Supplementary S1 to “Impounding reservoirs – benefits and risks”
Extended summary of scientific publications concerning flood protection and failures of reservoirs

Research paper	Size of the reservoir under analysis	Study area	Result
C1.1 - Flood protection			
[17]	17 reservoirs, mostly with a large capacity.	The causes, course and consequences of flooding in Karela State (India) are described. A scenario was analysed without reservoirs and also when they were emptied early to a capacity of 85%, 75%, 50% and 20%.	An extreme rainfall event with a probability of occurrence of 0.6% was identified as the cause of the flood. Although the reservoir system was not thoroughly prepared for the arrival of the water, they played a significant role in reducing the surge and the discharges from the overflowing facilities did not contribute significantly to the magnitude of the flood. Earlier emptying of the reservoir would have suppressed the peak of the wave by a value in the range of 16–21%.
[18]	A reservoir with a very large capacity.	The impact of water engineering on flood changes was analysed, based on the case study of Danjiangkou Reservoir (China).	Indicators such as maximum average flows over a given period and peak-over-threshold flow values were studied. Danjiangkou Reservoir was shown to have significantly altered flood characteristics for both seasonal and annual floods, with an average change rate of about 19% in flood characteristic indicators .
[19]	4 reservoirs with a large capacity.	The publication analyses the performance of five retention reservoirs with different flood capacities located in the upper Vistula river basin (Poland).	It was found that large reservoirs, whose flood capacities ranged from 38.8 to 60.1 million cubic metres, played a particularly important role in the last decade in reducing the intensity of high-water stages and positively stabilising flow values in regulated watercourses.
[20]	Reservoirs of various sizes, with capacities ranging from 1,000 to 300,000 m^3 per km^2.	On a large dataset covering catchments in the US, it analysed how storage reservoirs affect flood and drought protection at local and regional scales.	Reservoirs have been shown to play an important role in reducing the intensity of flooding and drought, while extending the duration of these events at the local scale. In addition, reservoirs reduce the risk of widespread flooding on a regional scale while potentially negatively affecting spatial drought linkages. It was highlighted that reservoirs can have a beneficial impact on both phenomena analysed, regardless of their primary function and purpose of creation.
[21]	The analyses involved the creation of two hypothetical reservoirs with medium capacities, i.e. about 6 million m^3.	The risk of flash floods in Wadi Sudr (Egypt) and the possibility of mitigation measures were assessed. A Geographic Information System (GIS) and catchment modelling in HEC-HMS software were used.	Based on the modelling results, two reservoir locations with the most effective flood protection potential were identified. Parameters such as retention capacity, shape of the reservoir canopy and area subject to flooding were analysed. Based on these criteria and using the “weighted linear combination” method, a “suitability index” was determined, which showed which location was optimal.
[22]	The analyses are for a hypothetical reservoir, where capacity was a variable value.	A model based on the Instantaneous Unit Hydrograph (IUH) was considered to easily determine the capacity of a hypothetical reservoir to reduce the flood wave.	The IUH model is based on three basic parameters: location, discharge capacity and volume. The model makes it possible to determine the location of the reservoir with the greatest potential for flood wave reduction. In addition, it is possible to check the impact of reservoir construction on the probability distribution of flooding in any region, without having to fit detailed hydrological models.

[23]	2 small reservoirs for different uses - dry and wet.	Different options for flood protection were assessed: afforestation, the use of permeable concrete, and the construction of dry or retention reservoirs. The river Glinščica (Slovenia) was chosen as a case study.	The results indicated that to achieve a significant level of flood risk reduction, reforestation and permeable concrete require the use of significant areas for this purpose and may involve disproportionately high costs. Reservoirs offer the potential for more effective flood wave reduction at a lower cost; however, their effectiveness decreases with scale and smaller facilities only have a localised impact.
C1.2 - Operation and management			
[24]	A reservoir with a very large capacity.	Using the Chengbi River reservoir (China) as an example, its optimum damming level at a given time was analysed, considering flood control as well as utility needs.	Three periods of reservoir operation were identified: pre-flood, flood and post-flood. For each of these, a damming level was proposed to ensure that the flood risk is as low as possible while maximising the benefits of electricity generation.
[25]	A reservoir with a very large capacity.	Using Longtan Reservoir (China) as an example, its optimum damming level at a given time was analysed, considering maximising flood capacity.	Three periods of reservoir operation were distinguished: pre-flood, flood and post-flood. For each of these, a "flood limit water level" was determined, resulting in an increase in the reservoir's flood capacity of 5.81 bn cubic metres in the flood period and 6.337 bn cubic metres in the post-flood period
[26]	2 reservoirs with a very large capacity.	The Awash and Omo-Gibe river basins (Ethiopia) were studied to improve flood monitoring services and facilities. Data covering atmospheric conditions during the flood season (June to September) were used as a case study.	An interactive web-based "flood tool" was developed, and its effectiveness was determined by the coefficients of determination (R2) and effectiveness (NSE), which yielded favourable results for river flows as well as reservoir water levels. Based on satellite observations, the model was also found to correctly represent the potential extent of the flood zone under given atmospheric conditions.
[27]	A reservoir with a very large capacity.	A section of the Ebro River (Spain) including a reservoir was simulated. Shallow water equations (SWE) were solved using a 1D and 2D model. An automatic regulation of the reservoir water level using the Proportional-Integral-Derivative (PID) algorithm was proposed.	It was concluded that the water level and reservoir discharge results of the 1D model are similar to those provided by the 2D model. By using the former, a significant saving in computing power is gained, at the expense of only visualising the floodplain. It has been shown that a control algorithm (PID) can potentially regulate the flow effectively to protect the facility from exceeding the allowable damming level.
[28]	The analyses are for a hypothetical reservoir, where capacity was a variable value.	An existing section of the White River (USA) with a hypothetical flood control reservoir was analysed. A genetic algorithm in MATLAB was combined with a rainfall–runoff model (HEC-HMS) and a	A methodology has been developed for real-time control of the bottom discharge gate of a hypothetical flood control reservoir. The model allows for the management of the reservoir discharge schedule to avoid exceeding a threshold water level in the analysed river section.

		1D and 2D unsteady flow model (HEC-RAS).	
[29]	6 reservoirs with a very large capacity.	Using the example of a system of six reservoirs on the Yangtze River (China), the implementation of a model to control their interaction in terms of flood control was considered.	Dynamic Programming (DP) was used with progressive optimisation algorithm (POA) and particle swarm optimisation (PSO) methods. The study indicated that the model created allows the flood control reservoir system analysed to maximise its potential and significantly reduce the risk of property damage.
[30]	11 reservoirs, mostly with a large capacity.	The research looked at the feasibility of implementing a real-time control model for a system of 11 reservoirs in the Sittaung River Basin (Burma).	A model called Multi-objective Model Predictive Control (MOMPC) was proposed, incorporating Genetic Algorithm II, a multi-criteria decision process and a regressive horizon principle. The model was simulated for 10 days (simulation horizon) using discrete time steps of 30 min, with an average computation time of 100 s per time step.
[31]	A reservoir with a very large capacity.	The accuracy of short-term forecasting–Forecast-Based Operation (FBO)–was analysed. The Ankang (China) facility was taken as a case study.	Possible sources of risk of FBO inaccuracy were identified, considering the process and characteristics of reservoir flood control. It was assessed that, of the various types of uncertainty, hydrological uncertainty should be considered a significant source of risk in reservoir flood control. Possible remedies were presented in case the forecast was incorrect.
[32]	A reservoir with a large capacity.	The application of a decision support system for flood control operations, Ensemble Forecast Operations (EFO), was analysed. The Lake Mendocino reservoir (in the USA) was chosen as a case study.	Simulation using EFO was found to provide a greater opportunity to hold more water in the reservoir during the flood season, while maintaining the volume required to take the surge effectively. At the end of the flood season, there was a 33% increase in average stored volume compared to operations without the use of EFO.
[33]	A reservoir with a very large capacity.	A model was developed to simulate the impact of reservoir operation on flooding in the Chao Phraya River Basin (Thailand).	The H08-CaMA model created was tested against the 2011 flood in Thailand, and the simulation reflected the actual historical events in a good way. The results indicated that changes in the management of reservoir operations would reduce the flood area by an additional 20 per cent, retaining 2.4 million cubic metres more water.
[34]	A reservoir with a very large capacity.	The short-term and long-term forecasting performance of six statistical and machine learning-based methods for predicting water levels in Angat Reservoir (Philippines) was compared.	Two Deep Neural Network (DNN) models were extracted: a univariate model (DNN-U) and a multivariate model (DNN-M). The DNN-U model was the most effective for the one-day forecast, with a Mean Absolute Error (MAE) = 0.2 m. For the long-term scenarios, the best results were achieved when the DNN-M model was used.

[35]	A review article based on a large dataset.	This article presents an overview of the application of artificial intelligence and computational intelligence methods in a flood management system.	Single methods were distinguished: fuzzy systems, neural networks, and evolutionary algorithms, and hybrid methods: soft computing and machine learning. Hybrid methods were shown to have the greatest potential for accuracy and turnaround time of flood forecasts.
		C1.3 - Dam failures	
[36]	A review article based on a large dataset.	In this paper, more than 1,000 cases of earth dam failures around the world were analysed to determine the causes of the occurrence. Dams were divided into four categories: homogeneous, zoned, with a "corewall" and with a concrete screen.	Overflow through the embankment crest and internal erosion ("piping") phenomena were identified as the most common causes of failure of earth dams, the latter occurring mainly in the case of homogeneous or zoned dams. Overflow through the dam crest affected 41% of all cases analysed and occurred due to insufficient capacity of overflow facilities or the occurrence of extreme floods.
[37]	2 reservoirs with a large capacity.	The Report takes an in-depth look at the causes of the 2020 reservoir failure on the Tittabawassee River (USA), in particular the scouring of a section of the Edenville Dam.	Static liquefaction of the embankment structure that forms the Edenville Reservoir dam was identified as the most likely circumstance that led to the failure. It was caused by the embankment having been created (in 1920) without regard to proper safety parameters and using outdated (by today's standards) technology.
[38]	3 reservoirs with a small capacity.	A hypothetical situation of dam failure in a cascading reservoir system was analysed. Three facilities on the Čižina River (Czech Republic) were taken over as a case study.	Three methods were used to analyse the problem studied: empirical formulae, hydraulic modelling and the use of analogies to historical events. The lack of accuracy of the application of empirical formulae and the higher risk of dam failure in small flood control reservoirs were demonstrated.
[39]	In the analyses conducted, capacity was one of the assumed parameters.	The effects of a dam breach were studied based on the catastrophe theory of eight parameters: reservoir capacity, dam height, population at risk, economy at risk, understanding of the failure process, type of industry, warning time and building vulnerability.	A method for rapid assessment of dam disaster impact estimation was developed, allowing it to be applied to numerous sites. The effectiveness of the method was confirmed using twelve historical events as examples. Using the example of Jiangang Reservoir (China), it was shown how many lives would be lost for different event characteristics.
[40]	A reservoir with a large capacity.	Thanks to hydrological and hydraulic models, flood risk was analysed in the context of the operation of Baysh Reservoir (Saudi Arabia). Different rainfall scenarios and the case of dam failure were considered.	Studies have indicated that the reservoir is prepared for high rainfall events, however, at the maximum likely intensity, the outflow from the reservoir will be at approximately 8,900 cubic metre per second, causing flooding downstream. Calculations considering dam failure showed the potential risk of total devastation of the area downstream of the facility and the consequent significant loss of life.

[41]	A reservoir with a large capacity.	The risk of water overtopping the dam crest of the Mietków flood control reservoir (Poland) was analysed. Calculations were made for various scenarios.	For scenarios assuming different real flow rates and initial water levels in the reservoir, the results indicate that there is a risk of overflow through the dam crest, especially in the case of limited operation of the discharge facilities.
[42]	A review article based on a large dataset.	A comparison of flood control standards in the context of reservoir operations was carried out. Regulations in 11 countries that can be described as “industrial” were analysed.	It was found that, despite some differences, in all countries analysed the inspection standards are relatively stringent and reasonable. However, it is not common to consider the effects of dam breakage as a factor affecting the class of structure.