Nature City. How our cities can adapt to climate change.

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Abstract: The effects of climate change on the New Zealand city will be the biggest disruptive event in the history of New Zealand urbanism. This paper discusses whether our existing urban development planning model can adapt to the coming environmental depredation occasioned by climate change or will this urban model have to change. The paper will explore how by re framing the typical urban development site within the wider urban catchment, an understanding of larger environmental problems can be apprehended. Through the use of catchment analysis and GIS modelling, the implications of climate changes for an urban development site can be understood. The consequences of applying appropriate environmental remediation remedies to combat the disruptive effects of climate change on the conventional urban development plan are explored. The investigation finds that an urban development can become a resilient to the effects of climate change by developing an adaptive landscape strategy. Building an indigenous and ecologically viable landscape will help to increase biodiversity, ameliorate the consequences of contaminated stormwater and reduce flooding. This process calls for an interdisciplinary approach of architecture-related disciplines to help improve the performance of buildings and urbanism in the face of the effects of climate change.

Keywords: Climate Change, Urbanism, Catchments, Resilience.

1.1. Climate Change

Climate change is expected to cause extreme weather events such as flooding, severe storms, droughts and heat waves (Pachauri, 2014). The average global rainfall is predicted to grow (however this will not be average across the planet). The atmosphere is warming, increasing the capacity to hold more water, thus causing more rain. Major widespread flooding will be the result. This will have catastrophic results for low-lying countries especially around deltas like Bangladesh and the islands of the Pacific, but a number of world cities are also built in low-lying coastal areas.
The increase in air temperature is leading to the melting of the ice caps. This will have the effect of raising sea levels. According to the Intergovernmental Panel on Climate Change (IPCC) sea levels are expected to rise by 1.00m by 2100, however their figures have recently been reconfigured and now sea level is expected to rise by 2.000mm (Pachauri, 2014) . The result will be increased coastal flooding and an increase in littoral damage from storm surges. The increase in storm events will also lead to pluvial flooding.

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The National Institute of Water and Atmospheric Research (NIWA) (Dean, 2017) has predicted more extreme weather events will occur in NZ. Increased flooding and increased droughts are very likely for different parts of the country. The effect of climate change on the urban development in NZ will be profound.

2.1. Effects of climate change on urban development

Cities will be especially vulnerable as large amounts of impervious surfaces present in many cities mean that flooding will be difficult to absorb (Boyd et al., 1993). The built environment and the physical infrastructure of the city are often obstructive to flooding pathways, causing increased damage. Because of the highly impervious nature of the typical urban development, the existing stormwater infrastructure can often be overwhelmed by sudden storm events. This causes surface flooding to varying levels of intensity (Houston et al., 2011).

Waterfront development, at the downstream end of the catchment, will be the recipient of the flood water from the catchment (Houston et al., 2011). The water's edge of the typical urban development is often the most critical part of the project. This is the location of the main public space and the location of the most valuable real estate. This is also the most vulnerable place because it is directly affected by coastal flooding. This condition will be exacerbated by the effect of sea-level rise and storm surges (Vitousek et al., 2017).

There will also be an increase in run-off from impervious urban surfaces. The run-off will pick up contaminants from dirty urban surfaces: roofs, roads and footpaths. The discharge of this untreated water into urban streams and waterfronts will lead to the pollution of the receiving environment (Cromwell, 2009). Many urban developments are at the end point for the production of contaminated run-off from roads and buildings that is collected in a piped infrastructure and discharged into an adjacent receiving environment. The discharge of toxins into this environments has a deleterious effect on the biota in the receiving environment (Schiffa et al., 2002) (Kelly, 2010).

3.1 A new urban development methodology.

The evolution of a new urban development methodology that can help build resilience to the environmental effects of climate change is desirable. The following description is a sketch of a design methodology developed by the author to address these issues. This is followed by a case study which demonstrates how the design methodology could be actuated. The methodology is broken into three parts; an inventory of an existing site, a consideration of the potential of the site for development, and lastly, the design process for developing an urban development for a site to ensure resilient from the effects of climate change.

The first part in the construction of the development methodology is to build an inventory and analysis of the development site within the hydrological catchment. A catchment is a geographical unit in which the hydrological cycle and its components can be analysed (Cretu et al., 2010). To understand how water will behave in the city or the countryside, the catchment (known as a watershed in America) is defined as a specific geographical unit.

The inventory would consist of; the location and boundaries of development site and the location and boundaries of the catchment. The placement of the development site within the catchment would be defined through aerial photos, mapping the topography and vegetation of the catchment, and the

mapping the hydrology, in particular the overland flow paths. The inventory would also encompass a study of any existing environmental problems with the site, in particular the ratio of pervious to impervious surfaces. The percentage of pervious and impervious surfaces within a catchment is a critical measure in understanding the hydrological behaviour within a catchment. If this information is not available as a shape file, then there are a number of ways of deriving this information. The simplest way to understand this ratio is through an aerial photo survey to measure the percentage of buildings and roads versus unbuilt surfaces such as parks and reserves. This method doesn't allow for any complex analysis to include factors such as the soil condition and the types of absorbent vegetation. To give more certainty, ground truthing (a site inspection) of the selected landscape can yield a more accurate analysis of the specificity of the ground conditions. Finally, a specialist investigation of soil and subsoil conditions will yield hard data on the ability of soils to absorb run-off.
and the possibility of flooding.

The second part of the proposed development methodology is concerned with the urban development potential of the site within the catchment. This can be measured in a number of ways. The financial return of the site can be understood with simple development ratios, the gross floor area (GFA) and the floor area ratio (FAR). Property developers use these ratios to understand the financial costs and returns on a development site. Gross Floor Area (GFA) is a term that refers to the total floor area within the building walls. This term includes all the structure and spaces but excludes the roof. The term Net Floor Area (NFA) refers to the GFA minus the structural area, while the Usable Floor Area or leasable floor area (LFA) is the NFA minus the functional areas and circulation areas, (corridors, atrium and lobby) (BOMA, 2017). The amount of allowable GFA on the site is usually regulated by local governments. They often use a ratio known as the Floor Area Ratio (FAR). This is the relationship of the building GFA to the area of the building plot. This ratio can be refigured in different ways: the typical example is FAR of 1. This can be a one-storey building occupying 100 percent of the site, or a four-storey building occupying 25 percent of the site. If planning authorities wish the building footprint to be totally occupied but want to indicate a building height, then the ratio could be 1.5 or 2.0 (Bertaud and Brueckner, 2005).
The development potential of a site can also be understood through the development of structure plans and master plans, these show how the site might be developed to different degrees of detail, from simple zoning layouts to detailed infrastructure layouts with building distribution.

The implications for building environmental resilience to the environmental effects if climate change can be analysed in a number of ways. The environmental implications of a development ratio, the potential GFA and FAR of a site, can be translated into a simple ratio of permeable and impervious surface for a development site, this can demonstrate how the hydrological balance of a site will be affected by a development.
The impact of a more sophisticated masterplan on the environmental character of a site can be tested by superimposing the plan over the existing site analysis. Some of the environmental implication of the master plan that can be understood in the way the urban development might for instance, block an overland flow path thus preventing the conveyance of future flooding or the way a development might be flooded by sea level rise. The implication of an increase of impervious surfaces can also be understood through the use of the rational method. The rational method is a commonly used mathematical equation to calculate the maximum value of flood run-off from a small catchment. This is a formula that relates the intensity of rainfall, the area of the catchment and the consequent run-off (Thompson, 2007). , in New Zealand, the National Institute of Water and Atmospheric Research (NIWA)

has developed an online calculator for any New Zealand location. There are also a number of online tools to help with this calculation (LMNO Engineering Research and Software, 2015).

The third part of the development methodology can be divided into two parts, landscape and architectural. Into these categories fall the actual techniques used to make the development site resilient to the effects of climate change. Some of the techniques that can be used are derived from LIUDD techniques and GIS operations. Low Impact Urban Design (LIUDD) is a theory and practice that looks at how the planning of cities can be achieved with the least impact on the natural environment, in particular, the original hydrological cycle. The NZ originators of LIUDD (van Roon et al., 2006) are influenced by two theoretical poles, the ecological, in particular the environmental mapping techniques of McHarg (McHarg, 1969) , and Arendt (Arendt et al., 1994) and urban sustainability, especially the ideas of Newman and Kenworth (Newman, 1999). Geographic Information System (GIS) is software that helps in the analysis and design of data, especially environmental data (Schuurman, 2004).
Specific techniques include; protecting the hydrological pattern of the site by buffering the overland flow paths that run through the development site from the greater catchment and protecting the littoral through buffering the harbour/ river edge. Protection of riparian margins is critical to the protection of stream networks. This goal can be accomplished with the indigenous planting of high biomass species in a buffer zone around the stream. This method helps to increase aquatic and terrestrial biodiversity within the riparian corridors. In addition to riparian corridors, wetland and flood detention areas should also be protected by planning a buffer area around these zones. By protecting the areas around urban streams through the replanting of indigenous species, erosion can be reduced, sediment trapped, and phosphorus, nitrogen, and other contaminants present in urban run-off can be filtered before reaching the stream, protecting and enhancing both aquatic and terrestrial wildlife habitats (Wenger and Fowler, 2000). To ensure buffer zones function, the planting should be a 15 to 30m margin. While grass will help absorb pollution in overland flows, the planting of indigenous vegetation, preferably from the appropriate ecotones, is the best-practice solution. The buffered hydrological network can also act as a flood corridor during extreme rainfalls, as well as being used as a connector of urban patches. Social activities such as parks, reserves and sport facilities can be located along stream margins, as they help to increase the amount of pervious surface within the urban development. A specific GIS function, buffering, can be used to delineate a buffer around existing stream and overland flow paths. (ArcGIS, 2015)

The design consequences of these operations are varied, for example, the buffered overland flow path (OLFP) could be used for pluvial flooding conveyance and detention. The OLFP could also be planting with indigenous vegetation to help encourage evapotranspiration and lower the urban heat island effect. The buffered OLFP network could also be used to locate stormwater treatments devices such as wetlands to treat stormwater from the larger catchment. The buffered harbour water edges could help to form and locate soft barriers to coastal flooding.
The net effect of these remediation techniques on the catchment can be measured through a recalculation of the permeable /impermeable surface ratio. The percentage of pervious and impervious surfaces within a catchment is a critical measure in understanding the hydrological behaviour within a catchment. If this information is not available as a shape file, then there are a number of ways of deriving this information. The simplest way to understand this ratio is through an aerial photo survey to measure the percentage of buildings and roads versus unbuilt surfaces such as parks and reserves. This method doesn't allow for any complex analysis to include factors such as the soil condition and the

types of absorbent vegetation. To give more certainty, ground truthing (a site inspection) of the selected landscape can yield a more accurate analysis of the specificity of the ground conditions. Finally, a specialist investigation of soil and subsoil conditions will yield hard data on the ability of soils to absorb run-off.

This has two consequences, the first is the development of a new urban masterplan that is more open and greener with a number of remediatory regimes to help build urban resilience to the effects of climate change. The implication of this new masterplan on the conventional real estate programme requires a change in thinking about how the required amount of GFA to make the project financially viable might be allocated. This can be accomplished through the LIUDD strategies of clustering the building programme. Clustering is an idea that uses the amalgamation of buildings in a subdivision to free up land for other purpose such as amenity, recreation, utility or, in the LIUDD world, protecting environmentally sensitive zones. The traditional way in which building clustering occurs is the village, an urban form where houses are grouped together. This basic housing morphology can be amended in different way to produce a number of different housing types that can still meet the definition of clustering, such as row housing. An early definition of cluster housing is by William Whyte (Whyte, 1964).

By recalculating the GFA into a new FAR, a reconfigured building footprint driven by the dictates of the environmental remediation programme, the financial returns of the original real estate investment can be accomplished. The urban and architectural consequences of the reconfigured urban programs can be modeled in ArcGIS, graphically represented through the extrusion of the proposed building footprint.

4.1 Case Study; The Rarawara catchment, Whenuapai, Auckland

Auckland is undergoing rapid urban growth. More than one million new citizens are expected to arrive in Auckland over the next 20 years. As a consequence of this growth there is an acute housing shortage. Whenuapai is located adjacent to SH16, an important motorway in the western growth corridor and near the new NorthWest Shopping Centre. Whenuapai also neighbours the successful Hobsonville housing development, making Whenuapai the next site for future urban development. To address the urban pressure Auckland is facing, the Auckland Council, in 2016, developed an urban structure plan for Whenuapai to help conceptualise the shape of future urban development. The structure plan efficiently zones the available land according to proximity to infrastructure; industrial land and an apartment zone are located adjacent to the main transport routes, SH16 and 18. Lower density housing zones are located nearer to the edge of the Waitematā Harbour. Single-storey housing with large sites are zoned for the coastal margin, while more intensive housing (medium density) is zoned between the coastal edge and the industrial zone.

To explore how the structure plan might be made more responsive to the environmental issues that will be occasioned by the environmental effects of Climate Change, a sub-catchment of the larger Whenuapai catchment was chosen as a case study site. The selected site was the Rarawara sub- catchment to both understand the consequences of the proposed urban development.

The effect of the Auckland Council's Whenuapai structure plan on the Rarawara catchment is to configure the catchment into four housing zones and an industrial zone (Auckland Council, 2016). The area closest to the coast is zoned for low-density, single-storey housing, along an approximately 100ha coastal margin. Allowing for one dwelling unit (DU) per 500m^2 gives 2008 DUs, and 50ha of impervious surfaces. A medium-density housing zone of 82ha is planned behind the coastal zone. Allowing for one

DU per 300m^2 equals 2743 DU, giving 61ha of impervious surface. The remaining area is zoned industrial/commercial with two apartment zones to the east of the airfield zone. Three parks are proposed of approximately 35ha in total. Roads proposed and existing housing make up 212ha of impervious surface.

5.2. Rarawara Catchment Site Analysis.

The 324ha Rarawara catchment is a moderately flat site bounded to the north by the Waitematā Harbour. To the west the site is defined by the Brigham Creek/Pitoitoi Stream catchment, to the east by Whenuapai village and airfield and, to the south, by the intersection of SHW16 and 18.

Vegetation

The predominant vegetation in the catchment is grass, the result of the rural economy of the catchment. The other vegetation type are decorative gardens around the housing areas, and shelterbelt species from the small horticulture and orchard blocks.

Hydrology

The catchment drains into the dominant stream, the Rarawara Creek (fig. 9). The creek runs roughly north south and bisects the catchment. There are three sub-catchments. The stream exits into an estuarine mouth before connecting to the Waitematā Harbour. There are smaller streams from the hinterland to the coast on either side of the Rarawara catchment.

Aspect and Slope

The aspect of the Rarawara catchment is mostly northerly with an east-west division along the sides of the stream corridors. The slope of the majority of the site is flat, 0-5 degrees, especially the aerodrome site. However, alongside the steam corridors the slope increases from 5 to 16 degrees.

Land Use

The land of the catchment is separated into two broad uses. The first is suburban housing, large lifestyle houses and sections on the northern coastal edge, and a smaller subdivision to the west of the airfield. The rest of the catchment is made up of rural lifestyle blocks, and small horticulture and orchard blocks.

Pervious/Impervious Ratio

Due to its mostly rural nature, the catchment is largely made of pervious surfaces . The impervious areas are the roading infrastructure and the airfield .

- The existing Rarawara catchment area is 324.1753 hectares.
- The impervious surface area is made up of roads (81.8428 hectares) and buildings (20.1004 hectares).
- The total impervious surface area is 104.1488 hectares
- The total pervious surface area is 220.0265 hectares
- Giving a ratio of pervious to impervious of 2:11.

5.3. Rarawara Catchment: Environmental Problems

With the construction of the new housing and the associated infrastructure, the hydrological pattern of the existing territory will be irrevocably changed; increased run-off with increased sedimentation will add to already high levels of sedimentation in the upper Waitematā Harbour. Run-off will also be polluted from roading contaminants and roof debris.

Pervious/Impervious Ratio

In the Auckland Council structure plan the impervious surface in the Rarawara catchment will increase markedly.

- The existing Rarawara catchment area is 324.1753 hectares
- The impervious surface area is made up of road, (81.8428 hectares), and buildings (206.9095 hectares),
- The total impervious surface area is 288.7523 hectares.
- The total pervious surface area is 35.423 hectares
- Giving a ratio of pervious to impervious of 8:1 (fig. 21).

If this plan was built, then the result of this high degree of imperviousness would be a large amount of contaminated stormwater run-off discharging into the harbour.

To calculate the volume of stormwater that would be discharged from the catchment under the new structure plan, the Rational Method can be used.(Thompson, 2007) To calculate the required volume for the construction of a storage and treatment wetland TP10 (Auckland Council, 2003) is used.

- The run-off discharge flow rate over two years (m^3/sec) would be 5.95 m^3/sec.
- The required storage and treatment wetland for this run-off is sized at 32140.04m^3.
- For a 10-year run-off discharge flow rate of 8.71 m^3/sec,
- The required storage volume is 47019.68m^3.
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- For a 100-year run-off discharge flow rate of 13.95 m^3/sec,
- The required storage volume is 75350.53m^3.

Rarawara Catchment: Environmental Remediation: Design Process

To ameliorate the effects of urbanisation on the coastal receiving environment, an understanding of the hydrological behaviour of the catchment is necessary. The first step is to determine the structure and shape and size of the catchment on the site, through mapping with ARCGIS. This data can be manifested as a series of maps showing catchment boundaries and a network of overland flow paths. From this mapping we can determine both the size of the catchment and the ratio of impervious to pervious surface. Using the Rational Method, we can gain an understanding of what the rainfall run-off will be with the expanded site. By measuring the increase in impervious surface due to the number and type of housing zones, the increase in stormwater run-off can be calculated. Once the connection of housing density to the impervious/pervious surface ratio is established, the different zoning densities and associated impervious/pervious ratios can be manipulated to allow for greater permeability, while at the same time ensuring that the planned number of dwelling units remains the same.

Hydrology

How can the environmental damage from an increase in stormwater discharge into the upper Waitematā catchment be ameliorated? Decreasing the amount of impervious surface through the

removal of infrastructure such as roads and housing will lead to an increase in the amount of pervious surface, leading to an increase in the absorption of stormwater run-off.
One way to increase the pervious surface of the catchment is by protecting and enhancing the existing stream network by establishing a protective buffer zone of at least 25m around the stream and overland flow paths Protection of the coastal edge is another important environmental measure; a buffer of 30m would give a zone of 43ha. These two measures increase the area of pervious surfaces within the catchment by 128ha. This intervention also has the effect of developing a new park system along the stream corridors and the waterfront coastal edge

Accommodating these two measures necessitates a change in the housing footprint. This is accomplished by decreasing the low-density zone from 100ha to 23ha, and decreasing the medium- density zone slightly, from 82ha to 74ha.

5.4. Rarawara Catchment: Urban Design.

To accomplish the increase in pervious surfaces and the consequent decrease in stormwater discharge means a loss of housing units. Under the Auckland Council structure plan the number of low-density DUs in the catchment is 2008 and medium density is 2743, equalling 4752 DUs (with no provision for high-density units). By enlarging the pervious surface area, the number of DUs in the low-density zone will drop to 473 DUs and in the medium density zone to 2471 DUs. The shortfall in DUs will be 1827.

One solution to this real estate shortfall is to substitute apartments for the missing lower density DUs. This solution will increase the number of DUs to 1468, making a total of 4420. By increasing the number of apartments by making the building denser or higher, the shortfall of 1827 DUs could be matched or even surpassed to give a better real estate return
The new apartments could be located in the coastal zone around the existing stream mouth, an area of 8.8ha would provide two high-density apartment zones within the low-density area.

Pervious/Impervious Ratio

- The Rarawara catchment area (324.1753 hectares)
- Impervious surface of 196.1642 hectares, roads, (65.9289 hectares), and buildings, (130.2353 hectares)
- Pervious surface, 128.001 hectares
- Giving a ratio of pervious to impervious of 2:3.

Using the Rational Method, the effect of the new pervious surfaces will lead to a two-year run-off discharge flow rate of 29304.15042m^3, compared to the discharge of 26468.26489m^3 from the original site and 32140.03594m^3 discharge with the proposed Auckland Council structure plan.
In the 10-year run-off discharge, the flow rate of the new plan is 42870.88672m^3, compared to the discharge of 38722.09123m^3 from the original site and 47019.68221m^3 from the proposed Auckland Council plan.
In the 100-year run-off discharge, the flow rate of the new plan is 68701.95265m^3 compared to 62053.37659m^3 in the original site and 75350.52871m^3 in the Auckland Council proposed plan.

5.5. Rarawara Catchment: Environmental Implications of the Design Process

Stream Network

A buffer zone around the revealed hydrological network will enable the stream corridors to be revegetated with native species. The zone also gives the opportunity to allow for the location of structural stormwater cleaning instruments – in particular, wetlands and a rain garden – these can all be installed within the new zone. This stream zone can form a deep connection from the coastal edge to the hinterland, creating an ecological corridor

Having housing adjacent to the new river zone will also help to increase real estate values. By locating medium-density housing along the edges of the new stream parks, owners can enjoy views of the water and native vegetation. The nature of the new river zones and the link from the coast to the hinterland provide the opportunity for owners in the centre of the development to have access to the coast.

Coastal Zone

Establishing a coastal buffer zone means that the critical environmental conditions in this zone will be protected. Critical riparian ecologies can be restored and protected, damage from building in this zone can be ameliorated.

Establishing a protective buffer zone around the coastal and stream hydrological networks will increase the ability of the Rarawara catchment to absorb rainfall, rather than add to run-off into the upper Waitematā Harbour. To ensure the same economic return is met – that the same number of DUs are constructed as specified in the Auckland Council structure plan – the loss of low- and medium-density housing is met by a greater number of apartments with a smaller, denser footprint. The result will be a low-rise domestic landscape of gardens and houses broken by tall, prismatic apartment towers that emphasise the unique stream system.

One criticism of this urban design proposal might be that building apartments in the coastal zone is an urban typology that is hostile to the Auckland suburban ethos. However, there are many existing examples of residential apartments in Auckland coastal suburbs such as Kohimarama, Herne Bay and Takapuna. These examples demonstrate the possibility of coexistence between low-density, two-storey, single housing on the coastal edge with apartment dwelling. A new 14-storey apartment building has also been recently proposed for the neighbouring suburb, Hobsonville Point (Gibson 2018)

5.6. Whenuapai Catchment: Environmental Implications of the Rarawara Case Study Investigation

The new structure plan shows how the coastline and stream corridors are protected through buffering. There are three consequences of this action; the first is that the vegetative buffers have the effect of protecting the hydrological network by protecting the streams from the influx of contaminated stormwater. The second effect is that the ratio of impervious to pervious surface is relaxed, ensuring that more rainfall is able to be absorbed by uncovered ground. A social consequence of this new green network is the establishment of a new path/park system that links the hinterland of the subdivision with the coast. The third consequence of this action is the clustering of the GFA that has been displaced by the new stream/buffer stream network into a series of apartment towers located at the intersection of the stream networks and the coast

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