HOW WIDE IS THE STREAM?

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ABSTRACT

Under the Resource Management Act 1991, a 20m wide esplanade reserve is required to be set aside if land is subdivided to allotments of less than 4 hectares and is adjacent to a stream of 3m or greater in width. The definition in the RMA requires the stream bed to be more than 3m wide "at its annual fullest flow without overtopping its banks". There is currently no standardised method for determining stream width. Historically stream width has been assessed by Surveyors based on a site visit and professional judgement based on cross section shape. Their ability to determine the stream width at the "annual fullest flow" has at times been questioned.

This paper presents a methodology which has been developed to address this problem by providing a set procedure for determining a stream's width for the purposes of setting aside esplanade reserve under the RMA. The procedure proposed is easily replicated, is transferable and will provide consistent results. The methodology relies on a hydrological modelling approach to determine the annual fullest flow, and hydraulic modelling with surveyed cross sections to determine the stream width. This together with a site assessment provides a more robust assessment technique which has recently been tested and upheld by the Environment Court.

KEYWORDS

Stream width, esplanade reserve, annual fullest flow.

1 INTRODUCTION

In New Zealand the Resource Management Act (RMA) 1991 requires that a 20m wide esplanade reserve is set aside if land which is adjacent to a stream of 3m or greater in width is subdivided into allotments of less than 4 hectares. The definition in the RMA requires the stream bed to be more than 3m wide “at its annual fullest flow without overtopping its banks”. There is currently no standardised method for determining stream width. Historically stream width has been assessed by Surveyors based on a site visit and professional judgement and cross section shape. In some instances this has resulted in a measurement based on water width at base flow. Surveyor’s ability to determine the stream width at the “annual fullest flow” has at times been questioned.

This paper presents a methodology for determining a stream’s width for the purposes of setting aside esplanade reserve under the RMA. The procedure proposed is easily replicated, is transferable and will provide consistent results. The methodology relies on a hydrological modelling approach to determine the annual fullest flow, and hydraulic modelling with surveyed cross sections to determine the stream width. This methodology together with a site assessment provides a more robust assessment technique which has recently been tested and upheld by the Environment Court.

2 BACKGROUND

The North Shore City Council is often faced with subdivision applications for land adjoining streams in which the wetted width under normal flow conditions is less than 3m wide. These streams tend to have relatively small, steep and often urbanized catchments, as a result they respond quickly to increased runoff during rainfall events. The flow in the stream and consequently the width of the stream can be highly variable. Many streams which appear to be less than 3m wide, have wetted widths of more than 3m wide a few times a year during periods of heavy rain.

The RMA definition of river bed for the purpose of esplanade reserve appears to acknowledge variability in stream width and refers specifically to the area covered at “the annual fullest flow without overtopping its banks”.

Historically stream width has been determined by surveyors based on a site assessment of the local topography and the surveyor's experience and professional judgement. There has been little attempt to determine the annual fullest flow and surveyors have instead relied on their interpretation of where the bank is. The council has usually accepted the assessment of stream width provided by the applicant at time of subdivision without question. There was often no reason to dispute the applicant's assessment as the council often waivered the requirement to set aside esplanade reserve due to reluctance by the council to assume responsibility for the on-going maintenance of this land.

The council's approach to stormwater management has changed in recent years including requirements to minimise environmental effects and protect and restore selected urban streams to a more natural state. There is also more pressure from developers to develop sites to the maximum because of the limited land available and the high price of land in urban areas. The council is now trying to protect riparian margins and avoid further development in areas at risk of flooding and is thus more inclined to require land to be set aside for esplanade reserve where it qualifies. The measurement of stream width for the purpose of setting aside esplanade reserve is now becoming a contentious issue and the council has identified the lack of a set methodology which is relatively robust and repeatable.

3 LEGISLATION

The Resource Management Act, 1991 (RMA) was enacted to promote the sustainable management of natural and physical resources. Sections 229 to 237: Esplanade Reserves, set out a number of matters governing the setting aside of esplanade reserve. More specifically Section 230.

Section 230: Requirements for esplanade reserves or esplanade strips …..

(3) Except as provided by any rule in a district plan made under section 77(1), or a resource consent which waives, or reduces the width of, the esplanade reserve, where any allotment of less than 4 hectares is created when land is subdivided, an esplanade reserve 20 metres in width shall be set aside from that allotment along the mark of mean high water springs of the sea, and along the bank of any river or along the margin of any lake, as the case may be, and shall vest in accordance with section 231.

(4) For the purposes of subsection (3), a river means a river whose bed has an average width of 3 metres or more where the river flows through or adjoins an allotment; and a lake means a lake whose bed has an area of 8 hectares or more.

Section 2: Interpretation, (provides the following relevant definitions)

River: means a continually or intermittently flowing body of fresh water; and includes a stream and modified water course; but does not include any artificial water course (including an irrigation canal, water supply race, canal for the supply of water for electricity power generation, and farm drainage canal);

Bed: in relation to any river for the purposes of esplanade reserves, esplanade strips, and subdivision, the space of land which the waters of a river cover at its annual fullest flow without overtopping its banks.

Note that bank of a river is not defined in the RMA but previous case law has accepted that on its ordinary meaning a bank means the land on either side of a river which confines the natural flow of the water, whether the normal flow or flood flows.

A recent environment court determination concluded the following: "We have found that the bank as described in the definition of the bed of a river in Section 2 is necessarily defined by a water level – being the annual fullest flow level (as represented by the mean annual flood (MAF)) – where the bank contains the flow. Other wise the bank is the point at which the water overtops and spills on to a more extensive flood plain or into a secondary flow path." (Decision No. W61/2008).

4 HISTORICAL APPROACH

Registered land surveyors who are qualified to carry out cadastral surveys have always been required to determine boundaries, including boundaries of water bodies. They have been responsible for identifying the width of streams and rivers which are plotted on survey plans and used as legal instruments. Streams and other water bodies often form cadastral boundaries.

The historical approach to the measurement of stream width has been for a registered land surveyor to conduct a site visit accompanied in some cases by a hydraulic engineer. During the site visit they would identify positions for measurement of cross sections and make an on-site determination of probable general flow levels by inspection of vegetation, any debris lines and profile to determine the flood level at which the banks would be overtopped. These sections and relevant levels, including actual water levels, would then be surveyed to the required accuracy.

The annual fullest flow is interpreted by some surveyors to be a yardstick to determine the width of the river bed where the stream obviously does not overtop the bank once a year. A hydrological assessment of the annual fullest flow is however rarely, if ever, conducted.

5 CONCEPTUAL NEW APPROACH

When determining how wide a stream is for the purpose of esplanade reserve, and whether a stream qualifies or not, there are two specific provisions within the definition which need to be considered:

The “annual fullest flow”; and “... without overtopping its banks”

Bringing the two aspects together, it appears the intent is for the width to be assessed in the context of storm flows, but with the “annual” aspect limiting it to the more frequent storms rather that the extreme floods. The “without overtopping its banks” aspect avoids excessive widths being measured where the flow can spill out on to extensive flood plains. The interpretation above was confirmed by the environment court declaration (Decision No. W61/2008).

Hydrological data will not always be required to determine the width of the bed of a river. Where there is no dispute and a river is obviously much narrower or much wider than 3m it would be absurd to require further assessment or proof using hydrological data. However the definition of bed uses terms that may be illuminated by hydrological data. Included in that definition are the words space of land which waters of the river cover. It is the extent of the waters of the river that is important and hydrology can assist in describing that in space and over time.

Where the stream width is disputed, one has to determine what the annual fullest flow is at a particular location, what the water level is during the annual fullest flow, whether or not this flow overtops the banks, and if so at what point this occurs. The average stream width at the annual fullest flow over the length of stream crossing or adjacent to the site then has to be determined.

5.1 DETERMINING THE ANNUAL FULLEST FLOW

The term annual fullest flow is not a commonly used hydrological term. A more commonly used hydrological concept is the mean annual flood (MAF), which is the mean of annual fullest flows over a period of time. Statistically this flow rate is equalled or exceeded on average every 2.3 years, i.e. it has an average recurrence interval (ARI) of 2.3 years.

An alternative interpretation would be to use the flow that is equalled or exceeded on average once per year (1 year ARI). The 1 year ARI flow would be slightly lower that the MAF. Where the 1 year ARI flow is being determined from historical data, it would need to be based on a partial series, which involves taking all flood and storm events, and ranking them to determine what size flood is equalled or exceeded on a long term average basis, once per year.

The annual fullest flow is better represented by the mean annual flood (MAF) than the 1 year ARI flow. This approach has been confirmed by the environment court declaration (Decision No. W61/2008).

For the vast majority of sites there will be no suitable gauged stream flow records available. Rainfall figures are however readily available and stream flows can therefore be calculated based on rainfall and catchment characteristics using a hydrological model.

5.1.1 HYDROLOGICAL MODEL:

There are a number of hydrological models available these days, ranging from the Rational Method to far more sophisticated computer based programmes. These different models have different data requirements and all have their own limitations. Ideally for a model to be used with any degree of confidence it should be calibrated for the catchment and purpose for which it is to be used.

The Auckland Regional Council (ARC) has developed a set of guidelines to ensure consistency when calculating flow from rainfall. This model has been calibrated for use in the Auckland region. The Auckland Regional Council's

TP108 method should be used to calculate the annual fullest flow at a particular location in the Auckland region.

5.1.2 CATCHMENT CHARACTERISTICS:

Hydrological models rely on rainfall and catchment characteristics to calculate flows. It is important that appropriate catchment parameters are used when calculating flow. Some characteristics such as catchment area and shape remain relatively constant, while others such as permeability change over time as the catchment develops. Streams take thousands of years to form and the width of a stream is generally considered to be sized for the 1.5 to 2 year ARI flow. The stream would therefore have evolved naturally for the pre-developed catchment state. It is well known that urbanisation changes the hydrological response of the catchment and increases flows which in turn result in stream widening. It may take many years before the stream reaches a new state of dynamic equilibrium in which the channel shape matches the catchment hydrology.

While the flows from an urbanized or partially urbanized catchment may be higher than the flows which originally formed the stream, the stream banks are more likely to be overtopped by more frequent events because the stream has not yet widened to accommodate the increased flows from the current level of development.

The current level of development in the catchment was determined to be the appropriate basis for determining flows and stream width as it relates to the current situation at the time of application.

5.1.3 RAINFALL:

Stream flows are not always proportional to rainfall, particularly for smaller more frequent rainfall events, as a result of different antecedent catchment conditions. For example a relatively small rainfall event may result in significant stream flows if it occurs after a prolonged wet period, while a larger rainfall event may only result in moderate stream flows after a prolonged dry period. For simplicity and practicality the occurrence of flood events was assumed to be generally equal to the occurrence of rainfall events and we can therefore use rainfall to calculate flood flows.

The 2.3 year ARI rainfall depth is not commonly available, however the 2 year ARI rainfall figures are generally widely available. Analysis of historical rainfall data from a rain gauge in Albany has determined that the 2.3 year ARI rainfall depth is 1.07 times the 2 year ARI rainfall depth. This ratio is relatively independent of location and we therefore propose that the 2 year rainfall depth be factored up by 1.07 times for use in determining the MAF.

5.2 DETERMINING THE APPROPRIATE WATER LEVELS

There are a number of methods available for determining water levels in a channel when flows and channel characteristics are known. Methods include the very basic Manning equation, to more sophisticated backwater analysis and ultimately dynamic routing. There are a number of computer based programmes which can be used to calculate water level in channel sections including network modelling software such as MOUSE and SWMM or Open channel modelling software such as MIKE11 or HEC-RAS. The different models have different data requirements and all have their own limitations. Both MIKE11 and HEC-RAS are specifically designed for calculating water levels in open channel sections. Both have the ability to carry out this analysis using a dynamic or steady state approach. The steady state approach is slightly more conservative, but tends to be less susceptible to instability and easier to use. We therefore propose the use of HEC- RAS or MIKE11 run in the steady state mode.

In terms of channel characteristics, it is important that these are collected and used in a consistent manner so that Channel properties include roughness (Manning’s n), slope, cross-section and cross-section spacing and boundary conditions. These requirements are discussed in the following sections.

5.3 MORPHOLOGY

In respect of stream banks, there are some principals of stream morphology that are of relevance. The size of a stream channel is strongly influenced by the landform, the geology and the catchment size and resultant flows. In flatter topography, it is common for there to be a main channel with capacity to convey a flood with an average exceedance interval in the range from less than 1 year to as much as 10 years, and with an average of 1.58 years. Internationally, values have been found to be as low as 6 to 9 months. During normal dry weather flows the stream water usually occupies only part of the stream bed. During flood flows, the water level will rise, and the width will increase, while initially staying within the stream banks. At higher or more extreme flood flows, the flood water will spill out of the channel onto the floodplain, which can in some situations be quite extensive.

In steep topography, or where the soils are very erodible, it is common to have an incised channel with high flood capacity, and little or no flood plain.

Where there are wetland areas that are wet at normal stream flows and water levels, these would be considered to be part of the stream bed, both hydrologically and ecologically. These areas would still be regarded as "space of land which the waters of a river cover at annual fullest flow" and therefore meet the RMA definition of bed of a river. Small on-line wetland areas therefore need to be considered as part of the stream and should be included in the length of stream which is assessed.

6 METHODOLOGY

The intent is to provide a methodology which will provide reasonably reproducible results with a minimum of subjective interpretation. The methodology relies on a site visit and survey to provide representative cross sections of the stream and an estimate of channel roughness, Hydrological modelling to determine flows, Hydraulic modelling with surveyed cross sections and a back water analysis modelling programme to determine stream bed width.

It is assumed that this methodology will only be applicable where there is a dispute over whether the average stream width at annual fullest flow is over 3m wide.

6.1 SITE ASSESSMENT

It is essential that a thorough site assessment is carried out. The walk over should be conducted by an engineer experienced in hydrology and hydraulics and a surveyor who is going to conduct the survey.

During the site assessment appropriate locations at which to take cross sections should be identified. The appropriate roughness to be used at each cross section location should be assessed. A photograph should be taken at each proposed cross section location.

Current water levels and vegetation should be noted and recorded at each cross section location. A location of suitable downstream control which will provide a boundary condition for modelling should also be identified. Other useful information that should be collected includes time of year, recent rainfall and current water levels, debris lines or tidemarks etc. This information can be useful in assisting with any interpretation and also validating the hydraulic model.

6.2 SURVEY

In obtaining survey data for the purposes of determining the stream width for esplanade reserve, consideration must be given to both the hydrological aspects, and the morphological aspects. Survey should be undertaken such that:

- It is representative of the variability in the stream cross-section. Sections should be taken in general at reasonably regular intervals, but should also include any specific narrow areas (hydraulic constraints), changes in slope, any culverts, bridges or other structures affecting stream hydraulics, any wider areas (potential flood plain storage), in accordance with normal practice for hydraulic modelling purposes. The recommended minimum spacing of cross-section is approximately 10 times the channel bank-full width, but locally there may need to be closer spacing in places.
- There should be at least three sections downstream of the downstream boundary of the reach in question, to provide appropriate determination of the hydraulic control on the downstream water level in the model. There should also be at least one cross-section upstream of the reach in question, including upstream of any tributaries where there is inflow.
- Any reach being modelled should have at least three cross-sections, to facilitate accurate hydraulic computation in the model. There should be at least three sections on any individual property for which the average width is to be determined, to provide a basis for averaging bed width.
- Sections must be at right angles to the flow direction during small floods, i.e. normal to the main channel direction, rather than through any minor meanders within the bed during low flows.
- There should be survey points taken at least at every change of grade within the section, so that the morphology of the bed is fully recorded.
- The survey should be in terms of a common datum (preferably the appropriate LINZ datum) for both level and location, so that channel distances and slopes can be determined for hydraulic analysis. This also enables this data to be used with other survey data to the same datum.
- Ideally a photograph of the channel and immediate flood plain will be taken at each cross-section location, looking downstream and including the section location.

- Where there are distinct vegetation bands on the cross section (e.g. grass on the lower banks and scrub higher up), the interface between these should be recorded.

6.3 HYDROLOGY

In most cases there will be no suitable long term flow records available for a particular site so flows will have to be calculated from rainfall and catchment characteristics. In the Auckland region, the Auckland Regional Council's TP108 should be used as the method for calculating flows. Either HEC-HMS using TP108 or TP108 graphical method should be used to determine the appropriate peak flows to use.

The 2 year ARI rainfall figures for the catchment should be used and multiplied by a factor of 1.07 to give the 2.3 year ARI rainfall depth. The rainfall will generate a flow which is statistically equivalent to the Mean Annual Flood flow or mean of annual fullest flows measured over a number of years.

The catchment land use characteristics should be based on the existing land use at the time of assessment. In areas where there has been recent change in land use upstream, the existing flows may be higher than historical flows, but the channel may not yet have adjusted to these new flows.

If the reach being assessed is relatively long or there are a number of tributaries feeding into the stream then the catchment should be divided into sub-catchments and flows added incrementally to the flow in the main channel at the appropriate locations.

The resulting flows should be used in assessing the stream hydraulics.

6.4 HYDRAULICS

The hydraulic analysis should be undertaken using a computer model, to properly represent backwater effects. Ideally this will use an open channel flow software package such as MIKE11 or HEC-RAS. Where there is data on flood flows and levels, this should be used to validate the model. However, it will normally be the case that such data is not available.

The mean annual flood (MAF) flow calculated earlier should be used for a steady state flow analysis.

The slope of the bed and channel section geometry should be taken from the surveyed cross-sections.

The channel roughness or Manning's n is a key assumption in the assessment. Where there are distinct vegetation types at different levels on the bank, different n values should be used for the central channel area and the banks. The following n values are suggested.

Channel description	**Manning's n**
Straight, smooth, uniform, low vegetation	0.025
Straight, smooth, uniform, long grass or tree roots in the bed	0.035
Straight, smooth, uniform, heavy scrub on banks	0.045
Channel meanders, some bank slumps, varies in width, low vegetation	0.040
Channel meanders, some bank slumps, varies in width, long grass or tree roots in the bed	0.052
Channel meanders, some bank slumps, varies in width, heavy scrub on banks	0.063
Significant meandering, bank slumping, channel variability, long grass or tree roots	0.072
Significant meandering, bank slumping, channel variability, heavy scrub on banks	0.085

Table 1: Determining channel roughness (Manning n)

Where there are tributaries, these should also be included within the model, so any backwater effects from the main channel are assessed.

For each surveyed cross-section in the model, the flow depth and level from the model, and associated surface width, should be plotted on cross-sections for subsequent assessment.

6.5 INTERPRETATION

The plotted cross-sections and mean annual flood flow water levels need to be interpreted. Stream width interpretation is undertaken partly within the cross-section, and partly by looking at the more general topography of the site, to understand the individual cross-section results in context. There are three distinct situations that may arise in interpreting the results.

- Where the channel is incised, and there is no obvious low level stream bank or flood plains, then the flow is likely to be contained within the stream banks. Within these banks there may sometimes be small benches, similar to narrow flood plains. The bed should be taken as the surface width of the mean annual flood.

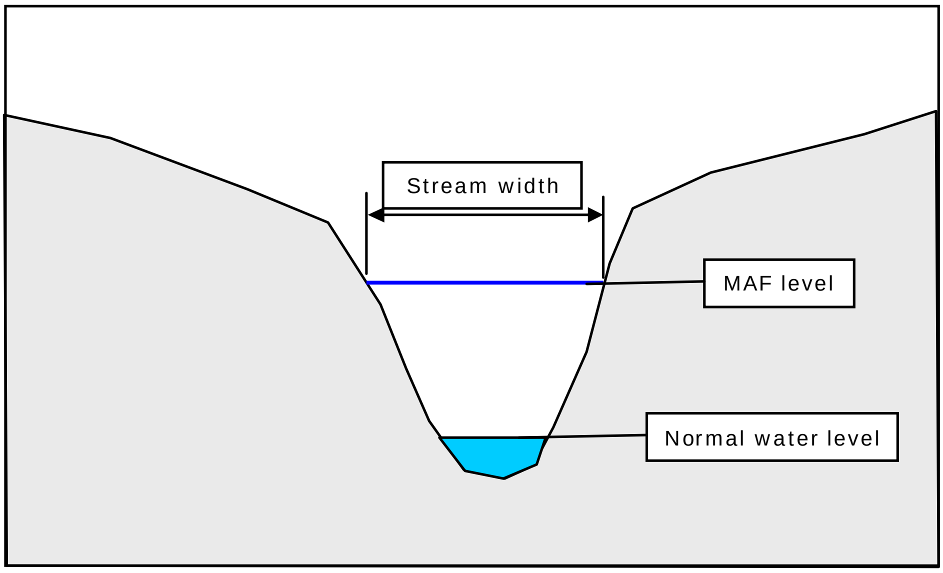

Figure 1: Incised channel

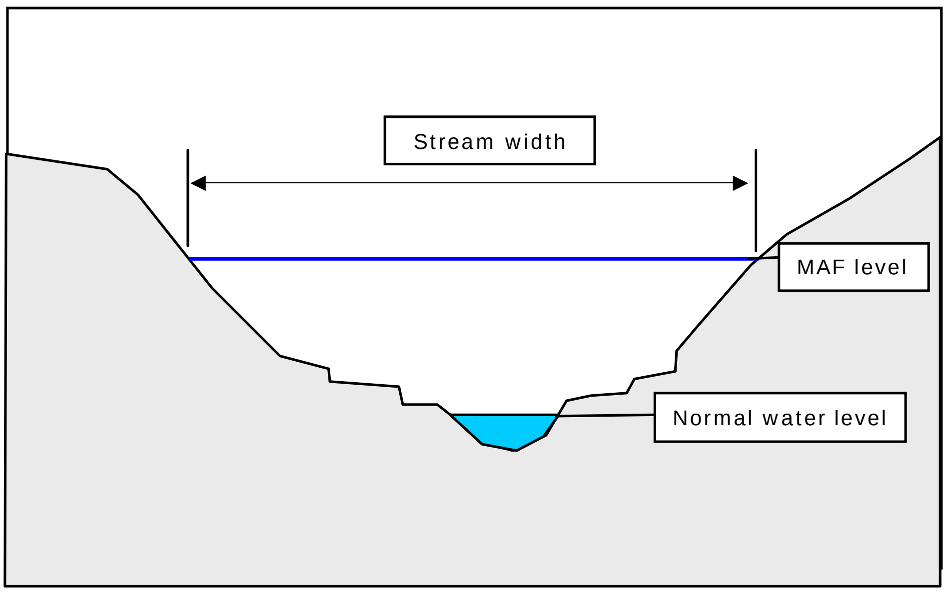

Figure 2: Incised channel with small benches

- Where there is a clear area where the flow spills from the channel into an extensive flood plain, or to a secondary flow path, then it is appropriate to interpret the bank as being the point at which this spill occurs. The width of the channel is then the width of the channel at this level.

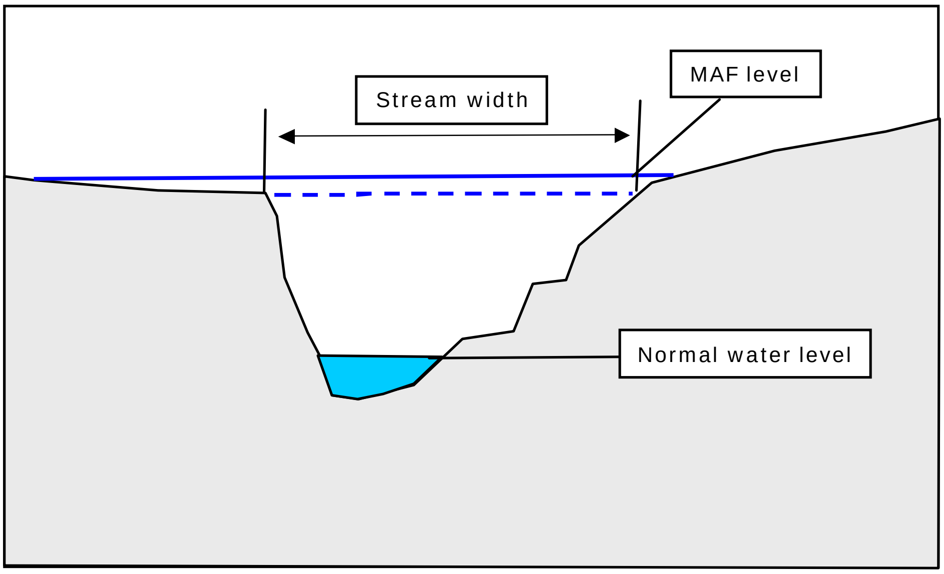

Figure 3: Channel with spill onto extensive flood plain

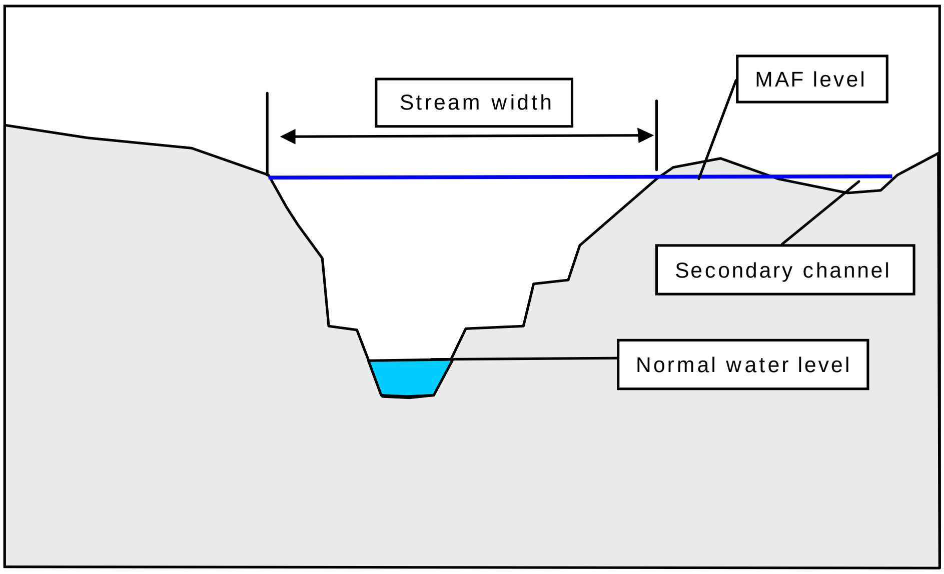

Figure 4: Incised channel with spill into secondary-channel

- Where there is a generally incised channel form, within which there is a small sub-channel with very limited capacity (i.e. significantly less that the mean annual flood flow), out of which the flow would spill on a regular basis, then it would generally not be appropriate to take the width of the small channel as being the bed. Rather, the bed width should be interpreted in the same way as for an incised channel, i.e. the surface width at the mean annual flood flow.

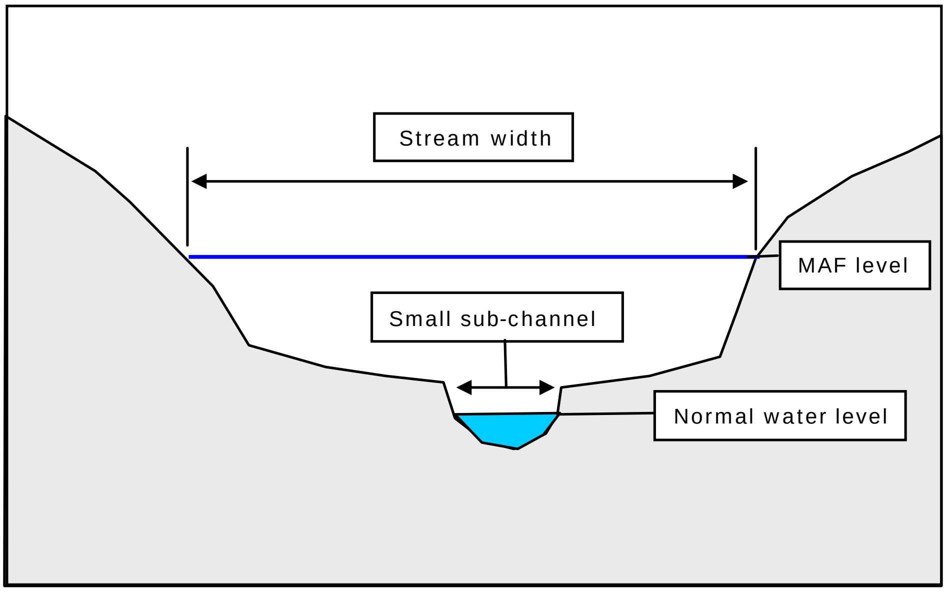

Figure 5: Incised channel with small sub-channel

- The legislation includes the word average in the definition of the width of the bed of the stream which means that a stream may qualify for taking of esplanade reserve even though some sections are less than 3m in width. The stream should therefore be assessed for the length that it crosses or adjoins the property in question, and where some sections are less than 3m in width, the average stream width should be used.
- In the case of larger sites which contain numerous waterways or a stream that has numerous branches or tributaries, it is necessary to identify the main branch and the various subsidiary branches or tributaries and consider the bed of each separately.
- The weighted average of the calculated widths for each channel reach section should be determined. The weighting is based on the stream length to which each section applies. The applicable stream length for each section is the distance from the downstream reach midpoint to the upstream reach mid point, as shown below.

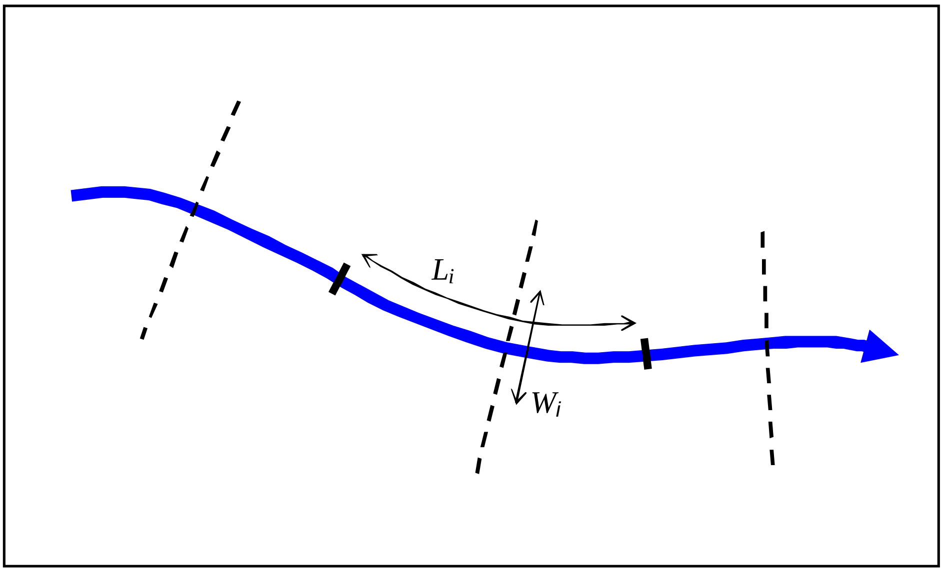

Figure 6: Using a weighted average method

$$W_{mean} = \frac{\bullet\ W_i\ L_i}{\bullet\ L_i}$$

Where W_i is the width determined for a given section, and L_i is the length of stream applicable to that section. Therefore • L_i is the total length of the stream reach in question.

- Where a cross section is the most upstream or downstream of a reach, then the applicable length in that direction will be either the end of the reach or property boundary. However, where there is also a cross-section immediately outside the property, the width at that external cross section should be applied to the relevant length of the reach within the property.
- The results should be presented as individual cross-sections with the water level and width plotted, and also on a plan of the stream through the reach of interest, including property boundaries, and with each section location and width plotted.

7 CONCLUSIONS

Determining the bed of a stream for the purposes of esplanade reserve under the RMA needs to take into account not just the physical bed form, but also the hydraulics of the channel in the annual fullest flow event.

In most cases stream width for the purpose of esplanade reserve under the RMA can be determined by registered land surveyors, however where there is a dispute about the stream width or the stream width is close to 3 metres, the use of hydraulic modelling is required.

The mean annual flood (MAF) flow is the most appropriate flow to use as the annual fullest flow where hydraulic modelling is required. The MAF equates to the 2.3 year ARI flood event which for Auckland can be calculated using a hydrological model and using the 2 year ARI rainfall depth multiplied by a factor of 1.07.

A standardised methodology needs to be used for determining the width of a bed of a stream for the purposes of esplanade reserve where a dispute is likely.

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