RESUMEN

La provisión sustentable de agua es esencial para la humanidad, tanto para consumo como para el funcionamiento y el crecimiento de sectores económicos basados en recursos naturales tales como la energía, la minería y la agricultura. Con el fin de preservar los recursos acuáticos para el presente y el futuro, el mantenimiento de la integridad del ecosistema debe ser un principio central en el manejo de los cuerpos de agua dulce. En la presente tesis se desarrollan modelos biogeoquímicos basados en primeros principios, en el marco de problemas de optimización dinámica, con el objetivo de planificar políticas óptimas de restauración para cuerpos de agua. Estos modelos, que poseen numerosos parámetros, deben ajustarse a las condiciones de los sitios bajo estudio, para proveer luego predicciones confiables. En particular, el caso de estudio es el embalse Paso de las Piedras, un reservorio artificial construido para proveer de agua potable a las ciudades de Bahía Blanca y Punta Alta y a un polo petroquímico, que presenta un marcado grado de eutrofización, con reiteradas proliferaciones masivas de algas.

A lo largo de la tesis, se formulan modelos ecológicos de creciente rigurosidad, sobre los cuales se lleva a cabo un análisis de sensitividad global para determinar los principales parámetros a identificar. A continuación, se formula un problema de estimación dinámica de parámetros, que se resuelve con técnicas de optimización dinámica con enfoque simultáneo. El modelo se valida posteriormente con datos adicionales del embalse. La siguiente etapa consiste en la formulación de problemas de optimización dinámica cuyas restricciones diferenciales algebraicas están constituidas por el modelo ecológico desarrollado. El objetivo, en todos los casos, es la reducción de la concentración de fitoplancton y de nutrientes en el cuerpo de agua, mediante la determinación de perfiles óptimos de las variables de control que se corresponden con la aplicación de técnicas de restauración externas (a través del empleo de un humedal artificial para reducción de la carga de nutrientes) y su combinación con técnicas internas (biomanipulación y aireación de las capas inferiores). Finalmente, se formula un problema de control óptimo en el cual se extiende el modelo ecológico desarrollado para incluir las dinámicas de zooplancton y peces, de forma tal de proveer una descripción detallada de las estrategias de restauración, así como los costos operativos asociados. Los resultados

obtenidos para el caso de estudio muestran que la biomanipulación a través de la remoción de peces zooplanctívoros es la técnica más económica y efectiva para controlar el crecimiento algal.

ABSTRACT

Access to clean, sustainable supplies of water is essential for humans, both as drinking water and for the operation and growth of major natural resource sectors, such as energy, mining, forest and agriculture. Alterations to the timing and volumes of flow, quality, and temperature of freshwater affect both aquatic and terrestrial ecosystems. To safeguard water resources for present and future uses, water bodies must be managed with maintenance of the integrity of ecosystems as a core principle. In this work, ecological mechanistic and first-principle based models are formulated within a dynamic optimization framework to determine restoration strategies for water bodies. These models have a large number of physical, chemical and kinetic parameters that need to be tuned to the specific site conditions to be able to provide reliable predictions. In particular, the case study is an eutrophic reservoir, Paso de las Piedras, which has been built to supply drinking water to more than 450,000 inhabitants of two cities in Argentina (Bahía Blanca and Punta Alta) and for industrial proposes at a petrochemical complex nearby.

As a first step, a global sensitivity analysis is performed to determine main model parameters that have to be identified. The second step includes the formulation of a parameter estimation problem within a simultaneous dynamic optimization framework, based on collected data from the Reservoir, as well as model validation with an additional data set. Successive optimal control problems are formulated, constrained by the calibrated ecological model, to reduce phytoplankton and nutrient concentration within the water body. Control variables are associated to the different restoration strategies that include nutrient loading decrease through derivation of part of a tributary to a wetland, biomanipulation and hypolimnetic aeration. Finally, the initial ecological model is extended to include zooplancton and zooplanktivorous fish dynamics to provide a more detailed planification of restoration strategies, as well as their associated operating costs. Numerical results enforce the fact that biomanipulation is the most effective and economical strategy to control algae growth in the case under study.

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