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A Comparative Review of Japan’s Framework for Developing a Comprehensive Flood Control Master Plan

Ali Chavoshian[1], Shinji Honda[1], Yuka Sasaki[1], Shara Astillero[1]
PACIFIC CONSULTANTS CO., LTD., Kanda Nishikicho-3, Chiyoda City, Tokyo 101-0054, Japan[1]
E-mail: ali.chavoshian@tk.pacific.co.jp

ABSTRACT

Japan’s river systems are characterized by steep slopes, short concentration times, and dense urbanization within flood plain. This paper provides a comparative review of the unique technical pillars within Japan’s framework for developing a Comprehensive Flood Control Master Plan. Specifically, the paper clarifies two core technical elements: (i) the “stretching” approach used to develop design hyetographs from observed storm events, and (ii) the iterative High-Water Level (HWL) trial process used to finalize the vertical design datum. The Japanese approach to developing design hyetographs differs from the non-Japanese practices that are commonly used internationally. In contrast to synthetic design-storm methods (e.g., SCS-type distributions or the Alternating Block Method) that impose idealized, often symmetric temporal patterns derived from IDF relationships, the Japanese approach preserves event realism by scaling historical rainfall time series, so the basin’s characteristic storm structure is retained. Moreover, the planned high-water level in Japan is set through practical trade-off analyses among channel excavation, widening, and levee height, with explicit attention to avoiding excessively elevated “ceiling river” conditions. This study highlights how Japan’s framework combines historically grounded hydrology with safety-driven hydraulic design to improve robustness in urbanized basins exposed to flooding.

KEYWORDS: Ceiling Rivers, Design Hyetograph, Flood Control Master Plan, High-Water Level (HWL), River Basin Management

1 INTRODUCTION

Japan is characterized by steep mountainous terrain and short, rapid river channels that drain into densely populated alluvial plains. Unlike the continental rivers of North America or Europe, which often have longer concentration times and broader floodplains, Japanese rivers are prone to flash flood caused by destructive typhoons and active seasonal fronts (Koike, 2021). River management in Japan is governed by the River Law, which mandates a two-tiered planning structure: the long-term "Basic Policy for River Improvement" and the mid-term "River Improvement Plan" (MLIT, 2020).

Central to this framework is the determination of the Basic Flood Discharge[1], which represents the peak flow generated by a design rainfall before any regulation by facilities. While the fundamental principles of hydrology are universal, Japanese methodology differs significantly from standard practices. A key distinction lies in the construction of the Design Hyetograph. While non-Japanese approaches often utilize synthetic storm distributions (e.g., SCS Type curves or alternating block methods) derived from Intensity-Duration-Frequency (IDF) curves (Chow et al., 1988), the Japanese methodology prioritizes the use of actual observed rainfall patterns from past major floods. These historical patterns are "stretched" or

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[1] The "Raw" natural peak. In Japanese, *Kihon Takamizu*

scaled to match probabilistic design rainfall volumes, ensuring the design storm reflects the specific meteorological "personality" of the basin (JICA, 2003).

Furthermore, the determination of the river's High-Water Level (HWL)[2] involves a unique iterative trial process that balances riverbed excavation against embankment height (JICA, 2002). Unlike standard approaches that may fix the design water level based solely on existing topography and peak discharge, the Japanese framework utilizes a unique, iterative trial process. This process seeks an optimal hydraulic balance among three physical variables: riverbed excavation, river widening and embankment height. By carefully weighing these factors, engineers ensure that the final HWL is set at an elevation that minimizes the risk of a catastrophic breach, preventing the creation of “ceiling rivers” where the water level significantly exceeds the elevation of the surrounding protected low-lying land.

According to Takeuchi (2022), the success of Japan’s flood control lies in its ability to treat the river basin as a holistic system where structural measures, such as dams and levees, are integrated with the "wisdom of the past." This includes analysing the actual hydro-meteorological behavior of historical floods to ensure that modern infrastructure is not merely built to a theoretical number, but is resilient against the specific, observable temporal distributions of rainfall that characterize Japanese storm events. In recent years, in response to intensifying climate change risks, Japan has transitioned from a facility-centric approach to a more holistic paradigm known as "River Basin Disaster Resilience and Sustainability by All"[3], which integrates land-use regulation and stakeholder cooperation into the master plan (MLIT, 2020).

This paper aims to elucidate these unique technical features, specifically the scaling of historical hyetographs and the setting of HWL, by providing a detailed comparison with international methods.

2 BRIEF REVIEW OF JAPANESE FLOOD CONTROL MASTER PLAN FORMULATION

The formulation of a flood control master plan in Japan is not merely a technical exercise but a legally binding process that balances hydrological theory with socio-economic reality. The methodology is designed to ensure that the river's "carrying capacity" is sufficient to convey the “design flood” safely. This relationship is anchored by the High-Water Level (HWL), which serves as the foundational vertical datum for all flood control plans and river works.

2.1 The Two-Tiered Legal and Planning Hierarchy

Following the 1997 revision of the River Law, Japan transitioned to a two-tiered planning system to improve transparency and incorporate environmental considerations alongside flood control (Takahasi, 2009):

Basic Policy for River Improvement[4]: This document establishes the long-term, fundamental goals for the entire river system. It identifies the "Design Flood" (target return period) based on the importance of the basin and determines the Basic Flood Discharge. The Basic Flood Discharge is a theoretical value representing the peak runoff generated by the design rainfall, assuming no flood control facilities (such as dams) are present. This represents the "natural" threat the basin faces.

River Improvement Plan[5]: This is a phased-based implementation plan (e.g. 20- to 30-year) focused on specific projects. It defines the Design Flood Discharge, which is the actual flow rate the river channel must safely carry after a portion of the Basic Flood Discharge has been regulated (peak-cut) by upstream dams or retention or retarding basins. This plan is developed through consultation with local stakeholders and academic experts.

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[2] In Japanese, *Keikaku Kōsui*

[3] In Japanese, *Ryuiiki Chisui*

[4] In Japanese, *Kasen Seibi Kihon Houshin*

[5] In Japanese, *Kasen Seibi Keikaku*

2.2 The Technical Workflow for Plan Formulation

The transition from the "Basic Policy" to a finalized "Improvement Plan" follows a sequential six-step technical workflow as follows:

Step 1) Defining Design Conditions: The process begins by establishing the target safety level (return period) based on the river's national or regional classification. A defining characteristic of this step in Japan is the designation of "Flood Control Reference Points"[6]. These are fixed geographic locations (e.g., major confluences or urban bottlenecks) where discharge and water level targets (HWL) are legally set. These points ensure a unified, non-decentralized approach to safety across the entire river system (JICA, 2003).

Step 2) Natural Condition Hydrological Study: In this step, the Basic Flood Discharge is calculated at each flood control reference point. This represents the peak runoff generated by the design rainfall in the catchment's natural state, assuming no flood control facilities (like dams) exist. A unique Japanese feature here is the use of actual historical rainfall patterns from past major floods. These patterns are "stretched" or scaled to match the probabilistic rainfall volume, ensuring that the design hydrograph retains the realistic temporal "personality" of the basin (Takahasi, 2009). This unique Japanese technique, and how it differs from non-Japanese methodologies, will be explained in Section 3 of this paper.

Step 3) Existing Condition Hydrological Study: This step is broadly consistent with the widely used general approach, in which the model is re-run to incorporate the effects of existing and planned upstream infrastructure (e.g., dams, reservoirs, and retarding basins).

Step 4) Setting Target Discharge: The result of the previous steps is the finalization of the Design Flood Discharge. This is the specific discharge that the river channel must be physically built to convey safely after accounting for upstream regulation. These values are plotted on a Discharge Distribution Diagram, which serves as the official master document for all channel dimensions and bridge clearance requirements throughout the river system.

Step 5) Setting Tentative HWL: Using hydraulic models, planners calculate the water surface profile corresponding to the Design Flood Discharge. This determines the Tentative HWL that is the maximum expected elevation of the design flood. It is considered "tentative" because it must be cross-referenced with the surrounding ground level to ensure that the river's containment does not create an excessively high, and therefore dangerous, embankment. This step and its difference from non-Japanese methodologies, will also be explained in Section 3 of this paper.

Step 6) Adjusting and Finalizing HWL (The Trial Process): The final step is an iterative "trial" process where engineers balance riverbed excavation and river widening against embankment height (raising the levees). Multiple configurations of channel width and depth are simulated to find an optimal HWL that minimizes the risk of a catastrophic levee breach while remaining economically feasible. Once fixed, the HWL becomes the vertical datum for all future engineering works along the river.

3 REVIEW OF TECHNICAL DISTINCTIVENESS WITH NON-JAPANESE METHODLPGY

This structured workflow highlights why Japan’s flood control master planning is technically distinct from approaches commonly applied. The key pillars are Step 2, which preserves the hydro-meteorological “personality” of the basin by grounding design rainfall in observed historical events, and the safety-driven HWL finalization process in Steps 5 and 6, where iterative hydraulic trials are used to set a robust vertical design datum. Whereas many non-Japanese practices prioritize mathematical convenience through synthetic, statistically symmetric design storms and streamlined modeling assumptions (Chow et al., 1988), the Japanese framework intentionally avoids reliance on theoretical abstractions alone, emphasizing physical consistency and historical continuity. The following sections will examine the technical mechanisms underlying hyetograph scaling and the HWL trial process in Japan, highlighting their practical differences.

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[6] In Japanese, *Kijun-ten*

3.1 Construction of the Design Hyetograph Based on Historical Realism

While the total rainfall depth for a target return period (e.g., 1/100 years) is determined statistically in a common way, the "shape" of the storm (its intensity over time) differs significantly in Japan. Commonly adopted approaches worldwide indicate that the design hyetograph is typically developed using synthetic distributions based on Intensity-Duration-Frequency (IDF) curves. These techniques include the Alternating Block Method or SCS Type Curves and rely on theoretical formulas to generate a "Balanced Storm" often resulting in a perfectly symmetrical hyetograph where the peak intensity is artificially cantered or fixed (Chow et al., 1988). While effective for determining a "theoretical statistical maximum", these smooth curves often fail to capture the chaotic, multi-peak nature of real weather systems.

In contrast, the Japanese methodology, as governed by the Technical Criteria for River Works (MLIT), is rooted in actual historical events and the "personality" of the basin. The procedure includes selecting a set of "Representative Disturbances" comprising significant historical flood events from the basin's recorded data (typically the five to ten largest past flood events). These observed hyetographs are subsequently scaled linearly to align with the probabilistic design rainfall volume (R_{plan}). The scaling formula is defined as:

$$r_{design}(t) = r_{obs}(t) \times \alpha \qquad (1)$$

$$\alpha = R_{Plan} / R_{obs} \qquad (2)$$

Where:

$r_{design}(t)$ is the design rainfall intensity at time t

$r_{obs}(t)$ is the observed historical rainfall intensity

α is the scaling factor (magnification rate)

The following outlines the scaling process in a step-by-step manner:

i. Selection of Representative Disturbances: Planners select 5 to 10 of the largest historical flood events recorded in the specific basin.

ii. Calculation of the Scaling Factor (α): The total volume of each historical storm is compared to the target probabilistic rainfall (e.g., 1/100-year).

iii. Linear Stretching: Every hourly (or sub-hourly) rainfall block in the historical record is multiplied by α.

iv. Meteorological Validation: If α exceeds 2.0, the pattern is usually discarded because the resulting intensities may exceed physical atmospheric limits.

v. Identification of the "Champion Flood" and Selecting Rainfall Hyetograph: After scaling all representative disturbances (based on the past 5-10 major floods) to the same design rainfall volume, runoff simulations are performed for each rainfall pattern. Even though the rainfall volume is identical for all these scaled storms, the peak discharge they produce will vary based on their temporal rainfall pattern (e.g., where the peak rainfall occurs in the sequence). The pattern that generates the highest peak discharge at the designated flood control reference point is identified as the the Design Hyetograph. This ensures that the infrastructure is built to survive not just a specific amount of rain, but the most dangerous arrangement of that rain ever observed in the basin.

A critical technical constraint in this method is the limit applied to the scaling factor α. If a small historical storm is "stretched" too aggressively (e.g., by a factor of 3 or 4), the resulting rainfall intensity would exceed limits, rendering the model meteorologically unrealistic. According to MLIT guidelines and practical standards, the scaling factor is generally kept within a physically plausible range (typically 1.2 to 1.5 and rarely exceeding 2.0. If a target probability requires a scaling factor ≥2.0, that specific historical pattern is often discarded as unsuitable for the design flood simulation, or a "comprehensive probability method" is employed to find a more suitable base event (JICA, 2003; MLIT, 2022).

This reflects a pragmatic engineering philosophy: rather than asking what the abstract statistical limit is, Japanese planners ask, "What would happen if this specific, catastrophic historical disaster happened again, but with today's increased rainfall intensity?" This ensures that the resulting flood control structures are resilient against the complex, multi-peak temporal distributions, and specific storm tracks that characterize the basin’s climate.

3.2 Determination of Design Flood Discharge and Iterative HWL Trials

The Design Flood Discharge[7], is the specific peak discharge that the river channel is physically designed to carry. Its determination represents the bridge between hydrological theory and structural engineering. The process begins with the Basic Flood Discharge, which is the calculated natural peak flow at a flood control point, assuming no human intervention or flood control facilities. The Design Flood Discharge is determined using the "peak-cut" volume, which refers to the amount of floodwater that upstream structures (like dams, retarding basins, or diversion channels) will divert or store. This relationship is expressed as: $Q_{design} = Q_{basic} - Q_{regulated}$

This finalized value is plotted on a Discharge Distribution Diagram, which serves as the legally binding master document for the entire river system. This diagram dictates the required capacity for every reach of the river, ensuring that downstream urban areas are protected by a coordinated system of upstream regulation and downstream channel capacity

Once the Design Flood Discharge is determined, the next step is establishing the High-Water Level (HWL). This vertical datum defines the height of levees, the clearance of bridges, and the gravity urban drainage. The methodology for setting this level reveals a sharp divergence between standard international practices and the Japanese framework.

In widely used international methodologies, such as those often employed by the USACE or for FEMA flood mapping, the determination of the flood level is primarily a hydraulic conveyance analysis. In this approach, the design discharge is routed through the existing channel topography to calculate the Water Surface Elevation (WSE). The resulting elevation dictates the necessary levee height, treating the channel geometry largely as a fixed constraint. In contrast, the Japanese methodology treats the river channel geometry not as a fixed constraint, but as a flexible design variable. The setting of the HWL is an active optimization process known as the "Trial Calculation". Rather than simply accepting the water level produced by the existing topography, Japanese approach conducts an iterative trade-off among three physical variables to force the water level down to a socially acceptable elevation: Riverbed Excavation to deepen the channel, River Widening to expand the cross-sectional width, and Embankment Height to provide the necessary safety.

The driving force behind this trial process is the strict avoidance of "Ceiling Rivers". This is a dangerous condition common in Japan where the riverbed or HWL sits significantly higher than the surrounding residential land. In Japan’s densely populated flood plains, a high embankment creates immense potential energy; a breach in such a location would result in a high-velocity, destructive torrent far more lethal than a typical slow-rising inundation. Therefore, the goal of the trial process is to find the "optimal balance point" where the HWL is kept as low as possible through excavation and widening, minimizing the potential energy and the catastrophic risk of a levee breach.

4 CONCLUSIONS

Japan’s approach to flood control master planning integrates hydrological science, historical evidence, and risk-averse engineering in a coherent framework. A central technical advantage is its preference for basin-specific realism over purely abstract design assumptions. In the hydrological phase, the stretching method constructs design hyetographs by scaling observed storm events, allowing the design rainfall to retain the multi-peak temporal structure typical of major typhoons and seasonal fronts. This produces runoff simulations that are often more physically consistent than results derived from synthetic, symmetric storm patterns.

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[7] The "Regulated" channel peak. In Japanese, *Keikaku Takamizu*

In the hydraulic phase, the HWL finalization process for the design Flood Discharge relies on iterative trials that explicitly balance riverbed excavation, channel widening, and levee height. This shifts the objective from simple containment to reducing flood stage and limiting the potential consequences of levee breach in densely populated lowlands, while also helping to avoid excessive water levels associated with ceiling river conditions.

Under increasing climate-driven extremes, the underlying principles of this framework, namely historical continuity, physical plausibility, and safety-focused stage reduction, provide transferable insights for flood risk management in urbanized, flood-prone basins. Overall, Japan’s methodology supports infrastructure design that is resilient not only to target probabilities, but also to the observed hydro-meteorological behavior that has historically produced damaging floods.

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