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MAZAR · LOW-FLOW SEASON

**FGET-VRR-NFF Formulation for Mazar Reservoir
Behavior During the Low-Flow Season**

THEK-LREM-MAZAR

A parsimonious model built from real data from Ecuador's power system.

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ABSTRACT

This paper presents an empirical, parsimonious formulation for describing the evolution of Mazar Reservoir elevation during the low-flow season and relating that evolution to an estimate of daily power-rationing hours. The model emerges from the FGET $\rightarrow$ VRR $\rightarrow$ NFF methodological sequence developed by Moncayo Theurer: candidate relationships among observable variables are first explored; variables, coefficients, and scales are then reduced and ranked; finally, the relationships are reorganized into a compact system of linked equations.

The historical observation window covers real data from 2017 through 2025. The multi-year comparison reveals patterns of drawdown, recovery, and low-flow severity, while 2023 and 2024 provide the direct verification cases for the final expressions and 2025 provides a stable reference condition. The model defines an Invernal Type factor, I_T , from the September elevation loss, projects $Z(d)$ through a quadratic form, and estimates H through a nonlinear relationship between I_T raised to 3.7 and Z .

For 2023 and 2024, the calculated minimum elevation matches the observed values with relative differences of 0.0029% and 0.0540%, respectively. The estimated rationing hours reproduce 3.00 and 14.00 h/day with differences of 1.57% and 0.12%, yielding a mean absolute percentage difference of approximately 0.84%. The resulting formulation is a compact tool for characterizing the low-flow season, projecting the Mazar trajectory, and quantifying its relationship with power-rationing hours.

Keywords: Mazar Reservoir; low-flow season; FGET; VRR; NFF; Invernal Type; reservoir elevation; power rationing; hydropower; Ecuador; THEK Research Institute; Marcelo Moncayo Theurer.

LREM METHOD

LOW-FLOW RESERVOIR EVOLUTION MODEL

· THEK-LREM-MAZAR APPLICATION

The model condenses a historical sequence of observation and reduction into the chain $\Delta Z_{\text{sep}} \rightarrow I_T \rightarrow Z(d) \rightarrow H$. Formula 1 describes the reservoir-elevation trajectory during the low-flow season; Formula 2 translates reservoir elevation into an empirical signal of power-rationing hours.

1. INTRODUCTION

Mazar Reservoir is a regulating component of the Paute Integral Hydroelectric Complex. Its storage capacity allows water to be shifted across periods and supports medium-term hydrothermal operation; therefore, reservoir elevation is an operationally relevant state variable during the dry months [1–10]. CENACE technical literature notes that Mazar provides several months of regulation capacity and that its management affects the coordinated operation of Mazar, Molino, and Sopladora [10].

The development begins with direct observation of real series: Mazar elevation over time, elevation loss during September, minimum levels reached during the low-flow season, and, for years with rationing, scheduled power-rationing hours. From these observations, a compact formulation was sought that would retain physical-operational meaning and remain easy to apply.

The development window spans 2017–2025. The years 2017 and 2018 provide the initial hydrological context; the 2019–2025 sequence enables comparison of the reservoir's monthly evolution; and 2023–2024 provide the most informative cases for directly verifying the formulas. The year 2025 completes the picture with a high-elevation, stable condition. Taken together, the series captures different levels of low-flow severity and provides a multi-year basis for organizing the model.

2. THEORETICAL BASIS: LOW-FLOW CONDITIONS, REGULATION, AND STATE VARIABLE

In a regulating reservoir, elevation is a state variable that summarizes stored water and, therefore, part of the system's temporary capacity to sustain hydropower generation. During the low-flow season, the system combines inflows, storage, hydropower dispatch, thermal backup, international exchanges, and operating decisions. Within this system, Mazar elevation provides a direct and quantifiable signal of the hydrological state of the Paute complex [1–10].

The proposed model uses two principal ideas. First, low-flow severity is characterized by the elevation loss during September, thereby incorporating the reservoir's actual dynamics. Second, a drawdown–minimum–recovery trajectory is represented parsimoniously by a quadratic function. These two choices yield a dimensionless severity factor and a time-dependent elevation equation.

The second relationship empirically links Mazar elevation to power-rationing hours. The formulation combines the reservoir's hydrological state with the severity represented by I_T and transforms both elements into a quantity H expressed in hours per day. In this way, the model connects the physical evolution of the reservoir with an operational impact variable of direct relevance to the power system.

3. METHODOLOGICAL ORIGIN: FGET → VRR → NFF

The model architecture derives from three frameworks developed by Moncayo Theurer: Formula Genomics and Evolution Theory (FGET), Variable Reduction and Ranking (VRR), and the Nested Formula Framework (NFF) [11–13]. The FGET → VRR → NFF sequence moves from real observations to a compact formulation: FGET explores candidate relationships, VRR identifies dominant variables and scales, and NFF reorganizes the results into linked equations. This architecture has also been applied in other THEK formulations [14–17].

3.1 FGET: exploring candidate relationships

In the FGET phase, several representations of the same problem were explored: elevation–time, hours–time, and hours–elevation. Years were compared, reference lines were tested to measure relative scales, and parabolas were fitted to the reservoir's time trajectory. This exploration generated a family of candidate relationships and revealed the mathematical structure that recurred across the years studied.

3.2 VRR: reducing variables and ranking scales

The VRR phase compared coefficients and magnitudes. The elevation–hours relationship showed a relative scale of approximately 4.8 between 2024 and 2023, while the dynamic coefficients of the elevation parabolas showed a ratio of about 2.2. This comparison separated the relevant scales and reduced the problem to four principal variables— d , Z , H , and I_T —with ΔZ_{sep} used as the descriptor of low-flow severity.

3.3 NFF: reorganizing the solution into a compact chain

In the NFF phase, the reduced relationships were reorganized as a linked system and consolidated into a single factor, I_T . The final operating sequence is: September elevation loss → I_T → elevation $Z(d)$ → hours H . This structure preserves the meaning of each stage and allows each result to be checked directly against real data.

MODEL CHAIN

$\Delta Z_{\text{sep}} \rightarrow I_T \rightarrow Z(d) \rightarrow H$. First, low-flow severity is characterized; next, reservoir elevation is projected; finally, the empirical hourly signal is calculated.

4. REAL DATA USED: 2017–2025 WINDOW

The development relied on historical records of reservoir elevation, inflows, operation, and rationing for the 2017–2025 period [1–9,18–19]. Table 1 summarizes the contribution of each year to the process. This multi-year sequence made it possible to observe different low-flow conditions, compare Mazar’s evolution, and select the most informative cases for constructing and verifying the final equations.

Year	Real information used	Role in the development
2017	Elevations, inflows, and annual operation	Historical basis for hydrological behavior
2018	Reservoir, reserves, and inflows	Historical continuity of reservoir behavior
2019	End-of-month elevations	Multi-year comparison of elevations
2020	End-of-month elevations	Multi-year comparison of elevations
2021	End-of-month elevations	Multi-year comparison of elevations
2022	End-of-month elevations	Comparison of a relevant elevation drawdown
2023	Elevation, September loss, minimum, and power-rationing hours	Fitting and direct verification of the formulas
2024	Elevation, September loss, minimum, and power-rationing hours	Fitting and direct verification of the formulas
2025	End-of-month elevations and stable reservoir condition	Reference for a stable, high-elevation condition

Table 1. Historical window 2017–2025 and the role of each data subset in model development.

4.1 Multi-year comparison of reservoir elevations, 2019–2025

Table 2 organizes the historical sequence using the end-of-August elevation, end-of-September elevation, monthly elevation loss, historical I_T , and the minimum monthly elevation recorded in each year. This view shows how Mazar behavior changes across stable conditions, moderate drawdowns, and more severe low-flow seasons. The detailed 2023–2024 verification uses the specific higher-temporal-resolution verification series, so some values may differ from the monthly summary in this table.

Year	Aug. (m)	Sep. (m)	ΔZ (m)	Historical I_T	Monthly min. (m)	Year interpretation
2019	2153.67	2149.16	4.51	1.2819	2147.28	Stable condition
2020	2148.34	2152.19	-3.85	0.7594	2129.14	Stable condition
2021	2146.78	2149.08	-2.30	0.8563	2142.45	Stable condition
2022	2153.63	2144.94	8.69	1.5431	2120.26	Relevant drawdown
2023	2150.84	2139.29	11.55	1.7219	2115.85	Low-flow season with $H > 0$
2024	2139.28	2118.31	20.97	2.3106	2112.41	Severe low-flow season, high H
2025	2152.98	2152.95	0.03	1.0019	2139.43	Stable condition

Table 2. End-of-month elevations and historical interpretation, 2019–2025. Data source: annual series for 2019–2025 [3–9].

For 2024, the 20.97 m in Table 2 is the difference between the end-of-August elevation (2139.28 m) and the end-of-September elevation (2118.31 m), yielding $I_T=2.3106$ as a historical end-of-month indicator. Formula verification instead uses the strict September 1–30 loss, $\Delta Z_{\text{sep}}=20.49$ m, yielding $I_T=2.280625$. Likewise, 2112.41 m is the monthly minimum in the annual series, whereas 2110.73 m is the reference minimum retained in the regression/verification series. Thus, the two value pairs correspond to different temporal resolutions.

4.2 Low-flow classification using Invernal Type, I_T

A five-type classification is defined: $I_T \leq 1.00$ corresponds to Type 1; the interval from 1.00 to 2.30 is then divided into four equal bands, each with a width of 0.325.

Type 1 · Minimum · $I_T \leq 1.000$	Type 2 · Mild · $1.000 < I_T \leq 1.325$
Type 3 · Intermediate · $1.325 < I_T \leq 1.650$	Type 4 · Strong · $1.650 < I_T \leq 1.975$
Type 5 · Very Strong · $I_T > 1.975$	

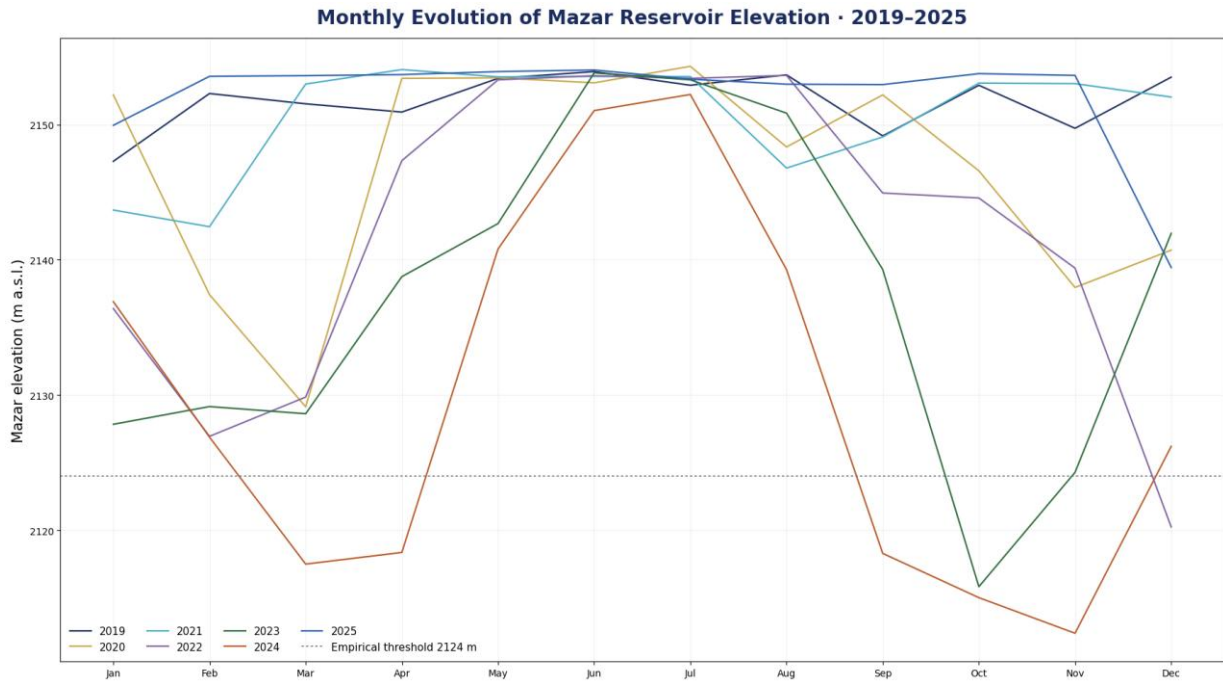


Figure 1. Monthly evolution of Mazar Reservoir elevation from 2019 through 2025. The 2124 m reference marks the transition point contained in the equivalent form of Formula 2.

5. MODEL FORMULATION

5.1 September elevation loss

The severity variable is constructed from the elevation loss between September 1 and September 30. As the drawdown increases, ΔZ_{sep} increases; when the reservoir remains stable or recovers, ΔZ_{sep} stays near zero and represents a low-severity condition.

$$\Delta Z_{sep} = Z_{1sep} - Z_{30sep}$$

Equation (1). Elevation loss during September.

Where:

ΔZ_{sep} = net Mazar elevation loss between September 1 and September 30, in m;

Z_{1sep} = Mazar Reservoir elevation on September 1, in m a.s.l.;

Z_{30sep} = Mazar Reservoir elevation on September 30, in m a.s.l..

5.2 Invernal Type, I_T

I_T transforms the September drawdown into a dimensionless factor. A value of 1 represents the baseline reference; values above 1 indicate increasing elevation loss during September. The constant 16 is the empirical scaling defined during model reduction.

$$I_T = 1 + \frac{\Delta Z_{sep}}{16} = 1 + \frac{Z_{1sep} - Z_{30sep}}{16}$$

Equation (2). Final definition of the Invernal Type factor.

Where:

I_T = dimensionless Invernal Type factor representing low-flow severity;

ΔZ_{sep} = September elevation loss, in m;

Z_{1sep} = Mazar Reservoir elevation on September 1;

Z_{30sep} = Mazar Reservoir elevation on September 30.

5.3 Formula 1: time trajectory of Mazar Reservoir elevation

Time is expressed through d , with $d = 1$ corresponding to September 1. The trajectory is represented by a parabola whose amplitude depends on I_T . The final form retains a simple structure and allows the theoretical minimum to be obtained directly.

$$Z(d) = \frac{-b_0}{2200} \left[\frac{I_T d^2}{141} - I_T d + 6663.51 \right], \quad b_0 = -705$$

Equation (3). Final formula for Mazar Reservoir elevation during the low-flow season.

Where:

$Z(d)$ = projected reservoir elevation on day d , in m a.s.l.;

d = day number counted from September 1, with $d = 1$ on that date;

I_T = Invernal Type factor for the year being analyzed;

b_0 = empirical base coefficient of Formula 1, fixed at -705 .

$$\frac{dZ}{dd} = 0 \Rightarrow \frac{2d}{141} - 1 = 0 \Rightarrow d_{min} = 70.5$$

Equation (4). Location of the parabolic minimum.

Where:

dZ/dd = rate of change of projected elevation Z with respect to day d ;

d = day number counted from September 1;

d_{min} = day at which the trajectory reaches its minimum elevation; in the model,

$d_{min} = 70.5$.

Equation (4) reveals an important structural property: the trajectory reaches its minimum at $d = 70.5$, approximately between November 9 and November 10. This position follows directly from the geometry of the

adopted parabola and provides a characteristic date for interpreting the point of maximum low-flow severity within the model.

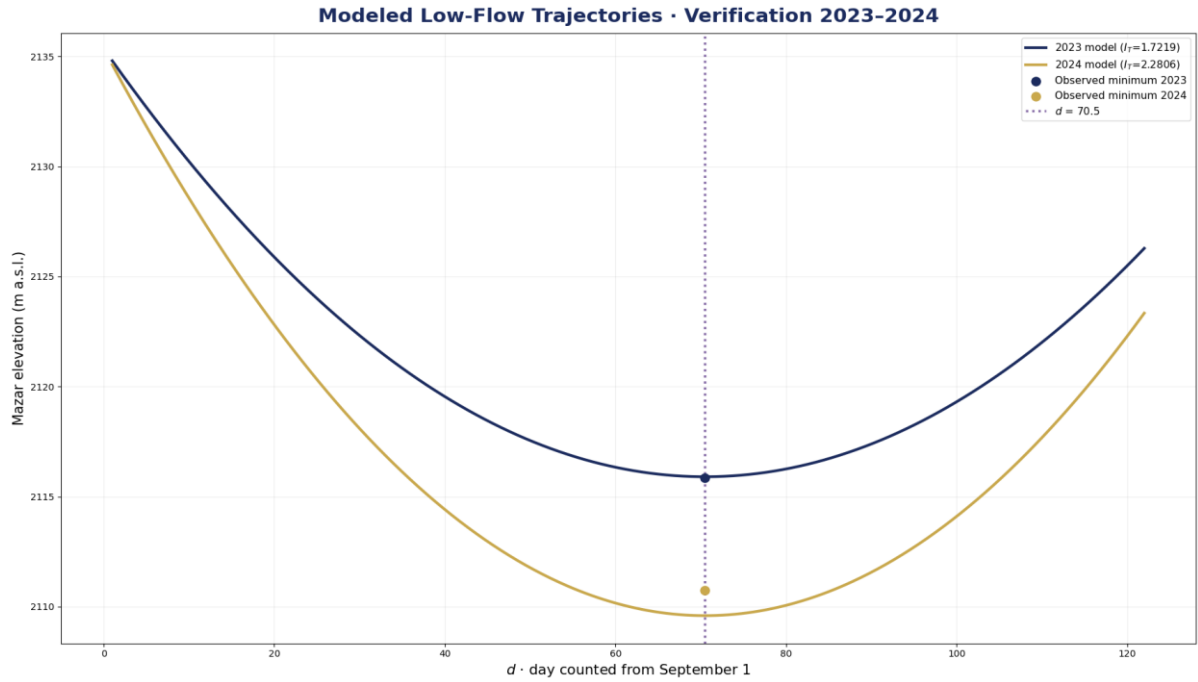


Figure 2. Modeled trajectories for 2023 and 2024 and observed minima used in the verification.

5.4 Formula 2: empirical relationship between elevation and power-rationing hours

The second equation uses elevation Z as input and amplifies the effect of the low-flow type through I_T raised to 3.7.

$$H = \frac{10620I_T^{3.7} - 5I_T^{3.7}Z}{100}$$

Equation (5). Final formula for daily power-rationing hours.

Where:

H = estimated daily power-rationing hours, in h/day;

I_T = dimensionless Invernal Type factor;

Z = Mazar Reservoir elevation used as input, in m a.s.l.;

Formula 2 establishes a transition elevation of 2124 m: when Z remains at or above 2124 m, the model assigns $H = 0$; as Z falls below that level, H increases progressively according to I_T and the elevation reached.

Symbol / constant	Definition	Unit / value
Z_{1sep}	Mazar elevation on September 1	m a.s.l.
Z_{30sep}	Mazar elevation on September 30	m a.s.l.
ΔZ_{sep}	Elevation loss during September	m
I_T	Invernal Type; dimensionless low-flow severity	—
d	Day number; $d = 1$ on September 1	day
b_0	Base coefficient in Formula 1	−705
$Z(d)$	Elevation projected by Formula 1	m a.s.l.
Z	Elevation used as input to Formula 2	m a.s.l.
H	Estimated daily power-rationing hours	h/day
3.7	Empirical nonlinearity exponent applied to I_T	—
2124	Implicit cutoff elevation in the factored form	m

Table 3. Variables and constants in the final formulation.

6. VERIFICATION OF BOTH FORMULAS WITH REAL DATA

Direct verification uses 2023 and 2024, years for which the September elevation loss, observed Mazar minimum, and scheduled power-rationing hours are available. The year 2025 adds a stable reference condition. The comparison is expressed through absolute difference and percentage difference:

$$E_Z = \frac{|Z_{calc} - Z_{obs}|}{Z_{obs}} \times 100$$

Equation (7). Relative percentage difference in elevation.

Where:

E_Z = relative percentage difference in reservoir elevation;

Z_{calc} = elevation calculated by the model, in m a.s.l.;

Z_{obs} = observed elevation used as the reference, in m a.s.l..

$$E_H = \frac{|H_{calc} - H_{obs}|}{H_{obs}} \times 100$$

Equation (8). Relative percentage difference in hours.

Where:

E_H = relative percentage difference in power-rationing hours;

H_{calc} = hours calculated by the model, in h/day;

H_{obs} = observed or reference hours, in h/day.

6.1 Verification of Formula 1

$$I_{T,2023} = 1 + \frac{11.55}{16} = 1.721875$$

Equation (9). Calculation of the Invernal Type factor for 2023.

Where:

$I_{T,2023}$ = Invernal Type factor calculated for 2023;

$$Z_{calc,2023}(70.5) = 2115.9017 \text{ m}$$

Equation (10). Calculated minimum elevation for 2023.

Where:

$Z_{calc,2023}$ = model-calculated reservoir elevation for 2023;

In 2023, the observed minimum was 2115.84 m and the model calculated 2115.9017 m. The absolute difference is 0.0617 m and the relative difference is 0.0029%, showing virtually exact agreement between the calculated trajectory and the observed value.

$$I_{T,2024} = 1 + \frac{20.49}{16} = 2.280625$$

Equation (11). Calculation of the Invernal Type factor for 2024.

Where:

$I_{T,2024}$ = Invernal Type factor calculated for 2024;

$$Z_{calc,2024}(70.5) = 2109.5901 \text{ m}$$

Equation (12). Calculated minimum elevation for 2024.

Where:

$Z_{calc,2024}$ = model-calculated reservoir elevation for 2024;

In 2024, the observed minimum used was 2110.73 m and the model calculated 2109.5901 m. The absolute difference is 1.1399 m and the relative difference is 0.0540%, maintaining close agreement with the observed low-flow value.

Year	I_r	Observed Z (m)	Calculated Z (m)	Absolute diff. (m)	Relative difference
2023	1.721875	2115.84	2115.9017	0.0617	0.0029%
2024	2.280625	2110.73	2109.5901	1.1399	0.0540%

Table 4. Verification of the minimum elevation calculated by Formula 1.

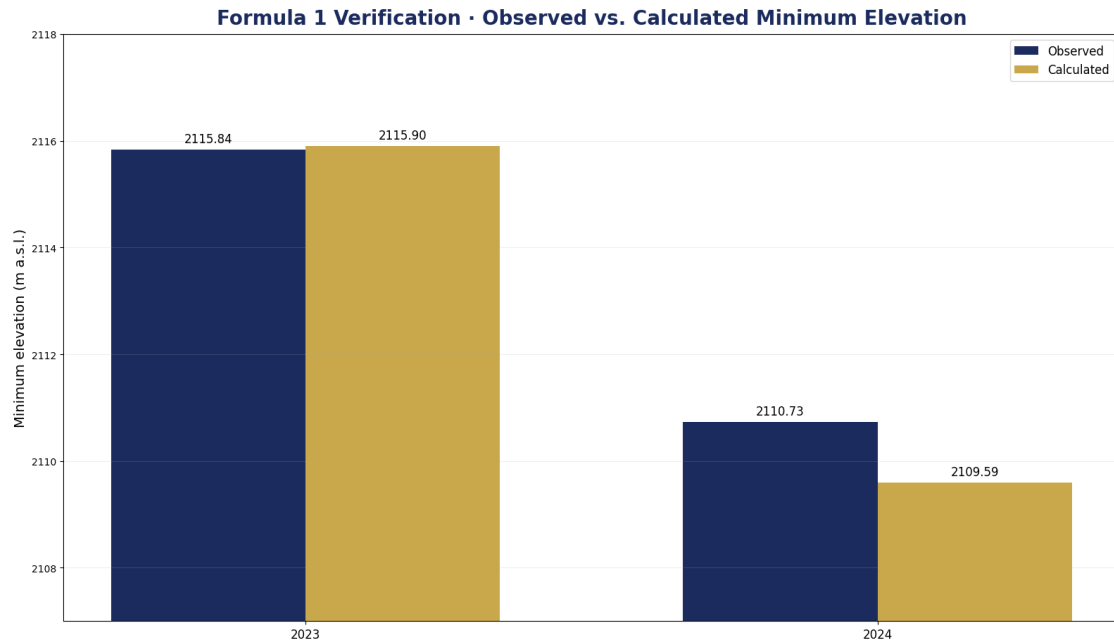


Figure 3. Comparison between observed and calculated minimum elevation for 2023–2024.

6.2 Verification of Formula 2

$$H_{calc,2023} = 0.05(1.721875)^{3.7}(2124 - 2115.84) = 3.04696 \text{ h/day}$$

Equation (13). Calculated power-rationing hours for 2023.

Where:

$H_{calc,2023}$ = daily power-rationing hours calculated by the model for 2023;

1.721875 = I_r value used for 2023;

For 2023, 3.00 h/day is used as the reference. The model yields 3.04696 h/day, with a difference of 0.04696 h and a percentage difference of 1.57%, closely reproducing the observed reference value [18].

$$H_{calc,2024} = 0.05(2.280625)^{3.7}(2124 - 2110.73) = 14.01652 \text{ h/day}$$

Equation (14). Calculated power-rationing hours for 2024.

Where:

$H_{calc,2024}$ = daily power-rationing hours calculated by the model for 2024;

2.280625 = I_T value used for 2024;

For 2024, 14.00 h/day is used as the reference. The model yields 14.01652 h/day, with a difference of 0.01652 h and a percentage difference of 0.12%, reproducing the observed reference value almost exactly [19].

$$MAPE_H = \frac{1.565\% + 0.118\%}{2} = 0.842\% \approx 0.84\%$$

Equation (15). Mean absolute percentage difference in hours.

Where:

$MAPE_H$ = mean absolute percentage difference for H;

The mean absolute percentage difference for the two hourly verification points is approximately 0.84%, summarizing the close agreement obtained for the two years used.

$$I_{T,2025} = 1 + \frac{2152.98 - 2152.95}{16} = 1.001875$$

Equation (16). Calculation of the Invernal Type factor for 2025.

Where:

$I_{T,2025}$ = Invernal Type factor calculated for 2025;

$$H_{2025} = \max(0, 0.05(1.001875)^{3.7}(2124 - 2139.43)) = 0$$

Equation (17). Calculated hours for the 2025 condition.

Where:

H_{2025} = daily power-rationing hours calculated for 2025;

In 2025, the end-of-August and end-of-September elevations remained virtually unchanged, and the minimum monthly elevation for the year was 2139.43 m. Formula 2 yields $H = 0$, matching the expected behavior for a high-elevation, low-severity condition.

Year	Observed / reference H	Model H	Absolute diff. (h)	Diff. (%)
2023	3.00	3.04696	0.04696	1.57%
2024	14.00	14.01652	0.01652	0.12%
2025 stable	0.00	0.00	0.00	—

Table 5. Verification of Formula 2 using 2023–2025.

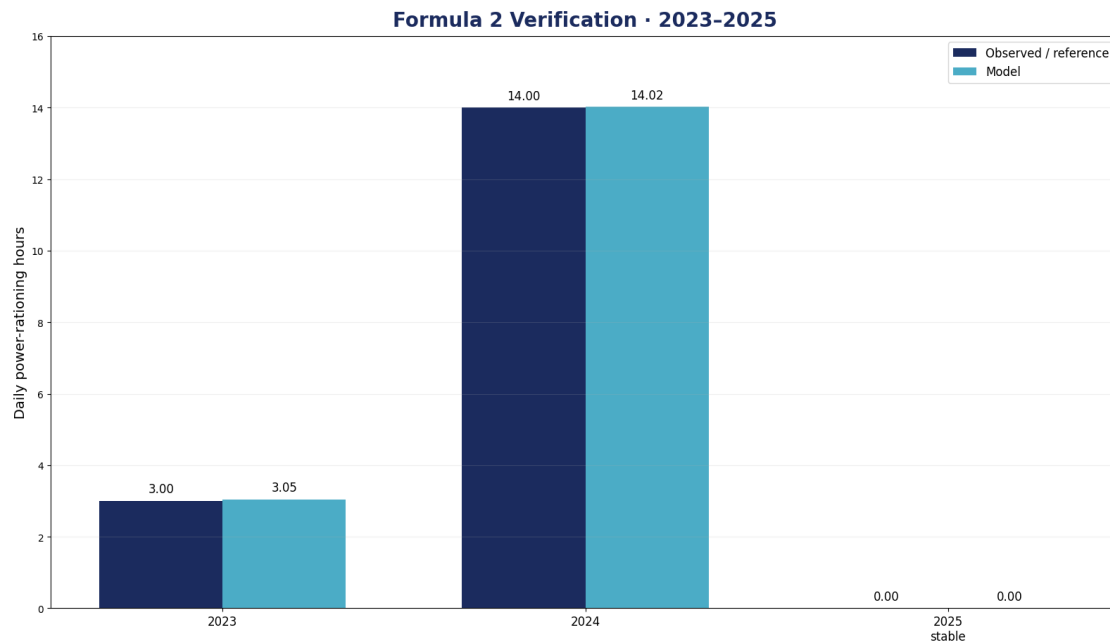


Figure 4. Comparison between observed/reference power-rationing hours and model-calculated hours.

7. MODEL INTERPRETATION

The 2023–2024 results show close agreement between observed and calculated values. Formula 1 reproduces the reservoir minima, while Formula 2 reproduces the power-rationing hours used as references. The agreement confirms that the chain $\Delta Z_{\text{sep}} \rightarrow I_T \rightarrow Z(d) \rightarrow H$ preserves the principal relationship identified through the $FGET \rightarrow VRR \rightarrow NFF$ development.

The historical sequence shows that the model clearly distinguishes different levels of hydrological severity. As ΔZ_{sep} increases, I_T increases and the $Z(d)$ trajectory deepens. When elevation falls below 2124 m, Formula 2 begins to produce positive values of H ; the larger I_T becomes and the lower Z falls, the larger the calculated magnitude. This relationship condenses the

evolution of the low-flow season and its expression in power-rationing hours into a single mathematical chain.

Formula 1 describes the time trajectory of the low-flow season as conditioned by I_T and places the characteristic minimum at $d = 70.5$. Formula 2 takes either the calculated or observed elevation as input and transforms the reservoir state into H . Together, the two expressions form a compact, reproducible, direct-calculation model suitable for comparing years, constructing low-flow scenarios, and tracking Mazar evolution throughout the low-flow season.

8. CONCLUSIONS

- The Mazar low-flow model was built from real observations over a 2017–2025 historical window, following a sequence of exploration, reduction, and mathematical formulation.
- FGET explored candidate relationships; VRR reduced variables and scales to d , Z , H , ΔZ_{sep} , and I_T ; NFF reorganized the result into the chain $\Delta Z_{\text{sep}} \rightarrow I_T \rightarrow Z(d) \rightarrow H$.
- The Invernal Type definition incorporates the observed September elevation loss and converts that dynamic into a dimensionless severity indicator; its mathematical expression is given in Equation (2).
- Formula 1 reproduces the 2023 and 2024 minima with relative differences of 0.0029% and 0.0540%, respectively.
- Formula 2 reproduces 3.00 h/day in 2023 and 14.00 h/day in 2024 with differences of 1.57% and 0.12%, respectively, and a mean absolute percentage difference of approximately 0.84%.
- The 2025 condition yields $H = 0$ at high reservoir elevation, while the 2023–2024 cases show the progressive increase in H produced by combining larger I_T values with lower elevations.
- The formulation is parsimonious, transparent, and directly applicable. Its structure allows I_T to be updated each year, $Z(d)$ to be projected, low-flow seasons to be compared, and H to be calculated within a single mathematical architecture.

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