Redox-Driven Stabilization of Complex Water Treatment Systems with the MATpure® catalytic water conditioning system.

Operational Lessons from a Full-Scale Groundwater Treatment Application

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1. Introduction

Complex water treatment systems often fail to achieve initial design criteria and performance targets; inherent process water instability and influent variability can compound operational degradation over time. Some common challenges and symptoms include escalating chemical demand, persistent fouling and scaling of treatment units, unreliable solids production, declining filtration, decay in optical performance, and growing maintenance needs. When attempts to address these issues are done through incremental chemical or mechanical adjustments, short-term compliance can temporarily be restored, but often these efforts often ultimately fail due to other secondary operational complexities

This paper summarizes observations and rescue of a full-scale groundwater treatment system that experienced significant degradation following capital intensive treatment upgrades. The system upgrades incorporated lamellar clarification, sand filtration and advanced oxidation process (AOP), and the eventually resolved issues are not unique to AOP-based treatment trains. The presence of a sensitive oxidative polishing step (AOP) made broader system-wide instabilities and performance limitations more sensitive and visible. Simple installation of a MATpure® catalytic water conditioning system provided significant remediation of these failing treatment processes. Final results demonstrate that targeted catalytic water redox stabilization upstream of conventional water treatment processes can fundamentally and advantageously alter their efficiencies, producing durable reductions in chemical demand, suppression of fouling and scaling, and improved operational reliability.

2. System-Level Instability in Complex Treatment Trains

2.1 Progressive Degradation Under Conventional Operation

Baseline design of the treatment system incorporated pH adjustment, chemical precipitation, coagulation and flocculation, clarification, filtration, and downstream polishing to achieve effluent quality targets required for advanced oxidation (AOP) and granular activated carbon (GAC) treatment (**see Figure 1**). Operational control relied on chemical additions, including sodium hydroxide and polymer (PAC) upstream of clarification, and sulfuric acid (H_2SO_4) and hydrogen peroxide prior to final discharge.

As turbidity and iron removal performance began to deteriorate, chemical dosing rates were increased to restore compliance. While this approach temporarily stabilized effluent parameters, it introduced secondary effects, including excessive and poorly controlled sludge production, accelerated scaling within process equipment, rising maintenance demands, and progressive loss of AOP/GAC polishing efficiency downstream of clarification.

Sludge recirculation was subsequently trialed in an effort to enhance solids capture without further increasing chemical inputs. Notably, this intervention intensified process instability and also failed to deliver sustained performance improvements.

Eventually, after approximately six months of system degradation, MATpure® catalytic water conditioning was installed with intent to reclaim system performance, mitigate excessive fouling, scaling and chemical use, and provide more efficient, dense and targeted sludge formation.

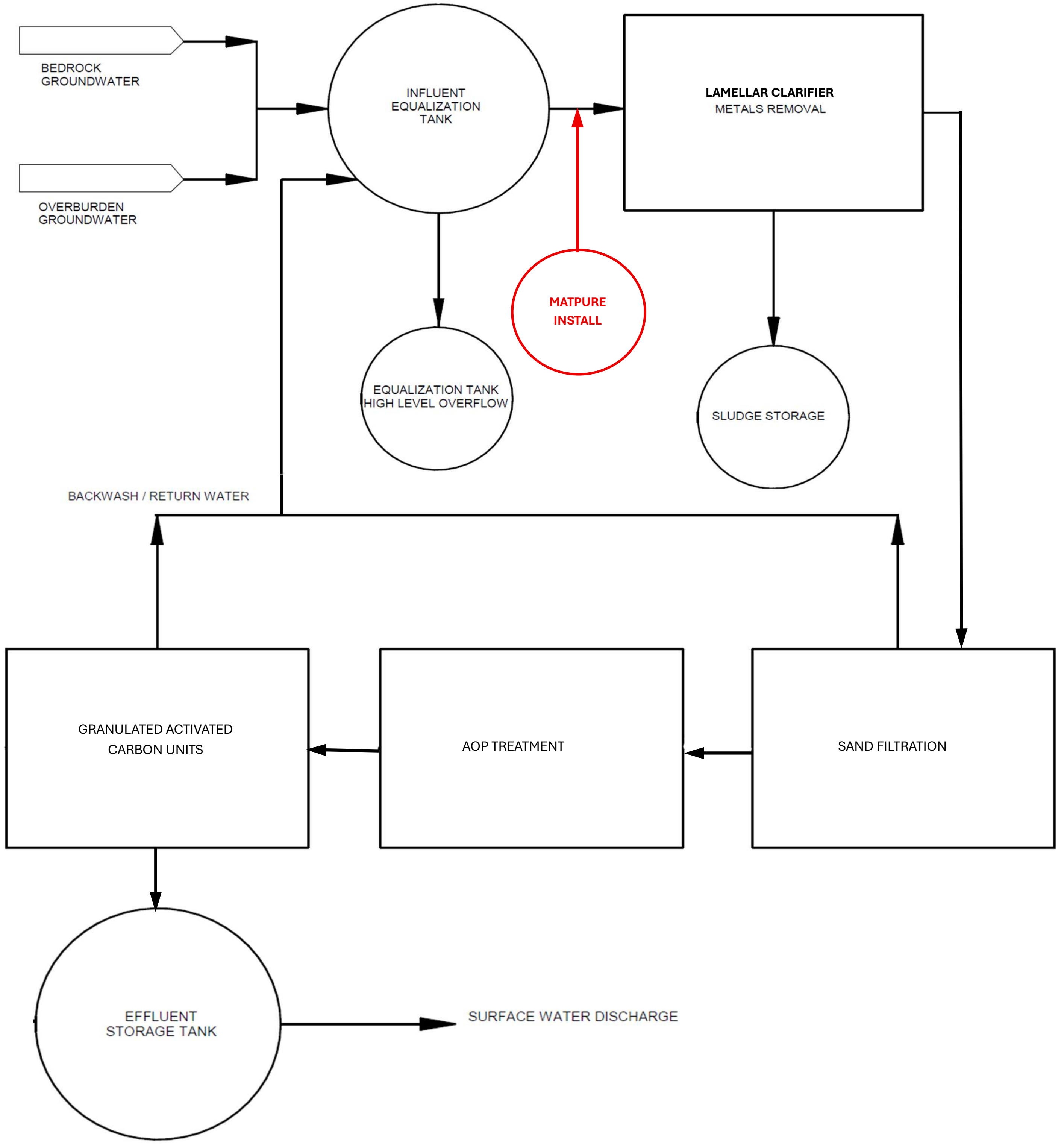

Figure 1: Referred Groundwater Treatment Design with AOP/GAC finishing.
Generalized diagram of the referred 400,000 GPD groundwater treatment system. Sodium hydroxide and PAC were added prior to clarification; H_2SO_4 and hydrogen peroxide were added after clarification and prior to polishing before final discharge. Catalytic water conditioning was eventually installed downstream of influent equalization tank (EQ) but upstream of NaOH and PAC additions.

Before catalytic water conditioning, baseline bulk water quality measurements indicated redox conditions were insufficient to effectively stabilize the system. Feedback indicators showed that iron chemistry, carbonate precipitation/scaling, and biologically mediated fouling became self-reinforcing processes that destabilized system operation, reduced treatment capacity and efficiency, and drove escalating maintenance requirements and costs. Treatment with MATPure® quickly reversed this system degradation, stabilized designed intended outcomes, and subsequently (and significantly) reduced system costs.

2.2 Sensitivity of AOP Polishing Units to Upstream Conditions

Downstream treatment units were sensitive to subtle changes in upstream water quality. Small increases in particulate load, colloidal iron, or biologically derived material produced disproportionate declines in UV transmittance and internal AOP reactor performance, even when upstream effluent met nominal specifications. In this context, measured downstream oxidative performance served as a sensitive indicator of upstream instability rather than a source of the problem itself. Prior to catalytic water conditioning installation, sludge recirculation trials (SRS) worsened process dynamics **(Figures 2, 3, and 7)**

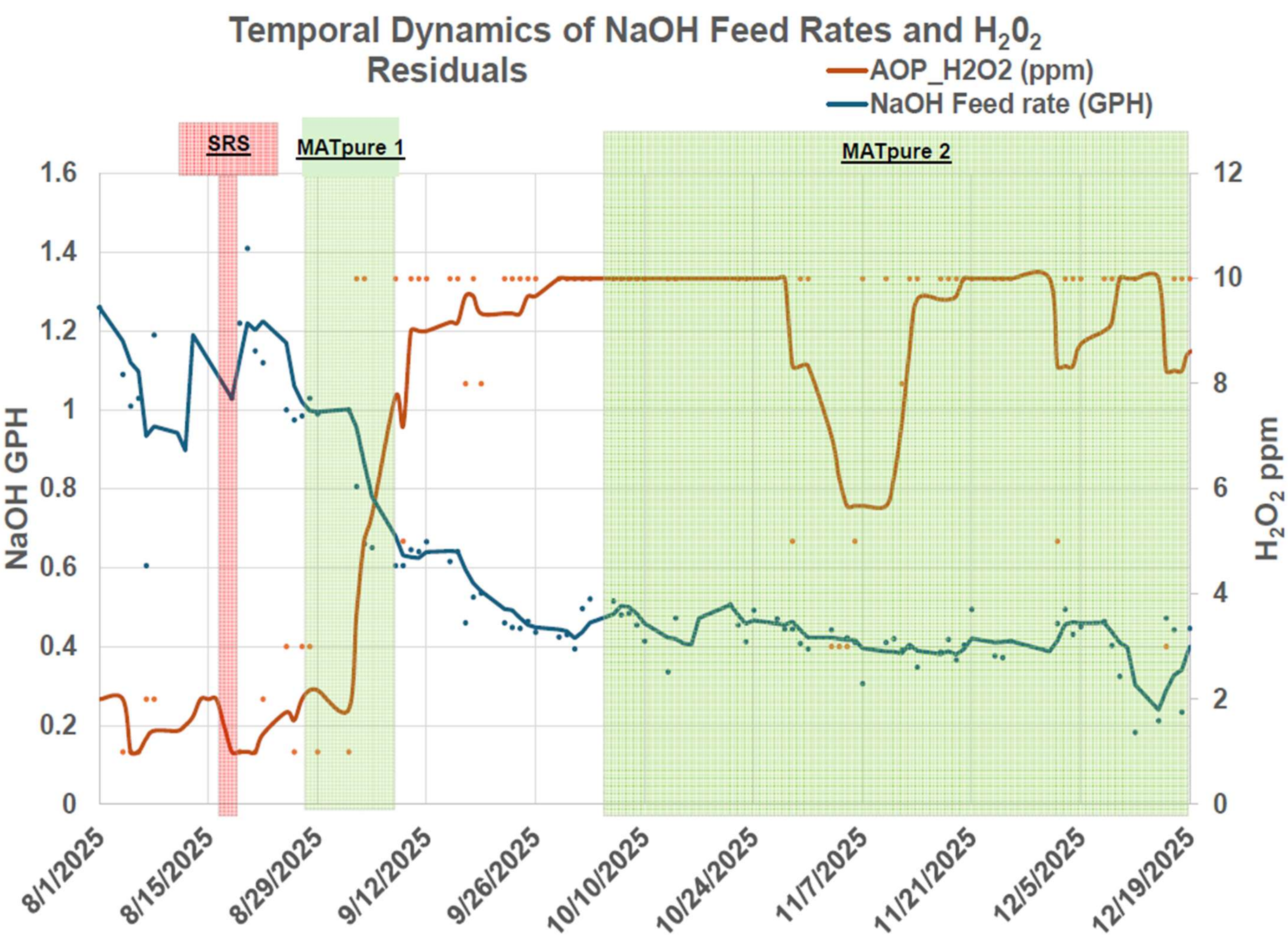

Figure 2: Temporal Dynamics of NaOH Feed Rates and H_2O_2 Residuals
Baseline AOP conditions improved by 70%+ (H_2O_2 residuals) with MATpure® catalytic water conditioning. Subsequent need for NaOH dosing dropped by 50%+, and need for peroxide dosing dropped by 15%+.

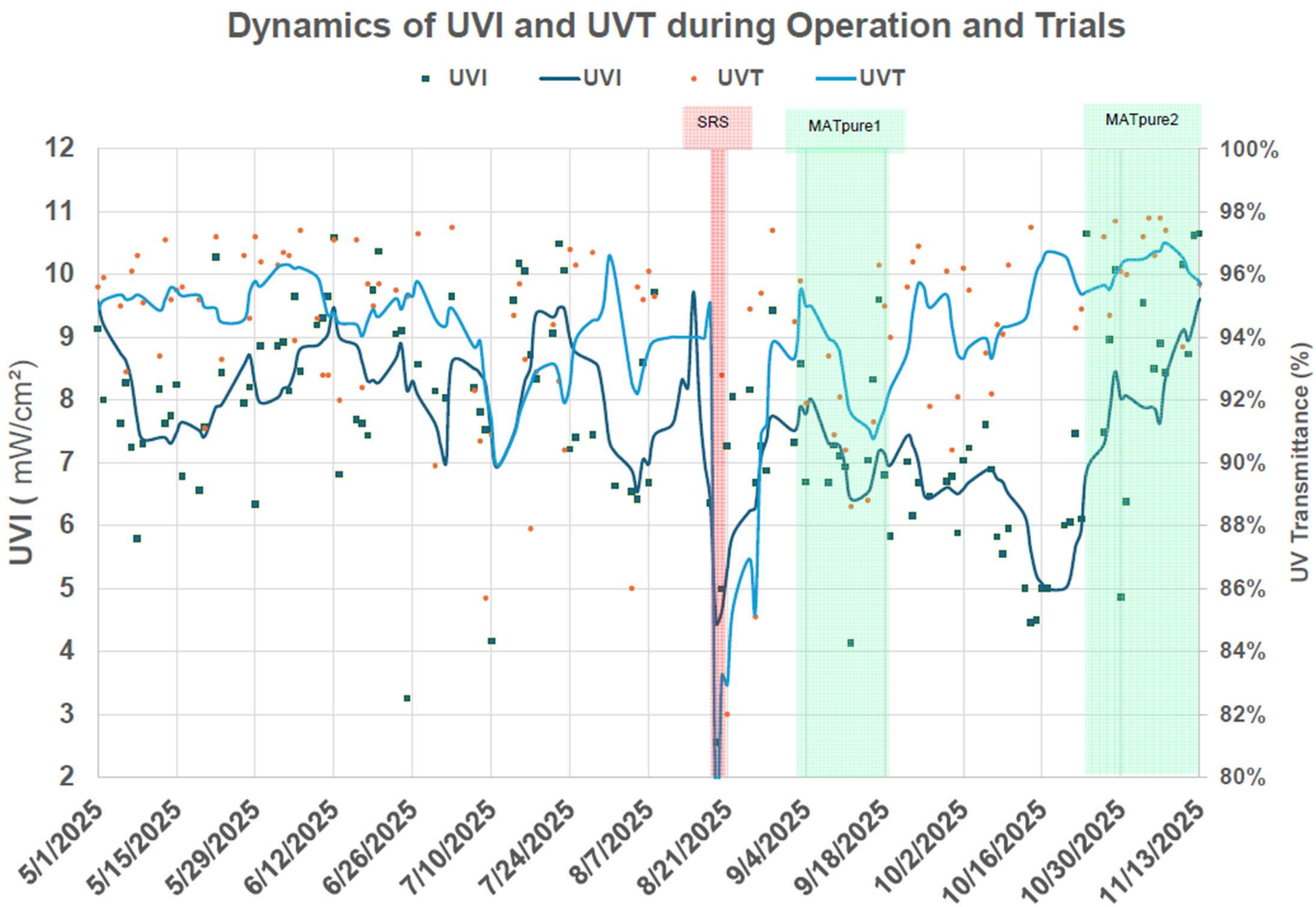

Figure 3: Dynamics of UV Transmittance and UV Intensity
After MATpure® treatment, baseline AOP UV intensity in the reactor recovered to the baseline range, while AOP UV transmittance re-stabilized at 96%+.

3. Redox Stabilization as an Operational Strategy

3.1 Rationale for Redox-Focused Intervention

Conventional treatment optimization typically emphasizes pH control, chemical dose adjustment, and physical solids separation. While pH affects aqueous speciation and can indirectly influence redox equilibria, it does not directly control electron activity, overall oxidation (reduction balance, or microbial metabolic energetics) which are key factors governing iron cycling, solids formation, and fouling progression.

In systems treating iron-rich or biologically active waters, redox state often becomes the dominant variable controlling long-term process stability. In fact, pH adjustment intended to manage precipitation or redox chemistry can inadvertently increase scaling potential and trigger other unintended, detrimental secondary reactions.

The catalytic water conditioning intervention evaluated in this study was applied upstream of clarification and filtration. The intent was not to replace existing unit operations, but to shift the entire system toward a more stable redox regime in which iron cycling and fouling-associated biological processes were less energetically favorable. This resultant stabilization also enabled operation at a lower pH, reducing carbonate scaling potential and chemical feeds while maintaining all other sand treatment objectives.

3.2 System Response to Redox Perturbation

A short-duration sludge recirculation system (SRS) trial was implemented to enhance sludge settling and improve overall groundwater treatment performance. Instead of improving clarification efficiency, the intervention produced rapid deterioration in effluent quality, increased fouling and scaling rates, and marked declines in downstream polishing and optical performance (**Figure 3**).

This response demonstrated the treatment train's sensitivity to redox perturbation and solids recirculation. Reintroducing chemically and biologically active solids into an already unstable system amplified off-target reactions, accelerating iron cycling, solids formation, and downstream process stress. The SRS event provides a controlled contrast, illustrating how quickly destabilizing feedback mechanisms can propagate through the system under unfavorable redox conditions.

4. Operational Outcomes of Redox Stabilization

4.1 Chemical Demand and Oxidative Efficiency

Following the unsuccessful SRS trial, catalytic redox stabilization was implemented upstream of solids removal. The system rapidly transitioned into a more stable oxidative regime, enabling sustained reductions in chemical demand.

Flow-normalized sodium hydroxide consumption decreased by approximately 60% relative to baseline, while polymer usage declined by roughly 40%. Hydrogen peroxide feed rates decreased by approximately 15%, yet peroxide residual concentrations increased by more than 70% (Figure 2). This divergence indicates improved oxidative utilization efficiency rather than reduced treatment intensity.

Collectively, these results suggest that elevated chemical demand under baseline conditions reflected compensatory dosing in response to systemic instability, rather than intrinsic treatment requirements.

4.2 Reduction in Scaling and Fouling

Physical indicators of scaling and fouling declined substantially following redox stabilization. Measured scale deposition rates within the metals removal process decreased by approximately 54% during the initial stabilization phase and by roughly 75% under sustained operation relative to baseline conditions (**Figure 4**). These reductions are consistent with suppression of iron cycling, moderated precipitation kinetics, and reduced attachment propensity at process surfaces, resulting in improved operational stability and lower maintenance burden.

These reductions were accompanied by improved hydraulic behavior, reduced maintenance requirements, and gradual recovery of downstream optical performance Importantly, these improvements persisted over time, indicating a fundamental change in fouling mechanisms rather than temporary suppression.

4.3 Reactive Catalyzed Water Increases in Metals and TOC Coagulation/Settlement

Catalytic water treatment increased the redox reactivity of water, resulting in accelerated, amplified and controlled coagulation and metals precipitation efficiencies with significantly less need for chemicals. Prior to chemical reductions, independent jar testing was conducted under a variety of conditions, including those prior baselines. Results with and without presence of catalytic treatment versus controls were evident under most testing conditions (pH) and polymers utilized. Typical results are shown in **Figure 5.**

Redox reactivity was also very evident in coagulant and settleability of groundwater treatment system TOC and metals in the lamellar clarifier as evidenced by sludge concentration and consistencies after caustic and polymer treatment **(Figure 6)**.

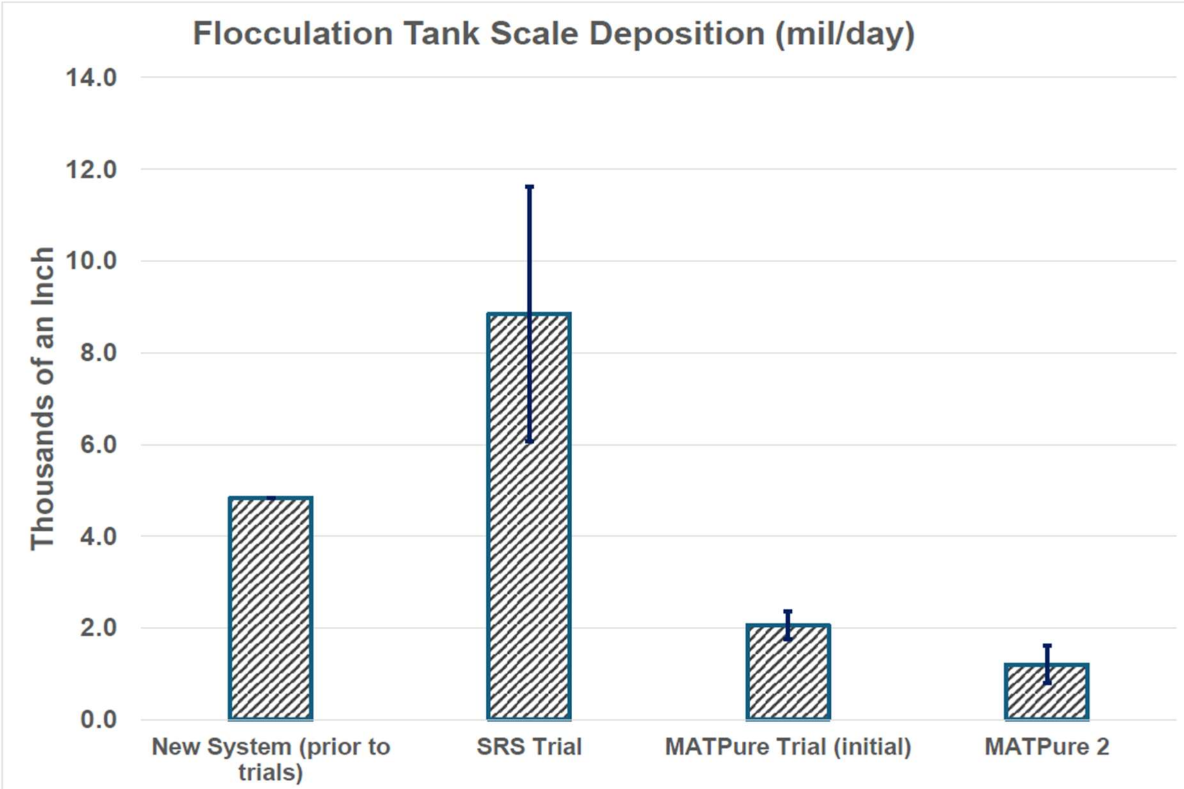

Figure 4: Flocculation Tank Scale Deposition Rate.
Baseline scale deposition rates decreased quickly and dramatically after MATpure® treatment.

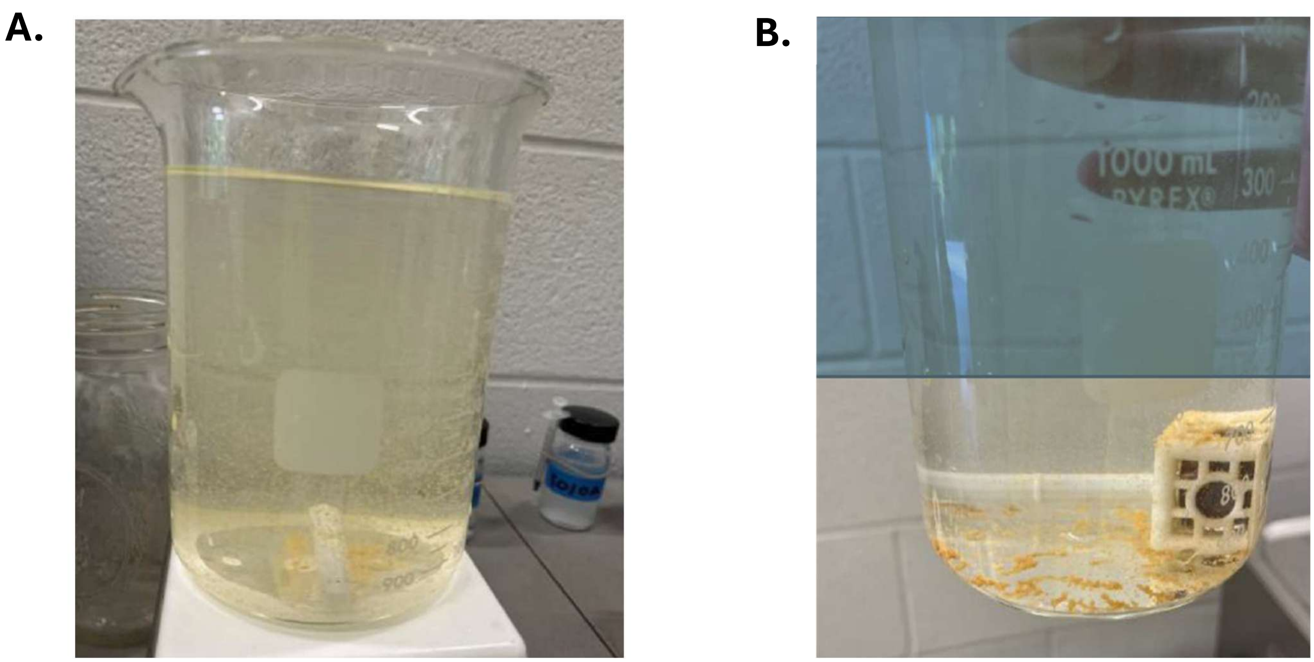

Figure 5. Jar testing of baseline treatment conditions (pH and polymer dosing) of groundwater treatment was conducted. Controls were stirred for 2 minutes and allowed to settle for 2 minutes **(A).** Catalytic water treatment was conducted identically to controls (same sample water with the same aforementioned constituents), but stirred with the addition of catalytic foil contained in the cube (for 2 minutes); floc was allowed to settle for 2 minutes. Clarity and efficiency improvements were consistently obvious between various trials.

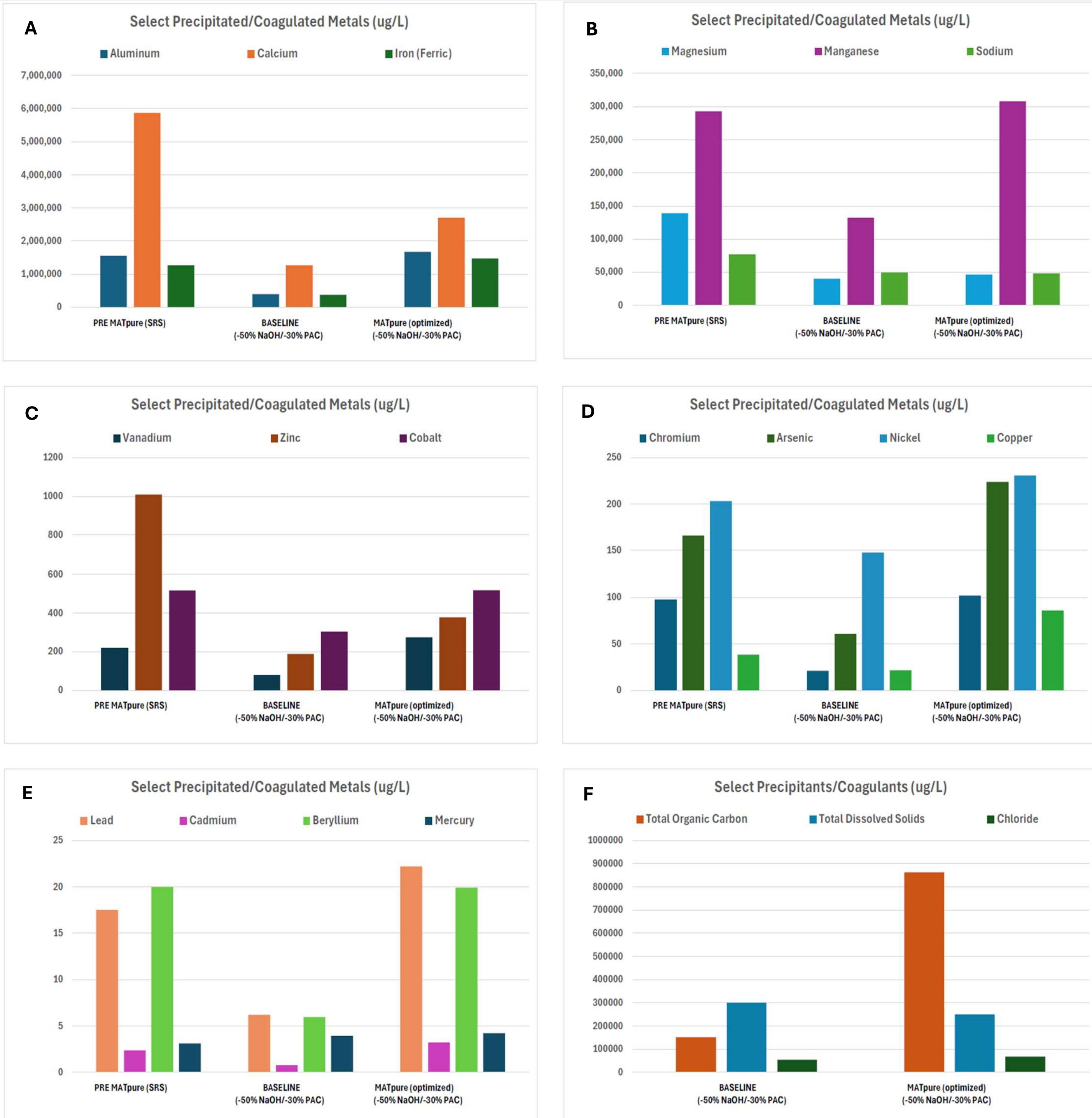

Figure 6. Metals composition and concentration of coagulate sludge under baseline conditions versus catalytic water treatment conditions. Assayed metals on relevant (ppb) scales are presented **(A, B, C, D** and **E)**. In most cases, catalyzed water conditioning with much less chemical use matched (or bested) the effectiveness of initial baseline treatments that incorporated far more chemical used. Baseline controls (with reduced chemical use and no catalytic water conditioning) are also included as comparison. TOC, TDS, and chloride in sludge formation were also assayed and compared (**F**) showing significant impact of catalytic treatment upon the ability to coagulate and settle TOC.

5. Redox and Biological Regime Shift

5.1 Catalyzed Water Redox Transition in the EQ Mediated by Sand Filter Backwash
The sand filter (downstream of the lamellar clarifier and upstream from AOP treatment) provides an operationally meaningful indicator of catalyzed water system stability, as it integrates upstream water quality, redox conditions, and biological activity. Electrochemical monitoring of EQ Basin over time (seeded by consistent sand filter backwashing) revealed a sustained upward shift in oxidation–reduction potential following MATpure® catalyzed water redox stabilization upstream and through the sand filter. EQ basin conditions transitioned from suboxic and iron-reducing regimes into a stable oxic transition range, and this redox shift reduced the availability of reduced iron species and altered the microbial seeding/feedback loop governing the EQ and subsequent treatment (including clarification, filtering, and oxidation). See **Figures 7, 8 and 9.**

5.2 Functional Collapse of Fouling-Associated Microbial Groups
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Microbiological analysis revealed a pronounced restructuring of the microbial community following redox stabilization. Baseline equalization (EQ) basin conditions were dominated by genera (**Figure 8)** associated with iron cycling, extracellular polymeric substance (EPS) production, and facultative anaerobic metabolism (organisms commonly linked to fouling, solids stabilization, and redox instability). Potentially pathogenic, human-associated taxa were also present under baseline conditions, consistent with protected biofilm niches. After MATpure® treatment stabilized operations, iron-cycling and EPS-producing functional groups collapsed to near-zero abundance. In the EQ basin, genera became more benign, diverse and focused on VOC/carbon degradation.

In the sand filter, total microbial biomass (**Figure 9)** quickly declined to below quantifiable levels and remained suppressed even after temporary shutdown of MATpure® catalytic intervention. These results indicate that the system crossed a functional threshold into an ecologically oxidative regime that no longer favored or supported fouling-associated metabolisms and/or attachment.

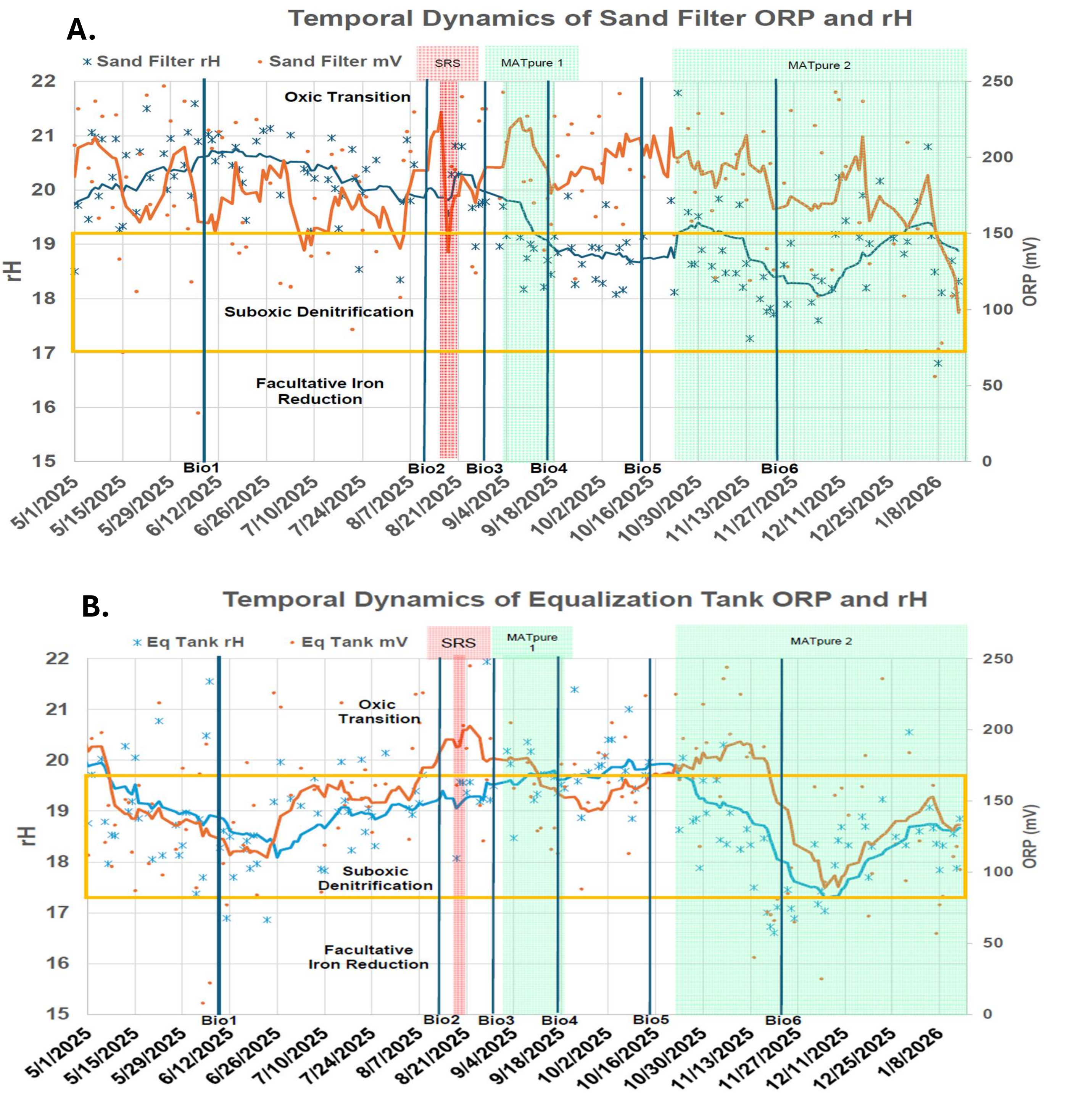

Figure 7: EQ ORP and rH Temporal Dynamics Influence in Sand Filter and Backwash Recycling The groundwater treatment system was configured to continuously return sand filter backwash to the EQ basin. Catalytic water conditioning applied downstream of the EQ progressively influenced the sand filter and its backwash **(A)**. EQ electrochemical conditions also changed gradually via the influence of recycled backwash, versus baseline (backwash) and influent (well) seeding alone **(B)**. Within relatively short operational periods, resultant MATpure® treated sand filter and EQ water accumulated pronounced shifts in EQ rH and ORP measurements. These measurements indicate that catalytic water stabilization effects persisted through coagulation, clarification, and subsequent sand filter (permeate/backwash) treatment and were partially retained upon recycle to the EQ basin.

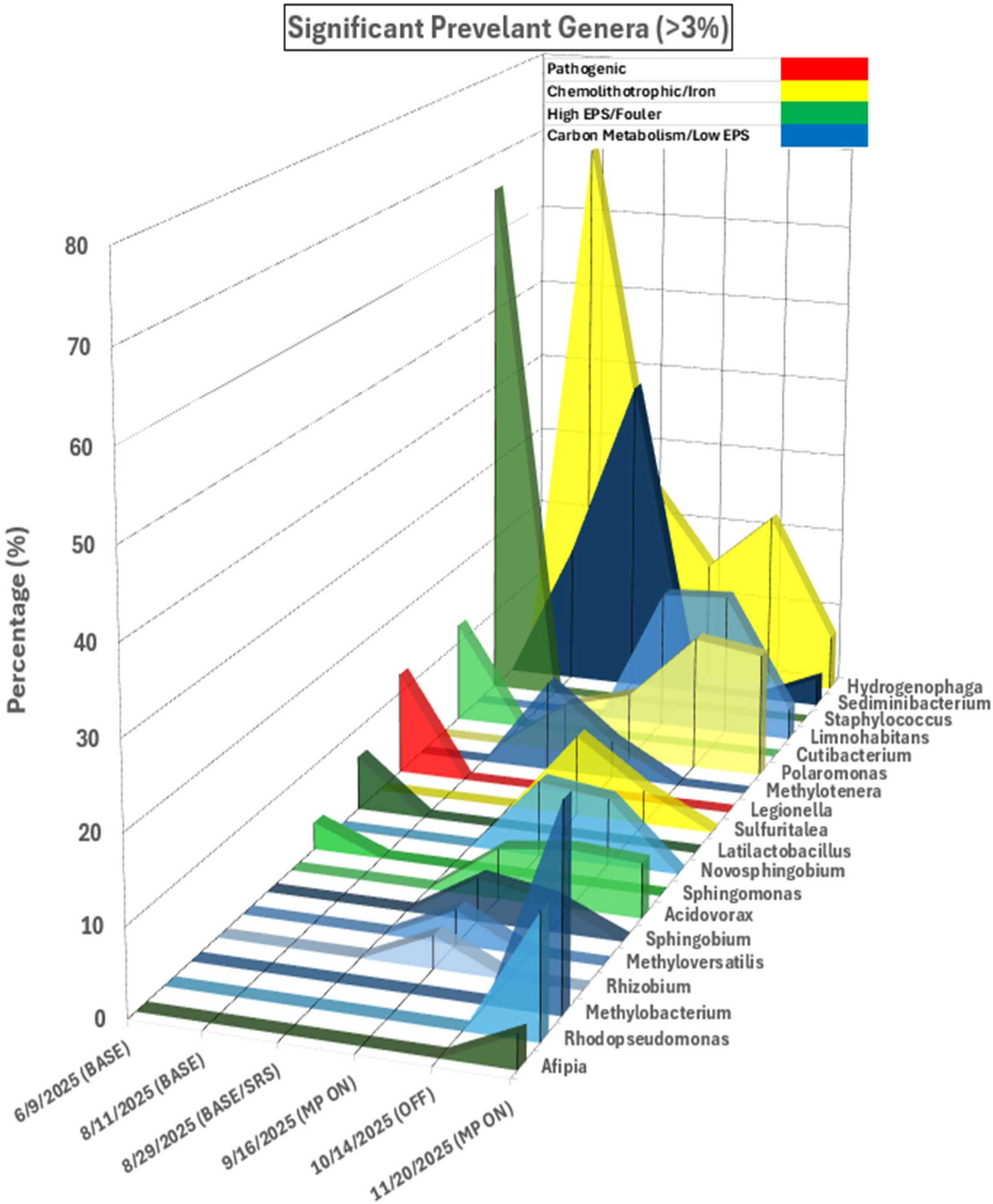

Figure 8: Redox Microbiological Shift in the EQ Basin after Catalytic Water Conditioning
MATpure® catalyzed changes in the EQ basin microbiology (influenced by sand filter blowdown recirculation). Non-diverse, pathogenic, fouling genera were replaced primarily with diverse, benign, carbon-metabolizing, and low EPS/fouling organisms after treatment.

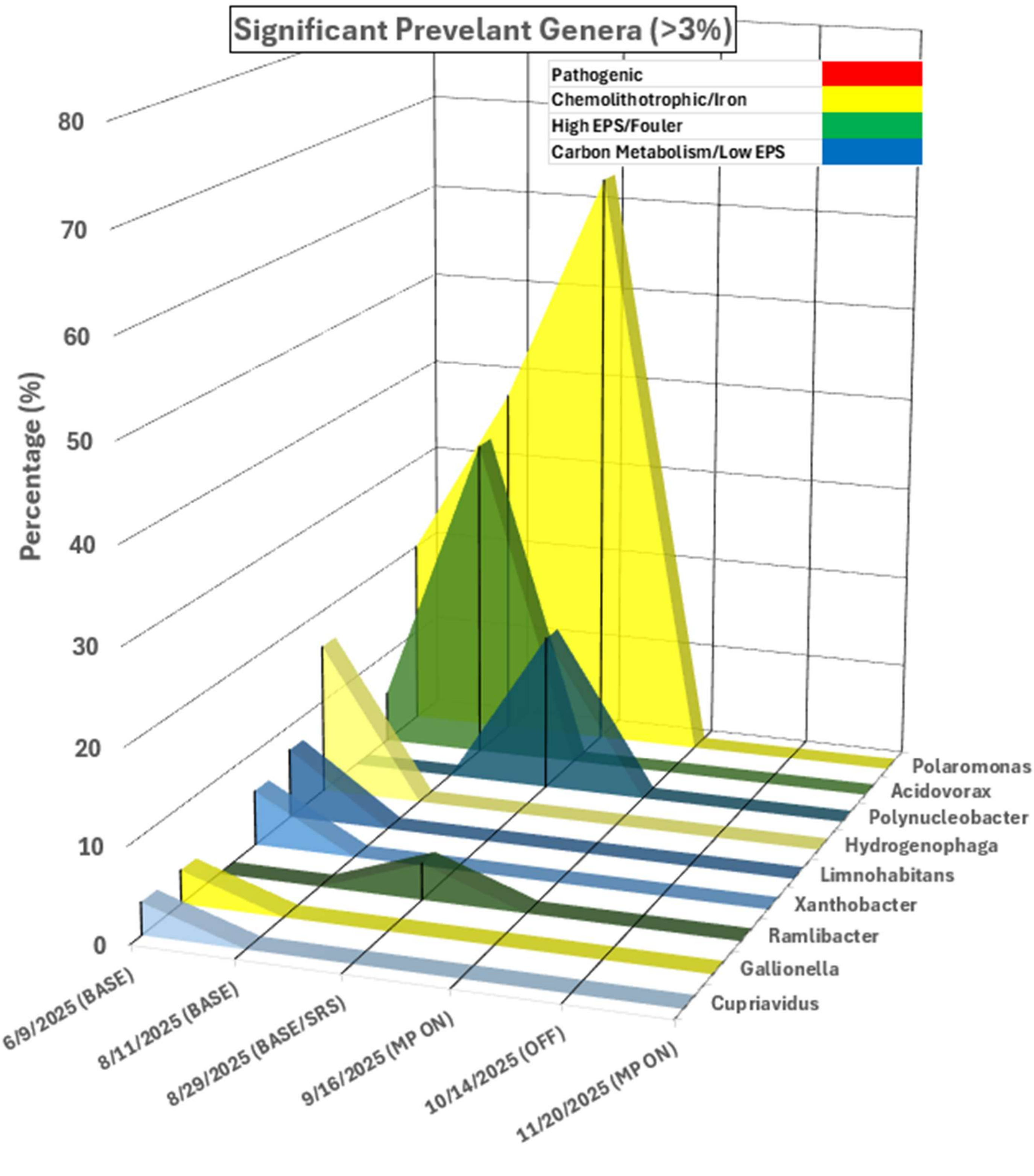

Figure 9: Redox/Microbiological Changes in Sand Filters after Catalytic Water Conditioning
Colonizing, non-diverse, fouling, chemolithic/iron-cycling genera quickly became genetically non-detectable in sand filters after MATpure® upstream treatment.

6. Implications for Water Treatment Design and Operations

Observations described in this study have broader implications for water treatment system design and operation beyond the specific installation evaluated:

- Catalytic redox stabilization was associated with sustained improvements in operational performance, including measurable reductions in scaling rates and chemical consumption.
- Stabilization of baseline redox conditions act as a significant governing variable influencing iron and metal speciation, solids formation dynamics, and overall treatment stability.
- Persistent fouling and escalating chemical demand may reflect underlying redox imbalance rather than deficiencies in physical separation or chemical dosing capacity. In such cases, upstream redox conditioning can address root-cause mechanisms more directly than incremental increases in chemical inputs.
- Suppression of fouling-associated biological activity achieved through redox stabilization, rather than continuous disinfectant reliance, may provide a more durable, cost-effective and sustainable strategy.
- Downstream polishing processes—particularly oxidation-dependent systems such as AOP—are sensitive to upstream redox instability. Stabilizing upstream redox conditions can improve the reliability and efficiency of these sensitive treatment stages.

Collectively, these findings suggest that integrating catalytic redox conditioning and redox-aware operating strategies into treatment design and optimization may enhance system robustness, reduce lifecycle chemical demand, and improve long-term operational predictability.

7. Conclusion

Catalytic water conditioning fundamentally altered the operational behavior of a 400,000 GPD groundwater treatment system through establishment of a stable and sustained redox regime. The transition suppressed iron/metal cycling and fouling-associated biological processes, reduced chemical demand, and improved downstream advanced oxidation (AOP) performance. These improvements persisted over extended operation and retention time, indicating a durable and cost-effective enhancement in overall system stability.

Upstream catalytic water conditioning created beneficial and persistent effects that extended well beyond initial individual reactive operations. In fact, early (upstream) catalytic conditioning stabilized system-wide water redox dynamics, and these improvements addressed multiple underlying feedback mechanisms responsible for recurring fouling, scaling, and escalating chemical consumption. Consistent chemical, physical, and biological datasets demonstrated suppression of iron, metal and biologically induced operational issues, resulting in reduced solids formation, lower scaling rates, improved oxidative utilization efficiency, and decreased reliance on corrective chemical dosing.

Thus, when integrated appropriately within treatment trains, catalytic water conditioning is proven to enhance coagulation and settling consistency with reduced chemical intensity, lower scaling and biological fouling pressure, and improve the reliability of sensitive downstream polishing processes. Water redox stabilization provided by MATpure® catalytic conditioning provides a simple, scalable framework for improving operational resilience and long-term treatment performance in complex water systems.