NAPIER'S CROSS COUNTRY DRAIN - A SMART STORMWATER ASSET

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ABSTRACT

The Napier Cross Country Drain was designed to future-proof the drainage of suburban Napier. The scheme was conceived in 1995 and a discharge consent for 20 m^3/s capacity and land designations over the full length were granted in the late 1990s.

The underlying principle is to capture runoff from areas south of Napier City, and divert them directly to a coastal outfall, rather than have them flowing through low-lying residential areas. This frees up existing urban capacity for future infill development. It also provides an alternate discharge, increasing system robustness.

The scheme consists of a 4.3km drain with a $10m^3/s$ pump station (with provision for future upgrade). The pump station has three main pumps, with a fourth smaller (250L/s) pump for low flows.

Three 230m rising mains discharge onto Awatoto beach via a unique outfall comprising three architecturally designed "pods" within a wide shallow basin along the beachfront, to disperse water across the stony beach.

Power is provided to the main pumps by three dedicated diesel generators, which was more cost effective than supplying power from the main grid and removed the risk from major mains power outage during severe storms.

KEYWORDS

Flood risk, stormwater, drain, pump station, coastal outfall

PRESENTER PROFILE

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1 INTRODUCTION

Napier City has an interesting geological history, which leads to some unique topographic and drainage features that continue to provide engineering and management challenges for Council. Old Napier was built on the Hill, and along the narrow coastal spit connecting the Hill to the coast to the south. This is illustrated in Figure 1, which shows the landform as it was in 1865.

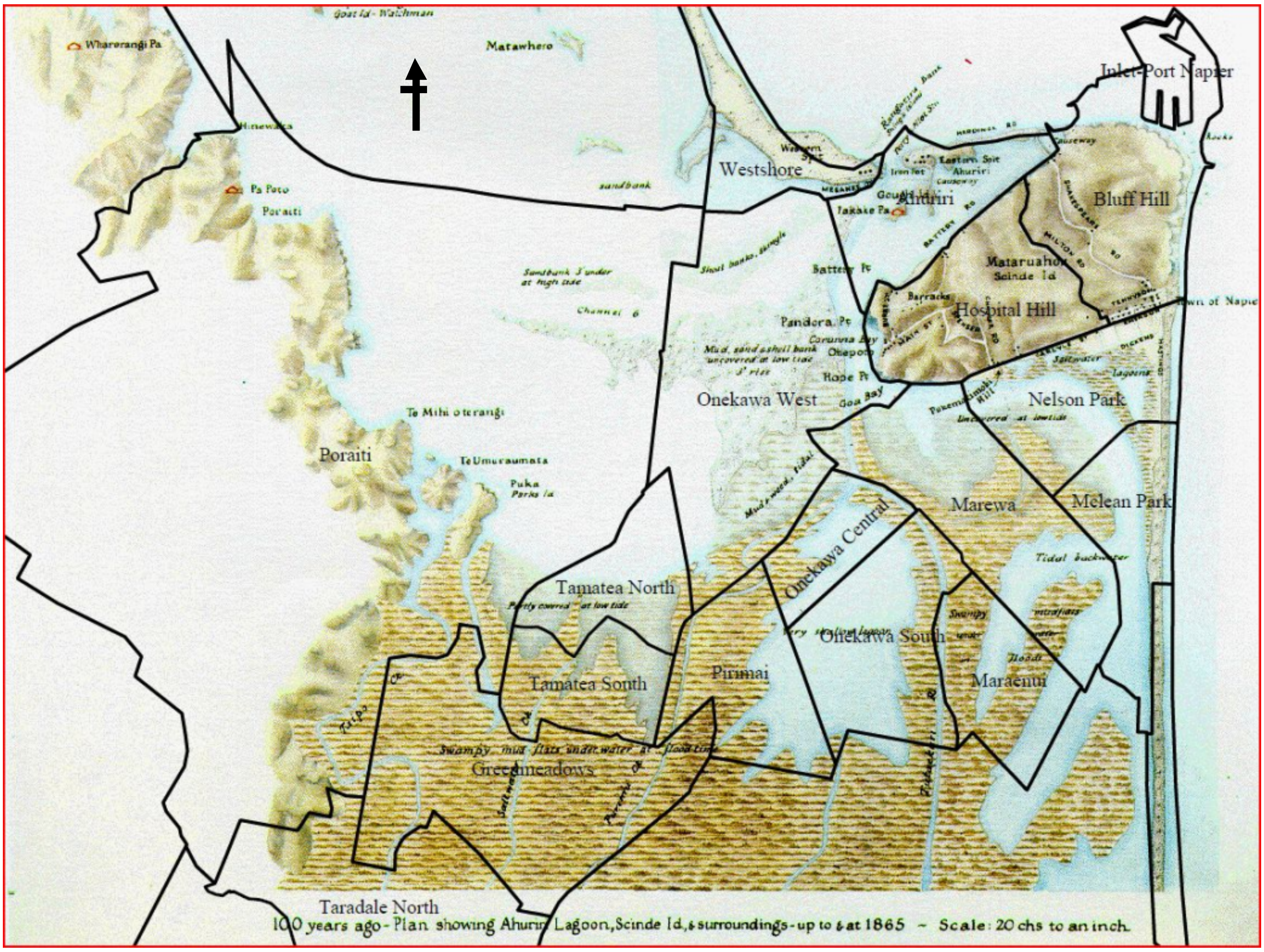


Figure 1: Napier landform pre-earthquake (Source: Napier City Council, 2000)

In the 1931 Hawke's Bay earthquake, there was uplift of about 2m in the northern coastal areas, and large parts of former estuary became dry land. Significant proportions of the city to the south and west of the Central Business Development (CBD) have developed on this new dry land, which is not much above sea level. The higher coastal dune in the east along Marine Parade and SH2 remains a topographic barrier, and adjacent land to the west of the dune drains west to the harbour, and out to sea at Ahuriri, with minimal gradient. Over the years the drainage of southern Napier has developed as a series of major trunk drains, flowing north and west by gravity during low tide, but with lift pumps to discharge during high tide and during larger flow events.

As Napier further develops to the south and west, and with infill, it will become increasingly difficult to provide the necessary flood management capacity within the constrained existing drain corridors and topography. The Cross Country Drain was a bold move to address both historical flood issues and future growth needs, by cutting across the existing drainage paths and providing a relief discharge directly to the coast just north of Awatoto.

This paper provides a conceptual overview of the Cross Country Drain, how the concept was developed, and addresses some specific unusual features. It pulls together what has been a long history, from initial conception in 1995 to final commissioning in November 2009.

2 WHY THE CROSS COUNTRY DRAIN?

2.1 THE NEED FOR DRAINAGE IMPROVEMENTS

As already described, southern Napier is relatively flat and low-lying. While Hawke's Bay generally enjoys a dry, mild climate, as for most parts of New Zealand it can also experience significant storm events. There is a history of flooding, particularly in older low-lying areas in the south of the City, such as Pirimai. This is illustrated in Figure 2, which shows both the existing flood footprint, and the expected reduction in that flood footprint due to the Cross Country Drain.

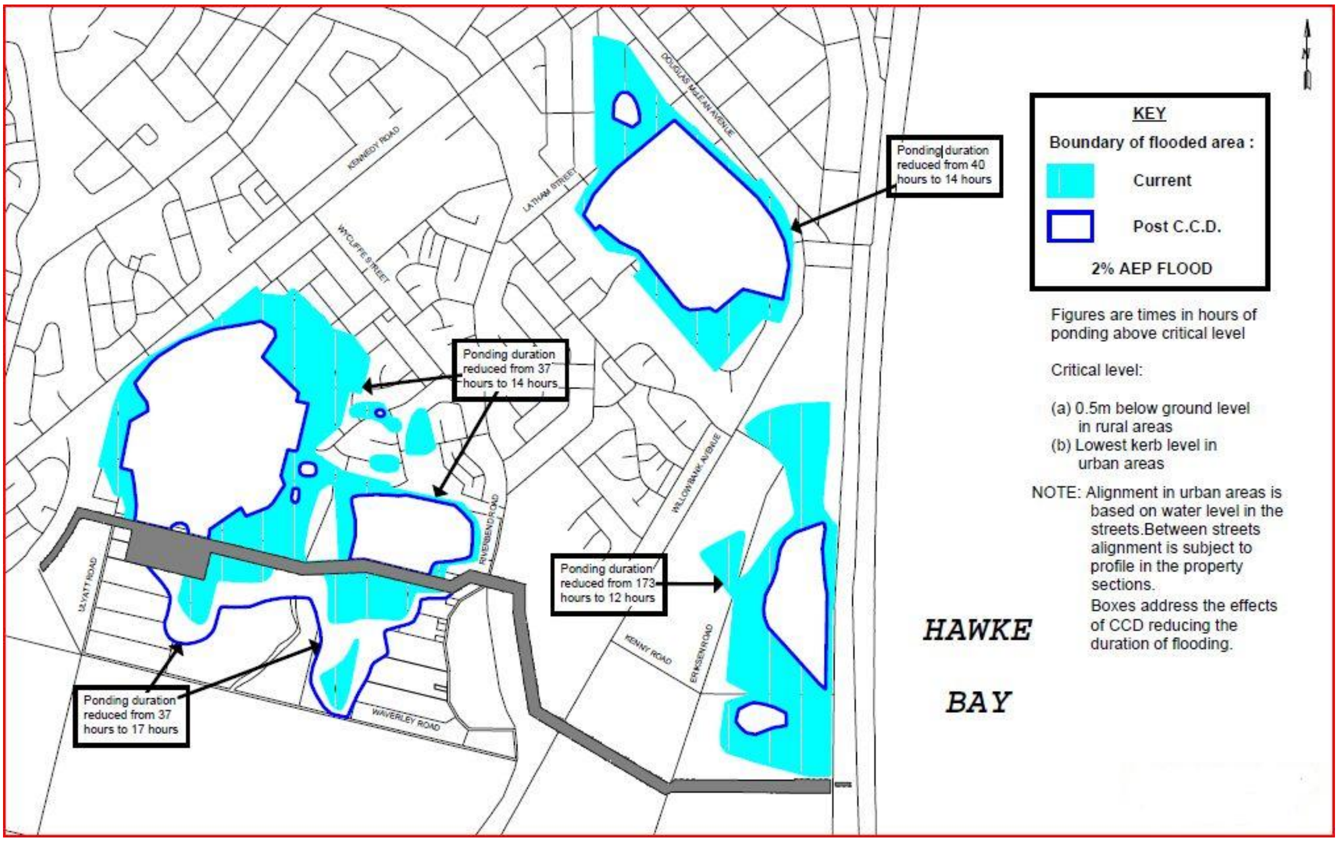


Figure 2: Southern Napier flood risk (Source: Napier City Council, 2000)

The CBD also experiences flooding, although that system operates largely independently of the catchment covered by this paper, and is not addressed further. Similarly, Taradale, to the south and west of the city, also has some flood prone areas, and again these are not addressed here, except in so far as some of the Taradale runoff discharges to the Purimu Drain, with flood consequences downstream. The Cross Country Drain provides discharge capacity to support drainage capacity improvements within the Taradale area.

The area covered by the study and influenced by the project is shown in Figure 3.

There are two principal drivers for drainage system improvements:

- Urban growth through greenfield and infill development;
- Existing flood problems in the southern city area.

Napier City Council undertakes a regular (5 yearly) assessment of infrastructure needs, including both the performance of existing systems, and the need for future system improvements. This was called their Essential Services Development Plan (ESDP) - this infrastructure planning process is now integrated with the Council's Long Term Plan and

Activity Management Plan processes. The 1995 ESDP, and the underlying stormwater technical report (Napier City Council, 1995), specifically identified the need to improve infrastructure for this southern Napier area and was the start of a process of investigations that led to the Cross Country Drain concept.

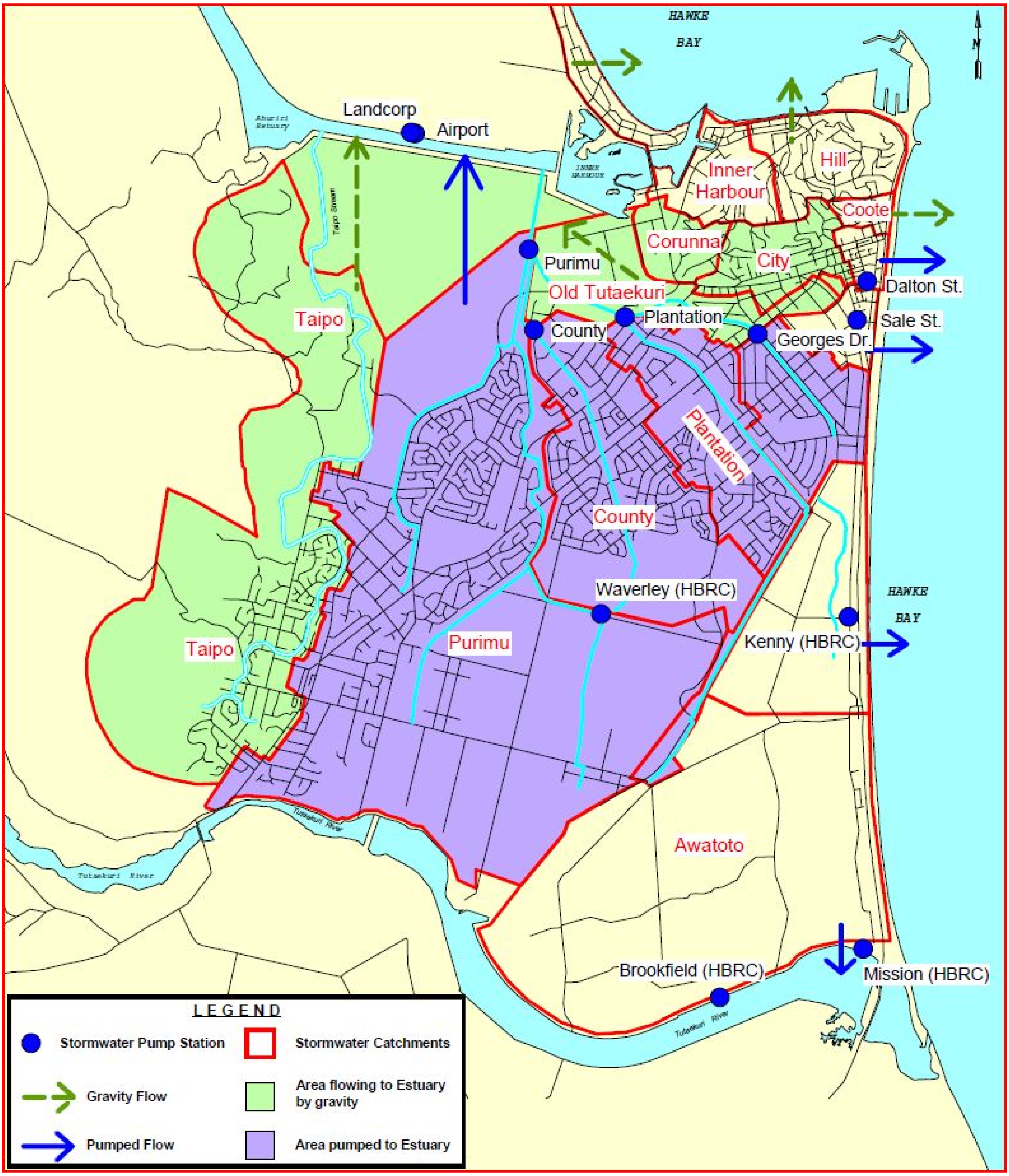


Figure 3: Napier City drainage overview (Source: Napier City Council, 2000)

2.2 OPTIONS STUDIES

With the need to address existing flood hazards, and to allow for growth, a range of options was considered and evaluated. This occurred in two stages. The first consisted of a comparison of the options to increase the capacity of the existing drainage system against the possibility of an entirely new approach to drainage of southern Napier. The performance of each of the options was evaluated using a MIKE-11 model developed for the wider Napier City area by Hydraulic Modelling Services. Engineering concepts were developed and costs estimated.

The option evaluation process involved qualitative comparison of the options, considering performance (flood levels, number of houses protected), costs, environmental and social effects, under a series of sub-categories selected specifically to suit the nature of the project. The outcome was that the Cross Country Drain concept came out as preferred.

Having established the preferred option as being a new Cross Country Drain, further options analysis was undertaken to confirm a preferred route. This options evaluation was undertaken in a similar qualitative manner.

There were two principal components needed to achieve the desired outcome: conveyance to the coast; and buffer storage to enable pump sizing to be optimised. Apart from several route options, there were also two conceptual approaches considered:

- A relatively narrow "conventional" drain, deep and steep-sided, with a flood storage pond at the downstream end. This option would have reduced the corridor width needed, though not necessarily the overall footprint.

- A wider corridor with a small main channel and flood plain conveyance. This option required no storage pond at the downstream end, as there was significant storage within the drain system. It also provided greater hydraulic conveyance and corridor flexibility, effectively future-proofing the route.

Napier City Council had experience with the different corridor options. County Drain is a narrow steep-sided drain with a limited corridor width for maintenance. It provides little opportunity for public amenity, and aesthetics are relatively low. This type of drain is relatively common in both urban and rural parts of Napier and the wider Hawke's Bay.

Georges Drive Drain is at the other end of the spectrum. While the main waterway is still relatively narrow, there is a wide grassed flood plain area, with trees and shrubs and public amenity. There are also roads both sides, and footpath access.

The narrow corridor of County Drain was one of the factors that counted against improvement of the existing drainage system – there was simply no room to increase conveyance without adopting expensive engineering structures to line the channel and improve cross-section, or buying additional residential property.

Council had a clear preference for the wider drain corridor option, both from a drainage maintenance point of view, and also because of the wider amenity function it could provide. Nevertheless, the options were still tested in the evaluation matrices. When all factors were considered, the wide corridor came out as being most appropriate. The evaluation matrix for this second stage of the process is illustrated in Figure 4.

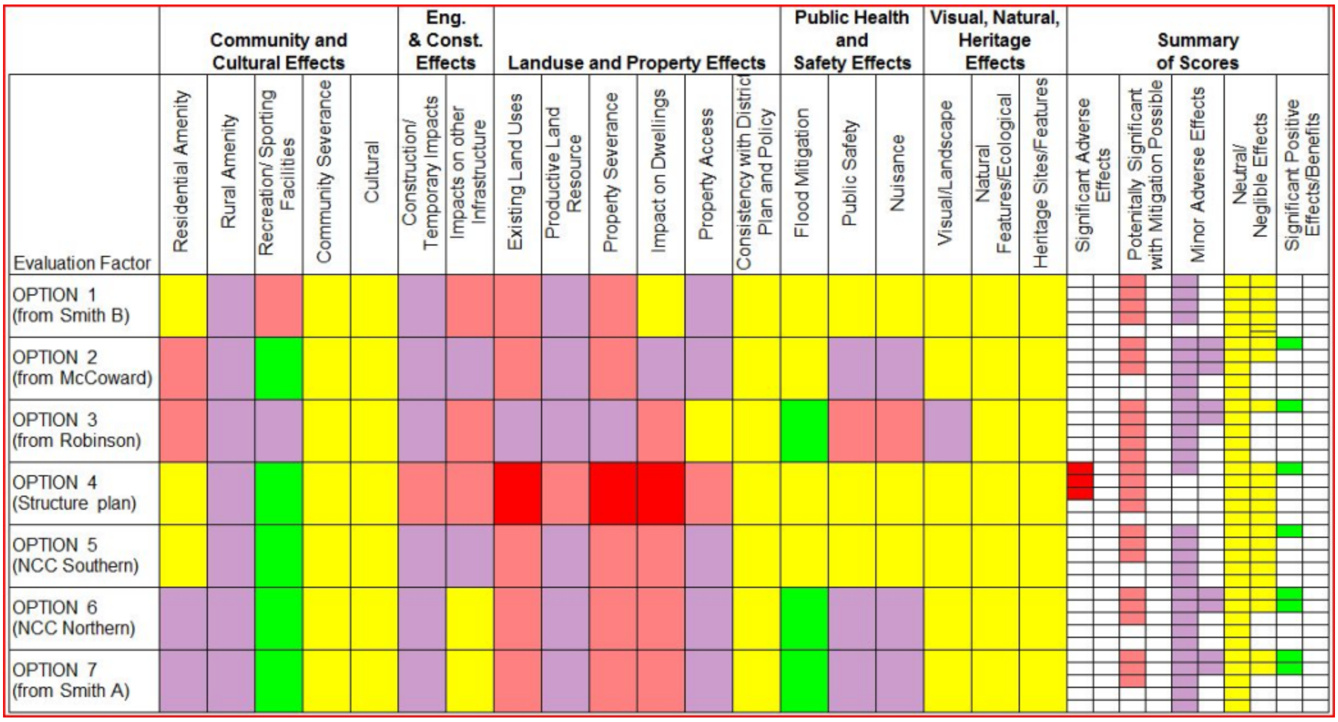


Figure 4: Evaluation matrix (Source: Beca Steven, 1996). Note colour coding for ratings is described in summary columns

The qualitative assessment and evaluation of the wide range of issues proved an important part not just of option section, but also as supporting evidence in the consent and designation hearings. It provided the AEE and the hearings with a robust justification for the selected option, against relatively strong opposition from several submitters. Despite having a designation, some opposition continued for many years, and delayed the process of purchase of land within the designation.

3 HOW DOES IT WORK?

3.1 OVERVIEW

The function of the cross country drain is illustrated in Figure 5. Key features are:

- The Purimu Stream can overflow at higher flood levels, with excess flow diverted east towards the coast.
- Upstream/southern rural reaches of County Drain, Plantation Drain and Serpentine Drain are cut off from the urban area, and redirected eastwards towards the coast.
- The southern urban reaches of County Drain and Plantation Drain can back-flow into the Cross Country Drain when flood levels in the urban area are high.

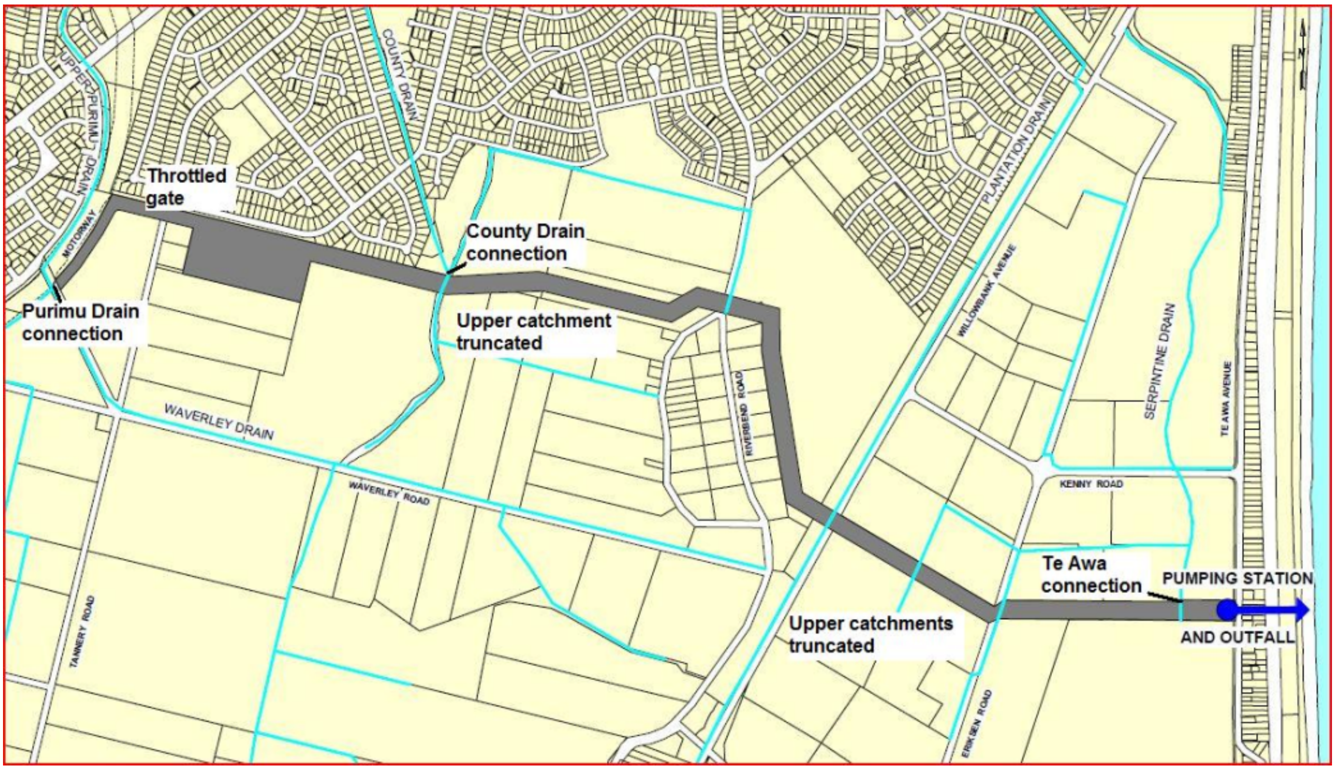


Figure 5: Cross Country Drain overview (Source: Napier City Council, 2000)

3.2 PURIMU DRAIN CONNECTION

The connection from Purimu Drain to the east has been carefully "tuned" in the hydraulic model to avoid making flooding any worse in the rural areas to the east. This is achieved by two means: an overflow sill that prevents flow from entering the Cross Country Drain in small events; and a throttled connection using hinged gates set on the first road crossing box culvert, with a maximum capacity of $4m^3/s$ flowing eastwards. The hinged connection will permit full flow in a westerly direction when water levels on the eastern side are greater than on the western side. This allows some relief of the Purimu system, without compromising flood risk to the east, but also lets the upper Cross Country Drain backflow to the Purimu when levels are lower there.

3.3 COUNTY DRAIN CONNECTION

The link to the County drain to the north is via a flood gate – water can flow south into the rural Cross Country Drain, but cannot flow north into the urban County Drain. County Drain contains some of the more flood-prone parts of southern Napier, and was badly affected in floods in 1971, 1974 and 2004. The Cross Country Drain relieves this to some extent by cutting off the inflow from rural areas to the south, and allowing some (relatively modest) outflow south.

3.4 TE AWA CONNECTION

At the downstream end of the Cross Country Drain, circumstances have changed since the Drain was initially conceived, and this has raised some interesting challenges. The low-lying Serpentine catchment to the north of the Drain was rural, and historically has had a small ($0.5m^3/s$) pump station at Kenny Road, discharging to the coast, managed by the Hawke's Bay Regional Council. In the last few years, the landowner in this area has obtained subdivision approval, and has developed residential properties. Following on from this, and from consideration of the wider area, Council is developing a Structure Plan and is proposing a Plan Change to make most of the catchment urban. This raised the question as to whether the Cross Country Drain should be modified to allow for drainage of this new development area, or whether a separate, upgraded, pump station should service the new growth area. The outcome was a combination, with primary discharge from the new Te Awa urban area to be from a new pump station, but with a managed cross-connection to the Cross Country Drain for emergency purposes. This enables some relief to either system in the case of a breakdown in performance of one of them.

A secondary aspect of the development at Te Awa is reverse sensitivity to the construction and operation of the pump station, which is addressed later in this paper.

This process has shown that, even with the best efforts at identifying optimal engineering solutions, circumstances can change, and the solutions need to be flexible enough to be able to adapt to those changing circumstances.

3.5 TYPICAL CROSS-SECTION

The drain has a typical cross-section consisting of a main, permanently wet channel of typically 7m base width, and typically 0.5m deep. This channel is at a low enough level (up to 5m below local ground level) to intercept the shallow water table in places, resulting in permanent seepage flows into and along the channel.

There is a maintenance track along one side at berm level, giving easy access directly to this main channel for maintenance purposes.

The grassed batters then slope up at 1 in 5 to meet adjacent ground, providing a gentle slope that is easily mowed and maintained. The resulting corridor is typically 50m wide, although it varies somewhat over the Drain length. At the downstream end the waterway widens out to provide sufficient forebay volume for pump operation, as illustrated in Photograph 1.

Photograph 1: Downstream end of drain, approaching pump station, looking west up the drain

The average gradient over the 4.3km length of the Drain is approximately 1 in 6000.

3.6 PUMP STATION AND OUTFALL

One of the features of flood pump stations is that their operation is very intermittent, with very little time spent at full capacity, and much of the time spent pumping either small base flows, or at partial capacity during small rainfall events. This is the case with the Cross Country Drain, and introduced some challenges which are addressed later in the paper, both for the pump station and the outfall.

The overall layout of the pump station and outfall is illustrated in Figure 6. The aerial photograph was taken while the pump station was still under construction.

Figure 6: Drain, pump station and coastal outfall (Source: Google Maps, annotated)

4 EARTHWORKS IMPLEMENTATION

Another factor that was a positive aspect of the project, but also resulted in some delays, related to management of the earthworks. There was a total earthworks volume of the order of 230,000m^3, most of which was cut to waste. With disposal options themselves having potentially significant consenting and cost hurdles, two "win-win" solutions were negotiated with third parties.

Transit NZ was planning to construct the Meeanee Road interchange on SH50, to the south west of the project. Timing of the Cross Country Dain works was adjusted to allow cut to be taken from the western parts of the Drain excavation directly to the site of the interchange fill.

To the immediate north-east of the Cross Country Drain, Te Awa Estates needed to raise the levels of their new subdivision to meet flood risk constraints. They undertook the excavation of the basic drain profile in the east, taking the cut material directly to their subdivision works.

These two joint arrangements made a significant difference to both the costs, and to managing the potential off-site effects, of implementing the Cross Country Drain project.

5 PUMP STATION

5.1 BACKGROUND

There were a number of challenges to the siting and design of the pump station. The first to be addressed was geological. The main coastal dune at Napier is coarse gravel, with the land behind being typically low-permeability riverine and estuarine deposits. The origins of this are evident from Figure 1. Historically the Tutaekuri River had flowed north behind this coastal dune, into the Ahuriri estuary and out to sea west of Napier Hill. Following the earthquake, it now discharges directly to the coast south of Awatoto, jointly with the Clive and Ngaruroro Rivers. A reminder of its original course is Riverbend Road, which is intersected by the Cross Country Drain.

5.2 SITE GEOLOGY

The dune gravels extend westward as lenses within the finer estuarine deposits, and provide a relatively direct hydraulic connection back to the coast. While Te Awa Avenue appears on the surface to be the boundary between the dune gravels and the low-lying deposits behind, subsurface investigations found that it was necessary to site the pump station 80m further west from Te Awa Avenue to avoid saline intrusion. One factor in this was the depth of the pump station invert (more than 3m below mean sea level), and the Drain normal operating level, at about 1.0m below mean sea level. The alternative would have been to site the pump station nearer to Te Awa Avenue, and to completely seal the forebay and downstream section of canal, but the risks associated with this for both construction and long term operation were decided to be too high.

5.3 PUMP STATION

The pump station was modelled to have an ultimate capacity of 16m^3/s, although for future flexibility a 20m^3/s capacity was consented. However, as a first stage, the capacity was set at 10m^3/s. This is provided by three axial flow pumps of 3.3m^3/s capacity, pumping against a static head of 5.6m and a dynamic head of 8.2m at full flow. Because these pumps start sequentially, and need to start against an empty rising main, three separate rising mains have been provided. Other options considered included the use of non-return valves for each pump, feeding into a single rising main. Reasons that this option was rejected included cost and reliability. The pump intake is shown in Photograph 2. Also visible in this photograph is the proximity of the houses developed as part of the Te Awa Estate area, post-designation but prior to pump station construction.

Photograph 2: Pump station intake screens and pumps

In addition to the provision of capacity for flood pumping, it was necessary to provide for the day-to-day seepage flows and inflow from minor rural drains. For this, a service pump of 250L/s capacity was provided. This pump also has its own rising main.

5.4 POWER SUPPLY

Power supply options were considered in some detail. The original concept was to operate the pumps from mains supply. For this, an upgraded power supply would have had to be brought into the area from some distance away. This option would have had to allow for the possibility of mains power outages, and an analysis of historical outages in the area showed that these could last for up to 4 hours. The risk of such an outage coinciding with a major storm event was considered to be relatively high, requiring sensitivity modelling of the flood risk with such an outage occurring. One potential mitigation for such a risk was to have a standby generator, and Napier City had been considering the possibility of having a portable generator that could be brought to the site if required. To operate even one $3.3m^3/s$ pump will have required a generator of about 900kVA capacity, which would have limited portability. In addition to this, the standing charges on the required mains power supply capacity would have been substantial, even if the pumps were not operating.

As a result of concerns around reliability and ongoing operational cost, an alternative approach was developed. This involved operating the much smaller and more regularly used service pump from the mains supply, but providing an individual diesel generator to power each main pump. These generators come in their own individual "containers", with a high level of sound insulation already provided. They are housed in a specially designed "shed" to further mitigate noise effects (as described below, and illustrated in Photograph 3). The generators start automatically based on level sensors in the forebay area.

Noise was clearly a potential risk to the project. When the Drain and pump station was consented and the designation put in place, there was rural land to the north, and a golf course to the south, with the nearest houses approximately 100m away to the east on the other side of Te Awa Avenue. By the time the pump station was being built, there was a subdivision immediately adjacent to the north, with the nearest houses only 15m away from the pump station, and 25m from the generators.

The principal source of noise was expected to be the diesel generators powering the pumps. While they would only operate intermittently, and only then during major storm events, it was nevertheless necessary to provide a high standard of noise reduction at the boundary. As described above, this was achieved through a combination of features on the generator units themselves, and through enclosing them in a "shed". The noise wall of the "shed" is to the north and east, where there is adjacent housing, but not to the south, which is golf course. This shielding was very successful. Despite their size, the generators are hardly audible beyond the site.

Photograph 3: Diesel generators and noise wall (viewed from golf course side), with control building at left rear

What was not expected was that there was further noise generated from vibration of the draft tubes of the pumps. In the event, this turned out to be caused by the tubes resonating at a frequency of about 1,000Hz, induced by a natural frequency of 118Hz due to pump blade/vane interaction and the flow characteristics through the tee connection with the pumping mains. Finite element modelling has shown that the vibration can be mitigated by installing a lobster back insert into the tee connection to direct flow, and acoustic wrapping the pump tubes.

Commissioning of the pumps and generators has proved very successful.

6 COASTAL DISCHARGE

6.1 BACKGROUND

Discharge to an open, high-energy coast such as at Napier is fraught with difficulties. There were the physical and morphological challenges of significant long-shore gravel movement, with potential to damage or bury any structures. Wave action was also a potential threat to the structures. In addition to this, the beach is pro-grading, and any intake faced the risk of being isolated within the dune, or becoming disconnected from the sea. On top of this, there were the aesthetic and environmental effects of large structures within a coastal environment that receives significant public use, with a very popular public walkway and cycleway along the foreshore.

These issues have been faced by Napier City before, and there are a variety of stormwater outfall designs along the foreshore to the north. The difference in this case was the scale of the outfall, particularly considering the higher discharges with future expansion of the CCD pump station’s capacity.

There are two "phases" to the outfall operation that the design needed to consider, and the concept development sought to address these in different ways. The first is the more regular "drainage" and service pump operation, which would occur on a more or less continuous basis, but only up to 250L/s. This was a much easier flow rate to manage. Second was the storm flow, expected to be relatively infrequent, a few times per year in operation, and only rarely at full capacity. It was recognised that the larger outfall could potentially cause scour on the beach that might need to be repaired afterwards.

6.2 OPTIONS

A range of options was considered. This included concepts similar to some of those further north, with a large concrete pipe or box, supported on piles, extending into the surf zone at high tide. This approach was rejected by Council on the grounds of aesthetics (due to scale), effects on the beach, reliability, and consequent difficulty with consenting.

The concept that was initially adopted and consented involved soakage of the smaller flows from the service pump into the beach gravels over approximately a 50m wide section of the front edge of the dune, with the larger flows jetting out through the centre onto the face of the dune. Provision was to be made for the central outlet to be extended coastward as the beach pro-graded over time, with the soakage area remaining at the original location. Potential risks with this approach were the possibility of long-term blockage of the soakage area over time, and the possibility of short term damage to the beach from focussed discharge of major flows. Both these concerns could have been addressed. The soakage capacity could be addressed by removing clogged surface gravel from the soakage area from time to time. The beach damage could be relatively quickly repaired with the use of bulldozers to redistribute beach gravel, enhanced by the natural long-shore gravel movement.

During the detailed design phase further investigations were undertaken into beach gravel permeability, and options were revisited. The final design involved a reversal of the original concept, with the service pump discharging through a relatively small fixed outlet similar to those elsewhere along the foreshore, and the large outlet being in a distributed form, spread along the top of the gravel dune. What was unusual in the context of a stormwater outlet was that, in recognition of the very prominent nature of the structure, Council commissioned an architect to come up with an aesthetically pleasing yet functional design. This resulted in a most unusual yet attractive design outcome.

The details are described below.

6.3 ADOPTED DESIGN

The adopted design involved the use of three architecturally designed "pods", which conceal the 1.8m diameter outlet risers. Each pump has a separate rising main, with lengths varying from 230 to 260m, and diameters in various sections varying from 1.0 to 1.3m. Each connects to an outlet pod, with the three pods set in a wider gravel basin. Some infiltration occurs, but at full sustained flow there will be overflow to and across the beach to the sea. The pods are illustrated in Photograph 4, which also shows the overflow sill (the lighter brown path to the left) and the beach beyond.

The pods were manufactured from COR-TEN steel and coated with a three layer corrosion protection system. In addition to the prime purpose of keeping the public at a safe distance from the discharge points, they symbolise a link between earth and water, serve as playground equipment and add to the visual experience to the south of the Marine Parade.

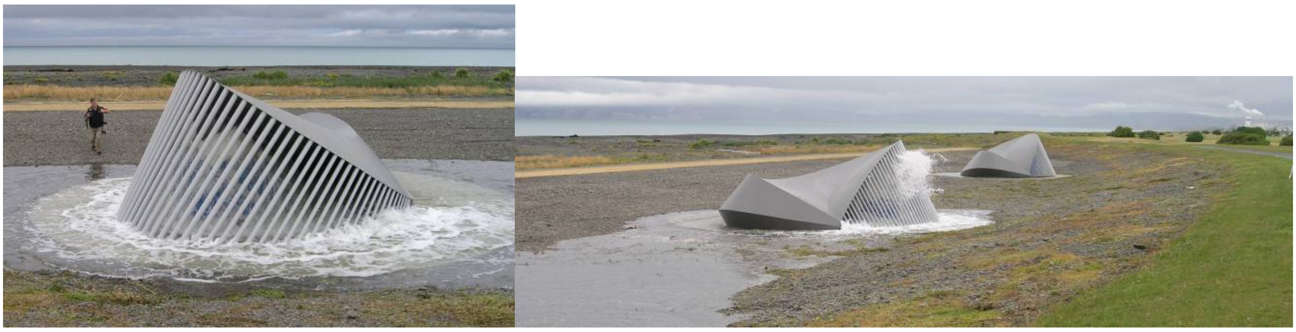
Photograph 4: Pod form – note third pod partly obscured in background

Small storms and drainage flows are pumped by the service pump, and discharge through a separate service outlet, illustrated in Photograph 5. This also provides for drain-down of the basin area around the pods following a larger storm event. The outlet is designed to be self-clearing in the event of blockage by beach gravel movement, and when operating it creates a localised scour hole on the foreshore. However, this effect is minor, and the structure will not provide any significant impediment to long-shore gravel movement. In the event of expected beach progression, the design allows for the end section to be unbolted, the outlet pipe extended, and the outlet reattached. This effectively future-proofs the design. Further, in the event of damage to the outlet section, it is relatively easy to remove it and replace with a new outlet.

This outlet is a trial use of coated COR-TEN steel in a very aggressive environment. Two years into its service life no corrosion has been observed and it is likely that a similar design will be used at other ocean discharge points. The outlet can be dismantled into segments small enough to re-coat if necessary.

Photograph 5: Service pump and drainage outlet

In larger storms the high flow pumps start sequentially. The riser is contained within the pod, and the discharge is vertically upwards through a 1.8m diameter riser 1.4 m high, spilling onto a concrete pad as shown in the first part of Photograph 6. This is contained within the pod structure, although as the pump reaches capacity there is significant turbulence, with water splashing out through the bars of the pod (as evident in the second part of Photograph 6). The discharge initially ponds within the gravel basin.



Photograph 6: Main pump start-up – first of three

Once the basin is full, flow spills towards the beach. Photograph 7 shows the basin full, and spilling about to commence over the sill. The overflow sill is 190m long, so at peak flow the water depth over the sill is less than 100mm. Nevertheless, for safety and serviceability reasons, the main coastal walkway has been deviated to the landward side of the outlet basin.

Photograph 7: Full operation – sill about to overflow to beach

One important maintenance requirement is that the beach crest between the sill and the coast be kept to a similar level as the sill. This is relatively easy to achieve through occasional maintenance with a bulldozer.

In the event of a future increase in pump station capacity to 16m^3/s, a further set of pumps, rising mains and pods can be built alongside the existing set.

The success of this outlet design lies in the way a relatively mundane function (a major coastal stormwater outlet) has been turned into an aesthetically pleasing feature that is consistent with the environment within which it has been placed.

7 OPERATION

Some reshaping of the beach to the east of the overflow weir was necessary post commissioning to remedy scouring of the beach crest. The pods were painted with a transparent anti-graffiti layer to ease the removal of graffiti but surprisingly graffiti has not been an issue. Children sometimes play on the pods and a few skateboarders have tried their luck but most of the time people do not climb on them.

The generators have proven to be very successful and it is possible to run all three pumps using two generators. When all three pumps are running at full speed the generators consume 350 litres of fuel per hour. Fuel levels are maintained at a relatively low level to prevent fuel ageing issues and when storms approach the tanks are filled to provide for 8 hours continuous running at full capacity.

Apart from the power source this pump station is operated in the same way as all the other stormwater pump stations in Napier.

8 CONCLUSIONS

There are a number of aspects of the Cross Country Drain project that are unusual, but contribute to its success. Key features are:

- The provision of a strategic cross-country diversion/relief drain, rather than a more conventional approach of increasing capacity on existing urban drainage systems.
- The use of a wide drainage corridor, allowing for wider amenity use, and giving sufficient room to allow capacity improvements in the future.
- The use of large diesel generators rather than mains supply to power the pumps, and the way in which noise issues have been able to be addressed in what is now a residential environment.
- The use of an architectural approach to creating a positive feature out of the stormwater outlet, in a manner that is also appropriate in the high energy coastal environment.

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