Fit of the ETI trophic state susceptibility typology to the NZ coastal hydrosystems classification

Prepared for NIWA Christchurch

October 2018

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NIWA CLIENT REPORT No: 2017007CH
Report date: October 2018
NIWA Project: ELF14249

Quality Assurance Statement		
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	Approved for release by:	Helen Rouse

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Executive summary

The New Zealand Coastal Hydrosystems (NZCH) classification is an overarching classification to cover all New Zealand's coastal water bodies ranging from lacustrine predominantly freshwater coastal lakes, to river mouths, to estuarine systems to fully marine coastal embayments. It is designed to be applied to wide ranging management applications such as mapping on a national and regional basis the location of pristine versus degraded systems, systems with poor flushing and susceptible to eutrophication and sedimentation, shorelines with susceptibility to coastal erosion and flooding, and systems vulnerable to the effects of climate change through saline intrusion and wetland loss. A detailed breakdown of types and classes is necessary to provide adequate definition for this purpose. In comparison, the Estuary Trophic Index (ETI) typology (Robertson et al. 2016 a, b); (Zeldis et al. 2017 a, b, c) is designed to provide a typology for assessing estuarine eutrophication susceptibility based on a system's response to proven physical susceptibility factors. This is for a more limited number of water body types and a narrower range of water body classes broadly termed "estuarine systems", although like the NZCH classification its spatial coverage includes associated tidal habitats and adjacent tidal wetlands. A less detailed breakdown is more appropriate for the ETI project where sample size is limited by datasets for water quality, nutrients and biological data, and processes driving susceptibility may span estuary types.

The water body boundaries are defined in a similar manner in both the NZCH classification and ETI typology, being defined by the shoreline, extending landwards from an imaginary line closing the mouth, with the upstream limit being a location where ocean derived salts measure less than 0.5 ppt during the period of average annual low flow and include the associated tidal habitats and adjacent tidal wetlands.

The way the four main estuary classes of the ETI typology fit into and span across the 11 geomorphic classes of the NZCH classification are shown in the table below. There are understandable similarities at this level because physical characteristics such as geomorphology, basin morphometry, river and oceanic forcing, are important in discriminating classes in both systems. The main difference is that the NZCH classification has greater variety and differentiation (as subclasses) in classes.

The NZCH geomorphic classes 1) *damp sand plain lake*, 3) *hāpua-type lagoon*, 5) *freshwater river mouth*, and 11) *coastal embayments* are palustrine, or riverine, or fully marine. There is no separate type for ICOLLs in the NZCH classification, because its overarching conceptual model directs that the classification is based on differences among hydrosystems that arise from the long-term average effects of multiple processes. ICOLLs described for the New South Wales coast occur on sandy coasts and exhibit different hydraulic characteristics (e.g., breaching more frequently and staying open for most of the time), compared to New Zealand systems (e.g., Waituna Lagoon) that have been described as ICOLLs, suggesting that using the term ICOLL in a New Zealand context is inappropriate.

The NZCH classification differentiates its 11 classes, plus subclasses in some categories, based on geomorphic characteristics which include the landscape and waterscape characteristics/factors such as geology, geomorphology and the hydrodynamic characteristics/factors such as basin morphometry, river and oceanic forcing. The ETI typology differentiates its four classes based on estuary physical characteristics and nutrient input/estuary response. It includes subclasses of two of its classes (lagoon and river types: SIDES and SSRTRES, respectively) which indicate if the estuary is an intermittently closed or open estuary, or 'ICOE') (Zeldis et al. 2017 a, b, c). While the ICOE subclass is not formally named in Robertson et al. (2016 a, b), it is recognised in its narrative, and it is more fully described in the ETI Tools Applications (Zeldis et al. 2017 a, b, c).

Table 0-1: New Zealand Coastal Hydrosystems (NZCH) classification.

Dominant hydrosystem type	NZCH classification geomorphic class	Corresponding ETI typology class
Palustrine	1. Damp sand plain lake	Coastal Lakes
Lacustrine	2. Waituna-type lagoon	Coastal Lakes
Riverine	3. Hāpua-type lagoon	Shallow, short residence time tidal river and tidal river with adjoining lagoon estuaries (SSRTREs) Some may be ICOEs
Riverine	4. Beach stream	Shallow, short residence time tidal river and tidal river with adjoining lagoon estuaries (SSRTREs) Some may be ICOEs
Riverine	5. Freshwater river mouth	Shallow, short residence time tidal river and tidal river with adjoining lagoon estuaries (SSRTREs) Some may be ICOEs
Estuarine	6. Tidal river mouth	Shallow, short residence time tidal river and tidal river with adjoining lagoon estuaries (SSRTREs) Some may be ICOEs
Estuarine	7. Tidal lagoon	Shallow intertidal dominated estuaries (SIDEs) Some may be ICOEs
Estuarine/Marine	8. Shallow drowned valley	Shallow intertidal dominated estuaries (SIDEs)
Estuarine/Marine	9. Deep drowned valley	Deeper subtidal dominated, longer residence time estuaries (DSDEs)
Marine	10. Fjord	Deeper subtidal dominated, longer residence time estuaries (DSDEs)
Marine	11. Coastal embayment	Deeper subtidal dominated, longer residence time estuaries (DSDEs)

This report was initially drafted in December 2015 to provide a description of the overall structure of the NZCH classification and to demonstrate how the ETI typology fits into, spans across and is underpinned by the NZCH classification. It was updated in December 2016 to be consistent with the final NZCH classification (Hume et al. 2016). It was updated again in 2018 to be consistent with the final terminology of the ETI Tools Applications (Zeldis et al. 2017 a, b, c).

1 Introduction

The Estuary Trophic Index (ETI) toolbox project began in late 2014 and is aimed at providing advice to support the development of a nationally consistent approach to the assessment of estuary eutrophication, including nutrient load thresholds, for New Zealand estuaries. It applies a desktop susceptibility approach that is based on estuary physical characteristics, and nutrient input load/estuary response relationships for key New Zealand estuary types or classes. It provides guidance on which condition indicators to use for monitoring the various estuary classes, and on assessing the trophic state based on the indicator monitoring results and their comparison to numeric impairment bands (e.g., very high, high, moderate, low). An estuary trophic state susceptibility typology (the ETI typology) developed by Wriggle – Coastal Management and NIWA was adopted by the ETI project in support of this work.

The NZ Coastal Hydrosystems (NZCH) classification project was initiated to develop a nationally consistent approach and overarching classification for a wide range of freshwater to marine environments. It links both the wetland typology of Johnson and Gerbeaux (2004) and the Estuarine Environment Classification of Hume et al. (2007), while expanding the definition of classes in Hume et al. (2007). The work began in June 2013 with workshops in June 2013 and January 2014 to explore ideas and the co-authors presenting ideas at conferences. In October 2015, the Ministry for the Environment (MFE) provided funding for NIWA, Hume Consulting Ltd and the University of Canterbury to work with the Department of Conservation to develop the classification further. Input from practitioners at a two-day stakeholders' workshop in February 2016 contributed to the development of the classification.

This report was initially drafted in December 2015 to provide a description of the overall structure of the NZCH classification and to demonstrate how the ETI typology fits into, spans across and is underpinned by the NZCH classification. It was updated in December 2016 to be consistent with the final NZCH classification (Hume et al. 2016). It was updated again in 2018 to be consistent with the final terminology of the ETI Tools Applications (Zeldis et al. 2017 a, b, c).

2 Typology, classification and terminology

Typology and classification processes[1] with easily understood and well-defined terms are key starting points for recognising the diversity and key groupings amongst coastal hydrosystems, in order to monitor, report on condition and implement effective management approaches. In addition to the scientific need for classification, there are an increasing number of legislative, administrative and socio-economic statutes, protocols and procedures that require terms to be defined (Elliott and McLusky 2002). Without consistent terminology there is confusion amongst scientists, managers and planners reflected in inconsistent or technically incorrect use of words in scientific, planning and legislative documents.

Environmental typologies and classifications (such as the Hume et al. 2007, the NZCH classification and the ETI typology) characterise and map environmental (i.e., abiotic) variation to assist in understanding processes and resultant patterns at large scales. Because broad environmental variations constrain the development and behavior of ecosystems, environmental classifications are used as a surrogate for defining ecological patterns (Carpenter et al. 1999, Grossman et al. 1999, Bourgeron et al. 2001). To be useful as a spatial framework for management, the classifications need to classify all the waterbodies within the geographic domain of interest. Classifications based on water quality or biological characteristics are dependent on collecting large and complete datasets and, therefore, may be costly to apply to large regions or whole countries. Comprehensive datasets describing the genesis or geomorphic attributes of estuaries are more easily collected but need to reflect the processes that determine the ecological properties of estuaries as they function today.

Classifications based on 'controlling factors' reflect hierarchical considerations and have been applied to ocean, terrestrial, and river environments (Bailey 1988, Klijn et al. 1994, Snelder et al. 2002, Hume et al. 2007). In this approach, broad scale abiotic factors (e.g., latitude position, topography and geology) are assumed to be the dominant controls on ecosystem characteristics at a series of hierarchically related system levels. Variation in these controlling factors is used to define classes and delineate patterns at a series of hierarchically related levels and spatial scales. This approach to classification has several benefits for environmental management applications. First, classification is based on a conceptual view of how ecosystems are organised, and thus codifies, in a simple way, an understanding of the processes determining spatial patterns in ecosystem character. Second, the hierarchical approach allows variation to be described and delineated at various levels of detail, enabling analysis at various levels of resolution (Haber 1994, Snelder et al. 2004). Third, classes can often be assigned to the entire spatial domain using existing environmental data.

Coastal terms are defined and applied in sometimes conflicting ways in common language, scientific literature, legislative and planning documents and need to be reconciled. A good example is the variety of terms applied to coastal waterbodies. People are familiar with terms such as 'harbour', inlet', 'sound', 'fiord', 'estuary', 'bay', 'lagoon', 'river mouth', 'coastal wetland', 'mangrove', 'saltmarsh' to name a few (some 17 different terms are used on the 1:50,000 NZ Topographic Map Series maps) but most, if asked, would probably have some difficulty to explain the differences between them. They are easily all called 'estuaries'. However, an 'estuary' may mean something different to the general public to what it means to scientist. Also, is 'estuary' synonymous to 'estuarine system' or is it an appropriate name for describing one of several classes of estuarine

[1] According to Bailey (1994) *classification* is the 'general process of grouping entities by similarity', mainly objective procedure of allocating cases on the basis of their measured attributes, whilst *typology* is conceptual, based upon *a priori*, subjective, judgements of class definitions and boundaries (often based on expert opinion). A hydrosystem classification is the definition of the major classes of hydrosystems and the identification of the major class attributes that distinguish them.

systems? Estuaries do not have a regular form in terms of shape and size and are difficult to define because, as an interface between land and sea, they encapsulate a gradient in conditions from almost entirely riverine to almost entirely oceanic (Elliott and McLusky 2002). For this reason, Hume et al. (2007) decided to use a broad definition for estuaries to include the full range coastal water bodies that are subject to coastal management needs. They followed Day's (1981) variation of Pritchard's (1967) definition and defined an estuary as: *a partially enclosed coastal body of water that is either permanently or periodically open to the sea in which the aquatic ecosystem is affected by the physical and chemical characteristics of both runoff from the land and inflow from the sea.* This definition includes many classes of coastal water bodies described in other classifications as estuaries, drowned river valleys, lagoons, coastal lakes, fjords and tidal river mouths. This has similar aspects to the broad definition adopted by Wriggle -Coastal Management who define estuarine systems as having attributes such as: *a <150 degree angle between the head of the estuary/embayment and the two outer headlands; being at least partially enclosed by land, access to the ocean can be open, partly obstructed, or sporadic and salinity may be periodically increased above that of the open ocean by evaporation; intermittently closed/open estuaries do not need to have a surface water tidal connection to be considered an estuary; extending upstream and landward, including tidal habitats and adjacent tidal wetlands*.

New Zealand's legislation (e.g., Resource Management Act (RMA) 1991) and policy documents (e.g., New Zealand Coastal Policy Statement 2010) use some of those terms and other terminology, sometimes well-defined and sometimes not, that relates to the coastal environment e.g., 'coastal marine area', 'water body', 'intertidal zone', 'coastal lakes'. This often creates confusion and debate in Council and Environment Court hearings. 'Lagoon' is another of these terms that is commonly used but which, depending on the location sometimes applies to coastal lakes (e.g., Waituna Lagoon, Southland) or features that are also called ICOLLs (Intermittently Closed and Opening Lakes and Lagoons), or river mouths with a hāpua (e.g., Ashley River mouth, Canterbury). Hāpua is a term that in Māori means 'a pool or lagoon, or 'a shallow lake. It has historically been applied by Māori to such sites as Te Roto o Wairewa (Lake Forsyth) and Te Waihora (Lake Ellesmere) on the Canterbury coast, and Pouerua hāpua (Saltwater Lagoon) on the West Coast. It has also been applied in the scientific literature to the riverine lagoon features at river mouths on the Canterbury coast such as the Ashburton and Rakaia (Kirk and Lauder 2000).

New Zealand is a contracting party to The RAMSAR Convention on Wetlands, an intergovernmental treaty signed in 1971. The Convention uses a typology of wetlands that includes a broad range of classes belonging to the coastal zone (e.g., shallow marine waters, estuarine waters, intertidal sand/mudflats, brackish lagoons). Under the Convention, '*wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres*' (RAMSAR 2010). Under that definition, many of the coastal systems referred to above are therefore "wetlands". For instance, application of this definition would see Tauranga Harbour, which is about 80 per cent intertidal, termed a wetland; a concept that does not sit comfortably with coastal oceanographers.

3 The ETI typology

Managing nutrients and sediment discharges to freshwater that cause eutrophication and sedimentation problems in estuarine environments has become an important New Zealand national issue due to ongoing intensification of agriculture over the last 20 years (Davies-Colley et al. 2003 and 2008; Snelder et al. 2014; Snelder et al. 2017). The Estuary Trophic Index (ETI) toolbox project is aimed at providing advice to support the development of a nationally consistent approach to the assessment of estuary eutrophication, including nutrient load thresholds, for New Zealand estuaries. The three ETI tools assist users in determining the susceptibility of estuaries to eutrophication, current trophic state and nutrient load limits, and priorities for estuary monitoring and management.

ETI Tool 1 developed two methods that provide guidance for assessing estuary susceptibility to eutrophication (i.e., the risk that an estuary will be eutrophic based on its physical characteristics). The first method: 'CLUES Estuary', predicts potential nutrient concentrations in New Zealand estuaries by combining predicted nutrient loads from catchments with simple dilution models to determine the mixing between ocean- and river- water in estuaries (Plew et al. 2018; Zeldis et al. 2017 a). It calculates an ETI susceptibility band that combines macroalgae and phytoplankton banding. It identifies estuaries likely to be sensitive to current nutrient loads based on their physical attributes. The second method: 'ASSETS', is adapted from the Assessment of Estuarine Trophic Status (ASSETS) protocol developed in the United States (Bricker et al. 2003). It is based on physical characteristics of estuaries and nutrient input load-estuary response relationships for key New Zealand estuary types (Zeldis et al. 2017 a; Robertson et al. 2016 a).

ETI Tool 2 is a monitoring approach that characterises the ecological gradient of estuary trophic condition for relevant ecological response indicators (e.g., macroalgal biomass, dissolved oxygen, macrobenthic health), and provides a means of translating these ratings into an overall estuary trophic condition rating (Zeldis et al. 2017 b; Robertson 2016 b). It provides guidance on which condition indicators to use for monitoring the various estuary types, assessing the trophic state based on the indicator monitoring results and their comparison to numeric impairment bands (e.g., very high, high, moderate, low).

ETI Tool 3 uses knowledge of the ecological connections between drivers of estuary trophic condition (e.g., estuary type, nutrient loads, estuary closure state) and responses of indicators (e.g., macroalgal biomass, sediment and macrobenthic health) to calculate an ETI score using a Bayesian Belief Network (BBN) (Zeldis et al. 2017 c). Its inputs include those calculated within Tool 1, and its responses depend on the estuary type under consideration.

Recognizing diverse types or classes of estuaries based on their physical and hydrodynamic characteristics and then developing appropriate tools for each estuary type underpin the approach adopted by the ETI project. This recognizes that the physical characteristics of these classes have a direct influence on their ability to dilute and assimilate nutrients and flush them to the sea and therefore their vulnerability to nutrient inputs. The robustness of the approach depends on appropriate definition of the estuary classes. The ETI classified estuaries into 4 broad categories, namely:

1. Coastal Lakes (freshwater-dominated).
2. Shallow intertidal dominated estuaries (SIDEs).

3. Shallow, short residence time tidal river and tidal river with adjoining lagoon estuaries (SSRTREs).
4. Deeper subtidal dominated, longer residence time estuaries (DSDEs).

The earlier work of Robertson et al. (2016 a) recognized a class: ICOLLS (intermittently closed or open lakes and lagoons). Subsequently, closure state in SIDEs and SSRTRE estuaries has been recognized in the ETI as a subclass (called ICOE or Intermittently Closed or Open Estuary: Plew et al. 2018; Zeldis et al. 2017 a, b, c). The ICOLL designation is no longer used to describe those systems. The Coastal Lake class incorporates remaining systems that were formerly designated as ICOLLS.

The key physical and hydrological characteristics, along with the susceptibility to nutrient retention and eutrophication of the ETI classes, are as follows:

3.1 Coastal Lakes

Coastal Lakes are freshwater dominated systems that are closed to the sea most of the time. We differentiate them from ICOEs in that Coastal Lakes are normally closed, while ICOEs may open and close on a regular basis. Coastal Lakes have no tidal prism, long residence times, and very little sea water input other than from wave over-topping, or residual sea water that entered during the brief periods that the mouth may have been open to the sea. Examples of coastal lakes include Waituna Lagoon, Okarito Lagoon, and Washdyke Lagoon. Coastal Lakes have high susceptibility to nutrient retention and eutrophication, with the most susceptible being those with closure periods of months (e.g., Waituna Lagoon). The high susceptibility arises from reduced dilution (absence of tidal exchange and increased retention (through both enhanced plant uptake and sediment deposition). Excessive phytoplankton and macroalgal growths and reduced macrophyte growth are characteristic symptoms of coastal lake eutrophication. Major primary producers in coastal lakes are macrophytes, macroalgae and phytoplankton.

3.2 Shallow, intertidal dominated estuaries (SIDEs)

These are shallow, short residence time (<3 days), and predominantly intertidal, tidal lagoon estuaries and components of other estuary classes where extensive tidal flats exist (e.g., Firth of Thames, Kaipara Harbour, Freshwater Estuary). They are separated from the open sea by sand bars and/or barrier islands and have a restricted inlet from the sea. The substrate tends to be sandy except in the upper reaches. The flushing can prevent significant retention of dissolved nutrients. Nevertheless, retention can still be sufficient to allow for retention of fine sediment and nutrients, healthy growths of seagrass and saltmarsh, and nuisance growths of macroalgae in at-risk habitat. This common estuary type in New Zealand includes Freshwater Estuary (Stewart Island), New River Estuary, Kawhai Estuary, Waikawa Estuary (Southland), Avon Heathcote Estuary. The ICOE subclass of SIDES occurs where there is occasional mouth closure. The mouth can be intermittently open or intermittently closed and therefore these estuaries vary between marine and close to freshwater salinities. They have a higher susceptibility to nutrient retention and eutrophication. In general, tidal lagoon ICOEs have longer periods of closure than the tidal river ICOEs (see below). The high susceptibility arises from reduced dilution (absence of tidal exchange at times) and increased retention (through both enhanced plant uptake and sediment deposition). The major primary producers can be macrophytes, macroalgae and phytoplankton.

3.3 Shallow, short residence time tidal river and tidal river with adjoining lagoon estuaries (SSRTREs)

These are shallow, short residence time (<3 days) tidal river estuaries, including those that exit via a very well-flushed small lagoon. They have such a large flushing potential (freshwater inflow/estuary volume ratio) that most of fine sediment and nutrients are exported to the sea. They can have a simple narrow elongate shape, or an intertidal delta, or a shallow lagoon at the entrance. They generally have a small area of tidal flat and a salt wedge. The substrate tends to be muddy. Flushing of sediments and nutrients to the ocean is generally strong, except in the shallow lagoon at the entrance which is mostly by-passed by the river flow. In general, these estuary classes have lower susceptibilities to nutrient retention and eutrophication and can often tolerate greater nutrient loads than shallow, intertidal dominated estuaries. Macroalgae tend not to proliferate in SSRTREs, because of high turbidity and lack of suitable intertidal substrate. Given adequate residence time, however, phytoplankton blooms can be expressed. Also, adjoining intertidal areas may still express macroalgal outgrowth. Examples of SSRTREs include Waimatuku Estuary (Southland), Whareama Estuary (Wairarapa), Whanganui River Lagoon, Toetoes Estuary, Ruataniwha Estuary, Waimakariri River/ Brooklands Lagoon), Wairau Estuary (North Canterbury), Takaka estuary (Tasman) and Motueka Estuary (Tasman). The ICOE subclass of SSRTREs occurs where there is occasional mouth closure. The mouth can be intermittently open or intermittently closed and therefore these estuaries vary between marine and close to freshwater salinities. They have a higher susceptibility to nutrient retention and eutrophication. In general, SSRTRE ICOEs have shorter periods of closure than SIDE ICOEs (unless they are small). The high susceptibility arises from reduced dilution (absence of tidal exchange at times) and increased retention (through both enhanced plant uptake and sediment deposition).

3.4 Deeper, subtidal dominated, longer residence time estuaries (DSDEs)

These are mainly subtidal, moderately deep (>3m to 15m mean depth) coastal embayments (e.g., Firth of Thames, Otago Harbour), with moderate residence times >7 to 60 days). They can have a circular shape, be narrow or taped, or dendritic with numerous arms and indented shorelines. Circulation is driven from the sea. Sediments tend to be sandy in the deeper regions or muddy nearer rivermouths. They can exhibit both sustained phytoplankton blooms, and nuisance growths of opportunistic macroalgae if nutrient loads are excessive and substrate is available. The latter are usually evident particularly on muddy intertidal flats near river mouths and in the water column where water clarity allows. Deeper, long residence time embayments and fjords are primarily phytoplankton dominated. The major primary producers are macroalgae (moderately deep) and phytoplankton (deeper sections). Examples of this type include Pelorus Sound, Firth of Thames, Otago Harbour.

4 The NZCH classification

New Zealand has a long coastline (18,000km including estuarine shoreline) with over 400 water bodies that can be broadly be called estuaries exhibiting a wide range of physical and hydrodynamic characteristics (Hume et al. 2007). In order to embrace the broad suite of coastal waterbodies that need to be managed the NZCH classification uses the term coastal hydrosystem to describe a: "*coastal ecosystem differentiated by broad landform, hydrological setting and water properties that spans a gradient through coastal freshwater – lacustrine and riverine, brackish – estuarine, and marine environments".* This includes features formed at the interface of freshwater and ocean environments, including "wetlands", "coastal streams", "river mouths", "deltas", "estuaries", "inlets", "lagoons", "sounds", "fiords", and "embayments". This wide range of environments is subject to a wide range of human use pressures that can compromise their values. This broad definition is considered appropriate for management purposes because it includes the full range of coastal water bodies that need management. While coastal hydrosystems comprise an integral part of the '*ki uta ki tai - mountains to the sea*' management concept, they suffer by being situated at the interface of freshwater and ocean environments and their management often falls between the cracks because of missing science links and policy.

4.1 Classification approach and hierarchy

The NZCH classification uses a controlling factor and top-down approach to classification as developed by Hume et al. (2007). It can be applied to a wide range of coastal hydrosystem classes over a large geographic domain with easily obtained and generated data so that the resulting classification can be mapped. The classification is hierarchically organised and classifies whole hydrosystems, or components of hydrosystems at six levels of detail based on the effect of a number of interacting processes. At each level within the six-level hierarchical classification (Table 4-1) there is a gradient in properties and differences within the environments and their components. The hierarchy of levels is based on factors that control processes that are the dominant cause of variation in hydrosystem character at the associated spatial scale. These controlling factors capture how coastal hydrosystems function, with abiotic components dominating the top levels and biotic components dominating the lower levels. That is, the classification postulates that climate, geological, oceanic, riverine and catchment factors control a hierarchy of processes and broadly determine the physical and biological characteristics of coastal hydrosystems. Each level relates to a different spatial scale and is suitable for specific applications.

Table 4-1: The NZCH classification hierarchy showing how the hydrosystem and geomorphic class levels nest within a wider hierarchical classification.

	Level	Controlling factors	Spatial scale (km^2)
I	Global Temperate Australasian Realm	Climate, landmass, watermass	Macro 10^6 - 10^4
II	Hydrosystem Palustrine, lacustrine, riverine, estuarine, marine	Landform, water regime	10^3
III	Geomorphic Class 11 classes and 21 subclasses	Geomorphology, hydrodynamics	Meso
IV	Tidal Regime Subtidal, intertidal, supratidal	Inundation by the tide	10^1
V	Structural Class Vegetation, substrate, water structure	Bio-, geo- and hydro-components	1
VI	Composition Dominant biota, substrate and water types	A mixture of the above	Micro 0.1

The NZCH classification provides detail at hydrosystem and geomorphic class (levels II and III respectively) of the hierarchy, because these levels are particularly important for coastal management and conservation needs at national and regional scales. Detail at the other levels is best developed for specific management needs and particularly for the lower levels, using the description of structural and compositional habitat features obtained at the locally. In levels II and III the classes define groups of hydrosystems that should be distinctive with respect to a broad range of physical characteristics such as water temperature, chemistry and salinity, turbidity and proportion of intertidal area. Because physical characteristics are the dominant cause of biotic pattern at large spatial scales, the classes are also expected to discriminate differences in the biological characteristics of hydrosystems. Of course, for short periods of time, a single process may determine the character of a hydrosystem (e.g., a flood, or a spring tide inflow, or seabed stirring by wind waves). However, the classification is based on differences among hydrosystems that arise from the long-term average effects of multiple processes. Thus, the classification averages the temporal domain in order to concentrate on variation in the spatial domain.

4.2 Geomorphic class

The classification recognises 11 geomorphic classes along with subclasses in some categories, discriminated on the basis of the landscape and waterscape characteristics/factors such as geology, geomorphology and hydrodynamic characteristics (Table 4-2). This recognises that processes in the hydrosystem are controlled by the ocean at the water body mouth, freshwater inflows at the headwaters and the morphometry of the basin (i.e., whether it is deep, shallow or largely intertidal, broad and open, long and narrow or a complex branching network of arms and whether it is permanently or temporarily connected to the sea). Together these forcing mechanisms produce: mixing, circulation, stratification, sedimentation, and flushing at the scale of the whole hydrosystem.

In choosing names for the classes and subclasses, the project responded to direction from participants at the February 2016 stakeholders' workshop. These practitioners recommended keeping the names simple, limited to two or three words, and linked to names in common use. Names where selected that captured the morphology and driving processes (e.g., tides or river forcing): for example, *tidal lagoon* and *tidal river mouth*. For some systems, namely those with limited occurrence, we have co-opted and expanded upon local names: for example, *waituna* and *hāpua* as introduced by Kirk and Lauder (2000). For other systems, such as the *fjord*, we chose a name that is widely used in day-to-day language and the scientific literature.

Descriptions of the key characteristics of each of these classes along with Google Earth images are provided in Appendix A. Additional detail and methodological approach is described in Hume et al. (2016).

The classification is designed to be scalable in application so that in cases where there in insufficient information, or where it suits the purpose, hydrosystems can be classified at the class level (rather than the subclass level). In addition, small hydrosystems (e.g., the tidal creeks draining into larger bodies of water) can be recognised and classified as components of larger systems (e.g., the tidal creeks of the Kaipara Harbour).

Table 4-2: Classes within the NZCH classification at Level III – Geomorphic class along with reference examples.

Dominant hydrosystem type	NZCH classification geomorphic class	Reference examples
Palustrine	1. Damp sand plain lake	Kaipara North Head lakes; Parengarenga Spit lakes; Manukau North Head lakes; Mangawhai Spit lakes; Okupe Lagoon (Kapiti Island)
Lacustrine	2. Waituna-type lagoon (with 2 subclasses)	Te Waihora Lake Ellesmere (central Canterbury); Washdyke and Wainono Lagoons (south Canterbury); Ohuia Lagoon (Hawkes Bay); Waituna Lagoon (Southland); Lake Forsyth Te Roto o Wairewa (central Canterbury); Te Awaiti (Wairarapa); Lake Kohangatera (Pencarrow Head)
Riverine	3. Hāpua-type lagoon (with 4 subclasses)	Waitaki, Rakaia, Rangitata, Waiau, Hurunui and Ashburton, Conway, Opihi, Waipara, Pareora and Kowhai Rivers (Canterbury); Ashley River (north Canterbury)
Riverine	4. Beach stream (with 5 subclasses)	Shearer Swamp and Waikoriri Lagoon (Westland); Piha Stream, Te Henga Stream/Bethells Beach (Auckland west coast); Hahaei stream (Coromandel east coast); Saltwater Creek/New River (just south of Kumara Junction west coast
Riverine	5. Freshwater river mouth (with 3 subclasses)	Clarence River (Canterbury); Fox River (West Coast SI); small rivers in the south Wairarapa coast; west coast Coromandel Peninsula streams if non-tidal (e.g., Tapu, Waiomu, Te Puru)
Estuarine	6. Tidal river mouth (with 5 subclasses)	Waihou River (Waikato); Kauaeranga River (Thames); Whanganui River; Whakatane River (Bay of Plenty);

Dominant hydrosystem type	NZCH classification geomorphic class	Reference examples
		Grey River, Karamea River, Totara Lagoon (West Coast SI); Motueka mouth
Estuarine	7. Tidal lagoon (with 2 subclasses)	Blueskin Bay (Otago); Motueka Lagoon (Tasman); Whangateau Harbour (Auckland east coast); Tairua Harbour (Coromandel); Hoopers Inlet (Otago), Saltwater Lagoon, Okarito Lagoon (Westland)
Estuarine/ Marine	8. Shallow drowned valley	Hokianga and Kaipara harbours (Northland); Waitemata and Mahurangi Harbours (Auckland); Tauranga Harbour (Bay of Plenty); Whanganui Inlet (West Coast, SI); tidal arms of the Waitemata Harbour (e.g., Lucas Creek and Tamaki River) and the Kaipara Harbour
Estuarine/ Marine	9. Deep drowned valley	Firth of Thames; Wellington Harbour; Queen Charlotte Sound
Estuarine/ Marine	10. Fjord	Charles, Thompson and Milford Sounds
Marine	11. Coastal embayment	Rocky Bay (Waiheke); Taemaro Bay (Northland); Sleepy Bay (Banks Peninsula)

4.3 Management applications

4.3.1 Environmental variables

In developing the classification (Hume et al. 2007 and 2016) identified and built a database of environmental variables for some 500 New Zealand coastal hydrosystems[2]. These variables have been used in the past for various purposes including: (1) examining the relationship between physical characteristics of intertidal areas and the size and diversity of wader bird populations (Whelan et al. 2003), (2) developing predictive models of small fish presence and abundance in northern harbours (Francis et al. 2005) and (3) predicting macrofaunal species distributions along estuarine gradients (Ellis et al. 2006).

The environmental variables along with the classification of 500 systems will be made available via the MFE website in the form of:

- Excel (.xls) spreadsheet of environmental variables.
- GIS shape files (polygons) and point files.
- Google Earth point files (.kmz) – when both these files are opened together, they show the system polygons and points at the mouths of the systems which if "clicked on" (selected) display the environmental variables for the selected hydrosystem.

[2] The list is largely complete for New Zealand coastal hydrosystems with the exception of *damp sand plain lakes* and *beach streams* as these systems are very numerous around the coastline and best mapped at a local level.

4.3.2 Geospatial mapping

Hume et al. (2016) demonstrated how the database for the hydrosystems can be used to build geospatial maps to show where the different types of system occur once the data are input to Geographical Information System (GIS) and linked to hydrosystem shape files. One such application is for mapping rare systems, which is a pre-requisite for implementing policy 11 (a) (iv) of the NZCPS to "avoid adverse effects of activities on habitats of indigenous species that are naturally rare". Estuaries, lagoons, damp sand plains and dune slacks have been identified by Williams et al. (2007) as 'historically rare'. It is possible to map the location of unmodified systems, once rules are developed to define "unmodified" for the various classes. In the simple example that follows (Figure 4-1) "unmodified" was defined by the level of modification of catchment land cover, where modified is "pasture + urban" from a landcover database, and unmodified is "indigenous vegetation, tussock, scrub & regenerating bush, bare ground, wetland". This, of course, assumes that changes in catchment land cover cause changes in runoff and soil erosion and a corresponding deterioration of water quality. The unmodified systems mapped in green were those where less than 20 per cent of the landcover is modified from its pre-European state.

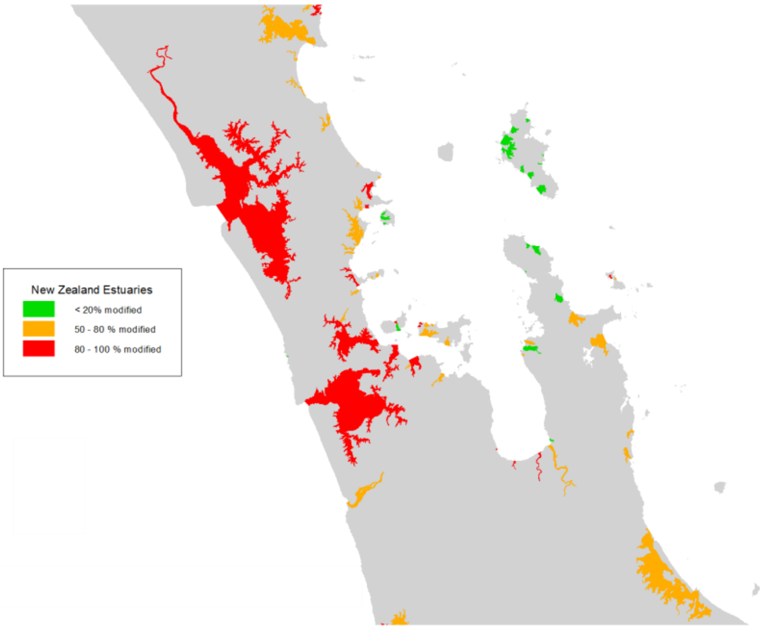

Figure 4-1: This example adapted from Hume et al. (2007) shows mapping of unmodified (green) and highly modified (red) estuaries.

5 How the ETI typology fits within and spans across the NZCH classification

5.1 Purpose and coverage

The NZCH classification is an overarching classification to cover all New Zealand's coastal water bodies ranging from lacustrine predominantly freshwater coastal lakes, to river mouths, to estuarine systems to fully marine coastal embayments. It is designed to be applied to wide ranging management applications such as mapping on a national and regional basis the location of pristine versus degraded systems, systems with poor flushing and susceptible to eutrophication and sedimentation, shorelines with susceptibility to coastal erosion and flooding, and systems vulnerable to the effects of climate change through saline intrusion and wetland loss. A detailed breakdown of types and classes is necessary to provide adequate definition for this purpose.

In comparison, the ETI typology is designed to provide a typology for assessing estuarine eutrophication susceptibility based on a systems response to proven physical susceptibility factors for a much more limited number of water bodies and a narrower range of water body classes broadly termed "estuarine systems", although like the NZCH classification its spatial coverage includes associated tidal habitats and adjacent tidal wetlands. A less detailed breakdown is more appropriate for the ETI project where sample size is limited by datasets for water quality, nutrients and biological data for some 24 water bodies.

5.2 Water body definition

In the NZCH classification individual waterbodies are defined as extending landward from the coast to include lacustrine, riverine, estuarine and marine environments, and the associated tidal and intertidal habitats and adjacent tidal wetlands. The boundary of the waterbodies is defined by high water line, which has its seaward boundary, or mouth, defined by an imaginary line that follows the general trend of the adjacent coast. The landward boundary is the location where the coastlines meet on the 1:50,000 topographic maps and, in the case of river dominated estuaries, the upstream limit of salinity intrusion under average tidal and river flow conditions. The ETI typology waterbody boundaries are defined in a similar manner, being defined by the shoreline, extending landwards from an imaginary line closing the mouth, with the upstream limit being a location where ocean derived salts measure less than 0.5 ppt during the period of average annual low flow and include the associated tidal habitats and adjacent tidal wetlands.

5.3 Fit to NZCH classification hierarchy

The ETI typology fits comfortably within Level II - Hydrosystem type (Estuarine) of the NZCH classification (Table 4-1).

The way the four main estuary classes of the ETI typology fit into and span across the 11 geomorphic classes of the NZCH classification are shown in Table 5-1. There are understandable similarities at this level because physical characteristics such as geomorphology, basin morphometry, river and oceanic forcing, are important in discriminating classes in both systems. The main differences are that the NZCH classification has greater variety and differentiation (as subclasses) in classes.

The NZCH temporal domain is averaged to concentrate on variation in the spatial domain. A class is thus defined based on the broad range of physical characteristics (e.g., basin morphometry, river input, tidal input) that occur for most of the time. However, in recognition of the importance of the temporal aspect, and that for periods of time a process such as mouth closure may determine the character of a hydrosystem, a subclass has been added to several categories in the NZCH classification. These are generally referred to in the NZCH classification as "intermittent" in geomorphic classes 3, 4, 6 and 7 (Table 4-2). Note that in the NZCH classification the *waituna-type Lagoon*, (termed a Coastal Lake in the ETI: Plew et al. 2018; Zeldis et al. a, b, c), is in a separate class, with two subclasses (subclass A: coastal plain depressions and subclass B: valley basins, to describe the environment). These waterbodies are in a category of their own because of their unique hydraulic characteristics. They stay closed for months to years because the nature of the rainfall/river input characteristics and drainage of lagoon waters by seepage through the gravel beach berm to the sea prevents them from breaching except under extreme events (floods and wave over topping). In New Zealand the opening regime (frequency and duration, in particular) of those intermittently closed and open systems is strongly influenced by human intervention.

ICOLLs such as those described for the New South Wales coast by the NSW Department of Primary Industries (http://www.dpi.nsw.gov.au/fisheries/habitat/aquatic-habitats/wetland/coastal-wetlands/management-of-coastal-lakes-and-lagoons-in-nsw) occur on sandy coasts and exhibit different hydraulic characteristics breaching more frequently and staying open for most of the time, suggesting that using the term ICOLL in a New Zealand context is inappropriate.

The NZCH classification differentiates its 11 classes, plus subclasses in some categories, based on geomorphic characteristics which include the landscape and waterscape characteristics/factors such as geology, geomorphology and the hydrodynamic characteristics/factors such as basin morphometry, river and oceanic forcing. The ETI typology differentiates its 4 classes based on estuary physical characteristics and nutrient input/estuary response (Plew et al. 2018, Zeldis et al. a, b, c). Note that while the ICOE subclasses of SIDEs and SSRTREs are not formally named in the original ETI typology of Robertson et al. 2016 a, they were recognised in its narrative.

Table 5-1: Correspondence of NZCH classification and ETI typology classes.

Dominant hydrosystem type	NZCH classification geomorphic class	Corresponding ETI typology class
Palustrine	1. Damp sand plain lake	Coastal Lakes
Lacustrine	2. Waituna-type lagoon	Coastal Lakes
Riverine	3. Hāpua-type lagoon	Shallow, short residence time tidal river and tidal river with adjoining lagoon estuaries (SSRTREs) Some may be ICOEs
Riverine	4. Beach stream	Shallow, short residence time tidal river and tidal river with adjoining lagoon estuaries (SSRTREs) Some may be ICOEs
Riverine	5. Freshwater river mouth	Shallow, short residence time tidal river and tidal river with adjoining lagoon estuaries (SSRTREs) Some may be ICOEs
Estuarine	6. Tidal river mouth	Shallow, short residence time tidal river and tidal river with adjoining lagoon estuaries (SSRTREs) Some may be ICOEs
Estuarine	7. Tidal lagoon	Shallow intertidal dominated estuaries (SIDEs) Some may be ICOEs
Estuarine/Marine	8. Shallow drowned valley	Shallow intertidal dominated estuaries (SIDEs)
Estuarine/Marine	9. Deep drowned valley	Deeper subtidal dominated, longer residence time estuaries (DSDEs)
Marine	10. Fjord	Deeper subtidal dominated, longer residence time estuaries (DSDEs)
Marine	11. Coastal embayment	Deeper subtidal dominated, longer residence time estuaries (DSDEs)

There is generally good correspondence at the geomorphic class level between the NZCH classifications and those of the ETI. The *Waituna-type lagoons* and *damp sand plain lakes* of the NZCH correspond to the ETI Coastal Lakes class which describes systems that are freshwater-dominated over long periods. The NZCH *Tidal river mouth* class and the ETI typology "Shallow, short residence time tidal river and tidal river with adjoining lagoon estuaries" (SSRTREs) correspond well. The subclasses in the NZCH classification provide more detailed discrimination that relates to diversity in flushing capacity of tidal river mouths for example, those with adjoining lagoon estuaries. This diversity can be accommodated in the ETI modelling via the subclass ICOE of SSRTREs, which can accommodate variable closure durations in its modelling. This capability also broadens the ETI's applicability to NZCH geomorphic classes 3, 4, and 5. At the class level the ETI typology "Shallow intertidal dominated estuaries" (SIDEs) spans the NZCH classification Class 7 *tidal lagoon* and Class 8 *shallow drowned valley* and their subclasses. While all these systems are strongly tidally dominated, their flushing and mixing will vary markedly between those systems with 1) wide open intertidal lagoons that largely empty of water at low tide and where adequate fetch allows wind mixing and resuspension of bottom sediments at high tide versus those with 2) dendritic drainage patterns and deep channels where water can be trapped on the ebb tide and where limited fetch does not allow mixing and resuspension by wind generated waves. Again, the ETI ICOE subclass of SIDEs can accommodate cases of closure of variable duration. At the class level the ETI typology "Deeper subtidal dominated, longer residence time estuaries" (DSDEs) span NZCH classification Classes 9 *deep drowned valley* and Class 10 *fjord*. These classes are differentiated in the NZCH classification because of their distinct basin shapes and hydrodynamic characteristics. While both are deep and with little intertidal area, except in the upper headwaters, the freshwater layer in the *fjords* gives them a different mixing and flushing characteristics to that of the *deep drowned valley*.

A general recommendation is that when using the ETI typology typology model, which amalgamates different classes recognized in the NZCH classification into single categories, is that results need be interpreted in light of an understanding of the characteristics of the geomorphic classes recognized in the NZCH classification. These are detailed in Table 3-2 of Hume et al. (2016).

5.4 Scalability

Both the NZCH classification and the ETI typology are scalable in a sense in recognition of the fact that a 'one size fits all' approach is not practical to all management applications. They both recognize that certain classes of systems and particularly the very large ones, may contain several classes or subclasses. For instance, in the Waitemata Harbour the shallow tidal arms in the upper reaches (e.g., Lucas Creek) have the characteristics of a *shallow drowned valley* (NZCH classification) or a SIDE (ETI typology). In the Kaipara Harbour, the tidal arm in the north (the Northern Wairoa River) has the characteristics of a *tidal river mouth* (NZCH classification) or a SSRTRE (ETI typology). Classifying components of estuaries in this manner permits better resolution and definitions and predictions of effects. The NZCH classification is scalable in a further aspect in that the detail at the geomorphic class level can be collapsed down to a smaller number of classes in situations where there is insufficient information to recognize subclasses and apply the classification. For instance, subclasses can be "binned" as classes. Also, as additional datasets become available for estuaries then it may be pertinent to create more categories in the ETI typology.

5.5 Applying and mapping the typology

The first step in applying a typology or classification is the same for both the NZCH classification and the ETI typology, that is to choose which category the chosen estuary (or component estuary) falls into. In the case of the ETI typology choice is made based on judgement informed by knowledge of the physical and other attributes of the system. A weakness with this methodology is that it is very dependent on the user having a good understanding of how a system functions. In this respect it is subjective, and it will be difficult to correctly identify classes that are borderline/transitional between the distinct categories. However, because there are only four classes in the ETI typology this may be an adequate methodology for its purpose. In comparison the NZCH classification method of choosing or recognizing the class to which individual hydrosystems should be allotted, is undertaken using either a classification key (Hume et al. 2016) or a classification engine in which rules and thresholds are defined and algorithms used to drive the assignment procedure (Hume et al. (2007). This facilitates the objective identification of borderline/transitional classes.

6 Acknowledgements

I gratefully acknowledge the ideas and thinking from Dr Philippe Gerbeaux, Dr Deirdre Hart and Helen Kettles that contributed to the development of the New Zealand coastal hydrosystems classification and input from Dr John Zeldis, Dr David Plew and Dr Bruce Dudley regarding the ETI.

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Appendix A Key characteristics of the 11 geomorphic classes.

The following narrative provides key characteristics for each of the NZ coastal hydrosystem geomorphic classes along with images of the classes. Detailed descriptions are available in Hume et al. (2016).

Damp sand plain lake - Class 1

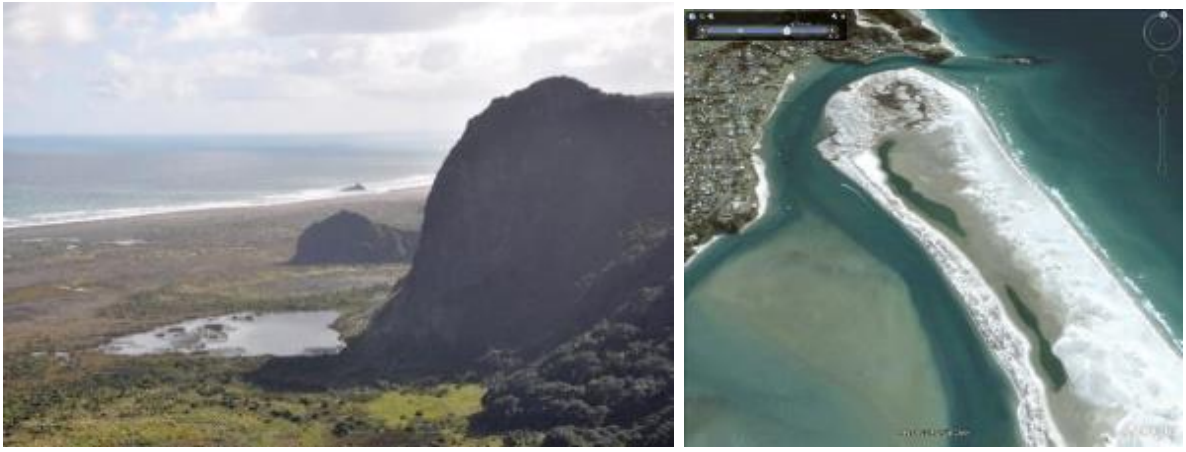

Figure A-1: Damp sand plain lakes on Manukau North Head and Mangawhai Spit (Auckland).

Small shallow (1-2 m deep), typically fresh water bodies. They never have a connection to the sea (no tidal inflow). Often elongate in shape and located in the depressions between rows of sand dunes on damp sand plains and often associated with vegetated wetland areas. The basins in which they occur form where the wind has removed sand to form shallow depressions down to about the level of the water table. They are fed by freshwater inputs from rainfall and groundwater and are brackish due to salt spray and evaporation. Variable planform, ephemeral in space and time and can dry out in drought conditions. Dominant substrate is muddy sand and peat.

Waituna-type lagoons - Class 2

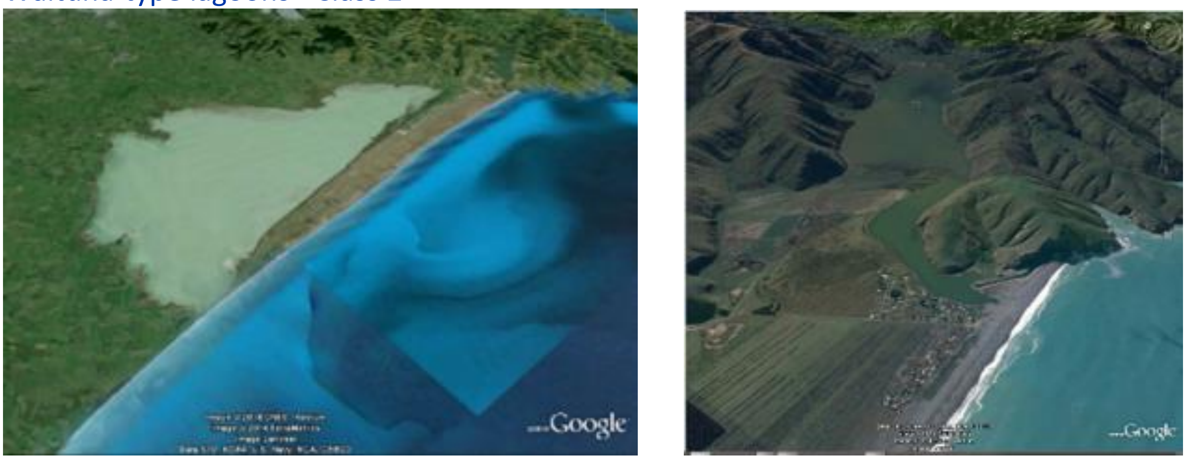

Figure A-2: Te Waihora Lake Ellesmere and Te Roto o Wairewa Lake Forsyth (Canterbury).

Large (several km^2), shallow (mean depth 2 to 3 m) coastal lagoons barred from the sea by a barrier or barrier beach (no tidal inflow). They occur most commonly occur in depressions on low-lying coastal land (e.g., Te Waihora and Lake Wainono) or in valley basins as more elongate shaped water bodies (e.g., Lake Forsyth). Waterbody is typically fresh, fed by small streams, with brackish pockets in time or space. Drainage to the sea is generally by percolation through the barrier. Their most frequent state is closed to the sea. Short-lived openings occur when water levels build a sufficient hydraulic head in the lagoon to breach the enclosing barrier, due to river inflows and/or severe storm wave overtopping. Sustained openings to the sea are rare (decadal-century time scales) unless created artificially. They may experience tidal inflows for short periods (1-2 tidal cycles) after natural barrier breaches whereas recent observations indicate that artificial breaches can result in openings that experience tidal ingress for up to several weeks (e.g., Te Waihora Lake Ellesmere). Wind waves and wind-induced currents are important agents for mixing. Observations of historical lagoon ridges suggest that these agents were even more important in pre-human times when depth and fetch of the waterbodies were greater than today. Situated on wave-dominated high-energy mixed sand/gravel coasts. Dominant substrate is very fine sand and mud.

Beach stream - Class 3

Figure A-3: Piha River (Auckland) and New River (West Coast, SI).

Occur where a very shallow stream flows over the beach face to the sea. This differs from a river where the larger flow cuts a subtidal channel through the beach face to the sea. Different subclasses occur depending on the geology of the catchment and how the outflow interacts with the wave driven littoral drift. Some form where the stream runs straight to the sea or backs up to form a small pond behind a beach berm. Other subclasses form where the stream runs along parallel to the shore for 100s of metres or several kilometers in the dune slack to form what are locally known on the West Coast of the South Island as "ribbon lagoons". Drainage to the sea occurs for most of time, except during drought conditions and/or when waves build a beach berm to bar off the outlet, at which time flow percolates through the beach face to the sea. No tidal prism (inflow) except during storm events coupled with high tides. Generally small. Dominant substrate is sand or mixed sand and gravel. Sometimes incorrectly labelled ICOLLs (Intermittently Closed and Opened Lakes and Lagoons of Haines et al. 2006). However, waituna barriers typically comprise coarser sediment and are therefore more permeable than those of ICOLLs. This, for most of the time, allows the lake to drain by percolation through the barrier, preventing build-up of water and hydraulic head. Hence the barrier breaches less often than in the case of ICOLLs.

Hāpua-type lagoon - Class 4

Figure A-4: Rakaia River and Ashburton River (Canterbury).

Narrow (10 s to 100 s m wide), elongated (<100 m to several km long) and shallow (several metres deep) river mouth lagoons that are, except for usually a single narrow outlet enclosed along their ocean boundary by coarse clastic barrier beaches formed by strong longshore sediment transport. They occur on coasts that are generally wave-dominated and exposed to high swell wave energies, typically mixed sand and gravel, have micro- to lower meso-tidal ranges, typically have rising backshores, and are characterised by late Holocene erosion, or recent stability trends. Narrow (restricted) outlet. Usually no tidal inflow (no tidal prism, only river outflow), although can temporarily experience tidal inflows for a few hours to days after a large flood breaches or widens the outlet, before longshore transport re-establishes the constriction. They typically experience a tidal backwater (freshwater) effect in the lagoon where water outflow/and/or percolation from lagoon to sea is reduced at high tidal levels. Salt-water entry occurs via spray and wave overtopping during storm events. The highly mobile outlet (positionally unstable) can migrate for hundreds of metres to kilometres along the shoreline at sub-annual time scales, with lagoon elongation growing in relation to outlet migration alongshore. They are not ICOLLs as they do not occur on sandy coasts and do not have a state where tidal ingress is sustained. They experience only very short-lived (minutes to hours) tidal flows under exceptional circumstances such as storm events with elevated water levels and large waves. There are four subclasses based on their size, river source and temporal state.

Freshwater river mouth - Class 5

Figure A-5: Clarence River (Canterbury) and Tapu River (Coromandel west coast).

Permanent connection to the sea, never closes off. Occurs where river flow is large enough to cut a permanent subtidal channel through the shoreline and beach to the sea. River channel gradient to the sea is steep enough to prevent tidal ingress. There may be some overtopping of the barrier beach by waves in storm events when water levels are elevated. River flow dominates the hydrodynamics. No tidal prism or saline intrusion (inflow), although there can be a tidal backwater effect. Dominant substrate is mixed sand and gravel. There are three subclasses relating to whether the entrance is constricted by a delta or a barrier or unrestricted.

Tidal river mouth - Class 6

Figure A-6: Waihou River (Firth of Thames) and Totara Lagoon (Ross, West Coast SI).

Figure A-7: Whanganui River (Manawatu) and Motueka River delta (Golden Bay).

Elongate, narrow and shallow (mean depth several metres) basins that have a permanent connection to the sea for most of the time. They occur where river and tidal flow are large and persistent enough to maintain a permanent subtidal channel through the shoreline and beach to the sea. River flow delivered during a tidal cycle is a significant proportion of the basin's volume, and is greater than the tidal volume entering. Thus, the hydrosystem-scale hydrodynamic processes are dominated by river flows and these classes are well flushed. Floods can expel all the seawater from the system for days. In deeper systems an estuarine circulation pattern can be set up where outflowing freshwater is balanced by the inflow of seawater entrained beneath freshwater and a salt wedge develops. Seawater can intrude kilometres up estuary in low-gradient coastal plains. Wind-generated mixing and wave-driven resuspension are minor as wind fetch and waves are small and depths are largely too great for significant bed stress to be produced. Thus sediments inside the waterbody tend to be muddy except in areas of high tidal flows. There are five subclasses depending on whether the system has an unrestricted mouth versus a mouth restricted by a barrier or delta and the planform of the water body.

Tidal lagoon Class - 7

Figure A-8: Blueskin Bay Hoopers Inlet (Otago).

Shallow (mean depth 1-3 m), circular to elongate basins with simple (not dendritic) shorelines and extensive intertidal area. A narrow entrance to the sea, constricted by a spit or sand barrier. Ebb and flood tidal delta sand bodies form in the sea and bay sides of the entrance. Strong reversing tidal currents flow through the entrance. The tidal prism makes up a large proportion of the total basin volume. River input is small compared to tidal inflow so hydrodynamic processes are dominated by the tides. Despite the narrow entrance they generally have good flushing because much of the water leaves the estuary on the outgoing tide. River inputs dominate the hydrodynamics for short periods (days) during floods when seawater can be completely expelled. On the incoming tide flood waters get backed up by the tide causing low-lying land around the margins to be flooded. Wind-generated, mixing and resuspension of bottom sediments occur at high tide; this is more pronounced in larger and circular open water bodies with larger fetch. The combination of wave resuspension of the substrate and flushing results in generally homogeneous and sandy substrates. These classes are also well mixed because strong flushing, wind mixing and the shallow depths prohibit density stratification. Salinity is close to that of the sea. Water clarity is good because of the flushing and the sandy substrate. The spit or barrier can be overtopped by waves and breached in extreme events leading to multiple entrances. Dominant substrate is sand. There are two subclasses relating to whether they are permanently open or intermittently closed.

Shallow drowned valley - Class 8

Figure A-9: Waitemata Harbour (Auckland) and Hokianga Harbour (Northland).

Shallow (mean depth generally less than 5 m due to extensive intertidal area) with complex dendritic shorelines and numerous narrow arms leading off a main central basin or channel. Extensive intertidal flats cut by drainage channels. Range in size from small tidal creeks (e.g., Mangemangeroa) to large harbours (e.g., Kaipara). Tidally dominated. Mouth always open and constricted by hard headlands or substantial barriers. Flood and ebb tidal sandy deltas are present at the tidal inlet on high wave energy littoral drift shores (e.g., Raglan, Kaipara, Hokianga) but absent on zero-drift shores (e.g., Mahurangi and Waitemata). While sand bodies at the entrance change in planform shape, the inlet does not migrate much because most are fixed by a rock headland on one shore. The systems are largely infilled with sediment. Large systems tend to be sandy at the mouth and in the central basin areas, and muddy in the tidal arms and headwaters. Wind-generated circulation and mixing and wave resuspension of the substrate is important in the wide open central water body where wind fetch is great enough for this to happen. Small tidal creeks are generally very shallow elongate waterways with extensive intertidal areas of muddy substrate. They occur on shores sheltered from wave energy and littoral drift. They often form the shallow arms of larger shallow drowned valleys such as the Waitemata and Kaipara Harbours. The water is generally turbid because of the muddy substrate. Sedimentation rates are generally high as the small fetch does not allow waves to develop and resuspend sediment. These systems are destined to infill. *Shallow drowned valleys* differ from *tidal lagoons* in that they have a greater mean depth. This, along with their planform complexity, means they are not as well flushed.

Deep drowned valley - Class 9

Figure A-10: Queen Charlotte Sound (Marlborough) and Akaroa Harbour (Canterbury).

Large, deep (mean depth 10 to 30 m), mostly subtidal systems formed by the partial submergence of an unglaciated river valley. They remain open to the sea. Typically, they have a straight planform without significant branches but they can be dendritic: this pattern is inherited from the drainage pattern of the flooded river valley. In the Marlborough Sounds and Wellington Harbour there are islands, summits of partly submerged hills. The size of the valleys seems large for the size of the rivers currently entering the system. Both river and tidal inputs over the tidal cycle are small proportions of the total basin volume. The wind may modify the circulation and become a dominant force on occasions, but it is not responsible for the mean circulation over extended periods of time. In elongate systems a circulation pattern (estuarine) is set up where outflowing freshwater is balanced by the inflow of seawater entrained beneath freshwater. There is also a strong longitudinal gradient (head to mouth) in hydrodynamic processes with riverine forcing and stratification dominating in the headwaters and tidal forcing near the entrance. The systems are characterised by poor flushing, which is pronounced in the headwaters and in more complex shaped systems that have multiple arms. Ocean swell and wind waves are unimportant in substrate resuspension processes because of the large depth of the basin. The substrate is generally fine sand or mud. They differ from *shallow drowned valleys* in that they are deeper, do not have sand deltas at the mouth, have far less intertidal area and hydrodynamics are less dominated by the tides.

Fjord - Class 10

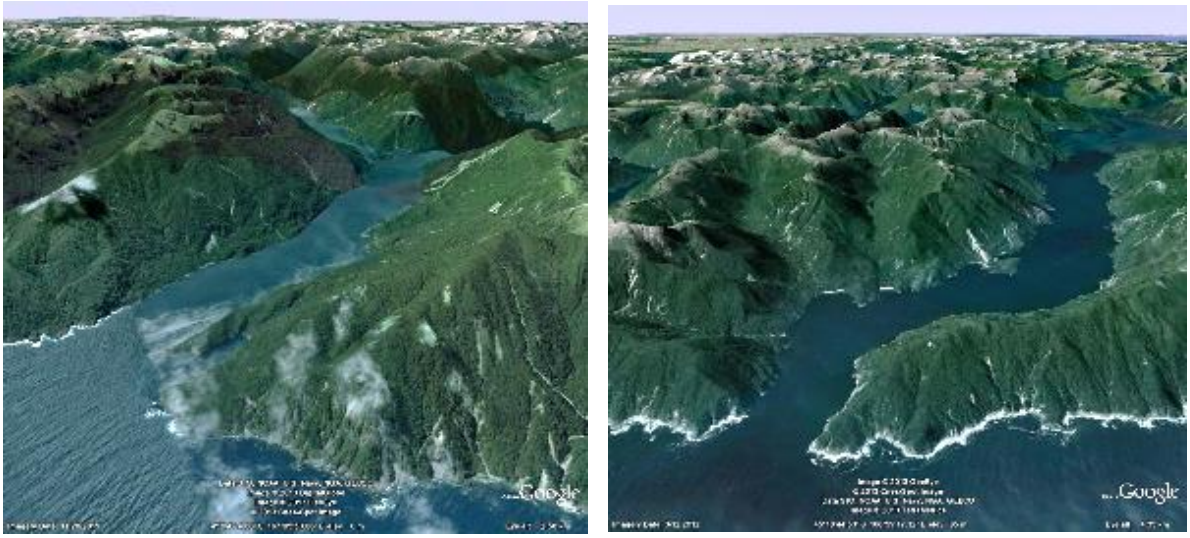

Figure A-11: Charles Sound and Thompson Sound (Fiordland).

Long, narrow and very deep (mean depth 70 to 140 m) U-shaped basins with steep sides or cliffs, formed in glacial valleys flooded by the sea following the last glacial and sea-level rise. The basin is subtidal, with only small intertidal areas in the headwaters and is characterised by sills at the mouth and along the length of the system that were formed as glacial terminal moraines. Both river and tidal inputs over the tidal cycle are very small proportions of the total basin water volume. Water movement near the surface is controlled primarily by thermohaline forcing where the circulation is maintained by the large density differences produced by the salinity contrast between freshwater and oceanic water. The resulting circulation pattern is characterised by out-flowing freshwater, which is balanced by the inflowing seawater entrained beneath freshwater. Wind may modify this circulation and wind-driven circulation may become a dominant force on occasions, but it is not responsible for the mean circulation over extended periods. Consequently, these estuaries are characterised by poor flushing, particularly in more complex-shaped (multiple arm) systems. The very deep basin and partitioning by sills means that flushing takes place in a relatively thin layer of freshwater, which moves over the top of a 'quiescent zone' of seawater. Substrate resuspension by ocean swell or wind waves is not an important hydrodynamic process because of the basin depth. As a consequence, the substrate is generally fine sand or mud.

Coastal embayment - Class 11


Figure A-12: Taemaro Bay (Northland) and Sleepy Bay (Banks Peninsula).

An indentation in the shoreline with a wide entrance, bounded by rocky headlands and open to the ocean. The waterbody is shallow to medium depth (4 to 8 m) and circular to elongate in planform. They are mostly sub-tidal with small intertidal areas restricted to the headwaters, or the sheltered side arms of the more elongate types. There is little river influence and circulation is weak from tidal and wind-generated currents. The entrances are wide and open to the ocean, allowing swell to enter the bay and resuspend seabed sediments, thus hydrodynamic processes are dominated by the ocean. Pocket beaches occur in the upper reaches. There are no sand bodies (tidal deltas) on the ocean side of the entrance. Wind- and wave-driven mixing occur. The substrate tends to be sandy. Wave refraction disperses wave energy through the bay and, along with the sheltering effect of the headlands, shelters the embayments from storms. Sedimentation and infilling is very slow because inputs from streams are small and waves entering resuspend sediments, which can then be transported out by currents. *Coastal embayments* occur on rocky headland coasts with good examples occurring on the Northland and Auckland east coasts. On Banks Peninsula the eroded flanks of two large shield volcano complexes formed narrow steep-sided valleys that were flooded during sea-level rise following the last glacial to form many small *coastal embayments*. They differ from *shallow drowned valleys* in that they are largely subtidal and the wide mouths allow ocean forcing by waves.