HUB TECH IA

Deliverable report 52

AI and IAGEN Application Use Case

Real-time monitoring of water sources in Vaca Muerta

I. Introduction

Vaca Muerta, located in the province of Neuquén, Argentina, represents one of the the world's largest reserves of unconventional hydrocarbons. Their exploitation Intensive farming, while offering significant economic potential, poses challenges crucial environmental issues, especially with regard to the management and quality of water resources.

Hydraulic fracturing operations require substantial volumes of water. freshwater and generate potentially polluting effluents, including sewage return loaded with chemicals and heavy metals, which has intensified the concern for the sustainability of water sources in the region.

Traditional water quality monitoring methods, based on mainly in periodic sampling and laboratory analysis, present inherent limitations in addressing the complexity and scale of potential environmental impacts in real time. The vast geographic extent of the activity hydrocarbon and the dynamic nature of the pollution processes require a more advanced and adaptable monitoring approach.

In this context, Artificial Intelligence (AI) emerges as a set of transformative technologies with the ability to significantly improve the depth, efficiency, proactivity and scalability of data monitoring water quality in this critical region. AI, which encompasses machine learning, deep learning, computer vision, and language processing natural, offers essential advanced analytical and automation tools for sustainable management of water resources in Vaca Muerta.

Nowadays, generative artificial intelligence, which has a special relevance, with the potential to further optimize the tasks it impacts. Generative Artificial Intelligence (GENI) is a branch of artificial intelligence that focuses on the creation of new content, such as models, images, code, or Text, based on existing data. This technology uses advanced algorithms to analyze large amounts of information, identify patterns, and generate content new and original that is often indistinguishable from that created by humans.

The combination of agents with generative AI models facilitates the automation of production processes and can be used in the activity to the one referred to in this report, as will be seen.

The need for continuous and intelligent monitoring becomes increasingly important. evident as unconventional hydrocarbon extraction continues expanding.

II. Current status of water monitoring in vaca muerta

Currently, the province of Neuquén has quality control programs water linked to the development of Vaca Muerta. Since 2013, a Periodic monitoring at critical points in the Neuquén River basin, including reservoirs used by industry (such as Barreales and Mari Menuco), with quarterly sampling at 21 strategic sites.

The use of sensors allows real-time reporting of variables such as pressure and injection flow, facilitating permanent monitoring of the conditions of final disposal of production water. During field campaigns, technicians Provincial authorities verify the accuracy of this data online against direct measurements, to ensure the reliability of the information.

These actions indicate that there is already a system in operation for remote monitoring of certain aspects of water quality (mainly linked to effluents industrial), complemented by projects in planning to expand the coverage and depth of controls (e.g., extension of networks of sensors in surface water bodies and new sampling stations in other basins).

In summary, the current state combines traditional periodic sampling methods with operational telemetry systems (in effluent wells) and initial steps toward real-time environmental sensor networks.

III. AI-powered water resource monitoring

The modernization of water monitoring in Vaca Muerta not only involves sensors, but also new data analysis methodologies. This is where the Artificial Intelligence (AI) is beginning to play a transformative role. The combination Sensors + AI allows handling massive volumes of information in real time and extract useful knowledge from them.

The deployment of integrated sensor networks and the use of the Internet of Things (IoT) are essential for the continuous, high-frequency collection of diverse water quality data in the extensive Vaca Muerta area.

Modern, low-cost sensors can constantly monitor a wide range of range of critical parameters, including physical characteristics such as temperature, turbidity and conductivity; chemical properties such as pH, dissolved oxygen, Salinity and the presence of specific ions and hydrocarbons; and even biological indicators, providing a much more detailed view of water quality. compared to periodic sampling. Advances in sampling technology Sensors include multiparameter probes and optical sensors, which, when combined With AI algorithms, they can offer immediate responses to events pollution.

Additionally, machine learning algorithms can correlate field measurements with external factors (rainfall, seasonality, nearby operations) to identify emerging pollution patterns.

Machine learning algorithms, trained on historical data, can learn normal operating baselines and natural variability water quality parameters, allowing them to point out even subtle deviations that could indicate pollution events (e.g., spills chemicals, leaks from fracking operations) or errors in the sensors.

An AI system could detect that an atypical increase in turbidity in a certain stream coincides with a recent hydraulic fracture upstream, or that variations Conductivity tests are related to saline discharges, issuing alerts before the problem worsens. In this way, AI provides an alert capability Early predictive, anticipating risk scenarios and recommending actions data-driven corrective measures.

In practice, we are moving towards intelligent *mass monitoring networks :* multiple Sensors distributed throughout the basin send data to a central platform, where Advanced algorithms analyze them in real time and trigger alarms if any parameter goes out of acceptable range. This increases the effectiveness compared to methods manuals, allowing immediate response to, for example, a chemical spill detected or an anomaly in the quality of groundwater.

There is no doubt that the synergistic integration of AI with sensor data in real time facilitates a critical shift from reactive environmental management to proactive in Vaca Muerta. This allows for immediate identification and response to pollution events, which could mitigate widespread contamination and protect vital water resources for both industrial and community use.
AI's ability to analyze data in real time enables a response timely response to environmental incidents, minimizing potential damage.

Another complementary technology is remote sensing using satellite images and drones. In large areas like Vaca Muerta, satellites (e.g., Sentinel-2) can help monitor indirect indicators: changes in the color of water bodies (signs of sediment or algae), or in the surrounding humidity/vegetation (possible leaks in waste ponds). In fact, the aforementioned *ObservAR* platform leverages satellite data combined with geological information.

to map areas of greatest risk of aquifer contamination due to proximity to wells.

Drones, for their part, could be equipped with sensors to fly over hard-to-reach waterways, taking measurements or thermal images in search of irregularities. These current methodologies – traditional sampling, IoT sensors, AI analysis, remote sensing and drones – are not mutually exclusive but complementary.

The use of computer vision and AI-driven analysis of remote sensing data, including satellite and aerial imagery (from drones and aircraft), represents a breakthrough for the detection, tracking and identification of sources of contamination events in the Vaca Muerta region.

High-resolution satellite images can be used to monitor Changes in water quality indicators (e.g., chlorophyll-a, turbidity, total suspended solids), detect the presence of oil slicks in surface water bodies, and assess the overall health and extent of vegetation

riparian, which plays a crucial role in maintaining the quality of the water.

On the other hand, the implementation of predictive maintenance strategies in the The oil and gas industry, where AI algorithms analyze sensor data from equipment (e.g., pipelines, storage tanks) to predict potential failures, offers significant benefits. For example, AI systems

AI can analyze vibration data from pumps or monitor pressure of filters to predict maintenance needs before a failure affect water management processes. AI-powered predictive modeling It has also demonstrated superior performance in predicting levels of groundwater and the risks of contamination.

In an optimal strategy, they would be used together. Sensors and AI provide continuous, panoramic monitoring, while traditional laboratories and sampling provide detailed confirmation and complex parameters (e.g., presence of traces of hydrocarbons, bacteria, radionuclides) that cannot yet be measured.
automatically on site.

The use of predictive analysis in water monitoring in Vaca Muerta will allow a transition from reactive responses to proactive environmental management. predict possible contamination events and equipment failures, Operators and regulators can implement preventive measures, optimize the allocation of resources for maintenance and mitigation, and ultimately, minimize the environmental footprint of energy production. The capacity of AI to predict groundwater levels and contamination risks allows proactive interventions.

IV. AI Agents and Agentic Workflows. The Evolution of Generative AI.

1. Concept of IAGEN agents

In recent years, generative artificial intelligence (GAI) has revolutionized the way we interact with technology, allowing the development of systems capable of generating content, answering complex questions and assisting in high-demand cognitive tasks.

Generative Artificial Intelligence (GENI) is a branch of artificial intelligence that focuses on the creation of new content, such as models, images, code or text, from existing data. This technology uses advanced algorithms to Analyze large amounts of information, identify patterns, and generate content new and original that is often indistinguishable from that created by humans.

From this capacity, a new technological architecture emerges: agents powered by IAGen. These agents are not simple conversational interfaces, but autonomous systems that can interpret instructions, make decisions, perform tasks and learn from their interactions with the environment.

An IAGen agent combines large language models with components additional features such as external tools, memory, autonomous planning and execution. This allows them to operate in complex environments, with the ability to break down objectives into steps, coordinate multiple actions, interact with digital systems (such as databases, APIs, or documents) and adapt to changes in context in real time. These qualities distinguish them from traditional chatbots, and open up a spectrum of more sophisticated and customizable.

At the organizational level, these agents are being used to automate processes, generate data analysis, assist in decision making and improve the user experience, both internally and externally. For example, they can take on human resources, legal, financial or logistical tasks, and even, linked to the technical areas of production processes, acting as assistants intelligent devices that collaborate with human teams. This ability to integrate knowledge and execute tasks autonomously transforms the way in which Organizations can scale their operations without losing quality or control.

In addition, agentic workflows—structures where multiple agents collaborate with each other to solve complex problems—allow responsibilities to be distributed between different agent profiles, each with specific functions. This generates Hybrid work environments where humans and agents coexist, optimizing times, costs, and results. The ability to connect agents with tools such as Google Drive, CRMs or document management platforms further expands their capabilities.

The development of IAGen-powered agents represents a crucial step towards a new era of intelligent automation.

Among the benefits of authentic workflows driven by business models generative artificial intelligence, the possibility of automating processes is found complete, end-to-end production systems, and even add value from the leveraging the skills of language models based on these technologies.

However, its implementation also poses technical, ethical and legal, from responsible design to human oversight. Therefore, Understanding its architecture, its operational logic and its potential impacts is essential for its effective and safe adoption in various contexts professionals.

V. Agents powered by IAGEN

Main objective:

Detect, alert and recommend actions in the event of possible contamination events water or operational inefficiencies in Vaca Muerta, using AI and integration of real-time data.

a. Workflow design proposal

Agent capabilities:

1. **Real-time monitoring**

    - Connection to IoT sensor networks to capture parameters such as turbidity, pH, oxygen, salinity, etc.

    - Continuous reading of data in reservoirs, streams, injection wells, etc

2. **Analysis with AI (Machine Learning and Computer Vision)**

    - Anomaly detection by comparing current vs. historical data.

    - Detection of spots, discolorations and suspicious changes in bodies of water using satellite images and drones.

3. **Alerts and predictive actions**

    - Automatic issuance of alerts in case of events outside of parameters.

- Recommendation of actions (stop operations, check valves, etc.).

4. **Automatic reports for authorities and companies**

    - Periodic reports in PDF or interactive web.

    - Access for different users (regulators, operators, communities).

5. **Suggestions for optimizing water use**

    - Identification of opportunities for reuse of treated water.

    - Efficient planning of the use of reservoirs and aqueducts.

6. **Legal and Social License Module**

    - Monitoring regulatory compliance.

    - Publication of open data to strengthen citizen trust.

Expected inputs from the agent:

- Sensor readings (temperature, turbidity, pH…).

- Satellite images (e.g. Sentinel-2) and drones.

- Operations data (fracturing, reinjection, waste transport).

- Current regulations and critical environmental thresholds.

Outputs generated:

- Early alerts via email, app, or dashboard.
- Automatic reports (PDFs, dashboards).
- Water risk heat maps.
- Diagnosis of probable source of contamination.
- Suggestions for predictive maintenance.

Suggested technology:

- **Backend:** Python + FastAPI
- **Frontend:** React or Streamlit for dashboards
- **AI:** ML models for anomaly detection and image classification
- **Databases:** PostgreSQL + TimescaleDB (temporary data)
- **Connectivity:** MQTT or HTTP for IoT
- **Integrations:** Sentinel Hub API, drones, ObservAR, etc.

VI. Main challenges in monitoring water sources

Real-time monitoring of water in Vaca Muerta entails significant challenges. of a technical, geographical and institutional nature. One of the first obstacles is the

Spatial and logistical coverage: hydrocarbon activity is expanding over a large, semi-arid territory, where water sources (rivers, streams and aquifers) are dispersed. Effective monitoring requires multiple control points. For example, in Neuquén alone there are almost 140 effluent injection wells periodically tour and audit, many in remote areas. The teams Inspection personnel must move *well by well* and comply with safety protocols in each site, so a complete campaign can take months.

This reality highlights the need to automate and prioritize: without systems Remote, manual monitoring is arduous and costly in time and resources Humans. Installing sensor networks in the field is one solution, but it involves infrastructure challenges (power supply with solar panels, connectivity in areas with poor signal) and constant maintenance to ensure reliable readings. Another major The challenge is the availability of baseline data and continuity in monitoring.

This lack of *a baseline* makes it difficult to assess changes: without robust historical data, It can be complex to discern whether an alteration in water quality is due to new activity or previous liabilities.

Transparency is crucial to building trust; however, until now much information remains in internal technical reports or dispersed among agencies. Optimizing monitoring will require integrating different data sources (provincial, corporate, academic) into accessible platforms, something that is beginning to be promoted with open tools (e.g., the *ObservAR* platform proposed by researchers to centralize data on wells and environmental risks).

Institutional and regulatory challenges are also notable. The region involves Overlapping jurisdictions: Neuquén regulates its territory, but the water basins are shared with Río Negro and other provinces. If each province imposes different standards or lack of coordination, gaps arise – for example, *“if Neuquén approves and monitors the wells on its side of the river, the impacts can move to the Río Negro side.”*

This requires integrated basin management, aligning criteria and efforts of interprovincial monitoring. Likewise, in a context of accelerated growth of industry, local regulatory bodies must strengthen their technical capacity and budget to cover the growing demand for environmental control. The Implementing advanced technologies requires investment and training; ensuring sustainable financing is a challenge in itself.

In summary, the main challenges include: the necessary monitoring density (many scattered points), the lack of historical data and public access, the regulatory coordination between entities, and the technical/economic limitations for deploy wide-ranging continuous monitoring.

VII. Environmental impact and operational optimization

The main objective of water monitoring in Vaca Muerta is to prevent impacts environmental risks and mitigate those that may occur. Among the known risks is the contamination of aquifers or rivers by spills of hydrocarbons or chemicals, whether from the surface (by accidental spill from flowback pools, transport of waste, etc.) or from the subsoil (due to a leak in a poorly cemented well).

There is also concern about the possible impact on water availability for other uses. (agriculture, human consumption) if the industry extracts excessive volumes or contaminates existing sources. Through monitoring programs implemented, no significant contamination has been detected so far in water for human use in the immediate area of influence: official sampling in the Neuquén River basin concluded that the water remained *"fit for consumption" human".*

This data provides reassurance, but must be interpreted with caution: the absence of serious contamination at the moment does not guarantee that it cannot occur, hence the importance of continuous monitoring.

On the other hand, environmental events have been recorded that underline the value of monitoring. For example, in 2018 a blowout incident in a non-existent well conventional generated soil spills that required remediation; dispose of

Constant vigilance helps ensure that if something like this happens again, immediate action can be taken. before it reaches waterways.

Additionally, monitoring allows for the observation of longer-term effects, such as the possible accumulation of salts or chemical traces in shallow aquifers due to to constant reinjection. While companies must confine effluents in very deep formations, monitoring of nearby water wells will confirm over time that there is no unwanted migration.

In short, a robust monitoring program minimizes the risk of irreversible impacts, protecting both aquatic ecosystems (flora, fauna, functions ecological conditions of rivers) as well as the health of communities that depend on water.

In addition to protecting the environment, real-time information about water provides operational benefits to the industry and the regulator. Tight control of variables how pressure and flow in injection wells has allowed deviations to be detected or suboptimal practices: for example, if an operator exceeds the injection rate permitted, the online system can alert and prevent damage to the training geological or induced earthquakes.

Likewise, knowing in real time the availability of water in certain reservoirs or aqueducts can help plan fracturing operations more efficiently. efficient, avoiding simultaneous withdrawals of large volumes that lower the level of a lake. AI applied to this operational data can optimize processes such as water reuse: using algorithms, it is possible to identify which fractions of water return water (already treated) meets conditions to be reused in new fractures, reducing the demand for fresh water. Neuquén has emphasized that final disposal (injecting for disposal) should be the *last resort,* prioritizing reuse to the greatest extent possible.

Thanks to monitoring, the quality and volume of water produced are verified. available for recycling. A collaborative scheme is even being explored where *"a company can use the water treated by another",* which requires traceability and trust in quality data: here a monitored and audited system is vital so that different operators to exchange water safely. In practice, optimizing the Water use not only has a positive environmental impact (lower net extraction and less discarded effluent) but also reduces costs for companies (less water transportation and less disposal fees).

Finally, robust monitoring reduces the likelihood of major incidents that stop production. If contamination is detected in time at a point downstream control, corrective measures can be taken in the operation upstream before it becomes a legal issue or a costly cleanup.

This protects the *social license to operate:* communities and authorities will be more willing to support the development of Vaca Muerta if they see a commitment tangible with water care, supported by open data and monitoring constant. In short, operational and environmental optimization go hand in hand: investing Continuous monitoring with AI support improves the efficiency of resource use water and reduces risks, contributing to a more sustainable exploitation and competitive.

VIII. Conclusions

Real-time monitoring of water quality in Vaca Muerta is emerging as a key piece to balance energy growth with protection environmental and responsible water management. There are currently programs underway – from periodic sampling in rivers and reservoirs, to remote sensing in wells

injection – which lay the foundation for a comprehensive water monitoring system in the region.

However, significant challenges remain: expanding monitoring coverage to all relevant water sources, improve inter-institutional coordination, and ensure data transparency so that it is credible and useful for both authorities and citizens. Modern technologies offer solutions promising; in particular, the application of IoT and artificial intelligence can lead monitoring from a reactive to a proactive and predictive modality, capable of anticipate problems and optimize water use in operations.

Going forward, a strategic and practical approach will be to integrate all of these elements: strengthen the specific regulatory framework for water control in unconventional developments, deploying real-time sensor networks in critical points of Vaca Muerta, take advantage of AI algorithms to process the information in large control centers, and encourage citizen participation through open and accessible data.

The examples analyzed show that Neuquén is already moving in that direction, with water conservation plans that incorporate advanced technology and scientific and technical collaboration. In short, smart water management in Vaca Muerta will not only mitigate the environmental impact and safeguard a vital resource, but will also will optimize oil operations, providing long-term stability. With With continuous monitoring, clear standards and AI support, Vaca Muerta can be a model responsible energy development, where the protection of water sources goes hand in hand with industrial efficiency and sustainability.

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