

## Remote Sensing Capabilities to Support EWN® Projects: An R&D Approach to Improve Project Efficiencies and Quantify Performance

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**PURPOSE:** Engineering With Nature (EWN®) is a US Army Corps of Engineers (USACE) Initiative and Program that promotes more sustainable practices for delivering economic, environmental, and social benefits through collaborative processes. As the number and variety of EWN® projects continue to grow and evolve, there is an increasing opportunity to improve how to quantify their benefits and communicate them to the public. Recent advancements in remote sensing technologies are significant for EWN® because they can provide project-relevant detail across a large areal extent, in which traditional survey methods may be complex due to site access limitations. These technologies encompass a suite of spatial and temporal data collection and processing techniques used to characterize Earth's surface properties and conditions that would otherwise be difficult to assess. This document aims to describe the general underpinnings and utility of remote sensing technologies and applications for use: (1) in specific phases of the EWN® project life cycle; (2) with specific EWN® project types; and (3) in the quantification and assessment of project implementation, performance, and benefits.

### BACKGROUND

**EWN® Initiative.** The EWN® Initiative originated in 2010, intending to highlight successful past practices of intentionally aligning natural and engineering processes to deliver economic, environmental, and social benefits efficiently and sustainably (Bridges et al. 2021a). The Initiative consists of four critical elements: (1) use science and engineering for project efficiency and sustainable benefits; (2) extend project value (i.e., economic, social, and environmental benefits); (3) increase organization and advance collaboration to improve project credence and approval; and (4) use natural processes to maximize the quality of project benefits and reduce impacts on the environment and resources (Bridges et al. 2021a).

The USACE, through its EWN® Initiative, is progressively employing nature-based features and solutions across agency mission areas. EWN® uses these natural and nature-based features (NNBF) to focus on preserving, restoring, and engineering natural systems for the benefit of people and the ecosystems they inhabit (Bridges et al. 2021b). While the primary purpose of USACE's nature-based applications is for flood risk management (e.g., attenuation of storm surge and waves), nature-based features can take many different forms and provide a wide range of additional benefits (i.e., environmental, economic, and social). To date, EWN® has participated in a wide range of nature-based specific projects, fifty of which were led by EWN® and highlighted in two published atlases (Bridges et al. 2018, 2021a).

**EWN<sup>®</sup> framework.** Through the EWN<sup>®</sup> Initiative, the USACE and its partners have established a set of real-world guidelines for integrating human engineering with natural systems. The guidelines, outlined in Bridges et al. (2021b), establish a general framework through which each project is divided into five phases: (1) Scoping, (2) Planning, (3) Decision-Making, (4) Implementation, and (5) Operations (Figure 1, King et al. 2021). Figure 1 highlights the general phase progression, from the initial Scoping Phase to the Operations Phase of a project (Bridges et al. 2018; King et al. 2021). These framework phases provide a general guide for integrating nature-based features into the broader and multidimensional project approach. The project development process often requires revision when new data are available or new information is obtained about the functionality or success of new or previously implemented measures (Bridges et al. 2021b). Therefore, a strategic remote sensing approach could benefit the project development process by better relating opportunities for remotely sensed data to inform specific project phases.

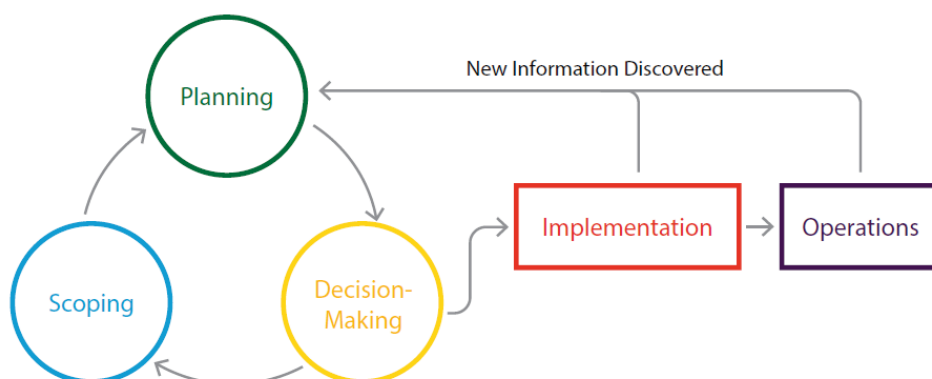


Figure 1. Project phases used within the EWN<sup>®</sup> framework (King et al. 2021).

**EWN<sup>®</sup> technical aids and tools.** Increasing nature-based feature development and application prompts a need for additional technical aids and tools to advance the practice and implementation of EWN<sup>®</sup> projects (Bridges et al. 2021b). Although remote sensing data and techniques are increasingly investigated in various applications, there is currently no comprehensive approach for using remote sensing technology more effectively throughout the EWN<sup>®</sup> project portfolio. Yet, innovative remote sensing technologies continue to rapidly evolve for proactive use in and optimization of project scoping, planning, decision-making, implementation, and operations. Additionally, there are many advantages of remotely sensed data (i.e., detailed data coverage over expansive and challenging to access areas) that can help expedite project pathways, resulting in greater efficiencies across a project life cycle. In turn, those efficiencies enable: (1) quantification of project progress, (2) examination of environmental conditions pre- and post- project phase, (3) tracking and evaluation of project milestones, and (4) project option comparisons across locations and scales. Without a more comprehensive approach, remote sensing data may be inappropriate, out-of-date, or misaligned with project needs, and if not directly linked with project outcomes or management actions, can lead to inefficiencies, costing time and money.

Due to these outlined considerations, there is a growing opportunity to enhance EWN<sup>®</sup> project efficiencies through the intentional integration of remote sensing technologies into project types and phases. Through the advent of increased spatial, spectral, and temporal resolution data, current and evolving advancements of remote sensing technology align with the goals outlined in USACE (2018). More specifically, incorporation of a more comprehensive remote sensing approach fits

with the expansion of capabilities, applications, and communication outlined in the Plan's Vision, whereby remote sensing data and methods can be used to assist with: (1) demonstrating EWN<sup>®</sup> project design, implementation, performance, and application, (2) increasing project forecasting and risk reduction, (3) improving inter-relationships in system processes, (4) increasing project efficiencies and resilience, and (5) improving adaptive management.

## REMOTE SENSING

**Remote Sensing - Overview.** Remote sensing data and analysis provide spatial and temporal perspectives on physical, chemical, and biological properties and conditions of Earth's surface features that would otherwise be difficult to monitor and quantify (Anderson and Gaston 2013; Barnsley 1999; Lillesand et al. 2015). Remote sensing systems are characterized by various platforms, sensors, and resolutions. The platforms, which carry a sensor or suite of sensors, fall into three general categories: ground-based (e.g., hand-held camera, tethered balloons, tripod-mounted), airborne (manned and unmanned aircraft), and space-borne (satellites). Each platform type has a typical operational altitude, which impacts the spatial and temporal properties of data collected by the onboard sensor. Figure 2 highlights examples of various platforms and sensors with respect to flying altitude. Sensors fall into two primary categories: passive and active sensors. Passive sensors record electromagnetic radiation reflected or emitted from the Earth's terrain – where the Sun acts as the source of energy (Shippert 2004). Active sensors provide their electromagnetic energy, emitting those energies onto the target (i.e., features on the Earth's surface) and recording the amount of radiant flux scattered back to the sensor, or the time it takes for the energy to return (Campbell and Wynne 2011; Jensen 2009).



Figure 2. Examples of ground-based, airborne, and space-borne sensors and their typical operational altitudes.

Sensors are also categorized by their spatial, spectral, and temporal resolution. Spectral resolution is a sensor's ability to distinguish wavelengths of energy within the electromagnetic spectrum. It is dependent upon the number of spectral bands (e.g., multispectral versus hyperspectral imagery (HSI)), their wavelength location (e.g., visible, infrared, and microwave regions), and their narrowness (Lillesand et al. 2015). Spatial resolution measures the most minor angular or linear separation between two objects that can be resolved by the sensor (Jensen 2009). It is generally a function of the sensor's altitude, and for space-borne sensors, it is determined by the distance from the ground (altitude) and the instantaneous field of view (Lillesand et al. 2015). Temporal

resolution refers to how often the sensor records imagery of a particular area (Jensen 2009). For satellites, this is referred to as the "revisit period" and is often subject to the satellite's orbit (e.g., sun-synchronous orbits or geostationary) period and inclination (Lillesand et al. 2015).

Remote sensing can provide an unobtrusive detection of fundamental biological, chemical, and physical information (e.g., location, elevation, biomass, temperature, moisture, etc.) about features and processes on the Earth's surface. Significant advantages of remote sensing include the ability to collect data across a wide range of spatial, spectral, and temporal resolutions in high-risk situations and in inaccessible or difficult to access areas, in which traditional survey methods may be difficult. Recent advancements in remote sensing systems (i.e., improvements and miniaturizations of electronics, navigation, and telemetry components), platforms (e.g., unmanned aircraft systems (UAS)), sensors (e.g., hyperspectral imagers), data (e.g., elevation), and techniques (e.g., machine learning and data fusion) provide flexible systems and products that, in many cases, overcome previous constraints and therefore, have the potential to supplement or maximize traditional field-based techniques (Hobbs and Herwitz 2006; Whitehead and Hugenholtz 2014). However, remote sensing is not without limitations. No single sensor and platform combination provides all spatial, spectral, and temporal information needed to fully conduct physical, biological, or social science research (Jensen 2009). Regardless, with recent and future advancements, remote sensing will have an increasingly valuable role in EWN<sup>®</sup> applications, such as improved efficiencies and enhanced project perspectives and products.

**Remote Sensing – Data acquisition and collection.** Currently, the USACE is well-equipped to collect, acquire, process, and analyze new and existing air- and space-borne imagery. There is a wide range of coarse- to high-resolution data publicly available or through in-house resources. Some of the more widely used external sources of public geospatial data include:

- USGS Global Visualization (GloVis) and EarthExplorer (EE) gateways (course- and high-resolution products) –
  - Digital Orthophoto Quadrangle (DOQs)
  - Digital Elevation Models (DEMs)
  - Aerial photos
  - Landsat and Sentinel satellite imagery
  - Land Cover data
- NASA Earth Observation portal (coarse-resolution global-scale products) –
  - Surface temperature
  - Albedo
  - Net Primary Productivity
  - Chlorophyll Concentration data
- NOAA Digital Coast portal (high resolution products) –
  - Elevation
  - Land Cover
  - Climate
  - Imagery

- Infrastructure
- Water Quality

Examples of additional exclusive data or in-house data collection capabilities (i.e., lidar elevation data, multispectral and hyperspectral imagery) that could significantly improve EWN<sup>®</sup> project efficiencies are those available through the:

- Department of Defense (DoD) contract agreements and collections –
  - National Geospatial- Intelligence Agency (NGA)
  - USACE National Coastal Mapping Program (NCMP)
  - UAS collections (e.g., US Army Engineer Research and Development [ERDC] and USACE District UAS fleets).

The NGA agreement provides access to numerous commercial, unclassified satellite imagery at no cost to the user (US Army, 2017). The contract also provides a sensor tasking option whereby a request can be made through the USACE Army Geospatial Center (AGC) to collect new imagery at the desired data or date range for a specific location. One example of the value of the AGC contract is MAXAR's WorldView-3 (WV-3) high-resolution multispectral imagery. Compared to other commercial satellite systems, WV-3 data have many advantages, namely its spectral (29 bands) and spatial (1.24 m) resolutions.

Another high-resolution data option is through airborne collections, whether from manned or unmanned systems. Airborne collections, whether from a single or multi-sensor system, provide many advantages over space-borne data, including better ground sample distance, control over collection period, lower cloud influence, improved classification accuracies, and feature extraction (Reif et al. 2011). For example, the NCMP provides an integrated airborne sensor suite that collects concurrent lidar elevation (topo/bathymetric), hyperspectral, and very-high-resolution true-color data that are routinely used for physical and environmental characterization of beaches, wetlands, marshes, estuaries, and barrier islands (Reif et al. 2013). The unmanned systems support high-quality data acquisition for an array of uses including environmental monitoring, infrastructure inspection, and adaptive management (Suir et al. 2018). These platforms can be commercial-off-the-shelf (COTS) or custom-built and configured with a wide array of sensor packages. Utilization of high-quality hyperspectral, multispectral, and thermal imagers, true-color cameras, and lidar sensors are now being employed regularly for environmental and ecological applications (Anderson and Gatson 2013). Additionally, advancements in computing, such as machine learning (computer-derived rules and classification from training data) and structure from motion (SfM) techniques, have added a new dimension to available data products collected by UAS (Jensen 1996; Fonstad et al. 2013; Longmore et al. 2017). UAS applications now go beyond traditional orthophotography and feature classifications and into high-resolution point cloud generation, 2D and 3D digital surface models, volumetric measurements, vegetative indices, and automated feature extractions.

**Remote Sensing – Improving EWN<sup>®</sup> efficiencies.** Remote sensing data and products provide a wide range of opportunities for advancing EWN<sup>®</sup> project implementation and assessing project performance (Table 1). The International Guidelines on Natural and Nature-Based Features

for Flood Risk Management recommends using metrics for performance assessments (Bridges et al. 2021b). Metrics are quantifiable parameters or properties of project features related to performance and can be helpful in describing benefits (Piercy et al. 2021). Performance metrics should be objective-specific and consider system efficacy, efficiency, and effectiveness (Piercy et al. 2021). Good performance metrics should also be complete and concise, transparent and unambiguous, accurate, direct, understandable, and operational (Bridges et al. 2015).

Remote sensing data applications and objectives can be directly related to specific EWN<sup>®</sup> project phases (Table 1). For the Scoping phase, remote sensing can provide helpful information for assessing and describing the system and problems, identifying opportunities and limitations, establishing goals and objectives; and developing a project strategy (King et al. 2021). Specifically, existing or cataloged imagery and data can play a critical role in characterizing the extent of the issue, mapping the area of interest, and defining baseline conditions, all of which are key components for project scoping. Remote sensing is also ideally suited for project planning. Geospatial data can provide efficient and detailed mapping elements for hazard and vulnerability assessments; ecosystem and habitat analyses (e.g., presence, health, and susceptibility), and serve as simple representations of measures and inputs into models; all of which are important components for assessing risks and environmental impacts, establishing project performance criteria, and communicating with stakeholders. For the Decision-Making phase, remotely sensed data and products can serve as essential information for engineering, ecological, social, and economic modeling and assessments. Combining geospatial data, remote sensing-based analyses, and maps with system models can provide efficient means for assessing project alternatives, completing cost-benefit analyses, and involving the community and stakeholders in plan selection. The Implementation phase requires higher detail modeling of individual measures to finalize the project design (Piercy et al. 2021). Remote sensing is adept at providing the accurate and high-resolution data (i.e., boundary conditions, bathymetry, and vegetation cover) needed to generate as-built specifications and assess potential environmental impacts, which are often necessary to establish construction timelines and milestones. Finally, the Operations phase, which includes adaptive management and the direct quantification of project performance, is best suited for remote sensing applications. The monitoring of the EWN<sup>®</sup> project and nature-based feature performance is highly efficient when using high spatial and temporal air- and/or space-borne data. Remote sensing data provide products and assessments of project indicators, target values, and triggers, all of which are useful for developing monitoring reports and identifying adaptive management needs.

Table 1. List of EWN® project phases and relevant remote sensing applications.

Project Phase	Remote Sensing Applications
Scoping	<ul style="list-style-type: none"> <li>- Characterizing the extent of the issue</li> <li>- Mapping area of interest</li> <li>- Assessing system processes</li> <li>- Defining baseline conditions</li> </ul>
Planning	<ul style="list-style-type: none"> <li>- Hazard and vulnerability assessments</li> <li>- Ecosystem and habitat analyses</li> <li>- Assessing risks and environmental impacts</li> <li>- Establishing project performance criteria</li> <li>- Communicating with stakeholders</li> </ul>
Decision Making	<ul style="list-style-type: none"> <li>- Serving as essential information and input for models</li> <li>- Performing engineering, ecological, social, and economic assessments</li> <li>- Evaluating project alternatives</li> <li>- Completing cost-benefit analyses</li> <li>- Involving the community and stakeholders in plan selection</li> </ul>
Implementation	<ul style="list-style-type: none"> <li>- Finalizing project designs</li> <li>- Generating as-built specifications</li> <li>- Assessing potential environmental impacts</li> <li>- Establishing construction timelines and milestones</li> </ul>
Operations	<ul style="list-style-type: none"> <li>- Quantifying project performance</li> <li>- Assessing project indicators, target values, and triggers</li> <li>- Developing monitoring reports</li> <li>- Identifying adaptive management needs</li> </ul>

**Remote Sensing – Monitoring EWN® projects and quantifying performance.** The goal of the EWN® Initiative is to promote projects that provide environmental benefits and enhance sustainability across USACE mission space (i.e., Navigation, Flood Risk Management, Ecosystem Restoration, and Water Operations) (Kurth et al. 2020). EWN® project success is tied to the performance of project measures and the benefits provided over the project's lifecycle. Natural processes, episodic disturbance events, climate change (sea-level changes), and anthropogenic activities can all impact EWN® projects; therefore, frequent monitoring of performance is required to quantify and evaluate project benefits over time. Predetermined metrics and targets are typically used to assess performance and determine if a project meets established objectives (Piercy et al. 2021). Whereas project success varies by type, metrics vary by project.

Performance indicators (e.g., habitat type, acreage, and biodiversity) are often required to assess project performance, evaluate adaptive management needs, and determine whether the project measures and features are delivering the expected performance and benefits (i.e., environmental, social, and economical; van Zanten et al. 2021). In most cases, direct and/or indirect measurements of EWN® project or feature properties are required to generate metrics or assessments of performance. In some cases, monitoring data are used to populate system performance models, especially in cases where the system may have changed in some fundamental way from when the project was implemented. The performance of EWN® projects, which can be quite diverse, is usually related to project category, infrastructure type, or intended environmental or social benefits (Fredette et al. 2015). Table 2 provides a list of EWN® project types (unique ecotones, systems, and applications) and intended benefits (i.e., environmental, economic, and social value).

Table 2. List of project types and examples of key benefits associated with EWN® projects (Bridges 2021a,b).

Project Category	Benefits
<ul style="list-style-type: none"> <li>-Beaches and Dunes</li> <li>-Environmental Enhancement of Infrastructure</li> <li>-Islands</li> <li>-Levee Setbacks and Floodplains</li> <li>-Reefs</li> <li>-Riverine Systems</li> <li>-Unique Projects</li> <li>-Use of Vegetation and Natural Materials</li> <li>-Wetlands</li> <li>-Other</li> </ul>	<ul style="list-style-type: none"> <li>-Aesthetics</li> <li>-Beach nourishment</li> <li>-Bird habitat</li> <li>-Fish habitat</li> <li>-Invertebrate habitat</li> <li>-Island restoration</li> <li>-Mammal habitat</li> <li>-Recreation</li> <li>-Reptile habitat</li> <li>-Shore protection</li> <li>-Vegetated habitat</li> </ul>

In addition to project phases, remote sensing also has a wide range of monitoring and performance assessment applications across EWN® project types, benefits, and impacts. Traditional monitoring and performance assessments can be challenging (i.e., costly and resource and time-intensive) because performance and impacts should be considered over an entire project life cycle and across a full array of possible environmental conditions (Piercy et al. 2021). Remote sensing data and techniques provide tools beneficial for analyzing EWN® project and feature performance because they can be used to detect and quantify system and feature structure and function at a multitude of scales. In particular, the use of high-resolution air- and space-borne imagery can provide the advantage of increased spectral and/or spatial capability crucial for quantifying and evaluating feature changes over space and time (Ruckelshaus et al. 2020). One example is the use of high-resolution UAS data to monitor and quantify fine-scale changes in geomorphological attributes of intertidal reefs (Murfitt et al. 2017).

While differences in geomorphic setting and/or application differentiate EWN® projects, many have similar characteristics or needs related to performance evaluation. For instance, beach and dune, wetlands, and riverine systems projects all have vegetation components with similar benefits and goals (e.g., sediment trapping, increased habitat, promoting resilience to stressors; Cahoon et al. 2020, Casazza et al. 2021, Suedel et al. 2021a). Therefore, similar remote sensing data (e.g., lidar, red-edge sensors) and metrics (e.g., plant and community density; structural, vegetation, and floristic quality indices) could be used to assess the performance (e.g., changes in biomass) and impacts (e.g., elevation changes over time) of those projects. The following paragraphs provide short summaries of some EWN project types and how remote sensing can be used to assess and quantify project performance and benefits.

**Beaches and Dunes.** Beaches and Dunes provide a wide range of coastal protection values, including natural coastal protection against storm surge and wave energy, preventing or reducing coastal flooding and structural damage, reducing coastal erosion, as well as providing crucial ecological habitat. Recent advancements in remote sensing technology have enabled rapid collection of geospatial data and production of metrics (e.g., shoreline location, dune height, vegetation cover) suitable for assessing biological and physical changes of beach and dune features over time, such as changes in vegetation community type and dune width (Yousefi Lalimi et al.

2017; Wernette et al. 2018). As such, high-resolution multispectral and HSI imagery can be used to identify and classify vegetation and habitat types (e.g., plant species, zones, or associations), quantify dune vegetation biological characteristics (e.g., vegetation density and biomass estimates), all of which can be used to monitor and analyze changes and trends in project area vegetation dynamics, including restored dune vegetation (e.g., health, mortality, and recovery). These data can be used alone or in combination with physical data, like airborne lidar data, which can also be used to derive key metrics, including geomorphic (i.e., dune crest, dune toe, beach width, volume change, sedimentation, and trapping) and environmental parameters (i.e., dune vegetation structural characteristics) to assess beach and dune features and project performance. UAS-derived data are also well equipped to quantify wave attenuation, sediment movement, and shoaling and assess impacts (i.e., erosion) from natural processes and disturbance events.

**Islands.** Islands serve multiple functions, including storm surge reduction, wave dissipation, erosion control, dredged material management, safe navigation, and safe haven, ecosystem diversity, wildlife habitat, recreation, and commercial opportunities (e.g., tourism and fisheries) (Gailani et al. 2021). The remote sensing-based performance metrics for EWN<sup>®</sup> island projects should include but are not limited to habitat type and area, survival of vegetation, changes in surface elevation, rates of erosion or accretion, shoreline position, area changes for different Island elements, frequency and duration of overwash events, water residence times, and water quality parameters (i.e., suspended sediment concentrations). Specific examples of previous use of remote sensing to assess nature-based feature-related projects include the use of high-resolution imagery and lidar data to evaluate changes in historical and recent Island features (e.g., beach, dune, back barrier wetlands, and shoals; Suir et al. 2016), elevation (e.g., irregularly flooded, regularly flooded, and irregularly exposed; Suir and Sasser 2019a), and habitat ranges (e.g., dune herbaceous, meadow, and intertidal beach; Enwright et al. 2019).

**Reefs.** Reefs provide many ecosystem services, such as fisheries, recreation, tourism, and coastal flooding and erosion (Lowe et al. 2021). Natural and engineered reefs can be self-sustaining ecosystems and continue to grow and maintain structures that protect shorelines (Lowe et al. 2021). In shallow, clear, and/or non-turbid waters, data collected from airborne and autonomous surface vehicles (ASVs) can be used to assess key reef characteristics, such as width and height, proximity to shore, roughness, porosity, and coral color (useful in detecting coral bleaching events) (Asner et al. 2020; Hong et al. 2021). Remote sensing can also assist in the monitoring of coral formation, sediment trapping, shoreline change (i.e., erosion and accretion), richness and diversity, and wave attenuation (Brodie et al. 2010; Zhang 2019; Sierra-Escrigas et al. 2020).

**Wetlands.** Wetlands provide a wide range of goods and services, including regulating (i.e., floods, drought, and wetland degradation), supporting (i.e., soil formation and nutrient cycling), provisioning (i.e., food and freshwater), cultural (i.e., recreational and aesthetics), and ecosystem services (i.e., high biological productivity and critical habitat) (Suir 2018). Remote sensing provides a means for classifying and monitoring wetland landscape features to assess the distribution and change of those features over time. Some practical remote sensing applications include assessing the areal extent of created wetland habitat (Suir et al. 2020), evaluating changes and trends in wetland conditions (Suir and Sasser 2019b; Jiang et al. 2020), assessing wetland elevation and shoreline change rates (Smith et al. 2021), quantifying changes in hydrology (Suir et al. 2014) and comparing wetland properties to reference wetlands or established targets.

These wetland structure and function measures can provide valuable estimates of performance and resistance to and recovery from anthropogenic activities and episodic events.

**Vegetation.** Implementing vegetation and plant communities is important in engineering projects (Sekoni 2016). Vegetation is a critical component of ecosystem energy flow as it provides habitat for many organisms and is often used to infer soil and climatic patterns (Bridges et al. 2015). For EWN<sup>®</sup>, vegetation-based measures are typically used to reduce erosion, trap sediment, attenuate waves and surges, provide critical habitat, regulate water temperature, and provide flood storage. The ability for vegetation-based measures to provide these services is largely tied to vegetation structural and biological properties. Vegetation properties are an excellent indicator of condition and project performance because of their rapid growth rates and their direct response to stressors and disturbances (Broussard et al. 2018). The monitoring and quantification of those structural components are largely done via measurements of plant and community characteristics (e.g., species composition, cover, density, and biomass) (Chamberlain and Ingram 2012; Cretini et al. 2012). Remote sensing is well equipped to monitor and quantify vegetation properties and project performance because the vegetation is typically easily observed with remote sensors. Remote monitoring of vegetation measures includes but are not limited to assessing changes in vegetation growth dynamics (i.e., shoot density, height) (Suir and Sasser 2019b; Jiang et al. 2020), detecting and monitoring plant diversity and switching (e.g., invasive plants, species abundance, and competition) (Royimani et al. 2019; Suir et al. 2021), and plant health (e.g., dieback), resiliency, and recovery (Suir et al. 2020).

**Environmental enhancements of infrastructure.** Another type of EWN<sup>®</sup> project is the environmental enhancement of existing coastal and riverine infrastructure. These projects, typically smaller in spatial scale, are often used to broaden environmental, economic, and social benefits by making simple and easily integrated low-cost modifications to the design or function of existing infrastructure (Suedel et al. 2021b). These modifications are typically performed on existing hardened structures like breakwaters, groins, jetties, rock revetments, seawalls, and bulkheads. The benefits these projects provide often include adding or improving aquatic or terrestrial habitat, improving access for people, improving social and recreational value (e.g., paths for bird watching), adding property value (e.g., aesthetics), providing regulating services (e.g., trapping pollutants in a fringe marsh), and serving as carbon sinks (Suedel et al. 2021b). The performance of these enhancements can be measured using remote sensing-derived data and metrics. For instance, multispectral imagery can be used to monitor erosion control (Osorio et al. 2020), vegetation performance (Oostdijk et al. 2018), as well as habitat change and biodiversity (Furberg et al. 2020); lidar data can be used to assess access, navigable paths, and inspect structure performance over time; and HSI and high-resolution satellite imagery can be used to evaluate sediment transport and water quality parameters (Magnuszewski et al. 2018).

**CONCLUSION:** This technical note (TN) establishes a fundamental foundation for developing a comprehensive remote sensing strategy to enhance and inform the EWN<sup>®</sup> project development process. It explores and links relevant remote sensing data, applications, and objectives to specific EWN<sup>®</sup> project phases and types. Collectively, remote sensing data and technologies can be instrumental in providing function and structure information related to key environmental, nature-based, and infrastructure features throughout the EWN<sup>®</sup> project life cycle while assisting in evaluating project milestones and comparisons across locations and scales. The foundation for a strategic remote sensing approach is critical for the next steps to identify environmental,

geomorphological, and landscape metrics that (1) can be developed using remote sensing data and methods, (2) are essential for assessing EWN<sup>®</sup> project benefits, and (3) are broadly applicable across EWN<sup>®</sup> project types and phases and can illustrate the unique capabilities of remote sensing technologies to capture ecosystem conditions. The next steps will build on the foundation set forth in this TN to evaluate and prioritize remote sensing applications and metrics most relevant to specific project phases and types. In turn, it paves the way to develop spatially explicit metrics through repeatable geospatial processing methods using a variety of readily available or newly collected remote sensing data. Geospatial tools will likewise be developed by collating evaluated methods into software-based workflows to help streamline the production of spatially explicit metric data products. Such tools can advance the monitoring and quantification of EWN<sup>®</sup> project performance and benefits, increasing project efficiencies and adaptive management strategies. Documenting the application of remote sensing data, methods, and geospatial software tools in EWN<sup>®</sup> project case studies can serve as guidance and best practices for the EWN<sup>®</sup> Initiative and improve the integration of remote sensing approaches into the EWN<sup>®</sup> portfolio. Therefore, the strategic incorporation of updated remote sensing technologies into the EWN<sup>®</sup> project lifecycle will ultimately be instrumental in evaluating project performance, which will enhance project efficiencies and advance the practice and implementation of EWN<sup>®</sup> projects.

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