Memo

To:	Mark Iszard and Carmel O'Sullivan (Auckland Council)	Job No:	1003297
From:	Charlotte Peyroux and Tim Fisher (T+T) and Pranil Wadan (Woods)	Date:	6 April 2020
cc:	David Schwartfeger (Kiwi Property), Greg Dewe (Fulton Hogan), Andrew McCarthy (Oyster), Nick Roberts (Barkers),		
Subject:	Response to Auckland Council Further Information Request on Stormwater Matters for Drury East - Stream Erosion Risk Assessment for Hingaia Catchment		

1 Introduction

This memo summarises the findings of a stream erosion assessment undertaken to verify the proposed hydrological mitigation approach, identify high risk areas and determine if additional mitigation measures are required for two developments (Kiwi Property and Fulton Hogan) at Drury East in the Hingaia catchment.

The third Drury East development by Oyster Capital is in the adjacent Slippery Creek catchment, which will be addressed separately. However, the context and the learnings from this assessment are relevant to the Oyster Capital plan change.

This memo builds on the *Response to Auckland Council Further Information Request on Stormwater Matters for Drury East* prepared by Woods and Tonkin + Taylor on 25 March 2020 in response to Item 4 of the *Further Information Request (FIR) - Drury East Plan Changes* included in the *Healthy Waters Review of Adequacy of Information for a Private Plan Change (PPC) Request – Drury East - Fulton Hogan and Kiwi Property* memo from Auckland Council on 2 February 2020.

2 Background

2.1 Proposed approach to hydrological mitigation

The three Plan Change Areas at Drury East are greenfield developments and the proposed approach for the developments is to provide a minimum of Stormwater Management Area control - Flow 1 (SMAF 1) hydrological mitigation (detention and retention) for all impervious surfaces.

This responds to Auckland Unitary Plan Operative in part (AUP OP) Policy E1.3.8 that requires *minimising or mitigating changes in hydrology including loss of infiltration, to: minimise erosion and* *associated effects on stream health and values; maintain stream baseflows; and support groundwater recharge.* This approach aligns with the Auckland Councils Region-wide Network Discharge Consent and Guidance Document 01 (GD01).

The minimum hydrological mitigation requirements follow SMAF 1 in AUP OP Table E10.6.3.1.1 as follows:

- Retention (volume reduction) of at least 5mm of runoff depth from impervious surfaces where possible with limitations set out in Table E10.6.3.1.1.
- Detention of the 95th percentile event for the difference between the pre-development and post-development runoff volumes from a 95th percentile, 24-hour rainfall event minus the achieved retention volume.

2.2 Proposed approach to stream erosion

Drury East Plan Change – Ecology Response (19 March 2020) and *Response to Auckland Council Further Information Request on Stormwater Matters for Drury East* by Woods and Tonkin + Taylor (25 March 2020) have identified the follow mitigation measures as being those, which will aid in the management of stream erosion and sedimentation in the Plan Change Area:

- Removal of stock from the site and therefore avoiding active bank de-stabilisation through stock access and pugging.
- Incorporation of green spaces adjacent to stream networks to provide for planting of riparian margins to improve bank stability and reduce erosion potential.
- Modification of hydrograph mitigated through stormwater retention/detention (SMAF 1 hydrological mitigation) measures which will slow flows.
- Remediation or removal of existing in-stream structures (culverts, inlets/outlets) which are currently identified as having erosion issues.
- Realignment of streams which have been channelised to a more natural alignment.
- Incorporation of erosion and scour protection measures at all outfalls to minimise erosion at new structures.
- Targeted in-stream erosion protection measures may be required within the Hingaia Stream and other larger streams.

3 Stream Erosion Risk Assessment

3.1 Auckland Council Stream Erosion Risk Tool

Auckland Council have assisted in this matter by supplying the Auckland Council Stream Erosion Risk Tool and by providing a technical briefing on 14 February 2020.

The Auckland Council Stream Erosion Risk Tool was initially investigated as a mechanism to analyse stream erosion. The tool was considered too simplistic for the Drury East area because better quality inputs were available, as summarised below:

Table 1 - Identified issues of use for Auckland Council Stream Erosion Tool

#	Issue	Next step
1	TP108 hydrology is too coarse for a large catchment such as the Hingaia where a refined hydraulic model is available	Use hydrographs from the flood model. Rebuild Stream Erosion Risk Tool to allow this. Note, input hydrology is not required if hydraulic shear stress is available from hydraulic models, refer issues #2 and #3
2	Hydraulic shear stress is very sensitive to Slope (S) and thalweg/bed levels are too variable and result in non-sensible results	Use bed shear stress calculated by the hydraulic model at all locations and at all time steps as this uses the actual channel cross-section and simulated flow, water surface slope, velocity and depth. Rebuild the Stream Erosion Risk Tool to allow for these inputs.
3	Simplification of channel cross-sections to a trapezoid is too coarse	
4	Critical shear stress cannot be determined from the geotechnical testing already done for the site.	Estimate this from Auckland Council databases and references.
5	Quantification of change in exceedance of critical shear stress will only indicate a change in erosion potential. It will not quantify how much extra erosion and what the change in sediment load will be to the receiving environment, so it cannot be used to assess effects.	Auckland Council to advise how they see this working. T+T/Woods consider that the tool will identify areas with increased erosion risk and where extra mitigation measures might be considered.

3.2 Modified Stream Erosion Risk Tool

In response to the issues identified with the Auckland Council Stream Erosion Risk Tool a Modified Stream Erosion Risk Tool was developed. The overarching principal remains the same, which is to compare the hydraulic shear stress[1] exerted by the driving force of water to the critical shear stress of the material lining the stream channel. The modified methodology is as follows:

- Select locations for the Stream Erosion Risk assessment – Refer to Section 2.1.
- Extract the 2, 10, and 100 year Annual Recurrence Internal (ARI) hydraulic shear stress at the analysis locations from the flood model for pre- and post-development scenarios – Refer to Section 2.2.
- Assess for potential erosion and identify high risk areas:
  - Use 2, 10, and 100 year ARI hydraulic shear stress as described above and compare against an expected critical shear stress – Refer to Section 2.3.
  - Use the Auckland Council defined erosion thresholds to determine the stream erosion potential at each location during each design storm - Refer Section 2.4.

The tool will indicate a change in **erosion potential** by quantifying the duration of exceedance of critical shear stress.

It will not quantify how much extra erosion will occur, nor will it quantify the change in sediment load to the receiving environment, so it cannot be used to directly assess effects. Therefore, to support the Plan Change, the tool will be used to identify areas with erosion risk, and where these change as a result of the development, and where extra mitigation measures may be required.

The results of this assessment are included in Section 3 of this memo.

3.3 Assessment locations

A stream erosion risk assessment was carried out at 10 locations relevant to the Kiwi Property and Fulton Hogan Plan Change Areas. These locations are along the Hingaia stream and tributaries including Fitzgerald Stream. The locations were selected to assess for potential erosion due to hydrology changes attributed to the land use change associated with the Plan Change.

The details of these locations are included in Table 2 and a locality plan included in Appendix A.

[1] Hydraulic shear stress is the MIKE output date type "bed shear stress" as given by Manning's equation $=\rho g V^2 n^2 / y^{1/3}$

Table 2 - Assessment locations for Modified Stream Erosion Risk Tool

ID	Description	Model Location	Chainage
Location 1	Hingaia Stream, mid-point of Kiwi Plan Change Area	HINGAIA STREAM	16585.5
Location 2	Hingaia Stream, upstream of Flanagan Bridge	HINGAIA STREAM	17105.5
Location 3	Hingaia Stream, upstream of Norrie Road	HINGAIA STREAM	17848.6
Location 4	Hingaia Stream, lower	HINGAIA STREAM	18918
Location 5	Fitzgerald Stream, upstream of Flanagan Road	HINGAIA TRIBUTARY 7	2086.75
Location 6	Fitzgerald Stream, downstream of Fitzgerald Road	HINGAIA TRIBUTARY 7	1323
Location 7	Fitzgerald Stream, mid-point of Kiwi Plan Change Area	HINGAIA TRIBUTARY 7	1768
Location 8	Hingaia Tributary, downstream of Fulton Hogan Plan Change Areas	HINGAIA SUB TRIBUTARY 2	851.5
Location 9	Hingaia Tributary, downstream of Fulton Hogan Plan Change Areas	HINGAIA TRIBUTARY 6	1241
Location 10	Fitzgerald Stream, within Fulton Hogan Plan Change Areas	HINGAIA TRIBUTARY 7	325

3.4 Flood models

The 2, 10 and 100 year ARI storm events (inclusive of climate change) were run in the Hingaia hydraulic model for both the pre- and post-development scenarios and a corresponding time series of the estimated hydraulic shear stresses occurring within the channel extracted at each location.

The 2 year ARI storm event is considered to be the most relevant frequency as the 2 year ARI flood event strongly influences the geomorphology of the stream, especially the size of the main channel.

The flood models included an allowance for climate change and used our baseline model for the pre-development scenarios which includes Drury South. Suitability of this baseline (pre-development) model is discussed in the *Drury East (Kiwi and Fulton Hogan) flood modelling – response to Auckland Council modelling requests* memo prepared by Tonkin + Taylor on 10 February 2020 for Auckland Council. For pre-development scenario the flood model assumed 10% imperviousness for undeveloped catchments within Future Urban Zone (FUZ) (including the Plan Change Area) and upstream rural zonings. The post-development scenario includes the development of the Plan Change Areas flood model in accordance with Table 2 of *Response to Auckland Council Further Information Request on Stormwater Matters for Drury East* prepared by Woods and Tonkin + Taylor on 25 March 2020, but does not include allowances for SMAF-1 hydrological mitigation as these target the smaller more frequent 95th percentile rainfall event.

3.5 Critical shear stress of the stream

The critical shear stress of a stream refers to when the hydraulic shear stress exerted by the driving force of water in the stream channel exceeds the critical shear stress of the material lining of the stream channel, at which point erosion is initiated. The critical shear stress is a parameter associated with the bed media. It is smallest (more erodible) for silts and sand but increases (less erodible) with grain size e.g. gravel and cobbles, and also increases (less erodible) for percentage of clays as these soils become cohesive. If the bed and bank materials and riparian planting vary along a stream, then it is challenging to find a representative critical shear stress.

According to geological maps, the 10 stream erosion assessment locations are located in three different geological units: Puketoka formation; Holocene river deposits and Kerikeri Volcanic group. The site geotechnical testing is not at these locations, nor does it cover all of these geological units so we do not have soils descriptions for all of these units, nor does the geotechnical testing include critical shear stress which is a very specialised test.

The geological maps aren't spatially accurate or reliable enough to describe the geology at specific locations along the streams. Even if they were, there isn't enough information in the following references and studies to support a specific critical shear stress based on a geological base unit, nor prove this correlation between Auckland streams and Auckland geological layers.

- *Erosion Parameters for Cohesive Sediment in Auckland Streams*, Auckland Council Technical Report 038 (2009)
- *Auckland Urban stream erodibility investigations,* Prepared by Elliot et al. for NIWA Client Report HAM2005-031 (2005)
- *Resistance and Critical Height of Streambanks in Selected Catchments of the Auckland Region*. Prepared by Cardno for Auckland Council (Draft version, March 2020)
- B-STEM (Bank-Stability and Toe Erosion Model) slides provided by Auckland Council

Furthermore, in light of the lockdown to slow the spread of Covid-19, site-specific investigation is not possible at this time.

In the absence of site-specific geotechnical parameters, the 50th percentile median critical shear stress (32.6 Pa) was adopted from Auckland-specific data compiled by Cardno for Auckland Council (refer Table 3) and included in the Stream Erosion Tool. This is supported by recommendations in Auckland Council Technical Report 038 / 2009 *Erosion Parameters for Cohesive Sediment in Auckland Streams* which suggests "using the median critical shear stress (approximately 33 Pa)" if specific parameters are not developed for a stream. A sensitivity assessment is included in Section 4.

Table 3 – Critical shear stress in the bank materials at various locations around the Auckland region.

All Cardno Data		Hoteo	Awaruku	Omaru	Oakley	Misc. Urban	Elliott et al. (2005)		
Percentile	τ_c	τ_c	τ_c	τ_c	τ_c	τ_c	τ_c	Avg	Median
99.99	403	404	164	218	64.2	336	72.3	237.4	218.4
99.9	395	398	163	218	63.9	334	72.1	234.9	218.4
99	324	335	158	218	61.4	312	70.1	211.2	217.8
95	208	158	134	215	50.5	262	62.1	155.6	157.8
90	138	121	117	168	39.7	237	57.6	125.7	121.2
85	113	109	109	147	34.8	194	57.1	109.0	109.1
80	85.3	72.0	95.4	128	30.9	155	55.9	89.0	85.3
75	**71.6**	**62.1**	**78.4**	**102**	**27.6**	**78.3**	**54.5**	**67.8**	**71.6**
70	61.3	54.5	76.6	97.6	22.9	76.9	53.3	63.3	61.3
65	52.4	45.2	72.3	90.2	19.8	65.3	47.5	56.1	52.4
60	41.4	29.7	63.3	64.6	19.4	51.7	36.9	43.9	41.4
55	32.0	24.7	54.4	57.2	19.3	40.5	36.1	37.8	36.1
50	**25.0**	**15.9**	**42.8**	**49.1**	**19.2**	**35.1**	**32.6**	**31.4**	**32.6**
45	19.4	13.5	33.8	36.1	16.9	30.7	26.4	25.3	26.4
40	13.8	10.2	30.1	25.0	15.2	21.9	24.5	20.1	21.9
35	10.4	8.6	21.2	21.7	14.2	8.3	22.1	15.2	14.2
30	7.8	6.6	15.3	19.9	10.9	4.4	22.0	12.4	10.9
25	**6.4**	**5.0**	**11.0**	**14.2**	**6.5**	**3.1**	**21.3**	**9.6**	**6.5**
20	4.4	3.1	8.4	10.3	6.4	3.1	19.7	7.9	6.4
15	2.8	1.5	6.3	7.0	5.7	2.8	16.8	6.1	5.7
10	1.0	0.61	4.2	4.2	3.5	1.5	13.7	4.1	3.5
5	0.34	0.17	2.4	2.6	2.1	0.46	9.1	2.5	2.1
1	0.06	0.05	0.78	0.67	1.2	0.22	5.3	1.2	0.7
0.1	0.04	0.04	0.42	0.22	1.0	0.18	4.4	0.9	0.2

3.6 Erosion Thresholds

Auckland Council use four bands to assess the magnitude of predicted erosion in the Auckland Council Stream Erosion Risk Tool. Each threshold is based on the excess shear - a ratio of the hydraulic shear stress exerted by the driving force of water in the stream channel to critical shear stress. Potential erosion occurs when the excess shear is greater than 1 and erosion is theoretically initiated in the channel. When excess shear is more than 2 there is potential for active erosion and the channel to be mobile. Anything greater than 10 indicates a very rapid rate of erosion. The basis of the thresholds for excess shear at 2 and 10 is not clear.

Table 4 - Auckland Council Erosion Risk Thresholds

Threshold	Excess Shear	Description
Green	<1.0	Indicates no erosion predicted to occur
Yellow	>1.0 <2.0	Indicates the potential for some erosion of the channel
Orange	>2.0 <10.0	Indicates the potential for channel to be mobile, (likely active erosion)
Red	>10.0	Indicates potential rapid rates of erosion and incision of channel

Many stream tributaries within the Drury East Plan Change Area have some erosion so excess shear greater than 1 is expected at peak flow. We are interested in the change from the pre and post development design storms and do this by comparing the duration that a threshold is exceeded.

4 Results

4.1 Erosion potential

Note: The 2 year ARI storm event was run for 24 hours while the 10 and 100 year ARI storm events were only run for 18 hours and this impacts the duration data, which invalidates comparison between the 2 year ARI storm and the 10 and 100 year ARI events. Also, there was a spike at the beginning of the design storm which is abnormal and attributed to initial conditions, so data is only presented from 1 hour into the storm event.

The excess shear for the 2 year ARI storm event is presented in normalised bar chart form in Figure 1. The 10 and 100 year ARI storm events are included in Appendix B. Time series of hydraulic shear stress at each location for all three storms are also included in Appendix B.

The results from the 2 year ARI storm suggest there is erosion potential (duration of excess shear >1) at Locations 1, 6, 7 and 10 during the pre- development scenario. For the post-development scenarios the erosion potential increases very slightly at these locations, with the excess shear exceeding 2 for a small amount of time at Location 6 and a small amount of new erosion potential at Location 9.

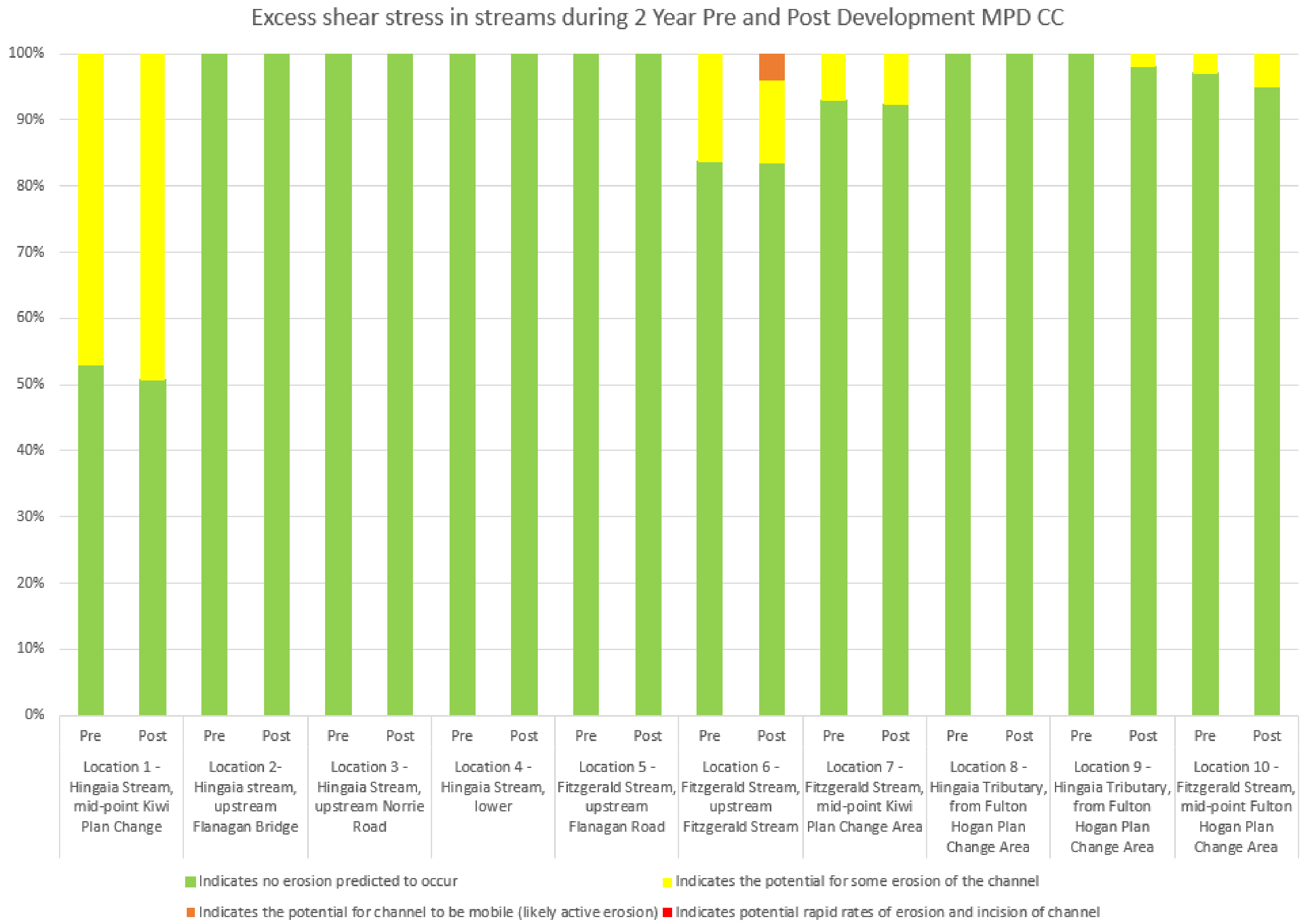
For Locations 1, 6, 7, 9 and 10, Table 5 quantifies the exceedance of critical shear stress by comparing maximum excess shear and durations for which the excess shear was greater than 1 (erosion potential).

Table 5 – Maximum excess shear between pre- and post-development 2 year storm events at five locations

	Location 1		Location 6		Location 7		Location 9		Location 10	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Max Excess shear	1.41	1.41	1.76	2.64	1.21	1.95	0.66	1.04	1.11	1.93
Difference		-		0.87		0.73		0.38		0.82
% of Duration >1 **1< & >2**	45%	47%	16%	12% **4%**	7%	7%	0%	2%	3%	5%

The change in duration over which excess shear exceeds the threshold for the five locations (1, 6, 7, 9 and 10) was 2%, 4%, 1%, 2% and 2%, respectively. These are considered to be very small changes. The changes in maximum excess shear are higher for four locations (6, 7, 9 and 10) that are smaller streams with more land use changes in the catchments.

Figure 1- Normalised bar chart comparing excess shear stress during 2 year pre- and post-development events



4.2 Verification

These changes in erosion potential were compared against a survey of the erosion scars and bank stability within the Hingaia Stream Catchment Watercourse completed by Auckland Council in 2018. The results of both the watercourse survey and this erosion assessment are summarised in Table 6. The map from the Auckland Council survey showing the engineering asset locations, stream bank and outlet erosion has been marked up with the ten assessment locations and included in Appendix A. There is no clear correlation between the observed erosion and the predicted erosion.

Table 6 - Comparison of results from 2018 Hingaia watercourse survey and Modified Stream Erosion Risk Tool

	Auckland Council Watercourse survey		Modified Stream Erosion Risk Tool	
ID	**Erosion Scars**	**Bank Stability**	**Maximum Erosion Threshold**	
Location 1	0 – 20%	Poor	1.41	1.42
Location 2	0 – 20%	Poor	0.98	0.99
Location 3	0 – 20%	Fair	0.66	0.66
Location 4	0 – 20%, 21 – 40%	Fair	0.33	0.34
Location 5	0 – 20% - 21 - 40%	Fair	0.46	0.68
Location 6	21 – 40%	Good	1.76	2.64
Location 7	0 – 20%, 21 – 40%	Fair	1.21	1.95
Location 8	0 – 20%	Fair	0.48	0.75
Location 9	21 – 40%	Fair	0.66	1.04
Location 10	0 – 20% *	Fair	1.11	1.93

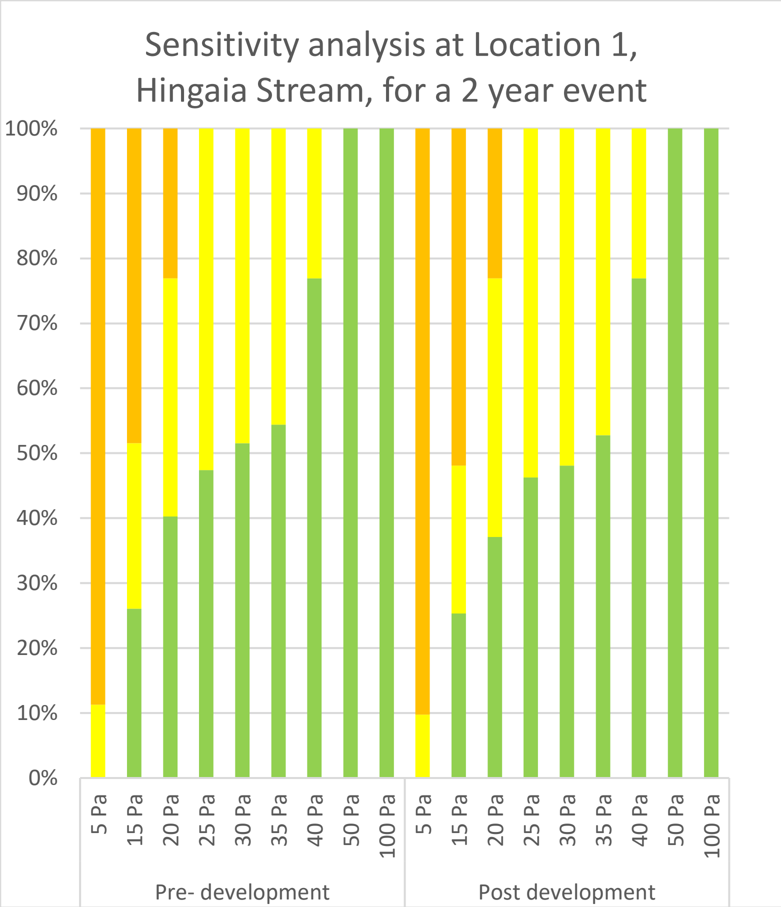
4.3 Discussion

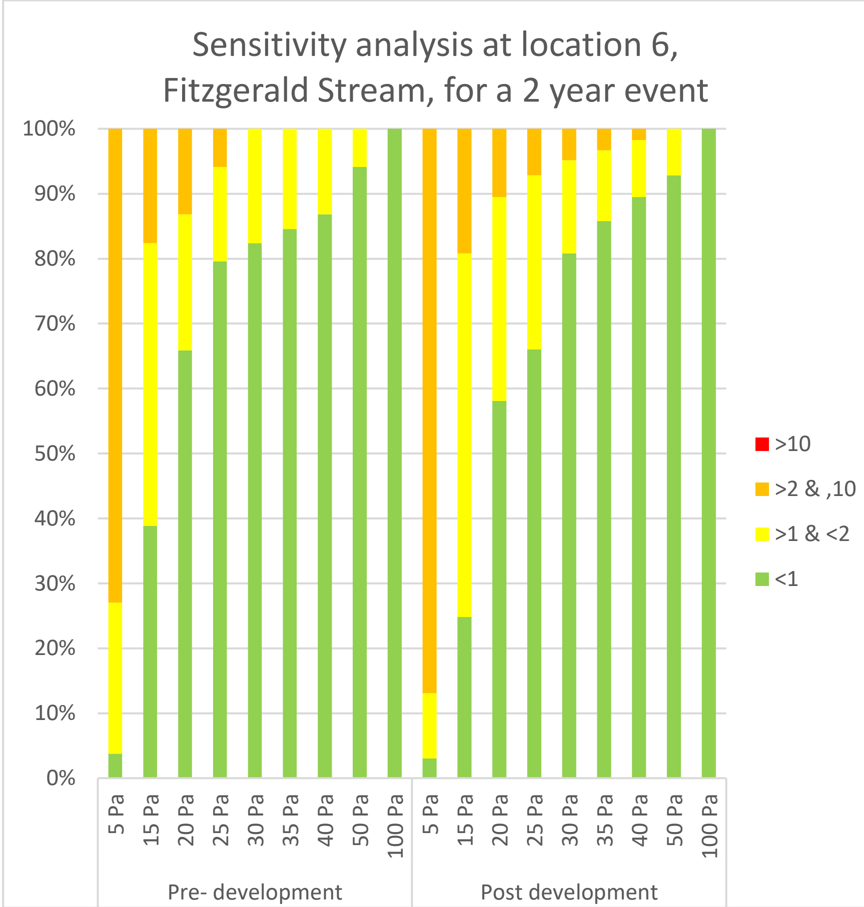
The lack of correlation between observed and predicted, puts doubt in the predictive ability of the stream erosion risk erosion assessment to identify erosion risk locations. Although the Stream Erosion Risk Assessment has value in assessing the change in erosion risk due to development.

5 Sensitivity

The critical shear stress of the stream is very site specific and dependent on factors including underlying geological features, substrate types, channel conditions such as the degree of weathering and the channel shape, and the conditions along the stream banks, such as vegetation. All of these variables change spatially along and across the stream channel. A sensitivity analysis was done at two locations to assess the suitability of estimating the critical shear stress from region wide testing due to the lack of site-specific testing. Figure 2 analyses the estimated erodibility potential at two locations (Location 1 at the mid-point along the Hingaia Stream of the Kiwi Property Plan Change Area and Location 6 along Fitzgerald Stream) for the 2 year event for a range of critical shear stresses between 5 Pa and 100 Pa. These both show a significant change in erosion potential depending on the critical shear stress.

Figure 2a and b - Sensitivity analysis for excess shear stress at Location 1, Hingaia stream and Location 6, Fitzgerald Stream for a 2 year event





However, Table 7 summarises the percentage increase in duration with an excess shear of more than 1 (which indicates that no erosion is expected to occur during that timestep).

Table 7: Percentage duration change in excess shear exceeding varying critical shear stress

	Duration change in excess shear exceeding 1 for varying critical shear stress (%)								
	5 Pa	**15 Pa**	**20 Pa**	**25 Pa**	**30 Pa**	**35 Pa**	**40 Pa**	**50 Pa**	**100 Pa**
Location 1	0%	0.7%	3.0%	1.2%	3.5%	1.6%	0.1%	0%	0%
Location 6	0.7%	14.0%	7.8%	13.5%	1.6%	-1.2%	-2.7%	1.3%	0%

This suggests that whilst there is a significant change in the predicted erosion for different critical shear stresses (shown by Figure 2), there are small percentage changes in erodibility potential between the pre-development and post development scenarios for each critical shear stress (Table 7) with Location 1 being more consistently low than Location 6. Therefore, the change in erosion potential (duration of excess shear >1) is reasonably insensitive of the critical shear stress.

6 Conclusion

A Modified Stream Erosion Risk Assessment was developed to utilise high quality hydraulic modelling results that were available for the site, which we consider has enhanced the Auckland Council Stream Erosion Risk Assessment.

A Modified Stream Erosion Risk Assessment has shown that there is existing erosion potential at four out of 10 assessed locations along the Hingaia stream and its tributaries. However, there was poor correlation between predicted erosion locations and observed erosion, which puts doubt in the predictive ability of the Stream Erosion Risk Assessment to identify erosion risk areas.

Nonetheless, the stream erosion risk erosion assessment has value in assessing the <u>change</u> in erosion risk due to development. There was a very minor increase to erosion potential (duration of excess shear >1) at five locations due to hydrological changes as a result of the development. The changes in maximum excess shear are higher for four locations (6, 7, 9 and 10) that are smaller streams (including Fitzgerald Stream) with more land use changes in the catchments. The erosion potential in the main Hingaia Stream was not materially changed.

At this stage we have not run flood models or assessed the erosion potential that accounts for the proposed SMAF 1 hydrological mitigation for all impervious surfaces in the Plan Change Areas. The application of SMAF 1 hydrological mitigation will result in an even smaller increase to the erosion risk than the post-development scenario assessed in this memo. The benefit from SMAF 1 hydrological mitigation will increase for smaller events.

In conclusion, the Modified Stream Erosion Risk Assessment adds a more detailed assessment, but uncertainty remains as to the existing and future erosion risk.

7 Recommendations

The ecology and stormwater experts for Kiwi Property and Fulton Hogan recommend stream erosion mitigation measures for the Plan Change Areas as follows:

- Removal of stock from the site and therefore avoiding active bank de-stabilisation through stock access and pugging.
- Incorporation of green spaces adjacent to stream networks to provide for planting of riparian margins to improve bank stability and reduce erosion potential.
- Modification of hydrograph mitigated through stormwater retention/detention (SMAF 1 hydrological mitigation) measures which will slow flows.

- Remediation or removal of existing in-stream structures (culverts, inlets/outlets) which are currently identified as having erosion issues.
- Realignment of streams which have been channelised to a more natural alignment.
- Incorporation of erosion and scour protection measures at all outfalls to minimise erosion at new structures.
- Targeted in-stream erosion protection measures may be required within the Hingaia Stream and other larger streams.

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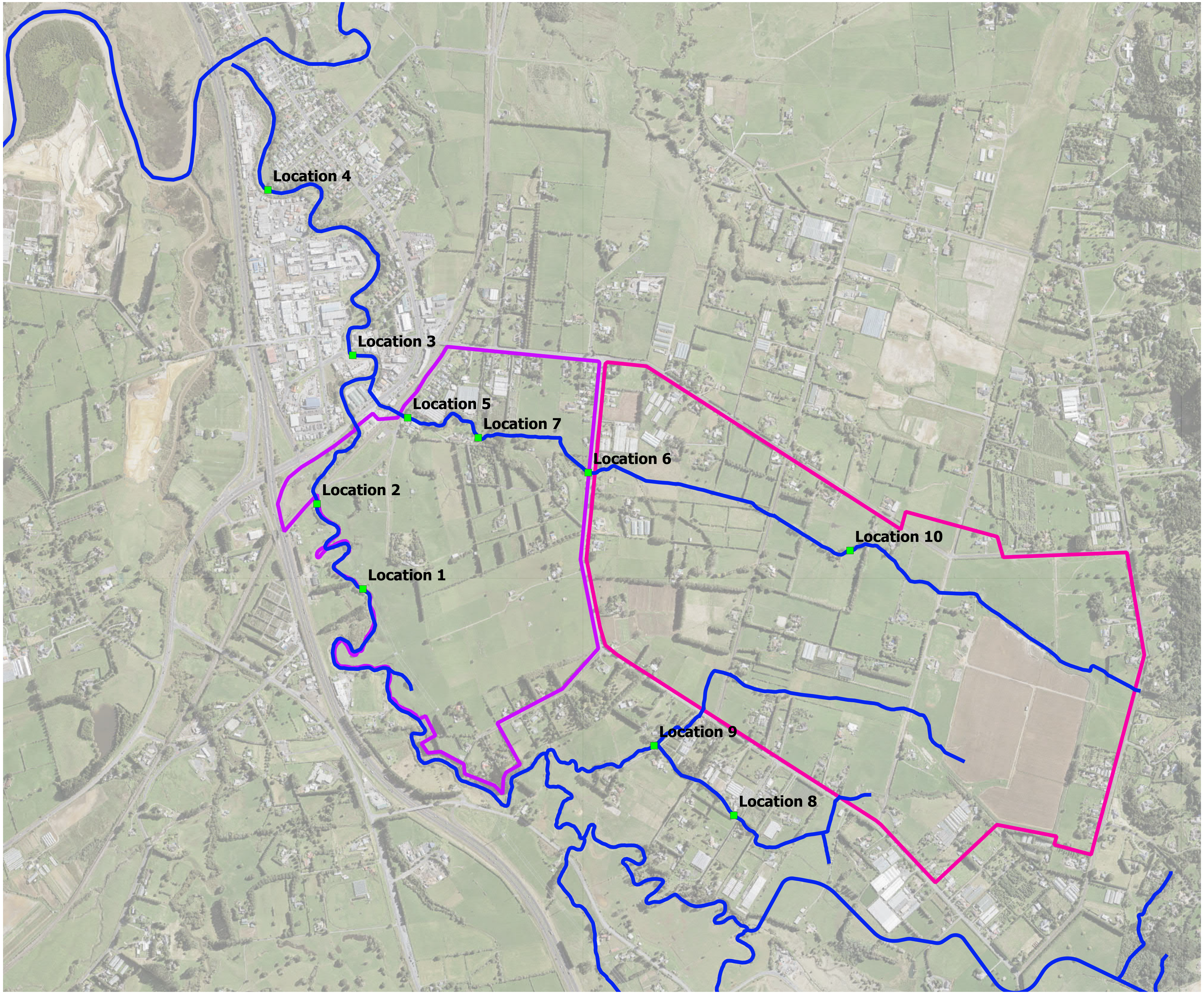
Appendix A:



Tonkin+Taylor

WOODS EST.1970

LEGEND

- Locations
- Rivers
- Fulton Hogan Plan Change Area
- Kiwi Property Plan Change

REVISION DETAILS		BY	DATE
1.0	Issued for Information	PW	31/3/2020

SURVEYED	AC
DESIGNED	PW/AD
DRAWN	SH
CHECKED	PW
APPROVED	PW

WOODS.CO.NZ

N

Modified Stream Erosion Risk Tool Assessment Locations

STATUS	ISSUED FOR INFORMATION	REV
SCALE	1:12000 @ A3	1.0
COUNCIL	AUCKLAND COUNCIL	
DWG NO	P16-335-SKT-0014	

This drawing was generated from QGIS

Map 4: Engineering Asset Locations, Stream Bank & Outfall Erosion

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Auckland Council

HINGAIA CATCHMENT STREAM SURVEY

Erosion Scars
- 0-20%
- 21-40%
- 41-60%
- >60%
- Erosion Hotspot

Bank Stability
- Excellent
- Good
- Fair
- Poor
- Wetland

Inlet/Outlet Erosion
- None
- Slight
- Moderate
- Severe
- Could not locate

0 0.25 0.5 1 km

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Scale:	1:10,000
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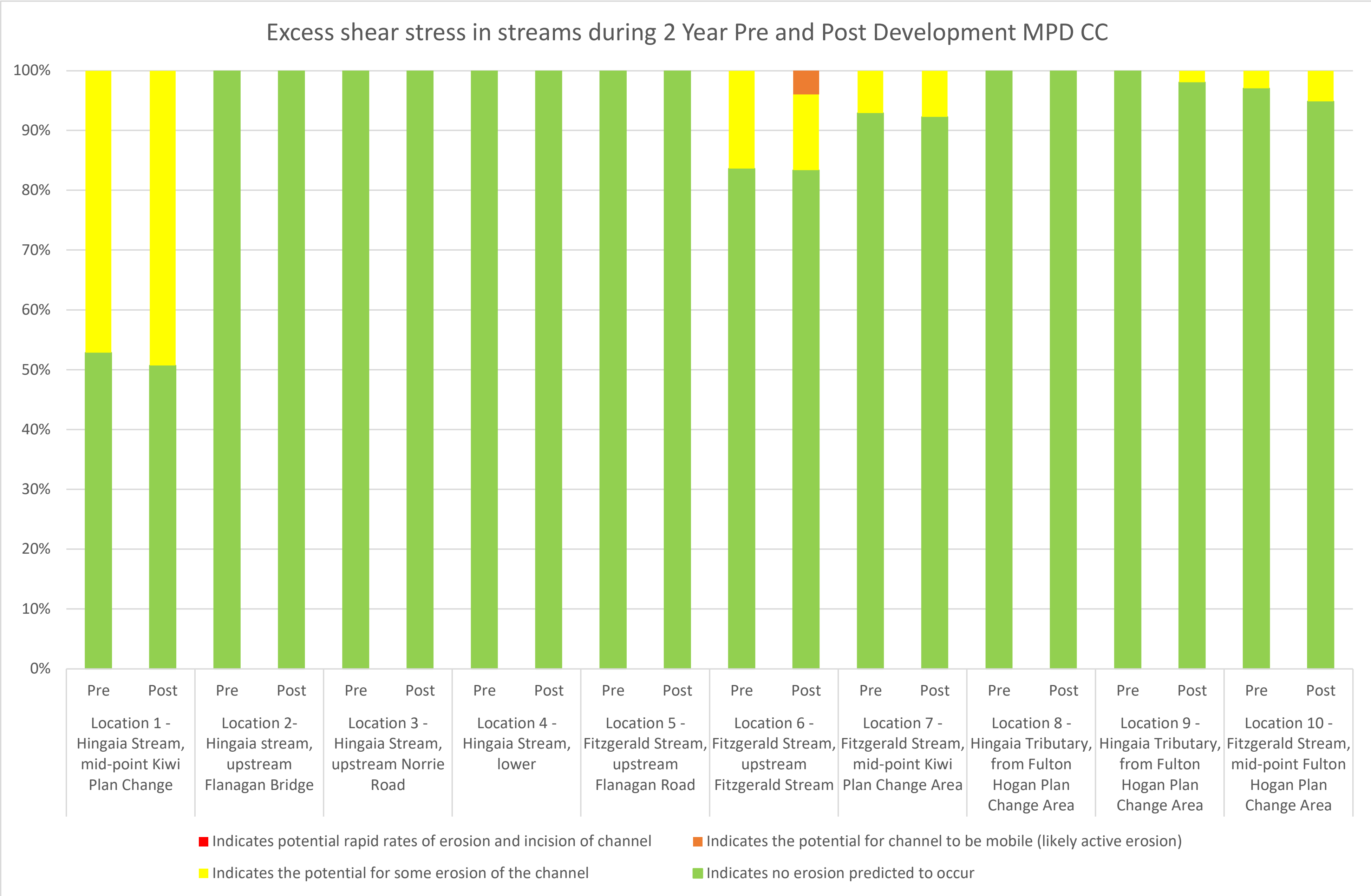
Status:	Draft
Author:	FP
Checked:	AS
Approved:	KB

Appendix B:


Excess shear stress in streams during 2 Year Pre and Post Development MPD CC
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Pre
Post
Location 1 - Hingaia Stream, mid-point Kiwi Plan Change
Location 2- Hingaia stream, upstream Flanagan Bridge
Location 3 - Hingaia Stream, upstream Norrie Road
Location 4 - Hingaia Stream, lower
Location 5 - Fitzgerald Stream, upstream Flanagan Road
Location 6 - Fitzgerald Stream, upstream Fitzgerald Stream
Location 7 - Fitzgerald Stream, mid-point Kiwi Plan Change Area
Location 8 - Hingaia Tributary, from Fulton Hogan Plan Change Area
Location 9 - Hingaia Tributary, from Fulton Hogan Plan Change Area
Location 10 - Fitzgerald Stream, mid-point Fulton Hogan Plan Change Area
Indicates potential rapid rates of erosion and incision of channel
Indicates the potential for channel to be mobile (likely active erosion)
Indicates the potential for some erosion of the channel
Indicates no erosion predicted to occur


Excess shear stress in streams during 10 Year Pre and Post Development MPD CC
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Pre
Post
Location 1 - Hingaia Stream, mid-point Kiwi Plan Change
Location 2- Hingaia stream, upstream Flanagan Bridge
Location 3 - Hingaia Stream, upstream Norrie Road
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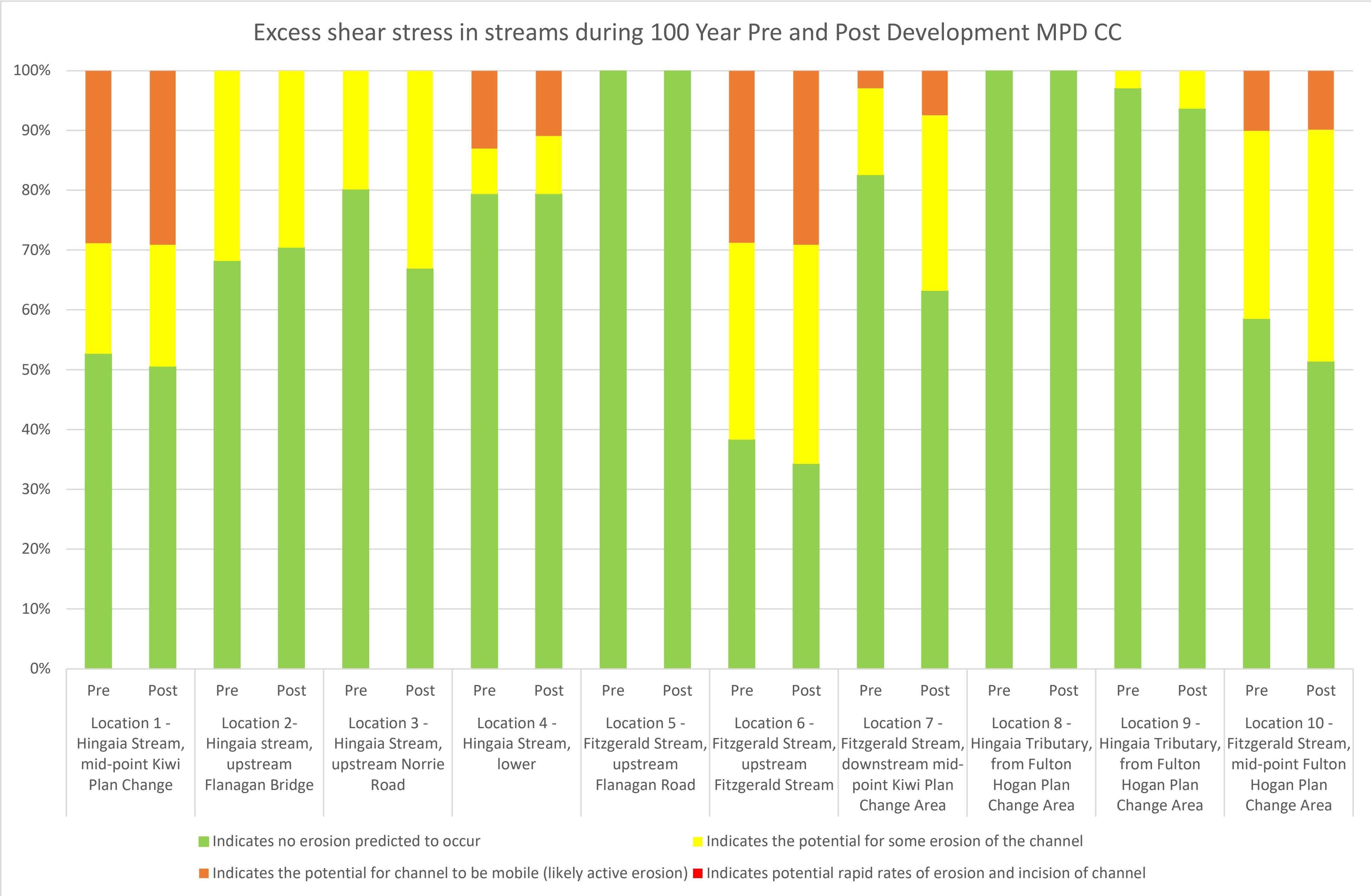
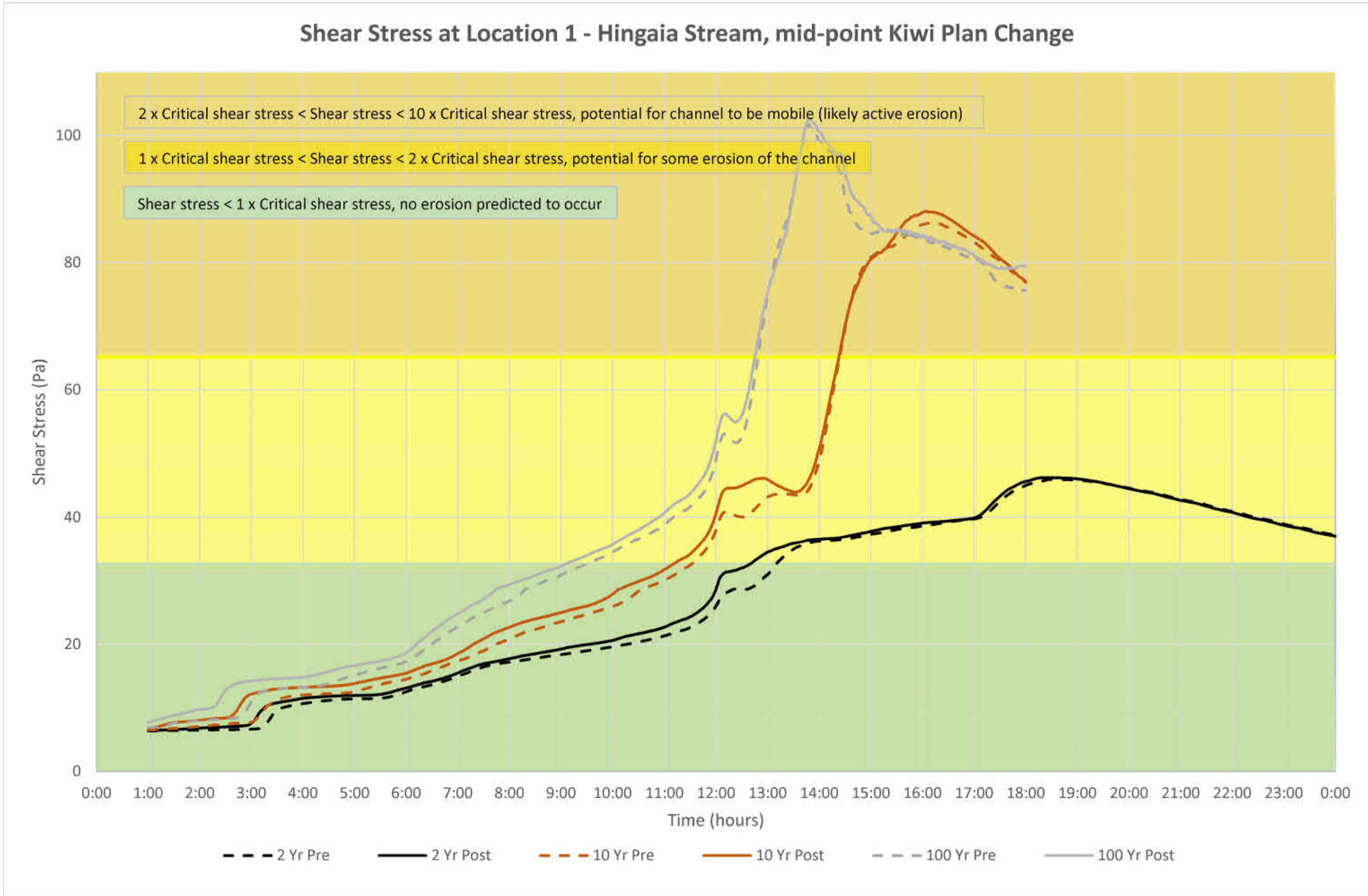
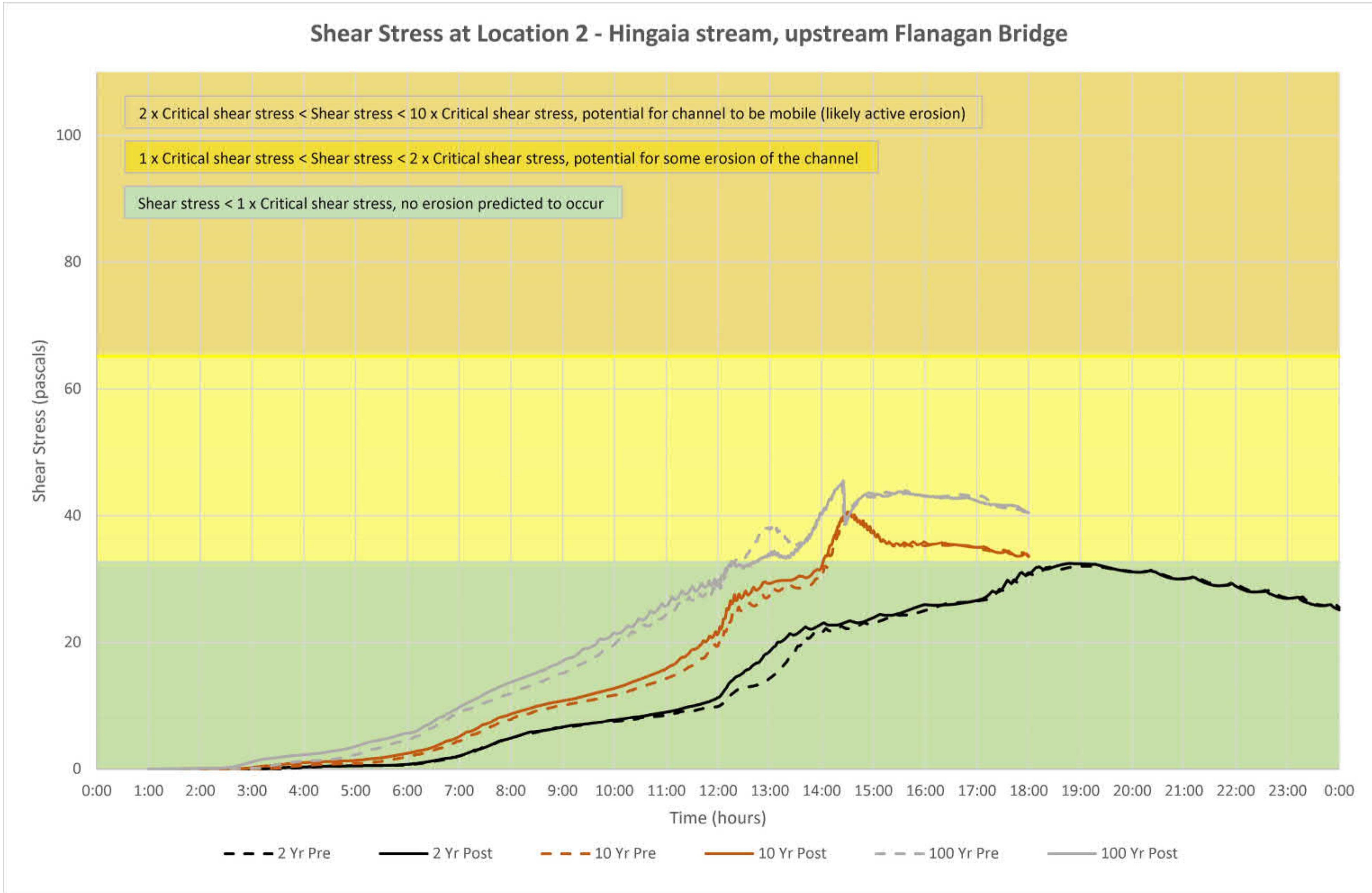
Indicates the potential for some erosion of the channel
Indicates no erosion predicted to occur

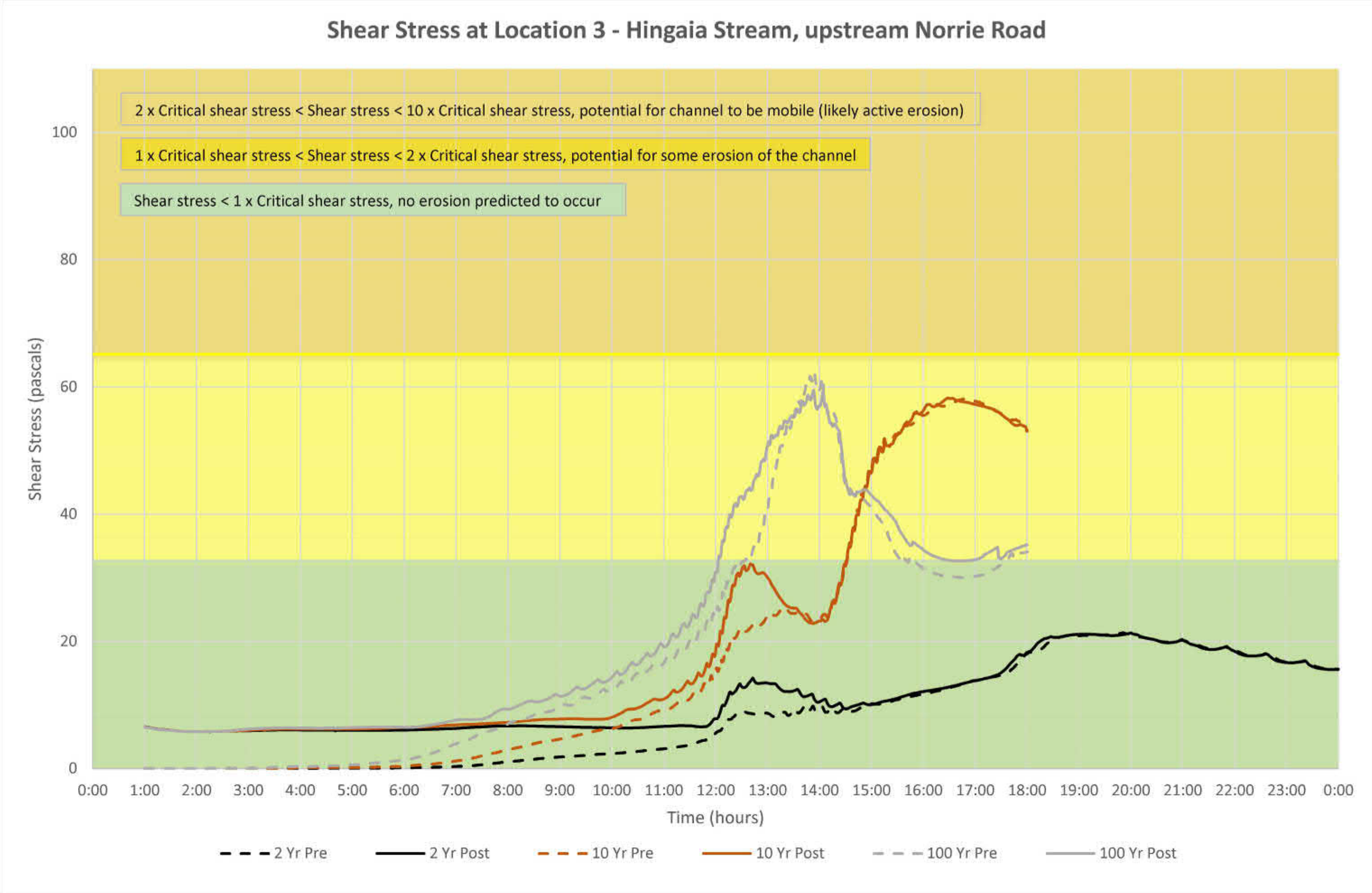


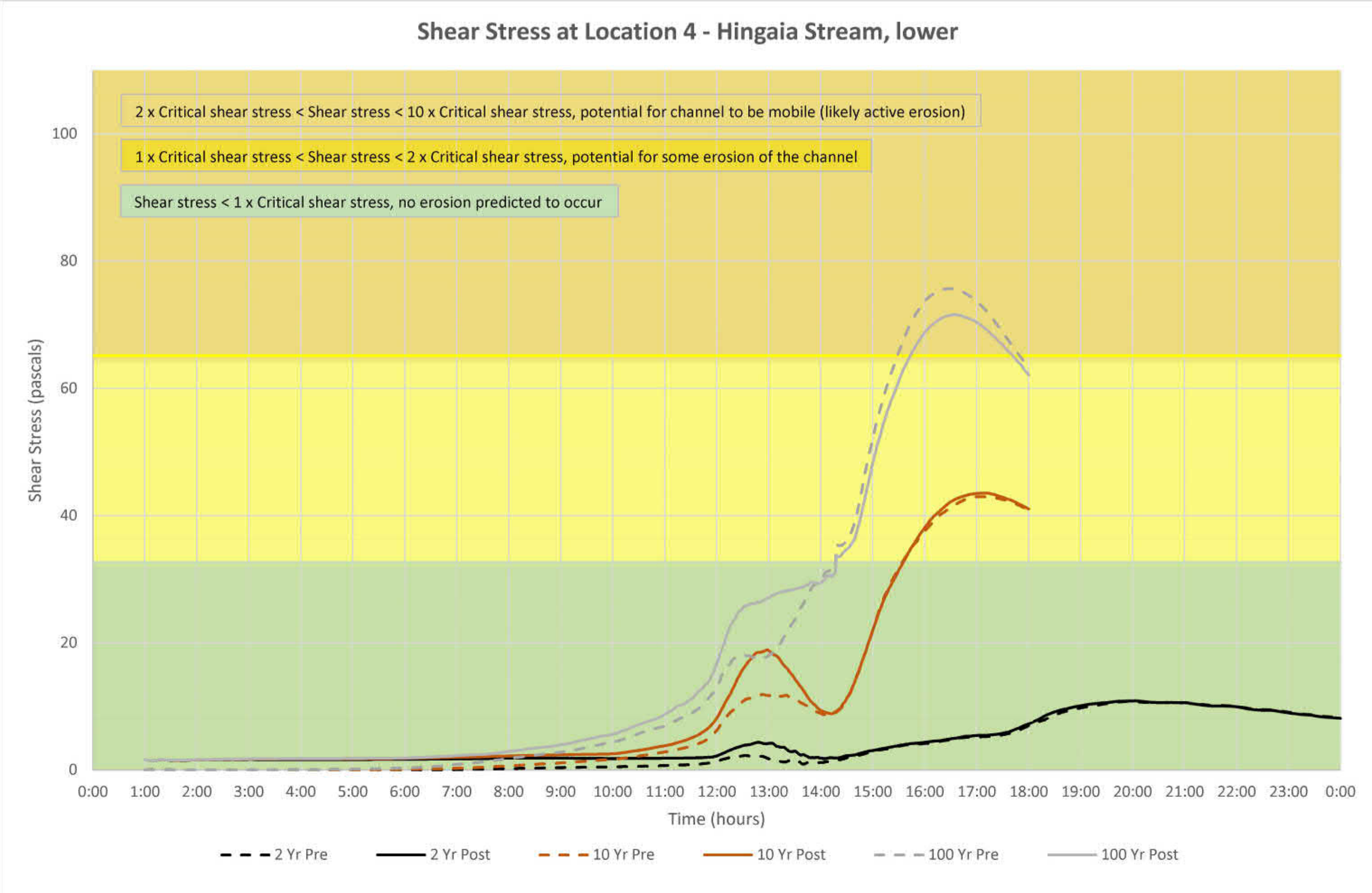
Excess shear stress in streams during 100 Year Pre and Post Development MPD CC
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Pre
Post
Location 1 - Hingaia Stream, mid-point Kiwi Plan Change
Location 2- Hingaia stream, upstream Flanagan Bridge
Location 3 - Hingaia Stream, upstream Norrie Road
Location 4 - Hingaia Stream, lower
Location 5 - Fitzgerald Stream, upstream Flanagan Road
Location 6 - Fitzgerald Stream, upstream Fitzgerald Stream
Location 7 - Fitzgerald Stream, downstream mid-point Kiwi Plan Change Area
Location 8 - Hingaia Tributary, from Fulton Hogan Plan Change Area
Location 9 - Hingaia Tributary, from Fulton Hogan Plan Change Area
Location 10 - Fitzgerald Stream, mid-point Fulton Hogan Plan Change Area
Indicates no erosion predicted to occur
Indicates the potential for some erosion of the channel
Indicates the potential for channel to be mobile (likely active erosion)
Indicates potential rapid rates of erosion and incision of channel



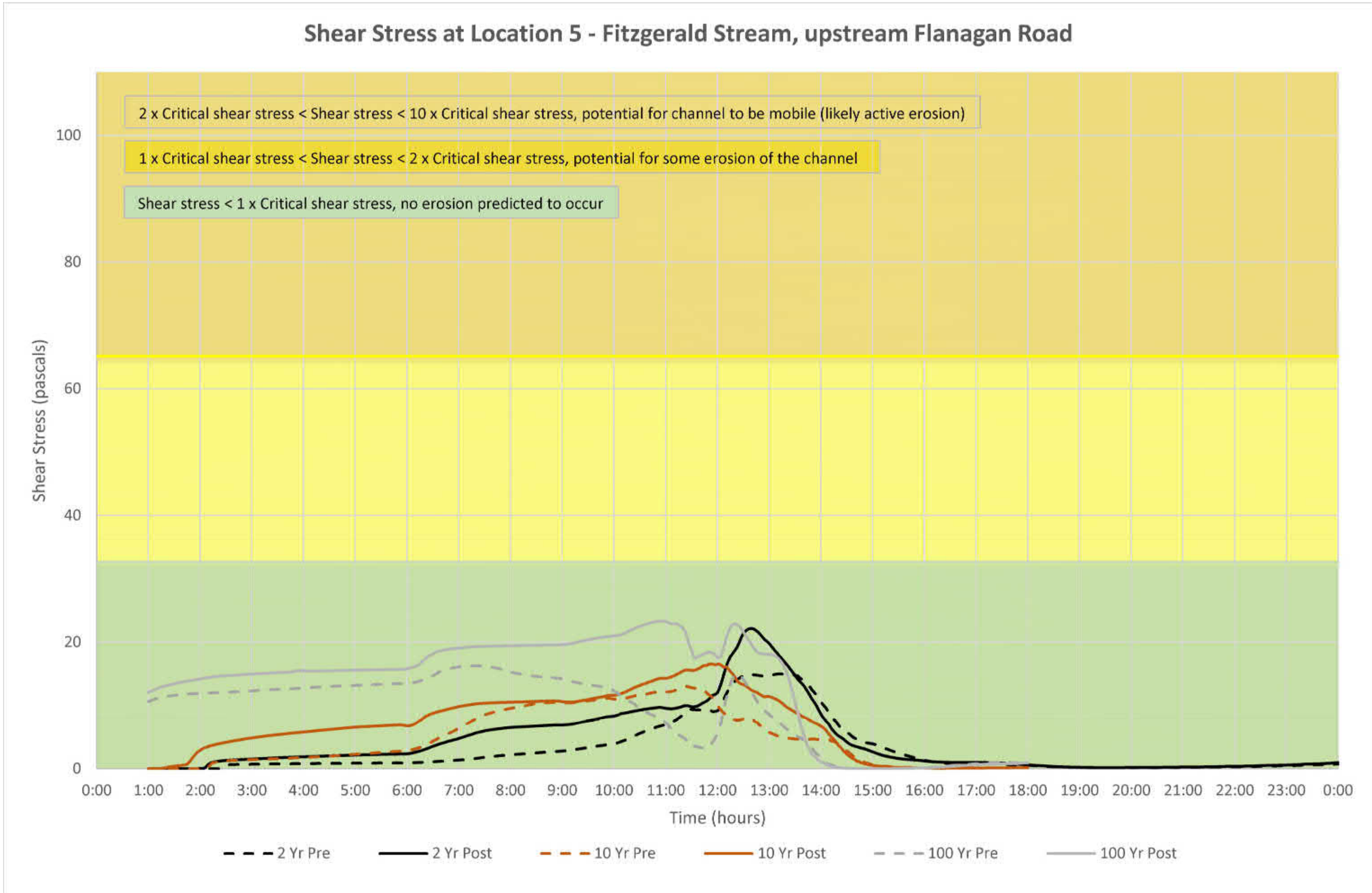
Shear Stress at Location 1 - Hingaia Stream, mid-point Kiwi Plan Change
2 x Critical shear stress < Shear stress < 10 x Critical shear stress, potential for channel to be mobile (likely active erosion)
1 x Critical shear stress < Shear stress < 2 x Critical shear stress, potential for some erosion of the channel
Shear stress < 1 x Critical shear stress, no erosion predicted to occur
Shear Stress (Pa)
0
20
40
60
80
100
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00
Time (hours)
2 Yr Pre
2 Yr Post
10 Yr Pre
10 Yr Post
100 Yr Pre
100 Yr Post

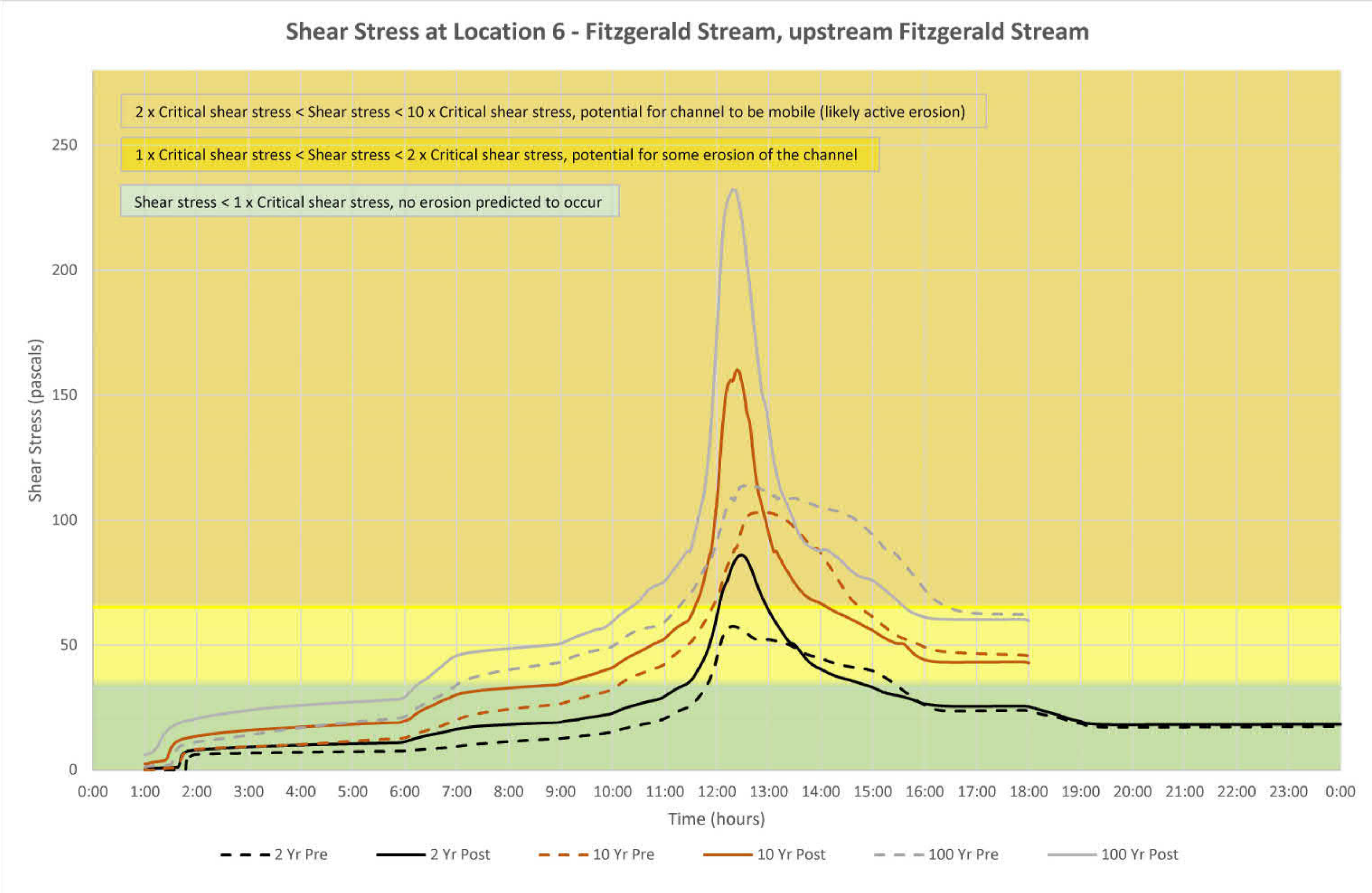

Shear Stress at Location 2 - Hingaia stream, upstream Flanagan Bridge
2 x Critical shear stress < Shear stress < 10 x Critical shear stress, potential for channel to be mobile (likely active erosion)
1 x Critical shear stress < Shear stress < 2 x Critical shear stress, potential for some erosion of the channel
Shear stress < 1 x Critical shear stress, no erosion predicted to occur
Shear Stress (pascals)
0
20
40
60
80
100
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00
Time (hours)
2 Yr Pre
2 Yr Post
10 Yr Pre
10 Yr Post
100 Yr Pre
100 Yr Post


Shear Stress at Location 3 - Hingaia Stream, upstream Norrie Road
2 x Critical shear stress < Shear stress < 10 x Critical shear stress, potential for channel to be mobile (likely active erosion)
1 x Critical shear stress < Shear stress < 2 x Critical shear stress, potential for some erosion of the channel
Shear stress < 1 x Critical shear stress, no erosion predicted to occur
Shear Stress (pascals)
0
20
40
60
80
100
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00
Time (hours)
2 Yr Pre
2 Yr Post
10 Yr Pre
10 Yr Post
100 Yr Pre
100 Yr Post

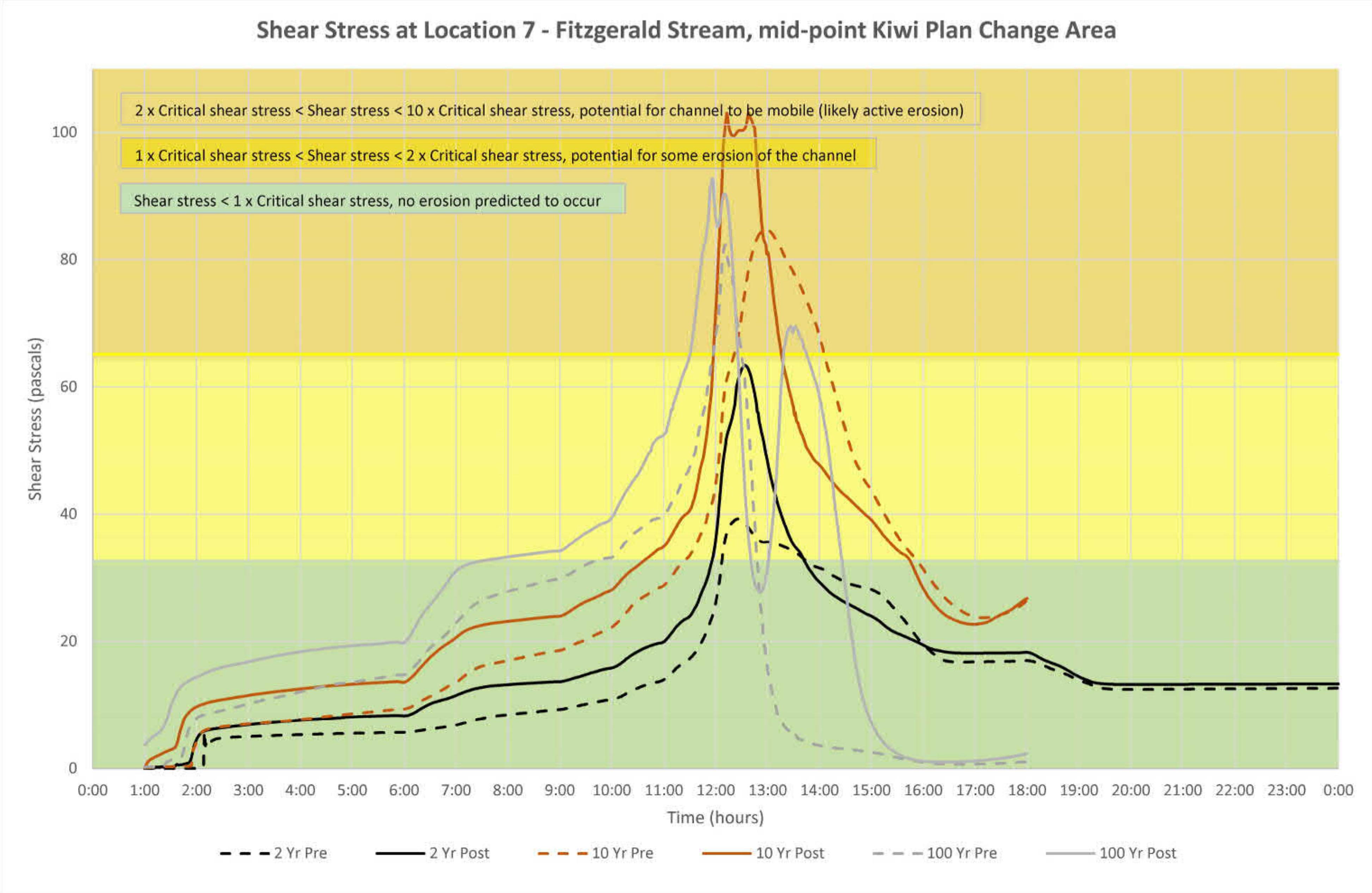


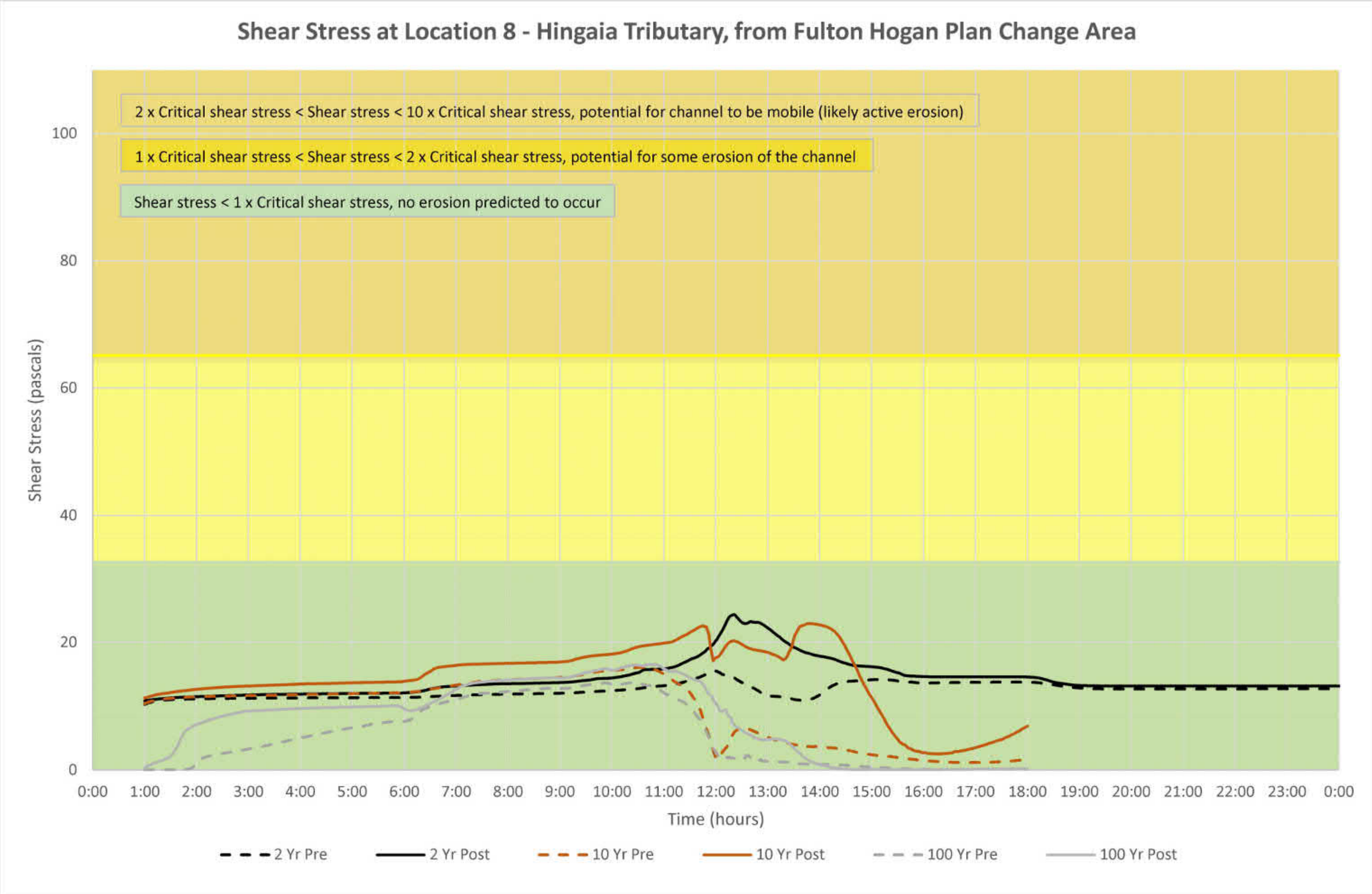
Shear Stress at Location 4 - Hingaia Stream, lower
2 x Critical shear stress < Shear stress < 10 x Critical shear stress, potential for channel to be mobile (likely active erosion)
1 x Critical shear stress < Shear stress < 2 x Critical shear stress, potential for some erosion of the channel
Shear stress < 1 x Critical shear stress, no erosion predicted to occur
Shear Stress (pascals)
0
20
40
60
80
100
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00
Time (hours)
2 Yr Pre
2 Yr Post
10 Yr Pre
10 Yr Post
100 Yr Pre
100 Yr Post


Shear Stress at Location 5 - Fitzgerald Stream, upstream Flanagan Road
2 x Critical shear stress < Shear stress < 10 x Critical shear stress, potential for channel to be mobile (likely active erosion)
1 x Critical shear stress < Shear stress < 2 x Critical shear stress, potential for some erosion of the channel
Shear stress < 1 x Critical shear stress, no erosion predicted to occur
Shear Stress (pascals)
100
80
60
40
20
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00
Time (hours)
2 Yr Pre
2 Yr Post
10 Yr Pre
10 Yr Post
100 Yr Pre
100 Yr Post

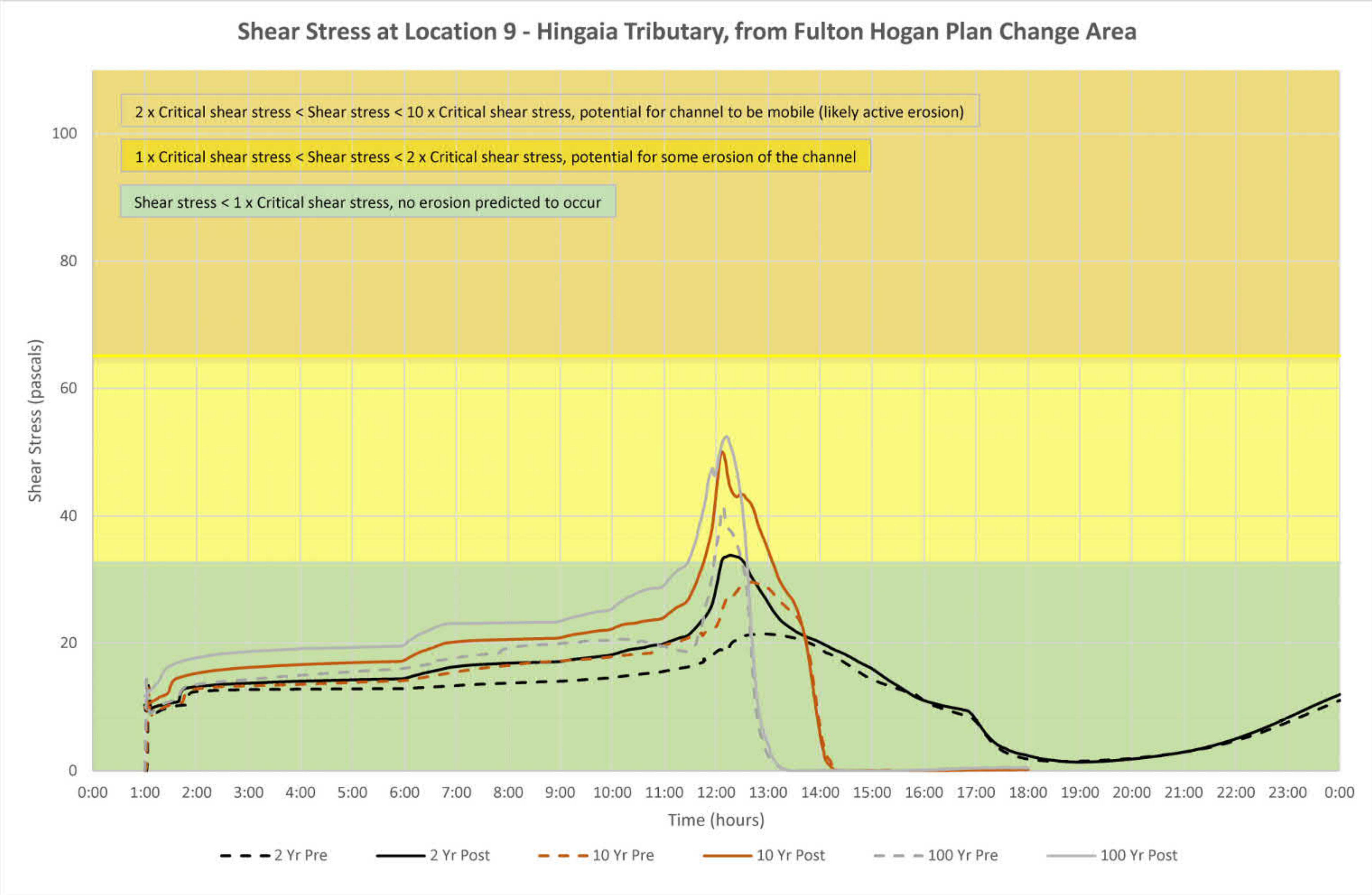


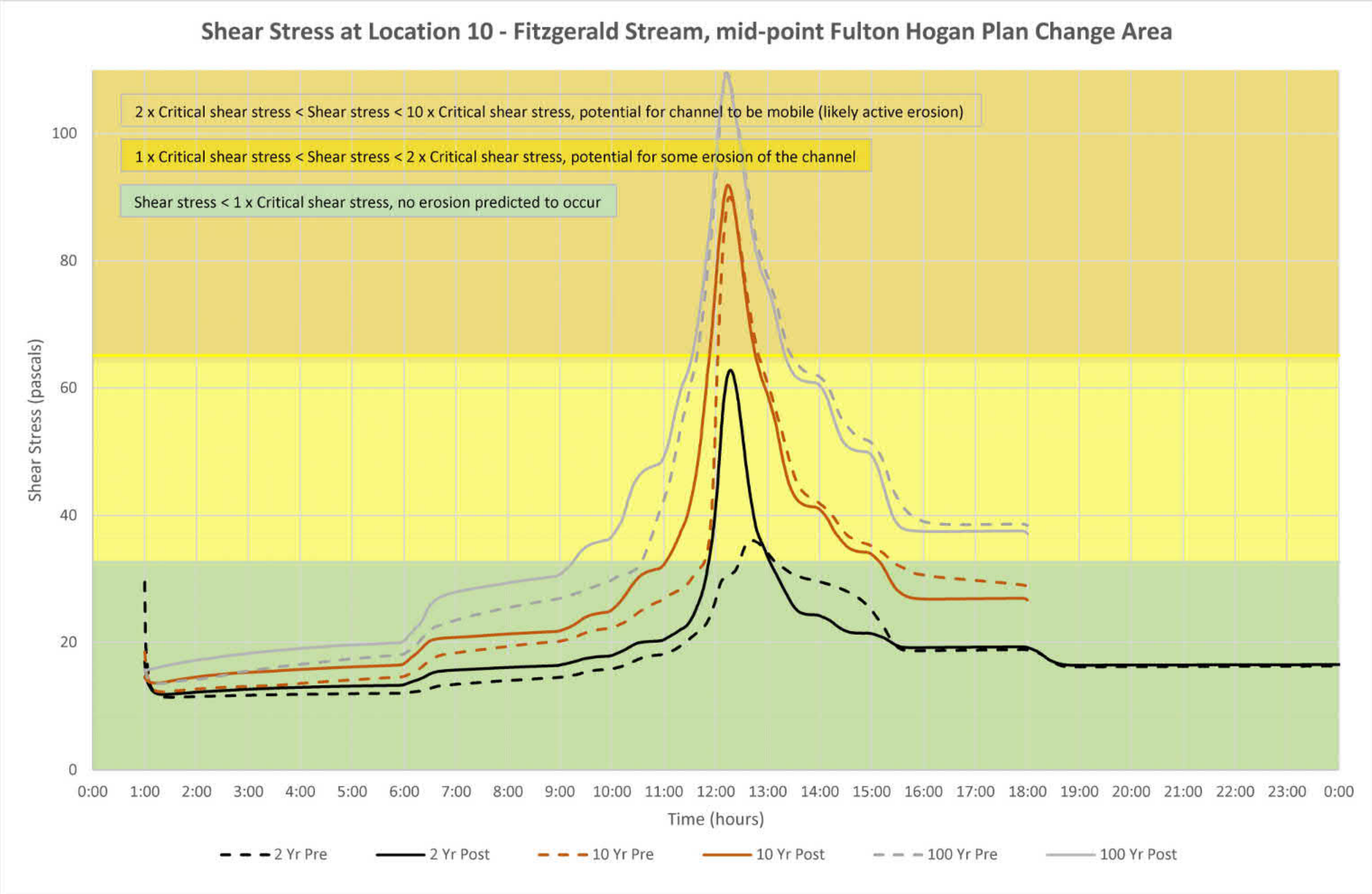
Shear Stress at Location 6 - Fitzgerald Stream, upstream Fitzgerald Stream
2 x Critical shear stress < Shear stress < 10 x Critical shear stress, potential for channel to be mobile (likely active erosion)
1 x Critical shear stress < Shear stress < 2 x Critical shear stress, potential for some erosion of the channel
Shear stress < 1 x Critical shear stress, no erosion predicted to occur
Shear Stress (pascals)
0
50
100
150
200
250
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00
Time (hours)
2 Yr Pre
2 Yr Post
10 Yr Pre
10 Yr Post
100 Yr Pre
100 Yr Post


Shear Stress at Location 7 - Fitzgerald Stream, mid-point Kiwi Plan Change Area
2 x Critical shear stress < Shear stress < 10 x Critical shear stress, potential for channel to be mobile (likely active erosion)
1 x Critical shear stress < Shear stress < 2 x Critical shear stress, potential for some erosion of the channel
Shear stress < 1 x Critical shear stress, no erosion predicted to occur
Shear Stress (pascals)
0
20
40
60
80
100
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00
Time (hours)
2 Yr Pre
2 Yr Post
10 Yr Pre
10 Yr Post
100 Yr Pre
100 Yr Post



Shear Stress at Location 8 - Hingaia Tributary, from Fulton Hogan Plan Change Area
2 x Critical shear stress < Shear stress < 10 x Critical shear stress, potential for channel to be mobile (likely active erosion)
1 x Critical shear stress < Shear stress < 2 x Critical shear stress, potential for some erosion of the channel
Shear stress < 1 x Critical shear stress, no erosion predicted to occur
Shear Stress (pascals)
0
20
40
60
80
100
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00
Time (hours)
2 Yr Pre
2 Yr Post
10 Yr Pre
10 Yr Post
100 Yr Pre
100 Yr Post


Shear Stress at Location 9 - Hingaia Tributary, from Fulton Hogan Plan Change Area
2 x Critical shear stress < Shear stress < 10 x Critical shear stress, potential for channel to be mobile (likely active erosion)
1 x Critical shear stress < Shear stress < 2 x Critical shear stress, potential for some erosion of the channel
Shear stress < 1 x Critical shear stress, no erosion predicted to occur
Shear Stress (pascals)
0
20
40
60
80
100
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00
Time (hours)
2 Yr Pre
2 Yr Post
10 Yr Pre
10 Yr Post
100 Yr Pre
100 Yr Post


Shear Stress at Location 10 - Fitzgerald Stream, mid-point Fulton Hogan Plan Change Area
2 x Critical shear stress < Shear stress < 10 x Critical shear stress, potential for channel to be mobile (likely active erosion)
1 x Critical shear stress < Shear stress < 2 x Critical shear stress, potential for some erosion of the channel
Shear stress < 1 x Critical shear stress, no erosion predicted to occur
Shear Stress (pascals)
0
20
40
60
80
100
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00
Time (hours)
2 Yr Pre
2 Yr Post
10 Yr Pre
10 Yr Post
100 Yr Pre
100 Yr Post