Interagency Monitoring of Protected Visual Environments (IMPROVE) Network Technical Systems Audit (TSA): Monitoring Sites audited in 2025 and 10-year Review of TSA program

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Introduction

In alignment with the quality assurance framework established by the Interagency Monitoring of Protected Visual Environment (IMPROVE) network, Technical System Audits (TSAs) are conducted annually. The primary objective of TSAs is to evaluate whether individual IMPROVE sampling sites are operating in compliance with the Quality Assurance Project Plan (QAPP) and applicable Standard Operating Procedures (SOPs). Additionally, the audit results from individual sites are aggregated to assess overall network performance. The comprehensive quality system is delineated in the IMPROVE QAPP, while the organizational structure and governance of the IMPROVE network are detailed in the Quality Management Plan (QMP).

Audit Program Overview

The current TSA process was introduced with the publication of the IMPROVE QAPP in 2016. Under this framework, a subset of monitoring sites is audited annually, with the goal of auditing all sites within a 10-year cycle. Auditors are required to possess familiarity with the network and undergo training conducted by an approved auditor. To ensure impartiality, auditors must not be involved in the routine operation of the sites being evaluated. Since 2016, the Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University has overseen the TSA program for the IMPROVE network, with Bonne Ford serving as the current Quality Assurance Manager (QAM) and lead auditor.

In 2017, the previous audit coordinator facilitated several training sessions for external auditors from EPA Region 2, Colorado (CO), Arizona (AZ), Missouri (MO), Wyoming (WY), and Delaware (DE). These sessions were designed to standardize audit procedures across the network and increase the annual audit throughput. By 2025, only auditors from the Missouri Department of Natural Resources (MDNR) and the Colorado Department of Public Health and Environment (CDPHE) continued to conduct audits for IMPROVE sites. However, these audits were limited in scope, focusing primarily on instrument performance and basic siting criteria, rather than conducting full TSAs as outlined in the QAPP.

At the start of 2025, the IMPROVE network consisted of 155 monitoring sites, though several sites were decommissioned by year-end. During the current 10-year audit cycle (2016–2025), 151 sites were audited, with some sites undergoing multiple audits. Additionally, several sites that are no longer operational were audited during this period. However, four sites had not been audited as of December 2025.

1. Toolik Lake (TOOL1) was not audited during the 2022 audit trip due to adverse weather conditions and was later decommissioned in 2025.
2. Egbert (EGBE1), located in Canada, was not audited due to its remote location and lack of proximity to other sites. This site was also shut down in 2025.
3. Carlsbad Caverns (CAVE1), installed in July 2017, was scheduled for audit in October 2025, but the audit was canceled due to a government shutdown.
4. MacDonald Pass (MAPA1), installed in October 2024, replaced Gates of the Mountains (GAMO1), which had been audited in 2018. Both MAPA1 and CAVE1 are scheduled for audit in 2026.

The map below illustrates the geographic distribution of IMPROVE sites as of 2025, with color coding indicating the year of the most recent audit (Figure 1). No audits were conducted by CIRA personnel in 2020 due to travel restrictions and in 2023 due to staffing transitions.

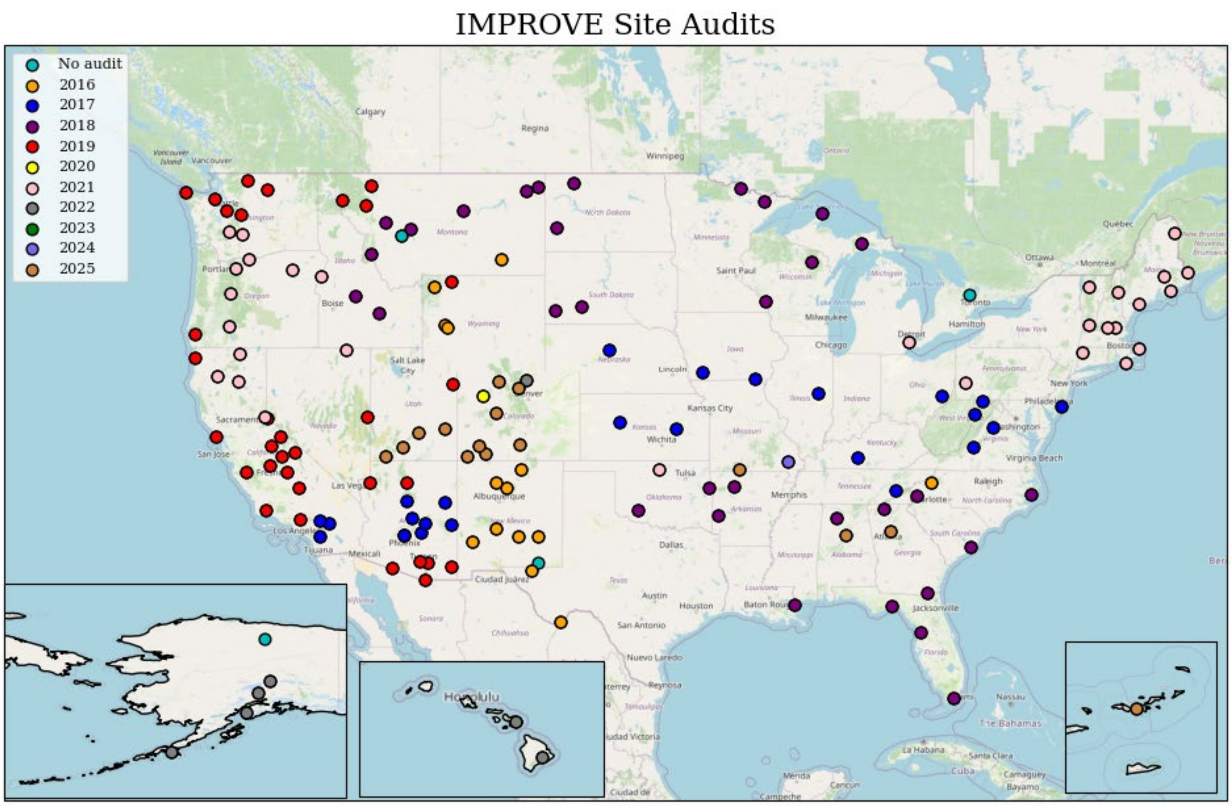

Figure 1. Locations of IMPROVE monitoring sites, colored by the year of the most recent audit.

Audit Procedure

The Technical System Audit (TSA) process involves a comprehensive evaluation of site compliance with IMPROVE network standards and operational procedures. The audit includes the following components:

1. *Verification of Site Coordinates and Elevation*: Confirming the precise geographic location and altitude of the site.

2. *Sampler Configuration Checks*: Validating the sampler's date and time settings and measuring key operational parameters, such as vacuum pressure, temperature, and flow rate for each module. Flow rates are measured using a certified flow meter that is calibrated and recertified annually to ensure accuracy.
3. *Physical Inspection*: Conducting an assessment of the sampler stand or shed for structural safety and integrity, ensuring proper configuration for unobstructed sample collection and compliance with siting criteria. The siting criteria are reviewed to confirm that samples collected represent local ambient background conditions, as outlined in IMPROVE SOP 126: Site Selection (current version 2.6, AQRC).
4. *Documentation of Site Conditions*: Capturing photographs of the sampler modules, stand/building, and surrounding environment.

Whenever feasible, audits are scheduled in coordination with site operators to observe sample-changing procedures and evaluate operator proficiency. Auditors assess the operator's knowledge of sampler operation and sample-changing protocols using questions from the approved TSA workbook. Additionally, operators are queried about any safety concerns and the adequacy of support provided by the current IMPROVE Operations Contractor (UC Davis AQRC) field team to maintain high-quality sampling standards. If an in-person meeting with the site operator is not possible, a phone call is arranged to complete this portion of the TSA.

Auditors utilize an approved TSA form for all audits, which is available on the IMPROVE website (https://vista.cira.colostate.edu/Improve/technical-system-audits/). The TSA forms are shared with site operators prior to the audit to outline the procedure. After the audit, completed forms are returned to the site operators and/or managers along with any recommendations and necessary resources. Additionally, the completed forms, along with updated site photographs, are submitted to the field team manager for recordkeeping and follow-up actions.

Audited Sites in 2025

Fifteen site audits were completed in 2025: 9 by CIRA, 1 by MDNR, and 5 by CDPHE. All sites audited by CIRA were full TSAs. While the audits conducted by CDPHE and MDNR were not full TSAs, all the audited sites had been previously audited within the 10-year audit period. Locations of all sites audited in 2025 are noted in Figure 1.

In 2025, 15 site audits were conducted: 9 audits by CIRA, 1 by MDNR, and 5 by CDPHE. All audits conducted by CIRA were full TSAs, whereas the audits performed by CDPHE and MDNR were limited in scope, primarily focusing on instrument performance and basic siting criteria. However, the sites audited by MDNR and CDPHE had all been previously audited during the current 10-year audit cycle. The geographic locations of the sites audited in 2025 are depicted in Figure 1.

Audit Flow and Leak Check Results for 2025

The results from individual site audits are documented in TSA workbooks, which are maintained by both the Lead Auditor and the Field Team Lead at UC Davis AQRC. A summary of the findings is provided below.

The IMPROVE sampler comprises four primary modules (A, B, C, and D) and, at certain sites, a fifth module (X), which duplicates one of the standard modules. Modules A, B, and C operate at a nominal flow rate of 22.8 liters/minute (lpm) and utilize a cyclone to achieve a 2.5-micron size cut. Module D operates at a nominal flow rate of 16.9 lpm and utilizes an impactor at the inlet to achieve a 10-micron size cut. Flow rates are tested using two methods:

1. Comparison to Nominal Flow Rate: Verifying the module's performance against its expected flow rate.
2. Comparison to Reference Instrument: Testing the module's flow rate against a calibrated reference device.

Modules are considered to have failed the flow rate test if the audit device's measured flow rate deviates from either the nominal or reference instrument flow rate by more than 10%. In 2025, all modules at audited sites passed the flow checks, except at SHMI1, where Modules A and C failed the flow rate test (Figure 2). However, the UC Davis Field Team had recently installed a new automated flow control at SHMI1. It is suspected that the audit results were influenced by procedural errors due to a new auditor who was unfamiliar with updated procedures. Remote checks conducted by the Field Team did not identify any ongoing flow issues. While CDPHE initially planned to re-audit SHMI1 in Fall 2025, CIRA will conduct a follow-up audit in Spring 2026 to ensure proper functionality across all modules.

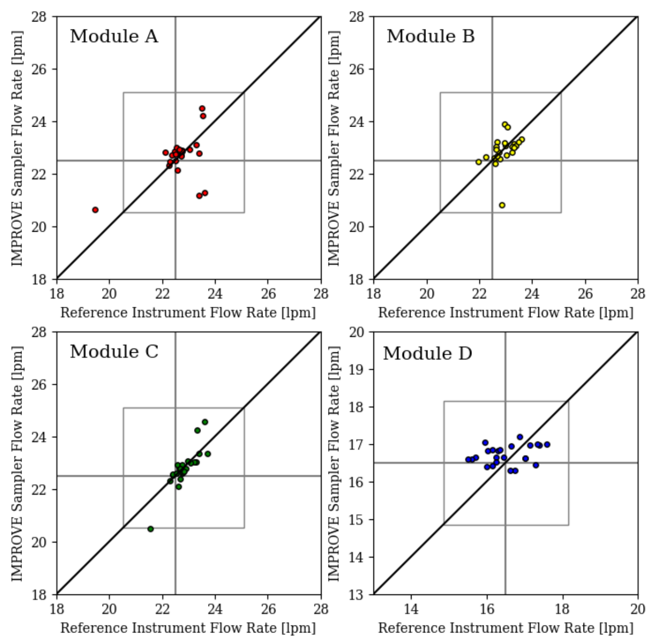

Figure 2. Flow rates results for all sites audited in 2025 for Modules A, B, C, and D (includes any duplicate measurements). Gray horizontal and vertical lines represent the nominal flow rate of the instrument; black line denotes the 1:1, and gray box denotes the range of acceptable values. The flow rate as given by the module is on the y-axis while the flow rate measured by the reference (audit) instrument is on the x-axis.

The vacuum pressure of the sampler is also measured to confirm minimal air leakage throughout the sample train, with a threshold of 3.5 psi or lower required to pass. For modules equipped with automated flow control, the standard automated leak test should be replaced by a manual leak test. However, some auditors were unaware of this protocol and conducted automated leak tests instead, leading to erroneous failure results. For instance, the auditor at HEGL1 later reported using the automated leak test and confirmed plans to perform manual leak checks in future audits.

Table 1. Leak check values for all modules. Modules pass if the value is below 3.5 psi. Failure results are shown in bold.

Site ID	Module A	Module B	Module C	Module D	Module X	Auditor
ATLA1	3.0	3.4	3.0	1.4	-	CIRA
BIRM1	3.1	3.2	3.4	3.2	-	CIRA
VIIS1	3.5	3.5	3.5	1.2	-	CIRA
WHRI1	1.3	2.1	0.9	1.1	-	CIRA
ROMO1	1.2	1.0	1.2	1.2	-	CIRA
MOZI1	1.4	1.4	1.5	0.8	-	CDPHE
GRSA1	2.4	2.6	3.2	1.1	-	CDPHE
WEMI1	1.7	1.6	1.5	1.2	-	CDPHE
SHMI1	3.3	**5.1**	3.3	1.0	-	CDPHE
MEVE1	**3.6**	3.4	3.4	1.2	2.2	CDPHE
CANY1	3.2	2.9	3.3	1.2	-	CIRA
ZICA1	3.5	3.0	**3.7**	2.1	-	CIRA
BRCA1	1.7	2.7	2.4	1.4	-	CIRA
CAPI1	3.2	3.1	1.8	1.2	-	CIRA
HEGL1	**4.9**	**5.5**	**5.8**	1.1	-	MDNR

Siting and Safety Audit Results 2025

In 2025, full Technical System Audits (TSAs) were conducted exclusively at sites audited by CIRA. Several siting and safety concerns were identified during these audits and were reported to the respective site operators and/or managers for corrective actions. Key issues are summarized below.

At the Virgin Islands IMPROVE site (VIIS1), tree branches were observed encroaching on the sampler inlet, as documented in Figure 3. According to IMPROVE SOP 126, trees located within 10 meters of the inlet must be positioned at least 1 meter below the height of the inlet to ensure unobstructed airflow and accurate sampling. This issue was reported to the site operator, along with recommendations for corrective action to trim the branches and restore compliance with siting criteria.

Figure 3. Photographs of the trees near the inlets at the Virgin Islands IMPROVE site (VIIS1).

At the Canyonlands IMPROVE site (CANY1), a new structure was installed in 2025, resulting in the site being relocated slightly. However, power for the sampler was still being drawn from the previous location via long extension cords, as illustrated in Figure 4. This configuration violates both IMPROVE SOP 126 and OSHA workplace guidelines. IMPROVE SOP 126 specifies that the site must be equipped with two 120-volt, 60-hertz, 20-amp circuits, terminated with two fourplex outlets. OSHA regulations only allow extension cords to be used temporarily (< 90 days), do not allow multiple cords to be connected to make longer lengths, and require that cords be protected from damage. The issue was discussed with the site operator and was due to an electrician being unable to visit the site.

Figure 4. Photographs of the extension cords in use at Canyonlands IMPROVE site (CANY1) during the audit. Photograph on the left is of the old outdoor rack, middle photograph is of the connection between extension cords, and photograph on the right is of the new mounting on the side of a structure.

At the Zion Canyon IMPROVE site (ZICA1), the sampler modules were mounted on an exterior rack attached to a structure. During the audit, it was noted that the pump box had sustained damage and water had leaked inside due to heavy rains, as shown in Figure 5. The wood surrounding the pump box was soft. This compromised the structural integrity of the equipment and could pose a hazard to the electrical equipment.

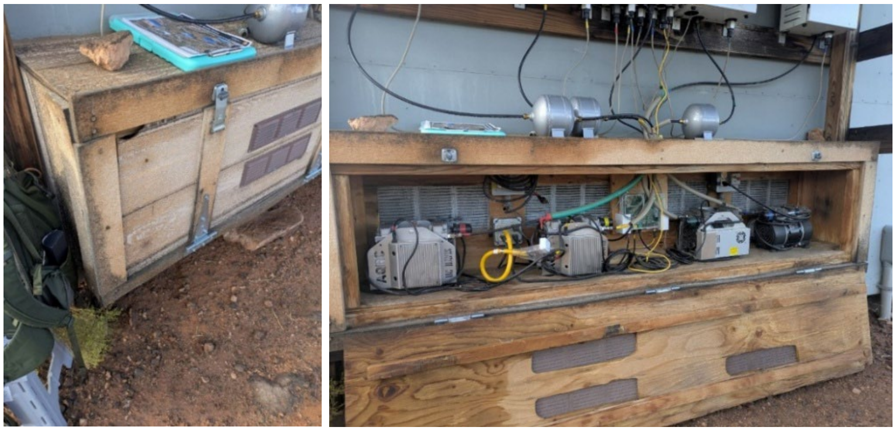

Figure 5. Pump box at Zion Canyon IMPROVE site (ZICA1) showing water damage.

Operator Training and Review

As part of the Technical System Audit (TSA) process, auditors assess whether site operators are aware of and utilizing available resources. Additionally, auditors evaluate the support provided by the UC Davis Field Team, observe sample handling procedures, and document routine maintenance practices.

Feedback from operators was generally positive regarding the responsiveness and problem-solving capabilities of the UC Davis Field Team. However, several issues were identified during the audits. Most operators were unaware of the online resources available to them, including updated SOPs, training materials, and logistics-related tools such as filter shipping lists. The ZICA1 site had an outdated SOP and was unaware of where to obtain new versions of the SOP. At the Birmingham IMPROVE site (BIRM1), the audit revealed that incorrect filters had been installed. The operator was new and was not checking the filter labels and following the sample change schedule.

A significant contributing factor to these issues appears to be operator turnover. While some sites had operators with extensive experience (e.g., the operator at MOZI1 had 15 years of tenure), other sites relied on operators with only a few months of experience or temporary backup staff. The relatively straightforward nature of the filter-changing procedure may contribute to gaps in training, as it often does not include detailed explanations of the available resources or the scientific purpose behind the measurements. Furthermore, operator morale was noted as a concern during the audits. Several operators expressed apprehension regarding their employment status and changes to their job responsibilities, which may impact their engagement and performance.

Audit Results Compared to Previous Audits

The Birmingham (BIRM1), Atlanta (ATLA1), and Virgin Islands (VIIS1) sites were audited for the first time in 2025.

The Great Sand Dunes IMPROVE site (GRSA1) was previously audited in 2016, 2022, 2023, and 2024 (CIRA). In 2022, it was noted that the stacks for Modules B and C were not seated into the sampler inlet. It was assumed that this was likely due to strong winds. The field team installed extra collars on all the inlet stacks (these are generally only on Module D stacks) and that appears to have worked to keep the stacks seated. GRSA1 has never failed a flow or temperature audit, but the agreement between the audit instrument has improved over time, specifically for Module D. The 2024 audit noted that the sampling stand was in poor shape and would need to be replaced. NPS coordinated with ARS to replace the stand in May 2025 (see next section).

Rocky Mountain National Park (ROMO2) was previously audited in 2016 (CIRA), 2018 (CIRA), 2019, 2020, 2022, and 2024 (CIRA attended). No issues have been reported at the ROMO2 site.

The Shamrock Mines IMPROVE site (SHMI1) was previously audited in 2016, 2019 (CIRA), 2023, and 2024. No previous audits found flow or leak issues. The 2019 audit noted a failure for the controller clock.

The Mesa Verde IMPROVE site (MEVE1) was previously audited in 2016, 2017 (CIRA), 2020, and 2024. The denuder for Module B was compromised during the 2024 audit and a replacement denuder was shipped.

The Hercules Glades IMPROVE site (HEGL1) was previously audited in 2017, 2020, 2021 (CIRA), and 2024. In 2021, it had a leak check fail for Module A. The audit in 2025 had leak check failures for Modules A, B, and C. However, as discussed this was due to relying on the old automated leak check test which cannot be used with the new flow control system.

The Mount Zirkel IMPROVE site (MOZI1) was previously audited in 2016, 2018 (CIRA), 2020, 2023, and 2024. Module A failed the flow test in 2020. In 2023 and 2024, the modules all passed the flow tests.

The Weminuche Wilderness IMPROVE site (WEMI1) was previously audited in 2016 (CIRA), 2020, and 2024. The 2016 audit noted that the structure needed work and that there were several trees too tall and too close to the inlets. The Forest Service was notified that these would need to be trimmed back. Module B also failed the leak check. All modules passed in 2020 and no site issues were noted.

The White River IMPROVE site (WHRI1) was previously audited in 2016, 2019, 2020, 2021, 2023, and 2024. In 2016, all modules passed. However, in 2019, Module D failed the flow test; in 2020, Module C failed the flow test (and the display was not reading correctly); in 2023, Module D failed and Module B was close to failing. In 2024, Module D was close to failing with a 10% difference between the audit instrument and module.

Audit Follow-ups

In the 2024 TSA report, it was noted that the GRSA1 stand needed to be replaced. The site was replaced by Air Resource Specialists (ARS) in May 2025. The new site is shown below in Figure 6.

Figure 6. Photographs of the replacement shed at Great Sand Dunes (GRSA1) in May 2025.

In the Canyonlands IMPROVE site (CANY1) audit, it was noted that the site was operating off the power supply at the old site using a series of long extension cords. There was a significant delay in transferring power to the new stand due to difficulties in getting an electrician scheduled to visit the site. Power was finally transferred on 11 November 2025 (Figure 7), and the site was fully operational on 2 December 2025.

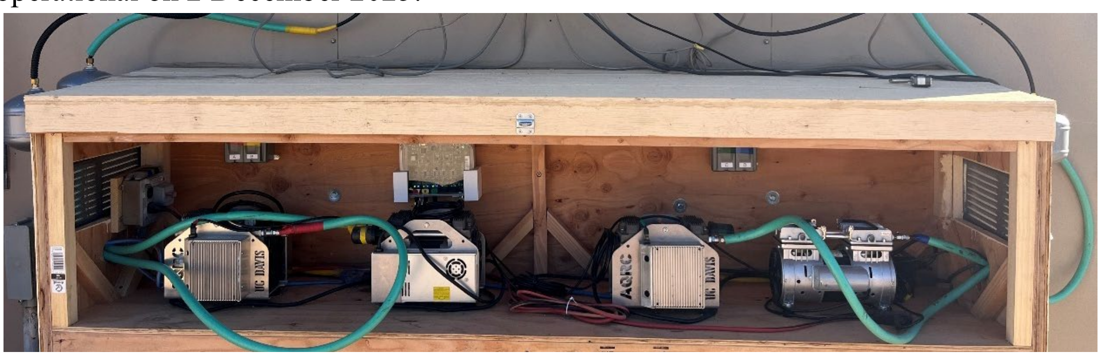

Figure 7. Photograph of the new outlets in the pump box at the Canyonlands (CANY1) site.

Review of Audit Program 2016-2025

Over the first 10-year audit cycle established by the IMPROVE 2016 QAPP, a total of 226 audits were conducted across the network, with several sites in Missouri (MO) and Colorado (CO) audited multiple times. The timeline of flow checks, presented in Figure 8, illustrates the comparison of flow rates to both the reference instrument and the nominal flow of the sampler for all audits conducted since 2017. Audits from 2016 are excluded due to procedural and workbook changes introduced after the initial year. The results indicate that flow issues have been minimal across the network, reflecting consistent sampler performance and effective maintenance efforts.

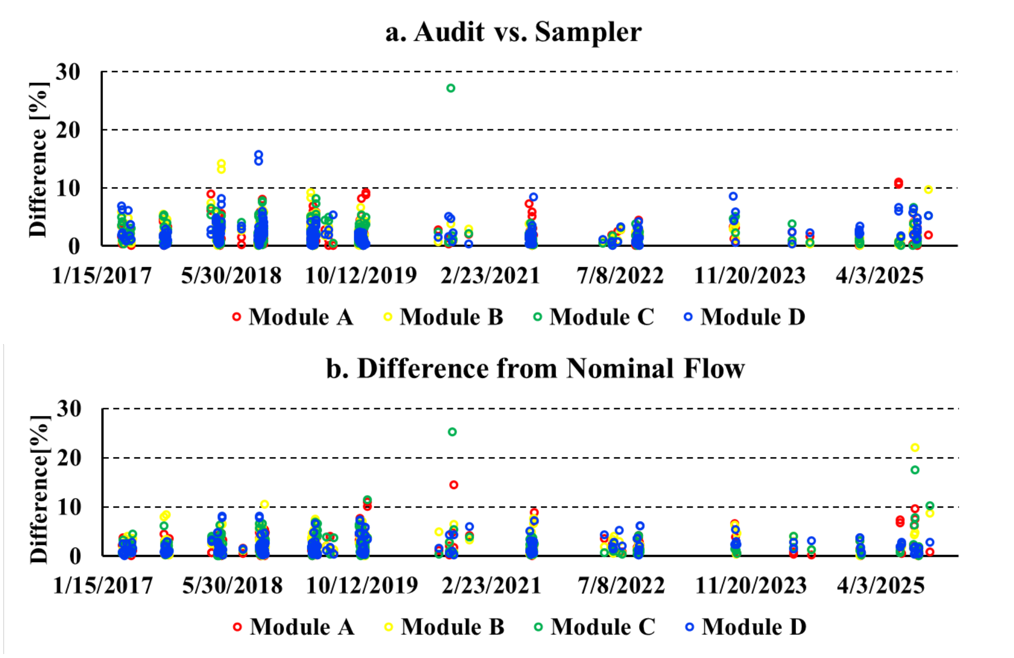

Figure 8. Timeline of IMPROVE site audit flow check differences between (a) the module and the reference device and (b) the module and the nominal flow. Colors denote modules.

Figure 9a provides a timeline of the number of audits performed each year, categorized by whether issues were reported. In most years, over half of the audits did not identify any issues. However, it is important to note that some audits were not full TSAs, so siting-related concerns may not have been systematically documented. Figure 9b further categorizes the types of issues identified during audits, showing that while issues are routinely found, the majority are minor, such as clock resets or encroaching tree branches. The data also highlights a positive trend: the number of issues identified during audits has decreased over time. This improvement is largely attributed to advancements in instrumentation, including updated controllers and automated flow control systems. These enhancements have contributed to improved reliability and performance across the network. Overall, the findings suggest that the IMPROVE network has successfully maintained its quality standards while achieving continuous improvement over the past decade.

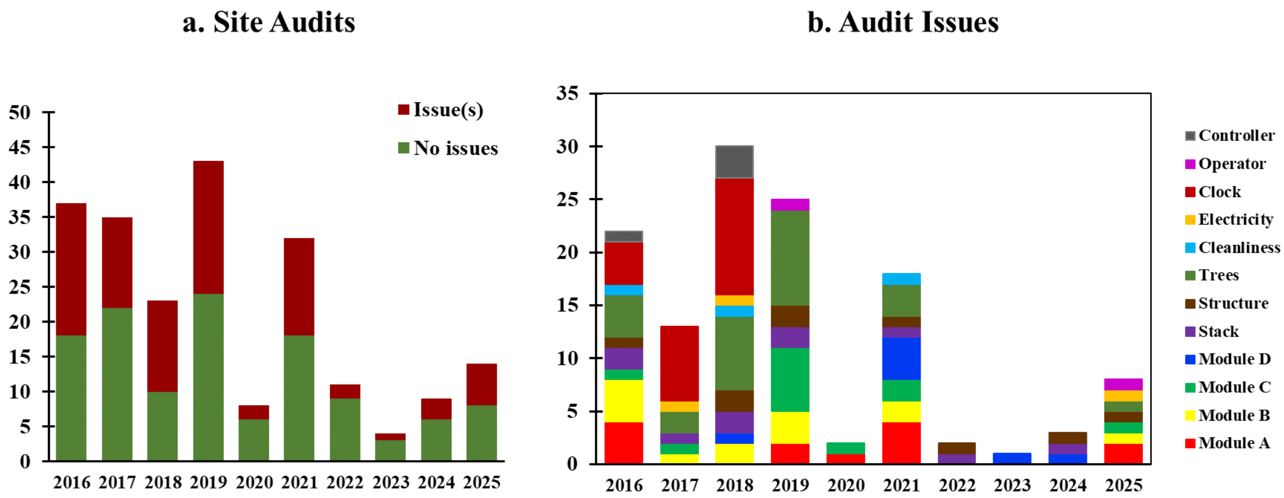

Figure 9. (a) Number of audits per year in the 10-year time period (2016-2025) colored by whether an issue was noted or not in the audit. (b) Number of different types of issues noted by the audits (note that a single audit may note multiple issues) over time.

Summary

The 2025 audit results confirm that the IMPROVE network is functioning effectively, with its existing quality and management systems deemed adequate to support high-quality operations. A review of all audits conducted during the 10-year audit cycle (2016–2025) further demonstrates that the network has consistently maintained a high standard of performance. Moreover, the introduction of updated procedures and instrumentation, such as updated controllers and automated flow control systems, has contributed to improved reliability and reduced the likelihood of module failures during flow tests. Moving forward, it will be essential to ensure that auditors are properly trained and reminded of the updated audit procedures to avoid discrepancies during evaluations.

Despite the network's overall success, challenges remain. The aging of the network is a concern, as a growing number of structures require repair or replacement. Additionally, operator turnover and low morale are emerging concerns, with newer operators often less familiar with available resources and procedures. Addressing these issues will be critical to sustaining the network's performance in the next audit cycle.

The conclusion of the 10-year audit period in 2025 leaves only two active sites (GAMO1 and CAVE1) unaudited, as TOOL1 and EGBE1 were decommissioned during the year. With the IMPROVE QAPP currently undergoing an update to align with the end of the audit cycle, the results from the completed audits should provide valuable insights to guide revisions to TSA procedures. Prioritizing auditor training sessions and recruitment of auditors from partner agencies will be essential to ensure the continued success of the network quality system in the upcoming audit cycle.

Documents Referenced in Report:

Document	**Webpage Link with Document**
IMPROVE QMP	https://vista.cira.colostate.edu/Improve/quality-assurance/
IMPROVE QAPP	https://vista.cira.colostate.edu/Improve/quality-assurance/
IMPROVE SOP 126: Site Selection	https://vista.cira.colostate.edu/Improve/particulate-monitoring-network/
Technical Systems Audit Form	https://vista.cira.colostate.edu/Improve/technical-system-audits/