H23J-1811: Multi-objective Optimization for Conjunctive Water Use Using Coupled Hydrogeological and Agronomic Models

A case study in Heihe mid-reach (China)

Y. Li[1], W. Kinzelbach[1], WP. Li[2], X. Li[3], G. Pedrazzini[4]

1 - ETH Zurich, Switzerland; 2 - China Institute of Geological Environmental Monitoring; 3 - Northwest Institute of Eco-Environment and Resources; 4 - Holinger AG, Winterthur, Switzerland

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

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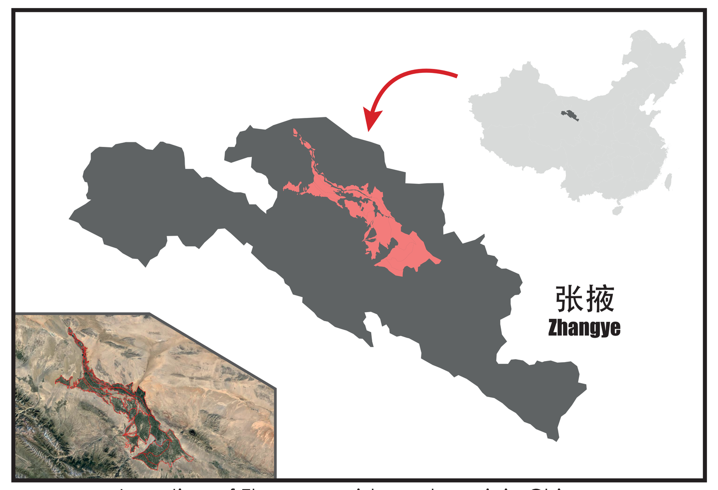
Background Zhangye mid-reach, an oasis within desert region



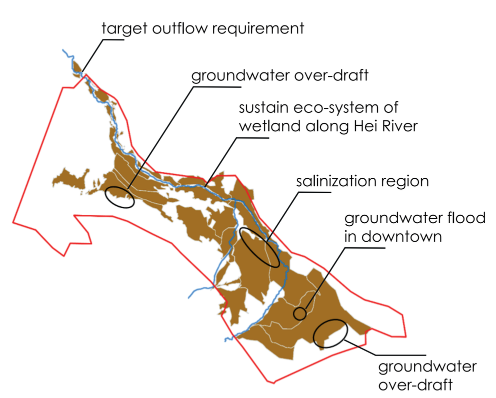
Location of Zhangye mid-reach oasis in China

Zhangye oasis is one of the most productive agricultural regions in China. Annual precipitation of 100 mm is negligible compared to potential evapotranspiration of around 1100 mm, making irrigation vital for crop production.
Currently, irrigation is based on surface water from Heihe River that runs through the oasis, and groundwater which is up to 60 m below surface in the districts of Daman and Luotuocheng.

- how to mitigate the groundwater over-draft regions through a better allocation scheme
- what is the maximum production value given constraints on water availability

Despite the explicit objectives expressed by our decision maker, there are other concerns that should be taken into account as well, particularly:

Figure on the right highlights regions which face different groundwater problems, respectively. The blue line is the river course.



In addition, current policy prohibits any increase of irrigation area and groundwater extraction in future.

Data and materials

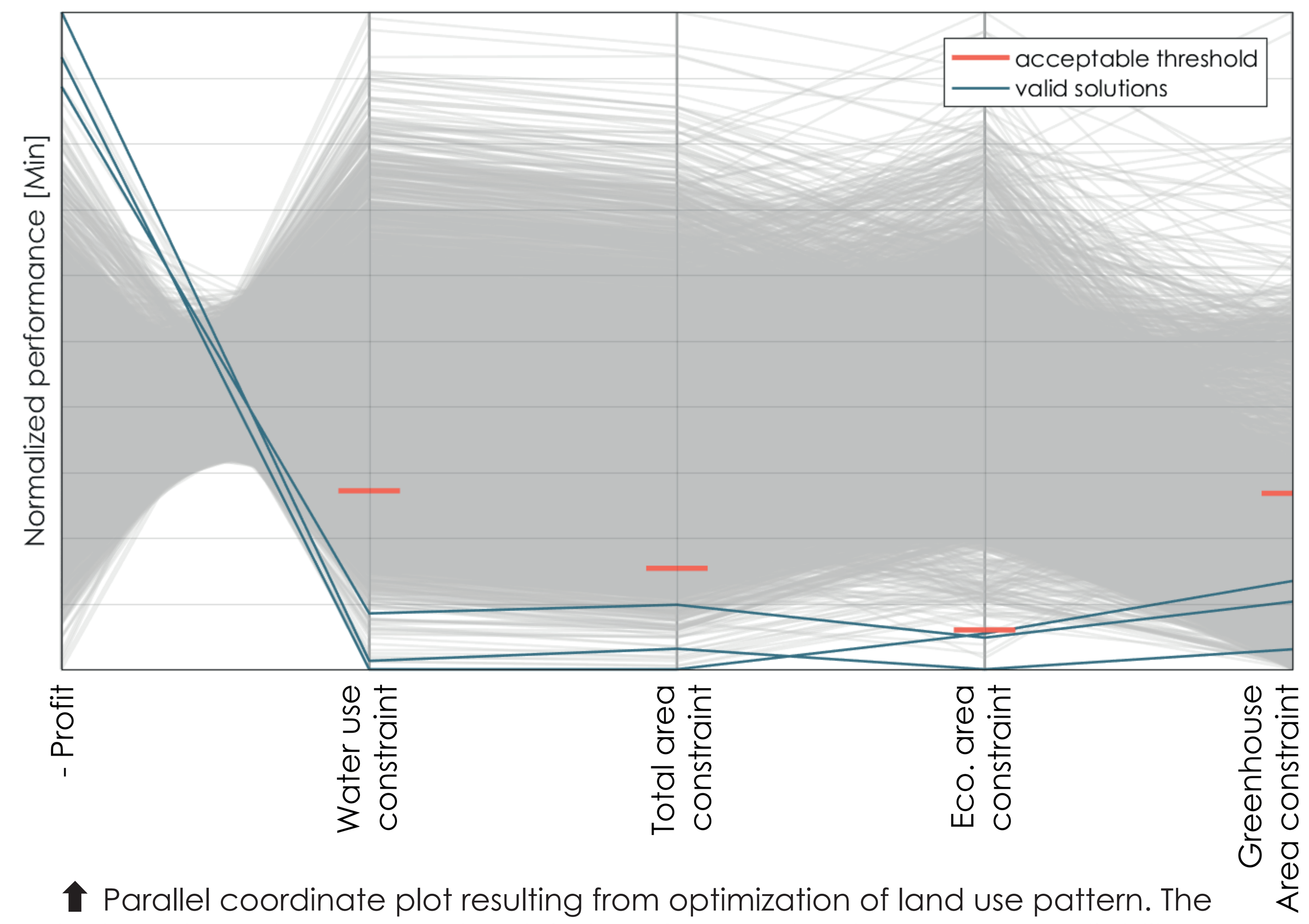
Numerical groundwater model. A detailed groundwater model was constructed using USGS Modflow 2005. Hydro-geologic data and well observations are provided by Chinese Geological Survey and local water bureaus.

Agronomic model. Linear crop water productivity functions are assumed, with crop irrigation water demand estimated using AquaCrop, and crop market price and detailed cost constituents obtained from Chinese statistical year books.

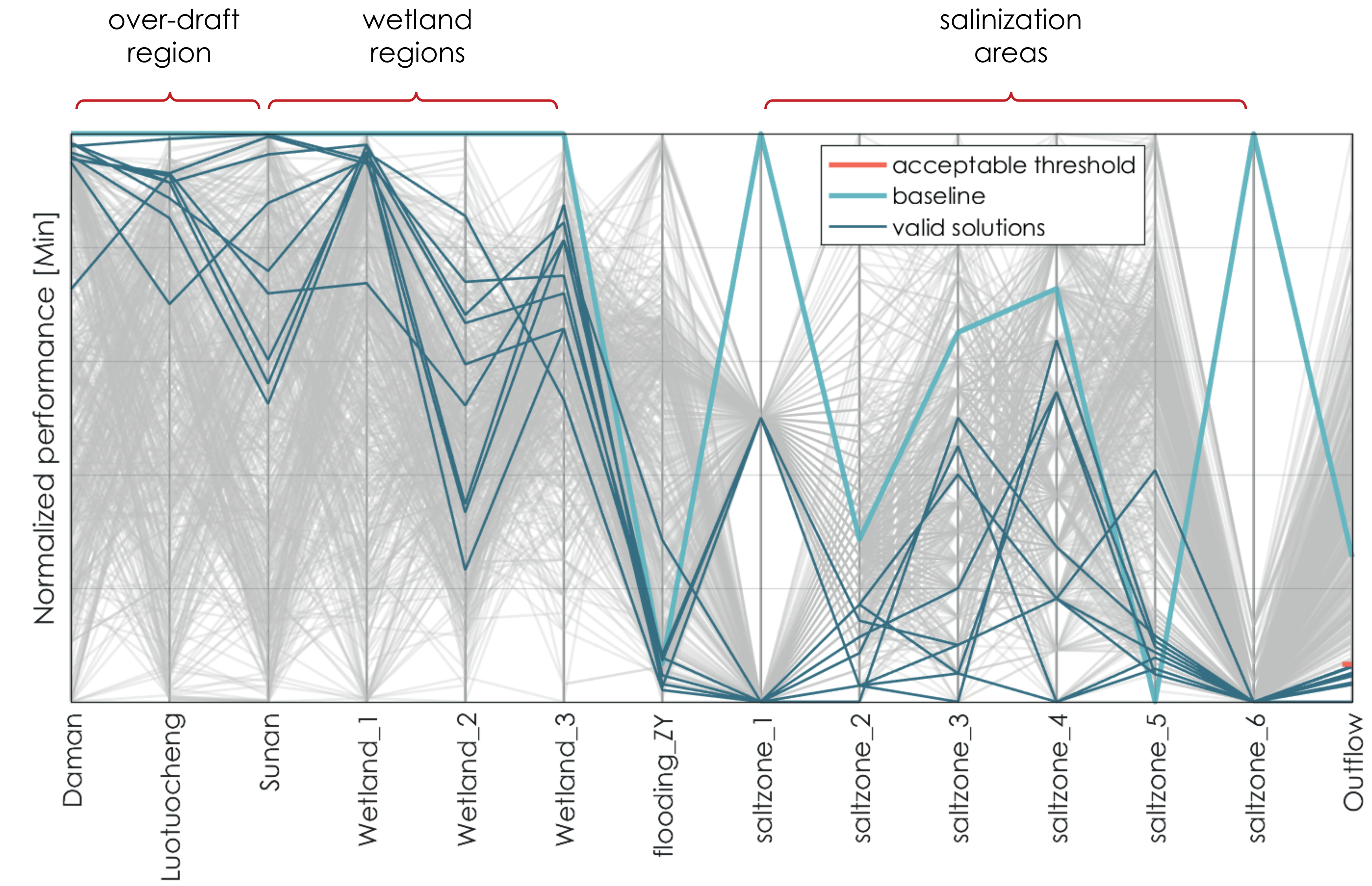
Multi-objective evolutionary algorithm. State-of-the-art Borg-MOEA algorithm is used for solving many-objective formulations in this work, and particularly:

1. for conjunctive water allocation, **13** decision variables (i.e., groundwater pumping rates) are used based on global sensitivity analysis to reduce the non-unique optimal solutions, and **14** objectives are considered;
2. for optimal cropping patterns, **16** feasible crop types were identified with **5** objectives, taking into account the constraints of water availability and irrigation area;

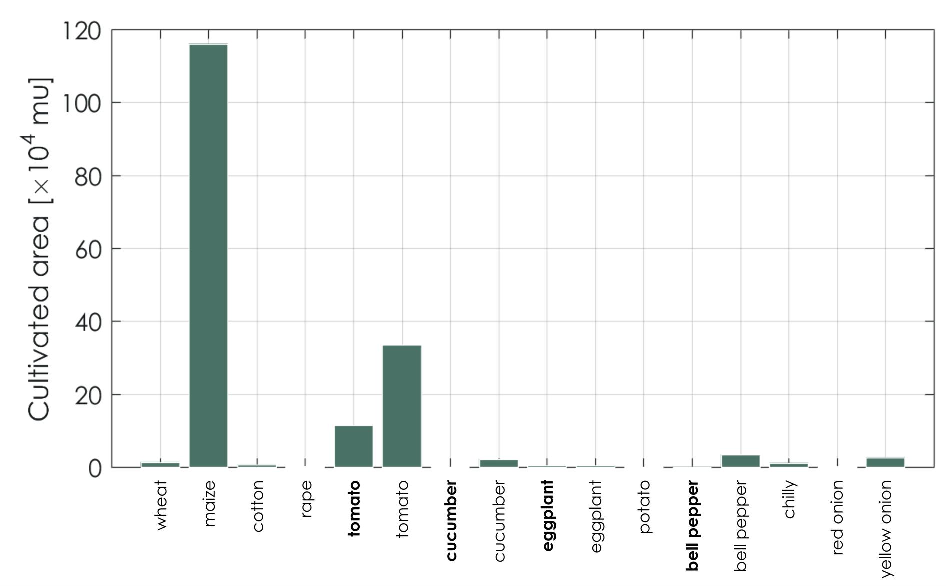
Optimization results



⬆ Parallel coordinate plot resulting from optimization of land use pattern. The 2nd to 5th y-axis represent the violation of constraints (e.g., water availability, total cultivated area, etc.), where the red bars are the actual upper bounds suggested by the decision maker. The "-" sign indicates the conversion of the maximization problem into a minimization problem.



⬆ Parallel coordinate plot resulting from many objective optimization of water allocation. Results are normalized and all lines collectively depict the approximate Pareto Front without imposition of decision maker's preferences, which will however be selectively brushed out given a threshold (red line at bottom right).



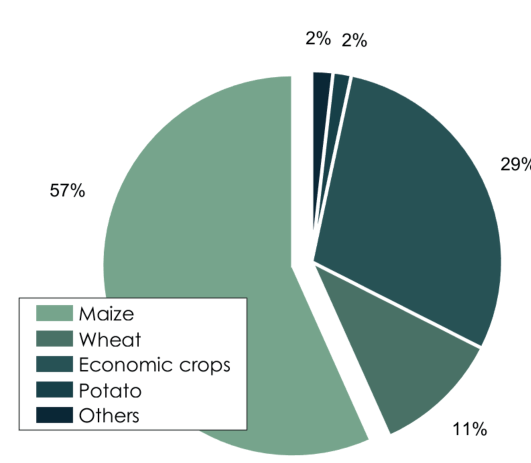
⬅ optimized land use dedicated to different crop types. Font in bold indicates vegetables grown in green houses. Note: for one hectare of green house area, only 0.6 hectares are actually planted.

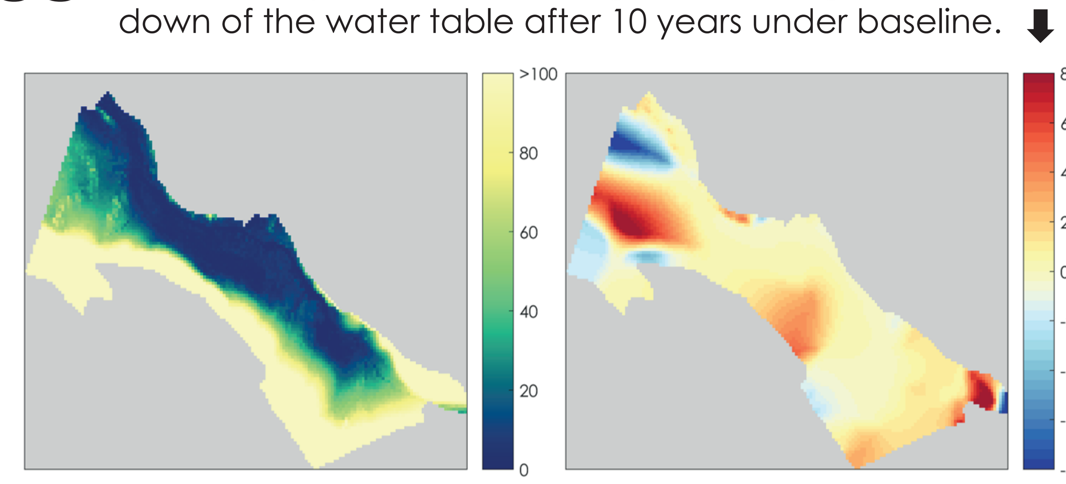
	Baseline	Optimization
total production value [x10^9 RMB]	6.87	10.37
total water use [x10^8 m^3]	9.2	6.57
total irrigation area [x10^4 ha]	12.9	11.56
total area with economic crops [x10^4 ha]	3.73	3.73
total area with greenhouse crops [x10^4 ha]	0.8	0.79

Comparison of results between business-as-usual (baseline) scenario and optimized land use. ⬆

Baseline statistics

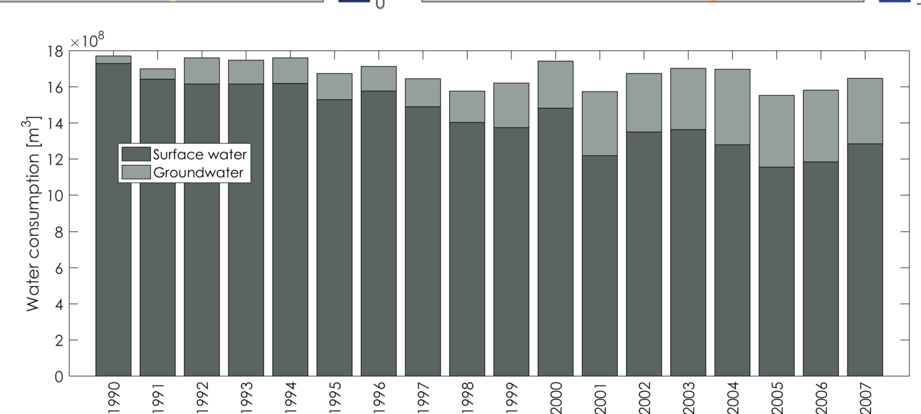
Figure on the left shows the initial groundwater depth (2013) simulated by the model. The figure on the right is the draw-down of the water table after 10 years under baseline. ⬇





⬆ Figure shows current land use pattern, where seed maize is the main crop grown in the area. All crops are planted in single cropping mode except for green house vegetables.

Figure shows the change of water use between surface water and groundwater from 1990 to 2007. ➡



Conclusions

- The water problem in Heihe mid-reach is due to mis-allocation of water resources rather than to water scarcity. Therefore, it can be mitigated through improvement of allocation scheme;
- Conflicts arise from the trade-off between sustaining wetlands and reducing salinization, and between maximizing profit and minimizing water use;
- Under current political restriction (i.e., no more irrigation area to be claimed and no increase of pumping allowed), the net production of agriculture can still benefit from changing cropping patterns

References and acknowledgements

- Jiang, Y., Xu, X., Huang, Q., Huo, Z., Huang, G., 2015. Assessment of irrigation performance and water productivity in irrigated areas of the middle Heihe River basin using a distributed agro-hydrological model. Agricultural Water Management 147, 67–81
- Lu, Z., Wei, Y., Xiao, H., Zou, S., Ren, J., Lyle, C., 2015. Trade-offs between midstream agricultural production and downstream ecological sustainability in the Heihe River basin in the past half century. Agricultural Water Management 152, 233–242.
- Hadka, D., Reed, P., 2012. Borg: An Auto-Adaptive Many-Objective Evolutionary Computing Framework. Evolutionary Computation 21, 231–259.
- Kinzelbach, W., Pedrazzini, G., Wang, H., 2016. Managing overpumped aquifers-a road to sustainable water use.

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中国科学院 西北生态环境资源研究院
Northwest Institute of Eco-Environment and Resources,CAS