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Developing Robust Fiscal Strategies for Water Management Under Deep Climate Uncertainty: A Probabilistic Assessment in South Korea

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Hydroclimatic non-stationarity invalidates the assumption that historical variability provides a reliable basis for water-sector fiscal planning. In environments of deep uncertainty, traditional "predict-then-act" models risk **"fiscal lock-in"**—where capital-intensive, long-lived infrastructure becomes either a stranded asset due to over-building or a systemic failure point due to under-preparedness. Consequently, robust fiscal estimation is a critical necessity for ensuring long-term economic efficiency and climate resilience. In South Korea, disaster restoration costs (2013–2023) reached $16.6 billion USD—triple the direct damages—while management budgets grew to $4.3 billion USD by 2024. Yet, a climate-informed framework is absent, obscuring the "additionality" of climate-driven expenditures.

We developed a hybrid framework coupling top-down fiscal classification with bottom-up vulnerability assessments. First, applying the additionality principle (adapted from OECD Rio Markers) to 166 programs (2020–2025) revealed a significant **labeling gap**: while 90% of budgets are nominally climate-related, only 32.4% satisfy strict additionality criteria, representing less than 10% of total spending.

Second, to address supply–demand uncertainty, we employed Monte Carlo simulations with probabilistic RCP scenarios, integrating the "Headroom" concept to quantify uncertainty allowances. A pilot assessment across South Korea's five major river basins evaluates fiscal needs under three pathways: Business-As-Usual (BAU), cost-efficiency (UA65), and precautionary (UA95). Nationwide water deficits are projected to increase 7.7-fold, with investment needs rising from $120 million (BAU) to $709 million USD (UA95). Basin-level responses are highly heterogeneous: the Geum River basin shifts from zero deficit to $559 million USD in needs, while the Yeongsan River basin shows reduced deficits—highlighting the risk of over-investment under uniform planning.

These findings underscore the necessity for **dynamic adaptive pathways** that sequence investment decisions flexibly as uncertainty evolves, moving beyond deterministic fiscal planning.