

Positioning the 2024 Drought in New York City's Drought History: A Demand-Sensitive Framework for Assessing Risk

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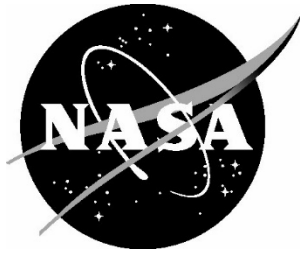
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The New York City Panel on Climate Change (NPCC) is an independent advisory board that regularly publishes assessment reports that synthesize several years of scientific research and analysis on climate change. The Panel advises New York City (NYC) policymakers on local resiliency and adaptation strategies to protect against rising temperatures, increased flooding, and other hazards. NPCC assessments provide climate projections of record for New York City and cover other relevant, climate-related topics. The NPCC works with the NYC Mayor's Office and other municipal stakeholders throughout their sustained assessment process to identify emerging issues. In response to this co-generation process, the forthcoming fifth assessment report (NPCC5) will include research on how climate change will affect the NYC water supply system. This technical memorandum is a component of the fifth assessment effort.

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1. Executive Summary

New York City’s water supply system serves more than 9 million people. Managing this system requires balancing multiple objectives associated with ensuring reliable drinking water, supporting ecosystems, and meeting downstream obligations. The *2024 Drought*, triggered by the second-longest dry streak on record, revealed the City’s vulnerability to flash droughts that can quickly stress operations. This white paper situates the *2024 Drought* in a 74-year historical record of streamflow-based droughts. Using a demand-sensitive drought index derived for feeder streamflow sites of the Pepacton, Cannonsville, and Neversink reservoirs (i.e., limited to Delaware System), we tracked the event’s duration, severity, flashiness, and recovery. The analysis shows that the *2024 Drought* spanned 87 days, produced a cumulative deficit of 22,251 million gallons, exhibited extreme flashiness of 490 million gallons of deficit per day, and recovered from its peak severity in 20 days. Six deficit days during this event ranked among the top 100 on record, placing the event in the top ten percent of all droughts since 1951 for the combined Pepacton, Cannonsville, Neversink feeder streamflow sites. When examined seasonally, it stood out even more, ranking in the 95th percentile among all September–October–November droughts, confirming its unusual and consequential nature. The *2024 Drought* was short-lived, ending in early January 2025 after significant rainfall restored water levels. Yet its timing, flashiness, and operational consequences make it a historically significant hydrologic shock. As climate change intensifies the Earth’s water cycle, New York City must prepare not only for prolonged droughts but also for emerging flash droughts.

2. Introduction

In the New York City metropolitan area, more than 9 million people are served by the Upper Delaware River Basin reservoirs. Mandated releases from these reservoirs are used to meet multiple objectives downstream, including supporting fisheries habitat by ensuring adequate cold-water pulse releases¹. An essential aspect of managing the New York City Water Supply System is mitigating droughts to provide high-quality water to a growing population of consumers in a reliable fashion². The New York City Department of Environmental Protection’s Bureau of Water Supply (NYCDEP-BWS), the bureau that manages water for the New York City area, examines how changes in climate, land use, population density, ecosystem processes, and both watershed and reservoir management policies affect water supply. The operating rules governing water management rely on performance testing using the 1960s drought as the standard (“drought of the record”). However, changing conditions in these watersheds present ongoing and new challenges that NYCDEP-BWS must plan for and respond to in its mission to ensure continued reliability and high quality of drinking water supply. The recent *2024 Drought* in the Northeast, triggered by a prolonged 29-day period with no precipitation, the second-longest dry streak³, has underscored the urgency of preparing for future water scarcity challenges⁴.

Since the 1960s “drought of the record,”^{5,6} annual precipitation in the region, heavily influenced by frontal systems and extratropical cyclones⁷⁻¹¹, has trended upwards¹²⁻¹⁵. However, climate model projections for the Northeast suggests little change or decreased summer precipitation and prolonged summer low-flow periods^{16,17}. A decreased summer precipitation and prolonged summer low-flow period will result in reservoir drawdowns, which

may increase the frequency of short-duration droughts¹⁸. Post 1960s, several smaller droughts in the 1980s, 1990s, and 2000s had measurable impacts¹⁹ until the recent *2024 Drought* episode triggered by the second-longest rainfall dry streak (days between measurable rainfall) on record. In the Fall of 2024, a ridge of high pressure developed in the upper atmosphere over the central and eastern United States, leading to favorable conditions for above normal temperatures and below normal rainfall. The westerly and northwesterly flow of air around the ridge brought dry air to much of the region. At the surface, high pressure (associated with dry conditions due to sinking air) also developed over the eastern United States. This ‘*high*’ blocked moisture from the Gulf of Mexico from coming into the Northeast, thereby keeping conditions dry. These atmospheric features were not present and/or persistent earlier in the summer, however, their development in the wake of Hurricane Helene is what led to the fast onset of drought conditions in the New York City watershed.

According to the ‘New York City Drought Data’ available from the “Historical Drought & Water Consumption Data” page of New York City¹⁹, during the winter of 2024, a drought watch was first recorded on November 02, 2024. Later a drought warning shows on November 18, 2024, as the storage percentage dropped to 65.6% (*Watch*) and further down to 60.1% (*Warning*). It was recorded as a drought watch again on December 16, 2024 when the storage percentage increased to 68.2% (*Watch*). Finally, this drought ended on January 03, 2025, when storage percentage returned to 75.9% (*Ended*)¹⁹. It prompted City agencies to implement water-saving plans, including reduced washing frequency for buses and trains and limits on water use in parks. When placed in a historical context, the *2024 Drought*, while alerted the public, was less severe than the 1980s or the 2002 droughts, which recorded a drought emergency at their peak. However, it can be characterized as being significant due to its timing and flashiness, which underscores the vulnerability of the City’s water system to short-duration droughts in the face of growing water needs and services.

In this technical memorandum, we attempt to rank and position this *2024 Drought* in the historical context. We take a deeper dive into the streamflow dynamics of this drought, with an emphasis on the timing, duration, severity, flashiness, and recovery of the event relative to climatological conditions (or proxy demand conditions). Readers should note that this analysis is Delaware System-focused and intended for illustrative purposes; it does not encompass the full operational complexity of the New York City water supply system. Further, we define and present drought from a streamflow perspective, and it is not suggestive of the definitions used by NYCDEP-BWS (based on the probability of refill) or the Delaware River Basin Commission (based on combined storage of the Delaware Water System reservoirs). While one can typically use the Palmer Drought Severity Index (PDSI) or the Standardized Precipitation Index (SPI) to quantify the severity of droughts, we focused on a streamflow-based and demand-induced drought measure, as it can directly relate to the reservoir inflow conditions and can capture operational factors like changing demands in a unified framework. The methodological framework is flexible enough to develop scenarios based on varying demand assumptions and highlights the importance of planning for demand-sensitive and climate-informed drought management strategies.

3. Methodological Framework

Different drought indices have periodically evolved from approaches based on measures of deficiency of rainfall to more complex models²². Federal and State agencies, most notably the National Integrated Drought Information System (NIDIS) and its regional divisions (Drought Early Warning Systems-DEWS), use several available drought indices to assess and respond to drought. Among various drought indices, the Palmer Drought Severity Index²², Surface Water Supply Index^{23,24}, and Standardized Precipitation Index²⁵ are used extensively for drought monitoring and water resources management. Nevertheless, assessment of drought and its impacts requires an understanding of both temporal variations in water supply (due to the interannual rainfall variability and streamflow dynamics), and sensitivity to demand (due to changing water use). As water demand is projected to increase, at the simplest level as a direct consequence of population growth²⁶, the use of a purely supply-based indicator to determine drought will become increasingly ambiguous, since the frequency, duration and severity of water deficits is also relative to demand, not absolute in terms of supply. Therefore, we attempted to unravel droughts arising from variability in streamflow and demand. Figure 1 presents a schematic of this drought accounting process.

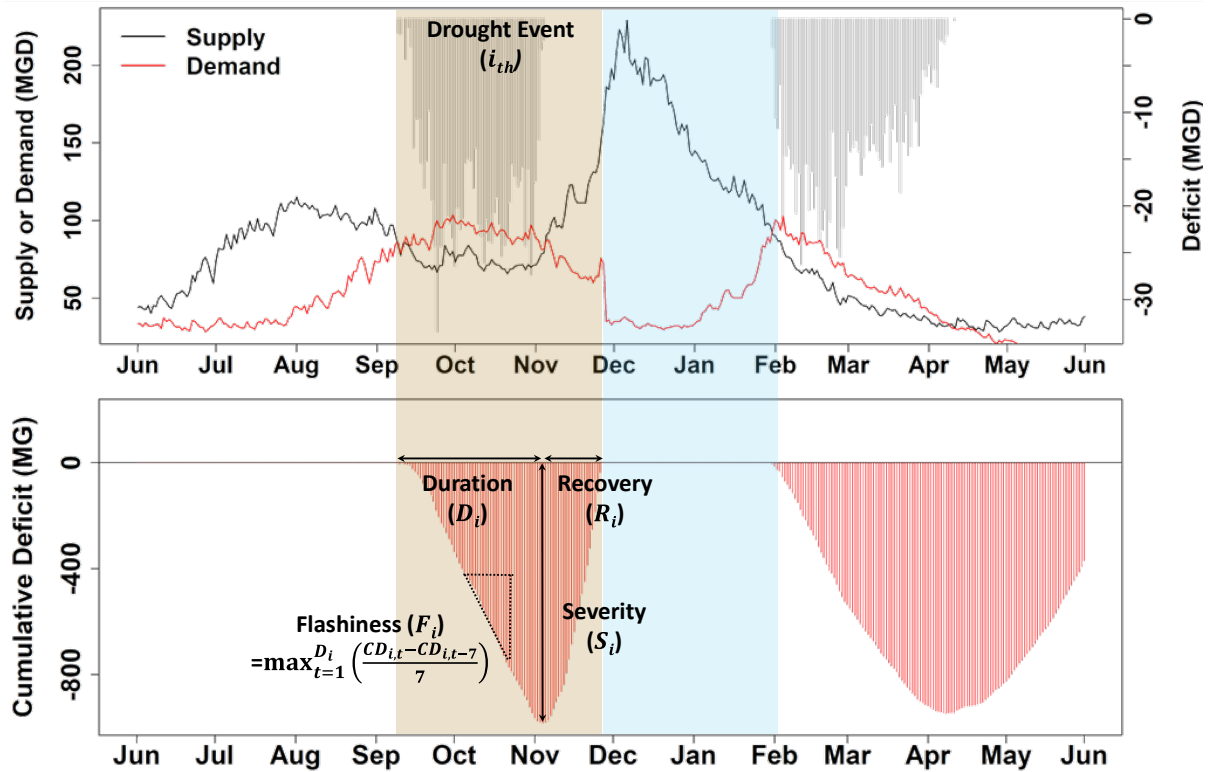


Figure 1: Conceptual representation of the streamflow-based and demand-sensitive drought index along with the drought metrics.

Given a time sequence of daily streamflow (supply, shown as the black-colored line for a representative release year (June 1 - May 31)) and proxy-demand (shown as the red-colored line), we first calculate the deficit as the

difference between supply and demand ($deficit_t = Supply_t - Demand_t$) such that the days when supply is lower than the demand will show up as dry periods. If a new deficit occurs, we initiate the calculation of a potential drought, and compute and record the cumulative deficit, ($CD_t = \min(0, CD_{t-1} + deficit_t)$) (red bars in Figure 1 bottom panel) for each subsequent day. We then record the number of consecutive days up to the maximum cumulative deficit (S_i) in that sequence as the drought duration (D_i). Subsequently, we track the drought recovery period (R_i) as the time from the peak of the cumulative deficit sequence for the event to the time when the cumulative deficit becomes zero. We term this cycle of drought duration (D_i), severity (S_i), and recovery (R_i) as a “drought event,” and multiple such drought events can happen each year or over the years. We also derive a flashiness index (F_i) as the maximum rate of cumulative deficit decline (i.e., steepest descent) over seven days as a measure of how rapidly the drought is intensifying. Examining multiple drought events allows for inference through the derivation of the multivariate probability distribution of these metrics.

For this investigation, we considered daily streamflow data from June 1, 1951 to May 31, 2025 for the East Branch Delaware River (USGS ID: 01413500, feeder creek to the Pepacton Reservoir with a storage capacity of 140 BG), the West Branch Delaware River (USGS ID: 01423000, feeder creek to the Canonsville Reservoir with a storage capacity of 96 BG), and Neversink (USGS ID: 01435000, feeder creek to the Neversink Reservoir with a storage capacity of 35 BG). See Figure 2 for a geographic location of these feeder sites. Total daily streamflow of the PCN (Pepacton, Canonsville, and Neversink) feeders is assumed as supply, while the daily climatology (i.e., long-term median of the daily combined inflow) is assumed as demand. We show the climatological plot in Figure 3. Median daily flow (across 74 years) is the solid blue colored line, and the interquartile range of values across the 74 years for each day is the blue band. Note that while we use the long-term median of the daily combined inflow as proxy-demand here to derive the streamflow-based and demand-sensitive drought index, it can be substituted with current or potential demands when readily available.

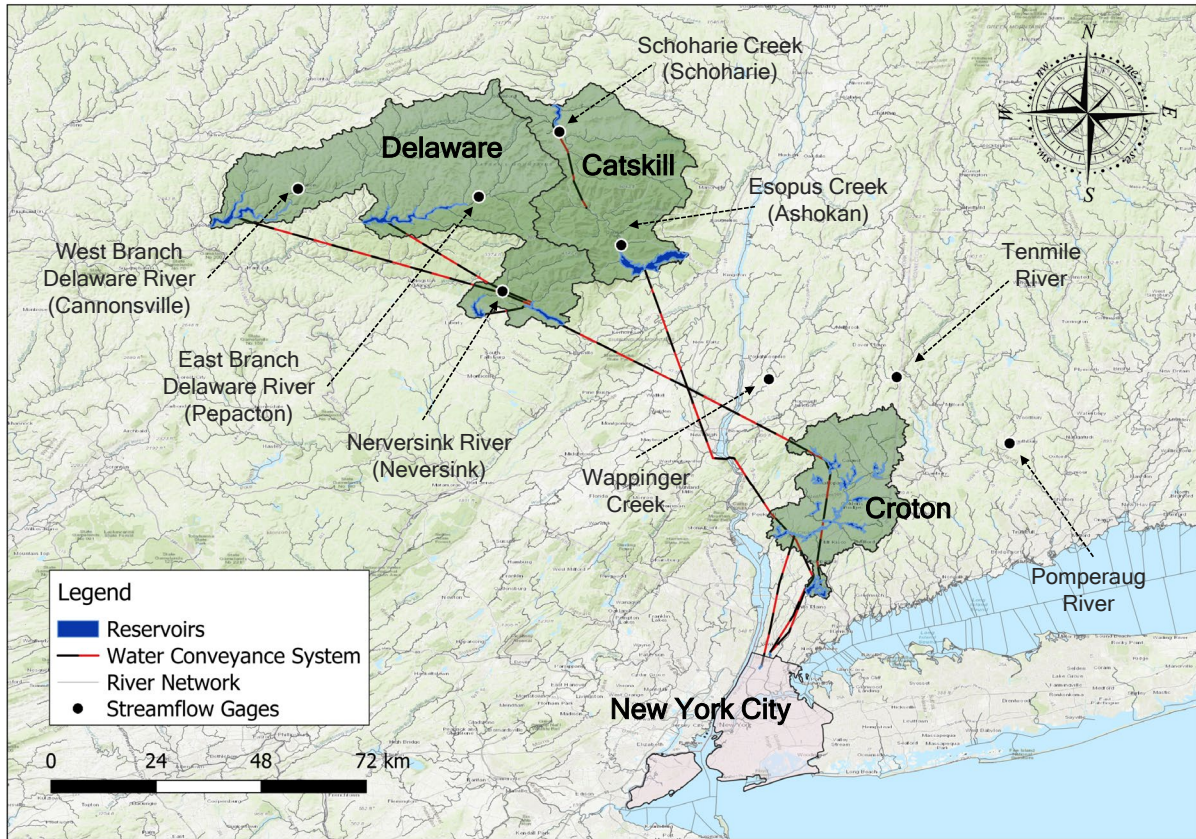


Figure 2: New York City Water Supply System.

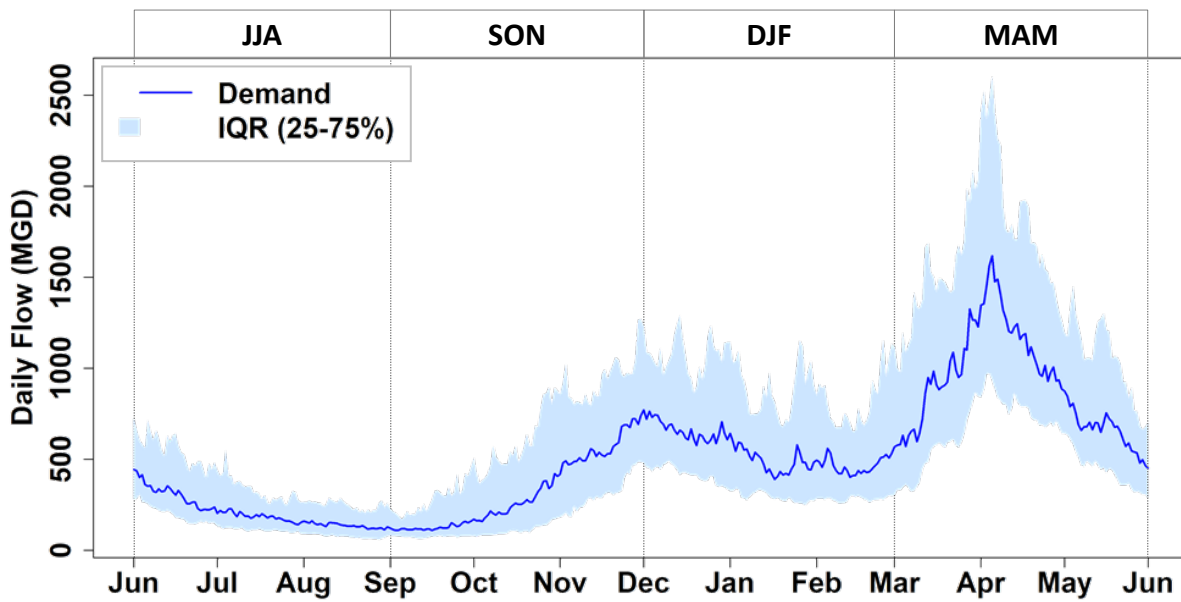


Figure 3: Climatology plot of the daily inflows for June 1, 1951 to May 31, 2025.

4. Multivariate Drought Measures for PCN Streamflow and the Position of the 2024 Drought

We first investigate the deficit days (i.e., days when supply is lower than the demand) over the entire span of 74 years from 1951 to 2025 on a normalized scale. Figure 4 presents this as percentage deficit $\left[\left(\frac{Supply_t - Demand_t}{Demand_t}\right) \%\right]$ for each day. In other words, we represent daily deficit as a percentage of the demand for that day to normalize them on a 0-100 scale for comparison. In Figure 4, we also show the top 100 deficit days by rank as black filled circles and indicate the years when they occurred. While we expect several of the top 100 deficit days to be from the 1960s era, it is also notable that the 1980s, the early 2000s, and the most recent 2024 event have deficit days in the top 100 deficit days. The 2024 Drought can therefore be classified as a substantial drought event, comparable to the worst historical drought events. This event, which triggered a drought *Watch* and *Warning*, has six deficit days in the top 100 deficit days.

Figure 5 shows a snapshot of the cumulative deficit and the drought events between June 1, 2022, and May 31, 2025. We can characterize the 2024 Drought mainly by the event that happened between September and December. It is the largest cumulative deficit event for the year, which started on September 14, 2024, lasted for 87 days (drought duration), and has a severity of 22,251 million gallons (i.e., a cumulative deficit of 22,251 million gallons over 87 days). Its flashiness is 490 million gallons per day. We measure flashiness as the steepest 7-day descent over the 87 days. The drought peaked around December 9, 2024, and recovered in 20 days. As it happens, the City¹⁹ documented a drought *Watch* on November 02, 2024, and then, a *Warning* on November 18, 2024. It was leveled back to *Watch* on December 16, 2024 before finally recording *Ended* on January 03, 2025.

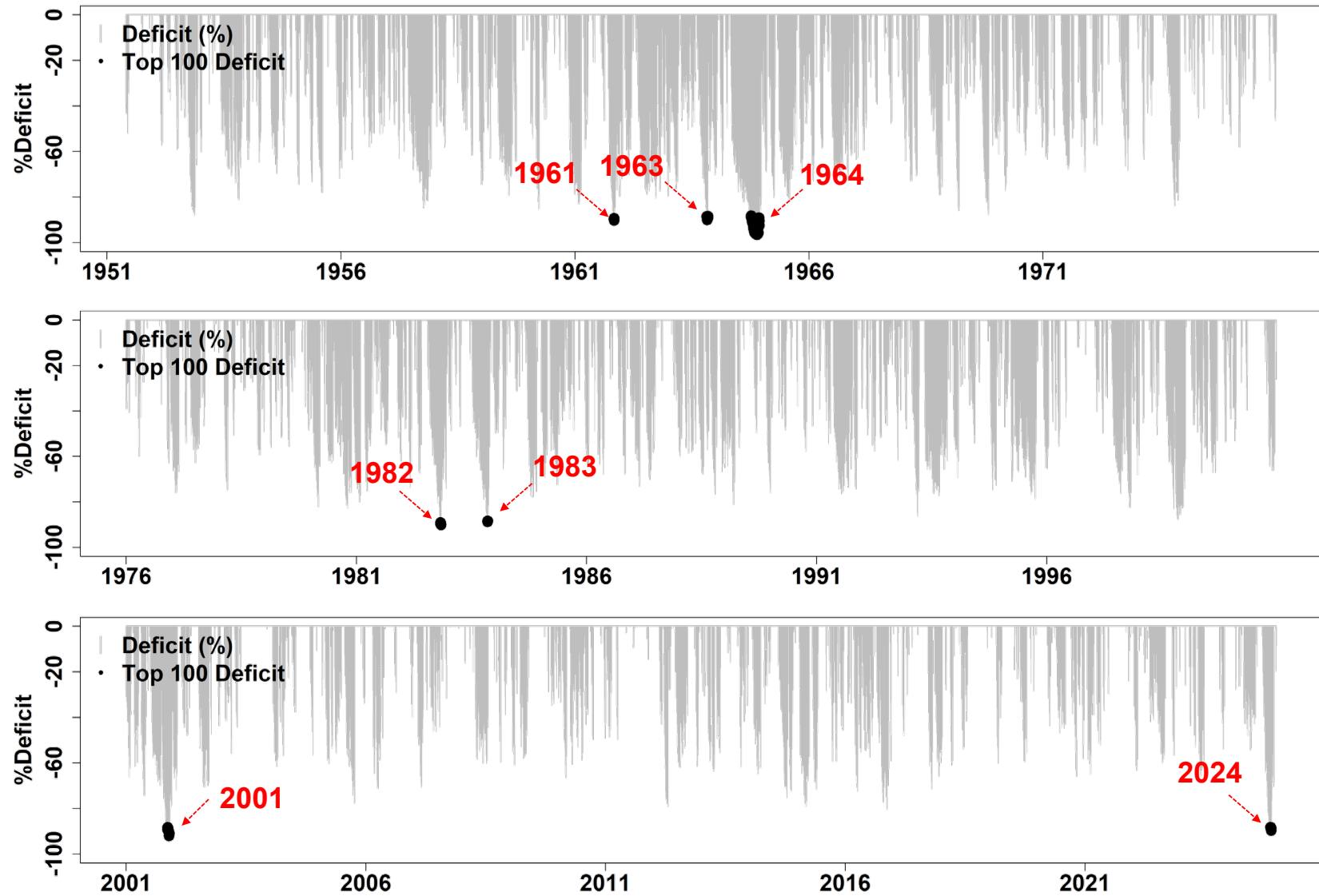


Figure 4: Historical deficit days (the days when supply is lower than the demand) and the top 100 deficit days by rank of the magnitude along with their years of occurrence.

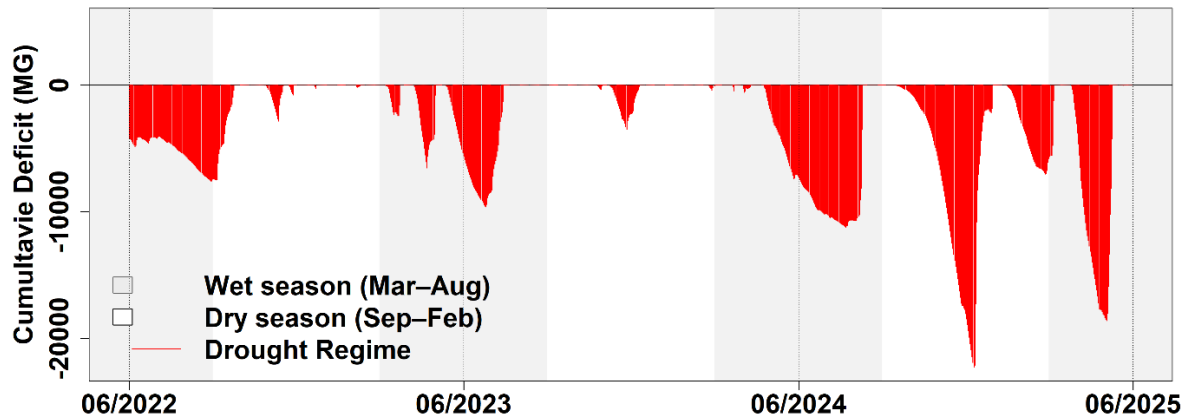


Figure 5: Snapshot of the 2024 drought event.

Next, we examine the *2024 Drought* in a multivariate context using all the events from June 1, 1951, to May 31, 2025. Specifically, we are interested in percentiles or the position of this event in the univariate space of duration, severity, recovery, and flashiness (D-S-R-F) as well as the multivariate (or joint probability) space. In Figure 6, we present the multivariate distribution of all 453 events. The x- and y-axes represent drought event duration (in days) and severity (in million gallons), respectively, while the color of the filled circle indicates the magnitude of flashiness (in million gallons per day). The *2024 Drought* is indicated using a square and a pointer to “Mid Demand.” As we can see, the *2024 Drought* stands in the high percentile space in terms of duration (87 days), severity (22,251 million gallons), and flashiness (490 million gallons per day) with values at the 92.1th percentile on drought duration, 94.9th percentile on drought severity, 89.0th percentile on drought recovery, and 89.6th percentile on drought flashiness. It stands at the 94.0th percentile in the joint ranked space of D-S-R-F based on the non-parametric joint percentile estimate. We also adjusted the proxy-demand for 2024 release year by $\pm 20\%$ (while keeping all others unchanged) to understand the sensitivity to potential demand changes in any given year. For the same streamflow variability, a 20% increase in proxy-demand (long-term median of the daily combined inflow) would cause a drought of 90-day duration, 29,040 MG severity, 636 MGD flashiness, and 98-day recovery. It would position as the 98.1th percentile in the joint D-S-R-F multivariate space. Similarly, a 20% decrease in proxy-demand would cause a drought of 83-day duration, 15,561 MG severity, 369 MGD flashiness, and 4-day recovery. It would position as the 86.4th percentile in the joint D-S-R-F multivariate space.

All this highlights the relative importance of the *2024 Drought* in a historical perspective and the role of demand. Taken one metric at a time or jointly across all the drought metrics, they rank approximately in the top 10 percent of the historical events, making this event a historically significant event that necessitates further study.

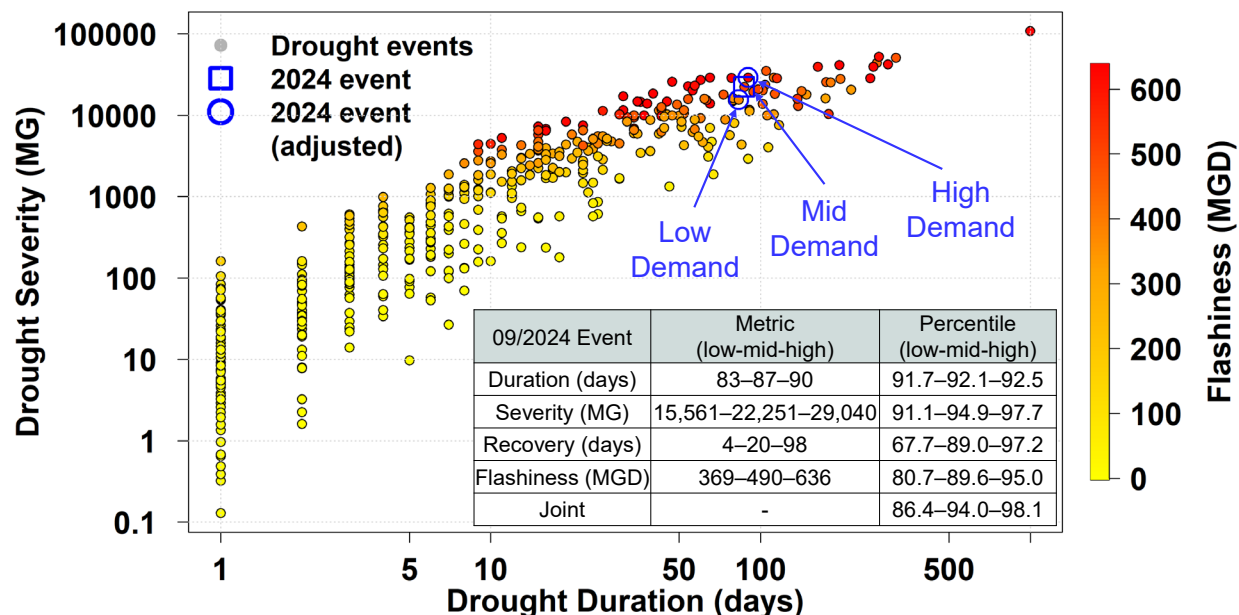


Figure 6: Multivariate distribution of all 453 drought events from June 1, 1951 to May 31, 2025 and the position of the 2024 drought event.

Finally, we examine the relative position of the *2024 Drought* in a multivariate context in the seasonal event space to understand where the *2024 Drought* event (that spanned September to December 2024) ranks when contextualized among all September-October-November (SON) seasonal drought events historically. Ninety-six drought events spanned the SON season. Similar to Figure 6, in Figure 7, we present the multivariate distribution of the 96 drought events that spanned SON. The *2024 Drought* is indicated using a square and a pointer to “Mid Demand.” The *2024 Drought* stands at the 92.7th percentile of drought duration, 93.8th percentile of drought severity, 92.7th percentile of drought recovery, and 96.9th percentile of drought flashiness. Further, it stands at the 94.8th percentile in the joint ranked space of D-S-R-F. It is interesting that when viewed from a seasonal perspective, this event is ranked very high, regarding it as an unusual event, and its timing and flashiness are what are particularly noteworthy. It underscores how a seemingly short drought emerges as one of the most important events in drought history for the City to consider. The exceptional flashiness and severity, when combined with the timing of when it occurred, characterize its risk and the City’s vulnerability to increasing hydrologic shocks.

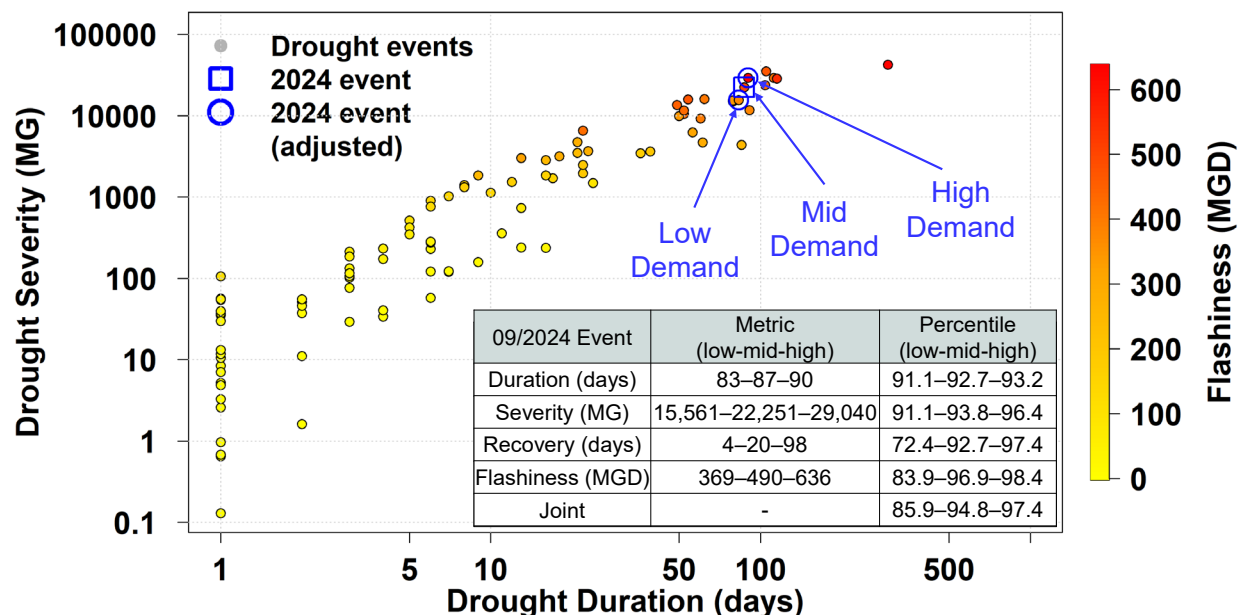


Figure 7: Multivariate distribution of the 96 SON drought events and the position of the 2024 drought event.

Notably, the New York City Panel on Climate Change (NPCC) previously made qualitative projections based on scientific literature and expert judgment²⁷ that suggest that it is more likely than not that late-summer short-duration droughts will increase in the New York metropolitan region by the end of the century¹⁸.

5. Discussion

The *2024 Drought* in New York City was unusual not only in its timing but also in its intensity and flashiness when measured through both hydroclimatic inputs (i.e., streamflow conditions) and proxy demand or dynamic drought thresholds. Deficient rainfall was the first sign, as the Central Park rainfall station recorded a meager 0.81 inches of precipitation in October, compared to a long-term average of close to 4 inches. It was the driest October in record in New York City^{28,29}. This trend continued into November across the Northeast United States, with 8 to 10 inches below normal rainfall³⁰. Reduced rainfall quickly translated into declining streamflow and dropping reservoir levels in the system. The New York State Department of Environmental Conservation (DEC) declared a drought watch³¹ on November 2, 2024, followed by Mayor Adams' declaration of a citywide *Watch*³². By November 18, New York City issued a *Drought Warning*, the first in over two decades^{32,33}.

The rainfall shortage, low streamflow, and falling water levels that drove this event were reflected in the streamflow-based and demand-induced drought index we derived for the PCN system's feeder creeks. This index, designed using a proxy-demand framework, directly reconciles inflows relative to system demand and captures the progression of the drought and closely matches the reservoir conditions. Six deficit days from the *2024 Drought* ranked among the top 100 deficit days of the entire 74-year record (1951–2025), placing this episode alongside the most significant droughts of the 1960s, 1980s, and early 2000s. The main event, spanning September 14 to

December 9, 2024, lasted 87 days, with a severity (cumulative deficit) of 22,251 million gallons and a flashiness of 490 million gallons per day. Recovery occurred in 20 days. Placed in the multivariate context of all 453 drought events over the observational record, the *2024 Drought* episode consistently ranks in the top 10 percent historically. Its duration lies in the 92nd percentile, severity in the 95th percentile, recovery in the 89th percentile, and flashiness in the 90th percentile. Jointly using a multivariate percentile estimate, it ranks in the 94th percentile, establishing its position as one of the most consequential events in the City’s hydrologic history. When checked on the seasonal scale, the significance becomes even more pronounced. Among the 96 September–October–November droughts in the record, the *2024 Drought* sits in the 93rd to 97th percentile across metrics, ranking 95th percentile overall. This sets it as an exceptional drought, distinguished by its flashiness, severity, and unusual timing. Together, these findings highlight how a relatively short-lived drought can still emerge as a historically significant hydrologic shock. The rainfall deficits that triggered the drought and the rapid decline in streamflow illustrate the multifaceted risks posed by flash droughts.

As climate change intensifies the Earth’s water cycle, the City’s drought vulnerability benchmarks should include prolonged, multi-year droughts of the past (for example, the 1960s “drought of the record”) as well as short-duration and flashy droughts such as the *2024 Drought* that could test operational flexibility. The *2024 Drought* demonstrates the need for continued innovation in drought monitoring, demand-sensitive management tools, and proactive scenario analysis to ensure the reliability of New York City’s water supply under increasingly dynamic conditions. Importantly, such proactive scenario analysis and drought response must also consider system-level interdependencies and basin-wide constraints under the Flexible Flow Management Program (FFMP), which governs releases and diversions across the Delaware River Basin and shapes the trade-offs between upstream storage, downstream ecological needs, and interstate water supply obligations³⁴.

The assessment of drought duration-severity-recovery-flashiness (D-S-R-F), considering proxy demands or dynamic drought thresholds and inflows, is usually only a first step in the development of a management process for adaptation and risk mitigation. Climate risk mitigation needs to integrally consider information from climate model simulations to characterize future trends as well as information from the instrumental record and pre-instrumental period^{35,36} to characterize the nature of persistence in the context of climate variability and its predictability. Adaptation to increasing flash drought risk in the future may entail changes in operational strategies to address changes in the seasonality of inflows and demands, which include changes in the rule curves based on Sub-seasonal to Seasonal (S2S) climate forecasts that leverage the predictability of the climate system at these time scales.

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