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Technical Memorandum #2

DATE: April 23, 2021

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

FROM: Chad Davey, M.Sc., R.P.Bio
Craig Sutherland, M.Sc., P.Eng.

RE: **Coastal Flood Mapping Project**
Technical Memorandum #2 – Fluvial and Coastal Geomorphology
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 (#2) documents the fluvial (river migration corridor) and coastal (shoreline erodibility) geomorphic assessment components of the project. Other technical memoranda will document the remaining project components.

1.1 Project Scope

The main project tasks include:

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

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 #2, which describes the fluvial and coastal geomorphic assessments that were conducted on the Oyster River and CVRD shoreline, respectively.

The fluvial geomorphic assessment of the Oyster River was conducted to provide information that will help guide future development and land use planning. This includes delineating a river migration corridor for the Oyster River that reflects the estimated extent of future river processes such as bank erosion and meandering. It is important to note however that the Oyster River migration corridor presented here is based on desktop study and is considered preliminary, and thus indicative only. This is a first step in identifying geohazards to inform land use management along the Oyster River.

A geomorphic assessment of the Courtenay River, Puntledge River and Tsolum River was not carried out as part of the current study; however, a geomorphic review was previously carried out as part of the Courtenay Integrated Flood Management Study for the City of Courtenay in 2013 (KWL, 2013).

For the coastal assessment, a high-level desktop study was conducted to map the vulnerability of the CVRD shoreline to coastal erosion. The purpose of the coastal geomorphic assessment is to identify reaches of shoreline in which an increase or reduction in building setbacks may be appropriate due to the potential for coastal erosion.

1.2 Glossary

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.
Channel Reach	=	Length of channel that is of similar setting (e.g., geologic, land use), and channel form (e.g., planform shape, morphology).

Channel Sinuosity	=	The degree of meandering of a channel. The higher the sinuosity the greater degree of meandering.
Fluvial Terrace	=	Fluvial deposit consisting of former valley floor that is now situated well above the current valley floor.
Meander Amplitude	=	Lateral distance between tangential lines drawn between two successive meander bends (Leopold et al., 1964).
Meander Axis	=	Conceptual line that shows the general down valley orientation of the meander pattern (Parish, 2004).
Meander Belt or Migration Corridor	=	Area surrounding the channel that has, and/or may experience erosion processes in the future.
Natural Boundary	=	Natural Boundary means the visible high-water mark of any lake, river, stream or other body of water where the presence and action of the water are so common and usual, and so long continued in all ordinary years, as to mark on the soil of the bed of the body of water a character distinct from that of its banks, in vegetation, as well as in the nature of the soil itself (from the BC Land Act).
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.

1.3 References

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

1. Bednarski, J. (2015). *Surficial Geology and Pleistocene Stratigraphy from Deep Bay to Nanoose Harbour, Vancouver Island, British Columbia.* Geological Survey of Canada Open File 7681. doi:10.495/295609.
2. British Columbia Ministry of Forests, Land and Natural Resource Operations (FLNR). (2018). Flood Hazard Area Land Use Management Guidelines.
3. Current Environmental. (2018). Comox Valley Regional District Coastal Shoreline Baseline Assessment.
4. Fyles, J. G. (1959). Map 49-1959. Surficial Geology of Oyster River. Comox, Nanaimo, and Sayward Districts, British Columbia. Geology Survey of Canada.
5. Fyles, J. G. (1960). Map 32-1960. Surficial Geology of Courtenay. Comox, Nelson, Nanaimo, and Newcastle Districts, British Columbia. Geology Survey of Canada.
6. GeoBC. (2016a). Map 092F084. Ministry of Forests, Lands, and Natural Resource Operations.
7. GeoBC. (2016b). Map 092F085. Ministry of Forests, Lands, and Natural Resource Operations.
8. Katnick, D. C., & Mustard, P. S. (2001). Geoscience Map 2001-3. Geology of Denman and Hornby Islands British Columbia.
9. Kerr Wood Leidal Associates Ltd. (2013). City of Courtenay, Integrated Flood Management Study, Hydrodynamic Model Development and Flood Management Options Evaluation.

10. Local Government Act. (2015). Retrieved from the BC Laws website: https://www.bclaws.ca/civix/document/id/complete/statreg/r15001_00.
11. Leopold, L. B., & Wolman M. G. (1960). River Meanders. Bulletin of the Geological Society of America, 71, 769-794.
12. NHC. (2016). Appendix D: Risk Analysis of CVRD Forcemain on Balmoral Beach: Draft Report.
13. Parish Geomorphic. (2004). Belt Width Delineation Procedures.

2. Regulatory Context

While the purpose of the coastal assessment is to determine if an increase or reduction in setbacks may be appropriate, the fluvial assessment was conducted to provide CVRD with preliminary information to support the development of riverine setbacks along the Oyster River.

2.1 Provincial Guidance

From a regulatory perspective, the *Local Government Act* (2015), RSBC 2015, s 524, enables local governments to create minimum watercourse-to-structure setback distance requirements for specific areas through a floodplain by-law (or similar tool such as development permit area designation). Furthermore, the BC Ministry of Forests, Land and Natural Resource Operations and Rural Development (FLNR) provides guidance with the *Flood Hazard Area Land Use Management Guidelines*, referred to herein as the “provincial guidelines” to support local governments in creating and applying floodplain management policies, including setbacks (FLNR, 2018). Additionally, Engineers and Geoscientists BC provides parallel guidance to qualified professionals through the professional practice guideline document *Legislated Flood Assessments in a Changing Climate in BC*.

The provincial guidelines discuss setbacks by hazard type and land use context. For rivers, the guidance on setbacks for buildings includes the following:

1. 30 m from the natural boundary[1] (as defined in the BC Land Act) of the watercourse.
2. The minimum 30 m setback requirement may be increased “*where a watercourse … has significant bank erosion*”.
3. The 30 m setback requirement may be decreased (to 15 m given that the floodway is not obstructed) for smaller streams as defined by an estimated designated flood (0.5% AEP / 200-year return period) peak flow of less than 80 m^3/s.

For areas bordering the coast, the provincial guidelines state that setbacks should be the greater of 15 m from the estimated location of the future natural boundary of the sea with 1 m of sea level rise, or landward of the location where the natural ground elevation contour is equivalent to the floodplain limit with 1 m of sea level rise. Special setbacks are established in the case of coastal bluffs.

[1] Natural Boundary means the visible high-water mark of any lake, river, stream or other body of water where the presence and action of the water are so common and usual, and so long continued in all ordinary years, as to mark on the soil of the bed of the body of water a character distinct from that of its banks, in vegetation, as well as in the nature of the soil itself.

2.2 CVRD Regulations

Locally, the CVRD has several relevant tools to regulate development near watercourses, including:

- Floodplain Management Bylaw, No. 600 (2020) – establishes flood construction levels, setbacks, and construction requirements for properties in unincorporated areas within the floodplain;
- Rural Comox Valley Zoning Bylaw, No. 520 (2019) – regulates development siting through setbacks and flood construction levels in the Floodplain Management Bylaw;
- Regional District Building Bylaw, No. 142 (2011) – requires buildings to adhere to setbacks, flood construction levels, and other siting requirements for flood management; and
- Rural Comox Valley Official Community Plan, No. 337 (2018) – includes development permit area (DPA) guidelines on shoreline and aquatic protection measures for waterfront properties.

2.3 Considerations for Project Work

The channel migration analysis conducted for the Oyster River can be considered as supplemental (not replacement) information to the guidance provided by the Province. As noted above, the provincial guidelines suggest that local governments may increase the setback requirement "*where a watercourse … has significant bank erosion*" (FLNR, 2018). It would be reasonable to also apply this provision in situations where additional analysis (i.e., the channel migration analysis for this project) shows that there is potential for migration beyond the 30 m setback requirement.

Accordingly, the CVRD may wish to consider expanding its setback requirement in areas where the channel migration analysis results suggest that migration beyond the 30 m setback line is possible. It would be inappropriate (and not recommended) to use the channel migration analysis results to reduce the setback requirement to <u>less</u> than the guidance provided by the Province.

Finally, for completeness, it should also be noted that coastal setback requirements from the Province would apply to the downstream portion of the Oyster River which is influenced by tides and coastal storms. In this area, the setback requirements may be considered as an overlap between riverine and coastal setback guidance.

3. Geological Setting

3.1 Oyster River

The headwaters of the Oyster River are along the western flank of Mt. Washington. The river flows northeastward across an irregular surfaced plateau, where it encounters a large coastal plain before exiting into the Strait of Georgia (Bednarski, 2015). A watershed map of the Oyster River is provided in Technical Memorandum #3A – Fluvial Modelling – Oyster River Hydrology and Model Assumptions.

The study area consists of river reaches downstream of the Highway 19 bridge crossing (Figure 1). In the upper portion of the study area the river channel is locally constrained by bedrock outcrops and is underlain by valley alluvium. Over time, the Oyster River has eroded into the coastal plain feature forming a valley comprised of terraced fluvial deposits (Capilano sediments) (Fyles, 1959). Further downstream in the study area there is a decreasing occurrence of bedrock outcrops. In addition, the Oyster River encounters a mix of fluvial, deltaic, and shore deposits (Salish sediments) (Fyles, 1959), situated approximately at the downstream limit of Reach 3 (Figure 1). In the lower section of Reach 5, the valley widens considerably as the Oyster River flows onto its alluvial fan (delineation of fan boundaries were guided by geology data from Fyles, 1959, see Figure 1). At the river mouth, a small deltaic feature is evident in the foreshore area, having been formed from fluvial processes as a result of river flooding as well as coastal transport processes.

3.2 CVRD Shoreline

The study area for the shoreline assessment extends along the east coast of Vancouver Island from Oyster River southwards to Baynes Sound and includes Denman and Hornby Islands (Figure 2). A description of the shoreline is provided below, split into different regions.

1. The northern shoreline from Saratoga Beach to Comox consists primarily of glacial sand/gravel deposits. In some locations, these deposits have been eroded by coastal processes to expose high (up to 50 m) sea bluffs consisting of erodible sand/gravel. This portion of the shoreline fronts onto the Strait of Georgia and is exposed to relatively high wave energy from the northwest and southeast prevailing winds.
2. From Comox to Royston, the shoreline has been predominantly formed by the transport of fluvial deposits from the Courtenay River and consists typically of sand/gravel/cobble beaches with relatively low coastal banks.
3. South of Royston, the shoreline consists of a variation of cobble, gravel, and sand beaches which have been deposited as a result of coastal transport of eroding coastal sediments and from fluvial deposits from the Courtenay River. The wave energy along this shoreline is lower than the northern section as it fronts Baynes Sound that is protected by Denman Island. The most southern portion of the shoreline, near Mud Bay, consists of fine sediment mudflats.
4. The shoreline of Denman Island is typically composed of low bluffs fronted by bedrock shelves or sand and gravel beaches. The southern Denman Island shoreline has higher bedrock cliffs, while the northeastern portion of Denman Island has similar geology to that of the northern shoreline of CVRD, with glacial deposits which have eroded to form high coastal bluffs in some locations, especially along the exposed north eastern shoreline (Komas Bluffs). Eroded sediments from these coastal bluffs have been transported north by coastal processes to form a sand spit at the northern end of Denman Island and a series of small islands including Sandy Island.

5. The Hornby Island shoreline is generally similar to that for Denman Island, with low bluffs fronted by bedrock shelves or sand and gravel beaches. However, higher bedrock cliffs are present at western Helliwell Park and the longer reaches of sandy beach at Tribune Bay, Little Tribune Bay, and Whaling Station Bay.

4. Geomorphic Assessment Methodology

This section describes the methods used in the geomorphic assessment that was conducted for the Oyster River (see study area in Figure 1), and to assess the erodibility of the CVRD shoreline (see study area in Figure 2).

It is important to note that both assessments were desktop-based; field visits were not conducted as part this study.

4.1 River Migration Corridor Assessment

Unless confined by bedrock, rivers have a natural tendency to shift course over time. Such shifts may be gradual or abrupt. In areas adjacent to a river where development has occurred, or might occur, there is a need to assess the hazard that river migration may pose to development. Although a variety of methods exist for defining a river migration corridor, they generally share common core concepts.

The assessment used in this study is based on the concept of the meander belt which is a fundamental concept in river migration. The specific procedure described in Parish (2004) has been selected because it offers a means to quantitatively estimate the impact of projected flow increases under climate change on the river migration corridor.

Delineation of the river migration corridor involved the following steps:

1. Assessment of individual channel reaches.
2. Mapping of historical channel positions over time using aerial photos.
3. Determination of migration corridor width based on historical channel position and features that restrict meander migration (e.g., valley wall, bedrock outcrop, etc.)
4. Estimating the impacts of projected flow increases under climate change on the river migration corridor.

Channel Reaches

Prior to defining the migration corridor, the study area was segmented into individual channel reaches. Channel reaches are segments of river that contain similar channel characteristics and have a consistent physical setting along their length. In general, the fluvial processes controlling channel morphology within each reach should be similar. The identification of reaches within the study area relied on the following information:

1. Surficial geology maps showing the presence of bedrock outcrops (Fyles, 1959).
2. Topographic maps showing the tributaries and their confluence locations along Oyster River (GeoBC, 2016a, 2016b).
3. Historical aerial photos (see Table 1) of the study area to show meander patterns over time.

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Service Layer Credits: Canada Hillshade: Sources: NRCan, Esri Canada, and Canadian Community Maps contributors.
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Coordinate System: Name: NAD 1983 UTM Zone 10N.

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

Project No. 2623-014
Date April 2021
Scale 1:30,000
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Oyster River Fluvial Geomorphic Assessment – Study Area

Figure 1

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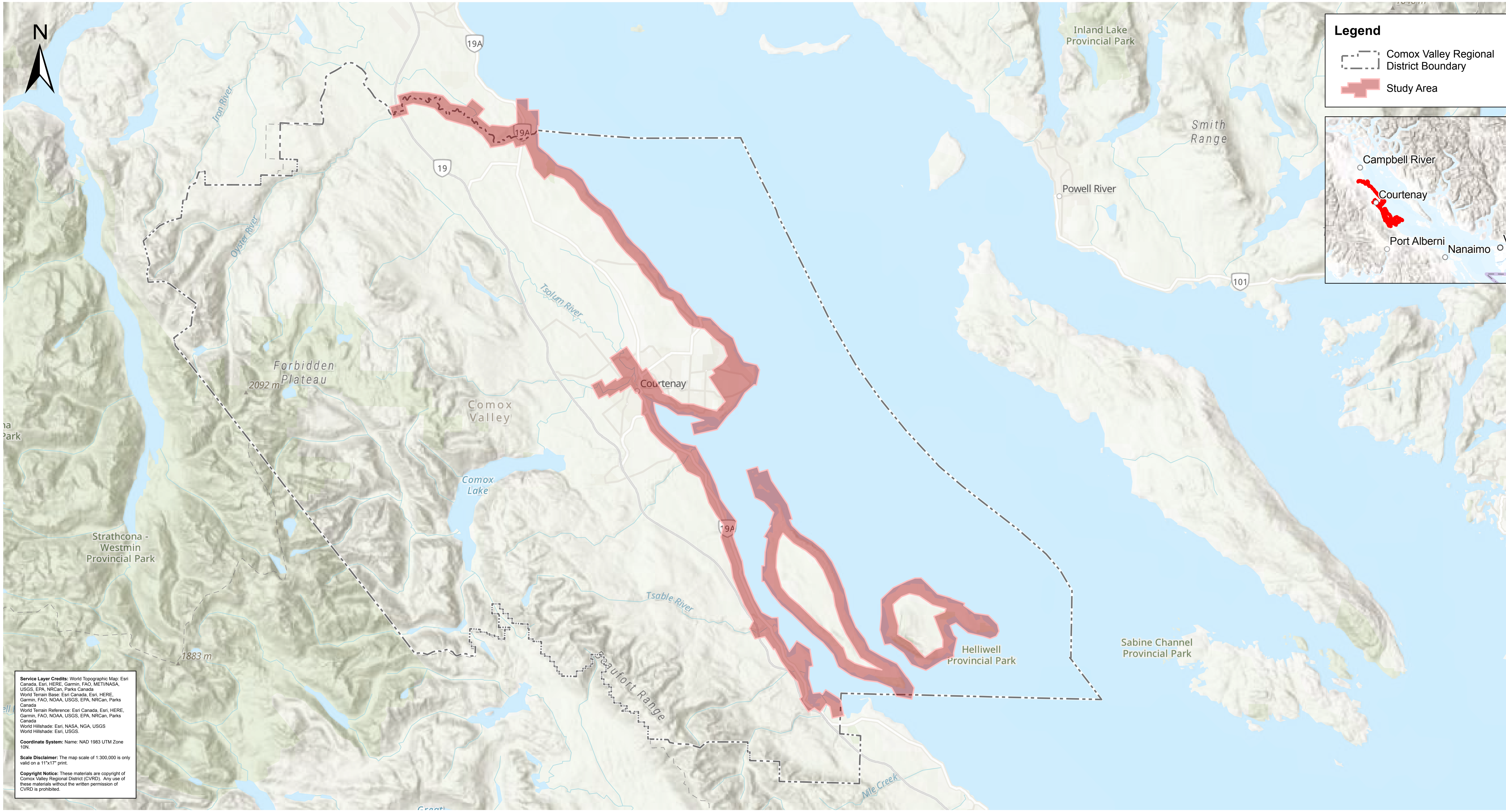

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CVRD Coastal Geomorphology Assessment – Study Area

Figure 2

Historical Channel Position

An assessment of the historical channel position of the Oyster River reveals the area that the channel previously occupied and provides insight as to where the channel could migrate to in the future. Aerial photos were obtained from the Geographic Information Centre (GIC) at the University of British Columbia's Vancouver campus. A list of the photos that were obtained for this assessment is provided in Table 1. The aerial photos cover a period of record between 1938 and 2016. Note, the 1938 imagery provides only partial coverage of the study area. As such, this photo set was not used for development of the migration corridor. However, geomorphic features observed in the 1938 aerial photos (e.g., meander cut-offs, etc.) are discussed.

Aerial photos were used to determine the historical channel bank line positions for the Oyster River. To compare channel position changes over time, aerial photos were geo-rectified in ArcGIS using control points and the 2016 ortho-rectified imagery. Once geo-rectified and transformed, a trace along the edge of each bank was performed for each year of coverage to illustrate the evolution of the bank line over time within the study area. In some cases, poor resolution of the aerial photo, vegetation, and/or varying water levels caused some difficulty in aligning control points used for the geo-rectification. This reduces the accuracy in quantifying changes in mapped features over time. Table 1 presents the range in root mean square (RMS) error associated with each set of geo-rectified images.

Table 1: Summary of Imagery Used for the Geomorphic Assessment

Date	Source/Roll/Photo Number	Scale	RMS Error Range (m)
2016	Bing Imagery[1]	N/A	N/A
1993	15BCB93085/86 #47, 51, 66, 146, 151, 212	1:~20,000	1.1 – 9.3
1980	30BCB80002/03 #35, 37, 54, 56, 137, 188, 211	1:~15,000	1.1 - 9.6
1968	BC7077/78 #15, 169, 171, 172, 205	1:~25,000	1.2 – 8.4
1957	BC2312 #9, 38	1:~60,000	8.2 – 8.7
1938[2]	BC77/78/79/80 #18, 38, 53, 58, 66, 67,	1:~20,000	0.0 - 5.3

Notes:
1. Publicly available satellite and aerial imagery.
2. Partial coverage of study area.

A channel survey of the Oyster River was conduced in 2019 to support the hydraulic modelling (see Technical Memorandum #1 – Coastal and River Base Map Development), however the survey did not include channel boundaries and does not cover the entire length of the Oyster River assessed for this study. Thus, the survey was not included in the channel bank line assessment.

Migration Corridor Delineation

Prior to defining the extent of the migration corridor, a meander axis is delineated along the study area to help guide the delineation. The meander axis illustrates the general down-valley meander trajectory for each reach. The meander axis of one reach links to the meander axis of an adjoining reach. An illustration of the general location of the meander axis, and delineation of the migration corridor is shown in Figure 3.

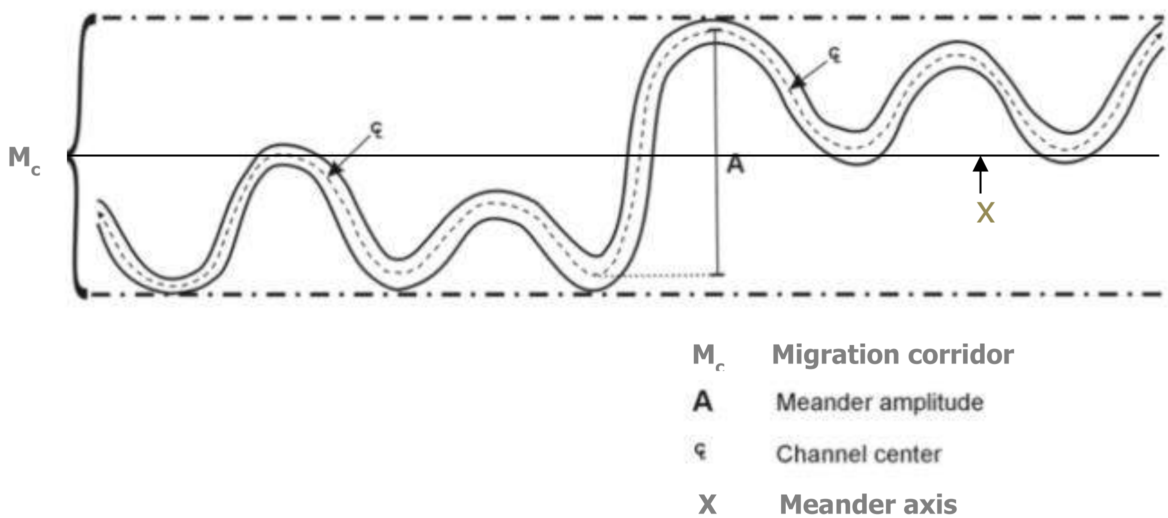

Figure 3: Illustration of Migration Corridor and Associated Features of Meander Patterns (adapted from Parish, 2004).

The preliminary migration corridor can be defined once the meander axis has been delineated. The preliminary migration corridor consists of parallel lines drawn tangentially to the outside bends of mapped historical meanders in each reach. Typically, historical (or current) meanders with the largest amplitude define the preliminary migration corridor for each reach (Figure 3). The mapped bank lines for all years (Table 1), with the exception of the partial coverage of the 1938 photos set, were used to guide the delineation of the migration corridor.

The final migration corridor can be determined once adjustments are made to the preliminary corridor width. The following adjustments were used to determine the final corridor width (adjustments are listed in the order applied):

1. Increasing the preliminary migration corridor width by a climate change adjustment factor.
2. Adjusting the boundaries of the migration corridor where migration may be restricted.

Climate Change Adjustment

The climate change adjustment factor is used to account for the impact of the expected increase in peak flow and frequency that is anticipated to occur from climate change. The meander belt protocol assumes that an increase in flow magnitude and frequency, with no change occurring to the erodibility of floodplain materials and riparian vegetation, will result in an increase in the meander belt width (Parish, 2004). Parish (2004) assumes that the expected increase in meander belt width is proportional to the increase in peak flow. The climate change factor used in the river migration corridor is a 30% increase in flow. The climate change factor is further described in Technical Memorandum #3A – Fluvial Modelling – Oyster River Hydrology and Model Assumptions.

Restrictions to Migration

The second adjustment of the migration corridor is the modification of the boundary where the position of the channel may be restricted. In the case of the Oyster River, several terrace features are present within the study area and appear to have restricted the migration channel in the past. While these terrace features are present on both sides of the Oyster River, they are discontinuous and appear to vary in age (i.e., elevation) within the study area. It is suspected that during deglaciation, the Oyster River experienced several downcutting events, resulting in the abandonment of former floodplains. For the purposes of this study, the more prominent terrace features (e.g., tall and steep) were considered to restrict the channel position. These features were defined as slopes >10 m in height. The terrace features were identified using 1 m contours derived from 2019 LiDAR data. The crest lines of these terrace features were digitized using ArcGIS.

The crest lines of these terrace features were used to adjust the migration corridor boundary when these features were located inside the preliminary corridor boundary. Figure 4 shows an example on the Oyster River where the migration corridor (white line) was adjusted to follow the crest of the terrace feature (red dashed line) as identified by 1 m topographic contours (not shown). It is important to note that the migration corridor does not include allowances for geotechnical instability of steep slopes on the river side of terraces.

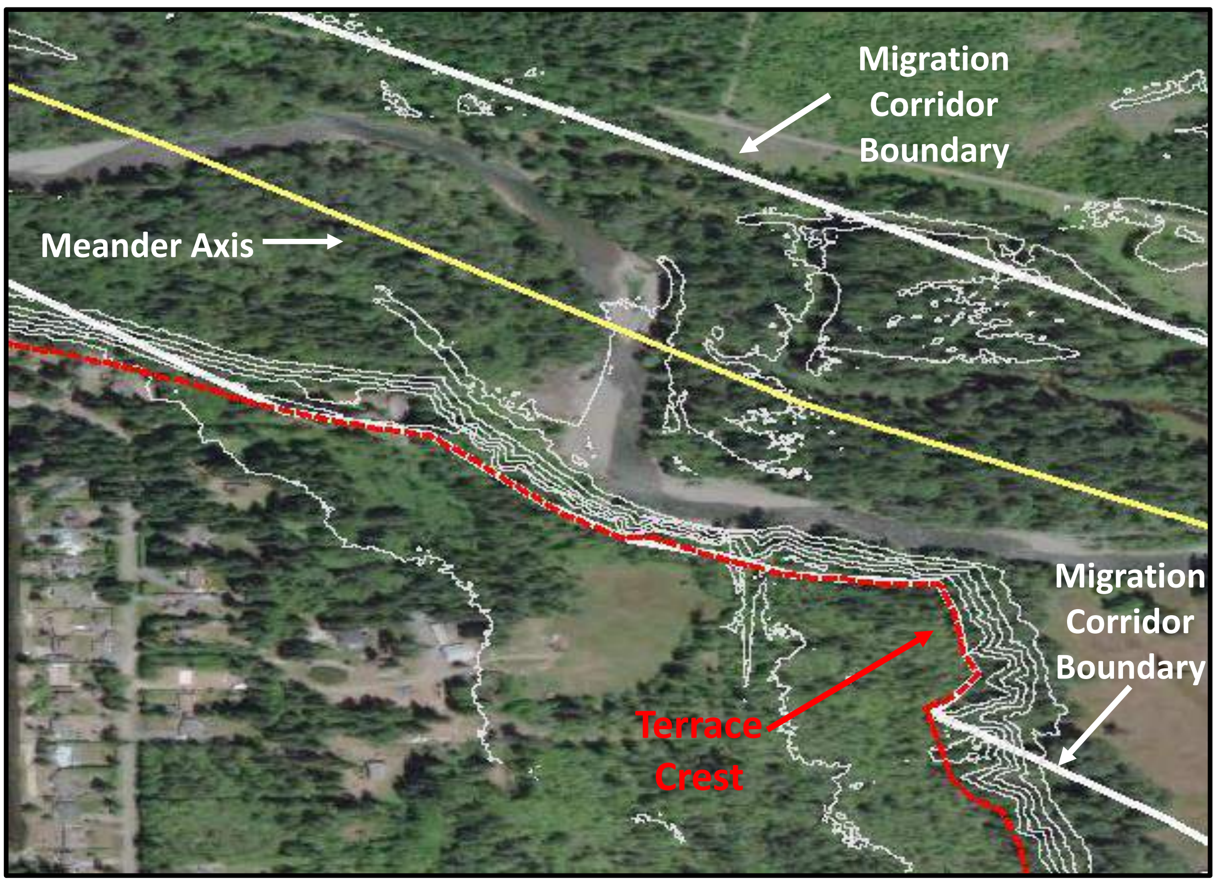

Figure 4: Illustration of Adjustment of Migration Corridor Boundary Along Crest of Terrace. White Lines are 5 m Contours.

4.2 Shoreline Erodibility Assessment

The purpose of the CVRD shoreline erodibility assessment is prepare a dataset of shoreline erodibility classifications which can be used for coastal land use planning and setback assessment. The dataset is intended to be a companion resource to the coastal setback mapping prepared as part of this project (refer to Technical Memorandum #5 – Coastal and Fluvial Mapping Products).

The identification of shoreline erodibility relied on a combination of the following information:

1. Surficial geology maps illustrating coastal sediment characteristics (partial coverage including Comox area and Denman island).
2. Site specific reports of known coastal erosion issues (refer to References).
3. Baseline assessment of the CVRD shoreline (Current Environmental, 2018), which included shoreline mapping and observed shoreline erosion (partial coverage: including Oyster River southwards to Comox).
4. 2018 orthophotography and associated LiDAR topographic data (full coverage).

Three classifications were used to describe the erodibility of the shoreline. These classifications primarily relate to the size of the shoreline material and observations made in other site-specific reports, and include:

1. **Erodible**: the shoreline is documented to be eroding or appears to be actively eroding based on the 2018 orthophotography.
2. **Semi-erodible**: shoreline is not documented to be eroding and sediments along the coast appear to be potentially erodible (e.g., sand, gravel, cobble).
3. **Non-erodible**: shoreline is not documented to be eroding and sediments along coast appear to be coarse-grained or resistant to erosion (e.g., boulder, bedrock).

All mapping of shoreline erodibility was digitized using ArcGIS.

5. Geomorphic Assessment Results

5.1 River Migration Corridor

Channel Reaches

A total of six channel reaches were identified in the study area. The reach locations are shown in Figure 1. A description of each reach is provided below:

1. **Reach 1** is ~ 1.2 km in length, starts at Highway 19 and ends at the confluence of Woodhus Creek. The channel is underlain by valley alluvium with bedrock outcrops present along both sides.
2. **Reach 2** is ~ 2 km in length, starts upstream at the confluence of Woodhus Creek where bedrock outcrops are no longer adjacent to the channel, and ends downstream where bedrock outcrops reappear near the channel. The channel is underlain by valley alluvium. (Note: a tributary fan is not evident based on imagery and contours).
3. **Reach 3** is ~ 3 km in length, starts upstream at the reappearance of bedrock outcrops adjacent to the channel, and extends downstream to the end of where bedrock outcrops occur adjacent to the channel. The downstream limit of Reach 3 is where the channel encounters Salish sediments (e.g., mixture of fluvial, deltaic, and shore sediments).
4. **Reach 4** is ~ 4 km in length, starts upstream where bedrock outcrops are no longer adjacent to the channel, and ends downstream at the confluence of the Little Oyster River. The channel is underlain by Salish sediments. (Note: a tributary fan is not evident based on imagery and contours).
5. **Reach 5** is ~ 6 km in length, starts upstream at the confluence of the Little Oyster River, and extends downstream to the bridge crossing at the Old Island Highway (Highway 19A). Along the downstream section of Reach 5, the valley widens as the Oyster River flows across its alluvial fan (approximate boundaries of fan are shown on Figure 1). The bridge crossing is the approximate upstream limit of where the river channel is tidally controlled. The channel is underlain by Salish sediments.
6. **Reach 6** is ~ 1.1 km in length, starts upstream at the bridge crossing at the Old Island Highway (Highway 19A), and extends downstream to the confluence with the Strait of Georgia as shown in Figure 5. This reach is situated along the Oyster River fan and is tidally controlled, and only includes the section of channel exhibiting a meandering morphology (i.e., the deltaic feature, where the channel becomes multi-thread or braided, is not included in the reach).

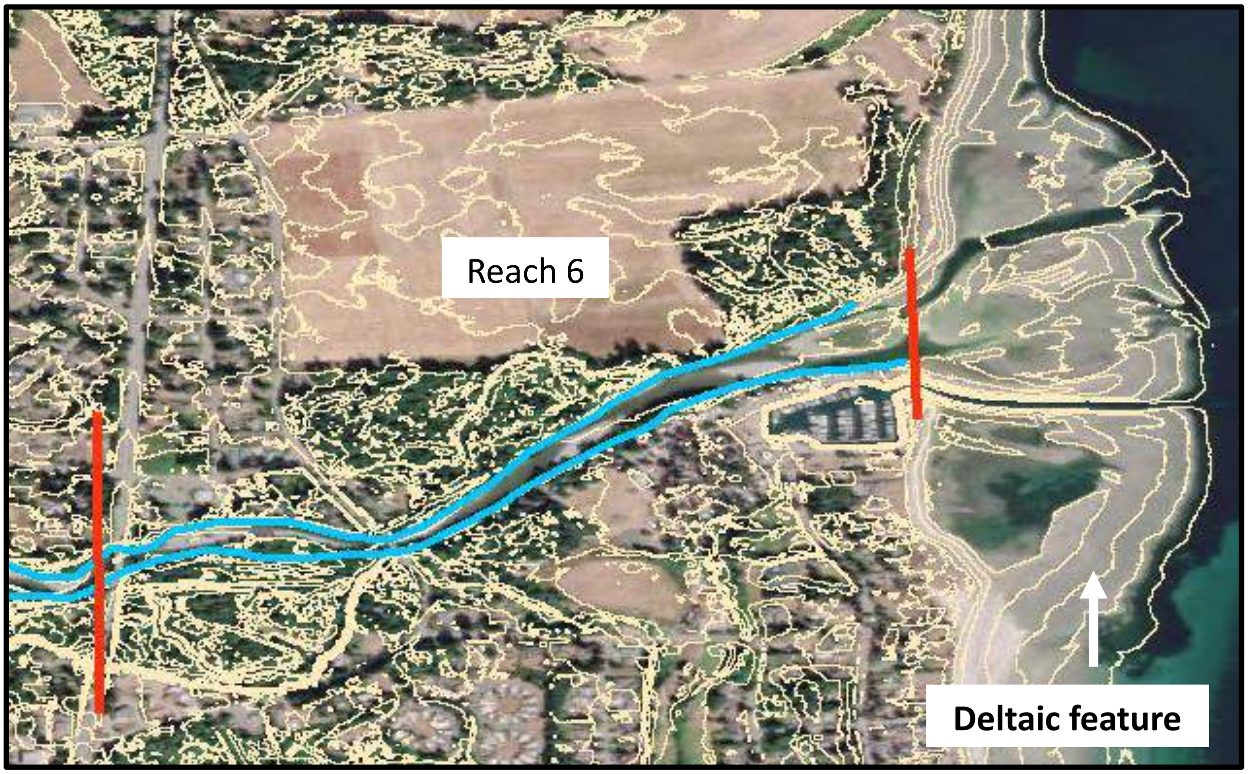

Figure 5: Reach 6 is Located Near the Mouth of the Oyster River. Yellow Lines Represent 1 m Contours and Blue Lines are the 2018 Oyster River Bank Position.

Historical Channel Position

Appendix A presents the results of the bank line mapping (Figures A1 through A5) that was completed for each set of historical aerial photos (Table 1). Chainage lines (m) are included on these figures to link the discussions below with corresponding areas within the Oyster River. Bank lines for the 1993 aerial photos do not appear to be notably different from the position of the 2016 bank lines, and thus are not shown on Figures A1 through A5 for clarity.

The following observations are made based on mapped historical Oyster River bank lines:

1. Within Reach 1, the Oyster River has remained relatively stable in its channel position from 1957 to 2016. This is likely the result of the bedrock outcrops presents on either side of the channel.
2. Within Reach 2, the two large meander bends appear to have migrated down valley over time. In particular, the downstream meander bend (chainage 3000 m) has migrated northeast ~ 50 m between 1980 and 2016.
3. In Reach 3, the Oyster River has remained relatively stable in its planform position from 1957 to 2016, with the exception of the channel at chainage 4200 m where the channel has migrated north east almost an entire channel width since 1957. The relative channel stability in this reach is likely the result of the bedrock outcrops present on either side of the channel.
4. In Reaches 4 and 5 (chainage 6400 m to 14800 m) the meanders within the Oyster River appear to generally migrate in the down valley direction.

5. At the downstream section of Reach 5 (between chainages 14,800 m and 16,800 m) three meander cut-offs were identified. These three cut-offs are illustrated in Figure 6. Meander cut-off #1 appears to have initiated between 1957 and 1968. Meander cut-off #2 appears to have initiated between 1980 and 1993. The largest meander cut-off, #3, appears to have occurred between 1968 and 1980 (Figure 6). The historical flood record on the Oyster River (see Technical Memorandum #3A – Fluvial Modelling – Oyster River Hydrology and Model Assumptions) shows that a large flood occurred in 1990 which may have cause meander cut-off #2, while a large flood in 1975 may have caused meander cut-off #3. The creation of meander cut-off #1 is not correlated with a major flood since no major flood was recorded between 1957 and 1968.
6. Meander cut-off #4 was identified in the upstream section of Reach 6 at chainage 17,000 m (Figure 7). This cut-off appears to have been initiated between 1938 and 1957. The historical flood record on the Oyster River (see Technical Memorandum #3A) shows that large floods events occurred in 1939 and 1941 that resulted in new channels across the highway, and damage to the highway crossing.
7. In general, the 1938 channel appears to be less sinuous and wider compared to the 2016 channel. This is evident in Figure 7 where the 1938 channel appears to be approximately twice as wide as the 2016 channel. The large sediment deposits evident in the 1938 channel (Figure 7) indicate a high sediment load compared to 2016 conditions.
8. The four meander cut-offs identified above (see Figure 6 and Figure 7) are avulsion[2] events that have all occurred within the Oyster River alluvial fan (approximate boundaries shown in Figure 1). Due to the depositional nature of alluvial fans, the risk of avulsions is higher. In addition to localised avulsion events (e.g., meander cut-offs) larger scale channel avulsions can also occur along alluvial fans (e.g., abandonment of entire migration corridor). The alluvial fan boundary illustrated in Figure 1 represents the avulsion hazard area for the lower Oyster River.

Migration Corridor Boundary

Appendix B (Figures B1 through B5) presents the migration corridor along the Oyster River. The corridor boundaries are shown by the dashed white lines. The blue line shows the bank position of the 2016 channel. The yellow line shows the meander axis for the 2016 channel position. Reach breaks are shown by the red dashed lines.

As described earlier, the final migration corridor boundary was determined using channel positions that were mapped for years 1957, 1968, 1980, 1993, and 2016. The 1938 channel position was not used to determine the migration corridor width due to only having partial coverage of the study area. It is important to note however that the 1938 channel appeared to be undergoing significant adjustment related to an apparent higher sediment load (e.g., wider, less sinuous channel – see Figure 7) compared to other years. Inclusion of the 1938 channel position in the migration corridor assessment could have resulted in a wider corridor than what is presented in Appendix B. Further analysis of potential factors that may introduce more sediment to the Oyster River (e.g., landslides) as a result of climate change could be considered as part of future work.

While the majority of meanders along the Oyster River appear to be migrating in the down-valley direction, there are several meanders that could also expand laterally and eventually encroach upon the corridor boundaries. Average annual migration values for specific meanders were calculated using the historical bank line mapping and used to estimate how long it would take (in years) for each meander to

[2] A sudden abandonment of a river channel

reach the migration boundary (starting from the mapped 2016 bank line). The results indicate that, should lateral extension continue at this same average rate, two meanders may reach the migration corridor boundary within about 50 years. However, lateral meander bend extension tends to reach an upper limit at which the bend is simply cut off; therefore, it is difficult to definitively state the period of time for which the river migration corridor would remain applicable. Future monitoring may be warranted to identify areas where the migration corridor boundary requires adjustment.

It should be noted that the channel migration corridor in all locations exceeds the 30 m setback recommended by the provincial guidelines (FLNR, 2018).

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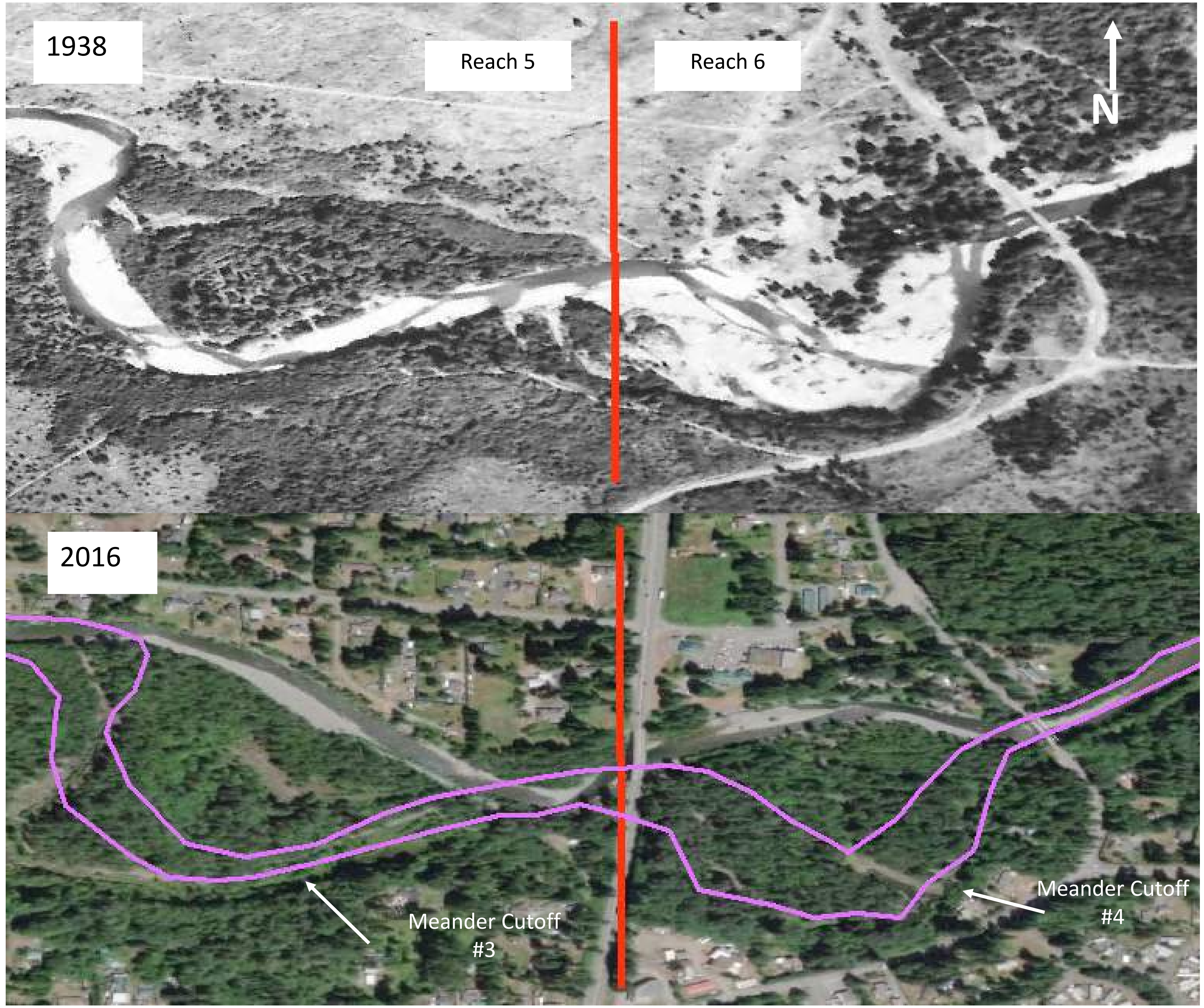
Oyster River Meander Cut-offs (#1 through #3) at the Downstream End of Reach 5

Figure 6



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Oyster River Meander Cut-off #4 at Upstream End of Reach 6

Figure 7

5.2 Shoreline Erodibility Assessment

Figure 8 shows the results of the erodibility assessment of the CVRD shoreline. Areas in red represent erodible shoreline, areas in green are semi-erodible, and areas in blue are non-erodible. The erodible areas (numbered #1 through #6) in Figure 8 are as follows:

1. Williams Beach is characterized by a tall bluff consisting of gravel and sand (Fyles, 1959). The baseline shoreline mapping completed by Current Environmental (2018) observed bluff erosion at this location.
2. This is an additional location of observed erosion along the Williams Beach bluff made by Current Environmental (2018).
3. Seal Bay is characterized by a steep, tall bluff that is experiencing ongoing erosion in the form of sliding and slumping (Current Environmental, 2018).
4. Cape Lazo, south of Kye Bay, is characterized by a fine-grained bluff of low relief (Fyles, 1960) that appears to be actively eroding based on the 2018 orthophotography.
5. Balmoral Beach is characterized by a tall sand and gravel bluff that is actively eroding (NHC, 2016).
6. The Komas Bluff area is located on Denman Island, and is a tall bluff comprised of sand and gravel (Katnick & Mustard, 2001) that appears to be actively eroding.

The boundaries of the mapped areas of erodibility are approximate, a field survey will be required to identify their exact locations. The mapped areas of erodibility are suitable to be used as a screening tool to determine areas which may warrant a reduction or increase in floodplain setbacks. In this context, erodible areas may represent locations where setbacks may be increased, semi-erodible areas will use normal setbacks, while non-erodible areas may represent locations where setbacks may be reduced.

The shoreline erodibility assessment was entirely a desktop exercise and relied on the interpretation of orthophotos, mapping and reports by others that provided only partial coverage of the study area. As such, the results of this assessment should be viewed as indicative only. The assessment is intended to serve as a potential screening tool when making land use planning decisions. Field investigations by qualified professionals should be conducted to confirm local conditions and setback requirements. The shoreline erodibility mapping should be updated as new information becomes available to ensure the mapping represents the best information available.

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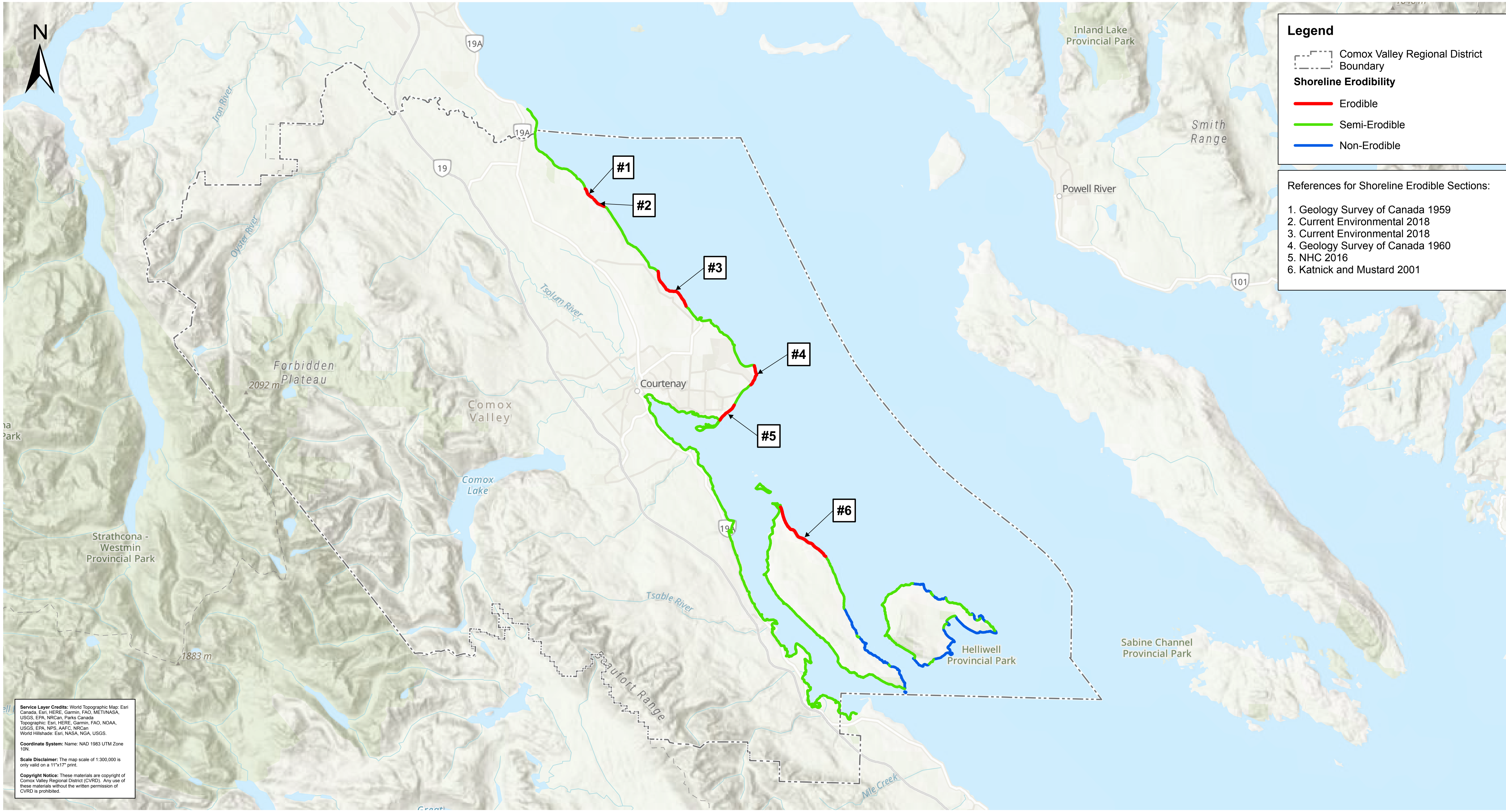

Service Layer Credits: World Topographic Map: Esri Canada, Esri, HERE, Garmin, FAO, METI/NASA, USGS, EPA, NRCan, Parks Canada
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Coordinate System: Name: NAD 1983 UTM Zone 10N.

Scale Disclaimer: The map scale of 1:300,000 is only valid on a 11"x17" print.

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0 2 4 8 Kilometres

CVRD Shoreline Erodibility

Figure 8

6. Summary and Recommendations

6.1 Summary

The following provides a summary of the Oyster River Migration Corridor and CVRD Shoreline Erodibility Assessments.

Oyster River Migration Corridor Assessment

1. A total of six channel reaches were delineated along the Oyster River study area. The reach breaks were related to bedrock outcrops, tributary confluences, and/or tidal influence (Figure 1).
2. The historical channel position of the Oyster River was mapped using aerial photos for the following years: 1938, 1957, 1968, 1980, 1993, and 2016 (Appendix A).
3. The movement of the channel position in Reaches 1 and 3 over time appear to be limited by the presence of bedrock outcrops.
4. The channel form in Reaches 2, 4, and 5 appears to have become more sinuous over time, with the meander migration occurring in the down-valley direction.
5. A total of four meander cut-offs were identified along the Oyster River between 1938 and 2016: Three are located in the downstream section of Reach 5 and one is located in the upstream section of Reach 6 (Figure 6 and Figure 7).
6. The 1938 channel appears to be less sinuous and wider compared to the 2016 channel. In addition, large sediment deposits are evident in the 1938 channel, which may indicate a high sediment load compared to 2016 conditions.
7. The four meander cut-offs identified have all occurred within the Oyster River alluvial fan (approximate boundaries shown in Figure 1). The alluvial fan boundary represents the avulsion hazard area for the lower Oyster River.
8. A migration corridor was delineated for the Oyster River. The preliminary corridor was defined using the 1957, 1968, 1980, 1993, and 2016 mapped bank line positions. The preliminary migration corridor was adjusted to determine the corridor width. These adjustments included a climate change factor of +30% and adjustments in locations of terrace features (Appendix B).

Coastal Shoreline Erodibility Assessment

1. A high-level assessment of coastal erodibility along the CVRD shoreline was conducted using surficial geology maps, coastal baseline maps, engineering studies, and 2018 orthophotography.
2. Three categories of shoreline erodibility were mapped along the CVRD shoreline: erodible, semi-erodible, and non-erodible. A total of six locations were categorized as erodible shoreline (Figure 8).

6.2 Future Considerations

Oyster River Migration Corridor Assessment

Delineation of river channel migration corridors has inherent uncertainty. The Oyster River channel migration corridor has been delineated based on a desktop study as a first step in determining appropriate fluvial setbacks to support land use planning activities. The consideration of expanding the setback requirements beyond the provincial guidelines (FLNR, 2018) is primarily related to erosion risk tolerance and land use planning. Discouraging or preventing development in the areas of the channel migration zone that are outside of the standard provincial setback would further reduce risk but may trigger land use planning issues.

If the CVRD is interested in expanding the setback requirements beyond the provincial requirements (i.e., due to concern about the current level of erosion risk), then additional work would be warranted. A potential starting step would be to review the additional areas that would be subject to the expanded setback requirements (i.e., channel migration corridor vs. 30 m setback) and the land use planning implications for these additional areas.

Should the CVRD wish to take additional steps leading to ultimately establishing setbacks, the next steps could include:

1. Defining a time horizon of interest for land use planning.
2. Conducting field assessments to confirm the nature and location of different bank materials, including bedrock, for the purpose of verifying the channel migration corridor and collecting data on related hazards.
3. More refined fluvial geomorphology analysis (e.g., bend evolution, assessment of channel erodibility) of specific meanders that are migrating laterally and could eventually reach the corridor boundaries.
4. Assessment for potential avulsion hazards in the upper reaches of the Oyster River.
5. Considering whether assessment of related hazards (e.g., geotechnical slope stability) is warranted.
6. Future monitoring of bank lines to determine if the migration corridor needs adjustment.

Coastal Shoreline Erodibility Assessment

It is recommended that the shoreline erodibility mapping presented in this memorandum be updated as new information becomes available to ensure the mapping represents the best information available.

The shoreline erodibility assessment has been completed as a desktop exercise based on analysis of aerial photography and existing reports. Although this approach is considered to be suitable for the intended use of the erodibility dataset (indicative screening tool), updating the analysis findings periodically as new site-specific reports become available, and conducting fieldwork to verify findings would improve the reliability of the dataset. It is recommended that the CVRD use the dataset as part of the land use management process and consider whether an enhanced dataset would be beneficial in practice. Field investigations by qualified professionals should be conducted to confirm local conditions and setback requirements.

7. Closure

We trust that the fluvial and coastal geomorphology assessment summary submitted in this technical memorandum provides Comox Valley Regional District with the information requested. If you have any questions, please contact the undersigned at 250-595-4223.

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Encl.: Appendix A: Historical Bank Line Mapping of Oyster River
Appendix B: Migration Corridor of Oyster River

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Revision History

Revision #	Date	Status	Revision Description	Author
0	April 23, 2021	FINAL		CD/ds

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Appendix A

Historical Bank Line Mapping of Oyster River

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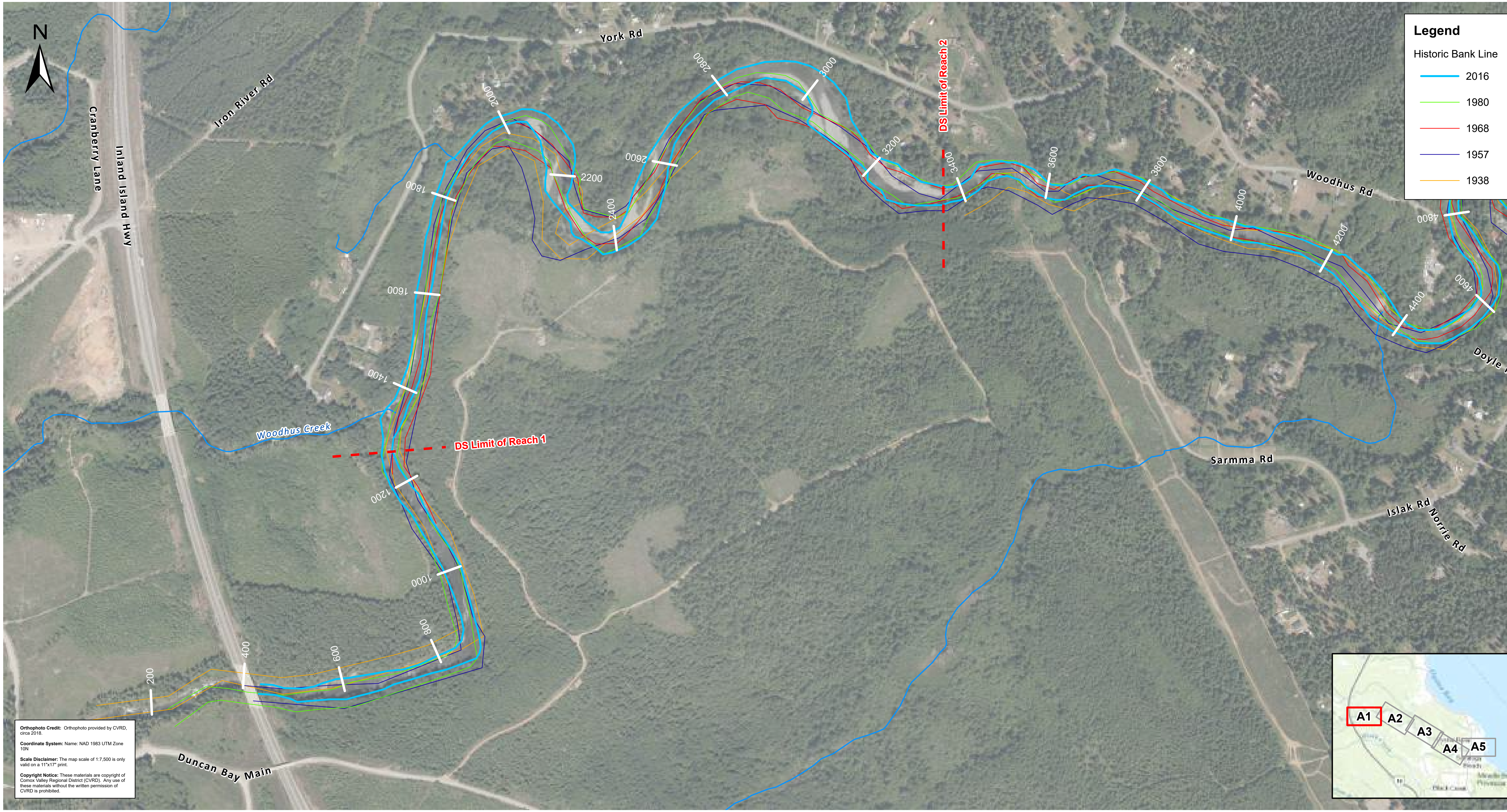

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Oyster River Historic Planform Assessment

Figure A1

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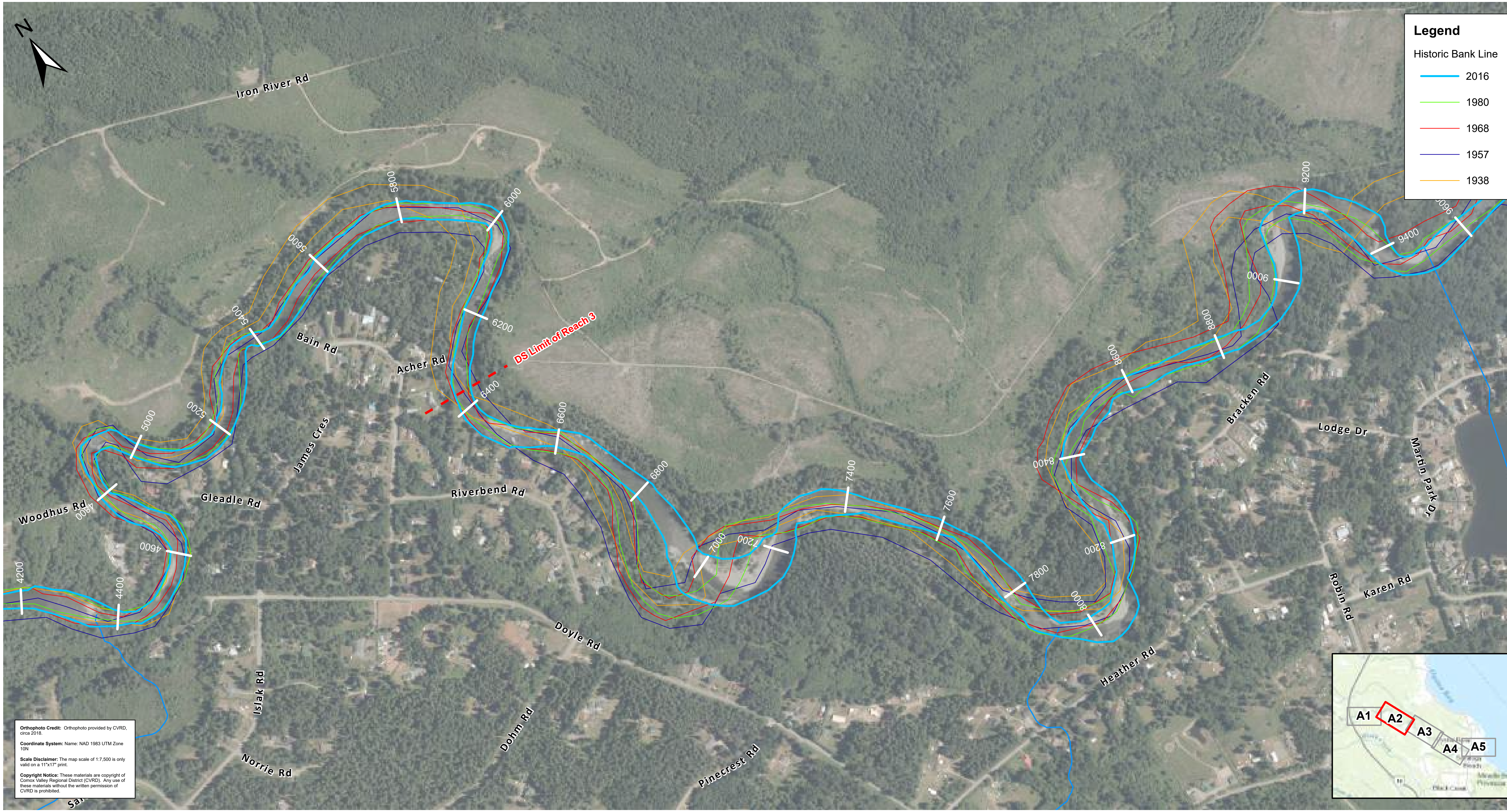

Orthophoto Credit: Orthophoto provided by CVRD, circa 2018.

Coordinate System: Name: NAD 1983 UTM Zone 10N

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

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Oyster River Historic Planform Assessment

Figure A2

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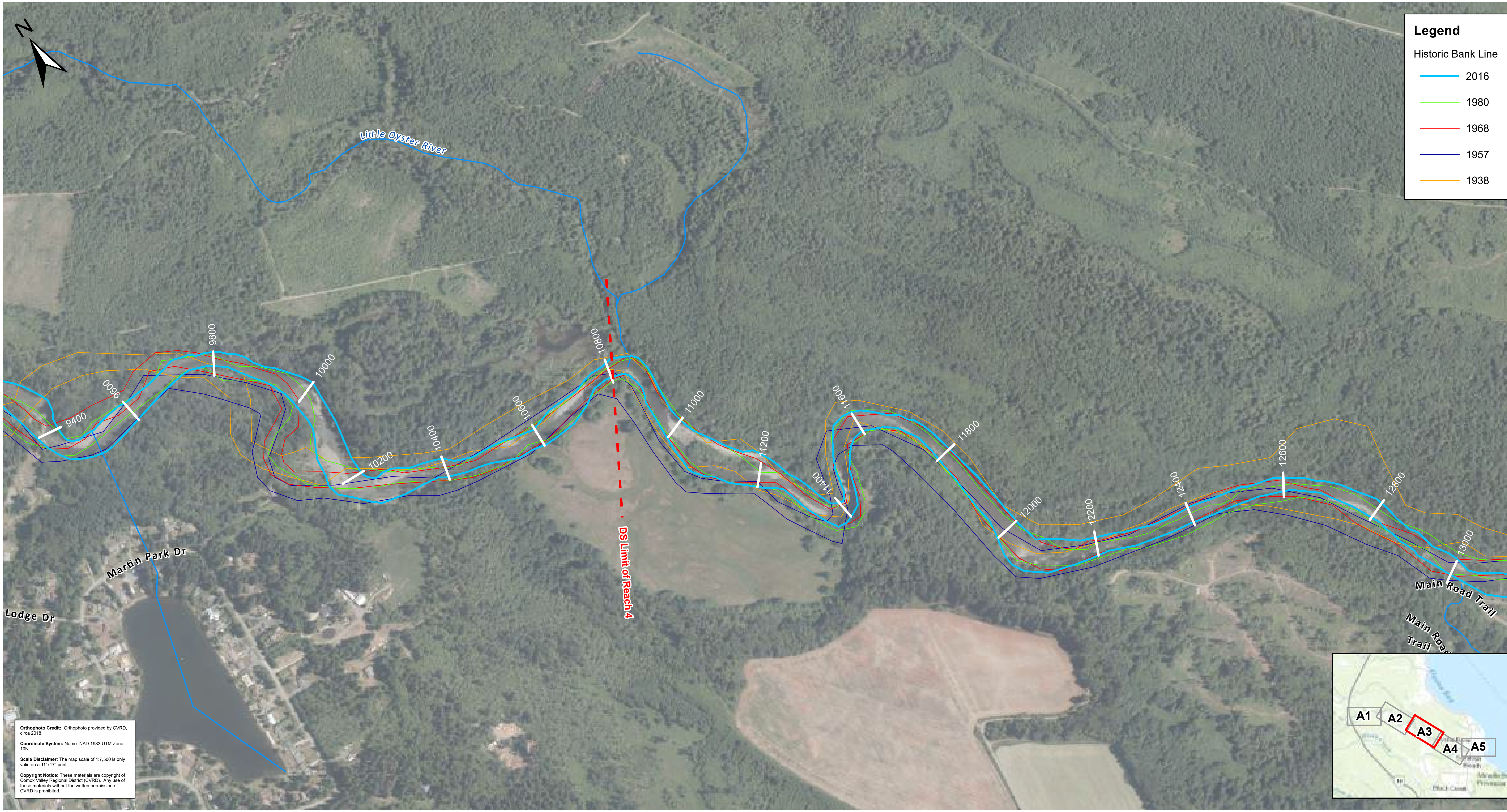

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Oyster River Historic Planform Assessment

Figure A3

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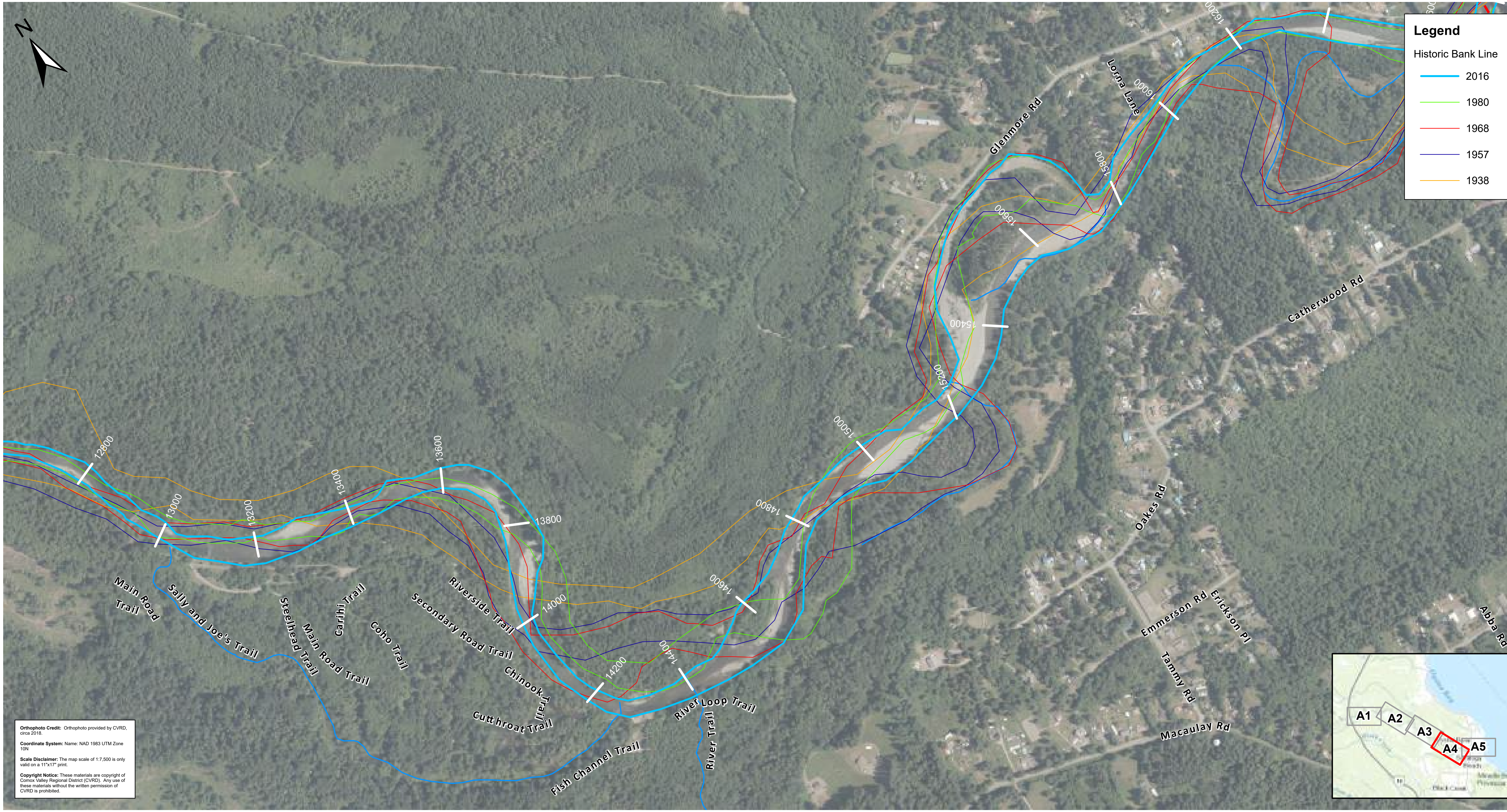

Orthophoto Credit: Orthophoto provided by CVRD, circa 2018.

Coordinate System: Name: NAD 1983 UTM Zone 10N

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Oyster River Historic Planform Assessment

Figure A4

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Oyster River Historic Planform Assessment

Figure A5

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Appendix B

Migration Corridor of Oyster River

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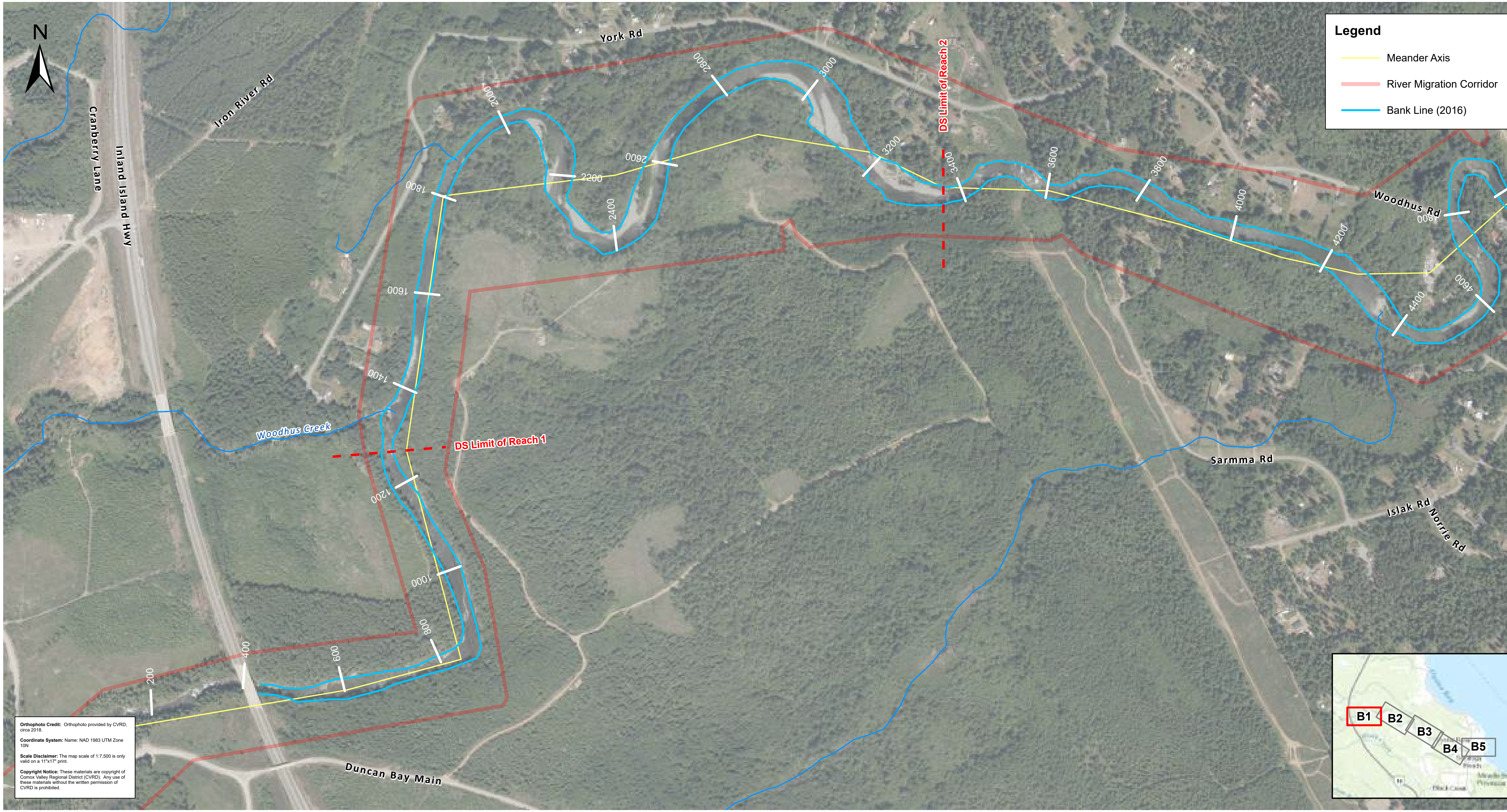

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Oyster River Migration Corridor

Figure B1

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Orthophoto Credit: Orthophoto provided by CVRD, circa 2018.

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Oyster River Migration Corridor

Figure B2

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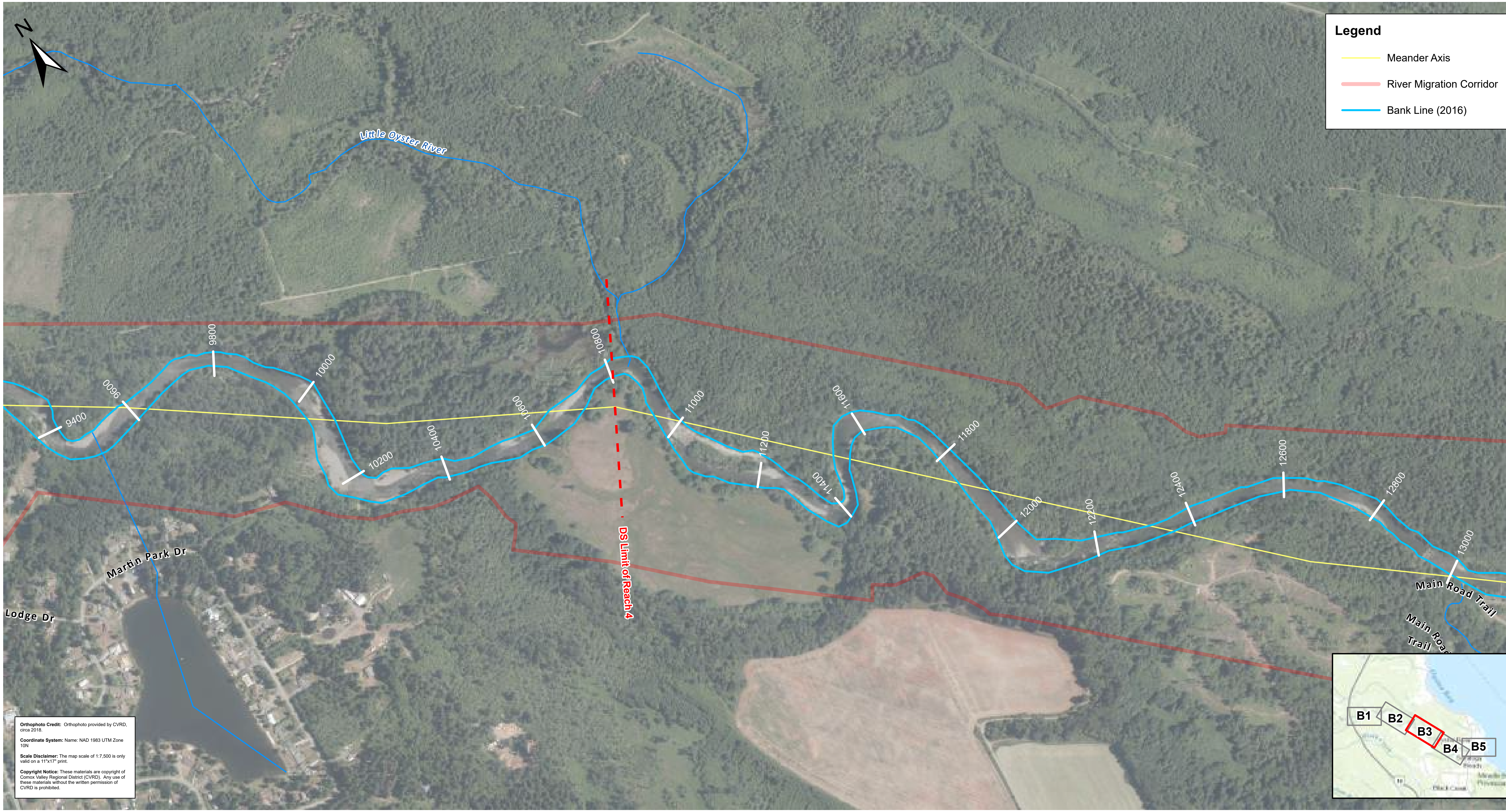

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Coordinate System: Name: NAD 1983 UTM Zone 10N

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Oyster River Migration Corridor

Figure B3

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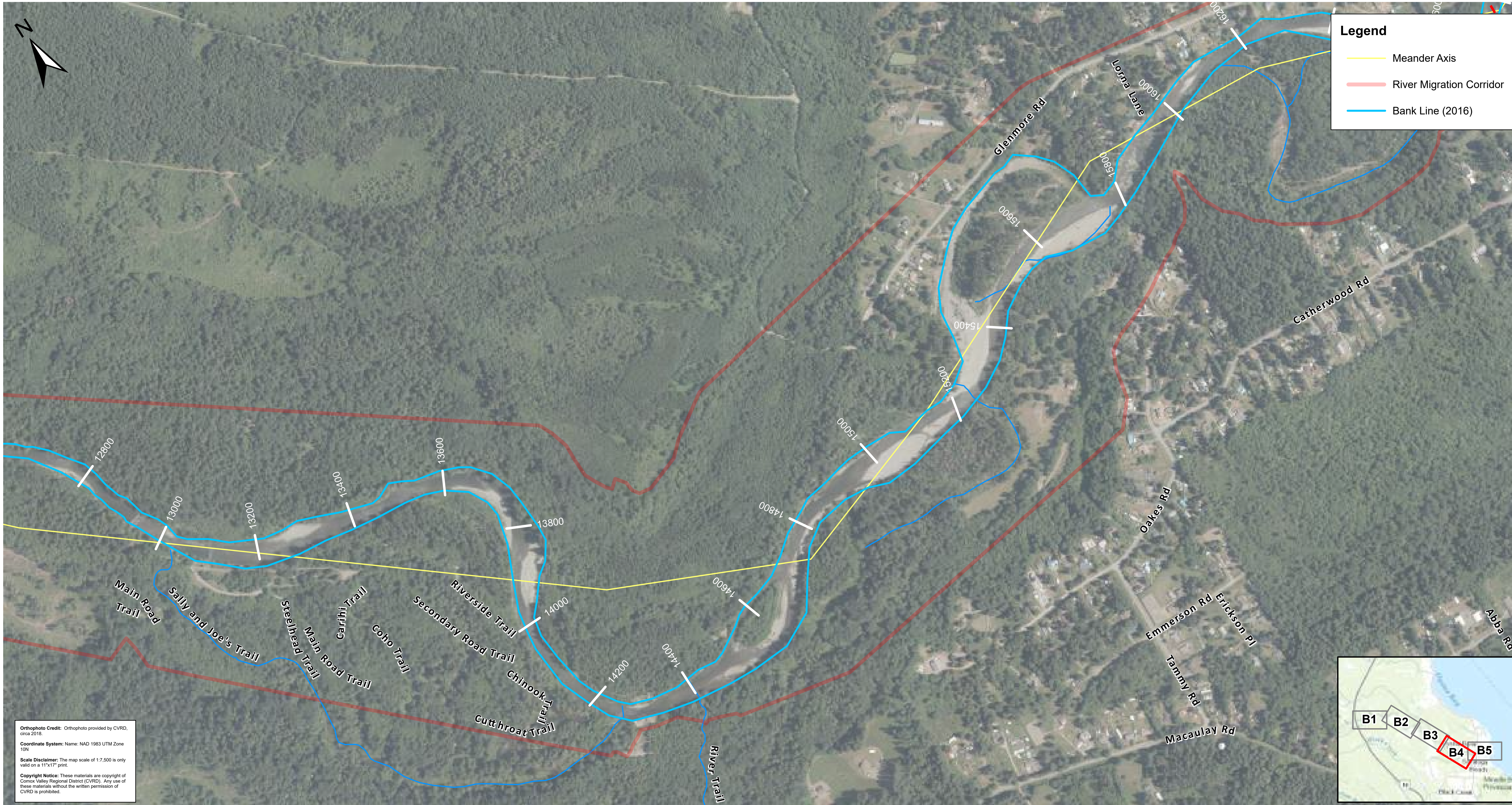

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Oyster River Migration Corridor

Figure B4

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Oyster River Migration Corridor

Figure B5