MEMORANDUM

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To: Bruce Howse

Kaihu Junction Questions

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Northland Regional Council (NRC) has requested Barnett and MacMurray (B&M) investigate two questions raised by stakeholders in relation to the Kaihu River.

1. Briefly investigate the effects of realigning the Kaihu River mouth to reduce possible backwater effect due to ebb tide and flood flows in the Northern Wairoa River.
2. Briefly investigate the water surface gradient in the lower Kaihu River (downstream of Baylys Coast Rd) at low tide in 2 and 5 year ARI flood events, using existing model results.

This short report gives the results of our investigation.

1. Realignment of the Kaihu River mouth

Background

There is relatively little research into the hydraulic treatment of junction flow in open channels. This is because of the large numbers of variables involved, and the complexity of the flow processes within the junction. Most of the available literature deals with experimental data measured on laboratory flumes, and derivation of empirical or more complicated equations to fit the experimental data. Relevant measurements in actual river situations are rare. Also, the bulk of experiments deal with junction angles less than 90^o. Our investigation is based mainly on this experimental literature, with some checks against results obtained from two dimensional modelling of junction flows.

The research reviewed indicated that the major factors in determining losses or relative water depths at junctions are the following:

- Ratio of tributary to main flow, q
- Angle of tributary to junction, δ,
- State of flow downstream of the junction, described by the downstream Froude number.

Broadly speaking, the greater q is, the less the effect the junction has on backwater in the tributary. The greater the angle δ is the greater the backwater effect for the tributary and the greater the downstream Froude number is, the greater the effect of the two flows on one another.

These parameters have been measured or estimated for the Kaihu-Wairoa junction.

Methodology

A conservation of momentum approach derived from the literature has been applied to a control volume at the Kaihu-Wairoa junction. The control volume is between surveyed cross sections on the Wairoa and is shown hatched in blue in Figure 1. If momentum in the direction of flow of the Wairoa is conserved, then momentum at cross section 8 on the Wairoa plus the component of the Kaihu momentum acting in the (Wairoa) flow direction must equal the momentum at cross section 9 downstream of the junction in the Wairoa.

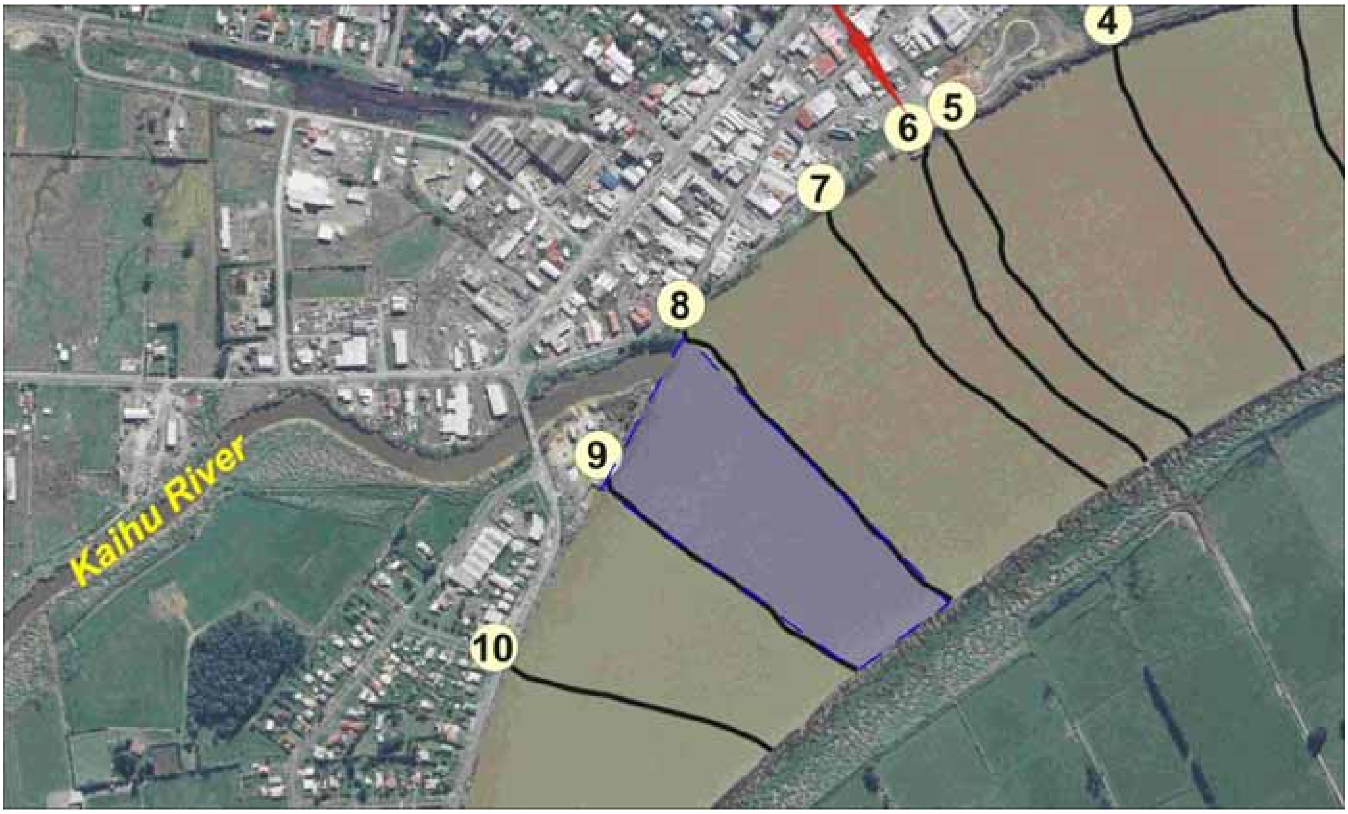


Figure 1: Control volume for junction analysis

Some simplifying assumptions were made in order to apply the equations:

- Flow is steady (flow in a tidal river reach is almost always unsteady, but this assumption allows us to solve simplified equations for the junction for a given flow condition).
- Bed slope and friction are small enough to be ignored.
- Main Wairoa flow upstream and downstream of the junction has nearly one- dimensional flow such that momentum correction coefficients are unity.
- Water level at upstream end of control volume is the same on the Kaihu and the Wairoa.

Not all of these assumptions hold for the real Wairoa - Kaihu junction, but they are sufficient to allow us to compare the effect of changing the junction angle on a simplified junction where all other parameters are kept the same.

<u>Flow parameters</u>

The main Wairoa flow factors affecting the junction are total flow and flow condition or Froude number downstream of the junction. The effect of the Wairoa on the Kaihu will tend to be increased by high flows in the Wairoa and increasing Froude number in the Wairoa downstream of the junction. Flow in the Wairoa is greatest when it is in flood, or the tide is flowing out at maximum speed sometime before low tide.

There are no flows measured for the Wairoa at Dargaville. The best estimate was from a study carried out in 1989 (Judd) which estimated the 100 year flood flow as being about 1680m^3/s at Tangiteroria. Modelling indicated that by the time this flood reached Dargaville, it would increase the river level by 0.15m above the MHWS tide level. The report does not state what the flow might be by the time it arrived at Dargaville. Because the flow conditions during a flood on the Wairoa at Dargaville are not known, it is difficult to calculate junction losses for this situation. In order to gather more data, NRC staff carried out a survey of a series of cross sections on the Waitoa upstream and downstream of the junction and two cross sections on the Kaihu just upstream of the junction. At each section, the bed cross section was surveyed, together with the velocity profile and total flow. This work was completed during the ebb tide on 2/07/09. The maximum flow in the Wairoa under the influence of the ebb tide was $1048m^3/s$.

While a flood would obviously provide a large flow, the likelihood that this coincided with a flood on the Kaihu is not great. Also, the highest Froude numbers downstream occur when velocity is high and depth low, as occurs at maximum outflow close to low tide level. We have chosen this situation to investigate for junction losses, as the influence of the Wairoa on the Kaihu should be greater than at other points in the tidal cycle. Possibly this case would also have more effect on the Kaihu than a Wairoa flood where the Wairoa flow was higher, but without comparing flows and downstream Froude numbers this is not known for sure.

The 100 year ARI design peak flow for Kaihu outlet has been taken from the model. This was $223m^3/s$. This gives a junction flow ratio of Kaihu / Wairoa of 223/ (1048+223) = 0.18

The Froude number is the ratio of kinetic to gravity forces for a given flow. The Froude number downstream of the Kaihu-Wairoa confluence has been evaluated for a total flow of $1271m^3/s$. This was done by assuming that the increased flow passed through the same cross section as that surveyed; ie the water level remained equal because the tidal effect is dominant). The Froude number was then Fr = 0.26. Despite the relatively high flow, the velocity across the large section of the Wairoa is approximately 1.3m/s. This low velocity contributes to the fairly low Froude number, indicating tranquil flow and small bed slope.

The junction angle was measured as 130^o from an aerial photograph of the confluence. The case with the existing junction angle has been compared to a case where the junction angle was reduced to 45^o. This means the Kaihu river outlet would be angled downstream, rather than upstream as at present. Research indicated that the tributary flow is already turning downstream as it enters a junction; so the effective flow angle is less than the junction angle. Estimated effective flow angles were calculated based on the experimental tests (Gurram et al, 1997). These became 112^o and 39^o for the existing and altered junction cases respectively.

<u>Results</u>

Solution of the momentum equations for the flow condition described above estimated that a junction angle of 130^o would result in a net water surface level increase in the Kaihu of 0.37m above that with a junction angle of 45^o. Because of the simplified approach taken, it is not believed that the actual water levels found for the Kaihu relative to water levels downstream of the junction are realistic.

The investigation indicates that the angle of the Kaihu outlet to the Wairoa does have an effect on backwater, with an increasing angle causing increasing backwater, but the backwater is also influenced by the relative flows in the Wairoa and Kaihu and the downstream flow conditions at the time. As these are ever changing, the maximum backwater effects would only be experienced for limited periods of time, for example when flow from the Kaihu was peaking, flow in the Wairoa relatively high, and water level in the Wairoa low. Most of the time, the backwater effect generated by the upstream junction angle would be much less than estimated here.

If the Kaihu outlet was changed to face downstream, the research indicates that this would improve the backwater effect at the outlet, *while the tide flowed out*. When the tide flows back in, the Wairoa flows upstream at the junction and the situation for the Kaihu is reversed. A downstream facing outlet would potentially cause the same backwater effect during flood tides as the upstream facing outlet during ebb tides.

Using data from the hydraulic model for the Kaihu 100 year ARI design flood, the maximum velocity at the Kaihu outlet was approximately 4m/s at low tide. Using a simple energy equation, the maximum energy that can be lost by this flow is equivalent to the velocity head, or 0.8m. Because energy is a scalar, not a vector quantity, it is not directly useful in assessing the effect of junction angle, but it sets an upper limit on the energy that could potentially be lost.

Limitations of investigation.
The investigation applies empirical equations derived from laboratory flume experiments to a large, tidal river junction. It is at best a crude estimate of the real flow regime at the junction.

A range of flow conditions can exist at the junction. A case where it is believed the influence of the Wairoa would be reasonably severe has been selected for this investigation. Potentially, a flood flow on the Wairoa might have greater effect on the Kaihu, but there was insufficient information available to investigate this. Also, the chance that a significant flood in the Wairoa reached Dargaville around the same time as a flood wave down the Kaihu is low. The low tide occurs regularly, and is more likely to coincide with a flood on the Kaihu.

The present analysis ignores some of the forces acting at the junction, such as friction, weight of flow, and shear forces. More data would be needed in order to investigate the junction flows in more detail.

The field investigation gave a good estimate of low tide flows in the Wairoa and cross section survey. The flow in the Kaihu on the day of the field investigation was around $30m^3/s$. Because this was so low relative to the Wairoa flow (less than 3%), it was difficult to test the momentum equations on the measured situation. The Kaihu flow was within the range of uncertainty of the Wairoa flow. An extension had to be made to flood conditions on the Kaihu.

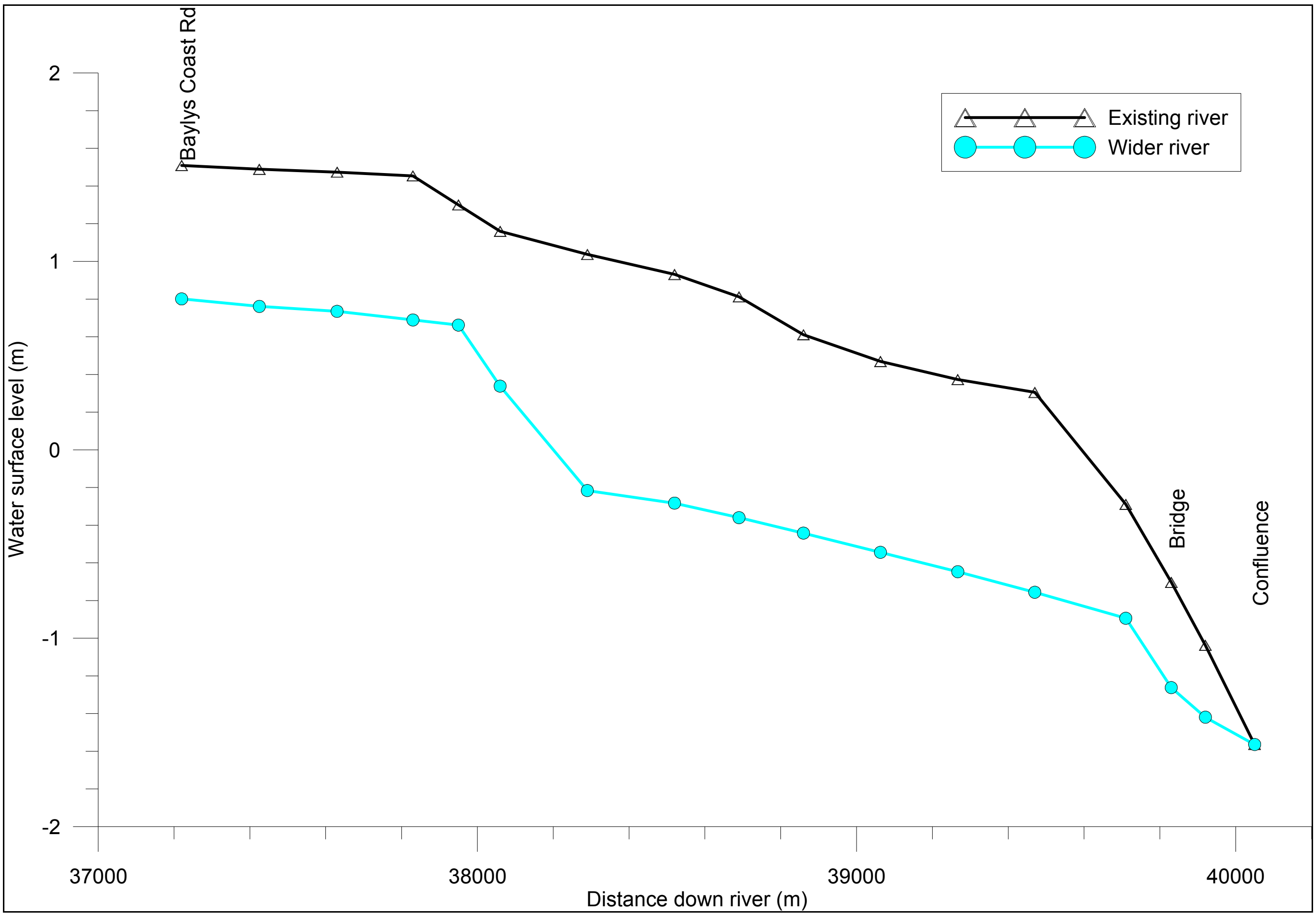
2. Water surface gradient in the lower Kaihu River

The water level results have been extracted from the hydraulic model for the existing and widened lower river simulations to see what effect the simulated river widening had on water level gradients from Baylys Coast Rd to the bridge in the lower Kaihu. The maximum water surface gradient for this reach was found for each flood run by checking the water levels at low tides close to the flood peak. The results are shown below.

Run	Baylys Coast Rd WL (m)	Bridge WL (m)	Wl difference (m)	Average gradient	Bridge clearance[1] (m)
Existing 2 year	1.037	-0.907	1.944	0.000745	4.74
Wide 2 year	0.473	-1.371	1.844	0.000707	5.20
Existing 5 year	1.509	-0.703	2.212	0.000848	4.53
Wide 5 year	0.801	-1.262	2.063	0.00079	5.09

1 Assuming a bridge soffit level of 3.83m, which is the average of the hog and pier corner soffit levels of the central span.

The water surface profiles for the 5 year ARI event are plotted below to show how the gradient is changed by widening.



Because the absolute water levels at both Baylys Coast Rd and the bridge have fallen, the difference in gradient is not as large as to the confluence. However, it can be seen that the water surface gradient is flattened slightly by widening the lower river cross sections. The net difference between water levels at Baylys Coast Rd and the bridge reduced by 0.1m in the 2 year ARI event, and 0.15m in the 5 year ARI event. This change is over a river length of 2.6km. It was achieved as a result of widening the lower river cross sections by excavation of 680,000m^3. In all cases, the clearance of the bridge soffit above the river is at least 4m, as observed by one of the stakeholders, and this is typical at low tide, but the model did not indicate any overtopping in the region of Baylys Coast Rd. In all, the water surface gradients for the lower Kaihu are already very low, and the improvement in gradient between Baylys Coast Rd and the bridge is minor. However, the water level at Baylys Coast Rd has decreased by 0.7m in the 5 year widened river run, relative to the low tide level at the confluence.

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