

IN THE MATTER of the Resource Management
Act 1991

AND

IN THE MATTER of an application by Meridian
Energy Limited for resource
consents for the Mokihinui Hydro
Project

**SECOND STATEMENT OF EVIDENCE OF DEREK GARARD GORING ON
BEHALF OF MERIDIAN ENERGY LIMITED**

ANDERSON LLOYD
LAWYERS
DUNEDIN

Solicitor: Stephen Christensen/
Philippa Jones

Level 10, Otago House
Cnr Moray & Princes Street,
Private Bag 1959,
DUNEDIN 9054
Tel 03 477 3973
Fax 03 477 3184

1. INTRODUCTION

1.1 My full name is Derek Garard Goring. I refer to the qualifications and experience set out in my first brief of evidence.

1.2 As set out in the section 92 response, for operation of the MHP Meridian proposed to ramp flows from 16 cumecs to full load in a series of steps in a scheme such as is shown in Figure 1. This figure shows for summer a set of flow steps at 15-minute intervals in which the flow is increased by 50% at each step. I was asked to address the following questions:

- a. Under what circumstances will the surges catch up with each other and form a larger surge?
- b. What is a suitable ramping scheme whereby the surges do not coalesce until they reach 9 km from the dam (i.e. into the tidal zone)?
- c. What are the associated increases in stage height resulting from the flow steps at various places down the river, including the tidal zone?

1.3 My work, which involved computer modelling using data from flow gaugings in the river, resulted in the following report:

Propagation of flow surges down the Mokihinui River, Mulgor
Client Report 2008/4, August 2008.

and I have prepared my statement of evidence in reliance on this work.

1.4 I have also reviewed the flow regime evidence of Mr Watts.

2. SCOPE OF EVIDENCE

2.1 I was asked by Meridian to prepare evidence in relation to the propagation of flow surges down the Mokihinui River considering how

the surges will propagate and what is a suitable ramping rate scheme that avoids large increases in water level in the swimming holes at Podge Creek and Warrigal Island.

3. EXECUTIVE SUMMARY

3.1 The main points of my evidence are that for a change in flow from 16 to 120 cumecs:

- a. If the flow is changed in a series of steps, the time between the steps needs to be carefully designed to avoid the steps catching up with each other. The likelihood of steps catching up is greater when beginning from lower flows than at higher flows, meaning that increases or steps from lower flows need to be further apart.
- b. Each surge of water will start at the dam and appear as a virtually instantaneous increase in water level. As it propagates it will flatten into a shape in which the water level slowly rises from its lower level, then accelerates, and very gradually tapers off to its upper level.

3.2 As a result of these findings Meridian reviewed the ramping rates set out in its section 92 request and has proposed new ramping rates which are discussed in the flow regime evidence of Mr Watts.

4. THE PROPOSAL

4.1 I confirm my evidence is based on the project proposal as described in the Assessment of Environmental Effects, brief details of which are described in Appendix 1.

5. SURGE PROPAGATION

5.1 Abrupt changes in flow, or surges, such as are shown in Figure 1 are known to applied mathematicians as “shocks”. As well as rivers they

occur in many different applications : gas dynamics (e.g., a nuclear blast) and traffic flow (e.g., an accident) are two examples. Shocks in a river propagate in a different manner to normal waves such as flood waves and they have a special set of mathematical models. I have described these models in Appendix II of my evidence.

5.2 I have had experience dealing with flow surges in rivers on two previous occasions and those provided a useful background for the Mokihinui:

a. *Tongariro Surges*

In 1989 I carried out measurements of flow surges in the Tongariro River. Surges of 20 to 40 cumecs in size were generated at Poutu by closing the tunnel gate thereby diverting the flow down the Tongariro River. The times of closure were varied between 0 and 45 minutes. The resulting surges were measured at Poutu, Puketarata (12 km downstream) and Turangi (18 km downstream). In each case the surge evolved into a wave known as a monoclinal wave¹ between Poutu and Puketarata. This wave then propagated to Turangi essentially unchanged in shape. For surges that were released almost instantaneously, the slope of the surge flattened and for those that were released over time, the slope of the front face steepened. The reason for the work was to determine an optimum operating strategy that would avoid the possibility of anglers in chest waders at Tongaririo from becoming swamped with the surge. The conclusion of the work was that no matter what ramping was applied at Poutu, the surge that arrived at Turangi would have the same shape (i.e., the monoclinal wave). Thus, diversion of flow down the Tongariro River at the Poutu Tunnel is not allowed under normal operations.

b. *Waimakariri Flood Waves*

The issue in the Waimakariri was the highly variable time of travel from the Gorge to the Old SH1 Bridge, a distance of 51 km. Flood waves take anywhere between 5 and 10 hours to propagate that

¹ The monoclinal wave is a gradual transition from low flow to high flow. Once the surge has evolved into this shape, it will propagate unchanged in shape.

distance. The reason for this large variability is that if the wave issuing from the Gorge is steep enough for a shock to form, then it propagates with a much slower speed or celerity (speed of propagation), so these very steep waves take longer to propagate the same distance.

5.3 The data required for my modelling of the Mokihinui River were: flow; cross-sectional area; and stage (or height) at various locations down the River. These data are usually obtained from flow gaugings in which velocities are measured at various locations across a river section. The velocity distribution is then integrated to give a flow for that section. The various sources of data are shown in Table 1 and the locations are shown in Figure 2. For only one of these (Welcome Bay) were the data from traditional gaugings. For Podge Creek and Gabion, the data were derived using Welcome Bay flows. The 10 sections from Ian Jowett were derived from instream flow incremental methodology (IFIM) studies carried out in 2007.

5.4 *Surge Propagation*

The gauging data were used to establish the celerity of the surges shown in Figure 1 and the results are shown in Figure 3. This Figure, called a characteristic map, is a plot of the trajectories of the flow steps in space (abscissa) and time (ordinate). The lines are called characteristics. The flow steps propagate along the characteristics. When two characteristics intersect, the flow steps combine and the resulting large step propagates at a speed somewhere between the speeds of the two steps that combined. For example Figure 3 shows that at about 4 km from the dam, the second step of 24 to 36 cumecs will have caught up with the first step of 16 to 24 cumecs and they will combine to form a larger step of 16 to 36 cumecs. Then, at 4.8 km from the dam the third step of 36 to 54 cumecs will have caught up with this step to form a step of 16 to 54 cumecs, and so on. At 7.4 km from the dam (just downstream of Warrigal Island), all 5 steps will have combined to form a step from 16 to 120 cumecs.

- 5.5 Because of the intersections relatively close to the dam, the ramping scheme shown in Figure 1 is not optimum. In particular, for safety reasons it is preferable to avoid large changes in depth over a short period of time in the swimming holes at Podge Creek (1.3 km from the dam) and Warrigal Island (6.8 km from the dam) .
- 5.6 One of the reasons for the intersections of the flow steps in Figure 3 is that flow steps at lower flows propagate much slower than those at high flows. Therefore, instead of ramping faster at low flows and slower at high flows, we need to do the opposite. Although it may sound counterintuitive, ramping high flows faster than low flows avoids a large step from 16 to 120 cumecs as shown in Figures 4a and b (the proposed ramping schemes for summer and winter respectively). Here, the time between the first and second flow steps has been increased to 45 minutes so that the first intersection does not occur until at least 8 km from the dam. The figures show that the size of the flow steps is not as important their spacing in time.

Changes in Stage

- 5.7 So far, I have only considered changes in flow because this is how flow propagation calculations are done. What is more important for users of the river is how those flow changes manifest themselves into changes in water level or stage.
- 5.8 The changes in stage as the flow steps pass the various sections are presented in Tables 2a and b for the summer and winter ramping schemes respectively. Looking down each column, corresponding to a particular step in flow, the changes in stage for Welcome Bay, Podge Creek, and Gabion are similar, but for the IFIM sites, the changes in stage are generally less, especially for riffles.
- 5.9 The increases in stage if the steps were to combine are shown in rightmost columns. For example, with the summer ramping scheme if the first and second flow steps were to combine (i.e., point 1 in Figure 4a), the flow step would be from 16 to 64 cumecs and the corresponding

increases in stage are shown in the second column from the right. If the point of intersection were upstream of Podge Creek, the table indicates that the increase in stage at Podge Creek would be 0.675 m, and if the point of intersection were upstream of Section 6, the increase in stage at Warrigal Island (near Section 6) would be 0.535 m. In fact, by pushing the point of intersection down into the tidal zone, as shown in Figure 3a, such increases in stage will not occur.

- 5.10 At Gabion (in the tidal zone), it is likely that no matter what ramping scheme is employed, the flow changes will have combined into a single step from 16 to 120 cumecs, in which case the change in stage will be 1.1 m. Note, however, that this large increase in stage will occur only at low tide. At high tide, the flow change will be absorbed by the lake whose level is governed by the ocean. However, I believe that by the time the surge has reached the tidal zone, it will have evolved into a monoclinal wave and the 1.1 m rise will occur over a period estimated to be greater than 1 hour.

Surge Shape

- 5.11 As pointed out in paragraph 5.2, if the step in flow propagates far enough, it will adjust to the shape of the monoclinal wave. Figure 5 compares the shapes of the monoclinal waves at Podge Creek and Section 6 (near Warrigal Island) for an increase in flow from 16 to 120 cumecs in one step. These are the theoretical shapes the flow steps will evolve to eventually, but the theory gives no information on how far a flow step needs to propagate before it evolves into this shape. The curves are characterised by a gradual rise from the minimum level, a steep portion and a very gradual tapering off to the maximum level.

6. ACTUAL AND POTENTIAL EFFECTS

- 6.1 At Welcome Bay, Podge Creek, and Gabion at low tide, a change in flow from 16 to 120 cumecs will result in an increase in water level of about 1 m. In the open river flats, the increase in water level is likely to be less, especially in riffles, but at Section 10 which has the median properties, the increase will be about 0.7 m. If such increases were to occur

instantaneously, there could be potential effects on in-river users. However, instantaneous changes in water level are not likely because the flow step will evolve into a monoclinal wave.

- 6.2 By reducing the flow change into a series of steps, the problem of rapidly rising water levels at the swimming holes at Podge Creek and Warrigal Island (Section 6) can be reduced because each change in level will be reduced. For the summer ramping scheme (Figure 4a), the water level at Podge Creek will increase in three steps each of about 0.35 m (Table 2a), while at Warrigal Island the increases will be 0.3 m or less. The exact shapes of these steps cannot be determined precisely, but each will be flattening towards the shape of the monoclinal wave.
- 6.3 The flow steps may catch up with each other and combine to form a larger step. However, the point of intersection can be shifted downstream by separating the flow steps in a manner shown by Figures 4a and b (for summer and winter ramping schemes respectively). The summer scheme is designed so that the intersection of flow steps does not occur until the flow steps have reached the tidal zone. In winter, rises in water level at the swimming holes are less of an issue, so the number of flow steps is reduced to two, 45 minutes apart, and the intersection occurs just upstream of the tidal zone.
- 6.4 Modelling the propagation of surges in a natural river like the Mokihinui is difficult because the cross section is changing every few metres. The analytical methods that I used in my analysis have used flow and cross section data from 13 locations, but there has been no analysis of how representative those are. These are the best models that can be obtained before the dam is operational, however the results should be viewed as indicative, rather than definitive. Thus, the work needs to be backed up by a series of full-scale experiments once the dam is operational. This will entail releasing flow steps of various sizes and time spacings, and measuring the resulting surges at various locations downstream. Of particular interest is the speed of propagation and the evolution in the shape of the surges. To obtain these, water-level recorders should be deployed at several locations including Podge Creek and Warrigal Island. To capture any sharp increase in water level

as the surges pass, the recorders should sample at 1 Hz (i.e., they will need to be wave recorders like NIWA's Dobie instruments).

- 6.5 In conclusion, to avoid adverse effects on swimmers at the water holes at Podge Creek and Warrigal Island, the increase in flow from 16 to 120 cumecs should be done in a series of steps separated by 30 to 45 minutes, with the steps at low flow being separated by longer periods than those at high flow.
- 6.6 I recommend that during commissioning a series of experiments be undertaken to validate the modelling I have undertaken by measuring the speed of propagation of the flow steps and their transition in shape.

7. **CONCLUSION**

- 7.1 Increasing the flow from 16 to 120 cumecs in a series of quick steps has the potential to affect river users downstream, particularly swimmers, because water levels will rise by up to 1.1 m. Natural river processes will cause the initially steep surge to flatten as it propagates until it reaches a uniform shape, but this process may take 10 km to occur. By splitting the flow change into a series of steps each separated by 30 to 45 minutes, the changes in water level can be decreased, thus reducing the risk to swimmers and other river users. In my evidence, I have proposed two ramping schemes, one for winter and the other for summer, which my calculations show will avoid large, rapid increases in water level and this ramping scheme is also referred to in the evidence of Mr Watts. These calculations were based on mathematical models using median properties from the river. They need to be validated by a series of experiments conducted once the river is controlled. The results of the experiments may require alterations to the proposed ramping schemes.

Table 1. Sources of data

Location	Data Description
Welcome Bay	17 gaugings from 8-Jan-2007 to 1-Mar-2008
Podge Creek	12 data points from Henderson (pers. comm.)
Gabion	Relationship from Goring (2007)
Various	10 IFIM sites from Ian Jowett

Table 2a. Changes in stage (m) in response to step changes in flow (cumecs) – summer ramping scheme.

Site	16 - 32	32 - 64	64 - 120	16 - 64	16 - 120
Welcome Bay	0.220	0.318	0.448	0.538	0.986
Podge Creek	0.367	0.307	0.352	0.675	1.027
Gabion	0.247	0.408	0.448	0.654	1.102
XS 1 Riffle	0.065	0.073	0.073	0.138	0.211
XS 2 Riffle	0.110	0.131	0.140	0.241	0.381
XS 3 Fast run	0.220	0.251	0.259	0.471	0.730
XS 4 Slow run	0.207	0.231	0.232	0.438	0.670
XS 5 Run	0.220	0.245	0.247	0.465	0.712
XS 6 Pool	0.251	0.284	0.289	0.535	0.824
XS 7 Wide Run	0.190	0.212	0.211	0.402	0.613
XS 8 Moderate Run	0.259	0.314	0.341	0.573	0.914
XS 9 Run	0.192	0.226	0.240	0.418	0.657
XS 10 Run	0.210	0.232	0.231	0.442	0.672

Table 2b. Changes in stage (m) in response to step changes in flow (cumecs) – winter ramping scheme.

Site	16 - 44	44 - 120	16 - 120
Welcome Bay	0.349	0.637	0.986
Podge Creek	0.524	0.503	1.027
Gabion	0.428	0.673	1.102
XS 1 Riffle	0.097	0.113	0.211
XS 2 Riffle	0.167	0.214	0.381
XS 3 Fast run	0.330	0.399	0.730
XS 4 Slow run	0.311	0.359	0.670
XS 5 Run	0.329	0.382	0.712
XS 6 Pool	0.378	0.446	0.824
XS 7 Wide Run	0.285	0.328	0.613
XS 8 Moderate Run	0.397	0.517	0.914
XS 9 Run	0.291	0.367	0.657
XS 10 Run	0.314	0.359	0.672

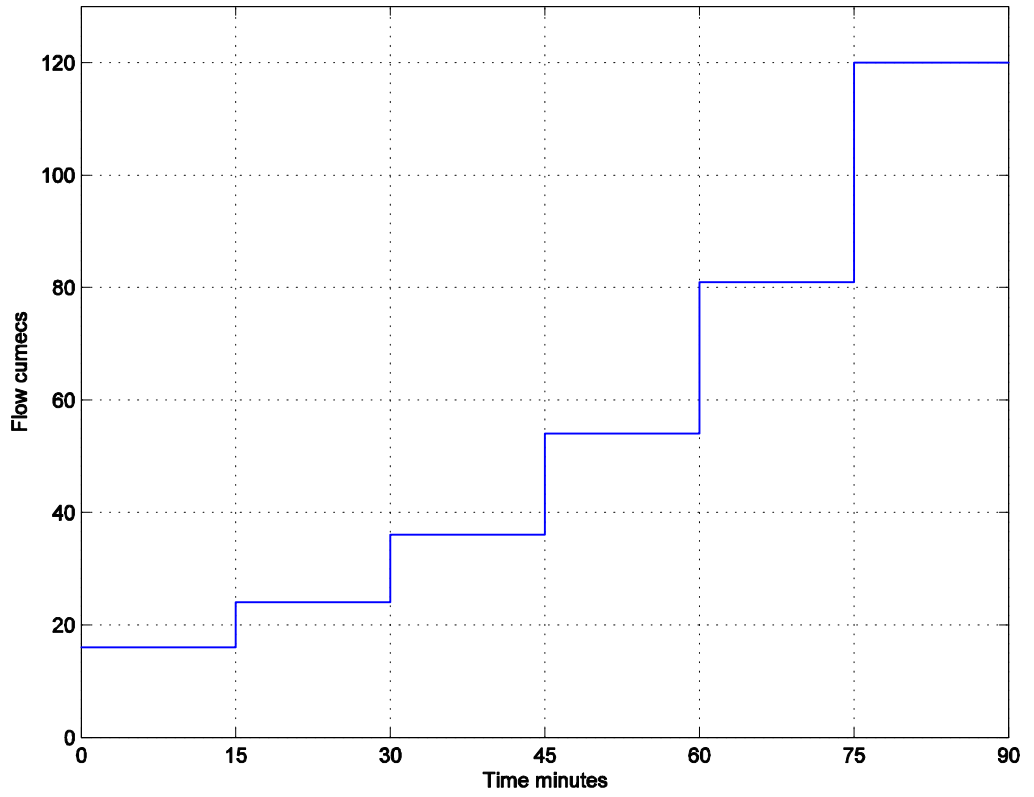


Figure 1. Proposed ramping from 16 cumecs to full load.

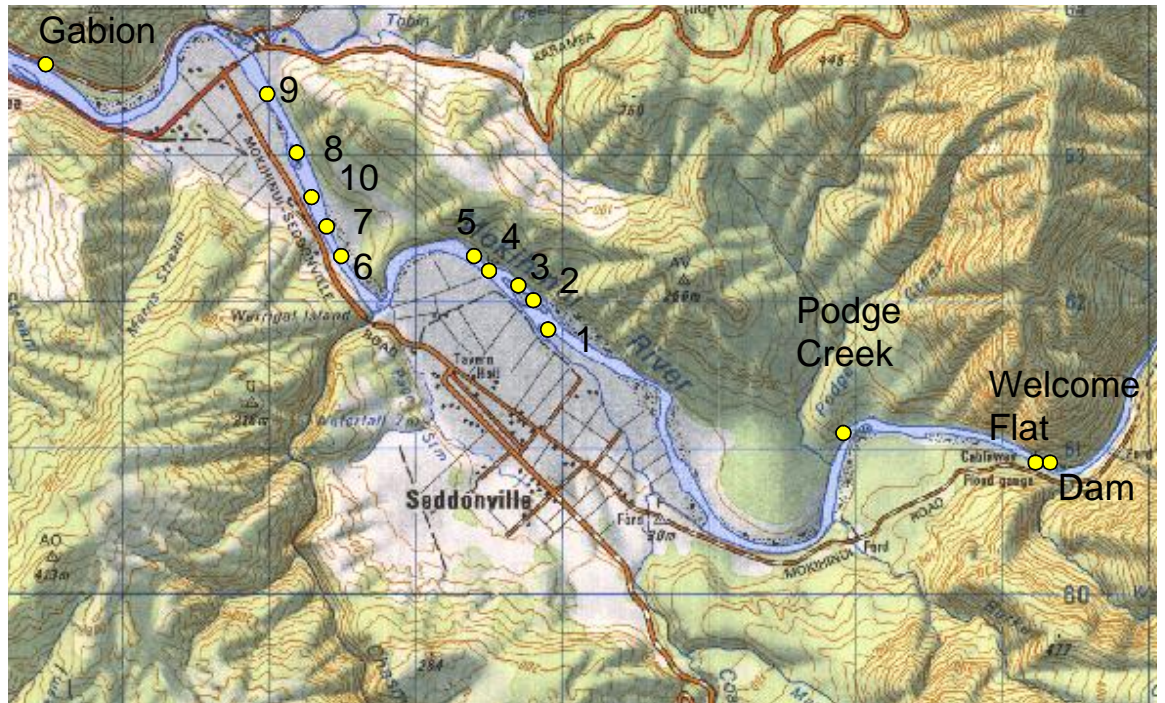


Figure 2. Map showing sites listed in Table 1.

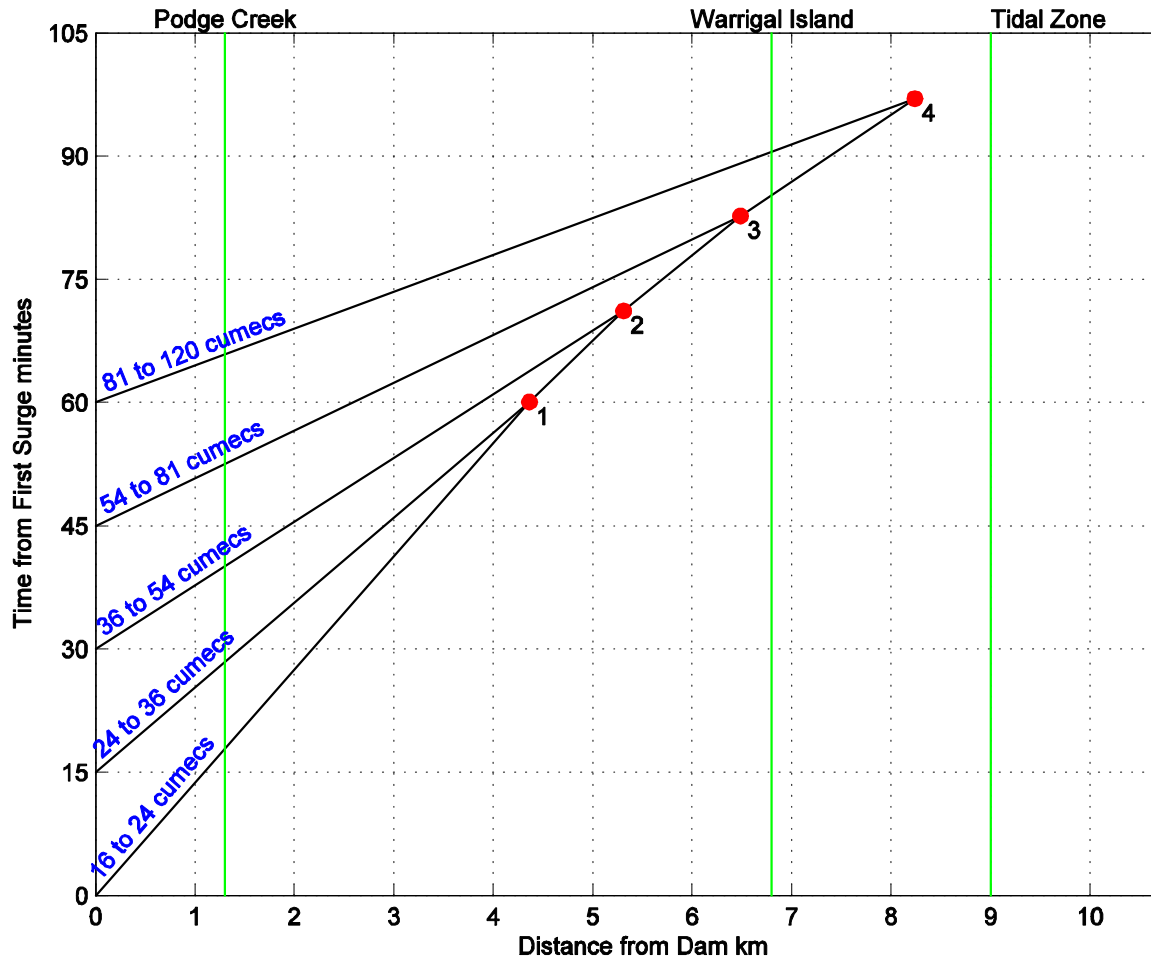


Figure 3. Characteristic map of the trajectories of each of the flow steps and their intersections, using median river properties.

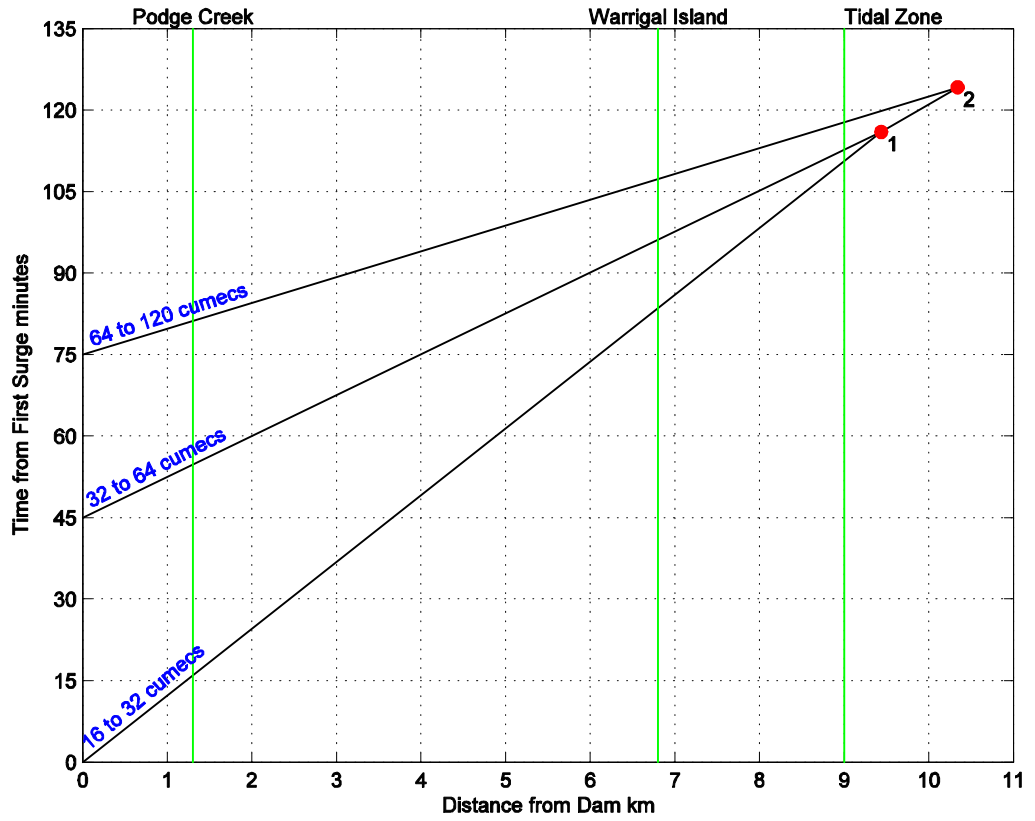


Figure 4a. Characteristic map for proposed summer ramping scheme.

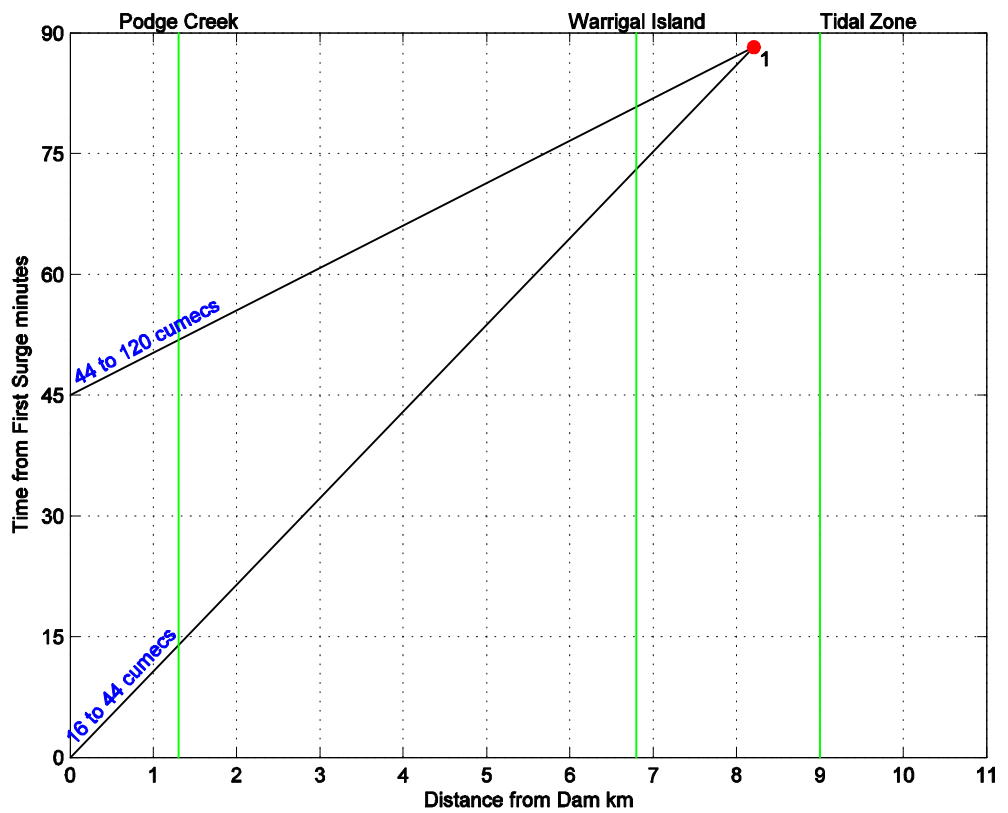


Figure 4b. Characteristic map for proposed winter ramping scheme.

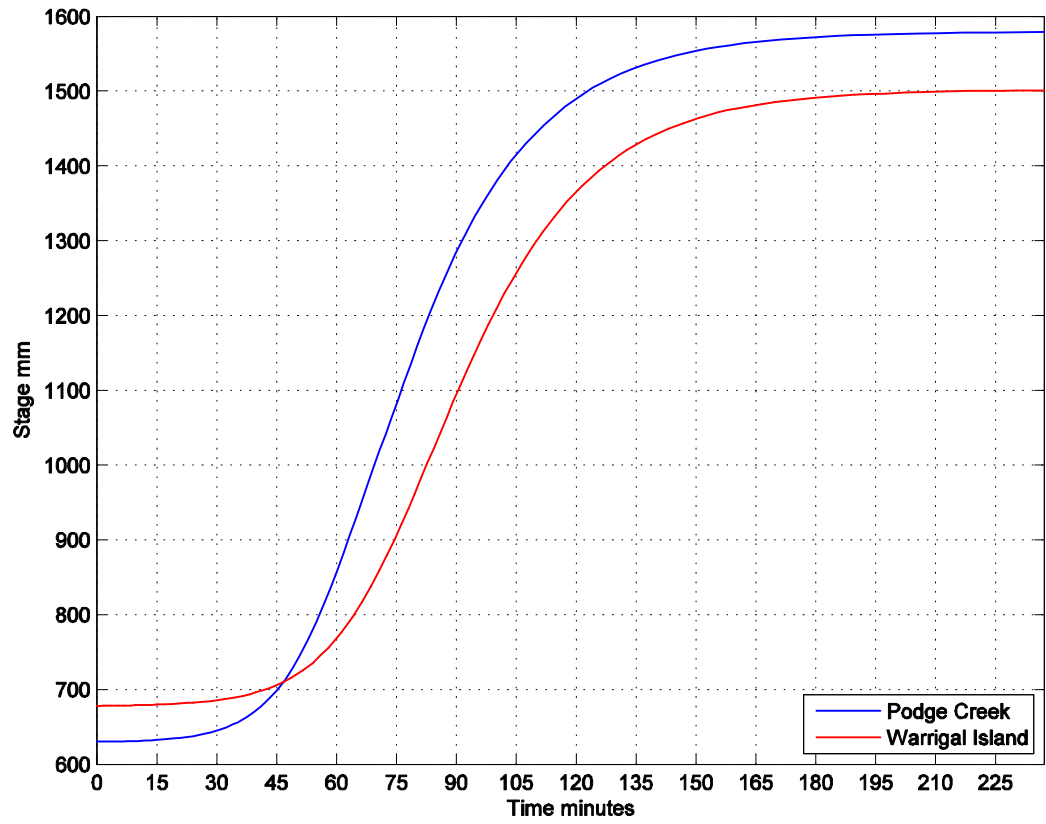


Figure 5. Monoclinal waves for flow steps from 16 to 120 cumecs at Podge Creek and Warrigal Island.

APPENDIX II

In steep rivers like the Mokihinui, flood waves propagate according to a theory called “kinematic waves” (Lighthill & Whitham, 1955) in which every part of the wave propagates with a speed, or celerity, given by:

$$c = \frac{\partial Q}{\partial A}$$

where Q is the flow and A is the cross-sectional area. In practice, c usually increases with Q , which means that the front face of the wave steepens as it propagates, while the back face flattens. If the distance of propagation is long enough, the front face will become vertical, and a “kinematic shock” forms. Referring to Figure 1, the flow pattern is a series of shocks of different sizes.

Traditional mathematical models such as Equation (1) cannot handle shocks because such discontinuities cause the underlying differential equations to break down. Whitham (1974) covers this subject in great detail for all sorts of applications including gas dynamics, traffic flow, and rivers. The mathematical solution to the problem of how shocks propagate is surprisingly simple:

$$c = \frac{Q_2 - Q_1}{A_2 - A_1}$$

where c is the wave speed or celerity of the shock, Q_2 and A_2 are the flow and cross-sectional area after the shock, and Q_1 and A_1 are the flow and area before the shock.

Of course, in practice, vertical walls of water as shown in Figure 1 are impossible. The flow changes will take a finite time, even if it is only a few seconds. What happens is that as the surges propagate away from the dam, they form a smooth transition from one flow to the next. This transition is called a “monoclinal wave” (Henderson, 1966; Goring, 1994). Theoretically, once this shape is attained, the wave will propagate unchanged in shape. However, in a real river, we would expect its shape to modify somewhat as it propagates through the various river features of runs, rapids and pools.

The shape of the monoclinal wave for a particular flow change at a particular river cross section can be calculated from its hydraulic properties (flow and area as a function of depth) by solving an ordinary differential equation given by

Whitham (1974). A typical result is shown in Figure II.1. This case is for the Welcome Bay gauging site where the flow increased from 16 to 120 cumecs in a single surge and the depth changed from 0.96 to 1.97 m. The solution is asymptotic, which means the shape shown is what the surge would evolve to if it were to propagate to infinity. If the initial surge were a step, the wave would flatten to the monoclinal wave, and if it were a gradual transition, it would steepen to the monoclinal wave. The theory gives no indication of the propagation distance that would be needed to attain the monoclinal shape.

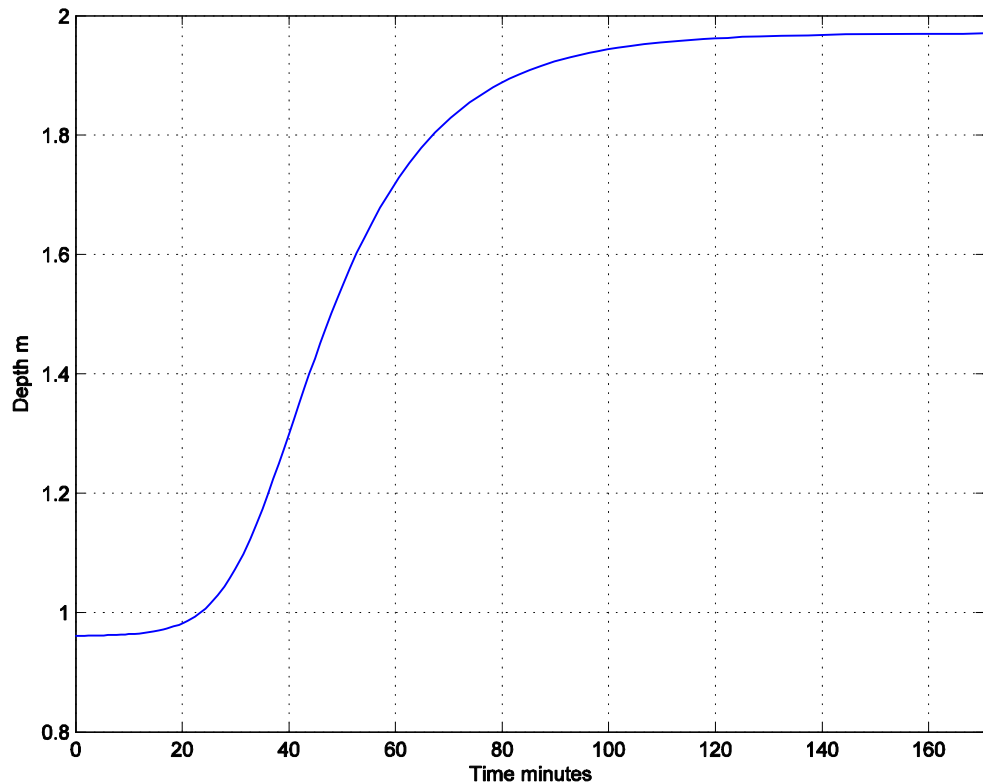


Figure II.1. Monoclinal wave for a surge from 16 to 120 cumecs at Welcome Bay.

References

Goring, D. G. 1994: Kinematic shocks and monoclinal waves in the Waimakariri, a steep, braided, gravel-bed river. Proc. International Symposium: Waves – Physical and Numerical Modelling, UBC, Vancouver, Aug 21-24 1994.

Henderson, F. M. 1966: Open Channel Flow. MacMillan.

Lighthill, M. B.; Whitham, G. B. 1955: On kinematic waves. I. Flood movement in long rivers. *Proc. Roy. Soc. Lon.* 229(1178): 281-316.

Whitham, G. B. 1974: *Linear and Nonlinear Waves*. Wiley-Interscience.