities.

Post-windstorm data collection and observations are critical to the continuous process of evaluating the effectiveness of implementation actions and identifying areas in need of further research and development. Additional stakeholders beyond those shown in Figure 6 are involved in the windstorm impact reduction process including other government agencies and academic institutions.

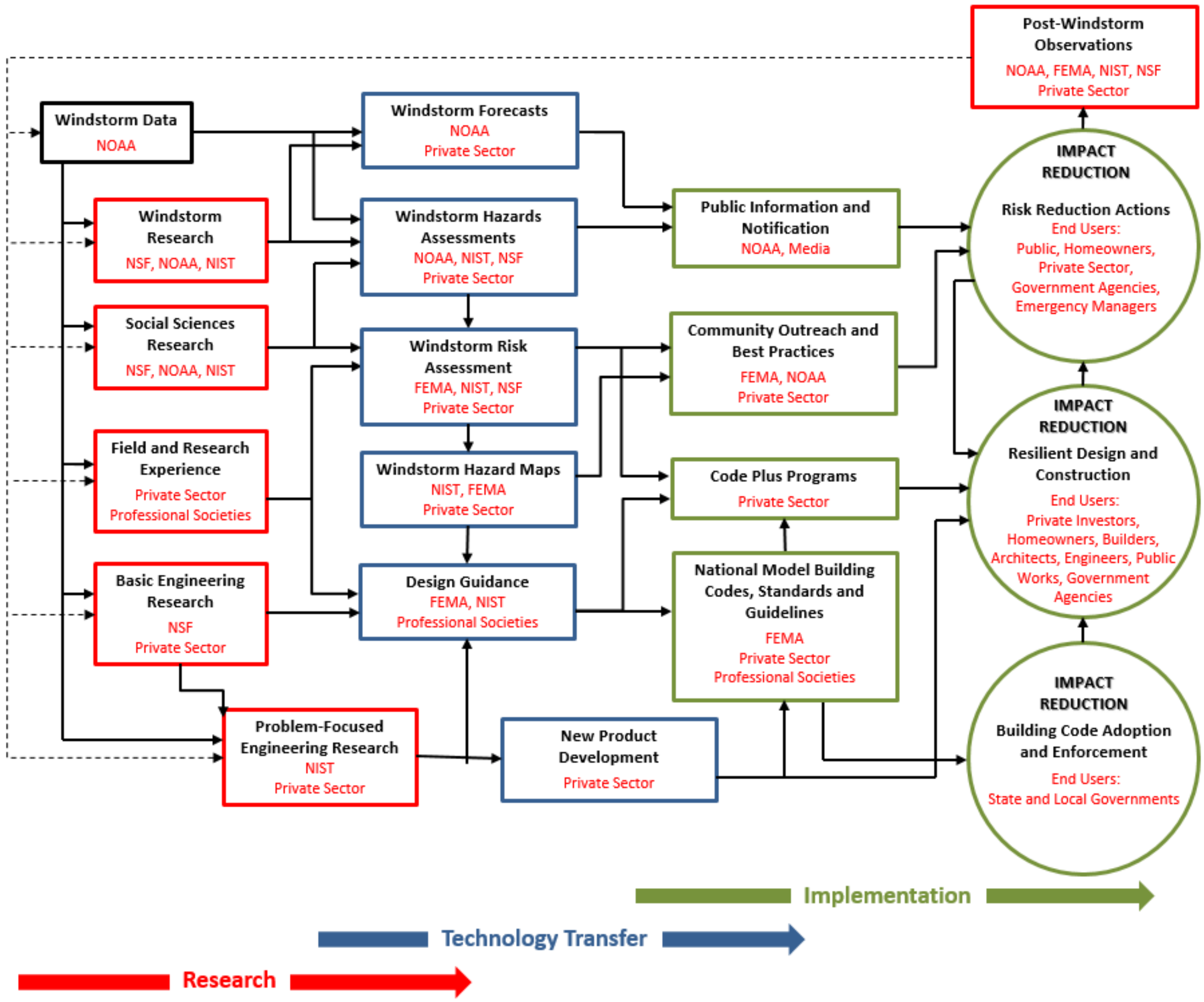


Figure 6. Roles of Program agencies and other stakeholders in the windstorm impact reduction process

Assessing Progress

The ultimate success for NWIRP will be the achievement of major reductions in loss of life and property from windstorms. However, achieving this goal will require a sustained effort over a significant period of time. An intermediate success measure will be slowing the rapid rate of growth in property losses described earlier in this chapter. Developing the data and metrics to better understand and document current losses and improve tracking of future losses is the focus of Strategic Priority 1, including nuances such as consideration of growth in population and wealth (see Chapter 3 for more information on SP-1).

It can be a long process from basic research to implementation actions that will result in observed impact reductions, so progress in the near term must also be assessed through additional means. For example, research advances in atmospheric science that lead to technologies for more accurate storm forecasts take additional years of development and testing before they can be sustained in operation. Similarly, much of the impact reduction through NWIRP is tied to improvements in building design and construction, which also takes time. Update cycles for building codes and standards commonly range from three to six years, not considering the time to conduct the R&D on the front end, and code adoption and enforcement on the back end. Other pathways to improved construction can be shorter. In certain cases, standards are adopted directly by state and local governments. Standards also find some level of usage even before adoption in regulation. Voluntary application of design guidance documents, which often predate standards, provides another means for more rapid delivery of research results into practice. Improvements to the resilience of building stock and infrastructure then provide the potential for reduced impacts that will be realized only when subjected to windstorms. Reductions in incremental costs associated with these improvements to the windstorm resilience of the built environment are important to increased adoption of better design and construction techniques. NWIRP contributions to potential impact reduction from across the spectrum of research through implementation will be documented and assessed as described in this section.

The National Windstorm Impact Reduction Act Reauthorization of 2015 (Reauthorization) directs the NWIRP to describe the methods by which progress towards the goals of the program will be assessed. NWIRP will assess and report progress through its biennial reports to Congress. The progress reports will include descriptions of Program agencies' activities supporting NWIRP, and information on how these actions have, and will continue to contribute to, the reduction in loss of life and property. Figure 7 depicts the relationship between the Reauthorization and the strategic goals and objectives, supported by Program agency projects and NWIRP progress assessments.

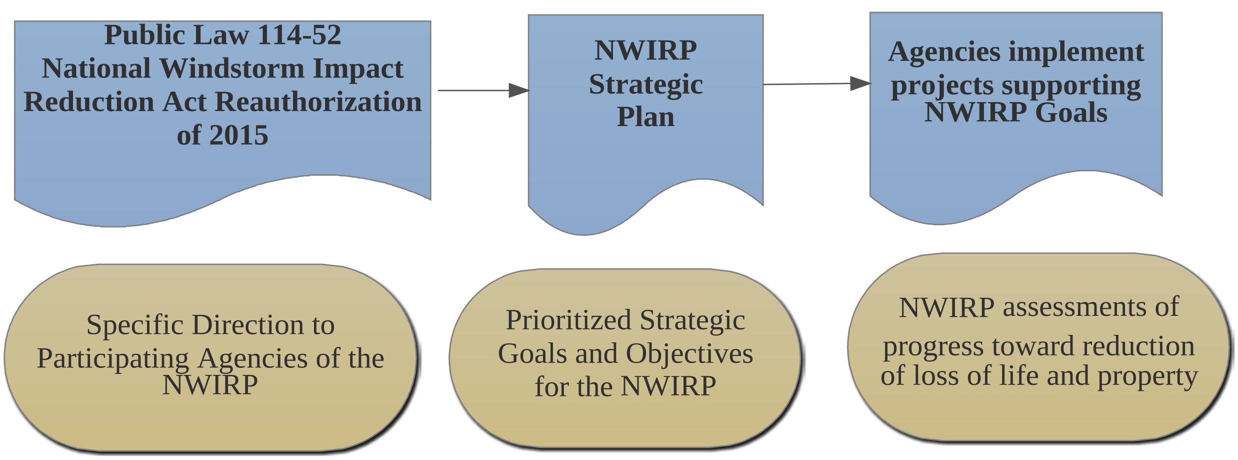


Figure 7. Conceptual diagram of relationship of Reauthorization to implementation

Chapter 2: Goals and Objectives

This Strategic Plan is built upon three long-term Strategic Goals that serve as the foundation for the Program vision. The goals are not independent; they are linked in a logical manner that will ultimately lead to reductions in loss of life and property from windstorms. Each overarching goal includes several objectives, strategies for implementation and anticipated outcomes that provide insight into its importance to the Nation. These goals address windstorm hazards, risks, and actions to reduce risk:

Goal A: Improve the Understanding of Windstorm Processes and Hazards;

Goal B: Improve the Understanding of Windstorm Impacts on Communities;

Goal C: Improve the Windstorm Resilience of Communities Nationwide.

A hazard is defined as a potential threat or incident, natural or human caused, that warrants action to protect life, property, the environment, and public health or safety, and to minimize disruptions of government, social, or economic activities. Windstorm hazards include high winds, windborne debris, extreme rainfall and inland flooding, hail, snow, ice, lightning, atmospheric pressure change, storm surge and coastal flooding, waves, and floodborne debris. Goal A focuses on developing a better understanding of the wind and coastal flood hazards caused by windstorms and their probabilities.

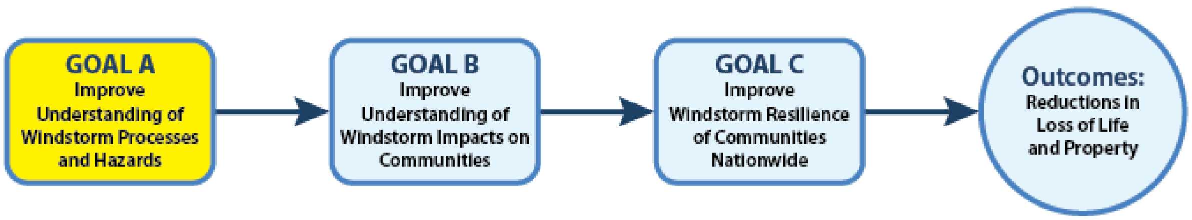
Risk is defined as the potential for loss or injury due to an adverse circumstance or hazard. Estimates of risk require knowledge of the hazard and its probability of occurrence, the vulnerability of a structure, system, or community given a hazard intensity, such as wind speed, flood water depth or wave height, and resulting consequences. Goal B identifies the research needed to better understand and reduce vulnerability and adverse consequences, and hence risk, and development of methods and tools to better quantify physical and social vulnerabilities and risk.

The results from research and development activities of Goals A and B provide a sound technical basis for development and implementation of windstorm impact reduction measures. Goal C addresses actions directly enabling impact reduction, including through improved building codes and standards, public policies to improve windstorm resilience, improved windstorm forecasts, and improved public response.

Each objective includes anticipated outcomes, which are identified as either short-term, medium-term, or long-term efforts. The time frame for a short-term effort is considered to be approximately seven years or less, a typical amount of time required for conducting research and translating the results into a code or standard. The medium term is 8 to 15 years, allowing new research findings to be incorporated in codes and standards over a two to three code cycle period. Long-term efforts would be those taking more than 15 years. Broadly, each of the objectives possess a long-term aspect, as the availability of additional knowledge and data over time will enable the maintenance and updating of the research, standards, design codes, products, materials, programs, and initiatives developed with currently available data.

As windstorm losses continue to trend upward, there is a greater need than ever for increased R&D, technology transfer, and implementation of windstorm impact reduction measures. NWIRP will support fundamental research aligned with Goals A and B in the atmospheric sciences, hazards engineering, and social sciences associated with extreme wind event phenomena, windstorm impacts, and effective measures to reduce the loss of life and property during hurricanes, thunderstorms, tornadoes and other severe windstorms. The Program agencies recognize that this research is foundational to improving our understanding of the damaging effects caused by severe windstorms, and producing effective policies and programs that prevent or mitigate loss of life and property. To achieve Goal C, NWIRP will support development of cost-effective windstorm-resistant materials and systems for use in new construction and retrofit of existing construction and development of more windstorm-resilient building codes and standards. NWIRP will also work to increase public awareness of windstorm risks and promote hazard mitigation policies and programs as well as improved windstorm emergency preparedness, communication, and response.

These Strategic Goals and objectives provide a framework for Program agencies, in collaboration with other Federal agencies, State and local governments, academia and the private sector, to work toward the ultimate objective, which is reduction of loss of life and property from windstorms. Progress by Program agencies on implementation of these goals and objectives, conducted under NWIRP and other Program agency authorities, will depend on the level of resources that are available to Program agencies.



Goal A. Improve the Understanding of Windstorm Processes and Hazards

Our current understanding of the detailed characteristics of strong winds near the ground and coastal flooding as it moves inland, which is so critical to understanding and mitigating windstorm risk, is very limited. Goal A focuses on filling these gaps in our knowledge. NWIRP research directions will include improved measurement and modeling of hurricanes, tornadoes, thunderstorms, and other windstorms, enabling a better understanding of the effects of extreme winds and wind-driven storm surge and waves on civil infrastructure and lifelines in the larger context of community resilience through Goal B. Tools for windstorm hazard assessment will be developed, including consideration of long term trends in windstorm frequency, intensity, and location, and how changes in these storm characteristics affect risk.

Objective 1: Advance understanding of windstorms and associated hazards

Investment in new research is critical to unlocking new pathways to mitigate or eliminate damage resulting from the effects of extreme wind events. Further investigation is required to advance the scientific understanding of tropical cyclones, thunderstorms, tornadoes, downbursts, Nor' Easters, and other storms, particularly as it relates to the interaction of surface winds, storm surge, and waves with buildings, bridges, and lifeline utilities (e.g., electrical power transmission lines).

Experimental field research will elucidate the surface wind field where damage to infrastructure occurs and improve our ability to refine computer models and laboratory simulations for many different windstorm types, including hurricanes, tornadoes and thunderstorms. Advancing new applications of field remote sensing technology (e.g., inexpensive sensors to capture flood elevation and current for surge measurements) will be critical to achieving this goal. Establishing standardized post-processing methods will complement these efforts, with the end goal of assimilating data collected from a wide range of terrain conditions, elevations, and sampling strategies into a common framework that allows forecasters, storm surge modelers, and others to apply them in the appropriate context for their field.

Tropical Cyclones: Accurate modeling of the track and intensity of tropical cyclones, including subtropical storms and post-tropical events (Hurricane Sandy at landfall), is critical to evacuation and response planning. While track forecasting has steadily improved over the last two decades because of advancements in computer modeling and data collection / assimilation, estimates of the surface wind field has not achieved the accuracy or the spatial resolution necessary for engineering practitioners to determine cause of damage. Additional research is required to accelerate progress in this area, particularly to better understanding the physical processes at all stages of a tropical cyclone's lifecycle (including when the storm moves far inland). A major challenge will be combining surface-, aircraft- and satellite-based weather observations in the regions impacted by hurricanes such as the front right quadrant of a hurricane transitioning from ocean to land. For example, the combination of NOAA dropsonde data, aircraft wind data and surface wind speed will improve models that describe the behavior of wind changes near the surface as the wind transitions from deep offshore to shallow water nearshore to land.

Extratropical Storm Systems: Extratropical weather systems such as Nor'easters, which are cold-core cyclones that can generate hurricane force winds, intense rain, and heavy snowfall, are even less well understood. The wind fields are often highly variable, therefore engineers mainly rely on nearby measurements, not computer modeling, to reconstruct environmental conditions. New research is required to improve computer modeling of surface-level winds, enabling explicit simulation of extratropical storms.

Thunderstorms: Thunderstorms pose a widespread risk to most of the United States. Fundamental questions exist about the representative characteristics of the surface winds, i.e. the velocity profile and turbulence characteristics and their dependence on the local terrain roughness and topography. More research in the field and laboratory will help explain the characteristics of the downburst winds at heights relevant to design of buildings and structures (e.g. rooftop heights and below), where there is a current paucity of data. There is also a need for a climatology of downbursts to be developed.

Tornadoes: Tornadoes present a very significant risk to life and property across a large portion of the United States, particularly east of the Rocky Mountains. As in the case or thunderstorms, fundamental questions exist about the representative characteristics of tornado winds at heights relevant to the design of buildings and structures, i.e. the vertical variation of tangential, radial, vertical velocities and turbulence characteristics, and their dependence on the terrain and size of the tornado. More analytical, computational, laboratory, and field research is needed to better understand the wind fields and atmospheric pressure change throughout the tornado vortex. Additional research is also required to better understand tornado climatology. The existing climatology is biased due to limitations of observation technologies and damage-based intensity reporting methods that miss many tornadoes or underestimate their intensity, particularly in sparsely populated areas. Improved methods of tornado detection, track and path width determination, and intensity classification are needed.

Special Winds: Other special wind events such as downslope winds (e.g., Chinook and Santa Ana winds) are not well described in the peer-reviewed literature. Engineering guidance for the design of structures prone to downslope winds is scarce. New research is needed to standardize the methods for these ‘special wind regions,’ which today can only be defined by regional climate data.

Key focus areas common to all of these windstorm events include (a) improving measurement science and technology to characterize the structure and intensity of windstorm events at high resolution in both time and space and (b) improving computational modeling to accurately and reliably recreate, or eventually predict, weather conditions at parcel (lot) level resolution.

Cross-cutting Data and Research: Enhancing collaborations between engineers and meteorologists is widely recognized by both communities as a critical synergistic opportunity. That being said, approaches for prediction of surface level wind speeds still varies between disciplines. Atmospheric scientists primarily rely on global and regional weather prediction models. A growing body of research suggests that these tools are suitable to estimate long-term (monthly or annual) statistics; however, recreating high resolution surface velocities is impractical today. Thus engineers and catastrophe modelers typically apply [a] models calibrated to storm parameters such as the central pressure deficit and the distance to the maximum winds from the center of the storm, [b] data-driven simulations that ingest wind field observations with adjustments for variations in height, terrain, averaging duration or [c] on smaller spatial domains, computer simulations that characterize the flow through and around infrastructure (e.g. large eddy simulations). Research to bridge or unify these efforts could be fundamentally transformative for finding solutions to better predict, prepare for, and respond to extreme wind events.

Outcome: Integrated datasets of wind, storm surge and wave observations that are accessible in the public domain; technological advancements in in-situ and remote sensing that improve the spatiotemporal resolution of collected data; and improved prediction and characterization of extreme windstorm events, including enhancing numerical weather prediction models to reconstruct or predict surface winds at sufficient resolution to model structural damage and produce better severe weather warnings to the general public. This is a long-term effort that will be on-going for the foreseeable future.

Objective 2: Develop tools to improve windstorm data collection and analysis

Observations of windstorm phenomena are crucial to increasing our understanding of windstorms and our ability to predict them. Existing observation systems face challenges with readily accessible archives and metadata allowing the appropriate use of the data. With coming advances in measurement technologies and the increasing number and type of sensors and data, it will be even more critical to develop improved systems for data archival and analysis, including documentation of observing system metadata. This data should be archived in publicly available databases. This objective promotes improving the quantity and quality of windstorm hazard data through the hardening of existing public observing systems; documentation and archival of observing system metadata such as precise anemometer location, height, and type, and development of data-driven tools to perform wind field analyses in real-time and post-event.

Hardening Observing Systems: The existing infrastructure of in-situ instrumentation for observing windstorm phenomena often fails during intense storms. For example, the maximum winds in hurricanes are often not recorded because of loss of power, and tide gauges often fail before they record the maximum water level produced during a hurricane or extratropical storm event. An effort to improve the reliability and durability of these measurement systems is needed. Wind speed and other meteorological measurements at airport and other official observation stations should be supplied with back-up power so that they continue to record data throughout a storm. The high wind and storm surge data generated by the observing systems are critical for evaluating hazard models and assessing the true magnitude of the winds, and storm surges in landfalling hurricanes. Portable anemometers and portable Doppler radar systems operated by academic and private research organizations are sometimes available to supplement the data collected by the fixed observing systems in wind storms, but more measurements are needed, using well characterized, permanent observing systems.

Observing System Metadata: The usefulness of existing windstorm data can be significantly improved through more detailed documentation of instrument types, locations, and surroundings. Many available windspeed measurements are of limited to no value because they were recorded using instruments with undocumented heights, anemometer types, and other key installation details. These data may have been able to be used if detailed metadata, including precise latitude and longitudes, instrument types, and photographs of the installations and surroundings were provided. Availability of such metadata will significantly increase the usefulness of many state and local weather observing systems and private mesonets, as well as publically available databases (e.g., National Climatic Data Center products). Guidance for documenting and archiving this crucial metadata are needed, along with guidance to improve siting of new observing systems to minimize interference with immediate surroundings (e.g., avoid placement on building roofs).

Data Analysis Tools: Better publicly available tools are needed to synthesize the data that is currently available, such as NOAA dropsondes wind speeds and remotely sensed surface over water wind speeds in hurricanes, with all of the land-based measurements that are used to generate post event hazard footprints. The number of sensors worldwide is anticipated to grow into the trillions by the 2020s; machine learning is rapidly advancing how meaningful information is extracted from large datasets; and autonomous systems will become commonplace in the not too distant future. These advances likely will fundamentally change how natural hazard data are collected, especially for compact or short-lived severe weather events that are difficult to target for data collection (e.g. downbursts). As more and more data become available, better tools will be needed to synthesize the new data and create 4-D reconstructions of windstorm events, including tornado outbreaks, hurricane winds and surge, thunderstorms and extratropical storms. Similarly, better methods to construct real-time 4-D analyses of current conditions are needed to help drive improvements to forecasts and warnings of windstorm events.

Outcome: The development of techniques to harden existing systems that measure wind speeds and water levels will increase the amount of data from severe storms, where data is needed the most (long-term effort). The development of a framework and guidance for collecting and archiving the needed metadata will go a long way to improve the usability of the data that are currently being collected, and data that will be collected in the future. Developing metadata guidance is a short-term effort, while promoting adoption and implementation of such guidance is a long term effort.

Objective 3: Understand long term trends in windstorm frequency, intensity, and location

Variations over time in the patterns of extreme wind events raise important questions about possible changes in expected magnitude and frequency of windstorm hazards experienced by civil infrastructure and lifelines over their service life, which can extend many decades and even centuries. Therefore, it is paramount that atmospheric scientists work toward quantifying and reducing the uncertainties associated with projecting changes in hazard scenarios. Insufficient data from the pre-satellite era is a limiting factor for assessing long-term climatology, particularly for hurricanes. Research is needed to improve confidence in the underlying predictive modeling and the interpretation of the results in the context of designing against windstorms. An important first step will be identifying the relevant scientific questions related to the adaptation of design and construction practices to meet the demands of current and future risks. Key questions include but are not limited to:

- How will sea-level rise affect the prediction of storm surge and coastal flood elevation and inland extent of inundation in hurricanes and extratropical storms?
- Is there a poleward migration of lifetime-maximum intensity of Atlantic tropical cyclones affecting hurricane wind speeds used in engineering design and risk estimation? This type of information will inform the development of hazard maps as discussed in Objective 4.
- Will future conditions foster an increase in the frequency and intensity of major hurricanes? Consensus on this subject has yet to be reached, and findings in the literature often conflict. Progress toward reconciling scientific opinions on this matter is essential to producing risk consistent climatological analyses for hurricane-prone areas, which is deeply sensitive to the frequency of major storms.
- Will warmer and moister conditions increase the number of thunderstorms and tornadoes, which are driven by instabilities? While scientific opinion generally agrees that future conditions will produce warmer and wetter extreme events, less is known about its effects on tornado genesis.

The answers to these and other questions about future windstorms characteristics will inform development of hazard and risk assessments used in planning, design and construction practices (Objective 4), as well as improve modeling tools to quantify the impact on the built environment and community functioning (Objective 9).

Outcome: An improved understanding of long term trends in extreme wind climatology and sea level rise, with applications to hazard mapping for risk assessment and engineering design as well as adaptation to variable climate extremes. This objective is a long-term effort.

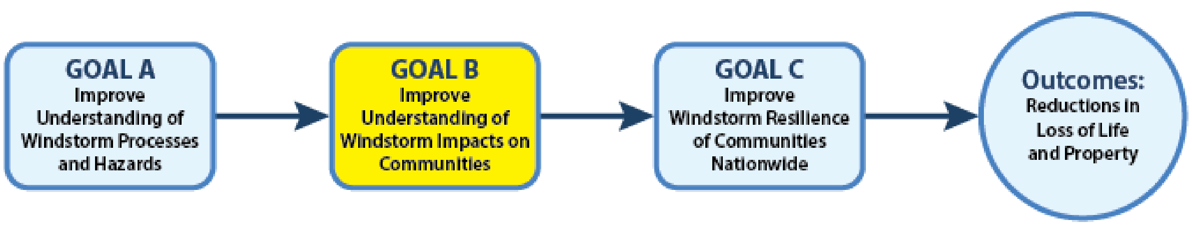
Objective 4: Develop tools to improve windstorm hazard assessment

There is a clear need to improve the data and computer models that are used to address deficiencies in wind and coastal flood hazard maps, and to account for effects not treated in current maps, including event duration. These hazard maps, usually developed for a range of annual exceedance probabilities, or return periods, need to be periodically updated to include results of new research, additional years of data, and, where possible, account for long term trends in storm frequency, intensity, and location.

Windstorm Types and Characteristics: To meet these needs, existing wind and coastal flood hazard assessment tools, including maps intended for use in national model building codes and standards, need to be updated to explicitly address thunderstorm downbursts, Nor' Easters, and special (e.g., mountain downslope) wind events. The standards do not address wind directionality effects that have regional variations or wind and flood storm duration, which also vary regionally. Improved understanding of these storm types and characteristics is key to the development of risk consistent approaches to assess the full range of wind hazards on structures located in areas subject to multiple windstorm types. This effort includes development of tornado hazard maps to support development of design standards and methods for tornadoes. Combined hazard intensity-duration statistics can be used to inform models addressing fatigue and erosion, both of which require storm duration information.

Combined Wind-Flood Characteristics: Assessment of storm surge and wave hazards from coastal storms such as hurricanes and Nor'easters presents a highly challenging problem, as the floodwater depth, velocity, and wave characteristics are highly dependent on local geographic, bathymetric, and topographic conditions in addition to storm track, size, intensity, and history. Existing methods, which rely on hindcasting (historical reconstruction to model the waves and water elevations that were not measured), need to be updated to enable the generation of synthetic storms, as is done with hurricanes. Existing flood hazard assessments, studies and maps, developed for flood insurance or evacuation planning purposes, can be extended for engineering design by providing flood maps for many return periods instead of focusing only on the 100 year and 500 year return period maps used in flood insurance rate maps. Combined wind-flood statistics of wind and coastal inundation hazards derived from computer simulations can be used to develop regionally varying load combination factors to address the combined effects of extreme wind and flood on the coastal built environment.

Outcome: Support the development of new hazard maps for engineering design that explicitly incorporate windstorm types not currently considered. New hazard maps should address current and future conditions. Recommendations for joint wind-flood load factors and intensity-duration statistics to inform load standards resulting in more resilient design (supporting Objective 11, as well as Objective 9 on risk assessment). The development of new wind hazard maps and load recommendations is a short-term effort, while the development of new flood hazard maps and load recommendations would be a long-term effort. The maintenance and updating of improved standards and building codes requires an ongoing effort.



Goal B. Improve the Understanding of Windstorm Impacts on Communities

NWIRP will support basic and applied research to advance the scientific and engineering knowledge of wind and windstorm-induced impacts. The efforts under this Goal, informed by the results of Goal A, will feed into Goal C to help support the development of innovative and cost-effective approaches and products to improve the performance of buildings, lifelines, and other structures. Research directions include building a deeper understanding of physical effects of windstorm hazards on buildings and infrastructure as well as the social, cultural, behavioral, and economic factors influencing windstorm impacts and the adoption of windstorm impact mitigation, supported by enhanced post-storm data collection. New computational tools will be developed for modeling interaction between wind and storm surge hazards and the built environment and for risk assessment and loss estimation.

Objective 5: Advance understanding of windstorm effects on the built environment

Basic and applied research to advance engineering knowledge of windstorm effects on the built environment is needed. Such research should seek to improve understanding of civil infrastructure vulnerabilities in extreme windstorm events, refine computational tools to predict performance of civil infrastructure including water and wastewater, communications, energy, and transportation systems, and advance knowledge to improve building codes and standards. This includes studying the effects of extreme winds, windborne debris, and wind-driven rain, as well as understanding the overland flow hazard, and the subsequent loads and structural responses for storm surge. For most of the United States outside of the hurricane-prone region, tornadoes and thunderstorms cause the greatest wind damage to buildings and power and communication infrastructure.

Thunderstorms: The effects on buildings and structures of the short duration and vertical variations of wind speed and turbulence intensity in thunderstorm downbursts are largely unknown. Although thunderstorms are the largest contributor to the wind speed hazard maps in locations outside hurricane-prone regions, the wind loading provisions given in codes are based on research for stationary boundary layer winds and their effects on buildings. It is therefore important to develop a better understanding of the relationship between transient thunderstorm downburst winds, their resulting loads, and response of structures to these loads. An improved understanding of theses loads could be achieved through experimental and computational modeling (downburst simulators) and full-scale experiments

Tornadoes: Our understanding of the mechanisms by which tornadoes impart loads on buildings and other structures is still in its infancy. For example, little is known about the role of atmospheric pressure change (APC) in tornado-induced loads, or the characteristics of the tornado turbulent winds near the ground and their effect on loads. The atmospheric pressure change load on buildings has largely been disregarded in the past by assuming buildings in tornadoes have been damaged to the extent that the internal and external pressures due to APC balance and therefore APC can be ignored when calculating loads. This assumption has never been validated and may well be wrong. Our understanding of tornadic wind loads can be improved using field and full-scale experiments, laboratory experiments, and numerical modeling.

Wind-borne Debris and Wind-driven Rain: Advancements needed in the understanding of wind-borne debris include the effect of the type of windstorm, the duration of the storm, and the density and sources of debris. Improved debris impact assessments and modeling will lead to improved probabilistic models to quantify windborne debris impact frequencies, velocities, momenta, and energy for developing risk-consistent design/test criteria. Similarly, improved testing methods are needed to evaluate wind-driven rain at the component and assembly levels. A better understanding of how water penetrates the building envelope and what damage it causes once inside is needed.

NHERI Research Facilities: The Natural Hazards Engineering Research Infrastructure (NHERI) provides a major national resource for conducting basic engineering research for earthquakes, windstorms, and coastal inundation events. Of relevance to NWIRP, NHERI currently includes two experimental facilities for wind hazards and one for coastal hazards, as well as a network-coordination facility, a computational modeling and simulation center, and an experimental facility for post-disaster, rapid-response research. These facilities should be leveraged when possible by the natural hazards engineering community when conducting research on the response and performance of buildings and infrastructure subject to windstorms.

Wind-tunnel Test Database: Engineers often use publicly available databases containing wind tunnel test data for their research.[14] These data have been used for developing new load criteria for wind loading standards and in loss modeling tools. It is desirable that these databases be expanded to assess the effects of extreme wind storms on more building types and geometries. These data can improve requirements for codes and standards.

Outcome: Improved understanding of the interaction between windstorm hazards (extreme winds, atmospheric pressure change, windborne debris, wind-driven rain, storm surge, and wind-driven waves) and buildings and other structures, lifelines, and infrastructure. Research conducted to improve the understanding of windstorm effects on the built environment is a long-term effort.

Objective 6: Develop computational tools for use in wind and flood modeling on buildings and infrastructure

Improved tools for estimating wind and flood induced loads are needed to enable the prediction of flood and wind loads without resorting to physical models, either full-scale or model-scale. Computational tools are needed to automatically incorporate structure specific location data that can affect the hazard data given in maps.

Computational Windstorm Loads: Wind and flood load criteria given in design standards have been developed using results from limited model and full scale tests. Computational methods for evaluating wind and coastal flood loads on buildings and infrastructure hold great promise to improve load estimates, expanding on the limited experimental data to provide better load standards compared to current engineering practice. These computational tools cannot yet provide reliable estimates of aerodynamic or hydrodynamic loads suitable for design calculations, and continued research is needed so that reliable load estimates can be made. The long term goal is to advance these computational tools to the point where they can replace physical tests and even be used in a design office, replacing the approaches used today where loads are estimated using simplified graphs and equations given in load standards. Improved computational fluid dynamics (CFD) for modeling overland water currents and waves, and their interaction with the built environment, will improve the estimation of coastal flood loads on structures, thereby improving load standards. A key to the verification of CFD tools is comparisons to model and full scale data, with the full scale data in real-time during windstorm events.

Automated Data Extraction: Computer tools that poll data bases, including aerial and satellite imagery, to automatically determine the surface roughness and terrain exposure in which a structure is located would improve the accuracy of the terrain category required in the wind design process. Computer tools that use digital elevation data to automatically evaluate topographic effects on wind speeds would eliminate the need for designers to estimate speed-ups with a difficult to use and very approximate method in current standards. Terrain and speed up effects are particularly important for the design of communication and transmission towers that are often intentionally located on top of hills.

[14] Examples include the NIST Aerodynamic Database (http://fris2.nist.gov/winddata/) and the NatHaz Aerodynamic Loads Database (http://aerodata.ce.nd.edu/).

Outcome: Tools to incorporate local data to further automate the design process, increasing efficiency and accuracy, and reducing errors. Advances in computational wind engineering to the point where it can replace model tests and wind load standards. The development of tools to incorporate local data into the design process is a short-term effort. The use of computational tools in lieu of model tests or load standards is a long-term effort requiring significant research, development, and validation.

Objective 7: Improve understanding of economic and social factors influencing windstorm risk reduction measures

Research is needed to identify and address social, behavioral, and economic factors that contribute to (and protect from) loss of life and property damages from windstorms.

Social Factors: Beyond the increased risk associated with poorly constructed structures or poverty, there are vulnerabilities related to social and cultural factors that can increase casualties from windstorms. These include issues regarding social capital, mobility, language, and access to safe emergency facilities. Research is needed to understand how different social groups respond to warnings and what impediments exist that reduce the likelihood of taking adequate precautions and preparations. Outreach programs are needed to ensure that all residents understand threats and how to properly respond.

Behavioral Factors: Many home owners ignore windstorm mitigation features when making purchasing decisions. Research is needed to understand what information would raise the level of understanding of the value of windstorm resilient construction features for homes located in communities at high risk of windstorms. Social science research can help to formulate appropriate messaging as well as the most effective channels to reach different home buying and owning publics.

Another lesson from previous deadly windstorms is the need to communicate urgency to promote rapid and effective public response. The NWS has begun using the phrase “Tornado Emergency” to signal an urgent need to respond when the probability for casualties and damage is high. Research is needed to determine the effectiveness of this new communication strategy as well as other approaches designed to improve public understanding of personal risks and response options.

Economic Factors: Building homes using windstorm resilient construction techniques increases cost which may dissuade some buyers from considering the purchase. It may also discourage municipalities from adopting stricter building codes. Research is needed in several areas to address the economic constraints that limit adoption of windstorm hazard mitigation. First, research is needed to understand the balance between safety and affordability. Are lower cost construction methods and materials available that can be implemented without sacrificing safety? Second, what are the best tools to overcome the economic constraints that discourage adoption of safer buildings designed for lower income households?

The mortgage origination and insurance industries may provide levers for reducing windstorm risks. Research has shown that better construction increases home values.[15, 16, 17] As a result, increased home

[15] Simmons, Kevin M., and Sutter, Daniel (2007), “Tornado Shelters and the Housing Market”, *Construction Management and Economics*, Vol. 25, No. 11, November 2007.
[16] Simmons, Kevin M., Kruse, Jamie, and Smith Douglas, (2002). “Valuing Mitigation: Real Estate Market Response to Hurricane Loss Reduction Measures”, *Southern Economic Journal,* Vol. 67, No. 3, January 2002.
[17] Awondo, S., Hollans, H. Powell, L., and Wade, C. “Estimating the Effect of FORTIFIED Home™ Construction on Home Resale Value,” Alabama Center for Information & Insurance Research (ACIIR), Culverhouse College of Commerce, University of Alabama. Accessed Dec. 2016. http://aciir.culverhouse.ua.edu/wp-content/uploads/2016/08/FORTIFIEDReport_V2-1.pdf.

prices should translate to the mortgage market by way of appraisals affecting loan valuation. Additional research into the relationship between construction quality and loss experience from windstorms will quantify the long term value of mitigation. Reduced losses should be reflected through the underwriting process resulting in lower insurance premiums. Further research is needed, including new knowledge of what sorts of educational programs should be targeted at real estate professionals, the insurance industry, zoning boards, and individual home owners.

In addition to enhanced construction, greater use of tornado saferooms would decrease the lethality of windstorms. Research has shown that saferooms increase the value of single family homes, and increases lot rent for mobile home parks that have community shelters.[18, 19] Additional study is needed to identify the value renters place on safety from windstorms for multi-family structures. Also, education is needed to acquaint renters with tools to identify safe housing and property managers on the benefits of providing properties built to enhanced standards as well as adequate sheltering options for their tenants.

Outcome: Increased understanding of the social, behavioral, and economic factors that play important roles in hazard preparedness and response will reduce windstorm casualties. It will assist both organizations and individuals to make wiser decisions necessary to survive an on-going event as well as better decisions to prepare for the next one. Increased understanding of socioeconomic factors influencing windstorm risk reduction is a short-term effort and a long-term one. The short-term effort is to apply new knowledge to promote effective response decisions in the face of current realities. The long-term effort is to apply new knowledge to create incentives and understandings that will increase the resilience of communities to windstorm hazards.

Objective 8: Develop tools to improve post-storm impact data collection, analysis, and archival

Improved collection, archival and analysis methods and procedures for data and information on damage, impacts and societal responses both during and after windstorms are needed. Such information is invaluable in understanding the causes of windstorm damage, identifying failure modes, informing improvements to codes and standards, validating damage and loss models, understanding the socio-economic costs of windstorms, informing policy and decision making, and identifying needs for future research. Having data archived, and properly documented, in publically accessible databases provides an effective means of dissemination data for research.

Post-storm Damage Surveys: Guidelines for collecting post storm damage data are needed. For example, a statistically based survey where information on the performance of all structures, not just those that were damaged, is key to better understanding storm impacts. Too many post-storm investigations performed in the past have focused on the damaged structures only. A new focus on the effects of windstorms on communities as a whole is needed, including data collection on characteristics of the emergency response and also recovery times for return to functionality for critical facilities and key infrastructure, such as hospitals, power, transportation networks etc.

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[18] Simmons, Kevin M., and Sutter, Daniel (2007), "Tornado Shelters and the Housing Market", *Construction Management and Economics*, Vol. 25, No. 11, November 2007.
[19] Simmons, Kevin M., and Sutter, Daniel, (2007), "Tornado Shelters and the Manufactured Home Parks Market", *Natural Hazards*, Vol. 43, No. 3, December, 2007.

Windstorm and Built Environment: In addition to the traditional boots-on-the-ground collection of data on building and infrastructure performance, aircraft- and satellite-based remote sensing allows for the rapid collection of damage data encompassing a large area. Advances are needed in automated detection of damage to make full use of current data acquisition capabilities. Light Detection and Ranging (LiDAR) as a disaster mapping tool has great potential, as truck-mounted systems can quantitatively assess damage to vertical surfaces of buildings and aerial-mounted systems can measure damage to roofs and other surfaces with horizontal projections. Small unmanned aircraft systems (UAS), commonly referred to as drones, hold enormous potential to provide on-demand, high resolution, and targeted data collection at the individual neighborhood and building scale. Their use for disaster data collection has begun expanding rapidly with advances in the past few years in flight and payload capabilities, flight control systems, and easing of regulatory requirements. Instrumentation of buildings and infrastructure during windstorms is a reliable but infrequently used method of evaluating wind effects on the built environment, and can provide response and performance data both during and post-storm at the building or component level.

Socio-Economic Data: To improve the understanding of the socio-economic impacts of windstorms, data should be collected on the pre- and post-storm demographics, migration, industrial production, the supply chain, and economic recovery. Such data would enable researchers to assess the effectiveness of mitigation, preparedness and response activities and their impacts on recovery and community resilience, to identify methods and tools for increasing adoption of best practices for windstorm hazard mitigation by people, businesses, and policy and decision makers.

Outcome: Tools and procedures for collecting, archiving and analyzing post-windstorm data. The development of guidelines to enhance post-storm data collection and UAS tools to provide new data collection capabilities are short-term efforts, and development of tools for automated damage detection is a medium-term effort. As in Objective 2, the tools and procedures should be adaptable in nature to support the long-term effort of post-windstorm data collection into the future, as advancements in technology, such as remote sensing, will likely enable the collection of new and additional data types not currently available.

Objective 9: Develop advanced risk assessment and loss estimation tools

There is a clear need for the development of an engineering-based wind storm loss estimation tool that can be used to develop estimates of annualized economic losses arising from wind storms. The estimates of the annualized losses, including building and infrastructure loss, and both direct and indirect economic losses, are needed to form a basis from which we can measure reductions in normalized economic losses and fatalities. Loss estimation tools can be used to support changes to load standards and building codes through cost-benefit analyses. Loss estimation tools need to be able to address effects of current and future risks from wind and coastal flooding hazards.

Built Environment Inventory: One challenge to improve loss estimation is developing detailed information on the wind- and flood-resistant characteristics of the stock of buildings and infrastructure in the United States. These characteristics vary significantly with region and date of construction. Information on wind-resistant characteristics of Florida's residential building stock has been gleaned from data collected during the *My Safe Florida Home* program, which provided free wind mitigation inspections to over 400 000 homeowners. Data included roof-wall connections, window protection (such as shutters), roof cover type, and roof shape. Other opportunities to collect such information need to be used, including data collected when buildings are being demolished, upgraded, or re-roofed. In the case of coastal flooding, a database of buildings' first floor elevations and foundation types will significantly improve the accuracy of damage and loss models.

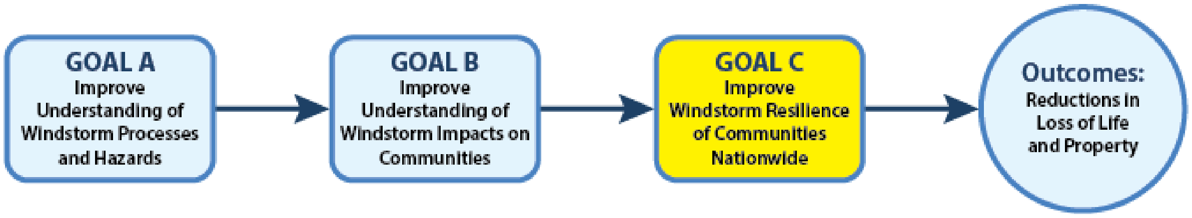
Water Intrusion: It is well known, but poorly documented in the peer-reviewed literature, that significant damage during high wind events is due to water intrusion, which damages building contents, interior finishes and systems (e.g., HVAC, electrical). Water intrusion results from both breaches of the building envelope and leakage through undamaged components. Research into the performance of the building envelope in high wind-rain events (i.e., design level windstorms) is needed. Damage and loss models should address the time dependent degradation of the facility's roofing, connections, windows and window seals, etc., which act to resist the wind loads and prevent water penetration.

Physical Damage and Financial Losses: Obtaining reliable estimates of the financial loss, given physical damage to buildings and infrastructure (roads, bridges, communication and power), is a critical step in estimating the total economic impact of windstorms. FEMA's Hazus Hurricane tool addresses some of the direct building losses, but Hazus does not address wind damage to the infrastructure. Similarly, the Florida Public Hurricane Loss model is in the public domain but it is only applicable to residential and commercial-residential occupancies in Florida. There are proprietary tools used by the insurance and re-insurance industries that create models using proprietary insurance loss data. Models for estimating physical damage and financial losses from windstorm-induced flooding will be more reliable as more and better data are available for the estimates.

Indirect Losses: If indirect economic losses are to be properly modeled, loss models should address communities as a whole. This would include costs associated with damage to business and industry and the downstream (supply chain) impact of local business interruption, including the effect of loss of functionality due to lack of power and communications, disruption of other lifeline utilities, or workforce disruptions, in addition to loss of functionality due to direct damage. It is important to capture information on restoration times of buildings and infrastructure, which is critical to the understanding of indirect economic losses and the ability of a community to recover from windstorms.

Loss modeling tools incorporate models, data, and methods discussed in other NWIRP Strategic Plan Objectives. Research will be conducted to determine the causes of loss of life in windstorms, with flood and wind fatalities examined separately. This information should be incorporated in the loss models to enable the loss modeling tool to estimate fatalities, as well as the reduction in fatalities due to improved construction and/or mitigation strategies.

Outcome: Development and application of state-of-the-art, cost-effective windstorm loss and risk modeling tools, which supports Goal C objectives on mitigation and improvements to the codes and standards used in the design of buildings and infrastructure. The short time frame is the development of an initial public domain, open source, loss modeling tool that would be updated with new research and data in the medium to long term.



Goal C. Improve the Windstorm Resilience of Communities Nationwide

The results from R&D activities of Goals A and B provide a solid foundation for the application and implementation of the windstorm impact reduction objectives of Goal C. NWIRP will support development of cost-effective windstorm-resistant materials and systems for use in new construction and retrofit of existing construction and development of more windstorm-resilient building codes and standards. NWIRP will support development and implementation of improved windstorm forecasting methods to increase accuracy and warning time. There is a strong need to integrate results of research on societal response, hazard vulnerability and mitigation, disaster preparedness, emergency response, and disaster recovery into the implementation activities that support hazard mitigation, as described in the Strategic Plan for the National Earthquake Hazards Reduction Program.[20] NWIRP will support integration of social science research findings into the implementation activities of Goal C, and work to increase public awareness of windstorm risks and to promote hazard mitigation policies and programs as well as improved windstorm readiness, emergency communications and response.

Objective 10: Develop tools to improve the performance of buildings and other structures in windstorms

New building products, materials, and methods are needed to reduce damage to buildings and infrastructure. Post-storm investigations continually point to poor performance of the building envelope, particularly the performance of roof covers, and the inability of windows and doors to keep water out, as being drivers of damage, economic loss, and the inability to use a building after the event, suggesting new products are needed. Inadequate fasteners, both the size and number of fasteners, are usually the cause of the failure of roof decks and even entire roofs.

Sensors are needed that are deployed in structures to inform owners of potential leaks in the building envelope, loose connections, etc. Inexpensive hand held or autonomous sensing systems to inspect buildings to obtain information on important hidden wind resistive features such as reinforcing bar size and spacing, bolt and nail sizes, etc., are needed to perform cost effective evaluations of building conditions for risk assessments.

Building Envelope: To meet this need, new materials, systems, and techniques for improving resilience of buildings and other structures against windstorms are necessary. One key area needing improvement is in maintaining the integrity of the building envelope, including developing systems that are better able to resist windborne debris impacts and water-infiltration. This is critical to buildings maintaining their functionality. Windborne debris impact criteria developed in Objective 5 can be used to develop new

[20] *Strategic Plan for the National Earthquake Hazards Reduction Program*, October 2008, http://nehrp.gov/pdf/strategic_plan_2008.pdf.

products to better resist windborne debris, to prevent significant internal pressurization of buildings that could result in additional damage, and to prevent water entering buildings through a damaged window, door, or vent. Research to improve our understanding of how to manage water as it enters a building through windows, doors and vents, so that it can be channeled away from water-sensitive areas, will result in new methods to minimize water damage.

Infrastructure: Engineers will work with power and communications industries to align their performance goals with those of communities. The current wind loading design standards for distribution of electricity do not consider high winds. Research with industry is needed to develop cost-effective ways to increase the resilience of the power system to the action of wind storms, ensuring the overall reliability is consistent with community performance objectives.

Post-storm damage surveys mapping failures of transmission and distribution systems following severe wind events need to properly document the cause and location of the damaged structures, or power lines, to provide quantitative assessments of current performance. Studies examining the rate of restoration of both transmission and distribution will inform risk-based decision modeling for establishing appropriate load factors and performance goals.

Sensing: Smart sensors provide an opportunity to minimize wind storm damage by alerting building owners of leaks, damaged roofing, etc., allowing for repairs to be made prior to the occurrence of major damage. Sensors used to automatically close vents when wind-driven water is sensed will reduce damage, as will window protection that automatically activates when high winds are sensed. New inexpensive sensors are needed to perform routine building and other structure evaluations in order to determine their capacity to resist windstorms.

Outcome: Improved windborne debris protection products and cost effective products, materials, and methods that minimize water infiltration into buildings during high wind events. Development of new inexpensive sensors to detect on-going damage, and to develop inexpensive sensors for use in building assessment studies. This objective comprises medium and long-term efforts which are largely driven by the long lead times needed to develop new products, and if needed, to get their use approved by codes or standards.

Objective 11: Support the development of windstorm-resilient standards and building codes

There is need for continued improvements to building codes and standards which are key to reducing both loss of life and property in wind storms. Development of new materials and product testing standards that properly replicate the effects of wind load, flood and rain that occur in windstorms is also required, as many current test methods do not meet this need.

Improved Design Standards: Results from the development of new hazard maps and improved understanding of current and future windstorm risks will be used to inform standards and code change proposals for improved wind and coastal flood hazard maps, reflecting current and potential future storm climatology and sea level rise. Information developed in Goal B will advance the understanding of interactions between hazards and the built environment to develop recommendations for code changes to improve provisions dealing with aerodynamic and hydrodynamic loads and the response of buildings and infrastructure to these loads.

Improved Materials and Product Testing Standards: Working closely with industry, new improved test standards should be developed to provide realistic wind loads for certifying products, since some of the current test methods are inadequate. For example, current wind fan test methods for roof shingles are unable to produce the type of wind loads that are caused by flow separation and the corner vortices resulting in unrealistic wind loads, leading to wind speed ratings that have questionable value. Unreliable ratings lead to roof coverings that do not perform as expected, enabling water to get into buildings. A consistent, repeatable observation after every hurricane is the poor performance of roofing, which could be solved if realistic test methods were developed. Product labeling should specify the product's performance requirement (e.g., design pressures, impact resistance, etc.). The labeling requirements need to ensure readability after the product is installed and in use. Proper labeling enables the performance of products to be objectively evaluated during post-storm damage investigations.

Test standards developed to evaluate rainwater infiltration need to be consistent with the physics driving the rain water into the building. New tests and design criteria are needed to prevent water from entering buildings through vented soffits and overhangs. Post-storm damage surveys have identified water entering buildings through soffits and can cause significant damage to the interior of a building.

Outcome: Improve design and test standards, product labeling, and methods to help demonstrate the cost-effectiveness of building code improvements. The development of wind-storm resilient standards is a medium-term effort, followed by long-term efforts for continual improvement.

Objective 12: Promote the implementation of windstorm-resilient measures

Public policies that increase windstorm resilience are needed, including regulatory approaches such as community adoption of windstorm-resilient building codes and floodplain management ordinances, as well as policies that promote voluntary mitigation.

Incentivized Mitigation: Fundamental to the increased use of mitigation is incentivizing individuals, suppliers, and communities to adopt it. Public initiatives that increase mitigation by individuals are encouraged. Voluntary mitigation requires that individuals feel strongly enough about the threat from windstorm hazards to take action. Mitigation is costly, so the decision to mitigate must weigh expected benefits against cost. Complicating the decision is the fact that benefits may take years to realize while the cost must be borne immediately. A valuable resource for a community seeking to increase its resilience to windstorm hazards is the Community Resilience Panel,[21] which works to reduce barriers to achieving community resilience by promoting collaboration among stakeholders to strengthen the resilience of buildings, infrastructure, and social systems upon which communities rely.

Voluntary mitigation holds the promise of reducing casualties and sets an example for others to follow. This trend can be magnified with better education and proper incentives. Research results from Objective 7 will help formulate incentive programs for mitigation that target those who would benefit the most and are least likely to mitigate without them. There are several incentive options, direct grants, subsidized loans, discounts on property insurance and tax incentives. After the 1999 Bridge Creek/Moore F-5 tornado, a grant program was established in Oklahoma that blended FEMA and state funds providing up to $2,000 to residents who installed a FEMA-approved safe room/shelter.[22] Another incentive is to

[21] Community Resilience Panel for Buildings and Infrastructure Systems, *About the Panel*, https://www.crpanel.org/?page_id=6
[22] http://newsok.com/article/2878726.

provide subsidized loans. The high upfront cost for a benefit that may take years to materialize is a deterrent to many. Low income families without opportunities to finance may be unable to install such mitigation features. A third possible incentive is for adopters of windstorm mitigation to be offered a discount on their property insurance. In Florida and other coastal areas of states that separate windstorm risk from the standard homeowner's policy,[23] using state-mandated discounts has encouraged mitigation.[24] Tax incentives for homeowners who upfit for windstorm resistance or homebuilders who use wind engineering techniques would be another option. Identification of which incentives are most appropriate, the optimal magnitude of the incentive and strategies to educate the public on mitigation are needed. The goal would be to raise the effective standard for windstorm-resistant construction through voluntary adoption.

Mandated Mitigation: NWIRP encourages communities to adopt modern building codes and standards as a basis for design and construction, without eliminating or reducing windstorm resistant provisions. Enforcement of building codes and standards through inspection and permitting should be performed to ensure the benefits are realized. Policies that assure building and inspections departments are adequately funded, staffed and trained are encouraged.

Communities can adopt provisions that exceed those required in model building codes, similar to floodplain ordinances in some communities that require construction elevations above National Flood Insurance Program minimum requirements, which lessen the risk of flood damage and also decrease flood insurance premiums for everyone in the community. Motivation to adopt higher standards often comes from tragic experience. This happened in Moore, OK, after the third violent tornado in less than 15 years caused 24 fatalities and an estimated $2 billion in damage in Moore and surrounding communities.[25] A wind-resistant building code was adopted for single family residential construction, increasing the design wind speed from an effective peak gust wind speed of 115 mph to 135 mph.[26] Even without such dramatic events, the more mundane process of adopting higher standards to influence the underwriting process that determines insurance rates can motivate, too. One such program is the Building Code Effectiveness Grading Schedule (BCEGS®).[27] The concept is simple: municipalities with well-enforced, up-to-date codes should demonstrate better loss experience, and insurance rates reflect that. The prospect of lessening catastrophe-related damage and ultimately lowering insurance costs provides an incentive for communities to enforce their building codes rigorously, especially as they relate to windstorm damage. The anticipated result is safer buildings, less damage, and lower insured losses from catastrophes. Most communities do not increase their standards, however, for fear of driving residential development to other towns. Programs which educate communities on the benefits of higher standards are needed to combat the fear of losing development and emphasize instead, the positive aspects of living in a community that makes safety a priority.

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[23] Kousky, Carolyn (2011), "Managing Natural Catastrophe Risk: State Insurance Programs in the United States", *Review of Environmental Economics and Policy*, volume 5, issue 1, winter 2011, pp. 153–171.

[24] Ripberger, Joseph, Czajkowski, Jeffrey, Simmons, Kevin M., (2016) "*Homeowner Willingness to Pay for Private and Public Oriented Tornado Risk Mitigation and the Role of Economic Incentives*", White Paper.

[25] FEMA P-1020. *Formal Observation Report Tornado: Moore, Oklahoma, May 20, 2013. Safe Room Performance, Observations, and Conclusions.* August 2014.

[26] Wind-induced pressures on buildings increase with the square of the wind speed, so this change in the local building code translates into a 38 % increase in wind loads the buildings must be designed to withstand.

[27] Administered by ISO, a subsidiary of Verisk Analytics, Inc.

Market Value of Mitigation: An indirect benefit of mitigation that affects both individuals and communities is the increased value mitigation adds to a home. In vulnerable areas, safety and better construction increases demand for homes that provide better protection. Homes in central Oklahoma with tornado shelters command a premium at resale.[28] Hurricane mitigation in a South Texas barrier island community was found to increase sales price.[29] Homes in Florida built to the stronger 1994 South Florida Building Code commanded a premium price, particularly after the 2004 and 2005 hurricane years.[30] Finally, homes built to the IBHS FORTIFIED™ standards in Alabama sold at a 6.8 % premium.[31] While these results show markets value mitigation, the mortgage industry has been slow to recognize them in evaluation of loan applications for homeowners. The real estate community needs to be apprised of these results to fully appraise and value the positive market effect of wind hazard mitigation.

Outcome: Supporting programs for mitigation adoption and supporting efforts from educational institutions, communities, and private entities that encourage mitigation will increase the public's overall awareness of windstorm hazards and increase adoption. Increasing mitigation by individuals and communities has direct and indirect benefits, including increased safety of those who adopt windstorm mitigation. Setting an example for others has the indirect benefit of signaling that mitigation is achievable and desirable. Effective education and strategic use of incentives will accelerate adoption of windstorm mitigation. Promoting the adoption of wind-resilient measures is inherently on-going in nature.

Objective 13: Improve windstorm forecast accuracy and warning time

Improved forecasts for hurricanes, tornadoes and other severe windstorms are needed to increase the available time for evacuation, sheltering, and other life safety, property protection, and lifelines protection actions. More accurate predictions will also allow for a decrease in the warning area, reducing the disruption and possible complacency in the public's response caused by over warnings or false alarms in locations where the hazard probability is sufficiently low.

Tropical Cyclones: Advances in knowledge of atmospheric dynamics, numerical weather prediction, supercomputing capabilities, and satellite-based observations have led to a significant reduction in hurricane forecast track errors in recent years. The average hurricane forecast track errors have decreased by approximately half in the past 15 years.[32] Despite these advances, the average errors in Atlantic forecast tracks at 120, 96, and 72 hours, the timeframes where evacuation decisions must be made, are still 222, 160, and 110 nautical miles, respectively.[33] Further advances in hurricane track forecasting will require the development of models that can accurately depict large-scale atmospheric flows, which are primarily responsible for steering hurricanes. Additional high-impact observations are needed to evaluate and improve model physics as well as for data assimilation to initiate model forecast runs. Improvements to hurricane intensity forecasts have come at a much slower pace. High-resolution atmospheric modeling

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[28] Simmons, Kevin M., and Sutter, Daniel (2007). "Tornado Shelters and the Housing Market," *Construction Management and Economics*, Vol. 25, No. 11, November 2007.
[29] Simmons, Kevin M., Kruse, Jamie, and Smith Douglas, (2002). "Valuing Mitigation: Real Estate Market Response to Hurricane Loss Reduction Measures," *Southern Economic Journal*, Vol. 67, No. 3, January 2002.
[30] Dumm, Randy E., Sirmans, G. Stacy, Smersh, Greg (2011), "The Capitalization of Building Codes in House Prices," *Journal of Real Estate Finance and Economics*, 42, 30-50.
[31] http://aciir.culverhouse.ua.edu/wp-content/uploads/2016/08/FORTIFIEDReport_V2-1.pdf.
[32] NOAA National Hurricane Center Forecast Verification, http://www.nhc.noaa.gov/verification/verify5.shtml.
[33] Official NHC 5-Year Average Forecast Errors (2011-2015), http://www.nhc.noaa.gov/verification/pdfs/OFCL_5-yr_averages.pdf.

systems based on dynamical and ensemble approaches offer the best hope for significantly improving intensity forecasts.

Improvements to forecasts of storm surge-induced flooding are an even more challenging problem. Not only are such flood predictions highly dependent on the hurricane track, size and intensity, the bathymetry and topography of the coastal areas are also critical factors, as well as tides, waves, and rivers. Advances are needed in the coupling of hurricane wind, storm surge, tide, wave, and river models, as well as modeling of overland flows. Understanding the wind speed dependence of the sea surface drag coefficient in coastal waters is critical to accurate modeling of wind-induced surges and waves.

Thunderstorms and Tornadoes: Advances in the understanding of tornado genesis and improvements in windstorm prediction have enabled NWS to double the average time for tornado warnings to 13 minutes over the past twenty years.[34] Integration of next generation radar and storm scale numerical models provides a potential means to significantly increase this warning time. NOAA's Warn-on-Forecast research project aims to create computer-model projections that accurately predict storm-scale phenomena such as tornadoes, large hail, and extreme localized rainfall. If Warn-on-Forecast is successful, forecasters will be provided with reliable guidance for issuing tornado, severe thunderstorm, and flash flood warnings up to an hour before they strike.[35] Additionally, NOAA's National Severe Storms Lab (NSSL) is conducting research to develop a new grid-based all-hazard watch/warning communication paradigm called *Forecasting a Continuum of Environmental Threats (FACETs)*.[36] If successful, FACETs will provide local emergency managers and responders with a fully-integrated continuum of weather threat information, lead to reduction in size of "warned" areas and false alarms, and provide affected communities with more useful, actionable, and recipient-specific information for responding to the threats.

Outcome: More accurate forecasts for hurricanes, tornadoes, and other severe storms that increase warning times and decrease warned areas and false alarms. Development and implementation of improved forecasting technologies is a long-term effort.

Objective 14: Improve storm readiness, emergency communications and response

Advances in forecasting and communications technology provide opportunities to increase the timeliness and geographic specificity of emergency alerts and warnings, enabling the public and first responders to react more effectively to minimize the impact of violent windstorms. Improved response by the public also depends on understanding the threat information and readiness.

Communications: The effectiveness of emergency communications to the public will be improved by integration of the social science research findings (Objective 7) into development of public-facing alerts and warnings. A particular challenge will be to improve alerts and warning messaging to and preparation

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[34] National Windstorm Impact Reduction Program Biennial Report to Congress for Fiscal Years 2013 and 2014, National Science and Technology Council. https://www.nist.gov/sites/default/files/documents/el/nwirp/NWIRP-FY2013-2014-Biennial-Report-to-Congress-2.pdf.

[35] NOAA National Severe Storms Laboratory Warn-on-Forecast, May 2015. http://www.nssl.noaa.gov/news/factsheets/WoF_2015.pdf.

[36] NOAA National Severe Storms Laboratory, Forecasting a Continuum of Environmental Threats, http://www.nssl.noaa.gov/projects/facets/.

of vulnerable populations, since receiving the alert/warning and/or understanding the urgency of the situation varies across populations. "Push" alerting and warning technologies (e.g., GPS-based mobile alerts, outdoor siren systems with or without voice communication, reverse 9-1-1, NOAA weather radios, and social media) provide enhanced alert and warning delivery to those in the path of a storm. Such technologies maximize each individual's opportunity to receive emergency information and respond in a safe, effective, and timely manner. Development and utilization of these systems should be encouraged.

Over the last twenty years, hurricane forecasts have improved significantly and now provide responders with time to anticipate where their assets are best deployed in advance of landfall. Tornadoes, however, provide a greater challenge, leaving responders little opportunity to be proactive. A new NOAA initiative may change that equation, however. Evolving radar technologies are providing more information that pushes back the timing on forecasts and may offer responders greater insight into a storm's potential earlier in its life cycle. One addition to the improved radar capability is a project that attempts to provide emergency managers with potential level of casualties and damage from approaching storms. This effort combines casualty and damage model estimates with Monte Carlo simulation that would give responders a probability distribution of a storm's potential impact. Various thresholds from this probability distribution could assist in the pre-positioning of assets, improving response time. This effort is linked to the NOAA FACETS program which will provide probabilistic warnings in lieu of the binary warnings used today.

Storm Readiness: While schools and many other facilities typically have well defined and practiced procedures for how to respond in the event of a fire, similar preparations and drills are also needed for high wind events. In the case of tornadoes and severe thunderstorms, there may be only minutes to respond. For schools and other facilities that do not have storm shelters or safe rooms specifically designed and constructed to withstand tornadoes, the best available refuge areas should be identified through an engineering assessment.[37] The Storm Ready Program[38] of the NWS, which provides guidance and training in severe weather readiness, should be expanded to include more school districts, municipalities, counties and other sites.

As storm forecasts and predictions continue to improve, subsequent increases in warning time are expected. For example, current average warning times for tornadoes are 13 minutes, double the average from two decades ago.[39] This provides an opportunity and a need to explore alternative scenarios for planning of evacuation and sheltering operations. Another doubling would bring the average tornado warning time to nearly half of an hour. It is an open question whether that would create new options for tornado protection, such as through networks of community tornado shelters, or if additional warning time would lead to more people taking to the road, with greater exposure to risk than the sheltering-in-place most common today. Research and planning are needed to investigate alternative and optimal community strategies for life safety protection through evacuation and sheltering.

Response: Emergency responders can save lives through timely rescue operations. New technologies can enhance and improve responder effectiveness. For example, recent advances in robotics technology

[37] A resource to support such assessments is FEMA P-431, *Tornado Protection: Selecting Refuge Areas in Buildings*, Second Edition (2009). https://www.fema.gov/media-library/assets/documents/2246.
[38] NWS Storm Ready Program, http://www.stormready.noaa.gov/.
[39] State of the National Weather Service – 2012, Appendix B, page 16 (https://www.ametsoc.org/cwwce/index.cfm/reports-and-studies/general-reports-and-studies/state-of-the-national-weather-service-in-2012/).

provide the potential for advanced tools to support first responders and search and rescue teams. Small unmanned aircraft systems (UAS) can provide increased situational awareness following windstorms, such as rapid damage assessment and if roads ahead are blocked by debris, and response robots can help locate victims in collapsed buildings. Additional research and development is needed to bring these technologies into widespread use, in areas including improved communications, human-system interaction, power, payload, and sensing. Small UAS also face complexities adapting to a challenging regulatory environment, where technical capabilities are evolving faster than Federal and state rules governing UAS operations.

Outcome: Evolving communication technology combined with improved forecasting provides the public and emergency managers with better emergency alerts and warnings. Improved storm readiness is achieved through expanding education and training programs for severe storms. Enhanced capabilities for situational awareness of first responders and search and rescue teams are enabled through research and development of small UAS and response robots. This objective is an ongoing effort that should build upon and add to community outreach and training procedures already in place.

Chapter 3: Strategic Priorities

The three Strategic Goals and 14 associated objectives described in Chapter 2 span the range of research, development, and implementation actions to bring about windstorm impact reduction. Many elements of the various objectives are currently supported by the Program agencies, as documented in the latest NWIRP biennial report to Congress.[40] Through its strategic planning process, NWIRP has identified several priority focus areas for new and enhanced efforts. These Strategic Priorities represent a combination of: 1) long-term research efforts to provide foundational windstorm hazard and loss data and models; 2) opportunities for more rapid windstorm impact reduction, building on existing programs; and 3) crosscutting themes to enhance development of the Nation's human resource base in windstorm hazard mitigation fields.

Seven Strategic Priorities are presented in Chapter 3, which build upon and support elements of multiple objectives (see Table 1). Strategic Priorities 1-3 are foundational to supporting future research advances. Strategic Priority 1 (SP-1), Develop Baseline Estimates of Loss of Life and Property Due to Windstorms, is needed to inform future directions and prioritizations for both NWIRP research and implementation actions, and provide data and metrics for long term tracking of Program success. Critical data needs are addressed in Strategic Priorities 2 and 3, which encompass long term efforts to significantly increase the types and spatiotemporal resolutions of measurements of windstorm hazards (SP-2) and hazard impacts (SP-3), and provide this crucial information to the broad spectrum of users who need it through publicly available databases (SP-3). Such measurements are crucial to many of the objectives, by enabling a better understanding the physical processes involved and development and validation of analytical, experimental, and computational models. Strategic Priories 4-6 are actions that will lead to more immediate impact reduction. Development of performance-based design procedures and standards for windstorms (SP-4) will provide the opportunity for explicit consideration of hazard probabilities and desired performance levels for buildings, lifelines, and other structures during the initial planning phases of a project. Strategic Priority 5 will promote programs to improve adoption of windstorm preparedness and mitigation. To improve life safety during tornadoes and hurricanes, Strategic Priority 6 will provide additional technical resources for community and project planning and design, construction, and operation for storm shelters and safe rooms, along with associated education and outreach to promote increased construction and retrofit of such facilities. Ensuring the Nation's human resources have the necessary knowledge and skills in windstorm science, engineering, and hazard mitigation fields to achieve the NWIRP vision of a more windstorm resilient nation is addressed in Strategic Priority 7.

These Strategic Priorities are not ranked in order of significance or criticality. Most will require coordinated multiagency, multidisciplinary activities. Each Strategic Priority includes a description and implementation strategy, connections to objectives 1-14, and estimated time frame to complete. As described in the introduction to Chapter 2, short, medium, and long time frames are considered as approximately seven years or less, 8 to 15 years, and more than 15 years, respectively. Program agency responsibilities for the Strategic Priorities are identified in Appendix C. The rate of progress on

[40] National Windstorm Impact Reduction Program Biennial Report to Congress for Fiscal Years 2013 and 2014, National Science and Technology Council. https://www.nist.gov/sites/default/files/documents/el/nwirp/NWIRP-FY2013-2014-Biennial-Report-to-Congress-2.pdf.

implementation of these Strategic Priorities as well as the broader goals and objectives in Chapter 2 will depend on the level of resources that are available to Program agencies.

Table 1. Strategic Priorities and Connection to Program Objectives

SP#	Strategic Priority (SP)	Objectives that Support the SP (Inputs)	Objectives Supported by SP
SP-1	Develop Baseline Estimates of Loss of Life and Property due to Windstorms	4, 9	5, 8, 10, 11, 12, 14
SP-2	Obtain Measurements of Surface Winds and Storm Surge Current and Waves in Severe Storms	1	1, 2, 4, 5, 6, 8,13
SP-3	Develop Publicly Available Databases of Windstorm Hazards and Impacts	2, 5, 7, 8	5, 7, 10, 11, 13
SP-4	Develop Performance-Based Design for Windstorm Hazards	4, 5, 9	10, 11, 12
SP-5	Enhance Outreach and Partnerships to Improve Windstorm Preparedness and Hazard Mitigation	4, 7, 9, 12, 13, 14	12, 14
SP-6	Enhance and Promote Effective Storm Sheltering Strategies	1, 3, 4, 5, 7, 8, 9, 11, 13	10, 11, 12, 14
SP-7	Develop the Nation's Human Resource Base in Windstorm Hazard Mitigation Fields	All	All

SP-1 Develop Baseline Estimates of Loss of Life and Property due to Windstorms

To achieve major measurable reductions in the losses of life and property from windstorms as intended by this Program, baseline values are needed; however, the data currently available on windstorm casualties and property damage is too coarse to be effectively used for these purposes. This Strategic Priority will develop detailed baseline data on windstorm fatalities, property damage, and disruptions of lifeline utilities, along with identification of causes for these losses, current trends in losses, and factors underlying the trends. This information will provide support for:

- Further identification and prioritization of NWIRP research and development, technology transfer, and outreach activities
- Baseline methods and data for tracking future losses of life and property
- Baseline methods and data for tracking additional socioeconomic impacts

These baselines can be developed through a combination of historical data and modeling. Modeling is required as it is very difficult to confidently adjust the historical data to account for changes in wealth, local inflation, population, and construction practices. Furthermore, modeling is required to enable estimates of potential reduction in life and property losses that cannot be made using historical data. The modeling component requires the development and validation of vulnerability functions that compute physical and financial damage to buildings and infrastructure due to the action of wind and coastal flooding. Models will need to include the costs associated with loss of use of facilities due to both direct (building) and indirect (infrastructure) damage.

The windstorm hazard models developed in Objective 4 support SP-1. Vulnerability, fragility and built environment inventory models developed in Objective 9 also support SP-2. These two objectives combine to produce an estimate of risk.

Damage and loss estimates developed in SP-1 identify components, at both the individual structure resolution and for a community as a whole, whose failure result in large economic loss. SP-1 supports Objectives 10 and 11 by focusing on product development efforts that yield large returns in terms of loss reduction, weaknesses or gaps in building codes, and mitigation strategies that produce the largest reduction in windstorm impact. SP-1 provides the tools to perform benefit-cost analyses, directly supporting Objective 12.

SP-1 is initially a short term strategic priority that would be continued to be updated through the incorporation of continued improvements to windstorm hazard assessment and loss estimation.

SP-2 Obtain Measurements of Surface Winds and Storm Surge Current and Waves in Severe Storms

Key to the collection of more and higher spatiotemporal resolution data from windstorms is the development of new sensors and new methods to measure wind speeds, pressures, and overland waves and currents. New sensors will need to be cost effective, and perhaps re-useable or disposable, enabling thousands of sensors to be deployed in advance of landfall hurricanes, severe thunderstorms and tornadoes. In the case of winds, these sensors need to be able to provide insights into the variation of wind speeds with height in addition to just near ground observations. Similarly, sensors that measure the variation in currents with depth will provide key data for models.

Knowledge of the characteristics of near surface extreme winds has been established though models and measurements. The measurements are used to validate numerical and empirical models, but most of these data have been obtained from storms having wind speeds much less than those used in the design of most structures. The structure of the wind in downbursts and tornadoes is largely unknown. This gap in knowledge can only be filled with more measurements. The effects of these winds on buildings are unknown, and codes and standards currently treat the effects of these winds as if they were due to standard atmospheric boundary layer loads. The impact of this assumption is unknown but could result in a significant underestimation of wind loads.

Similarly, there have been very few measurements of important characteristics of storm surge and waves, particularly coastal flooding over land, where most of the impacted buildings and infrastructure are located. The main data sources are stream gauges, which provide information on how the flooding is affecting stream and river flows, and post-storm high water marks. There is almost no data on flooding characteristics critical for understanding the hydrodynamics of overland flow and validating computational models. These critical flood characteristics include the velocity (current) of the storm surge, the variation of velocity over the depth of the water (velocity profile), wave heights and periods, floodwater depth, and how all of these characteristics vary over the duration of the inundation. These wind speed, storm surge and wave height data, and current are critically needed to improve understanding of wind and storm surge flooding hazards, and validate analytical and computational wind engineering models, storm surge, and inland wave models.

Objective 1 is also supported by SP-2 through data collection which improves our understanding of windstorms. SP-2 supports Objectives 1, 2 and 4 through the provision of basic data needed to improve our understanding of the structure of the wind, waves and currents that affect communities in windstorms, and through the development of models used to produce hazard maps. Objective 5 is supported by SP-2 through the provision of data needed to inform the models and experiments used to estimate loads in windstorms. Data collected in SP-2 will be used to support Objective 6 through the validation of computational fluid dynamics models for winds, waves, and currents. SP-2 supports Objective 8 by providing event hazard data that corresponds to event damage and loss data, informing vulnerability models.

SP-2 is an on-going long-term effort, which will continue to support other objectives through the provision of data.

SP-3 Develop Publicly Available Databases of Windstorm Hazards and Impacts

Prior to deploying field efforts focused on collecting real time windstorm data, coordination between private and public partners is necessary for these field efforts to maximize their efficacy. These efforts will ensure the spatiotemporal coverage of measurements is sufficient for reconstructing the storms wind and flood hazard information. Coordination of damage and hazard measurements is key to being able to properly address and validate the hazard-consequence modeling.

A consistent message arising from many of the breakout sessions from the NWIRP Strategic Planning Stakeholder’s Workshop was the need for a means to collect post-storm damage data using a common taxonomy and then, cataloging, preserving, and disseminating actual post-windstorm damage and effects observations. Field investigation data are virtually priceless in terms of “lessons learned” value as they provide full-scale performance data for real buildings and infrastructure systems. NWIRP will work with the wind and coastal engineering professional community, the insurance industry, and academia to improve post-windstorm reconnaissance and data collection methods; encourage the development of a national post-windstorm information management system; and stimulate the use of this information by researchers, practicing engineers, and government and business leaders. Having all these data (hazard measurements, structure performance, community response and recovery) available in one database, or linked databases, provides a unique resource for carrying out cross cutting research. Stewarding the development and adoption of these new metadata, data by establishing guidelines and standards for data curation, quality control and quality assurance will be critical to ensuring that engineers and meteorologists and other data users fully take advantage of new developments in archival of windstorm hazard and impact data.

SP-3 supports Objectives 5 and 7 by providing the data needed to advance our understanding of windstorm effects on the built environment and how communities respond to windstorms. Data provided by SP-2 supports Objectives 10 and 11 by providing information on problems and failures (e.g., through the development of new products or testing) that need to be addressed in building codes and standards.

SP-3 is a long-term priority requiring significant coordination between Federal agencies and private sector partners.

SP-4 Develop Performance-Based Design for Windstorm Hazards

The National Windstorm Impact Reduction Act Reauthorization of 2015 (Public Law 114-52), directed NWIRP to "support the development of performance-based engineering tools, and work with appropriate groups to promote commercial application of such tools, including wind-related model building codes, voluntary standards, and construction best practices." This Strategic Priority will engage the Program agencies in performing basic and applied research that supports PBD development and in the knowledge-transfer activities needed to support implementation.

Existing national model building codes emphasize prescriptive wind and coastal design procedures that implicitly seek to minimize loss of life but do not adequately address minimizing direct or indirect economic losses. Performance-based design (PBD) focuses on explicit expectations of building performance with respect to loss of life, damage, and operability, providing a wider range of design options than prescriptive code-based procedures. PBD promises to bring greatly improved economy and functionality for designs to resist windstorms. NWIRP will support development of PBD to resist windstorm hazards, including for tornadoes.

From a structural point of view, PBD has been facilitated by the advent of sophisticated computational capabilities in the practicing engineering community. However, PBD requires more detailed knowledge of how structures and nonstructural elements perform, including the infiltration of water, as well as a clear understanding of what level of performance is needed to achieve desired resilience. Because the step-by-step building-code-based procedure is not used, PBD also alters decision-making and liability processes to include more complete and complex analyses, additional consideration of risk levels, and more extensive consideration of cost-risk tradeoffs. This will require more extensive knowledge about social behavior, structural performance needed to support response and recovery, and investment decision making as described in the following Strategic Priority.

This effort will also leverage advances in PBD for seismic design. Earthquake engineering is far ahead of wind and coastal engineering in terms of developing performance-based criteria for seismic design. The wind and coastal PBD requirements will leverage the methods from the earthquake models for performance objectives applied to the wind and flood resistant structural systems. Different performance objectives are needed for the building envelope.

SP-4 supports Objectives 10, 11, and 12 by guiding the creation of tools to improve the performance of the built environment subject to extreme wind events, supporting the development of windstorm-resilient standards and building codes, and enabling implementation of such methods in professional practice.

Initial development of PBD for tornadoes is a short term effort, PBD for the broader range of wind hazards is a medium-term effort, and PBD for storm surge-flooding is a long-term effort.

SP-5 Enhance Outreach and Partnerships to Improve Windstorm Preparedness and Hazard Mitigation

NWIRP will support new and existing outreach programs and partnerships which seek to increase public awareness of windstorm hazards and measures that can be undertaken to reduce or eliminate the effects of such hazards. A variety of methods can be employed to inform the largest audience possible, including community-wide programs, education initiatives, cooperative efforts with public and private entities, and on-going public information campaigns that disseminate information using various channels such as fact sheets, public forums and conferences, and traditional and social media outlets.

The first step toward adopting hazard mitigation is to be aware of the hazard and how it may affect the community. Educating children about natural hazards is doubly effective. First, it reaches students who, using a solid curriculum, study a topic at an age where their future behavior is still being formed. Second, information children learn in school influences their parents' decisions about how the family will prepare for and react to a disaster. NWIRP will support the creation of curriculums that could be made available to schools or civic groups in an effort to increase the perception that wind hazards are a real and present danger. When a disaster occurs it also presents a "teachable moment" to educate people who otherwise would not be inclined to consider their role in mitigating damage from a windstorm disaster. But the heightened interest in the hazard is short lived. Therefore, NWIRP will support the development of community-wide public outreach programs well in advance of an event, to take advantage of the increased awareness. Anniversaries of tragic events are another opportunity that should be used to educate the public about windstorm hazards.

NWIRP will work to support Program agencies' outreach activities such as Weather-Ready Nation and Weather Ready Nation Ambassadors,[41] and America's PrepareAthon!SM.[42] NOAA's Weather-Ready Nation is an initiative which aims to increase the Nation's resilience to extreme weather events by working with government agencies, the weather industry, emergency planners, the media, nonprofits and businesses to motivate individuals and communities to prepare for extreme weather events. Weather Ready Nation Ambassadors serve as leaders in this community collaboration, inspiring others to be better informed and prepared. FEMA's America's PrepareAthon! implements drills, communication, and outreach at a community level to provide individuals, businesses, and communities with an increased understanding of their risk to relevant hazards as well as simple and effective actions that can be taken to increase safety and mitigate damages. #HurricaneStrong,[43] the national hurricane resilience effort developed by the Federal Alliance for Safe Homes, Inc. (FLASH) in partnership with FEMA and NOAA, is a program that increases awareness and motivates the public to take action prior to the next damaging storm. The program is a culmination of planning between industry and government partners to create a unified and consistent message and resources for hurricane preparedness. Working with private sector organizations, such as FLASH, and the Insurance Institute for Business and Home Safety (IBHS),

[41] Weather-Ready Nation, National Oceanic and Atmospheric Administration. http://www.nws.noaa.gov/com/weatherreadynation/.
[42] America's PrepareAthon! Be Smart, Take Part, Prepare. https://community.fema.gov/.
[43] #HurricaneStrong. http://flash.org/hurricanestrong.

NWIRP will promote building beyond the code minimum to create more resilient communities. Through the development, implementation, and sponsoring of reliable disaster safety education programs, FLASH informs individuals and communities with information and resources for strengthening homes from natural hazards beyond code requirements. The mission of the IBHS is to conduct objective, scientific research to identify and promote the most effective ways to strengthen homes, businesses and communities against natural disasters and other causes of loss. This mission has been executed in programs such as FORTIFIED Home™ and Open for Business® which enable businesses, home owners, and developers to strengthen buildings beyond code requirements in preparation for natural hazards and to more quickly resume normal operations following such an event.

The outreach and education programs and partnerships in SP-5 support Objectives 12 and 14 by increasing public awareness of the benefits and windstorm hazard mitigation, and increasing the storm readiness of individuals, businesses, and communities.

SP-5 is a long-term effort, as it will be an on-going activity.

SP-6 Enhance and Promote Effective Storm Sheltering Strategies

Storm shelters and safe rooms[44] have been proven effective at providing life safety protection in tornadoes, hurricanes, and other extreme wind events. There has not been a single reported failure of a safe room constructed to FEMA criteria.[45] NWIRP will support efforts to continue to improve the standards and guidelines for design and construction of storm shelters, including for new construction and retrofit in existing buildings, benefitting both residential and community storm shelters. Guidance for communities is needed to enable creation of safe and effective public sheltering strategies. In cooperation with private sector organizations, NWIRP will conduct outreach to promote wider adoption of storm shelters by homeowners, developers and homebuilders, businesses, and state and local governments.

To help protect the population in tornado-prone areas that does not currently have access to storm shelters or safe rooms, NWIRP can develop guidelines for evaluation of the best available refuge areas within existing buildings, and provide outreach, education and training to support implementation. Similarly, there is a need for improved guidance on selection of best available existing facilities in hurricane-prone regions, particularly in high density coastal areas where evacuation of much of the population is not feasible.

The development of effective storm sheltering strategies will be leveraged to influence wind-storm resilient standards developed in Objective 11. For example, knowledge gained in this strategic priority could be used to improve storm shelter standards such as those contained in ICC 500.[46] SP-6 supports Objective 12 by increasing options for voluntary mitigation through standards and guidance for retrofitting existing buildings with storm shelters, and Objective 14 by providing improved guidance for selection of best available refuge areas within existing buildings.

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[44] Storm shelters are defined as facilities constructed in accordance with the governing national standard (ICC 500: ICC/NSSA Standard for the Design and Construction of Storm Shelters).

[45] Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms, FEMA P-361, Third Edition, March 2015 (page i). https://www.fema.gov/media-library/assets/documents/3140.

[46] ICC 500: ICC/NSSA Standard for the Design and Construction of Storm Shelters.

Short-term efforts include expansion of the existing storm shelter standard to address retrofit shelter installations, and developing guidelines for assessing and designating best available refuge areas. Medium-term efforts involve a) developing improved design criteria reflecting advances in understanding of surface wind characteristics in tornadoes, atmospheric pressure changes on buildings, and the windborne-debris hazard, and b) guidance for communities to create safe and effective public sheltering strategies.

SP-7 Develop the Nation's Human Resource Base in Windstorm Hazard Mitigation Fields

NWIRP recognizes the need for a world-class workforce to make the United States more windstorm resilient. NWIRP will support relevant science and engineering education at all levels, including K-12, university, and informal education for the public, as well as continuing education of windstorm professionals and technology transfer of windstorm related research and design capabilities.

The study of wind hazards is multi-disciplinary, combining the fields of meteorology, engineering and the social sciences. NWIRP will support research and education partnerships across those disciplines, preparing students to become productive members of the disaster reduction workforce. In addition, to spark interest about the subject in younger students, outreach programs will be promoted to K-12 from universities, government agencies concerned with wind hazards, and practitioners such as local emergency management officials or local weather broadcasters.

The efforts of professional and academic organizations to work together in pursuit of enhancing safety from windstorms are encouraged. Creation and maintenance of a wind hazard community will build and support the efforts of individuals and institutions committed to wind hazard mitigation and can become a platform to recruit future professionals for the field. NWIRP will support continuing education and professional development of individuals involved in the wind hazard community in order to advance current knowledge and methods related to windstorm hazards, preparedness, mitigation, and assessment. Similarly, to advance understanding of windstorms and associated hazards, NWIRP will support technology transfer of research and expertise through channels such as publications, conferences, publicly available databases, and improved codes and standards. These initiatives will ultimately increase the windstorm resilience of communities and the built environment.

This Strategic Priority is recursive in that it will both support and be supported by each of the Objectives and Strategic Priorities in order to combine multi-disciplinary research across the fields of meteorology, engineering, and the social sciences.

Research collaboration across industry, academia, and the government is a short-term effort crucial to achieving Objectives 1-14. The creation and maintenance of a wind hazard community is an on-going medium-term effort which includes continuing education and professional development of individuals within the community. Initiatives at the K-12 level to increase interest and awareness about windstorm risk reduction is a long-term effort. Technology transfer is an on-going and long-term effort to further the understanding of windstorm phenomena, hazards, preparedness, and mitigation.

Chapter 4: Summary

This Strategic Plan for the National Windstorm Impact Reduction Program (NWIRP) was developed by the Program agencies with input from the stakeholder community. The Plan provides a rational and executable approach for reducing losses of life and property from windstorms in the United States.

The Program agencies have established three linked, overarching Strategic Goals: Improve the Understanding of Windstorm Processes and Hazards; Improve the Understanding of Windstorm Impacts on Communities; and Improve the Windstorm Resilience of Communities Nationwide. Fourteen objectives and implementation strategies necessary to accomplish these goals are provided in this Plan, spanning basic research, problem-focused research and development, and implementation, education, and outreach. Many elements of the various objectives are currently supported by the Program agencies, other governmental agencies, academia, and the private sector.

Seven priority focus areas are identified for new and enhanced efforts. These Strategic Priorities will provide: a) foundational data and models key to supporting future research advances; b) opportunities for more rapid impact reduction; and c) development of the Nation's human resource base in windstorm impact reduction fields. These priorities build upon and support elements of all 14 objectives.

The goals, objectives, Strategic Priorities, and implementation strategies of this Plan will serve as guidelines for NWIRP efforts, but NWIRP will also adapt to contingencies and opportunities as they arise. Progress on implementation of this Plan and the rate of Program accomplishment will depend on the level of resources that are available to Program agencies. Progress reports will follow the structure outlined in this Plan, reporting on activities supporting the Strategic Priorities and objectives, as well as progress toward anticipated outcomes. This will provide a direct basis for the Interagency Coordinating Committee, the National Advisory Committee on Windstorm Impact Reduction (NACWIR), and the windstorm stakeholder community to measure Program success. The Interagency Coordinating Committee will review the Strategic Plan periodically, and make updates as needed to improve its efficiency and effectiveness.

Key to success of NWIRP's mission to achieve major measureable reductions in the losses of life and property from windstorms is active engagement and participation of windstorm stakeholders in implementing the Strategic Plan. This broad stakeholder community includes other Federal agencies, state and local government, academia, and large swaths of the private sector, including construction-related industries and businesses, engineering, architecture, insurance, real estate, media, non-profit organizations, and many more. Only working together can we overcome the current rapid rate of growth of windstorm losses and realize the vision of a windstorm resilient nation.

Appendix A: List of Acronyms

- APC. Atmospheric Pressure Change
- ASCE. American Society of Civil Engineers
- ASTM. American Society for Testing and Materials
- CBO. Congressional Budget Office
- CEQ. Council on Environmental Quality
- CFD. Computational Fluid Dynamics
- CPI. Consumer Price Index
- DHS. Department of Homeland Security
- DoE. Department of Energy
- EF. Enhanced Fujita Scale
- FEMA. Federal Emergency Management Agency
- FHWA. Federal Highway Administration
- FLASH. Federal Alliance for Safe Homes
- GDP. Gross Domestic Product
- GPS. Global Positioning System.
- GSA. General Services Administration
- Hazus. Hazards U.S. A Geographic Information System (GIS)-based natural hazard analysis tool developed and distributed by the Federal Emergency Management Agency (FEMA).
- Hazus®-MH. Hazus Multi-Hazard.
- HUD. Department of Housing and Urban Development
- HVAC. Heating, Ventilation, and Air Conditioning
- IBC. International Building Code
- IBHS. Insurance Institute for Business and Home Safety
- ICC. International Code Council
- IEBC. International Existing Building Code
- LiDAR. Light Detection and Ranging
- MAT. Mitigation Assessment Team
- NACWIR. National Advisory Committee on Windstorm Impact Reduction
- NASA. National Aeronautics and Space Administration
- NEHRP. National Earthquake Hazards Reduction Program
- NHERI. Natural Hazards Engineering Research Infrastructure
- NIST. National Institute of Standards and Technology
- NOAA. National Oceanic and Atmospheric Administration
- NRC. Nuclear Regulatory Commission
- NSF. National Science Foundation
- NWIRP. National Windstorm Impact Reduction Program
- NWS. National Weather Service
- OSTP. Office of Science and Technology Policy
- PBD. Performance-Based Design

- PIMS. Performance Information Management Service
- R&D. Research and Development
- UAS. Unmanned Aircraft Systems
- USACE. U.S. Army Corps of Engineers
- USD. United States Dollars
- USGS. United States Geological Survey
- VA. Veterans Administration
- WWG. Windstorm Working Group

Appendix B: Glossary of Key Terms

Built Environment: The *built environment* consists of buildings and infrastructure systems, including transportation, energy, water, wastewater, and communication and information systems.[47]

Boundary Layer: The *boundary layer* is a region of reduced wind velocity near the ground or the surface of a body[48]. The boundary layer could be as low as tens of meters above the ground in downbursts and greater than two kilometers in hurricanes and extratropical storms.

Convection: NOAA defines *convection* as the vertical transport of heat and moisture in the atmosphere, especially by updrafts and downdrafts in an unstable atmosphere.[49] The terms "convective storm" and "thunderstorm" are often used interchangeably.

Critical Facility: Buildings that are intended to remain operational during hazard events and support functions and services needed during the short-term phase of recovery. These facilities are sometimes referred to as essential buildings.[50]

Critical Infrastructure: Systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters.[51]

Derecho: A *derecho* is a widespread and usually fast-moving windstorm associated with convection. Derechos include any family of downburst clusters produced by an extratropical mesoscale convective system, and can produce damaging straight-line winds over areas hundreds of miles long and more than one hundred miles across. [52]

Disaster Resilience: The ability[53] of social units (e.g., organizations, communities) to mitigate risk, contain the effects of disasters, and carry out recovery activities in ways that minimize social disruption, while also minimizing the effects of future disasters. *Disaster resilience* may be characterized by reduced likelihood of damage to and failure of critical infrastructure, systems, and components; reduced injuries, lives lost, damage, and negative economic and social impacts; and reduced time required to restore a specific system or set of systems to normal or pre-disaster levels of functionality.[54] Presidential Policy Directive 21 (PPD 21) defines resilience as the ability to prepare for and adapt to changing conditions and

[47] *Community Resilience Planning Guide for Buildings and Infrastructure Systems – Volume I*, National Institute of Standards and Technology, April 2015, https://www.nist.gov/el/resilience/community-resilience-planning-guides.
[48] Holmes, John D. *Wind loading of structures*, Taylor & Francis, Sec. Ed., 2010.
[49] National Oceanic and Atmospheric Administration. *Convection: National Weather Service Glossary*, cited 2016.
[50] *Community Resilience Planning Guide for Buildings and Infrastructure Systems – Volume I*, National Institute of Standards and Technology, April 2015, https://www.nist.gov/el/resilience/community-resilience-planning-guides.
[51] Presidential Policy Directive 21 [PPD-21], The White House, February 12, 2013, http://www.whitehouse.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil.
[52] National Oceanic and Atmospheric Administration. *Derecho: National Weather Service Glossary*, cited 2016.
[53] http://mceer.buffalo.edu/research/resilience/Resilience_10-24-06.pdf.
[54] Ibid.

withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents. [55]

Downburst: A *downburst* is a strong small-scale column of air that rapidly sinks toward the ground,[56] producing strong ground-level winds that originate with downward directed vertical winds and emanate in all horizontal directions. Downbursts occur in thunderstorms and can produce strong damaging winds.

Extratropical cyclone: A cyclone in the middle and high latitudes (i.e., north of 35°N) often being 2000 kilometers in diameter and usually containing a cold front that extends toward the equator for hundreds of kilometers.[57]

Hazard: A potential threat or incident, natural or human caused, that warrants action to protect life, property, the environment, and public health or safety, and to minimize disruptions of government, social, or economic activities.[58] Windstorm hazards are potential threats to life and property caused by the effects of extreme winds on communities and the built environment.

Hurricane: A *hurricane* is a tropical cyclone occurring in the Atlantic, Caribbean Sea, Gulf of Mexico, or eastern Pacific, with maximum one-minute sustained surface wind speeds equal to 74 mph or higher. [59]

Infrastructure: Physical networks, systems and structures that make up transportation, energy, communications, water and wastewater, and other systems that support the functionality of community social institutions.[60]

Lifelines: *Lifelines* are major elements of the Nation's infrastructure that are essential to community well-being and serve communities across all jurisdictions and locales.[61] The term *lifelines* means public works and utilities, including transportation facilities and infrastructure, oil and gas pipelines, electrical power and communication facilities and infrastructure, and water supply and sewage treatment facilities. [62]

Mitigation: Activities and actions taken to reduce loss of life and property by lessening the impact of hazard events.[63]

Nor'easter: A N*or'easter* is a cyclonic storm impacting the eastern coast of North America, named for the direction from which the coastal winds blow. Nor'easters typically develop in the lower-middle

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[55] Presidential Policy Directive 21 [PPD-21], The White House, February 12, 2013, http://www.whitehouse.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil.
[56] National Oceanic and Atmospheric Administration. *Downburst: National Weather Service Glossary*, cited 2016.
[57] National Oceanic and Atmospheric Administration. *Extratropical Cyclone: National Weather Service Glossary*, cited 2016.
[58] Presidential Policy Directive 21 [PPD-21], The White House, February 12, 2013, http://www.whitehouse.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil.
[59] National Oceanic and Atmospheric Administration. *Hurricane: National Weather Service Glossary*, cited 2016.
[60] *Community Resilience Planning Guide for Buildings and Infrastructure Systems – Volume I*, National Institute of Standards and Technology, April 2015, https://www.nist.gov/el/resilience/community-resilience-planning-guides.
[61] www.americanlifelinesalliance.org.
[62] National Windstorm Impact Reduction Act Reauthorization of 2015. Pub. L. 114-52. 129 STAT. 496. 30 Sept. 2015.
[63] *Community Resilience Planning Guide for Buildings and Infrastructure Systems – Volume I*, National Institute of Standards and Technology, April 2015, https://www.nist.gov/el/resilience/community-resilience-planning-guides.

latitudes (30°N to 40°N) from September to April within 100 miles of the coastline and can cause heavy rain or snow, strong winds, and coastal flooding.[64]

Post-tropical cyclone: A *post-tropical cyclone* is a former tropical cyclone that no longer possesses sufficient tropical characteristics to be considered a tropical cyclone. Post-tropical cyclones can continue carrying heavy rains and high winds.[65]

Risk: Risk is the potential for loss or injury due to an adverse circumstance or hazard. In the windstorm context, estimates of national risk are based on two primary factors: the inventory of structures, and the potential damage and consequences extrapolated from past experience to current conditions.[66]

Storm Surge: *Storm surge* is an abnormal rise in sea level accompanying a hurricane, extratropical storm, Nor'easter, or other intense storm, due to strong winds pushing water inland. The storm surge height is the difference between the observed level of the sea surface and the level that would have occurred in the absence of the storm.[67]

Tropical Cyclone: A *tropical cyclone* is a warm core, nonfrontal synoptic-scale cyclone originating over tropical or subtropical waters with organized deep convection and a closed surface wind circulation about a well-defined center.[68] Tropical cyclones can produce high damaging winds, large waves, and extensive inland flooding. Tropical cyclones with one-minute average sustained wind speeds between 39 and 74 mph are called tropical storms, and those with one-minute average sustained wind speeds exceeding 74 mph are called hurricanes.

Wind Professional: Any professional who is involved with windstorm risk and hazard mitigation, or with response to windstorms. Includes planners, designers (architects and engineers), builders, researchers, building code officials, and government employees (including legislators).

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[64] American Meteorological Society, *Nor'easter: Glossary of Meteorology*, cited 2016.
[65] National Oceanic and Atmospheric Administration. *Post-tropical Cyclone: National Hurricane Center Glossary*, cited 2016.
[66] National Research Council, *Improved Seismic Monitoring, Improved Decision Making—Assessing the Value of Reduced Uncertainty*, 2006.
[67] National Oceanic and Atmospheric Administration. *Storm Surge: National Weather Service Glossary*, cited 2016.
[68] National Oceanic and Atmospheric Administration. *Tropical Cyclone: National Weather Service Glossary*, cited 2016.

Appendix C: NWIRP Program Agency Statutory Responsibilities

Tables C.1 through C.4 provide a mapping from the statutory responsibilities (42 U.S.C. § 15703) of the four Program agencies to the Strategic Plan goals, objectives, and Strategic Priorities. Many other activities within the Program agencies, conducted under different statutory authorities, also support the NWIRP mission and specific goals and objectives. For example, while NOAA's assigned NWIRP responsibility is atmospheric science research (Table C.3), many other NOAA activities provide critical support for windstorm impact reduction, such as storm data collection and archival, forecasting, warning communications, and education and outreach programs. Other Program agency capabilities beyond those supporting the statutory responsibilities will be engaged by NWIRP as needed.

Table C.1: Federal Emergency Management Agency

Program Agency Responsibilities	Strategic Plan Goal	Strategic Plan Objective	Strategic Priority SP #
Support development of risk assessment tools and effective mitigation techniques. 42 U.S.C. § 15703(b)(5)(A)(i).	B C	9 10	1, 6
Support windstorm-related data collection and analysis. 42 U.S.C. § 15703(b)(5)(A)(ii).	A B C	2, 4 7, 8, 9 12	2, 3
Support public outreach and information dissemination. 42 U.S.C. § 15703(b)(5)(A)(iii).	C	12, 14	5, 6, 7
Support promotion of the adoption of windstorm preparedness and mitigation measures, including for households, businesses, and communities, consistent with the agency's all-hazards approach. 42 U.S.C. § 15703(b)(5)(A)(iv).	C	12, 14	5, 6
Work closely with national standards and model building code organizations, in conjunction with NIST, to promote implementation of research results and promote better building practices within the building design and construction industry, including architects, engineers, contractors, builders, and inspectors. 42 U.S.C. § 15703(b)(5)(B).	C	11, 12, 14	4, 6

Table C.2 National Institute of Standards and Technology

Statutory Responsibilities	Strategic Plan Goal	Strategic Plan Objective	Strategic Priority SP #
Lead Agency Responsibilities			
Ensure the Program includes necessary components to promote implementation of windstorm risk reduction measures by Federal, State, and local governments, national standards & model building code organizations, architects and engineers, and others with roles in planning & constructing buildings & lifelines. 42 U.S.C. § 15703(b)(1)(A).	All	All	All
Support development of performance-based engineering tools, & work with appropriate groups to promote commercial application of such tools, including wind-related model building codes, voluntary standards, and construction best practices. 42 U.S.C. § 15703(b)(1)(B).	C	11, 12	4
Request assistance of Federal agencies other than the Program agencies, as necessary to assist in carrying out the Act (Program). 42 U.S.C. § 15703(b)(1)(C).	All	All	All
Coordinate all Federal post-windstorm investigations, to the extent practicable. 42 U.S.C. § 15703(b)(1)(D).	A B	2 8	3
When warranted by research or investigative findings, issue recommendations to assist informing development of model codes & inform Congress on use. 42 U.S.C. § 15703(b)(1)(E).	C	11	4, 6
Program Agency Responsibilities			
In addition to the lead agency responsibilities, carry out R&D to improve model building codes, voluntary standards, and best practices for design, construction, and retrofit of buildings, structures, and lifelines. 42 U.S.C. § 15703(b)(2).	A B C	1, 2, 4 5, 6, 8, 9 10, 11	All

Table C.3: National Oceanic and Atmospheric Administration

Program Agency Responsibilities	Strategic Plan Goal	Strategic Plan Objective	Strategic Priority SP #
Support atmospheric sciences research to improve understanding of behavior of windstorms and their impact on buildings, structures, and lifelines. 42 U.S.C. § 15703(b)(4).	A B	1, 2, 3, 4 5, 6, 8	1, 2, 3, 7

Table C.4: National Science Foundation

Program Agency Responsibilities	Strategic Plan Goal	Strategic Plan Objective	Strategic Priority SP #
Support research in engineering and atmospheric sciences to improve understanding of behavior of windstorms and their impact on buildings, structures, and lifelines. 42 U.S.C. § 15703(b)(3)(A).	A B	1, 2, 3, 4 5, 6, 8, 9, 10	1, 2, 3, 4, 6, 7
Support research in economic and social factors influencing windstorm risk reduction measures. 42 U.S.C. § 15703(b)(3)(B).	B C	7, 8 10, 11, 12	1, 3, 7

Appendix D: NWIRP Statutory Program Components

Table D.1 provides a mapping of the statutory Program Components (42 U.S.C. § 15703(c)) to the Strategic Plan goals and objectives.

Table D.1: NWIRP Program Components, Goals, and Objectives

Program Components	Strategic Plan Goal	Strategic Plan Objective
Understanding of Windstorms		
Research to improve knowledge of and data collection on the impact of severe wind on buildings, structures, and infrastructure. 42 U.S.C. § 15703(c)(2).	A B	1, 2, 3, 4 5, 6, 8, 9
Windstorm Impact Assessment		
Development of mechanisms for collecting and inventorying information on the performance of buildings, structures, and infrastructure in windstorms and improved collection of pertinent information from sources, including the design and construction industry, insurance companies, and building officials. 42 U.S.C. § 15703(c)(3)(A).	A B	2 8
Research and development and technology transfer to improve loss estimation and risk assessment systems. 42 U.S.C. § 15703(c)(3)(B).	A B	4 9
Research and development and technology transfer to improve simulation and computational modeling of windstorm impacts. 42 U.S.C. § 15703(c)(3)(C).	A B	2 5, 6, 8, 9
Windstorm Impact Reduction		
Development of improved outreach and implementation mechanisms to translate existing information and research findings into cost-effective and affordable practices for design and construction professionals, and State and local officials. 42 U.S.C. § 15703(c)(4)(A).	C	10, 11, 12
Development of cost-effective and affordable windstorm-resistant systems, structures, and materials for use in new construction and retrofit of existing construction. 42 U.S.C. § 15703(c)(4)(B).	C	10

Outreach and information dissemination related to cost-effective and affordable construction techniques, loss estimation and risk assessment methodologies, and other pertinent information regarding windstorm phenomena to Federal, State, and local officials, the construction industry, and the general public. 42 U.S.C. § 15703(c)(4)(C).	**B** **C**	**9** **10, 11, 12, 13, 14**