KERR WOOD LEIDAL
consulting engineers

Greater Vancouver
200 - 4185A Still Creek Drive
Burnaby, BC V5C 6G9
T 604 294 2088
F 604 294 2090

Technical Memorandum

DATE: April 23, 2021

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

FROM: Craig Sutherland, M.Sc., P.Eng.

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

1. Introduction

Kerr Wood Leidal Associates Ltd. (KWL) has been 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 (#3B) documents the hydrologic and hydraulic modelling for the Courtenay 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. This project task is the focus of this technical memorandum.
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.
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 lower 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 #3B, which documents the hydrologic and hydraulic modelling of the Courtenay River and includes the following:

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 regional flood frequency analysis accounting for impacts on the magnitude of flood flows due to BC Hydro reservoir operations at Comox Lake.
4. A summary of how projected climate change impacts were accounted for in design flood estimates.
5. Details of the hydraulic model boundary conditions, assumptions, and limitations.
6. A review of the design flow simulation results.

The objective of the hydrologic analysis and hydraulic modelling of the Courtenay River was to develop flood water level profiles and flow velocities along the river channel and across the floodplain 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.

As the design flood levels for the Courtenay River were calculated using the existing hydraulic model prepared for the Courtenay Integrated Flood Management Study (IFMS) prepared in 2013 (McElhanney, 2013), no description of the development of the hydraulic model or model verification results for the Courtenay River hydraulic model are presented in this technical memo. Further details on model development and verification are provided in the modelling technical memorandum prepared for the IFMS (KWL, 2013).

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.
Bathymetric	=	Survey to establish elevations of underwater river channel bed or ocean bed surfaces.
CGVD28	=	Canadian Geodetic Vertical Datum, original vertical datum used in Canada, roughly equal to mean sea level.
CGVD2013	=	Canadian Geodetic Vertical Datum 2013, updated vertical datum used for mapping in this study.
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.
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).
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.
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 for the Puntledge River, Tsolum River and Courtenay River were done in accordance with professional best practices and the most recent flood hazard analysis guidelines (EGBC, 2018; EGBC, 2017; FLNR, 2018 & Natural Resources Canada, 2019).

1.4 References

The following references have been used in our work:

1. Ahmed, S. (2017). *Inventory of Streamflow in the South Coast and West Coast Regions. Ministry of Environment and Climate Change*.
2. Australian Institute of Disaster Resilience (AIDR). (2017). *Australian Disaster Resilience Guideline 7-3 Flood Hazard*.
3. BC Hydro (2010). *Generation Operating Order – Puntledge Generating Station v.6*.
4. BC Ministry of Forest, Lands and Natural Resource Operations (2018). *Flood Hazard Area Land Use Management Guidelines*, Amended January 1, 2018.
5. CSA (2019). *CSA 6:19, Canadian Highway Bridge Design Code.* 12th Edition. CSA Group. Toronto, ON, Canada.
6. Coulson and Obedkoff (1998). *British Columbia Streamflow Inventory. Report prepared by the Ministry of Environment Lands and Parks*.
7. Engineers and Geoscientists BC (2017). *Professional Practice Guidelines – Flood Mapping in BC, Version 1.0*.
8. Engineers and Geoscientists BC (2018). *Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC, Version 2.1*.
9. IPCC (2012). *"Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation – Chapter 3 Changes in Climate Extremes and their Impacts on the Natural Physical Environment"* A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 109-230.
10. Ker, Priestman & Associates (1990). *Floodplain Mapping Program: Courtenay, Puntledge and Tsolum Rivers*, Prepared for Ministry of Environment.
11. Kerr Wood Leidal (2013). *City of Courtenay Integrated Flood Management Study, Hydrodynamic Model Boundary Conditions*, Updated Final Technical Memorandum Prepared for City of Courtenay.
12. Kundzewicz, A. W., Kanae, S. Seneviratne, S. I., Handmer. (2013). *Flood Risk and Climate Change: Global and Regional Perspectives*, Hydrological Sciences Journal 59(1): 1-28.
13. McElhanney (2013). *Courtenay River Integrated Flood Management Study Final Report*, Prepared for City of Courtenay.
14. Northwest Hydraulic Consultants (2011). *Tsolum River Flood Hydrology Investigation*, Prepared for City of Courtenay, Comox Valley Regional District and Timberwest.

15. Pacific Climate Impacts Consortium (2020a). "PCIC Climate Explorer", https://pacificclimate.org/analysis-tools/pcic-climate-explorer, Accessed March 2020.
16. Pacific Climate Impacts Consortium (2020b). "VIC-GL BCCAQ CMIP5 RVIC: Station Hydrologic Model Output", https://pacificclimate.org/data/station-hydrologic-model-output, Accessed April 2020.
17. Schnorbus, M.A., K.E. Bennett, A.T. Werner and A.J. Berland (2011). *Hydrologic Impacts of Climate Change in the Peace, Campbell and Columbia Watersheds, British Columbia, Canada.* Pacific Climate Impacts Consortium, University of Victoria, Victoria, BC, 157 pp.
18. Septer, D. (2006). *Flooding and Landslide Events of British Columbia 1808-2006*. Prepared for Ministry of Environment.
19. Water Management Consultants, "Floodplain Mapping, Guidelines and Specifications", Prepared for Fraser Basin Council, 2004.

2. Background

The Courtenay River is located on the eastern side of Vancouver Island near Courtenay, British Columbia.

The watershed of the Courtenay River flows downstream of the confluence of the Puntledge River and Tsolum River to the mouth at Comox Harbour. The Puntledge River sub-watershed drains from its headwaters at Comox Lake. Water levels in Comox Lake and flows in the Puntledge River are regulated by BC Hydro at Comox Lake Dam at the outlet of Comox Lake. The Tsolum River sub-watershed drains from the north and east-facing slopes of Mt. Washington and then flows eastward towards the confluence with Puntledge River.

The Courtenay River watershed, including the Puntledge River, Browns River and Tsolum River sub-watersheds, the Comox Lake Dam as well as the hydrometric station locations, are shown in Figure 1.

There are several active Water Survey of Canada (WSC) hydrometric stations within the Courtenay River watershed including:

1. Tsolum River near Courtenay (08HB011)
2. Puntledge River near Courtenay (08HB006)
3. Dove Creek near the mouth (08HB075)
4. Browns River near Courtenay (08HB025)
5. Puntledge River below Diversion (08HB084)
6. Cruickshank River near the mouth (08HB074)

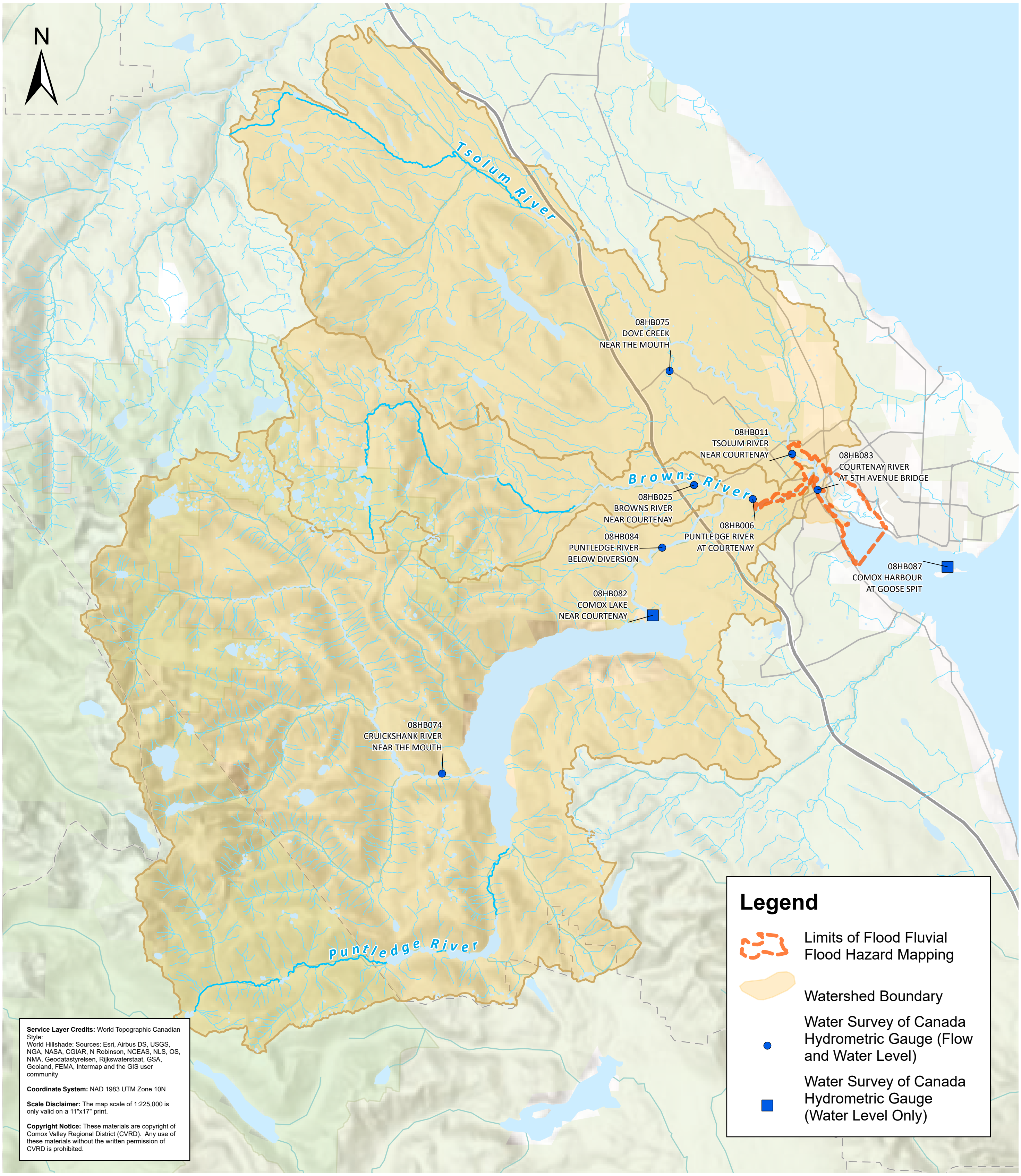
The hydrometric stations listed above provide a record of water level and flow. Additional water level only data is available from the Comox Lake near Courtenay (08HB082) Courtenay River at 5th Avenue Bridge (08HB083), and the Comox Harbour at Goose Spit (08HB087) WSC hydrometric stations.

Path: Z:\2000-2999\2600-2699\2623-014\430-GIS\Pro Projects\2623014_Memo_3B\2623014_Memo_3B_Figures.aprx Date Saved: 2021-04-19 10:30 AM | Author: TSoh

Comox Valley Regional District

Coastal Flood Mapping Project

KERR WOOD LEIDAL consulting engineers



Project No. 2623.014

Date April 2021

Scale 0 1 2 4 Kilometres

1:225,000

Courtenay River Watershed

Figure 1

3. Hydrologic Flood Analysis

3.1 Meteorological Drivers of Floods on Vancouver Island

Floods on the Courtenay 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 Courtenay area.

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 Courtenay 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 City of Courtenay, this combination of river flood and tide level flood results 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 Courtenay River will continue to increase into the future.

3.2 Historical Floods

Heavy rainfall and rain-on-snow events in the Comox Lake/Puntledge River sub-watershed and the Tsolum River sub-watershed combined with high tide/storm surge events in Comox Harbour have led to damaging floods along the Tsolum River, Puntledge River and Courtenay River within the Comox Valley Regional District, and the City of Courtenay. The Courtenay River floodplain has flooded many times since 1900 (KPA, 1990 & Septer, 2006). The dates of these floods and a brief commentary based on newspaper reports are provided in Table 1.

Table 1: History of Floods on the Courtenay River Watershed

Date	Puntledge River Peak Daily Flow[1]	Tsolum River Peak Daily Flow[2]	Comments
October 13, 1905	Not recorded	Not recorded	9 m of dike failed near floodgates on Comox Road.
February 1, 1935	Not recorded	Not recorded	Flow records indicate that a moderate flood occurred on the Puntledge River. Reports that Lewis Park was under about 1 m of water and that log debris collected on Condensory Road bridge resulting in the collapse of the bridge.
November 15, 1939	Not recorded	Not recorded	Floodwaters rose rapidly during the night of the 14th and peaked on the 15th just before a high tide of 1.32 m geodetic, which crested at 11:00 am. Southeast gale-force winds accompanied the heavy rain, which set a precipitation record of 83 mm in 24 hours on the 15th. Newspapers reported that residents found this flood to be more severe than the 1935 flood.
December 8, 1939	Not recorded	Not recorded	The second flood in 3 weeks occurred along the Courtenay River, however, the maximum stage did not reach the levels attained in the November flood.
November 28 to 30, 1941	Not recorded	Not recorded	Reported “usual” flooding of Lewis Park and Comox Road.
November 13, 1953	Not recorded	Not recorded	A total of 229 mm of rain in 5 days was measured at Courtenay, with 57 mm falling on the 13th. The storm was accompanied by a 59 km/h southeast wind. From the newspaper accounts. It appears that the 1953 flood was not as high as the 1939 flood. A new dike around Lewis Park was credited for reducing the extent of damage to the Park in comparison to the effects of the 1935 and 1939 floods.
November 5 to 13, 1975	334 m^3/s	170 m^3/s	Floodwaters caused considerable damage in the Rye Road area, entering homes and businesses in the lowlands north of Ryan Road. Some residents expressed the opinion that the construction of Ryan Road caused higher flood levels in this area. Flooding also occurred along with the approaches to the Condensory Road bridge. Puntledge Park and Lewis Park were heavily inundated. The Courtenay Flats received some floodwaters from the rivers but were not filled as they had been in earlier floods.

Date	Puntledge River Peak Daily Flow[1]	Tsolum River Peak Daily Flow[2]	Comments
December 26 to 27, 1980	281 m^3/s	136 m^3/s	Several days of record warm temperatures and heavy rain resulted in very high discharges, especially in the Puntledge basin. The highest record peak inflow to Comox Lake occurred with this event; however, the high flows were not sustained over a long period. The peak instantaneous flow for the Puntledge River also set a record. The Tsolum River flows, however, were not as extreme.
October 25 to 26, 1982	319 m^3/s	105 m^3/s	This was not a large flood, but it was associated with a high inflow to Comox Lake.
February 11, 1983	259 m^3/s	180 m^3/s	Warm temperature, high winds, and heavy rains of 80.2 mm on the 11th caused flooding along the Tsolum and Courtenay Rivers. In contrast to the 1980 and 1982 flood events, this flood was more extreme in the Tsolum River than in the Puntledge and was similar in some respects to the 1975 event. Dove Creek Road near its crossing of the Tsolum River was overtopped by floodwaters. The Old Island Highway near Ryan Road and the Rye Road area were flooded once again. Water did not, however, inundate the Courtenay Flats on this occasion. The tide was very low at the time when the Tsolum and Puntledge Rivers peaked.
March 5, 1987	354 m^3/s	136 m^3/s	No documented records of this high flow event were found.
November 12, 1990	324 m^3/s	73 m^3/s	No documented records of this high flow event were found.
January 30 to February 3, 1992	345 m^3/s	154 m^3/s	No documented records of this high flow event were found.
October 2 to 10, 1997	285 m^3/s	158 m^3/s	No documented records of this high flow event were found.
December 24 to 26, 2005	236 m^3/s	140 m^3/s	
November 12 to 19, 2009	303 m^3/s	220 m^3/s	Water level at 5th Street Bridge measured at 3.154 m which is roughly equivalent to the 5% AEP water level.
January 14 to 16, 2010	378 m^3/s[#]	155 m^3/s	Water level at 5th Street Bridge measured at 3.096 m.
December 24, 2010	157 m^3/s	256 m^3/s	Water level at 5th Street Bridge measured at 3.002 m.

Date	Puntledge River Peak Daily Flow[1]	Tsolum River Peak Daily Flow[2]	Comments
December 8 to 10, 2014	359 m^3/s	258 m^3/s*	Over 200 mm of rain fell in the Comox Lake watershed. This resulted in flooding along the Courtenay River. The event flooded Lewis Park, closed the Lewis Park recreation center, several roads and the 5th Street Bridge and resulted in damage to commercial properties. The City of Courtenay declared a state of emergency.
November 3 to 9, 2016	333 m^3/s	227 m^3/s	Heavy rains resulted in high flows in the Courtenay River. This triggered the City of Courtenay to install temporary flood protection in the form of aqua dams along the Old Island Highway and Comox Road to reduce the potential of flooding to properties in the Puntledge Business District.

Notes:
1. From recorded flows at WSC hydrometric station 08HB006 Puntledge River at Courtenay.
2. From recorded flows at WSC hydrometric station 08HB011 Tsolum River near Courtenay.

Maximum flood of record for Puntledge River with peak inst. Flow of 539 m^3/s on Jan 11, 2010 at 23:35.

* Maximum flood of record for Tsolum River with peak inst. flow of 327 m^3/s on Dec 9, 2014 at12:25

3.3 Flood Frequency Analysis

For the Courtenay River watershed, additional hydrological analysis was beyond the scope of this project. The results of the regional flood frequency analysis carried out for the Courtenay River IFMS in 2013 was used to calculate the AEP 10%, AEP 5%, AEP 1%, and AEP 0.2% flood events. The AEP 0.5% (200-year return period) flood estimated in the 2013 IFMS was used without any adjustments or changes. This means that flood events which have occurred after 2013, such as the 2016 flood, were not included in the analysis to estimate the AEP floods for the Courtenay River as part of the Coastal Flood Mapping Project.

The results of the analyses are discussed further below.

Regional Flood Frequency Analysis for 2013 Courtenay IFMS

The 2013 Courtenay River IFMS used a regional flood frequency analysis approach to estimate design floods. This approach used flood records from regional hydrometric stations located along the east coast of Vancouver Island to develop an empirical relationship between watershed physiographic characteristics, namely watershed area and mean elevation, to flood flow magnitudes. Further information on selection of the representative regional stations and the derivation of flood flow to watershed physiographic characteristics is provided in the technical memorandum supporting the Courtney River IFMS prepared by KWL in 2013.

As discussed above, the regional flood frequency results from the 2013 IFMS were used to derive estimates of the instantaneous peak flows for the annual exceedance probabilities for the Tsolum River, Puntledge River and Courtenay River (AEP 10%, AEP 5%, AEP 1% and AEP 0.2%) for the CVRD Coastal Flood Mapping Project as described below.

Tsolum River Design Flows

As discussed in more detail in the 2013 Courtenay River IFMS, the recorded peak flows for the Tsolum River are expected to underestimate the peak flows due to difficulties in measuring flood flows across the floodplain near the hydrometric station during high river water levels. Therefore, the regional flood frequency analysis was used in 2013 to estimate the design floods for the Tsolum River rather than results based on single station analysis. To be consistent with the 2013 Courtenay River IFMS, the same approach was used for the Coastal Flood Mapping Project.

The design flood events were estimated by calculating average ratios between the various AEP flood and the 0.5% AEP (200-year return period) flood flows estimated from the 2013 Courtenay River IFMS regional flood frequency analysis. These ratios were applied to the peak of the 2013 estimate of the 0.5% AEP peak instantaneous flow to calculate the 10% AEP, 5% AEP, 1% AEP and 0.2% AEP instantaneous peak Tsolum River flows for use in the flood mapping updates for the Coastal Flood Mapping Project; the results are outlined in Table 2.

Puntledge River Design Flows

As discussed in more detail in the Courtenay River IFMS, the BC Hydro has some level of control of the peak flows in the Puntledge River as a result of operation of sluice gates at the Comox Lake Dam.

BC Hydro's primary flood control approach is to reduce flow in the Puntledge River during periods of high tide at Comox Harbour or high flows on the Tsolum and/or lower Puntledge River (includes Browns River) to minimize the downstream flood risks (see Figure 2 for diagram of BC Hydro operations on Puntledge River). This is achieved by reducing outflow and storing water in Comox Lake to help reduce downstream flood risks and then increasing outflow and releasing water from storage at Comox Lake during periods of low tide at Comox Harbour and/or lower flow periods on Tsolum River / lower Puntledge River. However, due to the relatively small storage capacity of Comox Lake in comparison to the inflow volume during extreme flood events, BC Hydro has limited capacity to control flood discharges downstream of Comox Lake during extreme flood events.

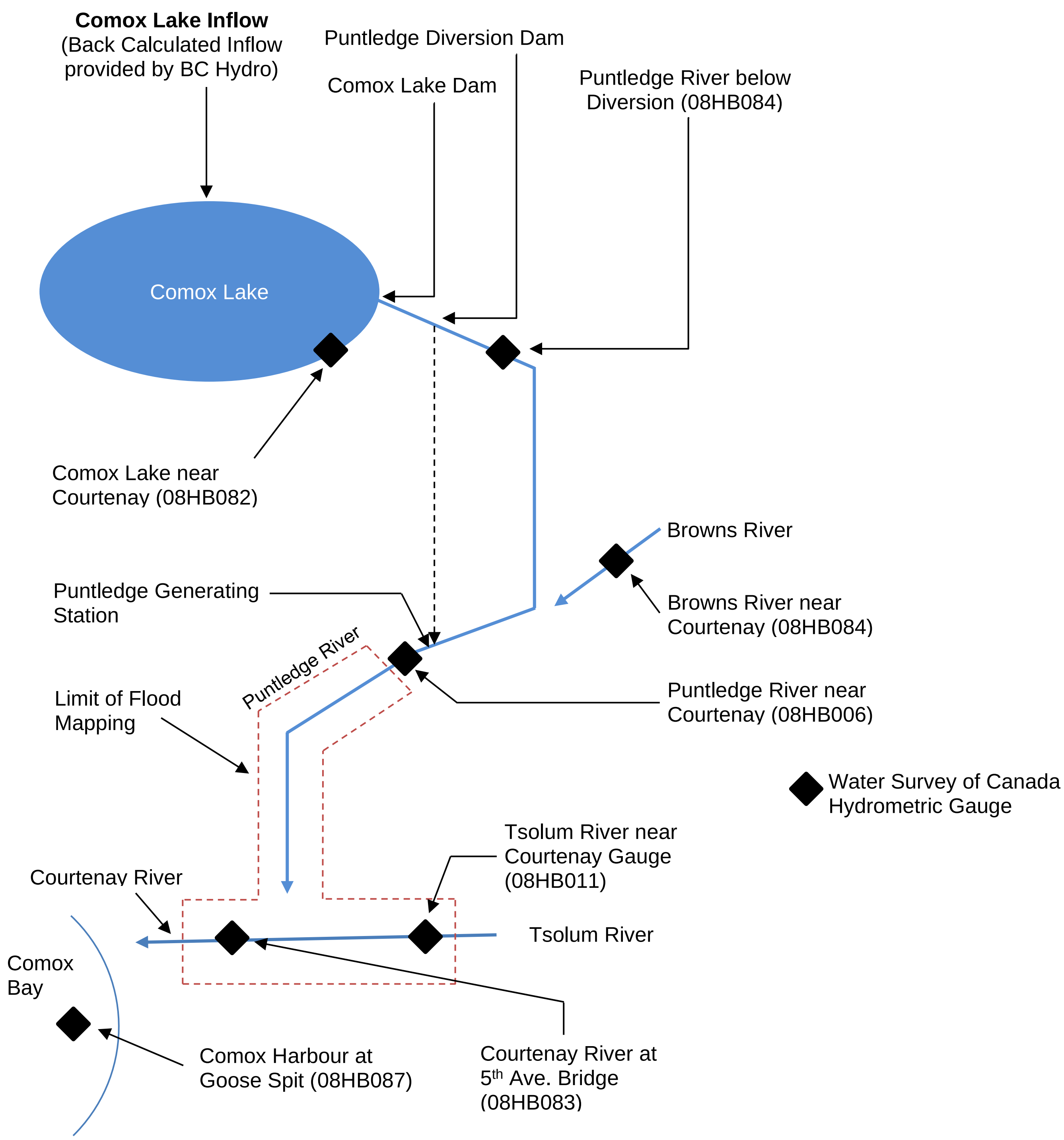


Figure 2: Comox Lake/Puntledge River Network

Accounting for Comox Lake Reservoir Operations

To account for the control of peak flows by BC Hydro, a reservoir operation algorithm was developed for Comox Lake as part of the 2013 Courtney River IFMS. The reservoir operation algorithm includes rules based on BC Hydro's operating guidelines for the Comox Lake Dam (BC Hydro, 2010). To be consistent with the 2013 Courtenay River IFMS, the design floods used for Puntledge River in the Coastal Flood Mapping Project were estimated using a similar approach as that used in 2013. This approach involves several steps to account for the buffering effect of the Comox Lake Dam on flood flows in the Puntledge River as well as inflow from the Browns River and the intervening watershed area below Comox Lake.

The peak design flows for the Puntledge River were calculated as follows:

1. Calculate peak flows for Comox Lake inflow and Browns River / Intervening Area flow for the %AEP scenarios by multiplying the %0.5 AEP peak instantaneous flood discharge by the regional average ratio of the peak instantaneous flow for each %AEP event and the 0.5% AEP event.
2. Adjust the design hydrographs for Comox Lake inflow and Browns River/Intervening Area inflow to match the peak instantaneous flows for each of the AEP cases.
3. Route the Comox Lake inflow hydrograph through Comox Lake using a level pool routing algorithm to calculate the Comox Lake outflow hydrographs for each AEP flood (using the assumptions outlined further below).
4. Combine the Comox Lake outflow hydrograph and Browns River/Intervening Area hydrograph to derive design flood hydrographs for the lower Puntledge River. A 3-hour lag was used between the Browns River/Intervening Area and Comox Lake outflows to account for travel times down the Puntledge River. This is consistent with the lag times used in the 2013 Courtenay River IFMS.

Starting Reservoir (Comox Lake) Water Level Assumptions

While carrying out the Courtenay River IFMS in 2013, the results of the peak design flows in the Puntledge River were found to be very sensitive to the selection of the assumed reservoir level at the start of the storm event. Although BC Hydro aims to keep Comox Lake within a specific operating range, flood events can result in water levels rising above the operating range. During periods of consecutive storms, there is often not enough time for reservoir levels to fall back within the operating range before the arrival of the following storm. Therefore, the starting reservoir level during the design flood events could be higher than the normal operating range, assuming there was a large storm event that occurred prior to the design flood. To account for this effect, two cases were assumed to estimate design flood flows for the Puntledge River used in the Coastal Flood Mapping Project.

1. For rare extreme flood events (AEP 1%, AEP 0.5%, and AEP 0.2%) the starting reservoir level is assumed to be at the spillway crest elevation (135.33 m, GSC) at the start of the flood event and assumes uncontrolled discharge over the spillway and dam crest throughout the storm event. This is the same assumption used in the Courtenay River IFMS and is considered to be a conservative approach for design floods. Using the assumed starting reservoir level at the spillway crest elevation accounts for smaller antecedent floods which could fill the Comox Lake reservoir before the onset of the design flood event.
2. For more frequent flood events (AEP 10%, and AEP 5%), the starting reservoir level is assumed to be at the maximum winter operating level (134.42 m, GSC) and assumes that BC Hydro operates the gates at Comox Lake Dam in general accordance with the operating rules such that:
   a. Discharge from Comox Lake is either 221 m^3/s (lake levels between maximum winter operating level and spillway crest) or 280 m^3/s (lake levels between spillway crest and top of the dam) when

downstream flood risks are lowest. Lower flooding risks are present when predicted tides are below 4.2 m, Chart Datum (CD), Tsolum River discharge is below 180 m^3/s and/or the Courtenay River is below 300 m^3/s (taken as the combined flow of Tsolum River and lower Puntledge River).

b. Discharge from Comox Lake is progressively increased (using a ramping rate of 25 m^3/s/hr) when water levels exceed the top of the dam (137.46 m, GSC) until lake levels are stabilized. Discharge is reduced once lake levels begin to recede.

The BC Hydro operating rules also have a Comox Lake discharge trigger based on Courtenay River recorded water levels at 5th Street bridge. However, for flood modelling, including this trigger would require iteration between the hydraulic modelling and Comox flood routing algorithms. This additional level of effort was not considered to add significant additional value to the development of the design flood event discharges. Not modelling the 5th Street Bridge water level operating rule results in conservative flow releases from Comox Lake for flood modelling.

The results of the analysis are summarized in Table 2.

Table 2: Estimated Peak Instantaneous Flood Discharges based on Regional Flood Frequency Analysis[1]

Location	Peak Instantaneous Flood Discharges for each Annual Exceedance Probability (AEP) Scenario – Current Climate Conditions				
	10% AEP[1]	5% AEP[1]	1% AEP[1]	0.5% AEP[2]	0.2% AEP[1]
Tsolum River at the Mouth	375	413	487	516	553
Comox Lake Inflow	771	847	999	1059	1135
Comox Lake Outflow[3]	280[3]	350[3]	399[4]	439[4]	494[4]
Browns River / Intervening Area	297	326	385	408	437
Puntledge River at the Mouth[5]	459	482	651	679	716

Note:
1. Peak instantaneous flow calculated using an average regional ratio between specified %AEP and 0.5% AEP based on results of regional flood frequency analysis for 2013 Courtenay River IFMS using historical flow records and does not include projected impacts of climate change.
2. Peak 0.5% AEP instantaneous flow based on the results of the 2013 Courtenay River IFMS.
3. Comox Lake outflow based on level-pool routing including the influence of BC Hydro regulation of flows for frequent large flood events (10% AEP and 5% AEP).
4. Comox Lake outflow based on level-pool routing through Comox Lake and does not include the influence of BC Hydro regulation of peak flows for extreme events (AEP 1% to AEP 0.2%).
5. Combination of Comox Lake outflow and Browns River / Intervening Area flow hydrographs. Note that peak flow of Puntledge River at the mouth does not equal the total of the Comox Lake outflow and Browns River / Intervening Area flow due to the relative timing of the peak flows.

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 were incorporated into the flood analysis.

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 were 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 results are summarized in Table 3. A copy of the details of the trend analysis for each of the stations is included in Appendix A.

Table 3: Trends in Vancouver Island Regional Recorded Flood Flows

Station Name	WSC Number	Period	Trend	Statistically Significant	Average % Change Per Decade (Sens 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 well as climate change impacts. This highlights some of the difficulty in using historical records to project potential climate change impacts on peak flows.

In 2011, Northwest Hydraulic Consultants (NHC) carried out an analysis of precipitation records and flood discharge records to assess trends in peak floods on the Tsolum River (NHC, 2011). In the study, the method of departure from the mean was used to assess trends within the data rather than the overall trend of the entire data set.

The NHC 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. Before the 1970s, both precipitation and flood flows were about average, during the 1970s and 1980s, precipitation and flood flows were below average and since the 1990s the precipitation and flood flows have been above average in general. No overall trend in the magnitude of precipitation or flood flows were found in the study. However, there appears to be an increasing trend in the frequency of occurrence of larger floods with about a 17% increase in the frequency of larger floods occurring on the Tsolum River over the period from 1965 to 2011.

Climate Change Projections

Climate projections from the Pacific Climate Impacts Consortium (PCIC) at the University of Victoria indicate that for the CVRD that 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 precipitation having AEP of 2% (50-year return period) is projected to increase by approximately 18% by mid-century and by 30% by end of the century (PCIC, 2020).

Changes in precipitation alone are a significant driver of projected changes in the magnitude of peak floods. However, the change in precipitation alone does not take into account changes in snowmelt at higher elevations and the related impacts to peak flows. In addition to projections of climate variables, PCIC has also carried out hydrological analysis using projected climate data (Schnorbus wt. al., 2011). The results of the hydrological modelling for the Campbell River watershed, the nearest available projected hydrological model data, indicates mean annual flood discharge in the Campbell River watershed is projected to increase by +30% by end of the century (PCIC, 2020b).

Sea Level Rise

Sea levels at the mouth of the Courtenay River are also projected to rise as a result of climate change. In order to account for this change, the flood modelling carried out has also included projected sea level rise (SLR) of +0.5 m, +1.0 m and +2.0 m. The latter two scenarios are consistent with provincial guideline policy planning values for the Year 2100 and 2200, respectively (FLNR, 2018).

Climate Change Allowance

As outlined in Table 4 and discussed above, several ranges of incremental increase in peak flow were considered to account for projected climate change impacts on peak AEP floods.

Table 4: Summary of Projected Climate Change Impacts to Peak Flows

Source/Approach	Projected Change in Peak Flood Flow Over Next 100 Years		Reference
	Low Bound	Upper Bound	
EGBC Guidelines	10%	20%	EGBC, 2017
Projected Change in 2% AEP precipitations	18%	30%	PCIC, 2020
Campbell River Projected Change in MAF	N/A	30%	PCIC, 2011
Selected incremental change in peak flows	15%	30%	

Based on the trend analysis and review of available background information, we have applied the following climate change factors to the design floods and sea level conditions as shown in Table 5.

Table 5: Summary of Projected Climate Change Factors

Design Flood Discharge (% increase in peak inst. flow)	Downstream Ocean Level (m, SLR)	Approximate Time Horizon[1]
+15%	+ 0.5 m	Mid-Century (nominally 2050)
+30%	+1.0 m	End of Century (nominally 2100)
+30%	+2.0 m	End of next Century (nominally 2200)

Note:
1. Approximate time horizons for climate change projections based on SLR guidance provided in FLNR, 2018.

Limitations 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 cannot be made with a high level of confidence (IPCC, 2012). These uncertainties in future changes in extreme precipitation combined with inherent uncertainties in hydrological 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 IPCC SREX3 report on climate extremes concluded *"presently we have only low confidence in numerical projections of changes in flood magnitude or frequency resulting from climate change"* (Kundzewicz , 2013).

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 Design Flood Discharges

The recommended peak design flows for the Courtenay River hydraulic modelling are shown in Table 6.

Table 6: Courtenay River Watershed Design Instantaneous Peak Flow Estimates (m^3/s) including Climate Change Allowances

Flood Event	Puntledge River at the Mouth			Tsolum 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	459	528	597	375	434	490
5% AEP	482	554	627	413	473	535
1% AEP	651	748	846	487	543	614
0.5% AEP	679	781	883	516	567	641
0.2% AEP	716	823	930	553	595	672

Note:
1. Projected change in flows for future river floods corresponding to +0.5 m SLR. Nominally Year 2050.
2. Projected change in flows for future river floods corresponding to +1.0 m and +2.0 m SLR. Nominally Year 2100 and year 2200, respectively.

3.6 Ocean Level and Design Flood Hydrographs

Design Ocean Level

The peak design ocean levels used at the downstream boundary of the Courtenay River hydraulic models are the same as those derived for the coastal flood mapping. The still water level was 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 events 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.

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

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.

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. For instance, combining the AEP 0.5% flood flow with the AEP 0.5% ocean water level would result in over prediction of maximum water levels near the mouth of the river and results in increased estimates of the design flood levels.

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 IFMS in 2013 and those used with the updated Courtenay River model in the Coastal Flood Mapping Project, the coincident flood and tides used in the modelling have the same AEP. In other words, the AEP 0.5% river flood is combined with the peak AEP 0.5% 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. In addition, this assumption is also similar to coastal wave runup calculations which combine storm surge and wind-waves having the same AEP.

An analysis of the influence of the selection of the combined coastal flood level and flood discharge on peak water levels is described in more detail in Section 4.3.

Courtenay River Design Flood Hydrographs

The design flood hydrographs developed for the Courtenay River IFMS hydraulic modelling were scaled to the updated design flood flows and design ocean levels.

The upstream boundary condition for the Courtenay River was based on scaling historical recorded hydrograph to the peak design flood flow condition while the downstream boundary condition was based on predicted tidal time-series adjusted to the calculated peak design ocean water levels for Comox Harbour at the mouth of the Courtenay River.

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 design flood events are the same.

The relative timing of critical tidal water levels and flows in the Puntledge River and Tsolum River were established during the development of the IFMS in 2013. The same relative timing was used in the update to the Courtenay River modelling carried out in the Coastal Flood Mapping Project. The Tsolum River, the Browns River, the Puntledge River intervening area hydrograph and the Comox Lake inflow hydrographs were scaled using the factoring approach described above. The Puntledge River at the mouth hydrograph is the result of adding the Browns River and the Puntledge River intervening area hydrograph and the Comox Lake outflow hydrograph, as described in Section 3.4. An example of the

AEP 5% (20-year return period) and AEP 0.5% (200-Year Return Period) design hydrographs for the Puntledge River, the Tsolum River and tide levels in Comox Harbour for current climate conditions are shown in Figure 3 and Figure 4, respectively.

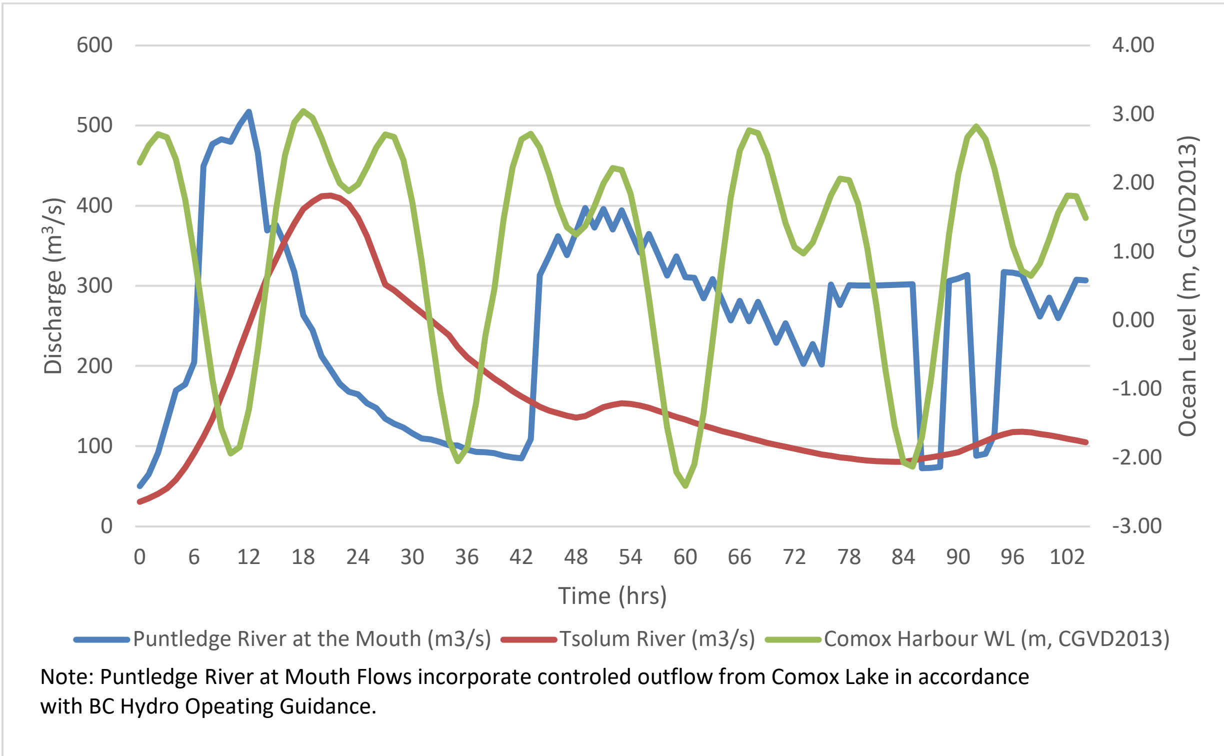
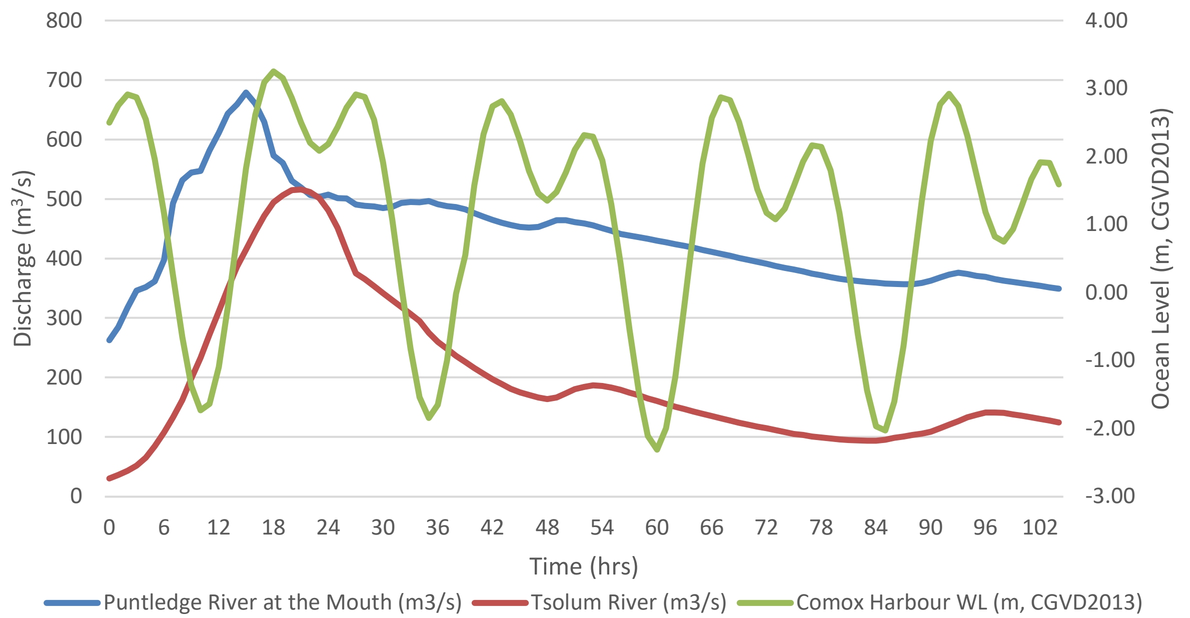


Figure 3: AEP 0.5% (200-Year Return Period) Design Hydrographs for Current Climate Conditions



Note: Puntledge River at Mouth Flows assume uncontrolled outflow from Comox Lake.

Figure 4: AEP 0.5% (200-Year Return Period) Design Hydrographs for Current Climate Conditions

4. Hydraulic Modelling

4.1 Software Selection and Modelling Approach

A combined one-dimensional/two-dimensional hydraulic model, using the MIKE Flood software, was developed as part of the Courtenay IFMS in 2013. This model suite uses a one-dimensional MIKE 11 hydraulic model to represent flow in the river channel and a two-dimensional MIKE 21 hydraulic model to represent overbank flow across the floodplain. The MIKE Flood software consists of a dynamic link between the MIKE 11 software and the MIKE 21 software to transfer flows and water levels between the two models along the boundary between the river channel and the floodplain.

The updated inundation mapping and flood hazard mapping prepared for the Coastal Flood Mapping Project used the model prepared in 2013 for the Courtenay IFMS without any adjustments, except to update the upstream and downstream model boundary conditions. The Courtenay IFMS model is based on topography, flood protection and drainage conditions within the river and floodplain at the time the model was developed in 2013. The Courtenay IFMS hydraulic model does not include the influence of the temporary flood protection measures that the City of Courtenay has implemented since 2013. No recalibration or verification of the hydraulic model prepared for Courtenay IFMS was carried out as part of the Coastal Flood Mapping Project.

Hydraulic Model Datum

The 2013 IFMS hydraulic model was developed based on LiDAR Data collected in 2013 based on the CGVD28 datum. Therefore, modelling for the Coastal Flood Mapping Project was first carried out in the CGVD28 datum, including converting the ocean flood levels from CGVD2013 to CVGD28 for use as downstream boundary conditions in the model. The maximum water level results of the hydraulic model were then converted back to CGVD2013 to prepare inundation and flood hazard mapping.

The extent of inundation and depth of flooding across the Courtenay River floodplain mapped for the Coastal Flood Mapping Project used the hydraulic model results, converted from CVGD28 to CVGD2013 and topography based on LiDAR collected by GeoBC in 2018/2019.

Courtenay Flood Protection

For the majority of the flood mapping for the Courtenay River, the topography in the model is based on the 2013 LiDAR data used in the Courtenay IFMS project including the adjustment of the topography to represent the existing floodwall surrounding the Canterbury Place development on Anderton Ave. This adjustment involved raising the DEM along the Canterbury floodwall alignment to the original MoE floodplain elevations. In this way, flooding of the area protected by the floodwall is not considered in the model until the existing floodwall is overtopped. This provides an understanding of the flood hazard for the area protected by the floodwall assuming that the wall is not raised in the future and that the wall does not fail.

The only exception to using the 2013 topography is for the regulatory mapping scenario (0.5% AEP with +30% climate change and 1.0 m SLR) where the impact on maximum water levels along the Courtenay River needs to account for potential of future flood protection measures. As outlined in the 2013 Courtenay IFMS, three options were proposed for flood protection measures; however, no preferred option has been selected to date.

Therefore, the hydraulic modelling carried out for the Courtenay River regulatory mapping as part of the Coastal Flood Mapping Project includes the following cases:

1. Flooding across floodplain using the 2013 topography.
2. Flood flows concentrated within the Courtenay River channel as a result of the proposed “Option 2 – Ring Dike” which resulted in the greatest increase in flood levels within the Courtenay River channel.

The alignment of the proposed flood protection measures used in the modelling are shown in Figure 5.

The highest maximum water levels for the two scenarios listed above were used to develop the regulatory mapping results.

4.2 Key Hydraulic Model Assumptions

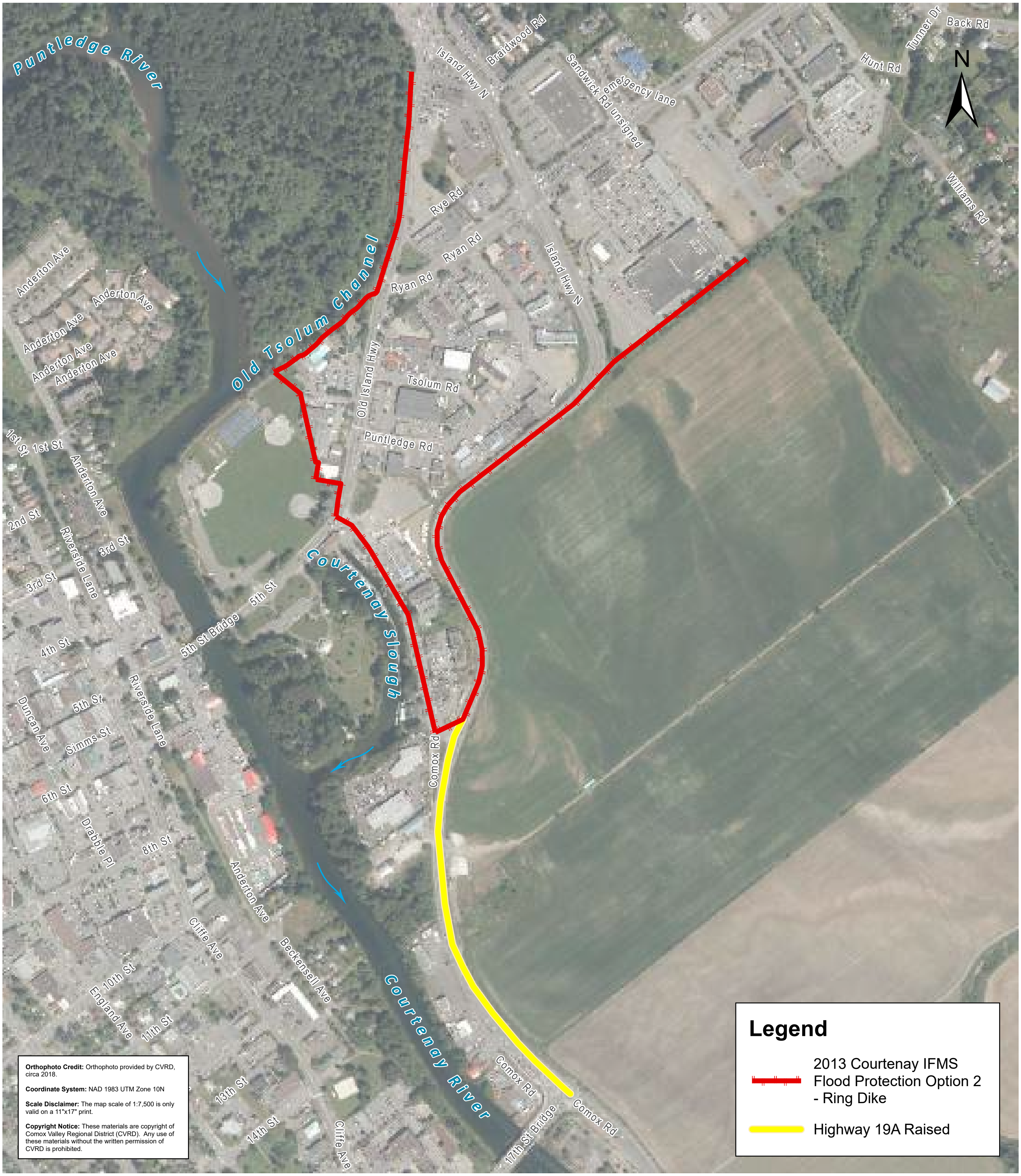
The key assumptions used for the hydraulic modelling of the Courtenay River can be found in the 2013 Courtenay River IFMS (KWL, 2013).

Path: Z:\2000-2999\2600-2699\2623-014\430-GIS\Pro Projects\2623014_Memo_3B\2623014_Memo_3B_Figures.aprx Date Saved: 2021-04-19 10:30 AM | Author: TSoh

Comox Valley Regional District

Coastal Flood Mapping Project

KERR WOOD LEIDAL
consulting engineers



Orthophoto Credit: Orthophoto provided by CVRD, circa 2018.

Coordinate System: NAD 1983 UTM Zone 10N

Scale Disclaimer: The map scale of 1:7,500 is only valid on a 11"x17" print.

Legend

- 2013 Courtenay IFMS Flood Protection Option 2 - Ring Dike
- Highway 19A Raised

Project No. 2623.014

Date April 2021

Scale 1:7,500 — 0 20 40 80 Metres

Proposed Flood Protection Measures

Figure 5

5. Model Results

The Courtenay River hydraulic model was run with updated boundary conditions for 5 AEP peak flow/sea level combinations, 3 projected climate conditions + sea levels and 2 flood protection condition assumptions for the regulatory mapping scenario (21 model runs in total). See Appendix C for a list of all model scenarios.

The mapping products resulting from the model runs are described and presented in Technical Memorandum #5 – Coastal and Fluvial Mapping Products. Technical Memorandum #5 also includes the Floodplain Mapping Assurance Statement for the mapping products.

The sections below provide a summary of the flooding mechanisms and model results.

Mechanisms of Flooding for Puntledge River, Tsolum River and Courtenay River

The primary driver of flooding in the Puntledge River and Tsolum River are peak river flows. However, the mechanisms of flooding in the Courtenay River are relatively more complex as they depend on the interaction of the timing and magnitude of:

1. Discharge in the Puntledge River, which can be controlled to some extent by BC Hydro at Comox Lake.
2. Discharge in the Tsolum River, which flows from a natural unregulated watershed.
3. Water levels in Comox Harbour, which are governed by tide and storm surge.

The peak flood water levels and general direction of overland flow for the Courtenay River and Courtenay Flats floodplain are shown in Figure 6 and Figure 7 for the 20% AEP flood and 0.5% AEP flood, respectively.

Courtenay Flats Industrial Area

During periods of high rainfall and/or snowmelt combined with high tides and storm surge, the water levels in the Tsolum River channel can rise sufficiently to overtop the Highway 19A (Old Island Highway) between Ryan Road and Headquarters Road. This results in overland flow entering the Courtenay Flats Industrial Area and Lewis Park to the north of the Courtenay River. As the land is generally sloped from northwest to southeast, the overland flood waters flow towards the Highway 19A road embankment.

Figure 6 shows the current climate flood levels and direction of overland flow for moderate (5% AEP period flood) conditions. This shows flooding in Lewis Park and across the Courtenay Flats Area. However, the Highway 19A embankment stops water from flowing further east along the floodplain and into the agricultural fields.

Courtenay Flats Agricultural Area

When a sufficient volume of water flows across Highway 19A from the Old Tsolum River Side Channel, the flows overwhelm the existing culverts under Highway 19A and water levels within the Courtenay Flats Industrial Area rise sufficiently to overtop the Highway 19A embankment. The minimum crest elevation of Highway 19A is about elevation 3.0 m.

The water overtopping the road embankment continues to flow into the Courtenay Flats agricultural area to the southeast of the Highway 19A embankment. Comox Road, to the south of Highway 19A, acts as a height of land which separates Courtenay Flats from the Courtenay River and Comox Harbour. Therefore, only water flowing over Highway 19A and water flowing from the local catchment on Urquhart Creek contribute to the volume of water in the Courtenay Flats agricultural area. Water does not typically flow over Comox Road from the Courtenay River or Comox Harbour directly into the Courtenay Flats agricultural area.

Comox Road Flood Boxes

Once the overland flow enters the Courtenay Flats area, the water generally follows the slope of the land to the east and southeast towards Glen Urquhart Creek and the Dyke Slough. A set of flood boxes which pass through the Comox Road embankment are located near the outlet of Duke Slough near Comox Harbour. These flood boxes normally provide the only hydraulic connection between Courtenay Flats and Comox Harbour.

It is at this point where the water levels in Comox Harbour start to play an important role in the flooding mechanism. If tide levels are low, then water flowing into Courtenay Flats area can drain into Comox Harbour via the Comox Road flood boxes. However, when water levels are high in Comox Harbour due to high tide and/or storm surge, the gates on the flood boxes close and water can not drain from Courtenay Flats area into Comox Harbour. When the flood box gates are closed, water levels in Courtenay Flats continue to rise until the water levels in Comox Harbour drop and the gates open to allow flow out through the flood boxes. Therefore, the maximum water level in Courtenay Flats agricultural area is a function of the amount of water flowing into Courtenay Flats agricultural area and how long the Comox Road flood box gates are closed.

Moderate versus Extreme High-Water Levels in Comox Harbour

During moderate high water level events, such as the 50-year return period flood event, in Comox Harbour, the water levels in Courtenay Flats remain at a low enough elevation to allow the water flowing through the Courtenay Flats Industrial area to flow over Highway 19A embankment. However, as the elevation of water levels in Comox Harbour increase to extreme events, such as the 200-year return period flood, the water levels rise sufficiently high in the Courtenay Flats agricultural area that the water elevation is higher than the crest of the Highway 19A embankment. Figure 7 shows the modelled 200-year return period flood levels and the general direction of flow.

Courtenay River, Tsolum River and Puntledge Water Level Profiles

The water level profiles each of the AEP floods for the Courtenay River, the Tsolum River, and the Puntledge River, based on 1D model results in the channels, are presented in Table 7. The flood levels shown are for the scenario where flood waters are concentrated in the river channel due to proposed flood mitigation works, which results in the maximum water levels along the river. A map of the flood mapping study area showing the river chainage corresponding to the flood profiles is shown in Figure 8.

Table 7: List of River Channel Maximum Water Level Profile Figures

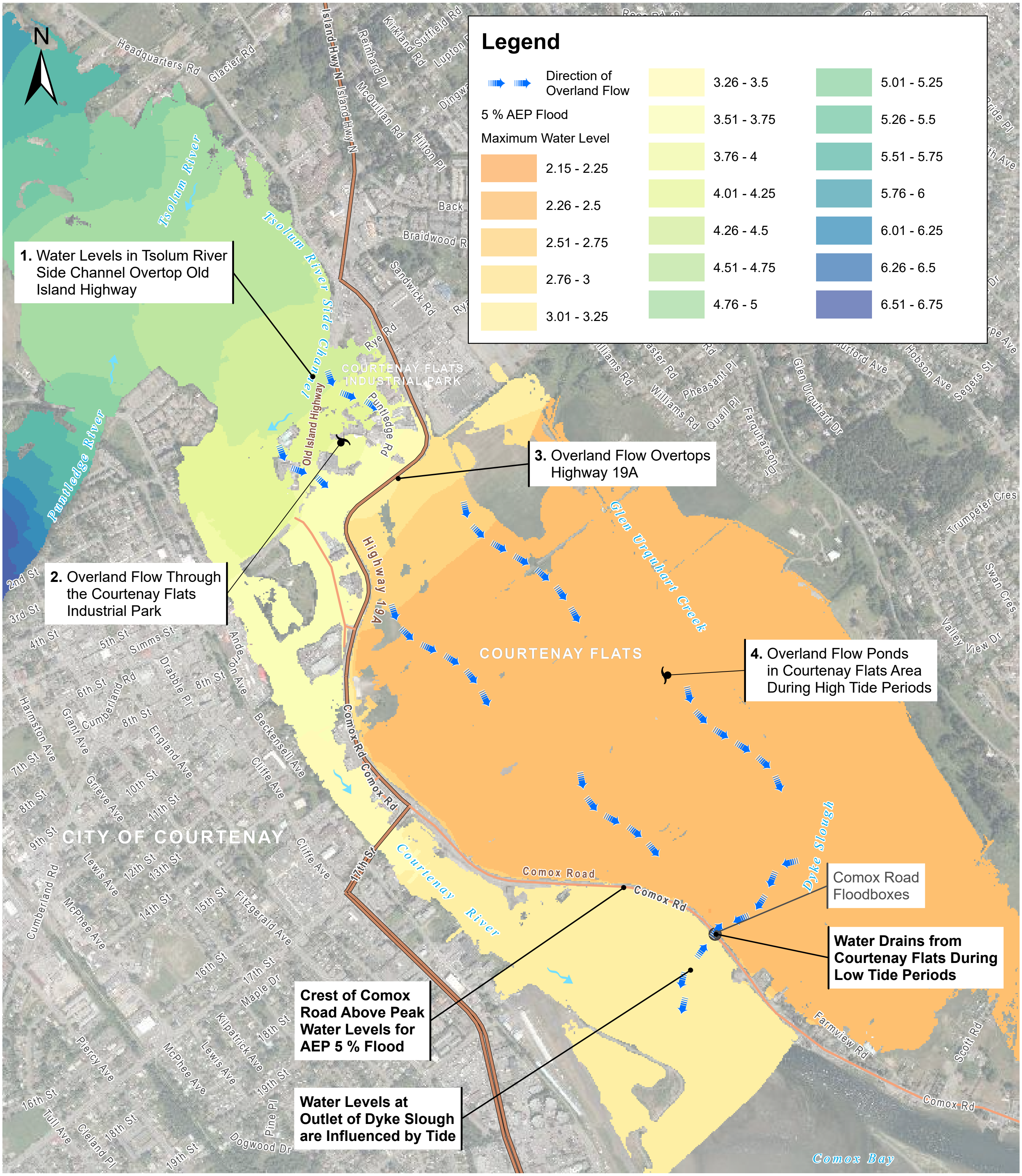
River Channel	Mid-Century (+0.5 m SLR and +15% peak flows)	End of Century (+1.0 m SLR and +30% peak flows)	End of Next Century (+2.0 m SLR and +30% peak flows)
Courtenay River	Figure 9a	Figure 9b	Figure 9c
Tsolum River	Figure 10a	Figure 10b	Figure 10c
Puntledge River	Figure 11a	Figure 11b	Figure 11c

Path: Z:\2000-2999\2600-2699\2623-014\430-GIS\Pro Projects\2623014_Memo_3B\2623014_Memo_3B_Figures.aprx Date Saved: 2021-03-31 1:03 PM | Author: JLau

Comox Valley Regional District

Coastal and Oyster River Flood Mapping Project (2020)

KERR WOOD LEIDAL
consulting engineers



Project No. 2623.014
Date April 2021
Scale 0 50 100 200 (m)
1:15,000

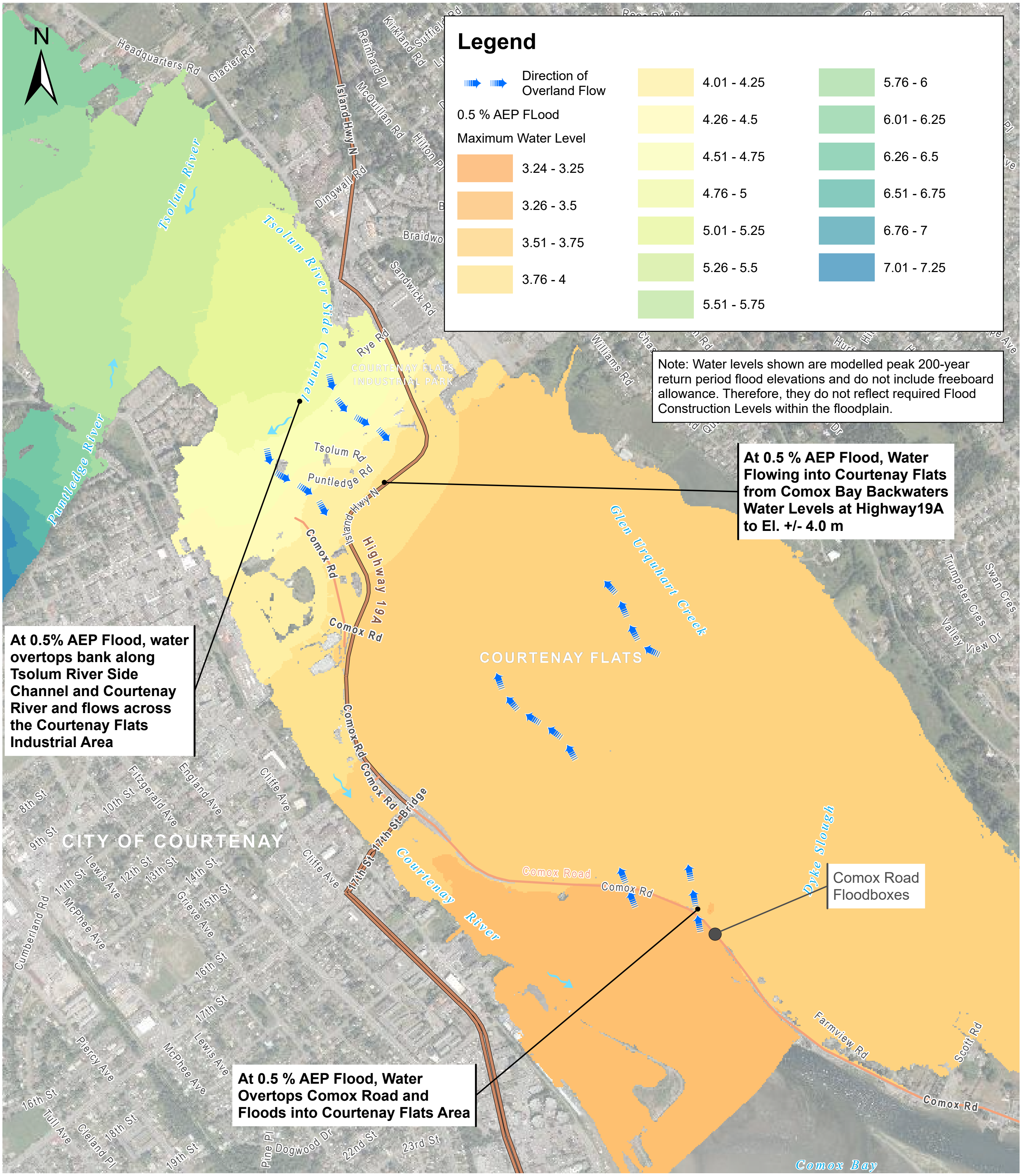
Flooding Mechanisms for Existing Conditions - Moderate Floods (5 % AEP Flood)

Figure 6

Comox Valley Regional District

Coastal and Oyster River Flood Mapping Project (2020)

KERR WOOD LEIDAL consulting engineers



Project No. 2623.014

Date April 2021

Scale 1:15,000 0 50 100 200 (m)

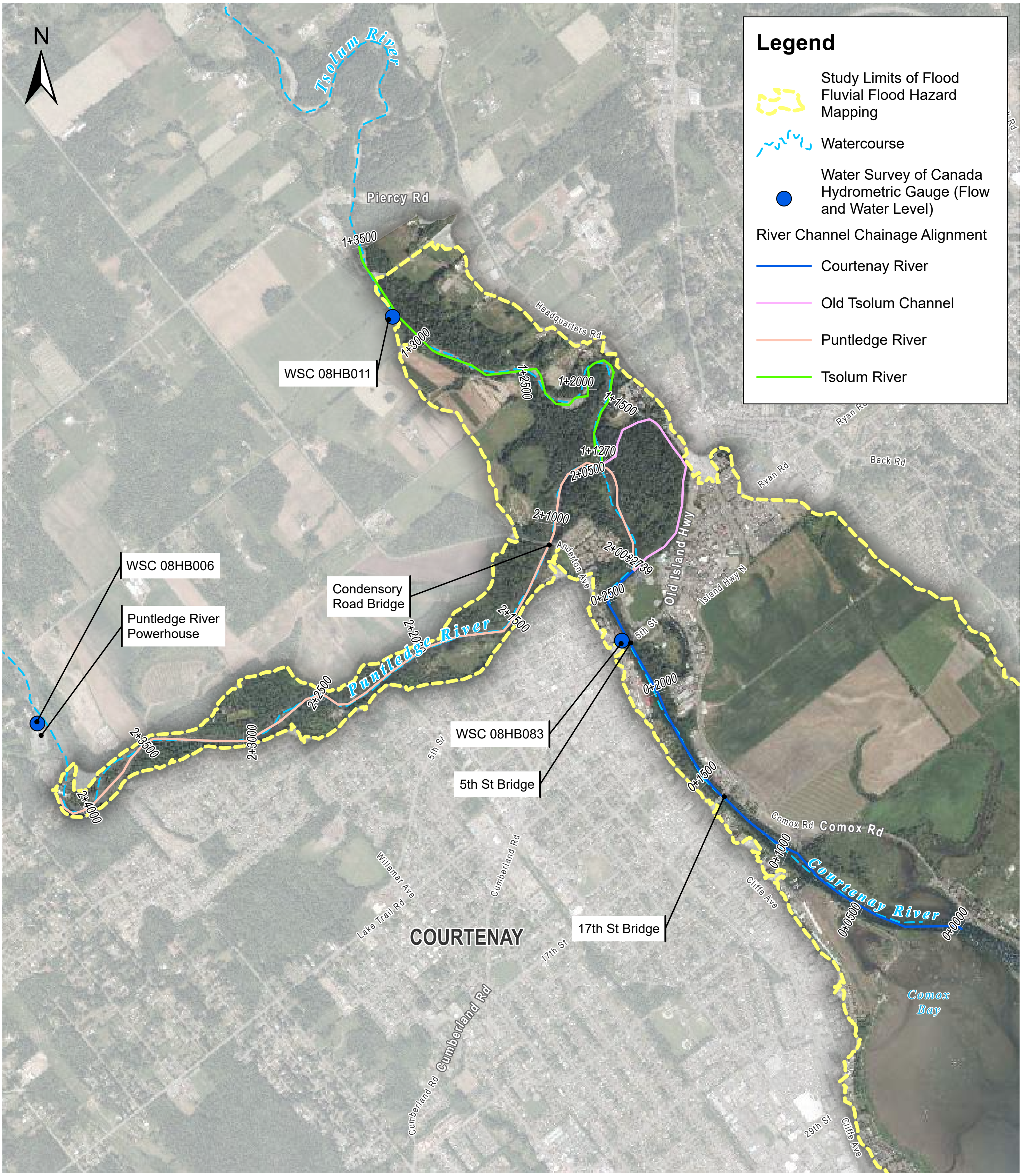
0.5 % AEP Flood - Existing Condition

Figure 7

Comox Valley Regional District

Coastal and Oyster River Flood Mapping Project (2020)

KERR WOOD LEIDAL consulting engineers



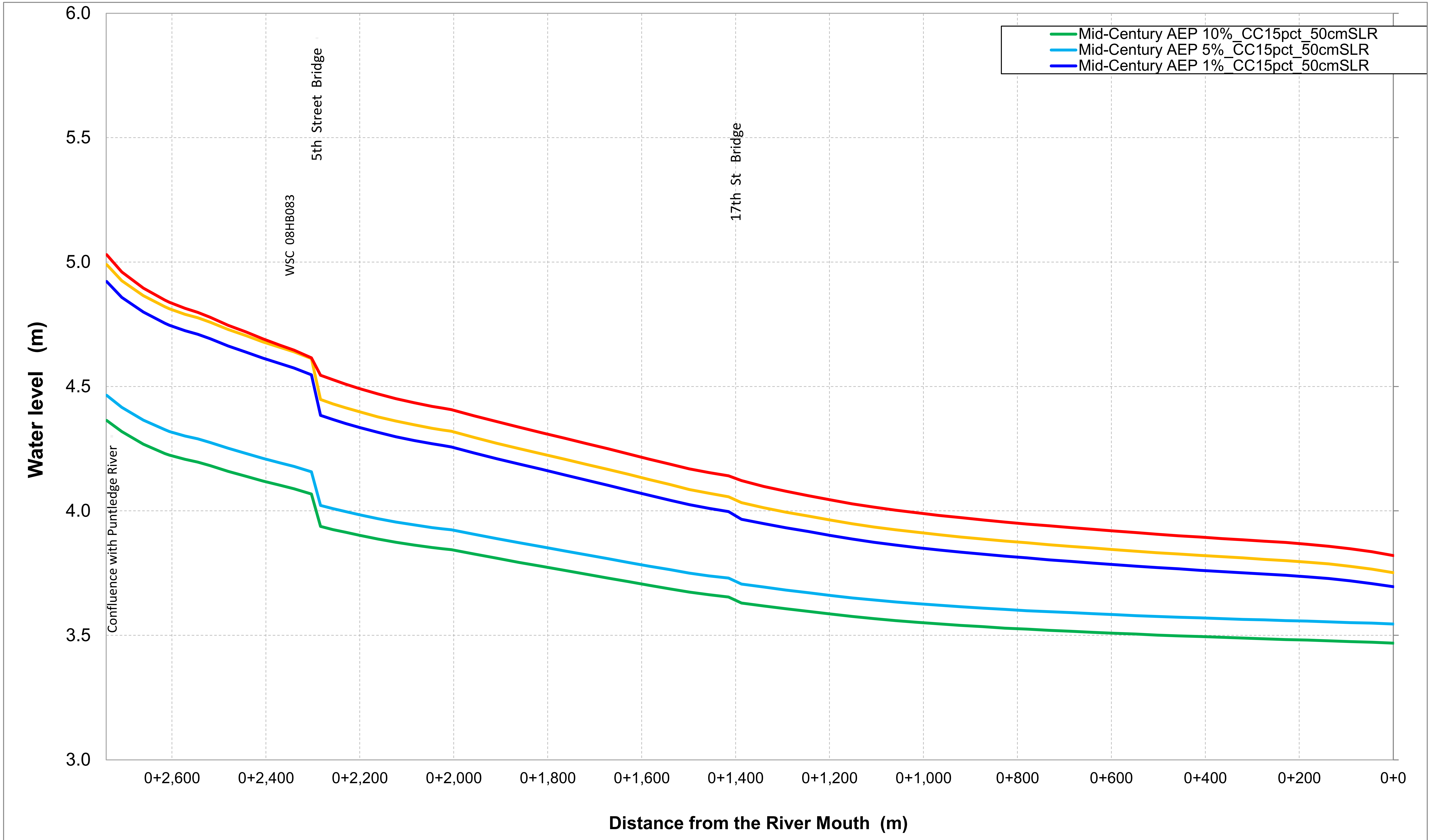
Project No. 2623.014

Date April 2021

Scale 1:25,000 — 0, 100, 200, 400 (m)

Flood Mapping River Chainages

Figure 8

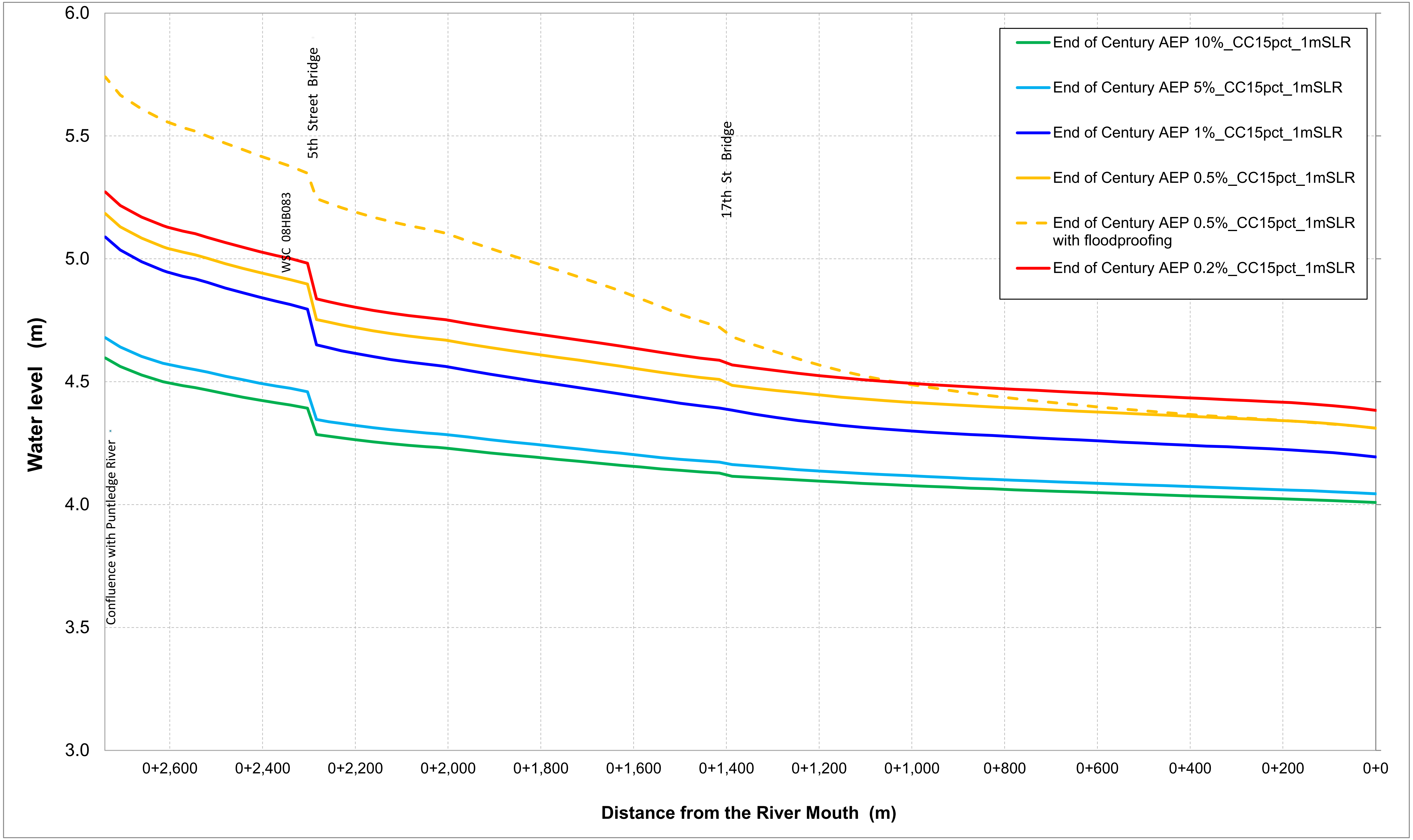


KERR WOOD LEIDAL consulting engineers

Coastal Valley Regional District

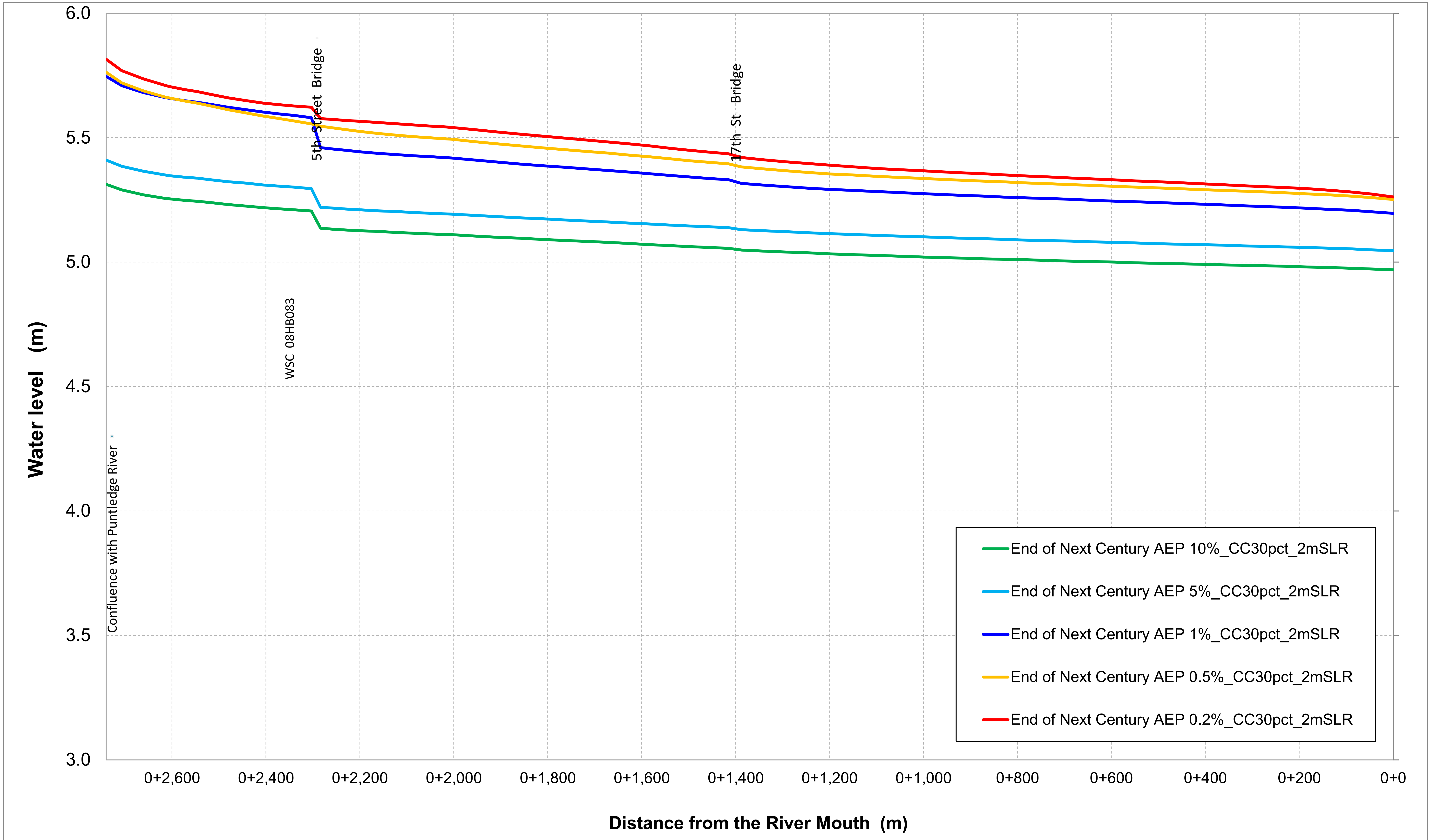
Coastal Flood Mapping Project

Figure 9a – Mid-Century Maximum Courtenay River Water Level Profiles



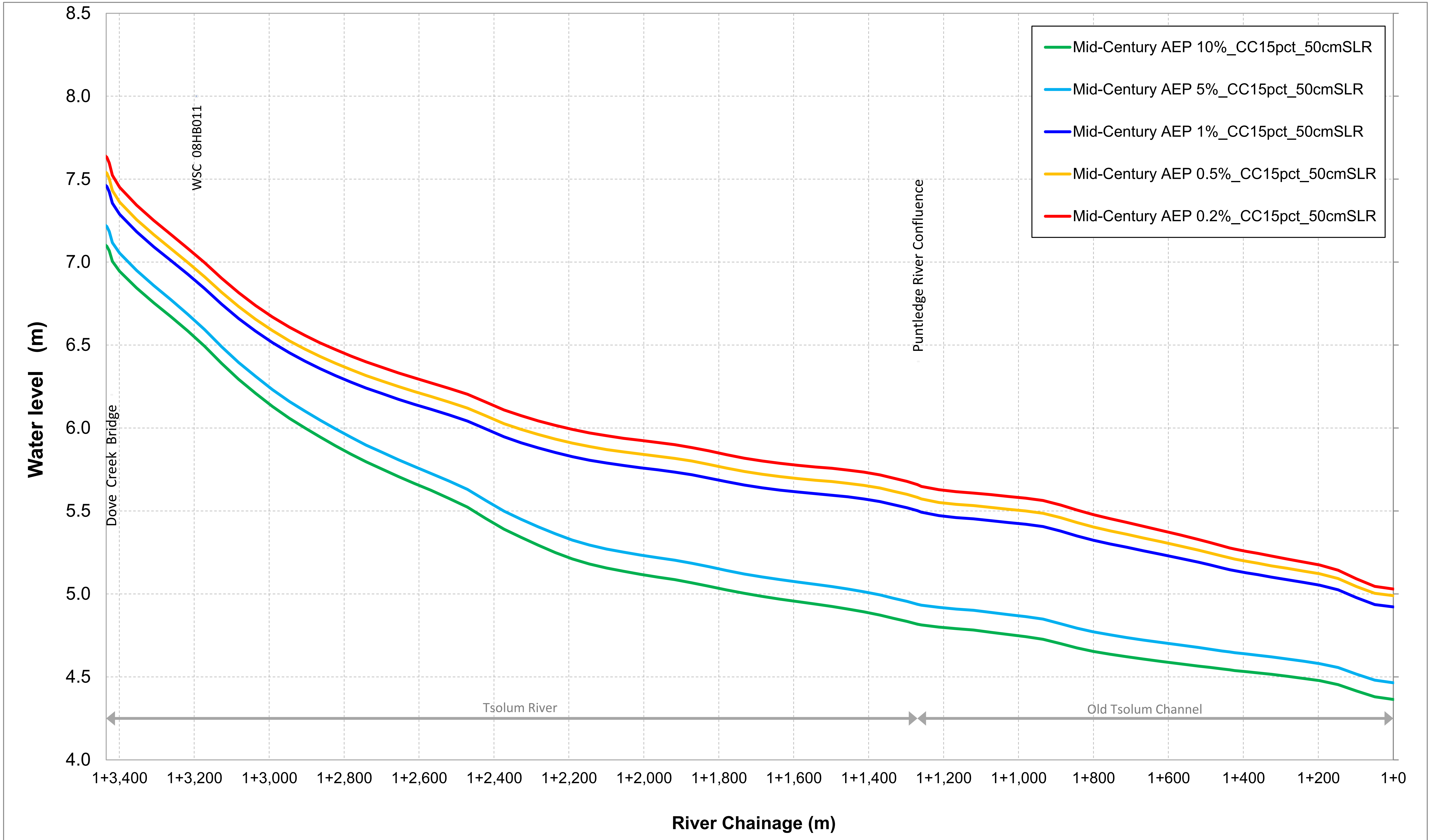
KERR WOOD LEIDAL
consulting engineers

Coastal Valley Regional District
Coastal Flood Mapping Project
Figure 9b – End of Century Maximum Courtenay River Water Level Profiles



KERR WOOD LEIDAL
consulting engineers

Coastal Valley Regional District
Coastal Flood Mapping Project
Figure 9c – End of Next Century Maximum Courtenay River Water Level Profiles



KERR WOOD LEIDAL
consulting engineers

Coastal Valley Regional District
Coastal Flood Mapping Project
Figure 10a– Mid-Century Maximum Tsolum River Water Level Profiles

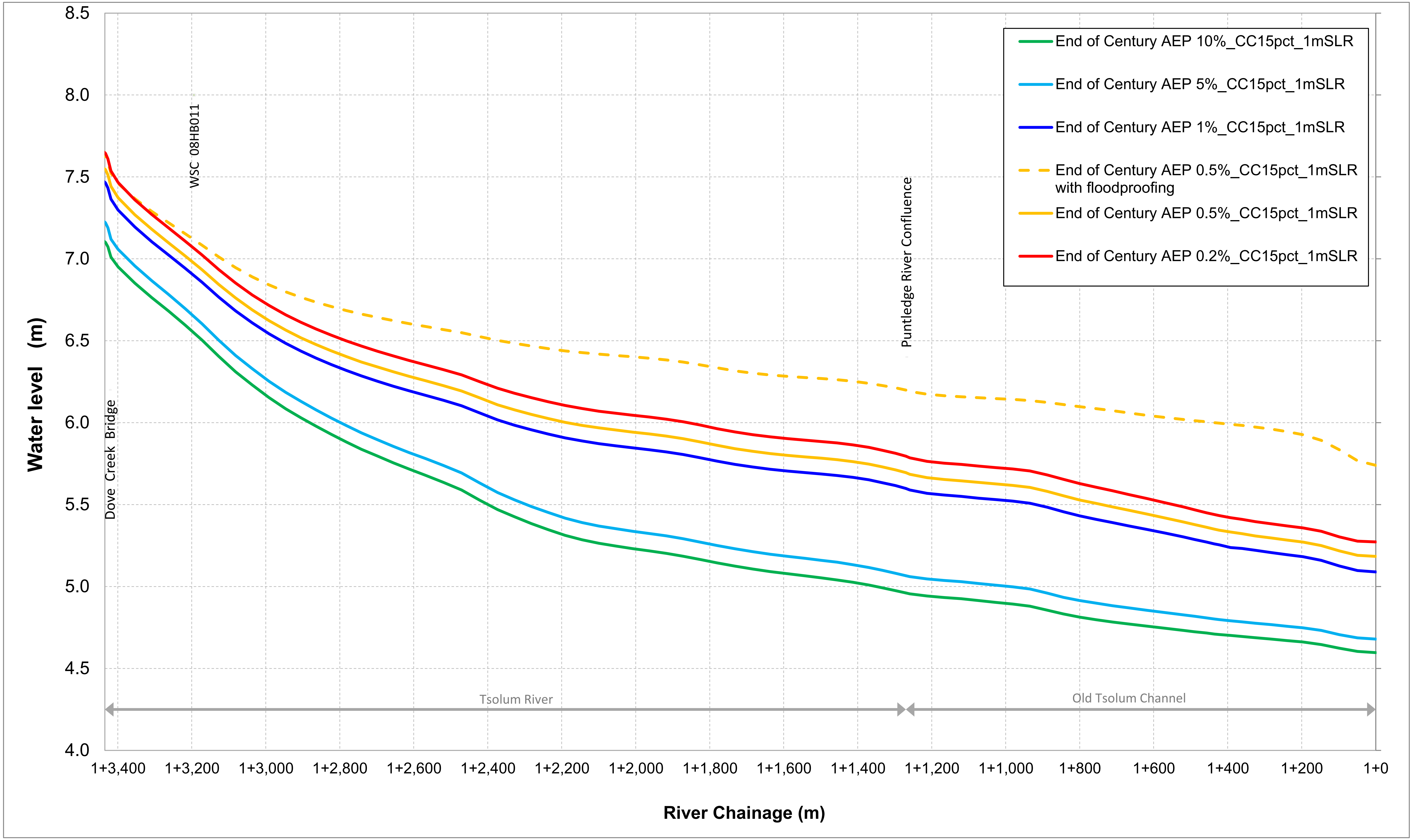
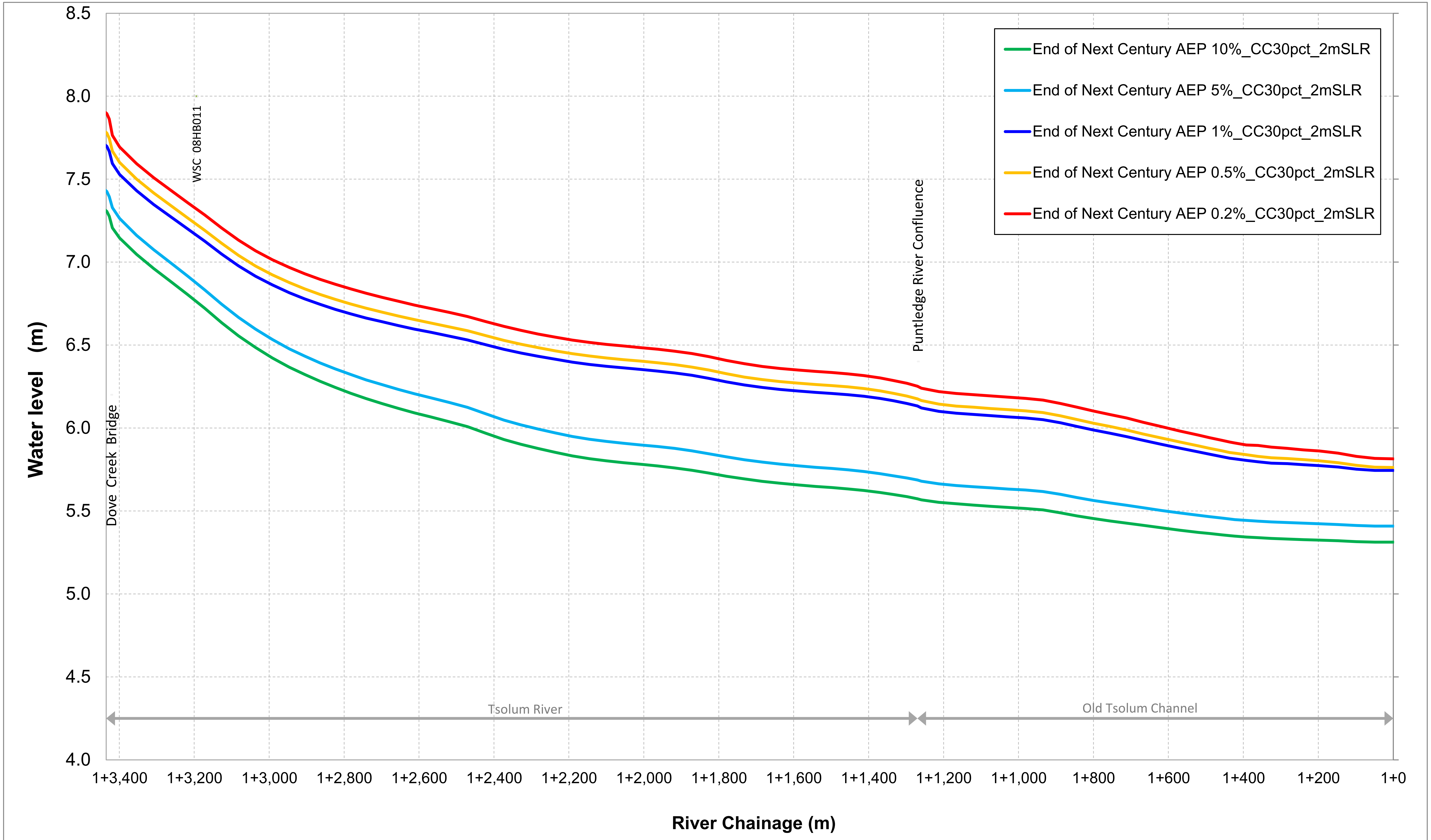
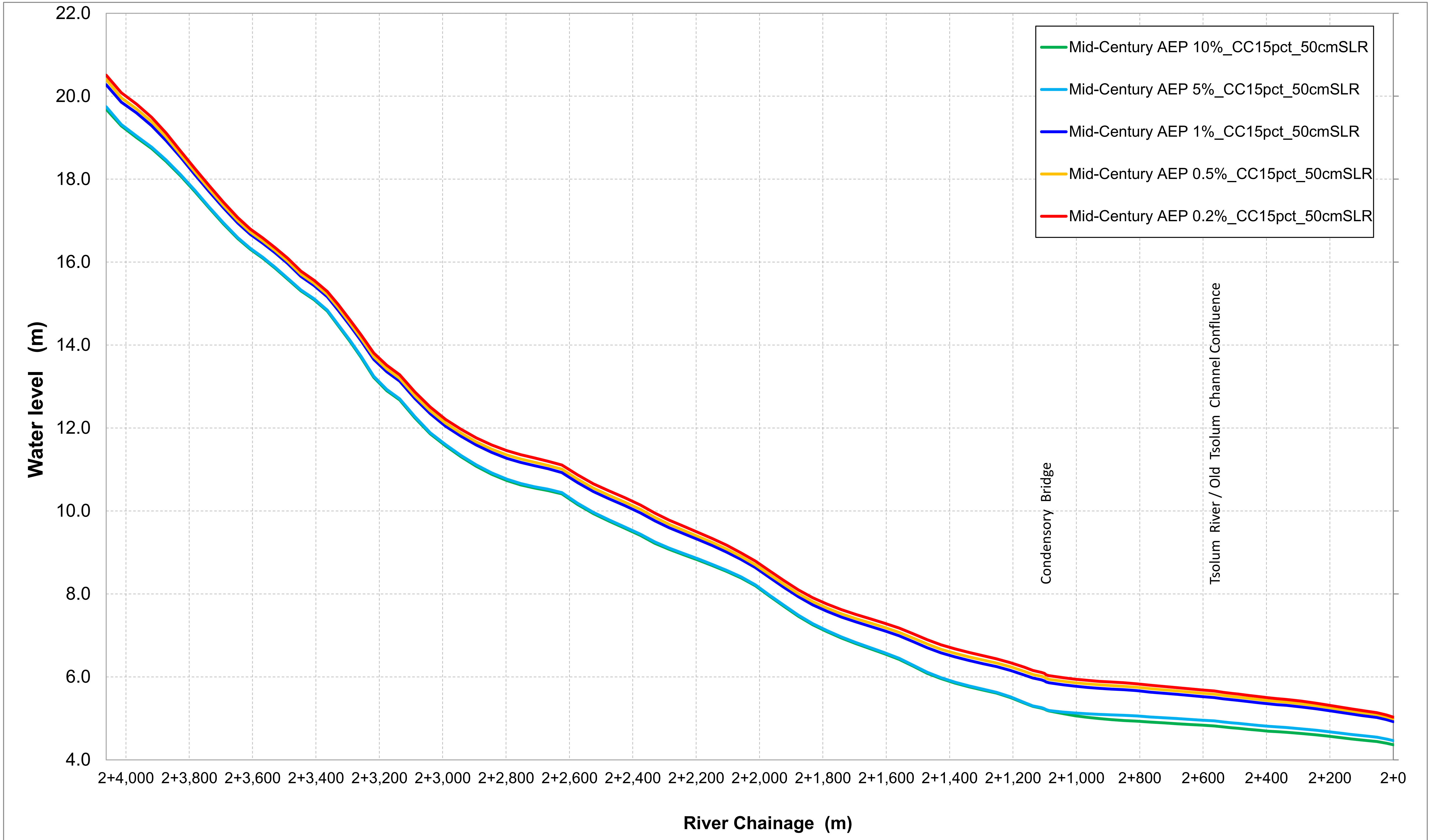


Figure 10b – End of Century Maximum Tsolum River Water Level Profiles



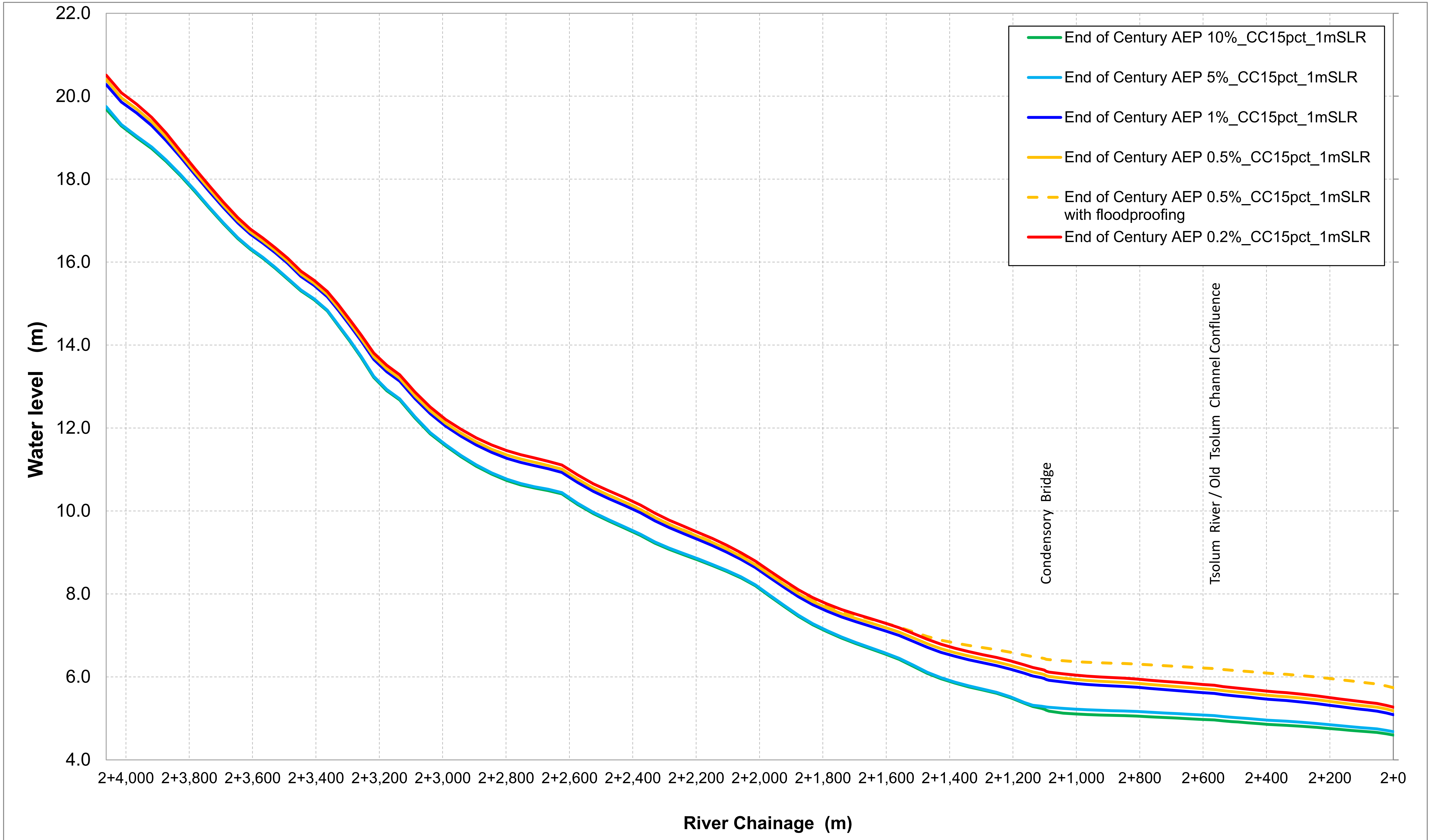
KERR WOOD LEIDAL
consulting engineers

Coastal Valley Regional District
Coastal Flood Mapping Project
Figure 10c – End of Next Century Maximum Tsolum River Water Level Profiles



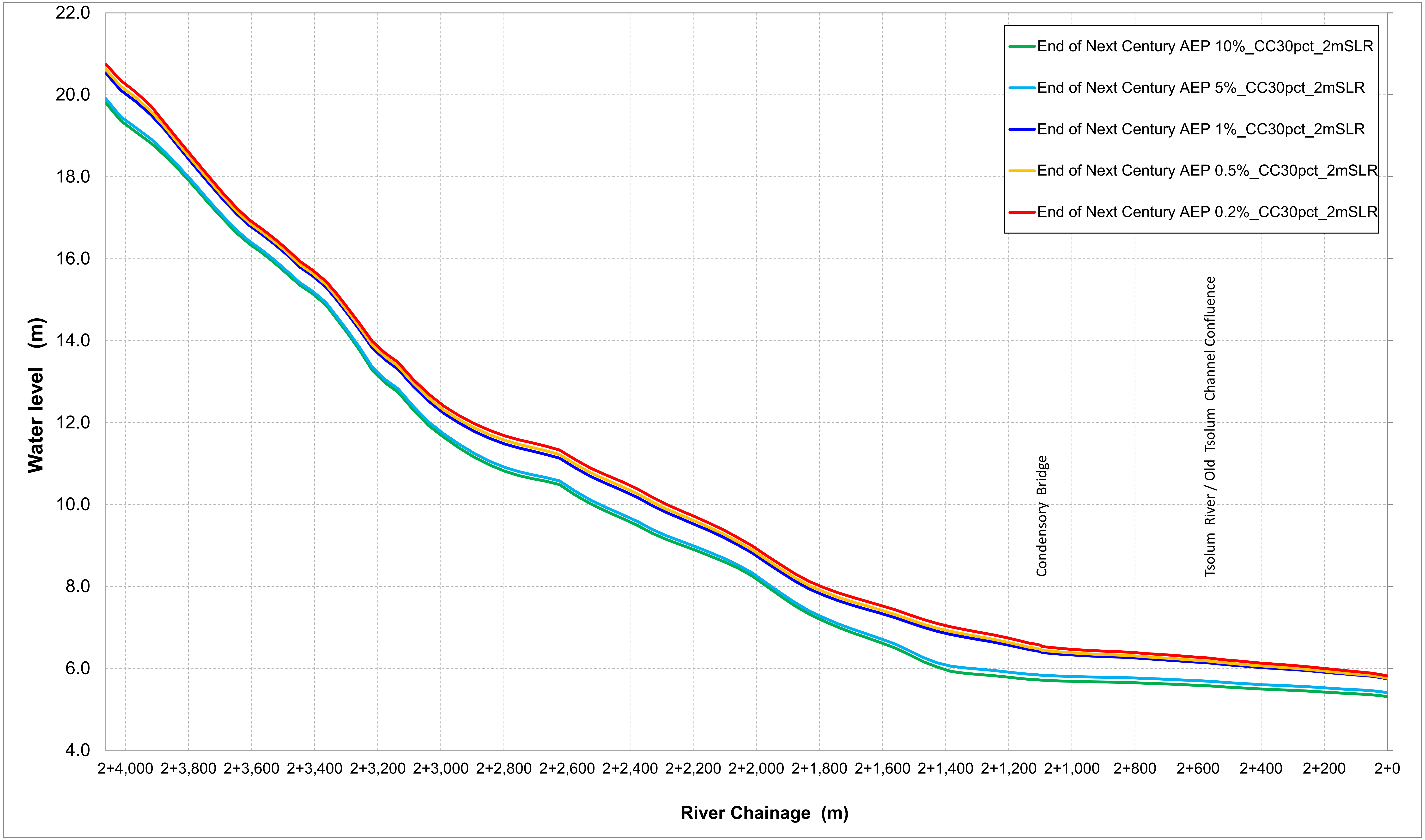
KERR WOOD LEIDAL
consulting engineers

Coastal Valley Regional District
Coastal Flood Mapping Project
Figure 11a – Mid-Century Maximum Puntledge River Water Level Profiles



KERR WOOD LEIDAL
consulting engineers

Coastal Valley Regional District
Coastal Flood Mapping Project
Figure 11b – End of Century Maximum Puntledge River Water Level Profiles



KERR WOOD LEIDAL
consulting engineers

Coastal Valley Regional District
Coastal Flood Mapping Project
Figure 11c – End of Next Century Maximum Puntledge River Water Level Profiles

Modelled Velocities

Average flow velocity across each of the channel cross sections are calculated by the 1D model at each time step. Due to the limitations of 1D hydraulic models used for the river channels, localized flow velocities along riverbanks, at bridge crossings and in river bends were not calculated. The maximum average channel flow velocities in the Courtenay River for the 0.5% AEP Flood based on the 1D model, range between:

- 2.4 m/s to 3.8 m/s for the Mid-Century (+15% Peak Flow and +0.5 m SLR) Scenario;
- 2.4 m/s to 4.5 m/s for the End of Century (+30% Peak Flow and +1.0 m SLR) Scenario; and
- 2.5 m/s to 4.5 m/s for the End of Next Century (+30% Peak Flow and +2.0 m SLR) Scenario.

The maximum average channel flow velocities in the Tsolum River and Old Tsolum River Side Channel for the 0.5% AEP Flood based on the 1D model, range between:

- 0.5 m/s to 3.0 m/s for all the climate change scenarios.

The maximum average channel flow velocities in the Puntledge River for the 0.5% AEP Flood based on the 1D model, range between:

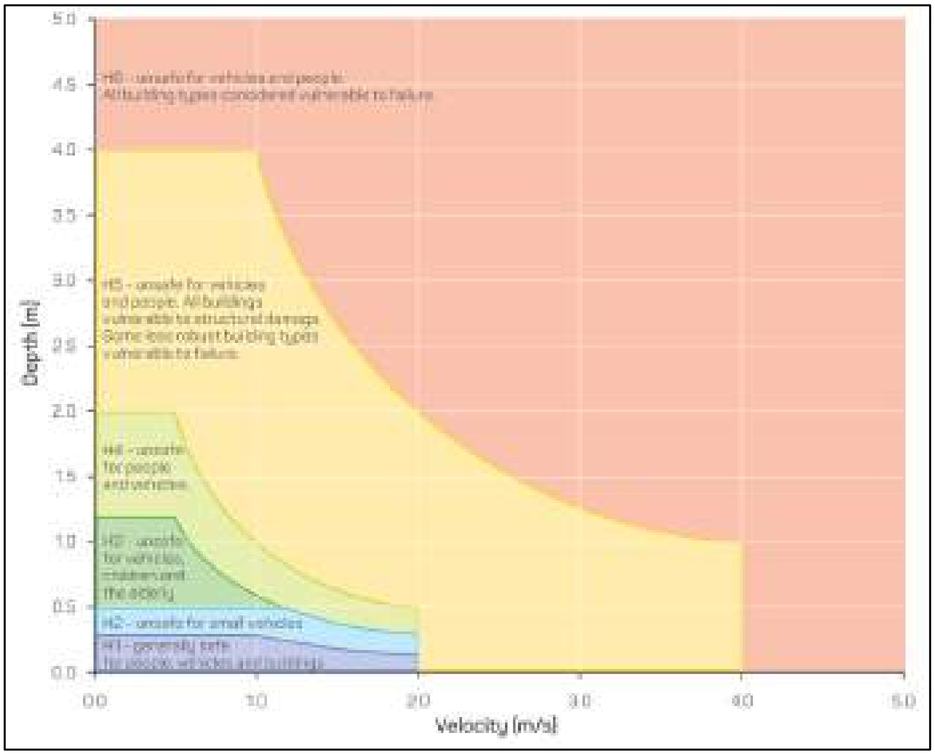
- 1.4 m/s to 3.4 m/s for all the climate change scenarios.

Tables 9, 10 ,and 11 summarize the modelled channel velocities for all the AEP floods and the three climate change scenarios for the Courtenay River, the Tsolum River, and the Puntledge River, respectively.

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 Courtenay River were 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 Flood Hazard Vulnerability Curves (AIDR, 2017)

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 8: Hazard Classifications – Vulnerability Thresholds

Hazard Vulnerability Classification	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 9: Hazard Classifications – Vulnerability Threshold Classification Limits

Hazard Vulnerability Classification	Classification Limit (D x V, m^2/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 Courtenay River during the 0.5% AEP current climate flood event are:

1. Generally, between 1.0 m^2/s to 4.0 m^2/s along the Puntledge River.
2. Between 0.6 m^2/s to 2.0 m^2/s along the Tsolum River, except along the edges of the floodplain where hazard rating is less than 0.6 m^2/s.
3. There are localized areas near the Confluence of Tsolum River and Puntledge river where hazard rating is greater than 4 m^2/s.
4. Along the Courtenay River, the hazard rating is generally less than 1.0 m^2/s, except localized area where the channel flows adjacent Lewis Park, where the hazard rating is greater than 1.0 m^2/s.
5. Within the Courtenay Flats floodplain area, the hazard rating is typically below 1.0 m^2/s except for localized areas along the roads within the industrial area and near the Comox Road flood boxes.

The digital mapping includes flood hazard rating maps as described in Technical Memorandum #5 – Coastal and Fluvial Mapping Products. Please note that the hazard mapping excludes the areas that were modelled in 1D (upper end of Puntledge River including adjacent floodplain, and top of bank to top of bank for all other rivers).

Bridge Freeboard Assessment

The 15th Street Bridge and the 5th Street Bridge cross the Courtenay River while the Condensory Road Bridge crosses the Puntledge River within the flood mapping study area. The standard freeboard allowance from the 0.5% AEP flood level to the low chord of bridges is 1.5m (CSA, 2019). To check freeboard allowances, the modelled water levels were compared to the bridge low chord elevation for the AEP 0.5% condition for the three climate change conditions. The results are summarized in Table 12.

Table 10: Courtenay River Maximum Average Channel Flow Velocities

River Chainage	Mid Century (+15% Peak Flow and +0.5 m SLR)					End of Century (+15% Peak Flow and +1.0 m SLR)						End of next century (+30% Peak Flow and +2.0 m SLR)				
	AEP 10%	AEP 5%	AEP 1%	AEP 0.5%	AEP 0.2%	AEP 10%	AEP 5%	AEP 1%	AEP 0.5%	AEP 0.5%*	AEP 0.2%	AEP 10%	AEP 5%	AEP 1%	AEP 0.5%	AEP 0.2%
0+ 00	Comox Bay															
0+ 23	2.80	2.81	3.57	3.83	4.13	3.05	2.86	3.72	3.95	3.99	4.24	2.95	3.12	4.32	4.46	4.65
0+ 160	2.34	2.35	2.75	2.90	3.10	2.47	2.35	2.83	2.96	3.10	3.15	2.40	2.51	3.20	3.31	3.43
0+ 297	2.11	2.11	2.39	2.47	2.59	2.19	2.11	2.41	2.51	2.72	2.62	2.15	2.23	2.64	2.70	2.78
0+ 434	2.23	2.24	2.53	2.59	2.70	2.31	2.23	2.52	2.62	2.83	2.72	2.28	2.36	2.74	2.81	2.88
0+ 571	2.27	2.27	2.56	2.61	2.69	2.33	2.27	2.55	2.61	2.84	2.71	2.31	2.39	2.72	2.78	2.85
0+ 709	2.31	2.31	2.60	2.64	2.69	2.36	2.31	2.57	2.62	2.87	2.68	2.35	2.43	2.68	2.73	2.80
0+ 850	2.34	2.34	2.63	2.67	2.72	2.39	2.34	2.60	2.64	2.89	2.69	2.38	2.46	2.69	2.74	2.80
0+ 990	2.48	2.48	2.77	2.80	2.85	2.53	2.48	2.73	2.78	3.01	2.81	2.52	2.60	2.81	2.85	2.91
0+ 1129	2.82	2.82	3.12	3.16	3.20	2.87	2.82	3.09	3.13	3.38	3.17	2.87	2.94	3.17	3.22	3.28
0+ 1269	2.96	2.96	3.29	3.33	3.37	3.00	2.96	3.25	3.30	3.55	3.34	3.00	3.09	3.34	3.39	3.46
0+ 1401	3.13	3.08	3.10	3.18	3.08	3.07	3.03	3.10	3.07	3.12	3.30	3.10	3.05	3.27	3.27	3.37
0+1451	17th Street Bridge															
0+ 1519	3.11	3.11	3.45	3.49	3.53	3.14	3.11	3.40	3.45	3.72	3.49	3.15	3.24	3.49	3.55	3.62
0+ 1650	2.87	2.87	3.10	3.13	3.16	2.89	2.87	3.07	3.10	3.34	3.13	2.91	2.97	3.13	3.18	3.23
0+ 1788	2.57	2.57	2.84	2.87	2.90	2.59	2.57	2.80	2.84	3.04	2.87	2.61	2.67	2.87	2.91	2.95
0+ 1933	2.72	2.72	2.96	2.99	3.02	2.74	2.72	2.93	2.96	3.20	3.00	2.75	2.81	2.99	3.04	3.09
0+ 2035	2.32	2.32	2.52	2.54	2.56	2.34	2.32	2.49	2.52	2.73	2.55	2.35	2.40	2.54	2.57	2.61
0+ 2142	2.51	2.51	2.69	2.72	2.74	2.53	2.51	2.66	2.69	2.99	2.71	2.53	2.57	2.68	2.72	2.76
0+ 2243	2.75	2.75	2.97	3.01	3.03	2.77	2.75	2.94	2.97	3.85	3.00	2.78	2.83	2.97	3.01	3.72
0+2303	5th Street Bridge															
0+ 2322	3.04	3.04	3.31	3.35	3.38	3.06	3.04	3.27	3.31	4.47	3.35	3.07	3.13	3.31	3.37	4.47
0+ 2424	2.96	2.97	3.18	3.21	3.23	2.98	2.96	3.14	3.17	3.54	3.21	2.99	3.03	3.17	3.22	3.26
0+ 2532	2.24	2.24	2.41	2.44	2.46	2.26	2.24	2.38	2.41	2.56	2.44	2.26	2.30	2.41	2.45	2.49
0+ 2610	2.83	2.83	2.83	2.83	2.83	2.13	2.83	2.83	2.24	2.36	2.27	2.83	2.83	2.83	2.83	2.83
0+ 2723	2.62	2.62	2.80	2.84	2.87	2.64	2.62	2.77	2.80	2.96	2.83	2.64	2.67	2.81	2.85	2.90

Note: Flow velocities shown are averages across the channel cross section. Localized flow velocities at riverbanks, bridge crossings and channel bends are not calculated in 1D hydraulic models.

Table 11: Tsolum River – Maximum Average Channel Flow Velocities

River Chainage		Mid Century (+15% Peak Flow and +0.5 m SLR)					End of Century (+15% Peak Flow and +1.0 m SLR)					End of next century (+30% Peak Flow and +2.0 m SLR)				
		AEP 10%	AEP 5%	AEP 1%	AEP 0.5%	AEP 0.2%	AEP 10%	AEP 5%	AEP 1%	AEP 0.5%	AEP 0.2%	AEP 10%	AEP 5%	AEP 1%	AEP 0.5%	AEP 0.2%
1+ 25	Old Tsolum River Side Channel	0.77	0.77	0.77	0.77	0.76	0.78	0.77	0.76	0.76	0.75	0.77	0.76	0.73	0.74	0.73
1+ 172		0.58	0.58	0.66	0.67	0.68	0.59	0.58	0.65	0.66	0.67	0.59	0.61	0.66	0.68	0.69
1+ 304		0.42	0.43	0.50	0.51	0.52	0.43	0.43	0.49	0.50	0.51	0.43	0.45	0.50	0.52	0.54
1+ 408		0.35	0.36	0.50	0.54	0.54	0.35	0.36	0.56	0.53	0.54	0.37	0.40	0.54	0.56	0.64
1+ 474		0.36	0.38	0.54	0.57	0.60	0.36	0.38	0.54	0.56	0.59	0.40	0.43	0.59	0.62	0.66
1+ 594		0.33	0.35	0.47	0.49	0.51	0.33	0.35	0.47	0.49	0.52	0.38	0.40	0.54	0.55	0.58
1+ 733		0.35	0.36	0.45	0.46	0.48	0.35	0.36	0.45	0.47	0.48	0.37	0.39	0.49	0.50	0.52
1+ 866		0.46	0.48	0.56	0.56	0.56	0.46	0.46	0.56	0.59	0.59	0.45	0.47	0.56	0.56	0.56
1+ 1004		0.43	0.43	0.61	0.61	0.61	0.43	0.42	0.61	0.57	0.57	0.41	0.40	0.61	0.61	0.61
1+ 1143		0.39	0.39	0.52	0.52	0.52	0.39	0.39	0.52	0.51	0.51	0.40	0.40	0.52	0.52	0.52
1+1259	Confluence of Tsolum River and Old Tsolum River Side Channel															
1+ 1265	Tsolum River	0.52	0.52	0.76	0.76	0.76	0.52	0.52	0.76	0.71	0.73	0.59	0.62	0.76	0.78	0.79
1+ 1284		1.61	1.61	1.40	1.43	1.47	1.63	1.60	1.39	1.42	1.46	1.51	1.34	1.44	1.50	1.55
1+ 1391		1.66	1.66	1.22	1.24	1.27	1.68	1.66	1.21	1.23	1.25	1.56	1.37	1.23	1.26	1.29
1+ 1520		1.45	1.45	0.88	0.88	0.89	1.47	1.45	0.86	0.87	0.87	1.38	1.20	0.84	0.85	0.86
1+ 1660		1.28	1.18	0.98	0.99	1.01	1.29	1.18	0.97	0.99	1.00	1.11	1.01	1.00	1.01	1.03
1+ 1803		1.47	1.36	1.23	1.25	1.28	1.48	1.36	1.23	1.26	1.29	1.29	1.19	1.31	1.34	1.38
1+ 1940		1.25	1.19	0.96	0.97	0.98	1.26	1.19	0.96	0.96	0.98	1.17	1.17	0.97	0.99	1.00
1+ 2077		1.27	1.28	0.99	0.99	1.00	1.27	1.28	0.97	0.98	0.99	1.26	1.15	0.97	0.98	0.99
1+ 2213		1.56	1.57	1.33	1.33	1.35	1.53	1.56	1.31	1.31	1.32	1.56	1.50	1.27	1.28	1.29
1+ 2350		1.72	1.76	1.61	1.62	1.64	1.69	1.73	1.59	1.60	1.61	1.68	1.72	1.54	1.55	1.55
1+ 2495		1.52	1.55	1.43	1.44	1.45	1.50	1.53	1.41	1.42	1.43	1.49	1.52	1.37	1.39	1.39
1+ 2633		1.41	1.43	1.35	1.36	1.38	1.39	1.42	1.33	1.34	1.36	1.39	1.42	1.31	1.33	1.34
1+ 2762		1.45	1.50	1.43	1.43	1.45	1.44	1.49	1.41	1.42	1.43	1.47	1.50	1.38	1.40	1.40
1+ 2885		1.62	1.66	1.61	1.62	1.64	1.61	1.65	1.60	1.61	1.62	1.63	1.66	1.58	1.60	1.59
1+ 3014		1.84	1.87	1.85	1.87	1.90	1.83	1.87	1.84	1.86	1.88	1.85	1.89	1.85	1.86	1.87
1+ 3150		2.14	2.18	2.17	2.19	2.22	2.13	2.17	2.16	2.18	2.20	2.16	2.20	2.17	2.19	2.20
1+ 3286		2.02	2.08	2.12	2.15	2.18	2.02	2.07	2.11	2.14	2.17	2.08	2.13	2.15	2.18	2.20
1+ 3409		2.63	2.71	2.87	2.92	3.00	2.62	2.70	2.86	2.91	2.98	2.75	2.85	2.97	3.03	3.08
1+ 3450		2.50	2.58	2.70	2.74	2.80	2.50	2.57	2.69	2.74	2.79	2.60	2.69	2.77	2.82	2.86

Note: Flow velocities shown are averages across the channel cross section. Localized flow velocities at riverbanks, bridge crossings and channel bends are not calculated in 1D hydraulic models.

Table 12: Puntledge River – Maximum Average Channel Flow Velocities

River Chainage	Mid Century (+15% Peak Flow and +0.5 m SLR)					End of Century (+15% Peak Flow and +1.0 m SLR)					End of next century (+30% Peak Flow and +2.0 m SLR)				
	AEP 10%	AEP 5%	AEP 1%	AEP 0.5%	AEP 0.2%	AEP 10%	AEP 5%	AEP 1%	AEP 0.5%	AEP 0.2%	AEP 10%	AEP 5%	AEP 1%	AEP 0.5%	AEP 0.2%
2+ 11	2.80	2.80	3.09	3.14	3.20	2.81	2.80	3.05	3.09	3.15	2.83	2.89	3.12	3.18	3.25
2+ 117	1.93	1.93	2.16	2.20	2.25	1.93	1.93	2.13	2.16	2.21	1.95	2.00	2.19	2.23	2.28
2+ 265	1.84	1.84	2.11	2.15	2.20	1.85	1.84	2.08	2.12	2.17	1.87	1.92	2.14	2.20	2.25
2+ 409	1.71	1.71	1.94	1.97	2.03	1.71	1.71	1.91	1.95	2.00	1.73	1.77	1.97	2.03	2.09
2+ 523	1.69	1.71	1.93	1.97	2.03	1.69	1.69	1.91	1.95	2.00	1.71	1.76	1.98	2.05	2.13
2+ 660	1.58	1.62	2.10	2.10	2.10	1.58	1.61	2.11	2.22	2.21	1.55	1.54	2.10	2.10	2.10
2+ 829	1.70	1.76	1.85	1.85	1.85	1.69	1.74	1.85	1.89	1.89	1.65	1.63	1.85	1.85	1.85
2+ 985	1.52	1.56	1.53	1.53	1.53	1.52	1.55	1.53	1.53	1.53	1.52	1.51	1.53	1.56	1.61
2+ 1091	2.11	2.47	2.02	2.04	2.06	2.43	2.88	2.02	2.03	2.03	2.06	2.36	2.69	2.05	2.20
2+1110	Condensory Road Bridge														
2+ 1186	2.43	2.45	2.48	2.51	2.54	2.43	2.45	2.48	2.51	2.54	2.47	2.49	2.55	2.58	2.65
2+ 1361	1.89	1.91	2.10	2.13	2.18	1.89	1.91	2.09	2.13	2.17	1.94	1.98	2.17	2.21	2.26
2+ 1537	2.64	2.65	2.68	2.70	2.73	2.64	2.65	2.68	2.70	2.73	2.66	2.66	2.73	2.76	2.80
2+ 1719	2.40	2.42	2.45	2.47	2.49	2.40	2.42	2.44	2.46	2.49	2.41	2.42	2.49	2.51	2.54
2+ 1900	2.98	2.99	3.23	3.27	3.32	2.98	2.99	3.23	3.26	3.31	3.02	3.07	3.32	3.37	3.42
2+ 2081	2.63	2.65	3.02	3.08	3.16	2.63	2.65	3.02	3.08	3.16	2.68	2.75	3.17	3.24	3.32
2+ 2262	2.51	2.53	2.88	2.93	3.01	2.51	2.53	2.88	2.93	3.01	2.56	2.63	3.02	3.08	3.15
2+ 2450	2.76	2.77	2.96	2.99	3.03	2.76	2.77	2.96	2.99	3.03	2.79	2.83	3.04	3.08	3.12
2+ 2645	2.49	2.51	2.83	2.88	2.94	2.49	2.51	2.83	2.88	2.94	2.55	2.61	2.95	3.01	3.07
2+ 2821	2.04	2.05	2.18	2.20	2.22	2.04	2.05	2.18	2.20	2.22	2.07	2.10	2.22	2.24	2.26
2+ 3015	2.51	2.53	2.77	2.81	2.85	2.51	2.53	2.77	2.81	2.85	2.55	2.60	2.86	2.90	2.94
2+ 3197	2.38	2.40	2.67	2.72	2.77	2.38	2.40	2.67	2.72	2.77	2.42	2.47	2.78	2.83	2.88
2+ 3346	2.66	2.68	2.93	2.97	3.02	2.66	2.68	2.93	2.97	3.02	2.70	2.75	3.04	3.08	3.13
2+ 3509	2.35	2.36	2.58	2.61	2.66	2.35	2.37	2.58	2.61	2.66	2.39	2.43	2.67	2.71	2.76
2+ 3669	2.51	2.53	2.84	2.90	2.97	2.51	2.53	2.84	2.90	2.97	2.56	2.61	2.98	3.04	3.12
2+ 3850	2.99	3.01	3.37	3.40	3.44	2.99	3.01	3.37	3.40	3.44	3.05	3.14	3.44	3.46	3.50
2+ 4038	2.69	2.69	2.88	2.91	2.97	2.69	2.69	2.88	2.91	2.97	2.69	2.71	2.99	3.05	3.11

Note: Flow velocities shown are averages across the channel cross section. Localized flow velocities at river banks, bridge crossings and channel bends are not calculated in 1D models.

Table 13: Summary of Remaining Bridge Freeboard at Peak of 0.5% AEP Flood

			Mid-Century (+15% peak flow and + 0.5 m SLR)		End of Century (+15 peak flow and + 1.0 m SLR)		End of next Century (+30% peak flow and + 2.0 m SLR)	
Location	**River Chainage**	**Bridge Low Chord (El. m)**	**Max Water Level (El. m)**	**Freeboard (m)**	**Max Water Level (El, m)**	**Freeboard (m)**	**Max Water Level (El.m)**	**Freeboard (m)**
17th Street Bridge	0+1,415	6.13	4.00	2.14	4.51	1.63	5.40	0.74
5th Street Bridge	0+2,303	5.66	4.55	1.12	4.90	0.77	5.56	0.11
Condensory Road Bridge	2+1,110	6.09	5.93	0.17	6.07	0.02	6.48	-0.39
Note: Bridge low chord and max water level elevations in metres above CVGD2013.								

Climate Change Impacts on Peak Water Levels

With projected increases in peak flows in the Tsolum River and Puntledge River as well as increases in tide levels at Comox Harbour as a result of SLR, the peak water levels along the Courtenay River, Tsolum River, and Puntledge Rivers are projected to increase in the future.

The difference between the modelled water levels under projected climate change and modelled water levels under current climate change are shown in the mid-century (+15% peak flow and +0.5 m SLR), end of century (+30% flow and +1.0 m SLR) and end of next century (+30% flow and +2.0 m SLR) in Figures 11, 12 and 13, respectively.

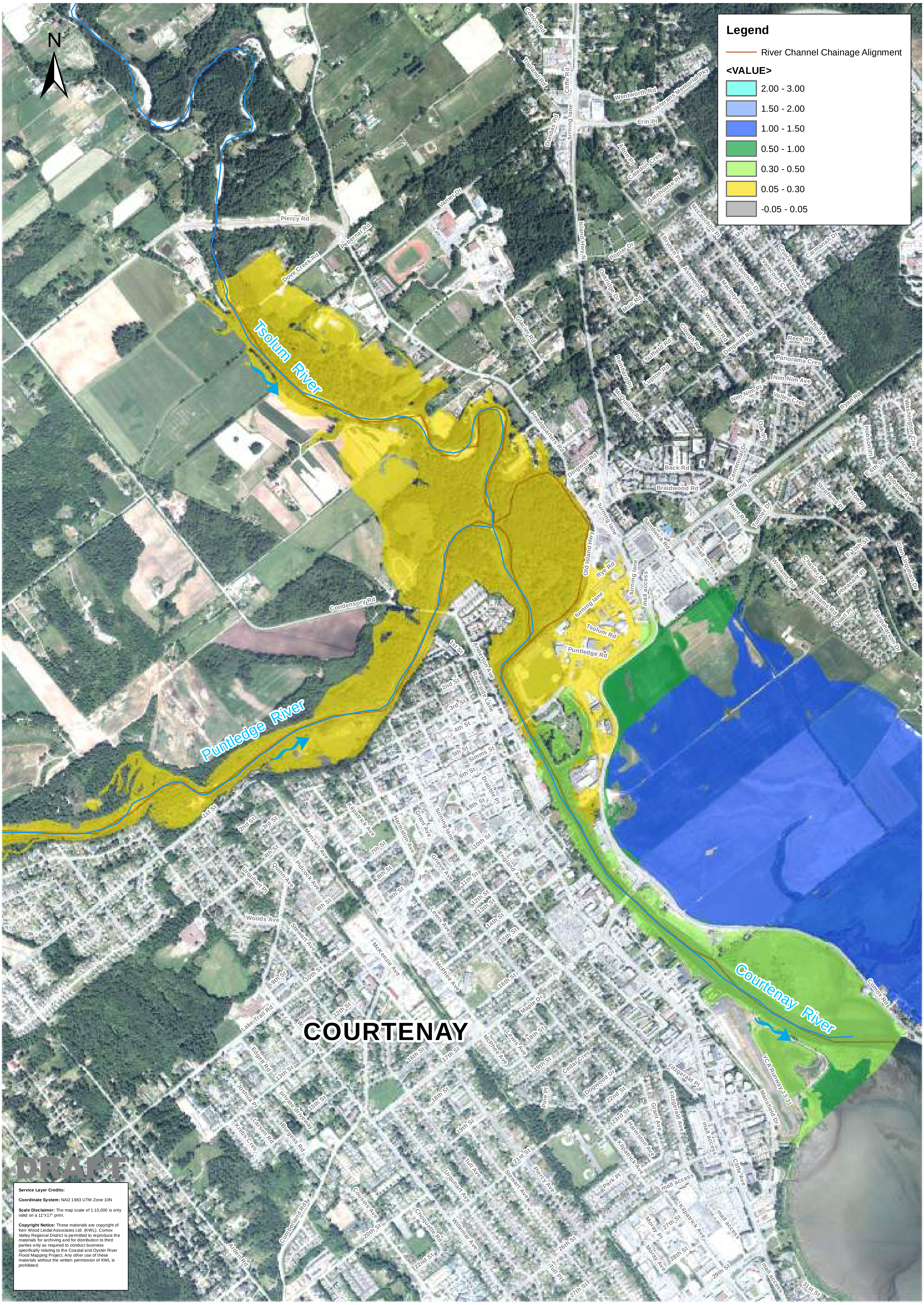
One of the key observations noted by comparing these figures is that the peak water levels in the upper reaches of the Puntledge River do not change significantly (less than 0.3 m) between the current climate and projected future climate. However, moving downstream, the incremental change in peak water levels increase with the maximum changes occurring at the downstream end of the study area at Comox Harbour. This is due to the influence of projected SLR on peak water levels in the river channels. As SLR increases, the influence of the peak ocean level moves further upstream. This is most apparent by comparing the differences for the 5% AEP flood shown in the Figures 12a, Figure 12b and Figure 12c at the confluence of the Puntledge River and Tsolum Rivers.

In Figure 12a, the 5% AEP peak water levels are projected to increase between 0 m to 0.3 m by mid-century at the confluence with the boundary between the 0 m to 0.3 m maximum water level change (yellow) and 0.3 m to 0.5 m maximum water level change (light green) downstream of 5th Street Bridge. By end of this century (Figure 12 b), the 5% AEP peak water levels are projected to increase between 0.3 m to 0.5 m at the confluence of the Puntledge River and Tsolum River, and the influence of the tide is projected to move upstream of the confluence as indicated by the boundary between the 0 m to 0.3 m range and the 0.3 m to 0.5 m range moving upstream. Finally, by end of next century (Figure 12c), the 5% AEP water level is projected to increase at the confluence by 0.5 m to 1.0 m compared to current levels, with the influence of the tide reaching upstream of Condensory Road Bridge on Puntledge River and up to Piercy Road Bridge on the Tsolum River.

Comox Valley Regional District

Coastal and Oyster River Flood Mapping Project

KERR WOOD LEIDAL
consulting engineers



Project No. 2623.014

Date April 2021

Scale 0 50 100 200 (m)
1:15,000

Water Level Difference 5% AEP Flood
Projected 0.5 m SLR minus Current 0.0 m SLR

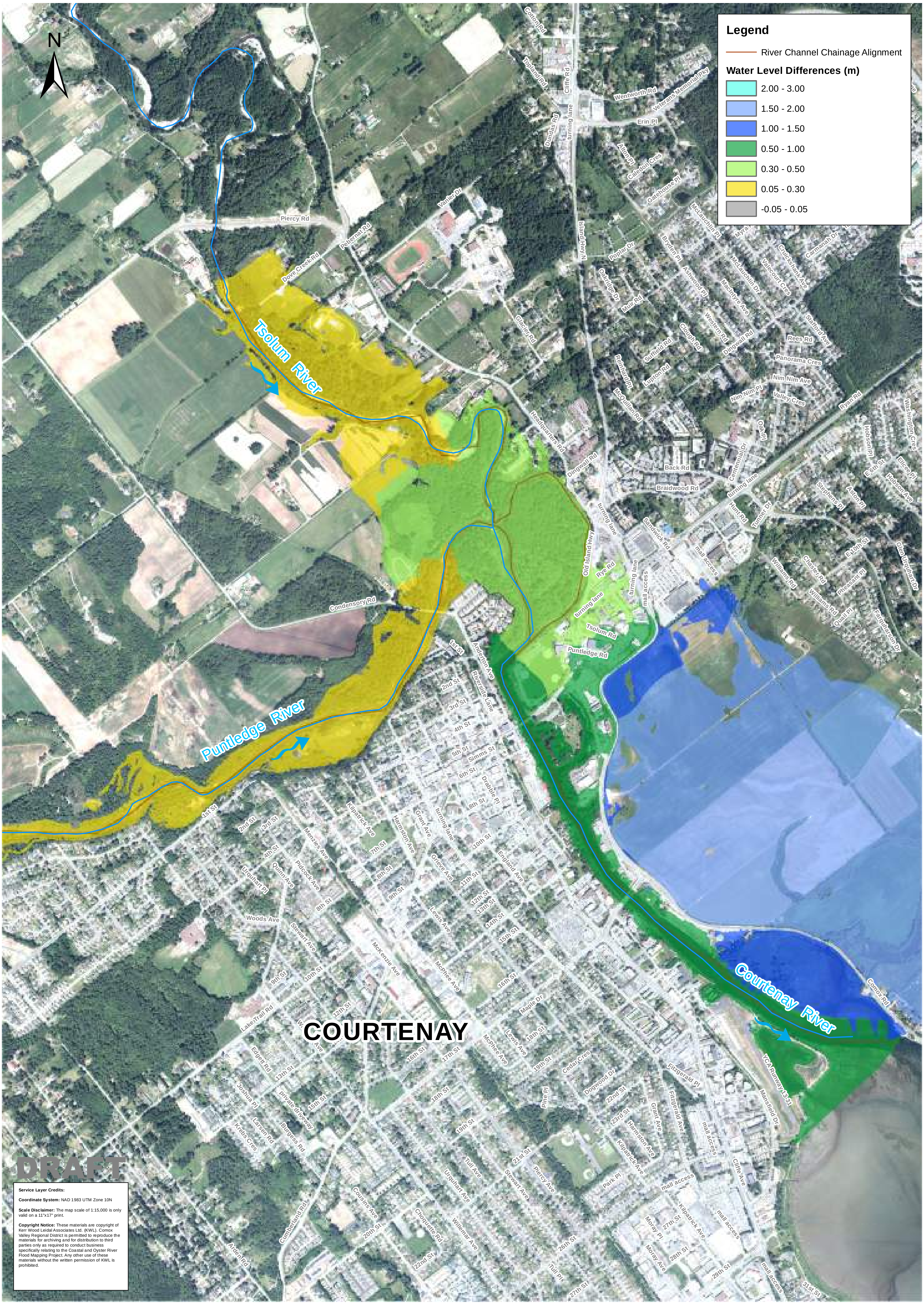
Figure 12a

Path: Z:\2000-2999\2600-2699\2623-014\430-GIS\MXD-Wk\CourtenayRiver_WaterLevel_SurfaceData\EdgeExpansion\2623014_CourtenayRiver_Figures_12a_to_13c_REV.mxd Date Saved: 3/30/2021 4:21:00 PM | Author: aseuarz

Comox Valley Regional District

Coastal and Oyster River Flood Mapping Project

KERR WOOD LEIDAL
consulting engineers



Service Layer Credits:

Coordinate System: NAD 1983 UTM Zone 10N

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

Project No. 2623.014

Date April 2021

Scale 0 50 100 200 (m)
1:15,000

Water Level Difference 5% AEP Flood
Projected 1 m SLR minus Current 0.0 m SLR

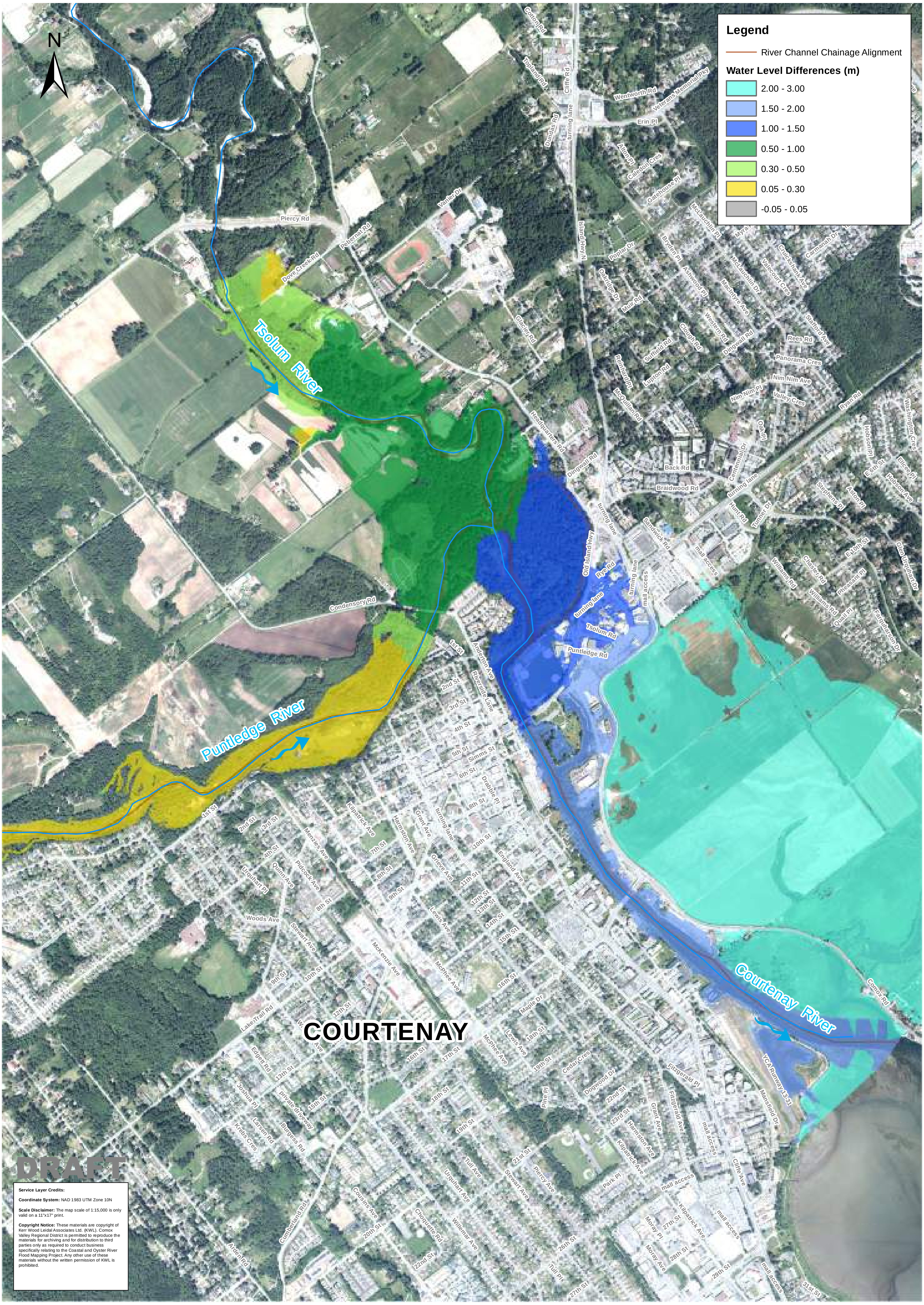
Figure 12b

Path: Z:\2000-2999\2600-2699\2623-014\430-GIS\MXD-Wk\CourtenayRiver_WaterLevel_SurfaceData\EdgeExpansion\2623014_CourtenayRiver_Figures_12a_to_13c_REV.mxd Date Saved: 3/30/2021 4:29:26 PM | Author: aseuarz

Comox Valley Regional District

Coastal and Oyster River Flood Mapping Project

KERR WOOD LEIDAL
consulting engineers



Service Layer Credits:

Coordinate System: NAD 1983 UTM Zone 10N

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

Project No. 2623.014

Date April 2021

Scale 0 50 100 200 (m)
1:15,000

Water Level Difference 5% AEP Flood
Projected 2 m SLR minus Current 0.0 m SLR

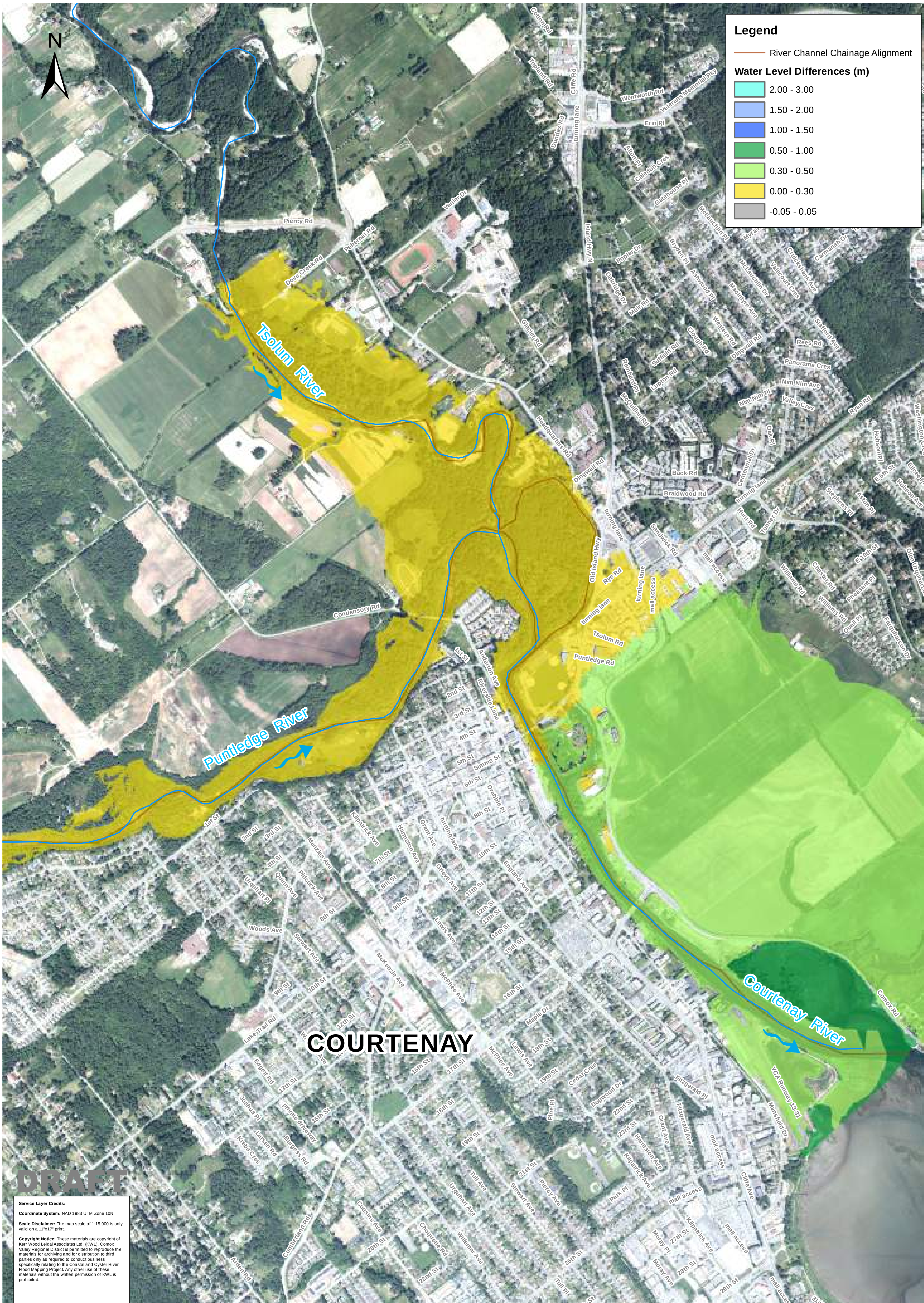
Figure 12c

Path: Z:\2000-2999\2600-2699\2623-014\430-GIS\MXD-Wk\CourtenayRiver_WaterLevel_SurfaceData\EdgeExpansion\2623014_CourtenayRiver_Figures_12a_to_13c_REV.mxd Date Saved: 3/30/2021 4:14:52 PM | Author: aseuarz

Comox Valley Regional District

Coastal and Oyster River Flood Mapping Project

KERR WOOD LEIDAL consulting engineers



Service Layer Credits:

Coordinate System: NAD 1983 UTM Zone 10N

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

Project No. 2623.014

Date April 2021

Scale 0 50 100 200 (m)
1:15,000

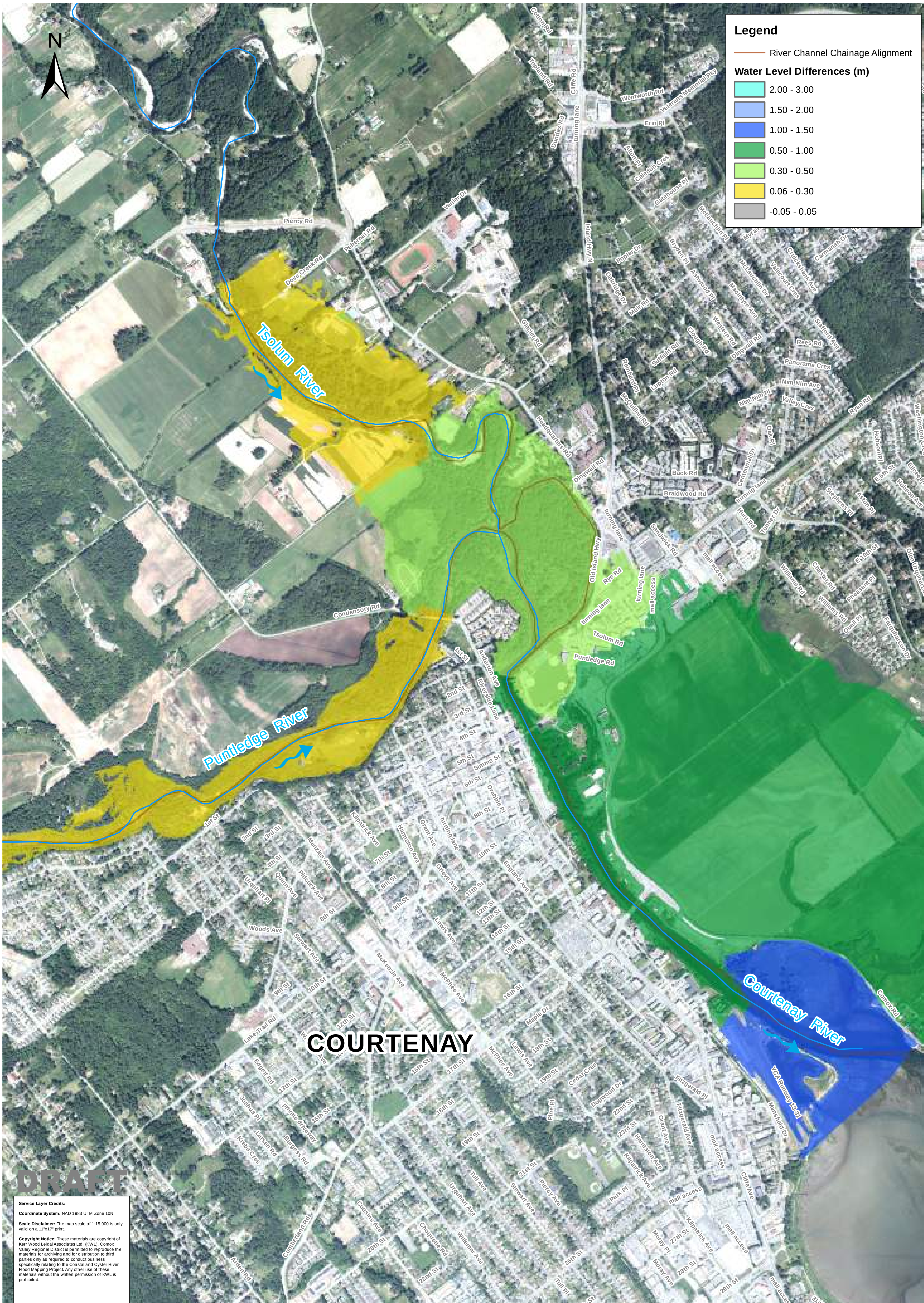
Water Level Difference 0.5% AEP Flood
Projected 0.5 m SLR minus Current 0.0 m SLR

Figure 13a

Comox Valley Regional District

Coastal and Oyster River Flood Mapping Project

KERR WOOD LEIDAL
consulting engineers



Project No. 2623.014

Date April 2021

Scale 0 50 100 200 (m)
1:15,000

Water Level Difference 0.5% AEP Flood
Projected 1 m SLR minus Current 0.0 m SLR

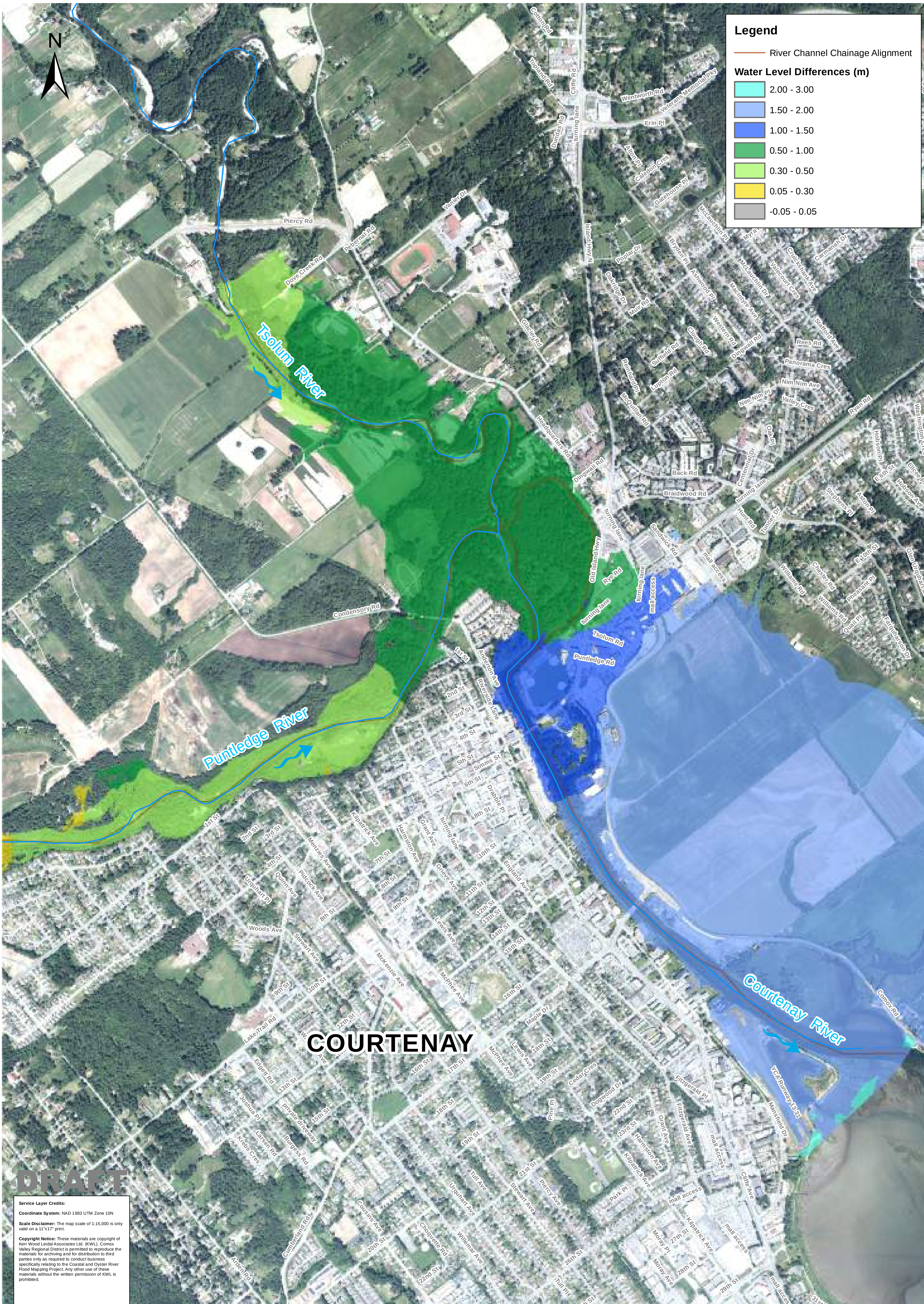
Figure 13b

Path: Z:\2000-2999\2600-2699\2623-014\430-GIS\MXD-Wk\CourtenayRiver_WaterLevel_SurfaceData\EdgeExpansion\2623014_CourtenayRiver_Figures_12a_to_13c_REV.mxd Date Saved: 3/30/2021 3:17:39 PM | Author: aseuarz

Comox Valley Regional District

Coastal and Oyster River Flood Mapping Project

KERR WOOD LEIDAL consulting engineers



Project No. 2623.014

Date April 2021

Scale 0 50 100 200 (m)
1:15,000

Water Level Difference 0.5% AEP Flood
Projected 2 m SLR minus Current 0.0 m SLR

Figure 13c

6. Limitations

The hydrologic and hydraulic analyses results presented in this memorandum 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, 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), influences of groundwater flow/seepage or other hydrologic or hydraulic processes which can impact flood hazards. In addition, future changes in operations at the BC Hydro Comox Lake dam could also impact peak flows in the Puntledge River and thus flood hazards along the Puntledge and Courtenay Rivers.

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 Practices 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 operation of BC Hydro facilities at Comox Lake, 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, or ground levels are raised in the floodplain using fill, particularly if the diking alignments or areas of fill 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.

7. Summary

The hydrological analysis and hydraulic modelling approach and key assumptions for the Courtenay River are summarized below.

1. Design flows for the Tsolum River (an upstream tributary of the Courtenay River) are based on the regional flood frequency analysis carried out for the Courtenay IFMS study.
2. Rare extreme flood design flows (AEP 1%, AEP 0.5%, and AEP 0.2%) for the Puntledge River (an upstream tributary of the Courtenay River) assume starting the Comox Lake reservoir level at the spillway crest which results in uncontrolled outflow.

3. More frequent large flood design flows (AEP 10%, and AEP 5%) for the Puntledge River assume starting the Comox Lake reservoir level at the maximum winter operating level, and outflows following the BC Hydro Operating Guidelines.
4. Factors of +15% and +30% were added to design peak flood discharges to account for projected climate change impacts projected to the Year 2100 and the Year 2200, respectively.
5. Tidal water levels at the downstream boundary for the Courtenay River are assumed to have the same AEP as the specified design flood.
6. Hydraulic modelling of the Courtenay River was carried out using the combined 1-dimensional/2-dimensional MIKE Flood hydraulic model developed for the Courtenay IFMS in 2013 with the maximum water level results converted to CGVD2013 to have a consistent datum with the coastal flood mapping.
7. For development of regulatory floodplain mapping using the 0.5% AEP Flood with 15% increase for climate change and 1.0 m SLR boundary conditions, an additional model scenario representing the flood protection mitigation Option 2 – Ring Dike identified in the Courtenay IFMS was modelled. The maximum of either the flood protection option or the base model (without flood protection) was used to set maximum modelled flood levels for the purpose of developing flood levels (including freeboard) for regulatory flood mapping.
8. Flooding of the Courtenay River floodplain is driven by three factors:
   a. Magnitude and timing of ocean water levels in Comox Harbour.
   b. Relative timing and magnitude of peak flows in Tsolum River.
   c. Relative timing and magnitude of peak flows in Puntledge River, which can be controlled to some degree by BC Hydro Operations at Comox Lake Dam.

   For moderate floods (10% AEP and 5% AEP), flooding across the Courtenay River floodplain is primarily the result of overtopping of riverbanks as flood flows exceed the conveyance capacity of the channels. During these moderate events, flooding within the Courtenay Industrial Park and the Courtenay Flats agricultural lands are primarily the result of overtopping of riverbank at the Old Tsolum River Side Channel. However, as the magnitude of the flood increases (both increased river discharge and increased ocean level) flooding within the Courtenay Flats Agricultural Area is the result of overtopping of Comox Road due to extreme high coastal water levels.

   With projected increase in SLR, the influence of these three factors on flooding will change over time. Maps showing the difference in modelled peak water levels for the 5% AEP flood and 0.5% AEP flood are included in Figure 12 and Figure 13, respectively.
9. Results of modelling scenarios, including water level profiles, maximum average channel velocities, flood hazard ratings and remaining freeboard to bridges, are presented in this technical memo. Refer to Technical Memorandum #5 – Coastal and Fluvial Mapping Products for details on the complete set of mapping deliverables provided for the Courtenay River.

8. 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.

Prepared by:

Craig Sutherland, M.Sc., P.Eng.
Senior Water Resources Engineer
(**Hydrology*)

Prepared by:

PROFESSIONAL
PROVINCE
23 Apr 2021
D. ZABIL
#27382
BRITISH COLUMBIA
ENGINEER

David Zabil, M.A.Sc., P.Eng.
Senior Water Resources Engineer
(**Hydraulics*)

Reviewed by:

Mike V. Currie, M.Eng., P.Eng.. FEC
Senior Technical Review

CS/cs/aah

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

Statement of Limitations

This document has been prepared by Kerr Wood Leidal Associates Ltd. (KWL) for the exclusive use and benefit of the intended recipient. No other party is entitled to rely on any of the conclusions, data, opinions, or any other information contained in this document.

This document represents KWL's best professional judgement based on the information available at the time of its completion and as appropriate for the project scope of work. Services performed in developing the content of this document have been conducted in a manner consistent with that level and skill ordinarily exercised by members of the engineering profession currently practising under similar conditions. No warranty, express or implied, is made.

Copyright Notice

Revision History

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

KERR WOOD LEIDAL
consulting engineers

Appendix A

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**	

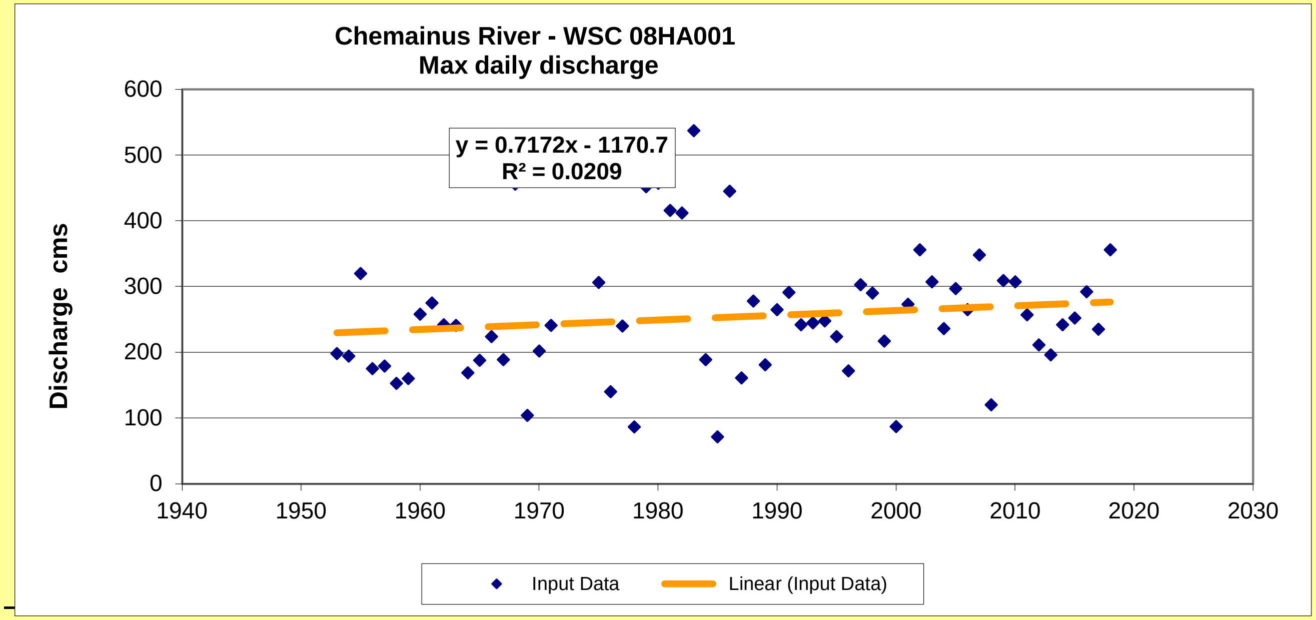
Confidence Level	95	%
Z(1-alpha/2)	1.9600	

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



KERR WOOD LEIDAL
consulting engineers

Mann-Kendall Trend Test

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

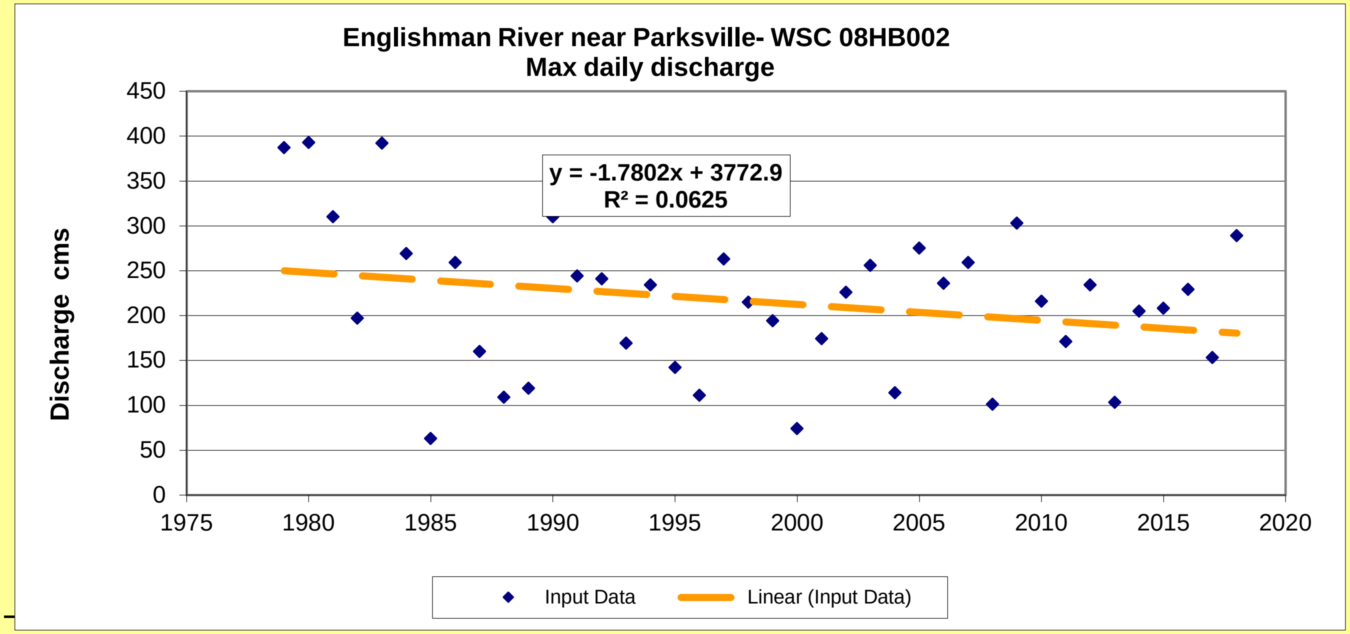
Confidence Level	95	%
Z(1-alpha/2)	1.9600	

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**	

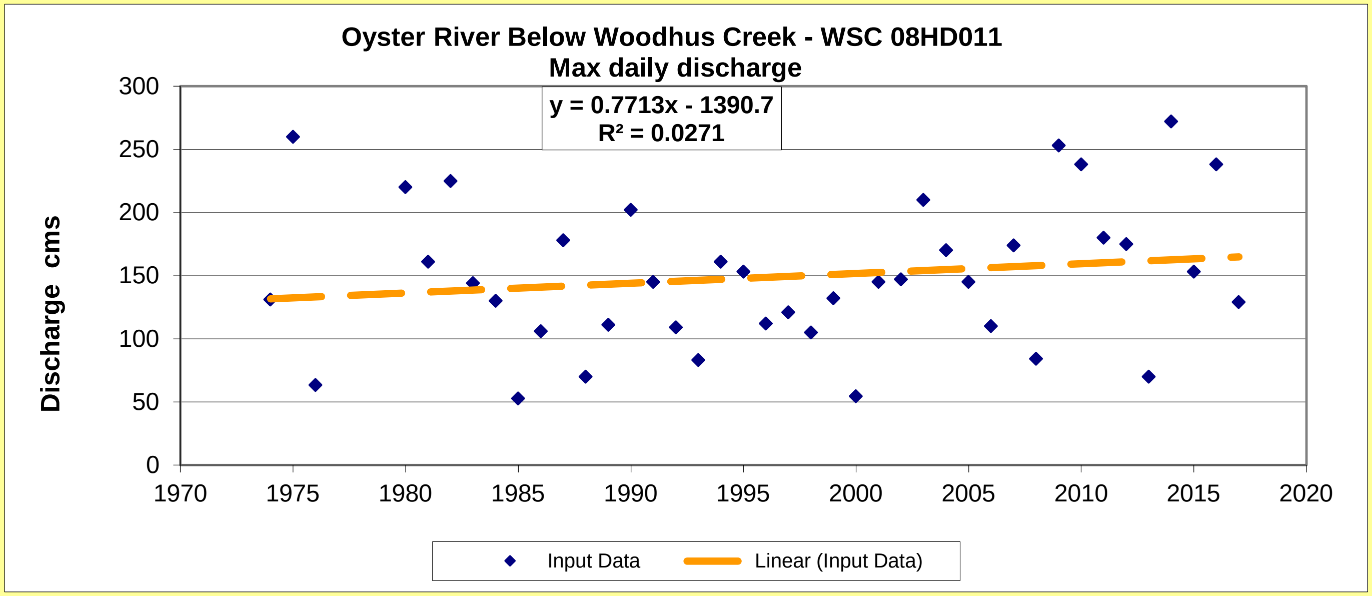
Confidence Level	95	%
Z(1-alpha/2)	1.9600	

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**	

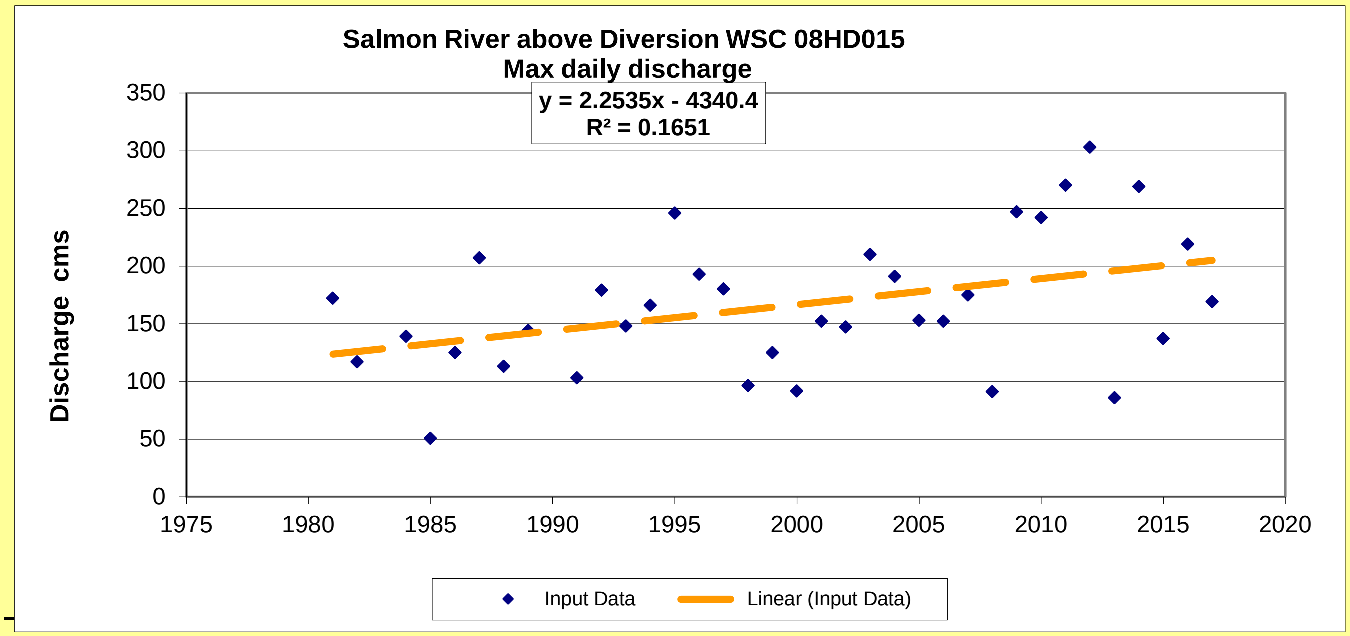
Confidence Level	95	%
Z(1-alpha/2)	1.9600	

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

Sen's Slope

Slope	15%	average % change per decade

Scatter Plot and MS Excel Trendline



KERR WOOD LEIDAL
consulting engineers

Appendix B

Hydraulic Model Run Database

Proposed Courtenay River 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**
Courtenay – 00002 - ExistingFP	Courtenay River – 0.2% AEP Channel Water Levels – Current Climate	Existing 1D/2D Fully Dynamic Model of Existing (2013) Floodplain Conditions. No updates to model proposed only changes to boundary conditions.	0.2% AEP (Full Hydrograph) – Current Climate[1]	0.2% AEP Joint Probability Sea Level + current sea level (Full Tidal Cycle)	Existing (2013) topography and flood protection measures (Canterbury Floodwall, etc.). No planned flood protection measures for Courtenay Flats.
Courtenay – 05002 - ExistingFP	Lower Oyster R. 0.2% AEP Channel Water Levels – Future 0.5 m SLR		0.2% AEP (Full Hydrograph) + CC Factor (15%)[1,2]	0.2% AEP Joint Probability Sea Level + 0.5 m SLR (Full Tidal Cycle)	
Courtenay – 10002 - ExistingFP	Courtenay River 0.2% AEP Channel Water Levels – Future 1.0 m SLR		0.2% AEP (Full Hydrograph) + CC Factor (30%)[1,2]	0.2% AEP Joint Probability Sea Level + 1.0 m SLR (Full Tidal Cycle)	
Courtenay – 20002 - ExistingFP	Courtenay River 0.2% AEP Channel Water Levels – Future 2.0 m SLR		0.2% AEP (Full Hydrograph) + CC Factor (30%)[1,2]	0.2% AEP Joint Probability Sea Level + 2.0 M SLR (Full Tidal Cycle)	
Proposed Courtenay River Flood Hazard Mapping Model Runs – 0.5 % Annual Exceedance Probability (AEP) Flood (200 Year Return Period)					
Courtenay – 00005 - ExistingFP	Courtenay River 0.5% AEP Channel Water Levels – Current Climate	Existing 1D/2D Fully Dynamic Model of Existing (2013) Floodplain Conditions. No updates to model proposed only changes to boundary conditions.	0.5% AEP (Full Hydrograph) – Current Climate[1]	0.5% AEP Joint Probability Sea Level + current sea level (Full Tidal Cycle)	Existing (2013) topography and flood protection measures (Canterbury Floodwall, etc.). No planned flood protection measures for Courtenay Flats.
Courtenay – 05005- ExistingFP	Courtenay River 0.5% AEP Channel Water Levels – Future 0.5 m SLR		0.5% AEP (Full Hydrograph) + CC Factor (15%)[1,3]	0.5% AEP Joint Probability Sea Level + 0.5 m SLR (Full Tidal Cycle)	
Courtenay – 10005 - ExistingFP	Courtenay River 0.5% AEP Channel Water Levels – Future 1.0 m SLR		0.5% AEP (Full Hydrograph) + CC Factor (30%)[1,3]	0.5% AEP Joint Probability Sea Level + 1.0 m SLR (Full Tidal Cycle)	
Courtenay – 20005 - ExistingFP	Courtenay River 0.5% AEP Channel Water Levels – Future 2.0 m SLR		0.5% AEP (Full Hydrograph) + CC Factor (30%)[1,3]	0.5% AEP Joint Probability Sea Level + 2.0 M SLR (Full Tidal Cycle)	
Proposed Courtenay River Flood Hazard Mapping Model Runs – 0.5 % Annual Exceedance Probability (AEP) Flood (200 Year Return Period)					
Courtenay – 10005 - ProposedFP	Courtenay River 0.5% AEP Channel Water Levels – Future 1.0 m SLR	Existing 1D/2D Fully Dynamic Model of Existing (2013) Floodplain Conditions. No updates to model proposed only changes to boundary conditions.	0.5% AEP (Full Hydrograph) + CC Factor (30%)[1,3]	0.5% AEP Joint Probability Sea Level + 1.0 m SLR (Full Tidal Cycle)	Existing (2013) topography and flood protection measures (Canterbury Floodwall, etc.). with Option 2 – Full Ring Dike identified in the Courtenay IFMS 2013

Note:

1 - Upstream boundary flow condition for Puntledge River assume uncontrolled outflow from Comox Lake at BC Hydro Comox Lake Dam.
2 - Upstream boundary flow condition for Puntledge River assume outflow from Comox Lake controlled in accordance with BC Hydro Operating Guidance for Comox Lake Dam.
3 - +15% and +30% CC Factor selected based on review of available climate change projections for CVRD.

The highest maximum modelled water levels from model runs highlighted in blue have been used to establish flood levels and flood extents (including freeboard) for regulatory mapping.

* - Model ID consists of the following elements (Model-XXYYY-Z
Model – Model Location
XX - Sea Level Conditions (Current - 00, +0.5 M Sea Level Rise - , +1.0 m Sea Level Rise, +2.0 m Sea Level Rise)
YYY - Annual Exceedance Probability of the river discharge

- Key flood protection assumptions (ExistingFP – Existing Flood Protection, ProposedFP – Proposed Courtenay IFMS Flood Protection 2013).

KERR WOOD LEIDAL
consulting engineers

Model Run ID*	Model Run Description	Hydraulic Model Type	Upstream Boundary Conditions	Downstream Boundary Conditions	Flood Protection
Proposed Courtenay River Flood Hazard Mapping Model Runs – 1 % Annual Exceedance Probability (AEP) Flood (100 Year Return Period)					
Courtenay – 00010 - ExistingFP	Courtenay River 1% AEP Channel Water Levels – Current Climate	Existing 1D/2D Fully Dynamic Model of Existing (2013) Floodplain Conditions. No updates to model proposed only changes to DS boundary conditions.	1% AEP (Full Hydrograph) – Current Climate[1]	1% AEP Storm Surge + current sea level (Full Tidal Cycle)	Existing (2013) topography and flood protection measures (Canterbury Floodwall, etc.). No planned flood protection measures for Courtenay Flats.
Courtenay – 05010 - ExistingFP	Courtenay River 1% AEP Channel Water Levels – Future 0.5 m SLR		1% AEP (Full Hydrograph) + CC Factor (15%)[1,3]	1% AEP Storm Surge + 0.5 m SLR (Full Tidal Cycle)	
Courtenay – 10010 - ExistingFP	Courtenay River 1% AEP Channel Water Levels – Future 1.0 m SLR		1% AEP (Full Hydrograph) + CC Factor (30%)[1,3]	1% AEP Storm Surge + 1.0 m SLR (Full Tidal Cycle)	
Courtenay – 20010 - ExistingFP	Courtenay River 1% AEP Channel Water Levels – Future 2.0 m SLR		1% AEP (Full Hydrograph) + CC Factor (30%)[1,3]	1% AEP Storm Surge + 2.0 M SLR (Full Tidal Cycle)	
Proposed Courtenay River Flood Hazard Mapping Model Runs – 5 % Annual Exceedance Probability (AEP) Flood (20 Year Return Period)					
Courtenay – 00050 - ExistingFP	Courtenay River 5% AEP Channel Water Levels – Current Climate	Existing 1D/2D Fully Dynamic Model of Existing (2013) Floodplain Conditions. No updates to model proposed only changes to DS boundary conditions.	5% AEP (Full Hydrograph) – Current Climate[1]	5% AEP Storm Surge + current sea level (Full Tidal Cycle)	Existing (2013) topography and flood protection measures (Canterbury Floodwall, etc.). No planned flood protection measures for Courtenay Flats.
Courtenay – 05050 - ExistingFP	Courtenay River 5% AEP Channel Water Levels – Future 0.5 m SLR		5% AEP (Full Hydrograph) + CC Factor (15%)[2,3]	5% AEP Storm Surge + 0.5 m SLR (Full Tidal Cycle)	
Courtenay – 10050 - ExistingFP	Courtenay River 5% AEP Channel Water Levels – Future 1.0 m SLR		5% AEP (Full Hydrograph) + CC Factor (30%)[2,3]	5% AEP Storm Surge + 1.0 m SLR (Full Tidal Cycle)	
Courtenay – 20050 - ExistingFP	Courtenay River 5% AEP Channel Water Levels – Future 2.0 m SLR		5% AEP (Full Hydrograph) + CC Factor (30%)[2,3]	5% AEP Storm Surge + 2.0 M SLR (Full Tidal Cycle)	
Proposed Courtenay River Flood Hazard Mapping Model Runs – 10 % Annual Exceedance Probability (AEP) Flood (10 Year Return Period)					
Courtenay – 00100 - ExistingFP	Courtenay River 10% AEP Channel Water Levels – Current Climate	Existing 1D/2D Fully Dynamic Model of Existing (2013) Floodplain Conditions. No updates to model proposed only changes to DS boundary conditions.	10% AEP (Full Hydrograph) – Current Climate[1]	10% AEP Storm Surge + current sea level (Full Tidal Cycle)	Existing (2013) topography and flood protection measures (Canterbury Floodwall, etc.). No planned flood protection measures for Courtenay Flats.
Courtenay – 05100 - ExistingFP	Courtenay River 10% AEP Channel Water Levels – Future 0.5 m SLR		10% AEP (Full Hydrograph) + CC Factor (15%)[2,3]	10% AEP Storm Surge + 0.5 m SLR (Full Tidal Cycle)	
Courtenay – 10100 - ExistingFP	Courtenay River 10% AEP Channel Water Levels – Future 1.0 m SLR		10% AEP (Full Hydrograph) + CC Factor (30%)[2,3]	10% AEP Storm Surge + 1.0 m SLR (Full Tidal Cycle)	
Courtenay – 20100 - ExistingFP	Courtenay River 10% AEP Channel Water Levels – Future 2.0 m SLR		10% AEP (Full Hydrograph) + CC Factor (30%)[2,3]	10% AEP Storm Surge + 2.0 M SLR (Full Tidal Cycle)	

Note:

1 - Upstream boundary flow condition for Puntledge River assume uncontrolled outflow from Comox Lake at BC Hydro Comox Lake Dam.
2 - Upstream boundary flow condition for Puntledge River assume outflow from Comox Lake controlled in accordance with BC Hydro Operating Guidance for Comox Lake Dam.
3 - +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 infrastrucrture, Breach – model includes hypothetical breach of flood infrastructure at critical location.