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Directive on the Safety of Water Retaining Facilities

Part C2: Flood safety and lowering the reservoir water level

This version replaces all earlier versions.

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Contents – Part C2

1. Introduction

1.1. Objectives of Part C2, "Flood safety and lowering of reservoir water level"

The objectives of Part C2 of the Directive are to guarantee the protection of water retaining facilities in the event of flood and to specify the prerequisites for lowering the water level of reservoirs for safety reasons.

Furthermore, it specifies the requirements relating to the verification of the functionality of the gated relief and outlet works and describes the content of the gate regulations.

Part C2 deals solely with the safety of water retaining facilities with the aim of preventing a failure that could result in an uncontrolled discharge of water. The management of outflow downstream from the facility and the associated issues relating to flood protection are not dealt with in this document.

1.2. Verification of flood safety

For the verification of flood safety, the operator has to show that, in extraordinary to extreme situations, flood water can be held back or diverted without endangering the water retaining facility. The term "flood water" refers to inflows of water into the reservoir, regardless whether these are of a natural (for example, due to precipitation or melting snow) or operational (for example, due to feed-in from pipelines or the operation of turbines or pumps) nature.

Verification of flood safety is required for

- new or renovated facilities;
- existing water retaining facilities if no verification of flood safety already exists;
- taking account of modified assumptions made in a previous verification (in particular, changed hydrological circumstances);
- taking account of changes in the state of the art in science and technology.

Based on the above requirements, operators have to periodically check whether a new verification of flood safety may be necessary. This has to be done as part of the 5-yearly safety assessment for Category I water retaining facilities (cf. section 1.6), every 10 years (as a rule) for Category II facilities and upon the instructions of the supervisory authority for Category III facilities.

1.3. Lowering the reservoir water level

The operator has to be able to lower the reservoir water level in the event of a threat of an uncontrolled discharge of water and in order to perform inspections and maintenance work. This document specifies the criteria for the dimensioning of the outlet works.

1.4. Existing water retaining facilities

The supervisory authority has to pay special attention to the principle of proportionality in the implementation of the dimensioning criteria relating to the lowering of the water level in existing facilities.

1.5. Water retaining facilities on the Upper Rhine and the Aare under direct federal supervision

For the verification of flood safety for water retaining facilities on the Upper Rhine and the Aare that are subject to federal supervision, the corresponding enforcement aids (currently: [BFE & RPF 2013; BFE 2015]) should be consulted.

1.6. Categories of water retaining facilities

Water retaining facilities that are subject to the provisions of federal legislation (WRFA and WRFO) are classified into three categories in which different requirements apply. Allocation to these categories is based on the following criteria:

- Category I water retaining facilities fulfil the criteria specified in Article 18, paragraph 1a or 1b, WRFO;
- Category II water retaining facilities have a storage height of at least 5 metres, fulfil the size criteria specified in Article 3, paragraph 2, WRFA, and are not allocated to Category I;
- Category III water retaining facilities do not fulfil the size criteria specified in Article 3, paragraph 2, WRFA, or only have a storage height of up to 5 metres.

Figure 1 shows the categories of water retaining facilities in terms of storage height and storage capacity (cf. definitions of terms in Part A of the Directive).

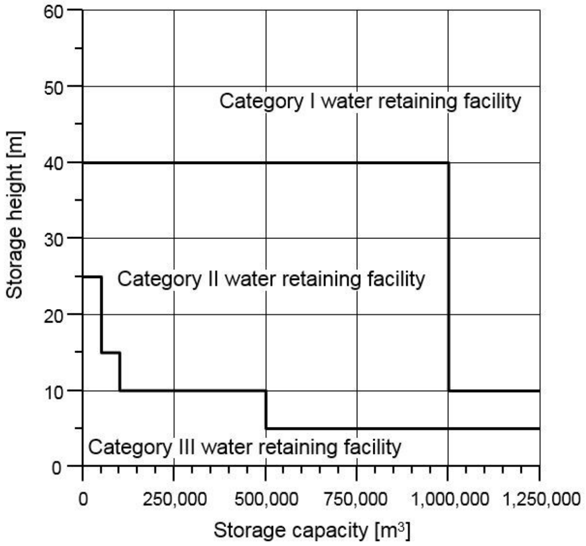

Figure 1: Definition of the three categories of water retaining facilities.

2. Flood safety

2.1. Verification of flood safety

For the verification of flood safety, the operator has to show that

a) in an extraordinary and in an extreme situation the respective maximum permissible water levels will not be exceeded.

   Extraordinary and extreme situations are defined by:
   - The initial water level (cf. section 2.2)
   - The maximum permissible water level (cf. section 2.3)
   - The flood event (cf. section 2.4.)
   - The existing relief options (cf. section 2.5)

b) the safety-related structural requirements for relief equipment (cf. section 2.6) have been met in full.

2.2. Initial water level

The initial water level to be taken into account for the verification of flood protection corresponds to:
- the maximum operational reservoir level (for water retaining facilities with active management of the reservoir);
- the relevant level for specifying the storage height (for water retaining facilities without active management of the reservoir) (cf. Part A of the Directive).

For **flood control reservoirs** it must be assumed that the initial water level in an extraordinary situation corresponds to the relevant level for specifying the storage height. It may, however, be assumed that in an extreme situation the flood water enters the initially empty flood control reservoir.

2.3. Maximum permissible water level

In an extraordinary situation, the maximum permissible water level lies below the danger level (cf. section 2.3.1) by the required minimum safety freeboard (cf. section 2.3.2).
In an extreme situation, the maximum permissible water level corresponds to the danger level (cf. section 2.3.1).

2.3.1. Danger level

The danger level corresponds to the water level above which the water retaining facility is endangered.[1]

For over-flowable dams the stability of the dam structure during an assumed stationary overflow has to be demonstrated.

If no specific analyses have been made for the facility, as a rule the danger level corresponds to

- the crest elevation at homogeneous embankment dams (Figure 2);
- the elevation of the highest point of the core/sealing element at other embankment dams (Figure 3);
- the crest elevation, resp. that of the parapet at concrete dams (Figure 4).

2.3.2. Safety freeboard

The term "safety freeboard" refers to the distance from the danger level to the maximum water level that can arise in an extraordinary situation (Figures 2, 3 and 4). Its purpose is to prevent damage caused, for example, by wind-induced waves in an extraordinary situation. The specifications for the required minimum safety freeboard are shown in Table 1. These should only be reduced if this can be substantiated on the basis of the facility-specific properties of the reservoir.

Height of the dam structure	**H ≥ 10 m**	**10 m < H < 40 m**	**H ≤ 40 m**
Safety freeboard at concrete dams	0.5 m	Linear interpolation	1.0 m
Safety freeboard at embankment dams - Without upstream riprap - With upstream riprap	 1.0 m 1.0 m	 Linear interpolation Linear interpolation	 3.0 m 2.5 m

Table 1: Guideline values for minimum required freeboard

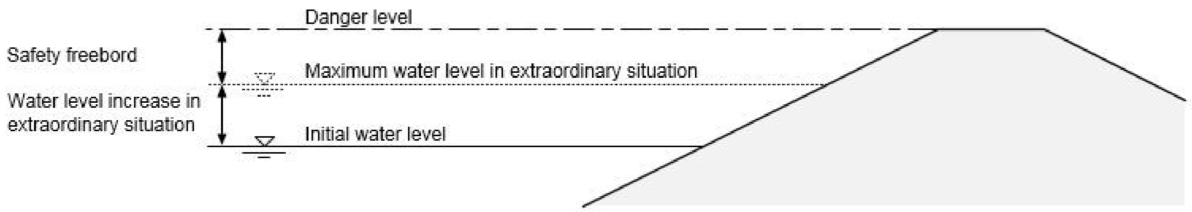

Figure 2: Danger level and safety freeboard (homogeneous embankment dams)

[1] To calculate the danger level, the effects and safety factors have to be applied that correspond to the extreme static load case t (cf. Part C1 of the Directive).

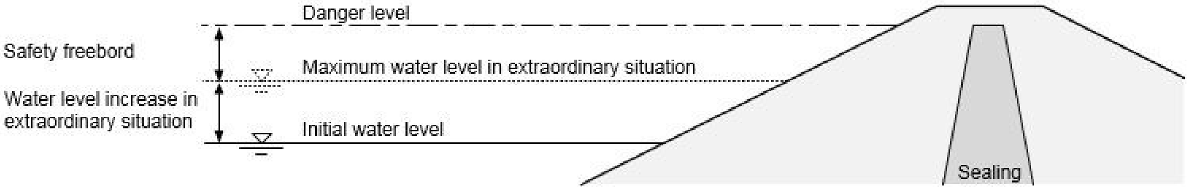

Figure 3: Danger level and safety freeboard (non-homogeneous embankment dams)

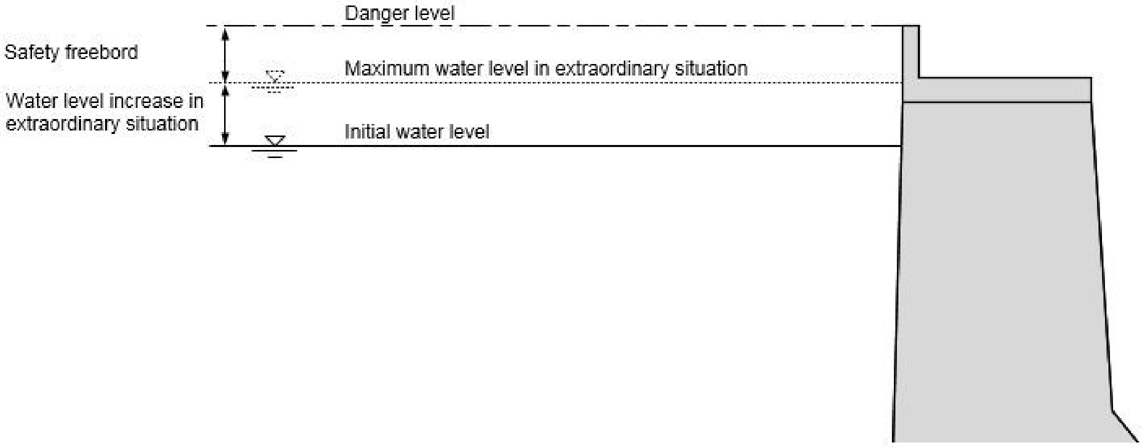

Figure 4: Danger level and safety freeboard (concrete dams)

No guideline values regarding minimum safety freeboard dimensions are provided for **weirs and lateral embankments in the immediate vicinity** (cf. section 2.7.2). However, the design flood (cf. section 2.4) has to be accommodated without any damage and without overflow of the dam structure.

For lateral **embankments beyond the immediate vicinity** (cf. section 2.7.2), the required safety freeboard should be at least 50 centimetres, subject to more stringent requirements stipulated by the licensing authority for water-rights.

If strong wind-induced wave formation at exposed locations, earthquake-induced subsidence or mass movements causing impulse waves have to be expected, an adequate total freeboard (in relation to the initial water level) must be planned in order to ensure that the safety of the water retaining facility is not threatened.

2.4. Flood event

The term “flood event” refers to the anticipated inflow (hydrograph) into the reservoir due to a potentially occurring extraordinary or extreme situation. This may be of a natural or operational nature and could include the following elements:

$Q_{\mathbf{D}}(t)$	Natural inflow from the direct catchment area (cf. sections 2.4.1 and 2.4.2)
$Q_{\mathbf{I}}(t)$	Quantity of water fed in from an indirect catchment area (feed-in capacity)
$Q_{\mathbf{T}}(t)$	Quantity of water fed in from turbines from a hydropower plant further upstream (turbine capacity)
$Q_{\mathbf{P}}(t)$	Quantity of water pumped in from a hydropower plant further downstream (pump capacity)
$Q_{\mathbf{R}}(t)$	Quantity of water flowing back from a surge tank of a hydropower plant further downstream

For the verification of flood safety, the design flood $Q_{\mathbf{B}}(t)$ has to be calculated for an extraordinary situation and the flood safety level $Q_{\mathbf{S}}(t)$ has to be calculated for an extreme situation.

Both the design flood and the flood safety level correspond to those hydrographs that give rise to the highest water level while taking account of the retention and relief capacities. As a rule, the retention calculations therefore have to be carried out for several scenarios and for several hydrographs for each scenario.

Extraordinary situation: design flood

The design flood $Q_{\mathbf{B}}(t)$ is obtained from the following scenarios:

Scenario 1	$Q_{\mathbf{B}}(t) = Q_{\mathbf{D}}(t) + Q_{\mathbf{I}}(t) + Q_{\mathbf{R}}(t)$	Direct inflows, indirect inflows, water backflow
Scenario 2	$Q_{\mathbf{B}}(t) = Q_{\mathbf{T}}(t)$	Quantity of water from turbines
Scenario 3	$Q_{\mathbf{B}}(t) = Q_{\mathbf{P}}(t)$	Pumped quantity of water

If redundant control systems[2] exist for turbine and pump operation, the verification only has to be provided for direct and indirect inflows and backflows:

$$Q_{\mathbf{B}}(t) = Q_{\mathbf{D}}(t) + Q_{\mathbf{I}}(t) + Q_{\mathbf{R}}(t)$$

If the fed-in quantity of water $Q_{\mathbf{I}}(t)$ from an indirect catchment area can be suppressed through operational measures, taking account of the fed-in water quantity may be waived with the consent of the supervisory authority.

[2] The control system has to be redundant in terms of measurement of input variables (e.g. water level), transmission of input and output variables, control unit and power supply.

Extreme situation: flood safety level

The scenario for flood safety level $Q_S(t)$ is defined as the total of the potential elements:

$$Q_S(t) = Q_D(t) + Q_I(t) + Q_T(t) + Q_P(t) + Q_R(t)$$

If redundant control systems[3] exist for turbine and pump operation, the flood safety level is obtained from the following scenarios

Scenario 1	$Q_S(t) = Q_D(t) + Q_I(t) + Q_R(t)$	Direct inflows, indirect inflows, water backflow
Scenario 2	$Q_S(t) = Q_T(t)$	Quantity of water from turbines
Scenario 3	$Q_S(t) = Q_P(t)$	Pumped quantity of water

If it is not possible to provide a verification of flood safety for scenario 2 or 3 in an extreme situation, and if redundant control systems[3] exist, flood safety can also be secured through an operational restriction. For this purpose it is necessary to ensure that at least as much retention volume is always available below the initial water level so that the volume of water present at this time in the upper reservoir (inflow via turbine) resp. in the lower reservoir (inflow via pumps) can be accommodated for. To sustain the operational restriction, the discharge works must comply with the requirements for keeping the water at a low level (cf. section 3.5). The corresponding operating restrictions ("conditions") have to be specified by the supervisory authority.

2.4.1. Natural inflow to the water retaining facility

The natural inflow $Q_D(t)$ of a flood event has to be associated with a return period as cited in Table 2.

Situation	Extraordinary situation	Extreme situation
Flood event	Design flood	Flood safety level
Return period	1,000 years	>> 1,000 years

Table 2: Return periods of natural inflow of flood events.

To determine the flood hydrograph, any existing restriction of the capacity of the inlet channel may be taken into account if this capacity restriction can be demonstrated.

For **lateral embankments beyond the immediate vicinity of a weir** (cf. section 2.7.2), the natural part of the design flood or flood safety level have to correspond to return periods of at least 100 and 300 years respectively, subject to more stringent requirements specified by the licensing authority for water rights.

For **retention basins in Category III**, the supervisory authority may adapt the requirements to the flood events to be taken into consideration (cf. section 2.7.1).

[3] The control system has to be redundant in terms of measurement of input variables (e.g. water level), transmission of input and output variables, control unit and power supply.

2.4.2. Methodology for estimating natural inflow

The natural part of a flood event has to be estimated with the aid of scientifically-based site-specific studies. Any uncertainties with respect to the applied methodology have to be examined and evaluated. Where possible, several methods should be used that are independent of one another.

The minimum requirements that apply for each category of water retaining facility regarding the methodology for estimating the natural inflow are indicated in Table 3. The limits of applicability for each method are shown in Appendix 1.

If the applied methods do not suffice for the specific circumstances of the water retaining facility, more detailed investigation have to be made and more refined methods have to be applied.

For the assessment of flood events in extraordinary and extreme situations, empirical and pseudo-empirical methods (cf. Appendix 1) are normally unsuitable.

Flood event	**Category I water retaining facility**		**Category II water retaining facility**		**Category III water retaining facility**	
Design flood	and	M1 M2 + SG or + NAM	and	M1 M2 + SG or + NAM	or	M1 M2 + SG or + NAM
Flood safety level	and	M3 M4 + NAM for comparison	possibly	M3 M4 + NAM for comparison	possibly	M3 M4 + NAM for comparison

Table 3: Overview of minimum requirements in terms of methodology;
M1-M5: Methods 1-5 (cf. section 2.4.2.), SG: Synthetic hydrograph (cf. section 2.4.2.1),
NAM: Precipitation discharge model (cf. section 2.4.2.2).

Overview of methods and procedures

M1: Statistical methods based on inflow measurement series:
With these methods it is possible to estimate peak inflow. If no details regarding the hydrograph are available, the retention effect may not be taken into account. Statistical methods based on inflow measurement series require a sufficiently lengthy duration of observation of the inflows and a sufficiently refined temporal resolution of the measurement series. If the duration of observation is insufficient (cf. Appendix 1), in the case of catchment areas without snow and glaciers, precipitation measurement series can be incorporated, for example with the aid of the Gradex [Guillot & Duband 1967) or Agregee [Margoum 1994) procedures.

M2: Statistical methods based on precipitation measurement series:
With these methods it is possible to estimate precipitation intensity. In order to allocate a flood hydrograph to precipitation events, synthetic hydrographs (cf. section 2.4.2.1) or precipitation discharge models (cf. section 2.4.2.2) can be used. Statistical methods based on precipitation measurement series require a sufficiently lengthy du-

ration of observation of precipitation. If the duration of observation is insufficient (cf. Appendix 1), an extrapolation may be made based on the “best estimate” values [MeteoSchweiz 2016 (2016 version or later)]. If the reliability of the results is classified as “questionable” or “insufficient” by [MeteoSchweiz 2016], or if no representative precipitation measurement station exists for the catchment area, preference should be given to the data contained in sheet 2.4 of the Hydrological Atlas of Switzerland [FOEN 2007]. If the duration of observation of the precipitation is insufficient, precipitation series generated with the aid of stochastic procedures (e.g. the Neyman-Scott model, [Burton et al, 2004]) may also be used.

With respect to return period, the assumption has to be made that that of the precipitation is identical to that of the flood event.

M3: Procedure for calculating the flood safety level based on the design flood:
With this procedure the hydrograph of the natural inflow of the flood safety level $Q_{\mathbf{D,S}}(t)$ can be estimated based on the hydrograph of the corresponding part of the design flood $Q_{\mathbf{D,B}}(t)$.

For existing facilities: by increasing the inflow by 50% [Biedermann et al. 1988]:

$Q_{\mathbf{D,S}}(t) = \mathbf{1.5}\ Q_{\mathbf{D,B}}(t)$ (cf. Figure 5).

For new or altered facilities: by increasing the inflow and event duration by 50% each [Biedermann et al. 1988 , SFOE 2008]:

$Q_{\mathbf{D,S}}(t) = \mathbf{1.5}\ Q_{\mathbf{D,B}}\left(\frac{\mathbf{2}}{\mathbf{3}}t\right)$ (cf. Figure 5).

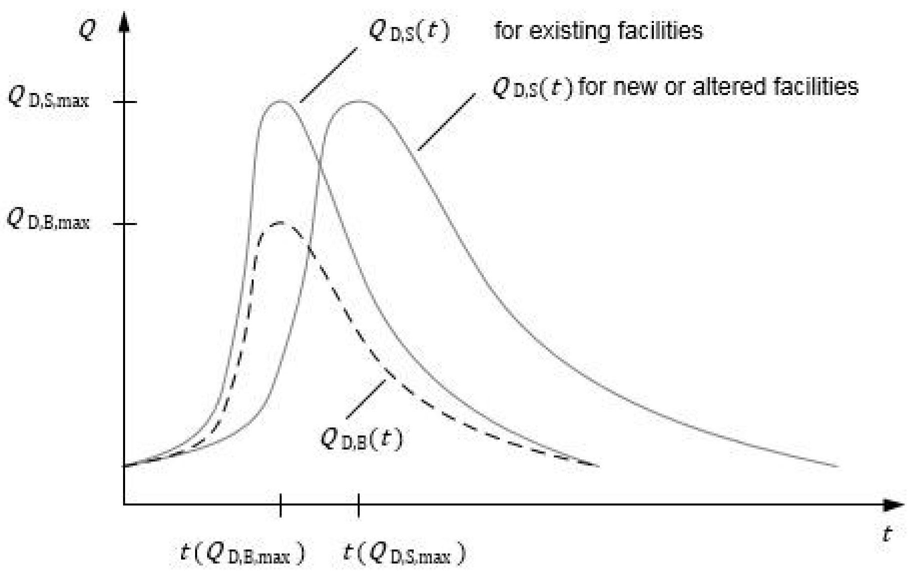

Figure 5: Schematic inflow hydrographs of the natural part of the flood safety level and design flood.

M4: Methods based on the probable maximum precipitation (PMP) procedure:
These methods can be used for estimating the site-specific maximum probable precipitation based on the assumption of most unfavourable meteorological conditions (cf. Appendix 1). A flood hydrograph has to be allocated to the precipitation events with the aid of a precipitation discharge model (cf. section 2.4.2.2). PMP maps for Switzerland are depicted in [Hertig et al. 2007].[4] If other PMP maps or site-specific PMP studies are referred to, the deviations from the cited PMP maps have to be substantiated.[5]

2.4.2.1. Assumptions regarding synthetic hydrographs

If synthetic hydrographs are depicted on the basis of precipitation, the assumption has to be made that the overall volume of precipitation contributes towards the volume of water flowing into the reservoir.[6] Deviating phenomena such as those that can occur for shorter return periods are not taken into account here for the considered flood events. If the contribution from snow and glaciers towards flood events could be significant, this has to be taken into account; here, preference should be given to a precipitation discharge model.

If no other specific clarifications have been carried out, in an initial approximation the synthetic flood hydrograph in accordance with Maxwell [Sinniger & Hager 1984]

$$Q(t) = \left(\frac{t}{t_{\max}} e^{\left(1 - \frac{t}{t_{\max}}\right)}\right)^n Q_{\max}$$

with the pertaining flood volume

$$V = Q_{\max}\, t_{\max} \frac{e^n n!}{n^{n+1}}$$

may be assumed. The time $t_{\max}$ corresponds to the duration up until the flood peak; it may be assumed that this is equivalent to the duration of precipitation. If synthetic flood hydrographs are prepared on the basis of precipitation (M3), value 6 should be set for the exponent *n*. Deviating values for *n* between 1 and 6 may be exclusively taken into account if these have been determined through studies of the specific characteristics of the catchment area.

[4] To date, little experience has been made with the use of these PMP maps. The calculated precipitation (PMP) and inflows (PMF) therefore have to be compared with the results of other methods and subsequently evaluated.
[5] If probabilistic observations are incorporated into the calculation of PMP values, the latter must correspond to an exceedance probability of approximately 10^{-4} per annum.
[6] Thus the so-called volume discharge coefficient is 1.

2.4.2.2. Assumptions concerning the precipitation discharge model

A precipitation discharge model can be used for allocating a time-dependent inflow into the water retaining facility to a precipitation event (event-based modelling) or a precipitation time series (long term simulation). Such a model can be used for depicting the hydrological behaviour of the catchment area during extraordinary and extreme events.

- With **event-based modelling** it is possible to calculate the flood event associated with a precipitation event. In the first step, the volume of the precipitation event has to be distributed over its duration. For this purpose, a rainfall mass curve can be used, for example [Zeimetz 2016]. In a second step, the resulting inflow into the water retaining facility can be calculated on the basis of the time-dependent precipitation. Here the following assumptions have to be made:
  When preparing the model, the initial conditions (such as saturation of the underground, thickness of the snow layer and its saturation, etc.) have to be defined as the least favourable possible or deduced from the prevailing initial conditions with rare to extreme events. In the latter procedure, the sensitivity of the inflows in terms of the initial conditions has to be noted.
  The inflow into the water retaining facility from snow melt from the various altitudes has to be taken into account with the aid of a hydrological snow model. If no such model and no site-specific studies of snow melt rates and snow depths are available, it may be assumed that the snow melt rate is 50 millimetres per day (water equivalent) [Würzer et al. 2016], and that this snow melt rate persists throughout the entire duration of the precipitation event.

- With a **long-term simulation**, based on lengthy time series for initial dimensions (e.g. precipitation, temperature, radiation) it is possible to calculate a continual discharge time series that can subsequently be evaluated in terms of extreme value statistics.

2.5. Relief options

<u>Extraordinary situation</u>

For **concrete dams** and **embankment dams** the design flood $Q_{\mathbf{B}}(t)$ can be verified based on the assumption that

a) the most efficient of the “n” gated relief and outlet works[7] is out of operation (“n - 1” rule);

b) no water can be diverted through intake works. This does not apply if the power plant is protected against flooding and the passive release of water (e.g. via turbines in open position) or the continued operation of the machines (e.g. thanks to the presence of two separate high-voltage power lines) can be demonstrated for the duration of the event. In any case, no more than “n-1” turbines may be taken into account for the verification.

[7] The term “relief and outlet works” refers to spillways, bottom outlets, middle outlets, diversion shafts, weir gates and sluices.

For **run-of-river facilities (weirs)** the design flood $Q_{\mathbf{B}}$(t) must be accommodated based on the assumption that

a) the most efficient among the "n" gated relief and outlet works[8] is out of operation ("n - 1" rule);
b) all turbines can be used if the passive release of water or the continued operation of the machines can be demonstrated.

For **retention basins**[9] the design flood $Q_{\mathbf{B}}(t)$ must be accommodated based on the assumption that

- any openings (bottom outlet or flow-through with or without grills or panel mechanisms) are out of operation or clogged. This does not apply if adequate structural measures have been taken that prevent clogging.

Extreme situation

For **concrete dams** the flood safety level $Q_{\mathbf{S}}(t)$ must be accommodated based on the assumption that

a) all relief and outlet works can be used;
b) no water can be removed via any existing pressure tunnels.[10]

For **embankment dams** the flood safety level is to be verified $Q_{\mathbf{S}}(t)$ based on the assumption that

a) the most efficient among the "n" relief and discharge systems[8] with movable mechanisms is out of operation ("n – 1" rule,
b) no water can be diverted through intake works.[10]

For **run-of-river facilities (weirs)** the flood safety level $Q_{\mathbf{S}}(t)$ must be accommodated based on the assumption that

a) all relief and outlet works can be used;
b) all turbines can be used if the passive release of water or the continued operation of the machines can be demonstrated.

For **retention basins**[9] the flood safety level $Q_{\mathbf{S}}(t)$ must be accommodated based on the assumption that

- any outlets (bottom outlet or flow-through with or without grills or panel mechanisms) are out of operation or clogged. This does not apply if adequate structural measures have been taken that prevent clogging.

If it has to be assumed that, in an extraordinary or extreme situation, other relief and outlet works could no longer be functional or put into operation, these may not be taken into account for the verification of flood safety.

[8] The term "relief and outlet works" refers to spillways, bottom outlets, middle outlets, diversion shafts, weir gates and sluices.
[9] For retention basins in Category III water retaining facilities the supervisory authority may stipulate other requirements, cf. section 2.7.1.
[10] In the case of pump storage facilities with independent and redundant control systems, the turbine and pump quantities of water for diverting scenario 2 and 3 flood events may be taken into account with the consent of the supervisory authority.

2.6. Structural requirements for discharge systems

2.6.1. Prevention of clogging

If in the event of a potential rise in the water level because of clogging due to debris (especially driftwood), preventive measures have to be taken, for example [STK 2017]:

a) reduction of the quantity of driftwood and other debris in the catchment area (cf. section 2.6.1.1);
b) enabling the transit of driftwood and other debris (cf. section 2.6.1.2);
c) retaining driftwood and other debris in the reservoir (cf. section 2.6.1.3).

2.6.1.1. Reduction of driftwood and other debris in the reservoir

The quantity of driftwood and other debris in the reservoir can be reduced through forestry management, maintenance of rivers and measures to strengthen and protect banks and slopes. It can also be reduced by installing grates and nets at tributaries.

2.6.1.2. Enabling the transit of driftwood and other debris

Relief systems can be designed so that they permit the flow-through of driftwood and other debris.

These should if possible take the form of free overflows without additional structural elements (such as weir bridges, road bridges or pedestrian bridges).

The required dimensions of relief works depend on the expected size of driftwood, which can be estimated on the basis of observations made during flooding, or of the forestation in the vicinity of the reservoir. Relief works should be wider than 80% of the expected size of the driftwood (tree length) [Godtland & Tesaker 1994]. If no such information are available, the figures presented in Table 4 [CFBR 2013] may be taken as a basis for determining the minimum width of relief works.

Water level	**$z \geq 600$ m.a.s.l.**	**600 m.a.s.l. $< z <$ 1,800 m.a.s.l.**	**$z \leq 1{,}800$ m.a.s.l.**
Minimum width of relief work	15 metres	Linear interpolation	4 metres

Table 4: Minimum width of relief work depending on water level z.

The height of a relief outlet, which is based on the clearance between its threshold and the lower edge of any existing weir bridge or other structures, should be at least 15% of the expected size of driftwood, as long as the actual width of the opening is greater than 100% of the relevant driftwood size (tree length). If the width of the opening is between 80 and 100% of the expected driftwood size, the height of the relief work should be equivalent to at least 20% of the driftwood size (tree length) [Godtland & Tesaker 1994].

If, in an extraordinary situation, the clearance between the weir bridge (or other structures) and the water level (cf. Figure 6) is less than specified in Table 5 [CFBR 2013], a higher risk of clogging has to be assumed. In this case, more detailed clarifications have to be made in order to be able to estimate the effective clogging risk.

Overflow height (cf. Figure 6) in an extraordinary situation	**$h_ü \geq 2$ metres**	**$h_ü > 2$ metres**
Minimum clearance (cf. Figure 6) in an extraordinary situation	2 metres	1.5 metres

Table 5: Minimum clearance between the weir bridge (or other structures) and the water level, below which there is an increased risk of clogging.

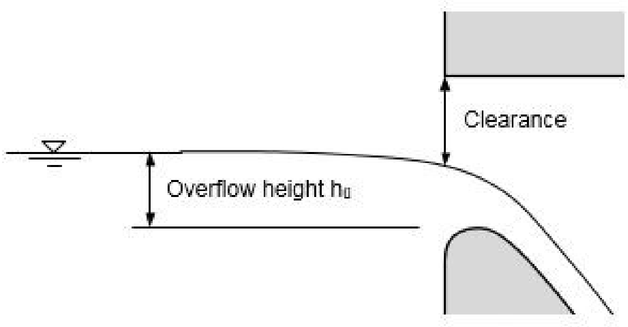

Figure 6: Height of overflow and clearance for relief works

2.6.1.3. Retention of driftwood and other debris in the reservoir

Generally speaking, retention in the reservoir is an option for water retaining facilities with a relatively high ratio of reservoir volume to annual inflow of at least 0.2 and small fluctuations in the reservoir water level. The driftwood and other debris can be retained in the reservoir with the aid of grates, baffles or floating barriers. These items have to be assessed on the basis of the current status of technology. They should be installed at locations where the flow rate is slow, and sufficiently far away from the relief work.

2.6.2. Prevention of scouring

In order to prevent scouring that could destabilise the dam structure, the base of the dam should be erosion-proof. Here the following principles should be observed:

- the discharge via the relief works should be slowed down in an energy dissipation structure (stilling basin) or, if the topographic and geological conditions are favourable, diverted under water via a spillway;
- if there are no plans to install a stilling basin at the base of the dam structure, the geometry of the scouring formation should be calculated and, where necessary, the stability of the dam structure at the identified location should be verified;
- in the case of debris barriers, the increased degree of scouring caused by the debris has to be taken into account.

2.6.3. Prevention of control mechanism malfunctions

Malfunctions of the control mechanism of gated relief works have to be prevented through the use of robust and redundant systems. The use of backup systems should also be planned. Here the following principles should be observed:

- robust detectors, control devices and drives should be installed. Redundant detectors and control devices should be installed. A separate emergency power supply should be installed: as a rule, an uninterruptible power supply (UPS) device for the control unit and an emergency power generator for the drives;
- if the gates of the relief works are operated via remote control, it should also be possible to operate these locally;
- it must always be possible to operate the gates manually;
- even during an extreme situation, the mechanisms for manual operation, the drives and a control unit must always be accessible and the power supply and its ducts must be fully secured against the influence of flood water.

2.7. Special situations

2.7.1. Small water retaining facilities in Category III

In the case of small water retaining facilities in Category III, the supervisory authority

- may adapt the extraordinary situation – it may, for example, ease the requirements with regard to the design flood or the necessary freeboard;
- may waive the verification for an extreme situation if the corresponding requirements relating to the protection of the population against natural hazards are met with respect to the overflow case [BWG 2001].

2.7.2. Lateral embankment dams

This term refers to the lateral embankments located in the vicinity of a run-of-river facility. The location extends as far as the licensed stretch of river or as far as the downstream foot of an upstream water retaining facility (cf. Figure A13 in Part A of the Directive).

For lateral embankment dams in the immediate vicinity of a weir[11] the requirements relating to flood safety are specified in this document.

For lateral embankment dams outside the immediate vicinity of a weir[11] the corresponding licensing provisions for water rights are applicable. This document merely specifies the minimum requirements.

Upon consultation with the relevant cantonal authority responsible for flood protection, the supervisory authority may impose more stringent requirements for certain sections of embankment dams.

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[11] The supervisory authority defines the immediate vicinity of a weir; the influence of the area concerned on the stability of the weir has to be taken into account to this effect.

2.7.3. Overhauls and construction

During overhauls and construction, the flood events that need to be accommodated are defined while taking account of the potential impacts for third parties.

Where possible, maintenance and repair work on relief and outlet works should be carried out outside of the flood season.

2.7.4. Flood safety after an earthquake

After an earthquake, it must be possible to accommodate a flood event with a return period of at least 10 years (cf. Directive, Part C3, section 2.2).

3. Dimensioning criteria for discharge works

3.1. General requirements

Discharge works have to be dimensioned for the following purposes:

a) Lowering of the water level in the event of an immediate risk of an uncontrolled discharge of water (cf. section 3.2)

b) Lowering of the water level in the event of a military threat (cf. section 3.3)

c) Lowering of the water level for inspection and maintenance purposes (cf. section 3.4)

d) Maintaining a low water level following a lowering of the reservoir water level (cf. section 3.5)

e) Regulation of the water level during the initial filling of the reservoir (cf. section 3.6)

f) Flushing the reservoir (cf. section 3.7)

g) Diversion of flood water (cf. section 3.8)

The positioning of the discharge work should be planned so that the above objectives can be met while taking account of the probable development of sedimentation and possible mass movements in the reservoir.

3.2. Lowering of the water level in the event of an immediate risk of an uncontrolled discharge of water

The aim here is to be able to halve the hydrostatic force versus the initial water level (cf. section 2.2) within 8 days. In addition, it must be possible to empty the reservoir within the maximum draining time specified in Table 6.[12] Here, inflows have to be taken into account that correspond to the mean long-term values during the summer months. Water discharged by the turbines may be added to the discharge capacity.

Storage capacity	**V ≥ 1 million m³**	**1 million m³ < V < 10 million m³**	**V ≤ 10 million m³**
Maximum draining time	(1 to) 3 days	Linear interpolation	21 days

Table 6: Draining time in dependence on storage capacity

[12] The facility-specific draining time should be specified upon consultation with the supervisory authority. Here, attention has to be paid to anticipated damage to third parties in case of a breach of the dam after the reservoir level has been lowered.

The necessary capacity of the discharge works for draining the reservoir may be adapted upon consultation with the supervisory authority, taking account of the discharge capacity of the reservoir downstream.

3.3. Lowering of the water level in the event of a military threat

In the event of a military threat, it must be possible for water retaining facilities that fulfil the criteria governing the installation of a water alarm system in accordance with Article 11, WRFA and Article 26, WRFO, to lower the water level to the critical military level within 3 days.[13] Here, inflows have to be taken into account which correspond to the mean long-term values during the summer months. Any water discharged through the turbines may be added to the discharge capacity.

For concrete dams, the critical military level is equivalent to the level at which the dam is 15 metres thick. For embankment dams, it is defined as the level that lies 20 metres below the dam crest. The critical military level may be set at a higher level if a high risk as defined in Article 26, paragraph 2, WRFO, does not exist when the water level is at that level or below.

The necessary capacity of the discharge works for draining the reservoir may be adapted upon consultation with the supervisory authority, taking account of the discharge capacity of the river downstream.

3.4. Lowering of the water level for inspection and maintenance purposes

No requirements are specified regarding the capacity of discharge work in connection with lowering the water level for inspection and maintenance purposes.

3.5. Maintaining a low water level following a lowering of the reservoir water level for safety reasons

The capacity of the discharge works must be sufficient to permit to maintain a low water level in the reservoir. It it must be demonstrated that it is possible to discharge direct natural inflows up to a return period of 5 years without an increase in the reservoir water level. For this purpose it has to be assumed that the lowered water level is at the point at which the hydrostatic force is halved. This point is normally at 71% of the dam height (or higher). Any water discharged through the turbines may be added to the discharge capacity.

This requirement does not apply to run-of-river facilities, installations intended to protect against natural hazards and those facilities that do not meet the geometric subordination criteria in accordance with Article 2, paragraph 1, WRFA.

3.6. Control of water level during initial filling of the reservoir

The requirements relating to the capacity of the discharge works for controlling the water level during initial filling of the reservoir are covered by those governing the maintenance of the water level after it has been lowered for safety reasons.

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[13] If this requirement is not met in an existing water retaining facility, the discharge capacity does not have to be increased for this reason. However, it may not be reduced.

3.7. Flushing of the reservoir

The requirements relating to the capacity of the discharge equipment for flushing the reservoir are primarily of an operational nature and are therefore not dealt with in this part of the Directive.

3.8. Flood diversion

Discharge workst can contribute towards the overall outflow capacity of a facility as long as it can also be operated during extraordinary and extreme flood events. More detailed information is provided in section 2.

3.9. Structural requirements for discharge works

Discharge works have to be designed so that any clogging due to sedimentation and blockage of the gates can be prevented. The cross-sections, intake grates and distances between maintenance and operation gates therefore have to be correspondingly designed. In addition, the system components have to be designed so that their functionality cannot be affected by the formation of ice.

If there is a risk of clogging due to sediment in the reservoir, suitable preventive structural measures or periodical flushing should be planned in order to ensure that a hopper in front of the outlet is kept free from sediment.

An emergency power supply has to be available for the mechanical operation of gates. It must always be possible to also operate these elements manually. As a rule, for Category III water retaining facilities it is usually sufficient to install exclusively manually operated drives.

Remote controlled gates should open in steps in order to ensure that they cannot be fully opened unintentionally.

In the case of newly constructed Category I and Category II water retaining facilities, the discharge works must be fitted with at least two gates (one for maintenance and one for operations).

4. Testing of the functionality of relief and outlet works

4.1. Extent of the test

The functionality of all gates must be tested at least once a year if they were not used in the course of the year.

All components have to be tested. The test must in particular encompass
- the drives (including manual operation);
- the control mechanisms (local and remote control, regulation);
- the energy supply (including the emergency supply).

The interaction between the individual components also has to be tested.

In addition, the condition of the relief and outlet works has to be examined. This must in particular encompass
- the hydro-mechanical components (gates, valves, grates, bearings, guide profiles, sealing elements, drives);
- intake structures;
- channels and shafts which are not under water;
- outlet structures, spillway chutes;
- foot of the dam structure.

The structure of the functionality test has to be specified in the surveillance regulations. Where possible, tests should be carried out by those persons who, in accordance with the dam and emergency regulations, are responsible for operating the gates in the occurrence of a flood or other event.

The test of the functionality of the gates of the relief and outlet works should be carried out under similar conditions to those that could occur in the event of an abnormal situation that calls for the operation of these components. In particular, the test must take place with water discharge (“wet inspection”) and with a high water level. The minimum water level for the test has to be specified in the surveillance regulations.

Before initiating a functionality test, the condition of the discharge structures (including shafts and spillway chutes) should be inspected. Any obstacles such as snow or deposits of sediment, etc., must be removed. It is also essential to ensure that no one is in, or in the vicinity of, the section of the watercourse in which water is to flow during the test.

4.2. Testing of the outlet gates

For the purpose of testing the outlet gates with water discharge, it is sufficient to only partially open them. The degree to which they have to be opened must be specified in the surveillance regulations (as a rule, 10 centimetres). The gate can then immediately be closed again so that the quantity of discharged water remains low. After the operational gate has been partially opened, it can then be fully opened under the protection of the closed maintenance gate or a dam bulkhead. The standard procedure is described in Appendix 2.

4.3. Testing of the spillway gates

The spillway gates (vertical gates, sector gates, valves) also have to be subjected to a functionality test. If the flow conditions permit, they should be tested with water discharge. Otherwise a detailed inspection of the drives has to be carried out and, where possible, the mechanisms should be fully opened (without water discharge).

4.4. Testing of the gates of run-of-river weirs

The gates of run-of-river facilities also have to be subjected to a functionality test if they were not used in the course of the year. This test only requires a partial opening.

Functionality tests with fully opened gates should be scheduled in accordance with a planning over several years, provided this is permitted by the operating conditions and no risk arises for facilities and people downstream.

4.5. Testing of the gates of retention basins

The gates in retention basins and in structures for stabilising the river beds may be tested under dry conditions.

4.6. Test report

Reports have to be compiled for functionality tests. Each report must include the course of the test, the degree of opening of the gates, the duration of opening and closure, hydraulic pressures, comments on manual operation, notes concerning any occurrences, deviations from the procedure specified in the monitoring regulations.

The results of the functionality tests have to be evaluated by the qualified professional and assessed in the annual report. For this purpose, reference should be made to target values and the results of previous tests. Functionality test reports must be enclosed in the annual report.

5. Gate regulations

5.1. Purpose and content of the gate regulations

Gate regulations have to be drawn up by the operators of all water retaining facilities that are equipped with gated relief and outlet works, and submitted to the supervisory authority for approval.

Gate regulations must contain instructions on how the gates are to be operated if a flood event should occur. It should specify the use of gates for safety reasons, but not their normal operation. The following aspects have to be specified:

- the position of the gates depending on the water level (as a rule, up to their complete opening, though at least to the degree of opening at which flood water can be safely discharged);
- the prerequisites under which the water retaining facility must be manned (weather conditions, water level);
- the procedure for the manual operation of the outlets if the control mechanism should malfunction.

If the inflows are diverted up to the flood safety level without the need to open the gates, it should be stated in the regulations that the latter should not be operated in order to deal with a flood event.

Dam regulations should also include the following content:

- the assumptions on which the verification of flood safety is based (design flood $Q_B(t)$, flood safety level $Q_S(t)$, initial water level, danger level, safety freeboard, applicable discharge capacities, references to the corresponding hydrological studies);
- the volume of the reservoir as a function of the water level;
- the capacity of the discharge and outlet works as function of the water level;
- the capacity of the turbines and the lowest possible turbining water level;
- technical specifications and diagrams of the relief and outlet works;
- locations at which the gates of the relief and outlet works are operated.

The gate regulations must be available at all locations at which the gates can be operated.

5.2. Preparation of the gate regulations

The following points should be noted concerning the preparation of the dam regulations:

- the operation of the gates during a flood event should be planned so that the peak outflow does not exceed the anticipated peak inflow into the reservoir;[14]
- the discharge rate should be increased gradually – sudden changes in the flow rate should be avoided wherever possible.

5.3. Examination and approval of the gate regulations by the supervisory authority

The supervisory authority has to verify whether the procedure described in the dam regulations enables flood events to be effectively managed up to flood safety level.

Other aspects, notably those of an ecological and operational nature, are not part of the approval process.

The supervisory authority will, upon their request, provide the cantonal civil protection authorities with a copy of the approved dam regulations.

[14] Here, other arrangements may be made upon consultation with the relevant supervisory authority for the purpose of ensuring flood protection.

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Appendix 1: Standard methods for estimating flood events

	Methods:	References	Scope of application		
			Period of recurrence [years]	Size of catchment area [km^2]	Characteristics of catchment area
M1	Statistical extrapolation of inflows with the aid of extreme level statistics Applied dataset: "Annual flood series, AFS" or "Peak over threshhold, POT"	[Fréchet 1927, Gumbel 1958, Coles 2001] AFS: [Jenkinson 1955] POT: [Davison & Smith 1990]	Up to 2-3 times the observation period (AFS)	-	Stationary tests have to be carried out. This applies especially to catchment areas with snow, glaciers or karst.
	Gradex	[Guillot & Duband 1967]	1,000-10,000	Up to 5,000	For catchment areas without snow, glaciers or karst
	Agregee	[Margoum et al. 1994]	10-10,000	Up to 5,000	For catchment areas without snow, glaciers or karst
M2	Statistical extrapolation of precipitation with the aid of extreme level statistics	[Coles 2001, Meylan et al. 2008]	Up to 2-3 times the observation period	-	-
M4	PMP-PMF	[WMO 2009, Hertig et al. 2007, Zeimetz 2016]	-	5-200 (for PMP maps of Switzerland)	-
Empirical and pseudo-empirical methods	BaD7	[Barben 2001, BWG 2003]	Any	10-200	Not suitable for catchment areas with extreme characteristics (e.g. urban catchment areas or areas with extensive glacier formations)
	GIUB'96	[Kan 1995, Weingartner 1999, BWG 2003]	100 (as well as maximum flood)	10-500	-
	Müller-Zeller	[Müller 1943, Zeller 1975, BWG 2003]	approx. 100	2-100	Problematic in mountainous and densely developed catchment areas
	Kürsteiner	[Kürsteiner 1917, BWG 2003]	approx. 100	5-500	-
	Melli	[Melli 1924]	Maximum flood	0.3-10,000	-
	Rational formula	[Kuichling 1889, BWG 2003, Hingray et al. 2014]	-	-	-
	Kölla meso	[Kölla 1987, BWG 2003]	2.33, 20 or 100	10-500	Problematic in mountainous and densely developed areas; not suitable for catchment areas with extreme characteristics (e.g. areas with extensive glacier formations or high average altitudes)

Appendix 2: Normal course of functionality test gates

Course of test for a single gate
For discharge systems with only one gate, the latter should be partially opened (as a rule by at least 10 centimetres).

Course of test for two gates in series:
In this case the functionality test is normally carried out as depicted in Figure 7.

Course of test for three grates or valves in series:
Here the operator should specify which gate is to be used for maintenance and which one for operational purposes. The functionality test of the two gates is carried out as depicted in Figure 7. The third gate may be regarded as an additional maintenance outlet and can to be tested without water discharge.

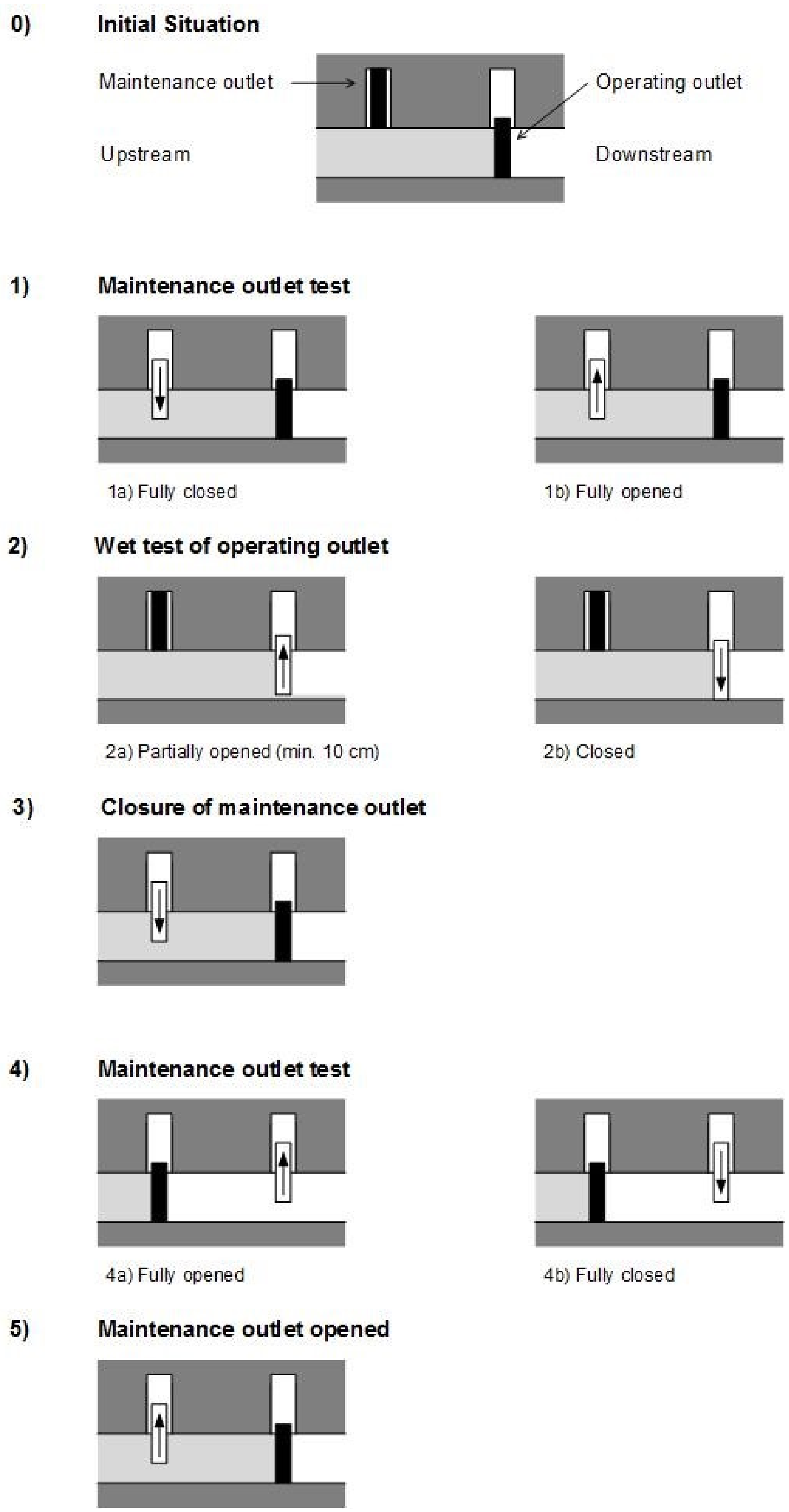

Figure 7: Procedure for testing the functionality of two gates in series.