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Technical Memorandum #3A

DATE: April 23, 2021

TO: Robyn Holme, RPP, MCIP
Comox Valley Regional District

FROM: David Zabil, M.A.Sc., P.Eng.
Craig Sutherland, M.A.Sc., P.Eng.

RE: **Coastal Flood Mapping Project**
Technical Memo #3A – Fluvial Modelling – Oyster River Hydrology and Model Assumptions
Our File 2623.014-300

1. Introduction

Kerr Wood Leidal Associates Ltd. (KWL) was retained by the Comox Valley Regional District (CVRD) to provide consulting engineering services for the preparation of coastal floodplain mapping. The coastal floodplain mapping includes the anticipated effects of sea level rise and will be used by the CVRD for land use planning, emergency planning and risk assessment.

This technical memorandum (#3A) documents the hydrologic and hydraulic modelling for the Oyster River. Other technical memoranda will document the remaining project components.

1.1 Project Scope

The main project tasks include:

1. Conducting a mapping workshop to discuss mapping objectives and deliverables.
2. Collection and integration of topographic and bathymetric mapping from a variety of sources including bathymetric data collected in the Oyster River as part of the project scope, bathymetric data in the sea obtained from the Canadian Hydrographic Service and topographic data in upland and intertidal areas obtained from GeoBC and other sources.
3. Hydrologic and hydraulic modelling of the Oyster River downstream of Highway 19 to its mouth at the Strait of Georgia and the lower reaches of the Courtenay River, Puntledge River (downstream of the BC Hydro Powerhouse) and Tsolum River (downstream of the Piercy Road Bridge/North Courtenay Connector). Modelling was conducted for floods having annual exceedance probabilities (AEP) ranging from 10% to 0.2% and included the anticipated effects of climate change. The hydrologic and hydraulic modelling of the Oyster River is the focus of this technical memorandum.
4. Hydraulic modelling of coastal water levels (tide plus storm surge) and wave effects in deep and shallow water to determine wave heights in the surf zone and the maximum elevation of wave run-up for storm events with AEPs ranging from 10% to 0.2% and sea levels ranging from current conditions to a projected scenario with two metres of sea level rise (to Year 2200).
5. A desktop geomorphologic assessment of the Oyster River and shoreline to identify areas that may be non-erodible or exceptionally vulnerable to erosion.

6. Determination of flood levels for the Oyster River, the lower Courtenay/Puntledge/Tsolum River system and coastal areas.
7. Preparation of 1:4000 scale regulatory floodplain maps which show flood levels and floodplain extents and digital mapping for flood levels, setbacks, inundation depths, wave heights and climate change planning areas.

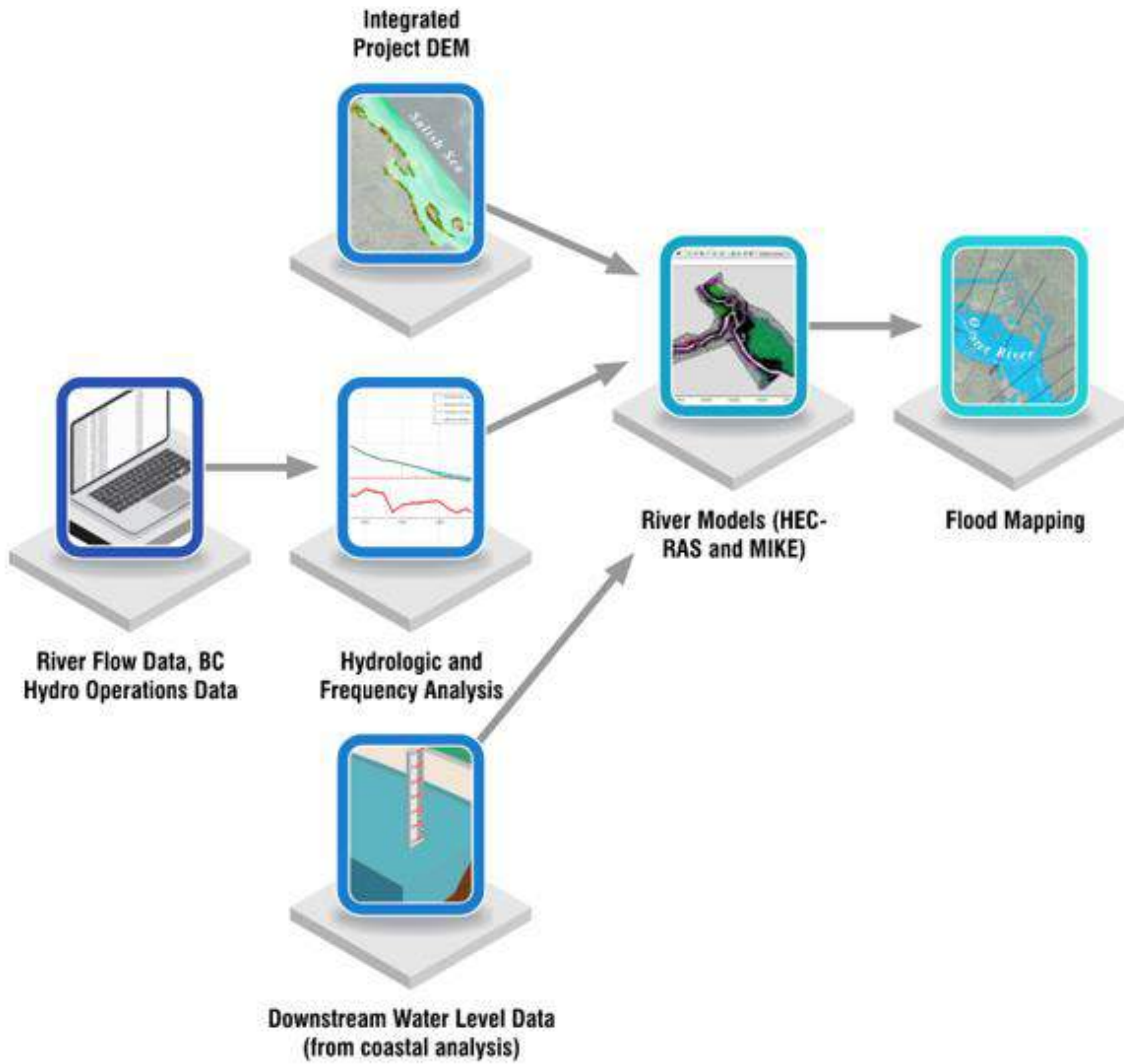
A series of reports and memoranda are provided to describe data sources, analysis approaches, assumptions, and study findings:

1. Technical Memorandum #1 – Coastal and River Base Map Development
2. Technical Memorandum #2 – Fluvial and Coastal Geomorphology
3. Technical Memorandum #3A – Fluvial Modelling – Oyster River Hydrology and Model Assumptions
4. Technical Memorandum #3B – Fluvial Modelling – Courtenay River Hydrology and Model Assumptions
5. Technical Memorandum #4 – Coastal Modelling
6. Technical Memorandum #5 – Coastal and Fluvial Mapping Products
7. Final Report – Coastal Flood Mapping Project
8. Coastal and Fluvial Models User Guide

This is Technical Memorandum #3A, which documents the hydrologic and hydraulic modelling for the Oyster River, including:

1. An introduction including the general scope of the CVRD Flood Hazard Mapping Project, how this technical memorandum fits within the overall project, a glossary/abbreviations, and a list of references.
2. Background including study area location, watershed characteristics and limits of flood hazard mapping.
3. The details of the hydrologic analysis including single station flood frequency analysis and regional flood frequency analysis.
4. A summary of the hydraulic model development including model extents, assumed dike breach location, dike breach parameters, channel and floodplain topography, channel, and floodplain roughness values.
5. Details of the hydraulic model boundary conditions, assumptions, and limitations.
6. A review of the hydraulic model sensitivity analysis and design flow simulation results.

The objective of the hydrologic analysis and hydraulic modelling of the Oyster River was to develop flood water level profiles and flow velocities along the river channel and across the floodplains for each of the selected AEP floods within the study area. These modelled water levels and flow velocities were then used to map floodplain levels, inundation extents, flood depths, flood flow velocities and flood hazard (depth x flow velocity) parameters. A diagram of the workflow for river modelling is shown in Figure 1.



Project No.	2623.014
Date	April 2021
Scale	N/A

River Modelling Work-Flow Diagram

Figure 1

1.2 Glossary and Abbreviations

AEP	=	Annual Exceedance Probability. Probability of an event (e.g., flood event) of equal or greater magnitude occurring in a given year. The AEP is the inverse of the Return Period.
CDM	=	Cumulative Departure from Mean. Statistical approach carried out to assess long term trends or cycles in historical climate or hydrometric data which involves carrying out cumulative sum of the difference between annual maximum data and the long-term average.
DEM	=	Digital Elevation Model. A generic term for a map that represents the topographic elevation of the earth's surface. A DEM can be represented as a raster (a grid of squares, also known as a heightmap when representing elevation) or as a vector-based triangular irregular network (TIN).
Design Flood	=	The magnitude of river discharge/ocean water levels having a specified AEP or Return Period selected to define flood levels and flood limits for regulatory floodplain mapping.
El Niño	=	El Niño is a periodic ocean circulation phenomenon that results in atypically warm surface water in the equatorial central and east-central Pacific Ocean. El Niño events can last for several years. The warm surface water results in changes to atmospheric circulation patterns (weather) and ocean water levels throughout the Pacific Ocean, and to a lesser extent, the entire globe.
Flood Hazard Maps	=	Engineering maps that display the results of hydrologic and hydraulic investigations (including water level, water depth, and velocity) and show areas that could be flooded under different scenarios. These maps are used for planning purposes related to land use planning, emergency management, and flood mitigation. Note that this is the working definition for this project and other projects, or organizations may have a different definition.
Flood Level	=	The maximum elevation of the water surface in a given flood scenario including freeboard.
Freeboard	=	A vertical distance added to the actual calculated flood level to accommodate uncertainties in flood levels. Such uncertainties include uncertainties in hydrological analysis, hydraulic modelling, and wave modelling, climate change projections, local river hydraulic effects such as waves and surges, and, to some extent, river, delta, and coastal geomorphic changes which could influence flood levels. The freeboard allowance does not accommodate uncertainties in flood levels related to significant changes in river channel shape/location or shoreline characteristics.
Maximum Water Level	=	The calculated maximum water surface elevations for the specific design flood magnitudes derived using hydraulic modelling software.
MAF	=	Mean Annual Flood. The average of all yearly flow maxima (found to be approximately 43% AEP or a recurrence of 2.33 years).

Pacific Decadal Oscillation	=	A recurring pattern of sea surface temperature variability centered over the mid-latitude Pacific basin similar to El Niño but with a longer duration (decades rather than years).
Regulatory Floodplain Mapping	=	Maps used for regulatory purposes, such as developing floodplain bylaws and informing official community plans. For the Coastal Flood Mapping Project, the regulatory mapping is based on inundation mapping for a 0.5% AEP storm incremented by a freeboard allowance to establish the Flood Level and floodplain limits.
Return Period	=	An estimate of the average interval of time between events of a certain intensity or size. The inverse of the Annual Exceedance Probability.
SRD	=	Strathcona Regional District.
Storm Surge	=	Increase in water level caused by low atmospheric pressure and winds.
Water Level	=	The calculated peak water surface elevations for a given AEP flood magnitude derived using hydraulic modelling software.

1.3 Flood Hazard Analysis Guidelines

The development of methodologies for hydrological analysis and hydraulic modelling on the Oyster River have been in accordance with professional best practices and most recent flood hazard analysis guidelines (EGBC, 2018; EGBC, 2017; FLNR, 2018 & Natural Resources Canada, 2019).

1.4 References

The following references were used for the preparation of this memorandum:

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2. Australian Institute of Disaster Resilience (AIDR). (2017). *Australian Disaster Resilience Guideline 7-3 Flood Hazard.*
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7. Coulson, C. H. and Obedkoff, W. (1998). *British Columbia Streamflow Inventory.* March 1998. Water Inventory Section, Resources Inventory Branch, Ministry of Environment Lands and Parks, Province of British Columbia.
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20. Pacific Climate Impacts Consortium. (2011). *Hydrologic Impacts of Climate Change in the Peace, Campbell and Columbia Watersheds, British Columbia, Canada*.
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2. Oyster River Watershed and Study Area

The Oyster River is located on the eastern side of Vancouver Island, British Columbia. The watershed has a total area of 362 km^2 and extends from headwaters near the top of the Forbidden Plateau to the river mouth at the Strait of Georgia. Most of the watershed is within the Comox Valley Regional District with some of the northern parts of the watershed laying within the Strathcona Regional District. Table 1 summarizes the watershed characteristics at three key locations along the Oyster River.

Table 1: Oyster River Watershed Characteristics

Watershed	Area (km^2)	Mean Elevation (m)	Hydrologic Zone
Oyster River Below Woodhus Creek (08HD011) Hydrometric Station	298	915	Eastern Vancouver Island
Oyster River above Little Oyster River	314	889	
Oyster River at the Mouth	362	777	

The upstream reaches of the watershed drain the eastward slopes of the Vancouver Island mountains. The highest point in the watershed, located at Mount Albert Edward, has an elevation of 2,093 m. The middle reaches of the river flow across the coastal lowlands of the east coast of Vancouver Island before flowing into the Strait of Georgia near the communities of Saratoga Beach and Oyster River. The upstream reaches of the watershed are located within Strathcona Provincial Park. The majority of the remaining watershed is located within privately owned forest lands with some agricultural and rural residential development located along the lower reaches.

The limits of the floodplain mapping extend along the mainstem of the Oyster River from the mouth at the Strait of Georgia north of Saratoga Beach to the Inland Island Highway (Highway 19) bridge crossing about 17 km upstream of the mouth. One of the largest tributaries, the Little Oyster River, flows into the Oyster River within the floodplain mapping study limits about 7.5 km upstream of the mouth. The watershed boundary and the limits of the flood mapping study area are shown in Figure 2.

3. Inflow and Water Level Boundary Conditions

Hydrologic analysis to estimate the magnitude and timing of flood discharges as well as the timing and magnitude of the design downstream coastal water level boundary condition for each AEP flood is described in this section.

3.1 Meteorological Drivers of Floods on Vancouver Island

Floods on the Oyster River are most often the result of high-intensity frontal rainfall storms that carry moisture from the Pacific Ocean eastward and across Vancouver Island. These storms often originate over tropical waters in the Pacific Ocean and are know as atmospheric river events or locally as a “Pineapple Express”. The orographic effect caused by the lifting of the warm moist air mass as it passes over the Vancouver Island Mountain Range increases the intensity of rainfall. This can often result in significant precipitation (>100 mm in 24 hrs) in the higher elevation portions near the western boundaries of the watersheds. However, the precipitation intensity reduces as storms travel eastward across the lowlands along the east coast of Vancouver Island and into the “rain shadow” of the Vancouver Island Mountain Range. The total annual rainfall in the Vancouver Island Mountains is about three times greater than the rainfall recorded along the lowlands along the east coast, including in the Oyster area.

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Comox Valley Regional District

Coastal Flood Mapping Project

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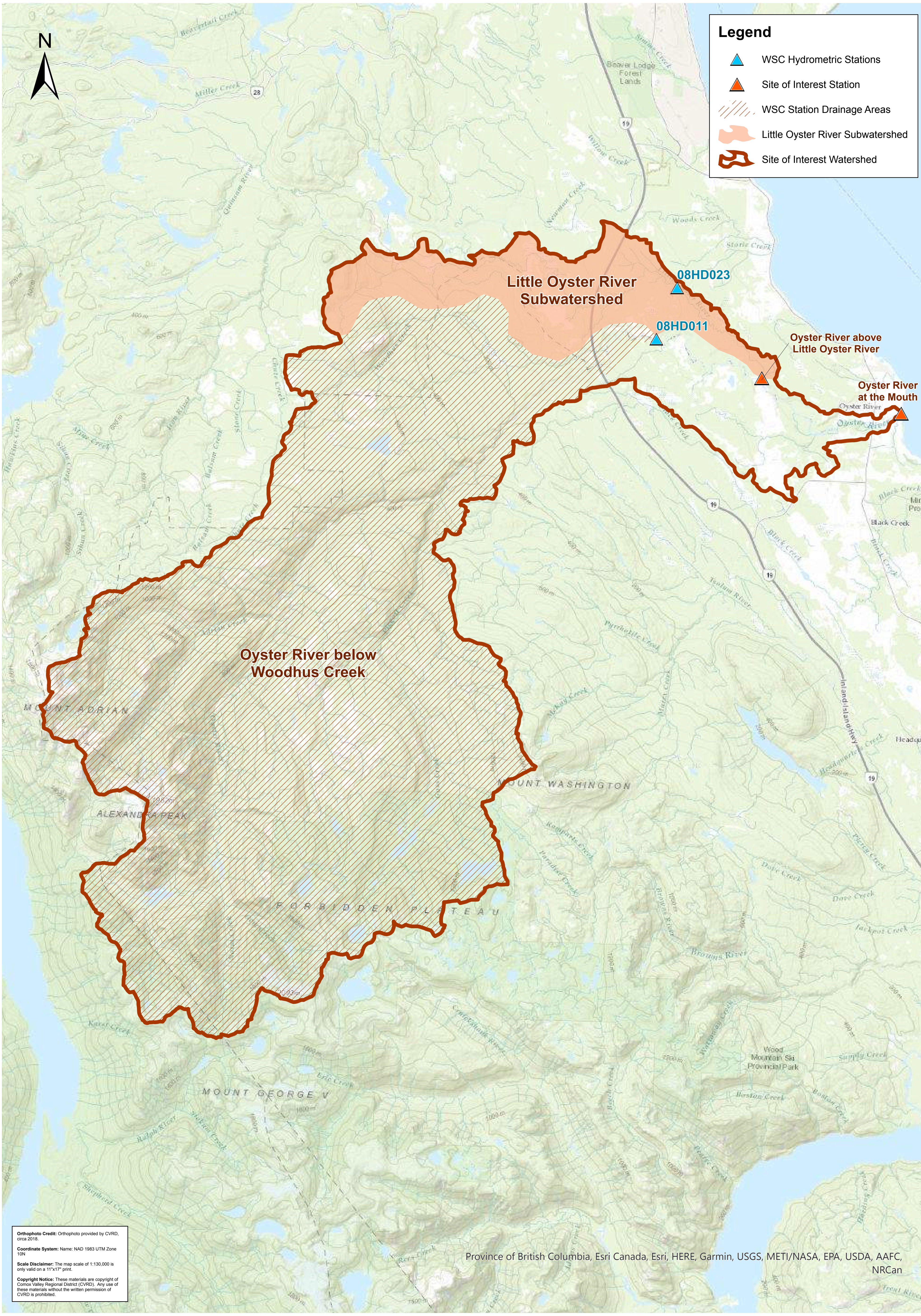


Project No.	2623-014
Date	April 2021
Scale	1:130,000

0 1,000 2,000 Metres

Oyster River Watershed

Figure 2

The largest floods on Vancouver Island rivers often occur in late fall or early winter (November to February) as a result of a period of cool weather with snow accumulation across the watersheds followed by an atmospheric river event. This combination of snow accumulation on the ground with warm air and wet conditions can result in both heavy rainfall as well as significant snowmelt resulting in extreme flows in rivers across Vancouver Island. Given the large spatial extent of atmospheric river events, which can be up to 200 km wide or more, they can often result in flood conditions across many Vancouver Island watersheds at the same time. Therefore, often the Oyster River can experience extreme flood conditions simultaneously with other rivers across the CVRD.

In addition to high flood flows in the rivers, high winter tide conditions combined with storm surge can often increase flood levels in the lower reaches of the rivers near the Strait of Georgia. Given that most community development within the watersheds is located near the river mouth, such as the community of Oyster River, this combination of river flood and tide level flood result in significant flood risk to these communities.

As flood levels increase due to the projected impacts of climate change on increased rainfall intensity and sea-level rise, the flood risk to communities near the mouth of the Oyster River will continue to increase into the future.

3.2 Historical Floods

High flow conditions combined with high tides have resulted in the flooding of communities along the Oyster River. These floods have prompted the construction of erosion protection at several locations along the length of the Oyster River as well as the construction of a dike to protect residential areas near Glenmore Road from flooding. The following section provides a summary of past flooding events that have occurred based on a review of previous flood assessment reports.

Recent known flood events along the Oyster River are outlined in Table 2 (BC Ministry of Environment, 2006; Ebbwater, 2018) for high flow events. The largest high sea level events occurred on December 5, 1967 and on December 16,1982 when the sea level reached 2.88 m (CGVD2013) in both events.

Table 2: History of the Oyster River High Flow Events

Date	Peak Inst. Flow[1]	Notes
November 14 – 20, 1939	Not recorded	Oyster River changed course with new channels across the highway. One channel was reported to be 2.1 m deep and 30 m wide.
November 28 – December 2, 1941	Not recorded	South abutment and approach to Highway Bridge washed out.
November 13, 1975	348	Bank erosion along the river channel. Approximately 150 cubic yards of riprap hauled to the site.
December 26, 1980	289	Flooding along the Oyster River.
November 23, 1990	284	Flooding along the Oyster River.
November 16, 2009	375	The south end of Lorna Lane eroded. Glenmore Dike Breach.
January 12, 2010	312	Localized flooding to residents along Glenmore Road and Wimbledon Road due to the high groundwater table.
November 27, 2011	278	Localized flooding to residents along Glenmore Road and Wimbledon Road due to the high groundwater table.
December 9, 2014	409 [2]	Property damage as a result of flooding.

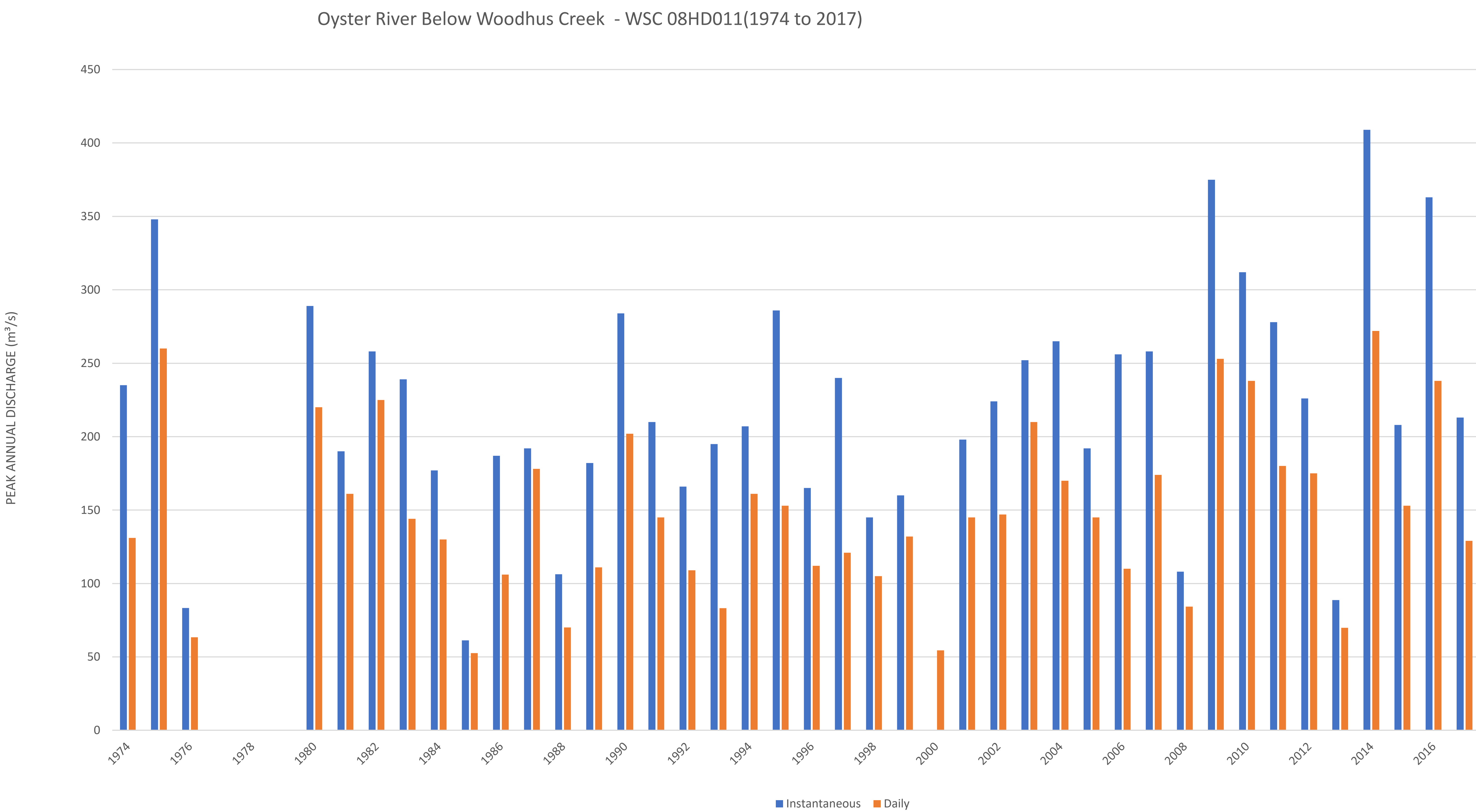
Notes:
1. From published Peak Instantaneous Flow records for the Oyster River below Woodhus Creek (08HD011) for the period from 1973 to 2017.
2. Largest flood on record since 1975. Peak flow as estimated by the Water Survey of Canada.

3.3 Flood Frequency Analysis

Water Survey of Canada (WSC) has been operating a hydrometric station on the Oyster River since 1973. Statistical flood frequency analysis was performed using historical river discharge records to estimate peak flood flows. A regional flood frequency analysis using flood records from nearby watersheds with hydrometric stations was carried out for comparison with the single-station analysis.

Single Station Flood Frequency Analysis

The Oyster River Below Woodhus Creek (08HD011) gauge, located approximately 12 km upstream from the river mouth, has been active since 1973 and has published data available until 2017 when hydrological analysis was carried out and provides a nearly continuous record with five years of missing daily peak flow data (1973, 1977-1979, and 2000) and seven years of missing instantaneous peak flow data (1973, 1977-1979, 1988, 1992, and 2000). The largest flood on record occurred on December 9, 2014, which resulted in some property damage near the river. The largest peak daily average flow and peak instantaneous flow on December 9, 2014 was estimated by WSC to be 272 m^3/s and 409 m^3/s, respectively. The maximum water level at the gauge was 2.96 m above the staff gauge datum, approximately 2 m above normal baseflow levels. A plot showing the record of the daily peak flows and instantaneous peak flows is included in Figure 3.



Project No.	2623.014
Date	April 2021
Scale	N/A

Oyster River Below Woodhus Creek Recorded Annual Peak Flows

Figure 3

A flood frequency analysis was carried out using a combination of the 38 years of recorded peak instantaneous flows from the Oyster River Below Woodhus Creek (08HD011) gauge plus two estimated instantaneous peak flows for 1988 and 1992 when daily peak flow records are available but without instantaneous peak flow record. The missing instantaneous peak flow records were obtained by multiplying the recorded daily peak flow by the average instantaneous to daily (I:D) peak flow ratio of 1.52 calculated from the entire period of record. The HYFRAN software was chosen to perform the FFA using the average of three statistical distributions:

1. Generalized Extreme Value (GEV): fitted by Method of Weighted Moments method.
2. Three Parameter Lognormal (3PLN): fitted by Maximum Likelihood method.
3. Log Pearson III (LP3): fitted by the US Water Resources Council method.

The results of the FFA analysis are included in Appendix A for reference.

Based on visual observations of the FFA result plots provided by HYFRAN, all distributions were proven to provide an acceptable fit based on the WSC 08HD011 peak instantaneous flow data (see Appendix A). Therefore, an average of the results for the three statistical distributions was used to derive the estimated peak flows for the AEP floods.

The instantaneous AEP peak flows estimated at WSC 08HD011 were scaled up to estimate the flows used as boundary conditions for hydraulic modelling. To account for the increased contribution of flow from the Little Oyster River in the downstream reaches of the flood mapping study area, two sites of interest were selected for deriving flows used in hydraulic modelling:

1. The Oyster River Below Woodhus Creek (08HD011) gauge, representing flows upstream of the confluence of the Little Oyster River.
2. The Oyster River at the Mouth, representing flows downstream of the confluence of the Little Oyster River.

Table 1 provides the watershed areas upstream of the Oyster River Below Woodhus Creek hydrometric station and the Oyster River at the Mouth, both of which were used for hydraulic modelling.

The following relationship estimated in 1998 (Coulson & Obedkoff, 1998) based on peak flow data across BC was applied to scale peak flows based on the two watershed areas within the Oyster River:

$$Q_{\text{site of interest}} = Q_{\text{08HD011}} * (\text{Area}_{\text{site of interest}} / \text{Area}_{\text{08HD011}})^{0.785}$$

Table 3 provides the peak flow estimates at the two locations: the Oyster River Below Woodhus Creek (08HB011) Hydrometric Station, and the Oyster River at the Mouth.

Table 3: Estimated Peak Instantaneous Flood Discharges using Historical Records (1973 to 2017)[1]

River Location	10% AEP (m^3/s)	5% AEP (m^3/s)	1% AEP (m^3/s)	0.5% AEP (m^3/s)	0.2% AEP (m^3/s)
Oyster River Below Woodhus Creek (08HB011) Hydrometric Station	324	354	406	424	444
Oyster River at the Mouth	377	412	472	493	517

Note:
1. Peak Instantaneous Flood Discharges shown above are based on historical records and are considered suitable for current climate conditions. These peak flow estimates do not include an allowance for projected climate change impacts.

The flood frequency analysis used to establish the magnitude of flood discharges assumes that data used in the analysis is stationary and does not have long-term increasing or decreasing trends. Climate change has and will continue to result in long term changes in the magnitude of peak flows. Therefore, the magnitude of estimated flood discharges using historical flood records does not account for non-stationarity of historical peak flood flows as well as projected future changes in peak flows as a result of climate change. To better understand the potential impacts of non-stationarity, a review of historical trends in flood magnitudes and a review of regional climate change projections have been used to select appropriate factors to increase estimated flood magnitudes to account for projected changes (see Section 3.4 for additional detail).

Regional Flood Frequency Analysis

Regional flood frequency analysis is often used to estimate flood discharge magnitudes for ungauged streams. Regional flood frequency analysis involves relating recorded flood statistics with characteristics (area, elevation, etc.) of the watersheds upstream of regional hydrometric stations to predict flood statistics for ungauged watersheds. However, for the Oyster River, a regional flood frequency analysis using flood records from nearby watersheds with hydrometric stations was carried out for comparison with the single-station analysis. The mean annual flood (MAF) versus drainage area for regional hydrometric stations are shown in Figure 4.

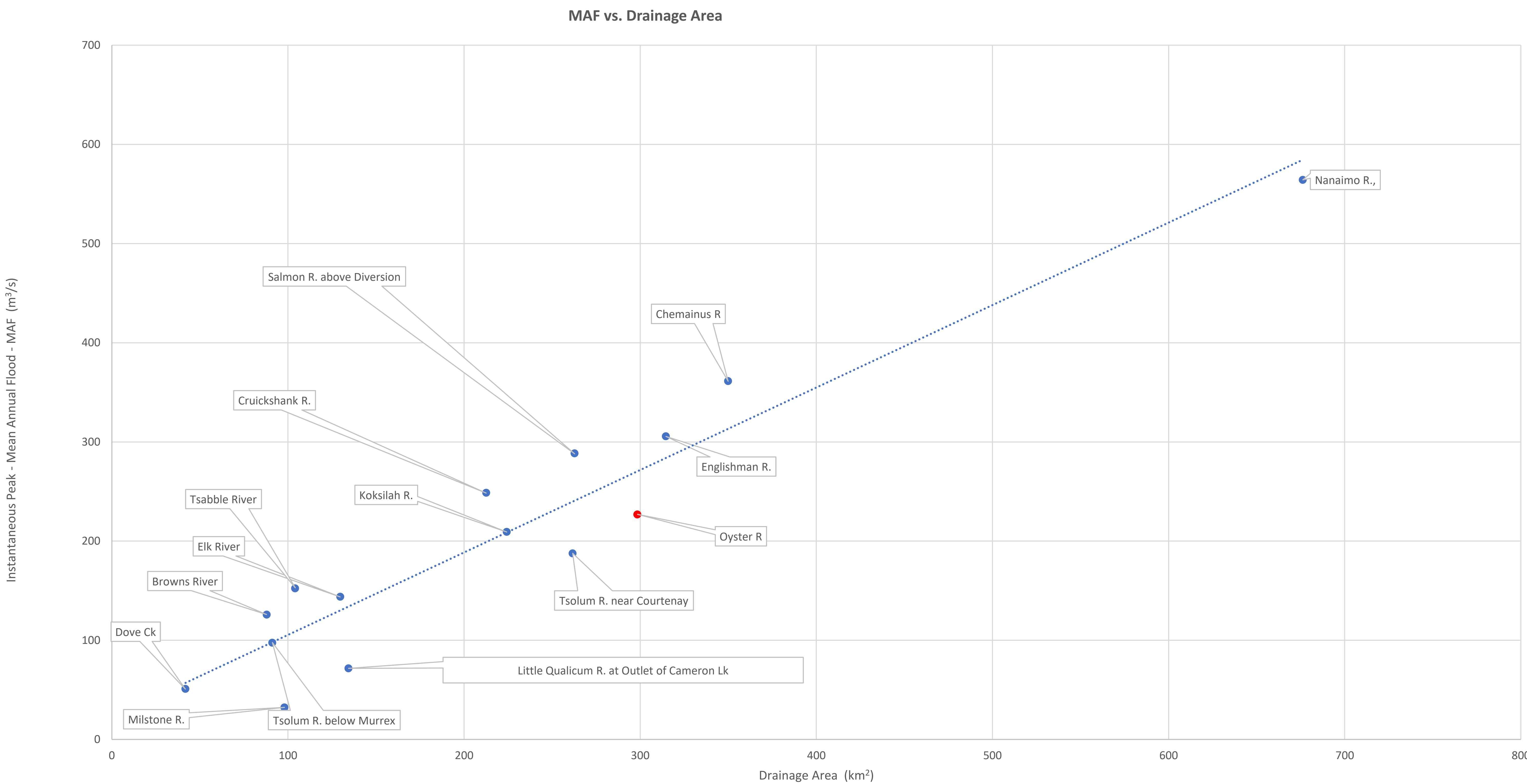
The results indicate that the MAF estimated using regional flood frequency analysis is approximately 23% higher than the single station analysis. As the flood estimates developed using regional flood frequency analysis represent the average flood response of watersheds in the region, the comparison of the regional analysis results with the single station results indicates that the magnitudes of the Oyster River flood are generally lower than those recorded on other streams in the region, likely due to watershed characteristics.

The Oyster River Below Woodhus Creek (08HD011) gauge is located within the study area and has a sufficiently long period of record to represent the range of historical flood response. Therefore, the results of the single station analysis are considered to be more representative of the Oyster River flood response and have therefore been adopted for this study.

Previous Oyster River Flood Flow Estimates

In 2017, Oyster River peak flows were estimated by McElhanney (2018) as part of the work done for the construction of the Glenmore Dike located about 10 km downstream of Station 08HD011. In 2018, peak flows of the Oyster River were estimated by Ebbwater (2018) for the Oyster River/Saratoga Beach Flood Assessment.

Table 4 provides a comparison between previous and current peak flow estimates for two key locations in the Oyster River.



Project No.	2623.014
Date	April 2021
Scale	N/A

Mean Annual Flood vs. Drainage Area – Regional Analysis

Figure 4

Table 4: Comparison of Peak Flow Estimates

River Location	0.5% AEP Peak Instantaneous Flow[1] (m^3/s)		
	2018 McElhanney	2018 Ebbwater	2020 KWL
Oyster River Below Woodhus Creek	430	N/A	424
Oyster River at the Mouth	N/A	484	493

Notes:
1. Flood frequency analysis results based on historical flow records and does not account for the projected impacts of climate change.

Based on the comparison with the previous flood estimates, the flood estimates provided in Table 3 are considered to be suitable for floodplain mapping and flood hazard assessment for current climate conditions.

3.4 Climate Change

The Federal Floodplain Mapping Guidelines (Natural Resources Canada, 2019) recognize that future climate patterns are projected to differ significantly from the historical record and therefore suggest that:

> *"..assessments of flood risks to property and human life or safety would benefit from considering the impacts of future flooding conditions under a changing climate both in coastal and inland situations".*

In addition, the 2018 Engineers and Geoscientists BC (EGBC) position paper on climate change indicates that engineers are expected to consider impacts of climate change in their professional practice (EGBC, 2018).

Therefore, the impacts of climate change in the Comox Valley region, including changes in temperature and precipitation, on peak flows as well as sea-level rise have been incorporated into the flood analysis similar.

As stated in the Case Studies on Climate Change in Floodplain Mapping (Natural Resources Canada, 2018), no broadly recognized standard methodology or approach has been established for incorporating climate change into flood projections. Therefore, several approaches have been reviewed to select a "climate change scaling factor" to consider climate change impacts on flood peaks. The following sections summarize the review of these approaches and the selected climate change scaling factor.

Climate Change Projection Guidelines

The EGBC Flood Mapping in BC professional practice guidelines recommend that climate change be considered in producing flood mapping in BC (EGBC, 2017). The EGBC Legislated Flood Assessment in a Changing Climate in BC professional practice guidelines (EGBC, 2018) recommend that in the absence of more detailed information, an additional 10% to 20% should be included on the peak flow estimates based on historical records. The guidelines recommend that the lower end of the range should be applied for watersheds where there is no significant trend in the historical data while the upper end of the range should be applied for watersheds showing statistically significant increasing trends in annual peak discharges.

Trends in Historical Data

As discussed in the previous section, EGBC in their Legislated Flood Assessment in a Changing Climate in BC professional practice guidelines (EGBC, 2018) has recommended that trends in historical peak flows be one way of projecting the magnitude of future changes in peak flows. Therefore, KWL performed a trend analysis on the maximum daily flow series for several of the regional stations on Vancouver Island using the statistical Mann-Kendall test. The trend analysis was carried out on the full period of record for each station to incorporate the cyclical El Niño – Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) climate patterns in the analysis. The results are summarized in Table 5. A copy of the details of the trend analysis for each of the stations is included in Appendix B.

Table 5: Trends in Vancouver Island Regional Recorded Flood Flows

Watershed	WSC Number	Period	Trend	Statistically Significant	Average % Change Per Decade (Sen's Slope)
Oyster River	08HD011	1974-2017	Upward	No	5%
Tsolum River	08HB011	1964-2018	Upward	Yes	11%
Browns River	08HB025	1960-2018	Downward	No	-5%
Englishman River	08HB002	1979-2018	Downward	No	-7%
Chemainus River	08HA001	1953-2018	Upward	No	4%
Salmon River above Diversion	08HB015	1981-2017	Upward	Yes	15%

The results indicate both upward and downward trends in recorded peak flows for the Vancouver Island region. This variation in trends is likely the result of natural variation, differences in forest harvesting in the watersheds, the varying lengths of the available records as they relate to cyclical climate patterns such as ENSO and PDO well as long term climate change impacts. This highlights some of the difficulty in using historical records to project potential climate change impacts on peak flows.

To better understand the influence of cyclical patterns on historical flood flows, a statistical analysis of flood records using Cumulative Departure from the Mean (CDM) was carried out. CDM is a concept sometimes used to understand trends or cycles in precipitation or flow. The analysis involves taking cumulative sum of the difference between the annual maximum precipitation or flow and the long-term average for each year in the record as follows:

CDMi = $\sum(F_i - F_{avg})$

Where

F_i = Annual Maximum Flow
F_{avg} = Long-term average of Annual Maximum Flow

An increasing trend in CDM indicates a period of above average conditions, a decreasing trend in CDM indicates a period of below average conditions and no trend in CDM indicates period of average conditions.

The analysis was carried out using annual maximum flow records for the Oyster River above Woodhus Creek (08HD011) over the period of record from 1974 to 2017. The analysis indicated that in general both precipitation and flood flows show a cyclical pattern which roughly corresponds with the phase of the Pacific Decadal Oscillation (PDO), see Figure 5. Before the 1990s, a period having generally warm PDO phase, flood flows were about average, during the 1990s and early 2000s, during period with warm and cool PDO phases, flood flows were about average and since about 2005 the PDO has transitioned to generally cool phase, the flood flows have been above average in general.

These findings are similar to the results of the flood hydrology analysis carried out for the neighbouring Tsolum River watershed (NHC, 2010) and indicate general trend across the East Coast of Vancouver Island that flood flows are generally higher during cool Phase of PDO and lower during warm phase of PDO.

Modelled Climate Change Projections

Climate projections from the Pacific Climate Impacts Consortium (PCIC) at the University of Victoria indicate that for the Comox Valley Regional District, the intensity of extreme precipitation is projected to increase over the next 100 years. Based on the median value of downscaled output from twelve global circulation models, the maximum daily 2% AEP (50-year return period) precipitation is projected to increase by approximately 18% by mid-century and by 30% by the end of the century (Pacific Climate Impacts Consortium, 2020, March).

Changes in precipitation are a significant driver of projected changes in the magnitude of peak floods. However, this does not take into account the impact that changes in snowmelt at high elevations have on peak flow. PCIC has carried out hydrological analysis using projected climate data to model the effect on stream flows in three watersheds in British Columbia (PCIC, 2011). The results of the hydrological modelling for the Campbell River watershed, the nearest available projected hydrological model data, indicates MAF discharge in the Campbell River watershed is projected to increase by +30% by end of the century (PCIC, 2020, April).

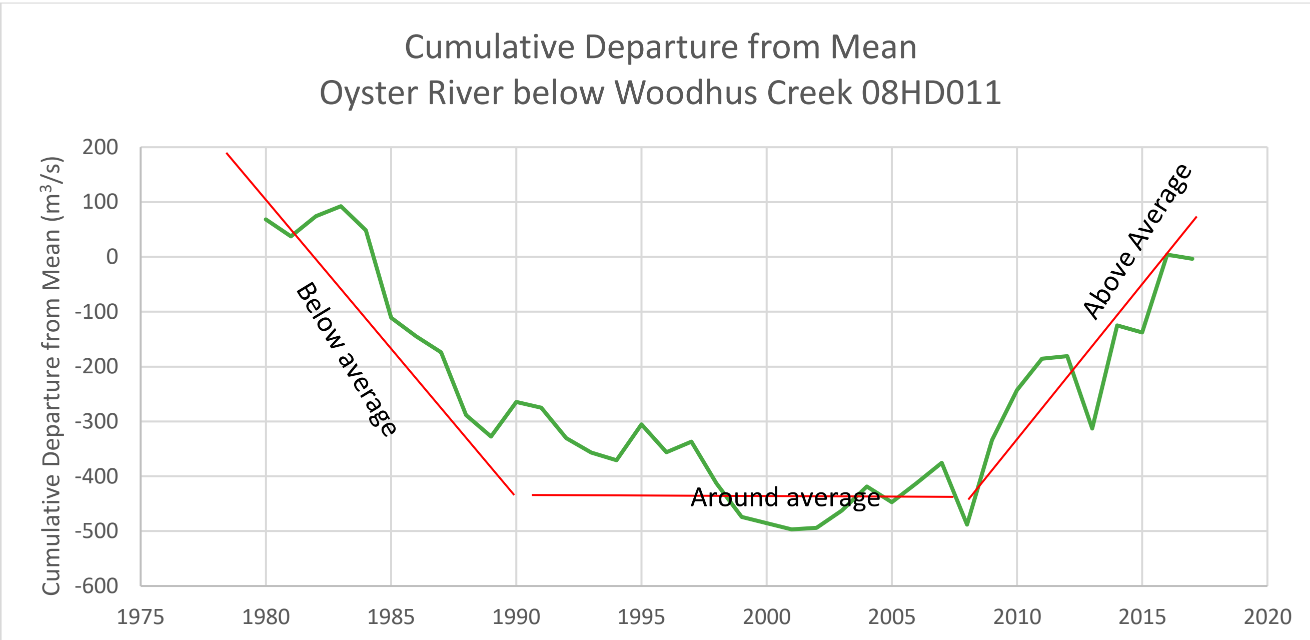
Climate Change Allowance

As outlined in Table 6 and discussed above, several ranges of incremental increase in peak flow have been considered to account for projected climate change impacts on peak AEP floods.

Table 6: Summary of Projected Climate Change Impacts to Peak Flows

Source/Approach	Projected change in peak flood flow over next 100 years		Reference
	Low Bound/Mid-Century	Upper Bound/End of Century	
EGBC Guidelines	10%	20%	EGBC, 2017
Projected Change in 2% AEP precip.	18%	30%	PCIC, 2020
Campbell River Projected Change in MAF		30%	PCIC, 2011
Selected incremental change in peak flows	**15%**	**30%**	

Based on the trend analysis and review of available background information, a factor of +15% was applied to the peak design flood discharge based on historical records to account for projected climate change impacts on peak floods to mid-century (nominally the year 2050) and end of the century (nominally the year 2100). A factor of +30% was applied to the peak design flood discharge based on historical records to account for projected climate change impacts on peak floods for the next century (nominally the year 2200).



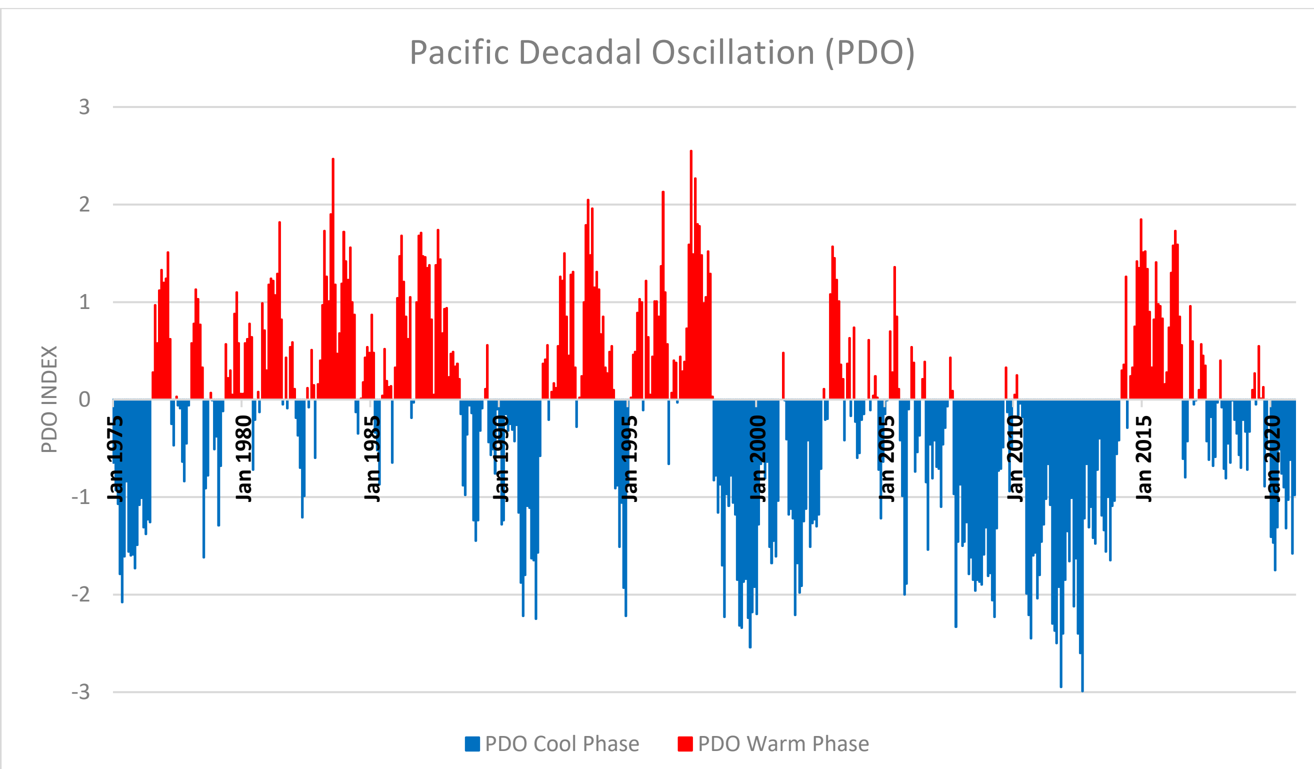


Figure 5: Cyclical Nature of Floods

Limitations and Uncertainty of Climate Change Projections

There is a consensus about the direction of future average climatic conditions globally and at a regional scale. However, when projecting future changes to extreme weather events and changes to peak river discharges in large, complex watersheds, there are significant uncertainties in the projection of changes in extreme climate events.

Many extreme events, especially those associated with precipitation, occur at small temporal and spatial scales, where current climate modelling skill is limited. Therefore, projections of future changes in extreme events can not be made with a high level of confidence (Intergovernmental Panel on Climate Change, 2012). These uncertainties in future changes in extreme precipitation combined with inherent uncertainties in hydrologic modelling[1], result in significant uncertainty in projections in future projections in flood magnitude.

An analysis based on a vast body of literature including the Intergovernmental Panel on Climate Change (IPCC) SREX3 report on climate extremes (Kundzewicz et al., 2013) concluded *“presently we have only low confidence in numerical projections of changes in flood magnitude or frequency resulting from climate change”*.

Therefore, the projected climate change scenarios used in the study do not represent accurate predictions of future changes but describe future plausible conditions based on the available level of understanding today.

3.5 Recommended AEP Flood Event Discharges

The recommended peak design flows for the Oyster River hydraulic modelling are shown in Table 7.

Table 7: Oyster River Design Peak Flow Estimates (m^3/s) including Climate Change Allowances

Flood Event	Oyster River below Woodhus Creek			Oyster River at the Mouth		
	Current Climate	+15% Climate Change [1]	+30% Climate Change [2]	Current Climate	+15% Climate Change [1]	+30% Climate Change [2]
10% AEP	324	373	421	377	434	490
5% AEP	354	407	460	412	473	535
1% AEP	406	467	527	472	543	614
0.5% AEP	424	487	551	493	567	641
0.2% AEP	444	511	578	517	595	672

Notes:
1. Nominally year 2050 and 2100.
2. Nominally year 2200.

[1] Uncertainties in hydraulic modelling include the limitations of model algorithms, which are usually based on representing small scale hydrological processes at the watershed scale, uncertainties inherent in representing future hydrological processes based on current land use/land cover, and uncertainties introduced at model calibration through measurement error and interpolation.

3.6 Design Ocean Level and Flow Hydrographs

The sections below describe the flow and water level hydrographs used in the unsteady simulation 2D model of the lower portion of the Oyster River (the modelling approach is described in Section 4).

Design Ocean Level Hydrographs

The peak design ocean levels used at the downstream boundary of the Oyster River 2D hydraulic model are the same as those derived for the coastal floodplain mapping. The design AEP ocean still water levels have been used in the river hydraulic analysis, which does not account for wave effects. Technical Memorandum #4 – Coastal Modelling provides additional details on how the design peak ocean still water levels were derived.

The time-series selected for the design event ocean levels are based on a review of the predicted tide series available from the Canadian Hydrographic Service. The average of the maximum peak water levels over a rolling three-day period was calculated for the predicted tide sequence. The period with the maximum three day rolling average peak water levels was then selected for the design flood events.

The predicted tide sequence was then adjusted to the design peak ocean level by matching the peak predicted tide levels to the peak design flood level for each AEP design run. Figure 6 shows the tidal sequence used as the basis for the water level boundary condition.

Design Flow Hydrographs

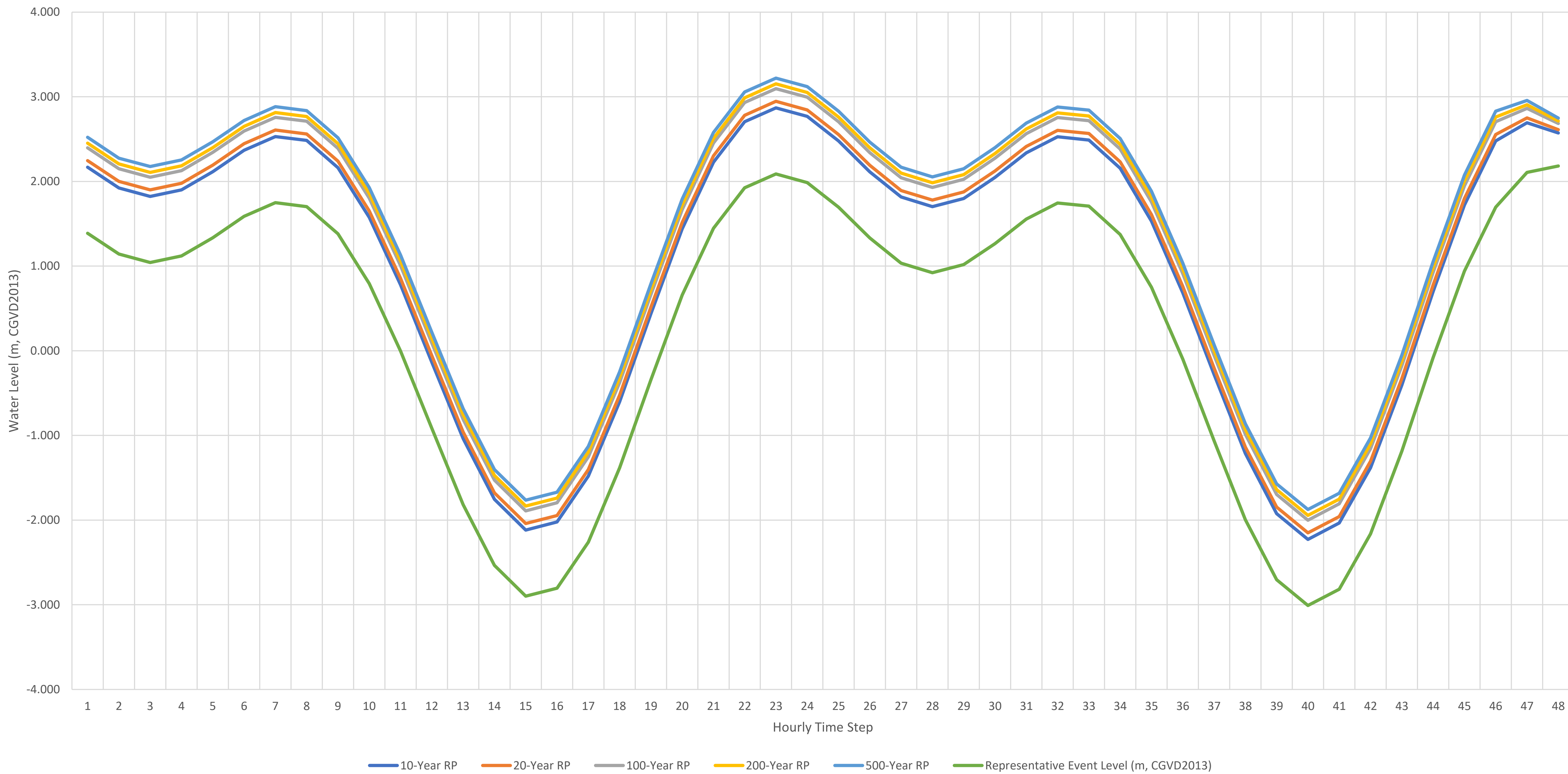
The design flood hydrographs for the Oyster River 2D hydraulic modelling are based on the recorded hydrograph for the December 9, 2014 flood event. This event was chosen as it was one of the largest floods on record and was a single peak with a single rising and falling limb which is appropriate for a design event.

The recorded hydrograph was scaled to the design flood events by factoring each hourly discharge in the flow record:

- first by the ratio between the baseflow at the start of the event and the peak flow; and
- then by the factor between the recorded peak flow and the design peak flow.

In this manner, the baseflow conditions for all the AEP events are the same. This approach also results in an instantaneous peak flow to daily peak flow (I:D) ratio of 1.25 which is lower than the average I:D ratio of 1.5 but is within the range of historical recorded I:D ratios (1.06 to 2.34). A storm event having a lower I:D ratio results in a higher daily average flow for a given instantaneous peak flow. This results in a storm event having more volume for a given instantaneous peak flow, which is a conservative assumption for establishing a design event.

Figure 7 shows the flow hydrograph shape used for the design events.



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Date	April 2021
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Oyster River Design Tide and Representative Event

Figure 6

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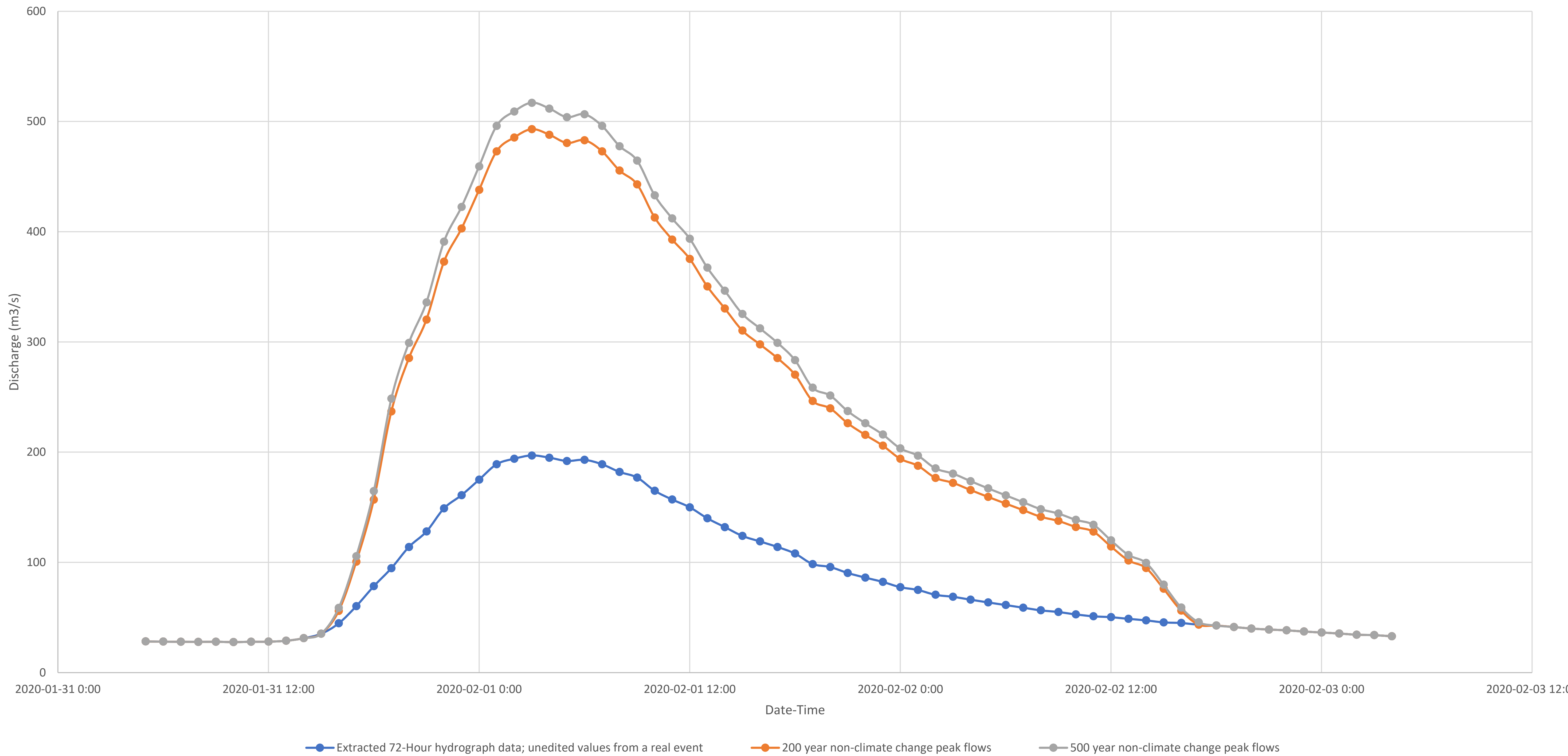

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Oyster River Design Flow Hydrograph and Representative Event

Figure 7

Coincident Flood/Tide Magnitudes

One key assumption in the development of flood inundation and flood hazard mapping is the magnitude of the co-incident river flood discharge and the peak ocean level for a design flood event with a specified AEP. The selection of the coincident flood magnitude and tide level needs to consider the combined probabilities of rare extreme flood events occurring simultaneously with peak ocean tide levels and need to be selected to ensure that the conditions are reflective of the target AEP condition.

Full combined probability analysis of storm surge events with flood events is beyond the scope of this study. However, to keep consistency between the previous assumptions used in Courtenay River hydraulic modelling carried out for the Integrated Flood Management Study (KWL, 2013) and those used with the Oyster River model in this study, the coincident flood and tides used in the modelling have the same AEP. In other words, the 0.5% AEP river flood is combined with the peak 0.5% AEP ocean level.

Although conservative, this assumption is reasonable as the underlying climatic storm events which result in extreme winter rainfall events are similar to those which produce storm surge. Also, this assumption is similar to coastal wave runup calculations which combine storm surge and wind-waves having the same AEP. An example of the coincident design flood hydrograph and design ocean water level hydrograph used for hydraulic modelling for the Oyster River is shown in Figure 8.

An analysis of the sensitivity of the selection of the combined coastal flood level and flood discharge on peak water levels is described in more detail in Section 4.5.

4. Hydraulic Modelling

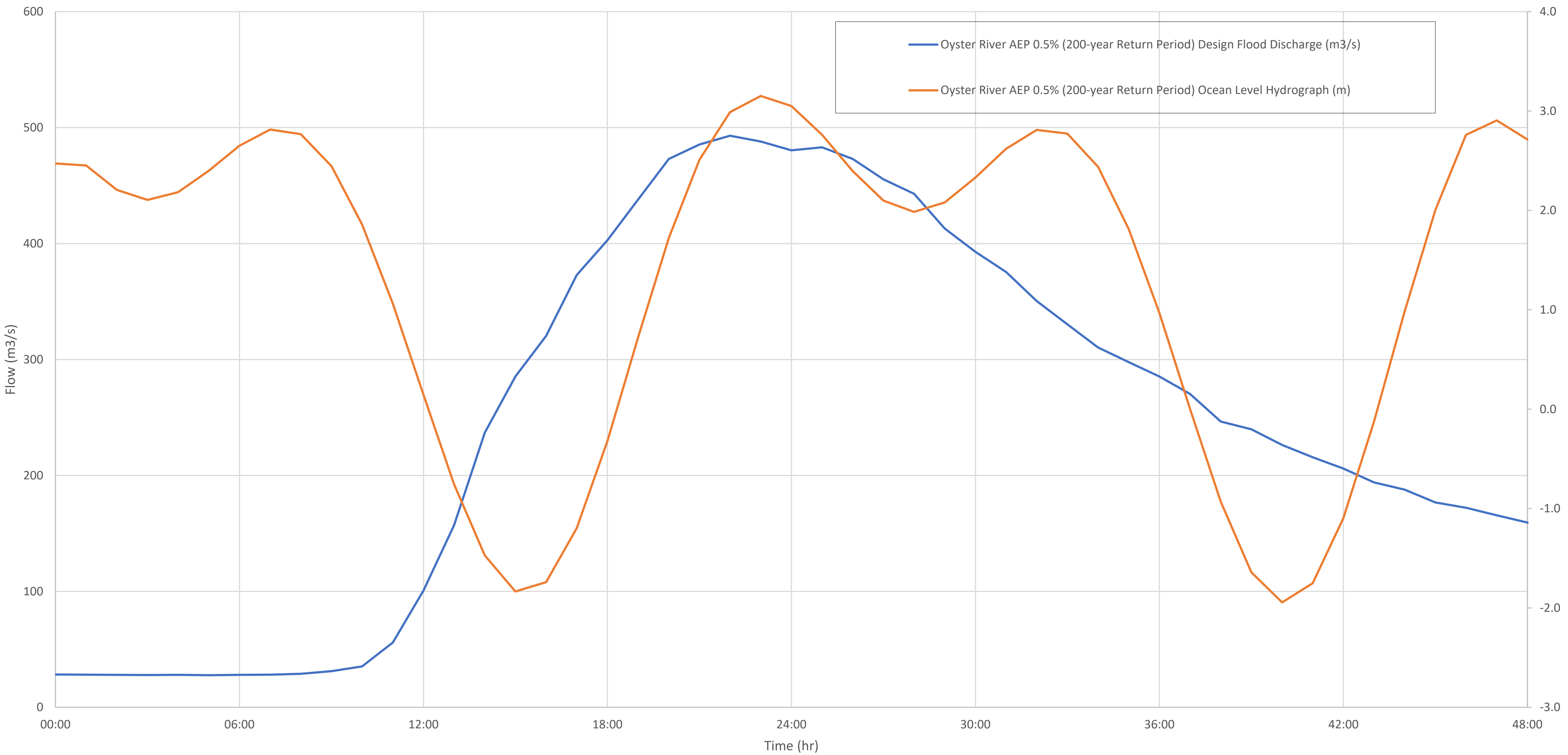
Hydraulic modelling to develop flood profiles and flow velocities for each AEP flood discharge and associated downstream water level boundary condition based on channel and floodplain conveyance for each of the AEP floods is described in this section.

4.1 Modelling Approach

The general planform of the Oyster River changes along its course within the study area. Two separate models were used to cover the entire area of interest. A one-dimensional model spans from the upstream end of the study area to approximately 3.5 km upstream of the Oyster River/Ocean confluence for a total length of approximately 14 km. A two-dimensional model was used to represent the remaining approximately 3.5 km of the Oyster River. The two models have been developed and run separately with water level boundary conditions extracted from the downstream model for boundary conditions for the upstream model. This is possible given that the flow at the interface of the two models is subcritical. Figure 9 shows the spatial extent of the two modelling approaches. The two modelling approaches are described in detail in Sections 4.3 and 4.4.

4.2 Software Selection

Floodplain mapping and spatial flood hazard data for the Oyster River will be prepared using hydraulic modelling software. KWL has selected the HEC-RAS modelling package (Version 5.0.7) developed by the US Army Corp of Engineers (USACE) for hydraulic modelling of the Oyster River. This package was selected as it is free open-source software, can perform both one-dimensional and two-dimensional flow computations, has a good track record of robust computations, has comprehensive documentation on underlying modelling assumptions as well as software updates and is supported both through technical community forums as well as through for-purchase training/support companies.



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Date	April 2021
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Design Flood and Ocean Level Hydrograph Peak Timing (0.5% AEP Example)

Figure 8

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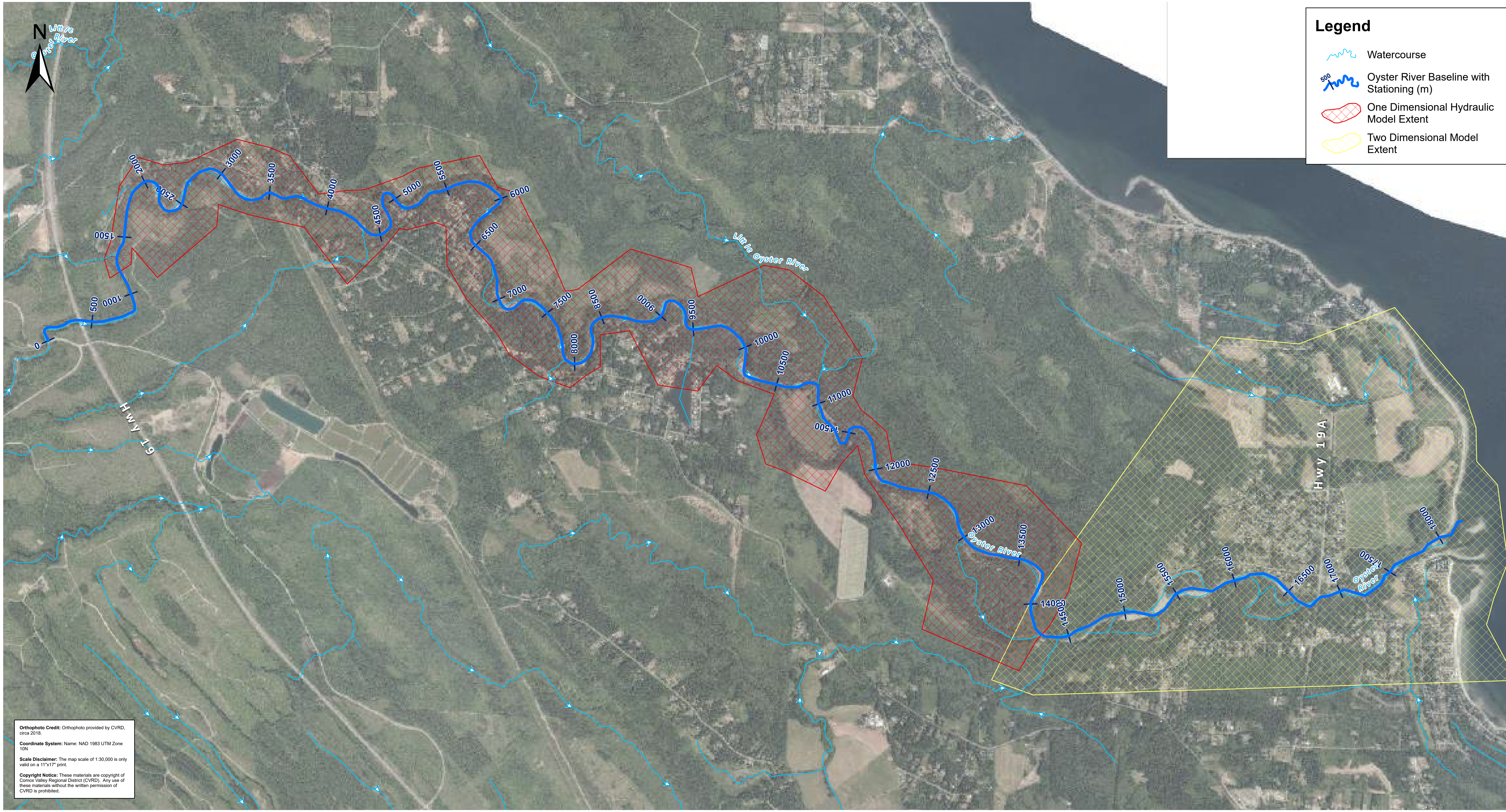

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Spatial Extent of the 1D and 2D Models along the Oyster River

Figure 9

For these reasons, KWL considers that HEC-RAS is the most appropriate software package to develop hydraulic models for CVRD. For ease of model development, KWL has used an independent software package, GeoHECRAS, for pre- and post-processing of model data. Model files and outputs from GeoHECRAS are directly compatible with the USACE HEC-RAS software.

4.3 Upper Oyster River 1D Model

The upstream reaches of the Oyster River, upstream of the western end of Glenmore Road to Highway 19, are located within a relatively confined river valley which has been carved into the Nanaimo Lowlands formation which runs along the east coast of mid-Vancouver Island. As a result, the dynamics of flood flows within the upstream reaches of the Oyster River behave in a fashion that can be represented by one-dimensional flow modelling. The underlying assumptions of these models are that flow hydraulics can be represented using a series of cross-sections across the river channel and floodplain. Additional assumptions include:

1. The direction of river flow is perpendicular to these cross-sections.
2. Water surface elevation is constant across the length of each cross-section.
3. Cross-sections are representative of the channel and floodplain topography for the areas between the cross-sections.

These assumptions do not significantly reduce the accuracy of the results and help to increase computation speed such that a large number of model runs can be executed efficiently.

The steps in the development and simulation of the one-dimensional model were as follows:

1. Defining the channel alignment, floodplain alignment, and model cross-section locations. The original provincial floodplain mapping was used as a guide (Ministry of Environment, 1984). In overland areas, where the extent of original floodplain mapping cross-sections was not sufficient, cross-sections were extended to high ground.
2. Preparing model cross-sections at the selected locations using a combination of river survey data (collected in 2019) and LiDAR data (collected in 2014 as well as 2018/2019).
3. Defining floodplain roughness based on orthographic photos to define floodplain roughness classifications (see Figure 10).
4. Carrying out model verification by comparing results with available water level records at the Water Survey of Canada Station as well as a sensitivity analysis.
5. Running the selected design runs for floodplain mapping and spatial flood hazard data. Due to the limited channel and floodplain storage along this reach of the river, the model was run with a constant discharge at the upstream boundary based on results of the hydrologic analysis and constant downstream water level based on output from the downstream 2D model (described in more detail in Section 4.4).
6. Extracting the model results for each design run and interpolated the results between the modelled cross-sections to prepare floodplain mapping and data. This interpolation and spatial mapping is performed in GIS and is described in Technical Memorandum #5 – Coastal and Fluvial Mapping Products.

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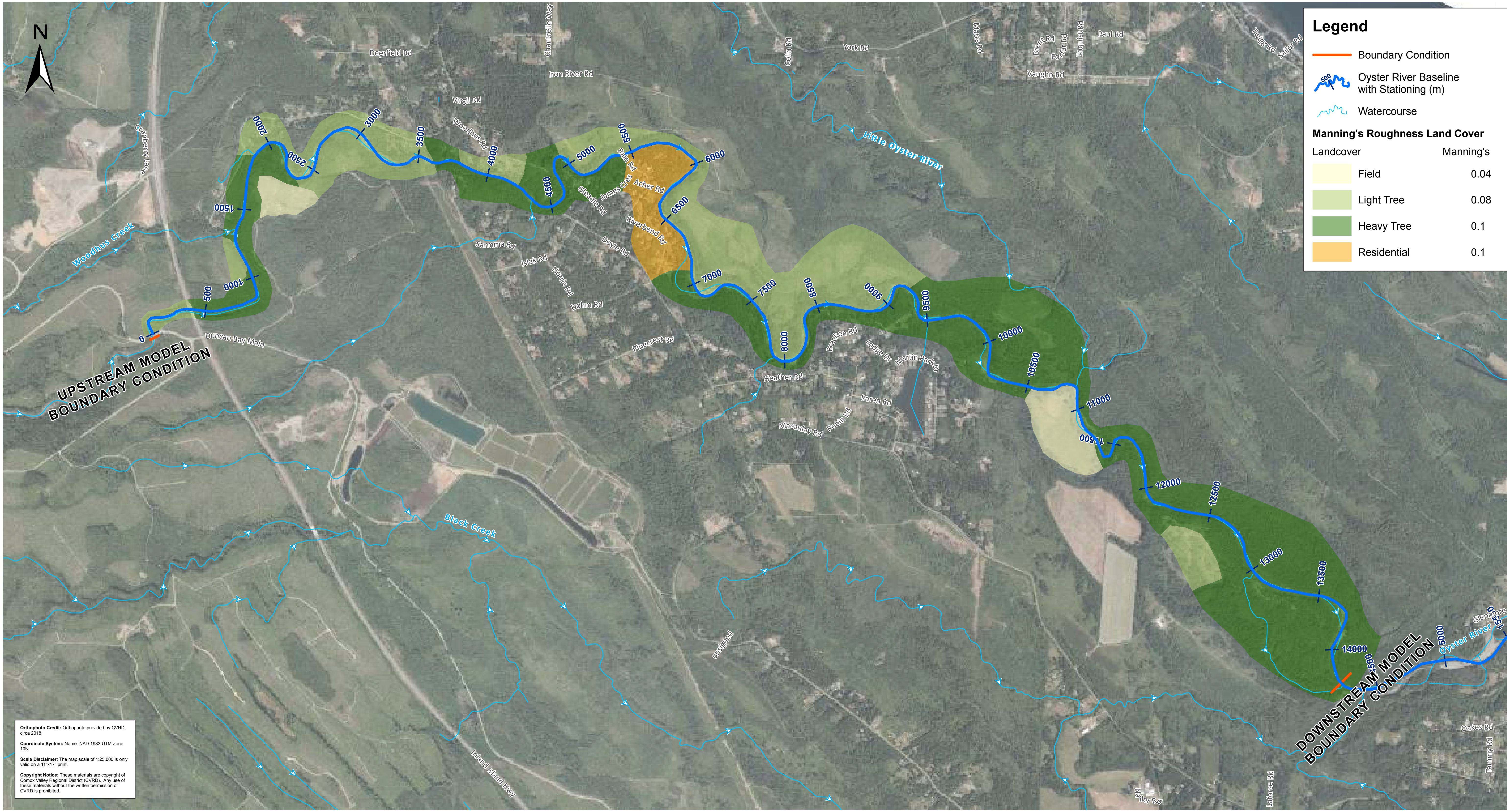

Project No.	2623-014
Date	April 2021
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Oyster River 1D Hydraulic Model – Manning's Roughness

Figure 10

Channel Cross-Sections in 1D Model

A river survey was carried out using RTK GPS and total station survey equipment in October 2019. The surveyed river channel cross-section locations roughly align with the locations of the original 1984 Ministry of Environment (MoE) river channel cross-section survey locations. The only exception to the alignment between the updated cross-sections and the MoE river channel sections are in locations where the river channel has moved significantly since the original survey. Maps showing the approximate locations of the original 1984 MoE and the updated 2019 cross-section locations and alignments are included in Figure 11. The locations of the 1984 cross sections were provided to a local coordinate system and were roughly projected to UTM coordinates. Technical Memorandum #1 – Coastal and River Base Map Development describes the survey and base mapping.

River survey data available within the channel at designated cross-section locations was considered the highest quality data. This data superseded the LiDAR data and, in locations of data overlap in the cross-section, was used instead of LiDAR data. There was no interpolation of cross-sections between river surveyed sections.

A comparison of the LiDAR elevations versus the surveyed elevations in areas of overlap shows that the maximum difference between the two elevation sources was up to 2 m. On average the LiDAR was 0.5 m to 0.7 m higher than survey elevations. The survey did not extend into the overbank areas and therefore the comparison is of channel elevations which, depending on water depth, may be overestimated by the LiDAR.

Manning's Roughness in 1D Model

Roughness values selected were primarily based on Manning's roughness values for open channel flow provided in Chow, V.T. (1959) *Open Channel Hydraulics*. Figure 10 shows the spatial extent of the different land cover types. Table 8 provides the roughness values and land cover type used in the model cross sections and Table 9 provides the roughness values used at each cross-section.

Table 8: **Oyster River 1D Model Land Cover and Manning's Roughness Values**

Land Cover Type	Manning's Roughness 'n' Value
Main Channel	0.045
Field	0.040
Light Tree	0.080
Heavy Tree	0.100
Residential	0.100

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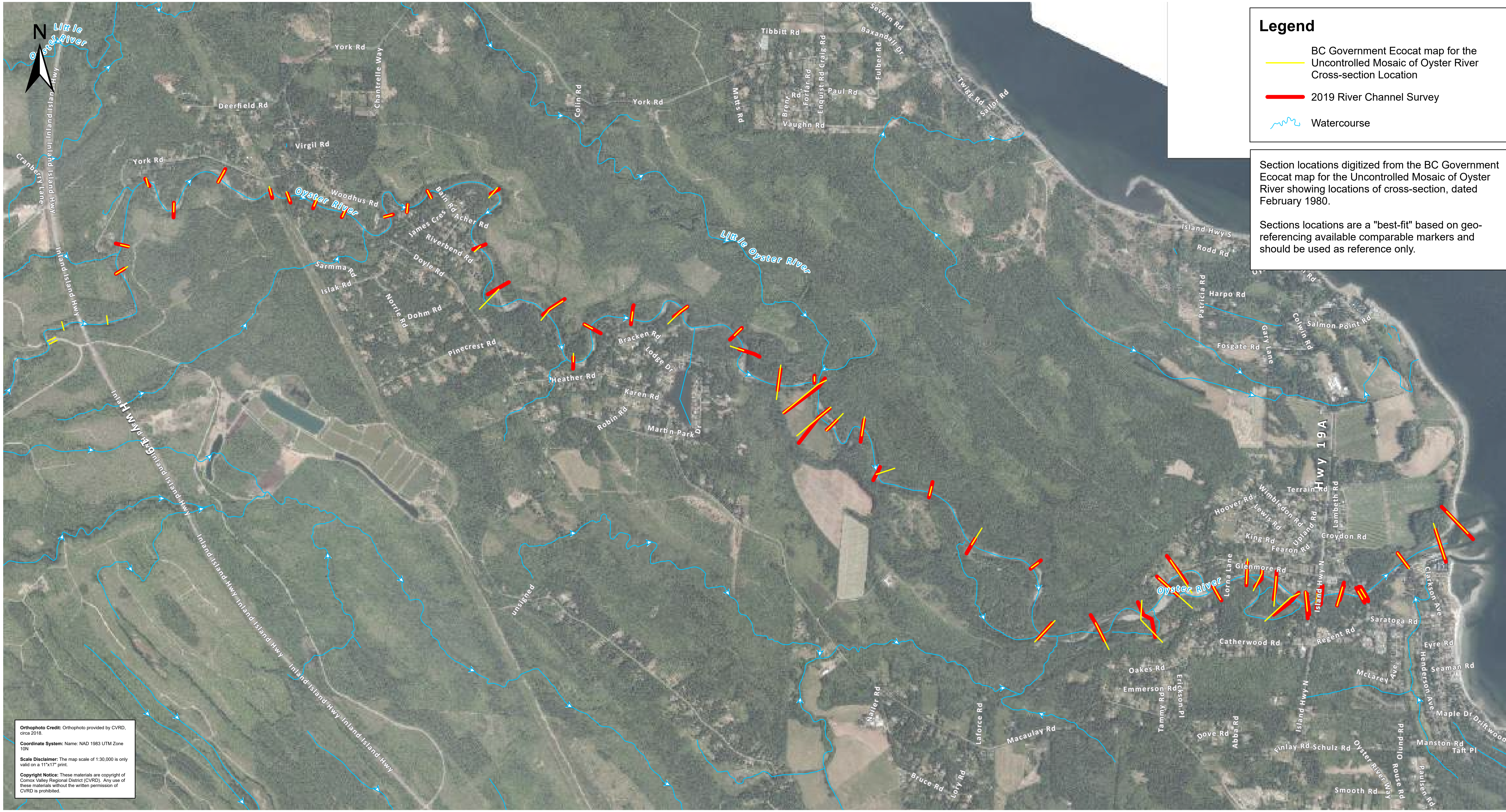

Project No.	2623-014
Date	April 2021
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Location of 1984 MoE Cross-sections and 2019 River Channel Survey

Figure 11

Table 9: Oyster River 1D Model Cross Section Manning's Roughness Values

Cross Section	River Station (m)	Mannings Roughness 'n' Value		
		Left Bank	Channel Center	Right Bank
1	14275	0.080	0.045	0.080
2	14025	0.080	0.045	0.080
3	13650	0.100	0.045	0.100
4	13070	0.080	0.045	0.100
5	12845	0.100	0.045	0.100
6	12260	0.080	0.045	0.100
7	11810	0.080	0.045	0.080
8	11175	0.080	0.045	0.080
9	10800	0.080	0.045	0.080
10	10605	0.100	0.045	0.100
11	10385	0.080	0.045	0.100
12	10135	0.080	0.045	0.100
13	9575	0.080	0.045	0.100
14	9145	0.080	0.045	0.100
15	8925	0.100	0.045	0.100
16	8360	0.080	0.045	0.100
17	7745	0.080	0.045	0.100
18	7345	0.080	0.045	0.100
19	6780	0.080	0.045	0.100
20	6375	0.080	0.045	0.100
21	5905	0.080	0.045	0.100
22	5530	0.080	0.045	0.100
23	4985	0.100	0.045	0.100
24	4410	0.080	0.045	0.100
25	4215	0.100	0.045	0.100
26	3765	0.100	0.045	0.100
27	3430	0.100	0.045	0.040
28	3185	0.100	0.045	0.040
29	3065	0.100	0.045	0.040
30	2635	0.100	0.045	0.100
31	2245	0.100	0.045	0.100
32	1765	0.100	0.045	0.100
33	1230	0.100	0.045	0.100
34	640	0.100	0.045	0.100
35	1	0.100	0.045	0.100

Boundary Conditions in 1D Model

Upstream Boundary Condition

The upstream boundary conditions for the Upper Oyster River model are steady flows representing the peak of the AEP floods.

The peak AEP flow values were calculated from the flood frequency analysis of the Oyster River below Woodhus Creek hydrometric station. The flood frequency analysis is discussed in Section 3.3. A climate change allowance was added to the flow value dependant on the model scenario being run.

In addition to the upstream end inflow, a flow change was added in the model at the Little Oyster River confluence location. At this location, the flows representing the Oyster River at the mouth were used.

Downstream Boundary Condition

The downstream boundary conditions for each Upper Oyster River model run are a constant water level representing the peak flood level for the specific AEP flood. The downstream water levels for the upstream Oyster River model are the peak water level results of the Lower Oyster River 2D model for the matching AEP flood event at the location of the interface between the separate 1D and 2D models.

Key Model Assumptions in 1D Model

The key assumptions used for the hydraulic modelling of the Oyster River are summarized in Table 10 for the upstream one-dimensional hydraulic model.

Table 10: Oyster River Hydraulic Model Key Assumptions for Upstream One-Dimensional Model

Parameter	Value	Notes/Source
Model type	One-dimensional steady-state flow.	HEC-RAS software v5.0.7
Channel Geometry	Combined surveyed channel section and lidar derived surface for floodplain areas. Channel sections are located at the approximately same location as those surveyed for MoE Floodplain Mapping (1984).	Bathymetric Survey by Bazett Land Survey 2019 2018/2019 GeoBC LiDAR
Channel Roughness Values	0.045	Manning's values were obtained from Chow, V.T. (1959) Open Channel Hydraulics, then reviewed
Floodplain Roughness Values	0.04 for fields. 0.08 for lightly treed areas. 0.1 for heavily treed areas. 0.1 for residential areas.	Manning's values were obtained from Chow, V.T. (1959) Open Channel Hydraulics, then reviewed
Flow Boundary Conditions	Peak Design Flows for the Oyster River below Woodhus Creek in the reach above the Little Oyster confluence, and for the Oyster River at the Mouth in the reach below the Little Oyster confluence.	The additional catchment area downstream of the Oyster River below Woodhus Creek gauge is represented as a flow change in the 1D steady model
Downstream Water Level Boundary Conditions	Steady state, constant peak water levels from the upstream end of the downstream two-dimensional model.	

4.4 Lower Oyster River 2D Model

Downstream of the western end of Glenmore Road and the Glenmore Dike, the valley and floodplain widen as the Oyster River flows across the alluvial fan which has formed near the mouth with the Straight of Georgia. Although the river channel is relatively confined between the valley wall to the south and Glenmore Dike/Glenmore Road to the north, there is the potential for overland flooding across the floodplain to the north of Glenmore Road. In the original provincial floodplain mapping, the floodplain level was indeterminate in this floodplain area due to limitations in the flood modelling approach taken at the time (Ministry of Environment, 1984).

However, with advances in hydraulic modelling and computational speed since the original floodplain mapping was prepared it is now possible to define flood levels in this area using two-dimensional flood modelling. Therefore, two-dimensional hydraulic modelling was used in the lower reaches to be able to define flood levels in the river channel as well as in the floodplain area to the north. The two-dimensional model can simulate how flow passes over the landscape without the limitations of the one-dimensional modelling approach described previously.

The steps in the development and modelling of the two-dimensional model for the lower reaches of the Oyster River were as follows:

1. Developing the DEM of the terrain surface using a combination of channel survey (2019) and LiDAR (2018/2019) for the floodplain areas. Channel survey superseded LiDAR in areas of overlap when developing the terrain surface.
2. Adding the two bridges which span the river in this reach to the model terrain surface. Bridge geometry and elevations were reviewed based on the topographic survey (2019) and available record drawings. Abutments and piers were added as part of the terrain surface, while the bridge deck and lower chords were not. It was initially assumed bridge decks and lower chords were above the modelled water surface, and this was verified in Step 4.
3. Two model geometries were developed incorporating the terrain surface. The first extends from the southern river valley wall to the Glenmore Dike crest and Glenmore Road centreline. This was used to determine floodplain mapping depth and flood hazard depth along the confined river channel. The second includes the entire river valley/alluvial fan width and a simulated dike breach of Glenmore Dike. This second model was used to map floodplain extent and flood hazard parameters across the floodplain north of Glenmore Dike.
4. A model mesh was created using the topographic DEM (Step 1) with mesh sizes selected to adequately represent the topography while minimizing model run times. A zonal mesh with 2 m spacing was assigned to areas within the river channel. Outside of the channel, a dynamically spaced mesh was created. Break lines were added along areas of important elevation changes such as road/embankments, side channels, and floodplain edges to ensure high points are represented in the model. Along the break lines, the mesh size was reduced to 2 m to provide additional topographic detail along potential flow paths.
5. Developing a map of Manning's roughness areas for the model by creating polygons of similar roughness areas from orthographic images.
6. Running, testing, and debugging the model for a range of flows starting from lowest to highest to confirm model stability.
7. Running the first model (no overtopping of Glenmore Road or Glenmore Dike) to establish floodplain levels and flood hazard data along the river channel and floodplain immediately to the north of the river.

8. Running the second model (simulated dike breach of Glenmore Dike) to establish floodplain levels and flood hazard data for floodplain areas to the north.
9. Using the second model results as well as results from previous modelling studies to establish dike breach zone of influence along where flood levels and flow velocities are anticipated to be higher due to the potential for dike breach anywhere along the length of the dike.

Floodplain Topography and 2D Model Mesh

The two-dimensional hydraulic model uses a computational mesh to define the finite volume elements in which the flux of water into and out of the mesh volume is solved. HEC-RAS 2D model uses a pre-processor routine to calculate detailed hydraulic tables representing the volume and flow conveyance along each face of the grid which is based on the underlying topography. The 2D model mesh grid defined for the Oyster River channel and floodplain is shown in Figure 12. The same mesh was used for the breach and no breach scenarios, the only difference being the different topography.

The topography used for the model scenario where the dike is sufficiently high to contain the flows within the river included a 'glass wall' at the dike to ensure that the flows were contained within the river corridor.

The topography used for the dike breach scenario model included a gap in the dike at the breach location (100 m wide with the invert matching the ground level at the toe of the dike). This topography also included a 'glass wall' along the dike and along Glenmore Road to prevent flows from returning to the river, thereby representing the worst-case scenario for the area north of the dike/road. This model scenario is used to produce the flood levels and extents in the floodplain north of the dike.

The topography used to derive the ground surface for modelling flow across the floodplain was developed from the Geodata BC 2019 LiDAR data. Within the river channel, the topography was based on a river channel survey (see Technical Memorandum #1 – Coastal and River Base Map Development for more details).

Elevation difference between the bathymetry and LiDAR within the channel is not applicable as LiDAR is not accurate in areas that are inundated. Bathymetric survey has overlap with the LiDAR along the bank and in general there is approximately 0.1 to 0.5 m vertical difference between the on-the-ground survey and the most recent LiDAR. This was found using spot checks at the estimated original 1984 model cross section locations. There was not a consistent vertical shift between cross sections (which could indicate a datum issue), the differences were seemingly random. The x-y (horizontal) location of the surveyed channel reasonably matches the bank location in the LiDAR data.

The mesh elevations were spot checked against the underlying topography to validate the mesh generation. The HEC-RAS 2D mesh uses area-elevation relationships to represent the topography within each mesh element. The area-elevation relationship of several large mesh elements was compared to an area-elevation relationship generated straight from the LiDAR topography. The two were identical indicating no issues with the mesh generation.

To review changes in the shape of the Oyster River channel over time, a comparison of the 2019 survey with the original 1984 survey data was attempted. In most cases, the overall shape of the channels where comparable, except at those locations where significant changes in channel location have occurred. Further discussion of channel planform changes is discussed in TM#2. No detailed comparison of the cross sections was possible as the original 1984 survey cross section locations were provided in a local horizontal coordinate system (not in UTM) and no evidence of the original surveyed cross sections was found in the field, and therefore the 2019 and 1984 surveys could not be geo-referenced to each other.

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Date	April 2021
Scale	N/A

Lower Oyster River 2D GeoHEC-RAS Mesh and Breaklines

Figure 12

Manning's Roughness in 2D Model

For the 2D model, each mesh element needs a roughness value. These roughness values were assigned to the mesh elements by first developing a map of Manning's roughness areas for the model by creating polygons of similar roughness areas from orthographic images. These roughness polygons were assigned Manning's roughness values based on those recommended in the HEC-RAS and GeoHEC-RAS software for the land cover types identified (see Table 11).

Table 11: **Oyster River 2D Model Land Cover and Manning's Roughness Values**

Land Cover Type	Manning's Roughness 'n' Value
Road	0.013
Side Channel	0.050
Main Channel	0.045
Treed Island	0.100
Field	0.035
Heavy Tree	0.100
Light Tree	0.080
Residential	0.100
Ocean	0.035

Figure 13 shows the distribution of Manning's roughness values throughout the 2D model domain.

Key Model Assumptions in 2D Model

Table 12 summarizes the model parameters and key assumptions used in the 2D model.

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Orthophoto Credit: Orthophoto provided by CVRD, circa 2018.

Coordinate System: NAD 1983 UTM Zone 10N

Scale Disclaimer: The map scale of 1:15,000 is only valid on a 11"x17" print.

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Scale 1:15,000
0 100 200 400 Metres

Lower Oyster River 2D Hydraulic Model - Manning's Roughness

Figure 13

Table 12: Oyster River Hydraulic Model Key Assumptions for Downstream 2D Model

Parameter	Value	Notes/Source
Model type	Two-dimensional hydrodynamic (time-varying) flow.	HEC-RAS software v5.0.7 (GeoHEC-RAS interface).
Channel Topography/ Bathymetry	Combined surveyed full channel bathymetry and LiDAR derived surface for bank areas.	Bazett Land Survey 2019 bathymetric survey. GeoBC 2018/2019 LiDAR.
Floodplain Topography	LiDAR derived surface.	GeoBC 2018/2019 LiDAR. SRD 2016 LiDAR.
Channel Roughness Values	Variable from 0.045 to 0.05.	Roughness regions mapped from ortho imagery. Values from Chow, 1959.
Floodplain Roughness Values	Variable from 0.013 to 0.1.	Roughness regions mapped from ortho imagery. Values from Chow, 1959.
Two-Dimensional Grid	Uniform mesh with 2 m cell spacing within the channel. Adaptive Meshing with a maximum element area of 400 m^2 everywhere else.	See Figure 12.
Model Computational Timestep	A fixed time step of 1 second.	Longer duration time steps were tested during model building and 1 second was found to be the longest duration that maintained model stability.
Dike Breach Length Breach Invert Elevation	100 m. 17.2 m (equal to surrounding ground).	Water Management Consultants, “Floodplain Mapping, Guidelines and Specifications”, Prepared for Fraser Basin Council, 2004 (Water Management Consultants, 2004).
Preliminary Dike Breach Time to Full Development	N/A. Breach development was not simulated due to instability issues. Instead, the 2D mesh topography was altered to include a gap in the dike.	
Upstream Boundary Condition	Unsteady hydrograph based on peak design flows for the Oyster River at the mouth.	Scaled up December 9, 2014 flood event.
Downstream Boundary Conditions	Coincident Peak Ocean Levels including Storm Surge with full diurnal tidal time-series for the larger tide.	Downstream boundary located within the ocean; 450 m offshore from the river/ocean confluence. Based on sensitivity analysis results discussed in Section 4.5, use ocean levels having the same AEP as the design floods.

Dike Breach Assumptions

The Glenmore Dike and Glenmore Road, which run along the north side of the Oyster River, provide a degree of flood protection for developed areas close to the Oyster River. However, dikes can breach and allow floodwaters into protected areas which can often result in flood damage. To better understand flood risk as a result of a breach of the Glenmore Dike, the modelling has also considered dam breach analysis in preparation for flood mapping.

Two locations were reviewed as potential worst-case breach zones. One along the Glenmore Dike near the middle of the structure at the upstream end and the other along Glenmore Road, just downstream of the Glenmore Dike and Glenmore Road intersection. It was assumed that the Glenmore Dike breach location would result in a worst-case scenario due to the longer flow path across the floodplain and the higher river levels at that breach location resulting in a larger extent of flooding. See Figure 12 for a location of the breach.

The results of the model run without dike breach found that the peak water levels at the breach location were significantly below dike crest elevation. Selecting dam breach parameters for this condition was difficult as documented model parameters are generally based on a fully or nearly submerged dike. To model the dam breach for the Oyster River, a portion of the dike (matching dike suggested dike breach width of approx. 100 m) was removed and the resulting dike gap set at the bordering floodplain elevation of 17.2 m. This gap allows water to flow into the protected floodplain area simulating a dike breach but without dynamic failure of the dike.

Boundary Conditions in 2D Model

Upstream Boundary Condition

The upstream boundary condition for the Lower Oyster River model is an unsteady flow hydrograph with peak flow equivalent to the peak AEP flood event calculated for the Oyster River at the mouth. The design event peak flow value was calculated by scaling the results of flood frequency analysis of the Oyster River below Woodhus Creek hydrometric station using a watershed area ratio. The flood frequency analysis is discussed in Section 3.3.

The design flood hydrograph for the Oyster River hydraulic modelling is based on the recorded hydrograph for the December 9, 2014 flood event.

Downstream Boundary Condition

The downstream boundary condition for the Lower Oyster River model is unsteady water level time series as described above in Section 3.6.

4.5 Model Sensitivity/Verification

Upper Oyster River 1D Model

The recorded water levels at the Oyster River below Woodhus Creek station were converted to CGVD2013 by comparing the surveyed water level (in CGVD2013) on 17 Oct 2019 with the recorded gauge datum water level. The model was run for the 2011 to 2017 recorded instantaneous peak flows and the modelled water levels were compared with the recorded CGVD2013 gauged water levels. The comparison shows that the model slightly overestimates the recorded levels by approximately 0.2 m.

Manning's Roughness Value Sensitivity

To assess sensitivity to model roughness selection, the channel and overbank roughness values were increased by 10% and a sensitivity model run of the 0.5% AEP current climate design flow was completed.

The results show that increasing the roughness by 10% raises the 0.5% AEP water level by up to 0.26 m (see Figures 14a to 14e).

Peak Flow Sensitivity

To assess sensitivity to design flow, the results of the three climate scenario models were compared for the 0.5% AEP design flows.

The results show that increasing the peak flow by 15% raises the 0.5% AEP water level by up to 0.40 m. Increasing the peak flow by 30% raises the 0.5% AEP water level by up to 0.78 m.

Lower Oyster River 2D Model

Manning's Roughness Value Sensitivity

To assess sensitivity in model roughness selection, the channel and floodplain roughness values were increased and decreased by 10% and a sensitivity model run of the 0.5% AEP current climate design flow was completed.

The peak water level profile along the Oyster River channel show that increasing the roughness values by 10% increases the 0.5% AEP water levels by up to 0.26 m and decreasing it by 10% lowers water levels by up to 0.38 m (see Figures 15a and 15b).

Downstream Water Level Boundary Condition Sensitivity

As outlined previously, the selection of the magnitude of the co-incident ocean levels with the design flood discharges is an important assumption in establishing design flood water levels. To assess the sensitivity of this assumption, the Oyster River hydraulic model was run with two additional combinations of flows and sea levels.

1. Combining the 0.5% AEP river flood with the 10% AEP ocean level.
2. Combining the 10% AEP river flood with the 0.5% AEP ocean level.

These two sensitivity scenarios were then compared to the model that had both the river flow and ocean level at 0.5% AEP to determine if this combination results in overly conservative flood levels. The results of the comparison are shown in Figure 16.

The results show that compared to the maximum profile of the above two combinations of river flood and ocean level, the 0.5% AEP river flood and 0.5% ocean level model results in higher water levels in a 200 m stretch of the river with the maximum difference in water level being 0.17 m.

The differences in the design flood profile as a result of the selection of the downstream boundary assumption for the Oyster River are relatively small. Therefore, the selection of the more conservative approach of combining the river flood and ocean water level having the same AEP has a limited impact on the water level profile and flood inundation/flood hazard results.

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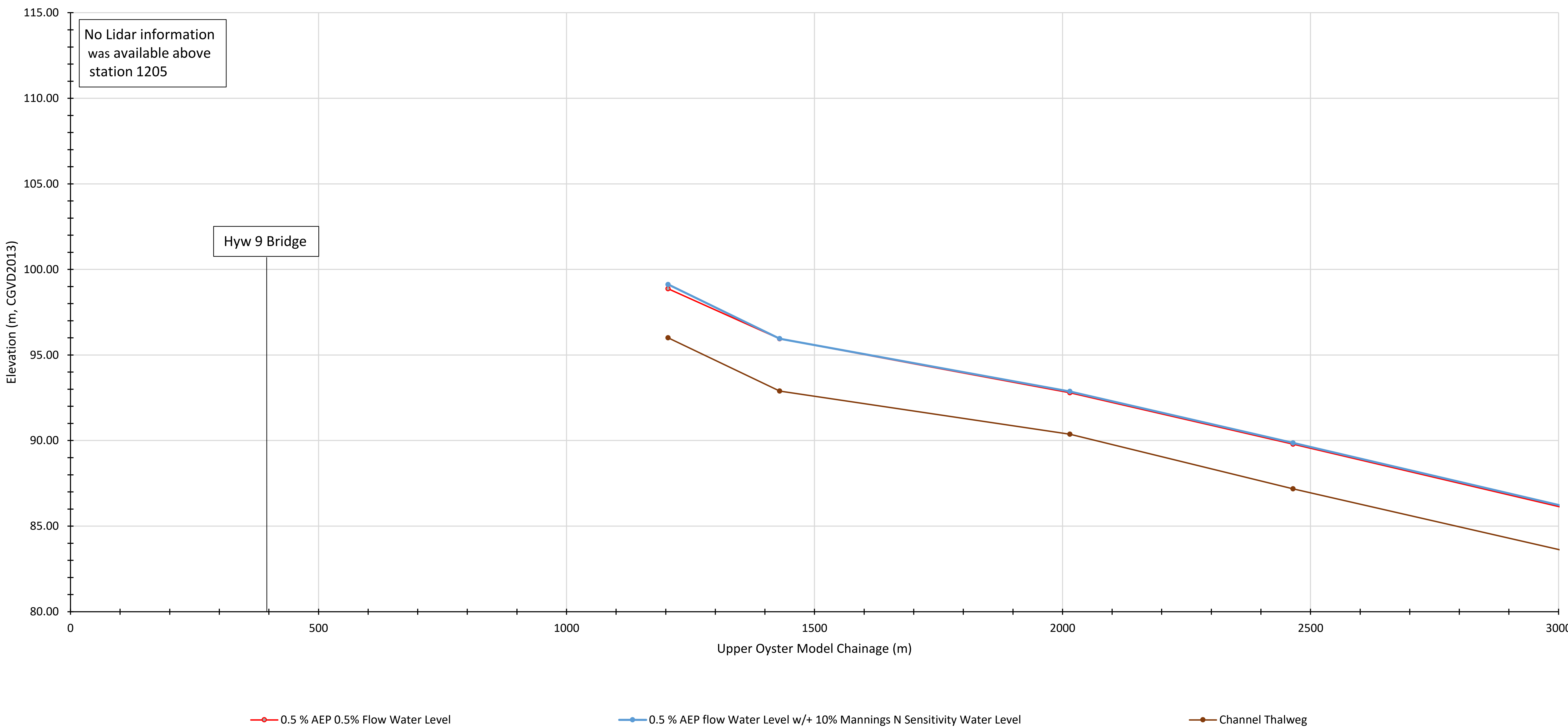

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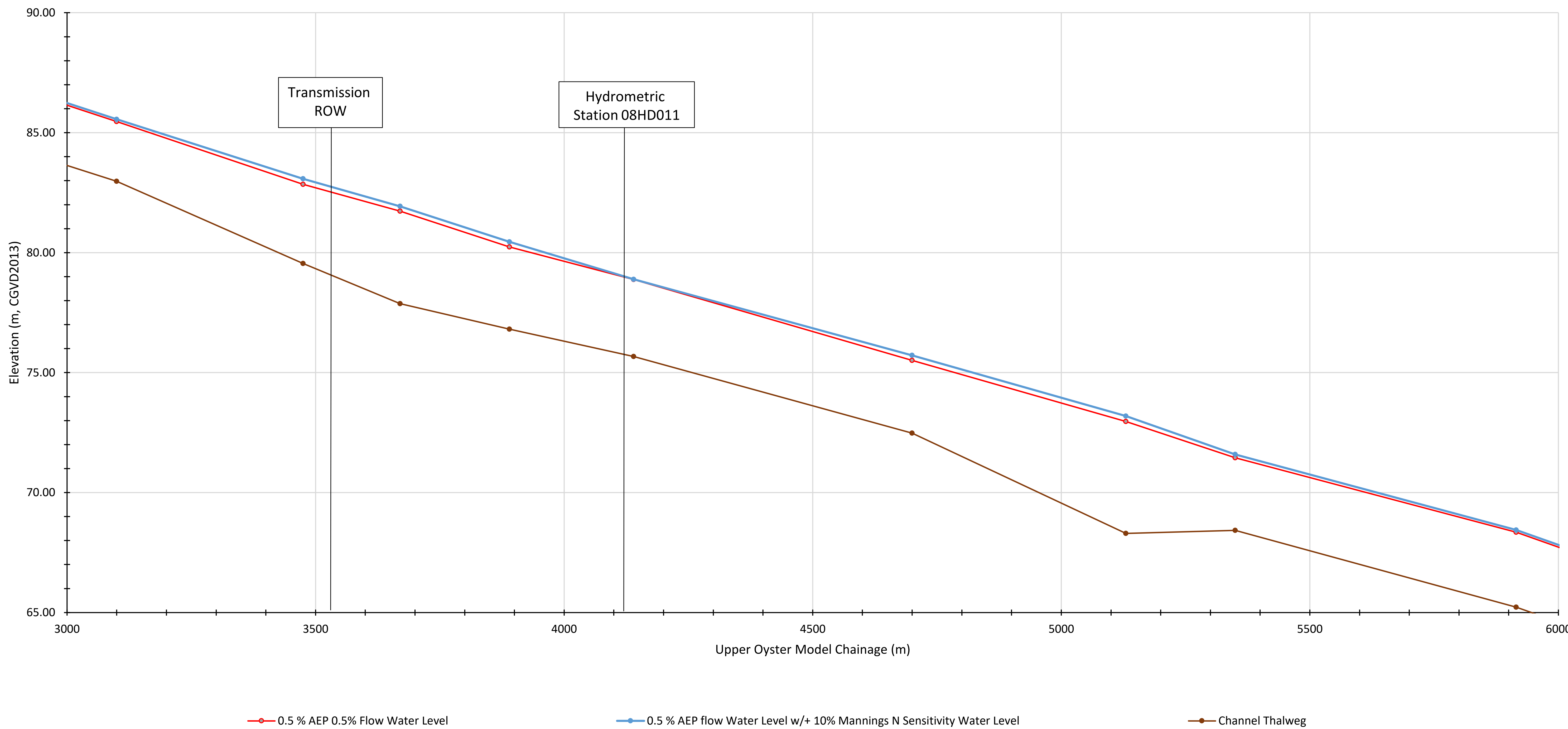
Oyster River 1D Model Manning's "n" Sensitivity Scenario Results (0.5% AEP with 30% Climate Change) Chainage 0 to 3000

Figure 14a



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Scale	N/A

Oyster River 1D Model Manning's "n" Sensitivity Scenario Results (0.5% AEP with 30% Climate Change) Chainage 3000 to 6000

Figure 14b

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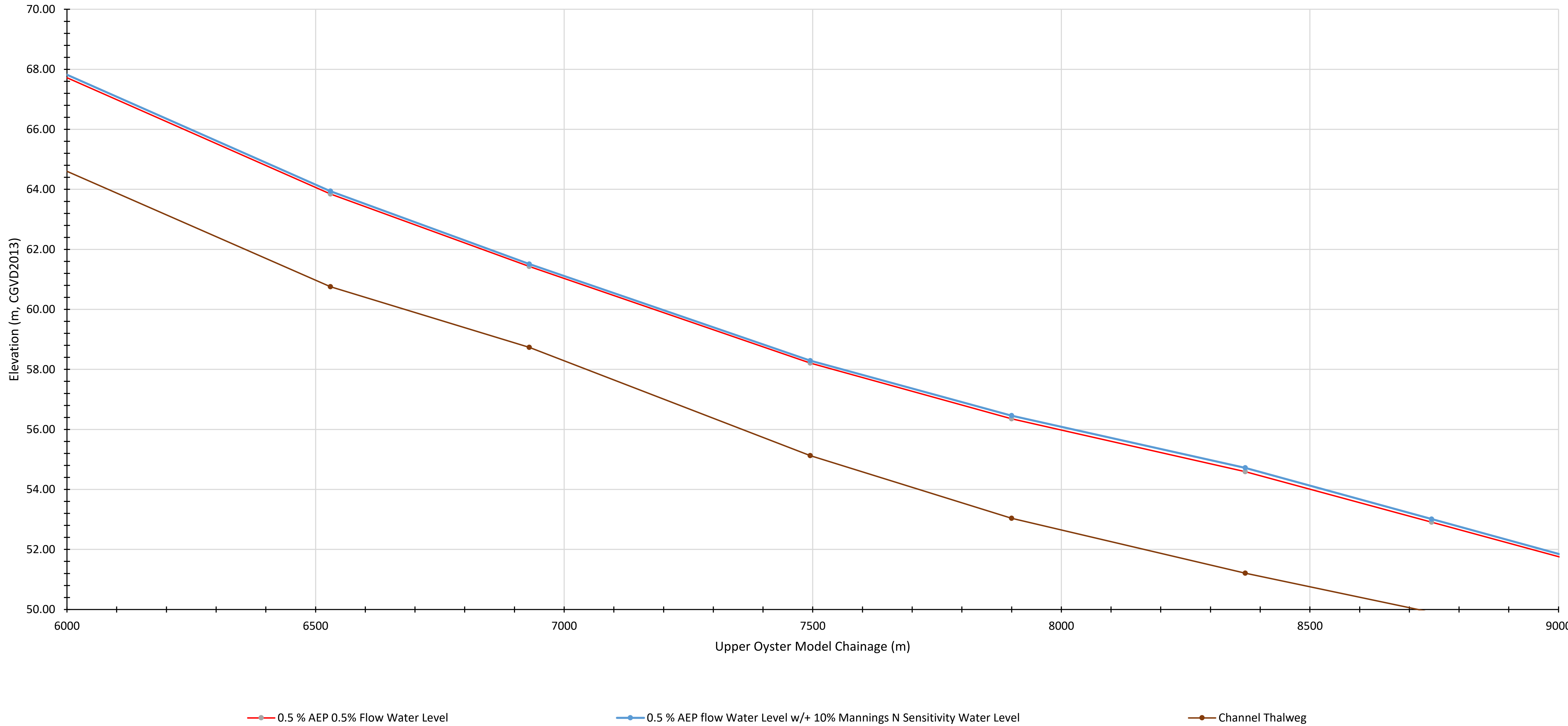

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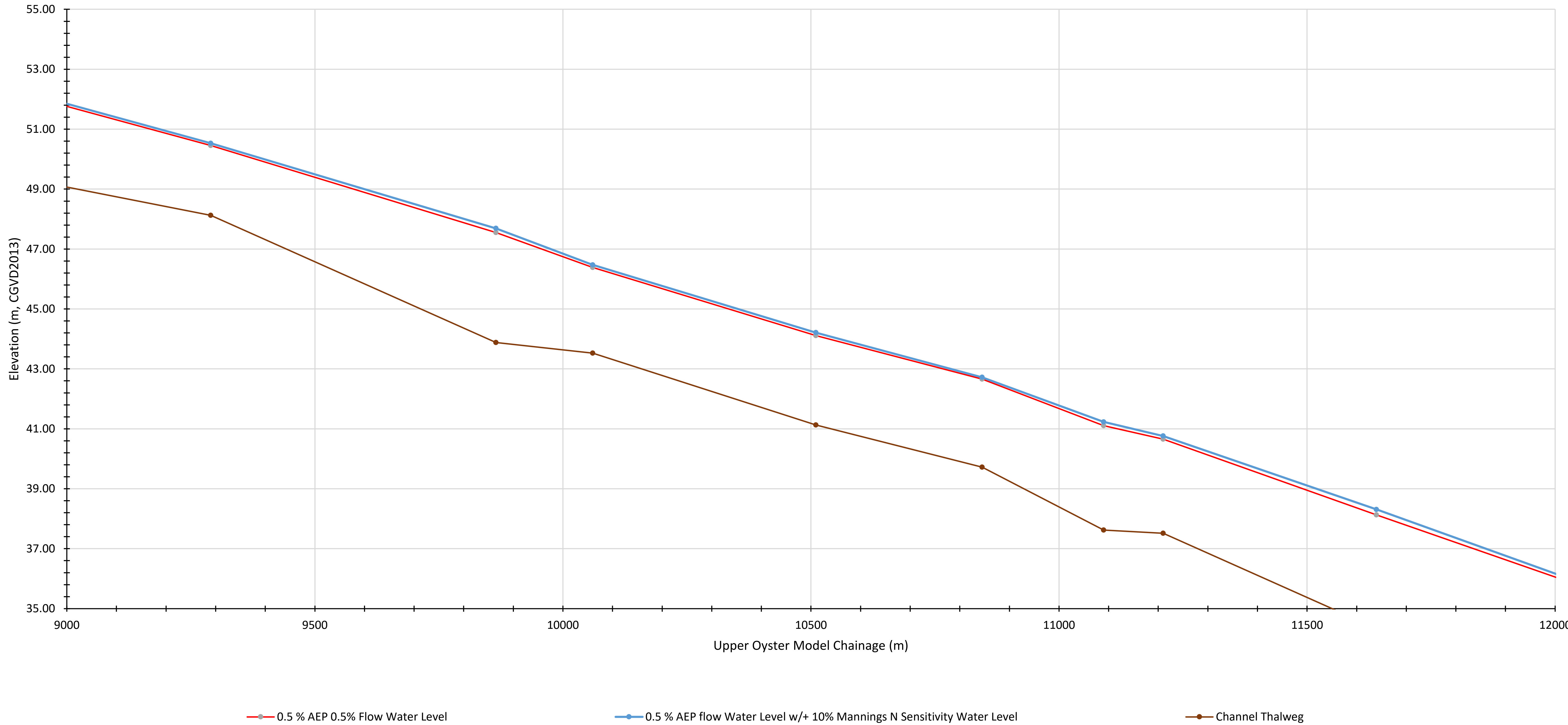
Scale	N/A

Oyster River 1D Model Manning's "n" Sensitivity Scenario Results (0.5% AEP with 30% Climate Change) Chainage 6000 to 9000

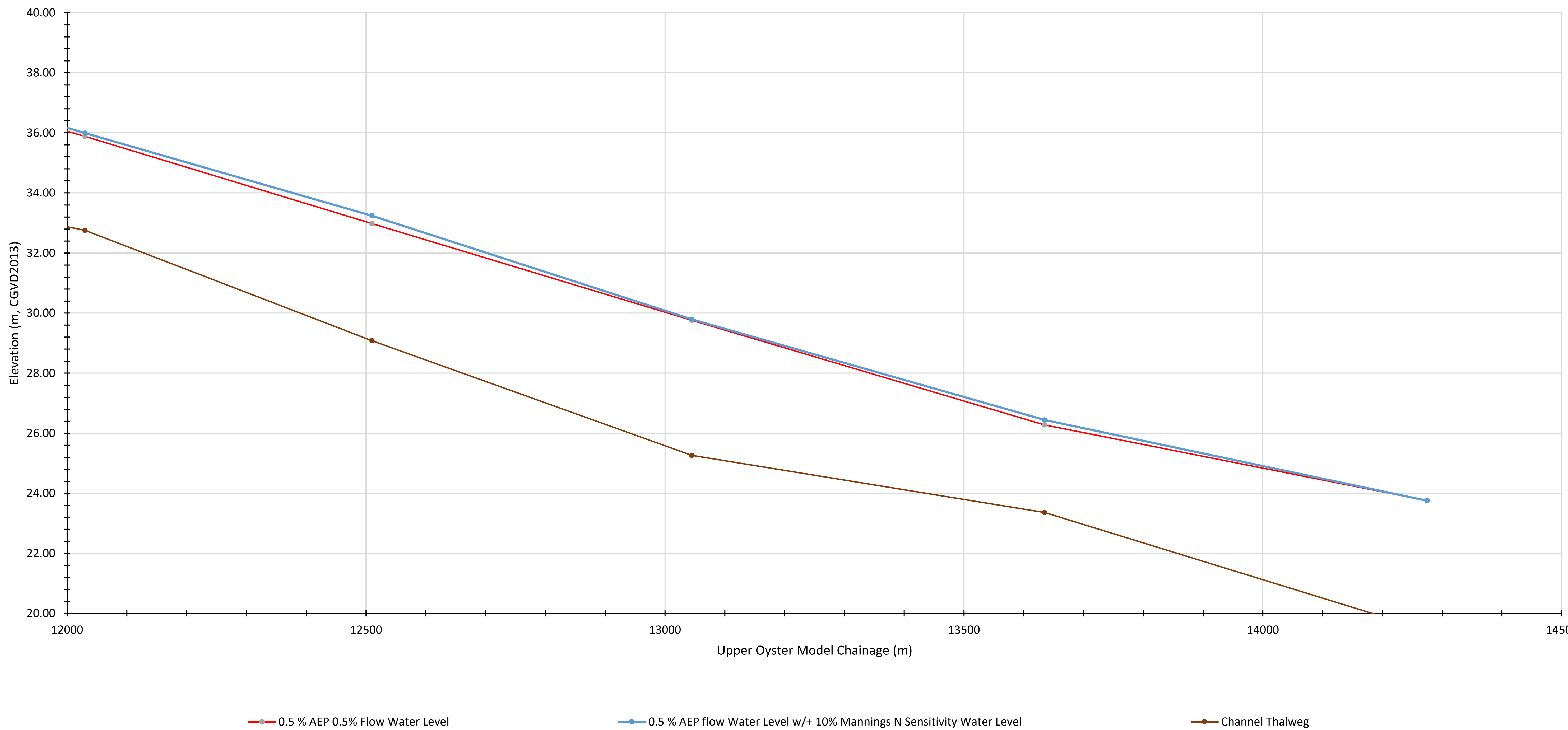
Figure 14c



Project No.	2623.014
Date	April 2021
Scale	N/A

Oyster River 1D Model Manning's "n" Sensitivity Scenario Results (0.5% AEP with 30% Climate Change) Chainage 9000 to 12000

Figure 14d



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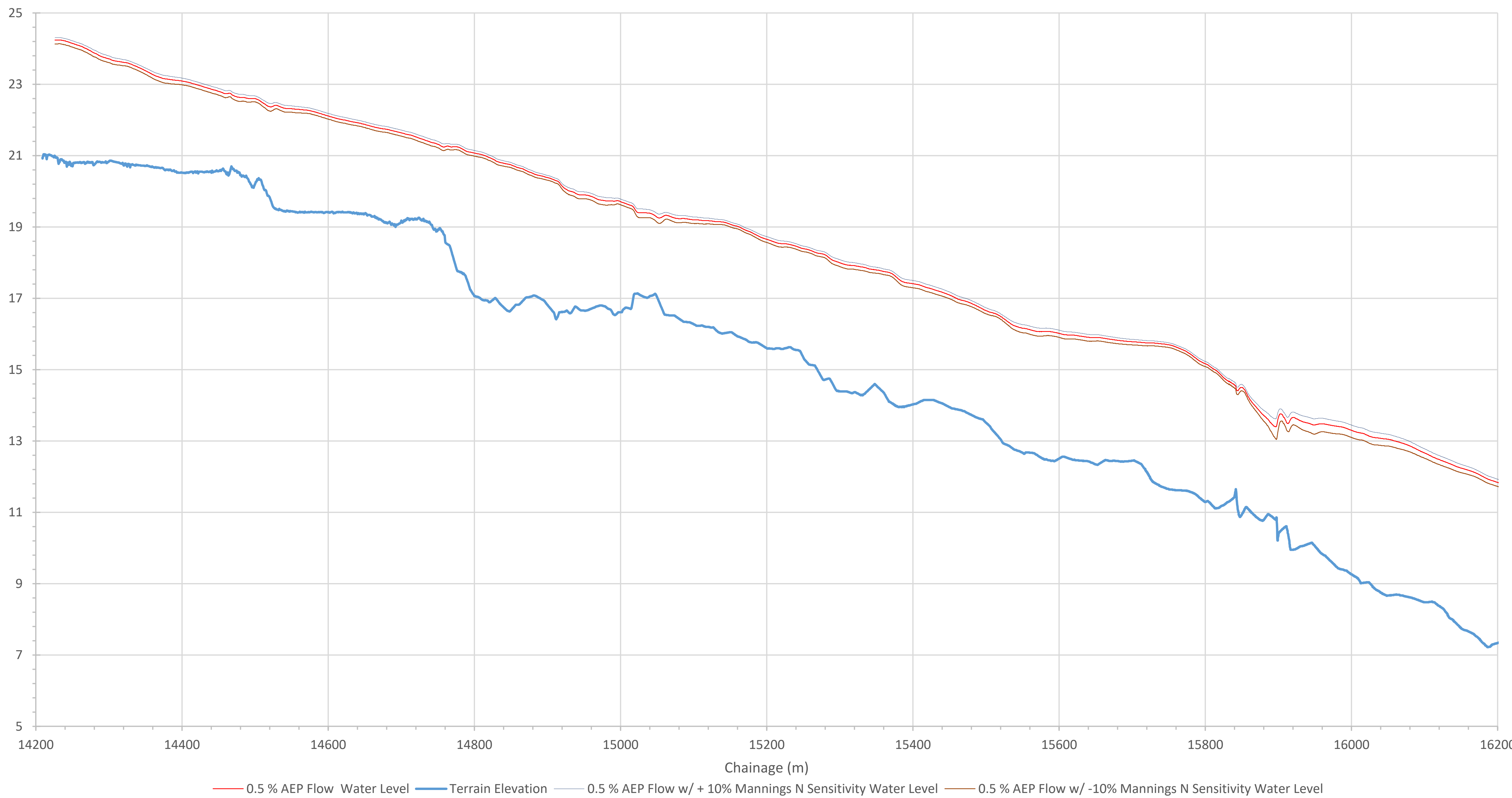
Scale	N/A

Oyster River 1D Model Manning's "n" Sensitivity Scenario Results (0.5% AEP with 30% Climate Change) Chainage 12000 to 14500

Figure 14e



Project No.	2623.014
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Scale	N/A

Lower Oyster 2D Model Manning's "n" Sensitivity Scenario Results (0.5% AEP with 30% Climate Change) Sta. 14200 to 16200

Figure 15a

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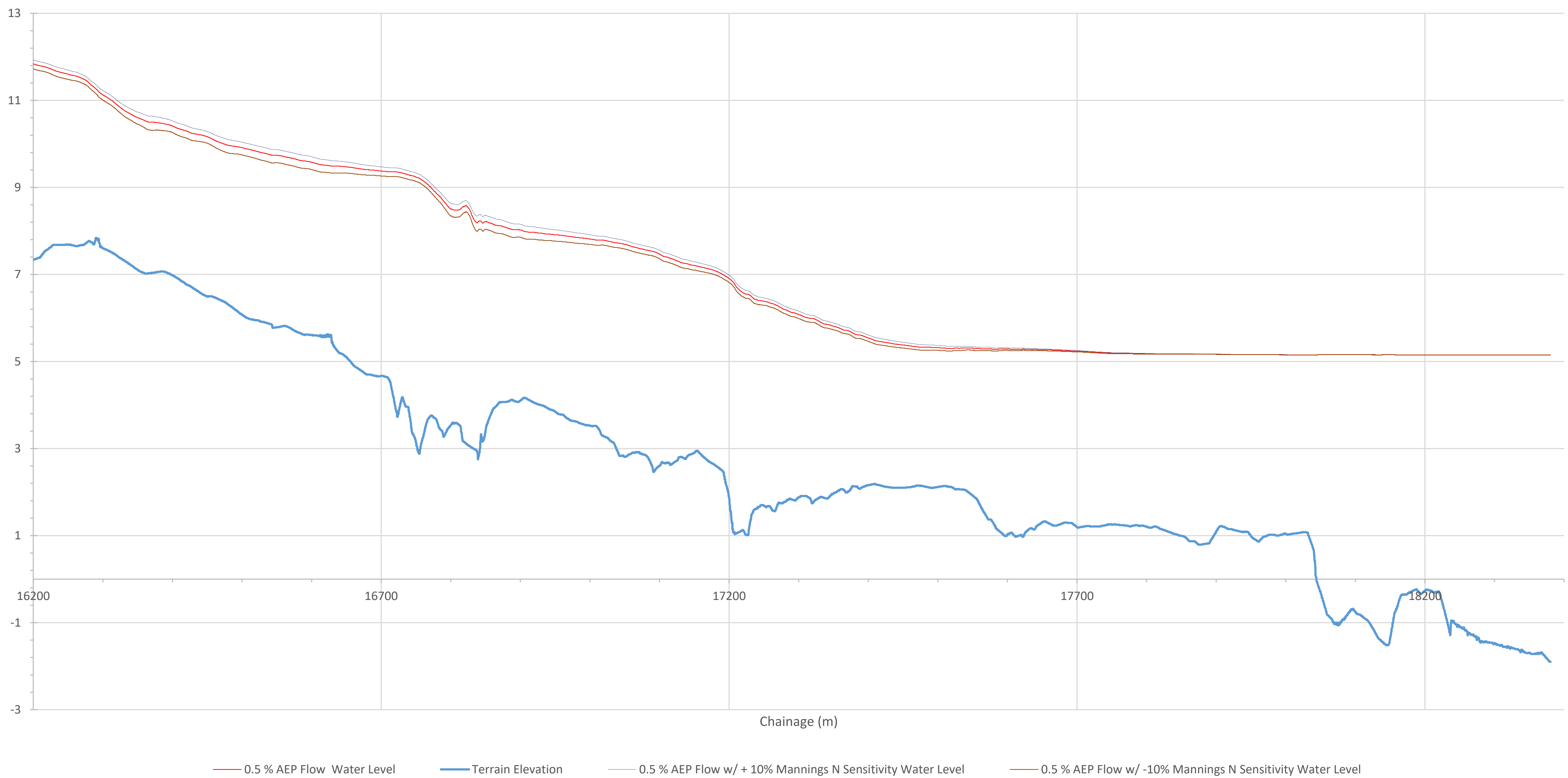

Project No.	2623.014
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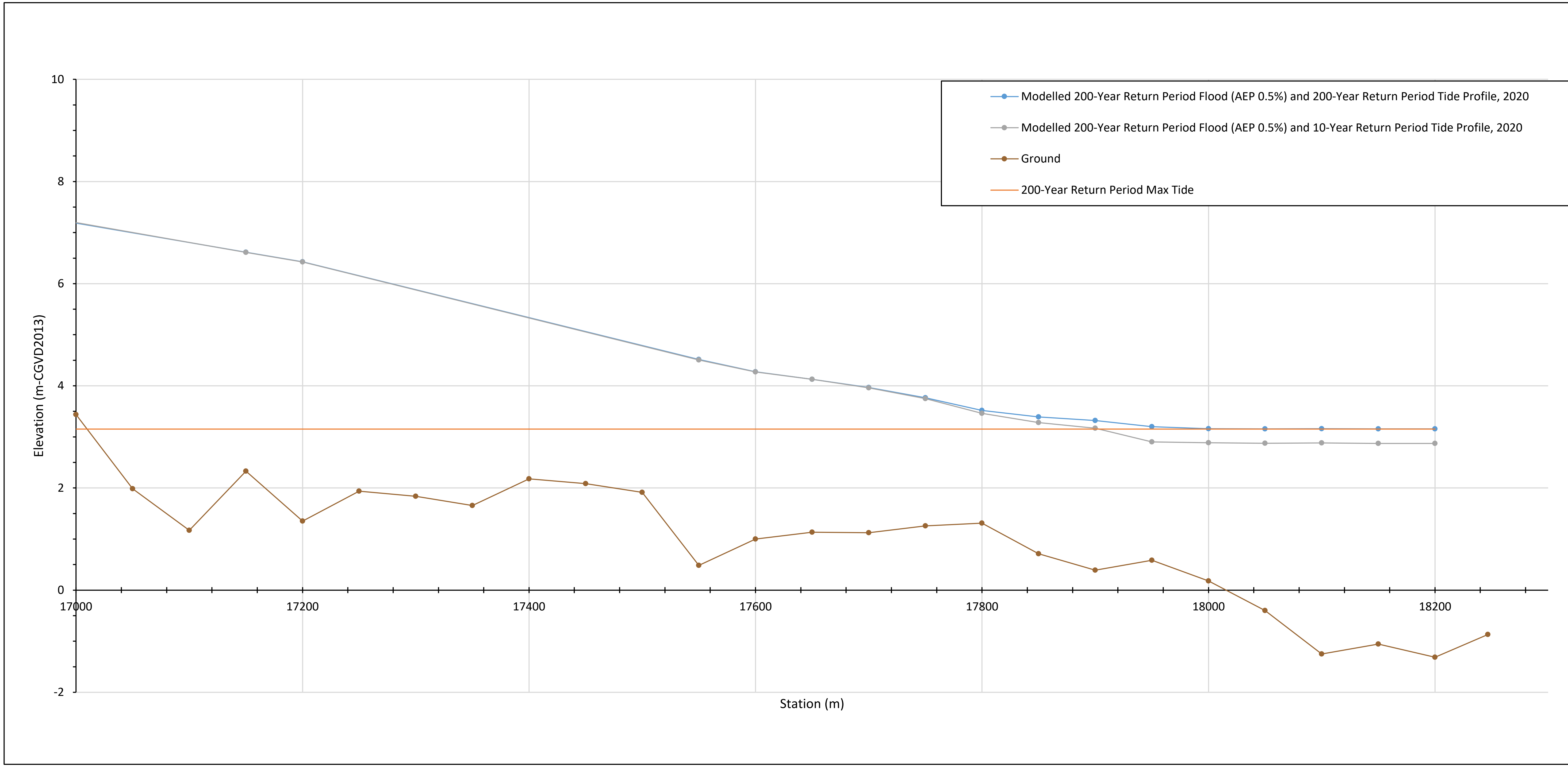
Scale	N/A

Lower Oyster 2D Model Manning's "n" Sensitivity Scenario Results (0.5% AEP with 30% Climate Change) Sta. 16200 to 18400

Figure 15b



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Scale	N/A

Sensitivity of Combining a High River Flow and High Ocean Level (0.5% AEP Example)

Figure 16

Flow Direction at Bridges

Particle flow tracking lines were reviewed at the two bridges within the Oyster River 2D model domain. As shown in Figure 17, flow directions at the Hwy 19A bridge are skewed to the bridge opening due to the angle of the channel upstream of the bridge. The flow lines at the pier show slight deflection at the upstream face and zone of low velocity at the downstream face. The flow lines at the Regent Street bridge converge from the wider flooded area upstream to the narrow bridge opening.

No Flow Reversal at Mouth

The sensitivity of the downstream boundary condition was tested using two model scenarios.

First, the water level boundary was extended to cover more of the edge of the model area along the coastline. The 0.5% AEP flow with 0.5% AEP tidal boundary with Year 2100 sea level rise model was rerun with the extended boundary. The extended boundary did not change the water levels at any location. The velocity vectors along the coastline did change as they now pointed toward the coast and away from the coast, with rising and falling tide.

Second, a 'worst case' model was created in an attempt to try to see if the flow direction could ever be up-river. To create this 'worst case' condition, a low flow (10% AEP which is the lowest flow hydrograph available) and the highest tidal level (0.5% AEP with Year 2100 sea level rise) were used. Even under these conditions the flow was not able to reverse and flow up-river. Figure 18 shows the slowest river velocity simulated, pointing downstream (see arrows). This result is supported by anecdotal information.

Dike Breach Verification

The dike breach model results were reviewed to verify the breach zone selection assumption. Modelled water levels at the alternative dam breach zone along Glenmore Road, just downstream of the Glenmore Dike and Glenmore Road crossing were investigated, and it was found that the water level on the land side of the road/dike during the Glenmore Dike breach scenario was already higher than the water levels on the riverside location. Breaching along the road/dike at this alternative location would create a less conservative scenario.

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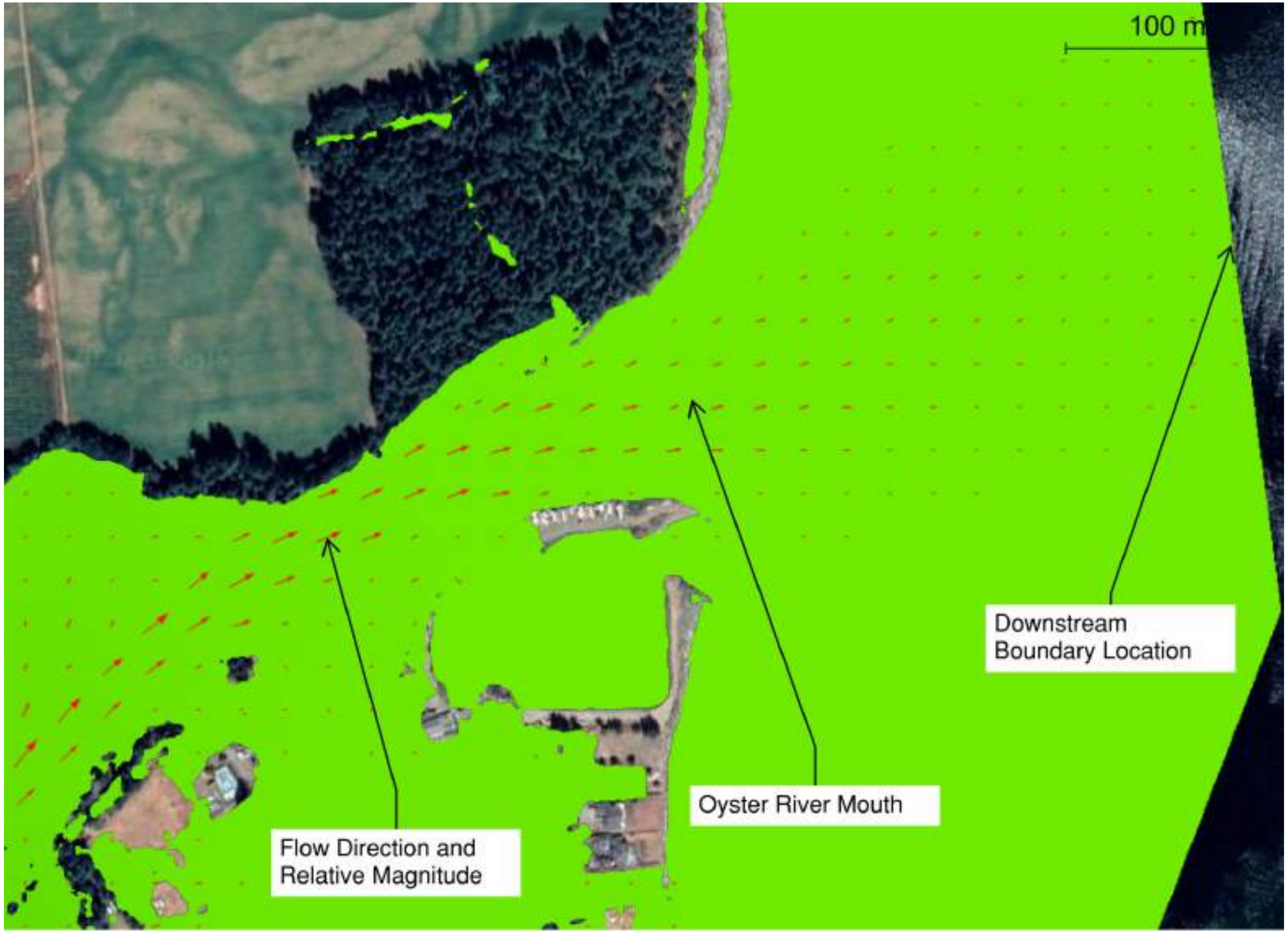
Oyster River Model Particle Flow Lines at Bridge Crossings

Figure 17



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Oyster River Flow Direction at Downstream Boundary (10% Flow and 0.5% Tide AEP)

Figure 18

5. Model Results

The 1D models were run for five AEP peak flows and 3 climate condition flows (15 model runs in total). The 2D models were run for five AEP peak flow/sea level combinations, 3 climate condition flows, 3 climate sea levels and 2 topographic extent/breach conditions (32 model runs in total). See Appendix C for a list of all model scenarios.

5.1 Mapping Products

The mapping products resulting from the model runs are described and presented in Technical Memorandum #5 – Coastal and Fluvial Mapping Products. Mapping produced from 2D model results was relatively straight-forward. However, mapping the flood extent from the 1D model of the Upper Oyster River required a process to ensure that backwatered side channel areas were assigned water elevations from the main channel location where the backwatered area connected to the main channel. The following procedure was developed to accomplish this:

1. Visually delineated the full width of the valley bottom based on the topography showing the location higher ground.
2. Manually created a flood contour polyline at each cross-section location, extending the full width of the valley.
3. Assigned the 1D modelled water level (or water level plus freeboard for regulatory mapping) value to each polyline.
4. Created a flood level surface raster from the polyline locations with elevations.
5. Created 0.5 m flood contour isolines throughout the surface.
6. Intersected flood level raster with topography raster to create a flooded areas (or flooded areas with freeboard) polygon.
7. Visually reviewed flood polygon and noted locations of what appear to be backwatered low spots separated by high ground from the river. Revised the alignment of the 0.5 m flood contour polylines to reflect the backwatering condition (extending 0.5 m polylines from location where the backwatered area is connected to main channel up and around the backwatered area).
8. Repeated Steps 3, 4, and 5 with updated 0.5 m flood contour isolines to create the updated flooded raster with lower water levels in the backwatered areas.
9. Intersected the updated flood level raster with the topography raster to create an updated flooded areas (or flooded areas with freeboard) raster. Removed floodplain flooded areas that are disconnected from the river flooded area (isolated pools of water).
10. From the raster created in Step 9, generated 1m flood contours for the with and without freeboard model results.

The above procedure was applied to the water level results of the 15 model runs noted above. The freeboard was added to the three-climate scenario 0.5% AEP flow models to produce the regulatory floodplain mapping and planning area limits.

The sections below provide results that are not included in the mapping products.

5.2 Upper Oyster River 1D Model Results

Water Level Profiles

The water level profiles in the upper portion of the Oyster River, modelled in 1D, are presented in the following figures and the chainage is shown in plan view on Figure 10:

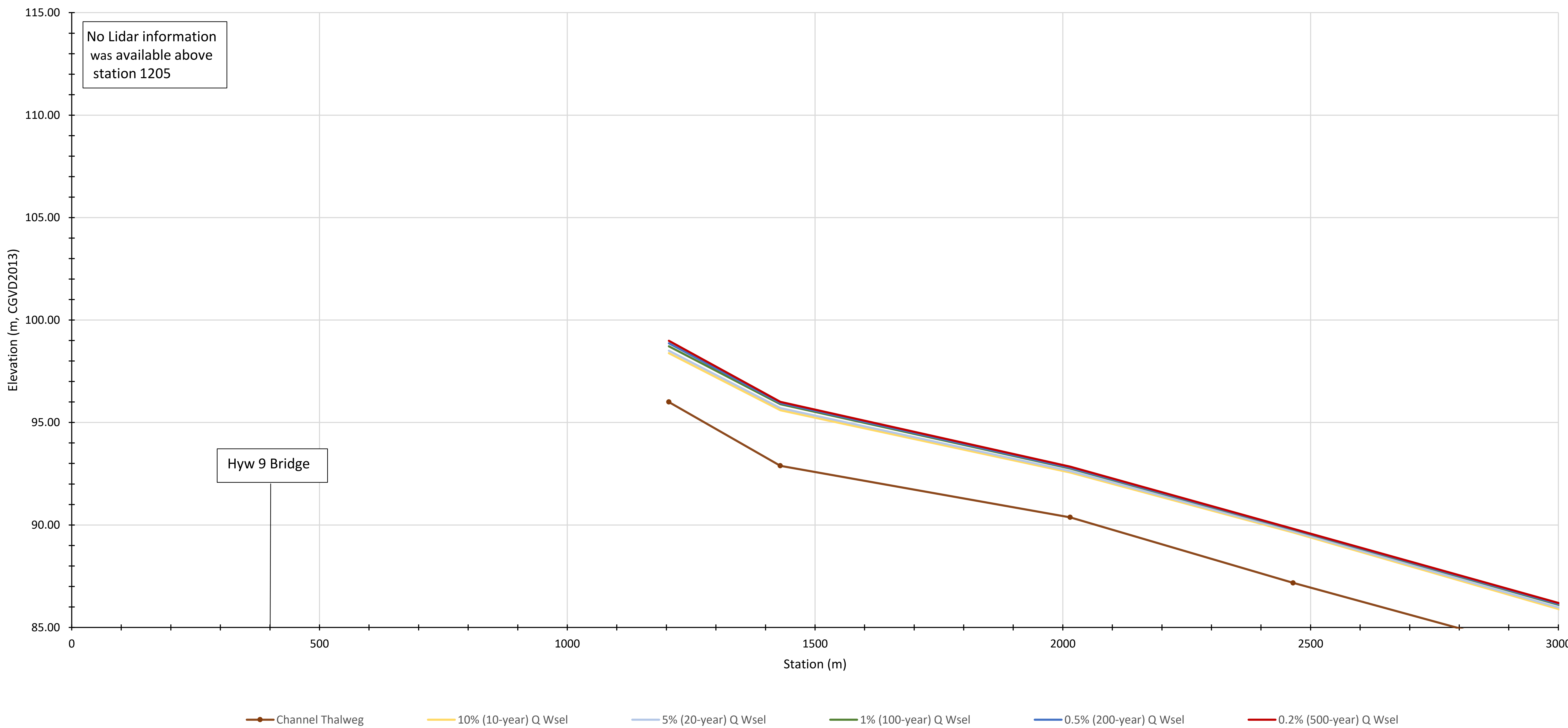
- Figures 19a to 19e: Current climate design flows
- Figures 20a to 20e: Nominally year 2050 and 2100 (+15% flow increase)
- Figures 21a to 21e: Nominally year 2200 (+30% flow increase)

Modelled Velocities

The velocities in the upper portion of the Oyster River, modelled in 1D, range between:

- 1.8 m/s to 5.7 m/s in the main channel
- 0.0 m/s to 1.6 m/s in the overbank areas

The highest velocity occurs in the channel near the upstream end of the model where the channel gradient is steepest. Tables 13, 14 ,and 15 show the modelled velocities for three climate scenarios (no climate change, 15% increase, and 30% increase respectively).



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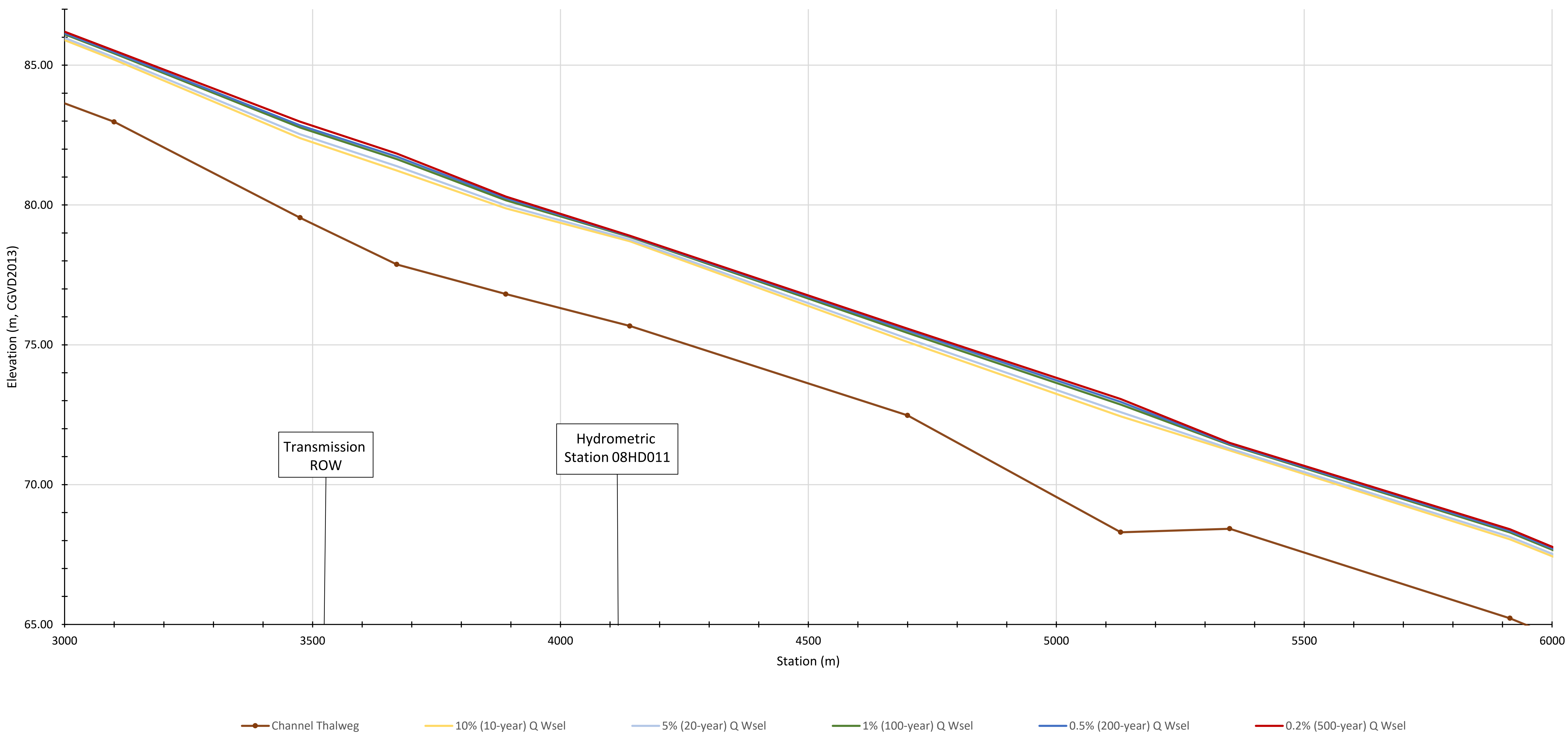
Scale	N/A

Upper Oyster Thalweg Water Surface Profile (No Climate Change)
Chainage 0 to 3000

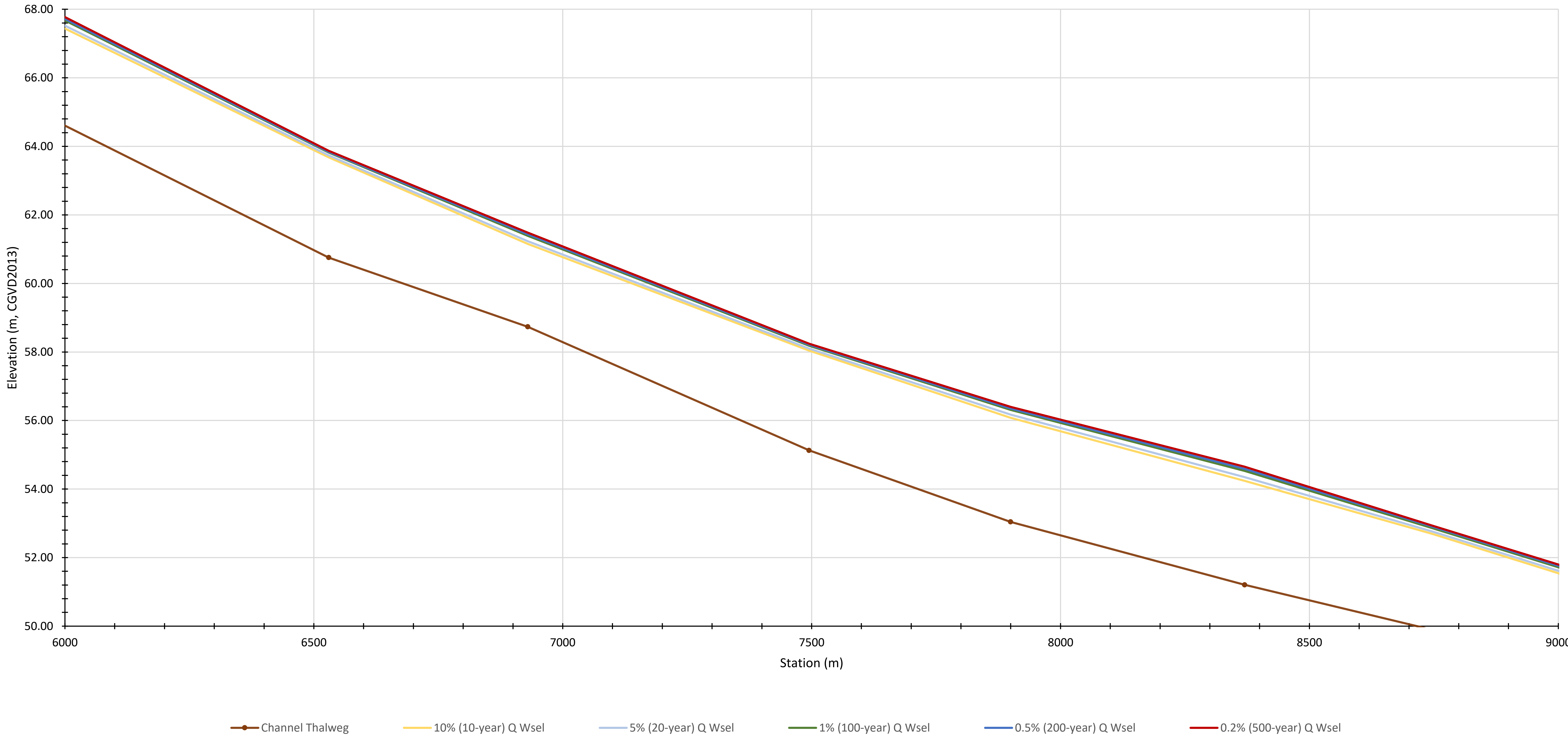
Figure 19a



Project No.	2623.014
Date	April 2021
Scale	N/A

Upper Oyster Thalweg Water Surface Profile (No Climate Change)
Chainage 3000 to 6000

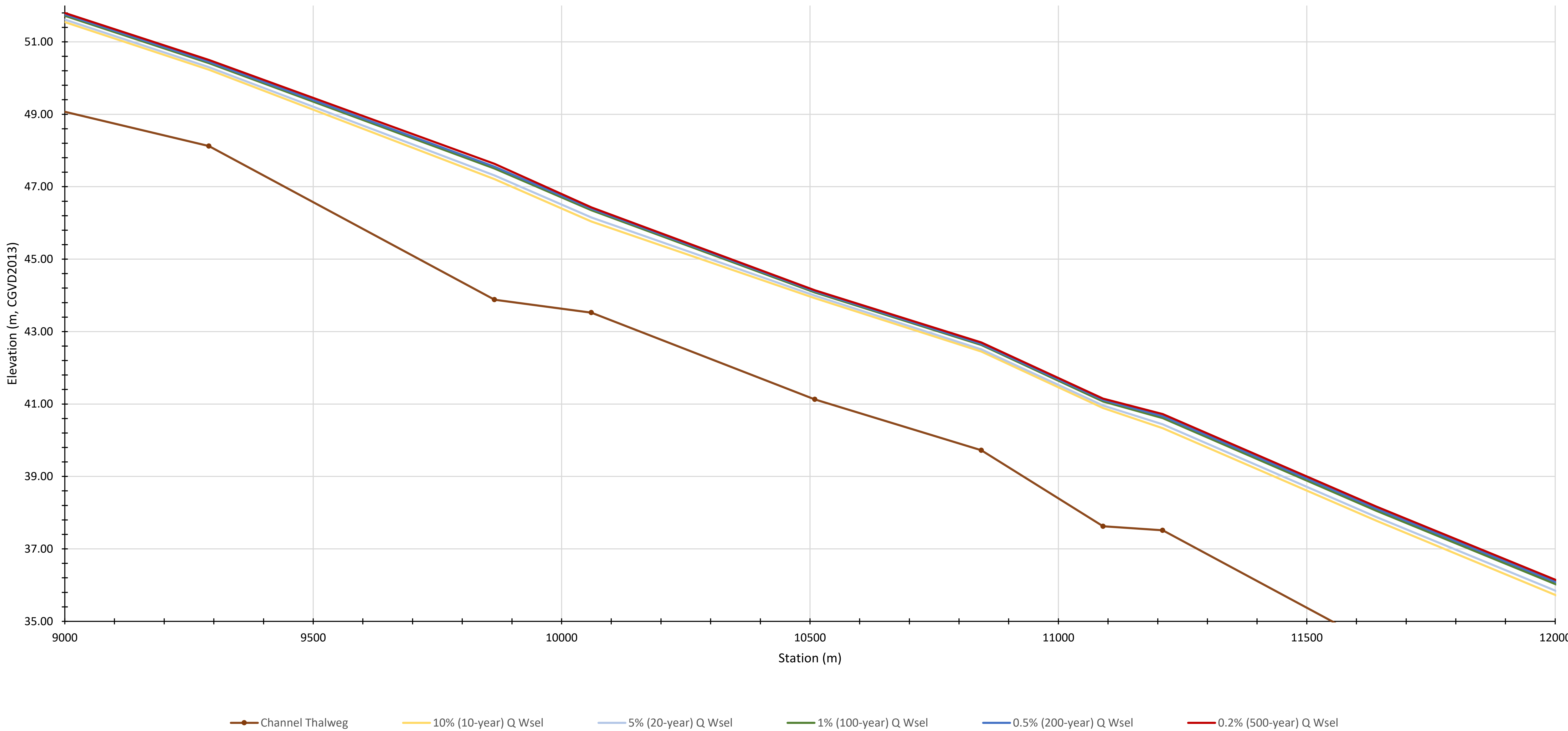
Figure 19b



Project No.	2623.014
Date	April 2021
Scale	N/A

Upper Oyster Thalweg Water Surface Profile (No Climate Change)
Chainage 6000 to 9000

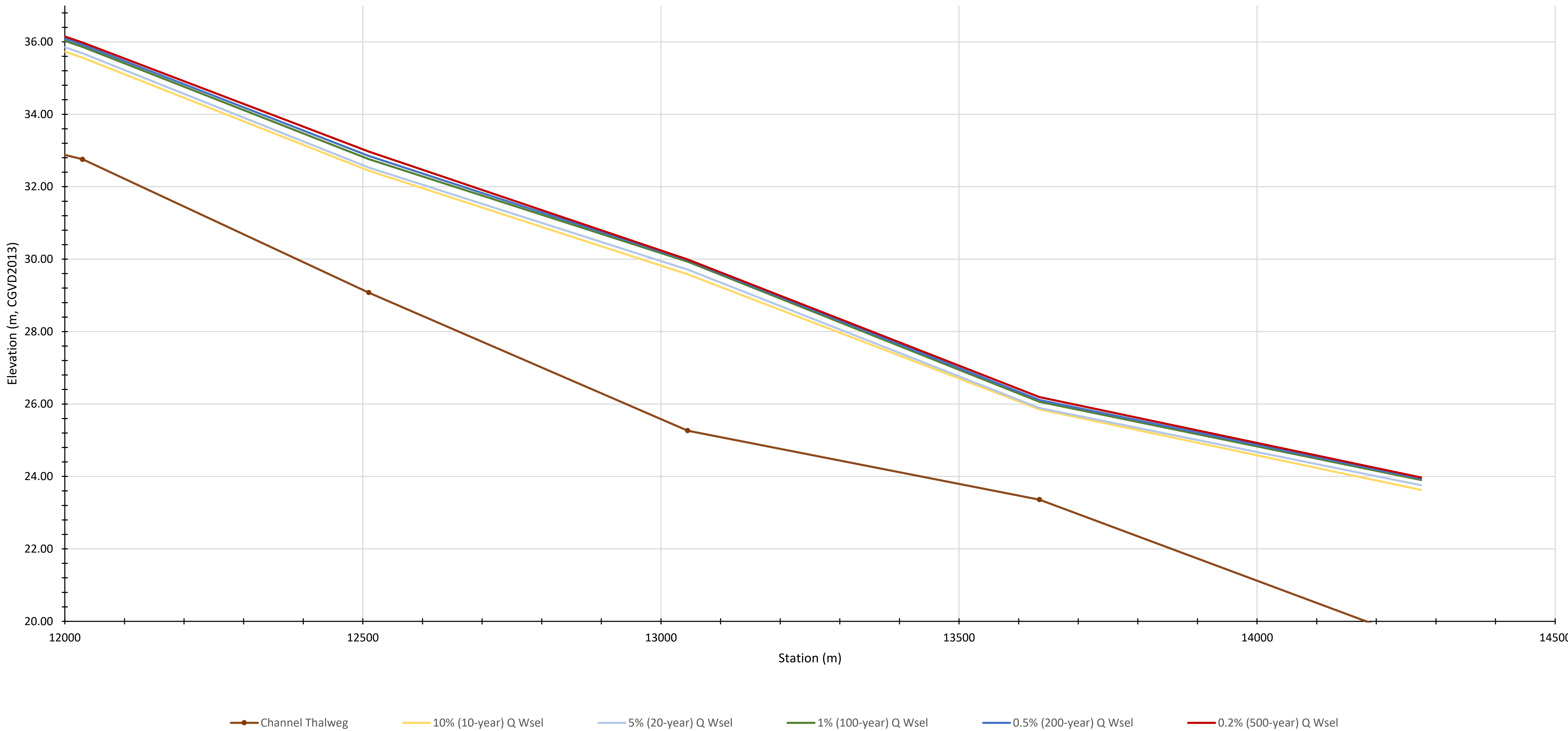
Figure 19c



Project No.	2623.014
Date	April 2021
Scale	N/A

Upper Oyster Thalweg Water Surface Profile (No Climate Change)
Chainage 9000 to 12000

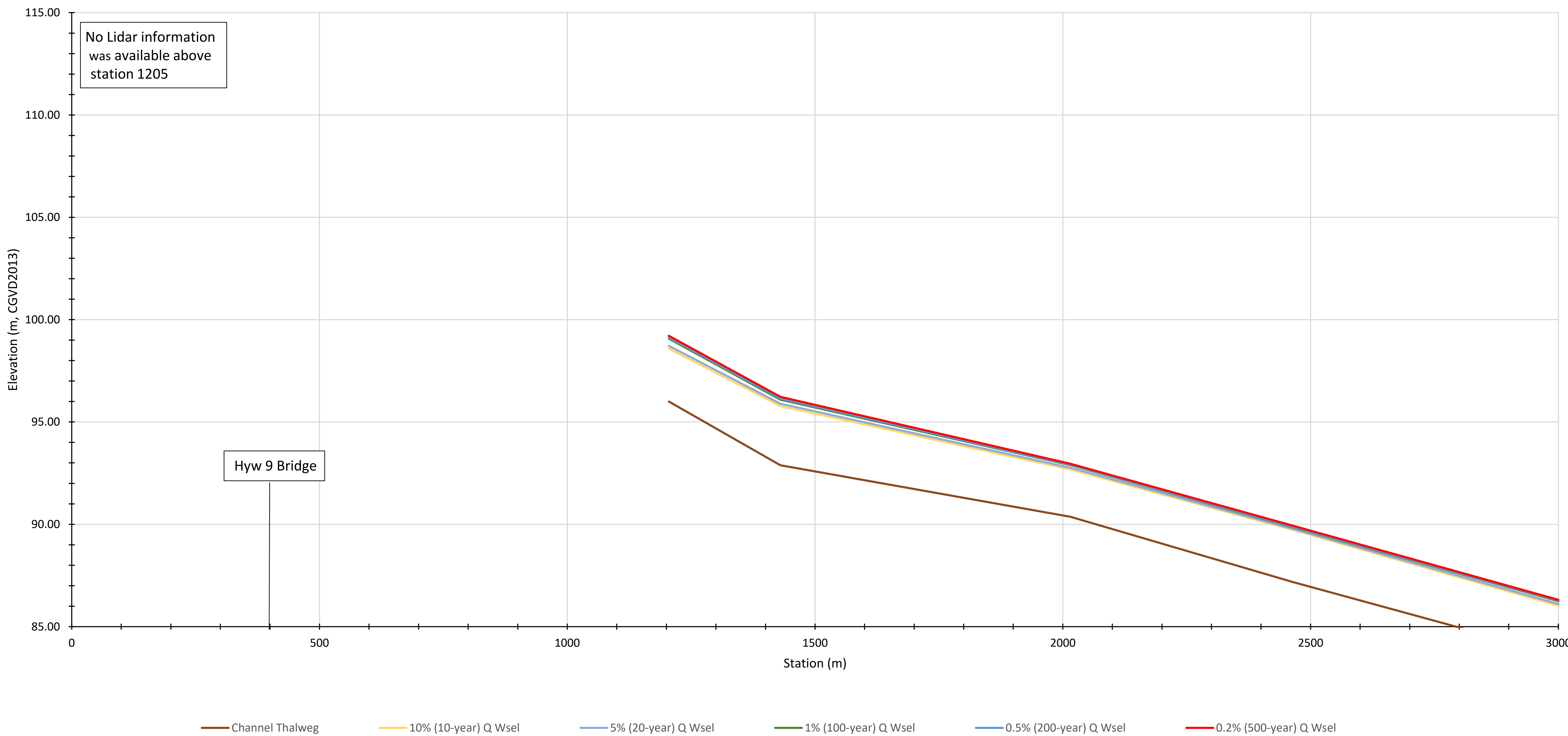
Figure 19d



Project No.	2623.014
Date	April 2021
Scale	N/A

Upper Oyster Thalweg Water Surface Profile (No Climate Change)
Chainage 12000 to 14500

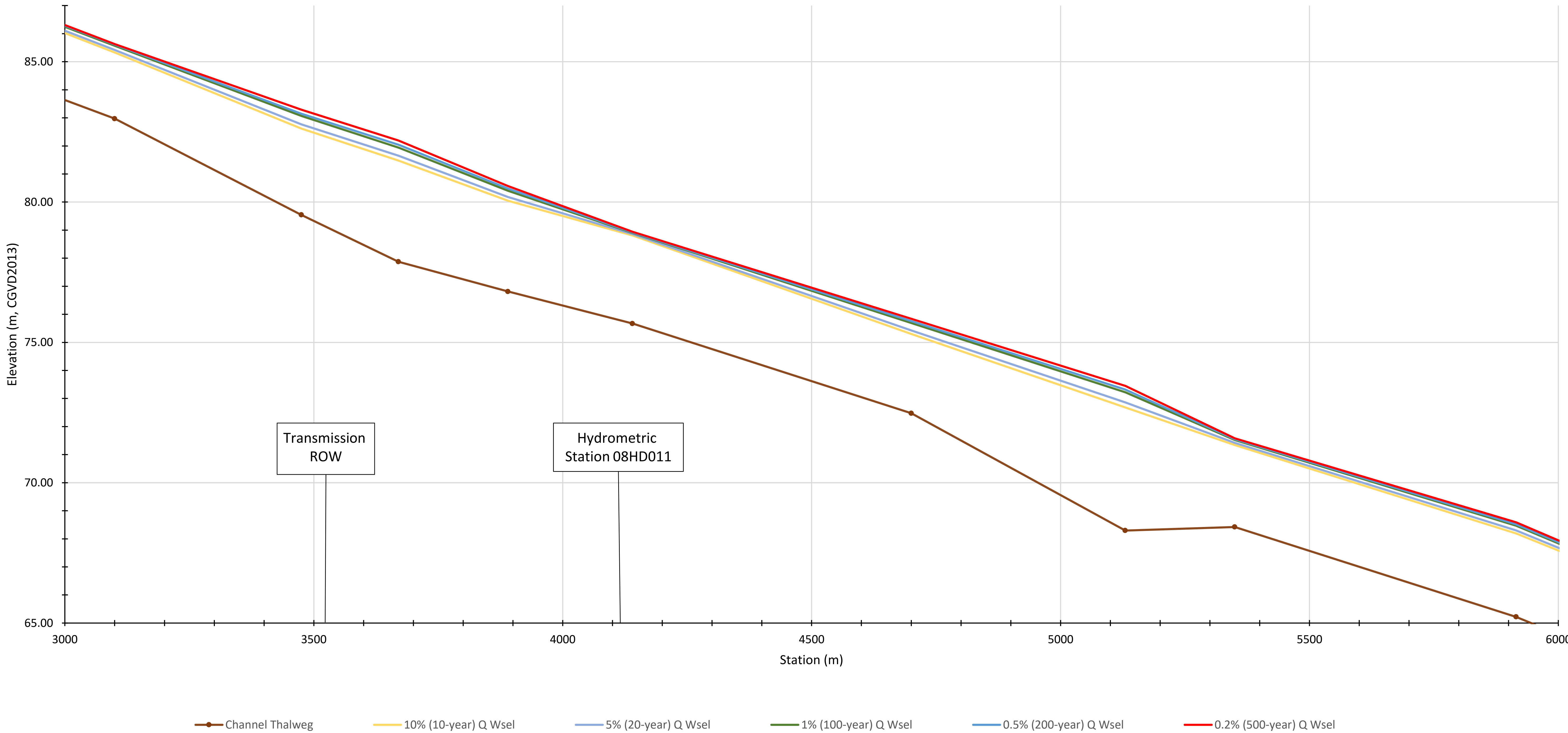
Figure 19e



Project No.	2623.014
Date	April 2021
Scale	N/A

Upper Oyster Thalweg Water Surface Profile (15% Climate Change)
Chainage 0 to 3000

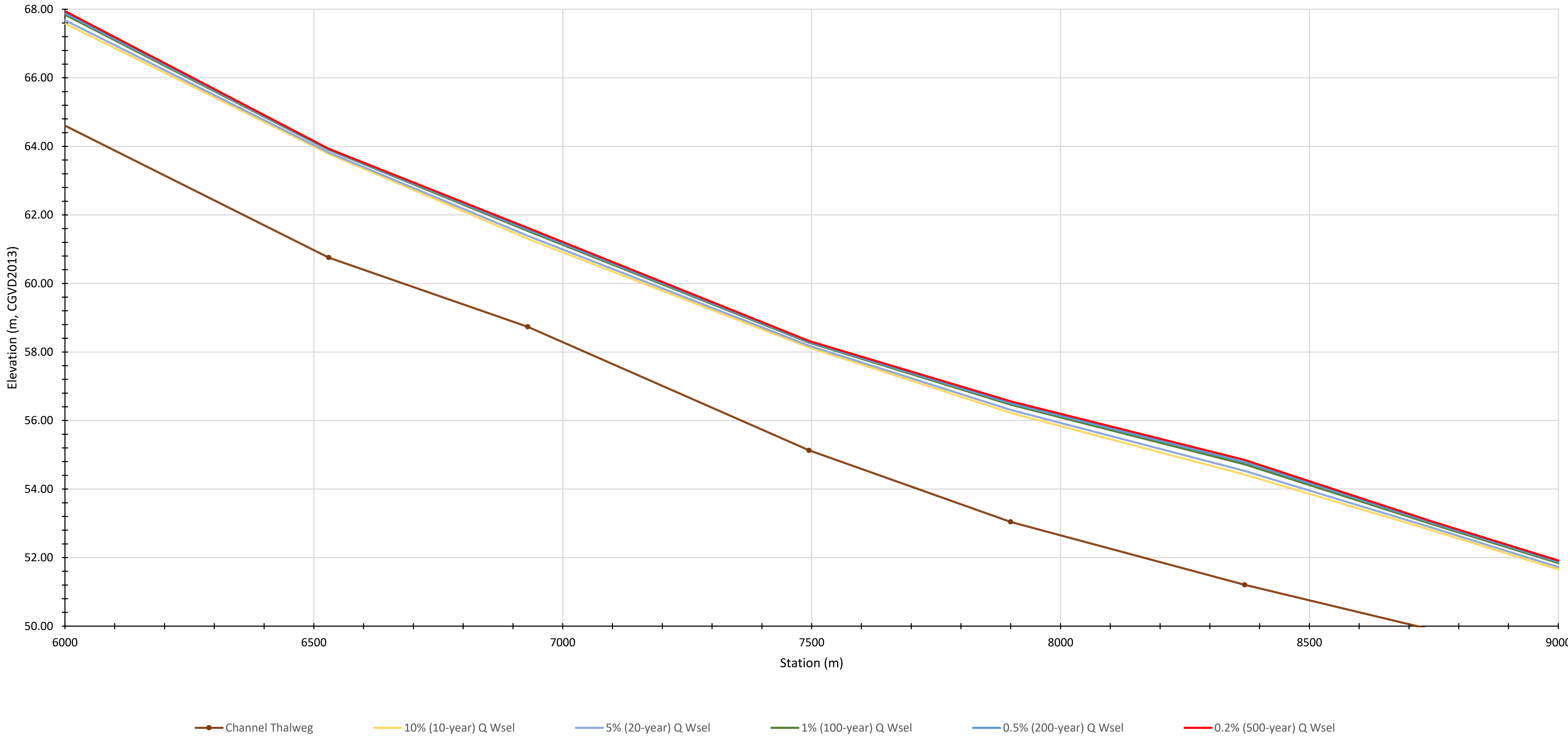
Figure 20a



Project No.	2623.014
Date	April 2021
Scale	N/A

Upper Oyster Thalweg Water Surface Profile (15% Climate Change)
Chainage 3000 to 6000

Figure 20b



Project No.	2623.014
Date	April 2021
Scale	N/A

Upper Oyster Thalweg Water Surface Profile (15% Climate Change)
Chainage 6000 to 9000

Figure 20c

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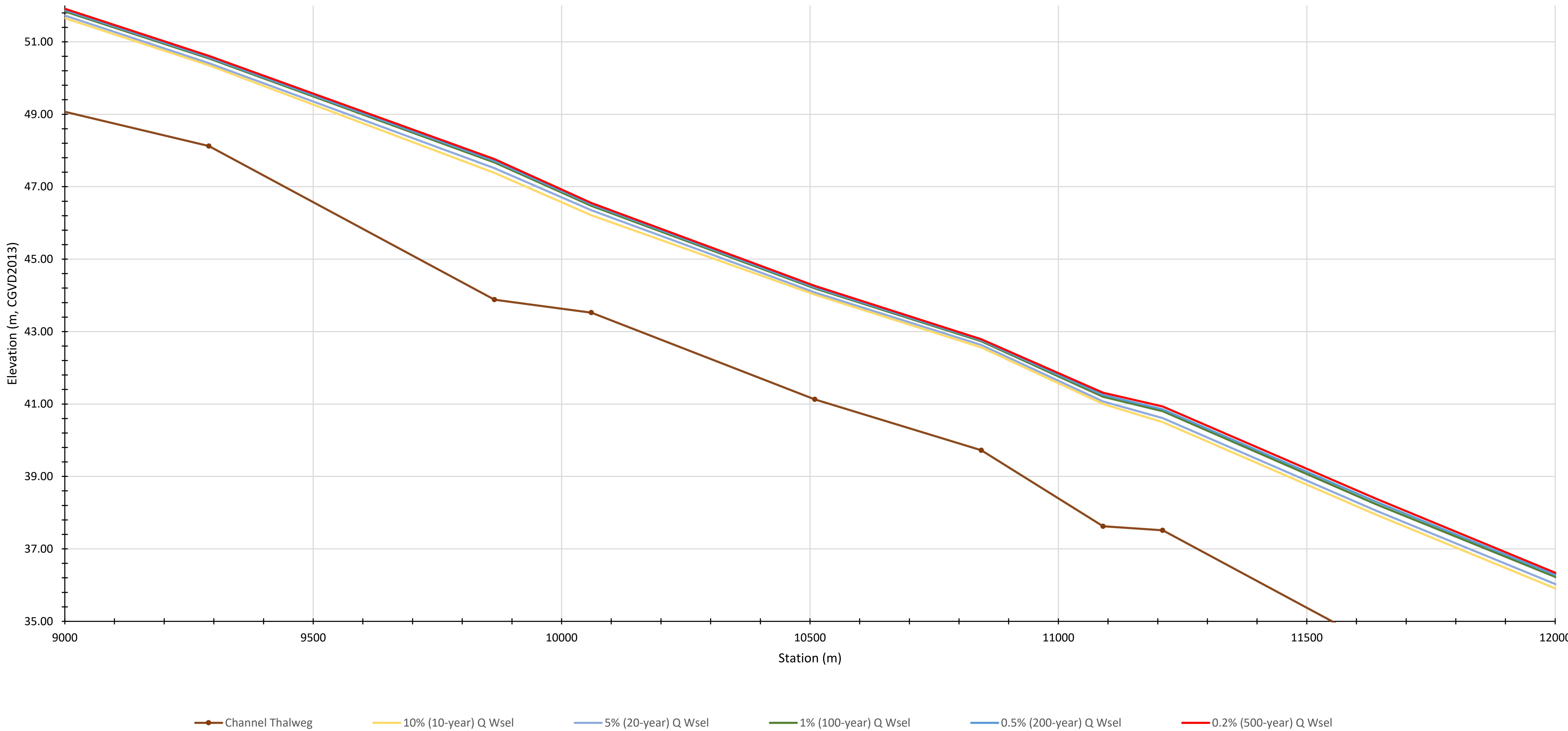
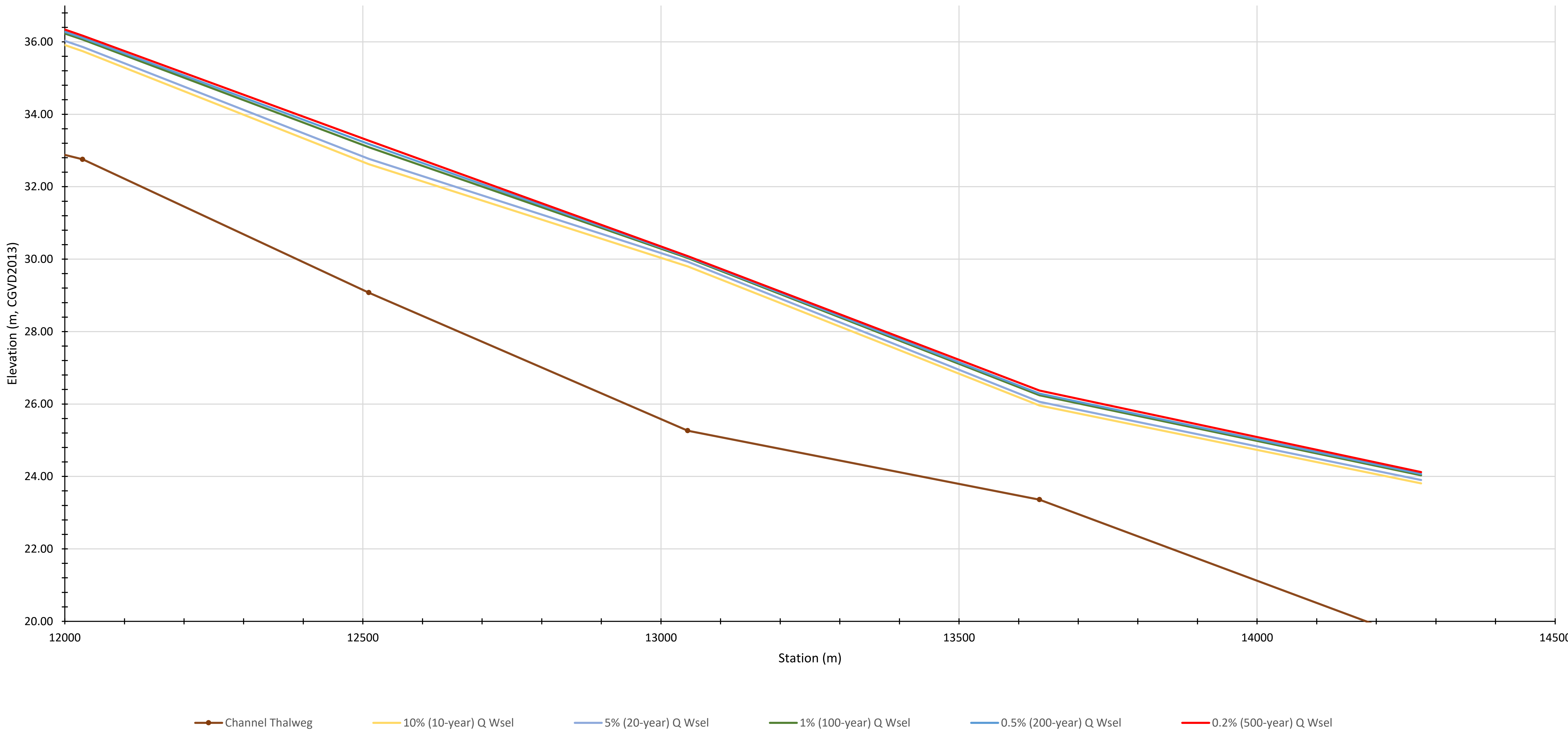


Project No.	2623.014
Date	April 2021
Scale	N/A

Upper Oyster Thalweg Water Surface Profile (15% Climate Change)
Chainage 9000 to 12000

Figure 20d



Project No.	2623.014
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Scale	N/A

Upper Oyster Thalweg Water Surface Profile (15% Climate Change)
Chainage 12000 to 14500

Figure 20e

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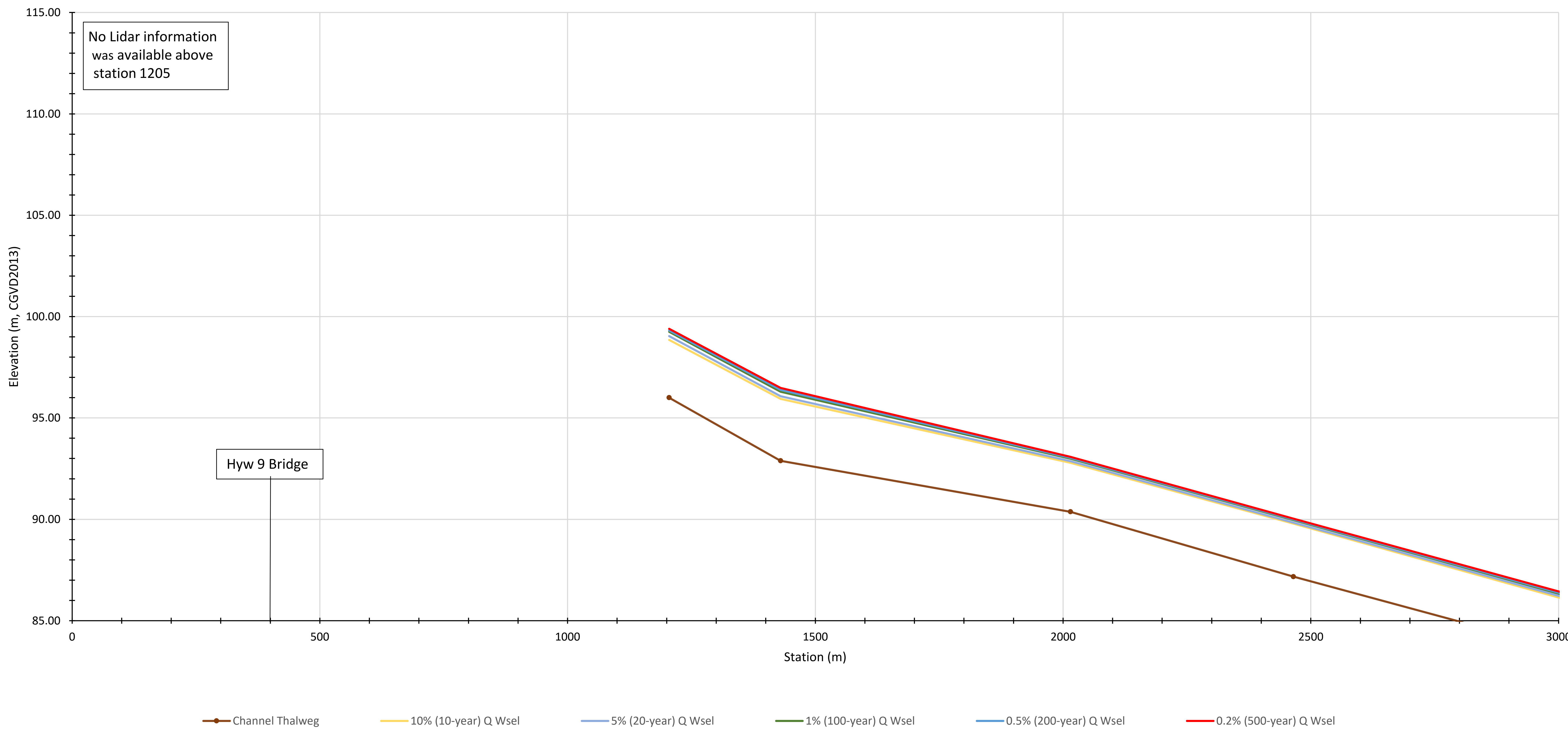
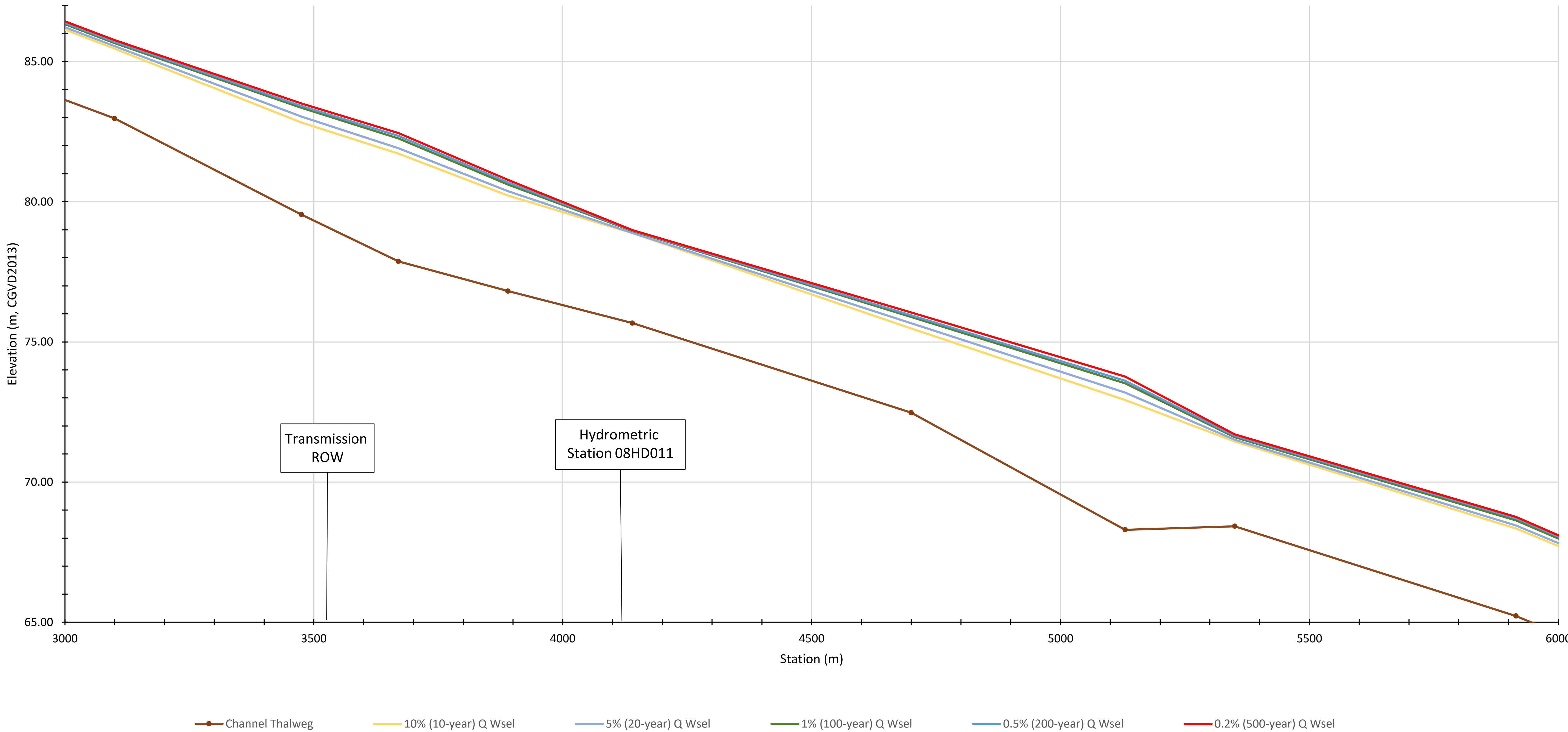


Project No.	2623.014
Date	April 2021
Scale	N/A

Upper Oyster Thalweg Water Surface Profile (30% Climate Change)
Chainage 0 to 3000

Figure 21a



Project No.	2623.014
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Scale	N/A

Upper Oyster Thalweg Water Surface Profile (30% Climate Change)
Chainage 3000 to 6000

Figure 21b

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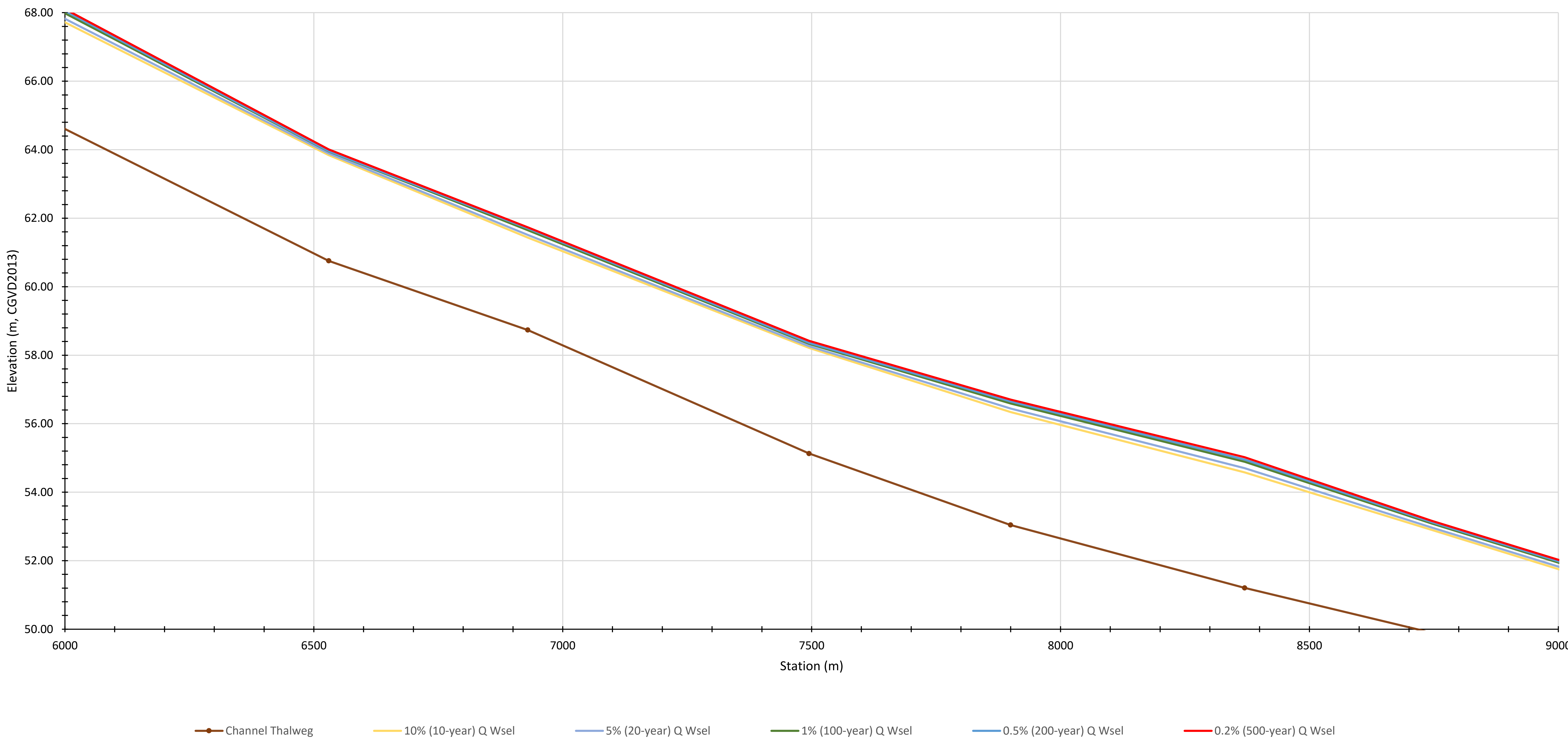

Project No.	2623.014
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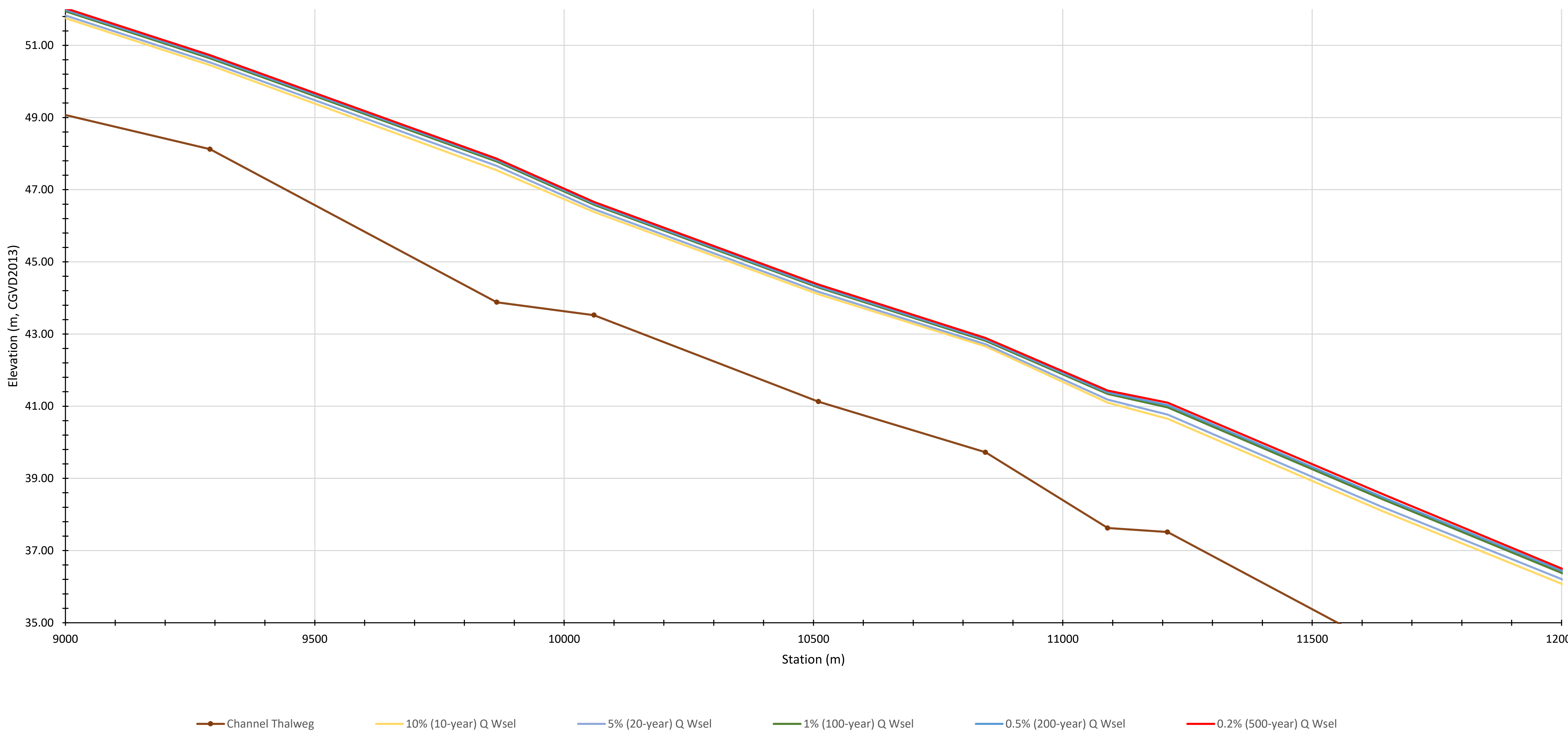
Scale	N/A

Upper Oyster Thalweg Water Surface Profile (30% Climate Change)
Chainage 6000 to 9000

Figure 21c



Project No.	2623.014
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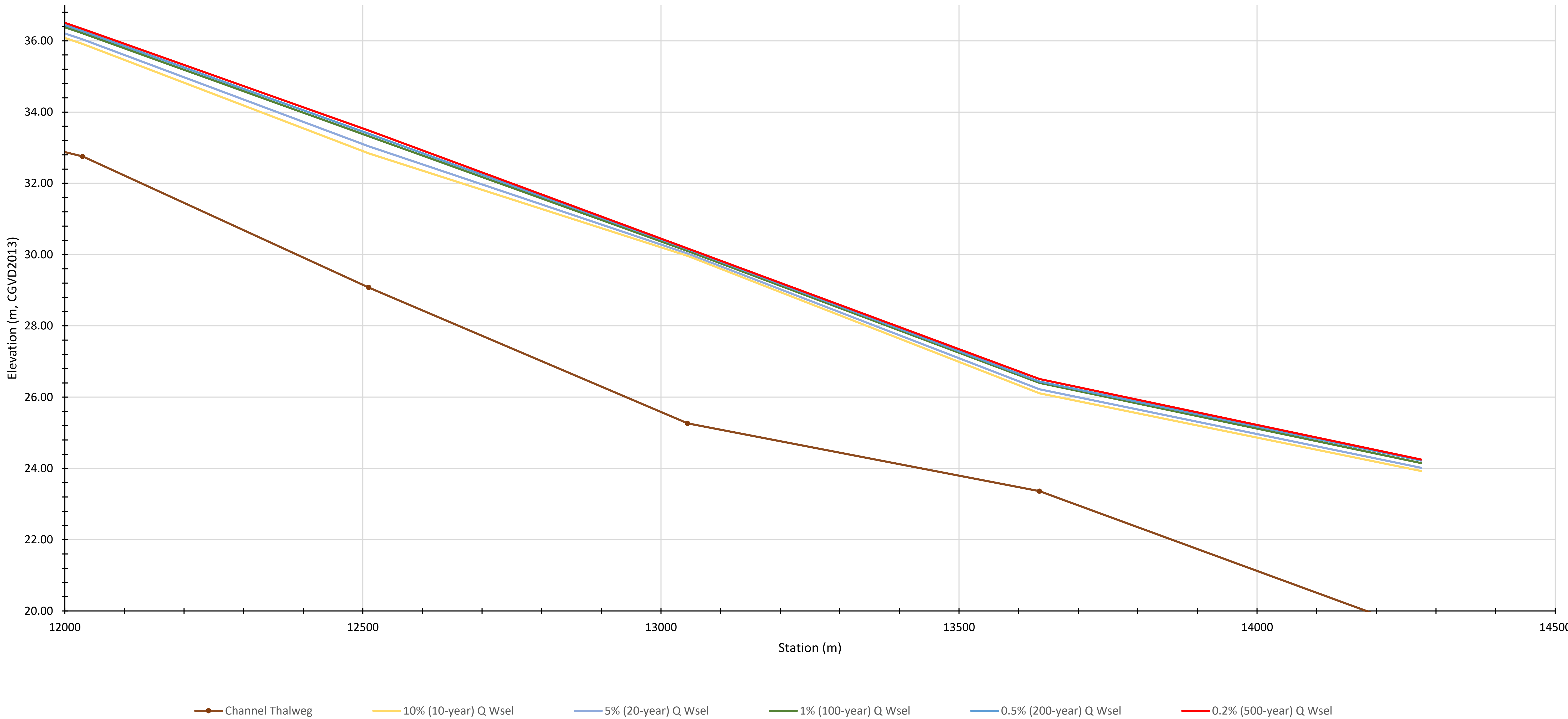
Scale	N/A

Upper Oyster Thalweg Water Surface Profile (30% Climate Change)
Chainage 9000 to 12000

Figure 21d



Project No.	2623.014
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Scale	N/A

Upper Oyster Thalweg Water Surface Profile (30% Climate Change)
Chainage 12000 to 14500

Figure 21e

Table 13: Upper Oyster River Modelled Velocities – No Climate Change

Chain-age	10% AEP			5% AEP			1% AEP			0.5% AEP			0.2% AEP		
	LB	Centre	RB	LB	Centre	RB	LB	Centre	RB	LB	Centre	RB	LB	Centre	RB
14275	0.48	1.84		0.49	1.84		0.53	1.95	0.03	0.55	1.99	0.04	0.57	2.05	0.06
13635	0.2	3.45	1.04	0.24	3.63	1.07	0.4	3.75	0.94	0.44	3.75	0.91	0.48	3.66	0.89
13045	0.5	2.75	0.88	0.54	2.78	0.87	0.6	2.77	0.83	0.62	2.82	0.85	0.65	2.91	0.88
12510	0.27	3.19	0.48	0.35	3.31	0.54	0.5	3.41	0.58	0.49	3.42	0.62	0.53	3.39	0.65
12030		2.39	0.24		2.45	0.3		2.58	0.36		2.62	0.4		2.66	0.43
11640		3.12	0.21		3.25	0.25		3.45	0.29		3.51	0.31		3.58	0.32
11210		2.09	0.85		2.08	0.94		2.07	1.05		2.07	1.08		2.07	1.11
11090	0.76	2.69	1.1	0.8	2.75	1.19	0.87	2.9	1.2	0.89	2.93	1.26	0.9	2.95	1.32
10845		2.35	0.78		2.38	0.85		2.42	0.97		2.43	1.01		2.46	1.05
10510	0.51	2.12	0.1	0.51	2.22	0.15	0.57	2.37	0.18	0.59	2.4	0.21	0.61	2.44	0.23
10060	0.68	2.66	0.76	0.68	2.66	0.76	0.63	2.64	0.74	0.65	2.65	0.74	0.67	2.66	0.72
9865	0.71	2.63	0.69	0.85	2.71	0.7	0.83	2.68	0.72	0.86	2.71	0.71	0.92	2.63	0.74
9290	0.61	2.11	0.56	0.62	2.13	0.58	0.62	2.17	0.61	0.6	2.19	0.62	0.61	2.19	0.63
8745	0.77	2.41	0.53	0.81	2.52	0.58	0.86	2.69	0.65	0.87	2.75	0.67	0.89	2.82	0.69
8370	0.26	2.24	0.26	0.3	2.31	0.32	0.35	2.44	0.39	0.38	2.48	0.42	0.41	2.52	0.45
7900	0.7	2.48	0.4	0.71	2.52	0.43	0.76	2.55	0.47	0.76	2.56	0.49	0.78	2.57	0.5
7495	0.43	2.73	0.44	0.48	2.86	0.47	0.56	3.09	0.53	0.58	3.15	0.55	0.61	3.24	0.57
6930	0.63	1.97	0.42	0.64	1.96	0.46	0.58	1.94	0.52	0.6	1.94	0.54	0.6	1.94	0.55
6530		2.5			2.61			2.83			2.9			2.99	
5915	0.02	2.73	0.63	0.1	2.76	0.66	0.18	2.83	0.68	0.2	2.84	0.69	0.22	2.86	0.71
5350		3	0.25		3.18	0.28		3.45	0.29		3.54	0.31		3.66	0.33
5130		2.73			2.83			2.97			2.99			3.03	
4700	0.92	3.33	0.19	0.93	3.33	0.26	0.88	3.31	0.37	0.81	3.28	0.4	0.81	3.27	0.41
4140	0.45	2.5	0.48	0.5	2.6	0.52	0.58	2.79	0.59	0.61	2.87	0.62	0.64	2.95	0.64
3890		3.11			3.25			3.47			3.53			3.61	
3670		2.88			2.96			3.09		0.05	3.12		0.09	3.15	
3475		3.02	0.38		3.08	0.48	0.08	3.17	0.63	0.15	3.19	0.66	0.29	3.15	0.67
3100	0.74	2.44	0.54	0.78	2.48	0.6	0.84	2.54	0.69	0.8	2.57	0.73	0.8	2.58	0.75
2465	0.89	2.33	0.67	0.92	2.41	0.68	0.98	2.58	0.77	1	2.63	0.8	1.02	2.7	0.83
2015		1.83	0.7		1.86	0.72		1.92	0.74		1.94	0.75		1.96	0.75
1430		4.1			4.21			4.37			4.43			4.5	
1205		2.98			3.06			3.2			3.13			3.08	
625		4.18			4.31			4.52			4.52			4.57	
250		4.51			4.68			4.95			5.08			5.2	
0		3.43			3.51			3.63			3.66			3.7	

Table 14: Upper Oyster River Modelled Velocities – +15% Flow Climate Change

Chain-age	10% AEP			5% AEP			1% AEP			0.5% AEP			0.2% AEP		
	LB	Centre	RB	LB	Centre	RB	LB	Centre	RB	LB	Centre	RB	LB	Centre	RB
14275	0.51	1.89		0.53	1.95	0.03	0.58	2.08	0.08	0.60	2.12	0.09	0.60	2.19	0.11
13635	0.29	3.68	1.00	0.40	3.75	0.93	0.51	3.67	0.89	0.53	3.63	0.89	0.53	3.55	0.87
13045	0.57	2.74	0.86	0.60	2.77	0.84	0.67	2.97	0.89	0.69	3.05	0.92	0.72	3.16	0.95
12510	0.41	3.36	0.56	0.51	3.41	0.59	0.57	3.36	0.71	0.62	3.35	0.74	0.66	3.36	0.77
12030		2.50	0.32		2.58	0.37		2.71	0.47		2.76	0.50		2.83	0.53
11640		3.32	0.24		3.45	0.29		3.66	0.35		3.72	0.37		3.78	0.38
11210		2.08	0.99		2.07	1.05		2.08	1.11		2.08	1.13		2.10	1.09
11090	0.82	2.80	1.23	0.87	2.90	1.21	0.92	2.96	1.38	0.93	2.98	1.42	0.94	2.96	1.46
10845		2.40	0.89		2.42	0.97		2.49	1.10		2.51	1.14		2.56	1.18
10510	0.53	2.27	0.17	0.57	2.37	0.18	0.63	2.48	0.24	0.65	2.52	0.27	0.67	2.55	0.30
10060	0.70	2.64	0.76	0.63	2.64	0.74	0.69	2.70	0.70	0.70	2.72	0.70	0.72	2.76	0.70
9865	0.83	2.71	0.70	0.83	2.68	0.72	0.96	2.65	0.76	0.99	2.67	0.78	1.02	2.70	0.80
9290	0.62	2.13	0.59	0.62	2.18	0.61	0.62	2.21	0.64	0.63	2.23	0.65	0.64	2.25	0.67
8745	0.83	2.59	0.60	0.86	2.69	0.65	0.90	2.89	0.72	0.91	2.94	0.74	0.92	3.00	0.77
8370	0.32	2.36	0.35	0.35	2.44	0.39	0.43	2.57	0.48	0.42	2.61	0.50	0.45	2.66	0.53
7900	0.73	2.53	0.44	0.76	2.55	0.47	0.79	2.58	0.52	0.80	2.59	0.53	0.81	2.60	0.54
7495	0.52	2.94	0.49	0.56	3.09	0.53	0.64	3.33	0.60	0.67	3.41	0.62	0.69	3.51	0.64
6930	0.58	1.96	0.49	0.58	1.94	0.52	0.61	1.95	0.56	0.62	1.95	0.57	0.63	1.96	0.58
6530		2.68			2.83			3.08			3.17			3.28	
5915	0.13	2.79	0.68	0.18	2.83	0.68	0.24	2.87	0.72	0.25	2.88	0.73	0.27	2.89	0.74
5350		3.27	0.27		3.45	0.29		3.79	0.36		3.91	0.38		4.04	0.40
5130		2.89			2.97			3.02			3.04			3.06	
4700	0.91	3.34	0.30	0.88	3.31	0.37	0.80	3.17	0.44	0.80	3.15	0.45	0.81	3.12	0.49
4140	0.53	2.66	0.55	0.58	2.79	0.60	0.67	3.10	0.68	0.70	3.20	0.70	0.74	3.31	0.74
3890		3.34			3.47			3.66			3.71			3.78	
3670		3.01			3.09		0.15	3.20		0.21	3.23		0.28	3.20	
3475		3.11	0.54	0.08	3.17	0.63	0.34	3.18	0.66	0.38	3.19	0.65	0.43	3.15	0.61
3100	0.81	2.51	0.64	0.84	2.54	0.70	0.82	2.62	0.79	0.84	2.66	0.81	0.87	2.73	0.85
2465	0.94	2.47	0.71	0.98	2.58	0.77	1.03	2.75	0.87	1.04	2.79	0.89	1.03	2.81	0.92
2015		1.89	0.73		1.92	0.74		1.99	0.76		2.01	0.77		2.05	0.79
1430		4.27			4.38			4.56			4.62		0.07	4.67	
1205		3.12			3.20			3.13			3.17			3.22	
625		4.38			4.53			4.67			4.76			4.87	
250		4.78			4.95			5.29			5.36			5.45	
0		3.56			3.63			3.75			3.79			3.84	

Table 15: Upper Oyster River Modelled Velocities – +30% Flow Climate Change

Chain-age	10% AEP			5% AEP			1% AEP			0.5% AEP			0.2% AEP		
	LB	Centre	RB	LB	Centre	RB	LB	Centre	RB	LB	Centre	RB	LB	Centre	RB
14275	0.55	1.99	0.04	0.57	2.06	0.07	0.61	2.22	0.12	0.62	2.24	0.13	0.65	2.31	0.15
13635	0.44	3.73	0.91	0.51	3.69	0.89	0.53	3.53	0.87	0.54	3.57	0.89	0.53	3.50	0.88
13045	0.62	2.82	0.85	0.66	2.94	0.88	0.74	3.22	0.97	0.76	3.27	0.98	0.79	3.38	1.01
12510	0.48	3.42	0.61	0.56	3.38	0.69	0.69	3.38	0.79	0.72	3.44	0.81	0.76	3.46	0.81
12030		2.61	0.39		2.69	0.46		2.88	0.55		2.92	0.59		2.99	0.62
11640		3.50	0.30		3.64	0.34		3.82	0.40		3.88	0.44		3.94	0.49
11210		2.07	1.08		2.07	1.12		2.10	1.12		2.09	1.15		2.09	1.17
11090	0.88	2.92	1.25	0.91	2.97	1.36	0.95	2.98	1.49	0.96	3.01	1.52	0.98	3.03	1.55
10845		2.43	1.00		2.48	1.08		2.58	1.21		2.60	1.25		2.62	1.30
10510	0.58	2.40	0.20	0.62	2.47	0.24	0.68	2.58	0.30	0.71	2.63	0.32	0.73	2.68	0.35
10060	0.64	2.64	0.74	0.68	2.68	0.71	0.74	2.78	0.70	0.75	2.81	0.70	0.78	2.84	0.70
9865	0.86	2.70	0.71	0.95	2.64	0.76	1.04	2.73	0.82	1.06	2.78	0.83	1.09	2.83	0.85
9290	0.62	2.18	0.62	0.62	2.20	0.64	0.65	2.26	0.67	0.66	2.28	0.69	0.67	2.30	0.70
8745	0.87	2.74	0.67	0.90	2.87	0.71	0.93	3.04	0.79	0.94	3.10	0.81	0.95	3.17	0.84
8370	0.38	2.47	0.41	0.43	2.55	0.47	0.46	2.69	0.55	0.44	2.74	0.58	0.47	2.79	0.61
7900	0.76	2.56	0.49	0.79	2.58	0.51	0.81	2.60	0.55	0.82	2.61	0.56	0.83	2.62	0.57
7495	0.58	3.14	0.55	0.63	3.30	0.59	0.72	3.58	0.66	0.73	3.68	0.68	0.77	3.68	0.69
6930	0.59	1.94	0.53	0.61	1.95	0.56	0.63	1.97	0.59	0.64	1.97	0.60	0.66	2.01	0.62
6530		2.89			3.05			3.35			3.47			3.53	
5915	0.19	2.84	0.69	0.23	2.86	0.72	0.28	2.90	0.75	0.30	2.92	0.72	0.32	2.96	0.73
5350		3.53	0.31		3.75	0.35		4.13	0.42		4.24	0.44		4.36	0.47
5130		3.00			3.00			3.08			3.12			3.12	
4700	0.85	3.30	0.40	0.79	3.17	0.43	0.81	3.12	0.50	0.82	3.11	0.53	0.81	3.06	0.56
4140	0.60	2.85	0.61	0.66	3.08	0.67	0.76	3.36	0.75	0.79	3.46	0.78	0.83	3.59	0.82
3890		3.53			3.63			3.83			3.90			3.97	
3670	0.04	3.12		0.13	3.18		0.33	3.22		0.39	3.26		0.45	3.30	
3475	0.15	3.19	0.66	0.34	3.17	0.66	0.46	3.16	0.61	0.48	3.19	0.59	0.45	3.22	0.62
3100	0.79	2.57	0.72	0.81	2.61	0.78	0.89	2.76	0.87	0.91	2.79	0.90	0.92	2.82	0.93
2465	0.99	2.62	0.79	1.03	2.74	0.86	1.04	2.84	0.95	1.03	2.90	0.98	1.04	2.96	1.01
2015		1.94	0.75		1.98	0.76		2.07	0.80		2.09	0.80		2.12	0.82
1430		4.42			4.53		0.15	4.69		0.26	4.70		0.34	4.72	
1205		3.12			3.12			3.25			3.31			3.35	
625		4.51			4.63			4.94			5.03			5.14	
250		5.07			5.27			5.50			5.59			5.68	
0		3.65			3.73			3.87			3.91			3.96	

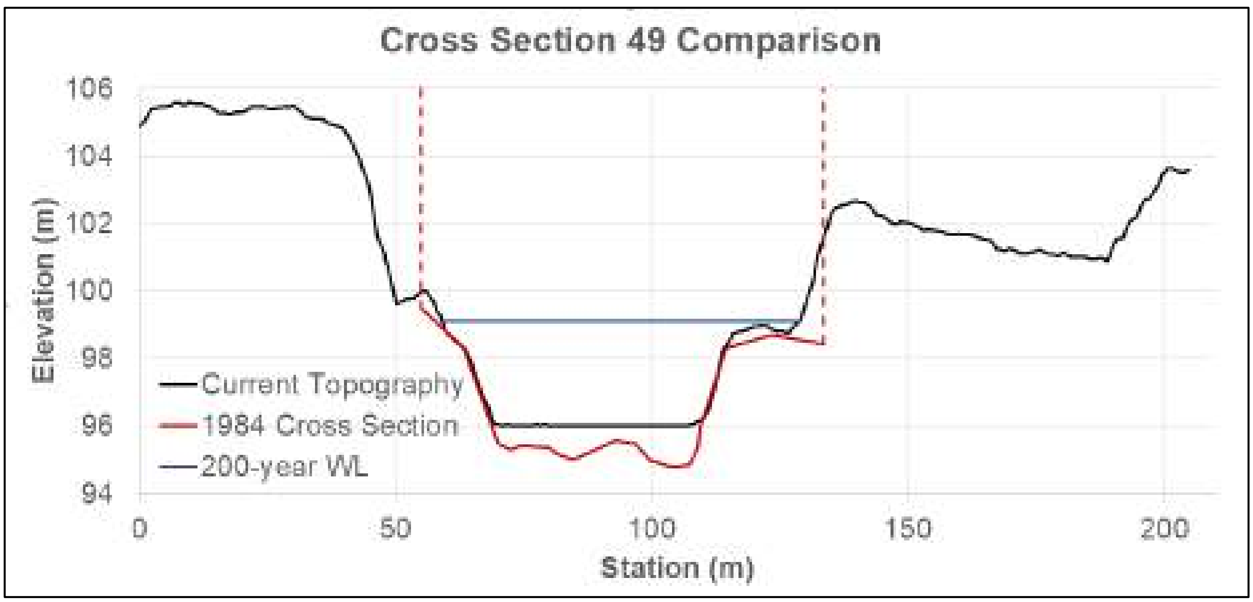
Comparison with Previous FP Mapping

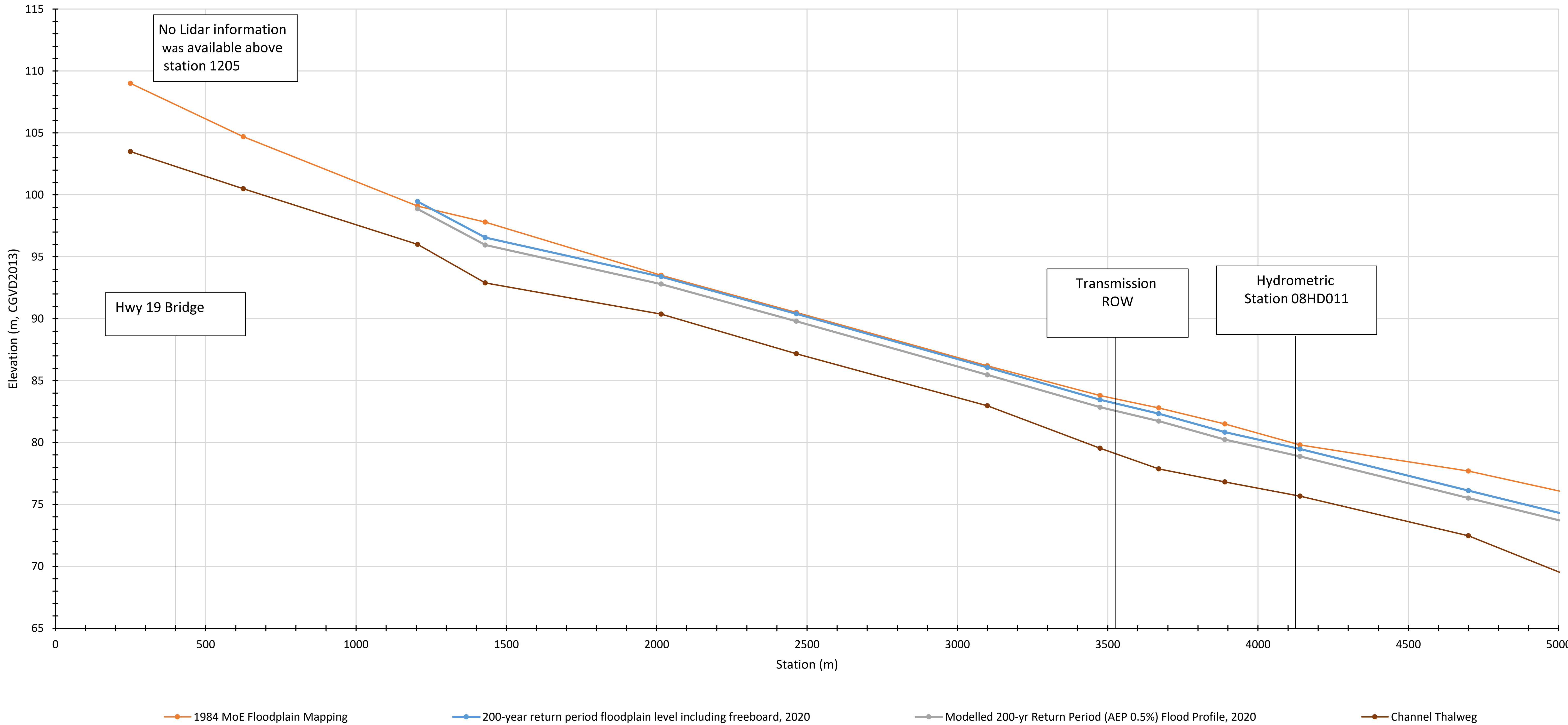
As no recent peak water level data is available to calibrate the hydraulic models for the Oyster River, a sensitivity/verification approach was used to verify the uncertainty of the model results. This involved running the models for the 0.5% AEP (200-year return period) event for current climate conditions and comparing the results with the previous MoE (1984) floodplain mapping elevations.

The historical MoE floodplain mapping elevations contain water levels with a freeboard allowance. To directly compare results between the 1D hydraulic model and historical MoE floodplain mapping elevations, a freeboard allowance of 0.6 m was added to the current climate model water level results. Up-to-date guidance from EGBC Flood Mapping in BC Professional Practice Guideline (2017) recommends 0.3 m to 0.6 m freeboard allowance be added to modelled water surface profile to account for model uncertainty and future changes in river channel conditions.

Figures 22a to 22c show the profile comparison and Figure 13 shows the chainage in plan view. In general, the modelled 0.5% AEP water levels plus 0.6 m freeboard compare well with the original 0.5% AEP floodplain level. There are locations where the current profile is up to 1.35 m higher than, and other locations where it is up to 1.84 m lower than, the 1984 MoE profile.

The largest increase in flood level occurs at chainage 1205 (XS 49). The 1984 surveyed cross section at this location has a lower invert elevation and a larger cross sectional conveyance area below the flood level (see comparison image below). A comparison of the current and 1984 cross sections at the next cross section downstream (XS 48) shows little difference in invert elevation and conveyance area.

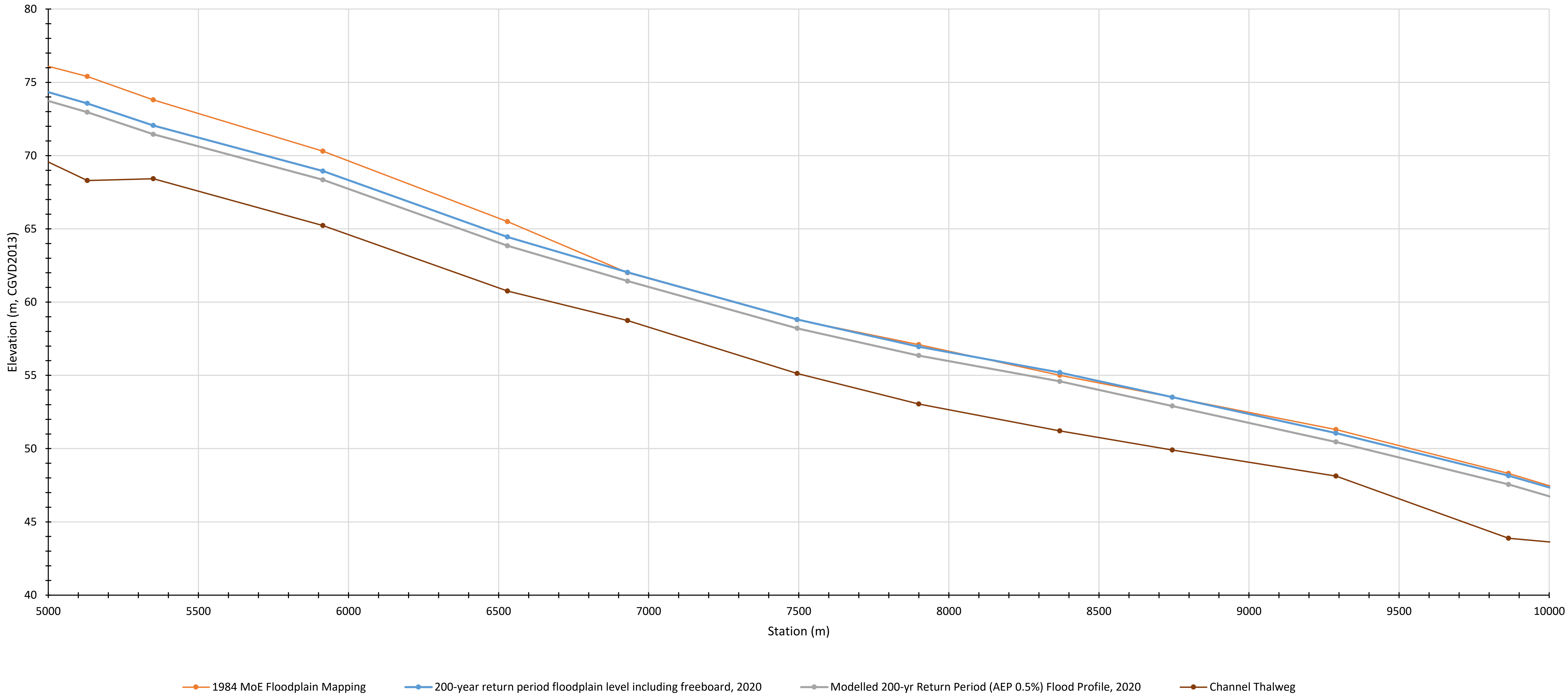




Project No.	2623.014
Date	April 2021
Scale	N/A

Upper Oyster River 0.5% AEP Flood Profile Comparison (No Climate Change) Station 0 to 5,000

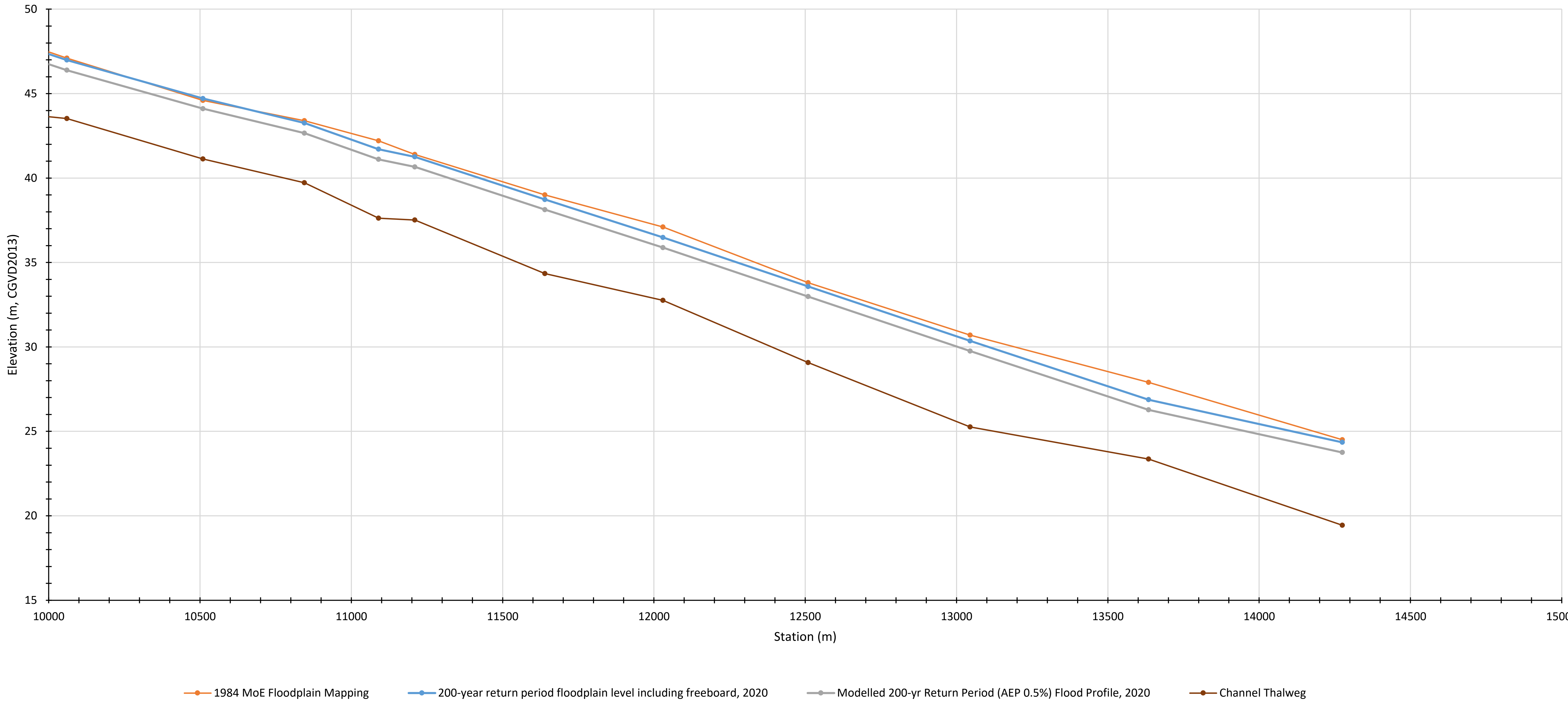
Figure 22a



Project No.	2623.014
Date	April 2021
Scale	N/A

Upper Oyster River 0.5% AEP Flood Profile Comparison (No Climate Change) Station 5,000 to 10,000

Figure 22b

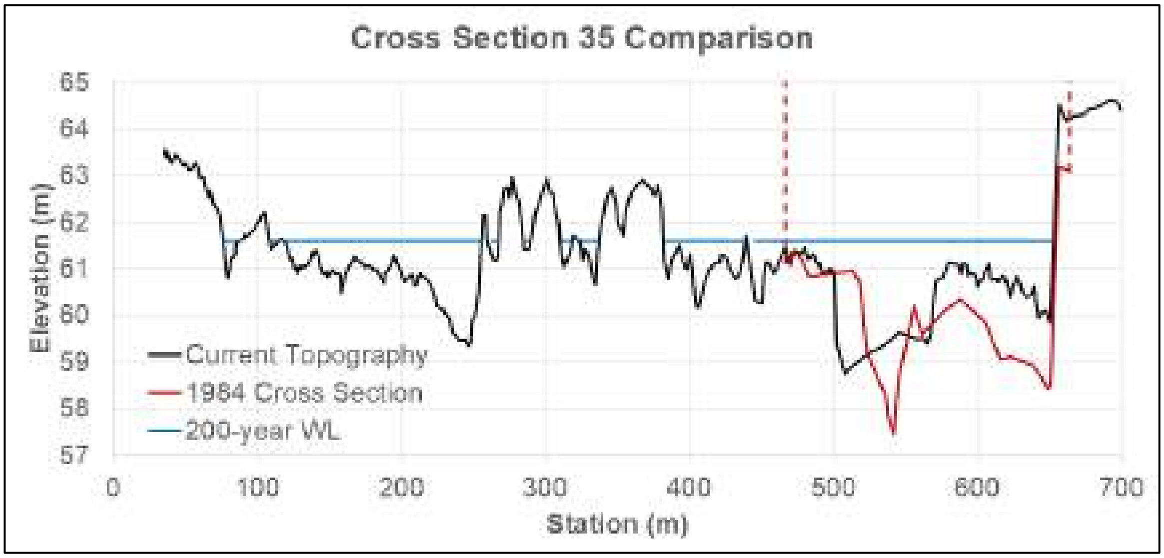


Project No.	2623.014
Date	April 2021
Scale	N/A

Upper Oyster River 0.5% AEP Flood Profile Comparison (No Climate Change) Station 10,000 to 15,000

Figure 22c

The largest decrease in flood level occurs between chainages 4700 and 5400 where the 1984 cross sections are much narrower than the currently modelled cross-sections (see example comparison image below). The 1984 cross sections do not appear to include the entire width of the floodplain and therefore the 1984 flood levels are artificially high.



5.3 Lower Oyster River 2D Model Results

Water Level Profiles

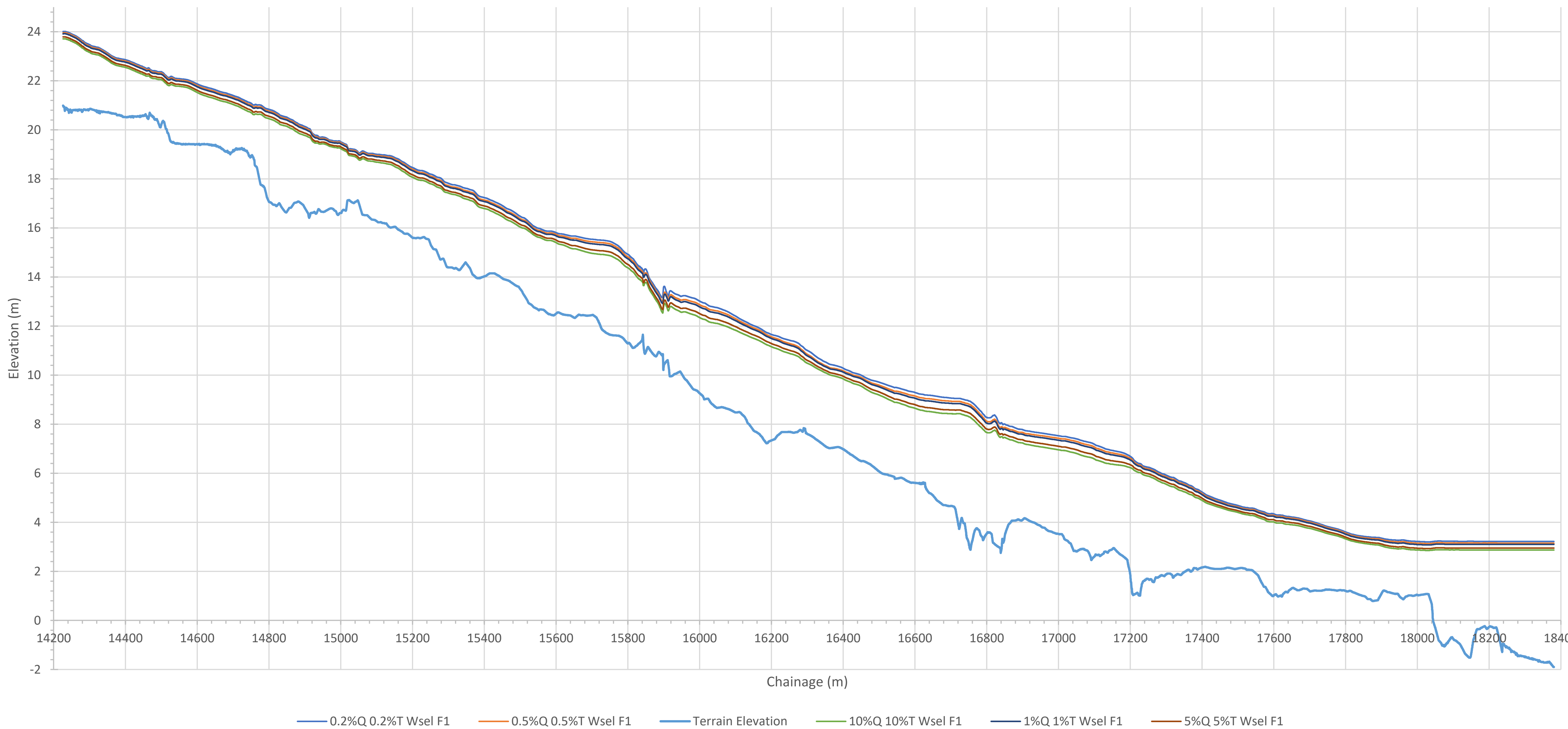
The water level profiles along the thalweg of the Lower Oyster River, modelled in 2D, are presented in the following figures and the chainage is shown in plan view on Figure 13:

- Figures 23: Current climate design flows and current ocean levels
- Figures 24: Nominal year 2050 (+15% flow and +0.5 m sea level rise)
- Figures 25: Nominal year 2100 (+15% flow and +1.0 m sea level rise)
- Figures 26: Nominal year 2200 (+30% flow and +2.0 m sea level rise)

Dike Crest Profile Assessment

The existing dike crest elevation was compared against the 0.5% AEP water level, in the model that did not allow dike overtopping, to determine how much freeboard is available for the current and future climate change time horizons.

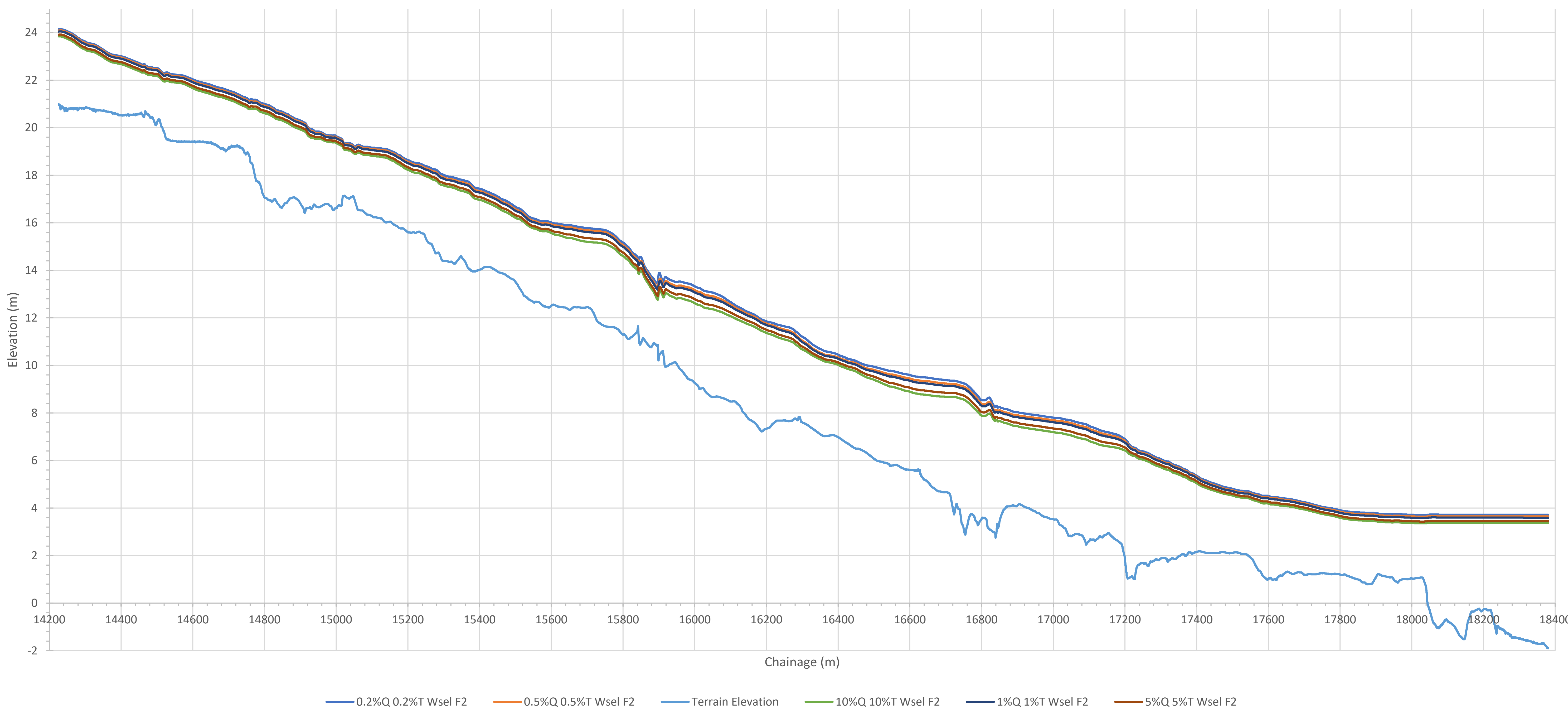
Figure 27 shows the dike profile assessment and the dike chainage is shown in plan view on Figure 13. As shown, the dike has sufficient freeboard during the 0.5% AEP flood. However, an approximately 90 m long section of the Glenmore Road embankment (from chainage 720 to 810) is lower than the 0.5% AEP water level without freeboard. A further 250 m of the Glenmore Road embankment has insufficient freeboard (650 m to 720 m, 810 m to 880 m, and 990 m to 1100 m).



Project No.	2623.014
Date	April 2021
Scale	N/A

Lower Oyster River Thalweg Water Surface Profile (No Climate Change)

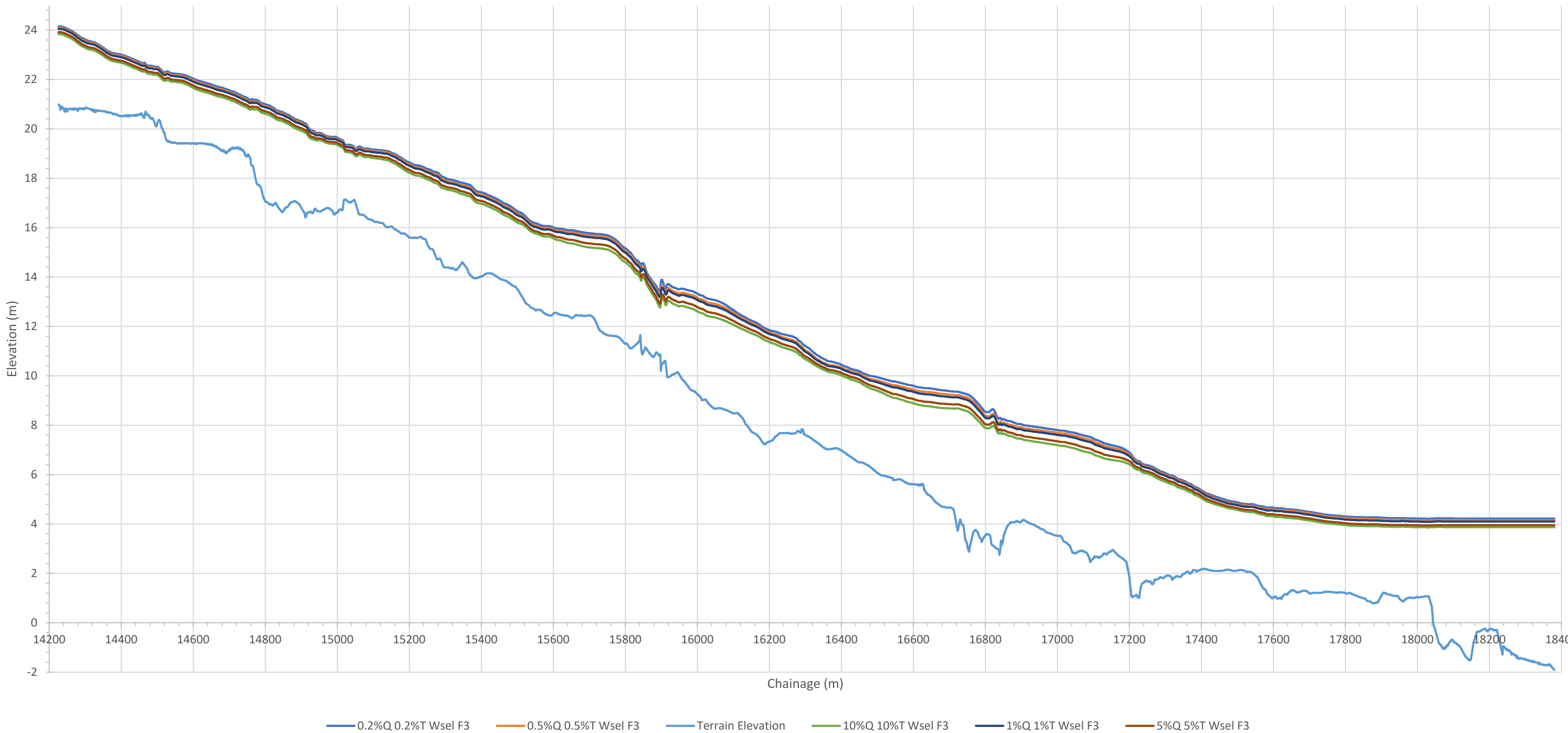
Figure 23



Project No.	2623.014
Date	April 2021
Scale	N/A

Lower Oyster River Thalweg Water Surface Profile (Climate Change: +15% Flow and +0.5 m SLR)

Figure 24



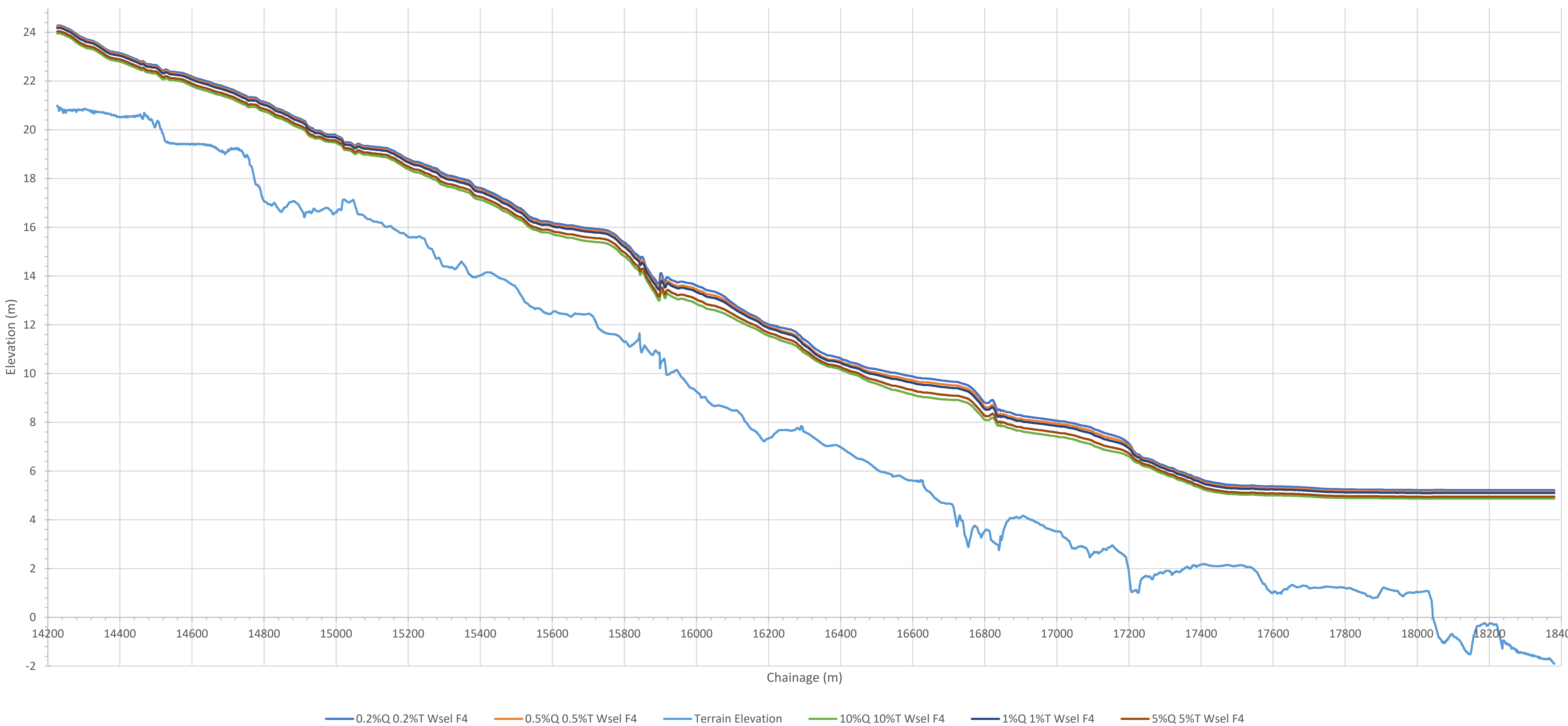
Project No.	2623.014
Date	April 2021
Scale	N/A

Lower Oyster River Thalweg Water Surface Profile (Climate Change: +30% Flow and +1.0 m SLR)

Figure 25

Comox Valley Regional District
Coastal Flood Mapping Project

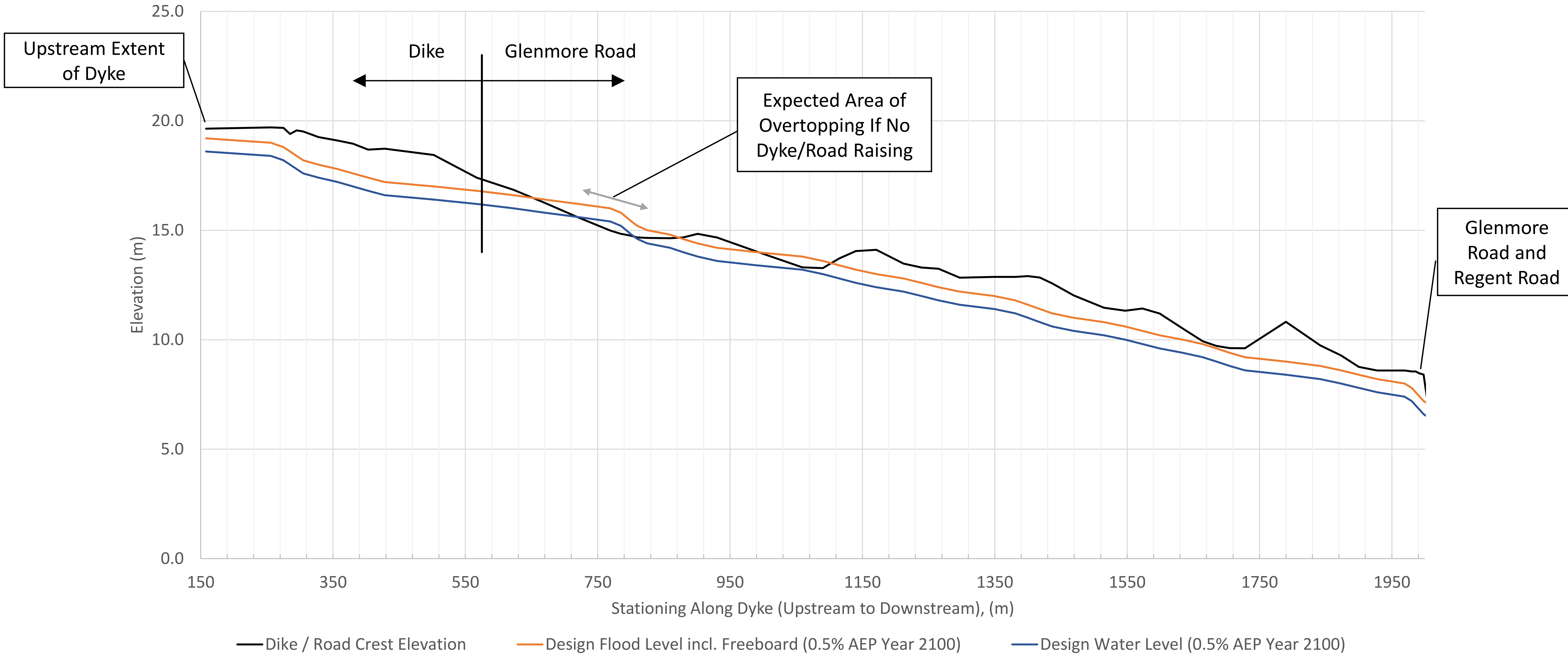
KERR WOOD LEIDAL
consulting engineers



Project No.	2623.014
Date	April 2021
Scale	N/A

Lower Oyster River Thalweg Water Surface Profile (Climate Change: +30% Flow and +2.0 m SLR)

Figure 26



Project No.	2623.014
Date	April 2021
Scale	N/A

Dike and Glenmore Road Crest Elevation Profile

Figure 27

Bridge Freeboard Assessment

Highway 19A and Regent Street cross the Lower Oyster River. The modelled water levels were compared to the bridge low chord to determine the available freeboard for the worst-case climate change (+30% flow and 2 m SLR) and the highest-assessed design flow (0.2% AEP). Figures 28 and 29 show that the two bridges have more than 1 m of freeboard even under this extreme condition.

Modelled Velocities

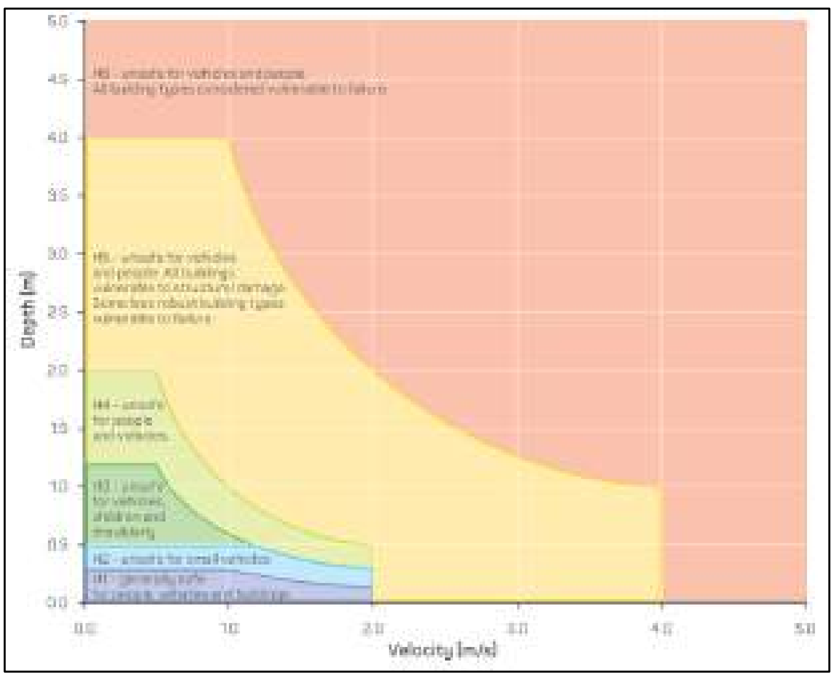
The velocities in the lower portion of the Oyster River, modelled in 2D, during the 0.5% AEP flood event range between:

1. 0 m/s to 5.5 m/s (2.6 m/s average) in the main channel. The low velocity occurs near the banks.
2. 0 m/s to 1 m/s (0.6 m/s average) in the side channels and floodplain areas south of Glenmore Road/Dike (in no breach model).
3. 0 m/s to 1 m/s (0.3 m/s average) in the floodplain areas north of Glenmore Road/Dike (in breach model).

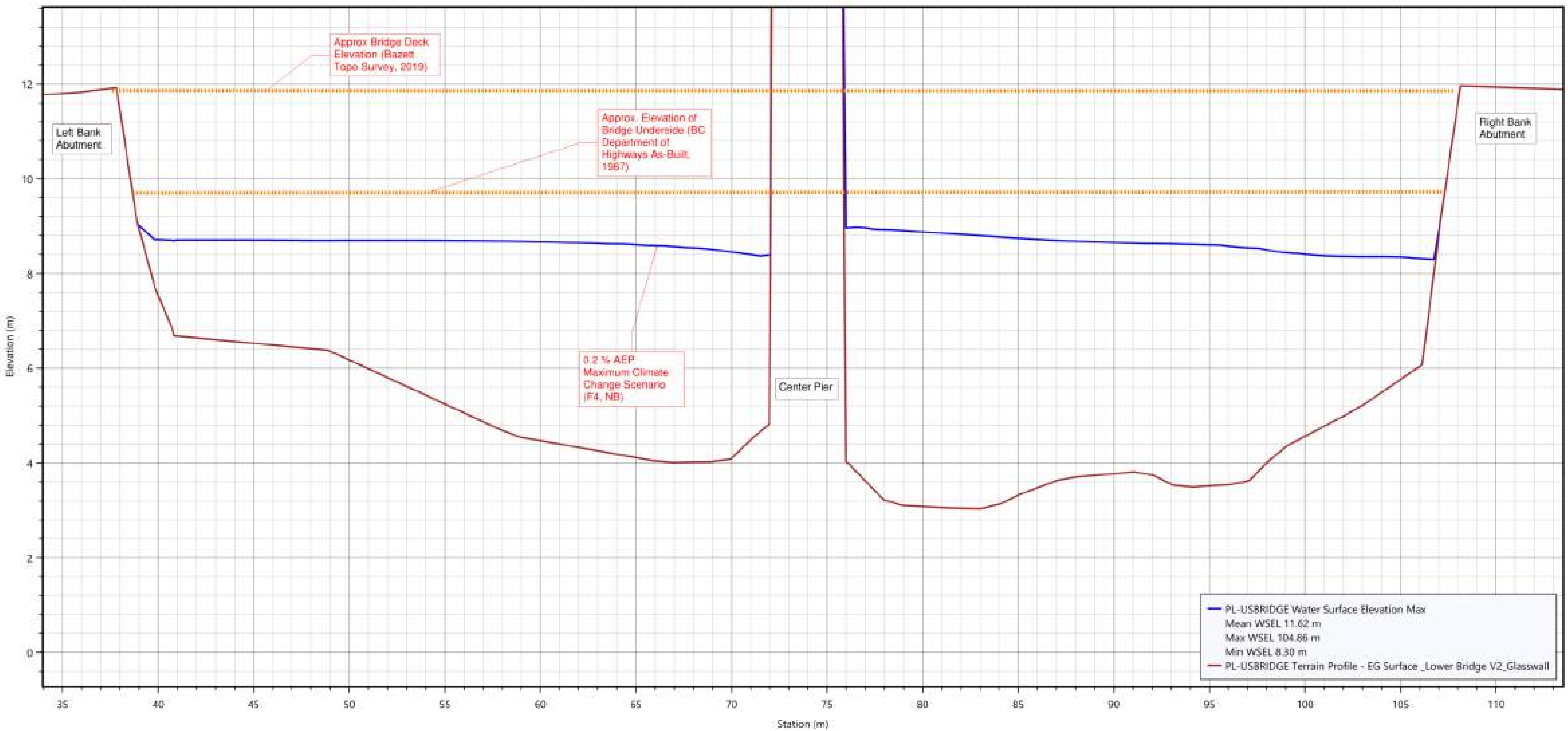
The digital mapping includes velocity maps as described in Technical Memorandum #5 – Coastal and Fluvial Mapping Products.

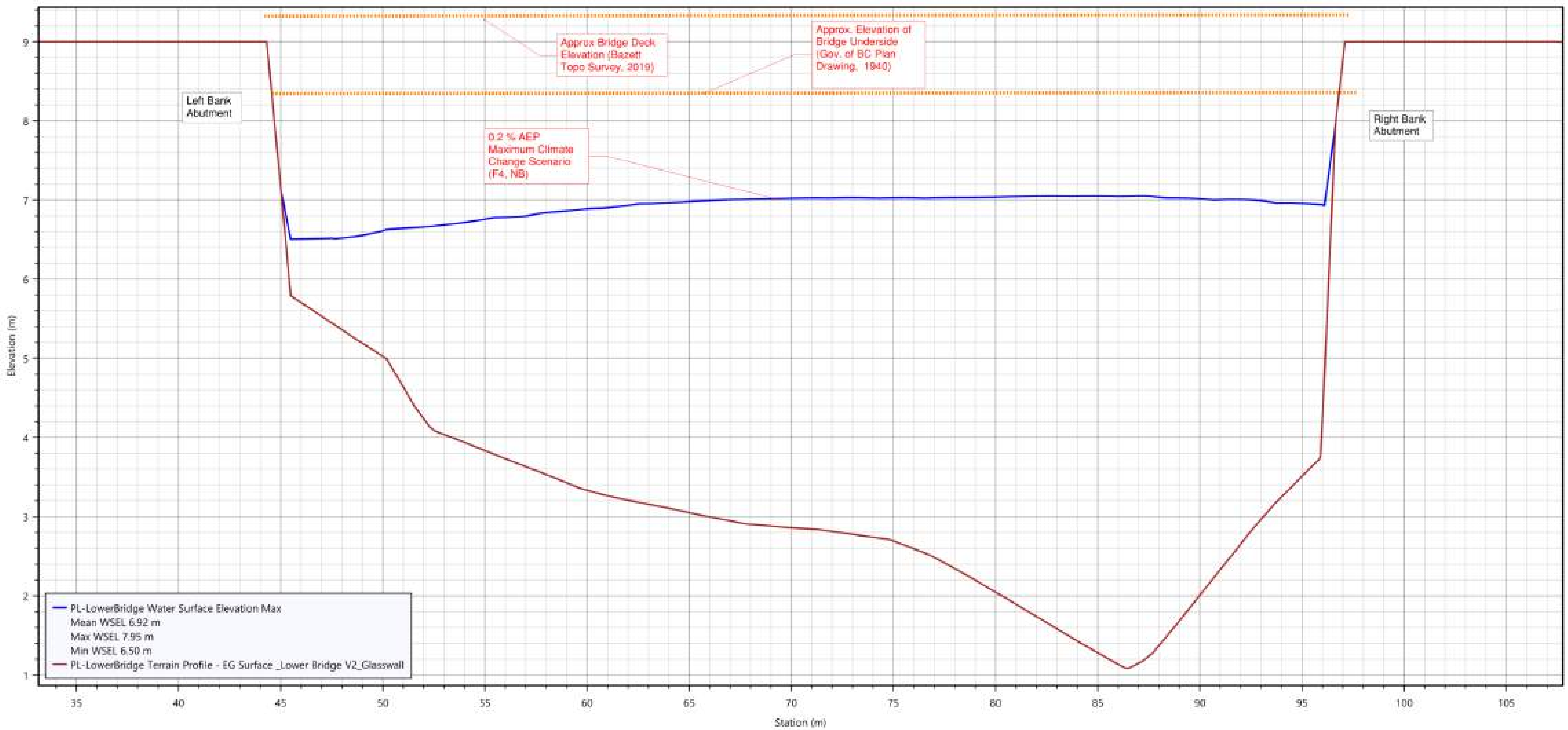
Hazard Ratings

The hazard ratings (depth x velocity) in the lower portion of the Oyster River have been extracted from the 2D model results. These hazard values can be categorized into six different categories as shown in the image below (AIDR, 2017).



Source: Figure 6 General food hazard vulnerability curves (AIRD, 2017)


Approx Bridge Deck Elevation (Bazett Topo Survey, 2019)
Approx. Elevation of Bridge Underside (BC Department of Highways As-Built, 1967)
0.2 % AEP Maximum Climate Change Scenario (F4, NB)
Left Bank Abutment
Right Bank Abutment
Center Pier
Elevation (m)
Station (m)
PL-USBRIDGE Water Surface Elevation Max
Mean WSEL 11.62 m
Max WSEL 104.86 m
Min WSEL 8.30 m
PL-USBRIDGE Terrain Profile - EG Surface _Lower Bridge V2_Glasswall



Project No.	2623.014
Date	April 2021
Scale	N/A

Regent Street Bridge Freeboard Assessment

Figure 29

The hazard curves are divided into hazard classifications that relate to specific vulnerability thresholds as described in Table 16. Table 17 provides the limits for the classifications provided in Table 16.

Table 16: Hazard Classifications – Vulnerability Thresholds

Hazard Vulnerability Classifcation	Description
H1	Generally safe for vehicles, people, and buildings.
H2	Unsafe for small vehicles.
H3	Unsafe for vehicles, children and the elderly.
H4	Unsafe for vehicles and people.
H5	Unsafe for vehicles and people. All building types vulnerable to structural damage. Some less robust building types vulnerable to failure.
H6	Unsafe for vehicles and people. All building types considered vulnerable to failure.
Source: Table 1 Combined hazard curves – vulnerability thresholds (AIDR, 2017)	

Table 17: Hazard Classifications – Vulnerability Threshold Classification Limits

Hazard Vulnerability Classifcation	Classification Limit (D x V, m^3/s)	Limiting Still Water Depth (D, m)	Limiting Velocity (V, m/s)
H1	D x V ≤ 0.3	0.3	2.0
H2	D x V ≤ 0.6	0.5	2.0
H3	D x V ≤ 0.6	1.2	2.0
H4	D x V ≤ 1.0	2.0	2.0
H5	D x V ≤ 4.0	4.0	4.0
H6	D x V ≤ 4.0	none	none
Source: Table 2 Combined hazard curves – vulnerability thresholds classification limits (AIDR, 2017)			

The hazard ratings in the lower Oyster River during the 0.5% AEP Regulatory Flood event are:

1. Up to 24 m^2/s (7.2 m^2/s average) in the main channel;
2. Up to 4 m^2/s (0.8 m^2/s average) in the side channels and floodplain areas south of Glenmore Road/ Dike (in the without dike breach model); and
3. Up to 2 m^2/s (0.2 m^2/s average) in the floodplain areas north of Glenmore Road/Dike (in dike breach model).

It should be noted that the AIDR flood hazard guidelines provide upper-bound water depths and velocities for each hazard classification and therefore cross-referencing with the depth and velocity mapping is required to perform a complete assessment.

The digital mapping includes hazard maps as described in Technical Memorandum #5 – Coastal and Fluvial Mapping Products.

Overland Flow Path Assessment

In the breach model, the flow in the floodplain area north of the Glenmore Dike/Glenmore Road spreads out to the edge of the valley at the west end of Glenmore Road (breach location). Making its way past the narrow corridor between the dike and the valley edge near 2424 Glenmore Road, the flow spreads northward away from the dike initially and then eastward out over the Oyster River fan. The natural topography of the fan guides the overland flow eastward through residential development, overtopping roads including Highway 19A before discharging to the ocean.

The water levels in the river with and without breach were compared. With the breach taking approximately 7.5% (43 cm) of the flow away from the river during the 0.5% AEP with 15% climate change allowance event, the river water levels were up to 0.12 m lower in the vicinity of the breach, downstream of the breach location (approx. 2.5 km), and a short distance (approx. 300 m) upstream of the breach location.

Comparison with Previous FP Mapping

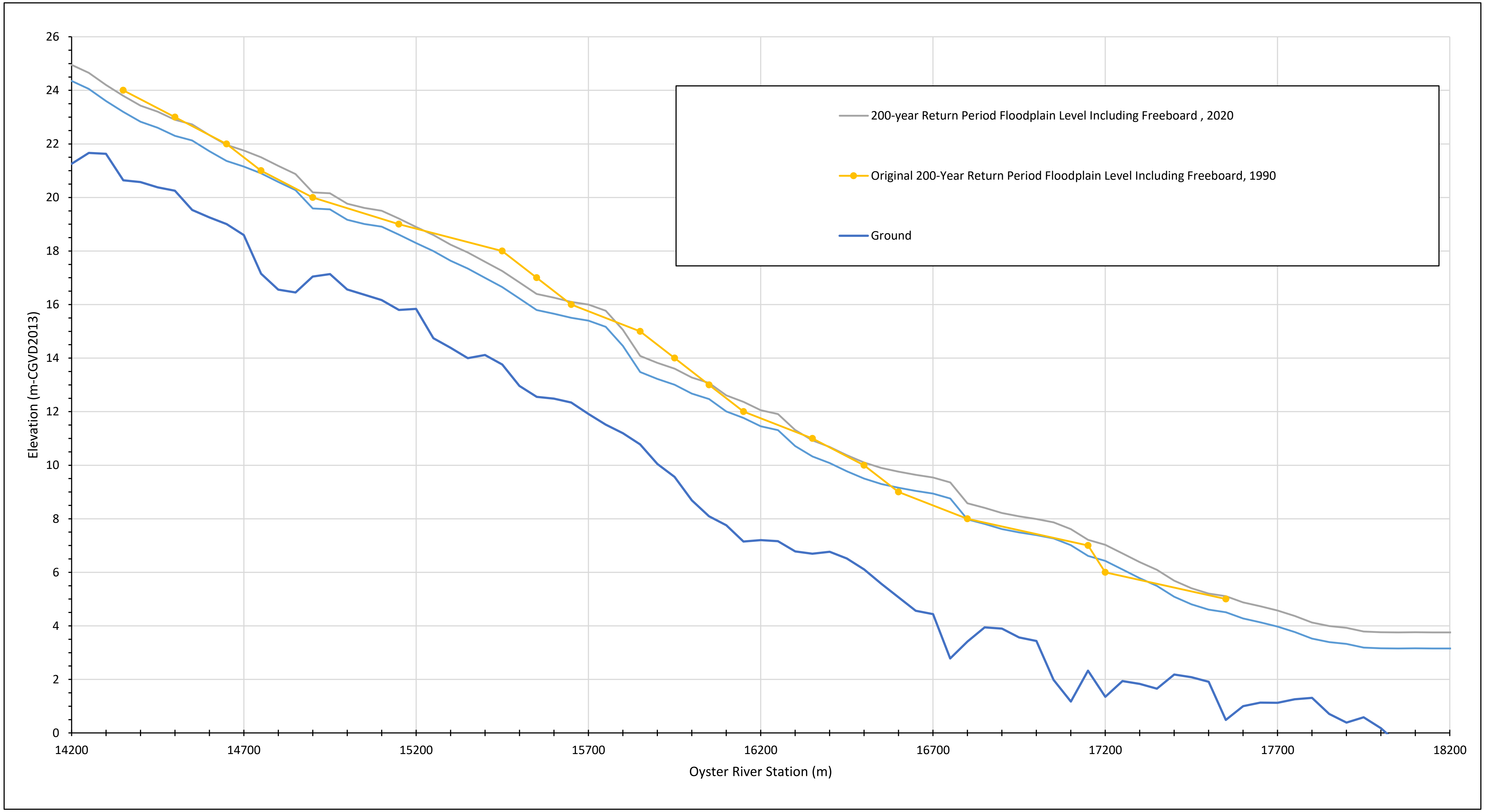
A sensitivity/verification approach was used to verify the uncertainty of the Lower Oyster River model results similar to the upper model. This has involved running the models for the 0.5% AEP (200-year return period) event for current climate conditions and comparing the results with the previous MoE (1984) floodplain mapping elevations.

The historical MoE Floodplain mapping elevations contain water levels with a freeboard allowance. To directly compare results between the 2D hydraulic model and historical MoE Floodplain Mapping elevations, a freeboard allowance of 0.6 m was added to the current model results. Up-to-date guidance from EGBC Flood Mapping in BC Professional Practice Guideline (2017) recommends 0.3 m to 0.6 m freeboard allowance be added to modelled water surface profile to account for model uncertainty and future changes in river channel conditions.

Figure 30 shows the profile comparison and the chainages are shown in plan view in Figure 13. In general, the modelled 0.5% AEP water levels plus 0.6 m freeboard are slightly higher and compare well with the original 0.5% AEP floodplain level. There are locations where the current profile is up to 1.0 m higher, and other locations where it is up to 0.9 m lower.

The largest increase in flood level occurs near chainage 16600, just upstream of where the channel is constricted by the two bridges. No significant channel changes were observed when comparing the 2005 to 2020 orthographic images. In general, the 1984 MoE floodplain thalweg in this area is deeper than the current thalweg, however it is difficult to directly compare due to the local datum using in the 1984 mapping. It is unclear whether the two bridges were included in the original 1984 mapping, which could be a likely reason for the water level increase. As well, more accurate topographic survey data and the use of 2-D modelling software could also explain the increase in water levels upstream of the bridges.

The largest decrease in flood level occurs near chainage 15900. Historically, upstream of chainage 15900, a wider and deeper primary flow path has been along the left bank, with a large island separating a secondary flow path to the south (right bank). Recently the primary flow path has shifted to the southern channel (right bank), which is now wider and deeper than the north channel (left bank). The north channel (left bank) now appears to act as a secondary flow path. This change was noted on the 2015 to 2020 orthographic images and through the project topographic survey. It is expected that the water level decrease is due to a less tortuous primary channel and increased flow conveyance area in this reach.



Project No.	2623.014
Date	April 2021
Scale	N/A

Lower Oyster River 0.5% AEP 0.5% Flood Profile Comparison (No Climate Change)

Figure 30

5.4 Limitations

The hydrologic and hydraulic analyses results presented above are professional opinions based on the scenarios selected for analysis using information and data provided to KWL at the time of the study. Actual flood events may exceed the modelled flood extent, peak flows, water levels and velocities as they are influenced by dynamic and uncertain natural and human-induced processes which are difficult to predict. These influences can include climate change (flow increases and sea level rise), changes in watershed landcover (urbanization, forest harvesting, road construction/drainage, forest fires, pest infestations), alteration of the floodplain or channel conveyance (channel aggradation/degradation, channel avulsion, landslides, debris, alteration of bridges or other instream structures), ground water flow and seepage, or other hydrologic or hydraulic processes which can impact flood hazards. The results of the hydrologic and hydraulic analyses presented are considered to be reasonable estimates based on best practices at the time of the study and should not be considered to be warranties, guarantees or assurances that only these areas are subject to flooding under all conditions.

As per the recommendations in the EGBC Professional Practice Guidelines for Flood Mapping in BC (2017), flood maps should be reviewed about every 10 years and updated if any of the following have occurred:

1. There is a change in the design flood because of changes to the criteria, changes in climate, or a significant hydrologic change in the upstream watershed.
2. There have been significant changes in the channel geometry as a result of a flood or other event.
3. Significant local subsidence has occurred that changes the land elevation in relation to SLR.
4. New flood hazards are identified.
5. Significant diking works are constructed in the floodplain, particularly if the diking alignments are new.
6. There are changes to the official community plan within a floodplain that would nullify the assumptions made in the hydraulic modelling (e.g., a development blocking a preferential overland flow route that was included in the model).
7. There are significant changes in the floodplain, such as community growth and urbanization.

6. Summary

The hydrological analysis and hydraulic modelling approach for the Oyster River are summarized below.

1. Design flows for the Oyster River are based on single station flood frequency analysis using annual instantaneous flow record from the Oyster River below Woodhus Creek (08HD011) WSC station and translated to the key locations (the Oyster River above the Little Oyster River and the Oyster River at the mouth) using the Coulson & Obedkoff Watershed Area Ratio Method.
2. Factors of +15% and +30% have been added to design peak flood discharges to account for projected climate change impacts.
3. Tidal water levels at the downstream boundary for the Oyster River are assumed to have the same AEP as the specified design flood.
4. Hydraulic modelling for the Oyster River was carried out using the HEC-RAS software package with one-dimensional hydraulic modelling for the upper reaches of the river, and two-dimensional hydraulic modelling for the lower reaches of the river.
5. Dike breach analysis for the Oyster River was carried out assuming a hypothetical breach of the Glenmore Dike to assess flood risk within the floodplain/alluvial fan area within the community of the Oyster River to the north of the Oyster River Channel.
6. Sensitivity analysis, including comparison with previous flood mapping levels and adjustment of the channel/floodplain roughness, indicates that using a freeboard of 0.6 m is appropriate to account for uncertainties in modelling results due to the lack of calibration data.
7. Results of modelling scenarios were presented. This work will provide input to Technical Memorandum #5 – Coastal and Fluvial Mapping Products.

7. Closure

We trust that the hydrological analysis and hydraulic modelling summary submitted in this technical memorandum provide Comox Valley Regional District with the information requested. If you have any questions, please contact the undersigned at 250-595-4223.

KERR WOOD LEIDAL ASSOCIATES LTD.

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Encl.: Appendix A: Flood Frequency Analysis Results
Appendix B: Trend Analysis Results
Appendix C: Hydraulic Model Run Database

Statement of Limitations

Copyright Notice

Revision History

Revision #	Date	Status	Revision Description	Author
0	April 23, 2021	Final	Final	CS

OQM CERTIFIED

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Appendix A

Flood Frequency Analysis Results

KWL Flood Frequency Analysis Summary Report

Station ID:	**WSC 08HD011**
Station Name:	**Oyster River Below Woodhus Creek**
Watershed Area (km²)	302
Software used:	HYFRAN
Date completed:	05-Feb-20
Completed by:	ASB
Date Reviewed:	04-Mar-20
Reviewed by:	CS

DesignFloodFlows\[OysterRiver-DesignFloodFlows.xlsx]Inst_HYFRAN_Results_n=40

FFA Summary

Flood Frequency Analysis Summary Table (HYFRAN):

T	GEV	3 Paremeter Log Normal	Log Pearson Type3	Average
	Weighted Moments	Max. Likelihood	WRC	
1.005	41.67	37.46	48.97	**43**
1.0526	98.64	98.72	95.17	**98**
1.25	153.4	155.2	150.8	**153**
2	217.2	218	220	**218**
5	287	285	291.3	**288**
10	324.9	321.7	325.7	**324**
20	356.1	353	351.4	**354**
50	390	389.2	376.9	**385**
100	411.4	413.9	391.8	**406**
200	429.9	437	403.9	**424**
500	450.4	465.6	416.7	**444**
1000	463.6	486.1	424.5	**458**
Decision	Accept	Accept	Accept	

Hypothese Tests	Results	Note	Conclusions
Independence (Wald-Wolfwitz) *H0: the observations are independent*	accept H0 at a signifcance level of 5%		Data are independent at a signifcance level of 5%
Stationary (Kendall) *H0: no trend is apparent in the observations*	accept H0 at a signifcance level of 5%		No trend is apparent in the data
Homogeneity test at annual scale (Wilcoxon) *H0: the averages of the two samples are equal*			
Homogeneity test at seasonal scale (Wilcoxon) *H0: the averages of the two samples are equal*			

Input Data

Years of missing data: 1977-1979 and 2000
Years of missinf inst. Flow but recorded daily flow (1988, & 1992) have been filled using average I:D ratio of 1.52

Year	Inst Peak Q (Annual)	Daily Peak Q (+/1 1 day from inst. peak)	I:D Ratio
	n =	40	
yyyy	m³/s	m³/s	
1974	235	111	2.12
1975	348	260	1.34
1976	83.3	63.4	1.31
1980	289	220	1.31
1981	190	161	1.18
1982	258	225	1.15
1983	239	138	1.73
1984	177	105	1.69
1985	61.3	52.6	1.17
1986	187	104	1.80
1987	192	178	1.08
1988	106		
1989	182	111	1.64
1990	284	202	1.41
1991	210	145	1.45
1992	166		
1993	195	83.2	2.34
1994	207	161	1.29
1995	286	153	1.87
1996	170	95.5	1.78
1997	240	121	1.98
1998	145	96.4	1.50
1999	160	132	1.21
2001	198	145	1.37
2002	224	147	1.52
2003	252	210	1.20
2004	265	170	1.56
2005	192	136	1.41
2006	256	110	2.33
2007	258	174	1.48
2008	108	74.9	1.44
2009	375	253	1.48
2010	312	238	1.31
2011	278	180	1.54
2012	226	175	1.29
2013	88.7	69.8	1.27
2014	409	272	1.50
2015	208	125	1.66
2016	363	238	1.53
2017	213	129	1.65

Average I:D Ratio: 1.52

Detailed Output Data

Generalized Extreme Value (GEV)

2623.014 - Oyster River Below Woodhus Creek - WSC 08HD011 - Inst - GEV

Results of the fitting

GEV (Method of weighted moments)

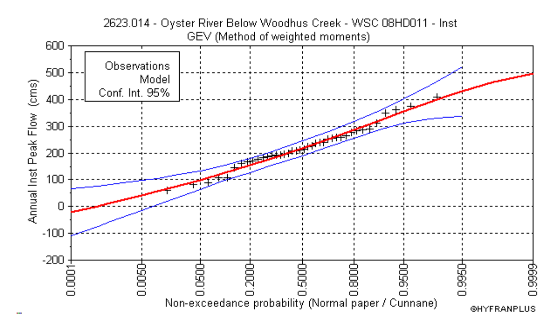
Number of observations 40

Parameters

alpha 74.73712
k 0.209636
u 190.8426

Quantiles
q = F(X) : non-exceedance probability
T = 1/(1-q)

T	q	XT	Standard deviation	Confidence interval (95%)	
10000	0.9999	495.6	92.46	N/D	N/D
2000	0.9995	474.9	74.95	N/D	N/D
1000	0.999	463.6	66.82	N/D	N/D
500	0.998	450.4	58.48	N/D	N/D
200	0.995	429.9	47.34	337.1	522.7
100	0.99	411.4	39.13	334.7	488.1
50	0.98	390	31.44	328.4	451.7
20	0.95	356.1	22.88	311.2	400.9
10	0.9	324.9	18.33	289	360.9
5	0.8	287	15.72	256.2	317.9
3	0.6667	252.3	14.6	223.7	280.9
2	0.5	217.2	13.73	190.3	244.1
1.4286	0.3	176.7	13.05	151.1	202.3
1.25	0.2	153.4	13.29	127.4	179.5
1.1111	0.1	122.7	14.99	93.35	152.1
1.0526	0.05	98.64	17.67	64	133.3
1.0204	0.02	72.83	21.82	30.06	115.6
1.0101	0.01	56.32	25.08	7.159	105.5
1.005	0.005	41.67	28.32	-13.85	97.19
1.001	0.001	12.76	35.59	-57.01	82.52
1.0005	0.0005	1.931	38.58	-73.69	77.55
1.0001	0.0001	-20.48	45.19	-109.1	68.11



Three-Parameter Log-Normal (LN3)

2623.014 - Oyster River Below Woodhus Creek - WSC 08HD011 - Inst - LN3

Results of the fitting

3-parameter lognormal (Maximum Likelihood)

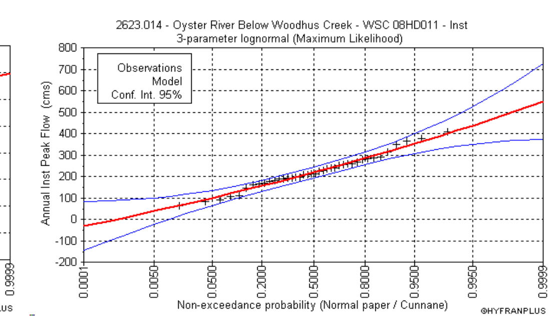
Number of observations 40

Parameters

m -810.009798
mu 6.935394
sigma 0.07497

Quantiles
q = F(X) : non-exceedance probability
T = 1/(1-q)

T	q	XT	Standard deviation	Confidence interval (95%)	
10000	0.9999	5.49E+02	90.19	371.8	7.25E+02
2000	0.9995	505.7	70.64	367.2	6.44E+02
1000	0.999	486.1	62.56	363.4	6.09E+02
500	0.998	465.6	54.72	358.4	5.73E+02
200	0.995	437	44.78	349.2	524.8
100	0.99	413.9	37.68	340.1	487.8
50	0.98	389.2	31.03	328.3	450
20	0.95	353	23.24	307.4	398.5
10	0.9	321.7	18.49	285.5	357.9
5	0.8	285	15.16	255.2	314.7
3	0.6667	251.7	13.76	224.8	278.7
2	0.5	218	13.16	192.2	243.8
1.4286	0.3	178.4	13.01	152.9	203.9
1.25	0.2	155.2	13.41	128.9	181.4
1.1111	0.1	123.8	15.18	94.07	153.6
1.0526	0.05	98.72	18.12	63.2	134.2
1.0204	0.02	71.28	23.12	25.96	116.6
1.0101	0.01	53.46	27.38	-0.2157	107.1
1.005	0.005	37.46	31.86	-24.99	99.91
1.001	0.001	5.405	42.65	-78.2	89.01
1.0005	0.0005	-6.744	47.36	-99.59	86.1
1.0001	0.0001	-32.13	58.32	-146.5	82.2



Log-Pearson Type III (LP3)

2623.014 - Oyster River Below Woodhus Creek - WSC 08HD011 - Inst - LP3

Results of the fitting

Log-Pearson type 3 (WRC)

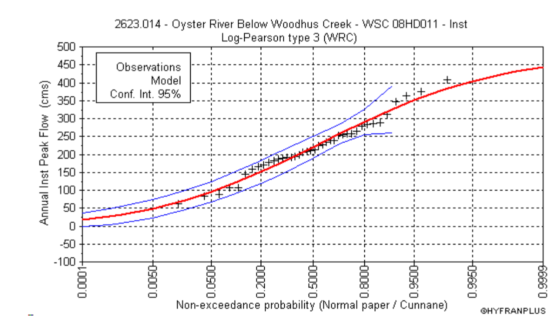
Number of observations 40

Parameters

alpha -11.072727
lambda 3.878954
m 2.663155

Quantiles
q = F(X) : non-exceedance probability
T = 1/(1-q)

T	q	XT	Standard deviation	Confidence interval (95%)	
10000	0.9999	442.7	184	N/D	N/D
2000	0.9995	431.1	158.8	N/D	N/D
1000	0.999	424.5	146.3	N/D	N/D
500	0.998	416.7	132.7	N/D	N/D
200	0.995	403.9	112.8	N/D	N/D
100	0.99	391.8	96.25	N/D	N/D
50	0.98	376.9	78.41	N/D	N/D
20	0.95	351.4	53.24	N/D	N/D
10	0.9	325.7	34.08	258.9	392.5
5	0.8	291.3	17.96	256	326.5
3	0.6667	256.8	13.44	230.4	283.2
2	0.5	220	15.56	189.5	250.5
1.4286	0.3	176	16.99	142.7	209.3
1.25	0.2	150.8	16.54	118.4	183.2
1.1111	0.1	118.7	15.2	88.88	148.5
1.0526	0.05	95.17	14.2	67.33	123
1.0204	0.02	72.36	13.54	45.82	98.9
1.0101	0.01	59.35	13.27	33.35	85.36
1.005	0.005	48.97	13	23.48	74.46
1.001	0.001	31.84	12.06	8.203	55.48
1.0005	0.0005	26.6	11.5	4.051	49.14
1.0001	0.0001	17.67	9.983	-1.904	37.24



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Appendix B

Trend Analysis Results

CVRD
Coastal Flood Mapping Project - Chemainus River - WSC 08HA001
2623-014

Mann-Kendall Trend Test

Trend Name	MaximumDAILYDischarge_Annual	
N	63	(needs to be atleast 10)
Test Statistic Z	1.738043642	
Trend Direction	**UPWARD**	

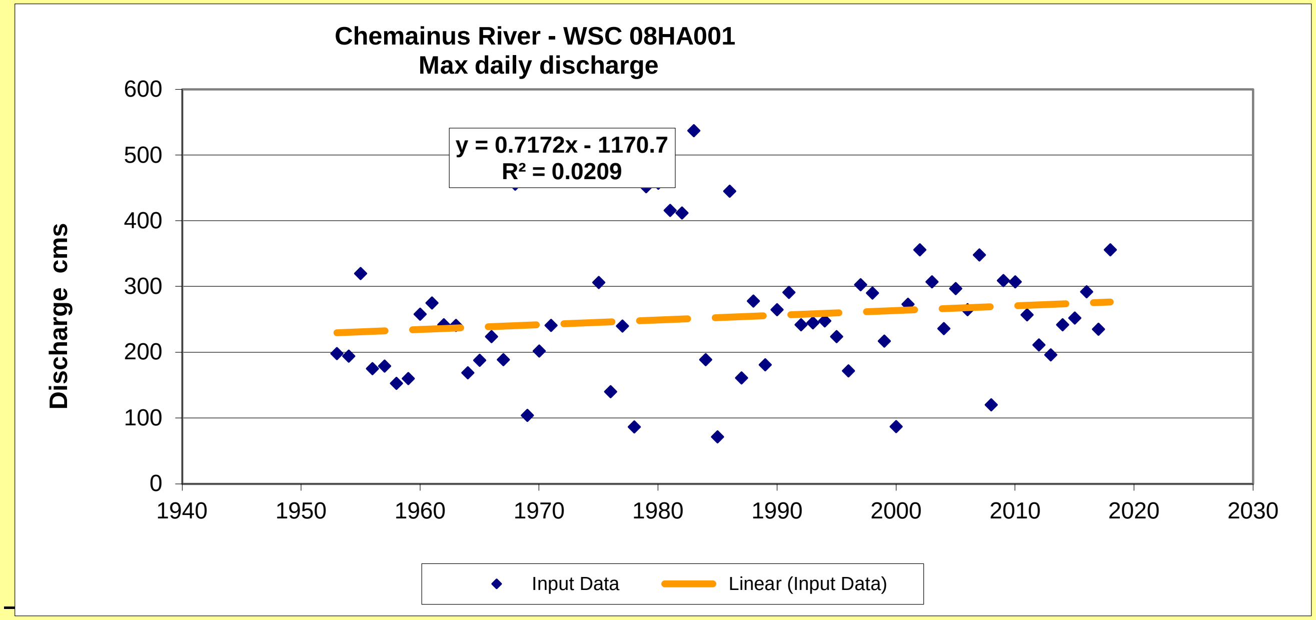
Confidence Level	95	%
Z(1-alpha/2)	1.9600	

The trend is NOT statistically significant (null hypothesis is confirmed).

Sen's Slope

Slope	4%	average % change in flow/decade

Scatter Plot and MS Excel Trendline



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CVRD
Coastal Flood Mapping Project - Englishman River - 08HB002
2623-014

Mann-Kendall Trend Test

Trend Name	MaximumDAILYDischarge_Annual	
N	40	(needs to be atleast 10)
Test Statistic Z	-1.35179529	
Trend Direction	**DOWNWARD**	

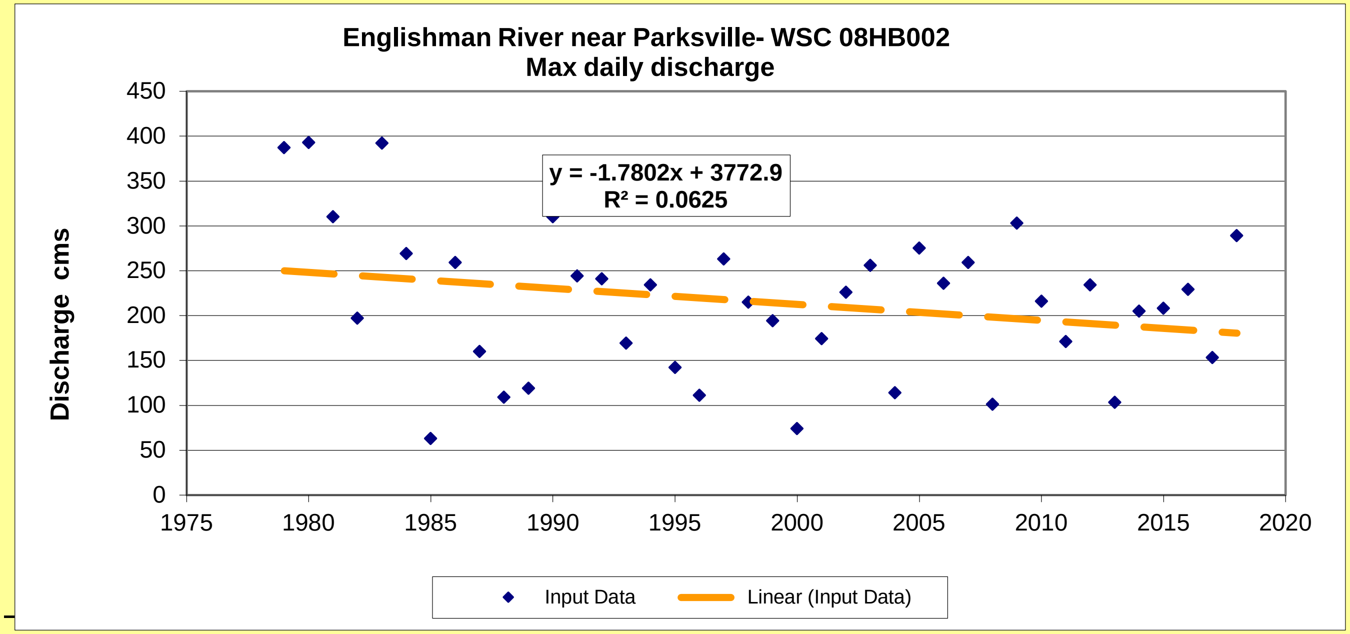
Confidence Level	95	%
Z(1-alpha/2)	1.9600	

The trend is NOT statistically significant (null hypothesis is confirmed).

Sen's Slope

Slope	-7%	average % change per decade

Scatter Plot and MS Excel Trendline



CVRD
Coastal Flood Mapping Project - Oyster River - WSC 08HD011
2623-014

Mann-Kendall Trend Test

Trend Name	MaximumDAILYDischarge_Annual	
N	41	(needs to be atleast 10)
Test Statistic Z	1.179849759	
Trend Direction	**UPWARD**	

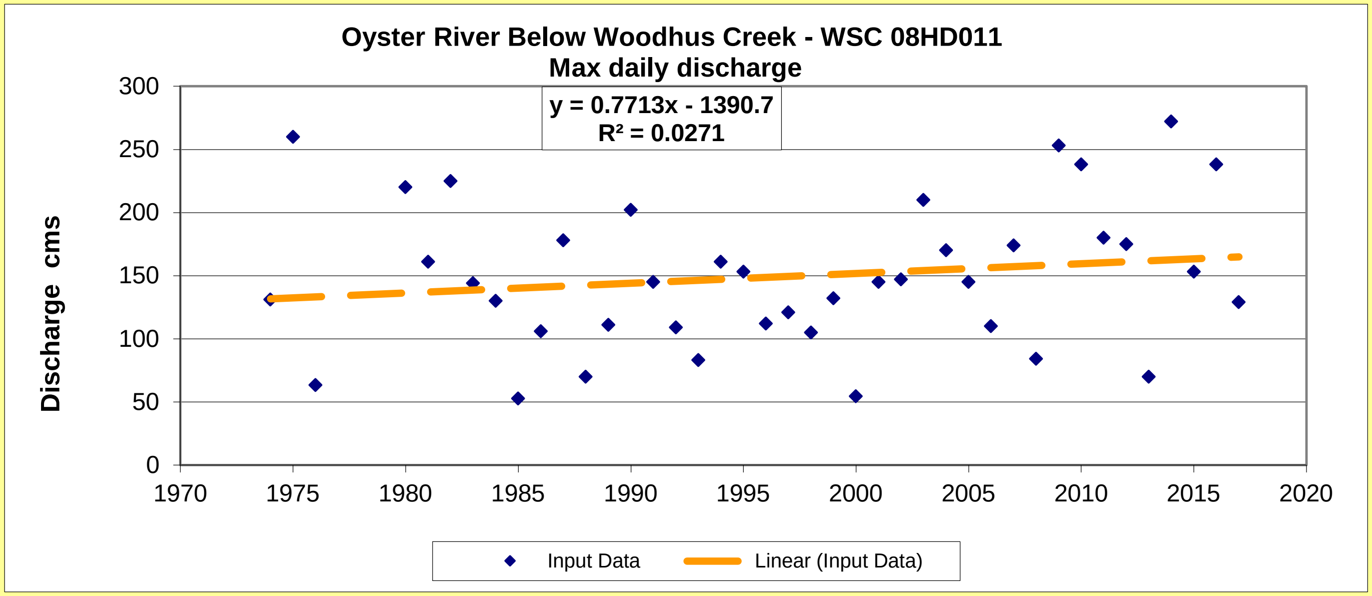
Confidence Level	95	%
Z(1-alpha/2)	1.9600	

The trend is NOT statistically significant (null hypothesis is confirmed).

Sen's Slope

Slope	5%	average% change/decade

Scatter Plot and MS Excel Trendline



CVRD
Coastal Flood Mapping Project - Salmon River above Diversion - 08HD015
2623-014

Mann-Kendall Trend Test

Trend Name	MaximumDAILYDischarge_Annual	
N	35	(needs to be atleast 10)
Test Statistic Z	2.159053155	
Trend Direction	**UPWARD**	

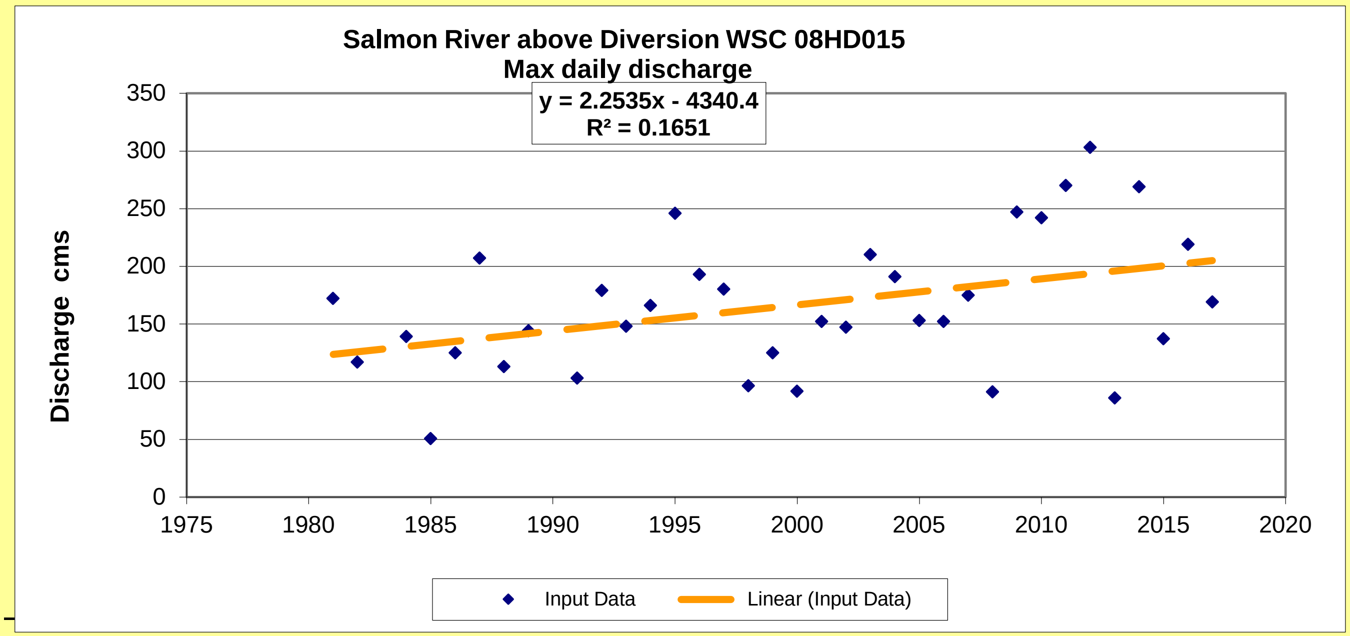
Confidence Level	95	%
Z(1-alpha/2)	1.9600	

The trend is statistically significant (null hypothesis is rejected).

Sen's Slope

Slope	15%	average % change per decade

Scatter Plot and MS Excel Trendline



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Appendix C

Hydraulic Model Run Database

Proposed Oyster River Floodplain Mapping[1]/Flood Hazard Mapping Model Runs - 0.2% Annual Exceedance Probability (AEP) Flood (500 Year Return Period)					
Model Run ID*	**Model Run Description**	**Hydraulic Model Type**	**Upstream Boundary Conditions**	**Downstream Boundary Conditions**	**Flood Protection**
LOR-0.2%AEP-Current-NoBreach	Lower Oyster R. 0.2% AEP Flood Channel Water Levels – Current Climate	2D Fully Dynamic Model with "glass wall" along Glenmore Rd Dike and Glenmore Road to prevent overtopping	0.2% AEP flood (Full Hydrograph) – Current Climate	0.2% AEP Joint Probability Sea Level + current sea level (Full Tidal Cycle)	No overtopping Glenmore Road Dike or Glenmore Road
LOR-0.2%AEP-0.5mSLR-NoBreach	Lower Oyster R. 0.2% AEP Flood Channel Water Levels – Future 0.5 m SLR		0.2% AEP flood (Full Hydrograph) + CC Factor (+15%)[1]	0.2% AEP Joint Probability Sea Level + current sea level (Full Tidal Cycle)	
LOR-0.2%AEP-1.0mSLR-NoBreach	Lower Oyster R. 0.2% AEP Flood Channel Water Levels – Future 1.0 m SLR		0.2% AEP flood (Full Hydrograph) + CC Factor (+15%)[1]	0.2% AEP Joint Probability Sea Level + current sea level (Full Tidal Cycle)	
LOR-0.2%AEP-2.0mSLR-NoBreach	Lower Oyster R. 0.2% AEP Flood Channel Water Levels – Future 2.0 m SLR		0.2% AEP flood (Full Hydrograph) + CC Factor (+30%)[1]	0.2% AEP Joint Probability Sea Level + 2.0 M SLR (Full Tidal Cycle)	
LOR-0.2%AEP-Current-Breach	Lower Oyster R. 0.2% AEP Flood Floodplain Water Levels	2D Fully Dynamic Model with hypothetical dike breach at Glenmore Road Dike	0.2% AEP flood (Full Hydrograph) – Current Climate	0.2% AEP Joint Probability Sea Level + current sea level (Full Tidal Cycle)	Hypothetical Dike Breach of Glenmore Road Dike to Simulate Flooding across Floodplain North of Oyster River
LOR-0.2%AEP-0.5mSLR-Breach	Lower Oyster R. 0.2% AEP Flood Floodplain Water Levels – Future 0.5 m SLR		0.2% AEP flood (Full Hydrograph) + CC Factor (+15%)[1]	0.2% AEP Joint Probability Sea Level + current sea level (Full Tidal Cycle)	
LOR-0.2%AEP-1.0mSLR-Breach	Lower Oyster R. 0.2% AEP Flood Floodplain Water Levels – Future 1.0 m SLR		0.2% AEP flood (Full Hydrograph) + CC Factor (+15%)[1]	0.2% AEP Joint Probability Sea Level + current sea level (Full Tidal Cycle)	
LOR-0.2%AEP-2.0mSLR-Breach	Lower Oyster R. 0.2% AEP Flood Floodplain Water Levels – Future 2.0 m SLR		0.2% AEP flood (Full Hydrograph) + CC Factor (+30%)[1]	0.2% AEP Joint Probability Sea Level + 2.0 M SLR (Full Tidal Cycle)	
UOR-0.2%AEP-Current	Upper Oyster R. 0.2% AEP Channel/Floodplain Water Levels	1D Steady State Hydraulic Model using combination of channel survey/Lidar for Cross Sections	0.2% AEP flood (Peak Flow Only) – Current Climate	Peak Water Level at Upstream end of LOR-0.2%AEP—Current Climate - No Breach model	No Flood Protection
UOR-0.2%AEP-CC+15%	Upper Oyster R. 0.2% AEP Channel/Floodplain Water Levels + CC (+15%)		0.2% AEP flood (Peak Flow Only) + CC Factor (+15%)[1]	Peak Water Level at Upstream end of LOR-0.2%AEP-+15%CC - No Breach model	
UOR-0.2%AEP-CC+30%	Upper Oyster R. 0.2% AEP Channel/Floodplain Water Levels + CC (+30%)		0.2% AEP flood (Peak Flow Only) + CC Factor (+30%)[1]	Peak Water Level at Upstream end of LOR-0.2%AEP-+30%CC - No Breach model	

Note:
1. +15% and +30% CC Factor selected based on review of available climate change projections for CVRD.
* Model ID consists of the following elements
- Model Location (LOR – Lower Oyster River, UOR – Upper Oyster River, CR – Courtenay River)
- Annual Exceedance Probability of the river discharge
- Sea Level Conditions (Current, +0.5 M Sea Level Rise, +1.0 m Sea Level Rise, +2.0 m Sea Level Rise)
- Key flood protection assumptions (No Breach – Model does not allow for dike breach or overtopping of flood protection infrastructure, Breach – model includes hypothetical breach of flood infrastructure at critical location)

Proposed Oyster River Floodplain Mapping[1]/Flood Hazard Mapping Model Runs – 0.5 % Annual Exceedance Probability (AEP) Flood (200 Year Return Period)

Model Run ID*	Model Run Description	Hydraulic Model Type	Upstream Boundary Conditions	Downstream Boundary Conditions	Flood Protection
LOR-0.5% AEP-Current-No Breach	Lower Oyster R. 0.5% AEP Flood Channel Water Levels – Current Climate	2D Fully Dynamic Model with "glass wall" along Glenmore Rd Dike and Glenmore Road to prevent overtopping	0.5% AEP flood (Full Hydrograph) – Current Climate	0.5% AEP Joint Probability Sea Level + current sea level (Full Tidal Cycle)	No overtopping Glenmore Road Dike or Glenmore Road
LOR-0.5% AEP-0.5mSLR-NoBreach	Lower Oyster R. 0.5% AEP Flood Channel Water Levels – Future 0.5 m SLR		0.5% AEP flood (Full Hydrograph) + CC Factor (+15%)[2]	0.5% AEP Joint Probability Sea Level + 0.5 m SLR (Full Tidal Cycle)	
LOR-0.5% AEP-1.0mSLR-NoBreach[1]	Lower Oyster R. 0.5% AEP Flood Channel Water Levels – Future 1.0 m SLR		0.5% AEP flood (Full Hydrograph) + CC Factor (+15%)[2]	0.5% AEP Joint Probability Sea Level + 1.0 m SLR (Full Tidal Cycle)	
LOR-0.5% AEP-2.0mSLR-NoBreach	Lower Oyster R. 0.5% AEP Flood Channel Water Levels – Future 2.0 m SLR		0.5% AEP flood (Full Hydrograph) + CC Factor (+30%)[2]	0.5% AEP Joint Probability Sea Level + 2.0 M SLR (Full Tidal Cycle)	
LOR-0.5% AEP-Current-Breach	Lower Oyster R. 0.5% AEP Flood Floodplain Water Levels	2D Fully Dynamic Model with hypothetical dike breach at Glenmore Road Dike	0.5% AEP flood (Full Hydrograph) – Current Climate	0.5% AEP Joint Probability Sea Level + current sea level (Full Tidal Cycle)	Hypothetical Dike Breach of Glenmore Road Dike to Simulate Flooding across Floodplain North of Oyster River.
LOR-0.5% AEP-0.5mSLR-Breach	Lower Oyster R. 0.5% AEP Flood Floodplain Water Levels – Future 0.5 m SLR		0.5% AEP flood (Full Hydrograph) + CC Factor (+15%)[2]	0.5% AEP Joint Probability Sea Level + 0.5 m SLR (Full Tidal Cycle)	
LOR-0.5% AEP-1.0mSLR-Breach[1]	Lower Oyster R. 0.5% AEP Flood Floodplain Water Levels – Future 1.0 m SLR		0.5% AEP flood (Full Hydrograph) + CC Factor (+15%)[2]	0.5% AEP Joint Probability Sea Level + 1.0 m SLR (Full Tidal Cycle)	
LOR-0.5% AEP-2.0mSLR-Breach	Lower Oyster R. 0.5% AEP Flood Floodplain Water Levels – Future 2.0 m SLR		0.5% AEP flood (Full Hydrograph) + CC Factor (+30%)[2]	0.5% AEP Joint Probability Sea Level + 2.0 M SLR (Full Tidal Cycle)	
UOR-0.5% AEP-Current	Upper Oyster R. 0.5% AEP Channel/Floodplain Water Levels	1D Steady State Hydraulic Model using combination of channel survey/Lidar for Cross Sections	0.5% AEP flood (Peak Flow Only) – Current Climate	Peak Water Level at Upstream end of LOR-0.5%AEP—Current Climate - No Breach model	No Flood Protection
UOR-0.5% AEP-CC+15%	Upper Oyster R. 0.5% AEP Channel/Floodplain Water Levels + CC (+15%)		0.5% AEP flood (Peak Flow Only) + CC Factor (+15%)[2]	Peak Water Level at Upstream end of LOR-0.5%AEP-+15%CC -No Breach model	
UOR-0.5% AEP-CC+30%[1]	Upper Oyster R. 0.5% AEP Channel/Floodplain Water Levels + CC (+30%)		0.5% AEP flood (Peak Flow Only) + CC Factor (+30%)[2]	Peak Water Level at Upstream end of LOR-0.5%AEP-+30%CC -No Breach model	

Note:
1. 0.2% AEP Flood with +30% CC factor and 1.0 m Sea Level Rise to be used for Regulatory Floodplain Mapping/FCLs
2. +15% and +30% CC Factor selected based on review of available climate change projections for CVRD..
* Model ID consists of the following elements
- Model Location (LOR – Lower Oyster River, UOR – Upper Oyster River, CR – Courtenay River)
- Annual Exceedance Probability of the river discharge
- Sea Level Conditions (Current, +0.5 M Sea Level Rise, +1.0 m Sea Level Rise, +2.0 m Sea Level Rise)
- Key flood protection assumptions (No Breach – Model does not allow for dike breach or overtopping of flood protection infrastructure, Breach – model includes hypothetical breach of flood infrastructure at critical location.

Proposed Oyster River Flood Hazard Mapping Model Runs – 1 % Annual Exceedance Probability (AEP) Flood (100 Year Return Period)					
Model Run ID*	**Model Run Description**	**Hydraulic Model Type**	**Upstream Boundary Conditions**	**Downstream Boundary Conditions**	**Flood Protection**
LOR-1% AEP-Current-NoBreach	Lower Oyster R. 1% AEP Flood Channel Water Levels – Current Climate	2D Fully Dynamic Model with "glass wall" along Glenmore Rd Dike and Glenmore Road to prevent overtopping	1% AEP flood (Full Hydrograph) – Current Climate	1% AEP Joint Probability Sea Level + current sea level (Full Tidal Cycle)	No overtopping Glenmore Road Dike or Glenmore Road
LOR-1% AEP-0.5mSLR-NoBreach	Lower Oyster R. 1% AEP Flood Channel Water Levels – Future 0.5 m SLR		1% AEP flood (Full Hydrograph) + CC Factor (+15%)[2]	1% AEP Joint Probability Sea Level + 0.5 m SLR (Full Tidal Cycle)	
LOR-1% AEP-1.0mSLR-NoBreach	Lower Oyster R. 1% AEP Flood Channel Water Levels – Future 1.0 m SLR		1% AEP flood (Full Hydrograph) + CC Factor (+15%)[2]	1% AEP Joint Probability Sea Level + 1.0 m SLR (Full Tidal Cycle)	
LOR-1% AEP-2.0mSLR-NoBreach	Lower Oyster R. 1% AEP Flood Channel Water Levels – Future 2.0 m SLR		1% AEP flood (Full Hydrograph) + CC Factor (+30%)[2]	1% AEP Joint Probability Sea Level + 2.0 M SLR (Full Tidal Cycle)	
LOR-1% AEP-Current-Breach[1]	Lower Oyster R. 1% AEP Flood Floodplain Water Levels	2D Fully Dynamic Model with hypothetical dike breach at Glenmore Road Dike[1]	1% AEP flood (Full Hydrograph) – Current Climate	1% AEP Joint Probability Sea Level + current sea level (Full Tidal Cycle)	Hypothetical Dike Breach of Glenmore Road Dike to Simulate Flooding across Floodplain North of Oyster River.
LOR-1% AEP-0.5mSLR-Breach[1]	Lower Oyster R. 1% AEP Flood Floodplain Water Levels – Future 0.5 m SLR		1% AEP flood (Full Hydrograph) + CC Factor (+15%)[2]	1% AEP Joint Probability Sea Level + 0.5 m SLR (Full Tidal Cycle)	
LOR-1% AEP-1.0mSLR-Breach[1]	Lower Oyster R. 1% AEP Flood Floodplain Water Levels – Future 1.0 m SLR		1% AEP flood (Full Hydrograph) + CC Factor (+15%)[2]	1% AEP Joint Probability Sea Level + 1.0 m SLR (Full Tidal Cycle)	
LOR-1% AEP-2.0mSLR-Breach[1]	Lower Oyster R. 1% AEP Flood Floodplain Water Levels – Future 2.0 m SLR		1% AEP flood (Full Hydrograph) + CC Factor (+30%)[2]	1% AEP Joint Probability Sea Level + 2.0 M SLR (Full Tidal Cycle)	
UOR-1% AEP-Current	Upper Oyster R. 1% AEP Channel/Floodplain Water Levels	1D Steady State Hydraulic Model using combination of channel survey/Lidar for Cross Sections	1% AEP flood (Peak Flow Only) – Current Climate	Peak Water Level at Upstream end of LOR-1%AEP—Current Climate - No Breach model	No Flood Protection
UOR-1% AEP-CC+10%	Upper Oyster R. 1% AEP Channel/Floodplain Water Levels + CC (+10%)		1% AEP flood (Peak Flow Only) + CC Factor (+15%)[2]	Peak Water Level at Upstream end of LOR-1%AEP-+15%CC -No Breach model	
UOR-1% AEP-CC+10%	Upper Oyster R. 1% AEP Channel/Floodplain Water Levels + CC (+10%)		1% AEP flood (Peak Flow Only) + CC Factor (+30%)[2]	Peak Water Level at Upstream end of LOR-1%AEP-+30%CC -No Breach model	

Note:
1. Dike breach model runs may not be required depending peak water level results of "no breach"/glass wall model runs
2. +15% and +30% CC Factor selected based on review of available climate change projections for CVRD
* Model ID consists of the following elements
- Model Location (LOR – Lower Oyster River, UOR – Upper Oyster River, CR – Courtenay River)
- Annual Exceedance Probability of the river discharge
- Sea Level Conditions (Current, +0.5 M Sea Level Rise, +1.0 m Sea Level Rise, +2.0 m Sea Level Rise)
- Key flood protection assumptions (No Breach – Model does not allow for dike breach or overtopping of flood protection infrastructure, Breach – model includes hypothetical breach of flood infrastructure at critical location.

Proposed Oyster River Flood Hazard Mapping Model Runs – 5 % Annual Exceedance Probability (AEP) Flood (20 Year Return Period)					
Model Run ID*	**Model Run Description**	**Hydraulic Model Type**	**Upstream Boundary Conditions**	**Downstream Boundary Conditions**	**Flood Protection**
LOR-5% AEP-Current-NoBreach	Lower Oyster R. 5% AEP Channel Water Levels – Current Climate	2D Fully Dynamic Model with “glass wall” along Glenmore Rd Dike and Glenmore Road to prevent overtopping	5% AEP (Full Hydrograph) – Current Climate	5% AEP Joint Probability Sea Level + current sea level (Full Tidal Cycle)	No overtopping Glenmore Road Dike or Glenmore Road
LOR-5% AEP - 0.5mSLR-NoBreach	Lower Oyster R. 5% AEP Channel Water Levels – Future 0.5 m SLR		5% AEP (Full Hydrograph) + CC Factor (15%)[2]	5% AEP Joint Probability Sea Level + 0.5 m SLR (Full Tidal Cycle)	
LOR-5% AEP - 1.0mSLR-NoBreach	Lower Oyster R. 5% AEP Channel Water Levels – Future 1.0 m SLR		5% AEP (Full Hydrograph) + CC Factor (30%)[2]	5% AEP Joint Probability Sea Level + 1.0 m SLR (Full Tidal Cycle)	
LOR-5% AEP - 2.0mSLR-NoBreach	Lower Oyster R. 5% AEP Channel Water Levels – Future 2.0 m SLR		5% AEP (Full Hydrograph) + CC Factor (30%)[2]	5% AEP Joint Probability Sea Level + 2.0 M SLR (Full Tidal Cycle)	
LOR-5% AEPr-Current-Breach[1]	Lower Oyster R. 5% AEP Floodplain Water Levels	2D Fully Dynamic Model with hypothetical dike breach at Glenmore Road Dike[1]	5% AEP (Full Hydrograph) – Current Climate	5% AEP Joint Probability Sea Level + current sea level (Full Tidal Cycle)	Hypothetical Dike Breach of Glenmore Road Dike to Simulate Flooding across Floodplain North of Oyster River.
LOR-5% AEP-0.5mSLR-Breach[1]	Lower Oyster R. 5% AEP Floodplain Water Levels – Future 0.5 m SLR		5% AEP (Full Hydrograph) + CC Factor (15%)[2]	5% AEP Joint Probability Sea Level + 0.5 m SLR (Full Tidal Cycle)	
LOR-5% AEP-1.0mSLR-Breach[1]	Lower Oyster R. 5% AEP Floodplain Water Levels – Future 1.0 m SLR		5% AEP (Full Hydrograph) + CC Factor (15%)[2]	5% AEP Joint Probability Sea Level + 1.0 m SLR (Full Tidal Cycle)	
LOR-5% AEP-2.0mSLR-Breach[1]	Lower Oyster R. 5% AEP Floodplain Water Levels – Future 2.0 m SLR		5% AEP (Full Hydrograph) + CC Factor (30%)[2]	5% AEP Joint Probability Sea Level + 2.0 M SLR (Full Tidal Cycle)	
UOR-5% AEP-Current	Upper Oyster R. 5% AEP Return Period Channel/Floodplain Water Levels	1D Steady State Hydraulic Model using combination of channel survey/Lidar for Cross Sections	5% AEP (Peak Flow Only) – Current Climate	Peak Water Level at Upstream end of LOR-5%AEP—Current Climate - No Breach model	No Flood Protection
UOR-5% AEP-CC+15%	Upper Oyster R. 5% AEP Return Period Channel/Floodplain Water Levels + CC (+15%)		5% AEP (Peak Flow Only) + CC Factor (+15%)[2]	Peak Water Level at Upstream end of LOR-5%AEP-+15%CC -No Breach model	
UOR-5% AEP-CC+30%	Upper Oyster R. 5% AEP Return Period Channel/Floodplain Water Levels + CC (+30%)		5% AEP (Peak Flow Only) + CC Factor (+30%)[2]	Peak Water Level at Upstream end of LOR-5%AEP-+30%CC -No Breach model	

Note:
1. Dike breach model runs not be required depending peak water level results of “no breach”/glass wall model runs
2. +15% and +30% CC Factor selected based on review of available climate change projections for CVRD.
* Model ID consists of the following elements
  - Model Location (LOR – Lower Oyster River, UOR – Upper Oyster River, CR – Courtenay River)
  - Annual Exceedance Probability of the river discharge
  - Sea Level Conditions (Current, +0.5 M Sea Level Rise, +1.0 m Sea Level Rise, +2.0 m Sea Level Rise)
  - Key flood protection assumptions (No Breach – Model does not allow for dike breach or overtopping of flood protection infrastructure, Breach – model includes hypothetical breach of flood infrastructure at critical location.

Proposed Oyster River Flood Hazard Mapping Model Runs – 10% Annual Exceedance Probability (AEP) Flood (10 Year Return Period)					
Model Run ID*	**Model Run Description**	**Hydraulic Model Type**	**Upstream Boundary Conditions**	**Downstream Boundary Conditions**	**Flood Protection**
LOR-10% AEP-Current-NoBreach	Lower Oyster R. 10% AEP Channel Water Levels – Current Climate	2D Fully Dynamic Model with “glass wall” along Glenmore Rd Dike and Glenmore Road to prevent overtopping	10% AEP (Full Hydrograph) – Current Climate	10% AEP Joint Probability Sea Level + current sea level (Full Tidal Cycle)	No overtopping Glenmore Road Dike or Glenmore Road
LOR-10%-0.5mSLR-NoBreach	Lower Oyster R. 10% AEP Channel Water Levels – Future 0.5 m SLR		10% AEP (Full Hydrograph) + CC Factor (15%)[2]	10% AEP Joint Probability Sea Level + 0.5 m SLR (Full Tidal Cycle)	
LOR-10%-1.0mSLR-NoBreach	Lower Oyster R. 10% AEP Channel Water Levels – Future 1.0 m SLR		10% AEP (Full Hydrograph) + CC Factor (15%)[2]	10% AEP Joint Probability Sea Level + 1.0 m SLR (Full Tidal Cycle)	
LOR-10%-2.0mSLR-NoBreach	Lower Oyster R. 10% AEP Channel Water Levels – Future 2.0 m SLR		10% AEP (Full Hydrograph) + CC Factor (30%)[2]	10% AEP Joint Probability Sea Level + 2.0 M SLR (Full Tidal Cycle)	
LOR-10% AEPr-Current-Breach[1]	Lower Oyster R. 10% AEP Floodplain Water Levels	2D Fully Dynamic Model with hypothetical dike breach at Glenmore Road Dike[1]	10% AEP (Full Hydrograph) – Current Climate	HHWLT + current sea level (Full Tidal Cycle)	Hypothetical Dike Breach of Glenmore Road Dike to Simulate Flooding across Floodplain North of Oyster River.
LOR-10% AEP-0.5mSLR-Breach[1]	Lower Oyster R. 10% AEP Floodplain Water Levels – Future 0.5 m SLR		10% AEP (Full Hydrograph) + CC Factor (15%)[2]	HHWLT + 0.5 m SLR (Full Tidal Cycle)	
LOR-10% AEP-1.0mSLR-Breach[1]	Lower Oyster R. 10% AEP Floodplain Water Levels – Future 1.0 m SLR		10% AEP (Full Hydrograph) + CC Factor (15%)[2]	HHWLT + 1.0 m SLR (Full Tidal Cycle)	
LOR-10% AEP-2.0mSLR-Breach[1]	Lower Oyster R. 10% AEP Floodplain Water Levels – Future 2.0 m SLR		10% AEP (Full Hydrograph) + CC Factor (30%)[2]	HHWLT + 2.0 M SLR (Full Tidal Cycle)	
UOR-10% AEP-Current	Upper Oyster R. 10% AEP Return Period Channel/Floodplain Water Levels	1D Steady State Hydraulic Model using combination of channel survey/Lidar for Cross Sections	10% AEP (Peak Flow Only) – Current Climate	Peak Water Level at Upstream end of LOR-10%AEP—Current Climate -No Breach model	No Flood Protection
UOR-10% AEP-CC+15%	Upper Oyster R. 10% AEP Return Period Channel/Floodplain Water Levels + CC (+15%)		10% AEP (Peak Flow Only) + CC Factor (+15%)[2]	Peak Water Level at Upstream end of LOR-10%AEP-+15%CC -No Breach model	
UOR-10% AEP-CC+30%	Upper Oyster R. 10% AEP Return Period Channel/Floodplain Water Levels + CC (+30%)		10% AEP (Peak Flow Only) + CC Factor (+30%)[2]	Peak Water Level at Upstream end of LOR-10%AEP-+30%CC -No Breach model	

Note:
1. +15% and +30% CC Factor selected based on review of available climate change projections for CVRD
* Model ID consists of the following elements

- Model Location (LOR – Lower Oyster River, UOR – Upper Oyster River, CR – Courtenay River)
- Annual Exceedance Probability of the river discharge
- Sea Level Conditions (Current, +0.5 M Sea Level Rise, +1.0 m Sea Level Rise, +2.0 m Sea Level Rise)
- Key flood protection assumptions (No Breach – Model does not allow for dike breach or overtopping of flood protection infrastructure, Breach – model includes hypothetical breach of flood infrastructure at critical location.