Aerial Monitoring Program: Integrated Autonomous Technology Advancing Environmental Performance

Background, Purpose, and Goals

The Port of Tacoma manages a large, industrial waterfront where environmental protection, regulatory compliance, and operational efficiency must be achieved simultaneously. Core responsibilities include routine inspection of stormwater infrastructure, outfalls, shoreline conditions, and other environmentally sensitive areas to meet permit requirements and protect water quality. Historically, these inspections relied on vessel-based surveys, ground crews, and limited aerial support, approaches that constrained inspection frequency, reduced coverage, and made it more difficult to proactively identify emerging issues.

With traditional monitoring conducted intermittently, conditions such as shoreline erosion or stormwater system failures could advance before detection, increasing environmental risk and limiting opportunity for early intervention.

To address this gap, the Port launched an autonomous drone program anchored by a permanently installed drone dock, establishing a more proactive, technology-enabled model for continuous environmental oversight. The Port is one of the only ports in North America operating a fully dock-based autonomous aerial monitoring system integrated into environmental compliance workflows.

The program's purpose is to modernize environmental monitoring by shifting from resource-intensive, field-based inspections to continuous, data-driven oversight that improves safety, efficiency, and data quality. Its goals are to increase inspection frequency and geographic coverage, reduce staff exposure to hazardous conditions, improve data consistency through repeatable high-resolution imagery, strengthen regulatory compliance through reliable visual documentation, and establish a scalable platform for integration with asset management systems and digital infrastructure tools.

Over the long term, the program supports predictive asset management, improved lifecycle planning, and more informed decision-making, enabling a transition from reactive inspections to proactive environmental management.

Implementation & Resources

The program was implemented through a phased, cross-functional effort that integrated technology deployment, safety and regulatory compliance, and operational planning. From the outset, Environmental, IT, Security, Operations, and Legal teams collaborated to ensure the system met enterprise technology standards, aviation and workplace safety requirements, privacy considerations, and airspace regulations.

At the center of the initiative is a network-connected autonomous drone dock system installed at the Port's Maintenance Facility. The dock enables automated charging, pre-programmed

missions, and remote flight operations without an on-site operator, significantly increasing the efficiency and flexibility of both scheduled and on-demand inspections **(Figure 1)**.

Implementation included procurement and installation of a secure, weather-resistant drone dock and unmanned aerial vehicle (UAV) designed for autonomous operations; development of standardized flight plans and geofenced operating areas aligned with FAA Part 107 requirements and Port safety protocols; integration of real-time aerial data into GIS and environmental compliance systems; and staff training supported by standard operating procedures for mission planning, data review, and maintenance.

This coordinated implementation delivered immediate operational value, including significantly faster inspections, expanded coverage, and measurable staff time savings. The program also reduced vessel mobilizations and field deployments, lowering fuel use and travel time while enabling a small internal team to conduct frequent, repeatable inspections across multiple sites.

These results demonstrate that the program extends beyond the deployment of innovative technology. It improves resource efficiency, expands monitoring capability, and maintains high environmental standards, providing a sustainable and scalable operational model.

Innovation & Relevance

The program introduces a leading-edge, fully autonomous, dock-enabled aerial monitoring system that extends well beyond conventional drone use. Traditional port drone operations typically rely on manual piloting, favorable weather conditions, and staff availability, limiting frequency, flexibility, and responsiveness. In contrast, this approach establishes an always available monitoring capability that supports automated routine inspections, rapid deployment in response to incidents or anomalies, and consistent, repeatable data collection over time.

Dock-based autonomy is central to this innovation. The system allows the drone to launch, land, and recharge automatically, supporting unattended operations and significantly increasing operational uptime. Flights can be pre-scheduled or triggered remotely, allowing the Port to capture timely aerial data outside standard working hours and immediately following storm events or other high-risk conditions.

The program is tightly integrated with the Port's GIS environment, where drone imagery feeds directly into shoreline monitoring and environmental workflows **(Figure 2).** Rather than functioning as a standalone tool, aerial data becomes embedded in daily operational processes, enhancing situational awareness, improving data accessibility, and accelerating decision-making.

A further innovation is the use of AI-assisted image analysis to support environmental monitoring. At an upland remediation sediment cap site, high-resolution drone imagery is analyzed to detect cracks or anomalies, enabling earlier identification of potential issues and more proactive maintenance planning **(Figure 3).** This capability expands the platform's value from data collection to early detection and risk-informed action.

This model is highly relevant to the port industry, addressing persistent challenges such as limited inspection frequency, constrained site access, and inconsistent data availability, while aligning with broader priorities around digital transformation, proactive compliance, safety, and resilience. It provides a practical, scalable framework that other ports can adopt to strengthen environmental oversight and improve decision-making.

Results, Evidence & Impact

Operational Effectiveness & Efficiency: The program's measurable results demonstrate significant gains in efficiency and resource optimization. Inspections are completed approximately 60% faster than previous methods, with each flight covering roughly three times the area of a typical ground- or vessel-based survey **(Figure 4).** In its first year, the program saved more than one hundred staff hours (equivalent to approximately $20,000 in direct labor). Vessel mobilizations and routine site visits have been substantially reduced, lowering fuel use and travel time. These outcomes highlight the program's ability to improve performance while using fewer resources.

Environmental Performance & Compliance: More frequent monitoring and higher-quality data strengthened environmental oversight. Inspections now occur monthly or immediately following major storm events, compared to previous quarterly or annual cycles, representing an approximately 300% increase in inspection frequency. As a result, minor issues are identified and addressed before they escalate. High-resolution, repeatable imagery provide consistent, defensible documentation for both internal decision-making and regulatory reporting strengthen adherence to permit requirements **(Figure 5)**.

Safety & Risk Reduction: The program has substantially improved workforce safety by reducing the need for staff to access hazardous or difficult locations. Working in high-risk environments (such as climbing over riprap or conducting vessel operations in challenging weather conditions) have been eliminated. To date, there have been zero safety incidents associated with drone inspections. Reduced field presence also minimizes disturbance to sensitive environmental habitats.

Port of Tacoma Case Studies: Real-World Impact

- Shoreline Erosion & Outfall: A routine autonomous flight identified severe shoreline erosion and a failing stormwater outfall not visible through ground inspections **(Figure 6)**. Early detection triggered immediate repairs, preventing further shoreline degradation and reducing the risk of a significant water quality incident.
- Habitat Survey & Tribal Coordination: At the Wapato Creek habitat site, the Port collaborated with the Puyallup Tribe of Indians to conduct non-intrusive drone surveys. In a single flight, 134 geotagged images were captured in under five minutes, producing a comprehensive dataset while minimizing site disturbance and supporting collaborative environmental stewardship.

- Remediation Cap Monitoring (AI-Enhanced Inspection): At an upland remediation site, drone imagery combined with AI-assisted crack detection enables identification of subtle surface anomalies that may indicate wear or potential failure This improves long-term compliance monitoring and reduces the risk of undetected degradation.

Together, these results demonstrate both quantitative and qualitative impact, from efficiency gains and cost savings to improved environmental outcomes and risk reduction. The program has fundamentally shifted the Port's approach toward proactive environmental management. Key lessons include the importance of cross-functional collaboration and the value of integrating new technologies directly into existing workflows.

Integration, Adaptability & Scalability

The drone program is fully integrated into existing Port systems and workflows, functioning as an operational tool rather than a standalone technology. Drone imagery feeds directly into the Port's GIS platform, where staff can overlay data on facility maps, track inspection history, and annotate site conditions.

The system is adaptable to evolving operational and regulatory needs. Flight plans and mission profiles can be updated as requirements change, allowing the same infrastructure to support routine compliance monitoring, post-storm assessments, and emergency response activities.

Scalability is a core strength. Because the system is dock-based, coverage can be expanded by deploying additional drone docks at other terminals or facilities. With standardized procedures and training in place, the approach is readily replicable and is already being shared with peer ports.

Aligned with the Port's long-term digital strategy, the program supports future integration with digital twin platforms, predictive maintenance systems, and additional sensor technologies. Together, these capabilities make the program durable, future-ready, and highly transferable.

Stakeholder Engagement & Collaboration

Strong collaboration has been central to the program's success. Internally, Environmental, Operations, IT, Security, and Legal teams partnered to design and implement the program, develop a Port-wide drone policy, and address key considerations including airspace compliance, FAA waivers for remote operations, cybersecurity, safety protocols, and communications.

Externally, the Port engaged regulators and community stakeholders early to build transparency, credibility, and support. The Port coordinated with the Washington State Department of Ecology to validate its approach and is working toward regulatory acceptance of drone-based monitoring for upland and intertidal remediation caps. The Port also collaborated with the Puyallup Tribe of Indians to ensure operations near environmentally and culturally sensitive areas respected Tribal priorities and were incorporated into program practices.

During incident response activities, including spills and vessel-rated events, drone imagery has supported coordination with agencies such as the U.S. Coast Guard, U.S. Army, U.S. Army Corps of Engineers, Tacoma Police and Fire, City of Tacoma Source Control, Washington State Department of Ecology Spill Response, and Citizens for a Healthy Bay. The drone dock's live-stream capability enhances real-time situational awareness.

By providing clear, visual information, the program improves communication, coordination, understanding, and trust among stakeholders, supporting faster decisions and more transparent environmental management.

Conclusion

The Port of Tacoma's autonomous aerial monitoring program represents a transformational advancement in environmental oversight and operational efficiency. By combining autonomous flight operations, GIS integration, standardized workflows, and AI-assisted analysis, the Port has increased inspection speed and coverage, improved worker safety, strengthened regulatory compliance, and enhanced its ability to detect and respond to environmental risks early.

The program demonstrates how advanced technology can be successfully integrated into core operations to deliver measurable environmental and operational benefits. Its proven results and scalable design position it as a leading model for ports seeking to modernize environmental monitoring while improving performance.

Beacon of Excellence Statement

The Port of Tacoma's autonomous aerial monitoring program sets a new standard for excellence at the intersection of environmental stewardship and technological innovation. By embedding autonomous drone operations into environmental workflows, the Port has transformed monitoring, delivering faster, safer, and more comprehensive oversight while strengthening regulatory performance and resource efficiency. The program demonstrates how advanced data-driven technology can proactively reduce environmental risk and enable smarter decision-making across a complex industrial waterfront. With proven results, strong cross-functional integration, and scalability, it represents a model for the maritime industry and a benchmark for high-impact, multi-category achievement.

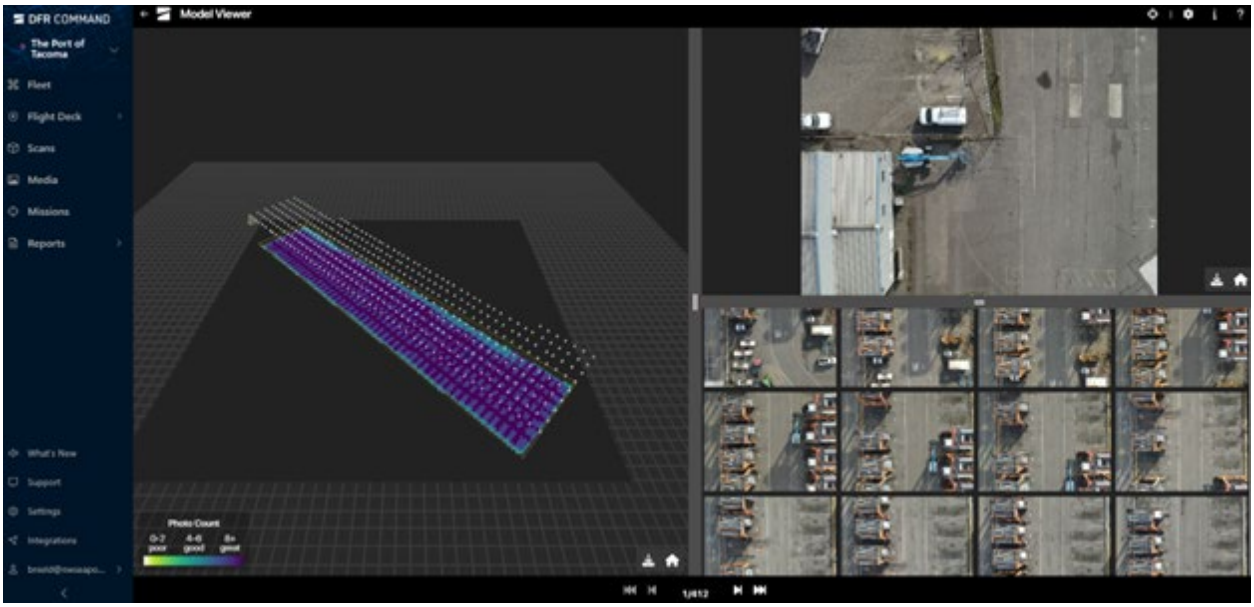


Figure 1: Drone imagery produced during a site assessment

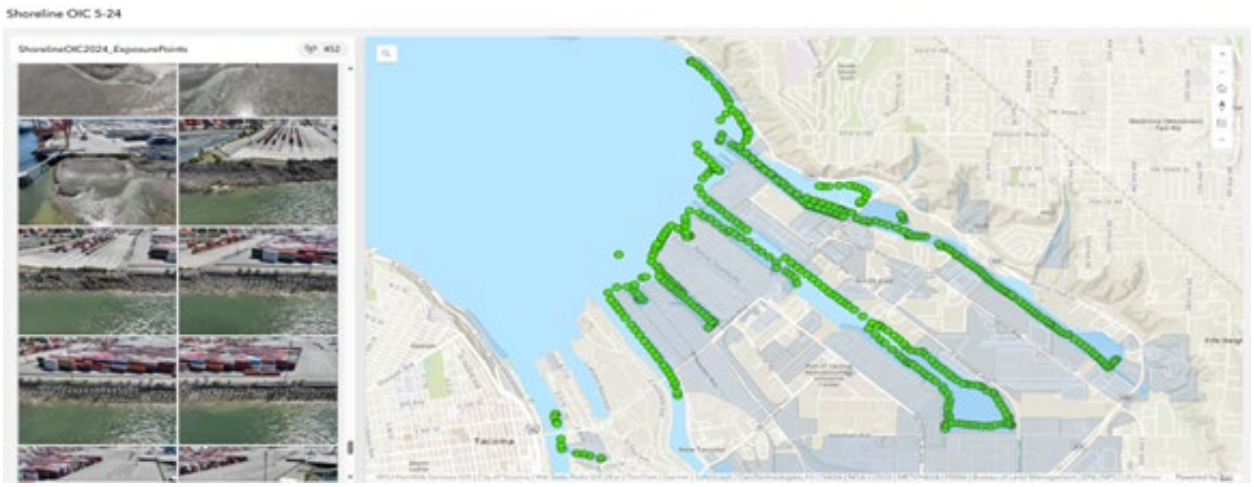


Figure 2: GIS-based imagery showing Port-owned shoreline



Figure 3: AI-assisted pavement crack detection on environmental cap

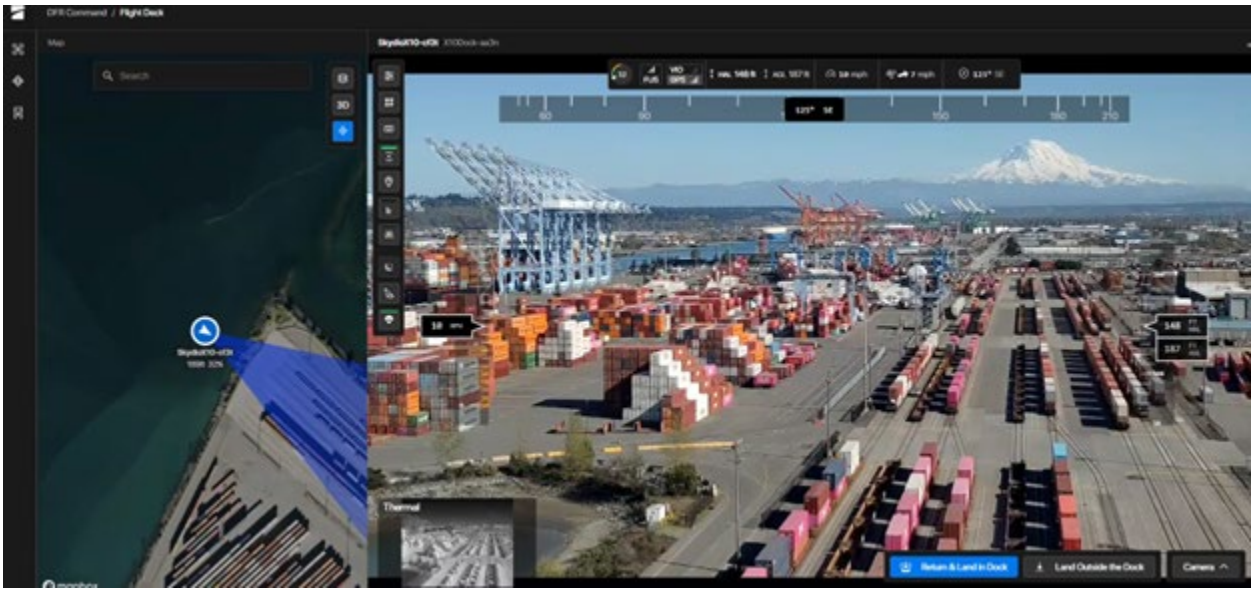


Figure 4: Drone imagery showing routine inspection of operations



Figure 5: Example of use of drone imagery for permit compliance and documentation



Figure 6: Drone imagery showing stormwater outfall collapse and shoreline erosion