water

Article

Dynamic Water-Level Regulation at Run-of-River Hydropower Plants to Increase Efficiency and Generation

Stephan Heimerl [1,*] and Niklas Schwiersch [2]

[1] Fichtner Water & Transportation GmbH, 70191 Stuttgart, Germany
[2] Institute of Hydraulic Engineering and Technical Hydromechanics, Technische Universität Dresden, 01219 Dresden, Germany; niklas.schwiersch@tu-dresden.de
* Correspondence: stephan.heimerl@fwt.fichtner.de

Abstract: In times of the energy transition and the intensified expansion of renewable energy systems, this article presents an optimization approach for run-of-river power, i.e., dynamic water-level regulation. Its basic idea is to use river sections influenced by backwater more evenly via the operating regime of a hydropower plant. In contrast to conventional dam and weir water level management, the head of the reservoir is not shifted toward the weir while the discharge rate increases but is kept in position by temporarily raising the water level. This generates a greater head for higher discharge rates of an operating regime. As can be shown using an example, this has a direct effect on the performance and, in interaction with the discharge duration curve, on the annual work of the plant. The dynamic water-level regulation, thus, represents an environmentally compatible, energy-efficient optimization for run-of-river hydropower plants.

Keywords: dynamic water-level regulation; run-of-river hydropower; efficiency increase; generation increase

check for updates

Citation: Heimerl, S.; Schwiersch, N. Dynamic Water-Level Regulation at Run-of-River Hydropower Plants to Increase Efficiency and Generation. *Water* **2021**, *13*, 2983. https://doi.org/10.3390/w13212983

Academic Editors: Jochen Aberle and Robert Boes

Received: 30 August 2021
Accepted: 19 October 2021
Published: 22 October 2021

1. Introduction

The transition of electrical energy supply away from fossil fuels, as well as from nuclear power in Germany, toward a purely regenerative power supply means a massive shift toward regenerative energy sources such as onshore and offshore wind power, biomass, photovoltaics, and hydropower, which have been used in Europe for a long time. This process must be flanked by a noticeable reduction in consumption, especially through efficiency-promoting measures, since generation capacities and generation possibilities are finite.

Particularly in Central European countries such as Germany, there are both physical and social limits that undoubtedly do not make the German path toward energy transition, so-called "Energiewende", easy. On the one hand, there are the physical limits of, for example, limited solar radiation in the northern hemisphere, wind and hydropower sites that are not available everywhere inland and that can be operated economically, and limited resources for biomass power plants. On the other hand, there is resistance in many regions to an overly intensive expansion of wind power due to the impairment of the landscape and the obvious conflicts with nature conservation and animal protection or a further intensification of maize monocultures for biomass plants. Hydropower is also in this area of tension and must face up to water protection within its facilities, especially regarding the implementation of the European Water Framework Directive.

The discussion and activities in the first decade of the 21st century in Germany were characterized by a very rigid implementation philosophy of the European Water Framework Directive with a focus on the protection and enhancement of the natural environment of water bodies. The undoubtedly existing climate change has led to a certain rethinking, and the use of renewable energy sources for climate protection has been placed on an equal footing with water protection. In Germany, as a federal state, this equivalence has also been enshrined in some state water laws, such as in Baden-Württemberg in §24 of its water law [1].

As the degree of hydropower development on large watercourses in Germany is already at a high level [2], hydropower on small watercourses has been essentially consolidated since the introduction of the Renewable Energy Sources Act (EEG) [3] with its guaranteed remuneration, and the construction of new weirs for hydropower use in Germany currently appears almost impossible in terms of licensing; thus, the efficiency of hydropower plants plays an essential role for their operators.

In this context, the sections of watercourses that are already affected by dust should continue to be used for energy production and should be used for this as efficiently as possible.

For this reason, existing plants are being converted to increase efficiency, sites without previous hydropower use are being redeveloped as plant locations, and sites with dormant water use rights are being put back into operation. In view of the possibility to precisely adjust the water level by means of movable weirs [4–6], the dynamic water-level regulation can be an additional efficiency-boosting measure in the planning of such measures at run-of-river hydropower, especially as a control optimization, in order to improve the environmentally compatible use of the respective site. The authors are not aware of any studies of the same or a similar kind; hence, this is the first time that dynamic water-level regulation and, thus, its basic principles are reported.

With the inclusion of dynamic water-level regulation, it can generally be expected to increase the average head available over an operating year and, thus, the annual work of a hydropower plant, without increasing the upstream influenced river stretch and, thus, the impact on the environment. In many cases, this mode of operation also helps to compensate to some extent for the increased water releases required for fishways for upstream and downstream migration and the ecological flow in diversion stretches for water protection reasons, and it does not unduly reduce power generation.

This article is structured as follows for the presentation and discussion of dynamic water-level regulation: in Section 2, the basic ideas of the control system are first presented, and its energetic effects, as well as the implementation of the control system, are explained. Then, in Section 3, results from feasibility studies and pilot projects are presented. Points to be discussed, a conclusion, and an outlook on the further development of dynamic water-level regulation are presented in Section 4.

2. Dynamic Water-Level Regulation

2.1. Basics

The separation of dam-influenced and non-dam-influenced sections of watercourses is based on the location of the head of reservoir in the headwaters of a dam. The conditions upstream of the head of reservoir are unaffected by the impoundment, and those downstream are influenced by it. The head of the reservoir is located at point x where the backwater curve $h(x)$ and the uniform flow depth $h_u(x)$ fulfill the condition $h(x) = 1.01 \times h_u(x)$ [7]. According to Patt et al. [4], the impoundment length l_{imp} is determined as the distance from the dam to the head of reservoir.

$$l_{imp} = \frac{h_u}{I} \times \left[\frac{h_s}{h_u} - \frac{h}{h_u} + \chi \times \left(f\left(\frac{h}{h_u}\right) - f\left(\frac{h_s}{h_u}\right) \right) \right] (\mathrm{m}), \quad (1)$$

where I describes the longitudinal slope of the riverbed, h_s is the height of the dam above the riverbed, χ is a coefficient to account for the flow velocity, and $f(h/h_u)$ is a function to account for the shape of the flow cross-section.

Basically, a steeper watercourse results in a shorter head of reservoir. This is in line with the experience that significantly longer reservoir lengths are found in lower reaches than in upper reaches. Furthermore, it follows from Equation (1) that large values for h_n produce small ratio values h_s/h_n and h/h_n; thus, the second factor becomes small. Consequently, the length of the reservoir that correlates with a static target becomes small for large discharges and large for small discharges. This means that the head of reservoir shifts toward the retaining structure in the event of an increase in discharge. At the same time, the tailwater level at the dam increases and, therefore, the usable head at the dam decreases.

The basic idea of dynamic water-level regulation is to raise the water level depending on the discharge to increase the energetically usable head and, therefore, to increase the annual work of a plant with this control optimization. An important aspect is that the length of the watercourse section affected by the dam is not extended, but is defined by the conditions at low and, thus, ecologically sensitive discharges.

As shown in Figure 1 below, an essential structural prerequisite for this is a weir system with movable control elements that can regulate the normal operating level, such as an attached flap.

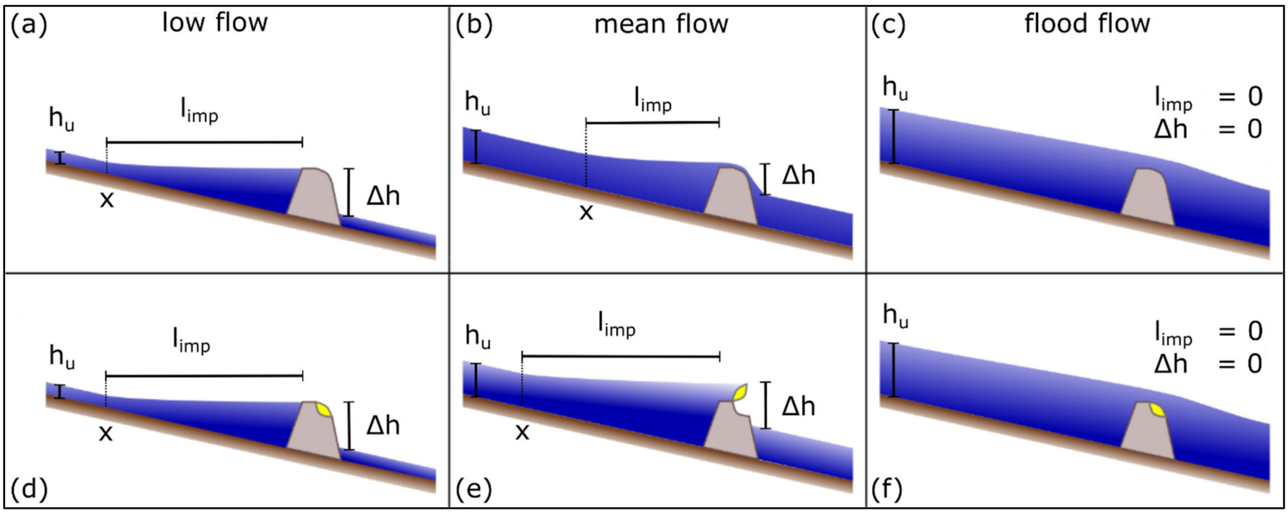

Figure 1. Principle sketch of static (**a**–**c**) and dynamic water-level regulation (**d**–**f**) [8].

In the case of dynamic water-level regulation, on the other hand, the head of reservoir target in the headwater Z_{weir} is gradually increased by means of the control element, such that the decrease in head is minimized as the tailwater level rises. Accordingly, more head is available for energy utilization over a longer period of the year, resulting in higher annual energy production. The dynamic water-level regulation is optimized with regard to the length of the head of reservoir l_{head}, such that free-flowing water stretches are not affected by the additional impoundment.

2.2. Consideration of Available Power

To calculate the electrical power P, the head h_f and the flow Q are linearly combined. In addition, the density of the water ρ, the gravity constant g, and the overall efficiency of the plant η are considered in the equation for determining the net power.

$$P = \rho \times g \times Q \times h_f \times \eta \text{ (W)}. \quad (2)$$

The efficiency depends, among other factors, on the admission, the drop height, and, if necessary, the turbine speed [6]. However, in the examples presented here, only the admission is taken into account; thus, the authors point out the additional influencing variables at this point. Experience shows that taking all these influences into account by using the best operating point and, thus, efficiency in each case would tend to increase the energy production.

From a hydraulic point of view, the two hydraulic opportunities to increase the power of a hydropower plant are either to increase the turbine flow or to add head unless the electromechanical equipment is modified and optimized. The latter is the approach of dynamic water-level regulation.

The value for the head h_f includes the water level, the tailwater level, and the sum of the head losses [9].

$$h_f(t) = Z_{weir} - Z_{tw}(Q(t)) - \sum_i h_{v,i} \text{ (m)}, \tag{3}$$

where t is the variable of time (s), Z_{weir} is the full supply level (masl), $Z_{tw}(Q(t))$ is the tailwater level (masl), and $\sum_i h_{v,i}$ is the sum of hydraulic losses (m).

Losses to be considered depend on the local velocity head, such as for rake, inflow, and outflow losses. For the implementation of dynamic water-level regulation, these are largely constant. In contrast, the water level in the tailwater is variable due to discharge, which causes an earlier reduction of the head in the case of a static water-level regulation. In order to counteract this, the normal water level in Equation (3) is also dependent on the discharge in the case of dynamic water-level regulation.

$$h_f(t) = Z_{weir}(Q(t)) - Z_{tw}(Q(t)) - \sum_i h_{v,i} \text{ (m)}. \tag{4}$$

This allows the head to be controlled by the increased normal water level and the decrease in head to be integrated into the plant control system. Changes to the head availability are propagated linearly into the annual work of the plant as a product of power and duration.

2.3. Control

The implementation of dynamic water-level regulation takes place in the operating limits of the installed machine sets. Accordingly, the maximum accumulation target $Z_{weir,max}$ is usually assigned to the highest operating flow rate. Correspondingly, the minimum accumulation target $Z_{weir,min}$ is assigned to the lowest operating flow rate. Within this operating regime, the dynamic water-level regulation is implemented in such a way that the length of the head of reservoir remains constant. At higher flows, flood control regulations take effect, such as predischarge to create additional retention space or retention damming to cap the flood peak.

In practical implementation, these considerations mean that the control system is divided into three control phases (Figure 2). Below the lower operating limit Q_1, regulations for the low-flow case take effect, and the hydropower plant stops due to insufficient discharge at the turbines. If Q_1 is exceeded, the plant is put into operation. In this case, the normal water level is increased over the entire operating phase I in such a way that the head and the position of the head of reservoir are kept constant. As soon as the control unit is fully set up at a flow mark of Q_2, the normal water level cannot be raised any further for design reasons and remains at the level of the maximum normal water level $Z_{weir,max}$ over phase II, such that the head decreases as a result of a further increase in the tailwater level. Lastly, from the upper operating limit Q_3, it may be necessary to lower the normal water level to ensure effective flood control through phase III. During this phase, a hydropower facility may not continue to operate completely because the existing head may fall below the limit of economic operation of the facility.

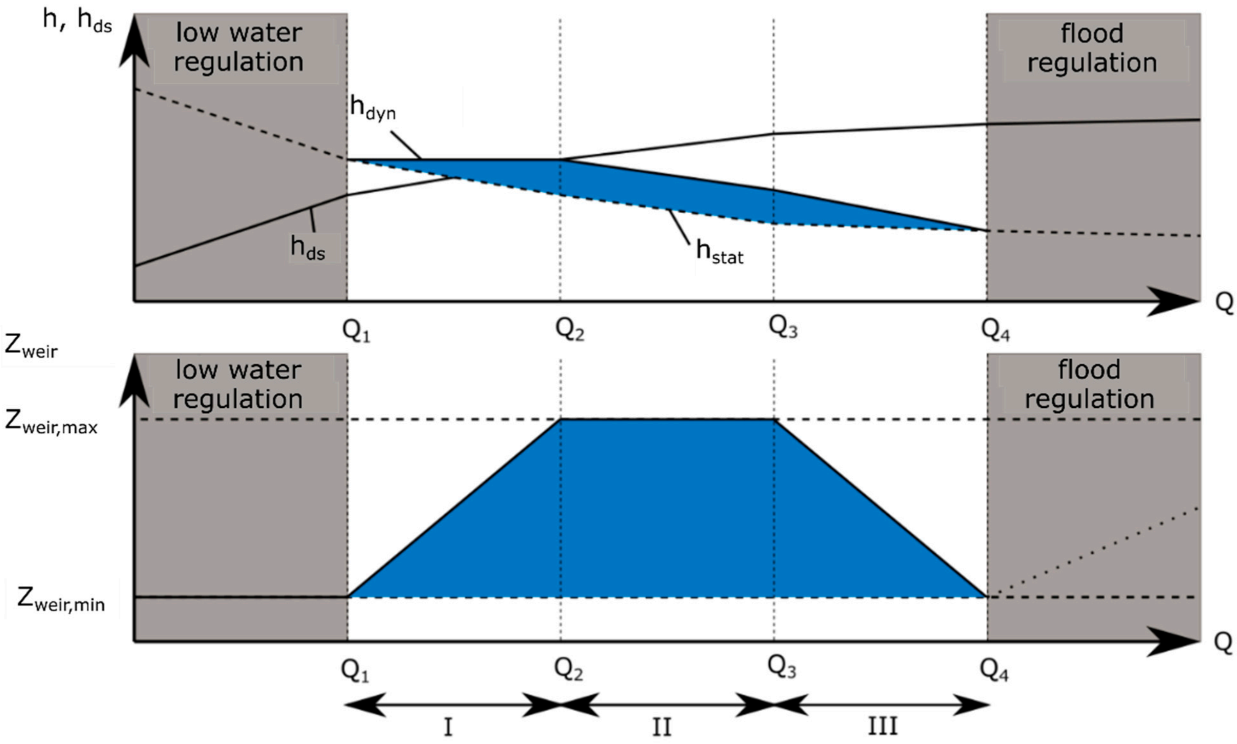

Figure 2. Schematic control and head curve for dynamic water-level regulation [8].

2.4. Operating Principle

If the normal water level is increased dynamically, the height of the impoundment in the river is temporarily increased, whereby the course of the water level, as well as the horizon of the seeping groundwater, is vertically lifted. This results in water pressures relevant for the design of a weir from the various operating conditions of the system. The lowest water level together with the low water discharge and the highest water level together with the flood discharge have to be considered.

With the use of such a control system, a larger head is available for energy recovery for a longer period of the year (Figure 3). The effect of a dynamic water-level regulation is particularly noticeable at medium to high turbine flows, as well as at plants with low head, since, in this range, the head is noticeably increased and, thus, the annual production of a plant is also increased.

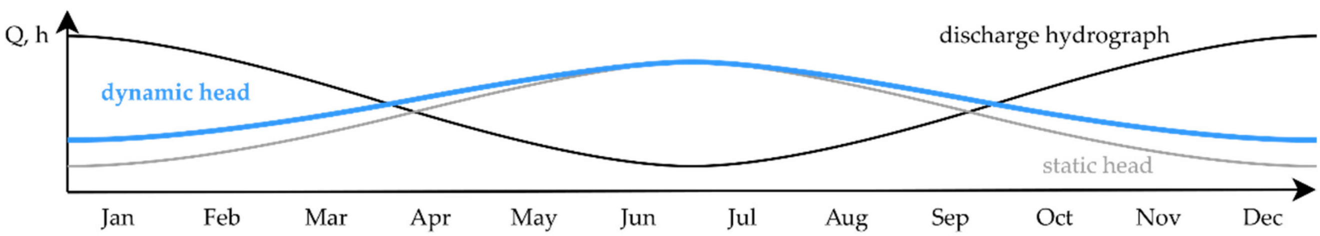

Figure 3. Principle of the dynamic water-level regulation of reservoir levels in a standard year [8].

If the scale of consideration is somewhat larger, the introduction of a dynamic water-level regulation would have the effect of expanding the economically viable potential of rivers and strengthening the role of hydropower in the renewable energy sector. Taking such a control into account, the technically usable potential of hydropower in Germany, which is currently about 33.2 TWh/a to 42.1 TWh/a [2], would have to be reevaluated.

2.5. Potential Conflicts

In addition to energy-economic advantages, the effects of a temporary, additional impoundment affect other interests. For this reason, the adverse effects of these impacts must be investigated and evaluated as part of the planning process [10]. Such an evaluation must include the fact that the additional impoundment does not mean a greater water depth, but rather a change in the duration and frequency of a certain higher impoundment target in the operating regime of the plant.

In particular, the following issues must be considered:

- Flood protection,
- Agriculture and forestry in connection with temporary changed groundwater levels,
- Nature conservation and environmental protection.

By adding movable elements to the barrage (see Figure 1), the dynamic water-level regulation is not only compatible with the requirements of flood protection but can even contribute to a local improvement of flood protection. In operating regime III (see Figure 2), the water level is lowered to the level of the static water level, such that the flow cross-section required for flood discharge initially remains unchanged. With the help of increasingly powerful real-time forecasts of precipitation and runoff time series [11], flood control can be prepared in time. In addition, the axis of movement could also be set below the static damming target, for example, in the case of a flap gate, so that a larger cross-section can be released in the event of a flood. However, the effects on downstream riparians must be taken into account in such an approach.

The seepage of water from the retention area into the groundwater influences the groundwater flood distance in the immediate vicinity. With the dynamic water-level regulation, the horizon of the seepage is temporarily raised. For this time period, the groundwater head is reduced. The degree of reduction depends, on the one hand, on the time of impoundment and, on the other, on the geohydraulic properties of the soil. In areas with too little precipitation and decreasing precipitation trends, dynamic water-level regulation can, therefore, have positive effects on the vegetation of the riparian areas.

As a result of the dynamic water-level regulation, the frequency and duration of the site-specific water levels change. With the upstream limitation of the reservoir space due to the location of the head of reservoir at low water, no natural aquatic habitats are affected by the dam. If the implementation of the regulation presented here is combined with measures to improve ecological continuity and, thus, to achieve the objectives of the EC Water Framework Directive [12], the ecological situation of a watercourse can even be improved through the targeted planning of adaptation strategies [13] in the context of hydropower utilization.

2.6. Economic Efficiency and Legal Aspects

Planning and approval of such a control system is necessary for the implementation of dynamic water-level regulation at existing plants. For example, it must be checked statically whether a temporarily higher impoundment exceeds the permissible loads on the structures or in the subsoil. Structurally, adapting an existing facility to the requirements of dynamic water-level regulation requires consideration of adding a control device to a fixed weir or, if necessary, readjusting the control device on an existing movable weir. Environmental impacts must also be considered.

It must also be checked, especially for existing plants, whether the increase in water levels under the dynamic water-level regulation is covered by the existing water permits. In many cases, a fixed full supply level or a control range is approved, which must then be adapted in an appropriate manner within the framework of a supplementary approval procedure.

After the plant has been upgraded, the costs incurred are offset as benefits by the additional revenue from the increased annual work.

3. Results, Experiences, and Practical Implementation

3.1. First Experiences at Beuron Hydropower Plant

The hydropower plant St. Maurus is located at the upper Danube in South Germany between Tuttlingen and Sigmaringen close to Beuron (river kilometer 2712.2). The Danube is one of Europe's largest rivers.

The hydropower plant is owned by the Monastery of Beuron, the Arch-Abbey St. Martin. The tradition of the monastery reaches back to 1077. The hydropower plant was erected in 1922 to supply the monastery with electricity, which was not yet available elsewhere at the time.

After flood damage at the beginning of the 1990s, the plant was repaired; however, considerations simultaneously began to upgrade the existing plant with a design flow of 5.2 m^3/s and an installed capacity of 80 kW at a head of 2.60 m in order to be able to operate it safely again for several decades. The site should also be used as efficiently as possible.

In this area, the upper Danube, above the then existing head of reservoir, has a section of great ecological value, which, due to its free-flowing character with a corresponding bed structure and repeated bed relocations, is considered by fishermen in particular to be a valuable spawning habitat for fish.

This stretch of water lies in the FFH protected area (Natura 2000 site) and is assigned to the grayling region in terms of fishery biology. The existence of juvenile grayling fish (*Thymallus thymallus*), proven by a survey of the fish fauna, indicates that the area above the former dam root has suitable reproduction conditions for grayling [9]. In addition to the grayling, the author investigated the brown trout (*Salmo trutta fario*) as a typical accompanying fish species and the bullhead (*Cottus gobio*), which is potentially present in this section of the Danube and is protected under the FFH. According to these investigations [14], the water quality in the Danube section under consideration is predominantly classified as level II (moderately polluted). The oxygen supply is good in the reservoir area and very good in the upstream flowing stretches.

For the expansion considerations, some specifications were developed together with the fishery, which included the following points:

- Flow velocity above the existing dam root must not drop below 30 cm/s to prevent the interstitial from clogging with fine sediments (scouring).
- The habitat availability must remain at least as good as during the spawning periods of the various fish species throughout the year and, if possible, be improved.

According to these requirements, the concept of a seasonal and discharge-dependent dynamic water-level regulation was verified by the first author with the help of hydraulic modeling, and the corresponding evidence was provided using the Computer-Aided Simulation Model for Instream Flow Requirements (CASiMiR) [15–17].

Considering the determined boundary conditions, the planning was then implemented, which, due to the close communication with the approval authorities, led to a water law permit in a manageable amount of time. This was followed by the implementation, so that the completely new hydropower plant could go into operation in 2009 after 7 years of preliminary studies and planning and about 1.5 years of construction (interrupted by a very cold winter).

The existing head of 2.60 m could be increased by a dynamic water-level regulation of 0.60 m to 3.20 m and the installed power by approximately 50 kW to 263 kW. Together with an increase in the usable discharge from 5.2 m^3/s to 12 m^3/s, energy production was increased by about 150% to an average of 700 MWh/year, as the 12 years of operation now show. In this specific case, the dynamic water-level regulation share of this increase is likely to be half of the additional 50% increase in generation, as back calculations have shown.

At this hydropower plant on the upper Danube, the dynamic water-level regulation was implemented for the first time to protect a fish spawning habitat located upstream of the head of reservoir, and operational experience shows that the original concept could basically be realized.

3.2. Further Development of the Concept at a Site on the Nahe River

Due to the good experience with the dynamic water-level regulation, which demonstrably achieved the previously defined and modeled goals of ecological enhancement on the one hand and significantly increased annual energy production on the other by about +25%, this concept was pursued further.

As part of the preliminary planning of a new power plant with the merging of two sites, the feasibility of a dynamic water-level regulation was investigated in addition to the planning of a fish passage structure and a fish protection and fish descent facility. By means of a hydrodynamic–numerical 2D simulation, the extent of the dammed river section, as well as the water level positions in the actual state, was determined for the planning area [8]. On the basis of these findings, the control of the movable weir in the dynamic water level regulation was designed, and a planning variant was used to demonstrate that there would be no changes to the extent of the length of the impoundment. The height differences in the water levels caused by the control system are shown in Figure 4.

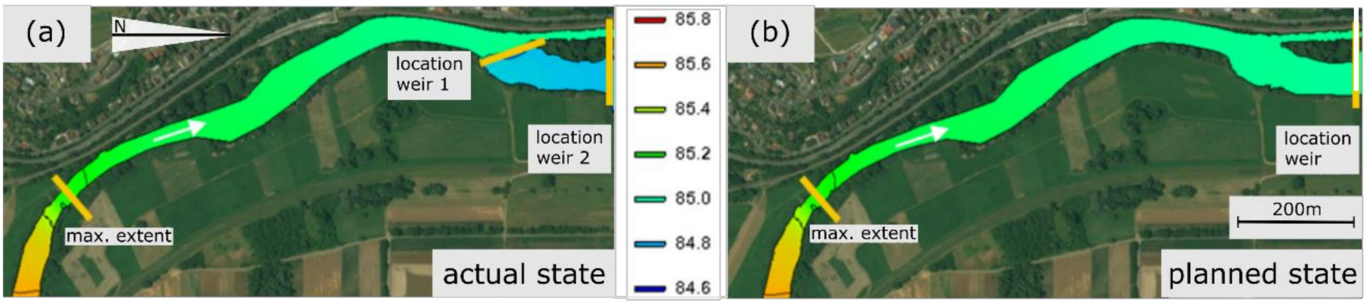

Figure 4. Water level at mean discharge in actual (**a**) and planned (**b**) conditions in masl [8].

By upgrading the existing fixed weir at downstream site 2 with a movable flap valve as a control device and introducing dynamic water-level regulation, part of the head for larger flows can be increased and used in power generation if the existing weir at upstream site 1 is omitted in the above project, thus increasing the plant capacity. However, because these occur less frequently in the year, a discharge-related point increase in electrical output of up to one-quarter (depending on discharge) cannot be fully reflected in the consideration of annual work. As shown in Figure 5, the annual work increases according to the underlying discharge duration curve. At this point, the duration lines with 95%, 50%, and 5% probabilities of exceedance are examined. It can be clearly seen that the increase as a result of the dynamic water-level regulation is more extensive for the discharge events with a low probability of exceedance and, correspondingly, the higher discharges, with values to be expected than for discharge events with a higher probability of exceedance.

The study found that the expected increase in annual production is up to 10% higher for the variants based on the less probable duration lines. For a very probable duration line, the increase in work is approximately 7%.

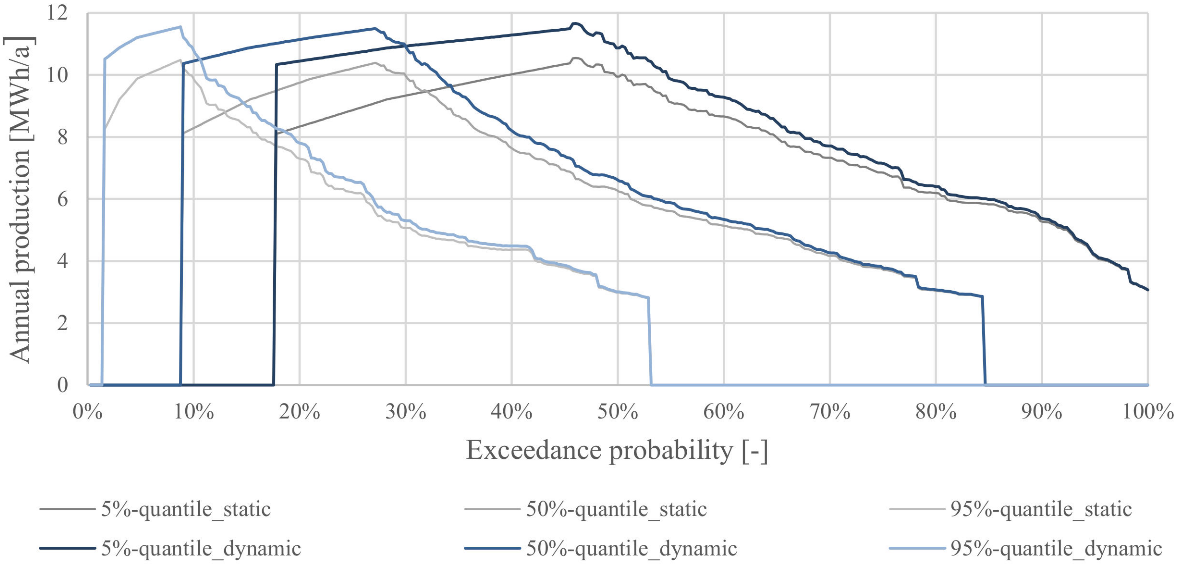

Figure 5. Comparison of the annual production of a static and a dynamic water level regulation with probability of occurrence [8].

4. Discussion, Conclusions, and Perspectives

Given this first article on dynamic water-level regulation, the results cannot be comparatively evaluated against studies of a similar nature. Simultaneously, it must be taken into account that the bathymetry in the headwaters of existing dams can change significantly over the years and, thus, no longer correspond to natural conditions at the beginning of planning. The reasons for this are the reduced flow velocity and water depth. As a result, the reservoir length cannot be determined via the natural normal discharge depth as described in Equation (1) but must be identified by means of hydraulic characteristics. For this reason, the following must be considered in the planning of existing facilities:

- that the flow velocity decreases compared to its value in the free-flowing watercourse section,
- that the course of the water level deviates from parallelism to the riverbed and asymptotically approaches a horizontal line,
- that the Froude number must decrease because of the two points mentioned above.

In practice, these characteristics can be determined using hydrodynamic numerical models.

The dynamic water-level regulation is an efficiency-increasing plant control for new plants, as well as for existing plants, which does not mean a direct additional burden for the environment. By limiting the upstream water level at the point where the head of reservoir is located in low water, no additional sections of the river are impounded. Only the duration and frequency of a certain normal water level are favorably shifted according to energetic aspects depending on the discharge.

This form of extended operation is particularly important for hydropower plants with low heads of less than 5 m, as the typical temporary increases in head that can be achieved in the course of dynamic water-level regulation of usually 0.30 m to 1.0 m result in notable increases in generation. For plants with a greater head, this proportion is correspondingly smaller and smaller, such that the necessary structural adjustments can no longer be covered by the economic advantage.

The current studies on the energy-economic potential of hydropower do not yet include dynamic reservoir regulation [1]. However, the findings show that a higher utilization potential is possible at suitable locations.

In the case of existing plants, it is advisable to implement a dynamic water-level regulation in combination with regular rehabilitation measures. Furthermore, the realization of such a control in combination with ecological upgrading of the plants, which is necessary anyway, such as the construction of a fish passage structure, is conceivable and reasonable. Increases in annual output of 5–10% and even more are possible.

Furthermore, once implemented, this regulation can be used to dampen undesirable surge and sinking phenomena in rivers. This requires a suitable control system with water-level gauges in the upstream and downstream sections, which either dampens the incoming flow changes by temporary intermediate storage (surge) or, if necessary, temporarily opens the turbine or gates more strongly in order to temporarily generate increased discharges in the downstream section (sunk). Care must be taken, however, to ensure that the control does not react too quickly but has a certain inertia; otherwise, there is a risk that the effects will be amplified in an undesirable way.

Author Contributions: Conceptualization, S.H.; methodology, S.H. and N.S.; software, N.S.; validation, S.H. and N.S.; formal analysis, S.H. and N.S.; investigation, S.H. and N.S.; resources, S.H. and N.S.; data curation, S.H. and N.S.; writing—original draft preparation, S.H. and N.S.; writing—review and editing, S.H. and N.S.; visualization, N.S.; supervision, S.H.; project administration, S.H.; funding acquisition, S.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available because they were compiled in connection with projects for third parties.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. *Water Act for Baden-Württemberg of 3 December 2013*; In the Version of 17 Decembar 2020; GBl: Stuttgart, Germany, 2020; p. 1233.
2. Anderer, P.; Dumont, U.; Heimerl, S.; Ruprecht, A.; Wolf-Schumann, U. The Hydropower Potential in Germany (Das Wasserkraftpotenzial in Deutschland). *Wasserwirtschaft* **2010**, *100*, 12–16. (In German) [CrossRef]
3. *German Renewable Energy Sources Act (EEG)*; Last Amended by the Act of 16 July 2021; BGBl: Berlin, Germany, 2021; p. 3026.
4. Patt, H.; Gonsowski, P. *Wasserbau—Grundlagen, Gestaltung von Wasserbaulichen Bauwerken und Anlagen*, 7th ed.; Springer: Berlin/Heidelberg, Germany, 2011.
5. Gebhardt, M. *Stand der Schlauchwehrtechnik, Anwendungsbeispiele und Betriebserfahrungen*; Bundesanstalt für Wasserbau: Karlsruhe, Germany, 2007.
6. Lattermann, E. *Wasserbau-Praxis, Band 1, Gewässerkunde, Flussbau, Stauanlagen, Wasserkraftwerke*, 1st ed.; Building Bauwerk: Berlin, Germany, 1999; ISBN 3-934369-12-X.
7. Bollrich, G. *Technische Hydromechanik 1—Grundlagen*; Beuth Verlag GmbH: Berlin, Germany, 2013.
8. Drews, N. Investigation of Dynamic Water Level Regulation with Respect to the Development of the Head of Reservoir (Untersuchung von Dynamischer Stauzielregelung Hinsichtlich der Stauwurzelentwicklung). Master's Thesis, Technische Universität Dresden, Dresden, Germany, 2017; unpublished.
9. Giesecke, J.; Heimerl, S.; Mosonyi, E. *Hydropower Plants—Design, Construction, and Operation (Wasserkraftanlagen—Planung, Bau und Betrieb)*, 6th ed.; Springer: Berlin/Heidelberg, Germany; New York, NY, USA, 2014. (In German)
10. Heimerl, S.; Drews, N.; Kohler, B. *Dynamic Water Level Regulation as Environmentally Compatible Hydropower Optimization (Dynamische Stauzielregelung als Umweltverträgliche Wasserkraftoptimierung)*; Hydraulic Engineering Symposium: Water Management—Innovation from Tradition; Zenz, G., Ed.; Publisher of Technical University Graz: Graz, Austria, 2018; pp. 115–122. (In German)
11. Liu, Y.; Wang, H.; Lei, X.; Wang, H. Real-time forecasting of river water level in urban based on radar rainfall: A case study in Fuzhou City. *J. Hydrol.* **2021**, *603*, 126820. [CrossRef]
12. European Parliament; European Council. *Directive 2000/60/EC of the European Parliament and of the Council Establishing a Framework for the Community Action in the Field of Water Policy*; Official Journal of the EU; European Parliament; European Council: Brussels, Belgium, 2000.
13. Zhang, X.; Liu, X.; Wang, H. Developing water level regulation strategies for macrophytes restoration of a large river-disconnected lake, China. *Ecol. Eng.* **2014**, *68*, 25–31. [CrossRef]
14. Grimm, R. *Makrozoobenthos und Fischökologische Gewässerbeschreibung der Donau im Abschnitt*; Wasserkraftanlage St. Maurus/Donau: Beuron, Germany, 1991.

15. Jorde, K. Ökologisch begründet, dynamische Mindestwasserregelungen bei Ausleitungskraftwerken. In *Mitteilungen des Instituts für Wasserbau der Universität Stuttgart*; Institut für Wasserbau der Universität Stuttgart: Stuttgart, Germany, 1997.
16. Giesecke, J.; Schneider, M.; Jorde, K. Analysis of minimum flow stretches based on the simulation model CASiMiR. In Proceedings of the 28th IAHR Congress, Graz, Austria, 22–27 August 1997.
17. Schneider, M. Habitat- und abflussmodellierung für fließgewässer mit unscharfen berechnungsansätzen. In *Mitteilungen des Instituts für Wasserbau der Universität Stuttgart*; Institut für Wasserbau der Universität Stuttgart: Stuttgart, Germany, 2001.