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Long-term Economic Analysis of Flood Protection Infrastructure: A River Basin Approach

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ABSTRACT

While cost-benefit analysis is standard practice for individual flood protection projects, long-term economic analysis at the river basin scale is less common. It is vital for policymakers to have evidence that investments in flood protection contribute to regional growth. This study proposes a retrospective-prospective methodology for conducting long-term economic analysis at the basin scale. The approach integrates past observed benefits from major floods with future expected benefits derived from probabilistic simulations. The methodology is applied to the Natorigawa River basin in Japan, with an evaluation span of 118 years. The findings indicate that the investment made over the last seven decades has resulted in a benefit-to-cost ratio of 6.1. This demonstrates the investment's substantial economic efficiency. The methodology requires further simplification for application in developing countries with limited data and capacity.

KEYWORDS: investment for DRR, cost-benefit analysis, flood simulation, evidence-based policymaking, Natorigawa River, Japan

1 INTRODUCTION[1]

The Sendai Framework for Disaster Risk Reduction (2015–2030) emphasizes that disaster risk reduction budgets are investments, not expenses (UNISDR 2015). However, while individual flood protection projects are evaluated through cost-benefit analysis, comprehensive assessments of long-term investments at the river basin or regional scale remain absent. Policymakers need evidence that such investments contribute to regional growth, yet this evidence is rarely available.

Investments in flood protection serve multiple policy objectives beyond immediate disaster loss reduction (Mizutori 2020). They enable long-term regional economic planning and attract private investment. They also support urban development and enhance quality of life by reducing disaster-related anxiety. Yet without robust economic evidence demonstrating returns on investment, securing sustained funding for flood protection remains challenging, particularly in developing countries facing competing development priorities (Ishiwatari and Sasaki 2024).

This study proposes a methodology for economic analysis of long-term flood protection investments at the basin scale and applies it to the Natorigawa River basin in Japan. The methodology assesses both past

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[1] The contents of this paper were released in JICA Ogata Research Institute research paper "Estimating the economic viability of long-term investment in flood protection: Case study of the Natorigawa River" (Ishiwatari, Sakamoto, and Sasaki, 2023).

benefits (from major observed floods) and future benefits (from simulated scenarios), providing comprehensive evidence of investment efficiency over decades.

2 ECONOMIC ANALYSIS OF FLOOD PROTECTION: CURRENT PRACTICE

This section reviews recent literature on the economic evaluation of flood protection measures, focusing on established methodologies and identifying limitations at the river basin scale.

2.1 Conventional Approaches and Standardization

The standard approach globally involves a cost-benefit analysis (CBA), comparing the value of investment and maintenance costs against the value of prevented flood damage benefits. Project-level evaluation is widely adopted for individual flood protection projects. Japan's Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has conducted such analyses since 1957 (Takebayashi and Yasuda 1995). Similar frameworks exist in Germany (Meyer and Messner 2005) and the United States (McGee 2021). These analyses are typically based on preventing damage from a specific design flood event. The Netherlands have advanced beyond simple CBA to adopt comprehensive risk-based approaches. These methodologies integrate probabilistic modelling to set tolerable death risk thresholds and inform social cost-benefit analysis for long-term planning (Tomura et al. 2018).

2.2 Fundamental Challenges in Damage Assessment

While the CBA framework is established, its accuracy is constrained by several fundamental challenges in quantifying both the risk and the resulting damages. Merz et al. (2010) identified key difficulties, including limited historical damage data and a lack of standardized, region-specific damage estimation methods. Reliable damage functions correlate asset damage ratios to inundation depth and asset type. However, these functions remain underdeveloped or inconsistent across many regions, hindering accurate loss estimation. Conventional methods often struggle to capture indirect economic damages (e.g., business interruption, supply chain disruption) and non-monetary damages (e.g., mental health impacts, loss of life).

2.3 Defining the Research Gap

Project-level and risk-based CBAs have become increasingly sophisticated. Nevertheless, few studies systematically evaluate the accumulated economic efficiency of multiple flood protection projects at the river basin scale over several decades. Conventional analyses fail to provide evidence for policymakers that addresses two critical needs: (i) Demonstrating the aggregated economic returns (B/C ratio) across multiple generations of projects, particularly by integrating the retrospective benefits derived from existing infrastructure during past observed floods. (ii) Assessing the cumulative economic value of protection across an entire system, which is necessary to link investment to regional economic planning and sustainable growth objectives.

This study addresses this gap by proposing and applying a basin-scale methodology that integrates observed past benefits with projected future benefits to provide a comprehensive, long-term economic assessment.

3 METHODOLOGY

The study estimates benefits by calculating the difference between damage with and without flood protection structures (Figure 1). Past benefits are calculated as: estimated damage without structures minus actual damage for observed major floods. This retrospective approach is justified when major protective structures predate the flood events analysed, ensuring structures provided protection for identified risk areas.

To accurately calculate historical flood protection benefits, the estimated damage requires adjustment. Present-day asset values are scaled downward based on the ratio of residential area at the time of the flood to the present day. This prevents overestimation of benefits by recognizing that asset concentration was lower historically.

Future benefits are estimated by calculating expected annual damage (EAD) reduction over a 50-year evaluation period. Damage is estimated using asset values (housing, infrastructure, crops) multiplied by damage ratios based on inundation depth, business interruption, and costs for emergency response (MLIT 2020). Inundation depths are determined through flood simulations conducted per the MLIT manual (MLIT 2015).

Past costs include river improvement and dam construction expenses. Construction costs are allocated across the construction period to establish annual costs. Future costs are operation and maintenance expenses over 50 years.

Costs and benefits are converted to present values using a 4% social discount rate and deflators. This 4% rate is consistent with Japan's standard methodology for infrastructure project evaluation (MLIT 2020). Deflators are applied only to past costs; past benefits use current asset values to reflect protection value at present time. This treatment ensures consistency between the cost stream (historical expenditures) and benefit stream (current asset values protected).

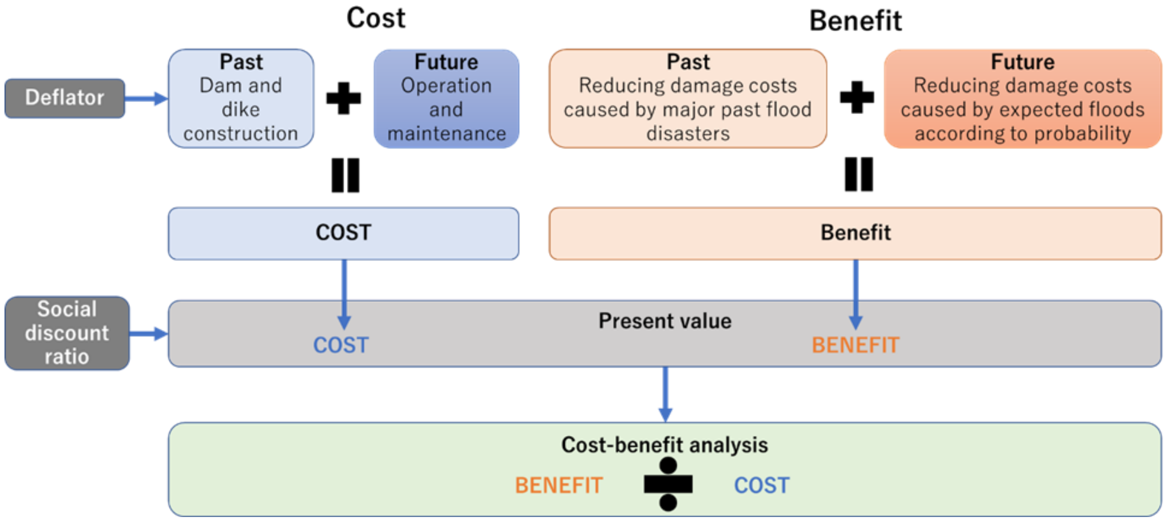

Figure 1: Concept of economic analysis in flood protection at the river basin scale

4 CASE STUDY: NATORIGAWA RIVER BASIN

4.1 Basin Characteristics

The Natorigawa River is designated as a first-class river under the Japan's River Law. This classification applies to rivers of significant national importance for land conservation and the national economy. First-class rivers are managed directly by MLIT, in contrast to second-class rivers, which are managed by prefectural governments.

The river has a main channel length of 55 km and a watershed area of 939 km². The river originates at the Miyagi-Yamagata prefectural border, merges with the Hirose River and other tributaries, and flows through Sendai City. It empties into the Pacific Ocean at Yuriage, Natori City.

The basin comprises Sendai, Natori, Iwanuma, Kawasaki, and Murata cities. Land use is approximately 76% mountain forests, 12% agricultural land (rice paddies and farmland), and 12% urban areas. Significant urbanization has occurred: the basin population increased from approximately 0.8 million (1960) to 1.1 million (2000). By 2010, the basin contained about 50% of Miyagi Prefecture's total population, demonstrating intense population concentration in this flood-prone corridor (Tohoku Regional Development Bureau 2012).

Population concentration reflects the basin's economic importance. Sendai City serves as the regional economic centre for the Tohoku region. It hosts diversified manufacturing, service industries, and administrative functions. The basin's low elevation and proximity to the river historically provided advantages for transportation and water supply. However, these same features now create elevated flood risk for the concentrated populations and infrastructure.

The risk areas are divided to three blocks. Block R1 (right bank), located in rapidly developing areas of Natori and Sendai cities, showed particularly high asset concentration, with modern residential developments and commercial facilities. Block L1 (left bank) was restricted as a disaster risk zone following the 2011 Great East Japan Earthquake and Tsunami. Since this disaster caused land subsidence and tsunami inundation, block L1 is preserved agricultural land. Block L2, proximal to downtown Sendai, concentrated office and commercial facilities representing high-value business assets.

4.2 Flood Protection Investment

The basin experienced catastrophic floods in 1947, 1948, and 1950. In response, MLIT commenced dike construction in 1951 and formulated the first formal flood protection plan in 1954. Major construction works were substantially completed by 1985, with subsequent modifications made following the 2011 Great East Japan Earthquake to address land subsidence.

Two major multi-purpose dams serve flood control and water supply functions. The Kamafusa Dam is a 45.5 m high gravity concrete dam constructed in 1971 on the Goishigawa River, with a total project cost of JPY 8.72 billion. The Okura Dam is an 82 m high arch-type concrete dam constructed in 1961 on the Okuragawa River, with a total project cost of JPY 2.76 billion.

The evaluation period spanned 118 years: 67 years of past investment (1951–2018) and 50 years of future projection (2018–2068). Total past costs, converted to present value using a 4% social discount rate and appropriate deflators, were JPY 624.6 billion (approximately \$4.16 billion). Future operation and maintenance costs for structure completed totalled JPY 1.5 billion (approximately \$10 million) in present value terms.

4.3 Benefit Estimation

Past benefits were calculated using Typhoon Hagibis (October 2019)—the largest recorded flood in the basin with a flow volume of 3,300 m³/s—as the base case. This typhoon caused the highest flood damage ever recorded in Japan (approximately 1.86 trillion yen nationwide, or approximately \$12.4 billion). The typhoon resulted in 87 deaths or missing persons, 21,000 destroyed houses, and 60,000 flooded houses nationally (Ishiwatari 2022).

Under the scenario of no flood protection structures in the Natorigawa basin, estimated damage was JPY 350 billion (approximately \$2.33 billion) (Figure 2 (a)). This damage was distributed as follows: general assets (houses, offices, factories) 36% (JPY 126 billion, or \$840 million), public facilities 60% (JPY 210 billion, or \$1.40 billion), and emergency measures 4% (JPY 14 billion, or \$93 million).

Damage varied significantly by location: Block R1 experienced potential damage of JPY 240 billion (approximately \$1.60 billion), representing 69% of total basin damage. Blocks L1 and L2 combined faced JPY 109 billion (approximately \$727 million), representing 31% of total. This distribution reflected the concentration of modern development in Block R1, which contains newly developed residents and extensive commercial-industrial infrastructure in Natori and Sendai City.

Six major historical floods (August 1986, August 1989, September 1994, July 2002, September 2007, September 2011) were analysed. Damage for each event was scaled proportionally to Typhoon Hagibis using a linear relationship between flood volume ratios and damage ratios. This simplified approach reduced computational requirements while maintaining reasonable accuracy. For example, the August 1986 flood (2,690 m^3/s, 0.82 of Hagibis volume) was estimated to cause damage of approximately JPY 284 billion (approximately $1.89 billion) without protection structures.

Total past benefits from structures protecting against these major flood events were JPY 3.7 trillion (approximately $24.67 billion). This figure represents the cumulative protection value provided by dikes, dams, and channel improvements completed by 1985, protecting residents and assets during seven decades of flood events.

The future benefits were calculated based on a target flood magnitude of a 1/150-year return period for the ongoing programme's safety level over a 50-year evaluation period. This safety level represents the target design flood magnitude for protecting the river basin. Damage from a 1/150-year flood without protection structures was estimated at JPY 1.3 trillion (approximately $8.67 billion) (Figure 2 (b)). With existing and planned structures in place, this damage would be reduced to JPY 260 billion (approximately $1.73 billion), yielding a baseline benefit of JPY 1.05 trillion (approximately $7.00 billion).

Expected annual damage (EAD) reduction was calculated across ten flood probability scales: 1/10, 1/20, 1/30, 1/40, 1/50, 1/60, 1/70, 1/80, 1/100, and 1/150 years. The calculation used a linear damage scaling model weighted by interval probabilities. This probabilistic approach captures flood risk across the full distribution of possible magnitudes, rather than focusing on single design events. The average annual EAD reduction totalled JPY 4.998 billion (approximately $33.32 million). Accumulated over 50 years and discounted to present value at 4%, future benefits totalled JPY 112 billion (approximately $747 million).

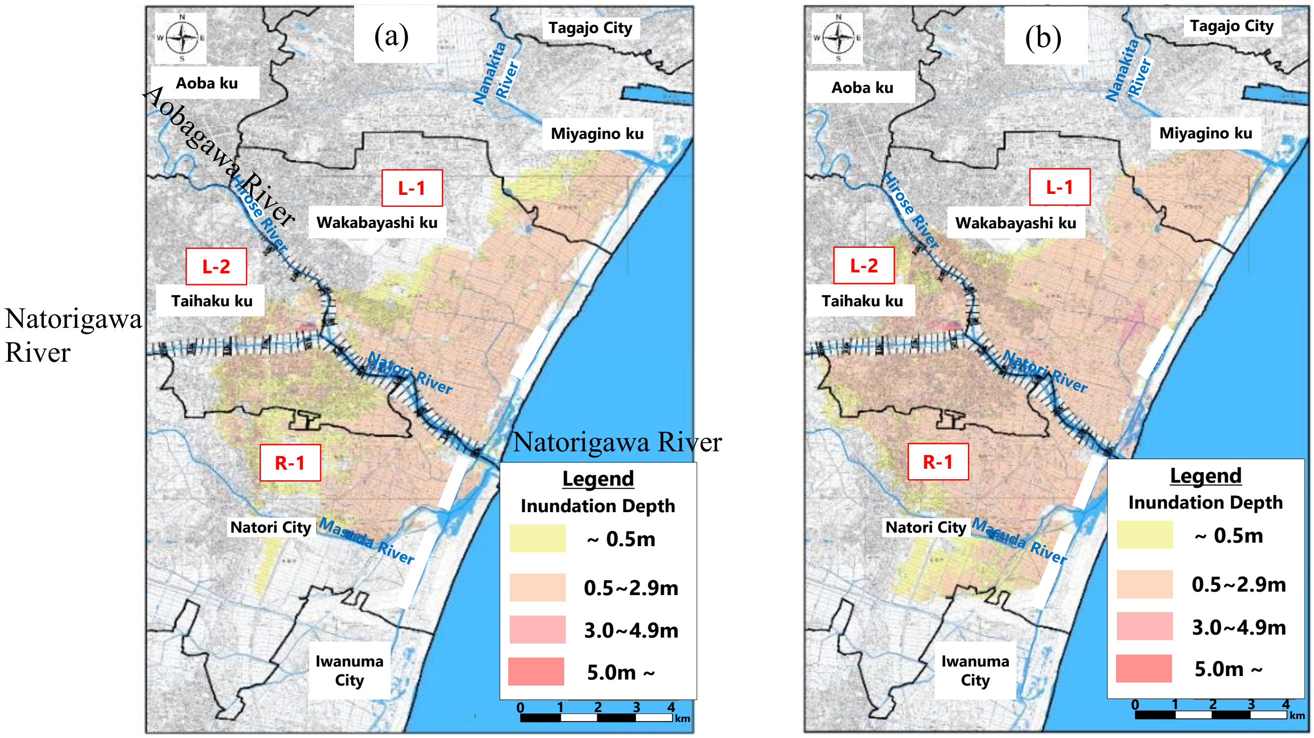

Figure 2: Inundation simulation map (a)Typhoon Hagibis in 2019, (b) 1/150-year flood)

5 Results

Total costs: JPY 626 billion (approximately $4.17 billion)

Total benefits: JPY 3.81 trillion (approximately $25.4 billion)
Net Present Value: JPY 3.2 trillion (approximately $21.3 billion)
Benefit-cost ratio: 6.1

The analysis demonstrates that flood protection investment in the Natorigawa basin generated substantial returns, with each yen invested producing approximately 6.1 yen in benefits. The net present value of JPY 3.2 trillion (approximately $21.3 billion) indicates that after accounting for all costs, society received a significant net benefit from flood protection investments.

6 DISCUSSION AND LIMITATIONS

6.1 Methodological Contributions

The proposed methodology is a significant improvement on the conventional approach of conducting cost-benefit analyses on an individual project basis. By integrating past investments and their observed protective effects with future projections, it provides a more comprehensive view of the long-term efficiency of flood protection measures. The basin-scale approach considers the cumulative impact of various projects, including embankments and dams, over several decades. This gives policymakers stronger evidence on which to base decisions on investment prioritisation and budget allocation.

The use of a linear damage scaling model simplified computational requirements. For practitioners in resource-constrained environments, this simplified approach provides workable alternative to computationally intensive full-physics simulations.

The methodology explicitly accounts for urbanization effects by adjusting past benefits based on residential land area changes. Ignoring urbanization would substantially overestimate damage—the Natorigawa basin experienced development of residential area.

6.2 Policy recommendations

This methodology provides practical tools for evidence-based decision-making. Its retrospective element provides compelling evidence to support the need for sustained flood control funding. By demonstrating the measurable benefits of past investments during actual flood events, policymakers can strengthen their case for continued budget allocation. This is particularly valuable when competing for limited public funds against other infrastructure sectors.

The 118-year evaluation period used in this study reflects the true lifespan of major flood control infrastructure. Similarly, policymakers should adopt a long-term perspective when evaluating flood control investments. Short-term evaluation periods systematically undervalue flood control because its major benefits only become apparent over decades.

Authorities should conduct comprehensive economic evaluations every 10 to 15 years, incorporating new flood events and updated climate projections. The results should be communicated in an accessible format to promote public understanding and support.

While this methodology requires extensive data, a simplified version can be used in developing countries where data is limited. Assessments can estimate values using globally available satellite flood mapping, satellite-observed topography and rainfall data, population datasets, publicly available flood simulation models, and simplified damage functions. Key simplification techniques include focusing on major historical floods, applying linear damage scaling and using regional damage functions. Pilot applications in basins with recent flood events and planned investments can demonstrate value and promote broader adoption.

6.3 Limitations and Future Research Needs

This study has several limitations. Each limitation also suggests directions for future research.

The analysis excludes facility replacement costs, a significant limitation given the 100-year evaluation period. Dams and major structures typically have 50-year design lives in asset management guidelines, yet some Japanese structures have functioned for over 100 years. The Kamafusa Dam (built 1971) and Okura Dam (built 1961) are now 50+ years old, approaching potential replacement periods. Future research needs to develop standardized cost estimation methods for aging flood infrastructure, including maintenance, rehabilitation, and replacement scenarios.

The study used current flood probability relationships. Future flood risk assessments must incorporate climate change effects. MLIT projects that rainfall will increase by 10% and flood volumes by 20% nationally under representative concentration pathway 2.6 scenario (consistent with Paris Agreement 2°C target) (MLIT 2021). Future research should integrate climate-adjusted flood frequency curves and damage functions into basin-scale economic analysis.

A fundamental conceptual issue arises from feedback between flood protection and development. Because flood protection investments enhanced perceived safety, urbanization accelerated in protected areas. Without such investments, assets would not have accumulated at current levels. The relationship is complex: investments enabled development, but development also justified further investments. Separating induced development effects from pure risk reduction remains methodologically challenging. Future research must develop counterfactual scenario modelling techniques. These methods would estimate the level of development that would have occurred without flood protection. Such approaches would enable a more precise separation of induced development effects from pure risk reduction benefits.

The analysis excludes several important benefit categories, such as supply chain disruption, mental health impacts from flood anxiety, and mortality reduction. Typhoon Hagibis caused 87 deaths nationally—a toll that would have been higher without flood protection. Including these benefits would strengthen the economic case for investment. Human life is not monetized due to ethical concerns, yet flood fatalities represent one of the most important benefit measure. Systematic inclusion of mortality reduction in future analyses would strengthen the case for flood protection investment, particularly for urban basins with high population density.

7 CONCLUSIONS

Flood protection investment in the Natorigawa River basin proved highly economically efficient. The benefit-cost ratio of 6.1 indicates that each yen invested generated over six yen in societal benefits. The net present value of JPY 3.2 trillion (approximately $21.3 billion) confirms substantial net gains from seven decades of sustained investment.

Three key findings emerge from this analysis. First, retrospective assessment of actual flood events provides compelling evidence that complements traditional prospective analysis. Second, basin-scale analysis captures cumulative benefits that project-level evaluations miss. Third, the methodology demonstrates that flood protection enables regional development, as evidenced by the 32% increase in residential area within protected zones.

These findings carry important policy implications. Flood protection should be framed as economic investment rather than defensive expenditure. Budget decisions should adopt evaluation horizons matching infrastructure lifespans. Periodic reassessment incorporating new flood events strengthens the evidence base over time.

The methodology offers a replicable framework for other river basins. With appropriate simplification using satellite data and global datasets, the approach can inform investment decisions in developing countries where such evidence is urgently needed.

8 ACKNOWLEDGEMENTS

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REFERENCES

Ishiwatari, M. (2022). “Effectiveness of investing in flood protection in metropolitan areas: lessons from 2019 Typhoon Hagibis in Japan”. International journal of disaster resilience in the built environment, 13(1), 89-98.

Ishiwatari, M., & Sasaki, D. (2024). “Investing in Resilience: Estimating Financial Needs and Benefits of Flood Protection in Developing Asian Countries.” Proceedings of IAHS, 386, 87-93.

McGee, K. (2021). “A Place Worth Protecting: Rethinking Cost-Benefit Analysis Under FEMA's Flood-Mitigation Programs.” University of Chicago Law Review 88 (8): 1925–70.

Merz, B., H. Kreibich, R. Schwarze, and A. Thieken. (2010). “Review Article: ‘Assessment of Economic Flood Damage’.” Natural Hazards and Earth Systems Sciences 10: 1697–1724, https://doi.org/10.5194/nhess-10-1697-2010.

Meyer, V. and F. Messner. (2005) . “National Flood Damage Evaluation Methods A Review of Applied Methods in England, the Netherlands, the Czech Republic and Germany.”, UFZ Discussion Papers 21/2005, Helmholtz Centre for Environmental Research: Leipzig.

Ministry of Land, Infrastructure, Transport and Tourism (MLIT), (2015). “Manual for Drawing Flood Inundation Assumption Area Maps (4th Edition)” (in Japanese). MLIT: Tokyo.

———. (2020). “Manual for Economic Evaluation of Flood Protection Investment (Draft)” (in Japanese). MLIT: Tokyo, https://www.mlit.go.jp/river/basic_info/seisaku_hyouka/gaiyou/hyouka/r204/chisui.pdf.

———. (2021). “Proposal for Flood Protection Planning Based on Climate Change” (in Japanese). MLIT: Tokyo.

Mizutori, M. (2020). "Reflections on the Sendai Framework for Disaster Risk Reduction Five Years Since Its Adoption.” International Journal of Disaster Risk Science 11: 147–51.

Takebayashi S., and G. Yasuda. (1995). “Status Quo of Economic Appraisal Methods for Rivers in Japan and Their Future Prospects.” Journal of Japan Society of Hydrology and Water Resources 8 (1), 19–37.

Tohoku Regional Development Bureau. (2012). “River Improvement Plan for Natorigawa River” (in Japanese). http://www.thr.mlit.go.jp/sendai/kasen_kaigan/nahi/pdf/12112002.pdf.

Tomura S., M. Nakatsugawa, T. Yamamoto, M. Chiba, T. Yamada, and T. Hoshino. (2018). “The Point on Risk-based Flood Management Plan in the Netherlands.” (in Japanese), Proceedings of Hokkaido Branch of Japan Society of Civil Engineers 75. https://www.ric.or.jp/gyoumu/data/ric_paper/20191210/201901_B-22.pdf.

United Nations Office for Disaster Risk Reduction (UNISDR). 2015. “Sendai Framework for Disaster Risk Reduction 2015-2030”. UNISDR: Geneva.