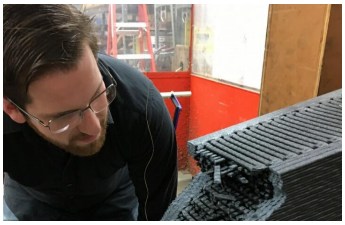
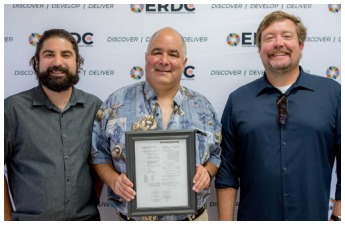
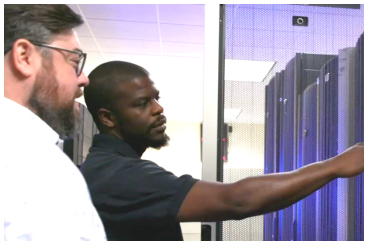
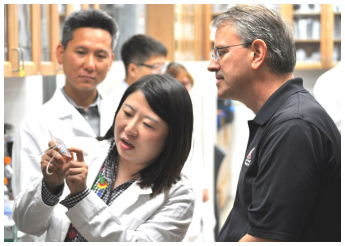


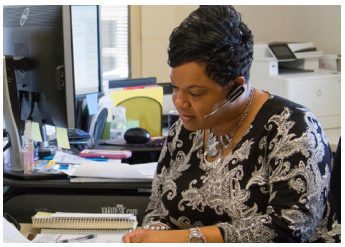


THE POWER OF ERDC

ENGINEER RESEARCH & DEVELOPMENT CENTER

ERDC 2020 - 2030 STRATEGY










The U.S. Army Engineer Research and Development Center (ERDC) solves the nation's toughest engineering and environmental challenges. ERDC develops innovative solutions in civil and military engineering, geospatial sciences, water resources, and environmental sciences for the Army, the Department of Defense, civilian agencies, and our nation's public good. Find out more at www.erdc.usace.army.mil.

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The Power of ERDC

ERDC 2020–2030 Strategy

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Final report

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Executive Office
Strategic Integration Office (SIO)
Vicksburg, MS 39180-6199
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Abstract

The ERDC 2020–2030 Strategy outlines the origination of the organization, future direction, and the methods used to accomplish its research and development mission. The Strategy details the Ends (where we are going and why), the Ways (how we will get there), and the Means (the resources needed to get there) by which we will achieve the US Army Engineer Research and Development Center (ERDC) strategy. To realize its vision and maintain its world-class status, ERDC strives to be the go-to organization for the Warfighter and the nation to solve large complex problems in its mission space. To strengthen the outcomes from the Ends, Ways, and Means, ERDC has adopted the philosophy of the Understand-Predict-Shape (UPS) paradigm. The UPS paradigm maximizes the potential of ERDC's current research programs and helps contemplate, develop, and define the organization's future portfolio. UPS represents a holistic view of the operational environment: How to better Understand the Present, Predict the Future, and Shape the Outcome. The ERDC leadership team has looked toward the future and defined major strategic Science and Technology campaigns that offer challenges that ERDC can, and should, effectively address.

THE POWER OF ERDC
ERDC 2020-2030 STRATEGY

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This study was conducted for the U.S. Army Engineer Research and Development Center, Executive Office (ERDC-EXO). The technical monitor for this report was Dr. J. Paige Buchanan, Chief of the Strategic Integration Office. The project was funded using ERDC Revolving General and Administrative (G&A) Funds.

The work was performed by the Corporate Communications Office and the Strategic Integration Office, ERDC-EXO. At the time of publication, LTC Christian Patterson was the Director of Communications; Ms. Debbie Quimby was Chief of the Corporate Communications Office; and Dr. J. Paige Buchanan was Chief of the Strategic Integration Office. The Deputy Director of ERDC was Dr. Elizabeth Fleming.

The Commander of ERDC was COL Teresa A. Schlosser, and the Director was Dr. David W. Pittman.

FOREWORD

The U.S. Army Corps of Engineers (USACE) has been providing engineering solutions to the nation's toughest challenges since the Revolutionary War. Over the years, the problems have evolved, as have the ways in which USACE provides solutions. Since 1929, USACE has relied upon its research laboratories, now called the Engineer Research and Development Center (ERDC), to solve some of our nation's greatest challenges.

Those challenges are indeed great. From crumbling infrastructure; to escalating costs of constructing, operating and maintaining our waterways; to increased storm events and major disasters; to emerging and growing national security threats; to the current pandemic – the nation needs the Engineers now more than ever.

While ERDC traces its beginnings to studying waterways in Vicksburg back in 1929, following the Great Flood of 1927, its existence as seven laboratories in four states is only two decades old. In that brief history, ERDC has helped the nation through many emergencies and crises – 9/11, the wars in Iraq and Afghanistan, Hurricane Katrina, the hurricanes of 2017 (Harvey, Irma and Maria), and now the COVID-19 pandemic. Through it all, ERDC has discovered, developed and delivered new ways to make the world safer and better every day.

Much has changed in the Army, USACE and ERDC in the past few years. The Army has organized its newest four-star command, the Army Futures Command, to build the future Army, and relies on ERDC to help realize its six Army Modernization Priorities. The USACE workload has more than doubled; supporting civil works, our nation's military and other agencies; and USACE needs ERDC's support to help deliver the program faster, better and cheaper than ever before.

In the past few years, ERDC has changed leadership in almost every laboratory, and our Army research programs have changed significantly to meet Army priorities. Our research programs are steadily growing, and our new workforce has increased dramatically. As the Baby Boomer generation, once the largest single group at ERDC, retires in increasing numbers, Millennials have now become the largest single demographic group in the ERDC workforce. ERDC is investing millions of dollars in new facilities and finding innovative ways to work with partners to deliver new capabilities for our nation's security and well-being.

The next decade, 2020-2030, our third decade as ERDC, offers the promise of even greater challenges, and even more opportunity. The 54th Chief of Engineers, LTG Todd Semonite, calls upon the "Power of ERDC," a phrase he personally coined, when he needs a new way to tackle some of the nation's toughest challenges. That power rests inside you and will always be manifested in your great efforts. I could not be more proud of you and how well you've responded, no matter how tough the challenge!

The future of ERDC is very bright, and there is no better time than now to plan and get ready for that future. This strategy lays out our current thinking on those future plans. President Eisenhower once said, "Plans are worthless, but planning is everything." This plan lays a good foundation for our future, but your continued great work will create that future. I look forward to building it with you as we make our next decade as ERDC the brightest one yet!
Essayons!

David W. Pittman, PE, PhD, SES
Director of ERDC
Director of Research and Development and Chief Scientist
U.S. Army Corps of Engineers

INTRODUCTION

To understand where ERDC is heading over the next 10 years, it is important to understand where we came from and where we stand today.

ERDC is the research and development (R&D) arm of USACE and a world-renowned public and military engineering R&D organization. ERDC's vision and mission statements (Figure 1) guide the organization and define the space within which it operates.

ERDC'S VISION

"To be a World-Class Research & Development Organization that ***Discovers, Develops and Delivers*** *New Ways to Make the World Safer and Better Every Day."*

ERDC'S MISSION

"To conduct research and development leveraging science, technology, engineering and mathematics to solve our nation's most challenging problems in civil and military engineering, geospatial sciences, water resources, and environmental sciences for the Army, Department of Defense, Civilian agencies, and our nation's public good."

FIGURE 1: ERDC VISION AND MISSION

USACE is one of only four Army commands or entities that has a research organization (Figure 2). ERDC is the second-largest Army R&D organization in terms of the proportion of the Army Science and Technology (S&T) program it executes – 13 percent of the Army S&T budget in 2019.

ERDC consists of seven research laboratories, whose names describe each laboratory's research expertise: Coastal and Hydraulics Laboratory (CHL), Cold Regions Research and Engineering Laboratory (CRREL), Construction Engineering Research Laboratory (CERL), Environmental Laboratory (EL), Geotechnical and Structures Laboratory (GSL), Geospatial Research Laboratory (GRL), and Information Technology Laboratory (ITL).

ERDC is headquartered in Vicksburg, Mississippi, as are four of its laboratories – CHL, EL, GSL and ITL – and its primary support elements. CERL is located in Champaign, Illinois; CRREL in Hanover, New Hampshire; and GRL in Alexandria, Virginia. ERDC also has field test sites at locations around the nation, including the Permafrost Research Test Facility in Fox, Alaska; the Field Research Facility in Duck, North Carolina; the Lewisville Aquatic Ecosystem in Lewisville, Texas; and the Extreme Exposure Station on Treat Island, Maine (Figure 3). ERDC also maintains an International Research Office in London, England.

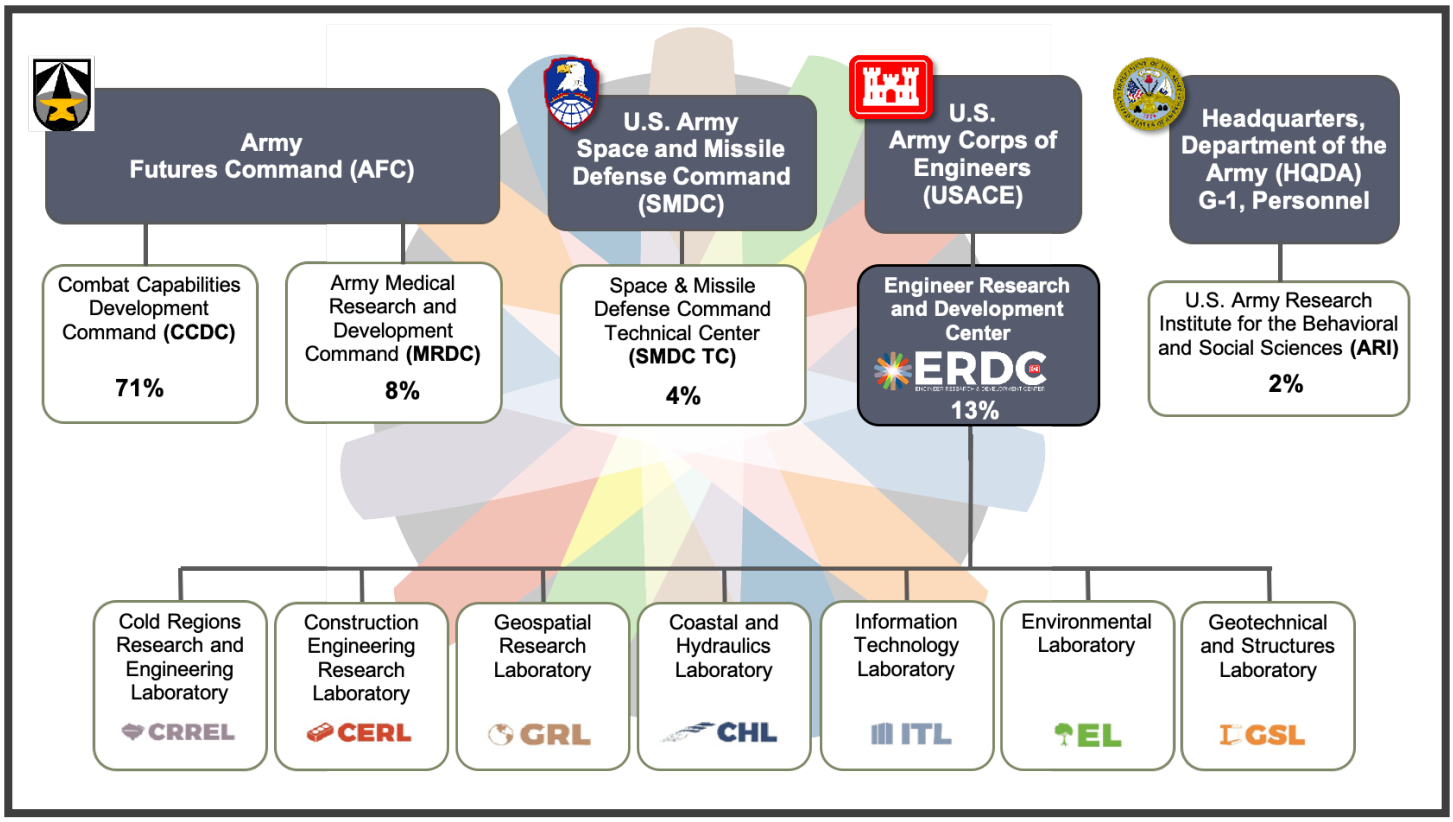

FIGURE 2: ERDC AS PART OF THE ARMY S&T LABORATORY ENTERPRISE (2020)

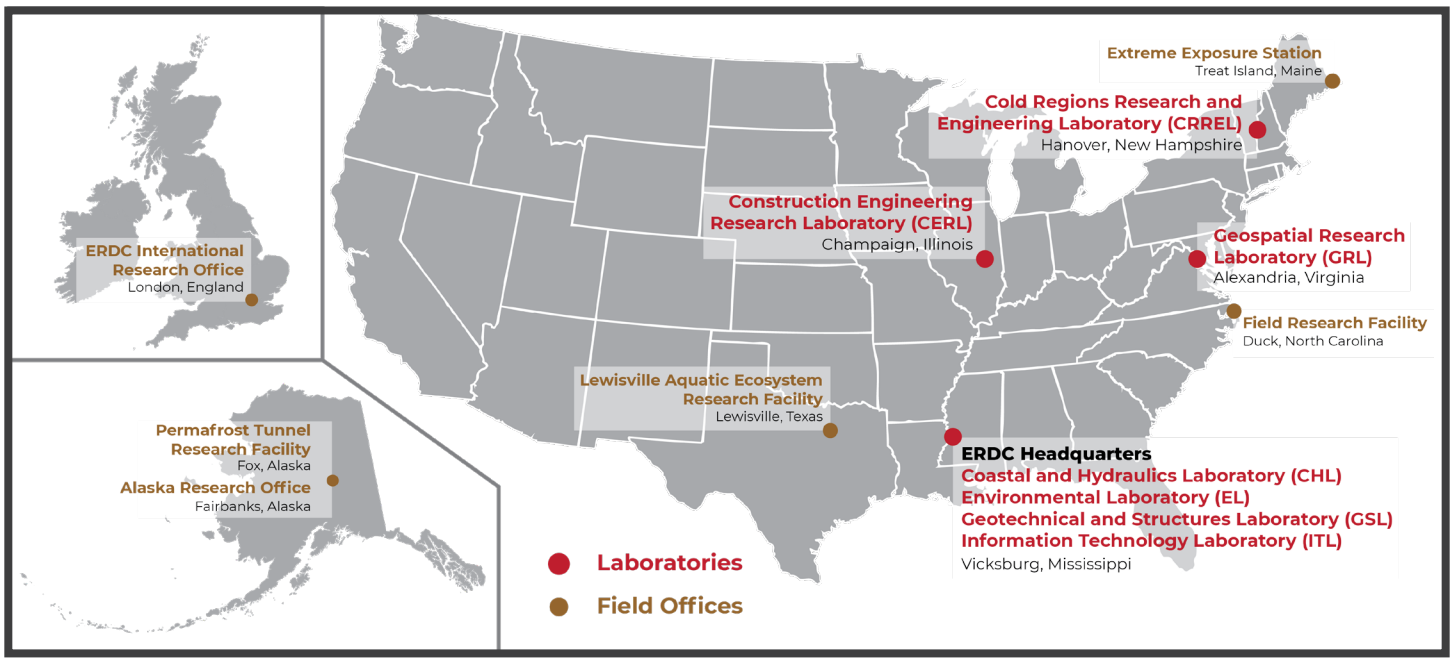

FIGURE 3: ERDC HEADQUARTERS, LABORATORIES, FIELD TEST SITES AND INTERNATIONAL RESEARCH OFFICE

ERDC'S PEOPLE

ERDC's greatest strength is, and always has been, its people. In 2019, ERDC had more than 2,200 engineers, scientists, technicians and administrative personnel, plus hundreds of contract support personnel and students. ERDC has hired more than 800 new employees in the past five years, which has resulted in the Millennial generation becoming the largest single group in the ERDC workforce (Figure 4). To support its research mission, two-thirds of ERDC engineers and scientists have graduate degrees, and over 30 percent have doctorates.

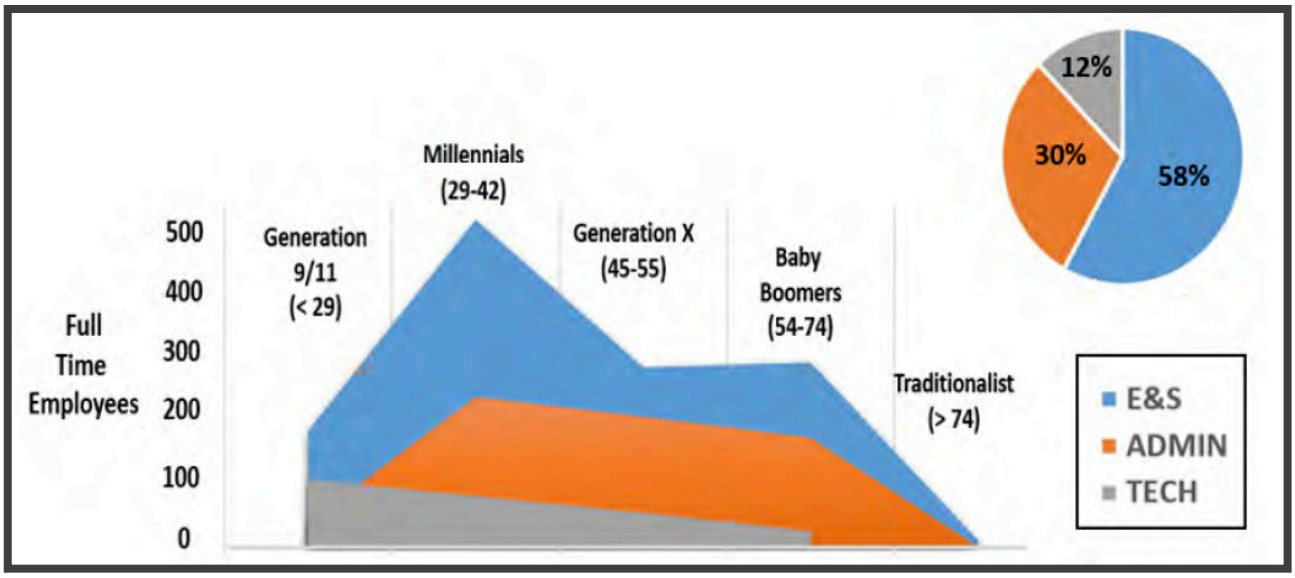

FIGURE 4: ERDC ENGINEERS, SCIENTISTS, ADMINISTRATIVE AND TECHNICIAN PERSONNEL

ERDC'S PROGRAM, PRODUCTS AND PARTNERS

ERDC's annual research program has exceeded $1 billion for the past several years (Figure 5). Our research portfolio consists of a diverse mixture of military and civil works support, as well as support for others. About a quarter of our portfolio is "direct" funded, which means that a portion of the Army S&T budget (part of the Army's Research, Development, Testing and Evaluation program) is executed by ERDC. For the USACE Civil Works program, a portion of the funding is set aside to address R&D issues and is executed by ERDC. The direct funding helps ERDC create new capability for the Army and USACE.

In our "reimbursable" program, the research funding comes from partners or customers, including our USACE Divisions, Districts and Headquarters; the Army, Navy, Air Force, Marines, and Department of Defense (DOD); other federal agencies, such as the Department of State, Department of Homeland Security, the Environmental Protection Agency, the Bureau of Reclamation; and many others. This reimbursable research helps create new capability for our partners but can also be very solutions-oriented to solve a specific problem our partner is facing. The ERDC also manages the DOD's High-Performance Computing Modernization Program (HPCMP), which provides supercomputers, software and a research network to hundreds of engineers and scientists across the DOD.

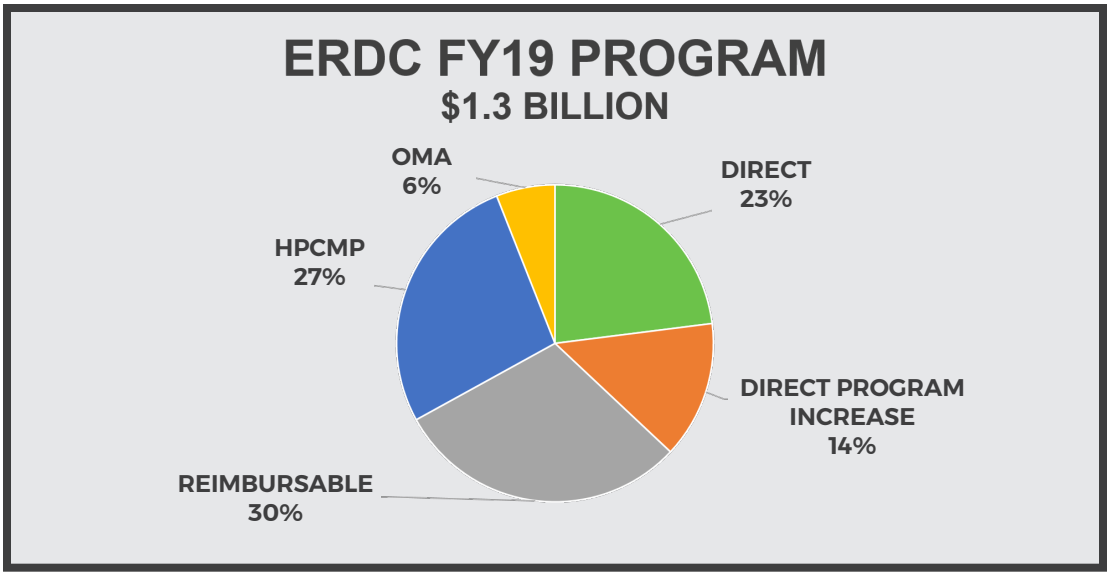

FIGURE 5: ERDC FY19 RESEARCH PORTFOLIO

ERDC products can consist of new materiel solutions, new computer programs, reports, journal articles, or other publications, and providing technical support for our partners. Our many partners are critical to our success in delivering research solutions, either by providing the guidance and resources necessary to conduct the research (our customers), supporting the execution of the research, or both. ERDC has many partners throughout USACE and DOD, and in all military services, many government agencies, in academia, industry and with our international allies (Figure 6). We cultivate and exercise these partnerships through personal relationships and formal agreements, such as Educational Partnership Agreements and Cooperative Research and Development Agreements.

FIGURE 6: ERDC PARTNERS

A BRIEF HISTORY OF ERDC AND ITS IMPACT ON THE NATION

ERDC has enjoyed a long and storied history supporting the security and well-being of our country. ERDC traces its roots back to 1929, when the Waterways Experiment Station was established by Congress and USACE to address the impacts of flooding following the Great Flood of 1927, one of the greatest natural disasters in U.S. history.

Our 91-year history offers multiple examples of world-class impacts for the Warfighter and the nation as a result of ERDC's R&D activities. In the 1920s-30s, engineers and scientists in what is now CHL literally wrote the book on hydraulic and coastal engineering, and our predecessors in GSL laid the foundation for much of the geotechnical and materials engineering used by the world today.

In World War II, the predecessors of CHL, GSL and GRL helped plan invasions at Normandy and the Pacific islands, and along with the predecessor to CRREL, helped develop critical airfield and pavement technology that is still being used worldwide today; developed critical force protection and blast and weapons effects capabilities; and helped map the battlefield faster and better than the enemy could adapt. Support to the Warfighter soon became a predominant portion of ERDC's research mission.

In the 1960s, our construction engineering research at CERL began paving the way for billions of dollars in energy, operations, maintenance and construction cost savings on U.S. military installations. Our cold regions research at CRREL helped our fighting forces adapt to extreme environments in the Arctic and high altitudes and today helps us adapt to the impacts of climate change. The environmental movement of the 1970s gave rise to the development of world-class environmental research in EL, which today sets the standard for toxic industrial compound and material mitigation; threatened, endangered and invasive species mitigation; and other technologies to protect our environment while promoting resiliency.

The 1980s and 1990s ushered in the computer age, when our researchers in ITL pioneered the art and science of numerical modeling and supercomputers to make all other R&D missions faster, better and cheaper than ever before. Today, ITL leads the Department of Defense's largest high-performance computing R&D program, which saves billions of dollars for DOD acquisition programs and accelerates their development.

On October 1, 1998, ERDC was formed as a combination of all USACE laboratories in Mississippi, Illinois, New Hampshire and Virginia and was headquartered in Vicksburg, Mississippi. The newly formed ERDC made an impact on the nation almost from its very beginning. On 9/11, during the worst terrorist attack on our nation's soil since Pearl Harbor, ERDC anti-terrorism technology that was being built into the walls of the Pentagon was credited with saving hundreds of lives – Soldiers and Civilians – on that fateful morning.

In the Iraq and Afghanistan wars that followed, many ERDC personnel deployed to support the country's military mission. In so doing, they deployed technologies developed by ERDC to support the Warfighter, particularly in Improvised Explosive Device (IED) detection and defeat, rapid

mapping and surveillance techniques, overhead cover and force protection, operational energy technologies, and rapid environmental assessment technologies. These technologies no doubt saved thousands of lives, improved the safety and security of thousands of Soldiers and Civilians in theater, and continue to do so to this very day.

After Hurricane Katrina, ERDC helped lead a major forensic investigation that outlined the extent of the flooding and storm surge and discovered the failure mechanisms for the failed floodwall systems in New Orleans. Thousands of hurricanes and storms in the Gulf of Mexico and Atlantic were modeled to help rapidly determine the impacts of future hurricanes. New and improved floodwall designs were developed and built following the forensic study. The surge modeling no doubt helped save thousands of lives and billions of dollars in property damage in later hurricanes, including Sandy, Harvey, Irma and Maria.

In the 2020 COVID-19 worldwide pandemic, ERDC researchers developed a world-class epidemiological modeling and mapping capability and built prototypes of new rapid temporary hospital rooms to help the nation's growing crisis to care for COVID-19 patients. ERDC also provided the Centers for Disease Control and Prevention with needed expertise as one of 17 – and the only government model – models used for COVID-19 tracking during the pandemic.

These are prime examples of ERDC's ingenuity, creativity and adaptability at work, qualities that have been a hallmark of its success for the past nine decades of its existence. These enduring attributes will be the key to ERDC's success over future decades as well.

THE ERDC 2020-2030 STRATEGY

STRATEGY PURPOSE

The ERDC 2020-2030 Strategy outlines where our organization came from, where we are headed, and the ways and means by which we accomplish our R&D mission. One simple construct for strategy development is to define the Ends, Ways and Means, a very typical framework for many military strategies. The ERDC 2020-2030 Strategy will use that simple construct: it will describe the **Ends** (where we are going and why), the **Ways** (how we will get there) and the **Means** (the resources we will need to get there) by which we will achieve the strategy.

Part of the answer to the questions above is laid out very simply in our vision statement: "To be a world-class research and development organization (**ends**) that discovers, develops and delivers new ways (**ways**) to make the world safer and better every day (**ends**)." This document will take a closer look at the end, ways and means components of the strategy (Figure 7), and how the strategy can be used as a springboard into the future, laying the foundation for how we will focus our capabilities and resources to solve the critical challenges of tomorrow.

THE POWER OF ERDC: THE ERDC 2020-2030 STRATEGY

ENDS – THE "WHY"	WAYS – THE "HOW"	MEANS – THE "WHAT"
OBJECTIVES AND GOALS	WAYS OF ACHIEVING OBJECTIVES AND GOALS	RESOURCES REQUIRED TO ACHIEVE OBJECTIVES AND GOALS
"World-Class R&D Organization" "Making the World Safer and Better"	"Discover, Develop, Deliver New Ways"	"The 5-P's"
Understand-Predict-Shape Paradigm **ERDC Strategic S&T Campaigns** 1. Enable Multi-Domain Operations 2. Revolutionize Civil Works 3. Enable Smart and Resilient Installations 4. Accelerate Digital Engineering 5. Understand and Adapt to Extreme Environments 6. Develop Robotics and Autonomous System Capabilities 7. Modernize National Security Engineering and Emergency Response 8. Unify Sensing, Intelligence, Geospatial Engineering, Mission Planning, and Contingency Operation Functions 9. Advance Materiel and Engineered Systems 10. Ensure Resilient and Sustainable Ecosystems	**Research & Development Areas** • Military Engineering • Civil Works • Geospatial Research & Engineering • Installations & Operational Environment • Engineered Resilient Systems **Core Competencies** • Blast & Weapons Effects on Structures and Geo-Materials • Civil & Military Engineering • Battlespace Terrain Mapping & Characterization • Cold Regions Science & Engineering • Military Installations & Infrastructure • Computational Prototyping of Military Platforms • Coastal, River & Environmental Engineering	• People • Portfolio • Premier Research Facilities • Products and Partners • Promote Understanding

FIGURE 7: THE ENDS, WAYS AND MEANS OF THE ERDC 2020-2030 STRATEGY

ENDS: WHERE ARE WE GOING AND WHY?

This may be both the easiest and hardest question to answer. The easy answer is the "why" and is found in our vision statement. We strive to make the world safer and better every day. This is our major motivation and why we come to work every day. As public servants and good stewards of taxpayer dollars, there is no nobler goal in life or work.

We also strive to be a "world-class R&D organization." Merriam Webster defines "world-class" as "being of the highest caliber in the world." We achieve that status because we solve some of the world's toughest challenges – world-class problems – as we have done countless times throughout our history. We make our share of mistakes – all world-class organizations do – but we learn from them and become even better in the process.

To realize our vision and maintain our world-class status, we always seek to be the 'go-to' organization for our Warfighter and our nation to solve big, complex problems in our mission space, to help put solutions into practice, and to ensure our results, outcomes and products become the world standard.

The harder question to answer is – where are we going? What big challenges will we be solving over the next 10 years? That question is much harder to answer because the future is always uncertain, and conditions and challenges we believe will be true even one year from now can change overnight. The following are insights that can help us as we contemplate that future.

THE UNDERSTAND-PREDICT-SHAPE PARADIGM

One paradigm that is useful for understanding current ERDC research programs, and will be useful in helping contemplate, develop and define future research programs, is the Understand-Predict-Shape (UPS) Paradigm: Understand the Present, Predict the Future and Shape the Outcome of the Operational Environment (Figure 8). This simple three-element paradigm can be used to explain what we do in every research program ERDC executes today and can help shape all major ERDC programs of tomorrow. Future research programs may contain one or more of the elements of this paradigm.

Understand the Present involves gaining a complete understanding of the operational environment around us, whether it is a battlefield, a watershed, a material or an endangered species, from its current condition or state of being to everything we know, or can find out, about its history. It involves measurement, collection, storage, dissemination, analysis, visualization and presentation of data in ways that are optimized to create near-perfect situational awareness and enhanced understanding of the operational environment and everything of interest and importance within it.

This element is analogous to a battlefield commander's "persistent surveillance" capability, understanding completely the surroundings and the position and state of the enemy, combined with whatever existing knowledge is available, to help make faster, more efficient and effective decisions in planning and executing the mission. Translate this battlefield commander's capability to a military installation, a civil works project, a region, a watershed, or even a nation, and the

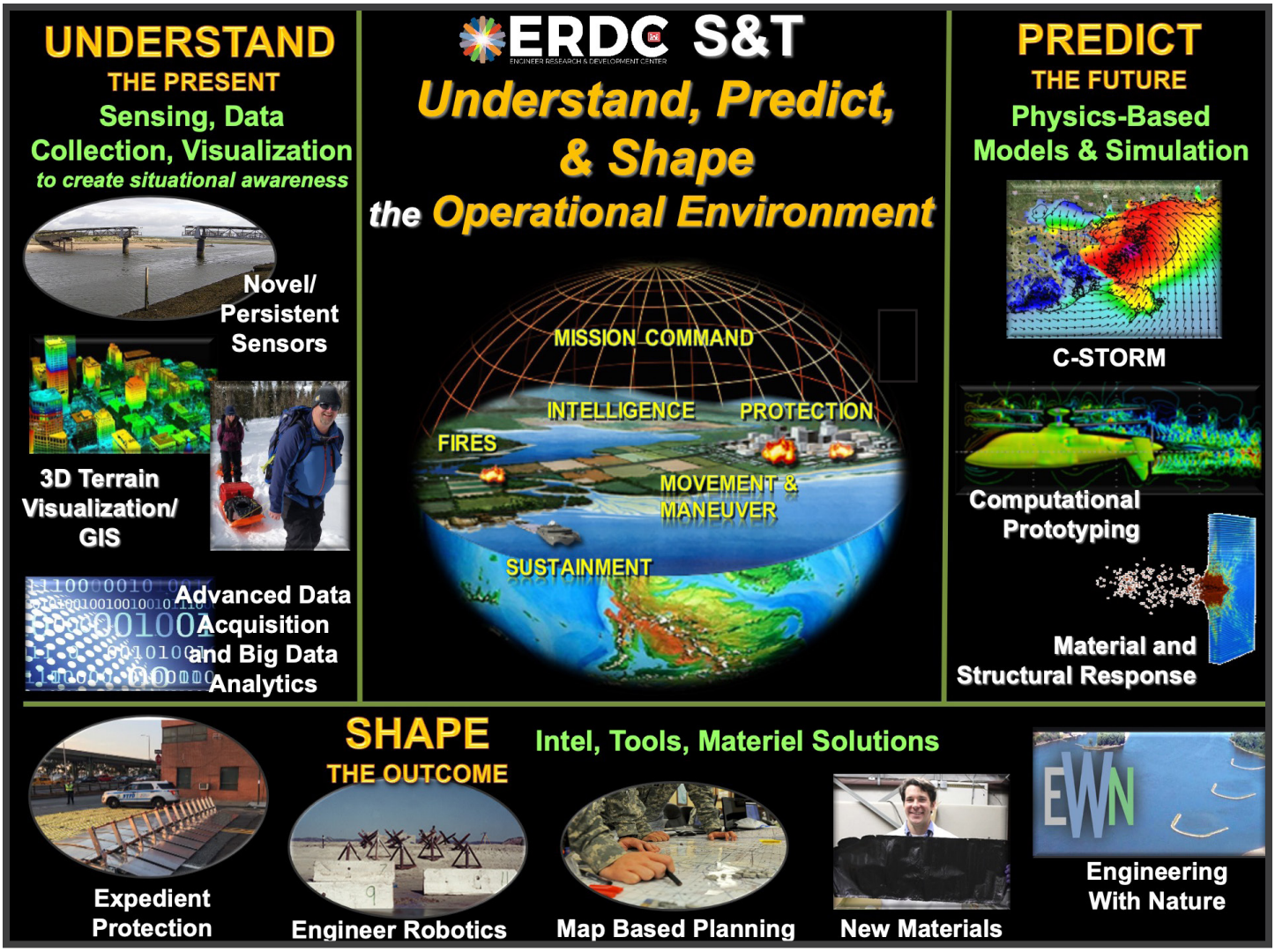

FIGURE 8: THE UNDERSTAND-PREDICT-SHAPE PARADIGM FOR DEVELOPING NEW R&D PROGRAMS

vision for "understand the present" becomes apparent. It addresses all aspects of gaining perfect situational awareness of the current state of the environment around us, including things we can see visually (e.g. water inundation levels in Addicks Reservoir immediately following Hurricane Harvey) and things we cannot see (e.g., seepage rates under the London Avenue Canal before Hurricane Katrina).

Gaining this capability will involve development of many different types of technologies. For instance, novel and persistent sensors, such as those used in drones, could be used to detect anything of interest, above or below the ground, in a body of water, or in the air. 3D terrain visualization and geospatial information services could be developed to help provide a common operating picture (COP) of a battlespace, watershed or installation. "Digital twins" or virtual representations of a weapons platform, or a dam or building or an entire installation could help decision makers understand how systems work and how they perform over time. Advanced data acquisition technologies and "big data" analytics could be used to acquire, process and manage the enormous quantities of data derived from past and present measurements, studies and investigations.

Data will include that needed to provide a complete characterization of the physical state of the environment, including physical infrastructure, terrain, bodies of water, plant and animal species, or whatever might impact, or be impacted by, the expected outcome of the research.
This includes data from measurements of any temporal or transient loading conditions, like hydraulic loads impacting a levee wall or blast loads on a structure; or environmental conditions like temperature and precipitation; or other elements that may depend upon or be impacted by the performance of a system, like barge traffic on a river or population densities of threatened species on an installation or an ecosystem response to a proposed water resources project.

The operational environment would include the built infrastructure (dams, locks, ports, levees, etc.) and the natural infrastructure (beaches, estuaries, wetlands, etc.) – any physical thing that impacts, or is impacted by, the performance of the system. Loads on the infrastructure could be natural loads, from water (hydrologic and hydraulic loads), sediment loads, river stages, storm surges, or reservoir depths; thermal loads (heat, freezing, thawing); impact loads (barges, etc.); earthquakes; chemically induced deterioration (corrosion, etc.); and static loads (weight of gates on hinges).
The loads could be manmade, such as those produced by a terrorist attack or a cyber-attack, or a combination of natural and manmade loads.

Measurements will involve both traditional and advanced sensor technologies, like those currently being deployed in Structural Health Monitoring of lock gates, to measure how a system is performing at any given time. Future measuring systems will take advantage of autonomous surveys and inspections using robots and drones (ground, air and underwater), and other advanced sensing technologies, both remote and persistent. They will employ advanced communication techniques for moving massive amounts of data securely from its point of origin to where it is needed and advanced data collection, management, analysis and display capabilities.

A major area of study in this element will be to establish an interactive COP, a map-based system augmented with the physical reality of the operational environment, including infrastructure, representing that which is normally seen and viewable and much that is not, such as underground foundation layers and geology or the inside workings of a lock or dam.

Embedded in the COP could be a “Digital Twin” of critical features, such as water resources infrastructure or buildings, and their surroundings. Digital Twins are representations of the real infrastructure and environment that update themselves using real-time data feeds such as those being provided through embedded sensors, and other valid information being pulled from the internet of things. This Digital Twin concept is already being used in manufacturing, buildings and major military acquisition programs.

A version of the Digital Twin capability is currently being developed by ERDC, called Engineered Resilient Systems (ERS), to support various DOD acquisition programs such as airframes, ground vehicles and Navy vessels. The intent is to transform the acquisition process by making solutions much faster, better and cheaper than existing acquisition methods and procedures can produce. The next logical step would be the application of a Digital Twin concept towards larger systems, like water resources infrastructure in a watershed, or an entire battlespace. The United Kingdom is currently considering a similar concept for all of its infrastructure. Clearly this is the way of the future for infrastructure and installation management.

The COP could be populated with interactive and "smart" versions of traditional displays of information, like charts, graphs and tables. It could also employ advanced visualization capabilities, like 3D augmented reality, that enables not only enhanced situational awareness but also results in key insights and sharper understanding beyond what we have ever experienced before.

Time scales will range from "right now" to historical data, as far back as we have data, but the primary focus is having perfect situational awareness of the current condition. The physical scale will range from a component level view (a quoin block on a lock gate), to a project level view, to a system-wide view (Mississippi River Basin), to a national view (the United States, or a continental scale) including our entire water resources infrastructure portfolio, supporting asset management, operations and maintenance, and emergency response missions.

Breakthroughs in machine learning, artificial intelligence and data science will be employed to ensure the massive quantities of data are translated to knowledge and understanding of the current state of the infrastructure and its surroundings, in near real time, wherever it is needed, from the tactical edge to a division or theater headquarters.

Predict the Future takes the data and information that is generated from the technologies described in the Understand element and includes data from other sources, combined with a state-of-the-art physics-based modeling and simulation capability and scaled physical models to "predict the future." That is, models will be developed that generate possible outcomes of the condition and performance of the system, or whatever the model represents, under various loading and environmental conditions and various operational scenarios. It will also allow exploration of various future options, those that exist and those that are being contemplated, to inform various "what-if" scenarios, with associated risks and probabilities of success.

This advanced modeling and simulation capability will involve development of many different types of technologies. For instance, advanced high-performance computing models and simulations such as C-STORM could predict the probability, extent and impacts of floods, hurricanes and storms on a continental scale more quickly and precisely than ever before. Advanced computational prototyping tools can be used to develop new parts for future weapons platforms, new chemicals or materials, or entirely new weapons platforms. New material and structural response models can be used to predict the behavior of new materials or structures under various loading conditions, such as blast loads or penetrating weapons.

The modeling results of various future scenarios could be analyzed and displayed in a forward-looking Digital Twin of the project or system, called a "Digital Thread." The Digital Thread would provide a formal framework for taking the Digital Twin beyond the current state and provide the ability to access, integrate, transform and analyze data from disparate systems throughout the project lifecycle to result in actionable information for users and decision makers.

These advanced models and simulations will require a computing capability that is second to none, from high-performance computing required to predict the behavior and performance of massive amounts of infrastructure over large scales in near real time (think of the ability to predict what happened in New Orleans during and after Hurricane Katrina, days, weeks, months, or even years before it happened); to advanced computing capability that employs machine learning and artificial intelligence technologies that replicate a super-computing performance prediction capability within a laptop or smartphone platform.

Loads will include natural or manmade loads (physical, chemical, thermal, energetic). Time scales could be fractions of a second (blast loads), minutes (levee breaches), hours (seepage under levees), days (loading of water behind Addicks Dam during Hurricane Harvey), weeks (impoundment of water behind Addicks Dam), years (performance of a miter gate on a lock), decades (performance of a dam over its life cycle and beyond, or fate and effects of toxic chemicals in groundwater systems) or longer. These longer time scales may be required to estimate the long-term effects of climate change, changing storm characteristics, precipitation patterns or rising sea levels on the operational environment. Physical scales will range from the component (quoin block) or subcomponent, projecting to system and ultimately to enterprise scales.

Model predictions will need to take into account uncertainty in the quality and quantity of the data and the inherent uncertainty in the models, to give a risk-informed prediction of performance with a quantified uncertainty. A data analytics, machine learning, and artificial intelligence capability could be employed when predictions must be made quickly using massive quantities of data. A trade-space analytics capability could allow the consideration of many possible "what-if" scenarios, or solutions, taking into account the risks and benefits of each, at a pace and scale not previously considered or imagined for civil, military, environmental and geospatial engineering projects.

The purpose of these predictions will be to inform decisions at tactical, operational and strategic scales and to shape the outcome of possible events for beneficial effect whenever possible.

Shape the Outcome is the final element of the UPS paradigm – once the situation is "perfectly" understood to the best of our ability; and the "future" of all possible outcomes is predicted to the best of our ability. This final class of potential solutions addresses our ability to "shape" the outcome – to mitigate against adverse effects, to achieve more beneficial effects, or both.

Shape the Outcome involves development of many types of technologies common to ERDC products, including tools, methods, materials, analytical techniques, or a combination. They might involve developing tactics, techniques and procedures for emergency response to catastrophic events (e.g., Hurricane Irma response); methods, materials, guidelines and procedures for design, construction, evaluation, assessment and/or operation and maintenance of our navigation infrastructure; evaluation of acquisition strategies for weapons systems; development of decision support tools; environmental testing techniques, risk characterization methods and remediation technologies; and short- and long-term risk mitigation strategies and decision aids.

New materials, exploiting advancements in high-performance concretes, nanomaterials, graphene, metals, alloys, ceramics, composites, advanced wood products, plastics, polymers, synthetic biology and other technologies could be explored for applications in maintenance, repair, rehabilitation, or new construction of our infrastructure and installations for warfighting applications, contingency operations support and other applications as appropriate. Smart materials and sensors could be developed and employed to help monitor infrastructure performance and optimize maintenance and repair operations.

New construction, operation, maintenance and repair techniques that take advantage of technologies such as 3D printing, autonomous and robotic construction, laser surveying, unmanned aerial vehicles (drones) and other techniques not traditionally used in infrastructure applications fall

within this element. New quality assurance and inspection tools, techniques and procedures will be developed and employed that give much higher confidence in the measurement and collection of quality assurance data, while ensuring that the right data is collected in the right way for the right reasons. As better performance prediction tools are developed (in the Predict element), quality assurance testing capabilities and techniques will need to be transformed so they provide much better indicators of future performance than current capabilities allow.

Augmented reality techniques will be developed and employed more frequently in the future to help construction representatives and quality control and assurance inspectors "see" key aspects of the project on the jobsite that are not normally seen, to put everyone on "the same sheet of music" and create a mutual understanding of "what is" and "what should be." Quality assurance data would not only be used to accept the final product but would also be used to feed the Digital Twin and Digital Thread of the structure discussed previously in the Understand and Predict elements of UPS.

Time scales will range from the immediate (emergency response, operational aids, etc.) to construction periods (weeks to months to years) to Operation & Maintenance (O&M) scales (years to decades) to long-range strategic scales (response to effects of shifting populations and usage). Response scales will range from component level (e.g., pintal socket or gate), project level, watershed level, regional level, national level, global level. Infrastructure performance and response and associated risks and uncertainties will be estimated from the Predict element to help shape mitigation alternatives by developing robust risk mitigation, risk management and risk-informed decision making capabilities.

Synergy within the UPS Paradigm. The true power of the UPS paradigm will be realized when the elements of Understand, Predict and Shape are fully integrated, with each element supporting the other and making the total capability more powerful as a result. The linear flow of Understanding the Present, followed by Predicting the Future, and then Shaping the Outcome is logical, but each element of the paradigm must support any other element or combination. For instance, the Shape element might result in a mitigation solution (a new maintenance technique for a lock, for example) that will result in an improved performance of the lock at a reduced overall cost, but the new repairs could also incorporate smart sensors that provide greater Understanding of the current performance of the infrastructure and new algorithms that Predict the performance of the system automatically with new data feeds. This is precisely how the Structural Health Monitoring Program works and is a good example of a comprehensive approach to developing a research program, employing all elements of the UPS paradigm.

The key question to ask when developing a capability in the Understand element is "how will the data gathered under the Understand element also benefit the Predict and Shape elements?" How will the models and analysis capability developed in the Predict element also benefit the Understand and Shape elements? How will the solutions developed for the Shape element benefit the Understand and Predict elements? When all elements are working together in synchronization, optimized for full effect, the greatest benefits of considering the UPS paradigm in developing a future research program will be realized.

THE TOP TEN ERDC STRATEGIC S&T CAMPAIGNS FOR 2020-2030

The ERDC leadership team has looked into the future and described a few major ERDC strategic S&T research areas, or campaigns, that offer challenges that ERDC can, and should, effectively address (Figure 9). Any one of these 10 challenges offer truly world-class problem sets worthy of our best efforts.

This list will invariably change with time as new challenges arise, or our ability to address them adapts and opens new doors to address challenges that had not previously been contemplated. This list is not intended to be exclusive, exhaustive or descriptive of all the superb research ERDC will execute over the next 10 years. Instead, each entry on the list describes a major research area that represents a continuation of a major research focus area for our partners, or those that are on the horizon, or a major national challenge that intersects well with our mission space and complements our current and future research capabilities. If we solve them – when we solve them or effectively address them – we will certainly achieve and maintain our vision. How we do this, and by what means, is the subject of the next two chapters of the ERDC 2020-2030 Strategy.

TOP TEN ERDC STRATEGIC S&T FOCUS AREAS: 2020-2030

The ERDC will Understand, Predict and Shape the Operational Environment by Discovering, Developing and Delivering World-Class Capabilities for the following Strategic S&T Focus Areas in 2020 – 2030:

1. **Enable Multi-Domain Operations**. ERDC will enable the Warfighter's ability to successfully compete, transition to conflict, and when necessary, fight and win under all conditions and in all domains by discovering, developing and delivering innovative technologies to support all Army Modernization Priorities while enhancing future Warfighter mission command and readiness, logistics, force projection and maneuver support, intelligence, sustainment and force protection.

2. **Revolutionize Civil Works**. ERDC will enable the Corps of Engineers to revolutionize the delivery of the USACE Civil Works program by creating and delivering innovative ways to Accelerate Project Delivery, Transform Project Financing and Reform, and Improve Permitting and Regulation Reform. ERDC will accomplish this within six strategic Civil Works R&D Focus Areas: 1. Comprehensive Hydro-Terrestrial Risk Management; 2. NextGen Water Resources Infrastructure; 3. Innovation in Sediment Management; 4. Sustainable Species Management; 5. Crisis Mitigation and Response; and 6. Data Science and Artificial Intelligence.

3. **Enable Smart and Resilient Installations**. ERDC will discover, develop and deliver innovative technologies to enable Smart and Resilient military installations and Installations of the Future concepts to enable installations as resilient power projection nodes, environmental sustainability for military ranges and lands, energy and cyber security, and modernization of aging facilities. ERDC will develop and implement innovative solutions and services to plan, design, construct, operate and maintain critical facilities worldwide.

4. **Accelerate Digital Engineering**. ERDC will leverage data science, artificial intelligence, machine learning, tradespace analytics, physics-based models and simulations, and high-performance computing to accelerate digital engineering in understanding the operational environment, predicting likely outcomes in advanced models and simulations with associated uncertainties, and shaping faster, better and cheaper solutions for our military, civil works and disaster response missions.

5. **Understand and Adapt to Extreme Environments**. ERDC will develop innovative technologies that enable the ability to understand extreme environments and environmental processes, from arctic to tropical conditions world-wide; to predict both the near-term and long-term climate and societal impacts on these environments; and shape innovative adaptive strategies and solutions that mitigate the harmful impacts of those changes across all missions – military, civil works and disaster response.

6. **Develop Robotics and Autonomous System Capabilities**. ERDC will enhance emerging autonomous vehicles' perception of, interaction with, and geolocation within the operational environment through accurate digital and physical representations of the geoenvironment to ensure that deployed ground, subterranean, airborne and maritime sensor platforms properly understand the complex world with predictable system behavior. Sensors and systems for the engineer mission will rapidly assess and repair critical infrastructure; gather and inform intelligence and surveillance; and shape decisions and operations at the tactical edge for the military, civil works and disaster response missions.

7. **Modernize National Security Engineering and Emergency Response**. ERDC will discover, develop and deliver innovative solutions to support National Security and Emergency Response for all echelons of government against natural and manmade threats.

8. **Unify Sensing, Intelligence, Geospatial Engineering, Mission Planning, and Contingency Operation Functions**. ERDC will provide seamless 3D geospatial information for map-based planning with continuous reanalysis and updates at brigade and below, enabling decision makers to optimize/accelerate Observe, Orient, Decide, Act loops. The development of the novel uses of sensors and environmental modeling will enable improved understanding of the operational environment and the design of sensors and platforms to support intelligence and operational requirements.

9. **Advance Materiel and Engineered Systems**. ERDC will understand and develop novel materiel solutions including advanced materials and engineered systems that enable the rapid deployment of expeditionary structures for force projection (airfields, ports, bridging, lines of communication), protective shelter/infrastructure materials, hardened structures and resilient infrastructure systems.

10. **Ensure Resilient and Sustainable Ecosystems**. ERDC will develop and deliver innovative technologies that improve the resilience, health and sustainability of ecosystems through innovative detection, modeling and simulation, testing, risk mitigation, cleanup, restoration and environmental remediation techniques.

FIGURE 9: TOP TEN ERDC STRATEGIC S&T CAMPAIGNS FOR 2020-2030

WAYS: HOW WILL WE GET THERE?

Since its inception, ERDC has operated as a matrix organization, executing research programs by leveraging competencies across the organization's seven laboratories to ensure the best possible solutions are discovered, developed and delivered to make the world safer and better. Many of the most complex challenges we face require multidisciplinary approaches and solutions, requiring expertise in several ERDC laboratories to address them. Therefore, enterprise approaches for how we develop, manage and execute programs and how we support the larger USACE enterprise are crucial to the successful accomplishment of our mission and are key enablers for our future success.

ERDC has developed two enterprise approaches for managing and executing major R&D programs within ERDC: the ERDC Research and Development Areas (RDAs) and the ERDC Core Competencies. The ERDC RDAs are used for enterprise program development and management, particularly the "direct" programs, although all reimbursable programs can be connected to, and many derived from, RDA direct research programs as well.

The ERDC Core Competencies are those key technical competencies that the Army and DOD recognize as ERDC leadership roles for the department. ERDC Core Competencies are critical technology enablers not commonly found in the private sector or academia that represent a critical and unique need for the Army and DOD, and should be maintained as critical enablers for the Army and DOD.

Finally, the ERDC plays a major role in the USACE Technology Innovation Strategy (TIS). The USACE TIS has five major tenets: Discover, Develop, Deliver, Sustain and Connect. ERDC plays a key role in the first three tenets and a supporting role in the remaining two.

These enterprise approaches, and the connection of ERDC to the USACE TIS, will be covered in this section of the ERDC 2020-2030 Strategy.

ERDC RESEARCH AND DEVELOPMENT AREAS

ERDC plans, develops and manages cross-laboratory research under five RDAs: Military Engineering (ME), Civil Works (CW), Installations and Operational Environments (IOE), Geospatial Research and Engineering (GRE), and Engineered Resilient Systems (ERS) (Figure 10). An ERDC Laboratory Director leads each RDA on behalf of the ERDC, and is supported by a Lead Technical Director and an associated Office of Technical Directors. Each RDA is described in more detail below.

Military Engineering. This RDA provides innovative technologies and capabilities to the Warfighter in order to enable force protection, force projection, maneuver, and maneuver support to enable Multi-Domain Operations (MDO). ME serves as the leader in developing novel, lightweight, rapidly constructed force protection and force projection systems that can be expediently deployed in remote locations. Research in this field leverages expertise in blast and weapons effects to help develop more powerful weapons for our Warfighter and to protect our structures and fixed facilities from a range of manmade threats.

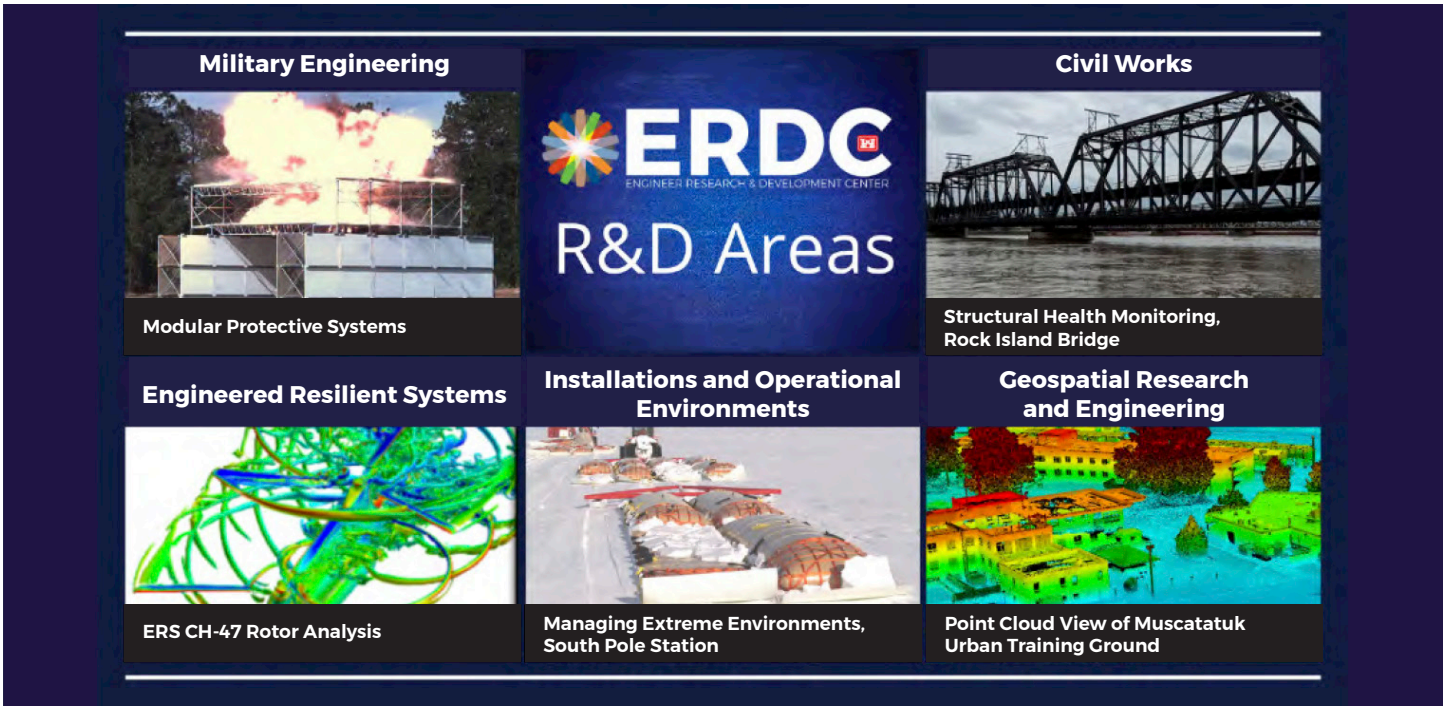

FIGURE 10: ERDC'S FIVE RESEARCH AND DEVELOPMENT AREAS

From the research and development of innovative protection systems, survivability decision aids have been developed to not only allow rapid assessment of current protection postures but also to provide enhanced designs to increase defense against attacks.

Civil Works. ERDC's Civil Works RDA contributes to the strength of the nation by providing innovative and environmentally sustainable solutions to the nation's water resources challenges, primarily in the navigation, flood and coastal risk reduction, and environmental Civil Works Business Lines of USACE, and also providing technologies to advance USACE hydropower and water supply missions. Our nation's water resources are under increasing pressure from competing uses. Our state-of-the-art technologies help improve the safety and resiliency of communities and infrastructure and help American goods compete in the global marketplace. ERDC R&D helps the Corps manage existing water resources infrastructure sustainably – in the face of expected climate change, land use change, invasive and nuisance species, demographic shifts, and aging infrastructure – to meet the needs of future generations.

Installations and Operational Environments. Military installations serve as our primary training and force projection platforms, connecting military bases to battlefields around the world. ERDC's research in the Installations and Operational Environments (IOE) RDA provides cutting-edge solutions for Army installations, training ranges and contingency basing, particularly in the areas of environmental sustainability and energy security. This includes innovative mitigation detection and mitigation techniques for toxins and environmentally hazardous materials like Per- and poly-fluoroalkyl substances (PFAS). "Operational Environments" includes the dynamics and extremes of environments – from the Arctic to the tropics, from wet to dry, and everything in between. It also includes understanding the environment, detecting hazards before they can harm our soldiers, and mitigating negative impacts on soldiers and operations in urban landscapes, industrial complexes and subterranean spaces. The capabilities and technologies developed for operational environments include, among others, sensing of non-weaponized biological or

chemical compounds, grey- or black-water reuse, forward/contingency operating base sheltering technologies, operational energy technologies, waste handling, water purification, and technologies to understand indigenous social and societal behaviors and interactions during operations.

Geospatial Research and Engineering. ERDC's Geospatial Research and Engineering (GRE) RDA develops and demonstrates mapping, geospatial analysis and mission planning technologies to ensure superior situational awareness of the operational environment for the Warfighter and to enable Mission Command. ERDC provides Warfighters with information superiority so they can accurately and quickly gauge operational environment effects on personnel, platforms, sensors and systems. GRE research enhances unit and individual Soldier performance with greater situational awareness, mission planning courses of actions, options for movement and maneuver, and protection. To support MDO, GRE plans research efforts that will merge intelligence preparation of the operation environment with geospatial mapping and analysis and map-based mission planning, all paced with the convergence and transformation of the Army's Mission Command systems.

Engineered Resilient Systems. ERDC's Engineered Resilient Systems (ERS) RDA combines advanced engineering techniques with high-performance computing to develop concepts and tools that significantly amplify design options examined during early stages of the DOD weapons system acquisition process. Advanced tradespace analytics tools can compare hundreds of potential design options and associated performance characteristics in hours rather than months, enabling much more robust designs to be considered in the engineering phase than traditional methods have allowed. Such designs are much more resilient – systems are dependable, easily modified to meet future mission goals, and possess a predictable lifecycle. The ERS efforts span all four DOD services, and methods have been effectively applied to analyses of fixed-wing planes, rotorcraft, ground vehicles and ships. The potential for adding tremendous value in many more applications, in military engineering, civil works, geospatial engineering, and installations and operational environments, is vast. By enabling more informed physics-based assessments much more rapidly than ever before possible, the ERS program is striving to ensure DOD acquisition time and money is well spent.

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ERDC CORE COMPETENCIES

ERDC's Core Competencies highlight the critical Army and DOD areas of expertise where we define standards and lead the R&D community. ERDC employs seven Core Competencies to discover, develop and deliver products across our research portfolio (Figure 11): Blast and Weapons Effects on Structures and Geo-Materials; Battlespace Terrain Mapping & Characterization; Cold Regions Science and Engineering; Civil and Military Engineering; Computational Prototyping for Military Platforms; Coastal, River and Environmental Engineering; and Military Installations and Infrastructure. A brief description of each ERDC Core Competency follows.

FIGURE 11: ERDC SEVEN CORE COMPETENCIES

Blast and Weapons Effects on Structures and Geo-Materials: This ERDC core competency is key to achieving the Army operational capability of survivability by enabling the Warfighter to understand and predict weapons effects on surface and underground structures and to shape offensive and defensive solutions that counter and neutralize our adversary's energetic weapons. ERDC's expertise includes testing and analytic/modeling and simulation capabilities in the areas of nuclear and conventional weapons and IEDs – knowledge critical in developing buildings, bridges, protective structures and bunkers that can withstand required blast loads or defeat certain weapons, and defining the protection level of existing structures. These capabilities also help weapons developers predict weapons' effects for design purposes and aid mission planners in pre-attack prediction and post-attack lethality assessments.

ERDC's expertise has been used to address hardened structure designs such as protective structures and nuclear weapon silos; the design, development and fielding of overhead cover systems and modular protective systems for rapid protection of critical assets in theater and from terrorist threats to critical infrastructure; and the design of test standards and the estimation of the underbelly blast loads resulting from IED detonation under vehicles for protective design and acquisition testing and evaluation. ERDC's objective for this core competency will be to predict weapons' effects against specific targets and to help design weapons to defeat any structural target above or below the ground and to help design structures to defeat any weapon.

Battlespace Terrain Mapping & Characterization: As the U.S Army's lead in geospatial engineering science and technology, ERDC supports Army Warfighters, U.S Marines, USACE Divisions and Districts, the National Geospatial Intelligence Agency, and the DOD Intelligence Community. This core competency focuses on geospatial understanding of the operational environment, ranging from development of innovative mapping technologies, data management and analytics, and spatial and temporal applications enabling mission command. Understanding the operational environment is a foundational element of mission planning and informs all warfighting functions. Geospatial Research and Engineering addresses capacities identified in Multi-Domain Operations

addressing the complexities of armed conflict in megacities, particularly the problematic issues of dense urban areas involving diverse, interconnected human and physical networks, 3D engagement areas, and terrain and infrastructure that provide varying levels of ready-made cover and concealment. The physical characteristics constrain maneuver, limit situational understanding and create unique problems for targeting and delivering effects against enemy positions. This core competency involves understanding and mapping the urban environment – including infrastructure interiors, subterranean spaces, overhangs and underpasses – in a 3D framework that allows for true 3D analytics for understanding and planning movement and maneuver, fires, protection and immediate situational awareness.

ERDC leverages this competency to develop a geospatially enabled, integrated and automated map-based mission planning and intelligence analysis capability that will create a collaborative environment for planning and operational support across echelons and the Joint Services. ERDC's objective for this core competency will be to understand the operational environment at the point of need to enable mission planning and mission command.

Cold Regions Science and Engineering: ERDC has led the Army's mission in understanding cold regions and their impact on military and civil works missions as the national resource for cold regions science and engineering. Successful and superior operations will demand a fundamental understanding of cold regions processes such as those governing snow, ice, ice flow/jams and ground conditions. This core competency focuses on understanding and managing the challenges of operations in cold regions and is key to achieving Army and Civil Works operational capabilities of enhanced mission command, particularly situational awareness, mobility and maneuver, navigation, environmental sustainment and flood risk management in Arctic regions and mid- to high-latitudes and high elevations.

Cold, ice and snow can have adverse effects on Army and Civil Works systems and components performance. Accordingly, this competency supports a variety of product lines and technologies, from improving situational awareness to informing materiel designs to engineering operations, all to enhance the enduring ability of U.S. forces to plan and operate effectively in extreme environments. It also supports, planning, engineering, design, construction, operations, and maintenance missions in the Artic and very cold regions, taking into account the unique challenges presented by these conditions.

Civil and Military Engineering: ERDC maintains civil and military engineering technology leadership necessary for force protection, force projection and sustainment, and civil works missions, including navigation, flood and coastal risk management, environmental sustainability, and hydropower and water supply. Military engineering includes logistics planning, amphibious assault and rapid port enhancement; base and in-theater planning and design, infrastructure optimization and management; and force protection on the battlefield and at installations and bases with an emphasis on expedient protection systems. ERDC's civil engineering competency includes specialties in structural, geotechnical, water resources, environmental quality, transportation and construction. This competency also includes significant capabilities in computational engineering, installation support and military engineering. Military engineering focuses on developing technologies to support combat engineering, including mobility, countermobility, survivability, route clearance, defense structures, explosive materials handling, and general engineering.
ERDC leverages capabilities in high-performance computing, geo-environmental physics modeling and simulation, Engineered Resilient Systems, and a complete range of testing capabilities in

this competency area. ERDC technologies enable rapid repair, upgrade and construction of transportation infrastructure to enable maneuver into and across the battlespace, and/or create obstacles to prevent such maneuver. Technologies for Civil Works applications provide engineering technologies for safe and effective navigation, flood and coastal risk management, environmental sustainability, and ecosystem restoration. ERDC maintains leadership in DOD and NATO in vehicle-terrain interaction research to generate cutting-edge ground vehicle mobility modeling and simulation tools.

As the Tri-Service lead for airfields and pavements R&D, ERDC supports the DOD doctrine of global force projection by developing models for improved predictions of airfield performance and deterioration, rapid airfield assessment and repair technologies. ERDC also leads the DOD in the design, construction, evaluation, maintenance and repair of permanent and expedient airfields and pavement. Using its expertise in geo-environmental effects on sensor performance and expedient structural design, ERDC develops innovative solutions that increase the survivability of critical national assets. ERDC's objective for this core competency will be to evaluate and assess the capacity of strategic transportation infrastructure to accommodate tactical and strategic maneuver and logistical throughput.

Computational Prototyping for Military Platforms: DOD success relies on the ability to develop and sustain combat systems that are effective in an ever-widening range of military operations. ERDC's Computational Prototyping for Military Platforms competency plays a major role in that mission by enabling high-quality and rigorous acquisition decisions. This core competency provides advanced engineering tools and techniques, combined with high-performance computing, to significantly amplify and accelerate design operations during early stages of the acquisition process. ERDC's competency enables rapid and robust modification of designs to meet mission needs and requirements at lower cost and higher fidelity than traditional methods. It includes virtual prototyping methods, tradespace analytics, and a computational proving ground to decrease time and cost for Army Acquisition. These methods have been effectively applied to analyses of platforms across all services, including fixed-wing aircraft, rotorcraft, ground vehicles and ships.

Additionally, ERDC manages the DOD's High Performance Computing Modernization Program (HPCMP), which provides infrastructure, software, networking and support for high performance computing (HPC). This includes computational modeling, data analytics, artificial intelligence, machine learning and decision support tools optimized for HPC. These tools provide high-fidelity, physics-based engineering analysis integrated into complex workflows to assess technology and system performance in operationally relevant environments. Civil Works R&D and reimbursable studies leverage the HPC, artificial intelligence and data analytics expertise to streamline decision support and rapidly converge on solutions.

Coastal, River and Environmental Engineering: ERDC's core competency in Coastal, River and Environmental Engineering forms the basis for its support to the USACE Civil Works water resources management mission area, including the navigation, flood and coastal risk reduction, and environmental business lines. ERDC has a long history of leading the engineering profession in coastal, river and environmental engineering and related sciences. From understanding the complex hydrodynamic interactions between flowing water and terrain features, to estimating storm surges in coastal areas and inland waterways, to developing new approaches to foster sustainable ecosystems, to understanding and managing sediments in our waterways, ports and coastal areas – much of what is known today was developed in ERDC's 91-year history. There is much

more to learn and understand, as the nation is challenged to find more sustainable and resilient means of reducing risk to life and property from storms and floods while enabling safe and reliable navigation on our waterways and supporting $5 trillion in economic activity in our ports alone.

This core competency has also enabled our military missions as well, particularly in maneuver support and mission command. ERDC's capability in military hydrology was born from our understanding of floods and impacts of breaching dams and levees, and has supported many military operational missions. Our coastal engineering capability supported the planning for the D-Day invasion at Normandy and today helps our military understand how to design and operate new watercraft for force projection applications. Our understanding of the environment supports mission command by enabling better situational awareness of the battlespace, such as route planning, improved landing site and base site selection, novel sensing modalities and capabilities, and prediction of potential impacts to Soldiers from natural or unintended exposure to environmental contaminants. Such knowledge can protect the health of our Warfighters and enable mission success.

Military Installations and Infrastructure: This ERDC core competency supports the USACE mission in military construction, installation support and support to Warfighter operations overseas and in the battlespace to ensure that facilities, infrastructure and installation services are resilient, ready and efficient. Our military installations serve as force projection platforms in support of MDO, as the primary training grounds for our Soldiers, as critical nodes in the network of military support operations, as home to many military families and supporting services, and as key members of communities around the nation and in many countries overseas. Most serve as mini-cities in and of themselves, with the critical infrastructure – roads, bridges, airfields, rail, buildings, housing, water, sewer, gas, electrical, networks, parks – that any large community might have, with the additional infrastructure required to support the military mission, like training ranges, secure communications, perimeter security, hangars, motor pools, military supply storage and logistics, to name a few. These enclaves are unique in that they are critical to national security and are where all military operations begin, but similar to any other community in the many services they must provide to their inhabitants.

This core competency supports cost-effective management of internal and external installation encroachment influences that threaten or constrain range and operating area activities. For example, the land on and around military installations is also a habitat for many species of plants and animals, some threatened and endangered, which can impede military training operations. The locations of communities nearby or adjacent to military installations can restrict military training exercises as well, particularly when the noise from exercises becomes disruptive. Installations overseas must also comply with local national standards and guidelines, which are often different from those in the United States. On the battlefield, small bases like contingency operations bases and forward operations bases have unique requirements as well and must minimize energy (operational energy), water and waste footprints while supporting operational missions in the battlespace.

The Army and Air Force leverage this core competency as they optimize their O&M activities to deliver optimal base performance under constrained budgetary conditions, while helping the Services justify larger O&M budgets to meet future performance demands. ERDC's Sustainment

Management System has been adopted across the DOD, and is used to manage infrastructure in other government agencies and across state and local governments as well.

This ERDC core competency not only develops new technologies and capabilities to support more efficient and effective current operations on our installations but also provides technologies needed to adapt installations and infrastructure to future requirements, like new weapons systems, units and doctrines developed by Army modernization, including materials, infrastructure management, operational and organizational optimization, sustainability, and resilience. This core competency is also being used to help shape future military installation concepts and designs, like the Army's Installations of the Future and the Air Force's Base of the Future concepts. These new approaches leverage concepts like Smart Cities and Smart Buildings and are driving change in how the military thinks about installations, how to make them more secure, sustainable and resilient, as well as more efficient and effective in delivering the critical capabilities they provide to the Warfighter.

Advanced Critical Infrastructure is also a strategic priority in Civil Works as the vast national portfolio of water resources infrastructure is aging and resources are insufficient to repair even the most vulnerable assets. ERDC's expertise for innovative materials, predictive modeling tools, and structural health monitoring technologies will optimize limited resources to deliver resilient, reliable and sustainable water resources infrastructure.

CONNECTING ERDC TO THE USACE TECHNOLOGY INNOVATION STRATEGY

As mentioned previously, another way to describe "how" we do what we do is found in the ERDC Vision: we Discover, Develop and Deliver new ways to make the world safer and better every day. These three words – Discover, Develop and Deliver – are also key tenets of the USACE Technology Innovation Strategy (TIS), along with Sustain and Connect (Figure 12). Since ERDC serves as the R&D laboratories for USACE, and our inherent role is to bring innovative ideas and solutions – the Power of ERDC – to support the USACE mission, it is important to understand ERDC's role in enabling the USACE TIS.

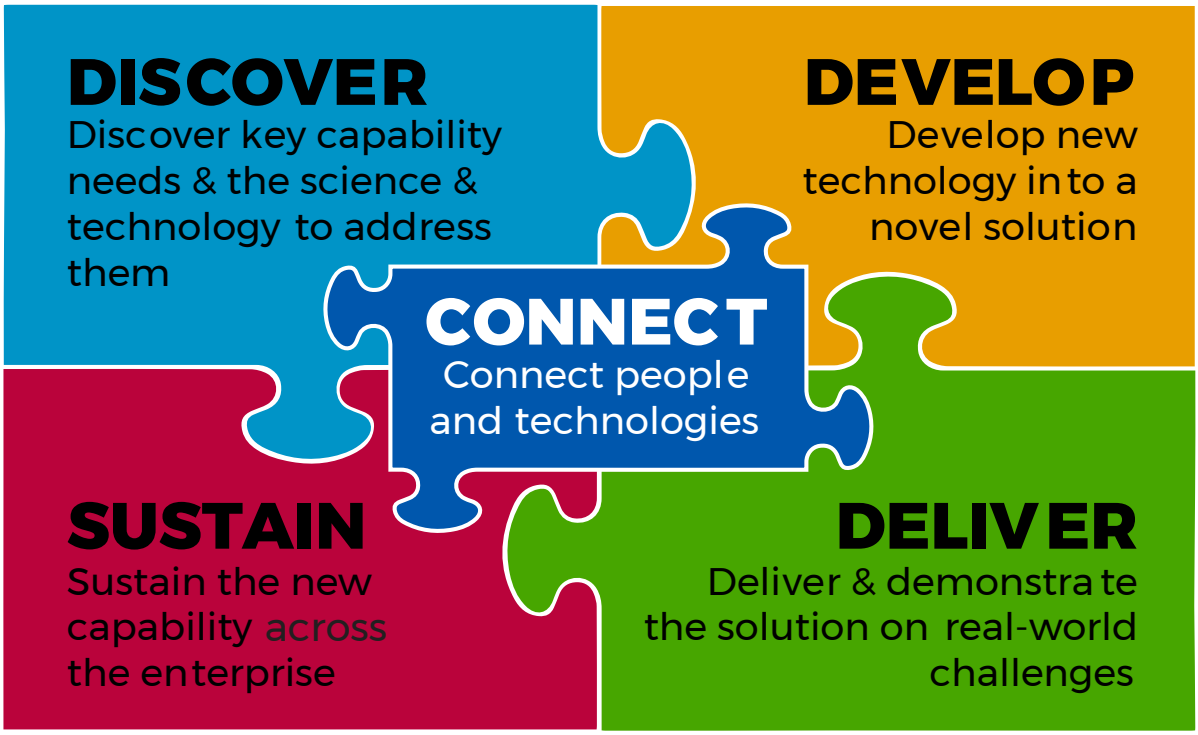

FIGURE 12: KEY TENETS OF THE USACE TECHNOLOGY INNOVATION STRATEGY

Discover: The Discover tenet involves finding and/or creating technologies that can help execute USACE and other stakeholder missions faster, better and cheaper than ever before. Discovery is a continuous process of identifying, with our partners, what is needed, what potential technologies or emerging science could address the need, and matching the requirements and potential solutions in a way that achieves high-impact (faster, better and/or cheaper) effects.

Some potential solutions arise before the problem is fully understood or identified. Disruptive technologies are often well ahead of their time, usually very risky at first, and it is sometimes difficult to realize their full potential when a partner is satisfied with the status quo. Smartphones were excellent examples of disruptive technologies when they were first introduced. They did not represent technology breakthroughs per se but rather combined several existing or newly developed technologies – tiny, fast processors, cameras, telephones, internet access, motion

sensors, artificial intelligence, biosensors, touchscreen surfaces, speakers – in a way that provided tremendous value to customers long before they knew they needed it.

The more complex challenges involve multidisciplinary approaches to achieve the most optimal solution. The Discovery phase is where new technology meets new challenges. Continuously scanning global science and technology horizons is essential to finding these opportunities and bringing the best and most promising back to ERDC to leverage for world-class solutions.

New technologies and capabilities may take many forms, by gaining enabling fundamental knowledge, by discovering an emerging research product that can be rapidly shaped into a prototype solution, or by creating a novel and innovative technical capability that can be immediately adapted to a critical need. A robust R&D program has multiple developmental time scales, from near-term to much farther reaching. Definitions and durations of these timescales vary among strategists. USACE has adopted the following definitions of near-, mid-, and far-term programs (Figure 13): near-term (1-2 years from full application), mid-term (2-5 years from full application), and far-term (> 5 years from full application). These definitions differ somewhat from other Army documents but represent timeframes used by USACE. The longer the timescale, the higher the potential payoff, impact on mission accomplishment, and return on investment (ROI) can be expected.

Stakeholders, Soldiers and experts inside and outside ERDC should be consulted in the Discovery phase, connecting research and technology experts directly to practitioners. Ideally, the "art of the possible" in science and technology will inform potential future practice and subsequent future requirements. New knowledge and solutions that have the potential for high payoff and value creation for the enterprise should be targeted. The approach should also leverage current mission and external research related to ERDC's five R&D areas, creating a reservoir of new ideas and capabilities to identify and exploit opportunities and resources to enable and accelerate future innovation. Interacting with the partner early and often in the Discover phase will help transition and adopt new technology into practice much faster and much more successfully than research that has not been coordinated with, or communicated to, potential end users.

NEAR-TERM R&D	MID-TERM R&D	FAR-TERM R&D
• **Target 1-2 years until delivery** • **Ideal for Industry partnership** • **Transition new technology with little/no additional development** • **Rapid Transition** • **ROI target: 5:1**	• **Target 2-5 years until delivery** • **Traditional applied R&D** • **Solves tough challenge, no existing solution** • **Partner with academia and industry** • **ROI target: 10:1**	• **Target 6-10 years until delivery** • **Big bet/moon shot** • **Most strategic R&D** • **Will transform Army/USACE** • **Riskiest, highest payoff** • **ROI target: 20:1**

FIGURE 13: CHARACTERISTICS OF NEAR, MID, AND FAR-TERM R&D PROGRAMS

Develop: The Develop tenet involves turning great ideas and technology, once discovered, into game-changing solutions. Along with the Discover phase, the Develop phase is where much of the R&D is conducted. ERDC – in concert with the broader community, including USACE, industry, academia, the user community and other key stakeholders – creates sustainable, adaptive and cost-effective solutions that address tactical, operational and strategic requirements. Early and continued interface with partners and users is essential to success, increasing opportunities for Soldier feedback, input into requirements, user interface discussions, and early product demonstrations. Development is the primary engine for exploring and customizing the opportunities identified during the Discover phase, relying on formal and informal partnerships and leveraged research whenever possible.

Deliver: The Deliver tenet focuses on taking capabilities and technologies that have been "Discovered" and "Developed" and providing those technologies or capabilities in a form (usually a prototype) that can be demonstrated and used by the customer. The Deliver stage involves translating R&D results into capabilities that add current and future value for practitioners. Decisions and activities of the Deliver phase are led by the user community with R&D support. Deliver is about moving from potential impact to actual impact in the field.

Transitioning demonstrated solutions to actual practice in the field – a key goal of the Deliver tenet – involves more than demonstrating new technologies. Successful delivery and transition of a new technology into practice will require careful and deliberate planning between developers and practitioners well in advance. This transition between capability development and implementation is often referred to as the "valley of death" in the DOD acquisition world because often technology that is developed is not ultimately implemented or put into practice by the user. Not every program works out as expected, but the lack of use and implementation of newly developed technology should never be the result of a dearth of proper planning, programming and testing by the researcher. Ideally, a potential user is identified at the project onset, in the Discover phase, and the broader community agrees that the new technology represents an advancement: improved performance or quality, reduced cost, or faster production than the current solution.

In USACE, the critical role of Centers of Expertise (CXs) and Communities of Practice (CoPs) in successful technology transition from the development phase to the implementation phase cannot be overstated. One major role of CXs and CoPs is to ensure that the latest planning, design, construction, operation and maintenance procedures, techniques, methods and technologies are used properly on projects worldwide. Another key role can be to assist in developing requirements and capabilities for near-, mid-, and far-term R&D and to assist in successfully implementing the new capability into practice. In other words, they can act as key integrators between technology development and practice.

USACE Districts play an essential role in implementing new technology and innovation in project delivery within USACE. Along with the R&D community, CXs and CoPs, Districts must be cognizant of new technologies being developed, plan for the integration of new technologies on projects, create a "technology pull," and be prepared for a "technology push" as standard practice, rather than the exception. A culture of innovation is essential, where prudent risk-taking in implementing new technology is both accepted and expected within the practicing community. ERDC can help drive innovation by creating a culture of innovation from the top down, acknowledging and accepting associated risks inherent in the developing and implementing new technology, and shaping and developing the necessary policy, direction and resources essential to success.

Sustain: The Sustain tenet involves inculcating the new capability into standard practice so innovative technologies and practices become widespread, (i.e. become the accepted new standard). This must be accomplished along multiple fronts: (a) incorporating new innovations and technologies into doctrine; (b) training the workforce and industry professionals on new standards, technologies and capabilities; (c) communicating new innovations frequently and deliberately, using various platforms, internally and externally to ERDC; and (d) establishing an innovation governance process that helps drive innovation throughout the enterprise.

Connect: The Connect tenet involves connecting people within USACE and beyond, who have ideas and knowledge to share, and ultimately connecting people to new or existing knowledge. This capability is a key function of Knowledge Management (KM). USACE is developing and distributing new KM tools to increase access to knowledge and information within USACE. These tools are available to ERDC researchers. The USACE Common Operating Picture and KM Portal are two examples of how USACE teams can access internal information to make better decisions faster. The USACE Reachback Operations Center provides another way for partners and stakeholders from inside and outside USACE to access information and seek solutions for challenging engineering problems, no matter where that solution exists. These KM tools and capabilities need to be expanded and strengthened, opening up to include proven technologies and practices globally, and providing access through mobile devices, for instance, so the true power of KM to reinforce and stoke innovation can be realized.

Another key aspect of the Connect tenet and KM is to provide an active Lessons Learned process and reservoir that is widely accessible, easy to use, and contains current and relevant information for potential users. In each step of the USACE TIS, from Discovery to Sustain, capturing and sharing lessons learned will be essential to enabling and fostering successful application and implementation of innovative tools, technologies and practices. Inherent to any process where new ideas and technologies are used and implemented daily and to an institution where high-risk, high-reward transformative projects are encouraged, ERDC will strive to create a culture where failing forward – turning setbacks into steps toward future success – has value and contributes to lessons learned and the overall knowledge base. Establishing an easy method for sharing, documenting, updating and accessing lessons learned will be critical to a successful KM program and to reducing risk associated with implementing new technologies going forward.

MEANS: WHAT RESOURCES WILL WE USE TO ACHIEVE OUR GOALS?

The third piece of the ERDC 2020-2030 strategy addresses **Means**, or the resources required to achieve our goals, now and into the future. These resources can be viewed in many ways. ERDC is using a framework called the "5 Ps" to describe the key resources we need to achieve our mission today and what we'll need to thrive in the future and achieve our vision: People, Portfolio, Premier Research Facilities, Products and Promote Understanding. These key resources create the foundation for ERDC's current and future success.

PEOPLE

A unique, dynamic, diverse and world-class workforce is ERDC's greatest strength. ERDC strives to have the Right people with the Right skills working on the nation's toughest challenges. ERDC's focus on **People** has three objectives: hire and retain the right people, develop and train our people, and cultivate an engaged workforce (Figure 14).

PEOPLE

"The right people with the right skills tackling the nation's toughest challenges."

Objectives

Hire and retain the right people.
Develop and train our people.
Cultivate an engaged workforce.

FIGURE 14: THE ERDC 2020-2030 STRATEGY - PEOPLE GOALS AND OBJECTIVES

Hiring and retaining the right people is aimed at increasing the depth of our talent pool with employees who have the right knowledge, skills and abilities to meet the challenges of today and tomorrow. Metrics for this first objective include seeking and hiring the best possible candidates to join our team, measuring net growth in the workforce, reducing loss rates for new and mid-careerists, measuring performance of new employees, and ensuring leadership positions are filled in a timely manner with high-quality and well-trained leaders.

The second objective focuses on sustaining a learning environment that helps employees build rewarding careers and fosters future leaders. Metrics for this objective will measure training opportunities and quality of leadership, including training and effectiveness.

The third objective seeks to improve employee engagement and increase retention and job satisfaction. Metrics for this objective will evaluate employee engagement and retention in a way that seeks to understand why employees may choose to leave ERDC early or work beyond retirement eligibility. The annual Federal Employee Viewpoint Survey's Employee Engagement Index is also a valuable assessment tool for this third objective.

PORTFOLIO

ERDC's **Portfolio** represents the actual research we do, who we do it for, and what resources (funding) we receive to support our mission. Portfolio is focused on "doing the right work to make the world safer and better" (Figure 15). Portfolio objectives include having the right business strategy, achieving the right portfolio balance, and cultivating the right stakeholder relationships.

PORTFOLIO

"Doing the right work to make the world safer and better."

Objectives

Have the right business strategy.
Achieve the right portfolio balance.
Cultivate the right stakeholder relationships.

FIGURE 15: THE ERDC 2020-2030 STRATEGY - PORTFOLIO GOALS AND OBJECTIVES

These three objectives are interrelated and mutually supporting. The right business strategy involves setting the course for the future state of the body of ERDC's R&D. It answers the question – how do we improve and increase our value to the nation, our stakeholders, and especially our customers?

Achieving the right portfolio balance involves assessing where we are in terms of the type of research we're doing (basic research versus applied research versus technical support, for instance); the relative size of efforts; how diverse our partnerships, stakeholders and customers are; and alignment of our research efforts to high-priority research areas within our mission space.

Relationships and interaction with strategic stakeholders are essential in understanding high-priority needs and shaping our future program, which feeds back into our business strategy. This will also drive the skill sets we need, partnering decisions, and facilities plans, in addition to informing our understanding of the future requirements, research and technology landscape.

PREMIER RESEARCH FACILITIES

Conducting world-class research requires world-class facilities and equipment. **Premier Research Facilities** and equipment are essential for conducting laboratory and field experiments, physical modeling, computational research, secure communications, research and collaboration, operations and maintenance, and business operations – all elements of a world-class R&D organization.

ERDC has over $1.4 billion in facilities across its four main campuses and field sites. While many of the facilities are state-of-the-art and world-class, many are in need of significant upgrades or replacement, and some new research capabilities will require totally new facilities and equipment to support them.

The first Premier Research Facilities objective is to be world-class today, to provide a safe work environment that supports current mission, people and infrastructure management practices at a superior level (Figure 16). Being world-class also requires efficient and effective use of assets, quality of life improvements, and direct lab support under a full spectrum of services. Finally, this objective requires compliance with DOD real-property tracking and facility life-cycle management.

PREMIER RESEARCH FACILITIES

"World-class facilities supporting world-class research."

Objectives

Be world-class today.
Achieve tomorrow's world-class.
Ensure resilience and security.

FIGURE 16: THE ERDC 2020-2030 STRATEGY – PREMIER RESEARCH FACILITIES GOALS AND OBJECTIVES

The second objective is to achieve tomorrow's world-class. This requires ERDC infrastructure and facilities to meet future R&D demands. This objective requires planning and programming of facility projects that expand upon and increase ERDC's research capacity and capability. Planning is critical in identifying, developing and positioning projects well in advance of the need. Programming is the approach to compete for limited resources and to prepare for alternative funding sources. This is accomplished by assembling plans and project documentation and compelling justifications for submission to Army Senior Leaders, Congress and other key decision makers.

The third objective is to ensure resiliency and security on our installations and facilities, particularly in terms of water, electricity, communication and networks. Ensuring resiliency and security is essential for providing a safe and uninterrupted work environment. ERDC employees and customers depend on R&D to be accomplished without disruption because of infrastructure shortfalls. This

objective requires identifying critical assets and providing secondary support or redundant back-up systems in case primary systems fail. It also provides the highest security and compliance with safety regulations, and addresses key employee concerns.

PRODUCTS

The strategic goal for **Products** is to deliver world-class products smarter, faster and better. There are four objectives identified to track this goal (Figure 17). Each objective has specific metrics with targets that will be tracked and reported periodically. The first objective is to increase product impact, which is defined as results-driven outcomes that establish ERDC as the standard or benchmark for others.

PRODUCTS

"Deliver world-class products smarter, faster and better."

Objectives

Increase product impact.
Improve efficiency and effectiveness of our business processes.
Increase and sustain Customer Satisfaction.
Enhance ERDC Technology Transfer.

FIGURE 17: THE ERDC 2020-2030 STRATEGY - PRODUCTS GOALS AND OBJECTIVES

The second objective is to improve efficiencies and effectiveness in our business processes. Being effective and wise stewards of taxpayer dollars and working in ways that are smarter and that increase productivity – saving time and money – are this objective's primary metrics.

The third objective specifies the importance of increasing and sustaining customer satisfaction using annual surveys and the Automated Customer Satisfaction Survey System for feedback and evaluations. The target is to maintain a minimum customer survey score of 4.2 on a 5-point scale on an annual basis.

The fourth objective is to enhance ERDC's Technology Transfer competency through improved and increased transition of products to end-users; increasing transfer through collaboration agreements and commercialization licenses; and increasing and improving knowledge and technology sharing, internally and externally.

ERDC is engaged with academia, industry, other research organizations and international communities at the forefront of science and technology development. These strategic partnerships allow ERDC to deliver innovation and game-changing solutions through its effective, scalable and sharable technology transfer model.

ERDC is a global leader across all R&D areas, leveraging relationships with global partners to influence the direction of science and engineering, advance American influence, and strengthen our partnerships and alliances in support of National Defense goals.

Another method for ERDC to facilitate joint R&D projects and accelerate technology transfer with industry, academia and even local governments is the use of Partnership Intermediary Agreements (PIAs). ERDC has established a new PIA, called ERDCWERX, to expand the opportunities offered by joint collaboration for new technology development and innovation. ERDC has also established a new acquisition tool, the Other Transaction Authority, which can accelerate development of prototypes with industry in ways not possible with traditional contracting methods. These and other partnering and acquisition tools should be explored as appropriate and leveraged to the maximum extent possible.

PROMOTE UNDERSTANDING

The goal of **Promote Understanding** is to communicate the right message at the right time to the right audience (Figure 18). Effective communication involves both speaking and listening with the intent to promote true understanding between two or more parties.

PROMOTE UNDERSTANDING

"Communicate the right message, at the right time, to the right audience."

Objectives

Increase consistent, timely and impactful **internal** communication across the enterprise.

Increase consistent, timely and impactful **external** communication beyond the enterprise.

FIGURE 18: THE ERDC 2020-2030 STRATEGY – PROMOTE UNDERSTANDING GOALS AND OBJECTIVES

ERDC communication strives for this level of effectiveness, and includes multiple purposes: 1) listen to our team members, stakeholders, partners and customers to seek understanding; 2) educate and inform the ERDC Team and our partners and stakeholders on the impact and value of what ERDC does to make the world safer and better every day; 3) provide clear, consistent one-voice messaging and strategic communication across the enterprise, at all levels; 4) facilitate and promote understanding of ERDC's vision, mission and brand; build a culture of trust; and demonstrate clear value with ERDC stakeholders and partners; and 5) provide targeted communication of ERDC expertise and capabilities to a wide range of customers, stakeholders and partners.

The two objectives for Promote Understanding are to increase consistent, timely and impactful **internal communication across the enterprise**, and **external communication beyond the enterprise**. Metrics will be gathered in multiple ways, including measurements obtained through Internal and External Communication Index Scores.

SUMMARY AND PATH FORWARD

The Power of ERDC 2020-2030 Strategy offers a roadmap for ERDC's next decade, one that holds as much challenge and potential as any in its 91-year history. This strategy outlines the Ends, Ways and Means necessary to accomplish that strategy and will serve as a springboard to future success.

Key steps for successful implementation of the Power of ERDC 2020-2030 Strategy going forward will include the following:

1. **Vision**. Define, with key stakeholders, the future operational capabilities that ERDC S&T campaigns must deliver, and the near-, mid- and far-term R&D necessary to accomplish them.

2. **Buy-in**. Cultivate an engaged, passionate, innovative, entrepreneurial and highly productive ERDC workforce that embodies a world-class capability and commitment for discovering, developing and delivering innovative, high-impact solutions and putting them into practice.

3. **Resources**. Develop and dedicate resources (Means) to enable discovery, development and delivery, and to support sustainment and connection, of new high-impact capabilities to foster innovation for USACE and our many partners.

4. **Competence**. Expand and promote the technical competence of the ERDC team across the board to enable more effective development and application of new ideas and technologies and to maintain ERDC as a world-class R&D organization.

5. **Connections**. Maintain global awareness of the best new ideas, science, engineering and technologies to facilitate necessary partnerships and R&D for innovation and lead the world in our areas of expertise and core competencies.

6. **Collaboration**. Actively enhance and maintain cross-functional relationships within and outside ERDC, USACE, the Army, the nation, and our allies.

7. **Implementation**. Develop implementation plans that define specific actions and metrics in alignment with the goals and objectives spelled out in this strategy.

8. **Renew**. Revisit the Power of ERDC Strategy on a regular basis, to renew the Ends, Ways and Means as necessary to maintain ERDC as a world-class R&D organization that delivers world-class, high-impact solutions for the Warfighter and the nation.

Throughout its history, ERDC has always responded to the call of the Warfighter and the nation, solving some of the world's greatest scientific and engineering challenges along the way. The dedication, skill, professionalism and passion of ERDC's people have always been the keys to its success, and will always be so. The Power of ERDC remains, as always, in their hands.

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14. ABSTRACT
The ERDC 2020–2030 Strategy outlines the origination of the organization, future direction, and the methods used to accomplish its research and development mission. The Strategy details the Ends (where we are going and why), the Ways (how we will get there), and the Means (the resources needed to get there) by which we will achieve the US Army Engineer Research and Development Center (ERDC) strategy. To realize its vision and maintain its world-class status, ERDC strives to be the go-to organization for the Warfighter and the nation to solve large complex problems in its mission space. To strengthen the outcomes from the Ends, Ways, and Means, ERDC has adopted the philosophy of the Understand-Predict-Shape (UPS) paradigm. The UPS paradigm maximizes the potential of ERDC's current research programs and helps contemplate, develop, and define the organization's future portfolio. UPS represents a holistic view of the operational environment: How to better Understand the Present, Predict the Future, and Shape the Outcome. The ERDC leadership team has looked toward the future and defined major strategic Science and Technology campaigns that offer challenges that ERDC can, and should, effectively address.

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