PRELOADING

A Transformative Approach to Flood Preparation and Relief

by
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AUTHOR’S DECLARATION

I herby declare that I am the Sole author of this thesis. This is a true copy of the thesis including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public

ABSTRACT

For islands and coastal cities, the body of water that nourishes the land can easily become a leading source of threat. Natural disasters are mostly unpredictable and often have devastating impact on life and property. Although intensive tsunami inundations rarely occur, annual recurring flooding caused by rising water levels and coastal inundation is a common problem. People are often repeatedly trapped in flooded homes or are forced to quickly evacuate to inadequate temporary shelters.

Two common approaches to flood threat are to build permanent barriers or to physically distance people from the water. However, as the water is essential to the livelihood of islands and coastal cities, these approaches often create more harm than good, destroying the normal beneficial relationship between the people and the water. Damage to homes and the destruction of communities are often inevitable, and thus require large amounts of material and time for post-disaster reconstruction. Since external resources are expensive and difficult to transport during times of need, the lack of immediate internal response to sudden natural disasters can cause severe delays in the disaster relief process and hinder the future redevelopment of the community. Consequently, the urgent issue is how to incorporate flood readiness into the built environment.

How do we prepare ourselves for the occurrence and recurrence of flooding in coastal cities? This thesis proposes that, in desgining for disasters, the architect's objective should be to design buildings that can respond to, recover from, and be resilient against water inundation. This thesis investigates a new strategy for flood protection and relief within the context of Port Alberni, British Columbia. The aim is to establish interconnected relationships between pre- and post-disaster buildings, materials, and resources. This means designing existing architecture in public space to contain the material and programmatic capacity to partially withstand flooding and strategically transform into spaces for flood relief. These, in turn, contribute to the rebuilding of a resilient community. Daily public interactions with these architectural elements can also preload the residents with disaster awareness and knowledge for disaster relief. The design aims to reduce the gap between the urgent need for shelter and the speed of reaction to flood events, at the same time, create an architectural syntax that constructs place and brings people back to the water.

ACKNOWLEDGEMENTS

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INTRODUCTION

Urbanization and global warming are causing the continuous rise of sea level, leading to increasingly unpredictable weather patterns and, consequently, a global increase in flood risk. Extreme seasonal flooding of rivers will soon become the new norm. With the water fluctuating between two states, changing from a source of joy to a force of destruction, more waterfront settlements will experience constant flux. Abandoning the waterfront settlements might be the most direct approach to avoid flood vulnerability. This, however, would break the long-established bond between people and the water. Therefore, designing to accomodate the duality of water is the topic of discourse. This thesis is interested in exploring methods to reduce the flood vulnerability of settlements within the floodplain and, at the same time, preserve the beneficial factors of living by the water. Consequently, the creation of a transformative public realm located close to water and preloaded with the ability to respond to flood, defined in this thesis as the *urban water space*, is the key to the design response.

Part I of the thesis provides an overview of the characteristics and effects of flooding, examines existing approaches to flood from different disciplines, investigates the method of integrated approach, and proposes a set of flood-design principles for the creation of the *urban water space*.

Part II of the thesis, the catalogue, is a design tool kit composed of components from four different categories: infrastructure, landscape, architecture, and resources for flood events. The catalogue can be used to form a syntax for designing for flooding. The combination of different components can produce a site-appropriate design responding to a specific set of flood mitigation design principles.

Port Alberni, the context for the design experiments, is introduced in Part III of the thesis. A set of in-depth flood vulnerability analyses are conducted to determine the scale and location of the sites of interest and establish a realistic setup to guide the corresponding design.

Part IV is the design response. Three sites with different flood vulnerabilities and flood design principles are chosen to create an interconnected *urban water space* serving the surrounding community within a 15 min walking radius. The design experiments represent three sample modules that can be expanded and constructed into a larger network of urban water spaces across the entire city.


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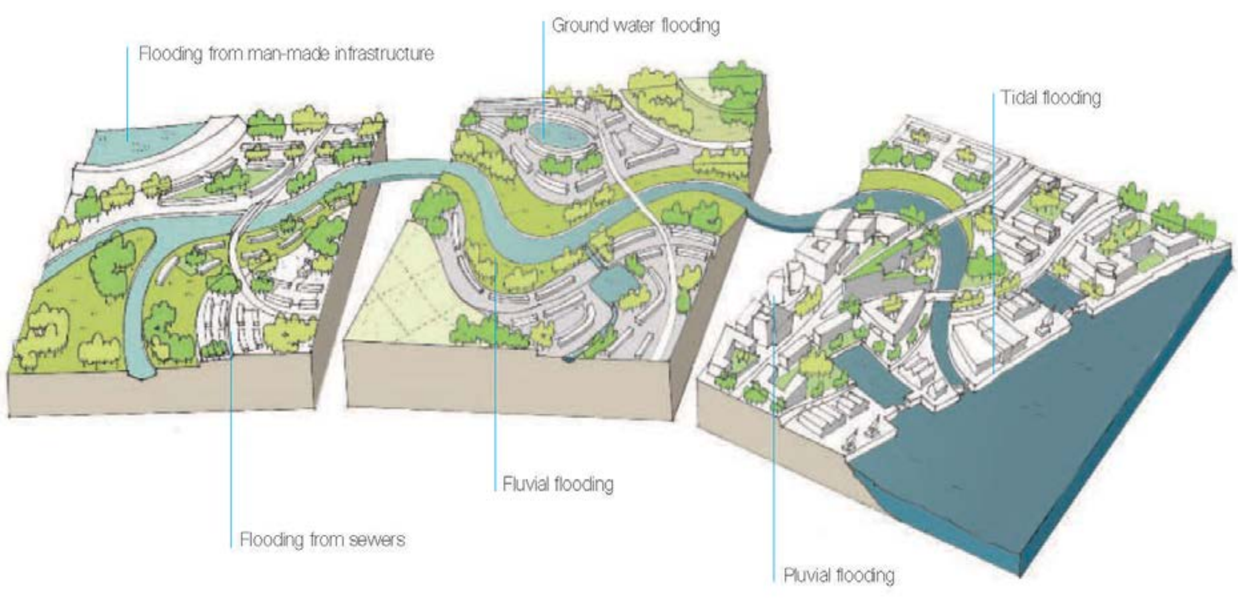
FOR RENT
DANGER
HIGH
WATER

PART I

THE SITUATION


Ground water flooding
Flooding from man-made infrastructure
Tidal flooding
Fluvial flooding
Flooding from sewers
Pluvial flooding

1.1 FLOOD

The Rising Risk

Since the earliest times of humanity, lands beside rivers, lakes, and oceans have almost always been attractive locations for settlements. Nowadays, many people around the globe continue to choose to live near bodies of water. According to UNESCO, “the 25 biggest cities, the 25 largest production locations, the 25 most prosperous area and the 25 most densely populated areas in the world are all located near waterfronts, almost all of them by the sea. This has been the case for at least 2,000 years.” [1] For these people, water is an inseparable part of their livelihood, entertainment, identity, and guides their ways of life.

Fig.1 [Previous Page] Flooded homes in Philippines forces people to relocate to rooftop

Water, however, is not always a friend. Flooding, a natural phenomenon of water temporarily overflowing onto dry land, has always been a known threat to humanity with the capacity to destroy the built environment and displace its people.

There are six recognised sources of flooding: tidal flooding, fluvial flooding, ground water, pluvial flooding, flooding from sewers, and man-made infrastructure. [2] Some of these are of natural causes, and others are created by infrastructural failure. Out of the six sources, tidal and fluvial flooding, known as coastal and freshet flooding in Canada [3], are part of the natural water cycle directly related to regions with ocean- or river-fronting conditions, whereas the remaining four sources can also occur in other regions and are not restricted by proximity to a body of water. Tidal flooding results from the combination of strong winds, low-pressure weather systems, and peak high tides. Although the pattern of tidal flooding can be predicted, the onset is often sudden and carries extreme forces.[4] Fluvial flooding is the overflowing of rivers caused by an accumulation of seasonal rainfall or upstream snowmelt. Fluvial flooding can usually be predicted with reasonable accuracy and has steady and slower onset. This thesis is interested in designing for lands with water-fronting conditions and thus will focus on the parameters of tidal and fluvial flooding.

Fig.2
Types of Flood and Location

Although most natural floods can be predicted, the flood risk is not static. According to Environment Canada, under given conditions, every large body of water has the potential to flood. [5] In fact, there has been a noticeable increase in flood risk around the globe. In the past decade, many places were inundated more frequently and with higher intensity. There are mainly two factors responsible for this increase in flood risk, urbanization and climate change. [6] The extent of flood risk is directly related to the settlement density within the floodplain. The beneficial factors of water have attracted large populations to settle in or close to floodplains. As the development density around the globe increases over time, more people are exposed to flood threats. The urbanization intensity also led to a decrease of natural porous surfaces, producing more surface water from storms with increased strains to existing drainage infrastructure and natural water basins. At the same time, the escalation of extreme weather patterns from climate change has resulted in more frequent returns of floods with unpredictable intensity.

Today, flooding ranks as one of the most damaging forms of natural disaster in the world, along with droughts, earthquakes, and cyclones.[7] From 1995-2015, floods made up 43% of total natural disaster occurrences around the globe and affected 2.3 billion people. (Fig. 4) The long-term impact of climate change in the form of sea level rise could also lead to an overall expansion of floodplains. Studies have projected a global sea level rise of 1m in the next 100 years.(Fig. 3)

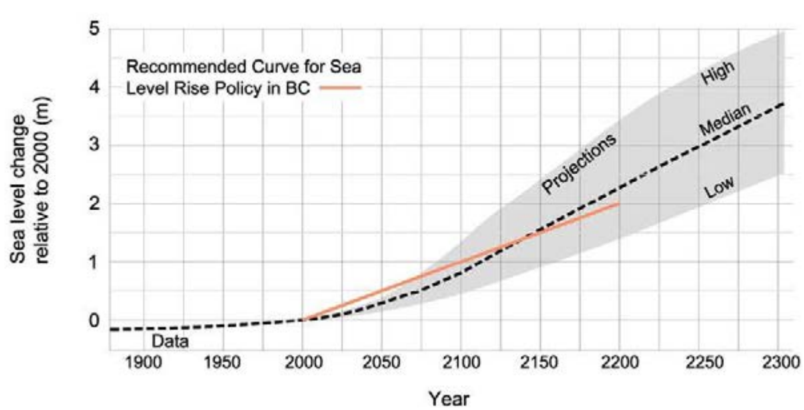


Fig.3
Projections of Global Sea Level Rise

Duality of Water

Water nourishes life but also brings destruction. This duality is increasingly straining its relationship with people. Often, due to lack of appropriate flood mitigation and response, the repetitive experience of physical and economic impact from flooding can overshadow the many benefits of living beside the water. It causes residents to struggle with existing or potential flood risks, often forcing them to relocate to higher ground, creating gaps between water and the built environment. On the other hand, when social and physical factors restrict the possibility of abandoning the waterfront, residents are often left to face the constant flood risk on their own. It is important to note that flooding is an integral part of the natural water cycle and cannot be eliminated by human intervention. Therefore, the question of designing for flood risk in the built environment is becoming increasingly relevant. Consequently, finding a way to work with water's dual role in the built environment is the fundamental goal for this thesis. The design response should be multifunctional, allow daily interaction with water, and strategically react to flooding.

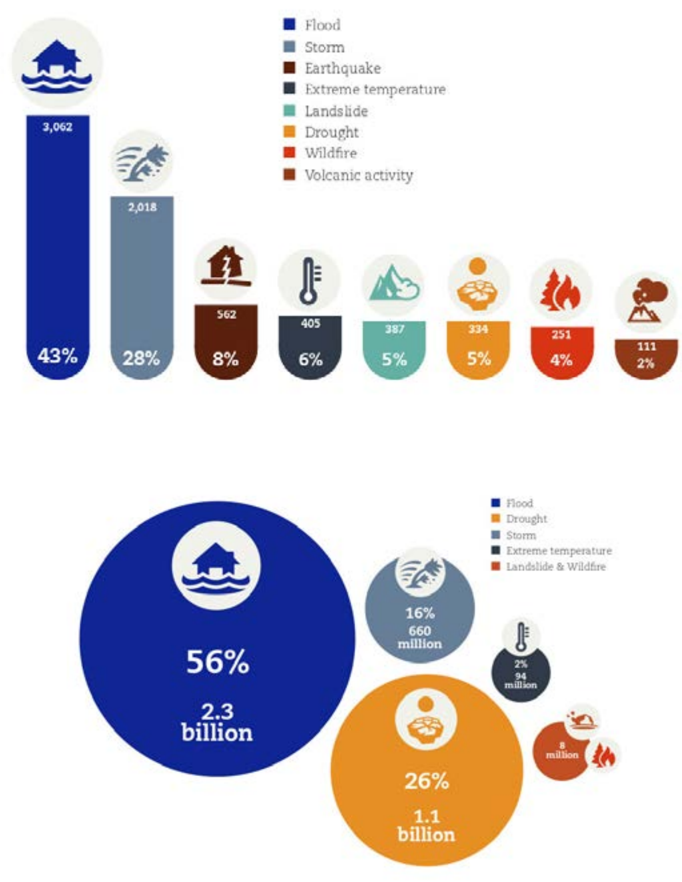


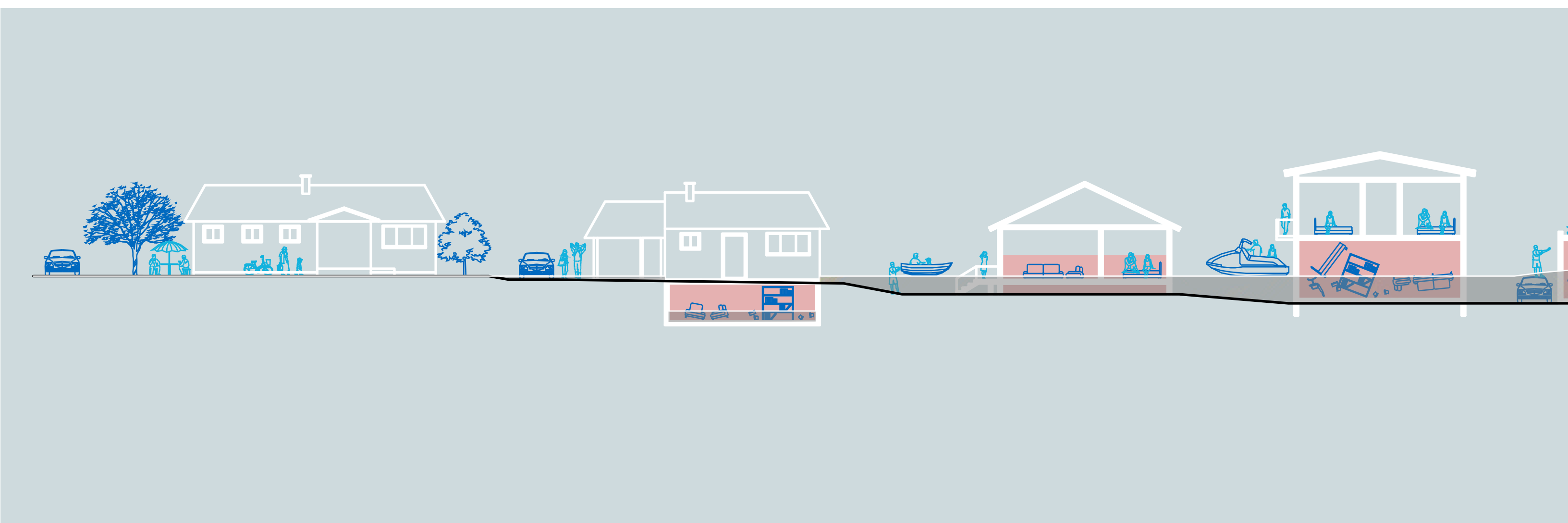
Fig.4
Weather-related disasters Statistics 1995-2015

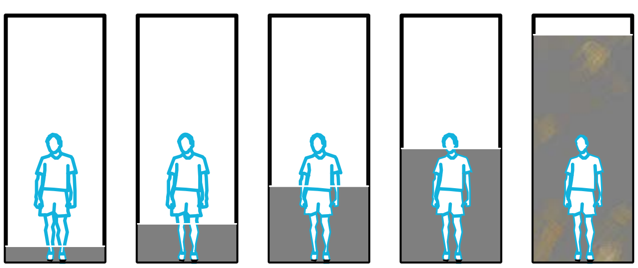
0.2m

0.5m

Flood Depth

Property Damage

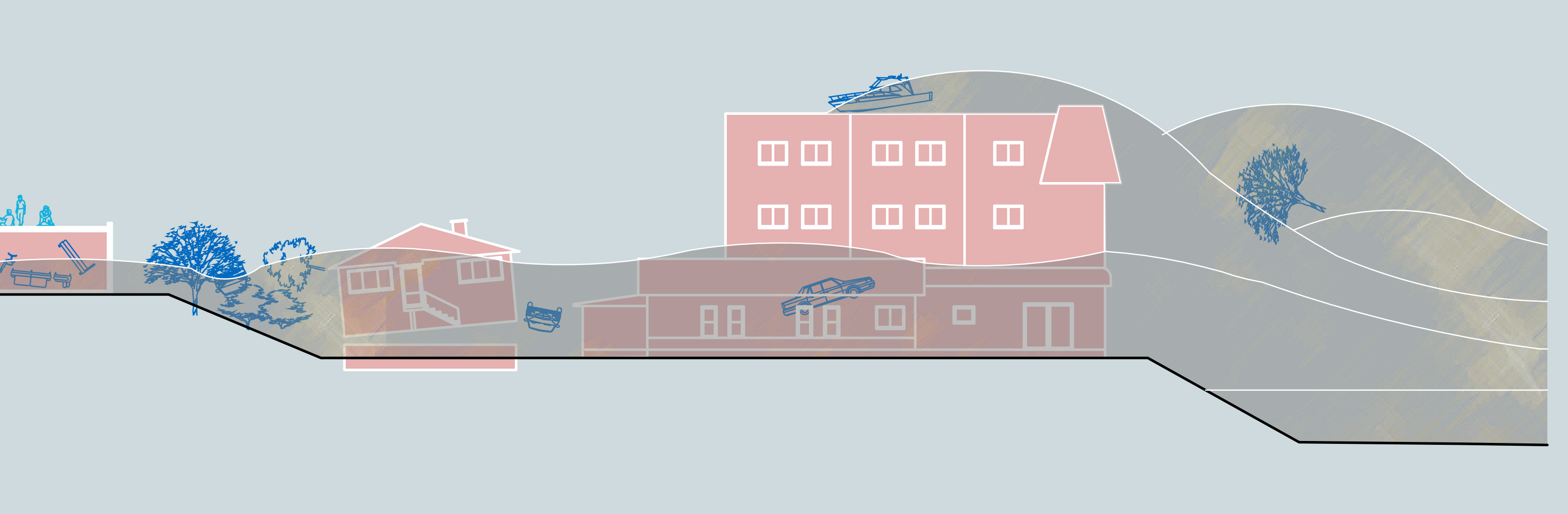




0.2m 0.5m 1m 1.5m >3m

Fig.5
Flood Intensities
Comparison Diagram

1m | **1.5m** | **>3m**



Personal and property damage are the most common forms of vulnerability from flooding. The combination of water height, water velocity, and flood duration all contribute to the degree of flood risk. According to UK planning guide: [8]

0.2m	Walking starts to become difficult
0.5m	Hazard to some people
1m	May cause structural damage to buildings
1.5m	Adults are typically unable to stand in still water, cars may stop or float
	Floating debris becomes additional danger to people and building
3m	Water can fully submerge and lift low-rise buildings from foundations

Fig.6 Breach of Flood Defence during the Japan 2011 Tohoku Tsunami

1.2 THE CITY AND THE WATER

Urban Measurement of Flood Risk

Flood risk is a combination of probability and consequence.[9] In other words, the frequency or likelihood of flooding in a given period combined with the potential flood intensity and impact determines the level of flood risk in an area. Oftentimes, the characteristics of the land determine the probability of flooding. Lands closer to rivers and oceans, with large areas of flat-low-lying topography, has a much higher chance of flooding than that with mountainous terrain. In addition, climate change and other human interventions are causing a rise in flood probability. As discussed in the previous chapter, one of the main reasons for the rising flood risk is the densification of urban development near water. This directly relates to the consequence of flooding

How to assess flood risk in the urban environment? The common method for flood risk measurement is through mapping of the floodplain by flood frequency, with flood frequency generally expressed as a likely return period for a certain depth of flood water. Commonly-used design frequencies include 1 in 20-year flood, 1 in 100-year flood, 1 in 200-year flood and 1 in 1000-year flood.[10]

"If a tree falls in a forest and no one is around to hear it, does it make a sound?"

The same is broadly true of flooding:

"If a river floods its banks but no one is in there to be flooded, does it cause a problem?" [12]

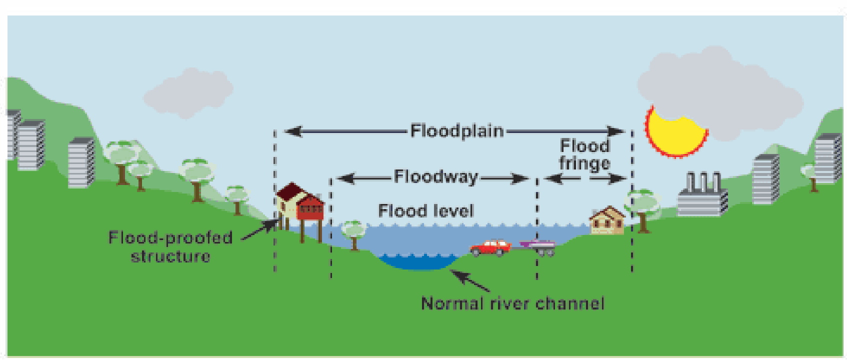


Fig.7 Enviornmental Canada's definition of the river and its floodplain

Since flood risk studies are conducted very infrequently, many recorded floodplains are outdated, leaving people unaware of their potential vulnerability. Moreover, the information on these floodplain maps is limited to water level and frequency. Other information that further determines flood risk, such as velocity, duration of flooding, consequential damage to buildings, infrastructure, and populations, are nowhere to be found. These are all neglected yet important parameters that govern how to design for flood events. Although the floodplain maps depict vulnerabilities to major events, other areas with more frequent and smaller recurring floods are often ignored. The nature of the floodplain maps has led to a focus on more significant but less frequent events. There is an inverse relationship between frequency and intensity of flooding, and repetitive minor floods can also build up vulnerability over time. Consequently, the "big one" should not be the only concern.

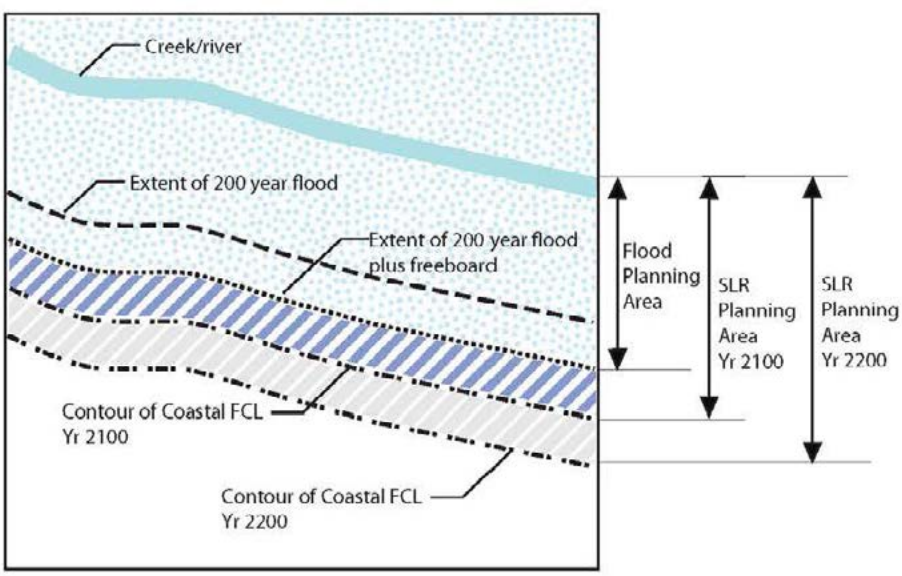


Fig.8
BCMoE Coastal Flood Hazard Landuse Map
FCL (flood construction level) is determined base on the floodplain. FCL will increase overtime as sea level rises.

Unhealthy Dependency on Defence Infrastructure

Once the flood risk is determined, actions need to be taken. The most common existing approach towards flood risk within the floodplain is through permanent physical protection. During the peak of industrialization, improved technical capabilities led to large-scale canalising of rivers through straightening meanders, land reclamation and flood protection.[13] The protection approach is conducted through the construction of defence infrastructures such as dams, floodwalls, dikes and levees.

Although this is an approach inseparable from reducing flood risk, there are many flaws in the current defence infrastructure design. As flood defences are often designed to the worst-case scenario, the defence infrastructure is very massive and costly. Moreover, the defence infrastructure needs to be continuously upgraded to meet the rising flood level. In the case of the 2011 Japanese tsunami, even the most intensive post disaster upgrade cannot fully defend the worst-case tsunami. “In 2011, tsunami surges 15 metres high or more blew past Japan’s costly coastal fortifications. The government’s solution is to build back bigger. In some places, that means walls 14 metres high…” [14] The high cost of defence infrastructure limits how much can be protected. Sometimes, this localized protection can even intensify flooding in other locations. Failure or breach of the defence infrastructure can cause a widespread unexpected flood. The false sense of security from defence infrastructure can delay locals’ evacuation from danger. This was the apparent during 2011 Japanese tsunami. “On 3-11, some people didn’t evacuate because they felt they were safe behind the seawalls.” [15] Many defence infrastructures have regularized and straightened natural water ways. Although this eases human control of water behavior, it depletes the

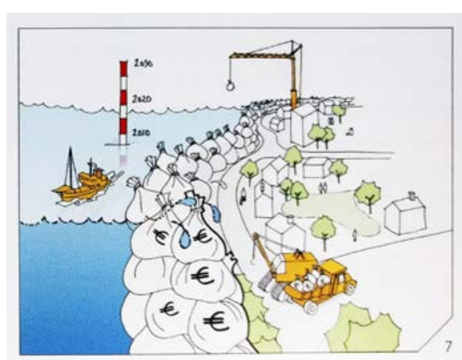


Fig.9
Continual pilling of investment in defense infrastructure creates vicous cost cycle that reinforces flood vulnerbility

river bed's natural ability to dissipate energy, consequently accelerating water flow rate and raising the high-water surge which further contributes to the rising flood risk. The canalisation of the waterways also eliminates many natural habitats such as marshlands, reed beds, riparian zones, woodlands etc. [16]

When the city is not flooded, the defence infrastructure is a physical barrier between people and the water. The lack of consideration for placemaking has produced countless straight bare walls that occupy a large amount of space. These barriers restrict views and physical access to the water and pose challenges to good space programming of the waterfront land. This disconnection contributes to the resident's lack of awareness of the water's changing behaviour and can become an additional cause of vulnerability.

Therefore, given the above reasons, one should not solely depend on defence infrastructures for flood. Instead, in addition to flood defence, there should be an integrated approach to flood resiliency, with consideration for multiple aspects of design requirements for before, during, and after the flood, as well as placemaking for daily usage of space alongside the water.

Fig.10 Lake Borgne Surge Barrier
Defence infrastructure designed without considerations for placemaking create isolated long walkways on Lake Borgne

Fig.11 Flood Barrier at Cockermouth England, before and during flood event

The Integrated Approach

In recent years, although most places continue to rely on defence infrastructure for flooding, people from different fields have been working together towards a multidisciplinary integrated systems approach. The concept of the integrated systems approach is to shift from flood control to flood management. With this approach, there is a proactive mentality recognizing that floods can never be fully constrained and all conditions relating to the flood (before, during, after) should be anticipated and incorporated into consideration for design.[17] The aim is to preserve positive aspects of water for everyday life, reduce damage from flood, and prepare in advance for post-flood recovery.

As a starting point, the referenced Five Flood Risk Strategies (FRSs) from EU Starflood flood management program is the example categorization method for the integrated approach.[18] Each strategy is analyzed and paired with similar existing flood approaches from different disciplines. Examples of specific flood approaches were taken from UK(RIBA), USA(FEMA), Canada, Germany, and international organizations (Redcross).

Traditional Protection Approach

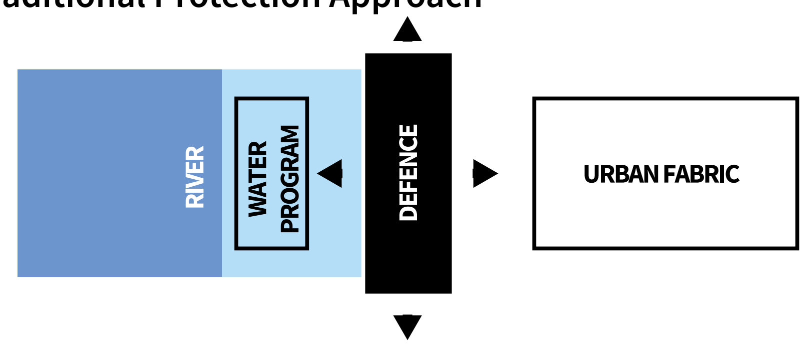


Fig.12
Traditional Protection Approach

Integrated Approach

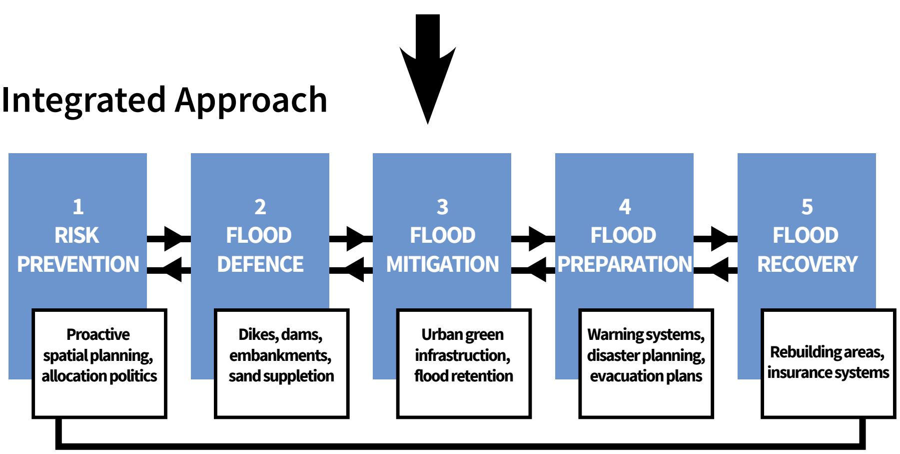


Fig.13
Integrated Approach

1. Risk Prevention

The first important strategy to flood resiliency is risk prevention through spatial and land use planning guided by governmental policies. This minimizes exposure to risk by strategically placing flood vulnerable programs away from the high-risk zones. Fig 15 shows appropriate land uses based on UK planning guidelines. The strategy is particularly useful for new development areas but is much harder to implement on existing densely built developments. This avoidance approach, if not carefully designed, can easily create gaps between the city and the water. Consequently, low flood risk programs, such as open public realms and water compatible programs, are critical to the success of this approach.

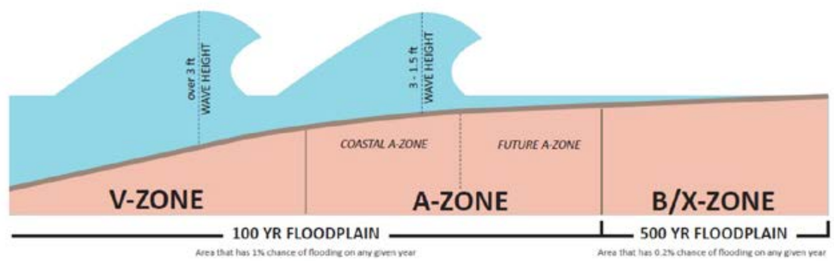


Fig.14
Risk Prevention Flood Plain Designations

	Very low flood risk	Low flood risk	Medium flood risk	High flood risk
Less vulnerable uses: • Shops and restaurants • Offices • Industry and warehouses • Agriculture and forestry • Water and sewage treatment	YES	YES	YES	NO
More vulnerable uses: • Residential house and flats • Residential institutions, hotels and prisons • Hospitals, health centres • Hotels, bars and nightclubs • Holiday lets or short let caravans	YES	YES	MAYBE [1]	NO
Highly vulnerable uses: • Basement flats • Caravans and mobile homes for permanent residence • Police, fire and ambulance stations • Telecoms centres needed during a flood	YES	MAYBE	NO	NO
Water compatible uses: • Flood defences • Docks, marinas and ship building • Water-based recreation • Amenity open space • Outdoor sports and recreation grounds	YES	YES	YES	YES
Essential infrastructure: • Essential transport links • Primary electricity sub-stations • Sewage and water treatment works	YES	YES	MAYBE	MAYBE

[1] Cells indicated as maybe correspond to use to which are required to pass the exception test in England

Fig.15
Vulnerability by building type UK urban planning

2. Flood Defence
Flood defence, as discussed previously, is an integral part of designing for flood resiliency and already exists in many flood proofed areas. To have successful flood defence systems, the attitude towards flood defence also needs to shift to an integrated approach. Instead of being the only strategy to solve flood risk, flood defences should work together with water fronting programs to maximize protective potential while maintaining the public connection to the water. Land reclamation through flood defence should be discouraged as it reduces natural water retention capabilities. One example of successful flood defence is the new flood dike park in Worth am Main Germany.(Fig 16)

3. Flood Mitigation
Flood Mitigation through urban green infrastructure and flood retention can enhance the flood defence system and drastically reduce flood load on remaining flood infrastructure. The strategy of flood mitigation is most apparent in hydroscapes, which are “landscape that is designed in harmony with water or is designed to accommodate water.” [19] This approach works with the duality of water, making room for water to cope with flooding and storing water for landscape irrigation. During daily usage, hydroscapes can bring visual and poetic enhancement to any urban space. At the same time, they can serve as an intuitive visual warning and guide residents in preparing for future flood risk.

Fig.16
Flood defence flood dike designed as open space park

Fig.17
Artificial rivers (flood rentention creeks) were created to make more space for water

4. Flood Preparation

Flood preparation is currently conducted through warning systems, evacuation route planning, and disaster planning. Through constant monitoring of waterways, upcoming flood risks can be detected in advance and broadcast with warnings and advisories. (Fig. 18) Evacuation routes are integrated into city planning. Specific personnel are appointed for flood preparation responsibilities such as resource allocation, emergency coordinations etc. Flood preparation planning is usually conducted through local municipalities and related emergency planning departments based on designated floodplains. As existing methods of floodplain studies lack many parameters, the consequential damage to people, buildings, and infrastructure are often not taken into consideration in designing for flood preparation. In comparison to the investment in defence infrastructure, there is still a lack of focus on flood preparation. Studies have shown that most resources are scrambled together from other places not directly affected by the event at the time of the emergency, and there is often a lack of immediately deployable local resources, which lengthens the exposure of people to risk. [20] In some cases, towns with known flood risks have little to no flood preparation. In other cases, flood preparation plans are not made available to the public until the actual occurence of a flood. Thus, many residents are unaware of these plans or even the potential flood risk, making it very difficult for people to react efficiently in times of emergency. [21] An example of the problem was seen during the Red River Valley flood in Winnipeg:

“Most of the emergency machinery had been put in place very hastily at the last minute and without much consideration given to cost. Now the day of reckoning was coming. It was time for premier Campbell to fulfill his earlier reassurances that financial matters would be dealt with after the emergency was passed.” [22]

Ministry of FLNRO

Flood Warnings and Advisories

Flood Warning - Somass River (UPGRADED)
ISSUED: November 26, 2017 10:30 AM

The River Forecast Centre is **upgrading to** a **Flood Warning** for:

- **Somass River** including Sproat River, Ash River and tributaries

A series of frontal systems have moved over Vancouver Island last week and this weekend, saturating the soil in this area and causing lake levels to increase considerably.

- The ASH RIVER BELOW MORAN CREEK (08HB023) is currently flowing at 230 m3/s, which is a 2-5 year return period flow, and is peaking now
- SPROAT RIVER NEAR ALBERNI (08HB008) is currently flowing at 250 m3/s, which is a 2-5 year return period flow, and is still rising
- SOMASS RIVER NEAR ALBERNI is currently estimated to be running at 785 m3/s, which is a 2-5 year return period flow and close to the 2015 flood level

Environment and Climate Change Canada (ECCC) forecasts about 10 mm rainfall for Port Alberni on each of Sunday and Monday and then 40 mm Tuesday. The current hydrologic modeling indicates that further rises equalling or exceeding 2016 levels for these three rivers are expected. The rivers are expected to peak on Monday.

The River Forecast Centre will continue to monitor conditions and update this advisory as conditions warrant.

A ***High Streamflow Advisory*** means that river levels are rising or expected to rise rapidly, but that no major flooding is expected. Minor flooding in low-lying areas is possible.
A ***Flood Watch*** means that river levels are rising and will approach or may exceed bankfull. Flooding of areas adjacent to affected rivers may occur.
A ***Flood Warning*** means that river levels have exceeded bankfull or will exceed bankfull imminently, and that flooding of areas adjacent to the rivers affected will result.

Fig.18
Screenshot of flood online warning notice for Somass River, Port Alberni in 2017

Fig.19
Volunteers work together to sandbag house

5. Flood Recovery

The apparent strength of flood defence infrastructure has blinded many to neglect the need of planning for flood recovery. However, history has proven countless times that flood defence can fail and may even cause greater damage. The present flood recovery strategies have been mainly dependent on humanitarian efforts and insurance policies. As floods often destroy transportation infrastructure, it is very inefficient to transport external aid to sites. The emergency shelters provided are designed to meet minimum needs and are associated with very high costs. Therefore, aside from the short-term supply of basic needs, humanitarian aid groups such as the Red Cross can offer little long-term support for post-flood recovery. On the other hand, the increasing density of development in flood risk areas has far surpassed the government's insurance capacity for catastrophic losses. Private insurance can also be unreliable in times of need.

"few were able to move right in and return to normal life immediately, many had trouble even getting in the house, because the dampness had swollen the doors shut. The initial reaction to the interior was one of shock, one's nose offended by at best a petrifying odour cause by a combination of mud and floodwater in a closed space. If there had be sewer backup, the stench was even worse." [23]

The situation described above in the post-1950 Red River Valley flood continues to this day in post-flood areas all over the world. It is very easy to ignore the degree of vulnerability a lengthy recovery process can bring to local communities. Recurring floods can further intensify that vulnerability, making it very difficult for flood prone communities to regain livelihood. Consequently, there is an urgent need for areas with known flood risk to locally plan for flood recovery by ensuring availability of resources, emergency shelter, and long term transitional housing, as well as strengthening local community support to improve the speed of recovery and achieve resiliency.

"The usual response by governments and humanitarian community has been the distribution of tent or kit of basic shelter materials and tools. The usual lifespan of tents is between a few months to two years and good quality platic sheeting is designed to last around 18 months [24]

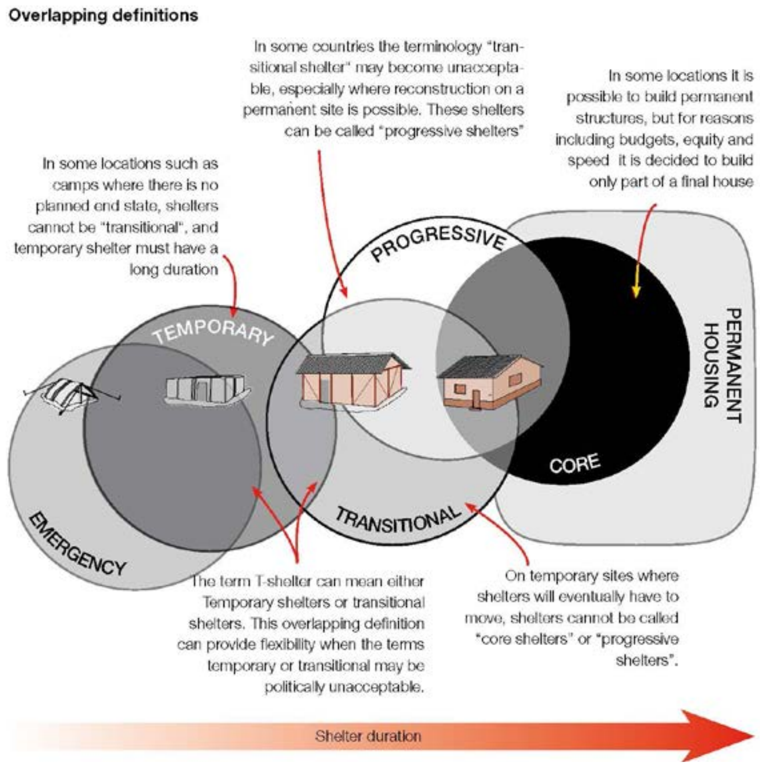


Fig.20
Flood recovery through humanitarian efforts

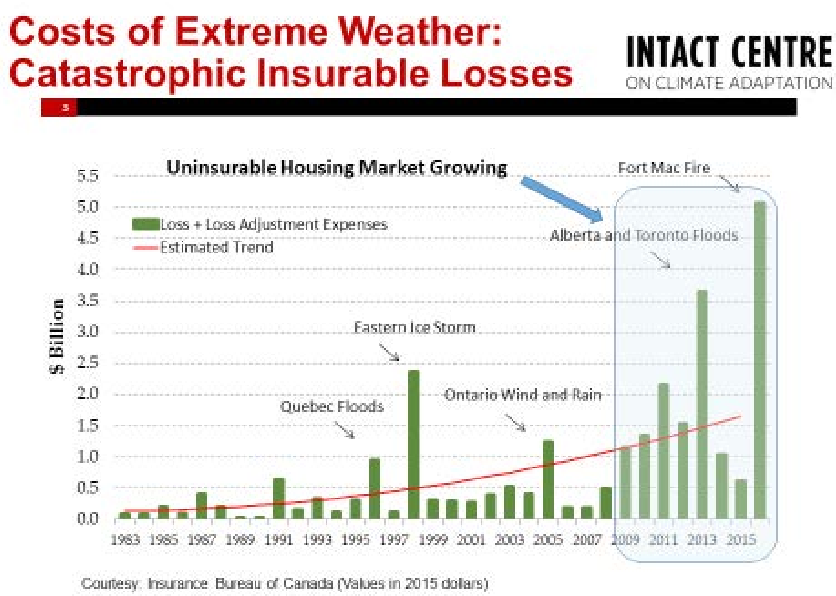
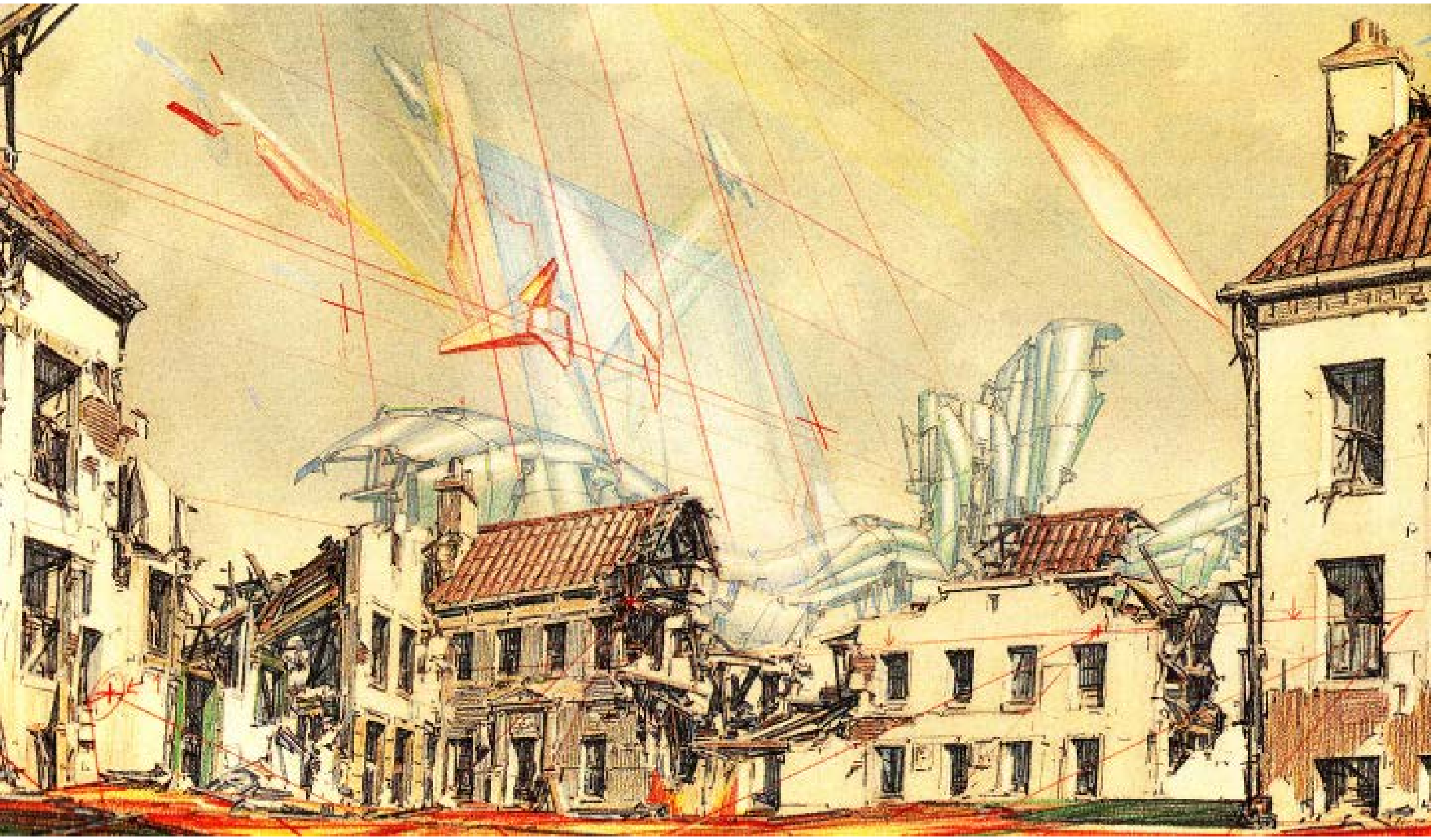


Fig.21
Uninsurable housing market growth



“ The new cities demand an architecture that rises from and sinks back into fluidity, into the turbulence of a continually changing matrix of conditions, into an eternal ceaseless flux -- Architecture that transmits the feel of movement and shifts, resonating with every force applied to it, because it both resists and gives way.”

--Lebbeus Woods, War and Architecture [25]

1.3 ROLE OF THE ARCHITECT

Vulnerability of The Single-Family House

Much of the existing literature on strategies for flood risk resides in the fields of civil engineering, planning, landscape architecture, and humanitarian aid. For a long time, very few architects were involved in designing for flood risk. As designers of the built environment, architect should ask themselves what they can contribute to the effort to resolve this rising crisis.

Low-rise building typologies, such as single-family houses, are the most vulnerable to flooding for many reasons. First, their inherent disadvantage in height and structure allows quicker inundation of the property and greater structural damage. Second, the loss of sentimental value of personal property intensifies damage from flooding. More importantly, flooding of homes creates displacement of people, depleting them of the necessities for living. Since houses are built in clusters, large scale inundation would put neighborhoods at risk, in turn creating more vulnerability for the entire community.

New Approaches to Flood Risk

In recent years, architects have started various investigations into reducing the vulnerability of buildings susceptible to flood events. Some strategies are adapted from vernacular architecture and others are new innovative ideas. Examples of these include elevated, floating, and amphibious architecture. These strategies allow buildings to tolerate and adapt to the rising water. Amphibious architecture, specifically, works with the force of water to automatically lift houses above the flood level at the time of need. The Buoyant Foundation Project led by Elizabeth English is working on the development of amphibious technologies for affordable housing and retrofitting existing homes.[26] Currently, since low-rise residential buildings are most vulnerable to flood, a majority of flood-related architecture has been designed for this building typology. As the housing industry slowly starts to implement these designs, much of the built urban fabric is still vulnerable to flood. It would take time for all the houses at risk to convert to adaptive ways of flood mitigation.

Fig.22
Lebbeus Woods, Radical Reconstruction Illustration

In the meantime, the thesis proposes to investigate an alternative approach to designing for flood risk. In addition to diffusing risk through redesigning residential architecture, the architecture for flood risk can also be approached from the scale of larger urban community spaces to support residential buildings vulnerable to flood. These spaces should be multifunctional and transformative, designed to be preloaded with the spatial and material capacity to respond to flooding. The community spaces are normally used as places of gathering and public interaction, which transform into safe-haven and resource centres in times of need.

Multifunctional and Transformative Spaces

For people living in the floodplain, having not experienced a recent flood doesn't mean the risk can be ignored. In addition to the diffusion of risk through resiliency of residential architecture, designing architecture for flood risk can also be approached from the scale of larger urban community spaces.

"How citizens respond to and use resources following a natural disaster is closely related to how we use and perceive urban space on a daily basis and, as such, the design of the built environment is integral to disaster preparedness." [27]

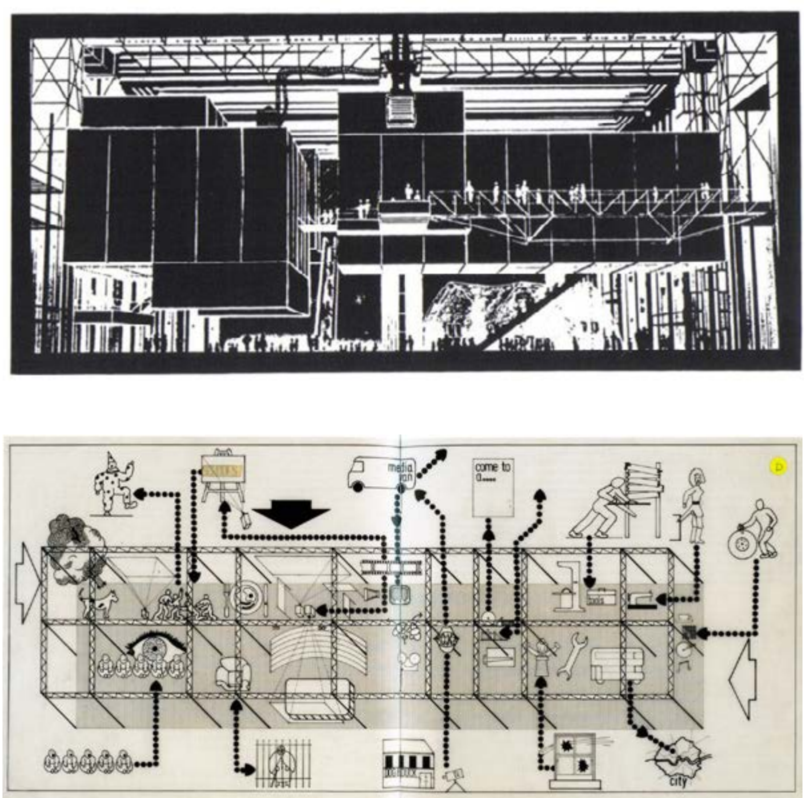


Fig.23
Cedric Price Fun Palace

As the condition of the water is fluid and changing, the proposed community spaces should not be merely a fixed single function space. To work with the duality of water, there should be an emphasis on designing spaces with multifunctional and transformative qualities, so they could function differently before, during and after a flood.

The concept of multifunctional and transformative space is depicted by Cedric Price's fun palace. "The Fun Palace was not a building in any conventional sense, but was instead a socially interactive machine, highly-adaptable to the shifting cultural and social conditions of its time and place."[28] In Price's sketch of the Fun Palace, he addressed the issue of flexibility in function and form. "Flexibility within the complex is not confined to the variation of the form and disposition of the enclosures and areas provided, but also by the ability to vary the public movement patterns through adjustment of mechanical movement aid."[29] The idea of multifunctional and transformative space is adapted by many projects. One example is the annual Toronto Winter Stations design competition, held at Woodbine Beach. As cold weather conditions restricted normal recreational usage of Woodbine Beach, the space and its lifeguard stations were always underutilized during the winter. Winter Stations reactivated the public realm of Woodbine Beach in the winter by transforming into art installations and temporary pavilions. The lifeguard stations became the structural support for the installations and are temporary given a new function.

Fig.24
ELEMENTAL
Half of a Good House

The concept of preloading space for capability of change was also explored in Elemental's project Half of a Good House.[30] By initially only constructing half of a good house, Aravena gave the control back to the occupants, making housing affordable, structurally stable, and at the same time, allowing for the possibility of future expansion by the occupants of the building.

Similarly, by designing flexibility into structure, material, spatial organization, and ways of circulation and access, the proposed community spaces can transform in function to support different needs at different times.

Architecture of Community Safety

The proposed community spaces for flood can be designed into a symbolic representation of community safety. The flood resources should be visible to the public and become part of the daily public interaction to bring awareness, familiarity, and a sense of safety and security. Traditionally, when the urban fabric was extremely vulnerable to mass fires, fire halls were physical manifestations of community safety, and their architecture was celebrated and designed with robustness and strength. Fire halls housed personnel, resources, and equipment that can be dispatched in times of need. Their robustness ensured the safety of firefighters and the availability of resources housed within the building for immediate reaction to emergency at places of vulnerability. Fire halls were distributed across the city, each responsible for its region. They were equipped with resources corresponding to the level of vulnerability of its respective region. When greater danger occurs, resources from more than one location can converge for greater support. Similarly, a smaller scale example is the lifeguard station at swimming pools and beaches. Rescue personnel is situated at lifeguard stations to ensure immediate reaction to people in need of help.

Both examples are localized, preloaded spaces fully-prepared with resources to act when the anticipated threat occurs. This principle can be applied to the architecture for flood events as well. These spaces can be deeply embedded in the urban fabric and people's daily lives and preloaded with flood resources, corresponding to local conditions and degrees of vulnerability. During daily use, its water-related public programs are activated, celebrating the existence of water, providing people with connection, access, and direct interaction with water. When the threat of flooding arises and water becomes a foe, the preloaded resources can be dispatched to surrounding areas or used on site for flood protective support. After a flood, the spaces transform into anchor points for disaster relief and reconstruction. When a greater threat occurs and the inevitable destruction happens, the robustness of these resource and support centres ensures continual post-disaster availability of resources and shelter, and the centres become points of origin to support the rebuilding and recovery of the remaining urban fabric. In this sense, preloading the space as a resource becomes critical for community engaged flood recovery.

In the book *War and Architecture*, American architect Lebbeus Woods explored the concept of regeneration of cities after destruction. In Woods' manifesto, he established a few clear principles for architecture of healing after destruction. "Once the existing patterns have been reduced by violence to a single, degraded pattern, they cannot be restored or replaced in any single step. However, there exists within this degraded layer of urban fabric another, more intimate scale of complexity that can serve as the point of origin for a new urban fabric." [31] These principles can be applied to the reconstruction of post-flood cities. One must respect the original culture and environment and refrain from implementing completely foreign ideas and constructions. New patterns can overlay and incorporate existing systems and allow the victims to decide which components can be rebuilt to work towards a more resilient city. There should be fluidity in the healing process instead of a forced implementation of an external system or principle. Thus, the remaining pieces of the old urban fabric become anchor points for new growth.

Fig.25
Cleveland Fire Station

Fig.26
Winter Stations Competition, Lifeguard Station Transformed into Art Installations at Woodbine Beach, creatively reactivating the beach in winter.


Wolsey

1.4 THE URBAN WATER SPACE

Filling the Gap With Reclaimed Public Space

The public realm at the border of water and city can be designed into *urban water space*. This thesis defines *urban water space* as a public realm located close to water that is composed of transformative community gathering spaces and water-related programs (interaction) and is preloaded with the ability to respond (defend, tolerate, recover) to flood. It holds great opportunities for resolving some of the critical concerns addressed in this thesis regards the current integrated approach. By deliberately locating community spaces with resources for flood events at areas most susceptible to flooding, it brings public flood awareness, allows people in the area to become familiarized with the available resources on site, and promotes daily interaction with the multifunctional spaces. In times of need, people at risk would be able to quickly access these community spaces and transform them into emergency recovery spaces without the help of external support. This sense of familiarity and security can contribute greatly to the speed of emergency response and recovery from flood events.

Since it is important for flood risk design to shift from a single line of defence to an integrated approach, prevention strategies such as zoning and land use restrictions will play an important role. The land use limitations and the desire to connect with water pose an interesting opportunity to create good urban water space within the floodplain. Traditional buildings, especially low-rise residential building types, are very susceptible to floods. Moving all the urban fabric away from the flood plain would eliminate the flood risk but also create a great gap between the city and the water. However, according to the UK guidelines, flood defences, open public space, and water-related recreational grounds can tolerate and quickly recover from all levels of flood risk.[32] These are perfect land use types for filling in the missing gap, bringing back the connection to water, and acting as a buffer space for flooding. The design for flood events in the urban water space as an integrated landscaped public realm can work with these flood programs to accommodate the dynamics of water and, at the same time, reduce vulnerability in the floodplain.

Fig.27 [Left]
Cheonggycheon Stream, Seoul
Landscape and pedestrian path along the river create a river activiated public realm

Many potential urban water spaces are currently occupied by flood defence infrastructure with very little considerations for placemaking. To achieve an integrated approach to flood risk, some of these defence infrastructures can be redesigned with consideration for water-related programs, reclaiming wasted infrastructure space and turned into an enhanced public waterfront. New urban water spaces also need to integrate defence infrastructure to strategically reduce flood risk. This requires the public realm to adapt to the form of the defence infrastructure. The New York High Line Park is a good example of a public realm created from reclaimed infrastructure space. The formal linearity of the highway established a good backbone for the overall circulation of the park. Various modular components of landscape and public amenity enhanced the circulation experience. Special pockets of space were created with site-appropriate programs to form places of gatherings and create visual connection back to the city. Similarly, urban water space with defence infrastructure such as dikes and flood walls also take on linear forms, therefore could form ideal public realms with similar formal and programmatic composition as the linear park of the High Line.

Along with the High Line, two additional examples of landscaped public realms dealing with flood risks are also included for reference, Poppy Plaza and the post-tsunami reconstruction of Constitucion by ELEMENTAL. There are similarities and differences between the two projects. The Poppy Plaza in Calgary has an integrated defence system for a 1 in 100-year flood. It is the first of a series of planned linear public spaces along the Bow River. The

Fig.28
Poppy Plaza in Calgary

flood wall is integrated and morphed into various folding forms, creating urban amenities such as surfaces for seating, eating and commemoration.[33] It takes on the form of dynamic linear public space, and successfully connects the river back to people with spaces at various heights, each creating different dialogues with the river's changing level.

ELEMENTAL approached a greater flood problem, the tsunami, in three different time scales, considering both short- and long-term implications. The design also included a threefold strategy for future tsunami preparation. Due to the extreme intensity of the threat, the urban fabric is pushed further away from the water. Consequently, instead of the small linear public realm, the urban water space in this project is the coastal forest. [34] Like the Poppy Plaza, the defence infrastructure for tsunami is integrated as part of placemaking design for the coastal forest. This project is only viable for Constitucion because a majority of the urban fabric was wiped away in the 2010 tsunami. Since many urban areas are currently built behind defence infrastructure close to the edge of the water, there needs to be a careful weighing of two factors--the extreme consequence of the rarely-occurring tsunami, and the economic and social implications of demolishing existing urban fabric for reduction of potential threat. It would be extremely costly and much more difficult to produce a public realm of similar scale in tsunami-prone cities before the occurrence of a tsunami. Consequently, this approach is suitable for post-disaster reconstruction and can be considered as a 2nd or 3rd phase of urban development for places with potential tsunami threat.

Before Tsunami   Post Tsunami   Post Reconstruction

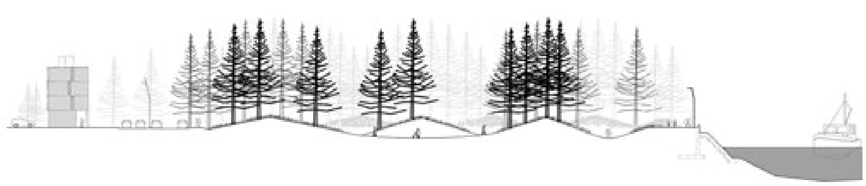
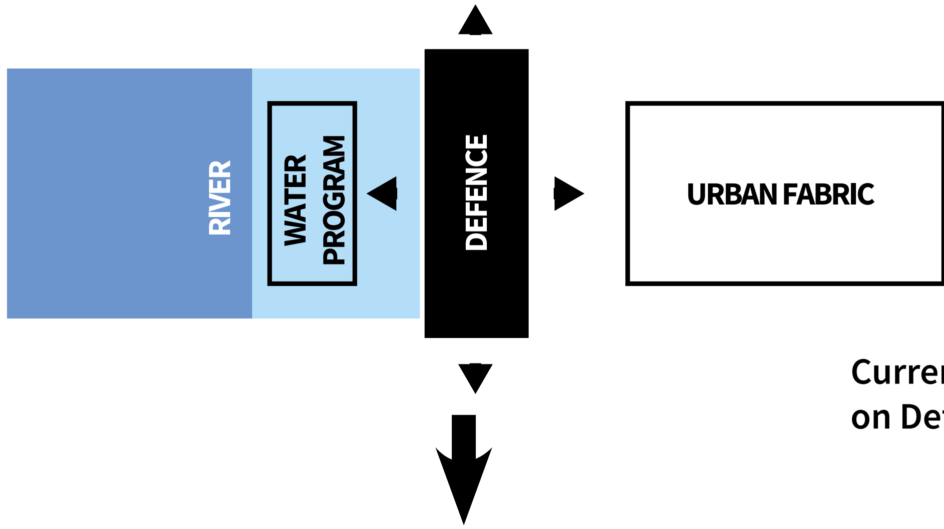
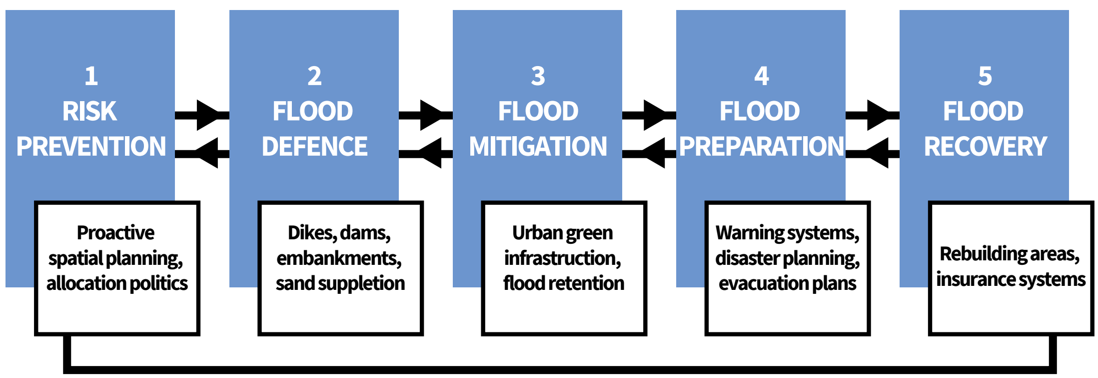


Fig.29
Elemental Post-Tsunami Sustainable Reconstruction Plan of Constitucion

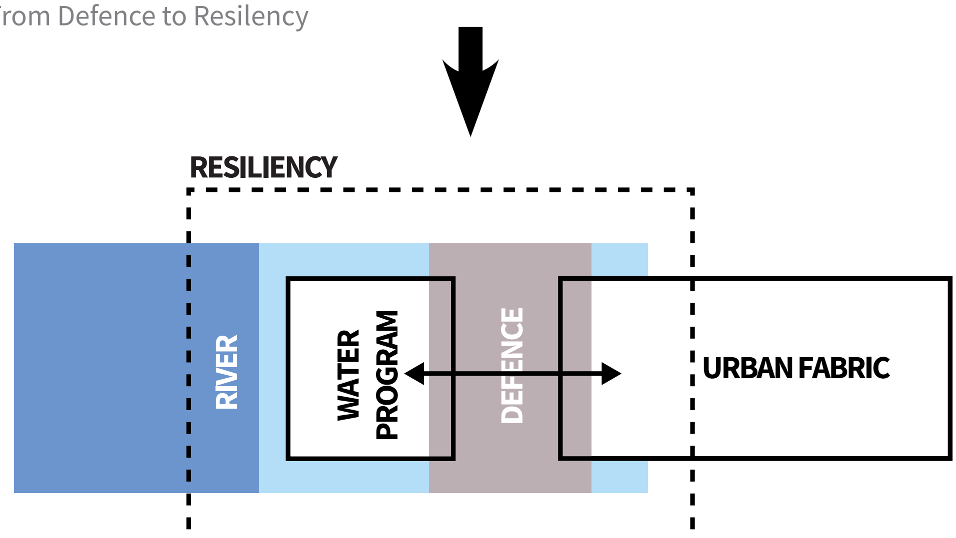


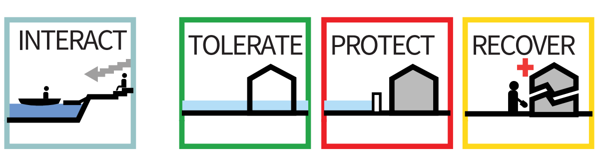
Current Dependency on Defence



Integrated Approach

Fig.13
From Defence to Resilency





New Urban Water Space

Fig.30
Urban Water Space

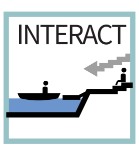
1.5 THE PROPOSED RESPONSE

Preloading the Urban Water Space for Flood Resiliency

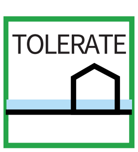
To summarize, three critical concepts were addressed in response to the current approaches to flood risk:

- There is an unhealthy dependency on flood defence infrastructure, and we should move from the single line of defence system to a more decentralized integrated approach
- Architecture for flooding can be designed as multifunctional community spaces that preload resources for flood events and transforms into service infrastructure at times of need.
- There needs to be a reactivation of the land bordering the urban fabric and the water, leading to the creation of the integrated water-fronting public realm -- the Urban Water Space.

Various components from three major disciplines -- landscape, infrastructure, and architecture -- need to be integrated into the design of the Urban Water Space. With reference to the integrated approach for flood resiliency, the function of the urban water space is categorized into four design principles corresponding to differences in water behavior.



1. Interact (normal)
When the water is flooding, the function of public realm is to provide interaction with the water. To strengthen the relationship between the water and the public, multiple forms of interaction should be promoted through space design. Elements of landscape, infrastructure, and architecture need to work together to guide physical access, create visual connection, and enhance the experience of water-related activities. The placemaking of public realm connects people to the water and allows the residents to become familiar with the public space, raise awareness of flood events, and understand the availability of resources stored on site.



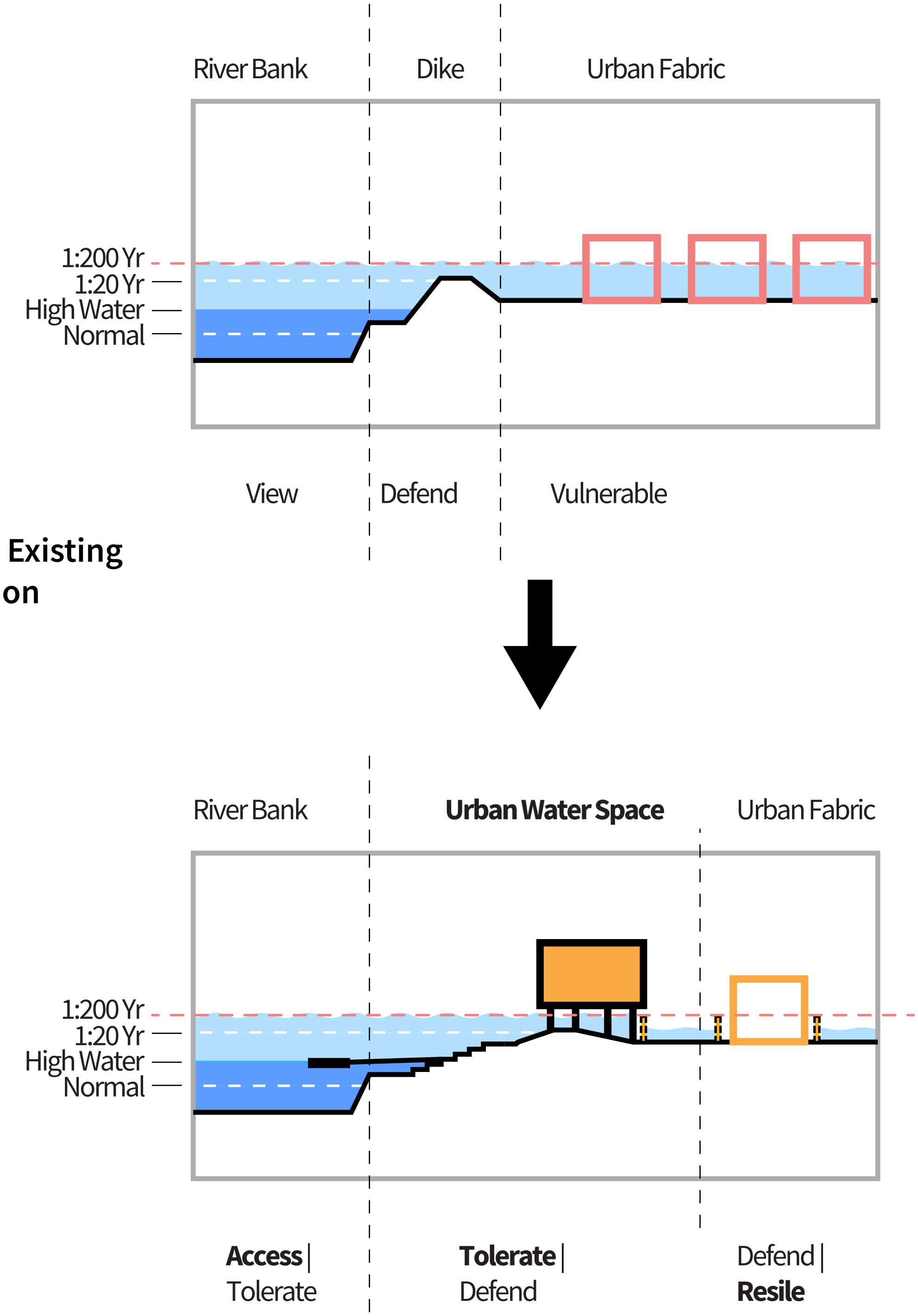
2. Tolerate (minor flood)
When the water is starting to rise, areas of the public realm can strategically tolerate the inundation, providing designed space for water to grow. This toleration can be designed through orientation of structure, choices of floodable landscape amenities, water

adaptable architecture, and water accommodating material and finishes. Specific water retention basins and hydroscapes can also be incorporated into the landscape design. This minimizes damage of the public realm from flood, delays the growth of flood, and allows for quick recovery back to daily functions. At the same time, the growth of the water can act as a visual signal for residents in the surrounding area to prepare for flood.

3. Protect (major flood)
As the flood level continues to increase, the function of the public realm transitions to protection. Stationary defence infrastructure needs to be integrated into the landscape and be strategically located to protect the areas closest to water with the most vulnerability. In addition, the second line of decentralized defence can be formed through portable and temporary defence mechanisms such as sandbags and water pumps. These are resources that need to be 1) prepared in advance according to the estimated level of vulnerability of the surrounding area, 2) stored on site, and 3) ready to dispatch to areas of vulnerability in the urban fabric.

4. Recover (post flood)
Depending on the intensity of the flood, the recovery process can take from a few days to years. The public realm needs to withstand the impact of flood events and quickly recover to function as a point of origin for the recovering urban fabric. The space of the public realm becomes, once again, a place of gathering. It is also a place of community support and a center of living resource for the displaced people. The daily familiarity with the public realm allows people to easily navigate and access available resources. Its proximity to the area of flood vulnerability also strengthens access to community support and reduces the need for external transportation of resources.

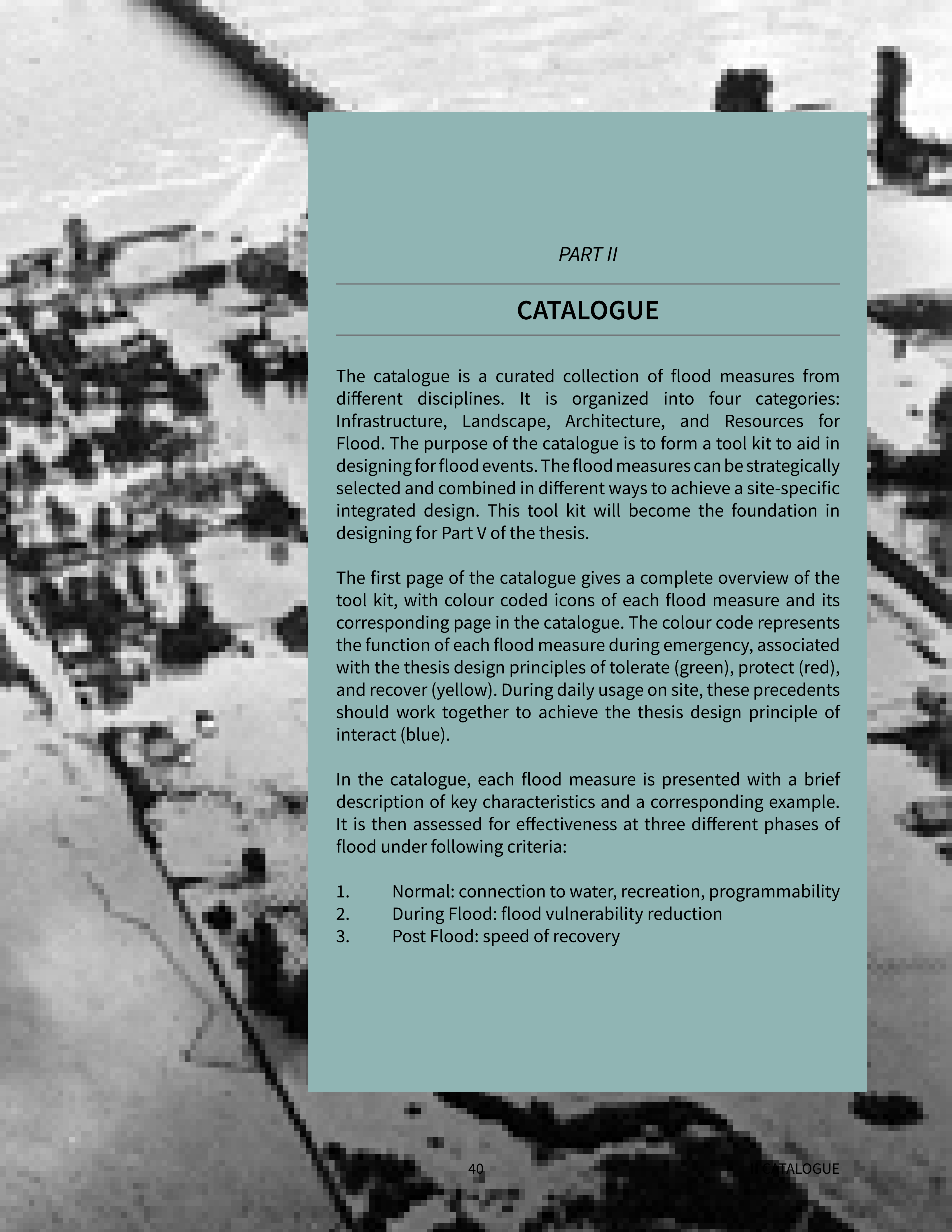
The proposed design of the urban water space is an exploration of the spatial syntax and should be viewed as a component in a kit of parts which can expand or be reduced according to the site-specific degree of flood vulnerability. The form and appearance of the design also needs to coincide with local characteristics. Therefore, the focus of the investigation is on a process-oriented design. The design will revolve around the interrelated movement of water, people, materials, and resources. The different components within the public realm need to work together to form spaces preloaded with the capability to react and respond to the changing conditions of the water.



Typical Existing Condition

Urban Water Space

Fig.31 Typical Existing Condition VS Urban Water Space



PART II

CATALOGUE

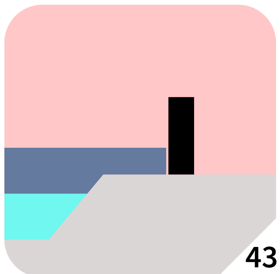
The catalogue is a curated collection of flood measures from different disciplines. It is organized into four categories: Infrastructure, Landscape, Architecture, and Resources for Flood. The purpose of the catalogue is to form a tool kit to aid in designing for flood events. The flood measures can be strategically selected and combined in different ways to achieve a site-specific integrated design. This tool kit will become the foundation in designing for Part V of the thesis.

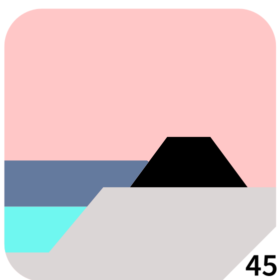
The first page of the catalogue gives a complete overview of the tool kit, with colour coded icons of each flood measure and its corresponding page in the catalogue. The colour code represents the function of each flood measure during emergency, associated with the thesis design principles of tolerate (green), protect (red), and recover (yellow). During daily usage on site, these precedents should work together to achieve the thesis design principle of interact (blue).

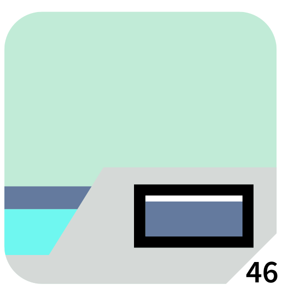
In the catalogue, each flood measure is presented with a brief description of key characteristics and a corresponding example. It is then assessed for effectiveness at three different phases of flood under following criteria:

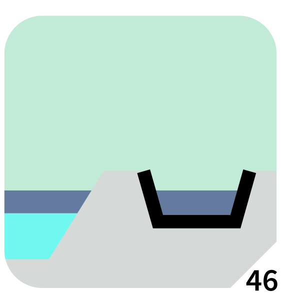
1. Normal: connection to water, recreation, programmability
2. During Flood: flood vulnerability reduction
3. Post Flood: speed of recovery

2.1 INFRASTRUCTURE

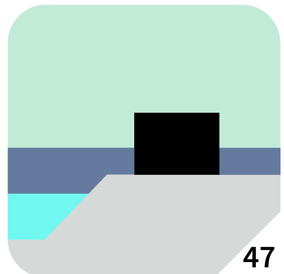


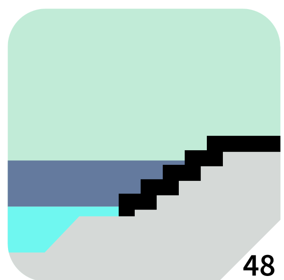


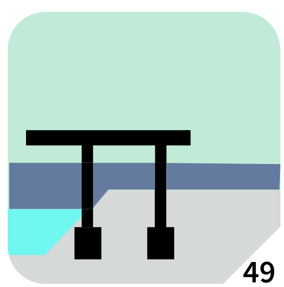


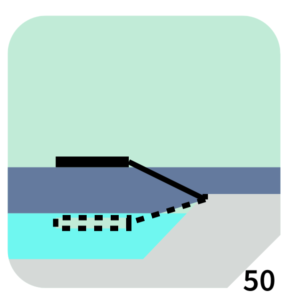


2.2 LANDSCAPE

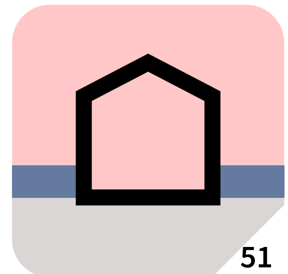


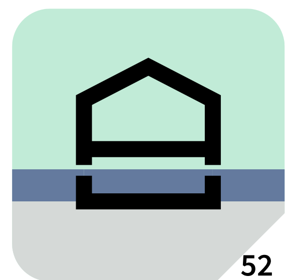


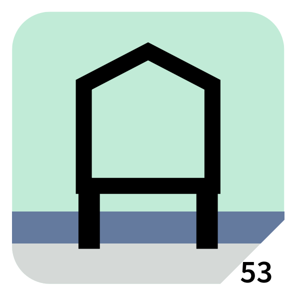


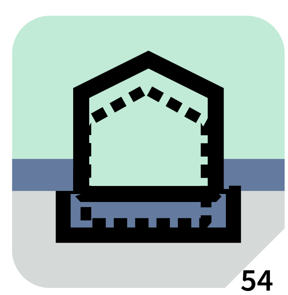


2.3 ARCHITECTURE







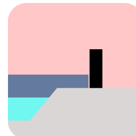


2.4 MATERIAL AND PROGRAM RESOURCES FOR FLOOD

Fig.32 Catalogue Icons

2.1 INFRASTRUCTURE

Protect - Flood Wall



Effectiveness

Normal	■□□□□
During Flood	■■■■■
After Flood	■■□□□

A flood wall is the most common approach to flood protection. It is a vertical barrier that restricts flood inundation into vulnerable land.[35] It is often used when there is minimal buffer space between the water and vulnerable buildings. Flood walls can be constructed as stand-alone structures or integrated into water fronting architecture. Although flood walls can effectively reduce flood risk, poor application of flood walls can create barriers and isolation. Sole reliance on flood walls can be very costly and have a negative impact on public space. Thus, flood walls alone may not be enough to create a successful urban water space. Integration of flood walls with buildings where possible is highly encouraged.

Fig.33
Flood Wall Cambridge Ontario

Fig.34
Flood Wall Nahe River Bad Kreuznach, Germany

Fig.35
Flood Wall at Zruc nad Sazavou, Czech Republic

Fig.36
Integrated Flood Wall Worth am Main Germany

Protect - Dike

Effectiveness

Normal	■■■□□
During Flood	■■■■□
After Flood	■■□□□

Dikes are similar to flood walls in how they are used to protect vulnerable land and structure from inundation. Dikes occupy a bigger footprint and are formed with artificially constructed soil fill. Flood walls can be integrated into dikes to create spatial variation. [36] An example would be the new flood park dike in Worth am Main Germany. The sloping form and the bigger footprint of the dike offers opportunity for program integration into the landscape and architectural design.

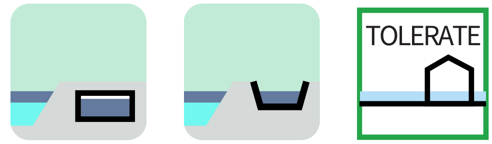
Fig.37
Dike at River Waal, the Netherlands

Fig.38
New Flood Park Dike
Worth am Main Germany

Effectiveness

Normal	■■■□□
During Flood	■■■■□
After Flood	■■□□□

Tolerate- Expansion



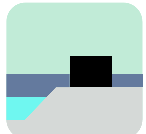
Instead of confining flood water behind a barrier, the expansion method assigns extra space and tolerance for water to grow during floods, redirecting the flood away from vulnerable areas. Infrastructural expansion can be in the form of hidden bypass culverts or additional open floodways.[37] This method offers the opportunity for floodable public programs to occupy the spaces of expansion during dry seasons.

Fig.39
Underground Bypass Culverts at Guadalupe River, San Jose

Fig.40
Red River Floodway Manitoba

2.2 LANDSCAPE

Tolerate - Submergible



Effectiveness

Normal ■■■■■
During Flood ■■□□□
After Flood ■■■■□

Submergible elements in riverscape and landscape design tolerate the growth of water to reduce flood vulnerability in the public realm. The sturdy and low maintenance nature of submergible elements can increase the speed of post-flood recovery of the public realm. The elements can also transition into supportive functions during the flood.[38] For example, the transformative stepping stones project in the Netherlands forms an alternative pathway during the flood.

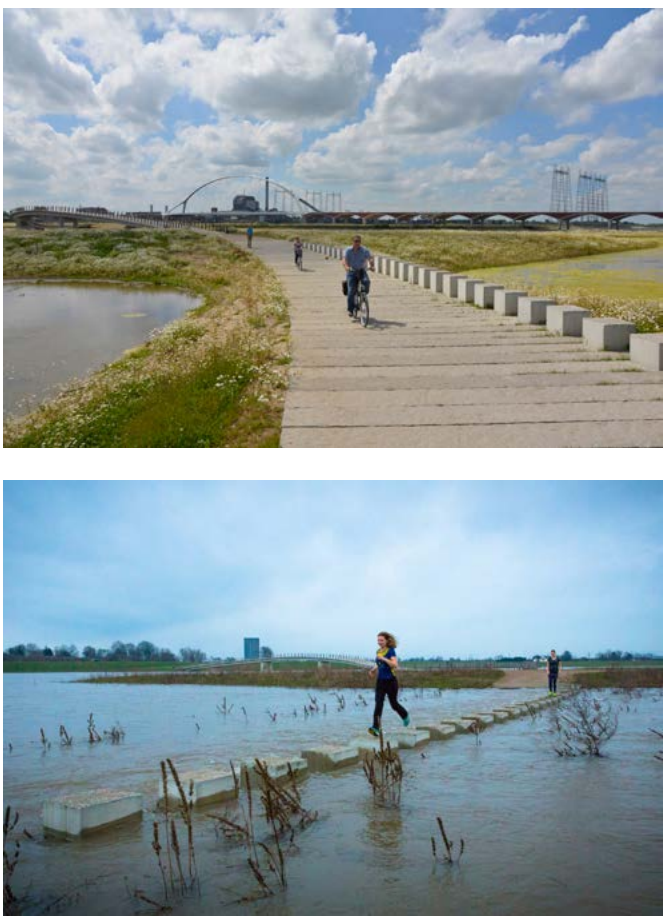
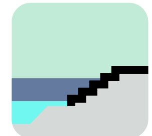


Fig.41 Transformative Stepping Stones by NEXT Architects in Nijmegen, The Netherlands

Fig.42 Submergible Seatings Berges du Rhone

Effectiveness
Normal ■■■■■
During Flood ■■■□□
After Flood ■■■■□

Tolerate- Expansion

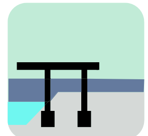


Similar to the expansion approach in infrastructure, expandability in landscape design offers additional space for river growth during flood events. The expansion of the river is incorporated into the landscape design through elements such as public seating or water features.[39] This offers people visual signals of changes in the water level while enhancing the experience of the water fronting programs during normal usage.

Fig.43
Stepped Seatings Berges du Rhone

Fig.44
Retention Basin at Scott Park, Champaign USA

Tolerate - Elevated



Effectiveness

Normal ■■■■□

During Flood ■■■□□

After Flood ■■■■□

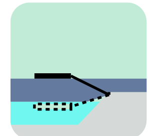
Elevated pathways can normally work as secondary walkways or viewing platforms and maintain connection of circulation during the flood. These elements work best with the expansion approach to form multiple levels of walkways and organize public program hierarchy. They allow the space to tolerate the growth of water and continue to function during flood. [40]

Fig.45
Qunli National Urban Wetland, China

Effectiveness

Normal	■■■■□
During Flood	■■■□□
After Flood	■■■□□

Tolerate- Adapting



Floating platforms and walkways are examples of landscape designs adapting to flood events. These water-adaptive elements maximize water recreational program functionality and can greatly promote closer public engagement with water. Due to its floating nature, this approach is only suitable for moderate water level changes with gentle river flows. High water level floods can easily destroy a platform and carry it away with the flood current. [41]

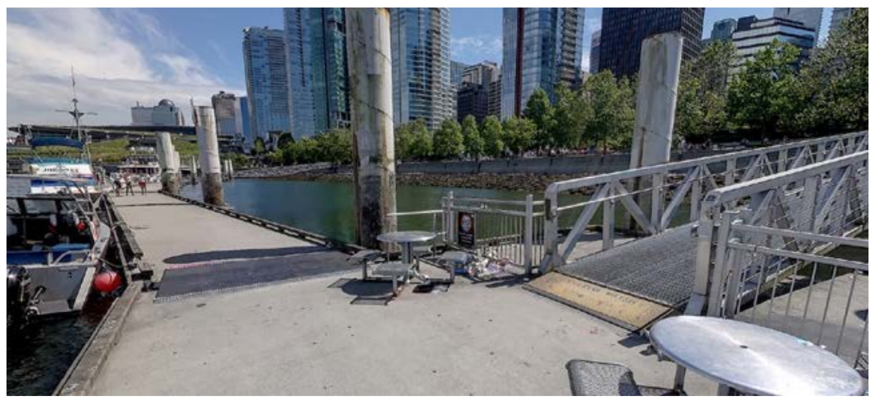


Fig.46
Vancouver Waterfront Floating Boardwalk

Fig.47
Leine Suite, Hanover, Germany

2.3 ARCHITECTURE

Tolerate - Elevated

Effectiveness

Normal	■■■■□
During Flood	■■■■□
After Flood	■■■■□

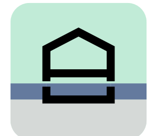
Elevated architecture is a very common approach against floods. Similar to elevated walkways in landscape design, this approach tolerates growth of water, and is used for water fronting buildings that experience frequent inundation. [42] Flood vulnerable programs are permanently raised above the flood plain with anchored and reinforced structural columns. This allows the building to function normally during floods. The supporting structural columns can evenly distribute the force of flood water across the building footprint, minimizing water pressure and greatly reducing structural damage from floods.
An important advantage of elevated architecture is the opportunity to create a multifunctional space under the building. The space can be designed as open public programs for non-flooded periods and activate street level connection with the nearby water.

Fig.48
Aluminium Centrum ,
Abbink X De Haas Architectures
Houten, the Netherlands

Effectiveness

Normal	■■■□□
During Flood	■■■□□
After Flood	■■■□□

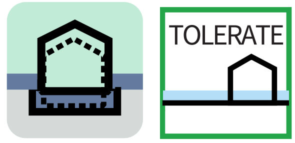
Tolerate- Wet Proof



Wet proofing [43] is applied to architecture that experiences less frequent flooding. Similar to elevated architecture, the main principle of wet proofing is to allow the water to pass through the building with minimum damage. Vulnerable programs in wet proofed architecture are strategically located above the flood level, and floodable programs such as storage and garage are designed to occupy the floodable spaces. All service equipment and floodable spaces are protected with water proof enclosures and finishes. Wall openings are designed to allow water to quickly enter and exit enclosed areas and achieve equilibrium of water pressure between inside and outside. This reduces hydrostatic pressure and, consequently, reduces the likelihood of structural damage. [44]

Fig.49
Wet-proof architecture concept from P206 Aquatecture

Tolerate - Amphibious and Floating



Effectiveness

Normal	■■■■□
During Flood	■■■■□
After Flood	■■■□□

Amphibious and floating architecture tolerate the growth of water with buoyant foundations. Instead of being statically elevated, amphibious and floating architecture can move up and down with the changing water level. This freedom of movement allows the building to have more versatile program and function. Since buoyant foundation is most suitable for small scale residential buildings, the limitation of this approach is the size of the building. Other than residential applications, this approach can be integrated into larger buildings as a small movable component that can completely tolerate flooding. [45]

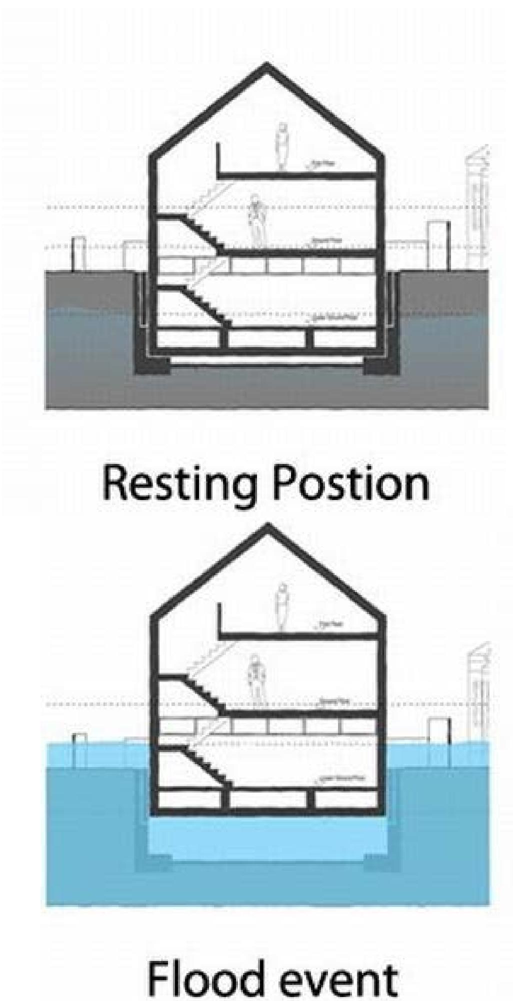


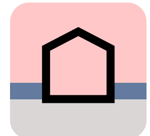
Fig.50 Amphibious Architecture by Beca Architects

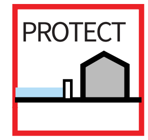
Fig.51 Floating House by +31 Architects Amsterdam Netherlands

Effectiveness

Normal ■■■□□
During Flood ■■■■■
After Flood ■■■■□

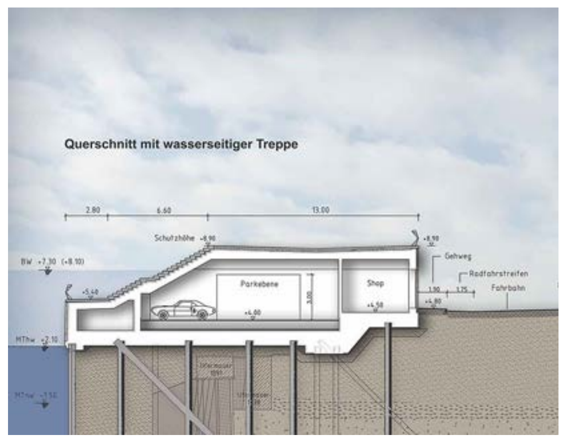
Protect- Dry Proof





Dry proofing architecture uses watertight assembly and reinforced structure to prevent water from entering the building. [46] This method is often used to reinforce existing buildings or integrated into flood infrastructure. The construction of dry proof architecture is very costly and restrictive, and thus should be used at strategic locations. Appropriate applications of dry proofing architecture can improve flood infrastructure and create multifunctional spaces.

Fig.52 Watertight Dry Proofing Measures for Waterfront properties in Hafencity, Germany



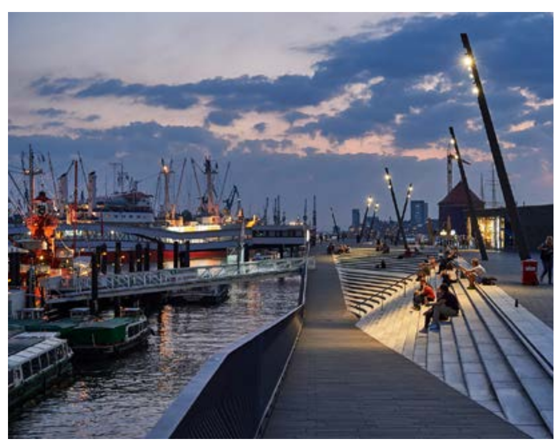
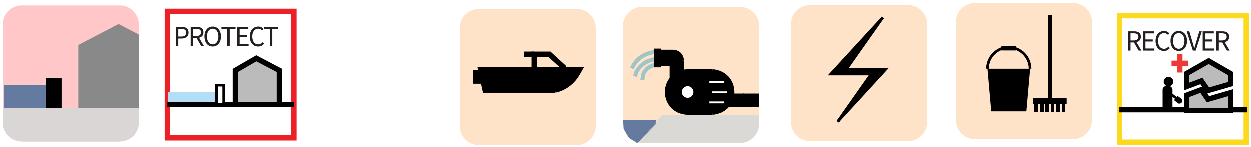


Fig.53 Integrated Parking Structure Promenade Niederhafen Hamburg, Germany

2.4.1 DISTRIBUTABLE RESOURCES



Protect
Temporary Flood Control

Recover
Transportation, water pumps, electricity, cleaning supply

Distributable resources are resources that could be distributed to areas of flood vulnerability. These resources are distributed to surrounding areas before and during flood for persons and properties at risk. These resources need to be purchased in advance and stored in nearby facilities for immediate reaction to floods.

Effectiveness	
Normal	■□□□□
During Flood	■■■■■
After Flood	■■■□□

SAND BAG AND MUSCLE WALL

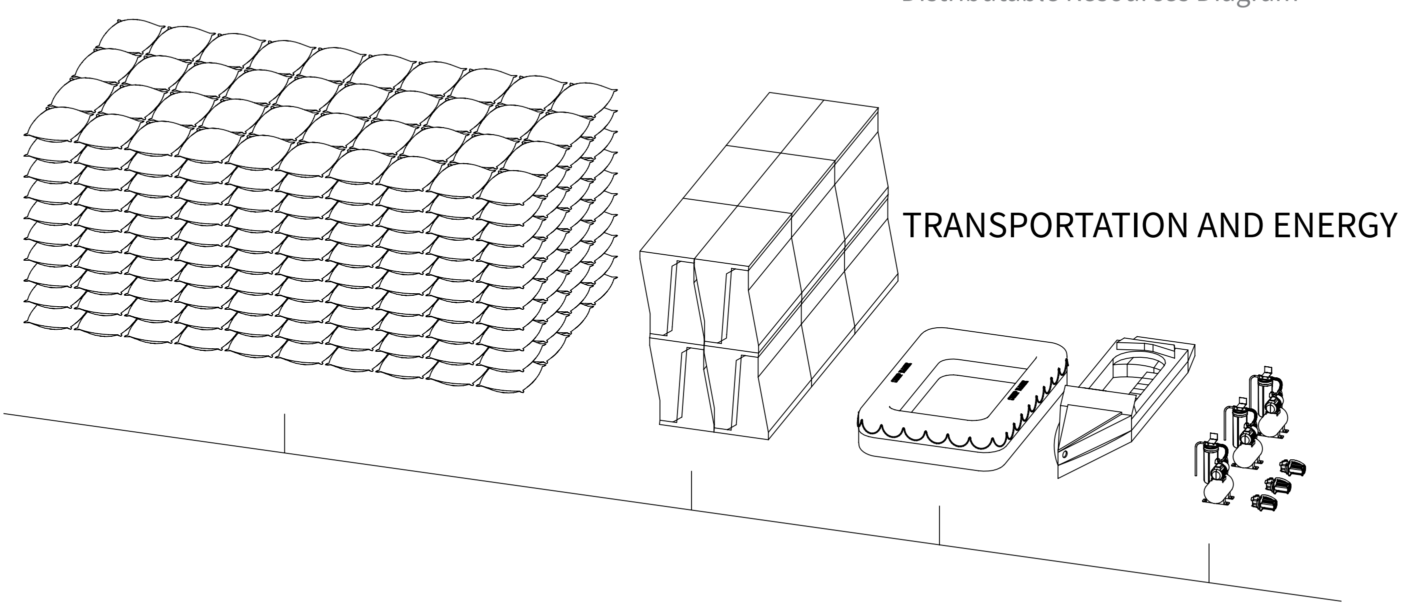


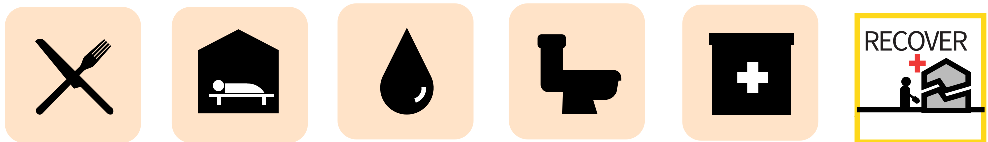
Fig.54
Distributable Resources Diagram

Fig.55
Sandbagging Station

Fig.56
Muscle Wall

Fig.57
Emergency Rescue Boat

2.4.2 RESOURCES FOR TEMPORARY SHELTER



Recover
Food, shelter, water, washroom, first aid

Effectiveness	
Normal	■■■□□
During Flood	■■■□□
After Flood	■■■■■

These are resources needed at a temporary shelter to provide the basic needs for displaced people. These resources need to stay dry, be stored in spaces that transform into temporary shelters, and be readily available during times of need.

Fig.58
Resources for Temporary Shelter Diagram

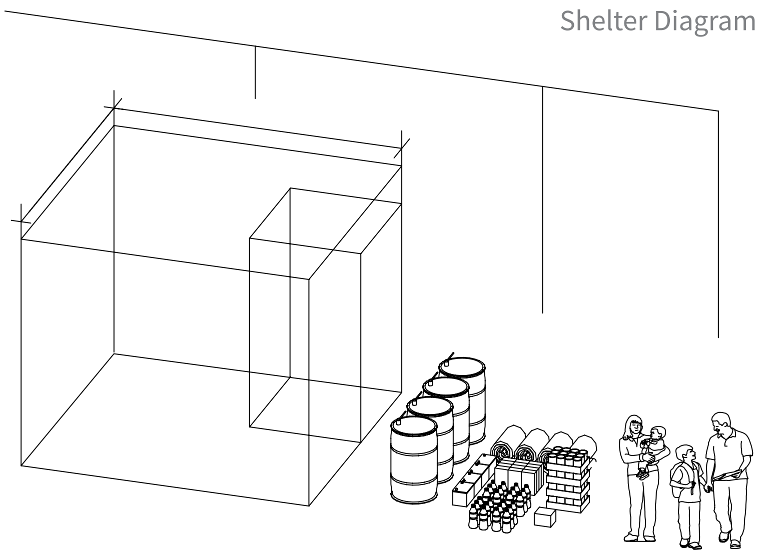
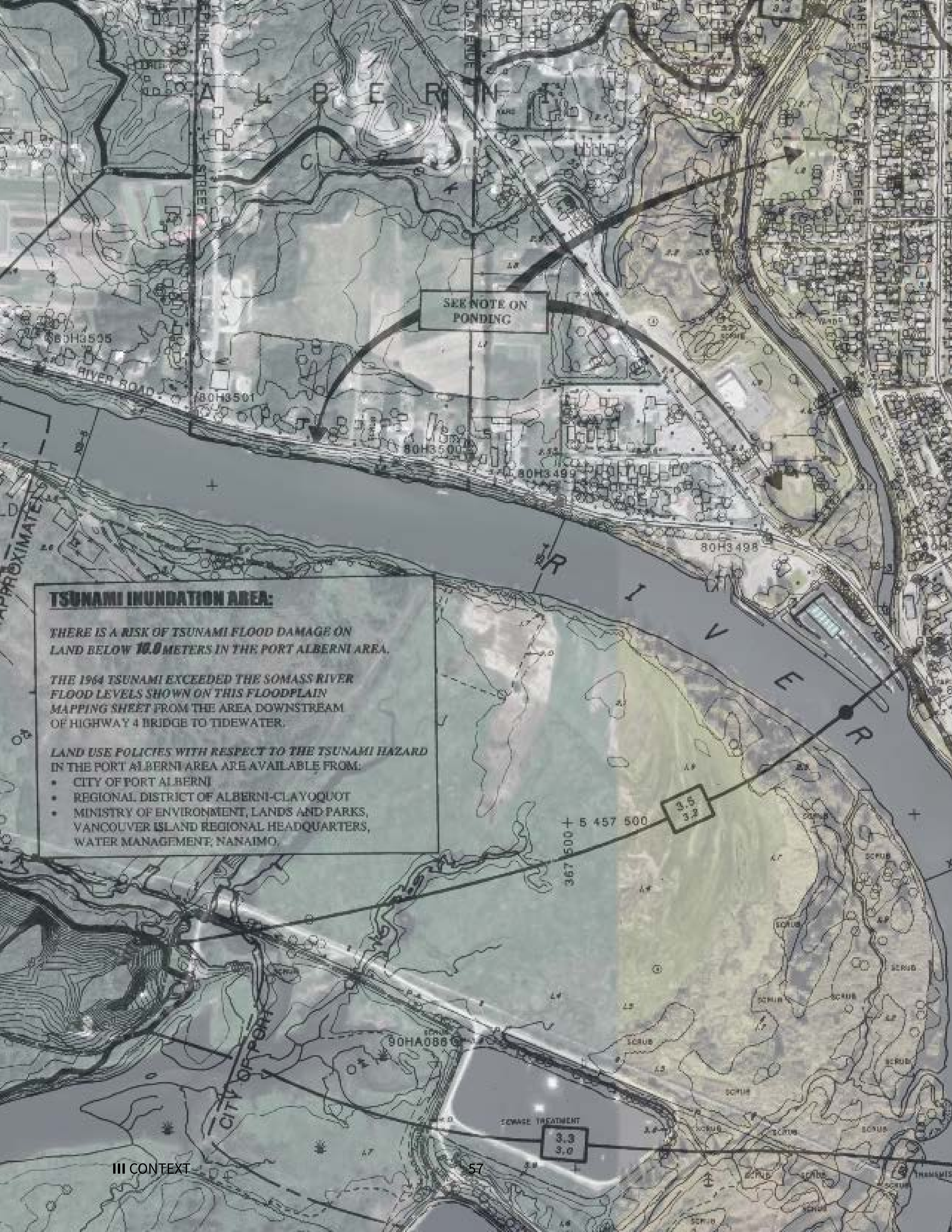


Fig.59
Shigeru Ban Temporary Shelter

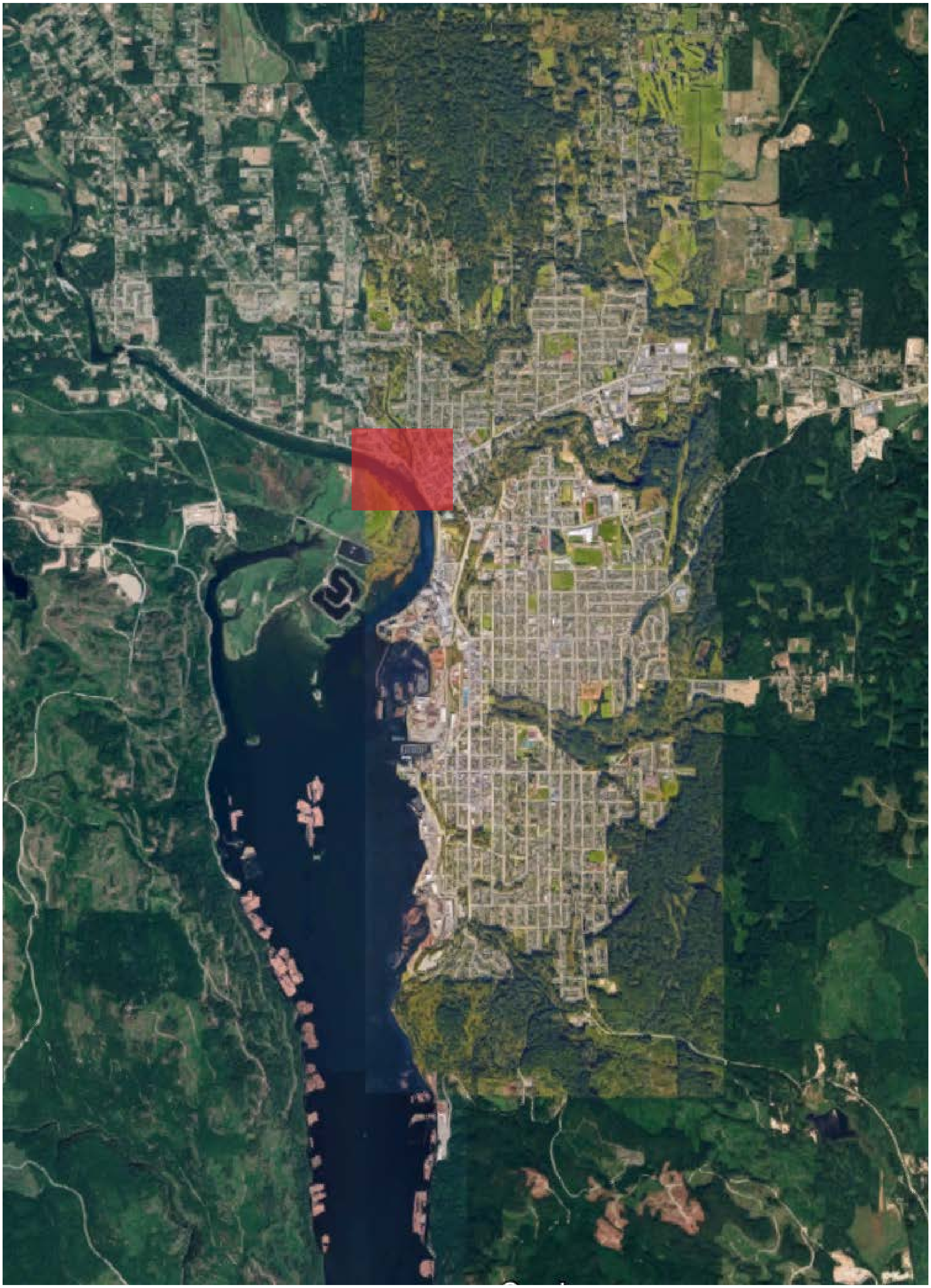
Fig.60
Emergency Preparedness Kit


TSUNAMI INUNDATION AREA:
THERE IS A RISK OF TSUNAMI FLOOD DAMAGE ON LAND BELOW 10.0 METERS IN THE PORT ALBERNI AREA.
THE 1964 TSUNAMI EXCEEDED THE SOMASS RIVER FLOOD LEVELS SHOWN ON THIS FLOODPLAIN MAPPING SHEET FROM THE AREA DOWNSTREAM OF HIGHWAY 4 BRIDGE TO TIDEWATER.
LAND USE POLICIES WITH RESPECT TO THE TSUNAMI HAZARD IN THE PORT ALBERNI AREA ARE AVAILABLE FROM:
• CITY OF PORT ALBERNI
• REGIONAL DISTRICT OF ALBERNI-CLAYOQUOT
• MINISTRY OF ENVIRONMENT, LANDS AND PARKS, VANCOUVER ISLAND REGIONAL HEADQUARTERS, WATER MANAGEMENT, NANAIMO.
SEE NOTE ON PONDING
RIVER ROAD
80H3505
80H3501
80H3500
80H3499
80H3498
90HA088
RIVER
5 457 500
367 500
3.5
3.2
3.3
3.0
SEWAGE TREATMENT
CITY OF PORT
APPROXIMATE

PART III

CONTEXT

VANCOUVER ISLAND
PORT ALBERNI



3.1 PORT ALBERNI

The first two chapters of the thesis established a set of principles and a design toolkit for the creation of the urban water space. The form of the urban water space is fluid and can change drastically in both scale and application depending on the degree of vulnerability and needs of a specific site. Therefore, the recipe for a good urban water space differs from site to site. To illustrate this new space type on realistic flood vulnerable sites, Port Alberni was chosen as the contextual background. Port Alberni is located on Vancouver Island, British Columbia. Since the city is located on an island, transportation of external aid and resources is very difficult during times of emergency. The need for a well-established set of internal reactions to flood is inevitable. Therefore, the implementation of urban water spaces is very appropriate as a valuable internal support system for flooding in the city. Port Alberni was chosen for its unique geographic location, its scale, its past experience with tsunami and flooding, as well as its local culture and heritage. In this chapter, local characteristics, the flood situation, and specific site conditions will be introduced to outline a set of parameters for the design. The goal of the design experiments in Port Alberni is to visualize how site-specific conditions can guide the choice and combinations of guiding principles and parts of the design toolkit. Different components will be chosen and combined based on the specific site conditions of Port Alberni.

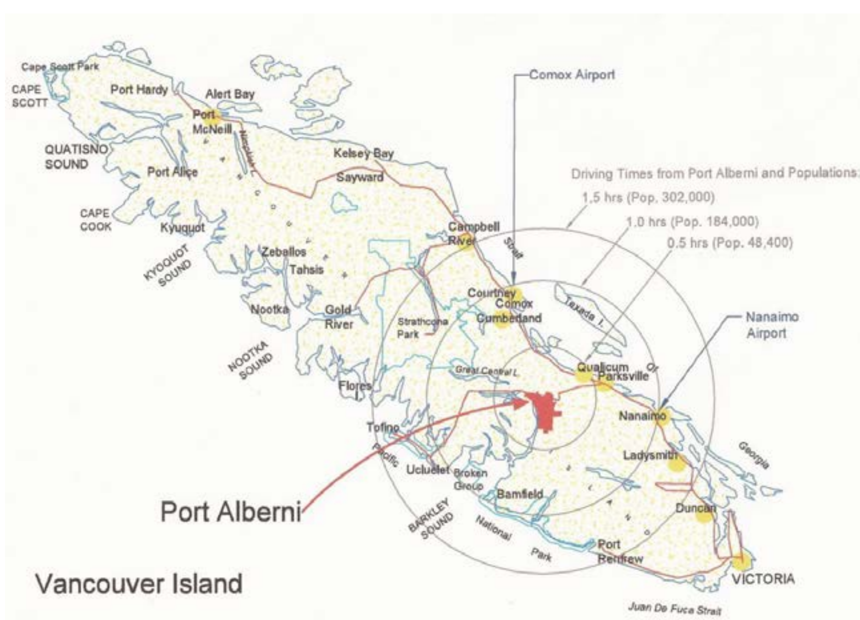


Fig.61 [Previous Page]
Topography Map of
Port Alberni North

Fig.62 [Left]
Map of Port Alberni

Fig.63 [Right]
Location of Port Alberni on
Vancouver Island


Scenic View Towards Mountain


Scenic View of Somass River


Local Marina


Commercial

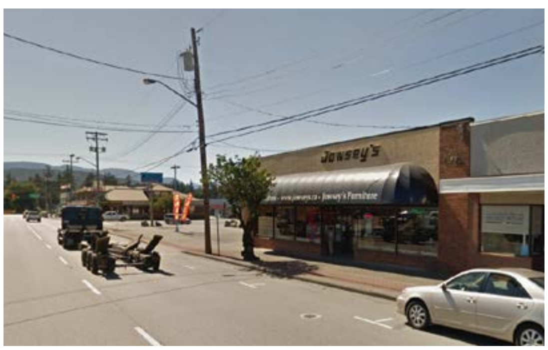

Low Density Residential


First Nations Region

3.2 LOCAL CHARACTERISTICS

The city of Port Alberni has a total population of 18,000. [47] It is a deep port city located at the end of the Alberni Inlet, composed of low-lying land surrounded by breathtaking mountainous views. The urban fabric is currently composed of low-density residential zones, large areas of green spaces and parks, and clusters of local business districts and industrial areas along the waterfront. Traditionally, the local economy of the city and its surrounding area was reliant on the primary resource sectors of forestry and fishing. In recent years, the instability of the resource sector has led to a decrease in employment and is significantly affecting the vitality of the city. Consequently, Port Alberni is shifting its focus towards the tourism industry. The breathtaking natural landscape offers the opportunity for redevelopment of the waterfront into public recreational spaces. The waterfront, slowly transitioning away from industrial uses, offers large open spaces for public recreational programs such as fishing, rowing, nature trails, and leisurely walks. The community would benefit significantly from an improved connection to the waterfront via walkways or strategically-located public spaces.[48] The waterfront open spaces are perfect candidates to transform into urban water spaces.

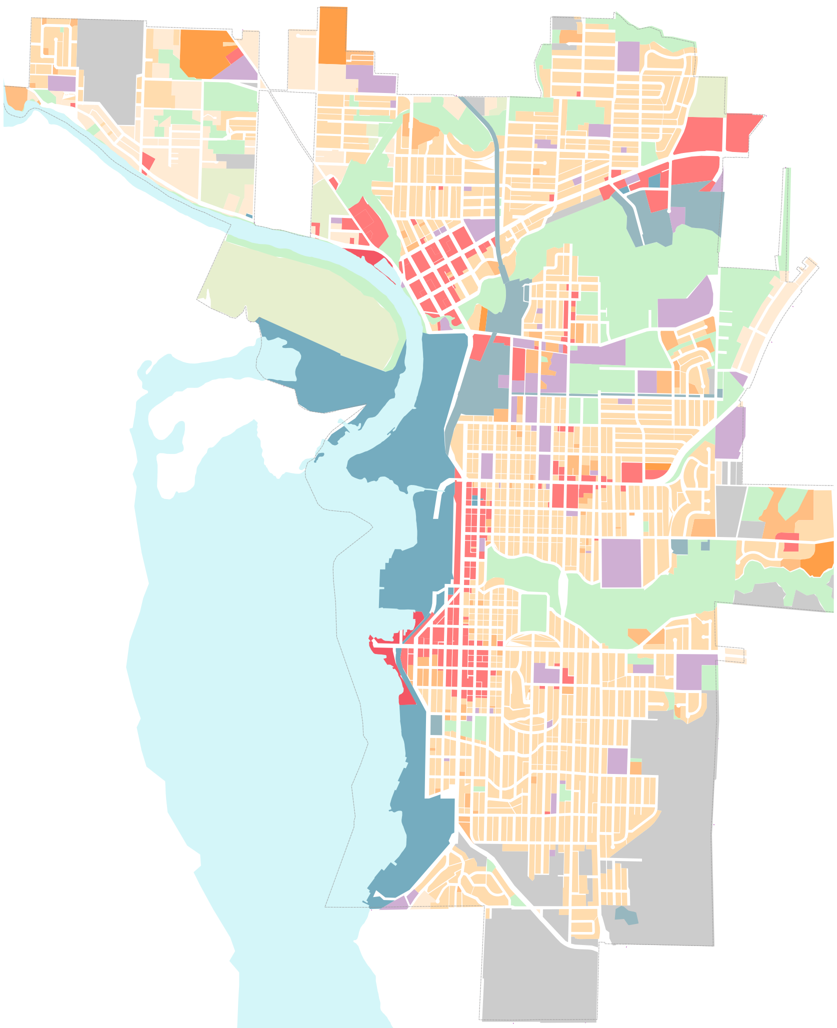
Fig.64
Port Alberni Street Views



Commercial

Nuu-Chah-Nulth Whaling Canoe Sculpture

Cultural Pavilion



PORT ALBERNI ZONING

Fig.65

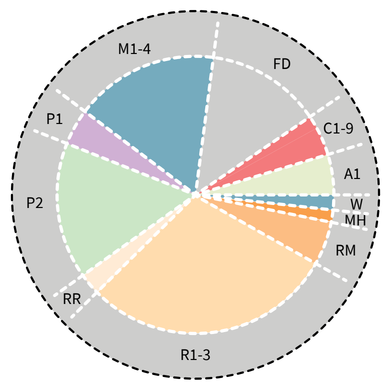
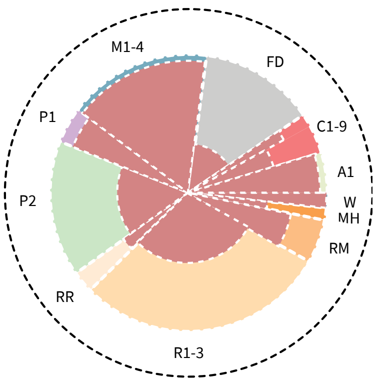
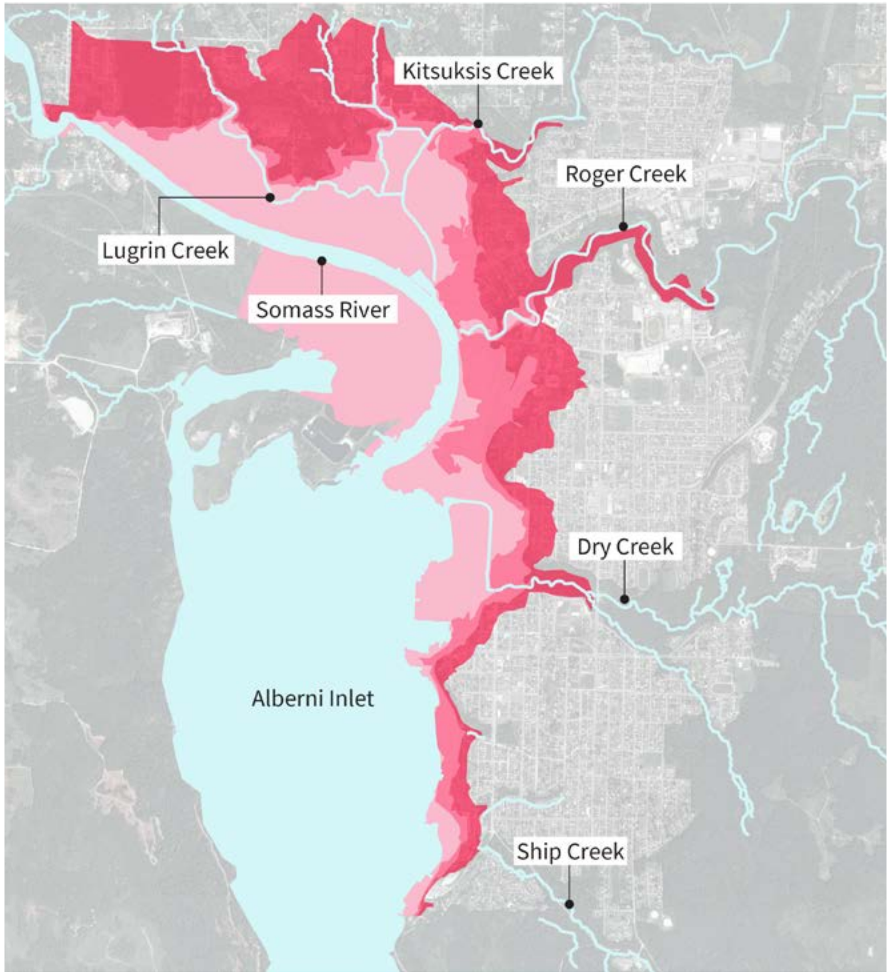


Fig.66
Port Alberni Landuse Dynamic



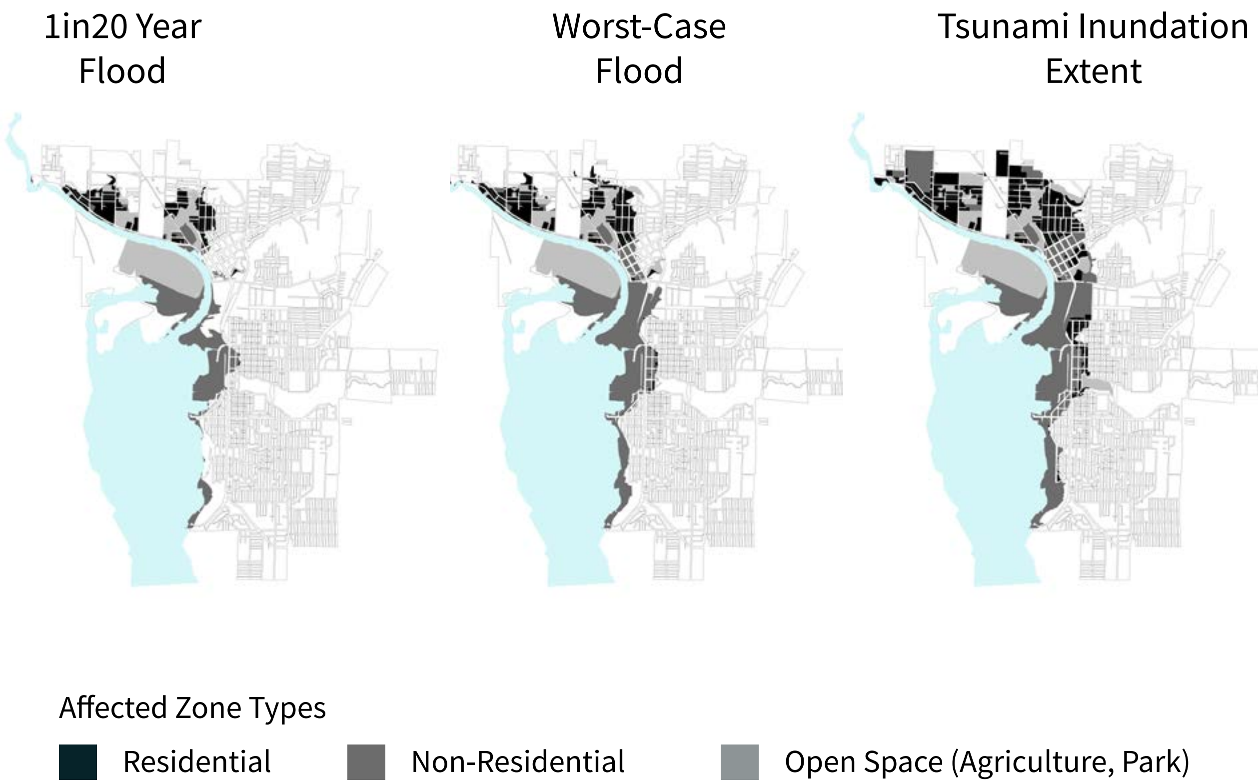
Percentage inundated by tsunami(20m) per landuse type



Tsunami (20m)
Worst Flood (6m)
1in20 Yr Flood (3.65m)

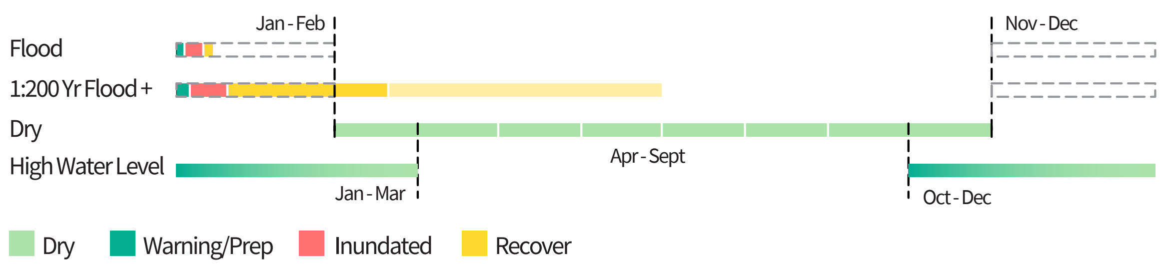
FLOOD PLAIN AND INUNDATION EXTENTS

Fig.67



FLOOD PLAIN AND VULNERBILITY

Fig.68



RHYTHM OF THE SOMASS RIVER

Fig.69

3.3 FLOOD VULNERABILITY ANALYSIS

Threat From Two Directions

On one hand, the Alberni Inlet and its low-lying surrounding area are subject to tsunami inundation. Although Port Alberni is located inland on Vancouver Island, the narrow and lengthy Alberni Inlet can drastically amplify the energy of a tidal wave as it travels up from the coast. This contributs greatly to the intensity of a tsunami inundation. “waves grew in size as they moved up Alberni Inlet and were two and one-half times larger at Port Alberni at the head of the inlet than at Tofino and Ucluelet on the Open Coast” [49] During the 1964 Alaska earthquake, sea surge from the earthquake traveled at the speed of 50 km/hr and inundated neighbourhoods in chest-deep water. The highest water level reached 4.3 metres above mean sea level. Houses were swept off their foundations, and the tsunami caused severe damage to 260 homes and total economic loss of about $50 million.[50] In response, Port Alberni OCP identified a “tsunami inundation zone” below the 6.0m contour line, and a 20m contour line delineates a worst-case scenario.[51]

On the other hand, this city is also being affected by recurring seasonal floods caused by heavy rain or snowmelt, leading to the flooding of Dry Creek and Somass River and the surrounding area. A floodplain bylaw was created to limit and regulate new developments within the floodplain. The city also encourages agricultural, park, and open space recreational uses of flood susceptible lands.[52] In recent years, there has been a noticeable increase in flood warnings and evacuations of Port Alberni and its surrounding area. In November 2006, the flooding shut down 4 blocks of residences and businesses as well as a major traffic corridor.[53] As seasonal flooding slowly becomes the new norm, the threat accumulated from recurring floods is just as great as the threat of a rare tsunami.

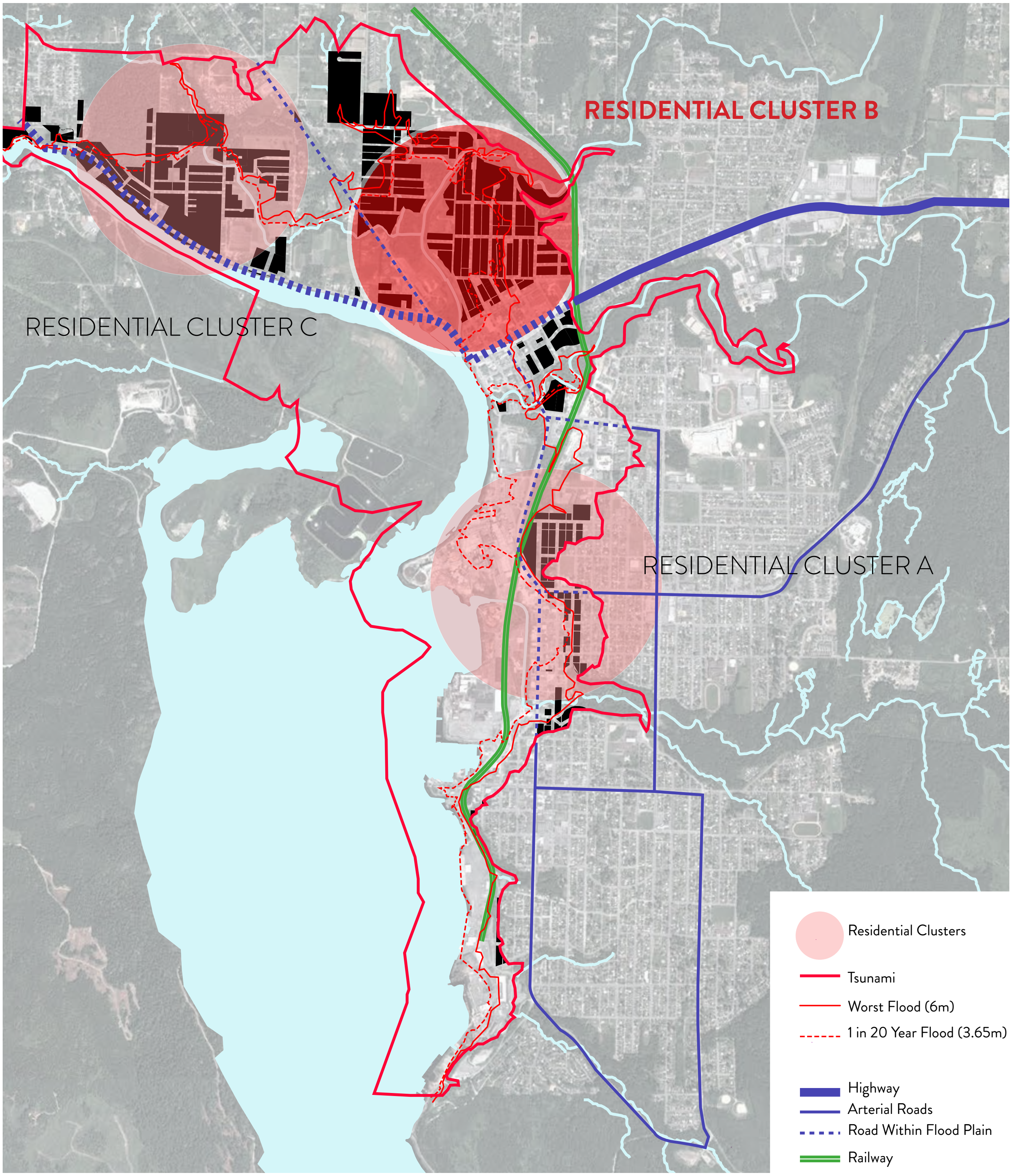
PORT ALBERNI 1964 TSUNAMI

Fig.70

PORT ALBERNI 2014 FLOOD
Fig.71

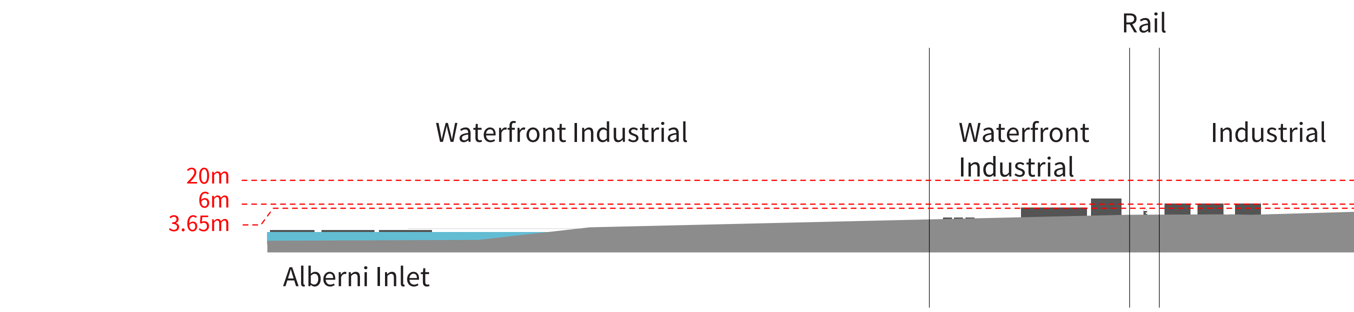
Vulnerable Residential Clusters

As discussed in Chapter 1.3, low-rise residential buildings are most vulnerable to flood. In the city of Port Alberni, there are three major residential clusters at high risk of flooding. (fig.72) The proposed urban water space should slowly develop and span across the entire waterfront in the form of a linear park at varying design intensities for flood, with focused activity/flood service nodes near walking radius to each residential cluster at risk. As a departure point, Cluster B is where the sample design will take place for this thesis. Residential cluster B (highlighted with dark red on Fig.72) is the area most affected by seasonal flooding in the city. In Fig.73 cross sections of all three clusters show that, in comparison to cluster A and C, cluster B has a greater concentration of residential buildings within the flood plain. Cluster B is composed of a relatively large area of flat low-lying land, with some waterfront commercial zoning, clusters of green space, and a large span of low density residential that could be inundated completely during a 1 in 20-year flood.

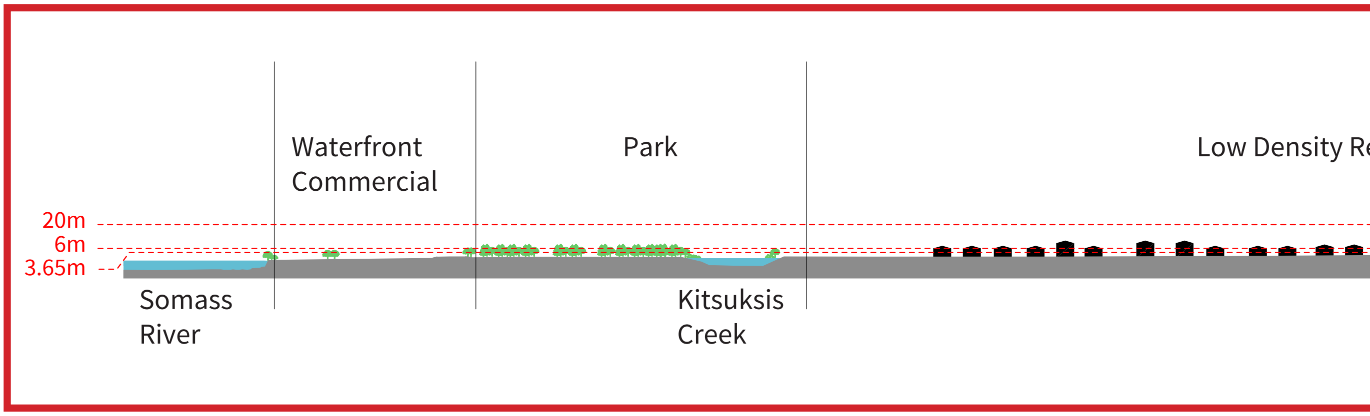


VULNERABLE NEIGHBORHOODS

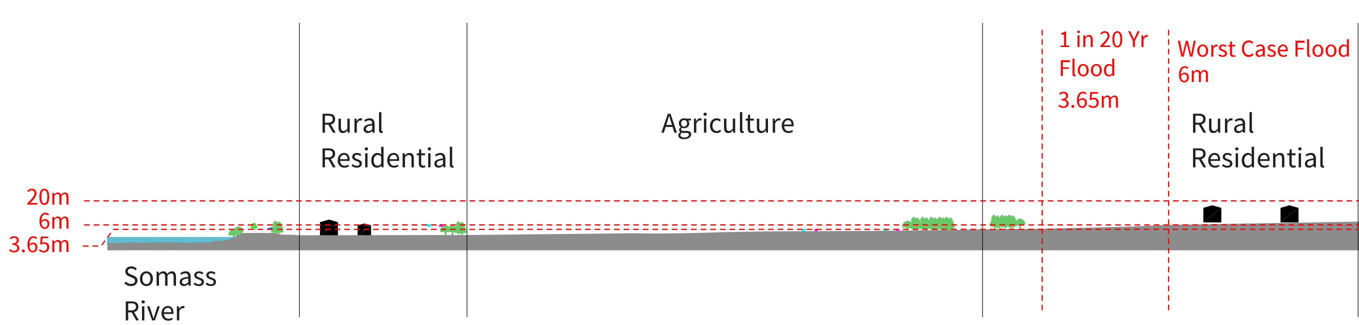
Fig.72



RESIDENTIAL CLUSTER C



RESIDENTIAL CLUSTER B



RESIDENTIAL CLUSTER A

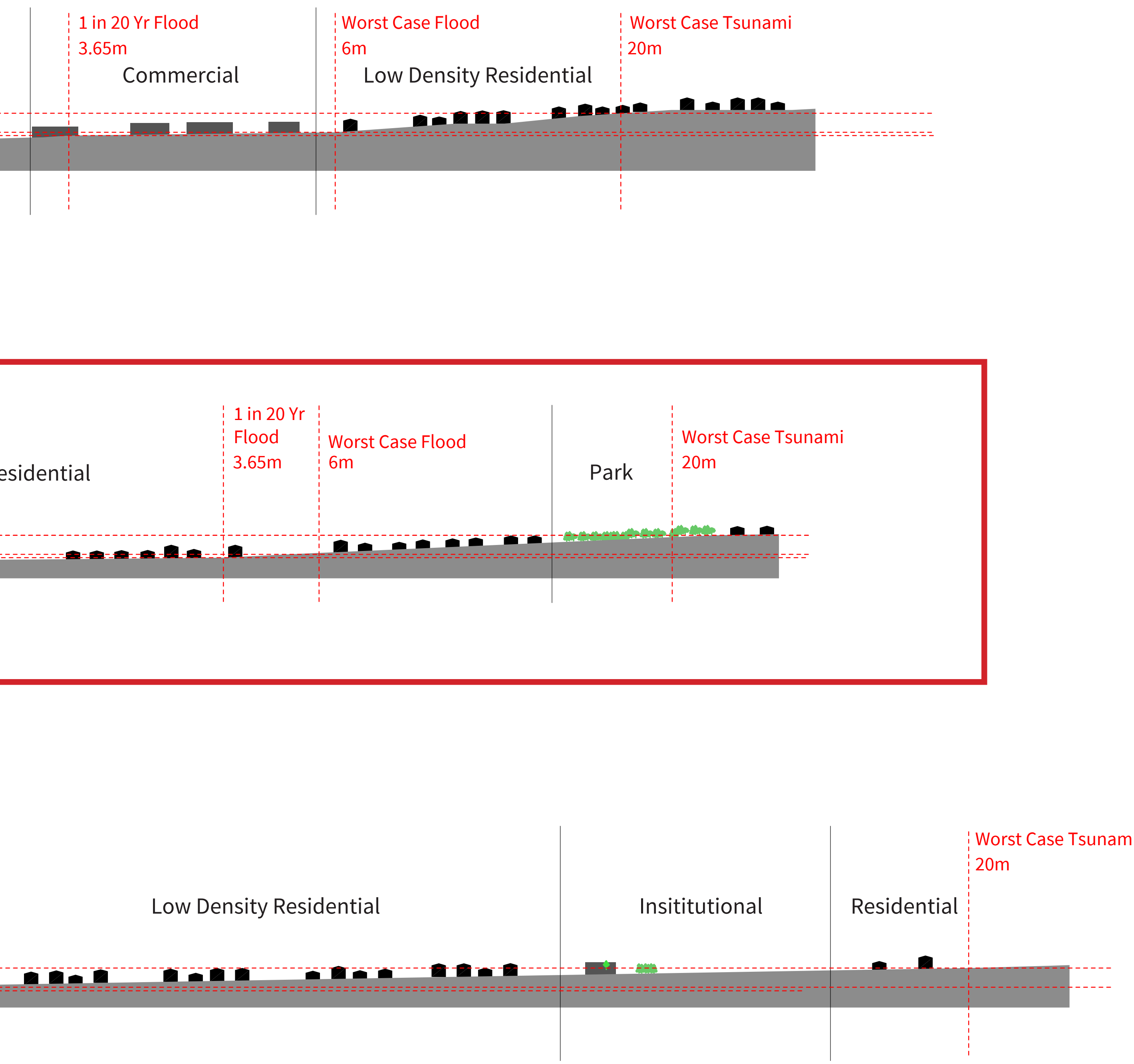


Fig.73
Context Site Sections

Closer Look at Cluster B

Natural Conditions

The low-lying lands of cluster B have ground elevation near sea level, with 1 in 20-year flood height of 3.65m, a worst case flood height of 6m, and a worst-case tsunami of 20m.[54] It is affected by both freshet flooding from snowmelt upstream, seasonal heavy rainfall, and downstream coastal inundation from tsunami.

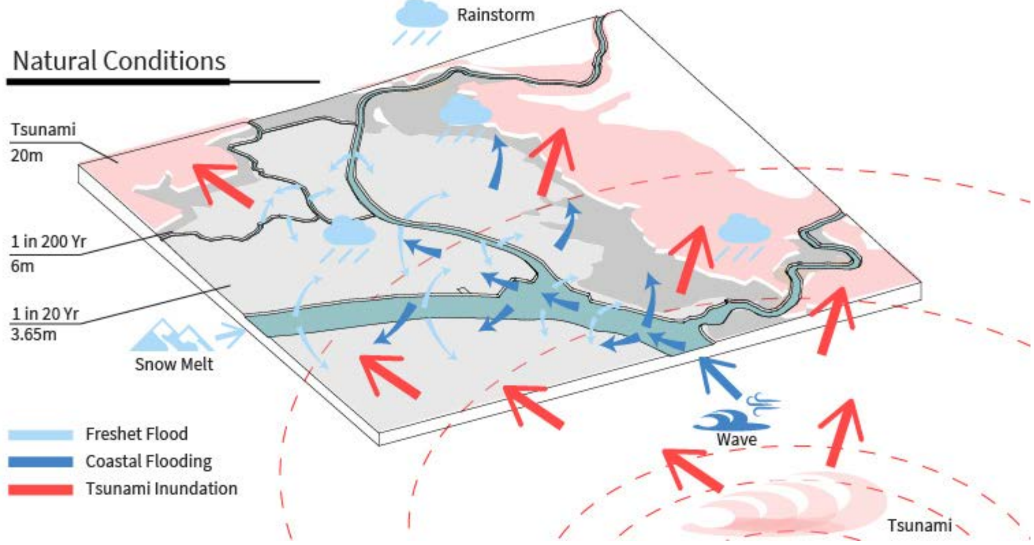
Existing Measures

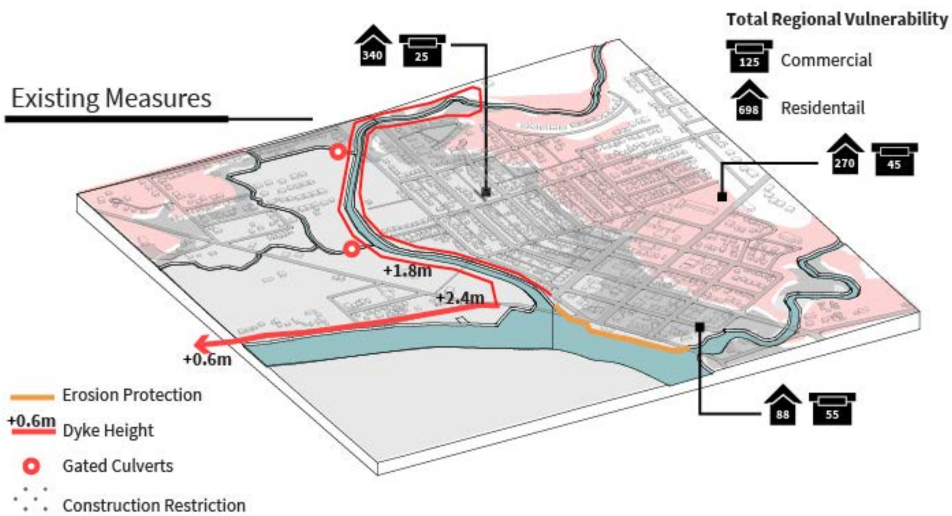
There are a few existing flood measures in place in Port Alberni around Cluster B, all of which are infrastructural measures. (fig.74) Dykes were built on the north side of the Somass River and the west bank of Kitsucksis Creek, and flap-gate culverts were installed at the mouth of Lugrin Creek. The height of the dikes ranges from 0.6m at the far upstream end to 2.4m above the surrounding area near the Estuary. Dikes on Kitsucksus Creek rise to about 1.8m.[55] These flood control measures were considered inadequate in the event of a tsunami or a 1 in 20 year flood, as developments below 6m contour would still be vulnerable to flooding.[56]

The proposed regional strategies are as follows:

1. the area between Kitsuksis Creek and Roger Creek to be designedwith concentrated flood protection
2. the area north east of Kitsusksis Creek to focus on interaction with the river and flood tolerance to allow water expansion.
3. the area beyond 1in 200-year flood plain to only focus on post flood recovery

By redirecting the water to areas with less concentrated urban fabric, the flood threat is released from the most vulnerable areas thus reducing physical damage and speeding up the process of recovery. Flood tolerance reduces the need for protective barriers at the waterfront to maximize recreational water activity and connection between the river and the city during non-flood periods.





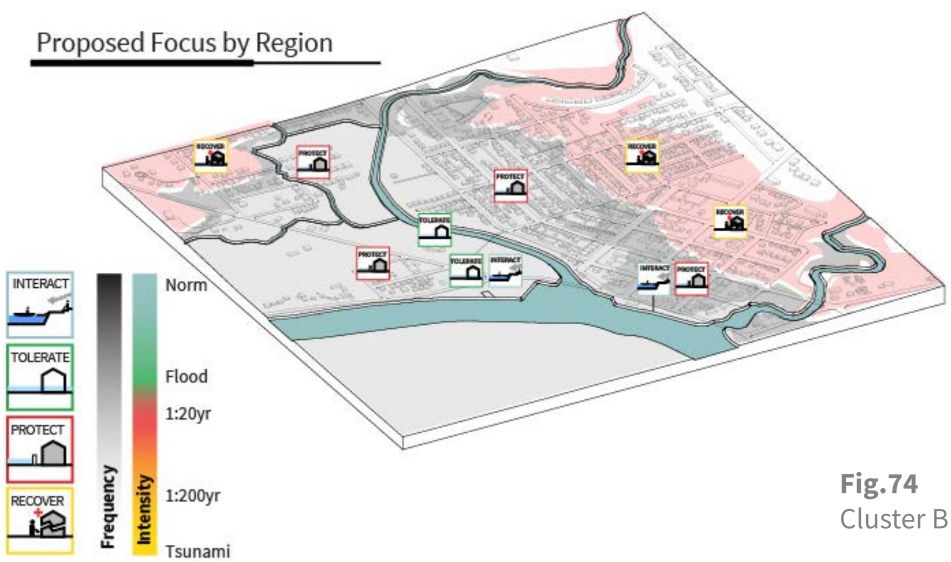
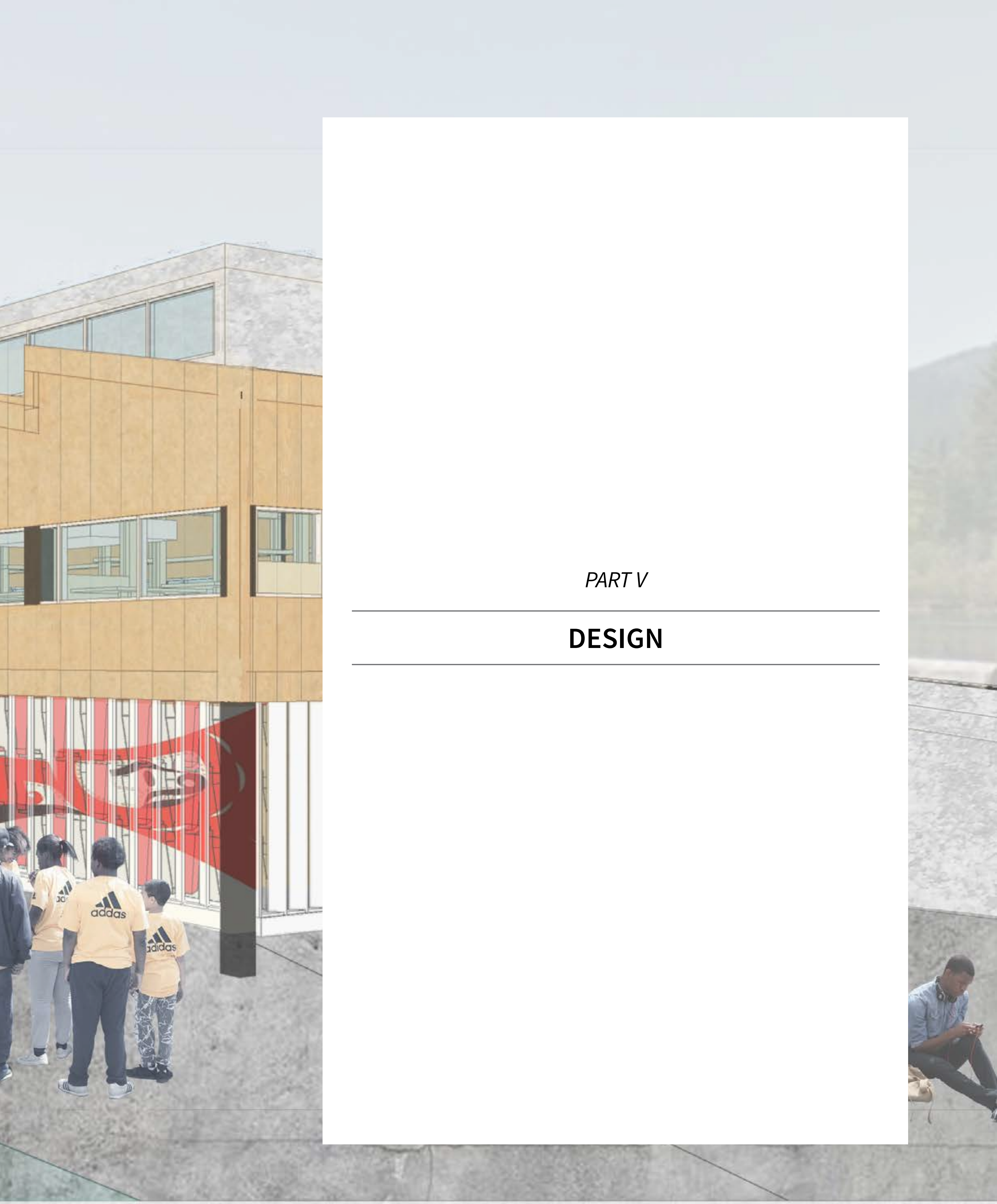


Fig.74
Cluster B Analysis


RESCUE BOAT NO.21



PART V

DESIGN

4.1 DESIGN SITES

Site and Program Strategies

The design study of the urban water space takes place at the turn of the Somass River. The design is responsible for urban fabric within a 15-minute walking radius from the existing Clutsi Marina. The design radius is determined based on a tolerable travel distance by foot during flood events. This can help setup the proximity between each future community service node for flooding.

The overall study area is separated into three zones:

Zone 1 East of Kitsuksis Creek, is a combination of concentrated single family residential, low-rise residential and the local retail commercial district.

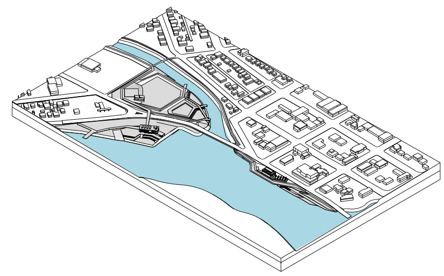
Zone 2 West of Kitsuksis Creek, has less density and more open green space, mobile homes, rural residential, and agriculture land.

Zone 3 At the fork between Somass River and Kitsuksis Creek, is forest and agricultural land with future potential to develop into park space.

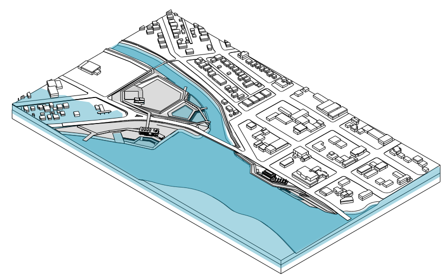
Overall site strategy

The overall flood design strategy is to focus on the principle of flood protection in zone 1, apply the principle of toleration to allow a partial inundation of zone 2, and allow a complete inundation of zone 3. This allows more outward oriented public programs with direct(physical) water interaction for zone 2 and 3, and creates public space with indirect(visual) water interaction and tighter inward connectivity with the urban fabric for zone 1. The capacity for flood recovery is also designed proportionally to the flood vulnerability of each zone.

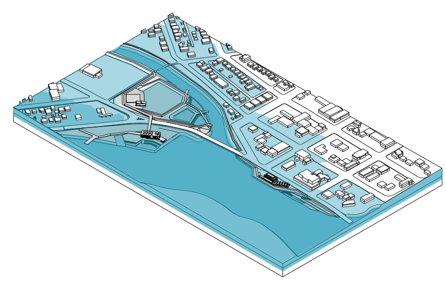
The proposed design is composed of three individual sites of public program “nodes” connected by walkable trails to form an urban water space along the Somass River. This design experiment serves as an example prototype module within a larger system of urban water spaces that can connect with existing public programs to grow and expand along the span of the river over time. For each node, the functions and form of public programs are chosen and designed to reflect the corresponding local flood principles. Each node is also designed to adapt and transform at three different flood levels -- normal state, 1 in 20-year flood (3.65m), or 1 in 200-year flood (6m). Each node utilizes a different combination of flood design principles and components from the toolkit to respond to site-specific conditions.



Normal State



1 in 20 Year Flood



1 in 200 Year Flood

Fig.75
Existing flood conditions

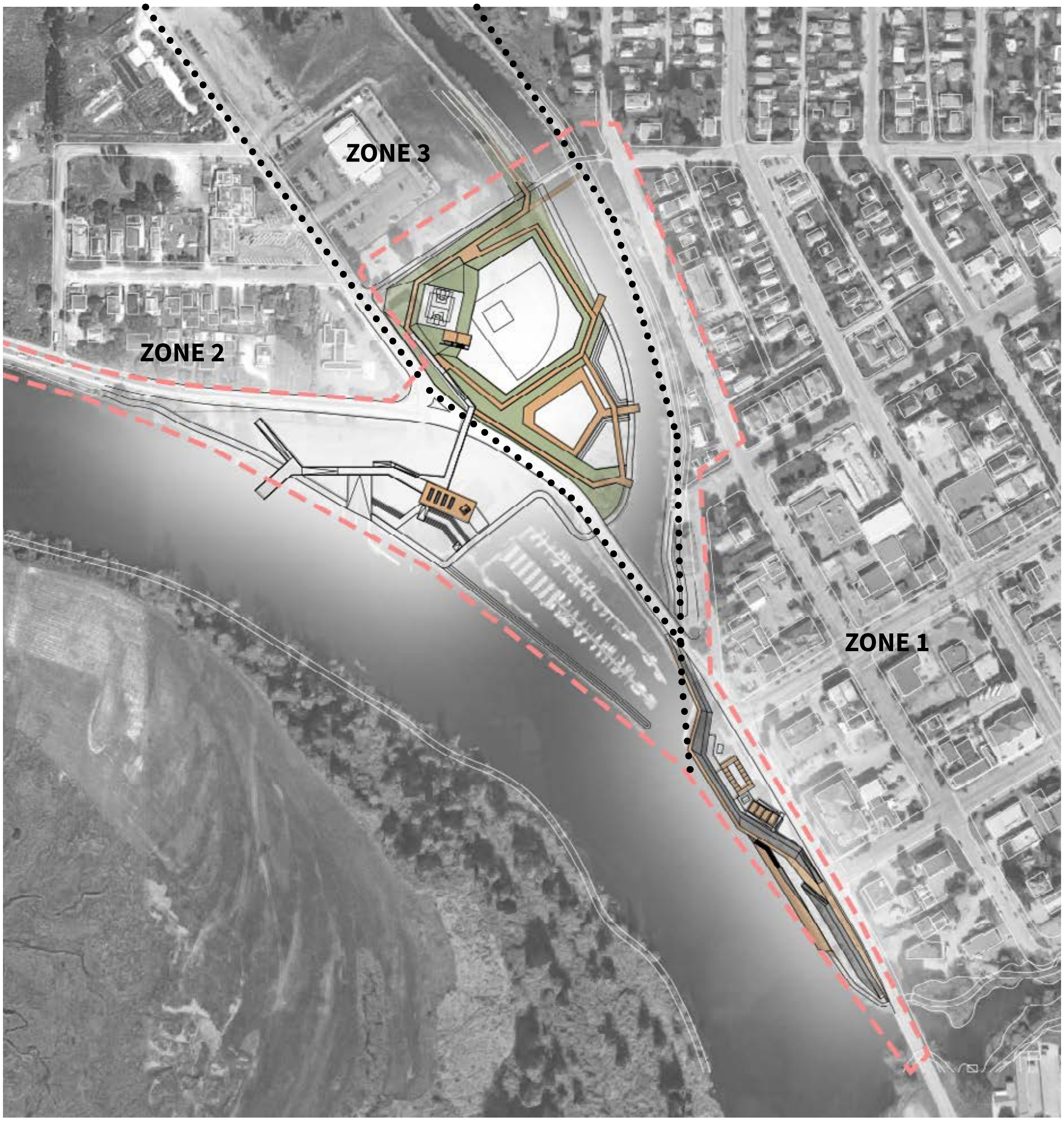


Fig.76
Overall Site Plan Indicating zone divisions with black dotted line and design extents with pink dash line

THE THREE SITES

Three sites, one from each zone, within cluster B were chosen for the detailed design experiment. Each site represents a unique flood design priority. These three sites serve as activity nodes that connect into a linear open public space.

SITE A (Zone 1) - DINER

Main Flood Principles – Interact, Protect, and Recover
(integrated dike protection with wet proofing and amphibious architecture)

Site A is located in the commercial district. The architecture and flood resources on site A are designed for defence up to 1 in 200 years flood(6m), with a focus on maximizing flood protection and providing for long-term recovery. There are three components. These components are preloaded with flood resources and the capacity to transform into different spaces of flood protection or recovery.
Site A is designed as a community gathering space that focuses on the principles of interact, protect, and recover. The design utilizes a combination of elements from the flood design tool kit. The integrated flood dike is designed into walkable public amenity spaces and ensures the protection of the building and its surrounding commercial and residential districts against up to 1 in 200 years flood(6m).

SITE B (Zone 2) - BOAT CLUB

Main Flood Principles – Interact, Tolerate, and Recover
(tolerative landscape with elevated architecture)

Site B is located near the low-density residential area adjacent to the local Clutesi Haven marina. Since there is more open space and less flood vulnerability, the architecture and landscape are designed to tolerate water inundation to allow direct interaction with the water. There are two components, both are outward oriented public programs that can enhance the existing marina and promote water recreational activities. During the event of flooding, site B functions as a visual indication of the rising water level. At the same time, the elevated walkways and architecture are able to maintain circulation and connectivity. The two components are preloaded with the spatial and material capacity for temporary relief.

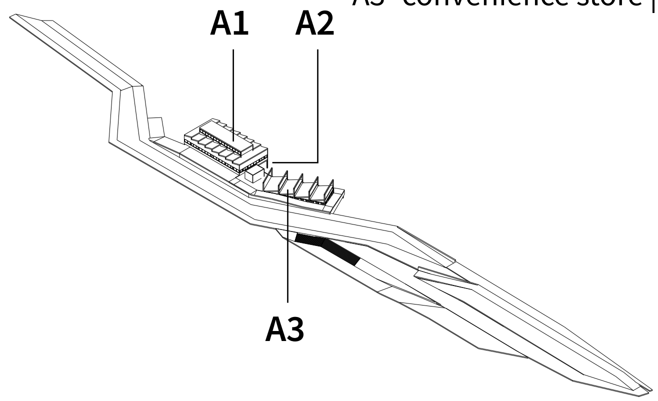
SITE C (Zone 3) - SUNKEN PARK

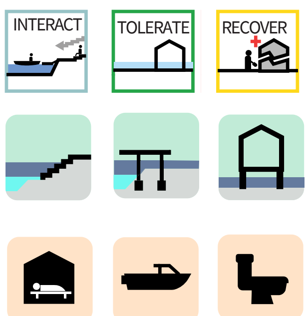
Main Flood Principles – Interact, Tolerate
(integrated dike protection with flood tolerative landscape)

Site C is at the fork of Somass River and Kitsuksis Creek. The site contains large areas of sunken green space at different levels. It is designed to tolerate water inundation, as well as retain water to delay and reduce inundation of surrounding flood vulnerable areas. The sunken park contains transformative programs that promote public gathering, leisure walks, and interaction with the river. During flooding, the lower sunken spaces will be inundated first and act as clear visual warnings of the rising water. The programs at higher grounds transform to serve as connection routes and provide emergency access to surrounding areas.

SITE A - DINER

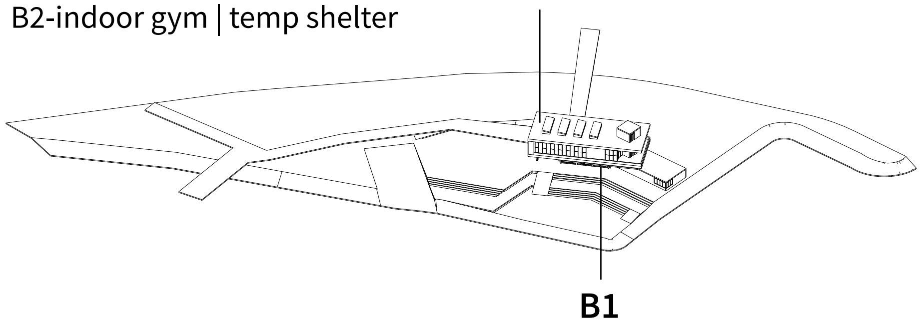
A1 - diner| safe haven
A2 - an art wall |wet storage
A3- convenience store | dry storage

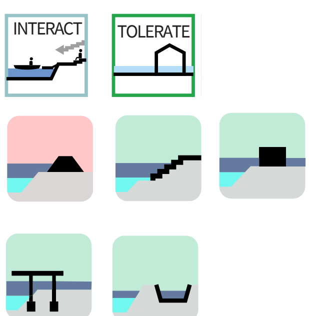




SITE B - BOAT CLUB

B1-boat racks | wet storage
B2-indoor gym | temp shelter





SITE C - SUNKEN PARK

C1 - sunken park | water retention

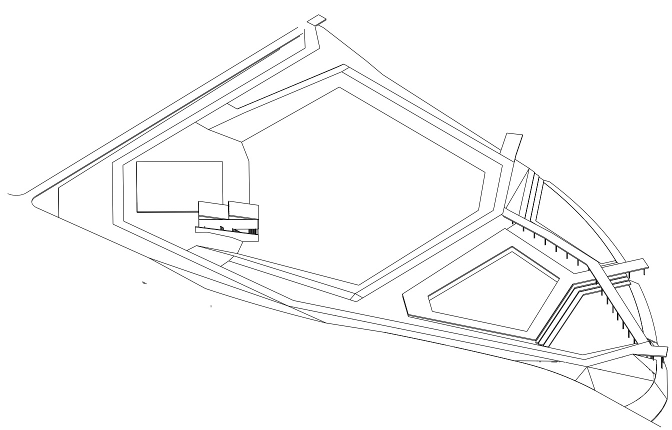


Fig.77
Site Schematic
Axonometric Diagrams

4.2 SITE A - DINER

Normal State

Fig.78 [Above]
Site A view from public plaza looking at art wall, normal state

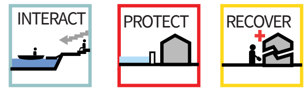
Fig.79 [Below]
Site A diner interior view, normal state

Flooded State

Fig.80 [Above]
Site A exterior view flooded state

Fig.81 [Below]
Site A diner interior after flood

SITE A - COMPONENTS



The architecture is composed of three main components:

A1. The Diner/Safe Haven
Component A1 is situated above the flood dike and functions normally as a diner. The central kitchen can be rented by restaurant owners or used as a self-serve communal kitchen for locals and visitors to prepare their fresh catches from the river. Thirty-two seating booths, located with views to either the river or the city, are perfect places for conversations, dining, or conducting private work. The space can be used by both locals and tourists, and offers great opportunities for visitors to meet and interact with the citizens of Port Alberni and learn about the city and its people.
After flooding, the diner transforms into a safe haven to house displaced people for long term recovery. Every module of two seating booths is preloaded with partition walls and beddings, which can be easily assembled by the occupants. This reconfigures the space into a private sleeping and living area for families of up to five people, with a total capacity of 16 families in the entire diner. The location of the diner allows easy access to washrooms and makes it possible for the kitchen to continue service both during and after a flood. As the safe haven is transformed from a space of everyday interaction and familiarity, there can be a sense of security and intimacy. People can stay in the safe haven for up to two years and work together to rebuild their community.

A2. Art Wall/Wet Storage
Component A2 is located on the ground level below the diner and behind the walkable flood dike. This component uses elements of wet proofing architecture. It is a floodable storage space for dispatchable temporary flood protection -- muscle walls. For everyday use, the muscle walls are stored behind porous metal louver walls and arranged into an art wall showcasing abstract art inspired by the local first nations group (Nuu-Chah-Nulth). The plaza in front of the art wall can be used as a pop-up market space.
When water levels start to rise, and a flood is anticipated in the surrounding area, the muscle walls can be distributed to vulnerable commercial and residential buildings for flood protection of water levels between 1 in 20 Year and 1 in 100 Year flood.
For floods beyond 1 in 100 Year, this component is flooded to allow the water to pass through and maintain interior and exterior water pressure equilibrium to protect the structural integrity of the entire building. The wet proofed floodable space also allows quick recovery and clean up for the building to quickly restore its everyday function after a flood.

A3. Convenience Store/ dry storage
The program of component A3 is a convenience store that sells everyday supplies such as perishable food, water, power supply, first aid kits, etc. The convenience store functions together with the diner and serves as a part of the community-gathering space. The items stored in component 3 become crucial living resources during a flood when external food and resource aid becomes difficult to transport. This component is designed as amphibious architecture, so the building can always rise during flooding and provide protection to the interior resources. Normal access to the store is from ground level. During a flood the space can be accessed via boats from the integrated ramp.

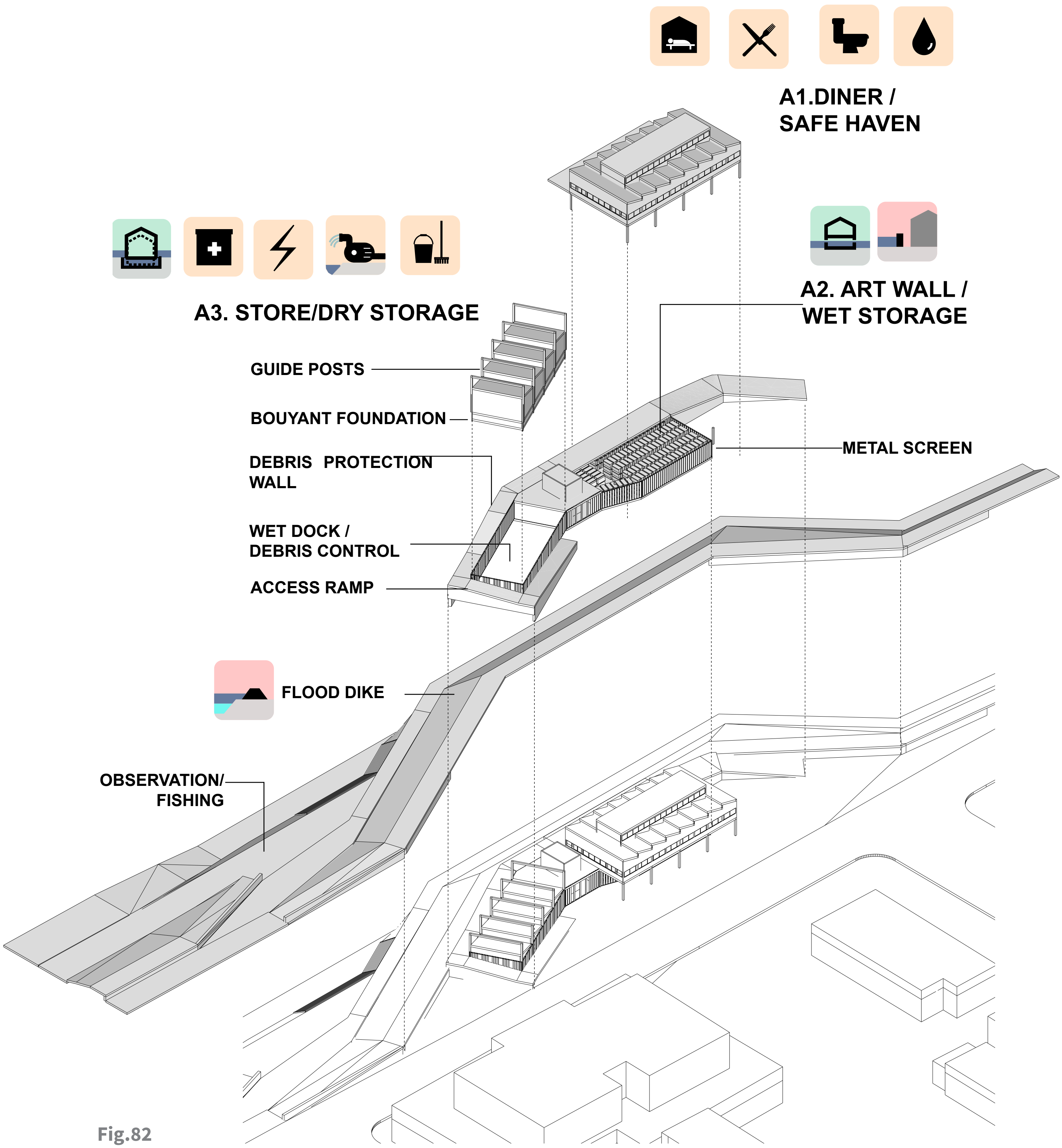
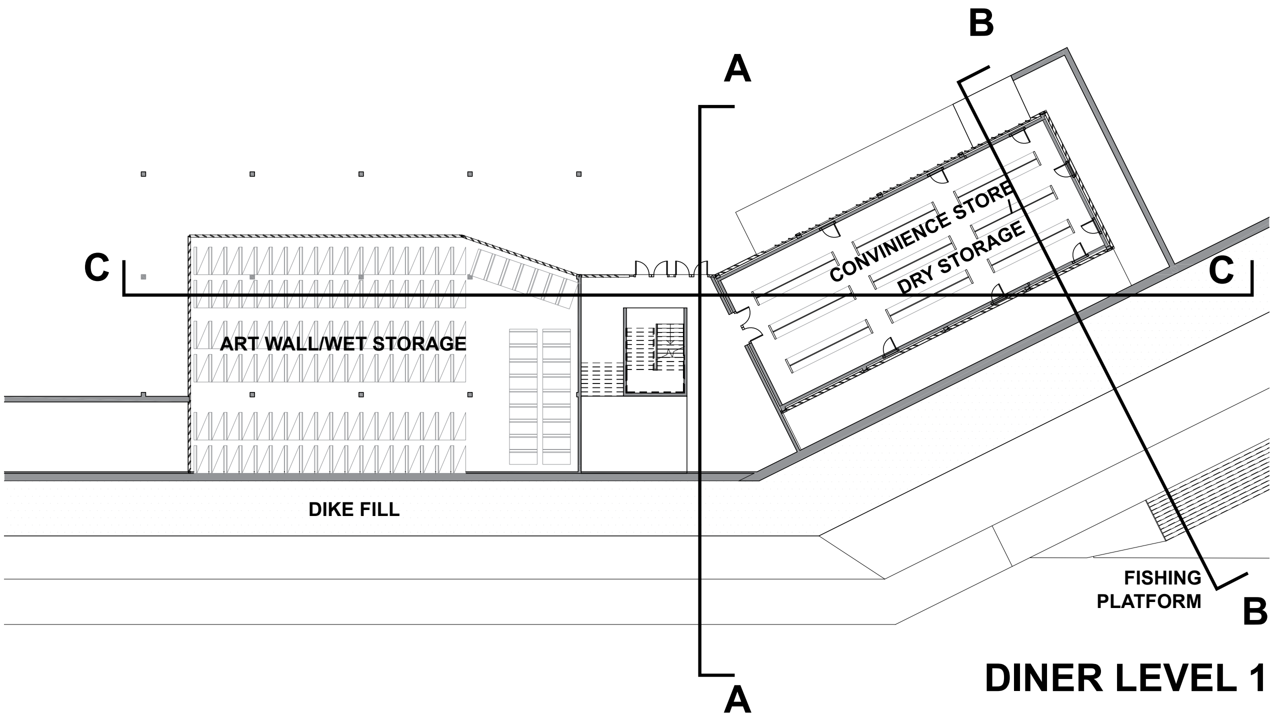


Fig.82
Site A Exploded
Axonometric Diagrams

SITE A - PLANS



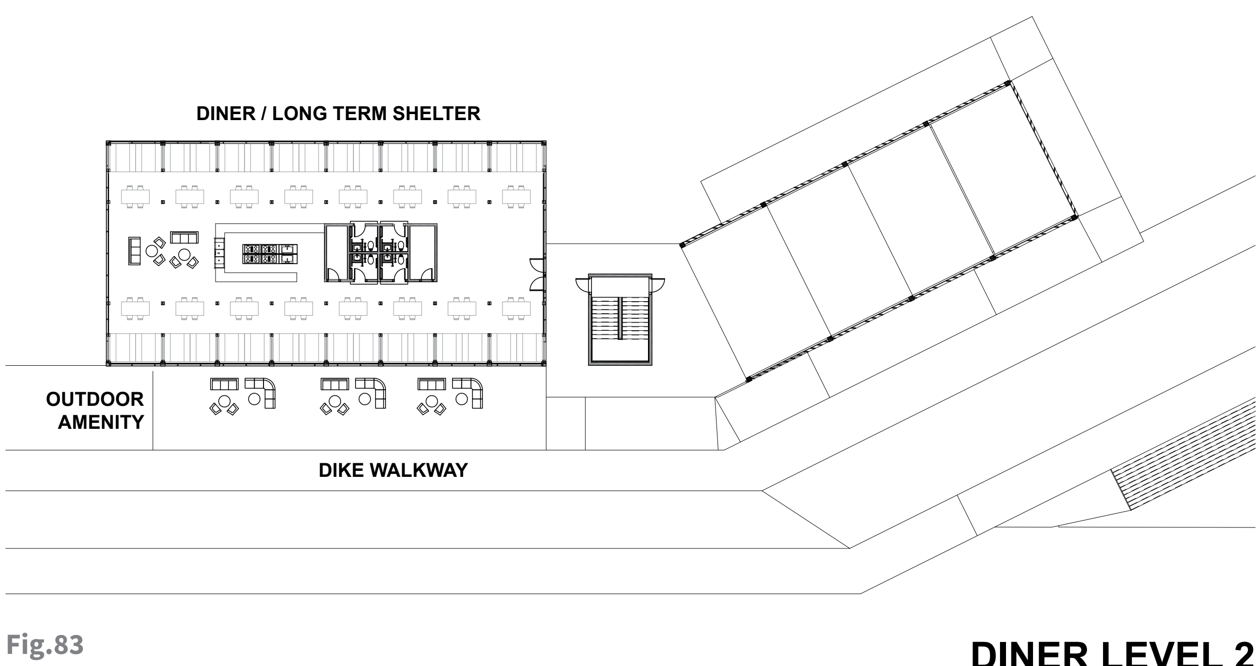
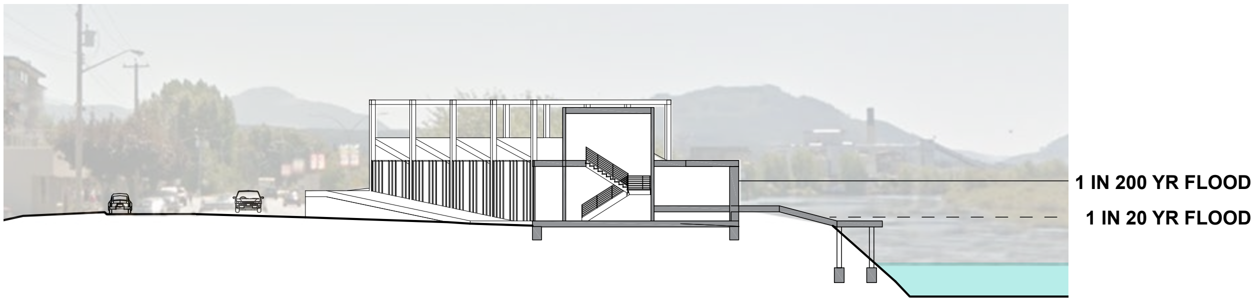
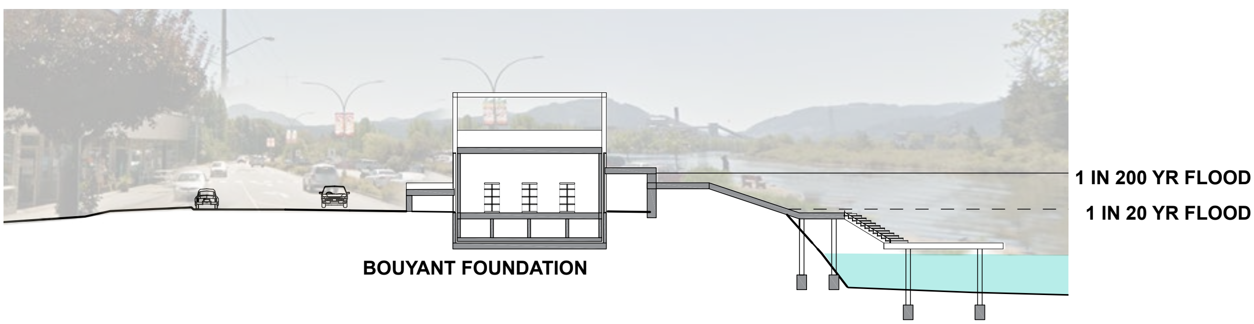


Fig.83
Site A Orthographic
Drawings

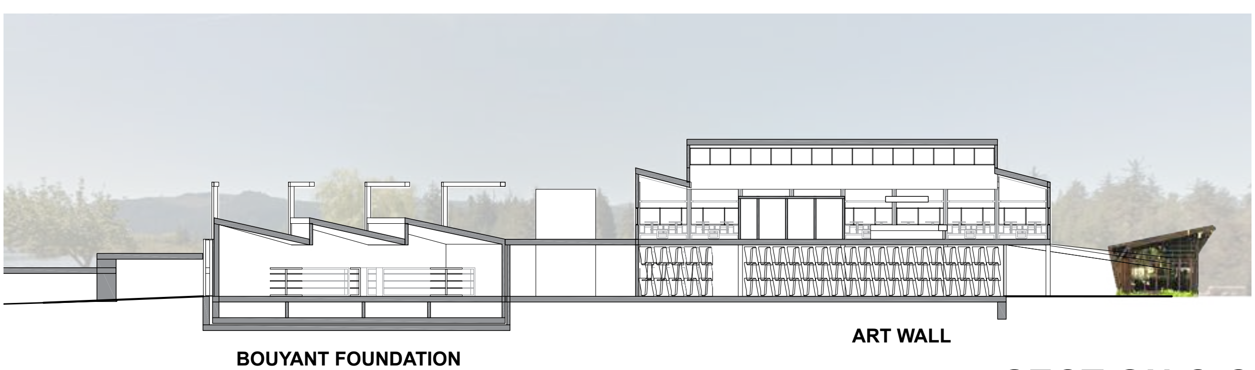
SITE A - SECTIONS



SECTION A-A



SECTION B-B



SECTION C-C

COMPONENT A1. DINER --> LONG TERM SHELTER

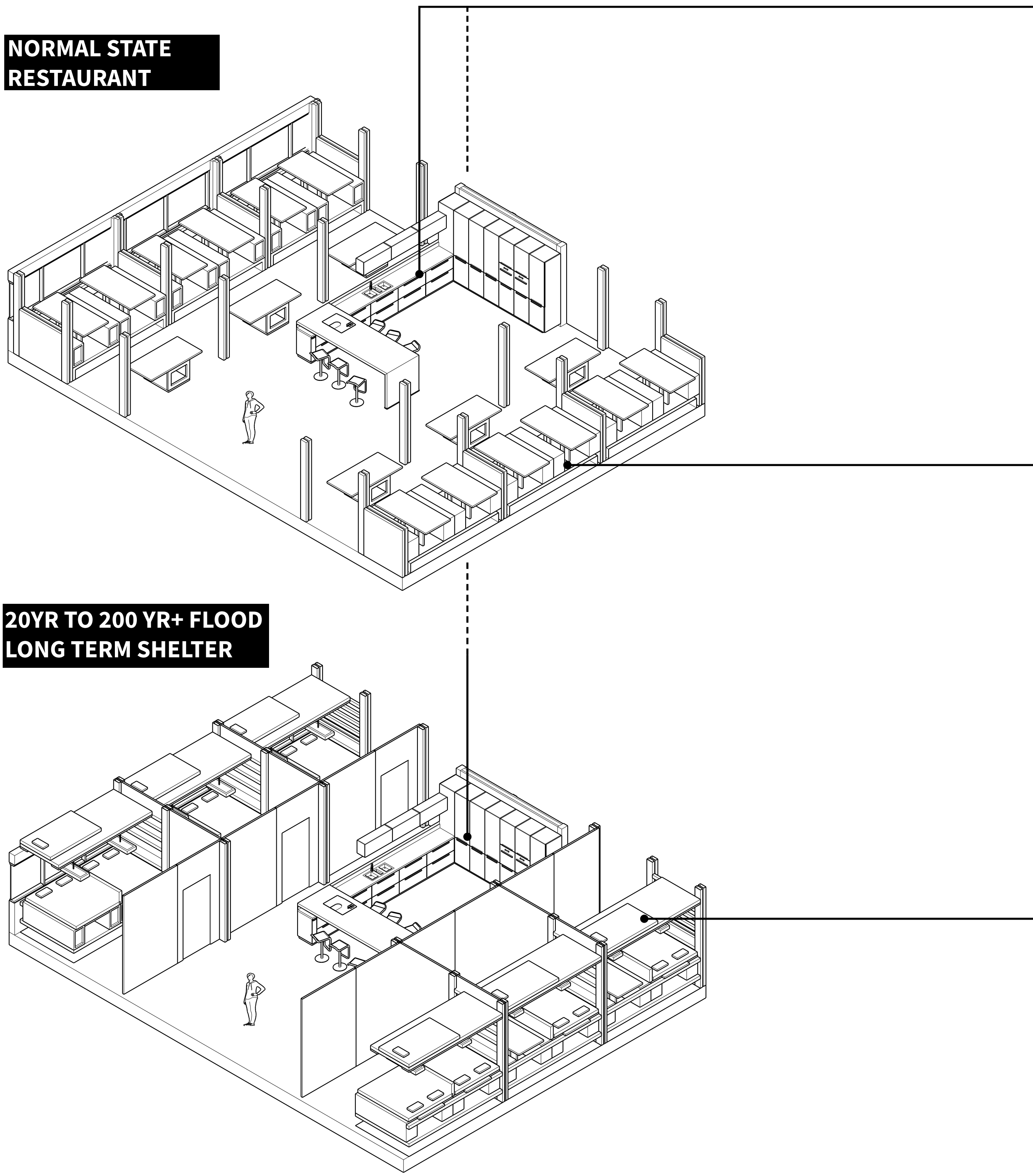
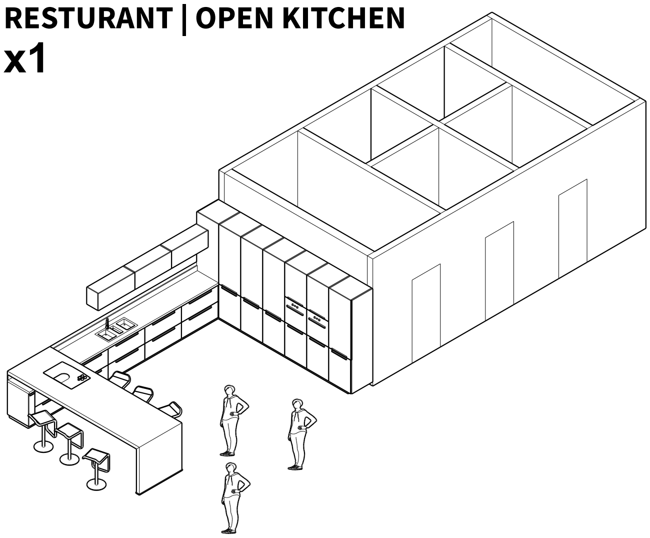
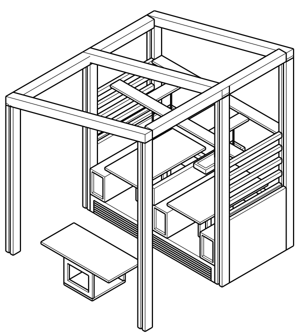


Fig.84
Component A1 Detail
Axonometric Diagrams

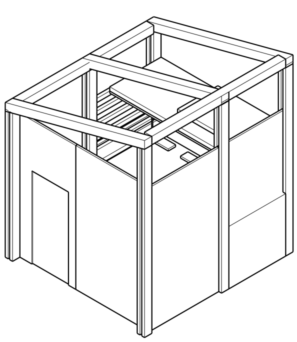
RESTURANT | OPEN KITCHEN
x1



DINING BOOTH
x32

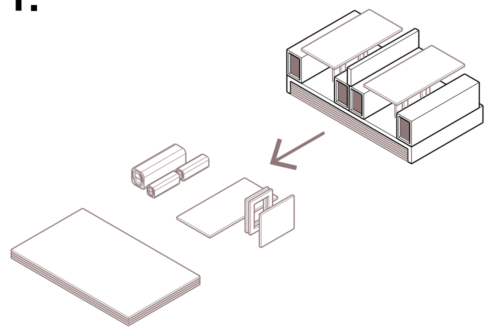


LONG TERM SHELTER
x16

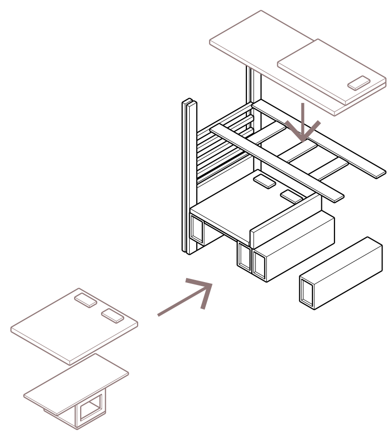


BOOTH TO SHELTER TRANSFORMATION

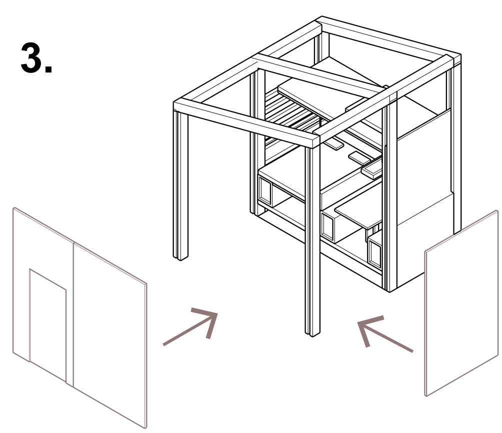
1.



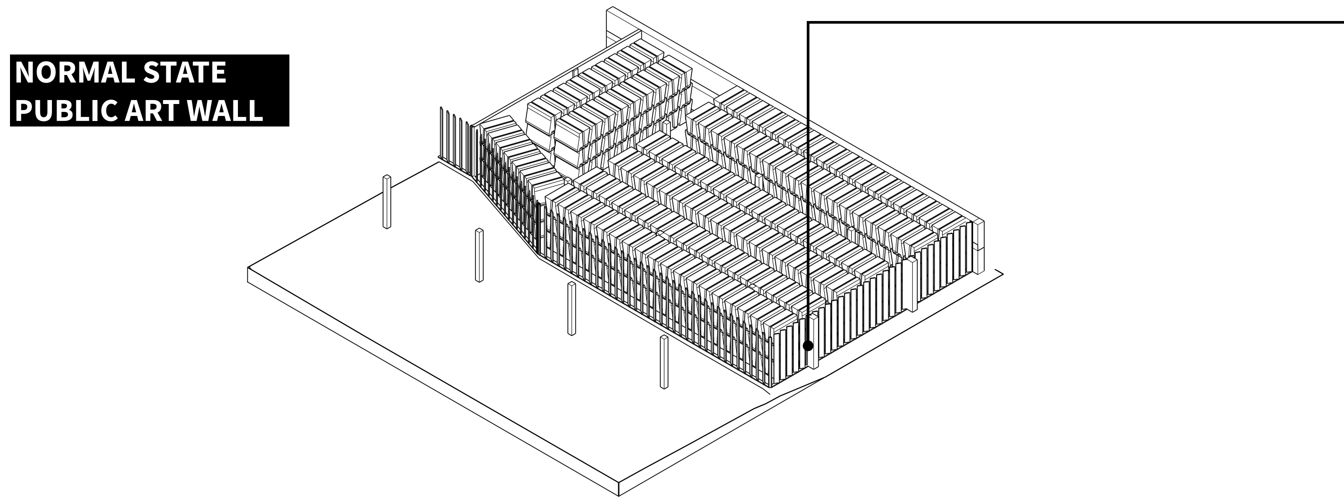
2.

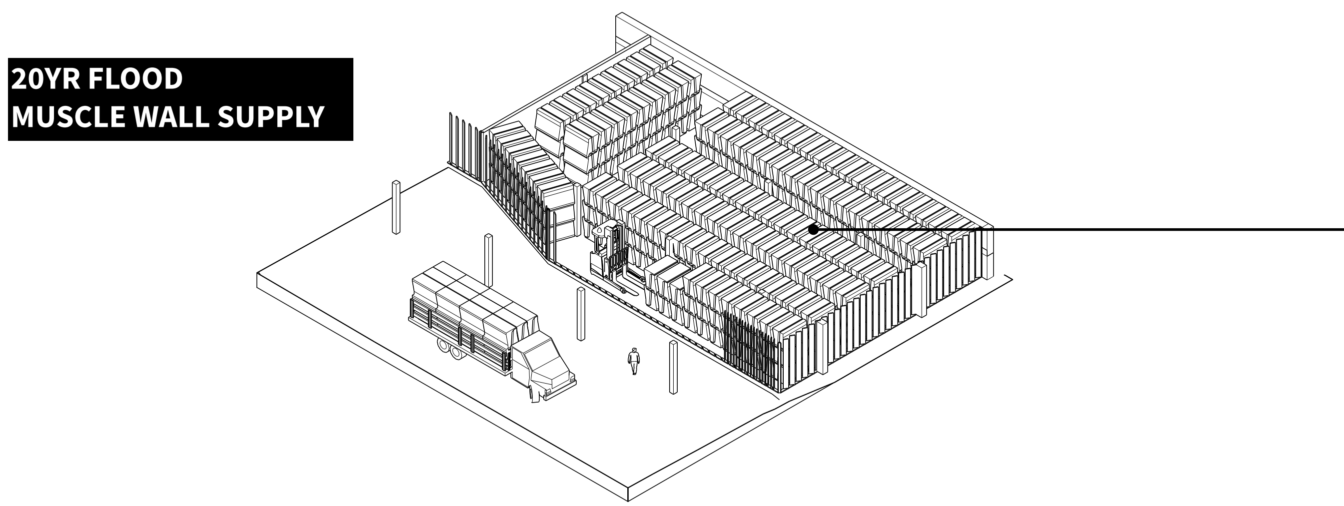


3.



COMPONENT A2. ART WALL --> WET STORAGE





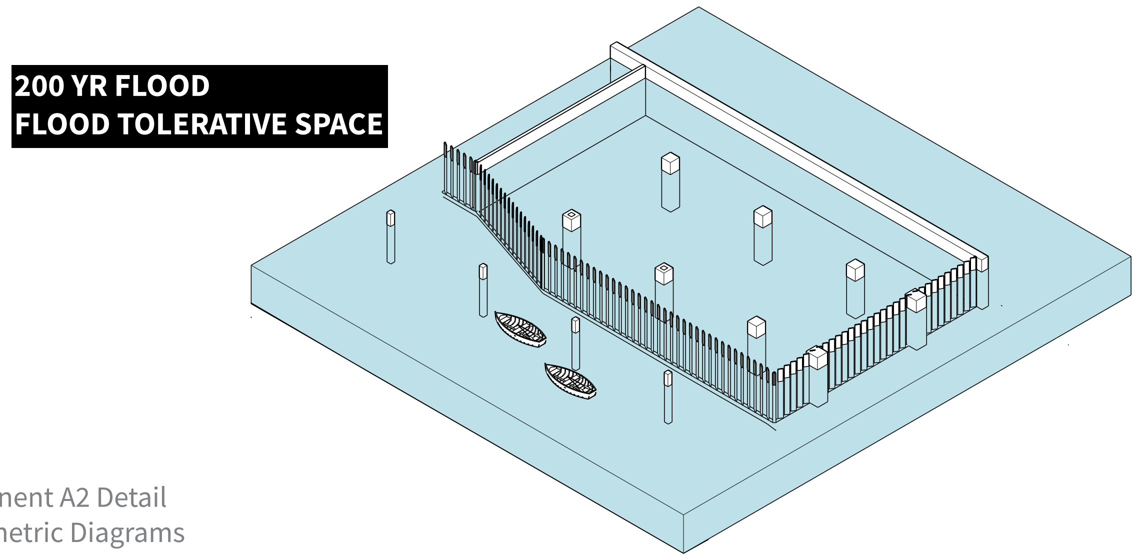
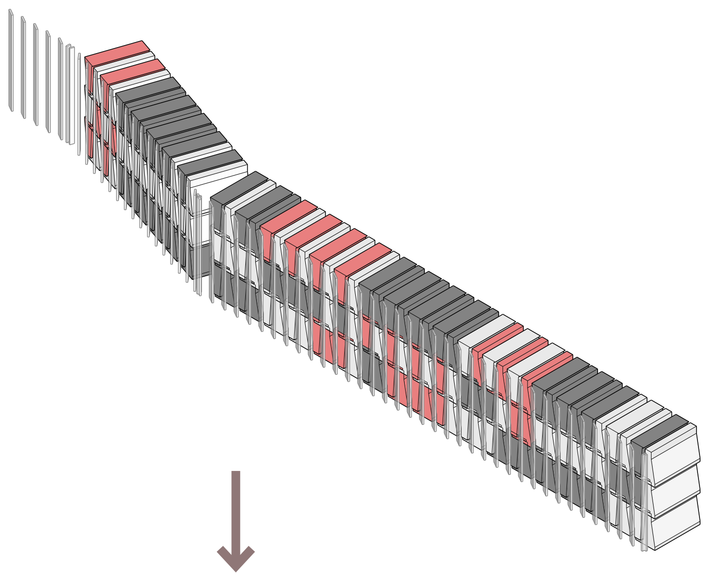
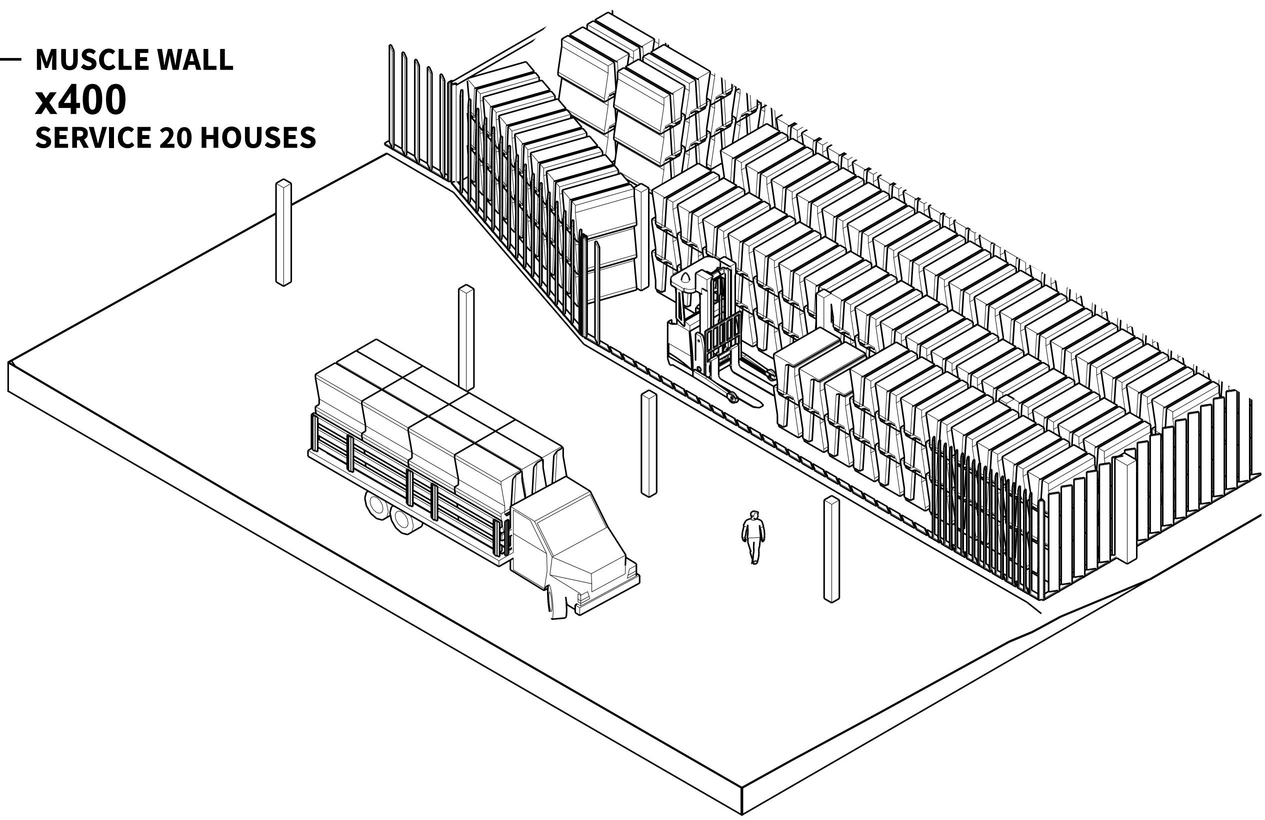


Fig.85
Component A2 Detail
Axonometric Diagrams

PUBLIC ART WALL
x1



MUSCLE WALL
x400
SERVICE 20 HOUSES



COMPONENT A3. CONVENIENCE STORE -->DRY STORAGE

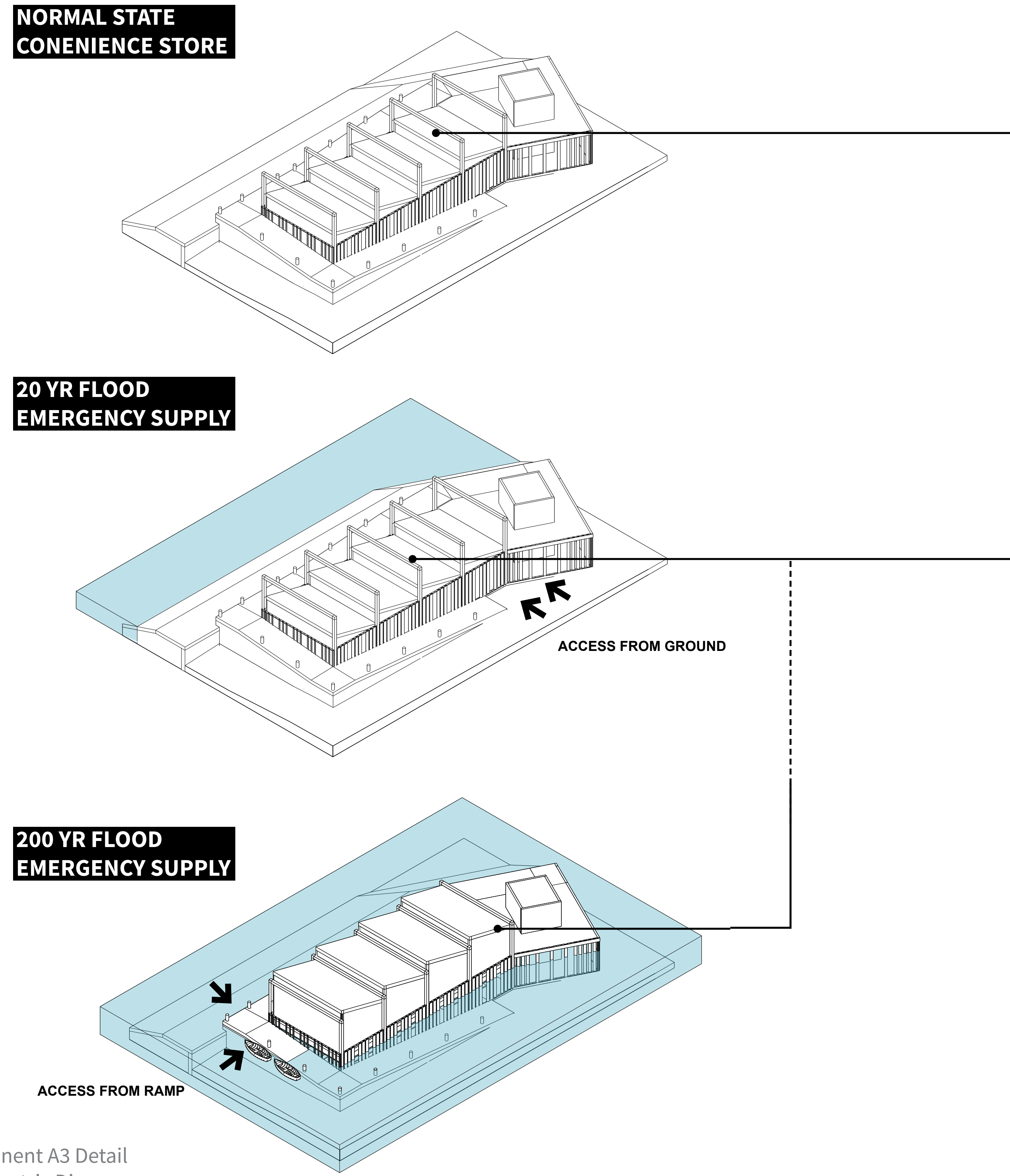
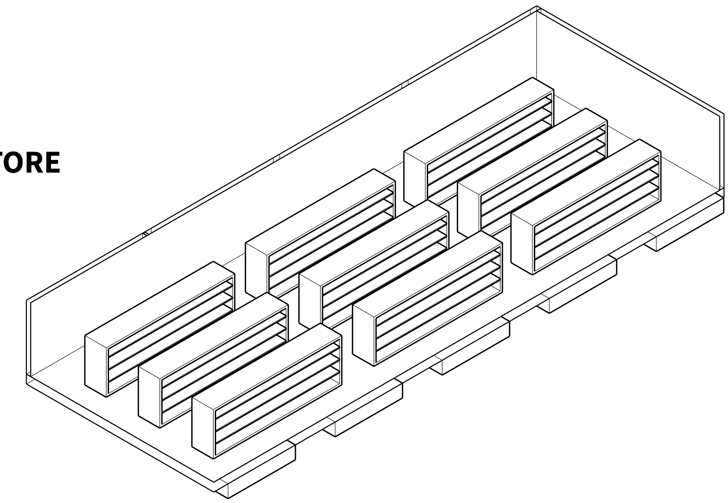
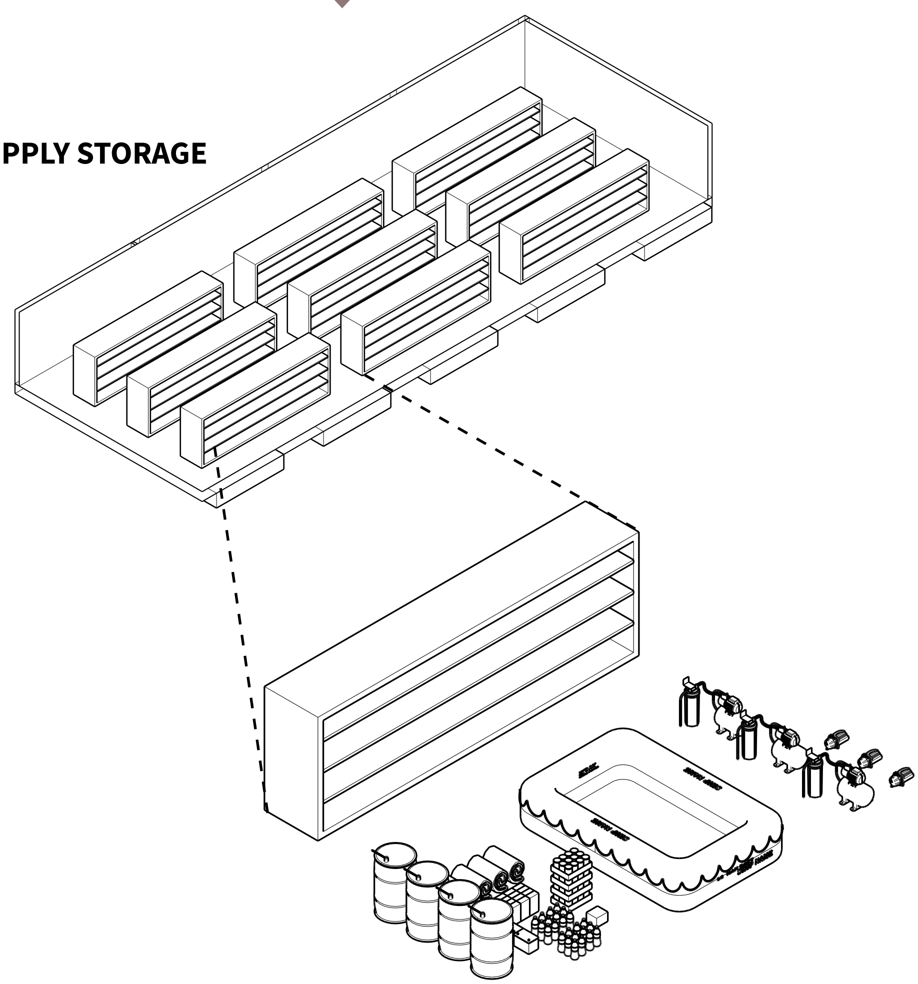


Fig.86
Component A3 Detail
Axonometric Diagrams

CONVENIENCE STORE
x1



EMERGENCY SUPPLY STORAGE
xN



4.3 SITE B - BOAT CLUB

Normal State

Fig.87 [Above]
Site B Exterior view towards boat house, normal state

Fig.88 [Below]
Site B interior view of multipurpose gym, normal state

Flooded State

Fig.89 [Above]
Site B exterior view flooded state

Fig.90 [Below]
Site B gym transformed into temporary shelter

SITE B - COMPONENTS

The program on site B is designed to enhance the existing site conditions of the Clutsi Marina and boat launch area. The site is integrated with elevated and flood-tolerating landscape elements to maximize direct interaction with the Somass River. There are two main design components for site B.

B1. Boat Rack / Wet Storage
Component B1 is a boat rack as well as a wet storage preloaded with lifeboats to be used as transportation during a flood. As the surrounding area is expected to be flooded with increasing frequency, lifeboats are very important tools in maintaining connectivity for the residents in the flood plain. Boat racks for smaller boats, such as canoes and kayaks, are accessible from the ground floor. This is a public amenity of the boat club that enhances recreational activity on site. Lifeboats are stored suspended with a pulley system at the intermediate level and become available when the water rises to 1 in 20 year flood level(3.65m). These lifeboats are always visible to the public as a display of safety preparedness, which enhancing public awareness of the flood potential and equipping them with appropriate flood responses.

B2. Indoor Gym/ Temporary Shelter
The upper level of the boat club is a multipurpose indoor gym with one full volleyball court or two badminton courts. There is also a gym with weights and rowing machines located at the mezzanine level. During and after flooding, displaced people can take shelter there. The space can be transformed into 24 temporary shelters with posts and curtains. The form of the shelters is inspired by Shigeru Ban's cardboard shelters.[57] The shelters in this gym follow similar logic as Ban's design, with the addition that the space itself can enhance the transformation to achieve a more durable structure and faster assembly. The gym floor contains a grid of sockets that ties into both the game court netting structure and the temporary shelter. The storage room is loaded with modular parts of posts and connectors that can be assembled into temporary shelters. These posts can be easily guided into position by sockets to allow fast, organized, and straight forward assembly process.

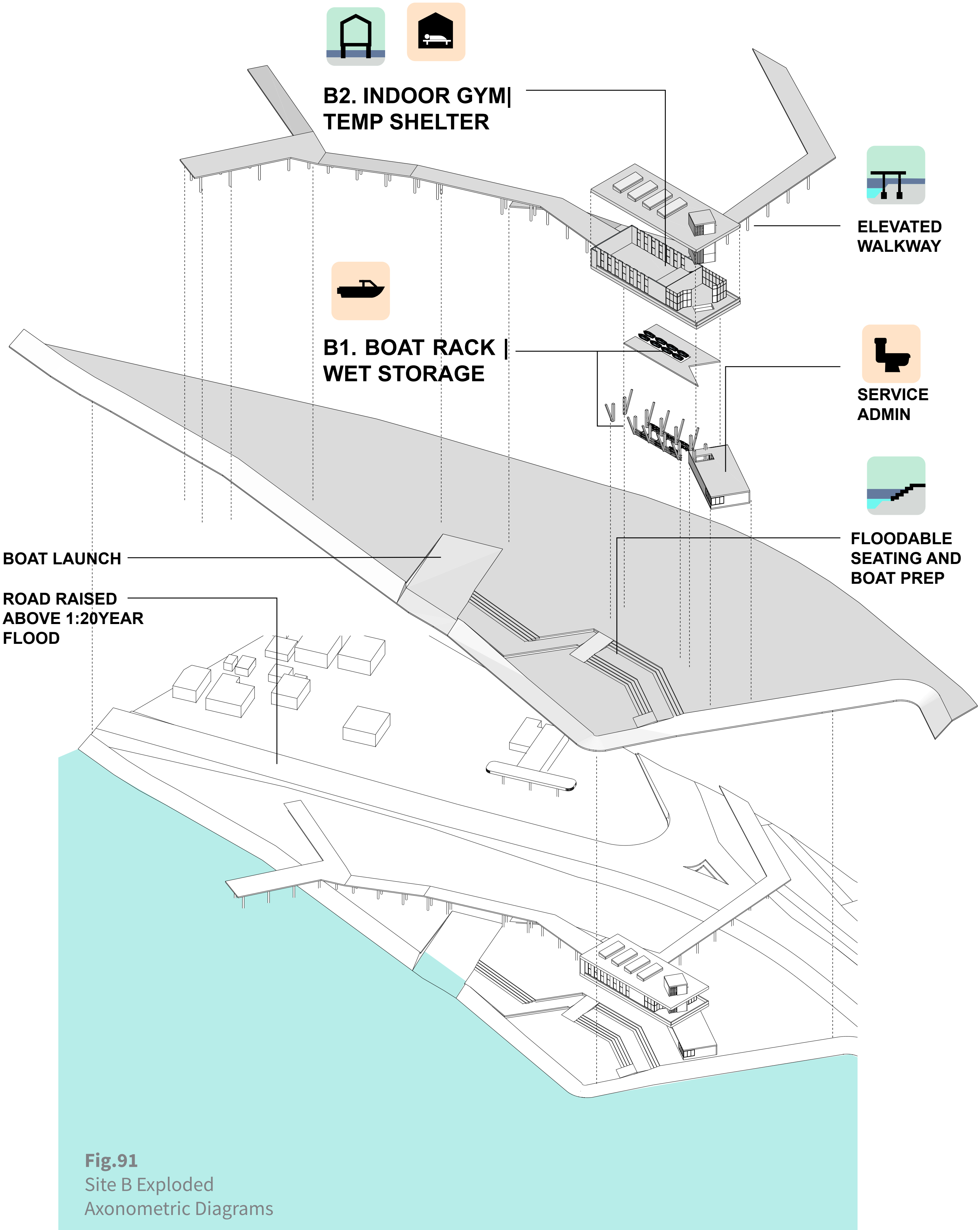
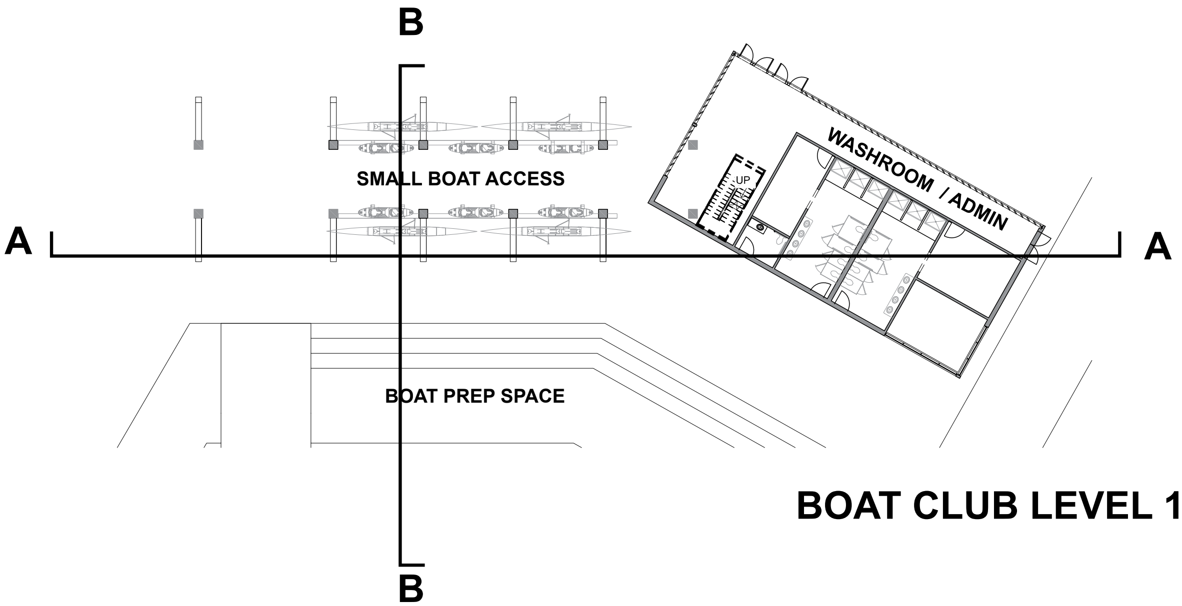
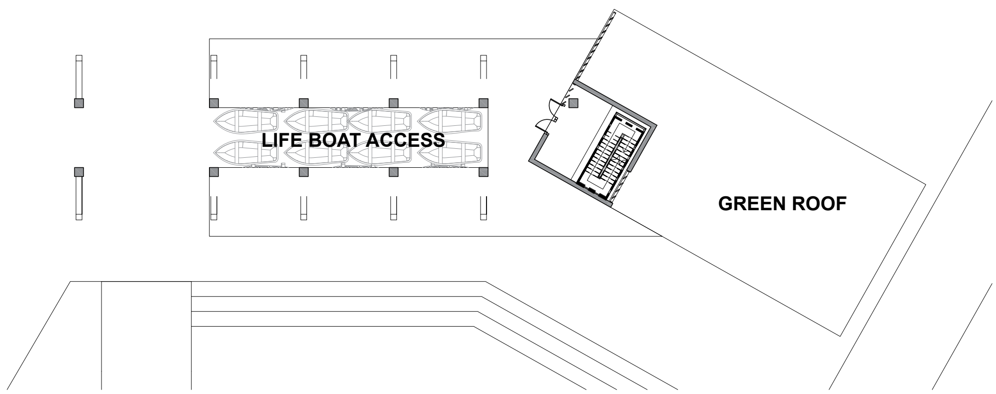


Fig.91
Site B Exploded
Axonometric Diagrams

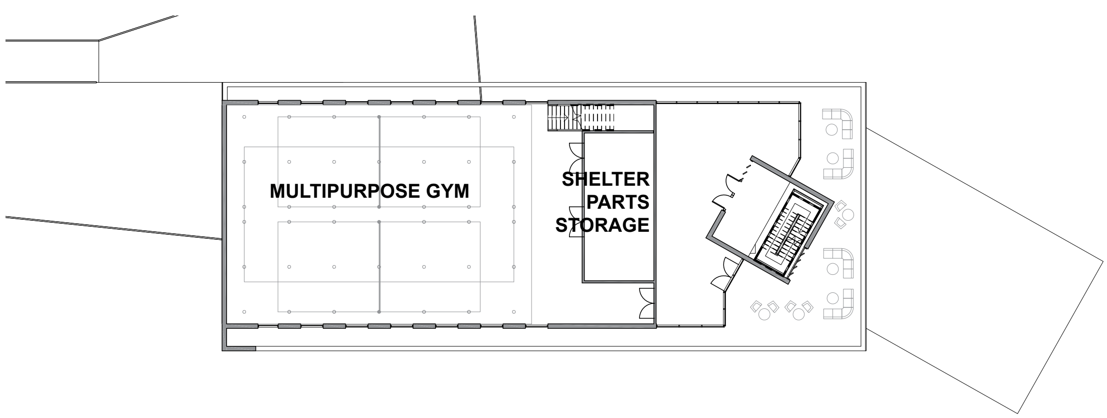
SITE B - PLANS



BOAT CLUB LEVEL 1



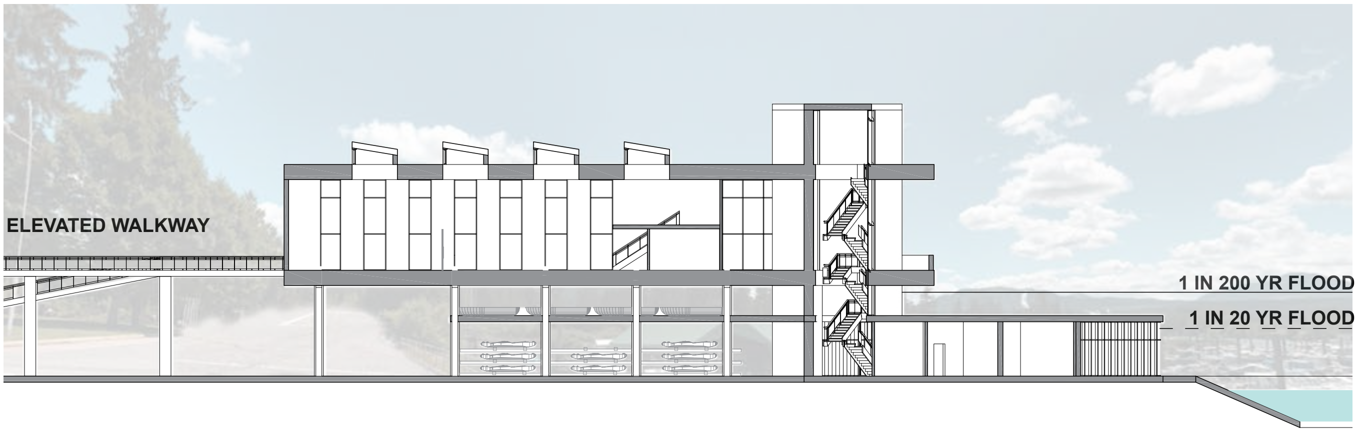
BOAT CLUB LEVEL 2



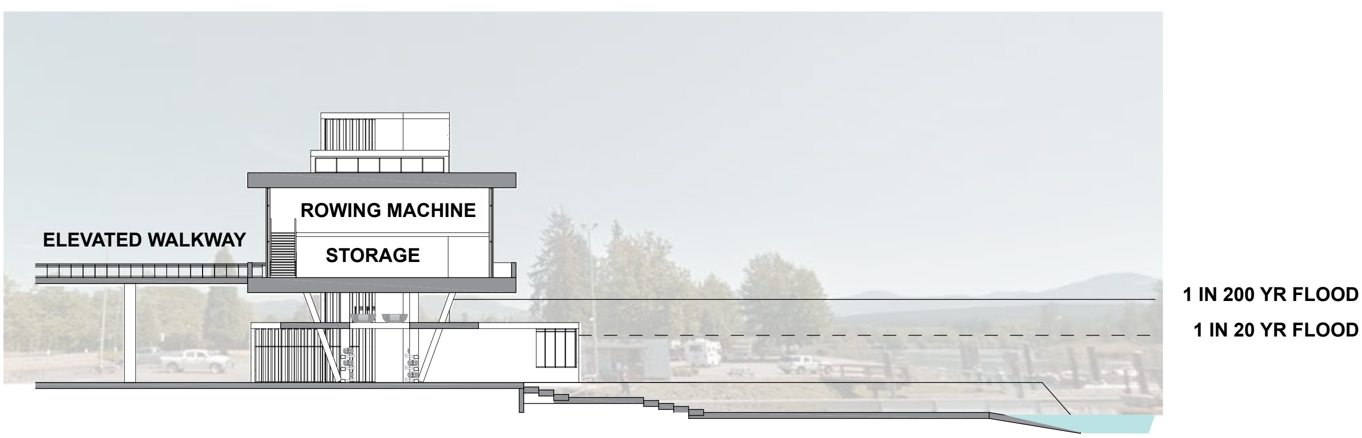
BOAT CLUB LEVEL 2

Fig.92
Site B Orthographic Drawings

SITE B - SECTIONS



SECTION A-A



SECTION B-B

COMPONENT B1. BOAT RACKS -->WET STORAGE

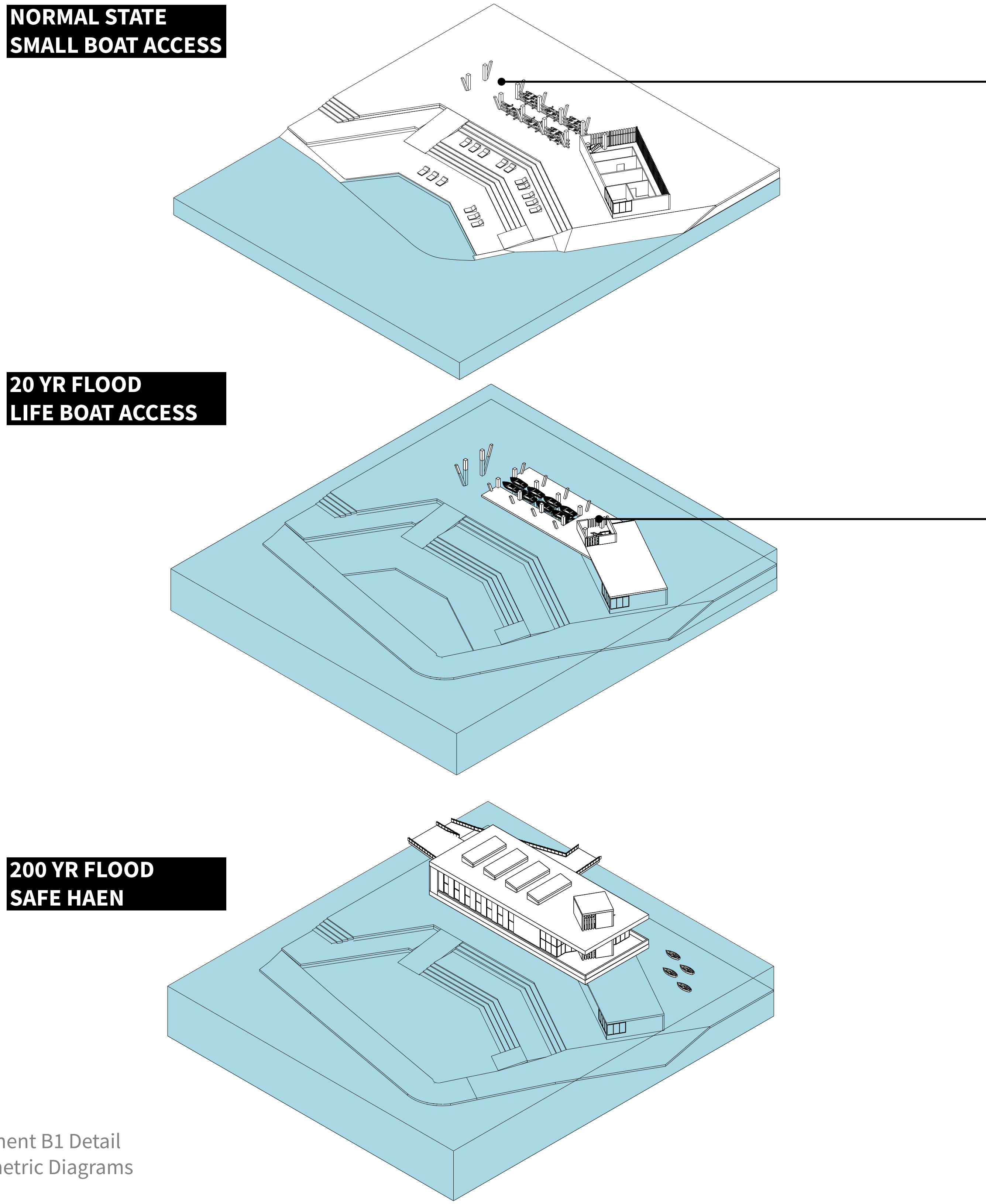
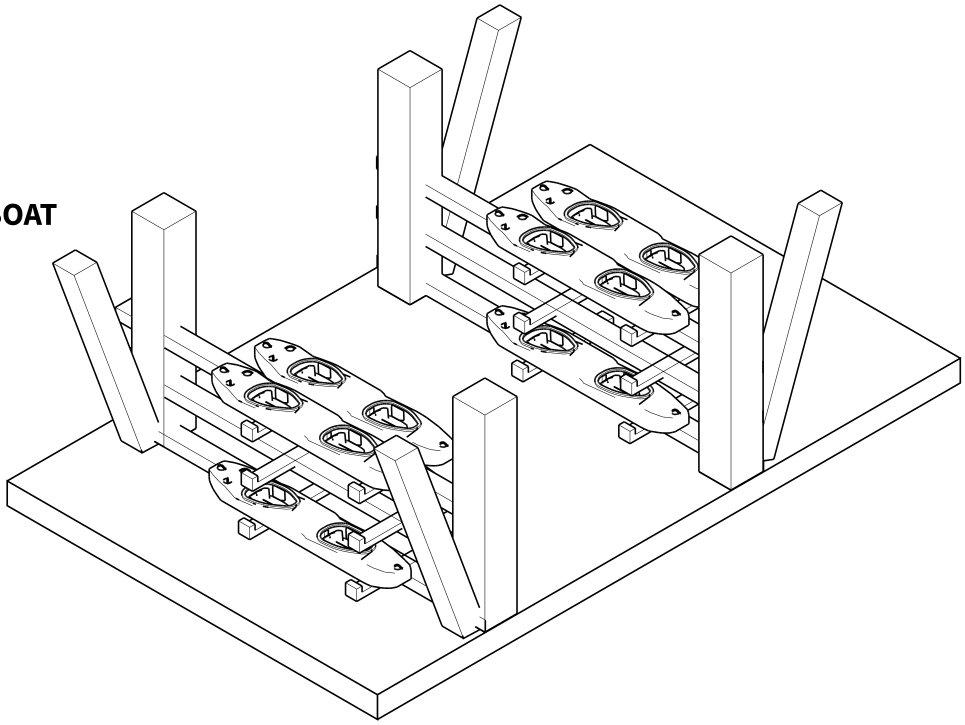
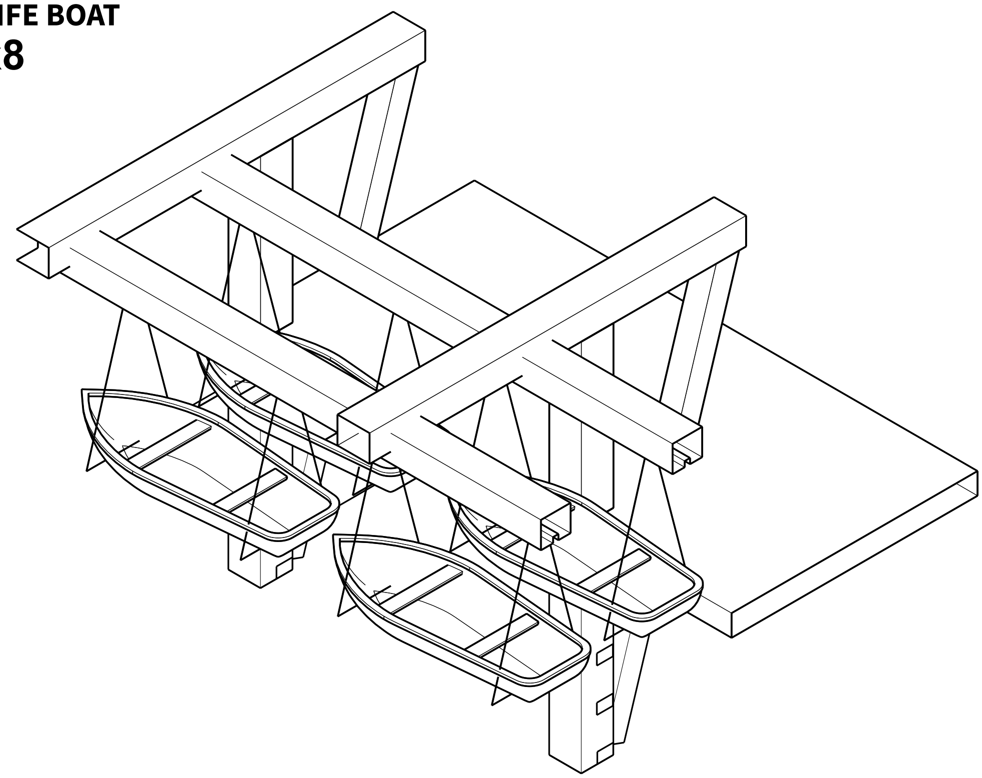


Fig.93
Component B1 Detail
Axonometric Diagrams

SMALL BOAT
x36

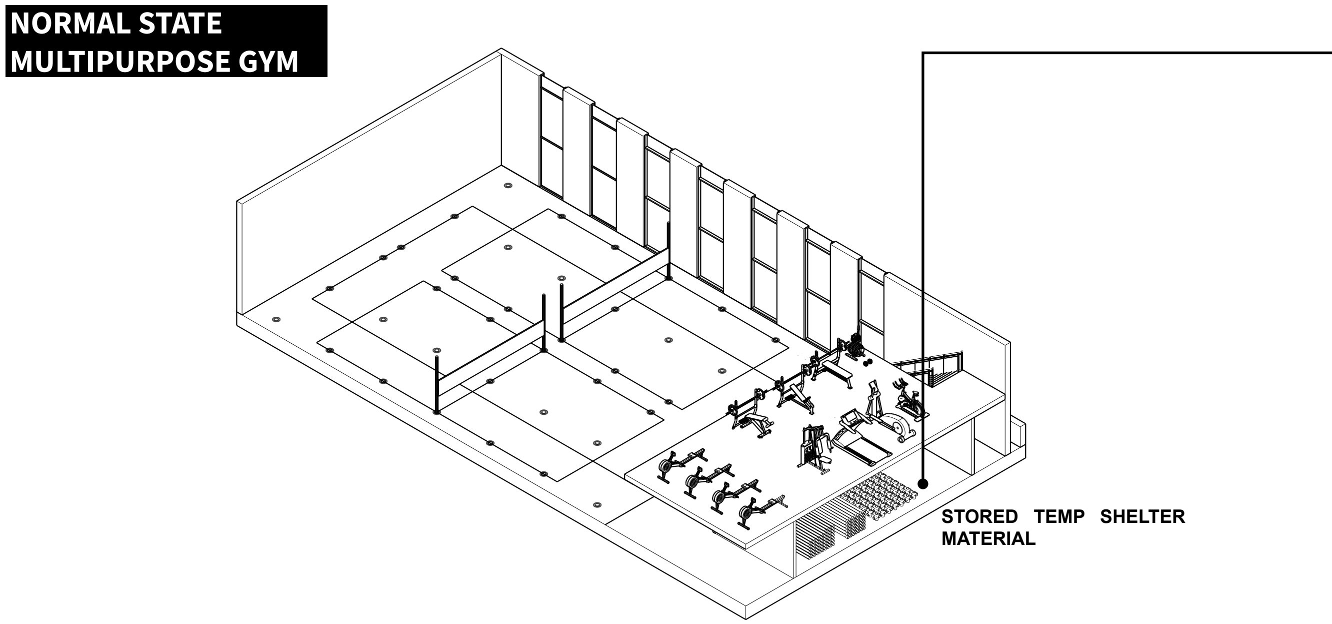


LIFE BOAT
x8



COMPONENT B2. INDOOR GYM -->TEMP SHELTER

B2. INDOOR GYM --> TEMP SHELTER



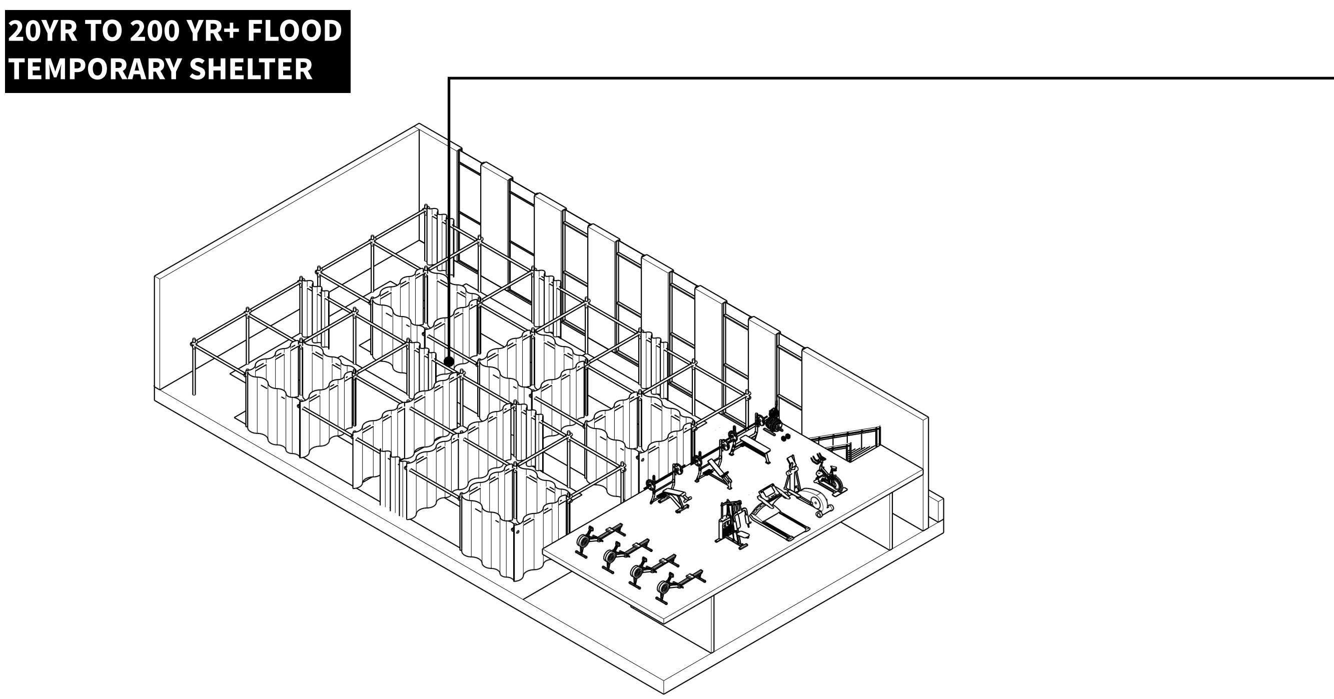
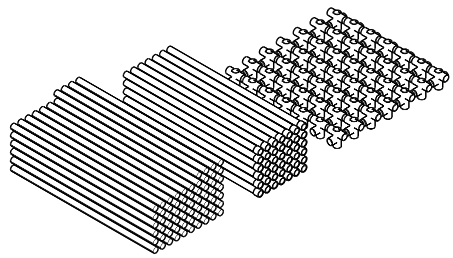


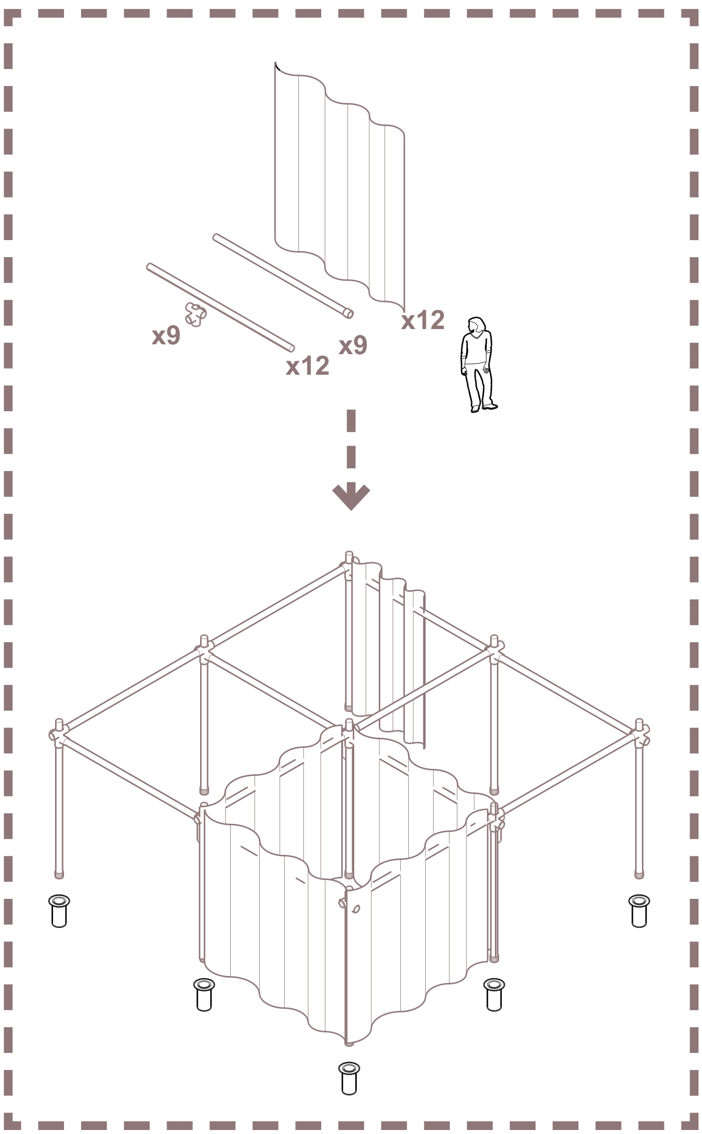
Fig.94
Component B2 Detail
Axonometric Diagrams

STORED TEMP SHELTER PARTS



SHORT TERM SHELTER
x6
SERVICE 24 FAMILIES

TEMP SHELTER ASSEMBLY



4.4 SITE C - PARK

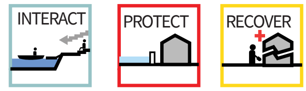
Normal State

Fig.95
Site C Normal State

Flooded State

Fig.96
Site C Flooded State

SITE C - COMPONENTS



Site C is composed of large open green space for public gathering, sports activities, and water recreational activities. The sunken parks, normally used as sports fields and viewing pond, are used as water retention tanks for different flood intensities. The basketball court, located at the highest ground, is used as a helipad for emergency transportation. A small service building, located beside the helipad, is preloaded with emergency supplies.

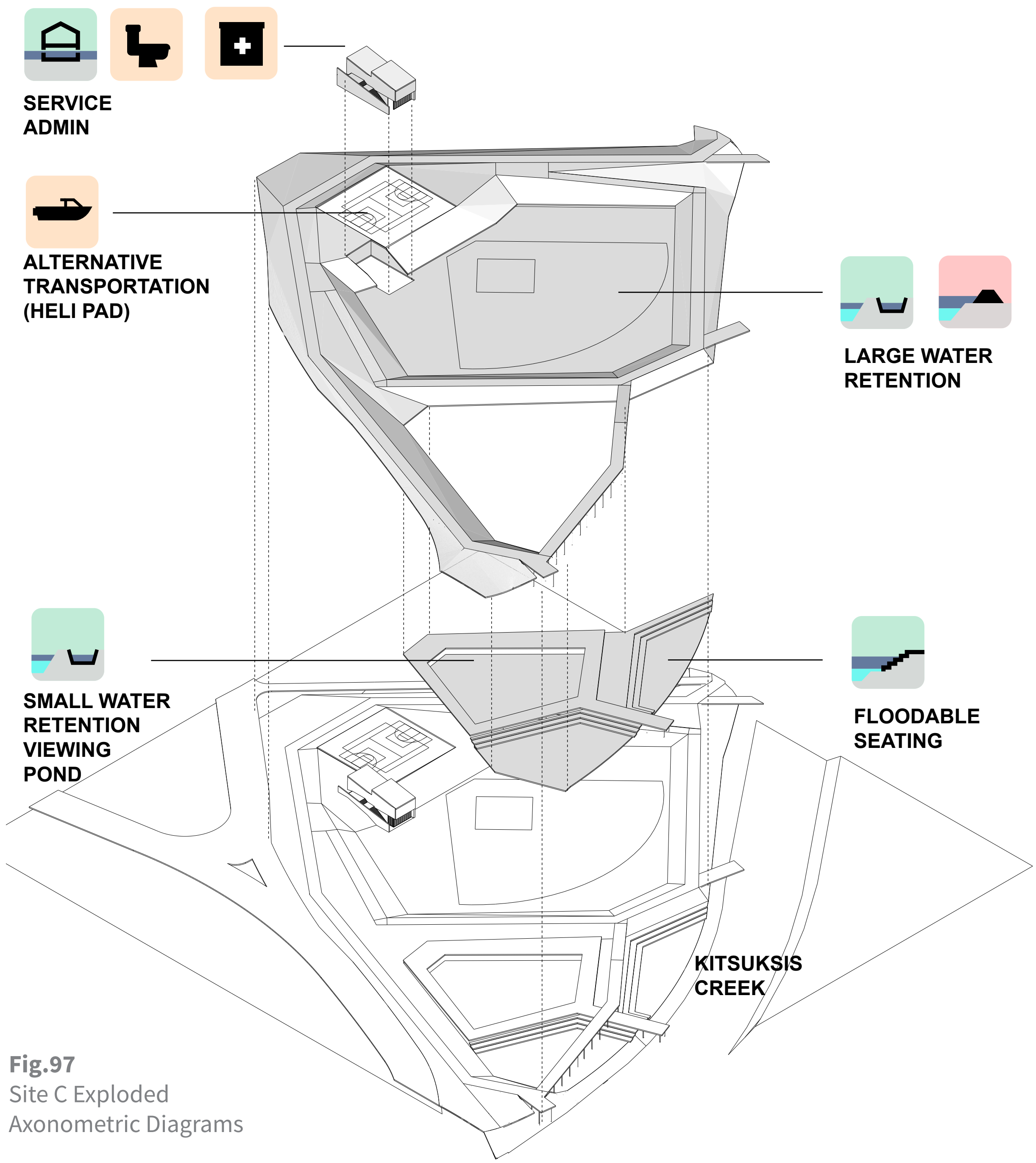
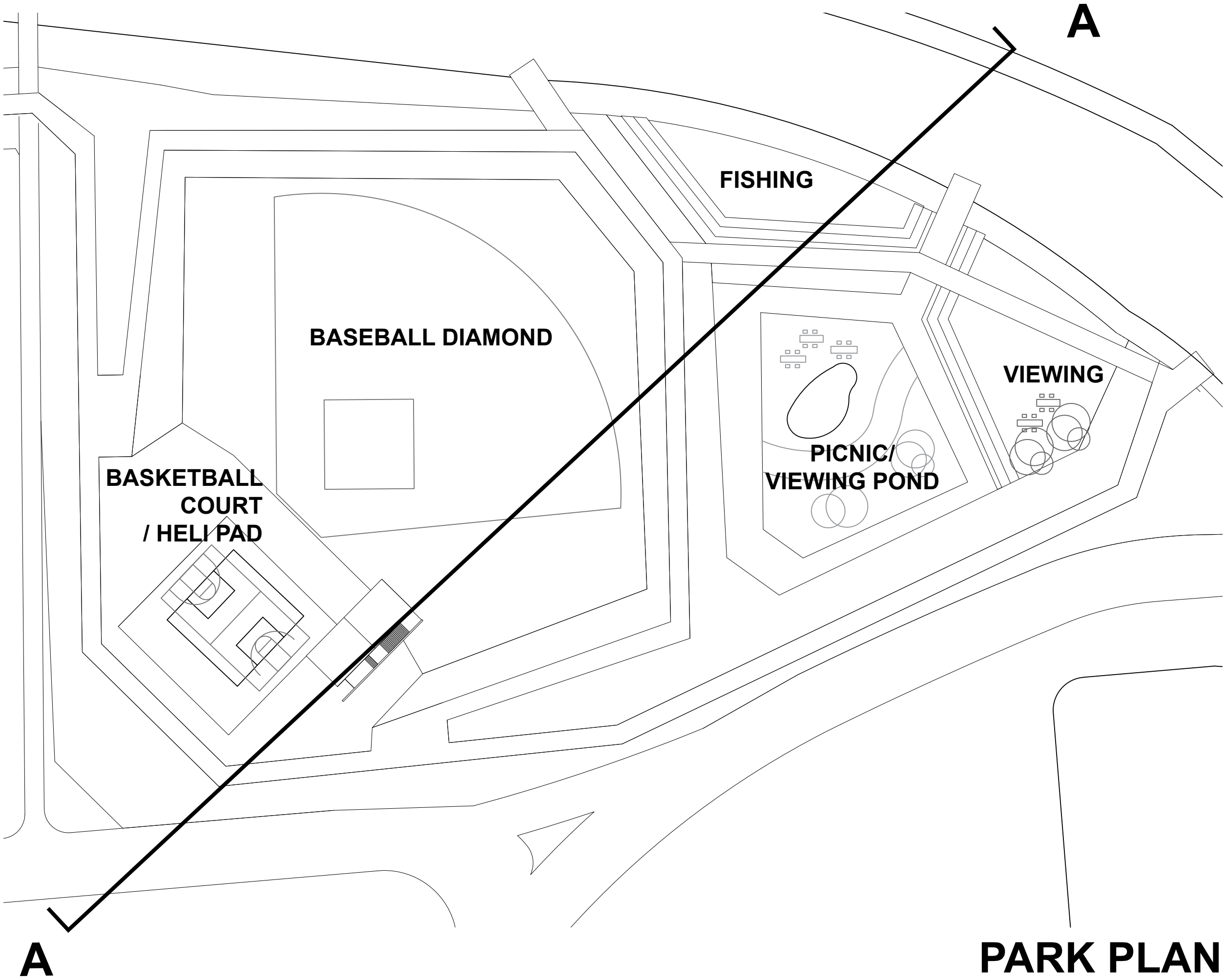


Fig.97
Site C Exploded
Axonometric Diagrams

SITE C - PLAN AND SECTION



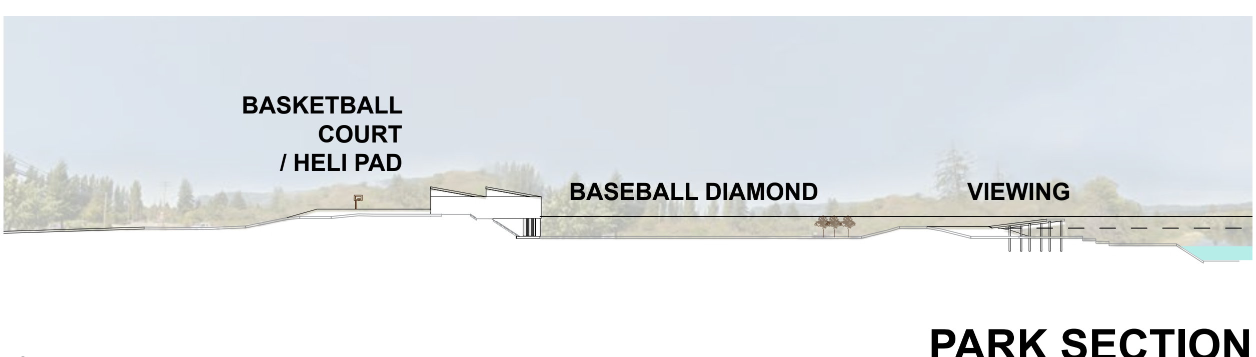
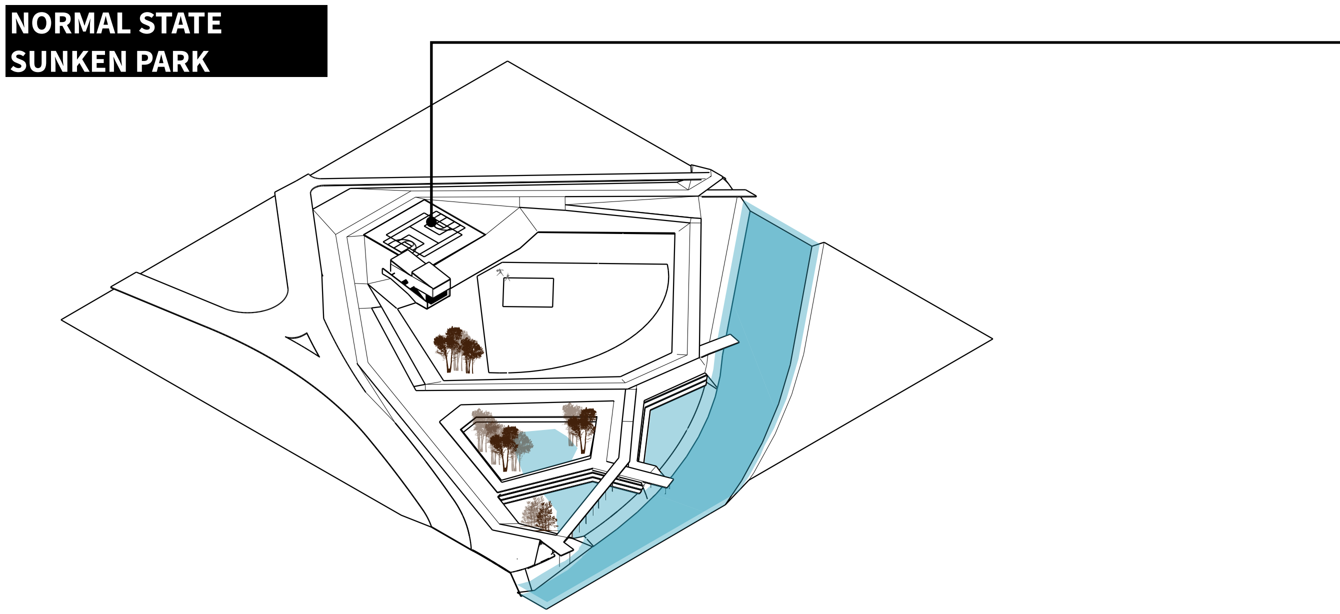


Fig.98
Site C Orthographic
Drawings

COMPONENT C1. SUNKEN PARK --> WATER RETENTION



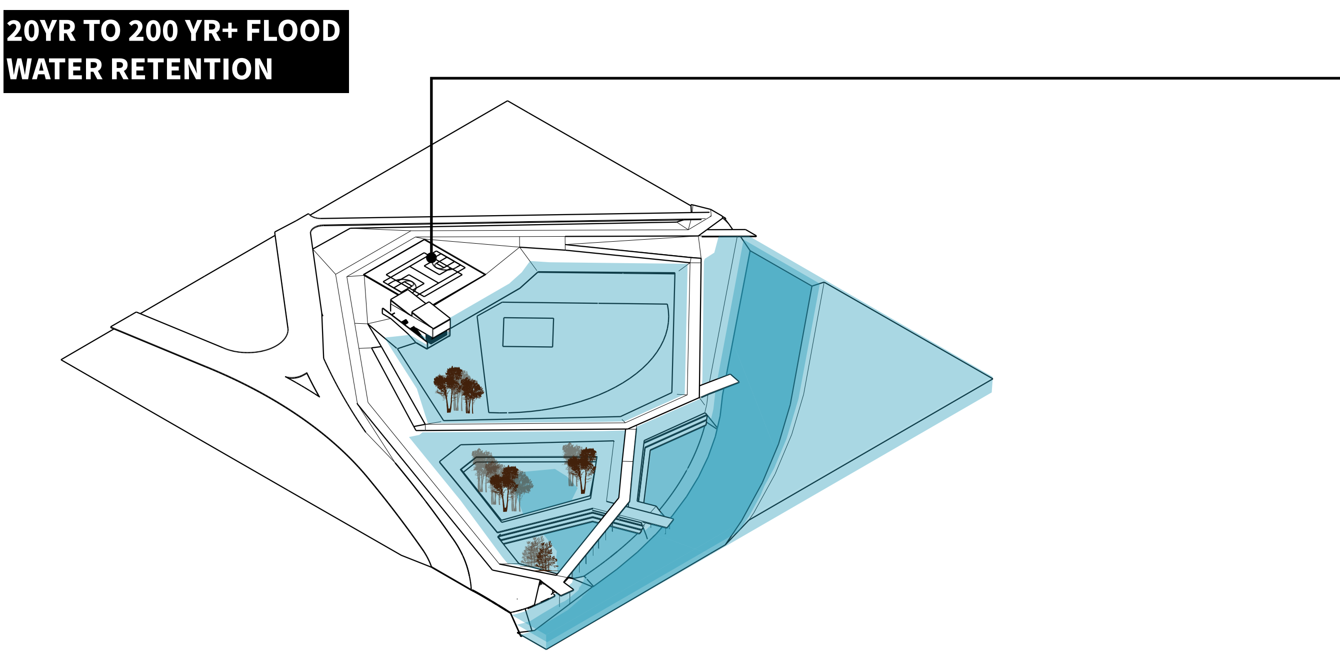
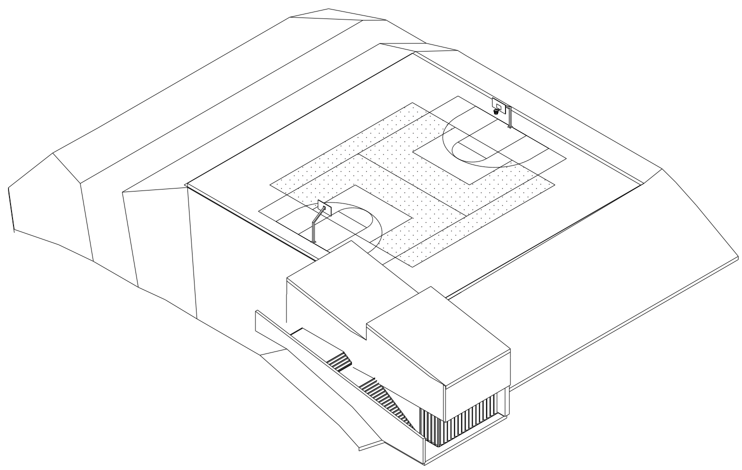


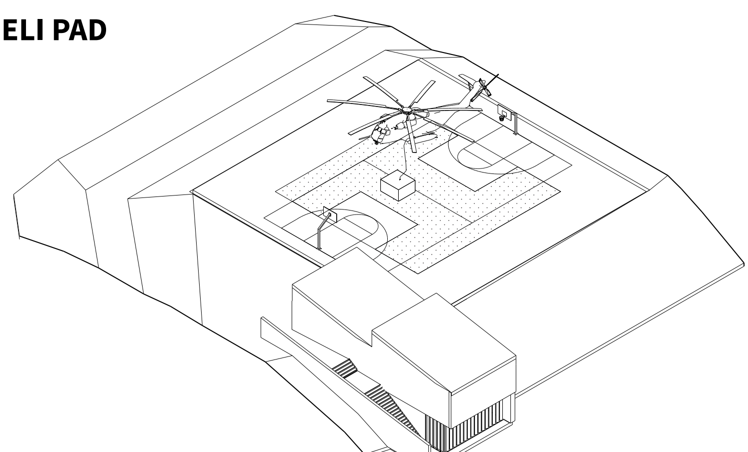
Fig.99
Component C1 Detail
Axonometric Diagrams

BASKETBALL COURT



WASHROOM AND SERVICE BUILDING

HELI PAD



WASHROOM AND SERVICE BUILDING

4.5.1 RESOURCE FLOW SITE A

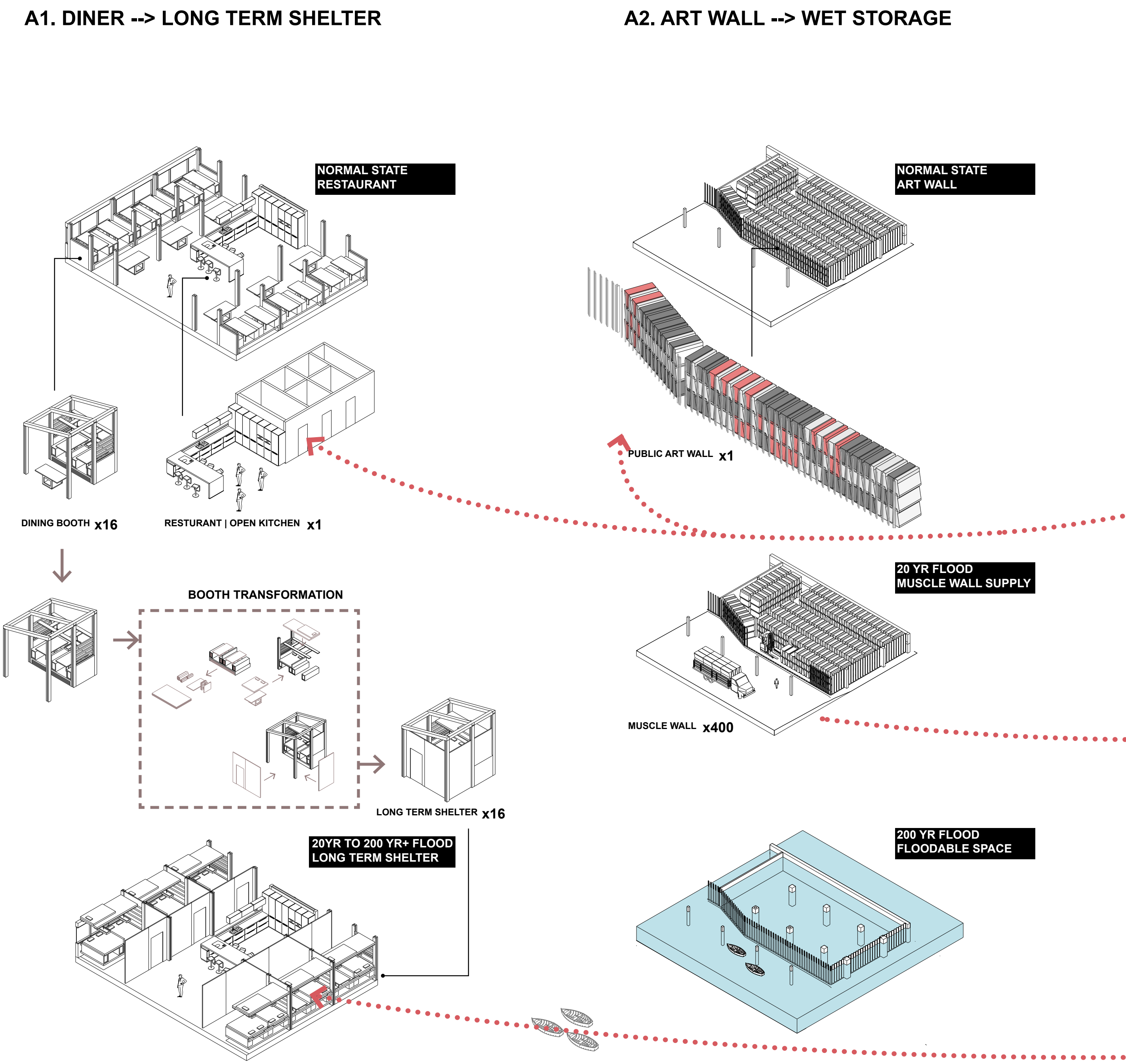
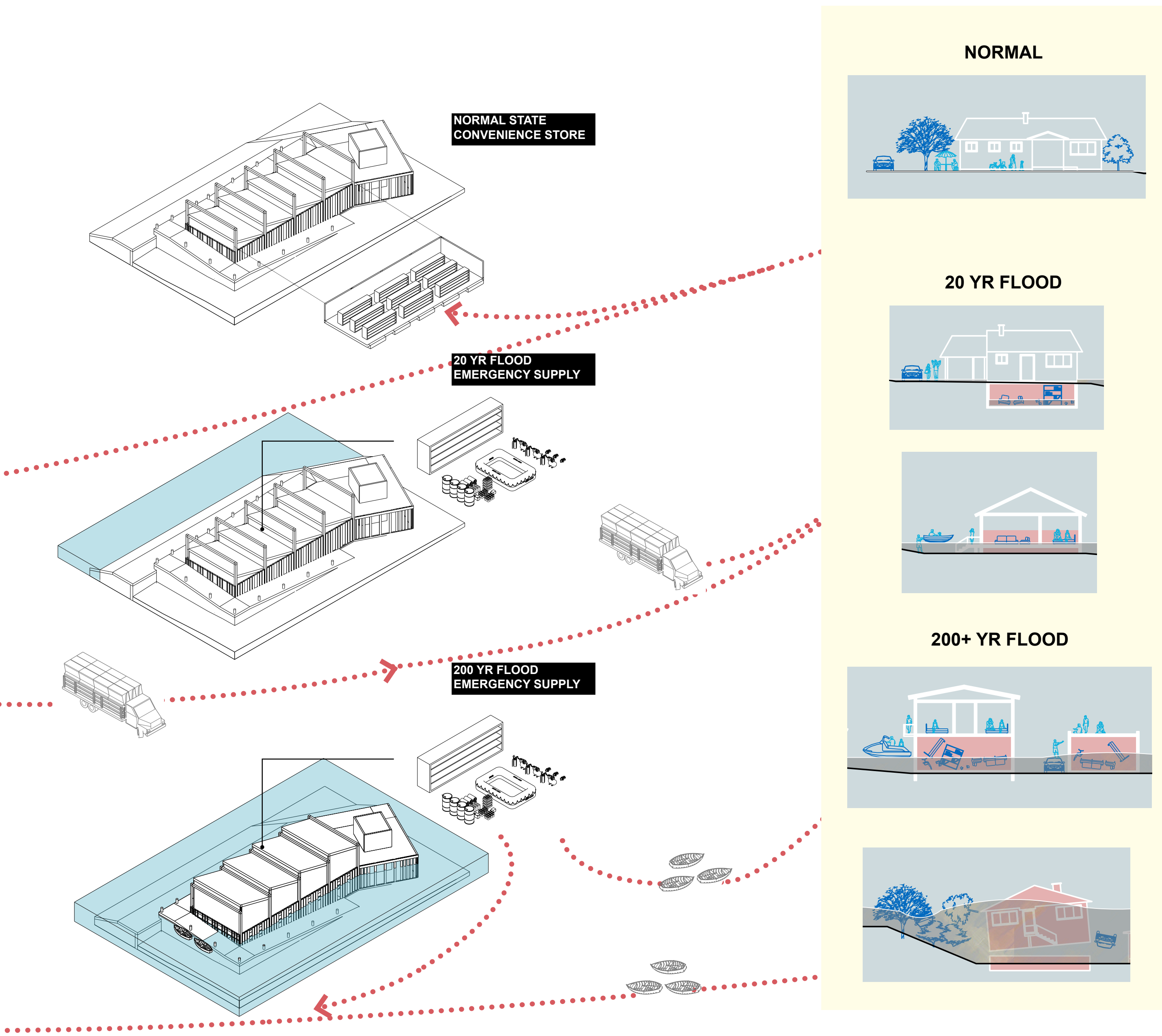


Fig.100
Resource Flow Diagram
Site A

A3. CONVENIENCE STORE --> DRY STORAGE

LOCAL VULNERABLE DWELLINGS



4.5.2. RESOURCE FLOW SITE B & C

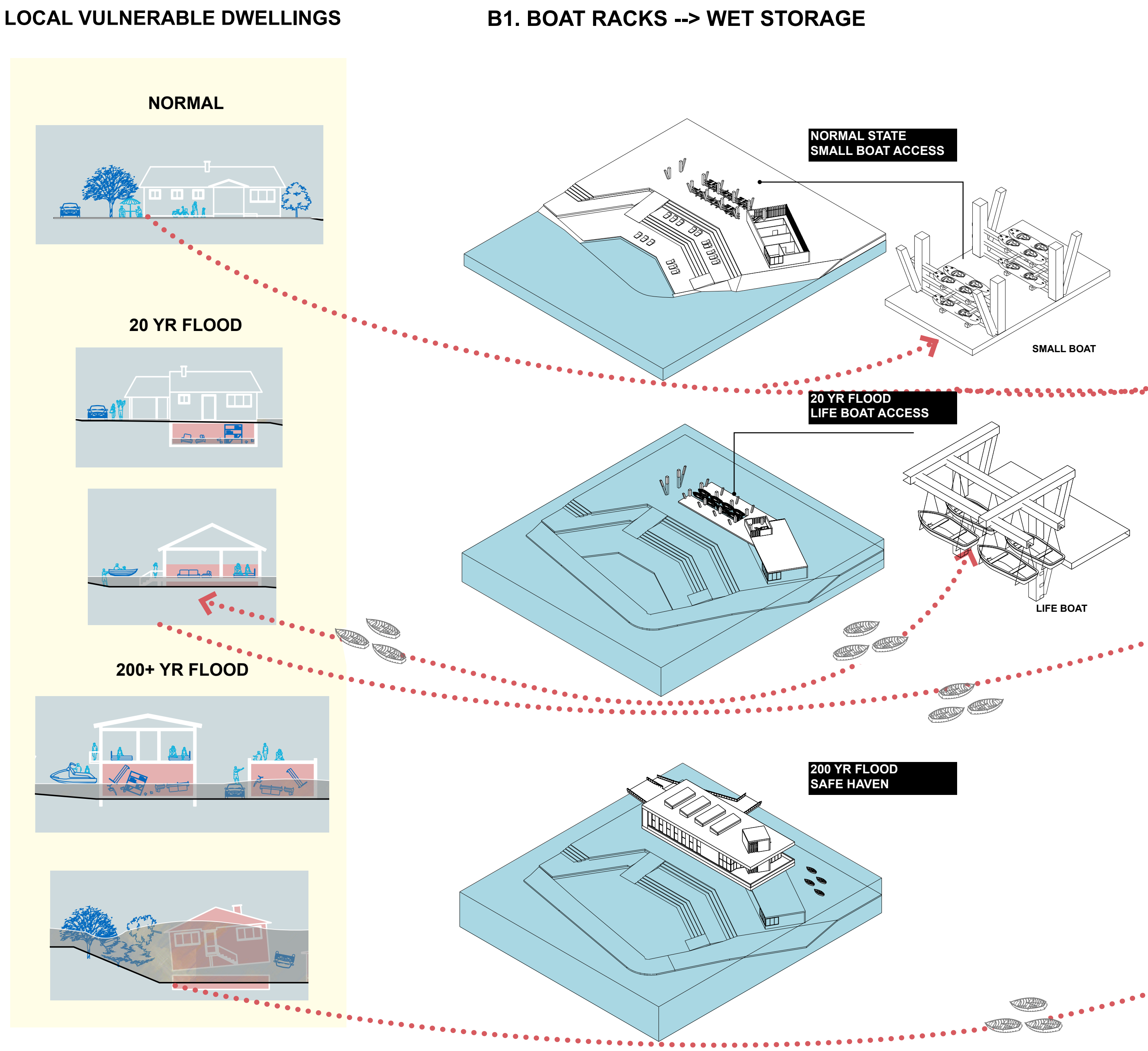
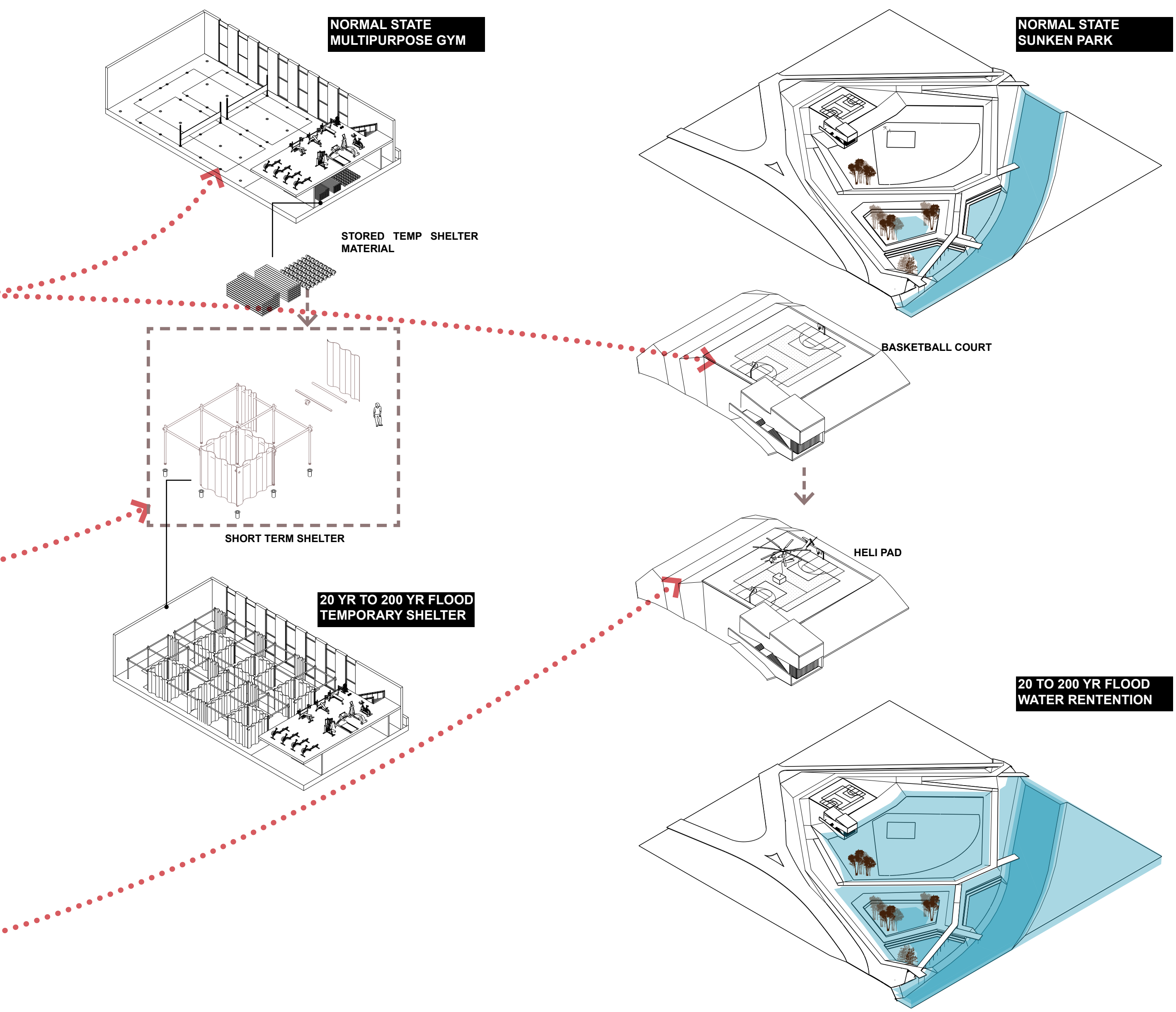


Fig.100
Resource Flow Diagram
Site B and Site C

B2. INDOOR GYM --> TEMP SHELTER

C. SUNKEN PARK --> FLOOD WATER RETENTION



CONCLUSION

This thesis is the exploration of the multidisciplinary syntax for the *urban water space*, with a focus on producing multifunctional spaces preloaded with the material and programmatic capacity to respond to flood events. The four design principles — interact, tolerate, protect, and recover — are all essential to designing spaces to respond to, recover from, and become resilient against flood events. Both the catalogue and the design explorations can be used as references for designing *urban water spaces* of similar context or scale.

The design explorations presented in this thesis showcase the preliminary framework of three site specific integrated designs and suggest a few appropriate combinations of component choices from the catalogue. Since the integrated design requires multidisciplinary input, each component would require further investigation from each discipline in terms of cost, feasibility, constructability, and is beyond the scope of this thesis.

The thesis intentionally positioned the multifunctional resource centers at the forefront of flood vulnerability, in the *urban water space*. This allows people living in areas affected by flooding to establish a close and familiar relationship with these public space sthrough daily interaction. Resources for flood events are showcased and become part of the space. This promotes flood awareness for the local community and conveys to people the correct responses to flooding through daily interaction. It would also help people associate positive memories to these public spaces and help reduce emotional stress in times of emergency. This sense of familiarity and security can contribute greatly to the speed of emergency response and recovery from flood events. During a flood, these robust resources centres would be able to provide immediate support to the surrounding area. After a flood, the proximity of the resource centre helps it provide community support and allows any displaced people to stay close to their home for the recovery process.

The scope of design for the thesis is for an up to 1 in 200-year flood. For flood intensity beyond this scope, such as tsunami inundation, there should be a focus on the efficiency of the evacuation and rebuilding process. It is unwise to invest everything in flood preventive/protective measures for extreme flood conditions because it can cause equal harm to the livelihood of waterfronts during the non-flooded periods. In this case, the concepts of preloaded multifunctional architecture discussed in the thesis can be applied to public spaces beyond the floodplain. Restaurants, community centres, and school gyms, for example, can be preloaded with the material capacity in a similar fashion to transform into emergency shelters. This transformative quality of the spaces should be made visible to the public during their normal functions to improve flood awareness.

In conclusion, the design proposed in this thesis is not a singular solution to the increasing flood risk but a shift of attitude towards flood events. It is important to acknowledge the potential failure of the flood defence system and preload the urban fabric with the capacity to respond and recover from flood events when there is minimum external support. At the same time, there is a need to understand the duality of water, and strategically design spaces to accommodate the growth and retreat of water to maximize the potential of water as a source of joy.

END NOTES

PART I THE SITUATION

[1] Barker, Robert, and Richard Coutts. Aquatecture: Buildings and Cities Designed to Live and Work with Water. RIBA Publishing, 2016., p6

[2] Curtis, Kiran. “Climate Change Toolkit 07 Designing for Flood Risk.” RIBA, 2009., p4-5

[3] Climate Change Canada. “Floods: General Information.” Canada.ca, Innovation, Science and Economic Development Canada, 2 Dec. 2010, www.canada.ca/en/environment-climate-change/services/water-overview/quantity/floods/general-information.html.

[4] Curtis (n2)., p4

[5] Climate Change Canada(n3).

[6] Barker (n1)., p21

[7] Climate Change Canada(n3).

[8] Barker (n1)., p40

[9] ibid., p34

[10] Curtis (n2)., p6

[11] Sellars, David, et al. “Flood Mapping in BC APEGBC Professional Practice Guidelines.” APEGBC, Jan. 2017., p11

[12] Barker (n1)., p34

[13] Prominski, Martin. *RIVER.SPACE.DESIGN: Planning Strategies, Methods and Projects for Urban*. BIRKHAUSER, 2017., p29

[14] Doughton, Sandi. “How Japan Is Struggling to Recover, Three Years after Earthquake and Tsunami | Toronto Star.” Thestar.com. N.p., 10 Mar. 2014. Web. 17 Nov. 2016.

[15] ibid.

[16] Prominski (n13)., p34

[17] Riboldi, Isabel. “Integrated Flood Management (IFM): a New Approach to Flood Management.” *AID & International Developement Forum*, 9 Apr. 2014, www.aidforum.org/topics/water-sanitation/integrated-flood-management-ifm-a-new-approach-to-flood-management/.

[18] Hegger, Dries, et al. “A View on More Resilient Flood Risk Governance.” *STAR-FLOOD*, 31 Mar. 2016, www.starflood.eu/about-the-project/research-topic/.

[19] Barker (n1)., p132

[20] Wilson, Sean, et al. “The Lack of Disaster Preparedness by the Public and It’s Affect on Communities.” *The Internet Journal of Rescue and Disaster Medicine*, vol. 7, no. 2, 2008, doi:10.5580/21f7., p4

[21] Ibid., p2

[22] Bumsted, J. M. *Floods of the Centuries: a History of Flood Disasters in the Red River Valley, 1776-1997*. Great Plains Publications, 1997., p65

[23] ibid., p65,68

[24] Ashbridge, Jo. "Transitional Shelter Guidelines." Shelter Centre, May 2012., pxvii

[25] Woods, Lebbeus. *War and Architecture = Rat i Arhitektura*. Princeton Architectural Press, 2002., p36

[26] English, Elizabeth C. "Buoyant Foundation Project." *Buoyant Foundation Project*, buoyantfoundation.org/

[27] Mazereeuw, Miho, and Elizabeth Yarina. "Emergency Preparedness Hub: Designing Decentralized Systems for Disaster Resilience." *Journal of Architectural Education*, vol. 71, no. 1, 2017, pp. 65–72., doi:10.1080/10464883.2017.1260928.

[28] Mathews, Stanley. "The Fun Palace:Cedric Price's Experiment in Architecture and Technology." *Technoetic Arts*, vol. 3, no. 2, 2005, p 73

[29] ibid., p74

[30] *2016 Laureate Alejandro Aravena Chile Image Book*, The Pritzker Architecture Prize, 2016, www.pritzkerprize.com/sites/default/files/file_fields/field_files_inline/2016-Pritzker-Prize-Image_Book_0.pdf.

[31] Woods, (n25)., p19

[32] Barker (n1)., p35

[33] "Poppy Plaza / The Marc Boutin Architectural Collaborative." *ArchDaily*, 1 Apr. 2016, www.archdaily.com/784646/poppy-plaza-the-marc-boutin-architectural-collaborative.

[34] Alejandro Aravena: My Architectural Philosophy? Bring the Community into the Process. TED, 6 Nov. 2014. Web. 13 Nov. 2016.

PART II CATALOGUE

[35] Prominski (n13)., p72-76

[36] ibid., p78

[37] ibid., p54

[38] ibid., p100

[39] ibid., p52

[40] Meulder, Bruno De, and Kelly Shannon. *Water Urbanisms East*. Park Books, 2013., p44-45

[41] Prominski (n13)., p106

[42] Barker(n1)., p202-203

[43] ibid., p206-207

[44] Frost-Tift, Seth, and Amit Mahadevia. *Homeowner's Guide to Retrofitting: Six Ways to Protect Your Home from Flooding*. U.S. Dept. of Homeland Security, Federal Emergency Management Agency, 2014., chapter 7-1

[45] Barker(n1)., p197-218

[46] ibid., p204-205

PART III CONTEXT

[47] City of Port Alberni., "Official Community Plan." *Official Community Plan | City of Port Alberni*. N.p., n.d. Web. 07 Feb. 2017. P10

[48] ibid., p5

[49] Clague PGeo, John J., and John Orwin. *Tsunami Hazard to North and West Vancouver, British Columbia*. 2005, p. 19,

[50] ibid., p2

[51] City of Port Alberni (n48)., p19

[52] ibid., p25Sta

[53] nford, Ben. "BC Gov News." *Dry Creek Improvement Project Complete*, BC Gov News, 2 May 2016, news.gov.bc.ca/releases/2016TRAN0086-000694.

[54] City of Port Alberni (n48)., p26

[55] Edgell, Phil. "Somass Estuary Management Plan." Catherine Berris Associates Inc., Sept. 2014., p47

[56] ibid., p49

PART IV DESIGN

[57] Ban, Shigeru. *Voluntary Architects' Network*. INAX, 2010. p76

BIBLIOGRAPHY

Aaronson, Deborah, and Cameron Sinclair. *Design like You Give a Damn*. London: Thames & Hudson, n.d. Print.

2016 Laureate Alejandro Aravena Chile Image Book, The Pritzker Architecture Prize, 2016, www.pritzkerprize.com/sites/default/files/file_fields/field_files_inline/2016-Pritzker-Prize-Image_Book_0.pdf.

“A Design Brief on the Floodplain Mapping Project for Somass River and Tributaries at Port Alberni, B.C.” Ministry of Environment, Lands and Parks Environment and Lands Headquarters Division, Mar. 1997.

Ashbridge, Jo. “Transitional Shelter Guidelines.” Shelter Centre, May 2012.

Alejandro Aravena: My Architectural Philosophy? Bring the Community into the Process. TED, 6 Nov. 2014. Web. 13 Nov. 2016.

Ban, Shigeru. *Voluntary Architects’ Network*. INAX, 2010.

Barker, Robert, and Richard Coutts. *Aquatecture: Buildings and Cities Designed to Live and Work with Water*. RIBA Publishing, 2016.

BC, Emergency Management. “Exercise Program.” *Province of British Columbia*. Province of British Columbia, 08 Dec. 2016. Web. 07 Feb. 2017.

Bumsted, J. M. *Floods of the Centuries: a History of Flood Disasters in the Red River Valley, 1776-1997*. Great Plains Publications, 1997.

Burden, Amanda. “Designing for Flood Risk Coastal Climate Resilience.” NYC Department of City Planning, June 2013.

Charlesworth, Esther Ruth., and Iftekhar Uddin Ahmed. *Sustainable Housing Reconstruction: Designing Resilient Housing after Natural Disasters*. New York: Routledge, 2015. Print.

Clague PGeo, John J., and John Orwin. *Tsunami Hazard to North and West Vancouver, British Columbia*. 2005, p. 19, *Tsunami Hazard to North and West Vancouver, British Columbia*.

Climate Change Canada. “Floods: General Information.” *Canada.ca*, Innovation, Science and Economic Development Canada, 2 Dec. 2010, www.canada.ca/en/environment-climate-change/services/water-overview/quantity/floods/general-information.html.

Curtis, Kiran. “Climate Change Toolkit 07 Designing for Flood Risk.” RIBA, 2009.

Doughton, Sandi. “How Japan Is Struggling to Recover, Three Years after Earthquake and Tsunami | Toronto Star.” Thestar.com. N.p., 10 Mar. 2014. Web. 17 Nov. 2016.

Edgell, Phil. “Somass Estuary Management Plan.” Catherine Berris Associates Inc., Sept. 2014.

English, Elizabeth C. “Buoyant Foundation Project.” *Buoyant Foundation Project*, buoyantfoundation.org/

Frost-Tift, Seth, and Amit Mahadevia. *Homeowner’s Guide to Retrofitting: Six Ways to Protect Your Home from Flooding*. U.S. Dept. of Homeland Security, Federal Emergency Management Agency, 2014.

Hegger, Dries, et al. “A View on More Resilient Flood Risk Governance.” *STAR-FLOOD*, 31 Mar. 2016, www.starflood.eu/about-the-project/research-topic/.

IFRC. *Post Disaster Shelter 10 Designs*. International Federation of Red Cross and Red Crescent Societies, 2013.

Mathews, Stanley. “The Fun Palace:Cedric Price’s Experiment in Architecture and Technology.” *Technoetic Arts* , vol. 3, no. 2, 2005, pp. 73–92.

Mazereeuw, Miho, and Elizabeth Yarina. “Emergency Preparedness Hub: Designing Decentralized Systems for Disaster Resilience.” *Journal of Architectural Education*, vol. 71, no. 1, 2017, pp. 65–72., doi:10.1080/10464883.2017.1260928.

Meulder, Bruno De, and Kelly Shannon. *Water Urbanisms East*. Park Books, 2013.

“Muscle Wall.” *Muscle Wall*, Muscle Wall Holdings LLC., 2017, www.musclewall.com/.

“Official Community Plan.” *Official Community Plan | City of Port Alberni*. N.p., n.d. Web. 07 Feb. 2017.

“Poppy Plaza / The Marc Boutin Architectural Collaborative.” *ArchDaily*, 1 Apr. 2016, www.archdaily.com/784646/poppy-plaza-the-marc-boutin-architectural-collaborative.

Prominski, Martin. *RIVER.SPACE.DESIGN: Planning Strategies, Methods and Projects for Urban*. BIRKHAUSER, 2017.

Riboldi, Isabel. “Integrated Flood Management (IFM): a New Approach to Flood Management.” *AID & International Developement Forum*, 9 Apr. 2014, www.aidforum.org/topics/water-sanitation/integrated-flood-management-ifm-a-new-approach-to-flood-management/.

Rosenfield, Karissa. “Resist, Delay, Store, Discharge: OMA’s Comprehensive Strategy for Hoboken.” (n.d.): n. pag. Arch Daily. 19 Nov. 2013. Web. 25 Nov. 2016.

Sandwell, Ausenco. “Guidelines for Management of Coastal Flood Hazard Land Use.” BC Ministry of Environment , 27 Jan. 2011.

Sellars, David, et al. “Flood Mapping In BC APEGBC Professional Practice Guidelines.” APEGBC, Jan. 2017.

Stanford, Ben. “BC Gov News.” *Dry Creek Improvement Project Complete*, BC Gov News, 2 May 2016, news.gov.bc.ca/releases/2016TRAN0086-000694.

Tardif, Melissa. "Community Profile." *Building Standards and Property Maintenance | City of Port Alberni*, www.portalberni.ca/community-profile.

UMA Engineering. "City of Port Alberni Tsunami Inundation Zone Study." UMA Engineering LTD., 10 Mar. 1992.

Wilson, Sean, et al. "The Lack of Disaster Preparedness by the Public and It's Affect on Communities." *The Internet Journal of Rescue and Disaster Medicine*, vol. 7, no. 2, 2008, doi:10.5580/21f7.

Woods, Lebbeus. *Radical Reconstruction*. Princeton Architectural Press, 1997.

Woods, Lebbeus. *War and Architecture = Rat i Arhitektura*. Princeton Architectural Press, 2002.