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After the Flood: A Standardized Method for Reporting Drinking Water Quality and Testing Requirements

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Abstract:
Background: *Restoring water delivery after flooding does not establish whether drinking-water criteria have been met or which supplies require further testing. Treating restored service as evidence of acceptable water quality may prompt households to resume consumption before assessing contamination.*
Materials and Methods: *Multiple published investigations of private wells, household water collection sites, and public supplies were compared to distinguish measured conditions, changes at repeatedly sampled locations, and testing coverage. These distinctions informed a reporting method illustrated through a hypothetical application involving 100 private wells.*
Results: *Analyses excluding repeat samples described patterns among submissions, while repeated sampling supported comparisons at monitored locations. Neither sampling design established conditions at untested supplies. The proposed method maintains dated supply records, reports operating conditions separately, and classifies supplies as criteria met, exceedance awaiting resolution, or assessment incomplete. Failed tests remain unresolved after repairs until required follow-up confirms that criteria are met. Each unresolved failure or incomplete assessment is linked to a next action and responsible person. In the hypothetical application, 24 of 30 assessed wells met an Escherichia coli criterion: 80% of assessed wells but only 24% of registered wells. A subsequent report distinguished 50 satisfactory assessments, eight unresolved failures, and 42 incomplete assessments.*
Conclusion: *This work presents a standardized procedure that links recovery statements to supply-specific evidence and outstanding testing. Utilities, health departments, and well-testing organizations could use the method to coordinate testing and communicate findings to households. Field evaluation should assess testing coverage and follow-up completion.*
Key Words: *drinking water; flood recovery; monitoring; private wells; public health*

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I. INTRODUCTION

Restoring a drinking water supply after flooding raises a critical question for households: what evidence justifies resuming consumption of the water? A functioning pump shows that water delivery is possible, whereas a satisfactory laboratory result applies only to the sampled water and the measured contaminants. Following Hurricane Harvey's landfall in Texas, USA, in August 2017, Pieper and colleagues documented microbial contamination in private wells and inconsistent participation in voluntary testing[1]. Private-well households need information specific to their own supply, even when regional testing suggests improvement. Consequently, recovery reports must specify which supplies were tested, the parameters measured, and whether additional testing is necessary.

For post-flood supplies, separate assessments are required for water delivery, treatment performance, and water quality[2,3,4]. The World Health Organization (WHO) distinguishes operational checks of treatment and disinfection from verification of drinking-water quality[5]. Researchers have also examined automated monitoring to inform post-repair return-to-service decisions[6]. The WHO integrates microbial results with sanitary inspections and water-safety-plan assessments to prioritize interventions[7]. Additional research has identified gaps in measuring drinking-water-system resilience[8], proposed indicators such as the proportion of water sources included in flood-readiness plans and the interval from warning to sampling[9], and evaluated reporting on the return to pre-flood conditions in surface-water studies[10]. This methodology aligns with linking hydrologic claims to their supporting measurements and associated uncertainties[11]. However, household decisions require evidence specific to the individual supply.

The following investigation critically compared multiple published studies to a) distinguish satisfactory measurements from improvements shown by comparable repeat measurements at the same supply, b) determine which supplies were affected by the observations, and c) develop a reporting method for identifying required

testing, corrective work, and responsibility for follow-up. The investigation was a focused comparative analysis undertaken to develop a reporting method, not a literature review. Studies were selected for contrasting sampling designs and accessible methods and results, enabling examination of how sampling locations, timing, and repeat measurements affect recovery interpretation. Private wells were the primary focus, with shared household collection sites and public supplies providing comparative context. The outcomes help scientists assess the evidence supporting recovery claims and help utilities, health departments, and well-testing organizations plan assessments, coordinate corrective follow-up, and communicate testing needs to households.

II. REVIEW APPROACH

Targeted web searches combined terms for flood, hurricane, drinking water, private well, recovery, monitoring, and verification. Recent peer-reviewed publications were prioritized. Five investigations with accessible full methods and results were selected, due to completeness of data sets, to compare voluntary submissions, paired seasonal samples, and repeated post-hurricane sampling. Sampling locations, dates, measurements, repeat visits, and represented populations were examined to distinguish measured conditions, same-supply change, and testing coverage. Missing dates or site identifiers can prevent linking results across places and times; coverage also requires the number of affected supplies. Unreported details were recorded as unknown. Table 1 summarizes the comparison used to specify the reporting method and hypothetical application.

Table 1. Sampling designs and recovery information in the five investigations. The Puerto Rico studies share sites and some observations.

Investigation and unit	Measurements and repeat visits	Supplies represented	Implication for recovery assessment
Private wells, 44 Texas counties; Hurricane Harvey, August 2017. Testing August 2017–June 2018[1].	8,822 samples; repeat locations excluded from the 1,405-sample analytical subset.	Voluntary submissions; affected-well count estimated.	Individual-well change requires linked repeat samples.
Private wells, 25 western North Carolina counties; Hurricane Helene, September 2024. Poststorm tests before March 1, 2025[12].	623 samples; one poststorm observation retained per repeated site.	Voluntary submissions across the affected region.	Contamination patterns identify testing priorities; recovery needs repeat sampling.
Household water collection sites, Savelugu Municipal and Talensi, northern Ghana; September 2020 flooding and February 2021 dry season[13].	57 flood-season and 40 dry-season observations; paired subset.	59 mapped points; availability changed between rounds.	Seasonal differences vary by source type; document unavailable and replacement sources.
Tap water, nine Puerto Rico sites; Hurricane Maria, September 2017. Sampling December 2017–October 2018[14].	Nine sites, six rounds of bacterial gene measurements.	Accessible, operational sites sampled from three months after the hurricane.	Changes in bacterial gene abundance at nine sites during the study period.
Tap water, 16 Puerto Rico municipalities; Hurricane Maria, September 2017. New sampling March–November 2018[15].	36 recurring-site samples and 23 separate household samples.	Same nine-site program plus selected households.	Separate changes at repeated sites from findings at additional households.

III. WHAT THE OBSERVATIONS ESTABLISH

The private-well investigations illustrate why patterns among submitted samples differ from changes at individual wells. For Hurricane Harvey, researchers collected 8,822 well-water samples across 44 counties in Texas, USA, from August 2017 through June 2018. A 1,405-sample subset used for temporal and mitigation analyses excluded repeat-location samples. The proportions testing positive for total coliform bacteria and Escherichia coli (E. coli), a fecal-contamination indicator, generally declined over time after flooding[1]. These trends describe submitted samples rather than documented changes at individual wells. Following Hurricane Helene in September 2024, Lin and colleagues used 623 submitted well samples from 25 counties in western North Carolina, USA, to identify contamination patterns and testing priorities[12]. Retaining one observation per repeatedly sampled site supported spatial comparisons. Notably, individual recovery would require comparable follow-up samples.

Repeated samples enable comparisons across locations and time. In the Savelugu Municipal and Talensi districts of northern Ghana, Dzodzomenyo and colleagues collected 57 measurements at household water collection sites, including wells, boreholes, and surface-water sources, during flooding associated with

Bagre Dam releases in September 2020, and 40 during the February 2021 dry season. Seasonal comparisons used available paired sources. Groundwater E. coli and thermotolerant-coliform counts were higher during the flood season, whereas surface-water E. coli counts were higher during the dry season[13]. Ultimately, a seasonal decrease at one source type could not be assumed for another.

Following Hurricane Maria on September 20, 2017, Sevillano and colleagues sampled nine accessible Puerto Rican sites in six rounds from December 2017 through October 2018. Bacterial gene abundance generally declined. Metagenomic differences between these sites and comparison drinking-water systems did not differ significantly from those among the comparison systems[14]. Lin and colleagues examined 36 new samples from the same nine-site program and 23 separate household samples collected in 2018, measuring chemical composition and cellular responses to concentrated water extracts[15]. The recurring-site samples enabled comparisons over time, while the 23 separate household samples described water quality at additional homes. Chemical concentrations, bacterial genes, and cellular responses each represent a distinct measurement and require separate interpretation.

Across these investigations, the sampling design determined whether results described differences among submitted samples or changes at the same location. Two analyses excluded repeat-location samples or retained one result per site; three retained repeat measurements for at least a subset of locations (Table 1). A satisfactory result indicated that the sampled water met the measured criterion, while improvement requires a comparable earlier result. Declining concentrations can also remain above an adopted limit. These distinctions explain why recovery reporting requires both individual sampling histories and a list of water supplies still awaiting assessment. Trends among tested locations do not define conditions at untested supplies.

IV. A METHOD FOR REPORTING RECOVERY EVIDENCE

The inter- and intra- study comparison identified key information needed to interpret recovery, including test results, links between successive samples, and the supplies represented. A proposed reporting method retains these details in a dated record for each supply (Figure 1). Utilities, health departments, or well-testing organizations adopting this method would assign staff to maintain records, report outstanding tasks to response teams, communicate supply-specific findings to households, and coordinate follow-up.

The method first requires recording the included supplies and defines the assessment unit, such as a private well, a shared collection site, or a specified public-system sampling location. Source and household-tap samples are kept separate; for example, Keenum and colleagues sampled these components of small Puerto Rican systems after Hurricane Maria[16]. Operating condition is recorded separately to distinguish water delivery from compliance with water-quality criteria[2,5]. Each record specifies the intended water use, sampling point, required contaminants or indicators, analytical methods, adopted limits, and events that require reassessment. These specifications define a satisfactory assessment and enable comparability across results. Microbial and chemical tests are selected based on plausible local contamination sources to define the assessment's scope[7].

Test selection must align with the specific research question. Gene assays detect microbial genetic material, while culture counts measure organisms that can grow under specified test conditions[17]. Automated measurements also require a defined target and quality control[6,18]. For example, in the West Run Watershed in Morgantown, West Virginia, USA, researchers monitored 11 stream sites and found human-associated fecal markers primarily at developed sites and cattle markers at agricultural sites[19]. These data demonstrate how source tracking can identify probable contamination inputs. Such information can guide further investigation, but recovery classification requires the prescribed tests at the drinking-water sampling point.

Using the reporting method, each supply is assigned one of three classifications at the report date. 'Criteria met' requires all prescribed results to be valid, satisfactory, and still applicable, with no unresolved failed tests or outstanding reassessments. 'Exceedance awaiting resolution' applies when a valid result fails an adopted water-quality criterion and required follow-up has not demonstrated that the criterion is met. Repairs alone do not alter this classification; the original result and finding remain dated to prevent confusion with current measurements. 'Assessment incomplete' applies when required information is missing, invalid, or due for renewal, and no failed test remains unresolved. An unresolved failure takes precedence over missing information for another required test, which remains recorded as unfinished work. Renewed flooding or a supply change can trigger reassessment of a previously satisfactory supply.

The report lists category totals, operating supplies, and unique supplies assessed at least once, specifying the population used for each proportion. Drewry and colleagues found that alternative inundation boundaries altered estimates of potentially inundated wells and testing coverage[20]. On this basis, reports must state how the affected-supply list was defined and whether it is complete. Collection, result receipt, notification, corrective work, and follow-up dates are recorded separately. A result received on day 23 for a day-18 sample cannot inform a day-20 report; subsequent reports still identify it as a day-18 measurement. Assigning a next action and responsible person to each unfinished assessment or unresolved failure enables response teams to distinguish initial testing, corrective work, and verification after repairs.

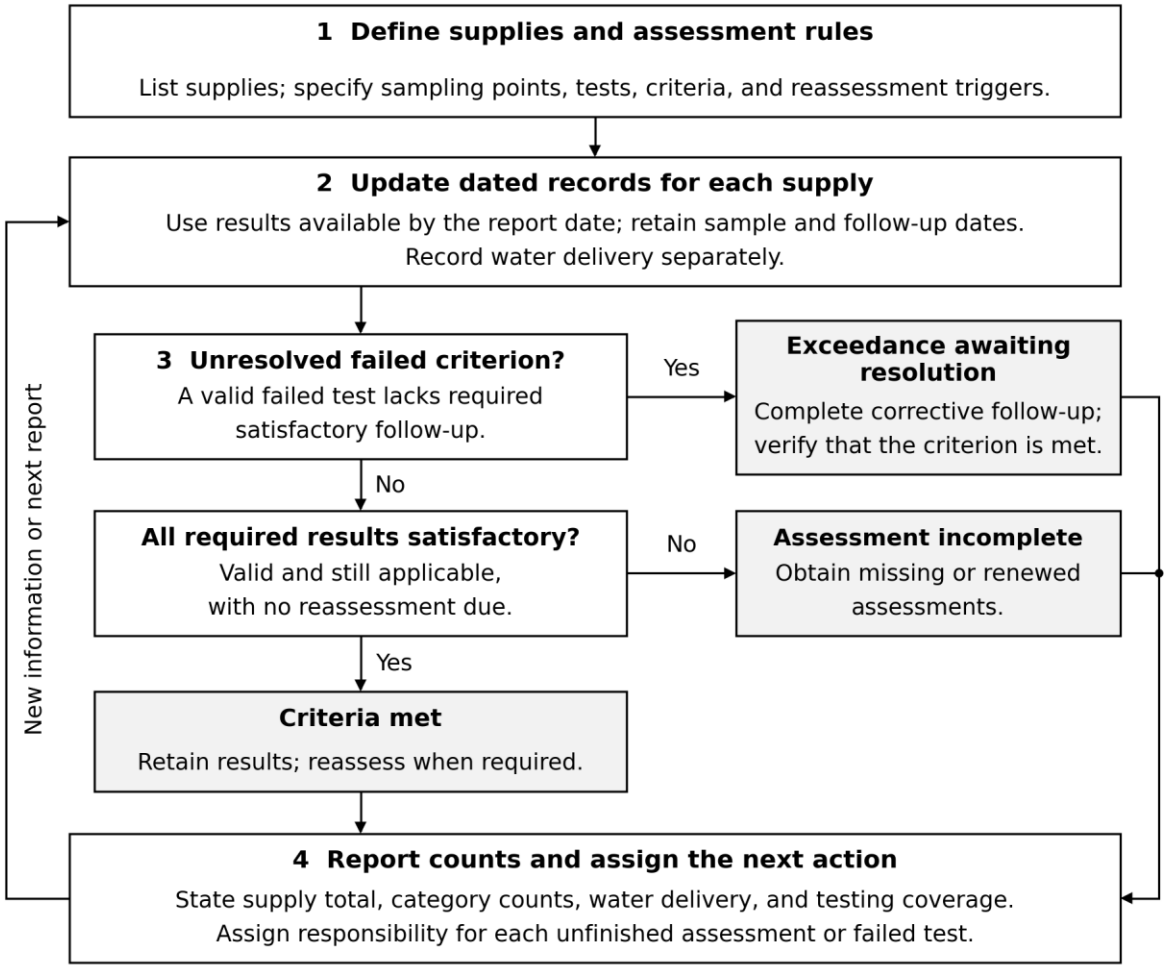


Figure 1. Proposed recovery reporting method. Classification is based on information available as of the report date. An unresolved failed test takes precedence over incomplete information for another required test; both are retained in the supply record. Operating conditions are reported separately.

V. WORKED APPLICATION AND MANAGEMENT IMPLICATIONS

A hypothetical application demonstrates how the method distinguishes satisfactory test results from the proportion of supplies assessed and identifies unfinished work. The example tracks 100 flood-affected private wells across two reports. Testing focuses on E. coli at household drinking-water taps, with the criterion being no detection in a 100 mL sample[7]. Collection, handling, analysis, and timing after corrective work must comply with the adopted local protocol. Initially, 24 wells meet the criteria, six fail, and 70 have incomplete assessments: 24 + 6 + 70 = 100. Satisfactory results represent 80% of the 30 completed assessments but only 24% of registered wells. Separately, 80 wells are operational; this operational count overlaps with the assessment categories and is not added to them.

The registered group and criteria remain unchanged; satisfactory results remain applicable unless a specified event necessitates reassessment. Before the second report, 30 previously unassessed wells yield 27 satisfactory and three unsatisfactory assessments. Of the original 24 satisfactory wells, 19 retain applicable results, three now fail, and two require reassessment after a disturbance. Of the original six failed assessments, four have satisfactory follow-up according to the protocol, and two await results after corrective work. The latter remain unresolved failures. The second report therefore includes 50 criteria met, eight exceedances awaiting resolution, and 42 incomplete assessments (Table 2). These categories total 100. Sixty wells have been assessed at least once, including the two previously satisfactory wells now requiring reassessment; only 50 currently meet the criterion.

Table 2. Hypothetical reports for the same 100 private wells. The first three categories are mutually exclusive and sum to 100. Subsequent rows may overlap these categories.

Reporting quantity	Definition for this example	First report	Second report
Criteria met	Required *E. coli* assessment meets the criterion and remains applicable.	24	50
Exceedance awaiting resolution	A failed test remains unresolved pending required follow-up.	6	8
Assessment incomplete	Required information is missing, invalid, or due for renewal; no unresolved failed test.	70	42
Awaiting results after corrective work	Subset of unresolved failures: work is complete; repeat-test results are pending.	0	2
Ever assessed, unique wells	At least one accepted assessment has been recorded by the report date.	30	60
Operational wells	Water can be delivered, regardless of test findings.	80	95
Satisfactory assessment coverage	Wells meeting the criterion divided by all 100 registered wells.	24%	50%

The eight unresolved failures require corrective follow-up; the 42 incomplete assessments include 40 wells never assessed and two that require renewed assessment. If 95 wells are now operational, including all 50 satisfactory wells and eight unresolved failures, then 37 operating wells have incomplete assessments: 50 + 8 + 37 = 95. The remaining five incomplete assessments pertain to nonoperating wells. Dates distinguish completed repairs awaiting test results from work not yet undertaken. Household water use must also be updated, as a tested well may no longer serve as the drinking-water source. In a 2020 retrospective survey of 69 well users, Gitter and colleagues found that fewer respondents reported drinking well water after Hurricane Harvey than before it[21]. Recording the current drinking-water source therefore helps determine whether well-test results reflect the water a household consumes.

Completing an assessment may require assistance with obtaining a sample, interpreting a result, or arranging follow-up. Hubbart and Gootman proposed a West Virginia testing and outreach program that integrates these activities[22]. Their proposed sequence identifies support tasks that can accompany the water-quality record. Recording the task, the responsible person, and the completion date indicates which households still require assistance. Inaccessible or nonresponding supplies remain listed; retirement or replacement is documented to ensure incomplete assessments do not disappear from reported coverage.

VI. LIMITATIONS AND EVALUATION

This analysis relies on published observations; unreported dates or follow-up remain unknown. The Puerto Rico investigations share sites and some samples, and monitoring began after the acute disruption, limiting interpretation to related observations of later conditions. Hurricane-related changes also include flooding, power loss, infrastructure damage, and prior supply conditions; their individual contributions cannot be inferred from these comparisons.

Classifications are applied to defined hazards, sampling locations, and criteria. The example focuses on E. coli; however, local hazards may require additional or alternative testing. Responsibility for protective guidance and decisions on resuming drinking water remains with the designated authority[5,7]. Field evaluation should compare the proposed method with current practices and assess agreement among evaluators, completion rates for required follow-up, notification delays, the proportion of affected supplies tested, and staff time allocation. Evaluation should also consider hazard severity, access limitations, and new detections from testing supplies previously unassessed.

Assessing health benefits requires a distinct evaluation that links household water use, exposure, and illness to the specific water supply. Gitter and colleagues estimated infection risks under defined exposure assumptions[23], while Mattioli and colleagues documented gastrointestinal illness associated with low-pressure events during primarily planned maintenance activities[24]. These study designs address different research questions: modeled risks depend on exposure assumptions, and findings related to maintenance do not establish effects specific to flooding. Herrador and colleagues reported no positive association between precipitation or runoff and gastroenteritis consultations in the large Norwegian water supplies studied[25]. Therefore, neither satisfactory test results nor environmental changes alone provide evidence of reduced post-flood illness.

VII. CONCLUSION

After flooding, restoring water delivery and satisfactory results from selected samples leaves an unresolved management question: which supplies meet the required drinking-water criteria, and which still require assessment or corrective follow-up? Multiple investigations were compared to differentiate measured conditions, changes at repeatedly sampled locations, and the supplies represented. Analyses of various submitted samples identified patterns among submissions, while linked repeat samples enabled comparisons at monitored supplies. Neither approach established the condition of untested water supplies. Furthermore, a declining concentration did not necessarily indicate that the adopted criterion had been met.

The proposed reporting method preserves these distinctions by providing a dated record for each supply, explicit criteria, and three classifications: criteria met, exceedance awaiting resolution, and assessment incomplete. Each unfinished assessment or failed test is linked to a subsequent action, while water delivery is reported separately. In the hypothetical application, 80% of assessed wells had satisfactory results, representing only 24% of registered wells. Tracking subsequent assessments distinguished unresolved failures, initial tests still required, and reassessments. This example illustrates how the classifications structure decision-making; however, effectiveness in practice remains to be evaluated.

Utilities, health departments, and well-testing organizations implementing the method would prepare reports for response teams and communicate supply-specific findings to households. Implementation would establish reporting schedules and responsibilities in accordance with local requirements. The scientific contribution is establishing a clear link between recovery statements and the sampling evidence required to substantiate them. The management contribution is providing a standardized procedure that connects this evidence with assigned testing and follow-up across a defined supply list. Evaluation should determine whether the method enhances assessment coverage and follow-up completion within feasible staffing constraints.

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