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Improving Multi-Objective Management of Water Quality Tipping Points: Revisiting the Classical Shallow Lake Problem

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Abstract: Recent multi-objective extensions of the classical shallow lake problem are useful for exploring the conceptual and computational challenges that emerge when managing irreversible water quality tipping points. Building on this work, we explore a four objective version of the lake problem where a hypothetical town derives economic benefits from polluting a nearby lake, but at the risk of irreversibly tipping the lake into a permanently polluted state. The trophic state of the lake exhibits non-linear threshold dynamics; below some critical phosphorus (P) threshold it is healthy and oligotrophic, but above this threshold it is irreversibly eutrophic. The town must decide how much P to discharge each year, a decision complicated by uncertainty in the natural P inflow to the lake. The shallow lake problem provides a conceptually rich set of dynamics, low computational demands, and a high level of mathematical difficulty. These properties maximize its value for benchmarking the relative merits and limitations of emerging decision support frameworks, such as Direct Policy Search (DPS). Here, we explore the use of DPS as a formal means of developing robust environmental pollution control rules that effectively account for deeply uncertain system states and conflicting objectives. The DPS reformulation of the shallow lake problem shows promise in formalizing pollution control strategies, while dramatically reducing the computational complexity of the multi-objective pollution control problem. More broadly, the insights from the DPS variant of the shallow lake problem formulated in this study bridge emerging work related to socio-ecological systems management, tipping points, robust decision making, and robust control.

***Keywords**:* direct policy search; multi-objective decision making, robustness, socio-ecological management, tipping points