RIDAS

Hydropower Industry Dam Safety Guidelines

Section 3
Consequence classification
Application instruction

15/12/2011

The industry guidelines for dam safety have been translated to enable wider dissemination of the guidelines to a broader public. However, the translation should not be considered as the official version of the guidelines. In the event of discrepancies between the two, the Swedish version shall take precedence.

Contents

3 CONSEQUENCE CLASSIFICATION

3.1 General

Dam safety work is governed by consequences. Therefore, dams must be classified on the basis of the consequences that may result from a dam failure. The consequences of dam failures are assessed in respect of the probability of:

- **severe strain on society**
- **serious injury or loss of human life**
- **other damage to the environment, local facilities and financial values**

Purpose

The purpose of **this application instruction** is to develop and describe criteria for implementing dam classification in accordance with RIDAS, and to propose, in an informative manner, methods and minimum requirements for information and documentation during classification.

Scope

RIDAS, like the Swedish Committee for Design Flood Determination, states that dams are classified on the basis of the consequences that may result from a dam failure. This classification is based on the **marginal consequence**; that is to say, additional damage resulting from a dam failure. The damage referred to in this context is the increase in the damage to the surrounding area caused by the collapse of the dam, over and above the damage which a high flow, for example, would have caused even if the dam had not collapsed. The purpose of classification, according to Swedish Committee for Design Flood Determination guidelines, is to establish design flood dimensioning class. The Swedish Committee for Design Flood Determination guidelines take into account only flow-initiated dam failures, while RIDAS also takes into account dam failures initiated in other ways.

The basis of distribution for consequence classification is based on an assessment of whether the damage (consequence) of a dam failure is unacceptable, limited or negligible in respect of the public interest. According to RIDAS, these criteria provide a basis for classification in three main classes.

All dams must be classified. This classification relates to consequences both upstream (e.g. landslides) and downstream of the dam in question. Where there are several dam units in one and the same facility, these are each classified individually. However, there is reason to classify different dam elements in one and the same dam only in exceptional cases. Definitions of dam units and dam elements can be found in the Power Industry Dam Register.

The nature of the dam failure must be taken into account when classifying a dam. Factors such as the amount of time the dam failure took and the size of the breach are studied. The dam failure with the most extensive consequence determines the classification.

The effect of the dam failure on downstream dams and the risk of continued dam failures (the domino effect; see section 3.2 below) are also taken into account when classifying a dam.

This instruction relates to classification of both new and existing dams. Upstream dams are also taken into account when constructing new dams. It is assumed that consultation takes place between dam owners with regard to classification.

Consequence classification is performed by the dam owner in question, on his own initiative. Classification is established by the person responsible for dam safety and reported to Kraftindustrins Dammregister (the Power Industry Dam Register), Swedenergy.

Investigation and documentation requirements

The consequence class must be documented and justified. In each individual case, classification must be based on a consequence analysis which is documented. The requirements concerning document content will vary in each individual case, depending on the nature of the damage in the event of a dam failure. Details on physical criteria such as geographical location, dam type, dam height, discharge arrangements, etc. for the facility may be included in the overall classification documentation. Alternatively, please see the manual concerning operation, status control and maintenance (the DTU manual) for the facility in question.

3.2 Dam failures, sequences of events and consequences

General

Consequence classification is relatively uncomplicated in many instances, and dams can be classified by means of a feasibility assessment. This is particularly true of the dams belonging to the highest and lowest consequence classes. In the dubious cases and when the dams will visibly be classified in consequence classes between these two extremes, evaluation of potential damage should be based on a dam failure assumption and a detailed flood study based on the most serious of dam failures. The degree of detail in the study is governed by how difficult it is to assess the potential consequences of a failure, along with how conservative one chooses to be with assessments. In simpler cases, the calculation methods and determination of calculation parameters can be simplified.

The consequences of a dam failure are assessed for **both normal situations and high flow situations**. The rise rate, water level and water speeds taken from flood studies and flood wave calculations constitute a basis. This classification is based on the **marginal consequence**; that is to say, additional damage resulting from a dam failure. A dam failure at the flow causing the greatest additional damage determines the consequence class.

Continuous dam failures along the waterway (domino effect)

When several dams are located along the same waterway, continuous dam failures may occur due to the flow arising from a dam failure upstream. This may also result in the collapse of dams located downstream (the domino effect). There is a link between dams upstream and downstream and the potential damage. This is why it is necessary to study, in a cohesive manner, the spread and effects of the flow or combination of flows that may result from the dam failure.

During classification, it must be possible to assume the collapse of downstream dams if the water level exceeds the safe washing-over level of the dam, normally the top of the core. Any ability of concrete dams to withstand overflow must be taken into account.

The procedures indicated below can be applied when classifying the various dams on one and the same section of river. The extent of the flow is calculated down to the downstream dam. The effects on the dam downstream can be divided into two situations:

1. The reservoir downstream can store and/or discharge the failure flow. In this instance, there will be no continuous dam failure in downstream dams, and hence each dam can be classified individually.
2. A downstream dam is unable to store or discharge the flow coming from an upstream dam, hence the dam can be assumed to failure. This gives rise to a new scenario which constitutes a dam failure, while at the same time the failure flow from the upstream dam is added to this. In this instance, the **overall effect** of the continuous dam failure is **taken into account** in the classification.

Many different dam failure situations may occur along a waterway which has several dams. These failure situations should each be analysed individually by determining the potential effects for each river section. Conservative criteria are always applied. **Generally, a dam located upstream which may cause failures in other dams downstream will always be placed in at least the same consequence class as the dam downstream which would have the most major consequences in the event of a dam failure.**

As there is a risk of continuous dam failures, a joint assessment of all dams on a river section must be carried out; in practice, this requires coordination and exchange of information between the various dam owners.

It is not necessary to assume that two dams, located on two different branches of a river which flow together downstream, will fail at the same time; instead, these dams can be classified independently of one another.

3.3 Consequence classes

The consequences of dam failures are assessed in respect of the probability of:

- **severe strain on society**
- **serious injury or loss of human life**
- **other damage to the environment, societal facilities and financial values**

This classification system consists of the consequence classes 1+, 1, 2 and 3, 1+ corresponding to the most serious consequences.

The control of dam safety work constituted by the consequences of a dam failure means that the classification is the decisive factor for the application of all elements in RIDAS. It is important for each and every one of the classes to correspond to decisive consequences in the event of a dam failure; unacceptable, limited and negligible. In the first instance, loss of human life is regarded as unacceptable as this damage cannot be compensated, but damage to public interests or financial damage may also be regarded as unacceptable in some instances. Other types of

damage may be both limited and possible to repair, while others may be entirely negligible.

The consequence classification system is shown in Table 1 below. This table takes into account the probability of serious injury or loss of human life, and the social, environmental and environmental values that may be lost in the event of a dam failure. The consequence resulting in the highest consequence class determines the consequence class to which the dam belongs.

Consequence class	**Consequence of dam failure, expressed as probability of damage/injury**
1+	The probability of severe strain on society due to the **overall effect** of the damage along the waterway is high: - Loss/destruction/loss of serviceability of human life, the homes of many people, cultural environment and workplaces due to water - Serious disruptions to the country's electricity supply - Serious disruptions to communications and transport - Destruction of or extensive damage to other facilities important to society - Destruction of significant environmental values - Enormous economic damage
1	The probability of loss of human life or of serious injury is not negligible. or Considerable probability of severe damage to - important societal facilities - significant environmental aspects or High probability of - - very large financial damage
2	Not insignificant probability of considerable damage to - local facilities - environmental aspects or - financial damage
3	(There is negligible probability of damage as stated above)

Table 1 Consequence classes relating to the probability of serious injury or loss of human life, and of damage to the environment, local facilities and other environmental values

According to **Table 1**, the probability of serious injury or loss of human life occurring in connection with a dam failure is divided into the levels **high probability** and **not insignificant probability.** Correspondingly, the probability of damage to the environment, local facilities and other financial values in connection with a dam failure is divided into the four levels **high, considerable, not insignificant** and **negligible.** These measures of probability, expressed in common parlance, can be found in the RIDAS guidelines (see also Guidelines for determination of design flows for dam facilities). The probability of serious injury or loss of human life due to a person or persons happening to be on the dam or in its immediate vicinity temporarily when the dam has failed (passers-by, berry pickers, etc.) may be regarded as **negligible**.

The table below illustrates the spread between the probabilities described in Table 1 above:

	Probability of damage occurring
High	> 90 %
Considerable	10 - 90 %
Not insignificant	1 -10 %
Negligible	< 1 %

For practical application of defined probability levels, please see river section 3.4 below, Classification, assessment of damage and losses.

3.4 Classification, assessment of damage and losses

The classification of a dam must be based on the nature (type) and size (seriousness) of the potential hazard which the dam poses to the surrounding area. This classification is based on the fact that in the event of a dam failure, was flows out in an uncontrolled fashion and affects and area in the form of a change in water depth and water speed. The consequence class of a dam is determined by the degree of impact on society, any loss of human life and/or damage to property and/or the environment directly subjected to this change in water depth and water speed.

3.4.1 Consequence class 1+

General

For consequence class 1+, there are extremely limited chances of reducing injury/damage if a dam failure occurs, apart from being able to save human lives by having good contingency measures in place. The uncontrolled outflow of stored water will result in such floods along the greater part of a river that the damage will be of an extent and duration that will have a long-term, persistent impact on a region and hence also at a national level.

The lives of many people will be at risk initially when the dam failure takes place, and major difficulties will then arise when it comes to establishing a functioning society for a long time henceforth. Areas outside the area directly affected may be affected in the form of long-term losses of infrastructures, such as power failures, major communication problems, etc. The starting point is that the region affected

will be unable to function without extensive, long-term support initiatives, to the extent that this will have a national impact.

The aggregated effects of the damage have to be analysed and assessed. If a number of the consequences listed below (points a - f) are realised, the facility is classified as 1+. The examples given for the respective points below are to be regarded as examples of the damage which may result in this classification. See also ***definitions in the main document*** "severe strain on society in peacetime". Evaluation of each point is best carried out in consultation with the relevant authority.

a) Loss/destruction/loss of serviceability of human life, the homes of many people, cultural environment and workplaces due to water

Human lives are under threat and hundreds of homes/residential buildings are destroyed and/or rendered uninhabitable. Thousands of individuals, or more, are affected. This situation persists for several months until the people affected have their accommodation and lives restored to a situation which is reasonably sustainable in the long term.

Historical, artistic and cultural values are taken into account in particular. Particular attention is paid to values which have been granted legal protection at national or county level (listed buildings, national parks, nature reserves, etc.). These values are also taken into account as regards the possibility of them being destroyed or damaged and being impossible to restore to their original condition. Particular attention must be paid to the risk/consequence of the cultural history of an entire river valley potentially being wasted in this context

As a consequence of an accident, a large number of places of work will also be destroyed or rendered unusable in purely physical terms. A fairly large number of companies will find it impossible to run their business for a long time (several months). As a consequence of this, the livelihoods of a large number of people (thousands) will be rendered impossible for a long time (several months).

b) Serious disruptions to the country's electricity supply

As a consequence of the failure of a facility in this category, the Swedish electrical system is highly likely to fail and cut power supplies to part of Sweden or a larger region (several counties or parts of several counties). Restarting the country's electrical system may take several days. The consequences of this are regarded as difficult to grasp for the country in terms of costs and consequences.

c) Serious disruptions to communications and transport

The breakdown of physical communications (roads, railways, air services) will be of an extent that renders the transportation of life essentials impossible or significantly impedes such transportation. Sustaining industrial and other social activities will also be rendered impossible in the local region where the actual dam failure take place, as well as in regions further away. If alternative transport routes with sufficiently high capacity exist or can be arranged within a reasonable time, this is a mitigating factor.

d) Destruction of or extensive damage to other functions important to society

Damage to local functions relates to – for example – disruptions in functions such as:

- water supply
- energy supply
- drainage systems
- healthcare
- communications (telephones, radio, TV, etc.)

For these criteria to be involved in classification of a dam as consequence class 1+, more than one type of facility has to be affected, or several facilities of the same type have to be affected by a dam failure.

For facilities to be regarded as **important from a local standpoint**, these functions must be indispensable in order to maintain normal human and economic activities for a collective population of thousands of people. A number of smaller facilities which will have at least the same consequences as those described above are deemed to be equivalent.

Destruction of or extensive damage to other functions/facilities important to society relates to damage rendering a number of such facilities completely unusable for at least several months.

e) Destruction of significant environmental values

Environmental value here refers to natural environmental values of regional (relating to the greater part of a section of river) or unique national nature (cultural environmental values are discussed in section a above). Particular attention is paid to environmental values which have been granted legal protection at national or county level (listed buildings, national parks, nature reserves, etc.).

Only the damage which is clearly different to the damage associated with natural flow conditions is taken into account as damage to the environment (marginal damage). Damage which may cause emissions of substances harmful to humans and/or the environment are taken into account, e.g. waste disposal plants, petrol stations, etc.

The future prospects for the areas affected must also be evaluated, e.g. changes to the landscape, altered habitats, long-term contamination from escaping environmental toxins, etc..

To determine what constitutes **destruction of significant environmental values**, factors such as the extent of the damage, the extent to which the environmental value is worth protecting and the possibility of undertaking restorative measures with acceptable results following a dam failure are taken into account.

f) Enormous economic damage

All costs must be included, both the company's costs and society's costs. These costs must include both direct and indirect costs. As it may often be difficult to assess the indirect costs for society, one reasonable starting point may be that these are generally of the same order as the direct costs. The future prospects for the areas affected must also be evaluated, e.g. changes to the landscape, altered habitats, long-term contamination from escaping environmental toxins, etc. All damage described above can essentially be described in economic terms and will probably be several times higher than the costs that can be insured.

3.4.2 Consequence classes 1, 2 and 3

Serious injury or loss of human life

The probability of serious injury or loss of human life must be assessed with regard to the following criteria:

- buildings being washed away
- the water level exceeding a housing level or a land area where people can normally be found, at a certain height in combination with a certain water speed
- A and B roads being inundated (and washed away) or flooded

The probability of loss of human life is dependent upon the water depth and water speed. Studies indicate a not insignificant likelihood of loss of human life at a water depth of 0.7 metres and a water speed of 0.5 metres per second. Other factors such as terrain conditions, the rise rate of the surface of the water, any warning time given, etc. should also be taken into account.

Injury leading to invalidity or long-term illness is deemed to be **serious injury**.

In practice, classification may be based on the conditions arising following a **dam failure** if water of the depth and speed stated above comes into contact with homes or locations where people constantly spend time. Holiday accommodation, schools, playgrounds, business facilities, general campsites and similar, plus locations where people spend time on occasions must be taken into account. For holiday accommodation, a guide value can be applied: if five holiday homes are affected, the dam is deemed to be a consequence class 1 facility.

If a dam failure may cause such damage to infrastructure and other local functions as may indirectly risk life, this must be taken into account separately. In the event of a dam failure which causes **such damage to very busy roads or important railway lines**, there is in some instances a **not insignificant probability** of the death of road/railway users. In these instances, traffic intensity must be charted and the dam classification has to be adapted to suit the local conditions in each individual case.

If roads with a traffic intensity of 3000 vehicles per day or more would be affected by a dam failure, the dam is normally classified as consequence class 1. If the local conditions are unfavourable - if, for example, vision is obscured on the road section where a dam failure would affect the road - the dam may need to be classified as

consequence class 1 even if the traffic intensity is < 3000 vehicles per day. If the time from the dam failure to the water affecting the road in question is > 8 hours and contingency measures are in place for cordoning off the area, the dam may be classified in a lower consequence class even if the traffic intensity is > 3000 vehicles per day.

If an important railway is affected by a dam failure, the dam is normally classified in consequence class 1 if the railway is utilised for passenger transport.

In the event of classification with regard to loss of human life, serious injury and damage to infrastructure, access to the relevant maps and a good knowledge of local conditions within the area affected are a must.

The likelihood of loss of human life or the occurrence of serious injuries can be reduced by means of active measures such as evacuation and cordoning off roads with high traffic intensity and railways used for passenger transport within the area affected. However, the possibility of implementing these measures is dependent on efficient collaboration with the relevant authorities, effective warning systems, a good knowledge of the spread rate of the water and on the time from the dam failure to the water impacting upon places where people habitually spend time, etc. being sufficiently long. The assessment of the criterion for implementation of the above measures must therefore be carried out on a per-case basis.

Given the uncertainty of the reliability of warning systems and the spread rate of the water, assumptions on scope for evacuation of people must be made with great caution. Implementation of evacuation, which is an authority action, is primarily dependent on the scope and the time available. When evaluating the anticipated loss of human life, the results of evacuation may only be considered if the number of people is limited, if it is thought that the action can be implemented with a good margin in the time available, and if the collaborating authorities can be involved in implementation of the action.

Damage to the environment, societal facilities and other financial values

Environmental values relate to both natural environment and housing environment values, including sanitary conditions. Historical, artistic and cultural values are also taken into account. Particular attention is paid to environmental values which have been granted legal protection at national or county level (listed buildings, national parks, nature reserves, etc.).

Only the damage which is clearly different to the damage associated with natural flow conditions is taken into account as damage to the environment. Historical, artistic and cultural values are taken into account as regards the possibility of them being destroyed or damaged and being impossible to restore to their original condition. Damage which may cause emissions of substances harmful to humans and/or the environment are taken into account, e.g. waste disposal plants, petrol stations, etc.

To determine whether **destruction of significant environmental values** occurs (Class 1), factors such as the extent of the damage, the extent to which the environmental value is worth protecting and the possibility of undertaking restorative measures with acceptable results following a dam failure are taken into account. Damage of a lesser extent and which will provide acceptable results with

limited input is classified as **considerable** (less serious) **damage of environmental value** (class 2). Damage to a very small extent and which will provide acceptable results with very limited input is classified as **insignificant damage of environmental value** (Class 3).

Damage to local functions relates to – for example – disruptions in functions such as:

- water supply
- energy supply
- drainage systems
- healthcare
- communications (telephones, radio, TV, etc.)
- transportation (roads, railways and airports)

For these criteria to be of decisive importance when classifying a dam with regard to the consequences for the above functions, more than one type of function has to be affected, or several facilities of the same type have to be affected by a dam failure.

At high flows, damage normally occurs to local functions in the form of lost or reduced function to such an extent that it is difficult in some cases to assess the damage that would be caused by a dam failure under these conditions. Damage from a dam failure in these cases can therefore only be subject to general assessment. This must be considered to be acceptable as classification of the dam with regard to financial damage as stipulated below is also applicable to local functions where there is a greater opportunity to assess the damage that would be caused by a dam failure at high flows.

The guidelines below for establishment of the consequence class of a dam with regard to damage to local functions in the event of a dam failure is therefore applicable mainly in the case of normal flows.

For facilities to be regarded as **important from a local standpoint**, functions must be indispensable in order to maintain normal human and economic activities for a collective population of at least 1000 people.

> **Serious damage** (Class 1) relates to damage resulting in some such facilities functioning at reduced capacity and not permitting immediate repair, and posing an obstacle with no alternative for at least one week.

For facilities to be regarded as **significant from a local standpoint**, these facilities must be important in order to maintain normal human and economic activities for a collective population of at least 100 people.

> **Considerable** (less serious) **damage** (Class 2) relates to damage resulting in such facilities functioning at reduced capacity and not permitting immediate repair, and posing an obstacle with no alternative for at least one week
>
> **Non-serious damage** (Class 3) relates to damage resulting in such facilities functioning at a certain reduced capacity but which permit immediate repair without restrictions on operation.

Financial damage includes both direct damage in the form of destruction of objects and indirect damage such as reductions in production capacity. The

financial losses of the dam owner as a consequence of a dam failure need not be taken into account.

Great financial damage (Class 1) relates to damage for which the total value exceeds 3000 base amounts.

Considerable (minor) **financial damage** (Class 2) relates to damage for which the total value exceeds 100 base amounts.

Other **financial damage** (Class 3) relates to damage for which the total value is less than 100 base amounts.