

FEASIBILITY OF COASTAL RESERVOIRS FOR FRESH-WATER STORAGE IN NEW ZEALAND

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ABSTRACT

In New Zealand, some cities must impose water restrictions in the summer. In the event of a disaster like an earthquake, the water supply pipelines may rupture and water supply to main cities can be disrupted up to one month. To give reliability to the water supply, several large reservoirs are used. There are consenting issues, including the residents' fear of dam failure, leading to another disaster. This concept paper looks at the viability of storing fresh water in the coast, in a coastal reservoir for two cities Wellington and Christchurch. A coastal reservoir is usually placed at the estuary of a stream or a river, storing freshwater. Modern examples of large sea-reservoirs include the saltwater intrusion barriers in Singapore, Adelaide (Australia), China and in Netherlands. The advantage of a coastal reservoir is that the total cost of the reservoir is much less than an upstream reservoir, with no land being inundated. The dam can be flushed (if required) easily. Also, the environmental consequences of a dam rupture (if any) are lesser. If membrane technologies like Reverse Osmosis (RO) are considered for water treatment, it is more viable to treat with fresh waters from a coastal reservoir, than doing RO with full strength sea water. This paper reviews dam building methods from literature. If a Wellington or Christchurch trial is successful, building similar reservoirs can be investigated for other cities like Whakatane (where saltwater intrusion is an issue) or even for Auckland which has water shortages/ restrictions in summers.

Keywords: Coastal reservoir, drinking water, climate change, water storage, civil defense

1. INTRODUCTION

A coastal reservoir is a freshwater reservoir built in the estuary of a river, storing freshwater. (Yang et al., 2012). This concept paper looks whether such a reservoir is viable in New Zealand and looks at various relevant aspects & studies. While the concept of storing freshwater at river mouths is relatively new, tidal water barriers have been in existence in many countries since 1930s, which essentially creates a freshwater storage at the upstream end. This paper considers various water resilience measures implemented and whether a coastal reservoir will supplement Civil Defense water supply options.

1.1 Is there a water shortage in NZ? Examples of summer water restriction notices.

While Wellington, the capital of New Zealand is a city well-endowed with water, in the summer months (December to March in southern hemisphere), gardening water restrictions apply. In 2020 the gardening restrictions were effective from 14th of February (Wellington-Water, 2020a).

The city of Christchurch has enough water for pipe-borne supply, but the surrounding Canterbury region is not so lucky in availability of water. It has level 4 water restrictions in some areas (CCC, 2020).

Auckland is experiencing one of its most prolonged dry periods in 2020 and from Saturday 16 May mandatory Stage 1 water restrictions were in place (Auckland Council, 2020).

New Zealand, while being a clean and green country, is aware of many possible natural hazards. "Quake center" (2019, page 11) has a list of possible natural hazards in New Zealand, namely Earthquake, Landslide, Flooding, Erosion, Tsunami, Volcanic Eruption, and extreme weather events which may occur yearly or may happen decades apart. According to the main water supplier in Wellington (Wellington Water, 2017), "It is a fact of living in our region, where active (earthquake) fault-lines cross our highly populated areas, that around 1400 kilometres of our water supply pipes are at risk in a significant event." Some Wellington suburbs could be

without water for more than 100 days after an earthquake of 7.5 (Richter Scale) or stronger. Among the Wellington suburbs, Miramar peninsula may not have water for up to one month.

Possible storm surge hazard scenarios due to climate change has been reported by NIWA-GWRC (2012) which assessed the storm inundation hazard for coastal margins around the Wellington region. The likely Tsunami scenarios are given in Mueller et al. (2015).

The National Institute of Water and Atmospheric sciences - NIWA (2011) report gives a case study in Whitianga on the Coromandel Peninsula (NZ), on engaging with coastal communities in NZ over adaptation to climate change.

1.2 Options for water resilience in Wellington

Why should a city have water resilience? As given in POW-Omororo Reservoir (2020), it is important for a city to have enough water stored to allow for at least two days' normal use and to enable repairs, maintenance and upgrades to be done without disrupting water supply. That is called operational resilience and at present (in Wellington in 2020) storage capacity is not satisfactory. Among the new steps suggested for water resilience, two notable projects are water storage reservoir at Prince of Wales Park, costing over NZ\$50 million and cross harbour pipeline estimated to cost NZ\$135 million.

According to Wellington city council (WCC, 2020), in the event supply pipes are disrupted, Omororo reservoir will improve storage from having less than a day's worth of supply to approximately 48-hours' worth. The construction of the 35 million-liter reservoir – enough to fill 14 Olympic swimming pools – above the playing fields at Prince of Wales Park in Mount Cook is being managed by Wellington Water (Water Utility Company).

The Wellington city's water supply network is also vulnerable. Underground pipes and reservoirs could be badly damaged in a significant earthquake and as a result some suburbs could be without drinking water for more than 100 days. The report (Wellington Water, 2020b) includes an assessment of alternatives in pages 25-33.

While Omororo reservoir is under construction, another option considered is the Wellington cross harbour pipeline. Dominion-Post (2018) reported that new pipeline would carry water from the Waiwhetu Aquifer, in Lower Hutt, through a high-density polyethylene pipe nestled into the harbour floor, coming ashore at Evans Bay. Estimated cost in 2018 was NZ\$116 million, in the Wellington Regional Council's 10-year plan. Another option considered was sourcing water using bores from the Waiwhetu Aquifer under Wellington Harbour, near Matiu/Somes Island which was expected to cost between \$60m and \$70m, with the cost of the harbour bores investigation work over \$5.2m. But the borewells were found to be unsuitable. This figure is an indicator of the possible investigation cost of any future water project in the Wellington harbour region. The geotechnical investigations have provided data about the seabed and land at the potential take-off and landing points (of pipeline) on both sides of the harbour. This data will be analyzed to refine the potential route and design for the pipeline. By January 2020 Wellington-Water successfully completed a series of land and sea-based bores in Lowry Bay and Evans Bay (in Wellington harbour) as part of determining the potential route of the Cross Harbour Pipelines (Wellington Water 2020c). These data will be valuable, and the cost of the investigations will be a guideline for any future investigations.

1.3 Coastal reservoir complementing existing/ proposed water resilience activities

With the above scenarios, with inputs from investigations, a rigorous analysis considering all aspects (technical, climate change, civil defense and cultural aspects) is required, if a coastal reservoir is ever considered. Considering the initiatives taken for storage reservoirs and pipelines in Wellington, a coastal reservoir may complement such options for future water security. This paper is only a concept paper, may be the first step in a long road of investigation and public consultation, before implementation.

2. CHRISTCHURCH (NZ) EXAMPLES AND FLOW DATA

Responsibility for water quality in Christchurch (New Zealand) is held by three agencies: Environment Canterbury, the Christchurch City Council and Canterbury District Health Board. Like any city, they also acknowledge that water allocation is an important and strategic issue and that decisions around water use need to both sustain the economy and protect the environment. According to Environmental Canterbury (E-Can, 2020), they have adequate water supplies. According to E-Can website, 375 million m³ are available per year, out of which 152 million m³ are extracted for water supply, with 223 million m³ flowing to sea. Considering these data, a coastal reservoir, if available, will serve as a storage for a disaster situation or useful for a drought scenario. Still if available, a reservoir can also be used for aquifer recharge and to prevent saltwater intrusion.

Christchurch city council has commissioned GHD (2015) to conduct a pre-feasibility study on a Tidal-Barrier (in Avon-Heathcote estuary). A tidal barrier will have freshwater on the upstream side. Therefore, in effect it creates a coastal reservoir. The rivers will flow freely into the estuary (reducing floods) and making a freshwater reservoir. The tidal barrier idea has been around for about 50 years. GHD (2015) study also considered potential sea level rise of 1m over the next century and will be essential reading for any future coastal reservoir project in New Zealand. GHD (2015) identified two locations in the Avon-Heathcote river estuary, with the primary aim of flood reduction. The investigation locations were at the mouth of the estuary adjacent to Shag-rock and an upstream location from Redcliffs to Southshore. Options comparison for recommended site locations is given in Table 5 of GHD (2015) report. The location parameters analyzed were Barrier Length, Utilisation of estuary volume, Sand spit connection, Connection to high ground at south, Geotechnical stability, Channel stability, Exposure to open ocean, Tsunami exposure, Currents, navigation, Pedestrian/vehicle passage, visual impact, potential to have a soft embankment (vs. a solid/hard engineered embankment) and Constructability/cost. The Redcliffs option was selected in this pre-feasibility report (GHD, 2015), because the sand spit is more stable in this location and the tidal barrier being less exposed to coastal conditions.

For the barrier structure they considered 9 options (with reasons given), namely: vertical lifting gate, vertical rising gate, segment gate, rotary segment gate, sector gate, flap gate, rolling gate, swing gate and inflatable gate (rubber dam). GHD (2015) shortlisted the three options vertical lifting gate, rotary segment gate and inflatable gate and finally recommended the vertical lifting gate. As given in table 6 (GHD, 2015) the gates were assessed for the criteria: reliability, maintainability, expandability for further sea level rise, earthquake land damage (liquefaction, subsidence or rising), low-tide outfall, resistance to sedimentation, visual intrusion, navigation, pedestrian/vehicle passage, construction cost and constructability.

The embankments proposed were assessed over the criteria: geotechnical requirements for earthquake resistance, maintenance requirements, area of disturbance, morphological integration and ecological integration, aesthetic impact and cost (Table7, GHD 2015).



Figure 1. The Wellington City streams map (retrieved from <https://www.gw.govt.nz/assets/Sustainable-Schools/Stream-assessment-kits/Wellington-maps/Wellington-City-map.PDF>)

GHD (2015) study concluded that a tidal barrier is technically feasible. It was estimated to cost in the range of \$300 - \$350M (2015 values, NZ\$), with operations and maintenance costs ranging from NZ\$2 to \$7M per year. This was shown to protect a considerable area of public and private assets (Maclaren & Parsons, 2016). The section 7.2.3 of GHD (2015) considered the scenario of permanently closed barrier (effectively creating a coastal reservoir), with the estuary becoming a freshwater ecosystem, with stormwater outflow provided by flushing during low tide (possibly combined by pumping across the barrier for river floods). GHD (2015) concluded environmental impacts associated with converting this estuary to a freshwater system was unacceptable in 2015 (considering flood protection benefits only). In future scenarios, the lower ecosystem impact and lower visual impact may favour a coastal reservoir if civil defense drinking water requirements call for water storage in coastal areas.

3. WELLINGTON EXAMPLES & FLOW DATA

3.1 Can we consider a coastal reservoir for Wellington?

For water resilience, let's look at areas of Wellington city east and south of the Wellington airport (including Miramar peninsula) as a case study. This is the area that may be isolated from the present water supply for a long time, after a disaster. To build a coastal reservoir we need a water supply (a stream) and a location (preferably an estuary or a bay).

Figure 1 (Wellington streams, n.d.) shows several streams available in this area. Some of these streams (shown in red) are already pipelines draining small catchments. The largest stream in the selected study area is the Owhiro stream.

The Greater Wellington Regional Council (GWRC, 2017) report give the water quality data of the Owhiro stream mouth and the Owhiro bay. As shown in the interactive stream flow data map (Figure 2) from Ministry of Environment (mfe, 2020), flow data are available for these streams and will be valuable in a future feasibility study. The water quality data are also available for all large streams, as shown in the text-box on Figure 3, this set of quality data being for Owhiro stream.

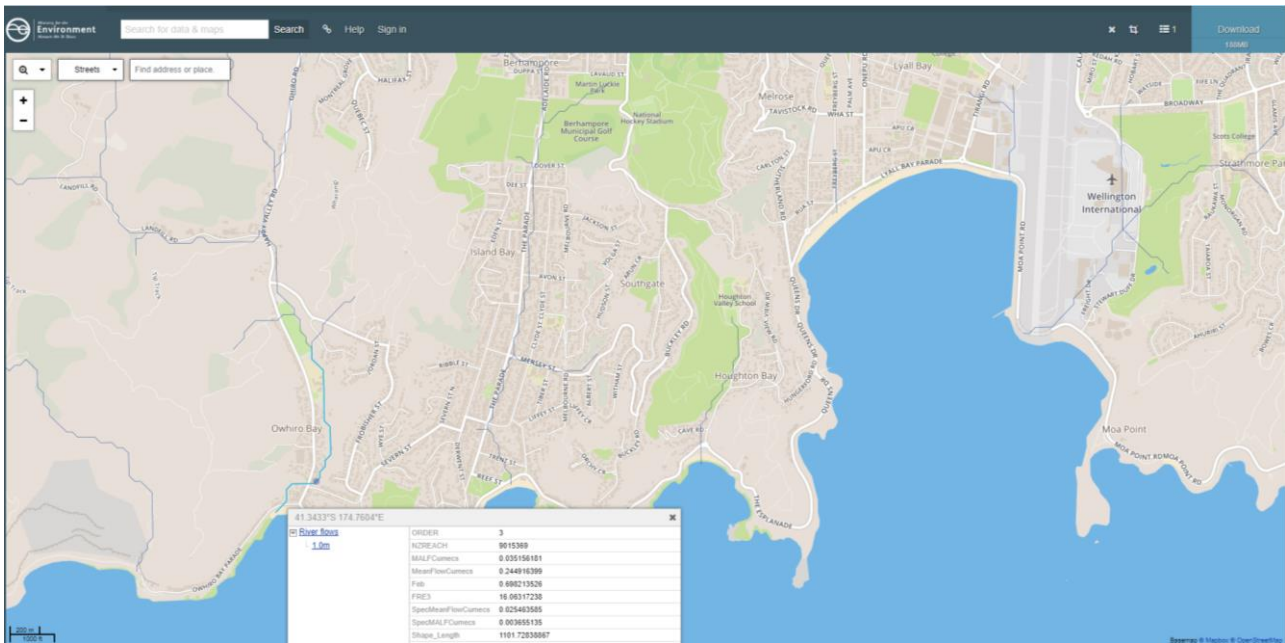


Figure 2. Stream and flow data example with stream water quality for Owhiro stream (retrieved from <https://data.mfe.govt.nz/layer/53309-river-flows/>)

Researching the availability of bays for storage in sea and possible bathymetry, various Bays in Miramar Peninsula can be seen in Google maps (Wellington Harbour). NIWA has 1 m grid bathymetry data for the Wellington harbour. Figure 3 gives the depths of several inlets in Wellington harbor (LINZ data service, n.d.). These data will be valuable if a pre-feasibility study on water storage locations is needed.

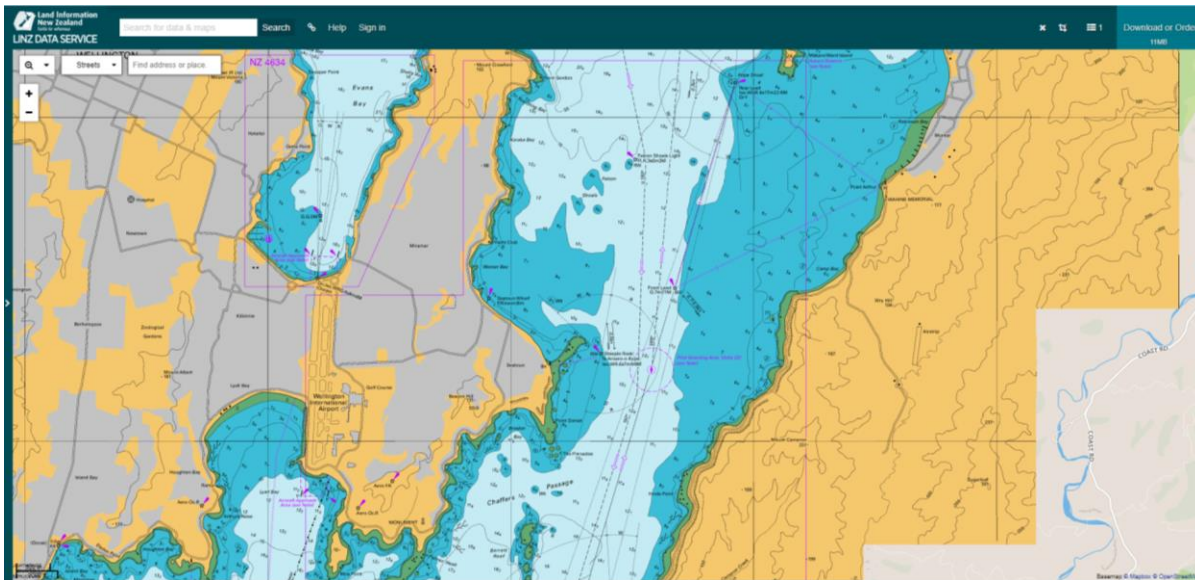


Figure 3. Depths (Bathymetry) of several inlets in Wellington harbour (Retrieved from <https://data.linz.govt.nz/layer/51305-chart-nz-4633-wellington-harbour/>)

4 CONSTRUCTION METHODS OF COASTAL RESERVOIRS

A good description of the coastal reservoirs of the world is given in the book chapter UoW (n.d.). They note that Plover Cove in Hong Kong (1968) was the first major reservoir built in the sea, by constructing a dam in the sea. The largest coastal reservoirs are also listed. One of the largest is the Qingcaosha reservoir in Shanghai. (China Briefing, n.d.). A USA paper (NASA, 2017) has a satellite photo taken on June 2016 and before construction of the reservoir, showing clear water inside the reservoir compared to the outer river Yangtze. Purer water within the reservoir appears blue; the more polluted, sediment-filled water of the Yangtze and the Huangpu rivers is brown. The same article reports that the reservoir, which spans about 70 square kilometers and has a capacity of 430 million cubic meters, supplies about 70 percent of Shanghai's tap water. Qingcaosha's water is drawn from deep within the middle of the Yangtze, which tends to be less polluted than the edges. The green wetlands in the northwestern portion of the reservoir help cleanse the water naturally, while serving as habitat for several types of birds and fish.

According to the Summary of the EIA report of Qingcaosha reservoir (World Bank, 2008), the construction work comprised building the dikes, pumping and sluice gate engineering and related temporary works. The dike part of the project included the construction of new roads, the height raising and the reinforcement of the Changxing old seawall, the strengthening and height raising of the Qingcaosha reclamation area and the renovation of dikes in the Zhongyangsha reservoir. The pump and sluice gate part of the project included upstream pump and sluice gate work, downstream water dams and water supply pumping stations. The main work activities covered dredging, geo-textile laying, gravel bedding, stone blocks' piling, reinforcement of concrete fence panels, reinforcement of the wave-facing concrete wall, protection of the bottom, water extraction (upstream) pump, water discharge (downstream) pump and water conveyance pumping station. The total project construction period was estimated to be 38 months. Dredging involved using mechanical and hydraulic dredges. To minimize the pollution and contamination to the raw water, water powered type of dredger like the cutter suction dredger was proposed to be used, which could operate in fixed-point locations and generate a relatively a small volume of suspended solids.

Yang et al. (2013) book chapter which gives an excellent overview of application status of coastal reservoirs, recommends using currently used harbour construction methods in constructing a coastal reservoir, considering the environment of coastal reservoirs is similar to harbours.

In New Zealand, considering the earthquake risks, flexible inflatable dams (Rubber Dams, n.d.), may be viable as detailed in Netherlands rubber dams (2014). Rubber dams are a magnified version of the inner tube of a bicycle. In existing large inflatable dams (like Ramspol in Netherlands), a total of three inflatable, flexible membranes are positioned next to each other, with a combined length up to 240 meters. They consist of a very heavy rubber membrane. When inflated the membrane rises no less than ten meters in height, high enough to withstand any heavy storm tide. Inflation is usually required once a year. The membrane reaches its full size within an hour and provides total protection against the rising water.

While the Ramspol dam in Netherlands is safely operating, rubber dam failure in USA is reported in Tempe (2012). The main cause identified was the exposure of the top of the dam to sunlight. While this is the current situation, with the improvements in the materials technology, and making sure sun exposure is prevented or mitigated, the viability of such dams could be improved.

Christchurch tidal barrier pre-feasibility report analysed the constructability/cost of the tidal barrier as given in tables 5 and 6 (page 32, GHD 2015). Table 6 noted that achieving the bottom seal can be somewhat complex (for a vertical lifting gate) and suggested dewatering a sheet pile box (coffer dam). The estimated cost (in 2009) of the tidal barrier was 310 Million NZ Dollars. This report also noted the extent of work below bed level (that may be required for an inflatable gate) and a 2009 estimate of 0.55 Million Euros per meter (about 1 Million NZ\$ per meter) was given for an inflatable barrier.

Adelaide in Australia has a series of flood barriers built from 1935, in the Barker-Inlet- originally a tidal estuary- 20km north of Adelaide-South-Australia (Poch et al., 2009). The data about these tidal barriers from Australia will be more acceptable from a NZ viewpoint, providing a wealth a data for a future NZ design.

Whakatane in NZ (a city with saltwater problems in drinking water) has a set of tidal pools, now filling with seawater in rising tide. (RNZ, n.d.). While these pools are unlikely to be developed for another use in near future, the costs of maintenance reported, will give an insight in to possible maintenance costs involved in a NZ coastal reservoir in future.

The earthquake commission of NZ has a valuable inventory (compilation and analysis) of dams over 3m in height, (EQC Quakecenter, n.d.). Both the inventory and the paper Crawford and Haskell (2016) may be useful in planning and analysis of any proposed dam for NZ.

4. RELEVANT NZ LEGISLATION

The resource consents for any dam project in NZ has be obtained from the regional councils. The foundation for all these is the Resource Management Act RMA (1991). RMA (1991) has guidelines on coastal and foreshore protection in New Zealand.

Some of the sections relevant to coastal reservoirs are sections are given below:

Resource Management Act (NZ) Section 12 Restrictions on use of coastal marine area, as retrieved from CMA activities, (n.d.) retrieved from <http://www.gw.govt.nz/assets/Plans--Publications/Regional-Plan-Review/Proposed-Plan/Section-32-report-Activities-in-the-coastal-marine-area.PDF> states

(1) No person may, in the coastal marine area (CMA),

(a) reclaim or drain any foreshore or seabed; or

(b) erect, reconstruct, place, alter, extend, remove, or demolish any structure or any part of a structure that is fixed in, on, under, or over any foreshore or seabed; or

(c) disturb any foreshore or seabed (including by excavating, drilling, or tunneling) in a manner that has or is likely to have an adverse effect on the foreshore or seabed (other than for the purpose of lawfully harvesting any plant or animal); or

(d) deposit in, on, or under any foreshore or seabed any substance in a manner that has or is likely to have an adverse effect on the foreshore or seabed; or

(e) destroy, damage, or disturb any foreshore or seabed (other than for the purpose of lawfully harvesting any plant or animal) in a manner that has or is likely to have an adverse effect on plants or animals or their habitat; or

(f) introduce or plant any exotic or introduced plant in, on, or under the foreshore or seabed; or

(g) destroy, damage, or disturb any foreshore or seabed (other than for the purpose of lawfully harvesting any plant or animal) in a manner that has or is likely to have an adverse effect on historic heritage unless expressly allowed by a national environmental standard, a rule in a regional coastal plan as well as a rule in a proposed regional coastal plan for the same region (if there is one), or a resource consent.

(2) No person may, unless expressly allowed by a national environmental standard, a rule in a regional coastal plan or in any proposed regional coastal plan for the same region, or a resource consent,

(a) occupy any part of the common marine and coastal area; or

(b) remove any sand, shingle, shell, or other natural material from that area.

(3) Without limiting subsection (1), no person may carry out any activity

(a) in, on, under, or over any coastal marine area; or

(b) in relation to any natural and physical resources contained within any coastal marine area,

in a manner that contravenes a national environmental standard, a rule in a regional coastal plan, or a rule in a proposed regional coastal plan for the same region (if there is one) unless the activity is expressly allowed by a resource consent or allowed by section 20A (certain existing lawful activities allowed).

The New Zealand Coastal Policy Statement (NZCPS, 2010) is a national policy statement under the Resource Management Act 1991 ('the Act'). The purpose of the NZCPS is to state policies in order to achieve the purpose of the Act in relation to the coastal environment of New Zealand. New Zealand Coastal Policy Statement guides local authorities in their day to day management of the coastal environment.

5. MAORI CONCERNS AND SEAWALL CONSTRUCTION CASE STUDY

The NZCPS (2010) does not have any specific policies on destruction in the Coastal Marine Area (CMA). However, it does highlight important values such as natural character and indigenous biodiversity that must be considered when activities are proposed in the CMA. Destruction in the CMA can also have significant adverse effects on ecosystem health and mahinga kai (Maori meaning - food-gathering place) especially in coastal habitats, where effects can be permanent and irreversible. In NZ considering the principles of the Treaty of Waitangi and kaitiakitanga, in relation to the coastal environment, recognise that Māori heritage where tangata-whenua (people of the land) have traditional and continuing cultural relationships with areas of the coastal environment, including places where they have lived and fished for generations. The NZ Environmental Protection agency (NZ EPA, n.d.) has a guideline website – on engaging with Maori people; so that their cultural sensitivities are respected and addressed in engineering projects.

A local example of a coastal construction from Wellington region can be cited from Scoop (2016). When the seawall had to be replaced in the city of Paekākāriki (Greater Wellington Region, KCDC), community participation was helpful. The seawall was constructed of timber, concrete and rock to replace the old timber seawall which has been in place for about 35 years. The consent covered the new seawall, as well as the existing rock revetments at either end of the wall, for a period of 35 years. A community design group was heavily involved in choosing the concept design to ensure the seawall reflected community values in Paekākāriki. The community had opportunity to discuss their preferred design in terms of amenity, as well as engineering issues such as access to dry beach, recreational possibilities and preferred materials. The project was given resource consent in 2016, allowing work to commence on the detailed design of the seawall followed by construction. This seawall was completed in 2018 with an estimated price tag of NZ\$11 million. This timeline and price for a small sea wall, is an indicator of the time that can be taken and costs for a larger coastal zone project such as a coastal reservoir in NZ.

6. CONCLUSIONS

This concept paper discussed the viability of having coastal reservoirs in NZ. Few possible locations were suggested, previous studies and relevant legislation were discussed. Also, the Maori concerns that must be addressed are highlighted. From the available literature, data and guidelines provided, it is seen that NZ problem is not that of water scarcity, but the coastal areas not having water in an earthquake or similar disaster event due to destruction of pipelines. A coastal reservoir may complement emergency civil defense water supply for low lying coastal urban areas, if it is made resiliently in the coastal (high value) zone and can provide the large populations resident there, until pipe borne water supplies are made available after repairs.

The possible technologies for a dam (in a coastal area) are mentioned. In the case of NZ earthquake resilience is emphasised. In a NZ context, if we can couple the coastal reservoir with many sea walls being constructed/repared, it will be a winner. Climate change and sea level rise too must be considered.

Advantages for a NZ coastal reservoir project are availability of high-quality data and studies and being a developed country, when need exists, funds being available. Disadvantages are the technical issues (which can be relatively easily overcome) but legal (policy) and cultural barriers will make it quite challenging. The project needs a mix of engineering, policy, ecological and sociological responses. A good strategy will be preparing the technological study and cost analysis and including the project in Council Long Term Plans. After a disaster when people ask why more drinking water storage is not there – construction may be viable.

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