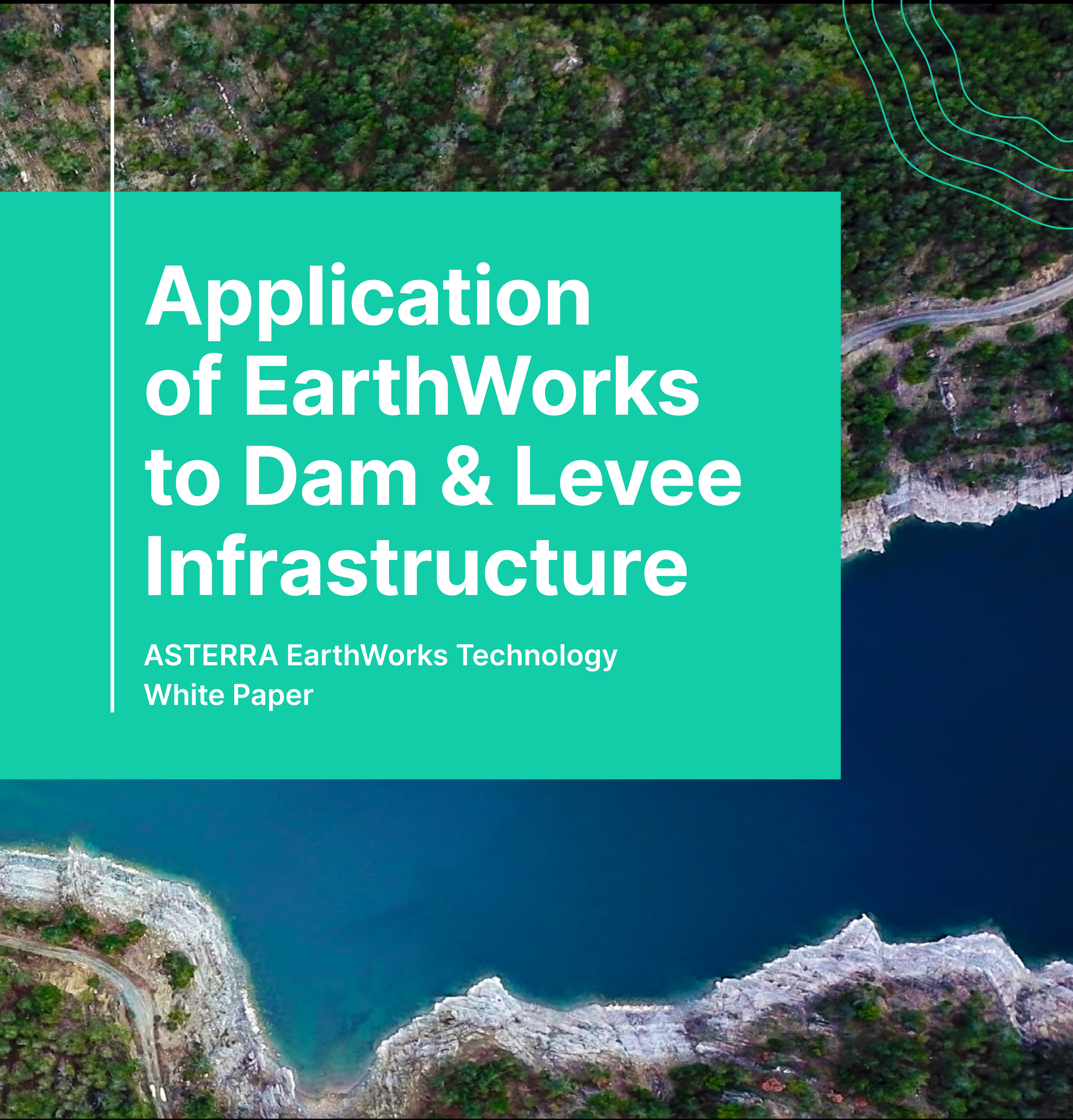
ASTERRA

Application of EarthWorks to Dam & Levee Infrastructure

ASTERRA EarthWorks Technology

White Paper



Determination of Soil Moisture from Space

Existing Challenges for Geotechnical Infrastructure

Linear infrastructure, encompassing roads, power lines, railways, canals, pipelines, and similar systems, faces severe testing from extreme weather events. This can result in delays, extensive remedial works, and tragic fatalities. Nevertheless, extreme weather events are just one of many challenges facing linear geotechnical infrastructure. Others include addressing risks such as sinkholes, unrecorded mine workings, the overall threat of failure due to asset deterioration over time, and adapting to Net Zero Carbon objectives.

Moreover, geotechnical assets along linear infrastructure are exposed to many complex site-specific characteristics and span hundreds of miles/kilometers through various landscapes, topography, soil types, bedrocks, and meteorological conditions. Any failure within the infrastructure chain incurs significant costs and hazards. Repairing landslips post-occurrence is especially costly, with emergency repairs estimated to be ten times more expensive than planned works, which are themselves ten times costlier than regular maintenance.

Asset managers have traditionally relied on visual inspections by engineers along roads, levees, and railways to identify potential failures. Installing monitoring equipment and capturing long-term data, often manually downloaded or automated where feasible within budget constraints, typically entails lane or track closures as well as weekend and night shifts to minimize public disruption. Furthermore, access for equipment placement and ongoing maintenance remains challenging and expensive.

As a result, these challenges need to be addressed and accounted for in asset management planning. Prioritizing preventative maintenance is critical for asset managers to prolong lifespan and reduce future costs.

The Current State of Play

Geotechnical asset management tools have been used by various operators over the past two decades. For instance, in the UK, Highways England and Transport Scotland follow the guidance provided in DMRB CS 641 – Managing the Maintenance of Highway Geotechnical Assets. Similarly, Network Rail adheres to regulations set by the Office of Rail and Road and utilizes data collection software to input earthworks data along with other relevant information into their asset management tools.

Drawing from past experiences, Network Rail typically directs their focus towards soil and rock cuttings due to their heightened risk of causing derailments in the event of rapid failure (Network Rail, Earthworks Technical Strategy, 2018). On the other hand, Highways England adopts a more general approach, although they acknowledge that soil cuttings are more susceptible to failure events compared to embankments. This is attributed to the fact that cuttings expose natural soils, whereas embankments are typically designed and constructed in a controlled manner. In Network Rail's case, soil cuttings are often historical, inherited, and characterized by steep slopes, with minimal or no records available regarding embankment and drainage design in their existing assets.

Figure 1. illustrates a deterioration curve of infrastructure assets over time, indicating a state of degeneration and unreliability typical of aging geotechnical assets. Conversely, assets managed by Highways England tend to fall within the central range, signifying a more stable yet still deteriorating condition. One of the primary outputs of asset management tools is the assessment of failure consequences and severity for users.

In anticipation of potential failures, it's essential to assess their potential consequences, likelihood, and timing. Network Rail has utilized a Hazard Index system for evaluating earthwork assets, covering cuttings, embankments, and rock slopes, since 2000. This system has effectively guided maintenance prioritization efforts. However, a review conducted in 2013 revealed an unacceptable frequency of failures in assets previously categorized as being in good condition. Acknowledging the significance of extending asset lifespan, Network Rail sought to develop a new approach or refine existing methods to predict earthwork failures as accurately as possible. This endeavor is particularly critical given the unpredictable nature of earthworks and the uncertain timing of climatic events, albeit with the certainty of their increased frequency in the future.

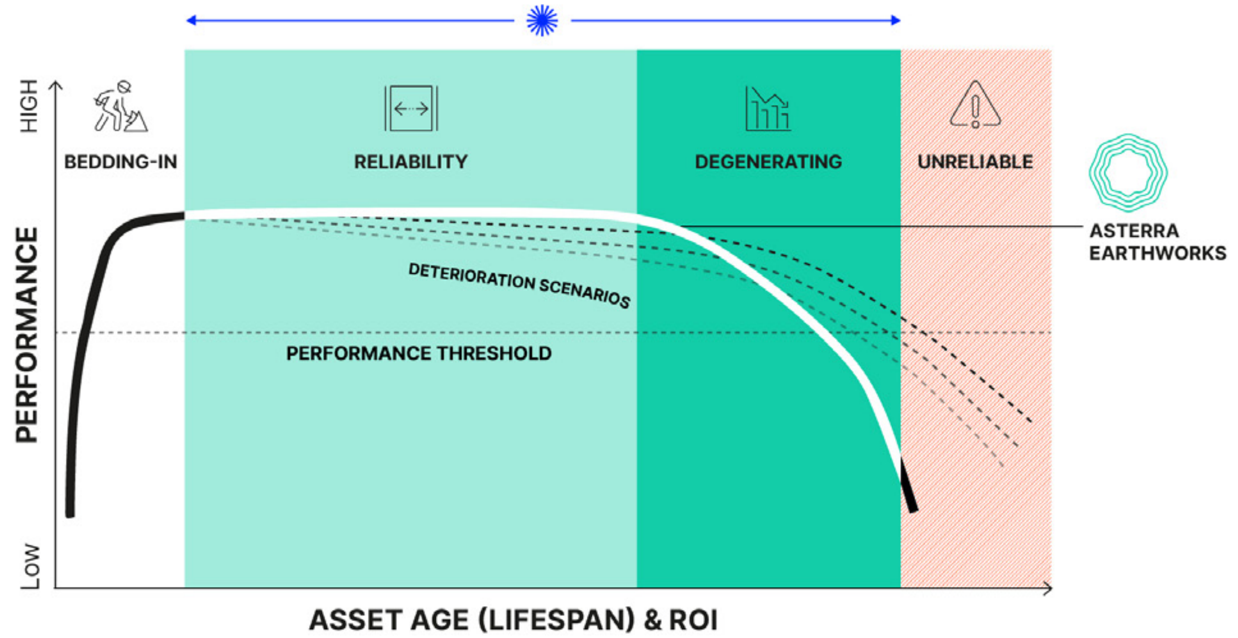


Figure 1. Infrastructure Asset Lifespan and ROI Performance Curve when EarthWorks is applied.

Revolutionizing Infrastructure Management with Remote Sensing

Historically, investigation and monitoring techniques were localized to problem areas, but the introduction of remote sensing has revolutionized large-scale spatial monitoring.

For example, InSAR offers the advantage of detecting incremental movements along geotechnical assets in real-time, potentially triggering alarms based on monitoring setups. However, with the onset of climate change, identifying problematic areas before significant issues arise is critical for asset managers to anticipate potential failures and make informed decisions to prevent them.

Another example is L-Band Synthetic Aperture Radar (SAR) that can identify the dielectric signature of water types mixed with soil. The wavelength and frequency with which this operates enables differentiation between various water types, such as groundwater and saline water. Satellite-based L-Band SAR can penetrate clouds and rain, operate day and night, and see through certain vegetation, dry snow and ice, and urban surfaces like asphalt. This technology captures soil moisture levels through dielectric properties, providing proactive insights into ground conditions within and surrounding critical infrastructure.

ASTERRA EarthWorks: Advancing Infrastructure Monitoring

ASTERRA EarthWorks leverages L-Band SAR technology to help owners and operators extend their infrastructure lifespan, improve operational efficiency, and accurately pinpoint at-risk locations across infrastructure assets by offering a system-wide view of subsurface moisture risks.

EarthWorks employs patented algorithms to convert L-Band SAR data into soil moisture content, enabling assessments of infrastructure and encompassing third-party areas like elevated hillsides above roads or railways that may impact infrastructure through potential failure events. With the capacity to map soil moisture over expansive areas (up to 3,500 km2 or 1,359 sq miles per image) without setting foot on site, EarthWorks significantly reduces the carbon footprint of inspection processes, while identifying both new and existing areas of concern for asset managers.

Ideally, seasonal or post-significant weather event image acquisition facilitates database accumulation over a monitoring period, considering the dynamic behavior of soils influenced by offsite land use changes. Regular monitoring offers the advantage of promptly detecting and addressing changes and emerging issues.

EarthWorks presents a grid-outlined soil moisture map (Figure 2), providing users with detailed information on soil moisture content within each cell. Categorized from Low to High, certain thresholds trigger alerts or alarms, notifying users of at-risk locations requiring attention. Users can access this information within ASTERRA's SaaS platform or export the data to any GIS system for further analysis.

EarthWorks' Application to Dam and Levee Infrastructure

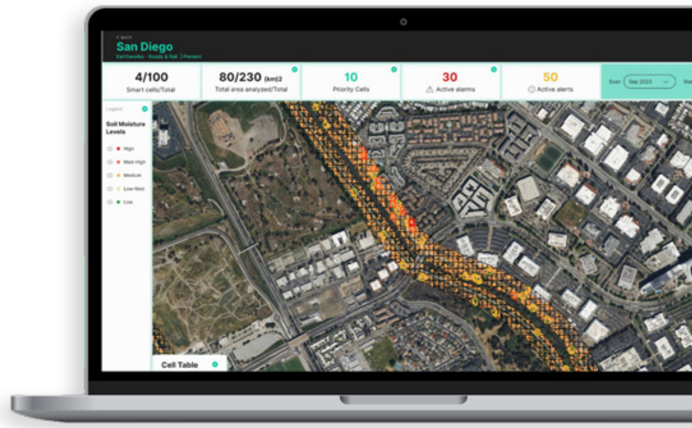


Figure 2. EO Discover platform by ASTERRA

Introduction to Dams and Levees

Dams and levees, crucial for water storage, flood control, recreation, and power generation, constitute critical infrastructure worldwide. However, they face various hazards such as flooding, storm surge, erosion, and equipment damage over their lifespan. Aging infrastructure is a significant concern, with dams in Japan and the UK averaging over 100 years old, while those in Germany, Italy, and the US have an average age between 60 and 70 years. The 50-year mark is often considered an "alert age" necessitating additional monitoring and maintenance to extend asset life. The construction boom of the 1950s-1970s saw approximately 1,100 dams built annually worldwide. The US, with approximately 92,000 dams, has an average dam age of 61 years, with 80% being earthen dams, and 76% considered high hazard potential.

The United States is also home to 6,972 levee systems, totaling 24,513 miles (39,450 km). These levees are typically designed to withstand specific flood sizes, but cannot eliminate flood risk entirely, as flood sizes are expressed as percentages of chance per year (e.g., 1% or once per 100 years). Primarily earthen embankments, levees may feature coverings like grass, gravel, stone, asphalt, or concrete. Failure can result from overtopping or breaching, caused by various factors including erosion, debris, ice flow, settlement, earthquakes, barge/boat strikes, or natural damage such as significant drought. Climate change is anticipated to exacerbate the risk of failure by altering storm event duration and intensity. With an average age of 58 years, US levees face growing repair costs estimated at around $100 billion.

Dam and Levee Failure

The majority of earthen dam and levee failures are caused by seepage that results in internal erosion and ultimately hydraulic or structural failure. Increased seepage increases the soil moisture content and impermeability of the structure can no longer be guaranteed. Internal erosion results in soil particles being carried downstream forming channels, increasing pore pressure, and initiating flow of interstitial water. These conditions all lead ultimately to failures. Seepage can occur through piping along outlet walls, abutments, or foundations. It can occur directly through embankments or due to the deposition of water-soluble materials. Seepage can also occur due to vegetation growth or burrowing animals. Since seepage is a hidden condition and that physical inspections are relatively rare events, being spaced out over years, a new way to determine if ongoing issues are inherent in earthen dams and levees is required to manage risks.

Slope Stability

Slopes along highways, earthen dams, levees, railroads, or those created during slope cut operations for building pads, as well as natural slopes, are all susceptible to water intrusion and potential failure. These slopes, which can stretch for miles, play a critical role in protecting or facilitating the construction of infrastructure in various terrains, necessitating continuous monitoring to predict failure.

Traditional monitoring methods struggle to cover the entire length of these extensive slopes effectively. Moreover, continuous monitoring is essential to detect changes in moisture content, a key indicator of slope stability. Stability hinges on ensuring that the soil's shear strength exceeds the shear stress that could trigger failure. Failure to meet this criterion may render the slope unstable. Ultimately, decreases in soil shear strength or increases in applied shear stress lead to slope failure. Various factors contribute to reduced shear strength, with particular significance attributed to the following:

- Increase in pore water pressure due to increase in groundwater table or upward seepage
- Fractures or tension cracks in soil at crest of slope
- Desiccation cracks on the slope
- Swelling of clayey soils
- Decomposition of clayey rock fills caused by water intrusion
- Creep under sustained loading
- Leaching water through voids in the soil
- Weathering caused by water, wind, or temperature changes

Additionally, various factors can affect the shear stress impacting a slope, including:

- Overloading at the top of the slope
- Removal of restricting load by cutting into the toe of the slope
- Water pressure in factures
- Increased soil weight caused by water seepage into slope causing increased water content
- Water level drop at base of slope reducing stability

As can be seen from this list of failure causes, most are the result of changes in water content of the soil in or around the slope.

EarthWorks for Dams and Levees

EarthWorks provides a remote inspection technique for assessing large linear zones of slopes, enabling the determination of soil moisture content and changes over time.

Using L-band SAR data and proprietary patented algorithms, EarthWorks generates high-resolution subsurface moisture maps along and around dams and levees. This data empowers owners and operators to proactively evaluate risks related to slope stability, leakage, internal erosion, and other geotechnical hazards months or years before surface signs become visible, leveraging the unique physical characteristics of the SAR wavelength. EarthWorks provides actionable insights, facilitating informed decision-making and resource allocation to anticipate failures, extend asset life, ensure safety, and proactively address issues. This not only saves money and time but also safeguards lives by helping to prevent failures.

This data can then be used to deploy additional monitoring methodologies to provide detailed inspections of areas identified as having high risk. These can be in-situ soil moisture monitors or devices to detect movement in slopes. The analysis provides early risk detection for asset deterioration.

Case Study:
Uniper Leverages EarthWorks for Enhanced Dam Assessment

Background

Dam safety is paramount, especially in regions like Sweden where freeze-thaw cycles and long-term wear can heighten seepage risks. Given that traditional monitoring methods have limitations, ensuring the safety and stability of dams in these regions requires innovative solutions and advanced monitoring to address these unique environmental challenges.

Challenge

Uniper, a global energy leader, faced this challenge with the Lövön Dam in Sweden. While they had existing instrumentation and sensors, they sought to improve assessment accuracy.

Solution

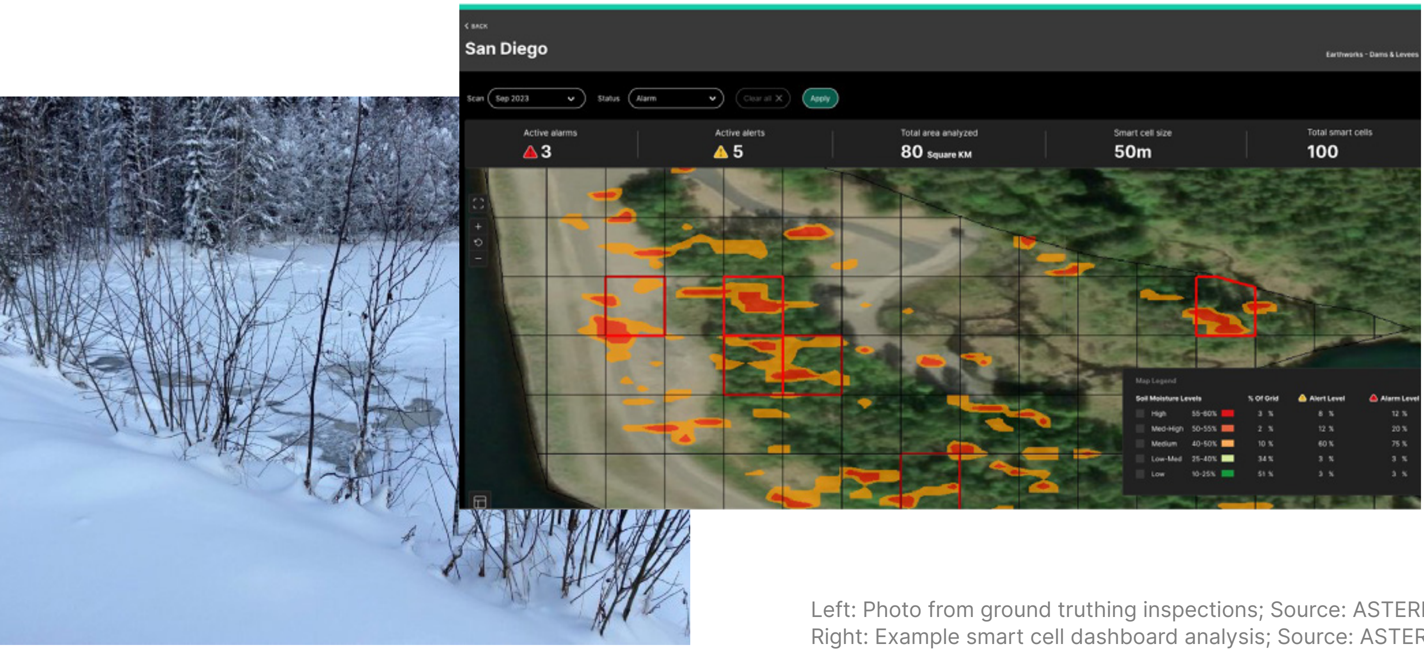
Uniper enlisted ASTERRA EarthWorks to evaluate the dam, aiming to identify areas with elevated concentrations of subsurface soil moisture potentially linked to seepage.

EarthWorks provides a valuable data layer to gain an overview of an entire area and identify at-risk areas. EarthWorks' smart cell system established a digital grid to monitor individual areas for soil moisture levels exceeding pre-set alert or alarm thresholds, enabling early warnings for Uniper to address potential issues proactively. Despite harsh winter conditions, EarthWorks' L-Band SAR analysis effectively penetrated snow cover, capturing soil moisture data within the dam. This analysis identified several areas with potentially elevated seepage, prompting the alert system to notify operators of at-risk zones.

This proactive approach directed field crews to specific sites around the dam for seepage inspection. Despite the snow blanket, field inspections revealed unmistakable signs of seepage, evidenced by localized snowmelt due to temperature differentials from water exfiltration. This alignment of EarthWorks' smart cell alarms with areas of higher temperatures identified by existing dam instrumentation enhanced Uniper's confidence in the accuracy of the L-band SAR data.

Conclusion

By detecting areas exceeding soil moisture thresholds, EarthWorks signifies potential problems before they escalate. This allows for optimized resource allocation, prioritizing inspections and interventions in at-risk areas. The Lövön Dam case study is a compelling demonstration of EarthWorks' effectiveness in enhancing dam safety. It not only confirmed existing concerns but also unveiled new areas requiring attention. These actionable insights empower dam operators to make informed decisions for proactive dam management and ensure safety.



Left: Photo from ground truthing inspections; Source: ASTERRA
Right: Example smart cell dashboard analysis; Source: ASTERRA

Smart cells in yellow (alert) and red (alarm) highlighting areas of concern, whilst in blue are known areas of seepage.
Source: ASTERRA

Case Study:
GCWA Addresses Levee Challenges with EarthWorks

Background

The Gulf Coast region encompasses a levee system spanning over 100 miles, crucial for canal networks and water distribution facilities serving its citizens.

Challenge

The Gulf Coast Water Authority (GCWA) faced significant challenges, including the high costs associated with monitoring, inspecting, and maintaining these levees. There were growing concerns about potential infrastructure failures, which could endanger lives, disrupt safety, and lead to severe environmental and financial repercussions, considering the region's history of flood events and levee breaches.

However, the primary concern for GCWA was about water loss. The canal system serves as a conduit for transporting water, making any seepage into the sidewalls tantamount to a loss of saleable product. Across the extensive canal network, such seepage translates into a substantial annual loss of product.

Solution

In response to these challenges, GCWA turned to ASTERRA's EarthWorks solution as part of its ongoing efforts to address longstanding issues.

EarthWorks rose to the challenge of analyzing the extensive Gulf Coast canal system using three satellite scans. Leveraging L-Band SAR data, EarthWorks assessed the entire network, providing GCWA with a soil moisture map. The map highlighted areas with elevated soil moisture levels, providing crucial insights into potential areas of concern and possible water loss for GCWA. This valuable insight empowers GCWA to allocate resources effectively, reducing the need for extensive manual inspections throughout the canal system.

Historically, GCWA relied on visual inspections, necessitating thorough surveys along the entire canal system. However, this subjective approach proved inefficient, as interpretations varied among engineers. EarthWorks' introduction revolutionized the process, providing objective data for targeted assessments.

Initial results from the GCWA project are promising, with on-site verification confirming areas of hydrophilic vegetation indicative of water ingress into embankments, as identified by L-Band SAR. Ongoing data analysis continues to pinpoint areas of interest, optimizing the inspection team's daily operations for greater efficiency.

Therefore, EarthWorks not only identifies areas of potential risk but also highlights regions where product loss occurs, allowing GCWA to address both operational and infrastructure integrity concerns. Beyond monitoring, EarthWorks demonstrates its utility as a water conservation tool within canal systems, offering clients tangible ROI insights alongside comprehensive infrastructure integrity data.

Conclusion

EarthWorks provides invaluable early risk detection for asset deterioration, enabling infrastructure asset owners and engineers to concentrate their maintenance and inspection efforts effectively. Leveraging SAR technology, EarthWorks offers a swift and cost-effective solution for monitoring large areas. It's capable of detecting changes in soil moisture at various depths, providing crucial insights into potential geotechnical failure. Unlike physical inspection methods that only offer surface observations, EarthWorks' remote sensing capabilities allow for a more comprehensive assessment.

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