DEL010 - Multi-stage Stochastic Optimization of Flood Mitigation Measures under Forecast Uncertainty

- Background

Ensemble Streamflow Forecasting becomes a well-established technique in operational (flood) forecasting centers to assess forecast uncertainty. Currently, these forecasts are communicated to decision makers; however, taking decisions is still up to the subjective experience of the specific stakeholder. Due to the large amount of information in ensemble forecasts, this task is a major challenge in particular when time is limited during ongoing flood events.

There is a lack of objective methods to take qualified decisions under consideration of forecast uncertainty. Whereas stochastic optimization techniques based on ensemble forecasts are applied in other water management domains (e.g. for scheduling hydropower assets using the RTC-Tools 1.4 open source software package), they are so far not used in the scope of flood forecasting and early warning systems and comparable system for daily operations and droughts. One major reason is probably the conceptual difficulty to integrate binary decisions (“Evacuate a region or not” or "Close barrier, or keep open"), logical constraints (“Measure A excludes measure B”) or priority based decisions ("If extra storage capacity is needed Polder A must inundate before Polder B is inundated"), into the decision-making under consideration of forecast uncertainty.

Objectives

This research will assess the application of several multi-stage stochastic and robust optimization approaches in combination with a mixed-logical, multi-objective optimization setup to model flood mitigation measures under forecast uncertainty. We will investigate the potential and applicability of these approaches to provide objective decision support to stakeholders in particular in the flood management domain. Where applicable, these approaches can also be applied in the general daily water management operations or for other purposes.

Approach

The project is organized in there phases: inception, implementation, evaluation and technical refinement

The project starts with an inventory of user stories from Rijkswaterstaat and the Waterboard Noorderzijlvest to identify representative problem setups. These problem setups are formulated in mathematical terms to enable implementation in an optimization model which can act as a formal test case to develop and evaluate the capabilities of the software package being used.

The conceptual assessment will be completed by a technical evaluation of in-house and external software packages with a focus on software features and software architecture. This evaluation should deliver a clear vision on the most suitable software framework to support stochastic and robust optimization approaches for representative user stories of our stakeholders.

The inception report summarizes these inventories, the representative problem setups and the proposed software framework for implementation.

The implementation phase will start with the development of this software framework under the name RTC-Tools 2.0, and use this framework to implement the various test cases and proof that the conceptual and technical difficulties of binary decisions, logical constraints and multi-objective decisions in operational water management under forecast uncertainty can be overcome. If successful, this prototype software framework will be developed into a more mature version to be released under open source license conditions and used by other TKI Deltatechnology projects such as DEL029 - JIP Slim Malen and DEL021 - Rekenen aan slim watermanagement in de praktijk.

Results

The results of this inventory is presented in this overview table. More details are available in the inception report.

Case	Description	Application	Comments
HM-FR	Hydrological Modeling (Flow Routing) with various variable-parameter routing schemes	Hydrological flow routing as component in distributed hydrological models with variational data assimilation, flow routing between and downstream of reservoirs	Optimization variables << model states, therefore, preference for a sequential setup, but also need for collocated setup between reservoirs, 2^{nd}-order derivatives required for collocated setup
RS	Reservoir System with multi-purpose reservoirs	Short-term optimization of the reservoir systems considering multiple objectives such as flood mitigation, hydropower generation, etc.	Optimization variables in the order of the model states, preference for collocated setup and 2^{nd}-order derivatives, optional extension to hybrid systems and stochastic optimization, simple upstream to downstream routing
CS-CON	Canal System with Continuously Operated Structure(s)	Short-term optimization of a low-land water system as operated by Dutch water boards, relevant objectives include flood mitigation and cost-aware drainage	Comparable to case RS, but with more sophisticated flow processes (hydraulic routing), pumps instead of turbines, tidal boundaries, option for stochastic optimization
CS-DIS	Canal System with Barrier (Open / Closed)	According to CS-CON, but with discontinuous decisions, logical conditions etc.	According to CS-CON, but with dedicated mixed-integer optimization algorithms, option for stochastic optimization

CS-LES	Canal System with Lateral Extraction requests under Shortage conditions	Multi-objective water allocation	Priority based allocation using deterministic goal programming optimization algorithm, option for weighting factor based LP approach or hybrid approach
EV	Evacuation Measure Based on Uncertain Forecasts	Decision if and when an authority should initiate an evacuation measure	Application beyond the water system to address the impact of a forecast and its uncertainty on decision making

Workshops

Stakeholder workshop 7 december 2015

- presentation
- inventory

PAO cursus Slimmer Waterbeheer met Real Time Control 14 maart 2016

- RTC sturing in de riolering (Elgard van Leeuwen)
- Intro RTC Tools (Klaasjan van Heeringen)
- Internationale toepassingen RTC-Tools (Dirk Schwanenberg)

RTC Tools workshop Nelen&Schuurmans: 30 maart 2016

- presentation

RTC-Tools workshop Int.Deltares Software Days 2017

- RTC-Tools2 General Introduction
- Exercises (37Mb)

RTC-Tools 2 software framework

Release overview (available at https://pypi.org/project/rtc-tools):

- RTC-Tools 2.2.0 beta1 released on May 26, 2018
- RTC-Tools 2.2.0 beta2 released on June 16, 2018 (using Pymoca 0.2.7)
- RTC-Tools 2.2.0 beta3 released on Aug 24, 2018 (using Pymoca 0.2.8)
- RTC-Tools 2.2.0 beta4 released on Sep 25, 2018 (using Pymoca 0.3)
- RTC-Tools 2.2.0 rc1 (release candidate 1) November, 5, 2018 (using Pymoca 0.3)
- RTC-Tools 2.2.0 (final release) November 18, 2018 (using Pymoca 0.3)
- RTC-Tools 2.2.1 (first bug fix), November 26, 2018 (using Pymoca 0.3)
- RTC-Tools 2.3.0 alpha 1 (development version), released on November 18, 2018 (using pymoca 0.4)

Associated URLs:

- License condition: GNU Lesser General Public License V3 (Lesser GPL)
- Website: https://www.deltares.nl/en/software/rtc-tools/
- RTC-Tools 2.2 python pip installation package: https://pypi.python.org/pypi/rtc-tools
- ChannelFlow Modelica library pip installation package: https://pypi.python.org/pypi/rtc-tools-channel-flow
- Python code repository: https://gitlab.com/deltares/rtc-tools
- ChannelFlow Modelica library repository: https://gitlab.com/deltares/rtc-tools-channel-flow
- Documentation: http://rtc-tools.readthedocs.io/
    - Optimization API: http://rtc-tools.readthedocs.io/en/latest/optimization.html
    - Simulation API (BMI): http://rtc-tools.readthedocs.io/en/latest/simulation.html
    - Tutorial: http://rtc-tools.readthedocs.io/en/latest/examples.html

Code dependencies are all managed within the installation package. RTC-Tools 2.2 has a strong co-development relation with pymoca.

Publications

Project deliverables

- Proposal
- Inception Report
- RTC-Tools 2.0.0 Beta1 release

Publications related to this project

- Application of Goal Programming Approach in Hydro-economic Optimization: A case study of the Citarum Reservoirs Operation Rules (MSc. thesis report, Tiarravanni Hermawan)
- Quick Scan Tool for water allocation in the Netherlands, Gijsbers, P.J.A., J.H. Baayen, G.J. ter Maat. reviewed version Published In: Hebiek, J. R. Denzer, G. Schimak (eds): Environmental Software Systems ISESS 2017, IFIP AICT 507 pp.97-109, Springer International Publishing. https://doi.org/10.1007/978-3-319-89935-0_9.
- Real-Time Flood Control by Tree-Based Model Predictive Control Including Forecast uncertainty: A Case Study Reservoir in Turkey, G. Uysal, R. Alvarado-Montero, D.Schwanenberg, A.Sensoy, Published in: Water 2018, 10, 340: https://doi.org/10.3390/w10030340
- Short-term control of a storage hydropower under flodd risk by multi-stage stochastic optimization, G.Uysal, A. Sensoy, D.Schwanenberg, R. Alvarado-Montero, Published in: G. La Loggia, G. Freni and V.Puleo (eds) HIC2018 (EPiC Series in Engineering, Vol.XXX), pages 1-7
- A continuation approach to nonlinear model predictive control of open channel systems, J.H.Baayen and T.Piovesan (submitted Jan 2018 to Journal of Water Resources Management, https://arxiv.org/abs/1801.06507)
- A continuation approach to the optimization of hydropower operations J.H.Baayen, J.Rauw, and T.Piovesan (submitted May 2018, https://www.researchgate.net/publication/324939723_A_continuation_approach_to_the_optimization_of_hydropower_operations, https://arxiv.org/abs/1805.01292, https://www.semanticscholar.org/paper/A-continuation-approach-to-the-optimization-of-Baayen-Rauw)

Rejected submissions:

- Optimization of Management for the Citarum Cascade Reservoirs: A Comparison of two fundamentally different methods, Tiaravanni Hermawan et al. submitted to HESS (hess-2018-340): rejected as the editor consider the article outside the scope of HESS. A similar article will be resubmitted to Journal of Hydroinformatics
- RTC-Tools 2.0: An open source toolbox for control and multi-objective convex optimization of environmental systems under forecast uncertainty (first submission rejected by Environmental Modelling & Software, revised submission in the works)

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