Title

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Author

Suzannah Rutherford, PhD

Affiliation

Mashapaug Watershed Coalition, Providence, Rhode Island

Email

save.mashapaug.pond@gmail.com

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Legacy brewery phosphorus as a management constraint in the Mashapaug Watershed: unresolved reservoirs and pathways in an urban pond cascade

Suzannah Rutherford*

Mashapaug Watershed Coalition, Providence, Rhode Island
**Corresponding author: save.mashapaug.pond@gmail.com*

Abbreviated title: Legacy phosphorus in the Mashapaug Watershed

Abstract

Spectacle and Mashapaug Ponds have been listed as impaired waters in Rhode Island since 2002, with 20 public-health advisories issued since 2011. Phosphorus is treated as the primary limiting nutrient for harmful algal blooms in the watershed, and Spectacle Pond is the largest direct phosphorus source to Mashapaug Pond and the lower pond cascade. In February 2026, the Rhode Island Department of Environmental Management issued a permit requiring 65–68 percent stormwater phosphorus reductions from regulated parcels but did not address legacy phosphorus from industrial sources. Tongue Pond, the uppermost kettle pond, received Narragansett/Falstaff brewery effluent from 1890–1981 and once discharged to Spectacle Pond through a constructed outlet. To evaluate whether brewery-derived phosphorus remains a plausible management concern, I estimate phosphorus delivered to, exported from, and retained in or near Tongue Pond during brewery operations. Using 1974 EPA water-quality data and a 1976 federal discharge permit application, I developed a literature-based input model, outlet-constrained export model, and mass-balance retention estimate to partition phosphorus loads. An estimated 281,000–1,405,000 kg P was delivered to Tongue Pond, with a best estimate of 54,000 kg P reaching

Spectacle Pond via Tongue Pond outflow. This model yields inferred legacy residuals of 227,000–1,351,000 kg P in or near Tongue Pond, with a central estimate of 643,000 kg P. Sediment cores, porewater profiles, groundwater transects, storm-event flow monitoring, and benthic-flux measurements are needed before managers can determine whether stormwater controls alone are sufficient or whether legacy reservoirs require targeted intervention.

Key words: brewery effluent; glacial outwash; groundwater transport; harmful algal blooms; legacy phosphorus; Mashapaug Pond; sediment phosphorus; stormwater management

Watershed best management practices (BMPs) are a necessary component of phosphorus control, but they may prove insufficient to restore eutrophic lakes where internal loading, legacy sediments, or groundwater phosphorus stores continue to sustain summer nutrient availability (Søndergaard et al. 2003, Schindler et al. 2016, Van Meter et al. 2021). The February 2026 Mashapaug General Permit—the most significant regulatory milestone in the watershed's history—requires stormwater phosphorus reductions of 65–68 percent from regulated parcels, targeting the impervious surfaces and recurring health advisories that have come to define this urban watershed (RIDEM 2026, 19, 27; RIDEM [date unknown-b]; RI Attorney General 2024, 7–8). Mashapaug Pond discharges through a culverted, underground connection to the west end of Roosevelt Lake in Roger Williams Park, a 435 acre (176 ha) civic landmark long known as the "Jewel of Providence," receiving more than 1.5 million visitors annually (Marshall 1987, City of Providence [date unknown]). Direct inflow from Mashapaug Pond contributes an estimated 232 kg/yr (512 lb/yr; Table 1), or approximately 23 percent of the Park's total annual phosphorus input, making upstream source control essential to reducing harmful algal blooms throughout the watershed (RIDEM 2026; RIDEM 2007a, 1, 54, Table 5.5).

Spectacle Pond is the dominant direct input of phosphorus to Mashapaug Pond, contributing an estimated 109 kg/yr (241 lb/yr; Table 1), or 47 percent of Mashapaug's annual total phosphorus (TP) loading (RIDEM 2007b, 41, Table 5-2). Although the Mashapaug General Permit addresses stormwater discharges across the Mashapaug watershed, the permit does not address two legacy processes with potentially outsized effects on downstream water quality. First, RIDEM previously identified in-lake phosphorus cycling in Spectacle Pond as requiring control alongside stormwater inputs (RIDEM 2007b, viii, 60). Because Spectacle Pond is already the largest identified phosphorus source to Mashapaug Pond, internal phosphorus recycling within Spectacle Pond could have outsized downstream consequences for Mashapaug Pond and the lower pond cascade. The magnitude and timing of that internal contribution, however, remain unresolved. Second, brewery-derived phosphorus retained in or near Tongue Pond may reach downstream ponds through episodic storm events or aquifer transport. These omissions matter because either or both processes could sustain phosphorus delivery to Mashapaug Pond even if regulated stormwater inputs are reduced.

For nine decades Tongue Pond was used as a “holding lagoon” for concentrated brewery effluent under conditions favoring long-term sorption to iron and aluminum minerals in pond sediments (US EPA 1974, 1). A 330 m man-made canal once connected Tongue and Spectacle Ponds (RIDEM 2026, 4). Since the brewery closed in 1981, surface flow has been limited to storm events. Although no direct perennial surface outflow remains between Tongue and Spectacle Ponds, the Tongue–Spectacle–Mashapaug kettle-pond system is linked in a downstream cascade with both surface and subsurface flow pathways.

Underground migration of legacy phosphorus through glacial outwash aquifers to downstream ponds is well documented. At the Massachusetts Military Reservation on Cape Cod, wastewater applied to rapid-infiltration beds from about 1936 to 1995 produced a phosphorus-enriched groundwater plume that discharged to Ashumet Pond approximately 0.5 km downgradient. Although much of the applied phosphorus was retained on aquifer sediments, dissolved phosphorus moved through the sand-and-gravel aquifer, with shoreline groundwater concentrations reaching approximately 3 mg/L and estimated flux to Ashumet Pond reaching 316 kg/yr in 1999. Reactive-transport modeling simulated peak discharge near 1,000 kg/yr during the 1990s and continued loading for decades after wastewater disposal ceased (Walter et al. 1996; McCobb et al. 2003, 32–35; Parkhurst et al. 2003, 28–32). The Tongue–Spectacle–Mashapaug system likewise lies within permeable glacial outwash, where groundwater and surface-water pathways could connect legacy phosphorus reservoirs to downstream ponds.

The adequacy of stormwater regulation and BMPs alone to control harmful algal blooms in this system depends critically on questions that the existing permit framework does not address: whether, and how much, legacy brewery phosphorus retained in or near Tongue Pond continues to reach Spectacle Pond through subsurface pathways and/or storm events, and whether phosphorus already accumulated in Spectacle Pond sediments is being recycled internally independent of stormwater regulation.

To evaluate whether stormwater-focused controls are likely to be sufficient, this study (1) estimates cumulative phosphorus delivered to Tongue Pond over the modeled 1900–1981 period using reconstructed annual brewery production and peer-reviewed brewery-effluent concentrations; (2) estimates cumulative export to Spectacle Pond using peak-period EPA phosphorus measurements and reported discharge flow; and (3) uses mass-balance retention calculations to evaluate whether legacy phosphorus reservoirs warrant investigation and prioritization in a broader harmful-algal-bloom management plan.

Study site

Tongue Pond is a small waterbody, approximately 2.19 ha (5.4 acres) in the upper Mashapaug watershed of Cranston, Rhode Island (RIDEM 2026, 3–4; Table 1), situated within a commercial retail corridor and bordered by extensive impervious surfaces associated with big-box retail and restaurant parking lots. Although the EPA described Tongue Pond as a “man-made lagoon” built to hold Narragansett Brewery waste (US EPA 1974, 1), the broader historical and cartographic record indicates that the pond predated the brewery. Historical maps inconsistently show Tongue Pond in the upper watershed. However, the pond is present in its current form on the 1889 USGS Providence Sheet, compiled from surveys conducted in 1885 and 1887, before the Narragansett Brewery was established in 1890 (USGS 1889; Fig. 1). Tongue Pond is also present on an earlier Cranston plat, Plan of Part of the Almoran Harris Estate, surveyed by John Howe in December 1874 and recorded in Plat Book 3, page 21 (Howe 1874). Finally, Providence-area land records from 1709 refer to Tongue Pond by name in a boundary survey of the Throckmorton-Carpenter landholdings (Providence Record Commissioners 1897, 8–12). Together, these records indicate that Tongue Pond was once a natural waterbody predating the brewery.

This point is not merely historical, it changes the inferred hydrologic setting from an engineered waste lagoon to a pre-existing kettle pond capable of exchanging water and solutes with the surrounding glacial outwash aquifer. Whether phosphorus retained in or near Tongue Pond continues to reach Spectacle Pond through the aquifer, and at what rate relative to stormwater inputs, cannot be determined from existing data. This question is consequential for the entire watershed; Spectacle Pond is the largest single phosphorus source to Mashapaug Pond, which is in turn a major source to the ponds of Roger Williams Park, a cascade in which the downstream system is linked by direct pond-to-pond connections.

Brewery history: from Narragansett to Falstaff

Origins and growth of the Narragansett Brewery (1890–1919)

In 1890, the Narragansett Brewing Company was established on the north shore of Tongue Pond in Cranston (Anderson [date unknown]). The 1900 Sanborn Fire Insurance Map depicts a narrow lagoon labeled Tongue Pond beside a brewery with a capacity of 125,000 barrels/yr (Sanborn Map Company 1900b, plate 306). The complex included production buildings, a bottling facility, an artificial ice factory, wash houses, and a canal or drainage ditch running from the brewery grounds south into Tongue Pond, establishing the hydrological pathway that would carry brewery effluent for decades.

Production grew rapidly, from 101,469 barrels in 1900 to approximately 115,000 barrels in 1901, about 196,000 barrels by 1908, and more than 200,000 barrels by 1909 (Anderson [date unknown], Narragansett Beer [date unknown-a], Visich et al. 2012). This growth established Narragansett as a dominant regional producer before the First World War.

A second brewery on Spectacle Pond (1859–c. 1915)

A separate brewing enterprise founded by N.D. Kelley operated on the southeast shore of Spectacle Pond beginning in 1859 (Theberge and Theberge [2009]). The facility later operated as What Cheer Brewery, Molter, Kelly & Baker, N. Molter and Sons Brewery, and Consumers Brewing Company, and appears on the 1889 and 1900 Sanborn Fire Insurance Maps (Sanborn

Map Company 1889, plate 5; 1900a, plate 313; Theberge and Theberge [2009]). Operations ceased around 1915, and unlike Narragansett Brewery, the Spectacle Pond brewery did not reopen after Prohibition, ending the 56-year history of brewery operations on Spectacle Pond. This earlier facility represents an additional unmodeled legacy source to Spectacle Pond.

Prohibition and resumption (1920–1933)

The Volstead Act suspended legal beer production from 1920 through early 1933. For the purposes of this analysis, no brewery waste discharge to Tongue Pond is attributed to the Prohibition years. Production resumed in 1933 following repeal, initially on a partial-year basis.

Mid-century expansion and the Falstaff acquisition (1933–1976)

After repeal, Narragansett rebuilt and expanded. By August 1935, the Cranston facility was producing at a rate equivalent to approximately 200,000 barrels/yr (Theberge and Theberge [date unknown]). Annual production reached 1 million barrels by 1959, and reported sales reached 1.275 million barrels in 1964, as documented in *United States v. Falstaff Brewing Corp.* (1973). The Cranston plant reached a maximum reported annual capacity of 1.7 million barrels in 1972 (Narragansett Beer [date unknown-b]).

Falstaff Brewing Corporation acquired Narragansett Brewing Company in 1965 and assumed operation of the Cranston facility associated with the Tongue–Spectacle pond system (Narragansett Beer [date unknown-a], *United States v. Falstaff Brewing Corp.* 1973). A 1976 National Pollutant Discharge Elimination System permit application confirms that brewery waste was still being discharged into Tongue Pond at least through 1976 (RIDWSPC and US EPA 1976, 2).

Closure (1976–1981)

By 1980, Falstaff's New England market share had fallen to approximately 17% (Papineau 2017). Applying that share to 1980 apparent beer consumption for the six New England states implies a market-derived Narragansett/Falstaff volume of approximately 1.68 million barrels (NIAAA 2024). This value is used as a late-period sales-volume anchor, not a direct plant-production record. The Cranston brewery ceased production on 31 July 1981, ending a 91 yr industrial association with Tongue Pond, including roughly eight decades of active brewery discharge outside Prohibition (Table 2).

Materials and methods

Documented discharge to Spectacle Pond

In 1974 the U.S. Environmental Protection Agency (EPA) conducted a water-quality survey in the north basin of Spectacle Pond along a west-to-east transect from the Tongue Pond inlet to the culverted outlet connecting to Mashapaug Pond. The survey reports that Tongue Pond "receives and holds waste from the brewery's boiler blow-down, cooling and bottling operations and general floor drains wash down bottle washing operation," and concludes that Falstaff Brewery was "contributing to, and responsible for," the phosphorus-fueled eutrophication of Spectacle Pond (US EPA 1974, 1, 20). The 1974 survey did not record discharge volume; a 1976 NPDES joint public notice for a Falstaff discharge permit (Supplement A) described 3 discrete discharges averaging a combined 650,000 gallons per day, consisting of "rinse water from bottle washing; cooling water for beer pasteurizers; rinse water to hose down packaging areas; water for steam condensers; boiler blowdown; and yard drainage (variable)" (RIDWSPC and US EPA 1976, 2).

Water-quality sampling at the point where effluent from Tongue Pond entered Spectacle Pond (Station 1) in June 1974 measured TP concentrations of 1.76, 1.81, and 2.21 mg/L (mean value 1.93 mg/L; US EPA 1974, 4). Although the brewery reported no domestic waste discharge to Tongue Pond, Station 1 fecal coliform counts reached 7,600 per 100 mL on 4 June and exceeded 250,000 per 100 mL on 6 June 1974 — concentrations not readily explained by process water or stormwater alone (US EPA 1974, 4). The survey acknowledges Tongue Pond effluent as the source but does not resolve the discrepancy with the brewery's claim.

Input and export model overview

Two linked models covering the period from 1900 to 1981 are presented; supporting model files, source documents, URIWW data, and supplemental figures are provided in Supplements A–D. The first is a literature-based input model estimating TP delivered to Tongue Pond by brewery operations. It applies scenario-specific combined-effluent phosphorus concentrations to a site-specific combined-wastewater flow series based on the 1976 NPDES discharge volume, scaled annually by reconstructed production. The second is an outlet-calibrated export model estimating phosphorus exported from Tongue Pond to Spectacle Pond. The export model applies the mean Station 1 phosphorus concentration measured in June 1974 to the production-scaled combined-flow series shared by both models.

Annual production was reconstructed from annual U.S. beer-industry barrelage (U_y) multiplied by an interpolated Narragansett/Falstaff market-share fraction (s_y) derived from brewery-specific anchor points. The 1980 late-period anchor is calculated independently from Falstaff's reported 17 percent New England market share and apparent New England beer consumption (Papineau 2017; NIAAA 2024). The difference between cumulative input and cumulative export is treated as a mass-balance residual (Supplement C; Table 5), not a direct sediment measurement or a localized sediment inventory.

Extending the model back 10 years using linear interpolation to the 1890 opening of the Narragansett Brewery with an assumed opening-year production of approximately 25,000 barrels would add less than 1 percent to the cumulative total under the central scenario, an amount considered negligible relative to the other uncertainties in the model. Finally, a previous model based on refillable bottles washed came to substantively similar conclusions (central estimate 662,000 kg P versus 697,000 kg P; Supplement C, Fig. S4). Bottle washing is retained as important historical and diagnostic context because it was a major phosphorus-bearing brewery process during the STPP era.

Model description and variable definitions

The combined modeling framework proceeds in 5 steps (Supplement B).

Step 1: Reconstruct brewery production. Anchor-year Narragansett/Falstaff barrelage or market-derived sales-volume estimates (B_a; Table 3) are divided by total U.S. beer-industry barrelage in the same years (U_a) to estimate anchor-year U.S. market-share fractions (s_a = B_a/U_a). Intervening annual market shares (s_y) are linearly interpolated between anchor years, and annual Narragansett/Falstaff barrelage is reconstructed as B_y = U_y × s_y × F_y, where F_y is a partial-year factor. Prohibition years (1920–1932) are set to zero; 1933 is treated as a 0.73 partial year following repeal; and 1981 is treated as a 0.58 (7/12) partial operating year because the Cranston brewery closed on 31 July.

Step 2: Compile diagnostic refillable bottle variables. Refillable bottle share (r_y) and estimated bottles washed (N_y = B_y × r_y × k, where k = 330.7 bottles/barrel) are retained as diagnostic variables because refillable bottle washing was a major phosphorus-bearing operation during the STPP era. These variables are not used to calculate TP input.

Step 3: Estimate combined wastewater flow. The site-specific reference flow is the 1976 NPDES combined discharge volume, $Q_{1976} = 2{,}460\ \mathrm{m^3/day}$ (650,000 gpd). Annual combined flow is scaled by reconstructed production as $Q_y = Q_{1976} \times (B_y/B_{1976})$. This yields a site-specific wastewater ratio of approximately 4.55 L wastewater/L beer in 1976, which is below but within the same order of magnitude as the historical brewery process-effluent range of 5.5–8.3 $\mathrm{m^3/m^3}$ beer reported by Joyce et al. (1977).

Step 4: Estimate phosphorus input to Tongue Pond. Published phosphorus concentrations of 10–50 mg/L describe combined brewery wastewater (Carnevale Miino et al. 2025). Annual input is therefore calculated as $L_{in,y} = C_{in,y} \times Q_y \times 10^3\ \mathrm{L/m^3} \times 365\ \mathrm{d/yr} / 10^6\ \mathrm{mg/kg}$. The low scenario uses $C_{in,y} = 10$ mg/L throughout. The central scenario uses 15 mg/L through 1949, increases linearly to 30 mg/L from 1950 through 1965, and holds 30 mg/L through closure. The high scenario uses 50 mg/L throughout.

Step 5: Estimate outlet export and retention. Annual export loads are calculated using the mean Station 1 TP concentration measured by EPA in June 1974 ($C_{ref} = 1.93$ mg/L, mean of 1.76, 1.81, and 2.21 mg/L) applied to the same production-scaled combined-flow series: $E_{out,y} = C_{ref} \times Q_y \times 10^3\ \mathrm{L/m^3} \times 365\ \mathrm{d/yr} / 10^6\ \mathrm{mg/kg}$. Cumulative retention $R = \Sigma L_{in,y} - \Sigma E_{out,y}$ is the difference between cumulative input under each scenario and cumulative outlet-calibrated export, treated as a mass-balance residual rather than a direct sediment measurement.

Secondary analysis of URI Watershed Watch monitoring data

University of Rhode Island Watershed Watch (URIWW) data were used to assess long-term phosphorus and dissolved oxygen patterns in Spectacle and Mashapaug Ponds. For Spectacle Pond, paired surface (1 m) and deep-station TP observations from 2007–2019 ($n = 43$ paired dates; data provided by E. Herron, URIWW, pers. comm.; Supplement D) were compared by date and season. Deep samples were collected at 4 m in 2007 and 3 m thereafter; the long-term surface record extends back to 1999. For Mashapaug Pond, biweekly summer profiles from the 5 most recent monitored years (2020–2024; URIWW 2024) were used to characterize seasonal thermal stratification, bottom-water dissolved oxygen sampled 1 m above bottom (4 m at the deep station; anoxia defined as $\mathrm{DO} \leq 0.5$ mg/L), and vertical phosphorus structure. Vertical phosphorus enrichment was evaluated by comparing paired surface and deep TP concentrations with the same-date surface-to-deep temperature gradient ($\Delta T = T_{1m} - T_{4m}$) for dates with both parameters measured at both depths ($n = 18$). The relationship was tested by Pearson correlation ($r = 0.609$, $n = 18$, $df = 16$, two-tailed $p = 0.0073$) and Spearman rank correlation ($\rho = 0.515$, $p = 0.029$). Sensitivity analyses excluded the single largest enrichment event (8 July 2023) and compared deep/surface TP ratios between stratified dates ($\Delta T \geq 4°C$) and mixed dates ($\Delta T < 1°C$). One Mashapaug DO record from 10 August 2024 had surface and deep values transposed; depth labels were corrected because a 0.0 mg/L surface value in a wind-mixed 25°C epilimnion was physically implausible and persistent bottom-water anoxia was documented on flanking dates. Analyses with and without this correction gave the same qualitative conclusion. These analyses provide screening-level evidence of seasonal stratification effects, not formal estimates of internal phosphorus flux; small sample sizes and ratio-based comparisons should not be interpreted as calibrated predictive relationships.

Dissolved oxygen was measured through URIWW using Winkler titration with azide modification (Winkler 1888; APHA et al. 2012, Method 4500-O C). Exact concentrations should be interpreted with ordinary method and observer uncertainty, but false low readings are not the main concern. In low-oxygen samples, air bubbles, incomplete capping, or exposure to atmospheric O_2 before fixation would bias results upward rather than create false zeros. The azide modification reduces nitrite interference, a positive bias in iodometric DO measurements (APHA et al. 2012, Wong 2012). Reductants that could bias readings downward, such as sulfide or ferrous iron, are most likely under strongly reducing bottom-water conditions and would corroborate, not contradict, anoxia. When no oxygen is present, no iodine forms and no titration endpoint is required. Therefore, 0 mg/L readings at depth, especially when paired with oxygenated shallower samples, were treated as strong evidence of bottom-water anoxia.

Comparative pond characteristics and screening-level reservoir estimates

To place these analyses in context, I compiled comparative morphometric, loading, transfer, and sediment-reservoir values for Tongue, Spectacle, Mashapaug, and the Roger Williams Park ponds (Table 1). Values were drawn from RIDEM TMDL reports (RIDEM 2007a, 2007b), the 2026 Mashapaug General Permit fact sheet (RIDEM 2026), USGS hydrography data (USGS 2024), and the screening-level calculations described below. Because these values were estimated in different years, from different source types, and with different modeling approaches, they are used as order-of-magnitude indicators rather than as a synchronous mass-balance dataset; mean water-column TP concentrations are treated as concentration indicators, not annual mass fluxes.

Morphometric values for Spectacle Pond and the Roger Williams Park ponds were taken from RIDEM (2007a), Mashapaug Pond values from RIDEM (2007b), and Tongue Pond surface area from RIDEM (2026). No published agency source was identified for Tongue Pond mean depth, volume, survey date, or bathymetric-method metadata; therefore, mean depth and volume were estimated from RIDEM bathymetric contours showing 3, 6, 9, and 12 ft intervals (RIDEM [date unknown-a], Tongue Pond plate, 208).

Whole-pond TP loads, source allocations, and inter-pond transfer values for Mashapaug Pond were taken from RIDEM (2007b) and for the Roger Williams Park ponds from RIDEM (2007a). For Spectacle Pond, RIDEM (2007a) reports a TP load of 216 kg/yr but no comparable source-component table, so point-source and nonpoint-source values were approximated using the impervious-area allocation approach in RIDEM (2007a). No comparable published current TP concentration, whole-pond load, or annual transfer value was identified for Tongue Pond. Surface-water connection lengths were taken from RIDEM (2026) where available; the Mashapaug-to-Roger Williams Park flow-path distance was estimated from USGS National Hydrography Dataset flow paths in The National Map (USGS 2024) and treated as an approximate mapped-flow-path distance, not a field-surveyed conduit length.

Screening-level legacy phosphorus indicators (Table 1, Fig. 2) were estimated with pond-specific methods. Spectacle Pond was estimated from measured 2020 sediment TP values (CDM Smith 2022), assuming an upper 10 cm active layer and dry bulk density of 100 kg/m³, consistent with soft organic surface sediments in shallow eutrophic lakes (Søndergaard et al. 2003). Mashapaug Pond used the same active-layer and density assumptions, with Spectacle Pond sediment TP as a proxy. The Roger Williams Park ponds were assigned a central screening value based on prior sediment characterization of phosphorus-rich accumulated sediments in the impounded lower watershed (Horsley Witten Group et al. 2013). Tongue Pond was represented by the central brewery-model mass-balance retention estimate divided by pond area. Because these estimates differ in evidence quality and method, they indicate possible relative reservoir magnitude and major data gaps, not a definitive sediment phosphorus budget or directly comparable measured inventories.

Results

Applying the 2,460 m^3/day (650,000 gpd) discharge flow documented in the 1976 NPDES public notice to Station 1 phosphorus concentrations measured in June 1974 (1.76–2.21 mg/L) yields an annualized peak-period outlet load of approximately 1,580–1,985 kg P/yr delivered to Spectacle Pond (US EPA 1974, 4; RIDWSPC and US EPA 1976, 2). Scaling the mean outlet-calibrated export estimate across the reconstructed production history yields a cumulative load of approximately 54,000 kg P (Table 5). Over the same 1900–1981 period, literature constrained values suggest that 281,000–1,405,000 kg P could have been delivered to Tongue Pond in brewery effluent.

Subtracting the cumulative export estimate from each input scenario yields inferred retained legacy phosphorus in or near Tongue Pond ranging from 227,000 to 1,351,000 kg P, or 81–96 percent of modeled input (Table 5). The central scenario implies 643,000 kg P retained (92 percent of modeled input). These mass-balance residuals imply substantial legacy phosphorus reservoirs are retained in or near Tongue Pond. However, the location, chemical lability, capacity for internal cycling, and present-day magnitude and mobility of Tongue and

Spectacle Pond legacy phosphorus reservoirs are unmeasured and lie outside the scope of the existing stormwater-focused permit framework.

Discussion

The regulatory question motivating this analysis is whether the 2026 Mashapaug General Permit's 65–68 percent stormwater phosphorus reductions will be sufficient to bring the Mashapaug pond cascade into attainment and reduce harmful algal blooms. The brewery-history reconstruction suggests they may not. Mass-balance calculations indicate that a large legacy phosphorus reservoir may remain in or near Tongue Pond. Even under the lowest input scenario, this inferred reservoir is approximately 227,000 kg P (Table 5), more than three orders of magnitude larger than the approximately 109 kg/yr that Spectacle Pond currently delivers to Mashapaug Pond and ~1,000 times the total annual external phosphorus load to Mashapaug Pond (Fig. 2; Table 1; RIDEM 2007b). The retained phosphorus reservoir is a stock, not a flux, but even minimum mobility could be consequential. Transport of even 0.05% of the lower bound estimate per year would deliver 114 kg P/yr, comparable to the current Spectacle-to-Mashapaug load. If even a small fraction of brewery-era phosphorus remains labile and hydrologically connected to Spectacle Pond through groundwater or storm-event flow, it could sustain harmful algal blooms throughout the lower watershed despite stormwater reductions from regulated parcels. This analysis extends Van Meter et al.'s (2021) legacy-phosphorus framework from diffuse agricultural watersheds to a localized industrial source, asking whether accumulated phosphorus stores from historical brewery discharge may now constrain recovery despite reductions in current external loads (Fig. 2). Recognizing this potential constraint is a prerequisite for setting realistic expectations for the 2026 General Permit.

These estimates carry substantial uncertainty. Narragansett production records are incomplete, so the model assumes that national beer-industry barrelage can scale regional production and anchors early output to the 1900 Sanborn Fire Insurance Map survey rather than the brewery opening in 1890. Brewery-effluent chemistry also changed over time. Bottle washing, a major phosphorus source, increasingly used phosphate-based cleaners, including sodium tripolyphosphate (STPP), from roughly 1950 through peak use in the 1960s and 1970s, coincident with peak Cranston production (Litke 1999). The reference discharge volume may also differ from conditions during the June 1974 Station 1 sampling. The 1976 combined discharge implies a site-specific wastewater ratio of approximately 4.55 L wastewater/L beer at the modeled 1976 production level, somewhat below but within the same order of magnitude as the 1977 EPA brewery process-effluent range of 5.5–8.3 m^3/m^3 beer (Joyce et al. 1977). The outlet-derived value is therefore treated as a Tongue Pond export constraint, not a direct measure of brewery effluent. In short, the model may overstate or understate specific periods because production scaling, effluent chemistry, post-discharge retention, and operating practice are all uncertain. The management implication is not that the legacy reservoir could be small, but that present-day mobility and ecological effect cannot be inferred from the mass-balance residual alone. Whether that residual is localized, chemically labile, and hydrologically connected to downstream ponds remains the empirical question on which the adequacy of stormwater-only controls depends.

Three unexplored pathways of legacy phosphorus delivery

Subsurface (groundwater) transport

Continuous groundwater transport of legacy phosphorus cannot be discounted. Kettle ponds are commonly in hydraulic connection with underlying glacial aquifers and can both receive groundwater from, and discharge water to, those aquifers (Walter and Masterson 2011). Under favorable geochemical conditions, glacial outwash can transmit dissolved phosphorus hundreds of meters downgradient, particularly after available sorption sites are saturated (Walter et al. 1996). Decades of brewery loading may have saturated near-source sorption sites around Tongue Pond, leaving the outwash plausibly capable of transmitting dissolved phosphorus downgradient to Spectacle Pond. Groundwater flow paths from Tongue Pond have not been mapped, but the straight-line distance from Tongue Pond to Spectacle Pond is approximately 0.33 km (RIDEM 2026, 4), comparable to the 0.52 km phosphorus-transport distance documented from the MMR disposal beds to Ashumet Pond's Fishermans Cove discharge area (McCobb et al. 2003) and the straight-line distance from Tongue Pond to Mashapaug Pond (0.65–0.75 km). If comparable geochemical conditions exist in the Cranston aquifer, groundwater transport from Tongue Pond to Spectacle Pond would therefore fall within the demonstrated distance range for subsurface phosphorus mobility in glacial outwash.

Existing Mashapaug Pond data show that subsurface phosphorus loading is already present in the watershed but do not identify its source. The 2007 Mashapaug TMDL hydrologic budget estimated groundwater underflow to Mashapaug Pond at 701,583 m^3/yr, or approximately 29% of total annual inflow; the same TMDL assigned groundwater underflow a phosphorus load of 16 kg/yr (35 lb/yr) and treated it as a nonpoint source receiving no required load reduction (RIDEM 2007b, 10, 41; Roseen 2018, 30). This load shows that subsurface phosphorus delivery occurs in the watershed, but existing data cannot determine whether it reflects legacy brewery phosphorus, background urban groundwater, or both. Together, the Ashumet Pond case and the measured groundwater inflow and phosphorus budgets for Mashapaug Pond indicate that groundwater-mediated phosphorus delivery is plausible and could materially affect harmful algal blooms in this system.

Episodic surface flow

When the Falstaff brewery closed in 1981, continuous surface discharge from Tongue Pond through the engineered outfall ceased. Episodic surface discharge from Tongue Pond to Spectacle Pond remains ungauged and is treated here as an unquantified event pathway rather than a measured annual load (RIDEM 2026, 4). Continuous flow monitoring at the Tongue–Spectacle connection during storm events, paired with event-based phosphorus sampling, would establish the first measured flow record for this pathway and quantify whether episodic transfers offset some fraction of the reductions targeted by the 2026 General Permit.

Internal loading

Internal loading in Spectacle and Mashapaug Ponds also warrants direct evaluation. Once in the pond system, phosphorus can be retained under oxic conditions through sorption to iron and aluminum mineral surfaces and remobilized under anoxia, with release rates governed by concentration gradients, redox potential, temperature, and pH (Søndergaard et al. 2003, Schindler et al. 2016). A 2020 limnological investigation commissioned by the City of Cranston concluded that active phosphorus cycling is occurring in Spectacle Pond and identified a potentially mobile sediment phosphorus pool dominated by iron-bound phosphorus that can be released under reducing or anoxic conditions (CDM Smith 2022, 29). CDM Smith reported a total sediment phosphorus concentration of 3,810 mg/kg at the north end of the pond, within the north-central transect range of 3,680–6,710 mg/kg reported in the 1974 EPA study, indicating persistence of high sediment phosphorus over 48 years.

Although the sediment fractionation results reinforces the case for active cycling, the same study concludes that internal phosphorus loading is a minor contributor to Spectacle Pond's nutrient budget (CDM Smith 2022, 29). The median deep-water TP value (69 µg P/L) rests on a sampling program of limited intensity, with 3 surficial sediment samples and 5 of 7 planned water-quality events. The mid-summer stratification window when anoxic phosphorus release is typically most intense was not captured.

Since 1999, URIWW has conducted long-term phosphorus monitoring in Spectacle Pond, with approximately 3 sampling events per year and deep-station sampling added in 2007 (E. Herron, URIWW, pers. comm.; Supplement D). Accumulation of soluble-phase phosphorus at depth is consistent with release of iron-bound phosphorus under hypolimnetic anoxia. Across the full 2007–2019 record, paired surface and deep total-phosphorus concentrations did not differ significantly (Wilcoxon signed-rank, $n = 43$, two-tailed $p = 0.47$). Median and mean deep/surface ratios, 1.00 and 1.21, respectively, did not support a continuous year-round depth gradient. However, elevated deep readings were clustered in late spring and during isolated fall events. For example, on 18 October 2007, dissolved phosphorus at the 4-m deep station reached 347 µg P/L — roughly 58 times the simultaneous surface dissolved-phosphorus concentration of 6 µg P/L; a total-phosphorus measurement 2 d later at the same depth, 367 µg P/L, was comparable in magnitude. This pattern is consistent with episodic stratification-related phosphorus accumulation and seasonal mixing rather than a continuous year-round depth gradient.

The 2007 Mashapaug Pond TMDL did not include internal loading in its phosphorus allocation, citing surface and 1-meter-above-bottom samples that “did not definitively support phosphorus release from the sediment” (RIDEM 2007b, 15). Before 2020, the URIWW phosphorus evidence was limited because paired surface/deep TP samples were sparse and often did not coincide with the strongest anoxic periods. However, more recent Mashapaug Pond data show that the preconditions for internal phosphorus loading are frequently met. Deep-water dissolved-oxygen profiles from the five most recent monitored years (2020–2024) document strong deep-water anoxia ($DO \leq 0.5$ mg/L at 4 m) developing between mid-June and late July and persisting into late August or mid-September in 3 of the 5 years (2022, 2023, 2024). Vertical phosphorus enrichment in Mashapaug Pond was associated with thermal structure: across 18 paired surface/deep TP and temperature observations, deep/surface TP ratio was positively correlated with surface-to-deep ΔT (Pearson $r = 0.609$, $n = 18$, $p = 0.007$; Spearman $\rho = 0.515$, $p = 0.029$), and stratified dates ($\Delta T \geq 4$°C, $n = 7$) showed a median deep/surface ratio of 2.24 (max 6.67), compared with 1.03 on mixed dates ($\Delta T < 1$°C, $n = 6$). The single largest enrichment event (deep TP 100 µg P/L vs. surface 15 µg P/L on 8 July 2023) coincided with the strongest observed stratification ($\Delta T = 9.0$°C) and deep-water DO of 0.7 mg/L; 2 weeks later, DO at 4 m had fallen to 0.0 mg/L. The correlation was sensitive to this single event: with the 8 July 2023 observation excluded, neither test remained significant (Pearson $r = 0.306$, $p = 0.23$; Spearman $\rho = 0.424$, $p = 0.09$; $n = 17$), again suggesting that the depth gradient is driven by episodic stratification-related enrichment rather than a continuous year-round process.

Why the existing regulatory framework did not test these pathways

The Spectacle Pond TMDL in the 2007 RIDEM eutrophic-ponds report, which provides the basis for the 2026 general permit, applied the Reckhow empirical loading-response model within an approach RIDEM characterized as "practical and simplistic" and requiring minimal data acquisition (RIDEM 2007a, 1). By contrast, the Mashapaug Pond TMDL used a more detailed Environmental Fluid Dynamics Code (EFDC) hydrodynamic and water-quality model calibrated with 2001 in-pond field monitoring (RIDEM 2007b, 25–28). Neither framework, however, evaluated legacy brewery phosphorus as a source category, directly measured mean annual or storm-event flow through the Tongue-to-Spectacle connection, or tested groundwater transport from the former brewery site. The 2026 General Permit inherited this limited scope. It regulates the stormwater inputs that the 2007 TMDLs were designed to allocate, but the three pathways identified above lie outside its measurement record. As a result, applying the permit's 65–68 percent reduction targets alone cannot reliably predict the watershed's recovery trajectory.

Measurements needed before recovery can be predicted

Resolving the watershed's phosphorus budget will require targeted monitoring of three pathways. First, groundwater transport may convey phosphorus through the glacial outwash aquifer to Spectacle Pond, including legacy delivery from the former brewery site and diffuse exchange across pond beds; porewater profiles in Tongue and Spectacle Pond sediments, seepage measurements along the Spectacle Pond shoreline, and groundwater transects from the former brewery site would test this directly. Second, episodic surface discharge from Tongue Pond during major storms may still deliver phosphorus pulses to Spectacle Pond; continuous flow monitoring at the Tongue-to-Spectacle connection would establish the first measured flow record for this pathway. Third, internal cycling within Spectacle and Mashapaug Ponds may sustain algal blooms even without additional external input, given accumulated sediment phosphorus, recurring summer stratification, and documented deep-water anoxia; sediment coring, continuous dissolved-oxygen monitoring, and summer benthic-flux measurements are needed to quantify it. Until these pathways are measured, the watershed's response to stormwater-only controls cannot be predicted with confidence.

The ponds of the Mashapaug watershed have remained impaired for decades and continue to experience recurring harmful algal blooms. The 2026 General Permit is necessary, but this analysis suggests that stormwater regulation alone may not be sufficient. Without direct measurement of legacy phosphorus reservoirs, groundwater and storm-event pathways, and internal sediment recycling, regulators and watershed managers cannot predict whether stormwater reductions will produce timely recovery or whether improvement may lag by years to decades.

Acknowledgments

The author thanks Robert Nero, Chair of the Pawtuxet River Authority and Watershed Council, whose foresight in preserving the 1976 NPDES permit made this analysis possible (Supplement A; no longer held in EPA records), and who first drew attention to the potential effects of legacy brewery phosphorus in Tongue Pond. Preliminary retrospective phosphorus-load reconstruction, source identification, code-checking, and editorial revision were assisted by OpenAI ChatGPT (GPT-5.5 Thinking) and Anthropic Claude (Claude Opus 4.7). These tools were used to explore model structure, check arithmetic and consistency, identify possible citation gaps, and improve clarity of expression. The author independently reviewed and verified all assumptions, parameter values, calculations, cited sources, final tables, and figures, and is responsible for all analytical judgments, interpretations, and conclusions.

Disclosure statement

The author reports there are no competing interests to declare.

Supplemental material

Supplement A. 1976 NPDES joint public notice for Falstaff Brewing Corporation Cranston Brewery discharges (RIDWSPC and US EPA 1976); PDF.

Supplement B. Combined-wastewater model workbook, variable definitions, and annual model outputs for the Narragansett/Falstaff brewery phosphorus reconstruction, 1900–1981; Excel workbook.

Supplement C. Supplemental figures S1–S4 and accompanying legends for the combined-wastewater model; PDF.

Supplement D. Spectacle Pond surface and deep-station total and dissolved phosphorus data, URI Watershed Watch long-term monitoring, 1999–2019 (E. Herron, URIWW, pers. comm.); Excel workbook.

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Table 1. Morphometric, phosphorus-loading, and transfer characteristics of Tongue, Spectacle, Mashapaug, and Roger Williams Park ponds.

Metric	Tongue Pond	Spectacle Pond	Mashapaug Pond	Roger Williams Park ponds
Origin	kettle pond / waste lagoon	kettle pond	kettle pond	Mashapaug Brook impoundment
Surface area (ha)	2.19	15.7	31.1	42.4
Mean depth (m)	2.1	2.3	3.0	1.7
Volume (m^3)	4.6×10^4	3.61×10^5	8.87×10^5	6.79×10^5
Mean water-column TP (µg/L)	unknown	57	40	82
TMDL-estimated total P load (kg/yr)	unknown	216	232	1,027
P input from upstream pond (kg/yr)	not applicable	unknown	109	232
Other point source (kg/yr)	unknown	123	81	310
Non-point source (kg/yr)	unknown	93	41	485
Distance to upstream pond (km)	not applicable	0.33	0.45	1.9
Screening-level legacy P indicator (kg/ha equivalent)	293,000	325	299	2,005

Source and derivation of values are described in Methods. Tongue Pond mean depth and volume were estimated for this study using available bathymetric information. Morphometric values are source-reported or rounded estimates; volume is not recalculated from rounded surface area and mean depth. Mean water-column TP concentrations, annual loads, and transfer values are approximate and are not synchronous measurements. “P input from upstream pond” represents phosphorus transferred from the immediately upstream pond to the receiving pond. For Spectacle Pond, point-source and nonpoint-source values are approximate allocations derived from the TMDL impervious-area approach because no comparable source-component table was identified.

Table 2. Chronology of brewery operations discharging to Tongue Pond, Cranston, Rhode Island, 1890–1981.

Period	Operator	Key events and discharge implications
1859–c. 1915	What Cheer / Consumers Brewing Co.	Brewery on southeast shore of Spectacle Pond; discharged directly to Spectacle Pond; no Tongue Pond connection; ceased operations c. 1915
1890–1919	Narragansett Brewing Co.	Established on north shore of Tongue Pond; canal connecting brewery to Tongue Pond documented on 1900 Sanborn map; capacity 125,000 bbl/yr; output reached ~200,000 bbl by 1909
1920–1932	—	Prohibition; no discharge attributed to Tongue Pond
1933	Narragansett Brewing Co.	Production resumed 29 Apr 1933 following repeal; 1933 treated as 73% partial year in model
1933–1964	Narragansett Brewing Co.	Rapid postwar expansion; output reached 1 million bbl by 1959; peak documented sales of 1.275 million bbl in 1964
1965–1981	Falstaff Brewing Corp.	Acquired Narragansett 1965; maximum reported capacity 1.7 million bbl in 1972; NPDES permit application filed 1976; combined discharge ~650,000 gpd; facility closed 31 Jul 1981

Sources: Sanborn Fire Insurance Maps (1900a, 1900b); EPA water quality survey (1974); NPDES joint public notice (1976); United States v. Falstaff Brewing Corp., 410 U.S. 526 (1973). Prohibition years (1920–1932) assigned zero discharge in the model. bbl = barrels; gpd = gallons per day.

Table 3. Narragansett Brewery production anchor points used in model reconstruction, 1900–1981.

Year	Central estimate (barrels)	Source / derivation
1900	101,469	Anderson, BeerHistory.com
1901	115,000	Narragansett Beer, Our Story
1908	196,000	Visich et al., Pearson case study
1909	>200,000	Narragansett Beer, Our Story - Details
1935	~220,000	Theberge & Theberge, NABA vol. 190
1959	1,000,000	Anderson, BeerHistory.com
1964	1,275,000	United States v. Falstaff Brewing Corp. (1973)
1972	1,700,000	Narragansett Beer, Our Story - Details
1980	1,681,000	Calculated as 0.17 x 1980 apparent beer consumption in the 6 New England states; Papineau 2017; NIAAA 2024

Anchor-year production or sales-volume estimates were divided by total U.S. beer-industry barrelage in the same years to estimate Narragansett/Falstaff's U.S. market share. Intervening annual shares were linearly interpolated and annual barrelage was reconstructed as U_y x s_y x F_y. The 1980 value is a market-share-derived late-period sales-volume anchor, not a direct plant-production measurement. Prohibition years were set to zero; 1933 was treated as a partial year following repeal; 1981 was calculated as a 7/12 operating year using the 1980 share and 1981 U.S. barrelage.

Table 4. Model variables, defined constants, scenario parameters, and derived loads used in the literature-based input model, outlet-calibrated export model, and mass-balance retention estimate.

Class	Symbol	Meaning / definition	Value / scenario	Units
Annual production reconstruction				
	U_y	Total U.S. beer-industry barrelage in year y; taxpaid withdrawals where available	Year-specific	barrels/yr
	s_y	Narragansett/Falstaff share of U.S. beer-industry barrelage in year y	Interpolated between anchor-year shares	fraction
	F_y	Partial-year operating factor	1 for full years; 0 for 1920–1932; 0.73 for 1933; 7/12 for 1981	fraction
	B_y	Reconstructed Narragansett/Falstaff barrelage = U_y × s_y × F_y	Computed annually	barrels/yr
Diagnostic bottle variables				
	r_y	Share of total production represented by refillable bottles; diagnostic only	Year-specific benchmark / interpolation	fraction
	k	Bottles per barrel = 31 gal/bbl × 128 oz/gal ÷ 12 oz/bottle	330.7	bottles/barrel
	N_y	Diagnostic bottles washed = B_y × r_y × k; not used in input-load calculation	Computed annually	bottles/yr
Combined-wastewater flow				
	Q_1976	Reference combined discharge flow from 1976 NPDES public notice	2,460 (650,000 gpd)	m^3/day
	B_1976	Modeled 1976 Narragansett/Falstaff barrelage used to scale reference flow	1.681×10^6	barrels/yr
	I_y	Annual production/flow index = B_y / B_1976	Computed annually	fraction
	Q_y	Annual combined discharge flow = Q_1976 × I_y	Computed annually	m^3/day
	W_site	Site-specific wastewater ratio derived from Q_1976 and B_1976; diagnostic check	4.55	L wastewater/L beer
	W_EPA	Historical brewery process-effluent benchmark from Joyce et al. (1977); diagnostic check only	Mean 6.9; range 5.5–8.3	L wastewater/L beer
Defined constant				
	M	mg-to-kg conversion factor	1,000,000	mg/kg
Input scenario parameter				
	C_in,y	Combined brewery-effluent total phosphorus concentration in year y	Low: 10 mg/L fixed; central: 15 mg/L before 1950, linear 15→30	mg/L

			mg/L from 1950–1965, 30 mg/L through 1981; high: 50 mg/L fixed	
Derived input load				
	L_in,y	Total input load to Tongue Pond = C_in,y × Q_y × 10^3 L/m^3 × 365 d/yr / M	Computed annually	kg P/yr
Outlet-calibrated export				
	C_ref	Reference total P concentration measured at Station 1 (mean of three June 1974 measurements)	1.93 (range 1.76–2.21)	mg/L
	E_out,y	Annual outlet-calibrated export load = C_ref × Q_y × 10^3 L/m^3 × 365 d/yr / M	Computed annually	kg P/yr
Mass-balance retention				
	R	Scenario-specific cumulative retention = ΣL_in,y − ΣE_out,y; not a direct sediment measurement	Computed by scenario	kg P

The 10-50 mg/L literature range describes combined brewery effluent. The revised model therefore applies combined-effluent phosphorus concentrations to a combined-wastewater flow series scaled from the site-specific 1976 NPDES discharge volume. Refillable bottle variables are retained to document the historical importance of bottle washing and STPP-era cleaning chemistry, but they are not used as independent input-load parameters.

Table 5. Phosphorus mass balance for Tongue Pond, 1900–1981: estimated input by scenario, outlet-calibrated export to Spectacle Pond, and mass-balance retention (kg P).

Input scenario	**Total input to Tongue Pond (kg P)**	**Cumulative export to Spectacle Pond (kg P)**	**Mass-balance retention in or near Tongue Pond (kg P)**	**Retained fraction of modeled input**
Low (10 mg/L fixed)	281,000	54,000	227,000	81%
Central (15 to 30 mg/L STPP-era transition)	697,000	54,000	643,000	92%
High (50 mg/L fixed)	1,405,000	54,000	1,351,000	96%

Input and export values both use the site-specific 1976 combined discharge flow scaled annually by reconstructed production (B_y/B_1976). Retention is calculated as cumulative modeled input minus cumulative outlet-calibrated export and should be interpreted as a screening-level mass-balance residual, not a direct sediment measurement or localized inventory. Values are rounded independently; sums may differ by +/-100 kg.

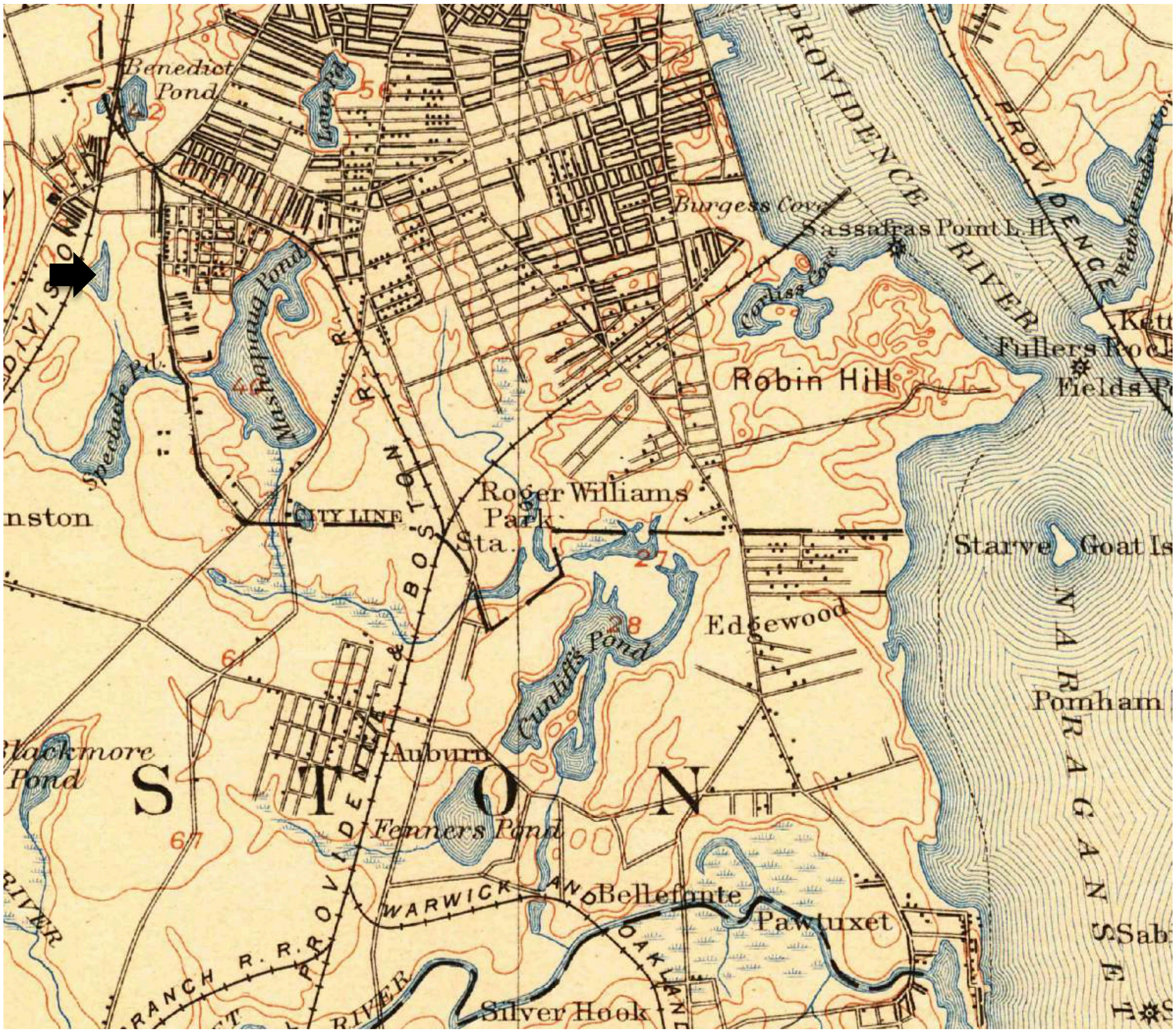
List of figures

Figure 1. Mashapaug watershed circa 1889. USGS Providence Sheet (Massachusetts–Rhode Island), 1:62,500, surveyed 1885 and 1887, edition December 1889; annotated by author (USGS 1889). Arrow marks Tongue Pond. Also visible on this survey are Benedict Pond (bisected by the railroad) and Long Pond, both intact natural water bodies in the upper watershed that were subsequently filled during early twentieth-century urban development. In the lower watershed, the ponds in Roger Williams Park, including Cunliff's Pond, were created by impounding Mashapaug Brook at some point between 1800 and 1870 (Marshall 1987), slowing flow and trapping sediment across the lower watershed long before brewery operations began and prior to the 1871 donation of the farmland for Roger Williams Park. The watershed would be further transformed by the filling of Benedict and Long Ponds in the decades that followed.

Figure 2. Potential phosphorus pathways and reservoirs in the Tongue–Spectacle–Mashapaug–Roger Williams Park Pond cascade. Pond cross-sections are shown as semi-ellipses, with semi-ellipse area proportional to estimated pond volume and height proportional to mean depth. Vertical scale is exaggerated uniformly across all four ponds; relative depths are preserved, but profiles are not shown at true aspect ratio. Horizontal arrows indicate downstream phosphorus transfer pathways, with relative magnitude shown by arrow shading; absolute values are provided in Table 1 and Methods. Rectangles below each pond represent legacy phosphorus indicators or proxies; darker shading indicates larger approximate magnitude. Shading is not linearly proportional to the Tongue Pond estimate, which is orders of magnitude larger than the others and would otherwise obscure differences among the lower ponds. Absolute values and proxy definitions are provided in Table 1 and Methods. Vertical arrows from sediment to water

column indicate potential internal phosphorus release pathways. Vertical downward arrows depict relative total annual phosphorus loads to each pond as outlined in the 2007 TMDLs. Variables lacking direct measurement include Tongue Pond water-column phosphorus, groundwater inputs from the former brewery site to Spectacle and Mashapaug ponds, and pond-wide sediment phosphorus inventories for Mashapaug and Roger Williams Park ponds. Tongue Pond legacy phosphorus is shown as a mass-balance residual from the brewery reconstruction model, 643,000 kg P, not as a direct sediment measurement or localized sediment inventory.

Figure 1


Benedict Pond
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Mashapaug Pond
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Spectacle Pd.
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PROVIDENCE & BOSTON R.R.
Roger Williams Park
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Burgess Cove
Sassafras Point L.H.
Corliss Cove
PROVIDENCE RIVER
PROVIDENCE
Robin Hill
Fullers Rock
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Starve Goat Is
27
28
Edgewood
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Pomham
NARRAGANSET
61
Blackmore Pond
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Fenners Pond
WARWICK AND OAKLAND
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Pawtuxet
Sabi
RIVER
BRANCH R.R.
Silver Hook

Figure 2