dam safety guidelines

Part 4: Investigation, monitoring and surveillance of dams

Introduction

This part of the guideline is intended as a guide for determining adequate levels of performance monitoring and surveillance for dams.

Monitoring can be defined as the measuring and recording of physical parameters such as flow and water levels.

Surveillance is defined as the observation of the dam and its associated structures.

While surveillance is less visual, rigorous and quantitative than monitoring, it is no less important. For smaller structures surveillance may be the only examination conducted, and it is adequate for this purpose (see Part 2, Section 6).

The type, sophistication and extent of monitoring depends on the size, type and hazard category of the structure.

Monitoring and surveillance are carried out at all stages of a dam's life as shown in Figure 4.4.

There is often considerable overlap between monitoring and surveillance, and operation and maintenance. Safe operation of the dam with appropriate levels of maintenance will help ensure that the required level of dam safety is achieved. For this reason this part of the guideline discusses dam operation and maintenance in full.

1.0 Types of investigation, monitoring and surveillance

There are seven main phases of investigation, monitoring and surveillance of dams and their associated structures:

- development investigations
- construction monitoring
- commissioning monitoring
- performance (structural) monitoring
- event monitoring
- compliance monitoring.

1.1 Development monitoring investigations

Development investigations assess the viability of the scheme before starting extensive investigations and design and its likely design limitation. For smaller schemes site specific monitoring may not be needed, because existing information is likely to be adequate. Larger schemes will almost certainly require specific development monitoring.

Development investigations are also typically required to assess the effects of the development. This information will then provide a basis for the granting of resource consents and the compliance monitoring which will then be required (refer below).

Pre-design monitoring would typically include stream flow measures and monitoring of key parameters identified during investigations such as groundwater and slope stability and other things listed in Figures 3.12 – 3.14 of Part 3.

1.2 Construction monitoring

Often the construction of a dam induces some of the most extreme load situations the dam will ever experience. Monitoring of construction parameters is often vital to ensure a safe construction. The results often frequently set the benchmarks against which ongoing performance monitoring will be based.

Construction monitoring is essential for ensuring that the dam is actually built to the required design standard.

1.3 Commissioning monitoring

Monitoring of the commissioning period is essential for safety purposes, as outlined in Section 9.4 of Part 3 of the guideline.

The type, sophistication and extent of monitoring is depends on the size, type and hazard category of the structure.

Monitoring and surveillance are carried out at all stages of a dam's life, as shown in Figure 4.4.

1. **Pre-design** – Pre-design monitoring would typically include stream flow measurements and monitoring of key parameters identified during investigations (eg groundwater, slope stability).

2 **Construction** – Often the construction of a dam induces some of the most extreme load situations the dam will ever experience. Monitoring of construction parameters is often vital to ensure a safe construction. The results obtained frequently determine the benchmarks by which ongoing performance monitoring will be based.

3 **Performance** – Performance monitoring aims to ensure that the structure meets and continues to meet the safety and operational expectations of the designer and owner. The performance monitoring and surveillance results will form the most important record on which performance reviews will be based.

1.4 Types of monitoring

Several types of monitoring reflect a range of safety and strategic considerations. The overall sophistication and extent of monitoring will also reflect the dam's hazard category. Typical types of monitoring include:

1 **Event** – Event monitoring is conducted on larger projects to enhance the ability of the dam to deal with extreme events, especially floods.

2 **Construction** – Construction monitoring is essential for ensuring that the dam is actually built to the required design standard.

3 **Structure** – Structural monitoring includes the physical monitoring of parameters that could affect the structure's performance or safety. Typical parameters include water pressures, seepage flows and settlements or movements.

4 **Commissioning** – Monitoring of the commissioning period is essential for safety purposes, as outlined in Section 9.4 of Part 3 of the guideline.

5 **Operational** – Operational monitoring is undertaken to ensure that the scheme performs to the owner's expectations and within its consent constraints.

1.5 Limitations of this guideline

The information in this guideline is intended to help Auckland Regional Council Staff assess whether levels of design and specialist input into dam construction and operation are appropriate. Every dam project is unique and this guideline should not be used as a design manual or for dictating dam standards.

The Council staff do not act as specialist reviewers or designers. Rather, they ascertain whether a dam has had the necessary design, construction or monitoring input and, where uncertainty exists, request more information. The Council may seek independant specialist advice.

When commissioning the monitoring provides an indication of the reaction various structures are having to induced events (eg lake filling), and a warning system if measured reaction exceed expected levels.

1.6 Performance (structural) monitoring

Performance or structural monitoring aims to ensure the structure meets and continues to meet the safety and operational expectations of the designer and owner. The performance monitoring and surveillance results will form the most important record on which performance reviews will be based.

Structural monitoring includes the physical monitoring of parameters that could affect the structure's performance or safety. Typical parameters include water pressures, seepage flows and settlements or movements.

Ongoing monitoring throughout the lifetime of the scheme is undertaken to ensure the dam and its associated structures perform to their expected levels of safety.

1.7 Operational monitoring

A distinction is made in this guideline between operational monitoring and ongoing performance monitoring. Operational monitoring is defined as monitoring to ensure that the scheme is meeting the required level of operational performance. This is not a safety issue, but is of economic interest to the owner.

Operational monitoring procedures are not covered in this guideline, although often performance monitoring and operational monitoring measure the same things, for example rates of water loss from an irrigation dam.

Operational monitoring is undertaken to ensure that the scheme performs to the owner's expectations and within its consent constraints.

1.8 Event monitoring

Event monitoring is conducted to enhance dam's ability to withstand particular events. Because events monitored for include floods, earthquakes and in some cases volcanic activity, this form of monitoring is often termed 'early warning surveillance'.

Event monitoring is also conducted during construction and commissioning of larger projects, when the structure will typically be more vulnerable to extreme events. Event monitoring may continue throughout the project's life to enhance the scheme's level of safety, provide early warnings and optimise its economic return.

Event monitoring is conducted on larger projects to enhance the ability of the dam to deal with extreme events especially floods.

1.9 Compliance monitoring

A modern derivative of performance monitoring is compliance monitoring. This is undertaken to ensure that the scheme operates within the allowable envelope defined by the various conditions given in the resource consents for the scheme.

Typically much of the information collected for performance monitoring of the scheme can be used for compliance monitoring. Some specific monitoring, particularly of environmental parameters will also be required.

1.10 Special reviews

Internal reviews, external peer reviews and performance reviews may be requested by the various agencies from time to time on a regular basis for compliance monitoring, as well as by potential purchasers or insurers.

These reviews will draw on the monitoring data and systems outlined in Sections 1.1 - 1.7 above, emphasising the importance of establishing good monitoring and surveillance systems all the way through a dam's life.

Safety audits and due diligence audits are summarised in Part 5 of this guideline. They will also draw on monitoring and surveillance data, again emphasising its importance.

1 **Internal reviews**

These will typically be undertaken on behalf of the owner for the purpose of monitoring performance. During construction of a dam they will provide a level of 'quality assurance' for both the owner and contractor to ensure the dam is built to the required standard and design.

Internal reviews of dam performance may be undertaken on a regular basis throughout the life of the structure to monitor the ongoing viability of the scheme.

2 **External peer review**

External peer reviews may be conducted during any phase of the investigation, design, construction and commissioning of a dam. External peer reviews are undertaken typically at the request of both the client and the regulatory authorities.

For larger dams a peer review panel will normally be established to keep an independent eye on the project throughout its development. The panel will be kept familiar with the design concepts and be informed of modifications to the development as they arise.

For smaller structures peer reviews would typically only be conducted on the final design concept with possibly additional input during construction.

External peer reviews will commonly form part of the resource consent process for larger structures. Often this will be undertaken by different reviewers than those on the project review panel. This is to provide an additional degree of independence for the public's benefit.

3 Performance reviews

Performance reviews are undertaken to ensure the scheme is operating within the expected and allowable bounds as defined by the design and the relevant consents. Internal performance reviews will be conducted by or on behalf of the owner to optimise the scheme and to define possible future maintenance costs.

External performance reviews may be requested by regulatory authorities to ensure consent compliance. This may be done in conjunction with safety audits (see Part 5 of this guideline).

2.0 Monitoring parameters

The parameters monitored are somewhat dependent on the nature of the dam, though mostly it is likely the same parameters are monitored on different dams. The main parameters that should be considered for monitoring for safety reasons are:

- groundwater levels
- settlement and movement
- leakage / seepage flows
- hydrological data
- ecological / environmental effects
- dam / storage condition surveillance
- general surveillance.

2.1 Groundwater levels

The monitoring of water levels and pressures in, under and around dams and their reservoirs is the most common form of safety monitoring.

During construction, monitoring of water pressures is undertaken to ensure pressures induced do not exceed levels assumed in the design.

In the commissioning phase, and onward throughout the dam's life, water level monitoring provides a direct means of assessing its ongoing performance and whether the structure is deteriorating.

2.2 Settlement and movement

Monitoring of the relative movement of dams, associated structures and slopes around the reservoir is typically undertaken only on larger structures. On smaller structures, the lower imposed loads in conjunction with greater inherent conservatism often makes monitoring of settlement of little value.

Movement and settlement monitoring is particularly important during the early stages of a dam's life during construction, commissioning and the first few years. With time the frequency and extent of this type of monitoring will typically be reduced or even discontinued.

2.3 Seepage or leakage

Monitoring of drainage flows, both natural, such as springs and engineered flows, is common on even the smallest of structures. Unlike settlement monitoring, monitoring of seepages may be continued at greater frequency for some time into the dam's life. This is in recognition of the delay that can occur between filling the dam and the stabilisation of seepage rates.

In addition to the actual rate or quantity of seepage flows, the quality of the water emerging can also be an important performance indicator. Sediment in the measured seepage flows can indicate internal erosion of the materials forming the dam.

2.4 Hydrological data

Monitoring of hydrological parameters is typically undertaken to provide early warning of extreme flood events. It may also be undertaken to act as a prompt for increasing the frequency at which other monitoring stations are read. This is particularly relevant for slope movement monitoring.

Hydrological monitoring is also useful for optimising the use of the reservoir both for safety reasons such as to reduce flood peaks and economic reasons, for example to capture of water.

2.5 Ecological and environmental effects

This type of monitoring is predominantly undertaken for resource consent compliance. Parameters monitored can include water quality, water temperature and fish stocks.

As this form of monitoring does not directly influence dam safety, it is not extensively covered in this guideline.

2.6 Dam/storage condition surveillance

This area of monitoring is typically a more observational approach. Typical aspects covered would include examining the reservoir perimeter for possible slope instability, reservoir condition (eg weed growth etc) and condition of the dam and associated structures.

While surveillance does not usually involve any measurable values, for smaller dams in particular, it is of equal or higher importance than the more direct measurements of performance. This is because surveillance provides a more global perspective of dam reservoir condition.

2.7 General surveillance

Matters outlined in Section 6.0 of Part 2 of this guideline should also be kept under regular surveillance.

2.8 The monitoring network

It is important to recognise that different types of monitoring should not be considered in isolation. Often more than one type will be required to adequately scrutinise a particular parameter. For this reason the complete monitoring system is typically referred to a monitoring network.

An example of the interrelationship between different types of monitoring is given in the following hypothetical situation:-

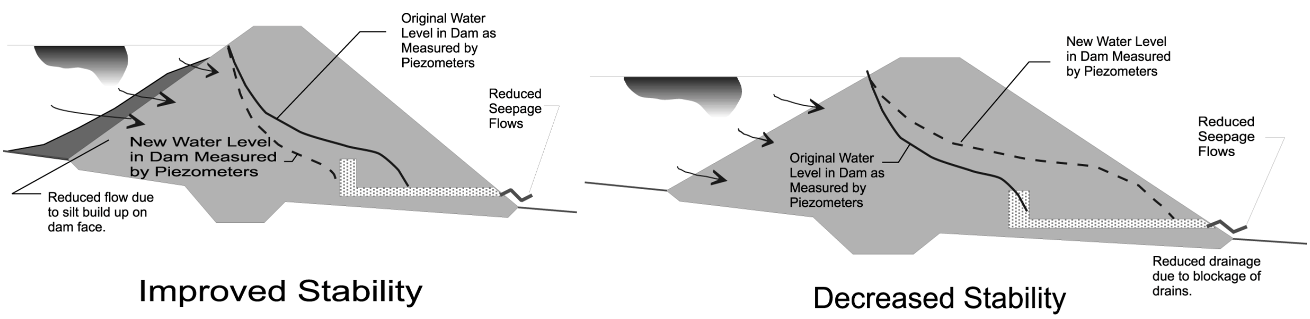
> An earth dam is showing a reduction in seepage flows from the monitoring of the internal drainage system. This could mean that:
>
> **Scenario a)** the dam has settled or silt has built up on the upstream face, reducing leakage through the embankment or
>
> **Scenario b)** the internal drains are deteriorating and the seepage through the dam is no longer being effectively intercepted

To determine which of these scenarios is more likely, water level monitoring will need to be examined. If the water levels downstream of the drainage system are not increasing, or are decreasing, then Scenario a) is more likely to be occurring and the situation is likely to be one of improving dam stability. If they are increasing, Scenario b) could be occurring, resulting in increased pressures within the dam which could detrimentally affect stability. These concepts are shown on Figure 4.1.

This example highlights the fact that changes in monitoring results both increases or decreases, could indicate a problem. This concept is often poorly understood, with the emphasis only being placed on increases, particularly in flow or water pressures.

A typical monitoring network for a moderate sized embankment dam is shown in Figure 4.2.

Figure 4.1: Water Level Monitoring Scenarios



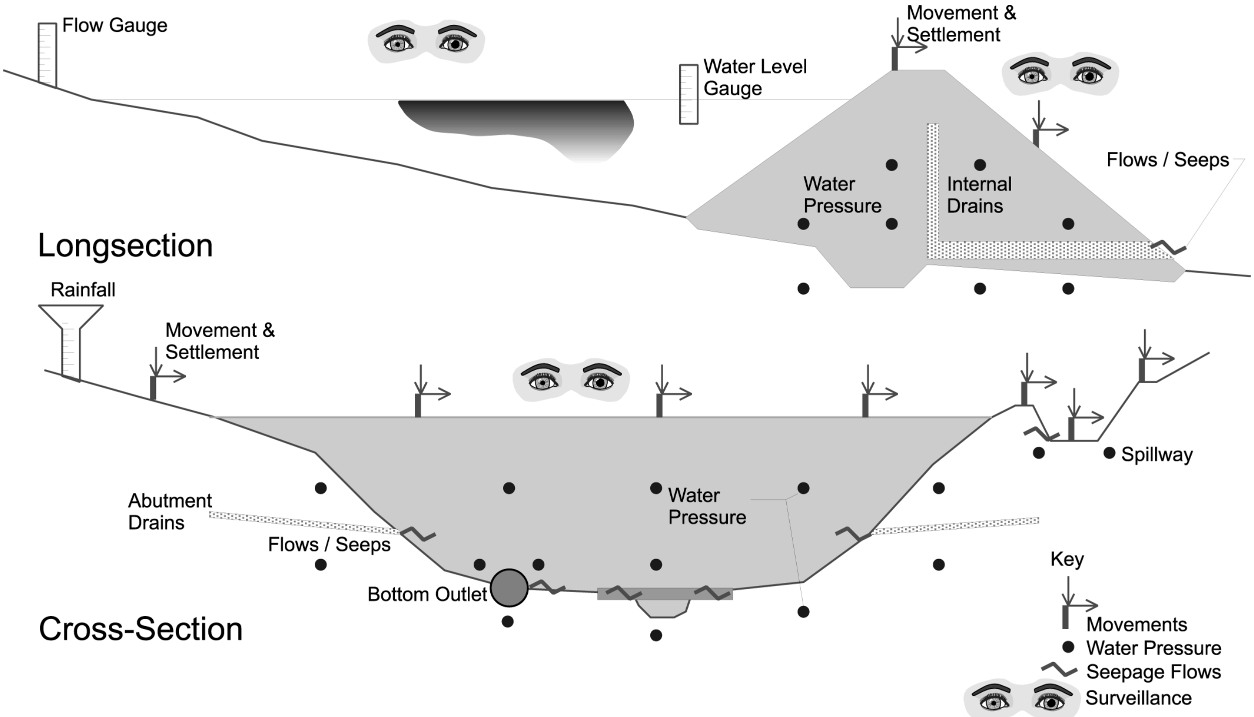


Figure 4.2: Typical Dam Monitoring Network – Moderately Sized Embankment

3.0 Monitoring instruments and systems

There are numerous manufacturers instruments and systems for measuring the parameters above. It is not the purpose of this guideline to discuss the proprietary products available for instrumentation, but to make some general points.

1 Simple vs complex

There is often a tendency to use highly complex monitoring systems and equipment. Such systems will give high quality output and are often continuously monitored in real time for early warning purposes.

However, complex systems and instruments are often less reliable because of their very fine installation and environmental tolerances. They are typically also more expensive, so only a few may be installed sometimes at the expense of providing adequate monitoring coverage.

Simple instruments are typically more robust and reliable but do not give the accuracy and rapid response of their complex counterparts.

A combination of simple and complex instruments, giving comprehensive coverage at an appropriate level of technology for the structure, is the best option.

2 Redundancy

An allowance should always be made for a proportion of the instruments failing or giving faulty readings. This is particularly true for water pressure measurements. Some types of instruments can only practically be installed during construction. It therefore advisable to allow for instruments malfunctioning with time.

For larger structures it is good practice to have additional instruments installed for the purpose of providing a cross-check on results. These back-up instruments should also be of a different type and a simpler style.

This is particularly true of structures relying on continuous recording for advanced warning. A network of backup instruments for cross-checking is vital to ensure that no potential safety incidences are missed and no false alarms are sounded.

3 Background readings

Background or baseline monitoring is important, particularly for structures with higher hazard categories, to give a comparison between the pre- and post-development information. This is also vital for compliance monitoring.

This is typically done for hydrological data such as river flow, but groundwater pressures in the slopes around the reservoir may also need monitoring before the reservoir induces changes on the groundwater regime. Other issues such as slope movement may also be of interest.

4 Alarm levels

Key instruments in a monitoring network are often selected for use as alarm triggers. Those selected should be the most reliable and/or located in the critical areas. The concept of alarms is discussed in greater depth in Section 6.0 of this Part.

4.0 Data recording and storage

The data collected during monitoring and surveillance is of vital importance in ascertaining the performance standard and tracking the performance history of a dam. A change in any reading can only be understood in the context of past results.

Trends, extreme values and patterns in readings all give indications as to the performance of the structure.

For this reason all monitoring and surveillance data should be retained for future reference. This is in the owner's interest, as the availability of historical data significantly reduces the uncertainty that will arise if no information is available. If there is any uncertainty about performance then reviewers undertaking safety evaluations of the structure may need to be conservative, possibly unnecessarily.

Monitoring and surveillance data from larger dams and their associated structures will normally be stored in a computer based database. This allows rapid retrieval of historical information and analysis of trends. Graphical presentation of data is vital so that rapid comparisons between measurements over time can be made.

5.0 Frequency and extent of monitoring and surveillance

Figure 4.4 indicates the type and frequency of monitoring and surveillance that could be expected for dams. Figure 4.3 indicates the extent of the monitoring network or numbers of instruments.

Both issues are only indicative as monitoring depends on the size of the structure, type of construction and site specific details. Although the frequencies given are not intended as minimal they are toward the lower end of appropriate monitoring frequencies. In many situations continuous monitoring of key points is undertaken.

The emphasis is on earth dams because they are more common. Some of the monitoring options given may not be appropriate for other dam types.

The extent of the monitoring network in Figure 4.3 is considered typical for earth dams in various hazard categories. Monitoring networks for specific items,

Figure 4.3: Typical Number of Instruments For A Hazard Category

Monitoring Type	Typical Number of instruments for a hazard category of:		
	Low	Significant	High
Water pressure / levels	0 - 10	4 - 20	10 +
Seepage / flows	up to 5	3 - 10	6 +
Settlement / movement	0 - 6	4 - 20	10 +

dam safety guidelines

Guidelines for construction, maintenance and monitoring

Frequency of monitoring and surveillance																
Components		Dam hazard category														
Area	Type	Low					Significant					High				
Dam / embankment		Daily	Weekly	Monthly	Quarterly	Yearly	Daily	Weekly	Monthly	Quarterly	Yearly	Daily	Weekly	Monthly	Quarterly	Yearly
Upstream downstream slopes	- visual	●		■			●		■			●		■		
	- movement / settlement							●			■		●			■
	- drainage flows	●		■			●		■	▲		●		■	▲	
	- water pressure		●		■		●		■	▲		●		■	▲	
	- erosion protection		●			■		●		■		●		■		
Crest	- visual	●		■			●		■			●		■		
	- movement / settlement					■		●			■		●			■
Abutments	- visual	●		■			●		■			●		■		
	- movement / settlement							●			■		●			■
	- drainage flows	●		■			●		■	▲		●		■	▲	
	- water pressure		●		■		●		■	▲		●		■	▲	
Spillways																
Service spillway	- visual		●	■				●	■				●	■		
	- movement / settlement							●			■		●			■
	- drainage flows		●		■			●	■	▲			●	■	▲	
	- water pressure		●		■			●		■			●		■	
	- erosion protection		●		■			●	■				●	■		
Flood spillway	- visual		●		■			●		■			●		■	
	- movement / settlement								●		■			●		■
	- drainage flows			●	■			●		■			●		■	
	- water pressure			●	■				●	■			●		■	
	- erosion protection			●	■				●	■			●		■	
Conduits and pipes																
Bottom outlet etc	- visual		●		■			●		■			●		■	
	- movement / settlement								●		■			●		■
	- drainage flows			●	■			●		■			●	■	▲	
	- water pressure			●	■				●	■			●	■	▲	
	- erosion protection			●	■				●	■			●		■	
Reservoir perimeter																
Slopes / shore erosion	- visual			●		■		●		■			●		■	
	- movement / settlement								●		■			●		■
	- drainage flows								●	■			●		■	
	- water pressure								●	■			●		■	
	- erosion Protection								●	■			●		■	
General / other																
Catchment / river	- visual			●		■			●		■			●		■
	- flows											■				
	- rainfall	■					■		▲			■		▲		
Vegetation	- visual			●		■			●		■			●		■

■ = Long-term monitoring (primary instruments)
▲ = Long-term monitoring (backup instruments)
● = Monitoring during construction / commissioning

Figure 4.4: Frequency of Monitoring and Surveillance

such as landslides that may threaten the dam have not been include in the numbers provided. These would be to be considered on an individual basis.

The large range for the low hazard category recognises the significant spread of dam size in that category. At the lower end, it is conceivable that no monitoring could be required, with reliance placed on observational surveillance. Toward the upper end of the low hazard category, several monitoring points may be appropriate.

Figure 4.4 gives monitoring frequencies for different components of a typical dam. The information has been summarised from the NZSOLD Guidelines, which should be reviewed for additional information.

Monitoring of specific threats such as seismicity, volcanism and active landslides will typically need to be continuous. River flow and rainfall are also often monitored continuously for safety and economic reasons.

6.0 Alarms: settings and response

It is normal practice to assign alarm levels or trigger and response to monitoring instruments. When a reading exceeds an alarm level, a predetermined procedure is triggered. This procedure may involve anything from simply cross-checking the reading with other instruments to evacuation of the public downstream.

Alarms can be set at different levels, which will also usually change during the lifetime of a dam as data on historical performance accumulates. For larger dams, given the level of hazard and complexity of the structures involved, two alarm levels are often set, a warning and an alert (or alarm). The term "alarm" is used less often these days because of the negative public perception of the term.

6.1 Setting of alarm levels

Three sets of alarm levels are generally used:

- warning level
- alert level
- data check.

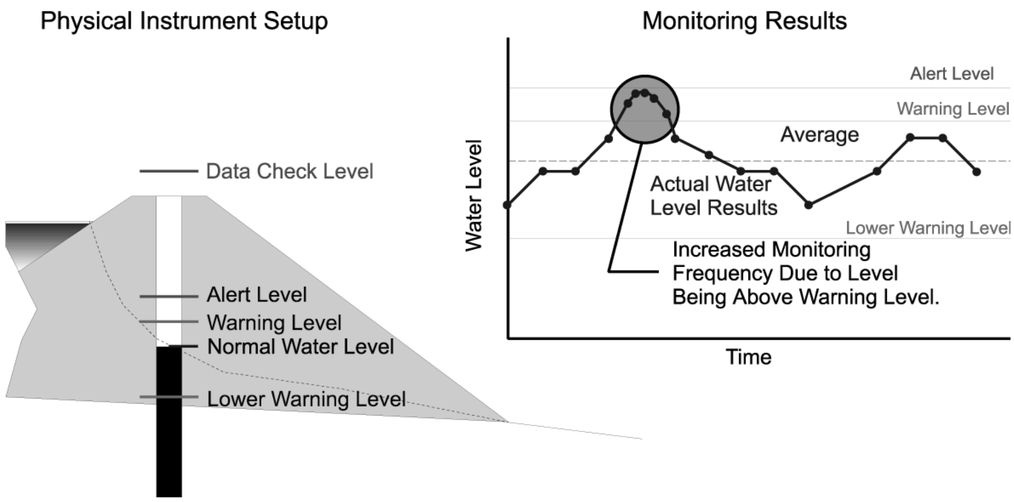
1 **Warning level**

The warning level is the first or lower setting and is typically defined as:

> The level at which the instrument is reading outside **expected** levels.

With time the definition may change to a more quantitative one based on comparison with previous records. For this reason the warning level alarm is sometimes known as a historical check or alarm. Simple statistical analysis is used to assess whether the reading falls outside the normal distribution for that instrument. The original design assumptions must be examined to check that warning alarm levels are in an appropriate range.

Figure 4.5: Physical Instrument Setup and Monitoring Results



2 Alert level

The alert level is the more extreme trigger and is typically defined as:

> The level at which the instrument is reading outside **acceptable** levels.

These are less likely to change with time, as they are often dependent on design parameters and assumptions for the dam.

3 Data check

A third trigger level is sometimes used, called data check. This is defined as:

> The level as which the instrument is reading outside **possible** levels.

This check is applied mainly to warn personnel taking the readings that the value is unlikely to be a valid result. For example a measured flow rate several times the maximum that a drain pipe could possible carry would be considered outside a possible level.

Alarm levels are not necessarily set on all instruments. Key instruments may be selected for one or more alarm levels based on their significance and assessed reliability. The remaining instruments without alarm settings will provide a degree of backup. An example of an alarm setting for a water pressure monitoring instrument is shown in Figure 4.5.

As shown in Figure 4.5 alarms often include both an upper and lower limit. This is because a low reading may be just as important as a high one, as shown by the example provided in Section 3, Figure 4.1, of this part.

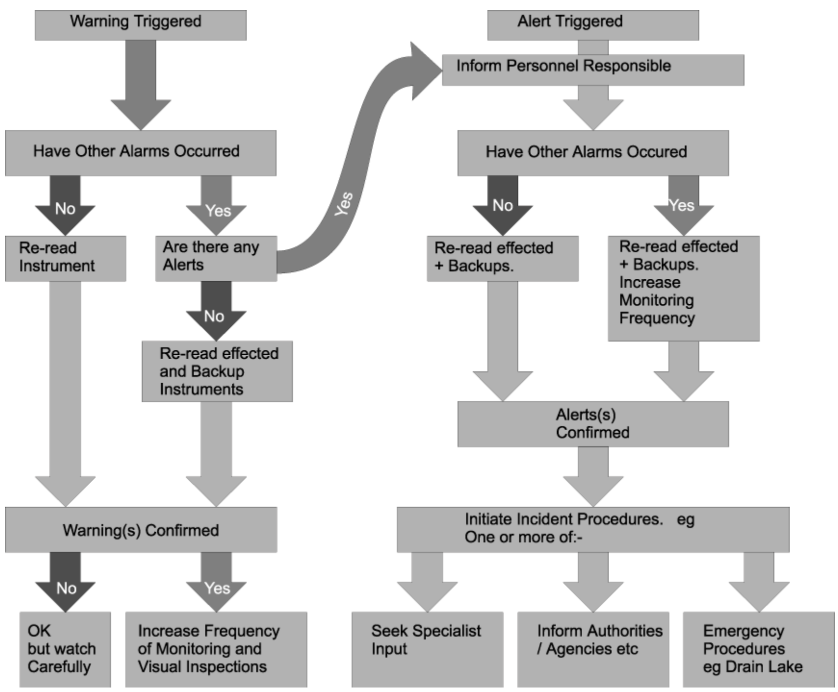
6.2 Responding to alarms

The response to an alarm depends on the level of alarm triggered (warning or alert) and the pre-defined significance of the alarm. A pre-determined set of guidelines should be in place so that alarms, when triggered, can be responded to as quickly as possible.

7.0 Emergency procedures

For larger dams, emergency procedures or an emergency action plan should be produced. The primary purpose of an emergency action plan is to reduce risk of loss of life and property.

Figure 4.6: Emergency Action Plan – Example Response Sequence



The emergency action plan needs to prescribe a set of actions that need to be undertaken in the event of an incident. Key information that needs to be in the emergency action plan includes:

- sequence and details of actions to be taken
- chain of responsibility for dam
- layout plans of the dam, monitoring network and downstream area that could be at risk
- persons and agencies to be notified including personnel and contact details.
- correlation between the emergency action plan and external, regional and central government plans
- communications systems and backups
- backup power supplies, monitoring systems and equipment
- list of contractors, specialists and other personnel that can be contacted.

The NZSOLD provides additional details on emergency action plans which should be referred to.