View on the King Abdullah Canal in the Lower Jordan Valley ©Klein

Multipurpose Management Tool of Lake Tiberias and the Lower Jordan Valley

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KEY FINDINGS

The operation of Lake Tiberias is a multi-objective optimization task as multiple management goals are considered.

A model predictive control-based optimization model has been developed to improve the lake´s water release according to defined constraints and management objectives.

Based on defined management scenarios, the tool allows to react dynamically to different hydrological situations.

To apply the predictive control optimization model of Lake Tiberias, forecast data on water inflows and withdrawals is necessary.

MOTIVATION

Lake Tiberias is the largest freshwater reservoir in Israel. It is located in the Northeast of Israel and stores mainly surface water of the Jordan River. In the past, the lake supplied significant amounts of freshwater to Israel, but due to the increasing production of desalinated water it lost some of its relevance. However, because of its size and its location above the Lower Jordan Valley (LJV), Lake Tiberias is highly relevant for Jordan's water supply. As agreed in bilateral agreements, the lake provides Jordan with ca. 50 Mio. m^3 water per year. This amount is set to increase to 100 Mio. m^3 per year, following recent agreements in 2021. The water is delivered to the Jordanian King Abdullah Canal (KAC), a major water supply line in the LJV. The KAC runs in a north-south direction for a length of 110 km from the Yarmouk tributary parallel to the flank of the LJV. The KAC conveys substantial proportions of the public water supply for Amman as well as for agricultural water supply in the LJV.

There is currently no water management instrument considering the water release of Lake Tiberias to the Jordan Valley on a transboundary basis. In the future, the importance of a coordinated transboundary water transfer will further increase, due to additional water transfer agreements with Israel's neighbors. For example, the water transfer to Jordan will increase by additional 200 Mio. m^3/a to annually 300 Mio. m^3 in exchange for Jordanian solar energy („Water-Energy SWAP"), according to the latest agreement in 2021. The SALAM Initiative developed innovative and cost-effective water transfer solutions via Lake Tiberias [Water Production and Transfer Strategies, p. 22], using the lake as regional water reservoir in connection with hydropower generation [Large-Scale Hydropower Plant at Lake Tiberias in the Context of Transboundary Water Transfer, p. 50].

To use the lake's available water resources most efficiently, water release from the lake to the LJV and regional water demand centers must be further improved, taking operating guidelines of the lake and the temporal and spatial water demands into account. This complex task can be realized for different scenarios by applying a hydraulic model of the LJV with a predictive multi-objective discharge optimization of Lake Tiberias. Therefore, a Multipurpose Management Tool as Decision Support System (DSS) for an optimized lake operation under different demand scenarios has been developed.

METHODOLOGY

The operation of surface water reservoirs pursuing short-term objectives can be challenging for the operating staff, because current and future hydrological developments

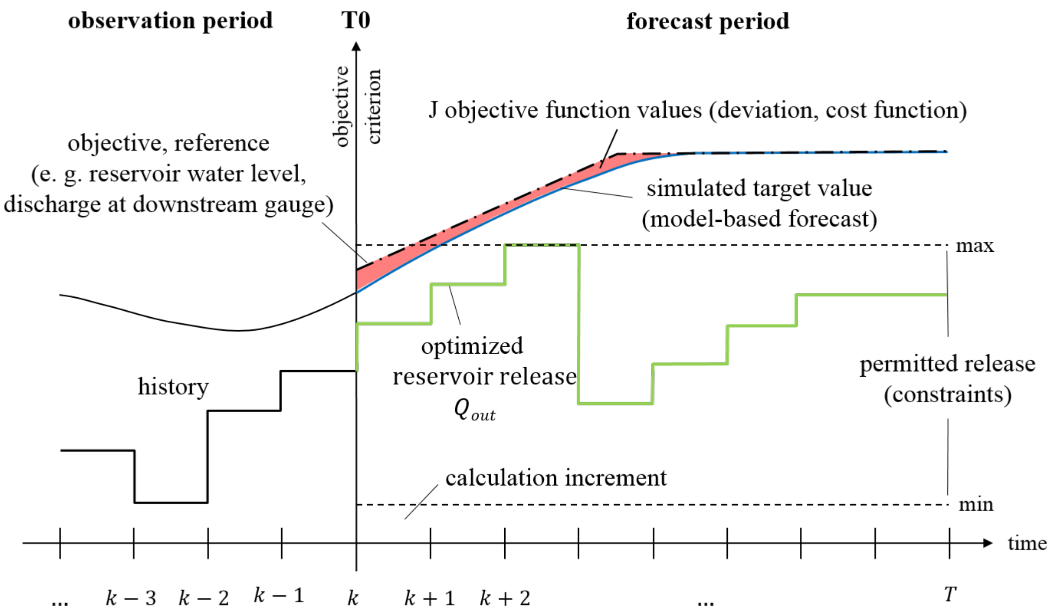

Figure 1: Principle of the Model Predictive Control (MPC) (Rötz & Theobald, 2019)

of the system must be considered in the decision-making process. Computer-based simulation and optimization processes can be used as a DSS with Model Predictive Control (MPC) to support the operating staff with this complex task (Rötz & Theobald, 2016). Such a MPC-based support system consists of a process model, which represents the hydrological system of rivers and dams, and a predictive optimization method, which determines the best possible control strategy for the dams.

For the process model, Lake Tiberias is defined as a reservoir with an optimizable water release to the KAC. The geometry of the lake is considered by a volume-elevation relationship. In addition, water level restrictions such as the upper red line (-208.8 m asl), lower red line (-213 m asl), and the black line (-241.87 m asl) are implemented as optimization constraints and objectives. The hydraulic model of the LJV calculates the hydraulic values of the KAC and the LJR according to the diffusive wave equation at the cross sections of the river systems. For both the KAC and LJR, all relevant in- and outflows are integrated into the model as objectives or boundary conditions.

Connected to the process model, the predictive optimization method identifies an optimal control strategy for achieving future objectives while taking defined constraints, e.g. fixed technical or operational restrictions, into account. With this method, starting from a point in time T0, a sequence of control steps is determined to achieve defined future optimization objectives, e.g. flows in a canal or water level in a reservoir, as accurately as possible (Figure 1). Due to the predictive character of this method, forecast data on the inflows and outflows of the system are essential.

To simulate the storage operation of Lake Tiberias and its connected water system in the LJV, the MPC approach is implemented by a computer-based simulation and optimization model using the Software RTC-Tools (Real Time Control-Tools).

RESULTS

The aim of the optimization is to minimize the water release of Lake Tiberias' (green arrow) while serving all water

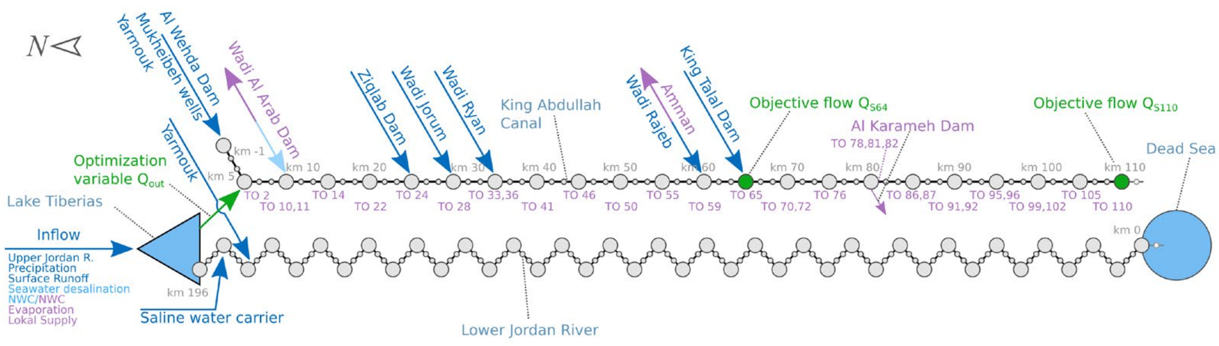

Figure 2: System sketch of the developed model

demands at the KAC. To address this goal, two auxiliary objectives with Q_{S110} = 0.20 m³/s (station 110) and Q_{S64} > 0.25 m³/s (station 64) for a minimum flow in the channel are defined. A system sketch of the model with the objected flows (green dots) and the in- and outflows (blue/purple arrows) are shown in Figure 2. Due to its high relevance for the water supply in the valley, the focus of the analysis is on the KAC.

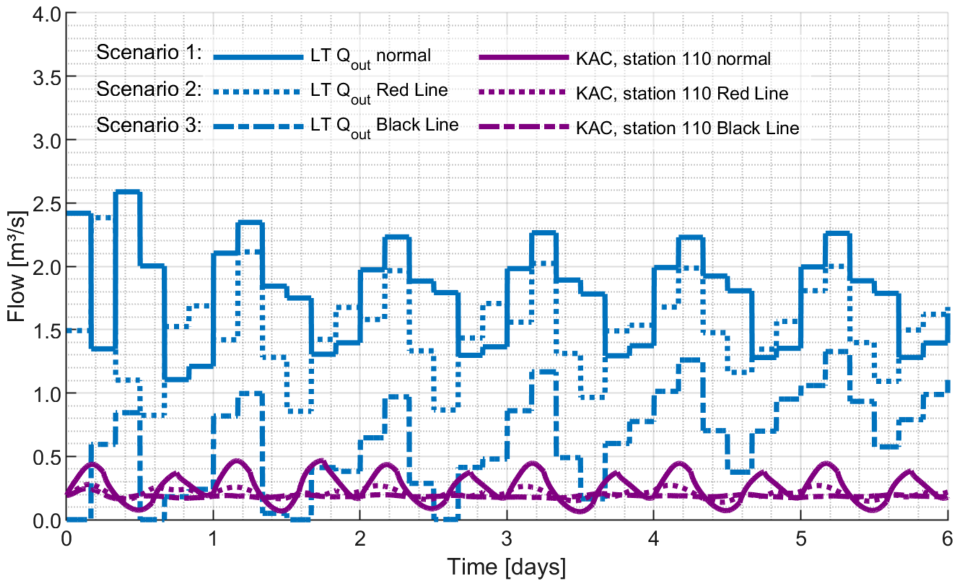

Figure 3: Comparison of the simulated water release of Lake Tiberias under different management scenarios

In this preliminary study, most of the boundary conditions, like rivers and dams, are implemented as steady values. Only the 31 agricultural water abstraction points at the so-called turn outs (TOs) are implemented as unsteady.

Simulation runs with constant water release of Lake Tiberias with and without optimization show, that the water release of the lake into the KAC can be reduced through optimization by ca. 8% while serving all water abstraction points.

To allow a further reduction of the lake discharge at low water levels, example scenarios for water levels at the lower red line (scenario 2) and the black line (scenario 3) are developed (Figure 3). For this purpose, the water abstraction points at the southern KAC are changed from solid boundary conditions, which have to be met, to flexible objective targets, which the tool is aiming at. Scenario 1 is an optimization simulation with a lake water level far above the lower red line (blue solid). The simulations of scenarios 2 (blue dotted) and 3 (blue dashed) significantly reduces the released water of the lake into the KAC by ca. 15% and 65% compared to scenario 1 (blue solid). In the context of the withdrawals by the TOs, the flow at station 110 oscillates with only small deviations around the objective value of Q_{S110} (purple lines) while Q_{S64} is maintained throughout the simulation (not shown). The reduction in water release is achieved at the expense of water withdrawals at the KAC and can be regulated by weighting in the optimization. However, the application of a model for predictive control of the Lake Tiberias presupposes that the necessary forecast data of inflows of dams and rivers and withdrawals of Lake Tiberias and the KAC are available.

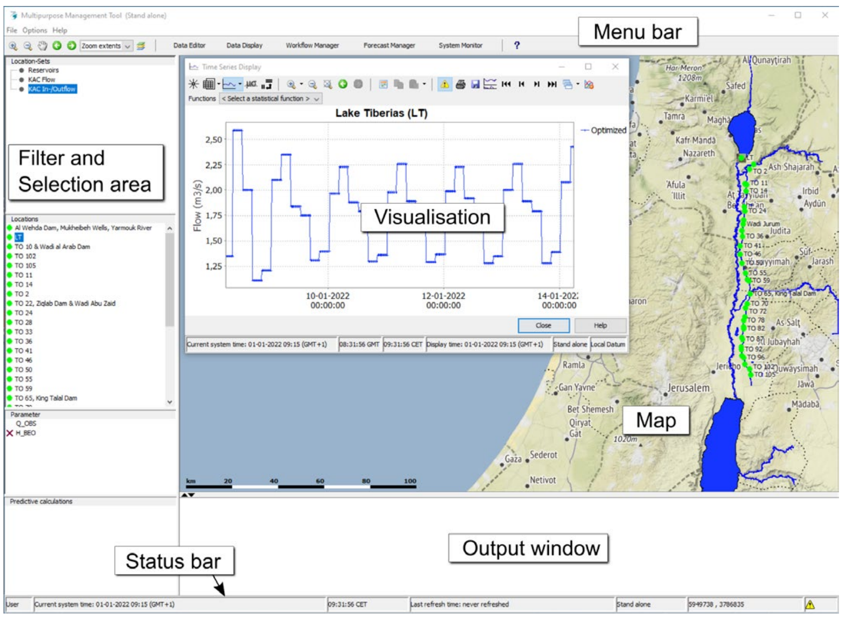

Figure 4: Graphical user interface of the developed Multipurpose Management Tool

For the intuitive and comprehensible application by the user, the functionalities have been integrated into a graphical user interface as a stand-alone application (Figure 4). The design of the interface is specifically geared to the requirements of the tool created and includes various functions such as importing observation and forecast data, running simulations, and displaying simulation results.

CONCLUSIONS

Given the increasing water shortage in the Middle East, the effective use of the available water resources of Lake Tiberias is of particular importance. The lake is of strategic relevance for Israel's water supply and an important freshwater source for the public and agricultural water supply in Jordan. In order to optimize the management and operation of the water transfer systems, suggested by the SALAM Initiative, this study demonstrates the application and benefits of an integral, transboundary, and MPC-based Multipurpose Management Tool. With the developed tool, the optimal control strategy for the water transfer to the LJV can be determined predictively according to defined management objectives, taking the temporal and spatial water demands into account. Thus, the DS-tool enables the development of optimized operational rules for Lake Tiberias as important regional water reservoir in case of freshwater transfers from the Mediterranean Sea to demand centers in Jordan and Palestine.

However, due to the predictive character of the applied method, forecast data on inflows and withdrawals must be available to the operating staff. This requires an exchange of data and a high level of transnational cooperation. In the next step, the Multipurpose Management Tool should be further refined and extended to include other relevant regional hydro-infrastructure such as the Jordanian dams.

MODEL PREDICTIVE CONTROL (MPC)

At the MPC, the n optimization objectives are described by a cost function for each time step k. Each optimization objective is defined by a reference set point $x_{i,sp,k}$, a specific weight ω, and an order a corresponding to the required or preferred prioritization. At each iteration step, the deviations J from the simulated objectives $x_{i,sim,k}$ to the reference set points are calculated as so-called costs. Through an iterative process, the control strategy is determined which, in total, contains the smallest deviations min J from the defined target variables. The software-internal optimizer IPOPT is used to optimize the cost function.

$$\min J = \sum_{i=1}^{n}\left(\omega_i \cdot \sum_{k=1}^{T}\left(x_{i,sp,k} - x_{i,sim,k}\right)^a\right)$$

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