

6 Case Study: Integrated Water Quality Control and Fish Health Management in a Commercial RAS Facility

6.1 System design and monitoring framework

A commercial RAS case study is best framed as a multi-unit control system in which tank performance depends on both water treatment design and continuous monitoring. Field and facility evaluations show that practical RAS layouts combine fish tanks with dedicated treatment and purification units, and that clear description of water process flow, treatment components, and species-specific water quality limits is essential for benchmarking performance and refining future commercial designs. This design logic matters because effective facility evaluation requires not only acceptable production outcomes but also explicit performance standards for water quality and system function across operating conditions (Mota et al., 2022).

Within that framework, the monitoring system in a commercial RAS must follow the variables most tightly linked to fish stress and operational failure. Reviews and commercial-scale monitoring studies agree that temperature, pH, dissolved oxygen, and related nitrogen compounds must be kept within narrow ranges, while recent kingfish data show that CO₂, pH, temperature, nitrogen compounds, and hydrogen sulfide can be maintained within published safety thresholds when monitoring is systematic and sustained. The same evidence base also shows that monitoring is moving from periodic handheld testing toward automated, real-time acquisition, because conventional lagged measurements are poorly suited to intensive systems where pump or aerator failure can trigger rapid oxygen depletion and water quality deterioration (Figure 2) (Lindholm-Lehto, 2023; Malandrakis, 2025).

6.2 Analysis of water quality variation and fish performance responses

Commercial and near-commercial RAS studies show that water quality variation is not biologically neutral, because shifts along the treatment train and over time translate into measurable differences in fish performance. In an integrated land-based RAS, water quality changed gradually along the direction of flow, and fish production responded to those differences through variation in final weight, survival, specific growth rate, and yield. Correlation analysis in that system further showed that the main cultured species performed better under mesotrophic or oligotrophic conditions, indicating that performance responses depend on how well local water conditions match species-specific tolerances.

Temporal variability inside RAS is also uneven across parameter classes, which has direct implications for fish health interpretation and management. In Atlantic salmon research facilities, sensor-controlled parameters showed relatively low variation, whereas parameters dependent on biofilter maturation and performance varied much more strongly, and variation among experimental trials exceeded variation within trials (Mota et al., 2022). Complementary dynamic modeling indicates that growth and mortality relationships can be used to predict fish well-being under changing environmental conditions and management strategies, supporting the use of water-quality variation as a leading indicator of both welfare risk and production efficiency (Kamali et al., 2022).

6.3 Development of intelligent management strategies

The next step in a commercial RAS case study is to convert monitoring into intelligent management, where sensor data drive adaptive interventions rather than passive record-keeping. Commercial-scale control research shows that reinforcement-learning architectures can combine feeding optimization with water quality management, using modular design, robust sensor networks, and fault-tolerant control to maintain fish growth and stable environmental conditions across large facilities. Performance gains from this approach are substantial, with reported improvements including 15.5% better feed conversion, 96.8% water-quality maintenance, and 31.5% lower operational cost, indicating that integrated control can improve both biology and economics (Elmessery et al., 2025).

Intelligent management also increasingly includes automated interventions, predictive analytics, and behavior-linked control. IoT-ML systems have supported more than 6000 corrective interventions, including automated oxygenation and pH adjustment, while maintaining survival above 90% under challenging seasonal conditions, and deep learning-based aeration control has reduced energy use while accelerating growth under stable water quality conditions (Baena-Navarro et al., 2025). Even so, the literature remains cautious: AI-assisted imaging, behavior