Extended Abstract
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Paper/Poster Title	Hydroeconomic Modelling for irrigated Agricultural Water Use in the Riviersonderend-Berg River Basin, South Africa

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Abstract	***200 words max***
Water shortage and quality degradation is a characteristic challenge of river basins in many developing countries. To deal with the problems, different stakeholders have been suggesting some compartment development plans including water sharing, installation of modern irrigation technologies, and modification of crop patterns and water allocation strategies. Accordingly, this paper presents the development of a dynamic hydroeconomic model in the context of a river basin in which irrigated agriculture is the dominant water user and climate change and pollution present a major environmental problem. Specifically, we combine a farm-based economic optimisation model that uses historical water availability and economic benefit patterns for agricultural demand and urban use at numerous locations in a large South African basin that supports a population of more than 4.8 million. The model addresses a gap in the existing literature by combining optimization with the ability to adapt to future climate and pollution scenarios. Our unique contribution is the development of base conditions that accurately reproduce historical patterns of water use, pollution and economic benefit. Results identify that water trade policy under climate water stress provides more economically efficient water use patterns, reallocating water from lower valued uses to higher valued uses such as food production.	

Keywords	Optimization model, Irrigated agriculture, Climate water stress, Adaptation patterns, river basin management,
JEL Code	Optimization Techniques: C610 Water: Q250 Climate: Q540 Water Pollution: Q530 Economic Growth and Aggregate Productivity:O40 see: www.aeaweb.org/jel/guide/jel.php?class=Q)

Introduction	***100 – 250 words***
Sustainable management of water resources faces the difficult task of coordinating multiple, often competing, uses of water in a way that balances environmental and socio-economic demands. The complexity drastically increases in many agricultural dominant regions where climate change alters rainfall patterns and makes extreme weather events more frequent and intense (Leippert et al., 2020). In addition, water quality degradation put more strain on already-scarce freshwater resources (Loi et al., 2022). Literature shows that most research on competing water demand lacks robust analyses of the long-term interactions between droughts, institutions, their ecological	

context, and economic implications (Hagenlocher et al. 2019). To effectively fill the gap, we use an optimisation framework that integrates historical agricultural and urban water use, quality and economic benefit patterns in a hydroeconomic modelling context. We evaluate the trade-offs and welfare implications of allocating water among water use sectors in the Riviersonderend-Berg River water scheme in South Africa. Several hydroeconomic models have been developed and applied assessing water use in different sectors, countries, and time periods. However, none to date has presented an optimization framework by which historical water use and economic benefit patterns can be replicated while presenting capacity to adapt to future climate water stresses to inform the design of policies not yet been implemented. This paper's unique contribution is to address this gap by designing and presenting results of a hydroeconomic model for which optimized base conditions exactly match observed data water use and economic welfare for irrigated agricultural use.

Methodology	***100 – 250 words***

We have developed a model calibration and climate water stress adaptation framework using mathematical programming. Our approach integrates economics, hydrology, climate stress, water quality, environmental flows of the basin and water-sharing policy design to optimise water supply and land use patterns. This builds on the work of Howitt (1995), who first used this method to infer the underlying parameters of agricultural production functions. In this study, we extend this approach to infer the parameters of urban water demand functions. Our optimisation framework uses observed data to reproduce the behaviour of a benefits maximisation model for both urban and agricultural regions, advancing the use of Positive Mathematical Programming (PMP) calibration in these sectors. The full hydroeconomic modelling framework showing the interactions among the model components is depicted in Figure 1.

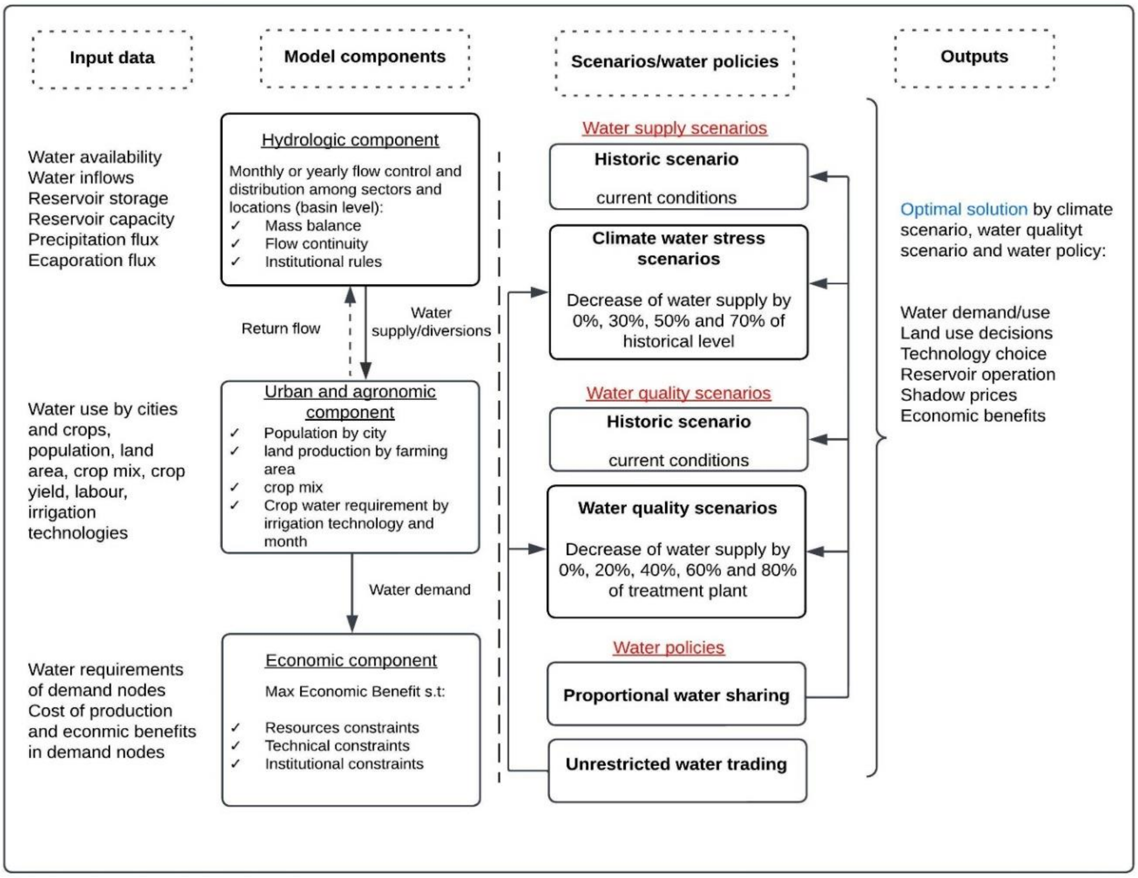

Figure 1: Flow chart showing model component and water policy scenarios. Source: Author estimation,

The hydrological component is a node-link network of supply nodes, such as rivers and dams, and demand nodes, such as irrigation districts, water treatment infrastructures, urban use and environmental flows. The reduced form hydrological component is built with information from the Department of Water and Sanitation using data on streamflows and water allocations during normal climatic conditions. The links between supply and demand nodes are characterised by simplified equations using the hydrological concepts of mass balance and continuity of river flows (Kahil et al., 2015). The hydrological component is used to estimate the volume of available water for economic activities after fulfilling the restrictions on environmental flows.

We investigate the economic performance of irrigated agricultural under different levels of climate water stress and water-sharing policies by developing an empirical hydroeconomic optimisation procedure using the software GAMS® (General Algebraic Modelling System). The optimisation framework aims to discover the least cost adaptation methods for allocating water among sectors and time periods to protect food security under climate water stress.

Results	***100 – 250 words***

The water use result indicate that agriculture is disproportionately affected by shortages of water caused by drought and climate stress. It was found that under conditions of severe climate water stress and pollution, which resulted in a 70% reduction in base water supply, agricultural water use was reduced by 2176 million cubic meters per year under unrestricted water trading and 1873 million cubic meters per year under proportional sharing. In contrast, water withdrawal by the urban sector was only reduced by a much smaller amount, 17 million cubic meters per year under unrestricted water trading and 320 million cubic meters per year under proportional sharing. These findings suggest that climate water stress disproportionately impacts agriculture, particularly when water shortages are shared under a water trading system, and prioritize the use of water for urban activities over irrigation.

The economic analysis indicates that the majority of economic benefits come from agricultural water use. Climate change can negatively impact the economic benefits of both agriculture and urban areas. When facing severe climate stress, the economic benefits of agriculture decrease by 54% under proportional sharing policies, but only decrease by 1.2% when unrestricted water trading is allowed to allocate shortages. Additionally, unrestricted water trading minimizes the total economic benefits lost under different levels of climate-induced water stress, resulting in a smaller reduction in urban water use. The data also shows that under a water trading policy, a 25% reduction in the total water supply leads to a mere 1% decrease in overall economic benefits for the entire region.

Discussion and Conclusion	***100 – 250 words***

This paper adds to the existing literature by identifying programs that can analyse the economic benefits of water allocation between agricultural and urban sectors under climate-induced water stress, while also taking into account institutional constraints for managing water shortages. Our research allows for the examination of various institutions for sharing water shortages and their economic consequences. In addition, this study demonstrates the potential of hydroeconomic modelling in conducting integrated assessments under different climate water stress adaptation policies, showing that hydroeconomic modelling can inform climate adaptation plans by minimizing the economic costs of responding to climate water stress and pollution. The results can assist in identifying the most economically viable policy options for climate adaptation, guiding policymakers in implementing these alternatives.

Implementing unrestricted water trading or proportional sharing policies for sharing water shortages can achieve both the goal of systematically allocating water among sectors and the means of doing so. In the case of water trading, the results suggest that reducing water use at the lowest cost can inform and guide policy design. Well-informed water management can support optimized planning, which can inform and guide decisions on the most economically and institutionally acceptable options. This work enhances our understanding of sustainable measures to protect water resources under climate water stress that are adaptable to economic, hydrological, and institutional conditions.