Deliverable report 51

AI and IAGEN Application Use Case

Environmental Risk Assessment in Water Management in Vaca Muerta, Neuquén

I. Introduction

The Vaca Muerta formation represents one of the most significant unconventional hydrocarbon reserves in the world, positioning Argentina as a key player in the global energy landscape. Its development is considered a national strategic priority, with projections pointing to energy self-sufficiency and significant export revenues, which could transform the country's economy.

However, this expansion of hydrocarbon activity poses complex environmental challenges, particularly in water resource management, which require comprehensive attention to ensure long-term sustainability. This report delves into the environmental issues associated with water management in Vaca Muerta, analyzes the limitations of conventional monitoring practices, and explores the transformative potential of artificial intelligence (AI) to improve environmental monitoring and protection in this crucial region.

In this context, AI applied to the analysis of geospatial, hydrological, and operational data offers an unprecedented opportunity to strengthen environmental risk assessment and optimize real-time decision-making.

Below, we detail a specific use case for AI in risk assessment and regulatory compliance for water management in Vaca Muerta, describing the identified challenges, AI-based solutions, potential benefits, and recommendations for effective implementation.

II. Opportunities to improve environmental water management through AI

Artificial intelligence offers a significant opportunity to transform environmental water management in Vaca Muerta, enabling a shift from a reactive to a proactive and preventative approach. By analyzing large volumes of data in real time, AI can generate early warnings and actionable insights, facilitating the detection and correction of deviations before they escalate into larger problems.

1. Intelligent geospatial analysis: Using GeoAI (AI-powered GIS) techniques, models are trained to identify patterns and changes in satellite images that could indicate environmental activities or impacts.

This system can be useful for mapping the annual expansion of wells and estimating their water consumption, even though industrial data were scarce.

2. Sensor monitoring and IoT with anomaly detection: Multiple sensors are already operating in the Vaca Muerta fields: flow and pressure meters at wellheads, pressure sensors in pipelines, pH meters and conductivity meters at water treatment plants, weather stations, etc.

AI leverages these real-time data streams by applying *machine learning techniques* to detect anomalies or subtle deviations that might otherwise go unnoticed. For example, an anomaly detection model (such as isolation forests or *autoencoders* trained on normal patterns) can identify atypical increases in the electrical conductivity of groundwater monitored near a well, which would suggest incipient contamination.

Similarly, a LSTM (long short-term memory) neural network trained on historical injection pressure data from sump wells could predict anomalous variations that indicate a potential failure in the well's integrity (pipe cracks, for example). When an alert is triggered, the system immediately notifies those responsible so they can investigate and take preventive measures before a major incident (such as an aquifer leak) occurs.

3. Predictive models and trend detection: Beyond alerting on anomalies in real time, AI can uncover long-term trends that aid in planning and prevention. Supervised learning algorithms can analyze historical data on operations and environmental outcomes to predict areas or times of greatest risk.

A model might indicate that certain patterns (such as a high density of fractures in an area with geological faults near the river) correlate with a higher probability of microseisms or leaks, allowing the company to strengthen monitoring there. Likewise, AI can optimize water management itself: through optimization and reinforcement learning techniques, it can recommend strategies for reusing fracturing water or optimal injection times in sinkholes to minimize impacts (for example, avoiding injection during river floods to avoid adding stress to the basin). These models incorporate multiple variables (climate, operation, geological characteristics) to inform operational decisions that keep production within safe and sustainable parameters.

4. Integrated platforms and intelligent dashboards: The practical application of the above is often embodied in digital platforms that integrate all data streams and AI algorithms, presenting clear information to users.

In this way, environmental engineers and managers can visualize the environmental status of the entire site on a unified dashboard: the levels of each waste pond, the quality of downstream surface water, the performance of treatment plants, etc., with AI-calculated indicators that simplify complexity. For example, a *dashboard* could display a "water compliance index" for each operational area, calculated based on metrics such as the percentage of water reused, quality deviations from standards, alerts addressed, etc.

Technically, applied AI includes a range of methods: anomaly detection algorithms (statistical and *machine learning*), convolutional neural networks (CNNs) for satellite image analysis, time series models for forecasting (e.g., Facebook's *Prophet* or

LSTM), and supervised machine learning systems for event classification (normal vs. incident). These tools run on data infrastructures that can be *cloud* -based or hybrid, since handling satellite images or IoT streams in real time requires scalability.

Additionally, digital twins that simulate water flow and the dispersion of subsurface contaminants, calibrated with AI based on real data, can be incorporated to predict how a contaminant might spread if a leak occurs in a certain geological stratum.

In short, AI acts as a "digital environmental watchdog" at Vaca Muerta: it constantly absorbs disparate and complex data and applies intelligence to reveal what the human eye or traditional methods miss in time. This allows managers to react quickly to any warning signs and adjust operations to avoid damage. Let's now look at the concrete benefits this AI application brings, both operational and strategic.

III. Comparison with traditional methods and key improvements of AI

The adoption of AI in environmental management marks a paradigm shift from traditional methods. Below, we compare the two approaches at critical points, highlighting the improvements AI brings:

- Monitoring coverage: Traditionally, surveillance relied on scheduled inspections and spot sampling (e.g., personnel walking locations with checklists or taking water samples monthly). Large areas were left without direct observation for days or weeks. With AI, monitoring is continuous and ubiquitous.
- Speed of detection and response: Previously, a problem could be detected only during the next inspection round or when someone noticed a visible change (dead fish, oil slick, etc.). That delay allowed a small incident to escalate into a disaster. Now, AI dramatically accelerates detection. For example, an anomalous change in a sensor triggers an immediate alarm to the control center. Instead of days, the response begins within minutes.
- Accuracy and volume of data analyzed: Manual methods are prone to human error and limited in the amount of data they can process. An analyst can overlook subtle correlations or trends when reviewing spreadsheets or

graphs. AI, on the other hand, handles large volumes of heterogeneous data with high accuracy, finding needles in haystacks of information. For example, it can correlate years of meteorological, operational, and water quality data to discover a pattern that indicates increasing risk in a certain area, something practically impossible to achieve without automation.

Integration of multiple variables: Traditionally, each department handled its part—production focused on extracted volumes, environment on water quality, equipment pressure maintenance, etc.—with poorly communicated systems. This makes it difficult to see *the complete picture* . AI facilitates an integrated view, combining variables from different disciplines in its models. For example, a model can simultaneously consider a well's fracture rate, that well's proximity to an aquifer, and the trend of microseisms in the area to determine the alert level. This multidimensional integration is a key improvement, as environmental impacts are often the result of a convergence of factors (not a single one in isolation).

- Adaptability and continuous improvement: Traditional methods typically rely on fixed procedures (static checklists, preset alarm thresholds). AI, especially with machine learning, adapts over time. As it collects more data, the system "learns" and refines its models, becoming more accurate and reducing false alarms. For example, if an algorithm initially generates some false pollution alerts (which later prove to be false), it will adjust its parameters to fine-tune itself. In other words, AI provides almost autonomous continuous improvement.
- Human resources and monitoring costs: With AI, many routine tasks are automated, freeing up professionals for higher-value activities (interpreting results, designing solutions). It's not about replacing humans, but rather empowering them: an analyst can now monitor 100 wells at once from a dashboard, a task unthinkable without AI. This reduces operating costs, as the company can operate with smaller but more specialized teams, supported by intelligent tools.

In short, AI outperforms traditional methods in scope, speed, accuracy, overall intelligibility, and efficiency. It's worth noting that traditional approaches (field inspections, audits) still have their place, especially for validation and to complement AI findings. In fact, optimal synergy occurs when AI is used to focus human efforts where they truly matter. For example, instead of randomly sampling 50 water sites, technicians can—guided by AI—sample the five sites the model identifies as most likely to pose a problem. In this way, the best of both worlds is combined: the tireless analytical capabilities of AI and human judgment and experience in final decision-making. This complementarity boosts environmental stewardship standards to levels previously unattainable.

IV. AI agents and agentic workflows. The evolution of generative AI.

1. IAGEN Agents Concept

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

Generative Artificial Intelligence (GENI) is a branch of artificial intelligence that focuses on creating 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 new and original content that is often indistinguishable from human-created content.

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

An IAGen agent combines large language models with additional components such as external tools, memory, planning, and autonomous 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 context changes in real time. These qualities distinguish them from traditional chatbots and open up a range of more sophisticated and customizable applications.

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 logistics tasks, and even tasks linked to the technical areas of production processes, acting as intelligent assistants that collaborate with human teams. This ability to integrate knowledge and execute tasks autonomously transforms the way organizations can scale their operations without losing quality or control.

Furthermore, agentic workflows—structures where multiple agents collaborate to solve complex problems—allow responsibilities to be distributed among different agent profiles, each with specific functions. This creates hybrid work environments where humans and agents coexist, optimizing time, 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 toward a new era of intelligent automation.

Among the benefits of authentic workflows powered by generative AI models is the ability to automate entire production processes, end-to-end, and even add value by leveraging the capabilities of language models based on these technologies.

However, its implementation also poses technical, ethical, and legal challenges, ranging from responsible design to human oversight. Therefore, understanding its architecture, operational logic, and potential impacts is critical for its effective and safe adoption in diverse professional contexts.

2. Agents powered by IAGEN

a. Workflow design proposal

IAGEN Agent: Environmental Guardian for Water Management in Vaca Muerta

Main features of the agent:

Multi-Source Continuous Monitoring

- Real-time integration of:
    - IoT sensors (pressure, flow, pH, conductivity)
    - Satellite images (Sentinel, Landsat)
    - Climate and operational data
- Application of LSTM networks and anomaly detection models.

Predictive Risk Analysis

- Prediction of water risk events (leaks, micro-earthquakes, contamination) using models trained with historical and geological data.
- Preventive evaluation of sensitive areas before expanding operations.

Simulations with Generative Models

- Generation of scenarios and simulations (digital twins) of contaminant spread in the event of incidents.
- Simulation of response plans and their environmental/operational impact.

Automatic Report Generation

- Creation of regulatory, internal, and public reports using NLP (such as ChatGPT) with data traceability.
- Production of indexes such as:
    - Water compliance index
    - Environmental risk score by location
    - Level of recycling and water efficiency

Integrated Smart Dashboard

- Clear visualization for management, environmental engineers and auditors.
- Early warnings, automatic recommendations, and comparative analysis between operational areas.

Transparency and Community Communication Module

- Publication of selected data in a stakeholder- and community-friendly format (e.g., open environmental observatory).
- Machine translation into citizen language.

b. Implementation phases

Phase 1 - Pilot :

- Selecting a high activity block.
- Installation of additional sensors.

- Initial model training with historical data.

Phase 2 - Modular Scaling :

- Expansion to more blocks.
- Integration of dashboards and reporting modules.

Phase 3 - Transparency & Regulation :

- Integration with regulatory bodies.
- Publication of selected indicators.
- Legal validation of AI-generated data.

V. Direct benefits in operational and strategic terms

Implementing AI in water environmental risk assessment offers immediate and tangible benefits for energy companies' operations and strategy:

- Early incident detection: An intelligent system can identify anomalous changes (in water quality, pressure, etc.) within minutes, allowing a leak or spill to be contained before it spreads. This contrasts with traditional detection, which can take days until the next inspection. Timely response minimizes environmental impact and prevents prolonged production interruptions.

- Automated regulatory compliance: AI acts as a continuous monitor for compliance with environmental permit limits and conditions. For example, it verifies 24/7 that discharges or injections remain within legal parameters (volumes, concentrations). In the event of any potential noncompliance, it generates proactive internal alerts to correct course or notify authorities if necessary. This reduces the risk of sanctions and improves relations with regulators, demonstrating a responsible approach.

- Operational optimization and cost savings: By analyzing patterns, AI can optimize water use—for example, by recommending increasing the flowback water recycling rate when it detects availability, or by adjusting water trucking logistics to minimize journeys. It also helps focus monitoring resources where they are most needed (rather than sampling uniformly everywhere). This translates into operational efficiencies: less water waste, lower treatment and transportation costs, and more efficient use of technical staff (who spend less time on manual data review tasks).

- Improved strategic decision-making: Intelligently processed data allows managers to make informed, evidence-based decisions. For example, if the AI system shows that a certain area has increasing water risk indicators, the company can prioritize investments in environmental infrastructure there (such as reinforcing pond liners or improving treatment plants) before scaling up production. More broadly, the identified trends (such as water consumption per well, reuse efficiency, etc.) inform sustainable field planning and even stakeholder communication strategies, as they can display improved environmental performance metrics thanks to AI.

- Transparency and trust: An AI-powered monitoring system can generate clear, automatic reports on environmental performance with traceable and objective data. Sharing some of this information with authorities and even the community (for example, through open environmental observatories) improves transparency. Stakeholders see that everything is monitored in real time and that the company adopts cutting- edge technology to ensure environmental safety, which increases public trust and reduces water-related social tensions.

VI. Challenges in AI implementation and strategies to overcome them

While the benefits are clear, incorporating AI into Vaca Muerta's environmental management faces several challenges that must be addressed with appropriate strategies:

- Data quality and availability: AI is only as good as the data it analyzes. An initial hurdle is the availability of reliable and sufficient data. At Vaca Muerta, much of the operational and environmental information is confidential or not centralized.

  Strategy: Establish data-sharing agreements between companies and regulators, under protocols that guarantee confidentiality where appropriate, but allow algorithms to be fed with essential data. Leverage public and third-party *datasets* : freely accessible satellite images (Sentinel, Landsat), climate data from the Meteorological Service, provincial water reports, etc.

  In parallel, invest in the necessary IoT instrumentation to fill gaps (installing additional sensors at critical points, groundwater monitoring stations, etc.). An initial stage of the project should focus on creating an integrated and clean data repository, applying validation and debugging techniques (eliminating spurious outliers, calibrating sensors).

- Technical skills and organizational culture: Implementing AI requires personnel with expertise in data science, geospatial analysis, and digital tools. There may be resistance from some traditional technicians who rely more on "the way it's always been done."

  Strategy: Promote a training and cultural change program. Start with demonstration workshops showcasing success stories (e.g., how AI detected an anomaly that would have escaped).

Form multidisciplinary teams that combine environmental experts with data scientists to develop solutions together (this facilitates acceptance by viewing AI as an ally and not as an imposed black box).

Additionally, senior leadership sponsorship communicating the vision of "sustainable digital transformation" will help overcome resistance and motivate adoption. Celebrating small early wins (e.g., "The AI system helped us avoid a spill last week") reinforces the team's confidence in the tool.

- Cost and technological infrastructure: Implementing sensors, communications networks, analytics platforms, and specialized personnel requires a significant initial investment. Some smaller operators may find this a difficult cost to bear.

  Strategy: Emphasize return on investment (ROI): Economically model how much it would cost to *not* have the system (cleanup costs for a large spill, fines, lost production) versus the investment in preventing it. Preventing just *one* serious event with AI will likely already pay for the entire system. Additionally, investments can be phased: start with a limited pilot project (for example, in a highly active Vaca Muerta block) to demonstrate the value, and then gradually scale up. Relying on *cloud infrastructure* can reduce upfront costs, avoiding the purchase of expensive servers—instead, use cloud services and pay only for necessary usage.

- Technical challenges (integration and maintenance): Integrating such diverse data (satellites, field sensors, databases from different companies) is not trivial. Issues may arise with format compatibility, connectivity in remote areas without signal, or the need to calibrate models to the unique local conditions of Vaca Muerta.

  Strategy: Adopt open standards and a modular architecture. For example, use formats like JSON/CSV for IoT data, OGC standards for geodata, and well-documented APIs for connecting different systems.

- Plan a pilot period where the models are locally adjusted and the system fine-tuned before full implementation. It's also key to plan for ongoing maintenance : updating AI models based on changing conditions (e.g., new chemicals introduced into fracturing fluids will need to be incorporated into the detection patterns) and providing technical support for the equipment.

- Regulatory and legal aspects: Currently, Neuquén's environmental regulations establish what monitoring should be carried out and how frequently, but they may not yet explicitly consider the use of AI. There may be uncertainty about whether automatically generated data is admissible in audits or trials.

  Strategy: Work collaboratively with regulatory authorities from the outset. Include the provincial environmental agency in the design of the AI system, so that its needs (reports, formats) are covered. Promote regulatory updates that incorporate the possibility of continuous AI-assisted monitoring as a valid complement. For example, an annual water quality report could include continuous sensor data analyzed by AI, and this could be recognized as compliance equivalent to or greater than X manual samplings. Regarding legal liability, ensure traceability of data and decisions: each important alert should keep a record of what triggered it, so that it can be explained if necessary (this helps with explainability, making AI more transparent and defensible).

- Cybersecurity and confidentiality: Digitizing environmental operations opens the door to cyberattacks or unauthorized access to sensitive data. Sabotage of the AI system could, in the worst case, disable critical alerts.

  Strategy: Implement robust cybersecurity measures from the design stage, such as data encryption in transit and at rest, strong authentication for platform access, industrial network segmentation, etc. Conduct periodic security audits and have contingency plans in place (e.g., if the AI system goes down, ensure local backup alarms are in place at critical sites).

Regarding confidentiality, clearly define which data is for internal use versus which is shared externally (e.g., with the community). Public data can be anonymized or aggregated to avoid exposing competitive information. Ultimately, protecting the system from cyber risks will ensure that trust in AI is maintained and its operation is uninterrupted.

Recommendation: Short-term investment in AI agent implementation teams, technology and training

Investment in proofs of concept and pilot testing is required. The focus here must be on developing the talent needed to implement the solution, as there is a trend toward cost reduction in systems that enable "no-code" and "low-code" automation. For the first stage, it is also recommended to recruit teams with experience in the design and implementation of AI agents. Finally, it is key to form an in-house team to support and foster an agentic culture that redefines human-machine interaction.

In conclusion, the effective integration of AI into Vaca Muerta's water management requires a strategic vision and phased execution, taking into account both technical, human, and organizational aspects. It's not just about purchasing software; it's about transforming the way we operate toward a culture driven by data and prevention. The above recommendations offer a roadmap for following this path, minimizing risks and maximizing the likelihood of success.

VII. Conclusion

The application of artificial intelligence to environmental water management in Vaca Muerta represents a strategic opportunity to advance toward a more sustainable, efficient, and transparent energy industry. Through the combined use of IoT sensors, geospatial analysis, predictive models, and generative intelligent agents, it is possible to transform environmental monitoring from a reactive approach to a preventive and proactive one.

This transformation not only enables earlier and more accurate risk detection, but also optimizes resources, automatically complies with regulations, and strengthens trust with regulators and communities. AI doesn't replace human oversight; rather, it enhances it, enabling more informed decisions and faster responses to potential incidents.

However, successful implementation requires addressing technical, cultural, regulatory, and infrastructure challenges through phased planning, initial investment in training, and the adoption of a data-driven culture. The shift toward smart water management in Vaca Muerta is not only possible but urgent, requiring leadership, multisector collaboration, and a commitment to responsible innovation.

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