Appendix D

Current and Predicted Stream Hydraulics for Stage 1 of the Mulloon Community Landscape Rehydration Project

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Current and post-structure modelled hydraulic conditions have been calculated for each of the surveyed sites throughout the 3.5km reach of lower Mulloon Creek that comprises Stage 1 of the Mulloon Community Landscape Rehydration Project (MCLRP). Most, but not all, of the surveyed sites are earmarked for bed control structures (Figure 1).

At each site, hydraulic values have been calculated for *primary channel full, (top) bank full,* and *post-structure (top) bank full.* The calculated hydraulic parameters include:

- **Discharge (Q)** – Volume of water flowing past a given point in cubic metres per second (m^3/s).
- **Average stream velocity (V)** – Speed of water flowing past a given point in metres per second (m/s).
- **Hydraulic radius (R)** – Cross sectional area divided by wetted perimeter. The higher the R value the less flow that is in contact with the wetted perimeter of the stream, therefore, the faster the flow.
- **Mean boundary shear stress (t)** – Measure of the drag exerted by the flow across a channel bed - expressed as Newtons per square metre (N/m2) bearing down on the bed and banks of the stream.
- **Total stream power (Ω)** – Measure of potential energy expenditure, expressed as watts, against the bed and banks of a stream. This reflects the total energy available to do work along a river channel.
- **Unit stream power (ω)** – Watts of power per cross-sectional square metre of channel. The threshold for channel instability is around $35W/m^2$ (Fryirs and Brierley, 2013).
- **Froude number (Fr)** – Dimensionless number to determine if stream flow is sub or super-critical. Number relates to likelihood of sediment movement. At subcritical (Fr <1), flow is relatively tranquil. At supercritical (Fr > 1), flow is high energy and turbulent.

Values for each of the above parameters have been calculated for all sites within Stage 1 of MCLRP. The results are shown in Table 1 at the end of this report.

For the purpose of this report, graphical representations comparing *(top) bank full* versus *post-structure (top) bank full* are presented against four of the above parameters; **discharge (Q), mean velocity (V), mean boundary shear stress (t) and unit stream power (ω).** These parameters are the most meaningful in interpreting the current hydraulic conditions of Mulloon Creek versus the predicted hydraulic conditions once bed-control structures are installed. Graphical representation allows a direct comparison at each site, and throughout the Stage 1 reach, of the current *(top) bank full* hydraulic conditions with the predicted *post-structure (top) bank full* hydraulic conditions.

The graphed hydraulic conditions of Mulloon Creek Stage 1 reveal some important insights that support the proposed instream works throughout Mulloon Creek. Each variable at each site can be compared against the current geomorphic conditions, and in some cases against recent extreme events and the observations of the landowners.

The first site in each graph is the upstream most site (MS4) and the last site is the downstream most site (WVM1C1). MS6 is the Mulloon Road crossing. Hydraulic conditions have not been calculated at this site.

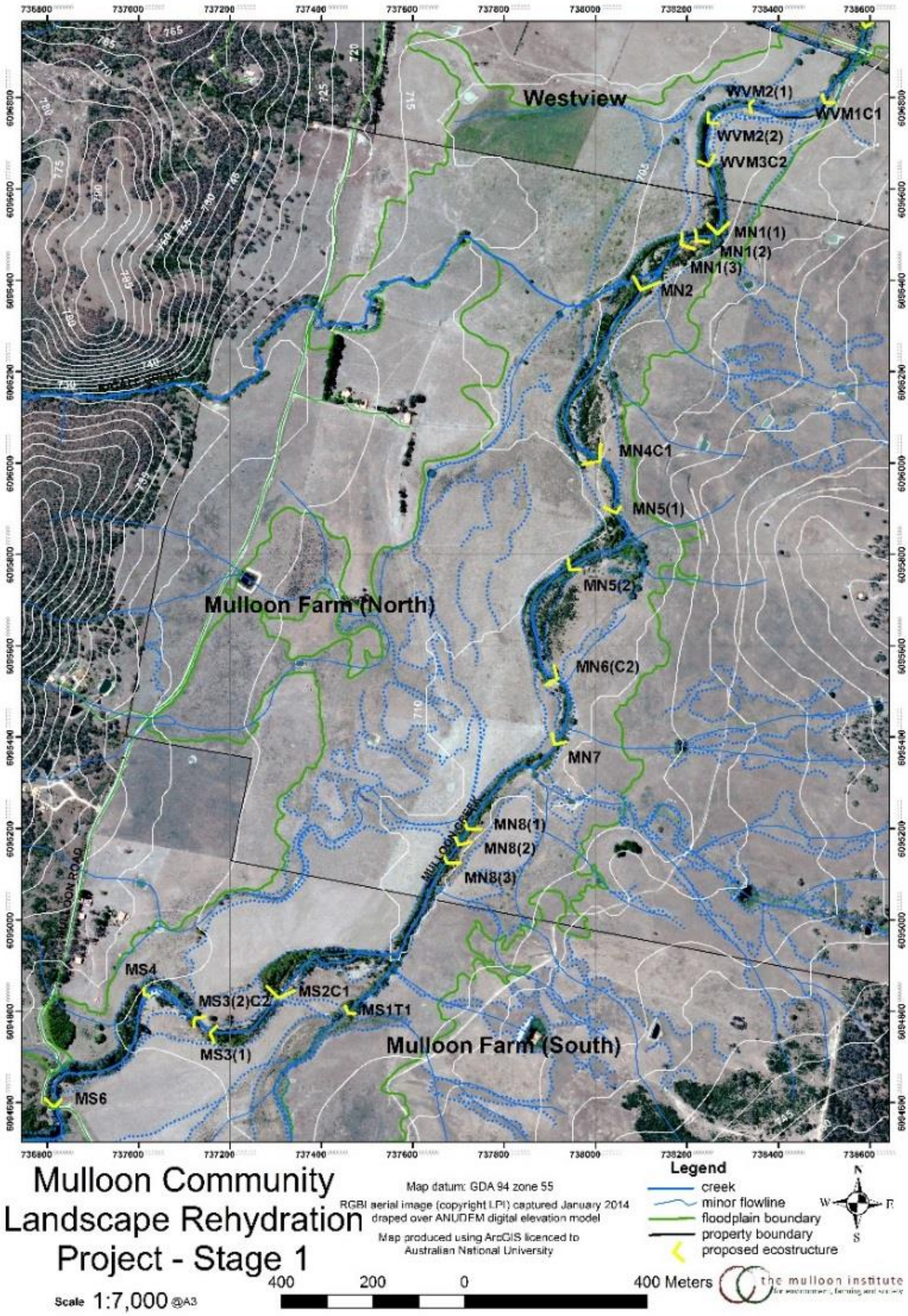

Figure 1 – Stage 1 of the Mulloon Community Landscape Rehydration Project.

Stream discharge

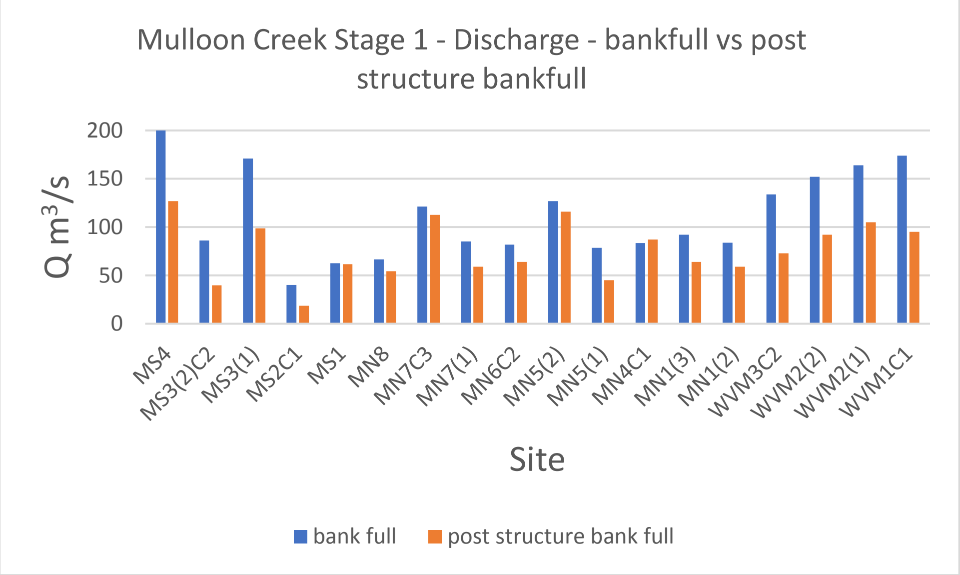

Figure 2 – Stream discharge under bank full and post structure bank full conditions.

Bank full discharge relates to the volume of water that can move within the channel of the creek before the flow breaks the banks and spills onto the floodplain. *Bank full discharge* is a function of channel capacity (cross-sectional area), stream gradient (slope) and stream roughness (usually the density and type of vegetation). Three (but not all) of the aims of building instream structures is to:

1. Reduce channel capacity so that high flows break the banks more regularly, dissipating the stream's energy across a far greater area.
2. Reduce the stream's average gradient which will reduce flow velocity and therefore its kinetic energy.
3. Increase surface roughness by increasing vegetation density and water turbulence, which will reduce the average flow velocity.

Naturally, in every case *bank full discharge* reduces post-structure. Discharge reductions are most significant at the upstream and downstream most sites because of the significant reductions in the modelled velocity of the flow (see Figure 4). Roughly the same amount of water discharges, but due to reduced velocity, that volume discharges over a longer period of time (Figure 3).

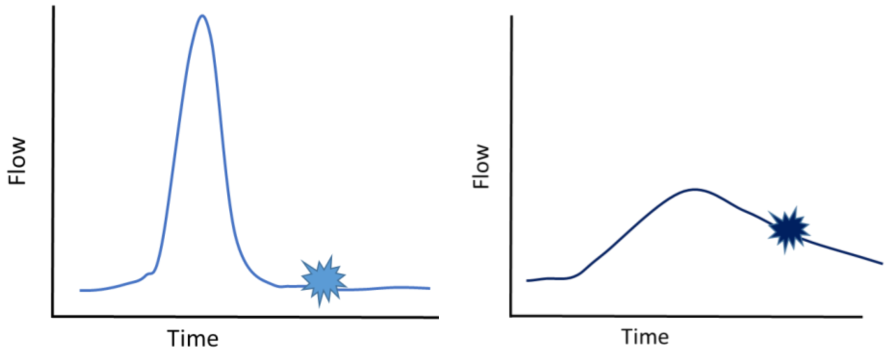

Figure 3 – Simulated flow duration curve pre vs post structure. Reduced peak flow (discharge) & elevated low flow.

It is also interesting to relate Figure 2 with the high flow event that occurred in early June 2016. This was described by several landowners as the largest since 1974 which, prior to June last year, was the last time

Mulloon Creek had broken its banks throughout the southern reach of lower Mulloon. Mulloon Creek did break its banks during the June 2016 event, but only between sites MS2C1 and MN8. It is between these two sites that channel capacity reduces significantly compared to sites upstream and downstream.

The channel capacity of Mulloon Creek is very high at the top end of the floodplain – 200m^3/s at MS4. Channel capacity reduces significantly by the time the creek reaches MS2C1 – 40m^3/s. This is immediately upstream of the confluence with the un-named tributary. There is no evidence of the creek having broken its banks beyond MN8. Assuming a Mannings roughness coefficient of 0.07, we can assume that the peak flow through this section of Mulloon Creek during this period was greater than 67m^3/s but less than 83m^3/s.

According to the Australian Rainfall and Runoff (ARR2016) Regional Flood Frequency Estimation (RFFE) modelling for the Mulloon catchment, the Average Recurrence Interval (ARI) for an event of this size is five years. Therefore, the Annual Exceedance Probability (AEP) would be 20%. According to RFFE model, each year there is a 20% chance of a flow that will break the banks.

However, the observational evidence suggests that the event of June last year was the largest in the last 40 years. The RFFE model included a disclaimer that the output data may be inaccurate because of the *unusual* shape of the fault-controlled Mulloon catchment. Given that the estimated discharge at the peak of the flow in June last year was between 67 and 83m^3/s, this places the discharge at the lower end of the modelled discharge confidence limits for AEP of between 2 and 5%, which would make the Average Recurrence Interval of between 20 and 50 years.

With growing climate uncertainty leading to increased possibility of extreme events, a suitable compromise between the modelled AEP and observed discharge for the sake of designing interventions would be an AEP of 10%. Therefore under current stream conditions we can estimate that a flow which over tops the bank between MS2C1 and MN8 could occur on average once every ten years, or alternatively there is a 10% chance of a flow over topping the banks in any given year.

Average velocity

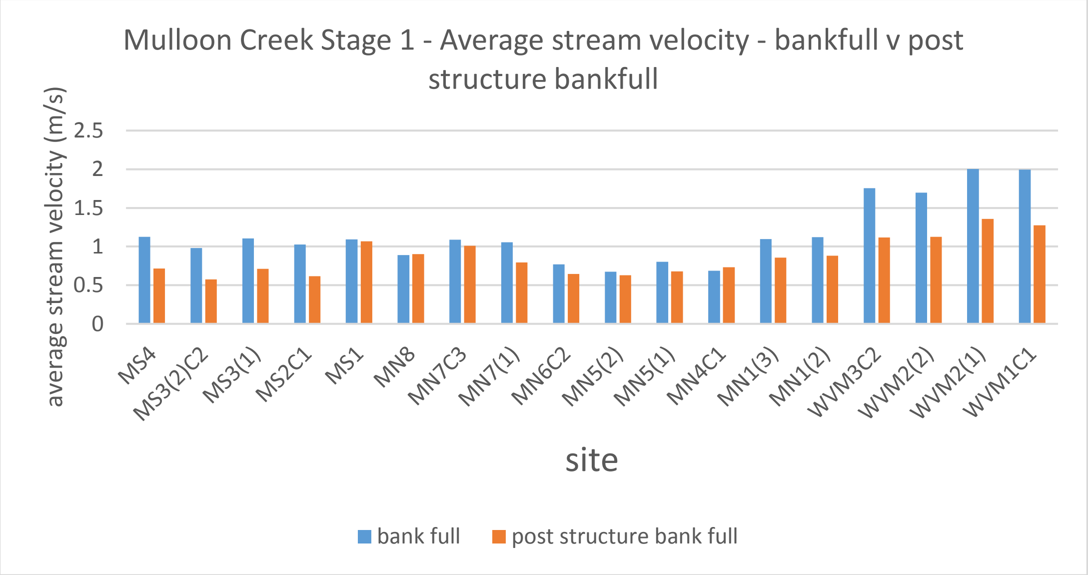

Figure 4 – Average stream velocity under current bank full compared to post structure bank full conditions.

Average *bank full* stream velocity is largely a function of stream gradient, surface roughness and the width/depth ratio of the stream. Average bank full velocity hovers around one metre per second until the flow passes through the most stable reach within Stage 1, which is MN6 to MN4, where the average velocity drops to between 0.6 – 0.8m/s. This part of the system is the most geomorphically stable and ecologically complex reach throughout all of lower Mulloon.

Velocity begins to increase significantly from MN1 through to Kings Highway bridge due to increasing stream gradient and a significant reduction in surface roughness once the flow reaches WVM1.

At every site, with the exception of MN4, *post-structure* modelled average velocity reduces. In the case of the most upstream and downstream sites, which currently display the highest average velocities (2m/s at WVM1 & WVM2), the proposed structures create a significant reduction in the average stream velocity. This is because the proposed structures will reduce the average stream gradient, spread the flow over a greater cross-sectional area of the channel, and associated riparian fencing and revegetation will increase surface roughness.

Mean boundary shear stress

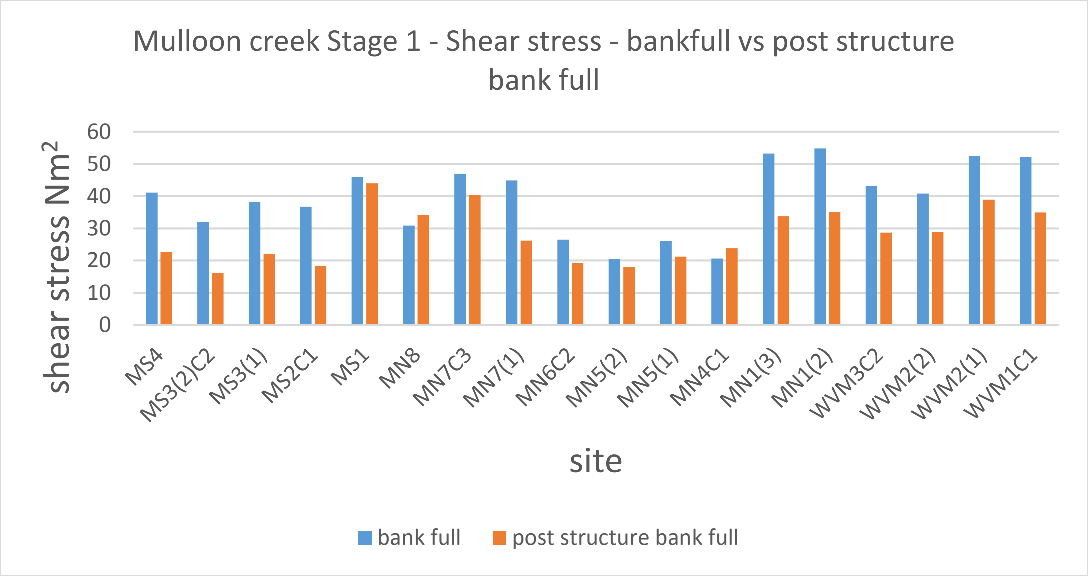

Figure 5 – Mean boundary shear stress under current bank full compared to post structure bank full conditions.

Along with unit stream power (Figure 7), mean boundary shear stress helps us understand the erosive forces at work on any part of the stream, and how that erosive force changes when any intervention, such as a bed control structure, is placed in the stream.

Figure 5 shows that the highest current mean boundary shear stress is at MN1(3) and MN1(2). It is no coincidence that adjacent to these sites during the high flow event of June 2016, a large hole was blown in the secondary channel (Figure 6).

At every site within Mulloon Creek Stage 1, whether or not a structure is proposed, mean boundary shear stress is predicted to reduce, which will lower the risk of erosion throughout the whole system.

Figure 6 – Large hole blown in the secondary channel adjacent to MN1(2) and MN1(3) as a result of the June 2016 flood.

Unit stream power

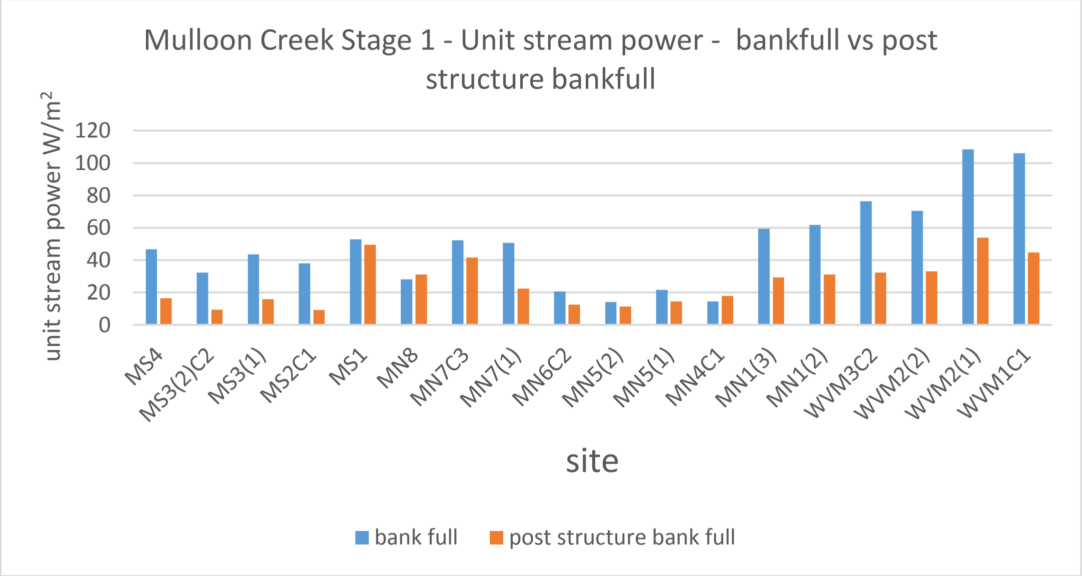

Figure 7 - Unit stream power under bank full compared to post structure bank full conditions.

Unit stream power is a measure of the energy per cross-sectional square metre that the stream is transmitting for any given flow. Unit stream power increases with increased slope, low surface roughness and greater stream depth.

Figure 7 shows a similar trend to Figures 2, 4 & 5. Unit stream power also begins to significantly increase downstream from MN1(3) as discharge, average velocity and mean boundary shear stress increase.

Modelled post-structure unit stream power decreases significantly at all sites and especially between sites MN1(3) and WVM1C1. Under current bank full stream conditions, only six of the 18 sites are around or below the 30W/m^2 threshold for channel instability. Under modelled *post-structure* stream conditions 14 of the 18 sites are around or below the threshold.

Discussion

A calculation of the current and post-structure bank full hydraulics provides insights into the stream flow dynamics of this section of Mulloon Creek. It may be axiomatic, but the numbers provide empirical evidence to support observed conditions in any given part of the system, as well as throughout the system as a whole. Observed evulsions as recent as June 2016, or dating back 50 years, can be related directly to the high energy transmission through that part of the system compared to other sites within the system.

Interventions such as the willow revetment work in the 1970s (Figure 8), and the log sill work in the early 2000s, have influenced the energy flow through the system. The willow revetment work confined the high flows within a defined channel, so that the stream's energy was transmitted into the unconsolidated bed of the stream. This caused gouging of the bed in some cases by up to three metres. All these willow revetments are now undermined, some seriously (Figure 9).

Figure 8 – One of many willow revetments constructed on the outside banks at Mulloon Creek between 1970 and 1980.

Figure 9 – In all cases, willow revetments constructed during the 1970s are now undermined.

The log sills that were built at sites MN1 and MN2 led to very stable conditions upstream. But the increased gradient as a result of raising the streambed level and the continued low surface roughness conditions downstream of MN1, led to an increase in the stream velocity and consequent stream energy through this reach. This contributed to the secondary channel adjacent to MN1 being gouged out in June 2016 (Figure 6).

These previous efforts to stabilise and rejuvenate Mulloon Creek have had both positive and negative effects on the system. In both cases however, they either did not or were not able to, consider the full scope of variables affecting the energy that periodically transmits through the system. In the case of the willow revetments, there was no opportunity for effective energy dissipation. Energy was confined to a steepening channel, and surface roughness in the channel remained low because livestock were never excluded from the stream. Therefore, a complex assemblage of armouring vegetation could not establish. Velocities remained high and are increasing in some parts of the system where the energy is continuing to gouge the bed, further increasing the slope of the stream.

The log sill work only treated a small section of Mulloon Creek. Even though this part of the system was also fenced at the time the sills were constructed, 15 years of regrowth couldn’t withstand the power of the event that was transmitted through this section of the system in June 2016. Reducing the average stream gradient between MN2 and the Kings Highway, coupled with increasing the surface roughness with vegetation between WVM3 and WVM1 will increase the resilience of this reach to future major events.

The proposed works for Mulloon Creek will address all the variables the effect stream energy as the modelled *post-structure* hydraulic Figures demonstrate. Even at sites where no intervention is planned, such as MS4, MS1 and MN7C3, a dissipation of energy can be demonstrated in the modelling because of the influence of the upstream and the downstream activities. This in itself highlights the importance of treating all, not just part, of the system.

References

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	Bank full							Primary channel							Post structure						
Site	Discharge m^3/s	Ave velocity m/s	Hydraulic radius (R)	Shear stress N/m^2	Total stream power (Watts)	Unit stream power (Watts/m^2)	Froude number	Discharge m^3/s	Ave velocity m/s	Hydraulic radius (R)	Shear stress N/m^2	Total stream power	Unit stream power	Froude number	Discharge m^3/s	Ave velocity m/s	Hydraulic radius (R)	Shear stress N/m^2	Total stream power	Unit stream power	Froude number
WVM1C1	174	1.995	1.716	52.2	5306.1	106.1	0.374	59	1.474	1.089	33.1	1805.2	50.1	0.384	95	1.273	1.481	34.9	2241.2	44.8	0.288
WVM2(1)	164	2.003	1.726	52.5	4993.1	108.5	0.389	12.6	0.912	0.531	16.1	382.8	14.8	0.339	105	1.359	1.634	38.9	2473.0	53.8	0.300
WVM2(2)	152	1.695	1.343	40.8	4615.7	70.5	0.324	18	1.117	0.719	21.8	546.6	24.8	0.291	92	1.124	1.229	28.9	2158.8	33.0	0.261
WVM3C2	134	1.756	1.416	43.1	4083.0	76.3	0.370	28	1.221	0.821	25	853.6	30.7	0.356	73	1.117	1.217	28.7	1722.1	32.2	0.274
MN1(2)	84	1.12	1.329	54.8	3458.2	61.8	0.253	9.4	0.626	0.556	22.9	386.5	14.4	0.214	59	0.881	1.193	35.1	1743.4	31.1	0.230
MN1(3)	92	1.098	1.292	53.2	3800.1	59.4	0.248	4	0.503	0.400	16.5	165.6	8.4	0.196	64	0.856	1.145	33.7	1873.9	29.3	0.231
MN4C1	83.5	0.685	1.311	20.6	1310.7	14.4	0.141	18	0.491	0.796	12.5	284.8	6.2	0.132	87	0.732	1.275	23.8	1618.1	17.8	0.165
MN5(1)	65.6	0.746	1.491	23.4	1029.9	17.8	0.127	27	0.713	1.393	21.8	420.4	15.9	0.145	45	0.679	1.138	21.2	842.4	14.5	0.116
MN5(2)	127	0.676	1.228	20.5	2117.7	14.0	0.138	19	0.557	0.919	15.3	315.5	8.8	0.154	116	0.63	1.214	17.9	1708.6	11.3	0.139
MN6C2	89	0.840	1.238	31.6	2280.9	26.8	0.155	13	0.636	0.816	20.8	330.8	13.2	0.181	64	0.647	1.15	19.2	1067.7	12.6	0.136
MN7(1)	83	1.036	1.696	43.2	2126.0	47.9	0.191	19	0.704	0.949	24.2	488	18.8	0.184	59	0.795	1.569	26.2	987.9	22.3	0.164
MN7C3	121.4	1.089	1.787	47	3191.0	52.3	0.201	27	0.935	1.422	37.4	712.6	36.2	0.299	112.5	1.009	1.786	40.3	2537.0	41.6	0.186
MN8	66.6	0.888	1.852	30.9	1110.5	28.1	0.164	14.7	0.601	1.030	17.2	244.3	10.4	0.157	54.5	0.902	1.51	34.1	1228.4	31.1	0.212
MS1	62.8	1.092	1.949	45.9	1477.8	52.8	0.180	62.8	1.092	1.949	45.9	1447.8	52.8	0.180	61.5	1.069	1.949	44.0	1386.4	49.5	0.177
MS2C1	40	1.026	1.03	36.7	1420.0	38.1	0.269	10.2	0.695	0.576	20.5	362.4	14.3	0.247	18.5	0.616	0.984	18.3	344.2	9.2	0.197
MS3(1)	171	1.105	1.442	38.2	4535.9	43.6	0.201	19	0.784	0.862	22.8	504.5	18.3	0.205	98.7	0.710	1.324	22.1	1645	15.8	0.160
MS3(2)C2	86	0.981	1.205	31.9	2285.5	32.2	0.181	26	0.934	1.120	29.7	692.4	28.8	0.222	39.7	0.574	0.961	16	661.7	9.3	0.145
MS4	200	1.124	1.28	41.1	6414.8	46.8	0.194	99	1.320	1.630	52.3	3175.1	70.6	0.298	127	0.715	1.281	22.6	2245.6	16.4	0.123

Table 1 – Hydraulic values each site in Mulloon Creek Stage 1 for primary channel full, (top) bank full, and post structure (top) bank full.