

REAL-TIME ENVIRONMENTAL MONITORING

[Environmental monitoring](#) is more critical than ever to the protection of our health and the health of the environment. As the human population continues to increase and industrial development continues to expand, energy use is surging and pollution is posing a major threat to the environment. Both world and community leaders and scientists are increasingly turning to advanced technology and data science to help quantify and mitigate the impact of human activity on the environment.

Despite advances in pollution control in recent years, the [Intergovernmental Panel on Climate Change's 2021 climate change report](#) served as a stark warning to leaders that policy changes must be enforced expeditiously to mitigate the unprecedented environmental changes already set in motion. As each new year ushers in a slew of record-breaking floods, wildfires, hurricanes, and global temperatures, it is all the more urgent to employ environmental monitoring methods and data science to gain full visibility of our activities on the environment.

Innovations in technology, in combination with data science, have introduced real-time environmental monitoring systems, which incorporate modern real-time sensor networks, the Sensor Observation Service (SOS), Geographic Information Systems (GIS), telemetry systems, machine learning techniques, the Internet of Things, [predictive analytics](#), and other technologies to gather and statistically analyze environmental data in real-time. This real-time data is used to make predictions and inform time-critical decisions related to environmental conditions.

A major benefit of the proliferation of real-time environmental monitoring is accountability. Our ability to conduct environmental monitoring and impact assessments in some of the most remote corners of the world ensures corporate compliance and adherence to government regulations. Real-time monitoring helps agencies and enterprises set environmental performance goals and emission reduction targets, and create environmental monitoring reports to track their progress.

Another major benefit is the improvement of [disaster response](#) and preparedness. Disaster management data collection and [emergency management](#) software facilitate innovative emergency management endeavors such as crisis mapping, social media mining, and event simulations, which use enormous volumes of real-time and historical data to assist emergency management directors and their teams in developing proactive, protective strategies, such as flood warning systems.

The technologies used in real-time environmental monitoring systems include a wide variety of hardware, software, and methodologies. Some of the most common technologies include:

Real-Time

Sensor

Networks:

A dispersed group of environmental sensors monitor and record the conditions of an environment, and stream data in real-time over the Internet via their own API or bespoke connection. Once data is transmitted to a data center, it is subject to anomaly detection, which identifies potentially inaccurate data produced from compromised monitoring devices. Typically a stream-based importer is used to ingest data into a database.

Analytics Platforms:

Provides a centralized location where massive GIS datasets can be ingested, queried, visualized on a granular level, and analyzed at scale in real-time. An accelerated analytics platform features [interactive data visualizations](#), and allows analysts to cross-filter billions of [geospatial](#) data records and polygons alongside other features in milliseconds.

Sensor Observation Service:

A web service to query real-time sensor network data and sensor data time series, and applicable to use cases in which real-time sensor data streams need to be managed in an interoperable way. SOS allows querying observations, real-time sensor metadata, as well as representations of observed features. Standards are defined by the Open Geospatial Consortium.

Geographic Information Systems:

[GIS](#) are computer and software tools for gathering and analyzing data connected to geographic locations and their relation to human or natural activity on Earth. GIS mapping software uses spatial data to create maps and 3D models out of layers of visual information, revealing patterns and relationships in the GIS data. [Remote sensing](#) data is pulled from sources like USGS Earth Explorer and the Socioeconomic Data and Applications Center.

Telemetry Systems:

Telemetry is the automatic in situ recording of measurements or other data at remote points and their transmission to receiving IT equipment at a different location. Common options include cellular, radio, or satellite. Telemetry platforms are appropriate for a variety of remote, real-time monitoring applications.

The Internet of Things:

IoT based environmental monitoring enable us to visualize, monitor, and control crucial phenomena in the environment with the use of devices that can sense, process, and wirelessly transmit data to remote storage such as the cloud, where data can be stored, analyzed, and presented in a valuable way.

Machine Learning:

Data history is recorded with data science tools like Pandas inside a Notebook environment. Machine Learning models can then be implemented as a way of infilling or back painting missing data. Deep learning algorithms have revolutionized the ability to detect complex objects in imagery, such as wisps of clouds. A human element is still necessary, a role filled by an environmental monitoring technician.

Real-time environmental monitoring applications:

The practical applications of real-time environmental monitoring are vast and varied. Wildfires, landslides, flooding, biodiversity, and waste and pollution are all issues of increasing concern as the climate crisis is predicted to worsen in coming years. Wildfire monitoring systems have been particularly useful in 2020, which saw a record-setting number of wildfires ravage California.

Real-time sensor data combined with data science and advanced analytics tools facilitate high visibility and granular analysis of environmental phenomena. The most common environmental monitoring types include air, soil, and water:

Air quality monitoring:



[Air pollutants](#) are atmospheric substances—both naturally occurring and [anthropogenic](#)—which may potentially have a negative impact on the environment and [organism](#) health. With the evolution of new chemicals and [industrial processes](#) has come the introduction or elevation of pollutants in the atmosphere, as well as environmental research and regulations, increasing the demand for air quality monitoring.

Air quality monitoring is challenging to enact as it requires the effective integration of multiple environmental data sources, which often originate from different environmental networks and institutions. These challenges require specialized observation equipment and tools to establish air pollutant concentrations, including sensor networks, [geographic information system](#) (GIS) models, and the Sensor Observation Service (SOS), a web service for querying real-time sensor data. [Air dispersion models](#) that combine topographic, emissions, and meteorological data to predict air pollutant concentrations are often helpful in interpreting air monitoring data. Additionally, consideration of [anemometer](#) data in the area between sources and the monitor often provides insights on the source of the air contaminants recorded by an air pollution monitor.

Soil monitoring:



Soil monitoring involves the collection and/or analysis of [soil](#) and its associated [quality](#), [constituents](#), and physical status to determine or guarantee its fitness for use. Soil faces many threats, including [compaction](#), [contamination](#), [organic material](#) loss, [biodiversity loss](#), [slope stability](#) issues, [erosion](#), [salinization](#), and [acidification](#). Soil monitoring helps characterize these threats and other potential risks to the soil, surrounding environments, animal health, and human health.

Assessing these threats and other risks to soil can be challenging due to a variety of factors, including soil's [heterogeneity](#) and complexity, scarcity of [toxicity](#) data, lack of understanding of a contaminant's fate, and variability in levels of soil screening. This requires a risk assessment approach and analysis techniques that prioritize environmental protection, risk reduction, and, if necessary, remediation methods. Soil monitoring plays a significant role in that risk assessment, not only aiding in the identification of at-risk and affected areas but also in the establishment of base background values of soil.

Soil monitoring has historically focused on more classical conditions and contaminants, including toxic elements (e.g., [mercury](#), [lead](#), and [arsenic](#)) and [persistent organic pollutants](#) (POPs). Historically, testing for these and other aspects of soil, however, has had its own set of challenges, as sampling in most cases is of a [destructive](#) in nature, requiring multiple samples over time. Additionally, procedural and analytical errors may be introduced due to variability among references and methods, particularly over time. However, as analytical techniques evolve and new knowledge about ecological processes and contaminant effects disseminate, the focus of monitoring will likely broaden over time and the quality of monitoring will continue to improve.

Water quality monitoring:



Water quality monitoring is of little use without a clear and unambiguous definition of the reasons for the monitoring and the objectives that it will satisfy. Almost all monitoring (except perhaps [remote sensing](#)) is in some part invasive of the environment under study and extensive and poorly planned monitoring carries a risk of damage to the environment. This may be a critical consideration in wilderness areas or when monitoring very rare organisms or those that are averse to human presence. Some monitoring techniques, such as [gill netting fish](#) to estimate populations, can be very damaging, at least to the local population and can also degrade public trust in scientists carrying out the monitoring.

Almost all mainstream environmentalism monitoring projects form part of an overall monitoring strategy or research field, and these field and strategies are themselves derived from the high levels objectives or aspirations of an organisation. Unless individual monitoring projects fit into a wider strategic framework, the results are unlikely to be published and the environmental understanding produced by the monitoring will be lost.

Freshwater environments have been extensively studied for many years and there is a robust understanding of the interactions between chemistry and the environment across much of the world. However, as new materials are developed and new pressures come to bear, revisions to monitoring programmes will be required. In the last 20 years [acid rain](#), synthetic [hormone](#) analogues, [halogenated hydrocarbons](#), [greenhouse gases](#) and many others have required changes to monitoring strategies.