






Guidance for resilience of flood warning infrastructure

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1 Introduction

This document provides guidance on the design, construction and maintenance of hydrometeorological recording stations, their associated infrastructure and communication pathways, for resilience during severe weather.

"*In a severe event, the speed that an event escalates can be extreme, and warning systems need to be credible, timely, supported by good infrastructure and good systems, and manned by suitable numbers of trained, capable, experienced and confident staff*" Martin Doyle Co-convenor, National Flood Warning Steering Group

There is no National Environmental Monitoring Standard (NEMS) documentation regarding flood warning site set up methodologies to ensure permanent live access to/from the field stations and their data, however (Walsh and Grace, 2023) NEMS guidelines for hydrological and meteorological structures, does go some way towards guidelines for the design of structures for resilience to floods.

Regional and Unitary Councils are responsible for civil defence emergency management (CDEM) in their area under the Civil Defence Emergency Management Act (CDEMA) 2002. This responsibility includes, in relation to hazards and risks such as from flooding, to identify and communicate information "in a way that contributes to the social, economic, cultural, and environmental wellbeing and safety of the public and also to the protection of property..." (CDEMA 2002). Hydrometric monitoring provides for flood monitoring and warning, both directly to the public and to CDEM Groups on river levels and flows during flood events.

Flood warning involves 5 elements:

- Maintaining a network of hydrometric sites with sensors
- Gathering data by telemetry systems and other means
- Staff using models and experience to provide context to the data
- Informing staff and the public by a variety of means
- CDEM response

This document addresses resilience for the first 2 elements above.

Hydrometric recording stations are built for many purposes and as a general rule, they need to be built to resist failure and produce an unbroken dataset for analysis. When the station is required to measure parameters for emergency management, particularly during floods, the need to have a recording station operational at all times becomes critical. The more severe the event is, the greater the need to have a robust supply of information to provide the critical situational awareness required for emergency management.

Every site used for flood monitoring has different characteristics, opportunities and risks, and different approaches maybe adopted to achieve resilience (Heather-Smith et al., 2022).

Recent floods in 2021, 2022 and 2023 across both Islands have shown the importance of these recording stations during a flood, with up to 50 %of station's rendered inoperable at key times during some extreme cases. As the climate changes this is likely to occur more often.

Points of failure include:

- Structural – structures, cables or sensors damaged by impact or other external forces
- Inundation - by silt or water
- Communication – failure of a telemetry system component
- Power – insufficient capacity
- Other considerations – upstream debris dam failure

In this regard council assets to provide critical situational awareness during emergencies should be designated as critical infrastructure and be funded and maintained accordingly. Herein guidance is arranged as follows:

1. Section 2, "Risks to structures" describes threats to the supply of information from hydrometric infrastructure. These threats are mostly environmental and related to extreme weather events. The methods to assess these risks and quantify them are described here.
2. Section 3, "Design of structures", gives a basis for deciding how important specific data is and therefore the level of risk that infrastructure should be designed for.
3. Section 4. "Physical elements of hydrometric structures", describes how the resilience of these elements can be designed to achieve the level of risk specified.

2 Risks to structures

2.1 Ground slope instability and erosion due to rainfall

Severe damage to structures and road access can be caused by slumps, slips and erosion which are more likely when soil is saturated, and therefore during extreme rainfall over an extended duration. There are other factors involved such as toe erosion, soil type, background moisture content, changes in drainage patterns, vegetation and earthquakes. Careful observation (or historic photos) of the land profile at and adjacent to the site is a good start to estimating risk. On a riverbank it is not unusual for slips to retreat back from the river uniformly. The history of this process can be indicated by vegetation of different ages, which can give some indication of the likelihood of stability problems. Hazard scientists in local councils or geotechnical experts can give advice on this.

2.2 Inundation, hydrodynamic forces, and large woody debris

2.2.1 Design flood levels

Flow stations should be designed in accordance with Table 2, with an additional allowance made for the build-up of bed material during a flood, and in small catchments, debris flows. Large and small catchments might also suffer higher than expected flood flows from dam release.

The design flood levels suggested in Table 2 involve annual exceedance probabilities based on historic records. Fortunately, many hydrometric stations have been in place for quite some time, so that when informal observations and other indicators are also considered, an AEP = 0.4% (250 year return period) flood might be reasonably estimated. Beyond that there is much uncertainty. However, hydrometric assets can be over-designed without too much expense, so for high importance sites, worst case scenarios can be used. The AEP > 0.1% level is any level that must exceed the unknown AEP=0.1% flood (1000 year return period). The probable maximum flood (PMF) is also relevant here. These flood levels used for design are based on historic records. Without a flow record at the site location, flood estimates can be derived from the NIWA online tool. They must be adjusted to account for climate change, which should use the Ministry for the Environment Climate Change Predictions as per the relevant local government requirements. This approach to climate uncertainty is intended to be consistent with the New Zealand Transport Agency Bridge Manual, which is a good resource, for some aspects of hydrometric design that involve public safety.

Figure 1: Twizel River at Lake Poaka. Photo by permission of ECan.

2.2.2 Estimation of water velocity at a local scale

The hydrodynamic load on an in-stream structure is very much influenced by the stream velocity. Stilling wells and other hydrometric assets are typically sited at the edge of a channel where, in flood conditions, there can be a large variation in local velocity over quite short distances. Being dependant on exact positioning, it is difficult to determine hydrometric load accurately. However, the water velocity at the location of a proposed or existing structure is a key design parameter which must be designed for, and minimised where there is a choice.

To estimate the maximum design water velocity at the location of a bankside structure, the following approach can be applied:

1. A ratio to the average stream velocity at the design flood (with surveyed cross-section) can be applied. For a typical stilling well for example, in the absence of other information a ratio of 1.2:1 allowing for surface velocities is not unreasonable.
2. This ratio can be modified by considering the actual shape of the channel and floodplain, and how it would appear during the design flood. The channel shape over different scales is relevant, including rock outcrops and vegetation, all of which will have different natural lifetimes and survival rates in flood conditions. Assets are often positioned to take advantage of local sheltering features, so the ratio to mean velocity will likely be much reduced by these site factors.

3. Observations of actual floods and the experience of local hydrological staff is a key resource. There is no substitute for eye-witness accounts of flood characteristics especially from people who are trained (although it is not likely that the design maximum flood has been witnessed). Keep in mind that conditions during a PMF (for instance) might not be consistent with conditions seen during a smaller flood.
4. For high importance sites, estimates and observations should be supplemented by hydraulic modelling across the surveyed cross section. The survival of sheltering vegetation should not be assumed, and allowance should be made for the possibility of permanent changes in channel and flood plain geometry.

2.2.3 Scour under foundations

It is not uncommon for access to structures and stilling wells to be undercut by scour (see Figure 2). This should be carefully looked for during regular site inspections particularly after high flow events. To assess risk to an existing structure requires knowledge of the as-built details of the foundations, which is not always easy to get.

Figure 2: Scour and bank erosion. Photo by permission NCC

2.2.4 Estimates of debris load

Debris in flood flow, particularly large woody debris is a significant threat to hydrometric infrastructure. There are two main mechanisms through which damage occurs: by the hydrodynamic pressure on debris rafts that become hung up on structural elements, and by the impact of large timber individually floating at fast surface velocities. With the increase/promotion of plantation forestry, damage from these floating missiles will only increase.

Figure 3 below displays an example of a debris dam release. Hydrological studies found the natural flood water level to be somewhere between this person’s knee and hip, however, the debris evidence is above the head. Flood flow frequency analysis is rendered much less useful in such circumstances, requiring a dependence on rainfall frequency analysis.

Figure 3: Waieke Stream (G Horrell photo by permission of Darroch Forrest Lawyers)

In the past the effect of debris was accommodated on a case-by-case basis, sometimes using local knowledge, and following guidelines such as the Bridge manual (SP/M/022. It was believed that the transport of debris was primarily a natural process, sometimes accelerated by changes in land use. Either way, assume a worst case situation.

2.3 Erosion and deposition of debris and sediment

Following an extreme flood event, deposits of sediment and debris can bury hydrometric sites or prevent access to them. The risk is, at present, difficult to assess, but at least utilise a conservative factor to allow for this. The risk of burial is generally higher for sites on flat terrain and less for sites on slopes, but the risk to access is dependent on the resilience of the road network, which is beyond our control.

2.4 Wind and wind throw

Wind is the main threat to poles, solar panels, and antenna masts. For some stilling wells, design maximum wind stresses exceed hydrodynamic stresses. Extreme wind loads may coincide with an extreme flood, particularly for an ex-tropical cyclone. Wind load on stilling wells, poles, and panels can also be a public safety issue. Masts and poles, and all their fittings and anchors, should be designed for wind as per AS/NZS 1170.2., along with a factor for water flow if necessary. The importance level given in Table 1 should be used in Table 2 of that standard to determine the design wind speed AEP.

Particular notice should be taken of wire fittings on stays, fasteners, and other small components. It is not unusual for shackles, rigging screws etc to be replaced over the life of a structure with components that are under-sized. Also, masts and poles are often a generic design and the “payload” attached may not be specifically designed for. Large antenna should be checked case by case. The attachment of antenna to the mast must also be sufficiently rigid to maintain the alignment of the antenna at the design wind speed. By contrast, the attachment of solar panels might be less critical as described below.

In practice sheltering from vegetation may be significant but design standards explicitly exclude consideration of this sheltering effect.

Wind throw of large branches and trees is a major cause of damage, but much less predictable than wind itself. Equipment under or near to large trees, including guy wires and aerial cables, are at risk, so these types of locations should be avoided. The risk is increased if trees are old, rotten, diseased or otherwise infirm. The annual site inspection should identify potentially dangerous trees.

Figure 4: Wind throw Opihi River at Rockwood site. Photo by permission of ECan.

2.5 Lightening strike

Lightning can strike anywhere, being more common in the West and North West of the South Island, and across the central North Island from North Taranaki and King Country to Bay of Plenty and North of East Cape. These regions are high frequency lightning zones in Table 2.

Allow for maximum protection from lightning strike. It is recommended that all radio repeater stations and all critical sites have lightning protection.

Proprietary lightning protection systems are available (www.LPI.com.au, Earthing Solutions Brochure is useful) to protect structures and the electronic components that are attached to them from lightning strike and associated power surges. The type of ground on which the site is built will determine the best type of electrical grounding system to use, which is the main site variable. Once in the ground, earthing strips and rods are not easily accessible for assessment and inspection. Therefore, it is essential that the as-built construction of the grounding is well documented. Grounding systems normally involve rods or copper strips buried in the ground over a wide area, with a conductive grout compound used to improve electrical conductivity between the grid and the earth.

2.6 Vandalism

Vandalism can seriously disrupt data collection. Instrument cabinets, cables, and in-stream sensors can be protected to some extent, but pole mounted sensors and panels tend to be vulnerable. There is no reliable way of assessing vandalism damage to unprotected equipment, it is certain in urban areas, and likely in rural areas with public access.

Figure 5: Vandalism on Ashburton River at State Highway One site. Photo by permission of ECan.

2.7 Age and maintenance.

Accuracy and reliability of sensors, loggers, and telemetry can be compromised by inadequate maintenance, calibration and servicing. Sensors should be verified and calibrated in accordance with the relevant NEMS document. Structural components can rot or corrode, and periodic inspection is needed to identify and remedy this. Newer structures should be designed to enable inspection, and that as-built details are available. Inspection in these cases could involve simply looking at the condition of the materials. Older structures may require more in-depth examination.

2.8 Earthquake.

Earthquakes can severely damage structures and equipment, rendering stations inoperable for future events, it is recommended in the case of flow stations, to check flow patterns for upstream earthquake dams. As an example, Canterbury Regional Council experienced damage from the two (7.1 magnitude at Darfield September 2010 and a 6.3 magnitude very shallow 4km depth at Christchurch in February 2011) large earthquakes in Canterbury. Most of the structural damage occurred in the Kaikoura earthquake in November 2016, (7.8 magnitude) with the steel towers being left on a lean. All the encoder sites did jump on the pulleys, but kept recording so

the data could be transformed at a later time (Phil Downes per com). Datums were affected over a much wider area, including Marlborough.
As you should insure against the effects for all natural events, have a mixture of sensors and communication systems within a catchment to ensure you still have some data coming in. Having robust and reliable IT networks are also critical in this situation. Earthquakes can occur anywhere in New Zealand (see Figure 6).

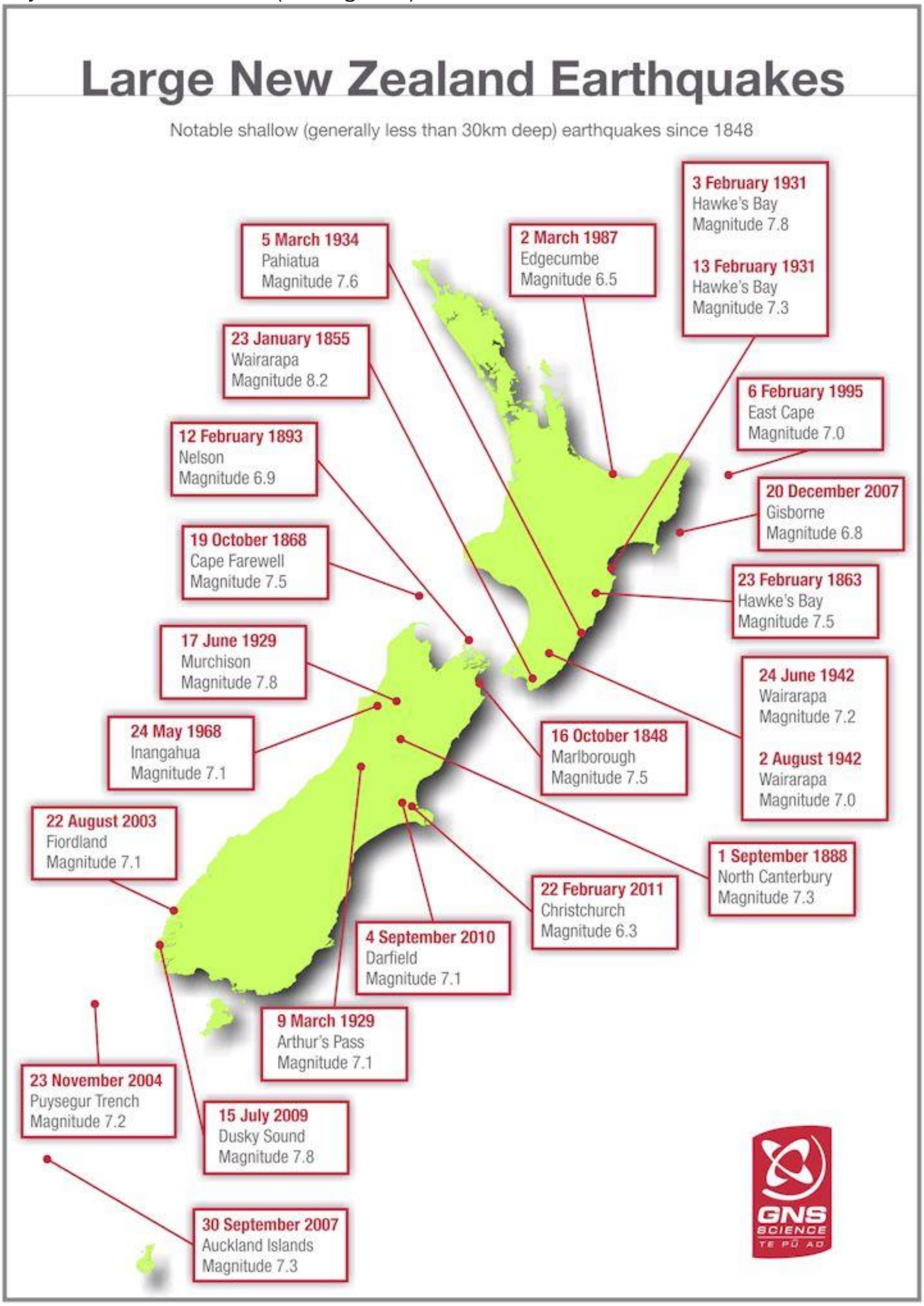

Figure 6: Large New Zealand earthquakes from 1848-2015.

3 Design of structures

3.1 Importance level; Data.

Here we consider the importance of data to flood management to determine the level of resilience required. Factors that will contribute to this include the following (allowing that different organisations use data for different purposes which may change over time e.g. sites installed for flood warning but now also used for low flow monitoring):

- The degree to which real time data removes uncertainties in the management of severe flooding, particularly where there is a risk to life or widespread severe damage.
- The importance of logged data to ongoing flood modelling/flood warnings.
- The degree to which alternative sources may be used as a surrogate for data. Note that this is only a factor if the surrogate can reasonably be expected to remain operating in conditions that may have compromised the primary source.
- The ability to collect flood gaugings at a site is key for defining the reliability of the data set and should be considered when designing the infrastructure to enable collection of that key data.

Importance:	Description:
High	Real-time data significantly contributes to effective emergency response.
Medium	Real-time data is useful but not essential. Real-time data contributes to effective emergency response, but partial surrogates are available from other reliable sources. Logged data significantly contributes to flood modelling and/or resource management.
Low	Logged data is useful but not necessary. Logged data contributes to flood modelling and/or resource management, but partial surrogates are available from other sources.

Table 1: Ranking the importance of sites for flood management

3.2 Importance level: Infrastructure

The importance of individual assets is determined by the importance of data that is handled by the asset. This is not diminished by having back-up assets to handle the same data path, for example, if stage at a site is measured by bubbler and radar, and is essential for flood management, then both those sensors should be considered high importance. Likewise, two independent communication pathways would both be of high importance.

It is paramount to ensure that the potential failure of less important assets cannot compromise high importance ones. This situation is especially pertinent to the physical mounting of gear and to power supplies. Either all assets are raised to the higher level of protection, or physical and electrical isolation must be used. For example if an auxiliary sensor is positioned such that the cable could be ripped out, then, at least, the power for it should be on a separate fuse.

3.3 Recommended design features based on importance.

Design parameter, all assets:	Importance:		
	high	medium	low
Design flood	AEP>1/1000 or PMF	AEP = 1/250 if sufficient history, otherwise PMF	AEP = 1/100
Design wind load to AS/NZS 1170.2 importance level	4	3	2
Lightning protection	Yes	Yes	In high frequency lightning zone
Solar power sites:	20 days	15 days	10 days
Battery storage and autonomous operation for mains powered sites:	7 days	7 days	N/A
Full equipment failure response plan	Yes	Use surrogate site	N/A
Alarms indicating fault	Pushed from server and monitored	Pushed from server	Able to be checked manually
Service plan and access (excluding extreme weather events)	Within 24 hours	Within 3 days	
Site safety inspection minimum frequency	6 months	annual	annual
Battery replacement schedule	3 years	3 years	N/A

Table 2: Design parameter recommended for levels of resilience.

Hydrometric assets:	Importance:		
	high	medium	low
Water level sensors	At least two sensors wired and positioned independently. One sensor non-contact.	At least two sensors.	Single
Rating curve	Prioritise high flow accuracy	Prioritise high flow accuracy	Not a priority
Soil moisture	At least two sources of data	At least two sources of data	Single
Rainfall	At least two sources of data	At least two sources of data.	No low importance sites
Loggers	Recommend separate loggers and power supplies	Consider separate loggers and power supplies	Single
Communication	At least two communication	Consider dual communications	Single

	pathways. One of which could be satellite.		

Table 3: Hydrometric assets recommended levels of resilience

4 Physical elements of hydrometric infrastructure:

4.1 Vehicle access

It is assumed that access to hydrometric sites may not be possible during and following an extreme weather event. Such sites must be designed to operate autonomously for the period specified. However scoping out a possible helicopter landing site, boat access and foot access should be undertaken.

4.2 Foot access to station and to water

Safe bank access in normal conditions can in flood conditions be very dangerous, and every effort should be made to avoid the need for this. For built components there are two competing aims; to provide secure barriers and handholds that prevent a fall into the flow, and to minimise structural components that can catch debris and cause structural failure. Sacrificial/sprung handrails, low profile rope holds, carefully considered work positioning, and use of personal protective equipment are potential solutions. But the best solution is to not have equipment that requires access close to a river's edge. Life jackets could be warn. Potential to install a trail camera to read staff gauge, so no need to go by rivers edge and can verify the logger from base.

4.3 Staff gauges and benchmarks

A requirement of staff gauges and benchmarks is that they are stable and durable.

For safety reasons and for manual readings (to provide backup), staff gauges used for high stage levels should be visible from as far as possible back from the water.

During a flood, benchmarks can be covered with debris or sediment, or washed away completely. All benchmarks should be geolocated with posts to help find them. If possible, at least one site benchmark should be positioned well above the design flood level in stable substrate. If that is not possible there should be one or more back-up benchmarks. Some locations are subject to slow creep of mass substrate, in which case a benchmark may be needed some distance from the site.

4.4 Stilling wells and encoders

4.4.1 Concrete stilling wells

Concrete stilling wells were constructed with heavy foundations and were often set back into the bank to some extent for shielding from debris impact. They are extremely durable and therefore most useful for flood monitoring during an emergency.

Spalding of the concrete can expose reinforcing and become problematic. If this is caught in time the steel can be cleaned and concrete repair applied. The areas of the stilling well that seem to be particularly susceptible include around the ledge that the footbridge sits on, around the door, and under the recorder house floor. These should be observed and noted in the annual site inspection.

4.4.2 Steel stilling wells.

Size, shape, orientation, wall thickness and condition all influence the strength of steel stilling wells. In addition there are two important factors; type and condition of the foundations, and secondly type and condition of lateral bracing elements. Engineering advice will usually be needed to estimate a stilling well resistance to design flood levels and wind loads.

The foundations will determine resistance to scour and resistance to overturning. The depth of the stilling well is often easier to measure inside the well than outside. The foundations may be deeper still, but without as-built information this should not be assumed. There may be a concrete surround which could be ballast or could be just a capping. The point at which the stilling well emerges from the ground, or from the concrete, is often a point of weakness. This is a position that is often significantly corroded. The degree to which the tower will hinge at this point is an important determinant of strength.

The stilling well may be braced by solid struts, or more commonly by wire ropes. The footbridge may contribute to the bracing depending on its design and end fastenings. Not all towers are braced. It is recommend having a structural engineer visit the site to advice on bracing.

Although lateral bracing is a major determinant of strength, it can attract damage from wind throw onto the wire ropes, and can increase loading from catching flood debris.

Access hatches and local buckling

The lower access hatch is a potential weak point in the design of a steel stilling well. At the hatch position the tower fabric is susceptible to local buckling when it is subject to axial compression, as is often the case on the downstream side of the well close to the foundation (which is also a common position for the hatch). Figure 7 gives an indication of this for the standard Ministry of Works steel stilling well with bending due to horizontal hydrodynamic load and the hatch one quarter of the circumference of the tower.

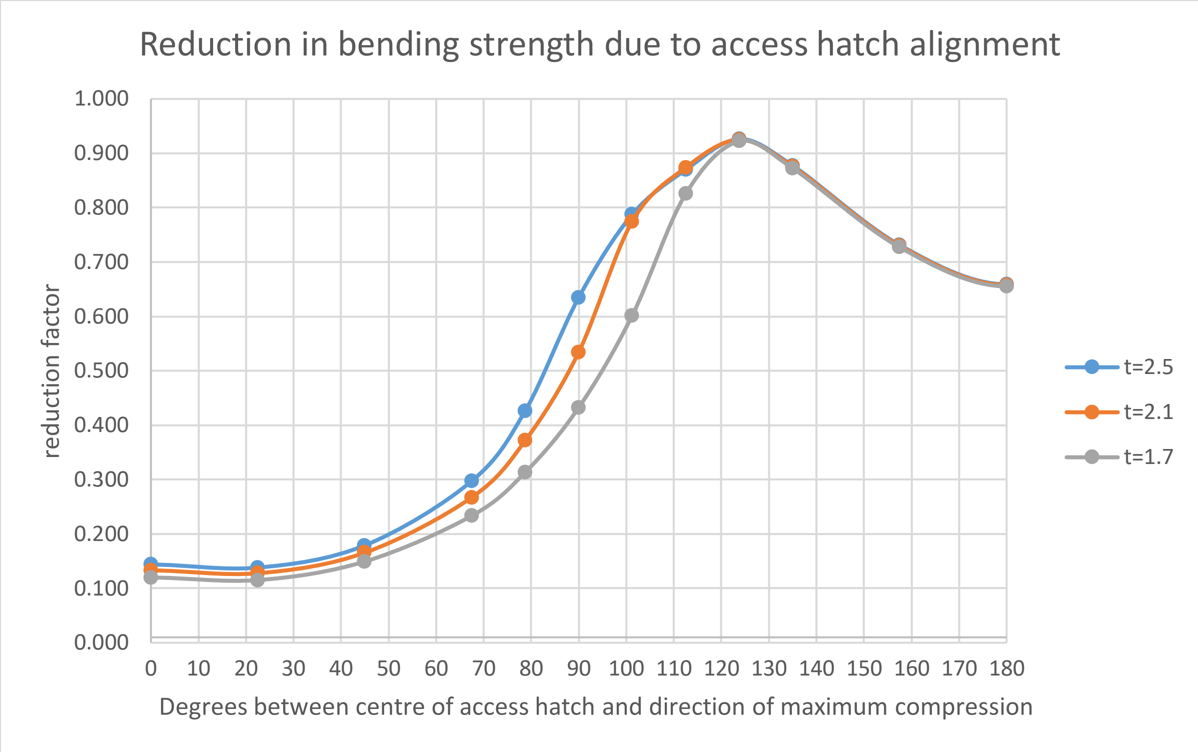

Figure 7: Reduction factor for bending strength due to the hatch location in relation to the direction of maximum hydrodynamic load force. t = wall thickness of the steel.

The magnitude and position of maximum compression depends on many factors including the design stage and velocity, and the nature of the foundation and lateral bracing, so engineering advice may be needed. If this is a critical issue, a possible solution is to rotate the tower section involved so that under design loading the hatch is on a side of the tower subject to less compression. Another improvement is to strengthen the edge of the hatch opening, for example with an extra thickness of steel.

4.4.3 Plastic stilling wells

Plastic stilling wells, being generally smaller, tend to be easier to locate out of the full impact of flood water and debris, and they are resistant to corrosion. Polyvinyl chloride (PVC) pipes are not suitably strong, particularly to impact, and can become brittle. High density polyethylene (HDPE) especially thick walled, is much more resilient and long lasting, however if also monitoring low flows, one must account for thermal expansion. Like any stilling tower, seek structural engineering advice on their design and use.

4.4.4 Stilling well catwalk

Debris caught on a catwalk can more than double the hydrodynamic load on a stilling well and can easily cause the failure of the structure if it is not anticipated in the design, structural engineering advice is recommended. Wherever possible, the catwalk should be well above the design flood level. The type of barrier (handrail) will influence how easily flood debris will collect on the structure. Pool fencing type barriers will collect more debris but may be necessary if the catwalk is easily accessible to the public and Chainlink will also catch debris. An industrial 3-rail geometry as described in NZS/AS 1657 or similar will probably have the lowest drag and is suitable where there is no easy public access.

Figure 8: Catwalk self supported on Pareora River at Huts site. Photo by permission of ECan.

Figure 8 above shows a lesson learnt during the 1986 (200 year flood) when the catwalk caused the tower to collapse into the river. The tower now no longer supports the catwalk.

4.5 Other water level sensors

It is recommended that important sites have dual sensors and 2 methods of communication with independent power sources, the backup secondary sensors selected, should be considered, which are reliable and accurate. If the primary sensor fails will you be comfortable with what you are receiving, checking of the historic raw secondary sensor dataset is recommended.

4.5.1 Bubblers and pressure transducers (PT).

The flexibility in routing bubbler tubes or PT cables within cracks and other sheltering features, and the ability to fasten the sensors out of harms way is a big advantage for these types of sensors. The data logging equipment can usually be housed well above flood level independently from a stilling tower, if one is used in conjunction. Of the two types, PT's tend to be more affected by excessive sedimentation, while bubblers are largely self-purging. Bubblers however, can under-read in high velocities and large waves. Pressure sensors can be difficult to maintain as they are located under the water, while bubblers sense pressure above the water surface.

4.5.2 Non-contact sensors

Mounting on bridges

If mounting radar or ultrasonic sensors on road bridges the resilience of the bridge should be treated the same way as any other hydrometric assets. The hydrodynamic and debris loads outlined above affect both hydrometric and roading infrastructure similarly, and in both cases a design flood level and debris load, appropriate to the importance of the data, should be used to assess the suitability of the structure. The NZTA can advise on the design flood level of state highway bridges, and the NZTA Bridge manual (3rd Edition) is a good starting point for assessing debris effects for bridges and for hydrometric structures more generally. Additional points to consider include:

1. Safety of staff (traffic hazard).
2. Bridge piers in mid-stream are subject to higher, but more predictable water velocities compared to bank-side structures. The ideal bridge is a single span well above the design flood.
3. Durability of the whole system. Cables connecting instruments to instrument cabinets require protection, and bridge approaches may be washed away even if the bridge is left intact. A work around could be the use of Wifi or NIWA's LoRA links.
4. Mounting of non-contact sensors on downstream side of bridge to protect against tree branches damaging or removing the sensors during flooding events.

Note that in flood conditions, hydraulic effects around bridge piers and debris caught on piers can cause unpredictable variation from the expected rating curve.

Booms, cables, and pole mounted cameras.

Cameras, radars and ultrasonic sensors can be mounted on pole structures positioned outside the channel to minimise direct damage from flood waters and debris. Clearance above the design flood is needed in order to prevent the impact of large woody debris, which can "stand up" in the flow. Crewed cableways employ a standard clearance of 3.8m for this purpose, so that would be a good starting point for high importance sites.

4.6 Tide gauge

The site should be protected from waves as much as possible and the site access should be safe in all conditions. The external reference gauge should cover the expected full range and sensors should be mounted on a solid structure and cover the greatest tidal range expected as well as storm surge, which could be an additional 0.8 m. (Note: Hurricane Katrina hit New Orleans with 160 km wind gusts, 902 millibar low, created a storm surge ranging from 5.5 – 8.6 m).

Dual sensors are recommended for validation of the data as well as dual communications for resilience.

4.7 Rating curve

A rating curve is a relationship between river water level to river flow. Water level on its own is moderately useful for flood prediction and flood warning, but knowledge of flow allows full use of collected water level data. With regard to this document rating curves are needed for:

- Calculation of flood frequency statistics used for design of structures and to indicate both the severity, and likelihood of an event occurring over time.
- Routing of flood flows to downstream locations for flood warning purposes.
- Providing knowledge of probable maximum river levels.

If the rating curve relationship is particularly complex it becomes difficult to predict its nature with some accuracy. Furthermore, if there are existing local conditions, or conditions created during a flood that create variable hydraulic effects, the rating curve becomes inaccurate.

It is important therefore when siting a flow recorder or establishing a rating curve that you understand any downstream conditions that affect the rating curve. While a change in flow may behave in a foreseeable manner, the change in water level may be unpredictable if any of the following occurs:

1. Choking of the river downstream (perhaps from a gorge) causing high flows to 'back up' once flows reach a certain high level
2. Debris deposited on downstream structures such as a bridge, or on banks to dam the river
3. Sediment raises the complete river bed and flood plain, such as happened in the Esk Valley (Cyclone Gabrielle) in 2023.
4. The recorder is close to the mean high water spring (MHWS) line and tide or storm surge causes a backwater effect
5. A bridge is washed away downstream, or a new channel develops upstream, perhaps even bypassing the recorder.

At highly critical sites more frequent recorder cross-section surveys are required to enable estimation/calculation of the discharge when extreme flooding occurs.

4.8 Gauging Cableways and slacklines

Emergency management flood warning/monitoring information is gained from the use of cableways and slacklines, it is important that they are acknowledged as a key component of hydrometric infrastructure.

Figure 9: Clarence River at Jollies cableway gauging. Photo by permission of NIWA Christchurch Field Team

Cableways and slacklines are essential for measuring flood flows to determine the stage/discharge relationships for informing hydrologists and engineers of flood flows during events and to inform the emergency response team. Cableways and slacklines tend not to be threatened by the direct erosion of flood waters, due to their location well above flood levels. Extreme weather events are a risk mainly via three mechanisms:

1. Wind throw of large branches or trees on to the cable.
2. Recession of the river bank towards the structure (Figure 10), associated with high soil moisture levels, and possible toe erosion.
3. Structural weakening of the soil around foundations, also associated with waterlogging.

Note that the local climate has an influence on the durability of steel structures and on cableways in particular. Regular testing and maintenance is particularly important in moist climates. The removal of debris and detritus from the cable saddles and around the anchor rods is also very important.

Figure 10: Cardrona River at Mount Barker slackline with river bank erosion. Photo by permission of Otago Regional Council

4.8.1 Identifying cableway/slackline anchor movement

The first two mechanisms 1 and 2 above can be observed on inspection. Subsidence of anchors or foundations due to soil weakness may be less obvious, but might be apparent by visual inspection if there are gaps between the concrete and soil. However, this would be extremely rare, although it is very common for gaps to open due to soil shrinkage in dry conditions. More common is large scale slumping or mass movement of large blocks of substrate material. There may be no indication of this at the structure, but it could be apparent by the inclination of structural components, or by reference to benchmarks beyond the slump. Both these local and large scale processes tend to be accelerated by waterlogged soil, more commonly due to rain than extreme floods.

An unusual increase in the unladen cable sag is an indication that the anchors or the tower foundations may have subsided. Adjustments on the main cable U-bolts, changes to the angle of the towers to vertical, or car placement are the more usual explanations for this, so these possibilities should be discounted first. The unladen sag is measured, usually by survey, between the underside of the cable at its lowest point at mid-span and the underside of the cable in the saddle. The two saddles may be at different heights, so one side of the river is nominated as the reference side. The measured unladen sag is compared to the historic record on a graph that allows for temperature dependency. The historic scatter of points also indicates if the deviation is "unusual". Engineering advice should be sought if there is any doubt about this. All this information should be kept in asset files.

4.8.2 Resilience; protecting cableways from extreme weather.

Scheduled maintenance of cableways typically includes maintenance of drainage, both for structural and corrosion purposes. New drainage works are recommended if local drainage patterns are such that run-off is directed over or adjacent to a structure. This can be one of the most damaging situations.

On occasions bank protection may be considered following engineering assessments, where toe erosion is ongoing.

Scheduled maintenance typically includes removal of overhanging timber that may threaten the cable. The risk posed by large trees is assessed on a case by case basis and the removal of large timber should take into account environmental and cultural needs.

4.9 Rain gauges and soil moisture

4.9.1 Rainfall and soil moisture

NEMS for rainfall should be followed for site selection and installations. Sensors for rain intensity and soil moisture are generally close together, at ground level, and robust in terms of extreme weather events. Compared to hydrometric sensors, there is naturally more choice regarding positioning, and a greater geographical spread with more redundancy possible. The risk to data resilience is primarily due to damage to communications infrastructure. For data quality reasons rain gauges should be positioned away from sheltering vegetation etc. and this is advantageous in terms of windthrow. If on a flood plain, or associated with a hydrometric site, inundation can be a risk that usually however it is possible to position meteorological sensors well above extreme flood level.

For critical, highly important rainfall and soil moisture sites it is recommended at least 2 sources of data (2 sensors) and 2 forms of telemetry communication, with independent battery storage, as well as lightening protection be installed. Effectively these could be two separate independent sites. It is recommended that the fenced compound be enlarged to accommodate the 2 rain gauges and the check gauge. Adequate capacity should be considered for the check gauge.

4.9.2 Rain radar

Rain radar is a very useful tool for flood management. It is not accurate in quantifying rainfall, and not suitable as a sole source of data at any importance level. However, for those councils with an adequate spatial density of rain gauges, rain radar compliments the network when tracking storms detecting the storm pattern movement, and in some cases councils can calibrate the radar image with known rainfall. For councils where the funding for their rainfall network is limited, rain radar, if present, is a key tool used to track storms.

At present, rain radar is managed by the MetService. If rain radar is an important component of regional civil defence, arrangements to ensure resilience should be made with that organisation.

4.10 Telemetry system

The system for retrieving data from remote stations and transmitting that to the base where it can be viewed, analysed and disseminated is a critical component for a flood warning system. It is essential that the telemetry system remain operational during an extreme weather event. This requires that the power system, structures, IT network, and third party systems are reliable and available when needed.

If contracting out components of the telemetry system, give strong consideration in the contract to the level of service relating to the reliability, ongoing maintenance, and call out agreement for that system. As an example, just one failed component (one repeater used by 40% of sites) was not under direct control of HBRC staff during Cyclone Gabrielle and failed due to poor maintenance, while all other repeaters and link stations operated throughout (Horrell, 2023).

4.10.1 Communication

Various forms of communication are available for the telemetry system.

The use of continuous water quality instrumentation in hydrometric networks has become common place. These can place additional load on the communications, data loggers, and power supplies used for critical flood management. At critical sites used for multiple purposes it may be worth considering separating the hydrometric functions from the water quality functions to reduce load on critical systems during an event.

Cellular communication

Cellular communication should only be employed as secondary backup or supported by a radio or satellite method, as during events cell towers are vulnerable to overloading and/or complete shutdown. Back-up power at these towers is often not designed to run for long periods. These systems also suffer from an inability to contact the network supplier to find the reason why the network drops out, and who can fix issues as they occur.

The cellular network type selected should allow loggers and modems be polled at high frequency, or on demand, during an event.

Radio

Radio is regarded by most councils as the most reliable form of communication for telemetry. Repeaters need to be built to a high standard with lightning protection and have reliable primary and back-up power systems.

It is beneficial and recommended to have digital mobile radio (DMR) to enable selection across multiple repeaters. The more repeaters that exist the better the redundancy should one or more fail. If radio link stations are employed, then look for and install a reliable backup link station to provide cover if one were to fail. Some digital setups require a connection to the base via fibre, which introduces another point of failure.

Repeaters must be well designed and maintained and be designated as critical infrastructure. There must be on-call access to a technician to fix any problems. In many cases, it is probably best to either operate a repeater yourself, or have close oversight over the operation of the repeater from within the hydrometric team.

It is recommended to set up portable back-up repeaters which have been configured to your frequencies, pre-tested and with pre-determined locations with safe access. It is also wise to set up a testing plan while stored in your radio shed.

Satellite

Satellites come with certain advantages. They are remote from any severe weather and depending on the location they can transmit into areas like gorges where other communication is difficult. Some of these systems however, can be heavy on power use, and typically, a satellite site would transmit hourly, which in some cases is not enough. Where high frequency access to data is essential instrumentation could be connected to an IP capable data logger connected to a continuous satellite broadband internet link such as Starlink.

Fibre

The telecommunications industry consider fibre to be very robust. Experience in New Zealand during extreme floods however, suggests that failure of fibre is possible. Landslips and bridge failure are two key areas that have shown to cause failure in fibre connection. It is considered that the small time fibre has failed is probably during very large storms. At the base, ensure you have a Starlink or other suitable way to obtain access to the internet.

4.10.2 Base station

The data that is sent from remote stations must be received at a base, where it is analysed and used to provide critical advice and automatically distributed notifications are generated. It is recommended to have a functional backup base station on separate power and generator supply, and preferably at a different location to the primary base station.

The base is a dedicated software package (e.g. Hydrotel) that is designed for the collection of data from remote sites via disparate communication methods. Often this system will be the single entry point for the site data into the systems were it is viewed and analysed by staff. It is absolutely critical that the base is resilient. It must be recognised as a critical system by the organisations Information Technology function and a specific level of service arrangement put in place for all components of it. That should include:

- 24/7 IT support
- Resilient power supplies.
- Back up of databases.
- Resilient communication pathways.Tight contracts with providers.
- Implementation of fail-over systems to allow continuous access in any event.
- Cyber security protections.
- Alternative remote access methods such as Starlink should local internet access be unavailable.

4.10.3 Power supply

Power systems must be able to operate a station at high polling rates for an extended period of time, and you must design and maintain your systems accordingly. Consider supplementary battery charge methods such as autonomous methanol generators for critical sites in remote locations that may be difficult to access for repairs.

Whilst most councils aim for 5 to 7 days battery supply, it is recommended to install additional capacity to account for autonomous operation following storm damage when power charging systems have failed or sunlight is in short supply.

Batteries must be replaced before they degrade to the point of failure and this should be included as a part of an asset management programme. Monitoring of battery health (at least weekly, and before any severe weather event) is essential to identify any developing power charging issues before they become a critical problem.

Mains power

Mains power can provide plenty of power at sites drawing a high load, but must also have battery back-up to the necessary capacity in order to operate during expected power outages during flood events.

Convert to 240 volts to 12V as close to the source as possible (in the interests of safety), and it is recommended to convert any mains power equipment (including lights) to 12V.

Solar panels

A properly designed solar charging system is generally considered to be the most reliable power supply. The design should consider all of the following aspects in the design process: the worst case sunshine deficit, the size and type of solar panels, an allowance for degradation of panels (age, dirt/pollen deposits) the losses between the panels and the batteries, whether they are in parallel or series, the solar regulators, and the size and type of battery storage. As a rule, with regard to panels, they are cheap so over-design anyway. High quality MPPT type solar charge controllers can improve the efficiency of the solar system.

Solar panels are susceptible to wind throw and other airborne detritus. It is best to avoid positioning panels near overhanging branches and to allow for ongoing growth of the vegetation, both from the viewpoint of future shading and damage.

Panels can be blown out of alignment by high winds. This is not necessarily a problem in terms of the reliability of the site if the battery has been sized correctly. However, in cases where site access is difficult or could be compromised, more robust ways of mounting the solar panels can be considered. A good (but more expensive) method is to use a plinth mounting which has poles to ground on all four corners.

Batteries

Batteries are a critical element at a monitoring station. In the absence of a proper “whole of system” design, the capacity of battery back-up power for a hydrometric asset should be at least as long as indicated in Table 2.

For solar powered sites battery storage has two functions: to run a station through a period of weather unfavourable for charging and to run the station for a prescribed period of time following storm damage or compromised access. Since an extreme flood can occur after a long period of overcast weather, the prescribed battery capacities for both these functions have been added and a longer period of inclement weather assumed for the high importance sites.

An advantage of over sizing your battery capacity is that flat batteries never need to be lifted out in between battery replacement. For high and medium importance sites, station batteries should be replaced every 3 years according to asset management procedures. From a full lifetime cost perspective, it is sensible to invest in high quality batteries and solar systems. Consider high capacity batteries such as AGM or Lithium note that lithium batteries do not operate well in extreme cold temperatures so are not suitable for alpine sites.

Regular checking of battery health is essential to identify problems with power supply. The testing for battery health can be improved by using devices such as the Victron Smart Shunt that provides data on battery capacity, discharge and general health and not just battery voltage. Your telemetry software should also provide you with alarms of low voltage.

Back-up generators

These are required at mains powered repeater stations, the base station, the back-up base station, and possible at any monitoring stations that have high power use, if they are critical to provide emergency response.

5 Webcams

Webcam setups can be extremely useful during floods. They provide a wealth of information as a communications tool. However, council IT teams need to consider if webcam livestream can meet the massive demand during floods, as there is a potential to cripple networks interfering with other emergency response functions. A basic alternative to livestream systems are webcams that take single images and send on a schedule.

Onsite recording at high resolution (for STIV processing purposes) for later retrieval is recommended. The use of an appropriate storage system for the environment is necessary (such as a hardened (industrial style) PC). Design the memory to keep footage for a long time in case access to the site is curtailed for a while.

Consider power independence from mains networks, or at least sufficient battery power to sustain gear to keep running for a number of days after a flood (to continue recording peak and recession flow).

One consideration is to turn off webcam IR LED's to avoid lighting up spider webs and rainfall. Install powerful external IR lamps away from your camera so you can see the river and staff gauge in the dark.

Trail cameras with an external power source and set to circular memory are a cheap alternative to record imagery.

6 Post-event

When conducting post flood sites visits approach sites that have experienced floods (even if only moderate flows) with caution as new hazards may have been introduced. Following an extreme flood it is a good idea to arrange for inspection of structures (stilling wells, catwalks, cableways) by a qualified engineer prior to access.

Take any opportunity to incorporate water level measuring equipment into new bridge designs, in a way that allow them to function well and be highly resilient to damage.

Mark historic flood peaks on staff gauges or bridges at areas where there is public interest, see Figures 11 and 12.

If sensors fail then repair immediately and survey and record the flood peak maximum stage and the method employed in this detection.

Seek any local cell phone or drone video footage of the flood event with the recorded date and time.

Figure 11: Whanganui River at Town Bridge, historic floods   Photo J Watson

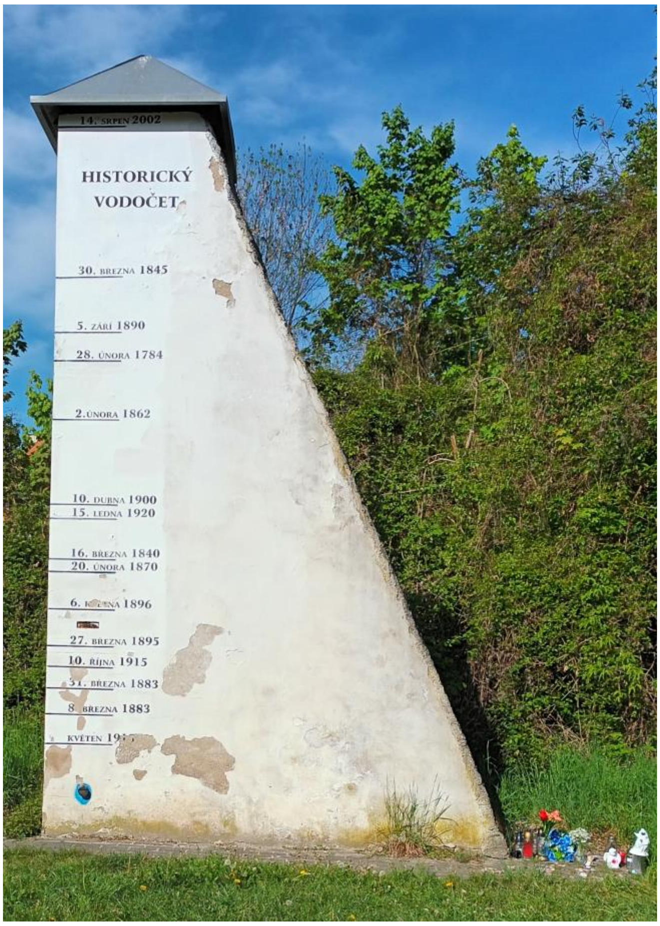

Figure 12: An elaborate example of recorded historic flood peaks. Elbe River Czech Republic. Photo:- G Horrell

7 Resourcing

An increase in resources is required to accommodate the additional workload created by these guidelines.

Knowledge and experience of the functioning of the full telemetry system including the identification of faults and their solutions takes some years to acquire.

Many councils are currently operating with a shortage of experienced staff and feel their resilience is vulnerable for day to day running of their system. This exposes the team further during flooding events which may last some days when the few rostered staff become exhausted. Outside help is recommended to fill the hole at such times. During large events it is not unusual for other councils to offer assistance to the affected areas. To enable this to happen efficiently it would be useful to have to hand documentation (e.g. Flood Manual) that allows those outside teams to quickly get the information they need to undertake work in the affected region.

Not all of the trained council staff have the freedom to carryout telemetry system repairs outside normal working hours when necessary, this should be revisited and encouraged throughout New Zealand.

8 Additional information

This section contains some additional information collected during this making of this document:

- Wireless networks are worthy of investigation for telemetry.
- Investigate Starlink satellite technology.
- Take photos of sites as they are constructed, including where cables are buried.
- Non-contact sensor positioned away from the river does not require being positioned vertically above the river like radar or ultrasound sensors. The newly developed Lidar water level sensors can measure up to 40 degree angle to the water surface, with a water level range of up to 35 m and 1 cm accuracy (John Fenwick email). NIWA are aware of this but have not got involved as yet. https://ichydro.github.io/Riverlabs/installation.html#
- If buying a drone to video flood footage, then be prepared to pay the additional expense to make sure it is waterproof.
- New installations should have a favorable geotech survey and then be designed by a structural engineer. Structures are to be inspected by a structural engineer every 2 years.

9 References

AS/NZS 1170.2:2021 A2., (2024) Wind actions. Australasian/New Zealand standard. ISBN 978-1-77686-851-3 (PDF)

Dodge, M., Holwerda, N., McLarin, M., Sowman, B., (August 2017) National environmental monitoring standards for rainfall recording, version 2.1. For MFE. 25 p

Horrell, G., Rowland, M., Peters P., (Sept 2022) National environmental monitoring standards for water level version 4. For MFE. 110 p

Horrell, G.A., (2023) Review of Hawkes Bay Regional Council telemetry system. Graeme Horrell Consultancy Limited Client Report 2023-001

NZS/AS 1657., (1992). Fixed platforms, walkways, stairways ,and ladders. Design, construction and installation.

Heather-Smith, G., Hopkirk, C., Jackson, H., (2022) Perfprmance standards for flood moitoring network resilience. Greater Wellington Regional Council. Technical report. 24 p.

Waka Kotahi NZ Transport Agency., (2022) Transit NZ Bridge Manual SP/M/022. Third Edition. Amendment 4. ISBN 978-0-478-37161-1 (online) https://www.nzta.govt.nz/resources/bridge-manual/

Walsh, J., Grace, C., (October 2023) National environmental monitoring standards guidelines for hydrological and meteorological structures, version 2. For MFE. 44 p

www.LPI.com.au, Earthing Solutions Brochure is useful