

**INFRASTRUCTURAL LANDSCAPES:
INTEGRATING RENEWABLE ENERGY WITH LANDSCAPE AND
COMMUNITY IN THE BAY OF FUNDY, NOVA SCOTIA**

by

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ABSTRACT

The Bay of Fundy is home to the highest tides in the world and among the strongest currents. The Minas Passage is a narrow body of water in the upper Bay of Fundy with a 13-metre tidal range and water speeds of 7-8 knots, providing an ideal landscape for tidal energy. The only in-stream tidal demonstration facility in North America is located along the Minas Passage, connected to the Nova Scotia Power grid. Tidal energy supply is intermittent, varying with the tides. Supplementing tidal with energy storage allows for a continuous supply of renewable energy. This thesis proposes a pumped hydro energy storage facility along the Minas Passage that integrates renewable energy infrastructure with landscape and incorporates community program, to provide an interactive architecture that makes evident the natural and energy processes that sustain it.

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CHAPTER 1: INTRODUCTION

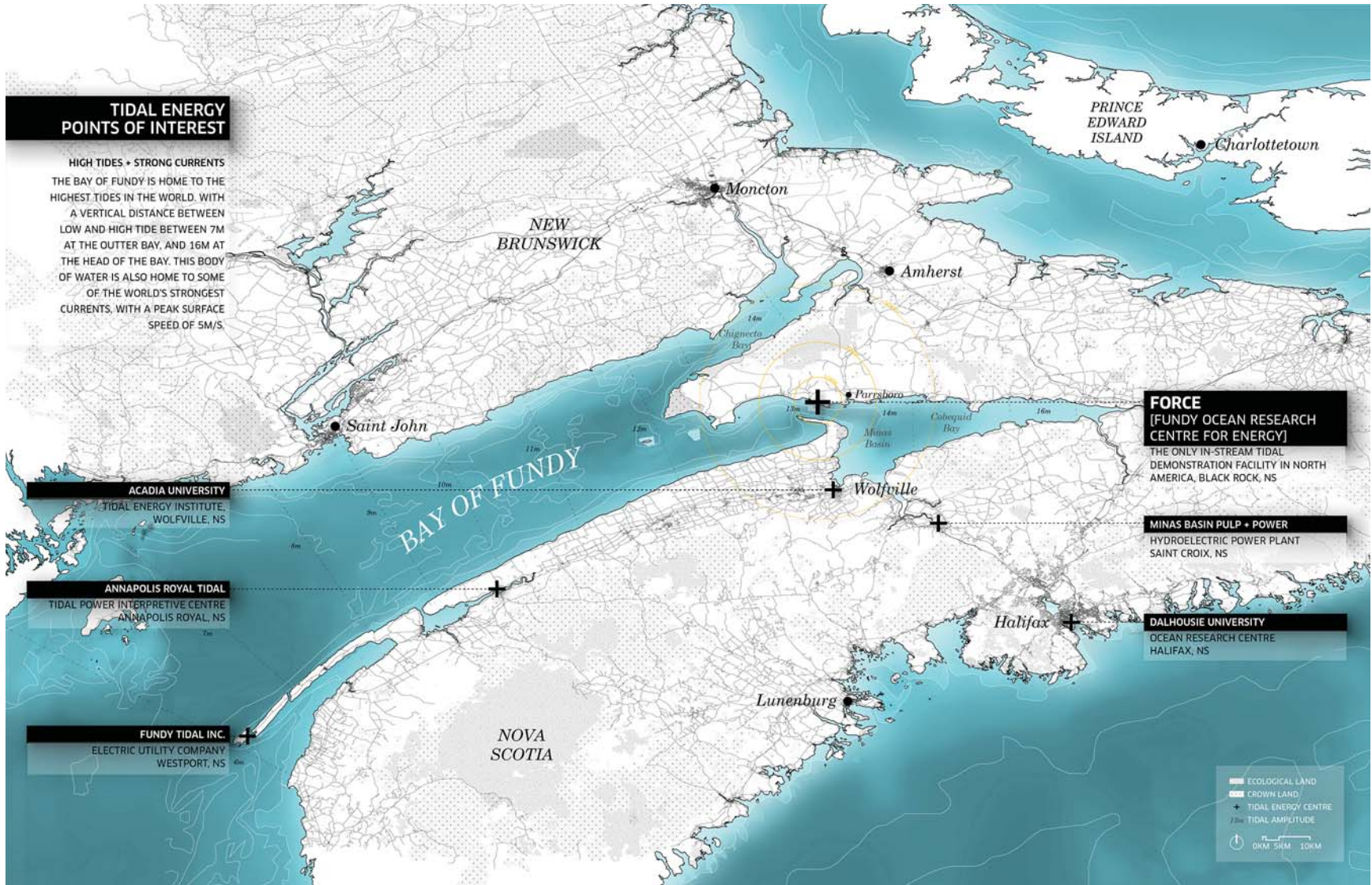
Renewable industries have a deep connection with landscape, but their processes and infrastructure often remain unseen. This thesis presents a framework for developing renewable energy that integrates landscape and community while making evident the processes that sustain it.

Energetic Landscape

The Bay of Fundy is home to the highest tides in the world and among the strongest currents. This body of water is wider at the mouth and narrows as you approach the head of the bay. This form creates a suction effect that amplifies the gravitational force of the moon, increasing the tidal range. This effect is strongest in the Minas Passage, a 5-kilometre-wide body of water in the upper Bay of Fundy. This narrow channel creates a pinch point, which generates high tides and strong currents. The tidal range in the Minas Channel is 13-14 metres, with water speeds averaging between 7-8 knots at the surface. The passage has accessible depths, and solid bedrock geology, making it an ideal location for tidal energy (FORCE: Bay of Fundy, 2017).



Model highlighting topography, bathymetry, and water speeds during tidal ebb and flood.



This map highlights tidal amplitudes in the Bay of Fundy, which increase towards the head of the bay, and sites of tidal energy research and development.

Tidal energy is the most reliable form of renewable energy when compared with solar or wind energy, but it is still an intermittent supply. Tidal power supply varies with the tide cycle, rising and falling with tidal ebb and flood. Slack tide is a period of still water which occurs before water changes direction between high and low tide. During this period there is no movement in the water and therefore no power supply, so we must compensate with another form of energy production; in Nova Scotia, this is often coal (Nova Scotia Power 2017). A critical goal of this thesis is to provide a continuous supply of local renewable energy.

Integrating energy storage with tidal energy can provide a continuous supply of renewable energy. Pumped hydro energy storage is the most widely used, and cost-effective form of energy storage. Tidal ebb and flood pump ocean water between a lower and upper reservoir, during periods of high energy supply when the tides are moving. During periods of low energy supply or high energy demand, water is released from the upper reservoir to pass through a turbine, generating energy (Barbour).

James Corner's essay, *Terra Fluxus*, describes approaches to integrating infrastructure and landscape, describing their successful integration as '*infrastructural landscapes*'. In this approach, built form emerges based on "how it relates to the processes that flow through, manifest, and sustain it" (Corner 2017, 28-29). The natural process of the shifting tides inform the formal development of this thesis.

Thesis Question

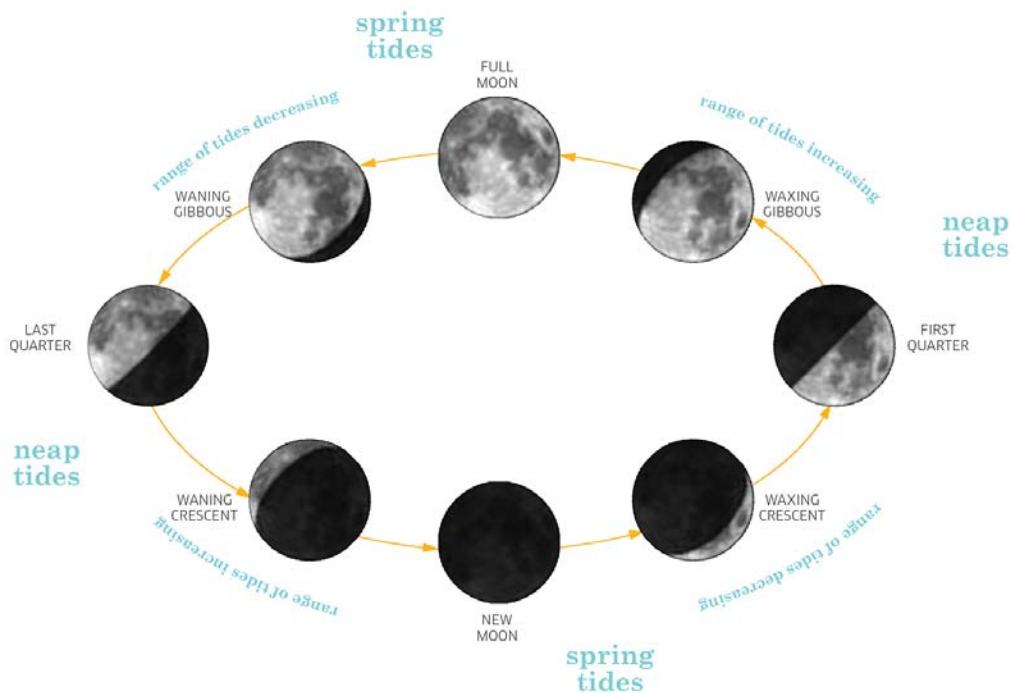
How can renewable energy infrastructure integrate landscape and community, while making evident the natural and energy processes that sustain it?

CHAPTER 2: SITE

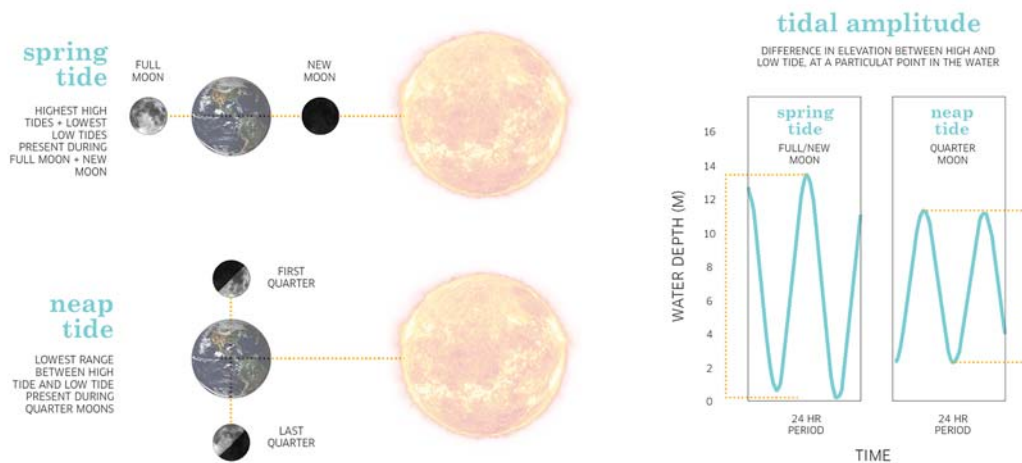
Natural Processes

Tides rise and fall due to the gravitational pull on the earth's oceans by the moon and the sun, augmented by the rotation of the earth. The gravitational pull of the moon creates a wave which increases as it travels to the bays head and falls back. The transition from high tide to low tide takes 6 hours, then repeats.

Tides are the highest when the moon and sun align with the earth, amplifying their gravitational pull, resulting in the greatest tidal range, and therefore the highest high tides and lowest low tides. The sun and moon align during the full and new moons. This alignment generates 'spring tides', named for the motion of the tides springing forward and back. A neap tide occurs during the quarter moon phase, when the moon and sun are at right angles to one another, lessening their gravitational effect. Neap tides have the smallest range between high and low tide (Thorsen 2018).



The 28-day lunar cycle and its relation to tidal range. Tidal range is greatest during the full moon and new moon. Image based on data from Thorsen.



The gravitational pull of the moon and sun impact the tidal range. The tidal range is largest when the earth is aligned with the sun and moon. Image based on data from Thorsen.

Rhythmanalysis

Henri Lefebvre describes *'rhythmanalysis'* as a method for understanding everyday life through the relation of space and time. Lefebvre distinguishes between cyclical and linear rhythms, which are constantly interacting (Lefebvre 2004, 3-8). Cyclical rhythms often exist in nature, such as the changing seasons, sun and wind direction, the transition from day to night, and the rhythm of the moon and tides. Linear rhythms are present in human movement and activity. Parrsboro and surrounding areas experience a significant population increase during the summer months when cottages are in use. During tidal demonstrations, the town fills with researchers and developers, filling the town's hotels.

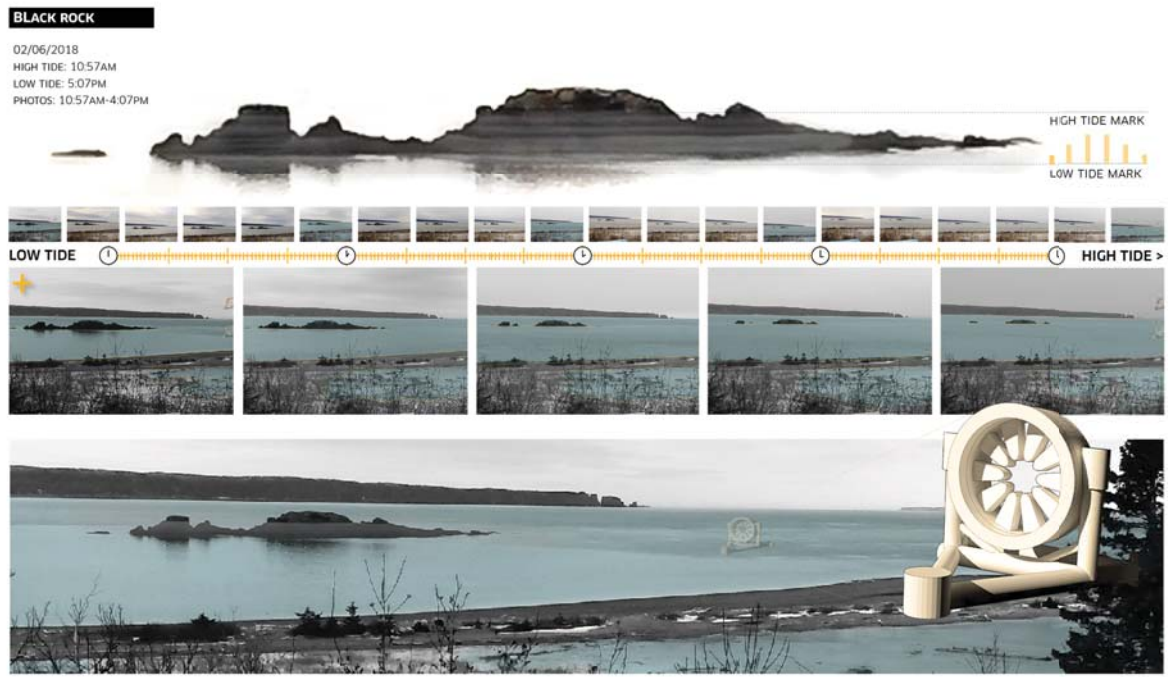
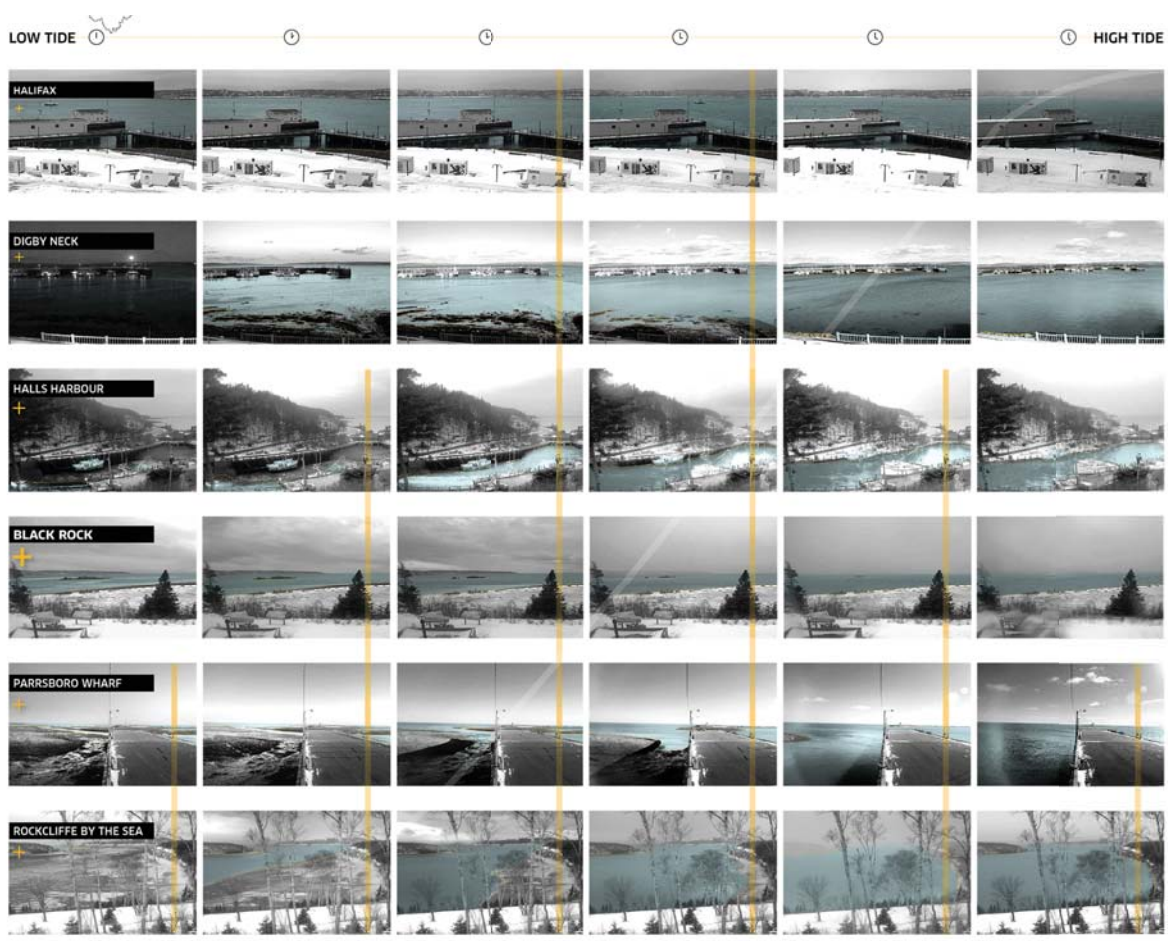
Studying rhythms by recording them, allows us to reflect on them, long after they have vanished (Lefebvre 2004, 67-69). The goal of this work is to analyse the natural rhythm of the tides, unique to the Bay of Fundy, to develop architecture informed by the natural and energy processes of this landscape. Building forms emerge from the land in a way that celebrates the natural rhythms that make this region so distinct.

Tidal Study

The average tidal amplitude off the coast of Nova Scotia ranges between one and two metres, which is the global average tidal range. In the Bay of Fundy, the tidal amplitude ranges from 6 metres at the outer bay, to 16 metres at the head of the bay, where the worlds highest tide was recorded (Bleakney 2004, 14-16). The Bay of Fundy fills and empties twice a day during each tide cycle, displacing 160 billion tonnes of water, which is more than all the world's freshwater rivers combined. The fastest tidal streams occur during the third and fourth hour after slack tide. Half of the total amount of water displaced moves during this two hour period. In the Bay of Fundy, 80 billion tonnes of water is displaced in just two hours (FORCE: Tidal Energy, The Bay of Fundy).

The following photo montage depicts a study of the tidal range at six sites across Nova Scotia, with one photo each hour between low tide and high tide. Yellow columns overlaid on the images represent the amount of water displaced during each hour of the tide cycle. You can see this drastic change in water levels during the third and fourth hour of the tide cycle in these photos. The white curve overlaid on the images represents the changing water level, between low tide and high tide.

The lower portion of the page shows photos from the thesis site, during the first five hours of the tide cycle. The site is in Black Rock, Nova Scotia, named for the rock off-shore that becomes hidden and revealed with the changing tides. Although the change in tides is dramatic at this site it is less visible on the shoreline, as there is a barrier beach that separates the ocean from a tidal lagoon. The tides do not come over this barrier beach, so the rock in the water is an important landmark in reading the tides. The image of Black Rock shows the water level at each hour of the tide cycle. The final image overlays low tide and high tide at the site, and the location of the turbine berth.

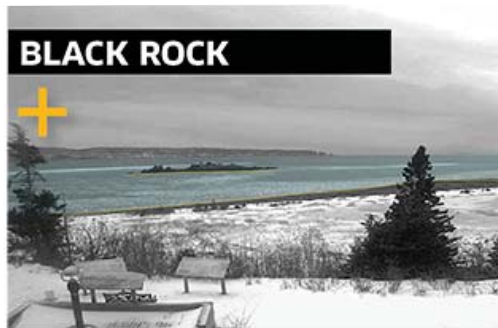


Tidal study done at six sites in Nova Scotia, beginning in Halifax where the tidal range is between 1-2 metres, and ending at the thesis site, where the tidal range is 13-14 metres (data from Nova Scotia Webcams 2018).



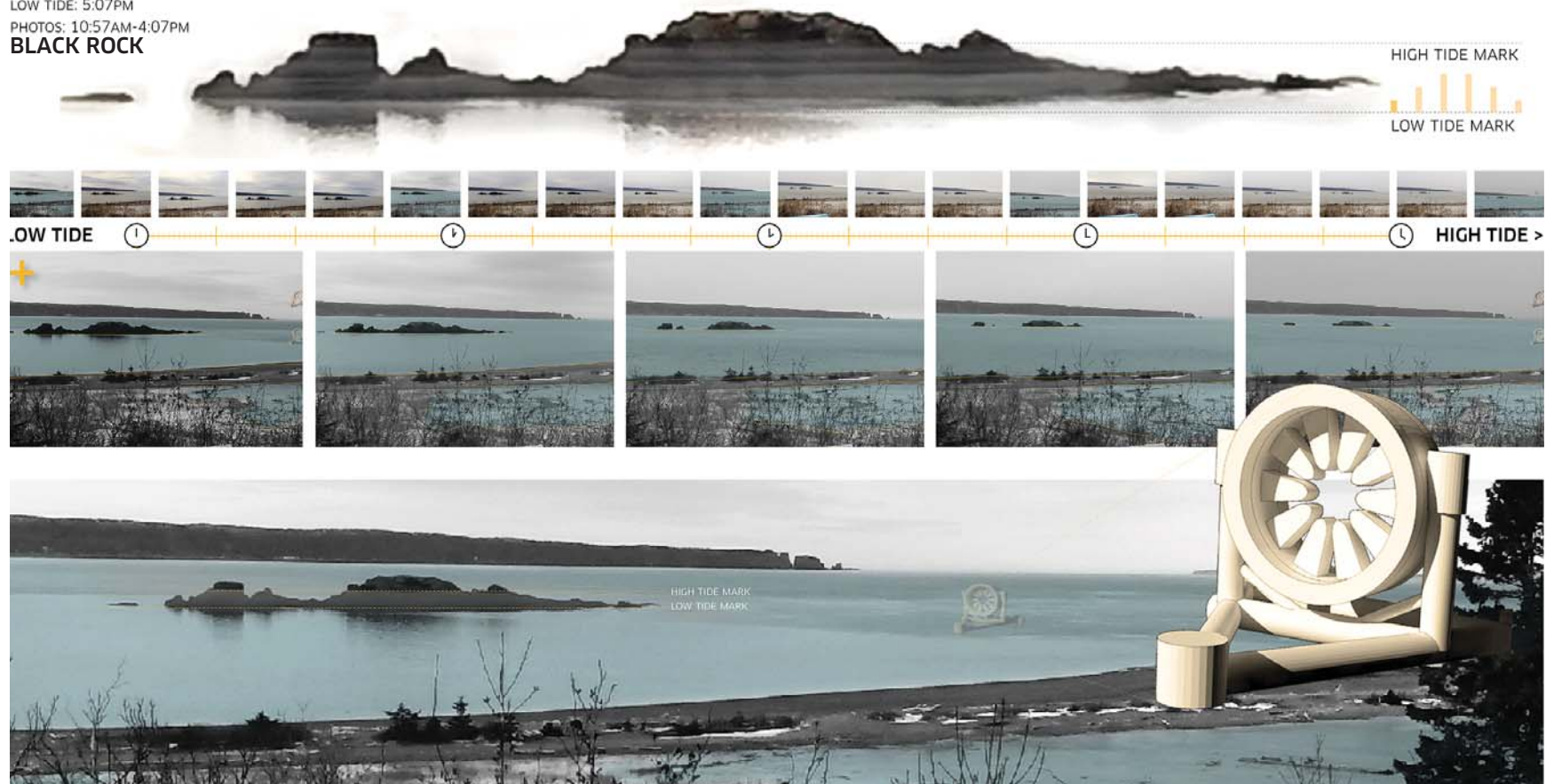
LOW TIDE

HIGH TIDE



Tidal study done at various sites in the Bay of Fundy, showing low tide on the left, and high tide, 6 hours later, on the right (data from Nova Scotia Webcams 2018).

02/06/2018
HIGH TIDE: 10:57AM
LOW TIDE: 5:07PM
PHOTOS: 10:57AM-4:07PM
BLACK ROCK



Tidal study from the study site at FORCE, showing the water level at each hour of the tide cycle. The area is Black Rock, named for the large rock that becomes hidden and revealed with the shifting tides.

Energy Processes

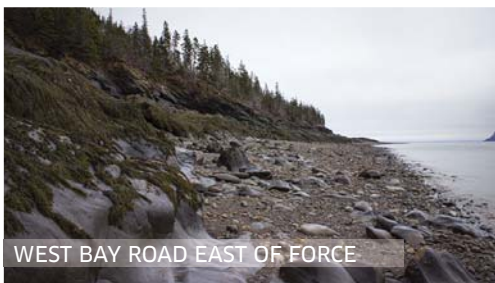
Fundy Ocean Research Centre for Energy [FORCE]

FORCE is the only in-stream tidal demonstration facility in North America, (Government of Canada 2017) and boasts the largest electrical infrastructure of any in-stream tidal centre in the world (Wagstaff 2017). It is located on the northern side of the Minas Channel, 10 kilometres West of Parrsboro, in Black Rock, Nova Scotia. The site houses a research facility, offices, an interpretive visitor's centre, a community room, turbine berths, subsea cables, and an electrical substation which connects tidal energy to the local power grid. This programming combines renewable energy infrastructure with public space for tidal workers and the public.

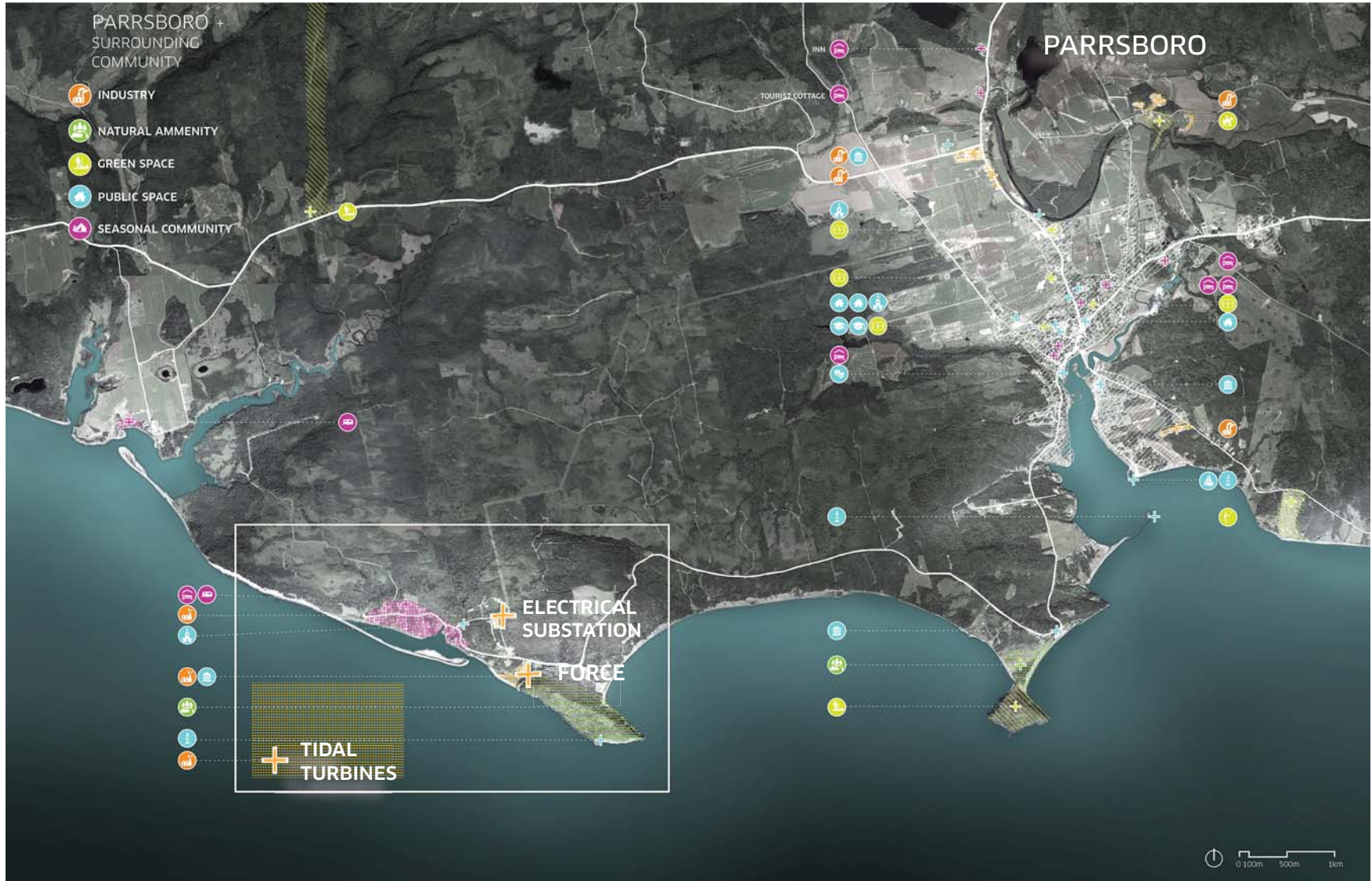
The FORCE site is home to striking ocean views of the dramatic Fundy tides, across the Minas Basin to the cliffs of Cape Split. Rolling hills with areas of dense tree cover dominate this landscape, with steep cliffs and salt marshes giving way to the ocean. The site is home to endangered species of seabirds, with a protected wilderness area located atop Cape Sharp. A delicate salt marsh ecosystem sits between FORCE and the beach below.



FORCE's scenic location on the coast of Black Rock, Nova Scotia, enjoys views of the Bay of Fundy and Cape Split; from FORCE Annual Report.

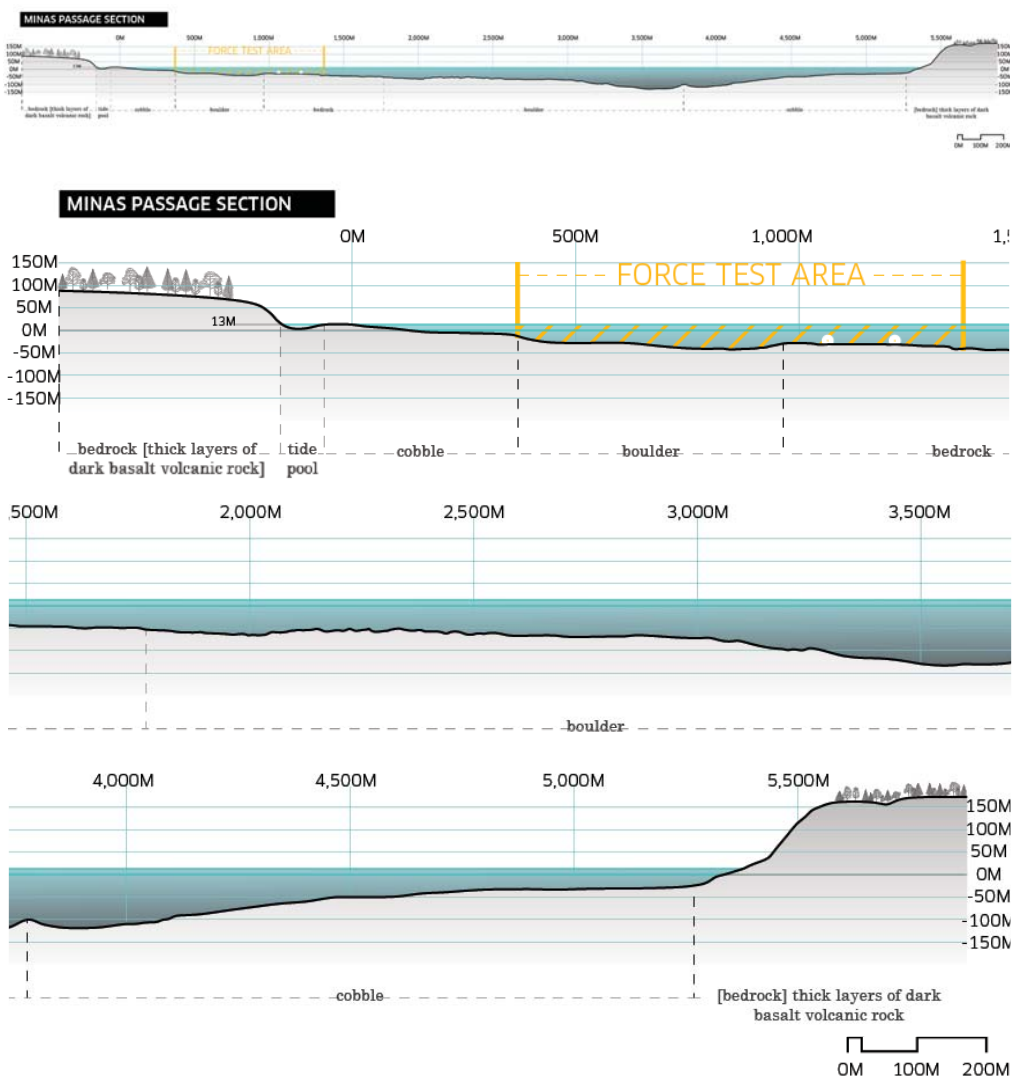


Site photos taken at various times throughout the year display the shifting natural colour palette.



FORCE's turbine test site, located in Black Rock, 10 km West of Parrsboro, the local town centre with a population of 1,200; from Google Maps, OpenStreetMaps.

The water depth in front of FORCE is 45 metres at low tide, with sediment-free bedrock sea floor, straight flowing currents and a water speeds of 5 metres per second. Water speed is fastest at the surface and slowest at the sea floor. The turbine berths are in water that flows between 0-8 knots, or 0-4.11 metres per second. Water speeds of 10-11 knots are equivalent to the force of a category 5 hurricane, which reaches 135 knots and is fast enough to blow a house down. The Minas Passage is home to high-speed currents at accessible depths, making it an ideal test site for tidal turbines (FORCE: Tidal Energy, They Bay of Fundy 2017). The following section is cut through the Minas Passage, showing the location of FORCE's turbine testing area.



Minas Passage Section, highlighting FORCE's turbine test site, the size of the tidal devices in relation to the Minas Passage, and the sediment geology. Image data from FORCE: Tidal Energy, The Bay of Fundy.

FORCE Turbines

The emerging tidal energy industry is testing world-leading innovative technology, here in Nova Scotia. Four organizations currently hold turbine berths at FORCE, with investors and researchers from across the globe. The first commercial-scale in-stream tidal turbine in North America was installed at FORCE in 2009, by Cape Sharp Tidal; a joint venture between Emera, a sector of Nova Scotia Power, and OpenHydro, (FORCE: Technology 2017) a Naval Energies company from Dublin, Ireland, who specializes in the design, manufacturing, installation and maintenance of tidal turbines (OpenHydro: Naval Energies, 2017). OpenHydro and Emera are the first organization to have a turbine installed at FORCE.

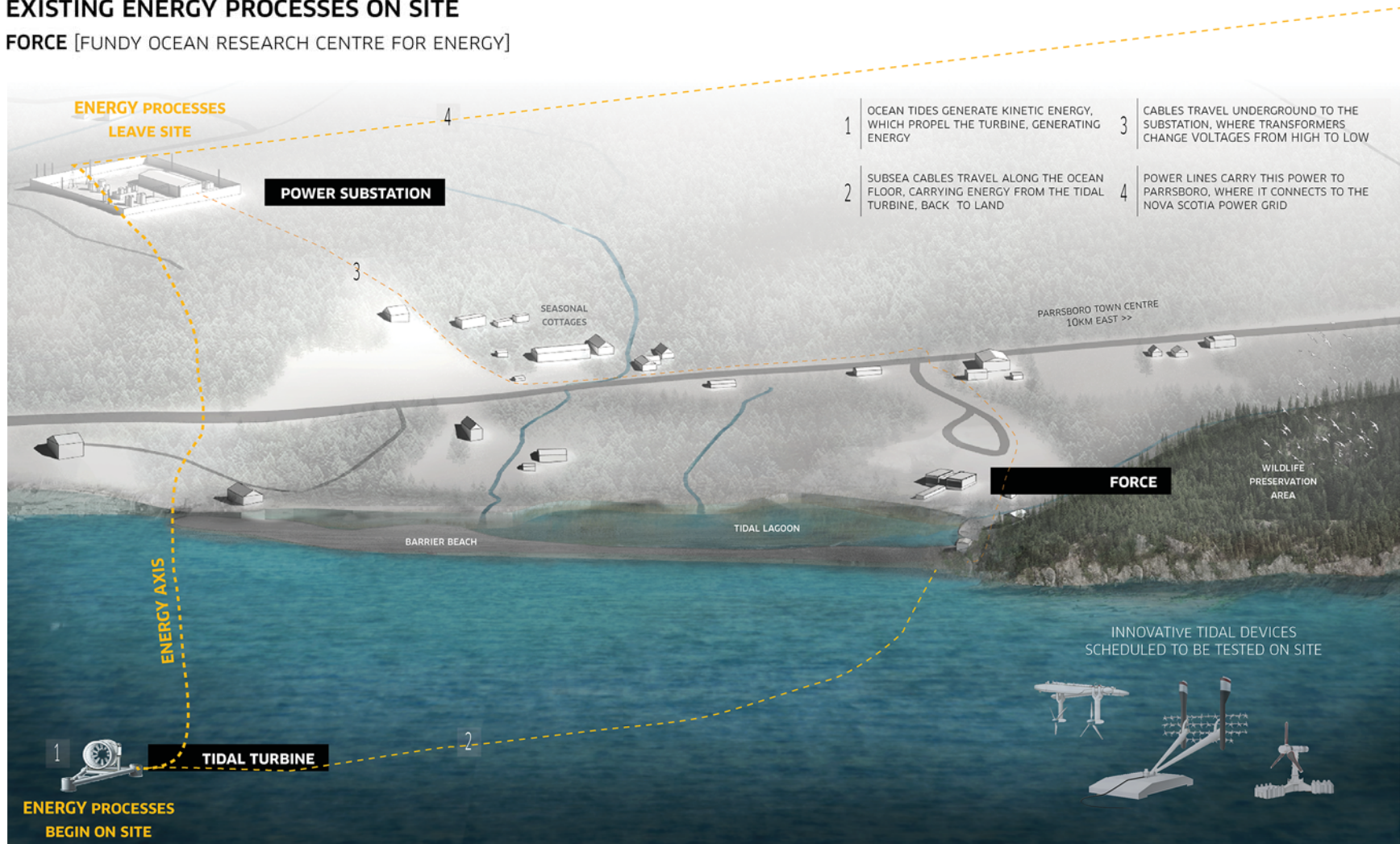
The OpenHydro turbine is 'in-stream', meaning it sits directly in the natural stream of the water, which propels the fins, causing the rotor to turn. This is different from the technology used in tidal dams, which obstruct the natural flow of water. The 2MW turbine is 16 metres in diameter, weighs 1,000 tonnes, and stands 21 metres tall. The turbine has 10 fins, rounded on all edges, measuring 1.5cm thick at the tip, and 20cm thick at the base. The turbine base sits on the sea floor, and requires no drilling for installation, reducing potential environmental impacts. This axial flow turbine requires no oil or lubricants, reducing its ecological impact (OpenHydro: Innovation 2017).



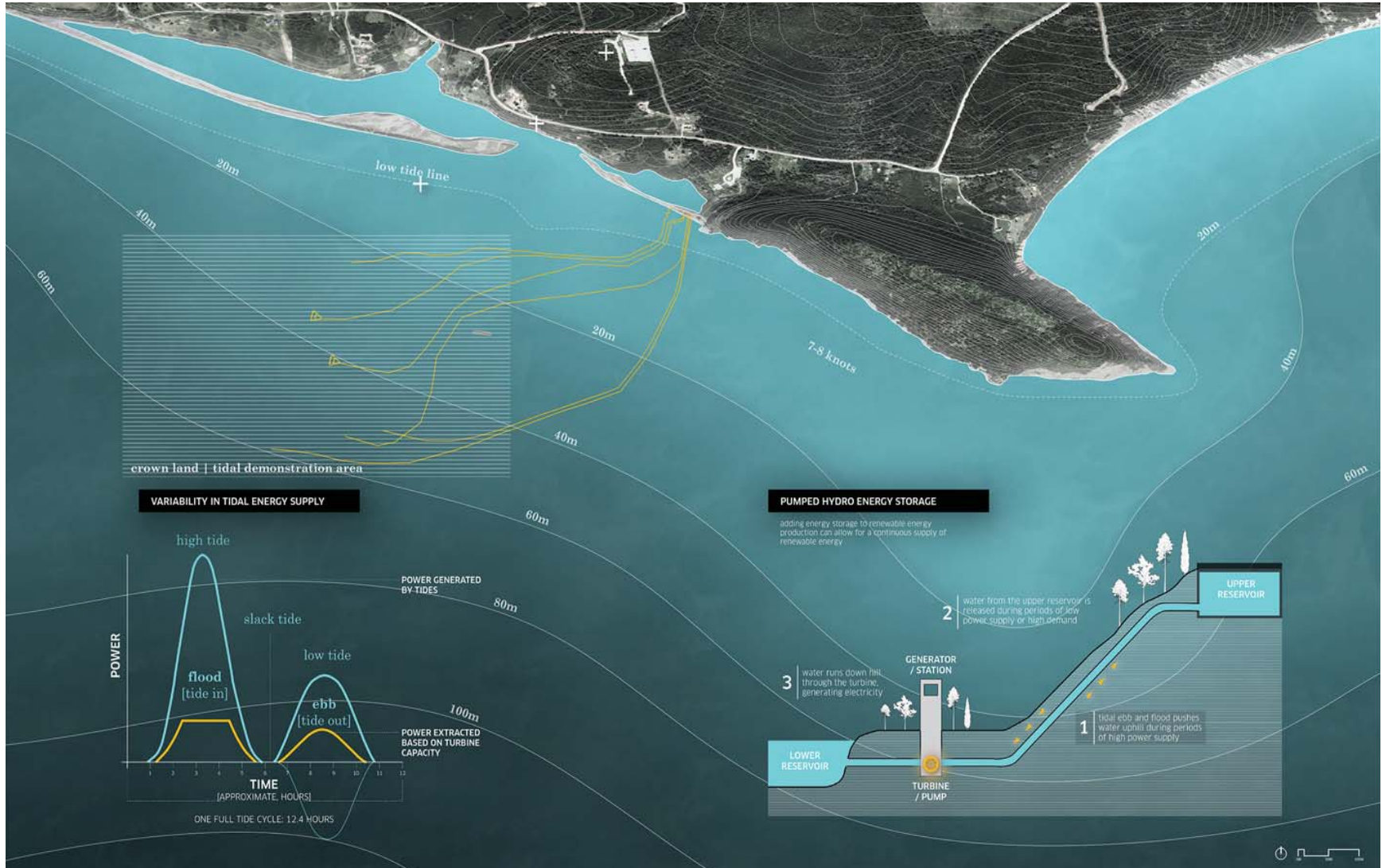
Physical model of the OpenHydro turbine. Left: The turbine shown at the waters surface, 45 metres above the ocean floor, secured in the Scotia Tide Barge, a device that was designed and built specifically for installing this large turbine. Right: The turbine as it sits on the ocean floor.

EXISTING ENERGY PROCESSES ON SITE

FORCE [FUNDY OCEAN RESEARCH CENTRE FOR ENERGY]



Existing site conditions at FORCE: highlighting the energy processes on site, the tidal turbine that is currently installed, the cables connecting it to the substation and then to the provincial power grid, and additional tidal devices that will be tested on site. Natural features of the site include the tidal marsh between FORCE and the ocean, and the barrier beach which protects it, and the wildlife preservation area that is tree covered, which serves as an important endangered bird habitat.



This map shows the existing renewable energy infrastructure on site: tidal turbines and berths, subsea cables, and the electrical substation. Overlays show a graph representing the intermittent supply of tidal energy (left), and the proposed method for energy storage: pumped hydro (right), data from: Google Maps and Babour

Infrastructural Landscapes

James Corner's essay, *Terra Fluxus*, describes approaches to integrating infrastructure and landscape. Corner views landscape as a generator of ecological and built form (Corner 2017, 23). Corner describes the successful integration of landscape and urbanism as 'Infrastructural landscapes', which "possess the capacity to function as important ecological vessels and pathways" (24). This thesis aims to generate built form that can function in this way, by making evident the natural and energy processes occurring on site. Public program will integrate with these processes, to provide a space that educates and engages users.

Based on Corner's theory, built form emerges from the flows and forces on site, which relates to '*rhythm analysis*' as a method for using natural processes and rhythms to guide design. Built form is generated based on "how it relates to the processes that flow through, manifest, and sustain it" (28-29). The natural process of the shifting tides plays a prominent role in the formal qualities of this thesis.

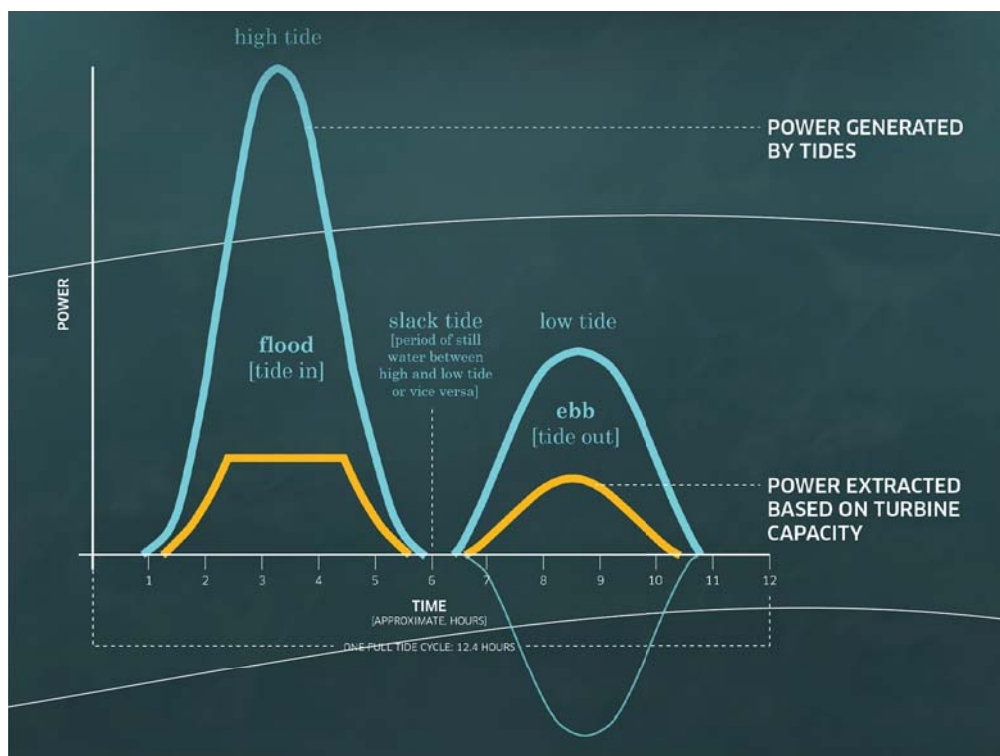
With an increased environmental and ecological awareness, landscape has become an integral part of our cultural identity. The growth of tourism and the associated need for communities to have a unique identity has heightened the desire to protect environmental and cultural landscapes. The Bay of Fundy has a unique opportunity for renewable industry, and tourism, thanks to their incredible tides and currents.

The built form of Infrastructural landscapes relates to the dynamic ecological processes that surround it. Form can be dynamic like the processes of the land. The end goal is not an object that is designed, but more an ecology of networks and systems. This theory has been applied to the thesis site, to develop built form that makes evident the natural processes of the land, specifically the dramatic tides, and the energy processes that are fueled by nature. This thesis proposes a form of landscape infrastructure that integrates landscape, energy storage and community program.

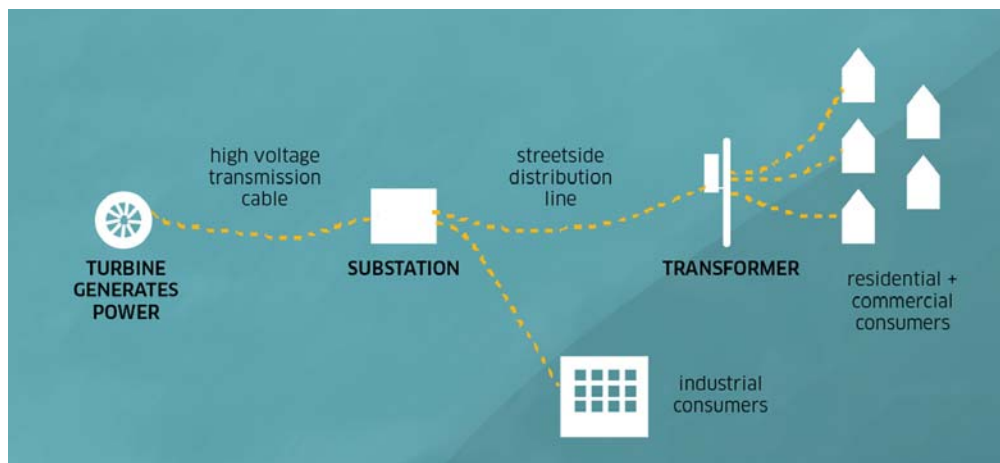
CHAPTER 3: IDENTIFYING PROGRAM

Renewable energy production is a critical element in this thesis. By speaking with representatives from FORCE, it became evident that a key component that would support renewable energy production in the Bay of Fundy would be energy storage (Lumley 2017).

Tidal is the most reliable form of renewable energy when compared with solar or wind. Tides can be predicted years in advance, but it is still not a constant supply. Tidal energy supply varies with the tide cycle, with energy supply rising and falling with tidal ebb and flood. There is a period of still water, called slack tide, which occurs before the water changes direction between high and low tide. During slack tide, there is no movement in the water and therefore no power supply (Akwensivie, Chandra, McAlister, Murray, and Sullivan 2018).



Blue represents the variability in tidal energy supply, showing intermittent supply, with periods of no energy production during slack tide. Yellow represents the energy extracted by tidal turbines, capping out based on the capacity of the device, based on image from: Akwensivie, Chandra, McAlister, Murray, and Sullivan 2018.



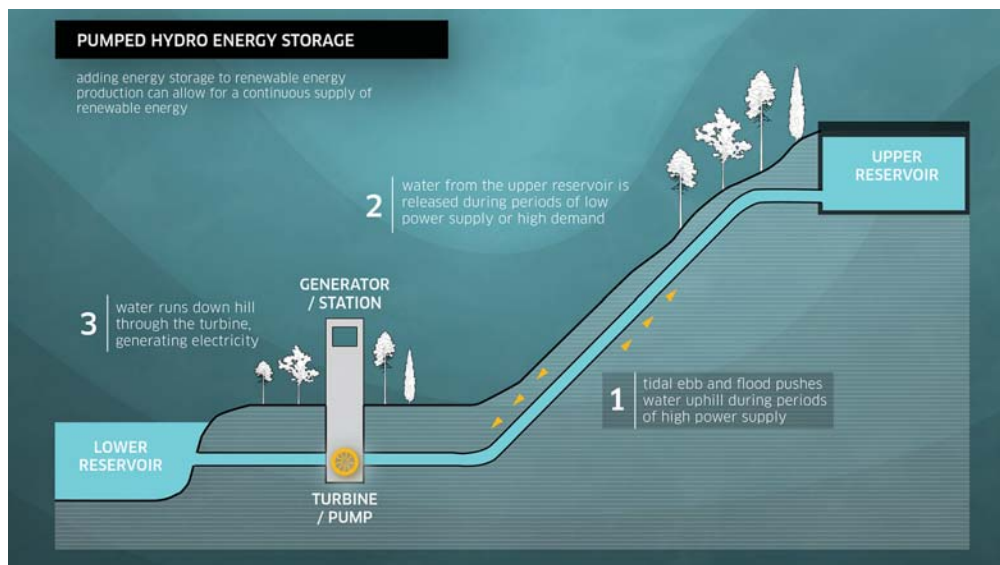
Path of energy from the tidal turbine to our homes and businesses. This path is only active when the tides are moving, with periods of no energy production during slack tide. Data from Nova Scotia Power.

Energy Storage

During slack tide, we must compensate with another energy source, which is Nova Scotia, is often coal. Coal supplies the majority of Nova Scotia's power, resulting in 42% of the province's greenhouse gas emissions caused by energy use (Province of Nova Scotia 2018). Until 1999, Nova Scotian coal mines provided local and economic energy supply. Many coal mining operations in the province have since closed, due to dangerous working conditions and negative environmental impacts. Much of the coal used in Nova Scotia is imported from other provinces, or international markets, leaving Nova Scotia with a lack of independence in their energy supply and cost (OEERA 2008, 10). Generating local renewable energy keeps expenditures in our communities. Nova Scotia is looking for innovative ways to generate and store electricity. Integrating energy storage with tidal energy would allow this renewable resource to provide an independent and continuous supply of local renewable energy for Nova Scotia (Nova Scotia Power 2017).

Pumped Hydro Energy Storage [PHES]

Pumped hydro is the most widely used, and cost-effective form of energy storage, accounting for 99% of energy storage globally (Barbour). In PHES energy is stored as gravitational potential energy. PHES facilities are 25 times smaller than an equivalent coal power plant. Ideal sites for pumped



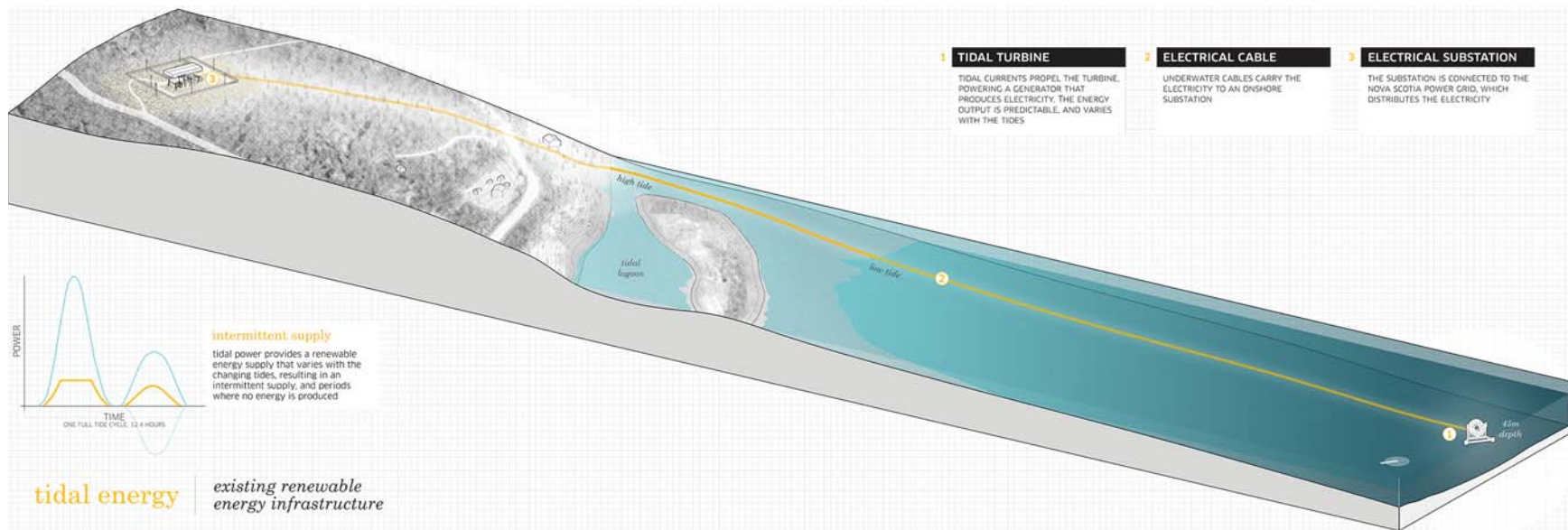
Pumped Hydro Energy Storage [PHES]: water is pumped from the lower reservoir to the upper reservoir using tidal ebb and flood, then released during slack tide or periods of high energy demand, when it passes through a turbine generating energy.

hydro have a significant grade change, access to water, and are located near a natural renewable resource and a high voltage transmission network. Ocean water can be used and recycled within this system. These conditions are well suited to FORCE's site along the Minas Passage.

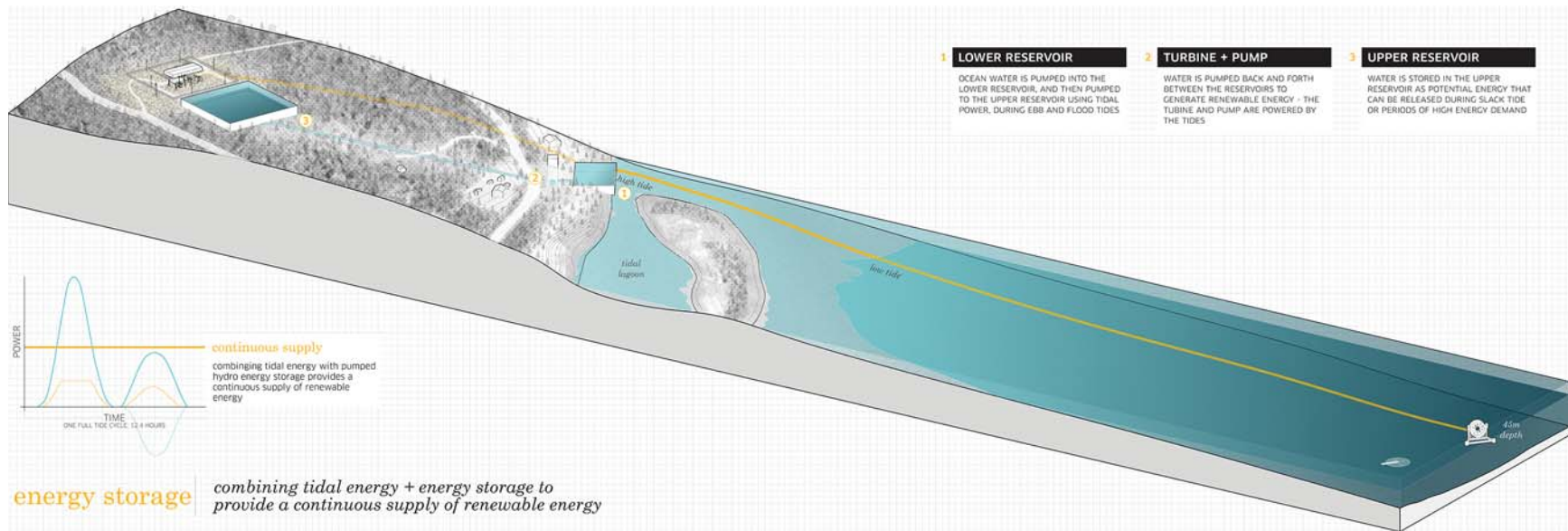
The components of this energy infrastructure are two reservoirs, a turbine and pump, and a pipe connecting these parts. Tidal ebb and flood pump water from the lower reservoir to the upper reservoir during periods of high energy supply. Water from the upper reservoir is released during periods of low power supply or high demand, passing through a turbine, generating energy.

Proposed and Existing: Renewable Energy Infrastructure

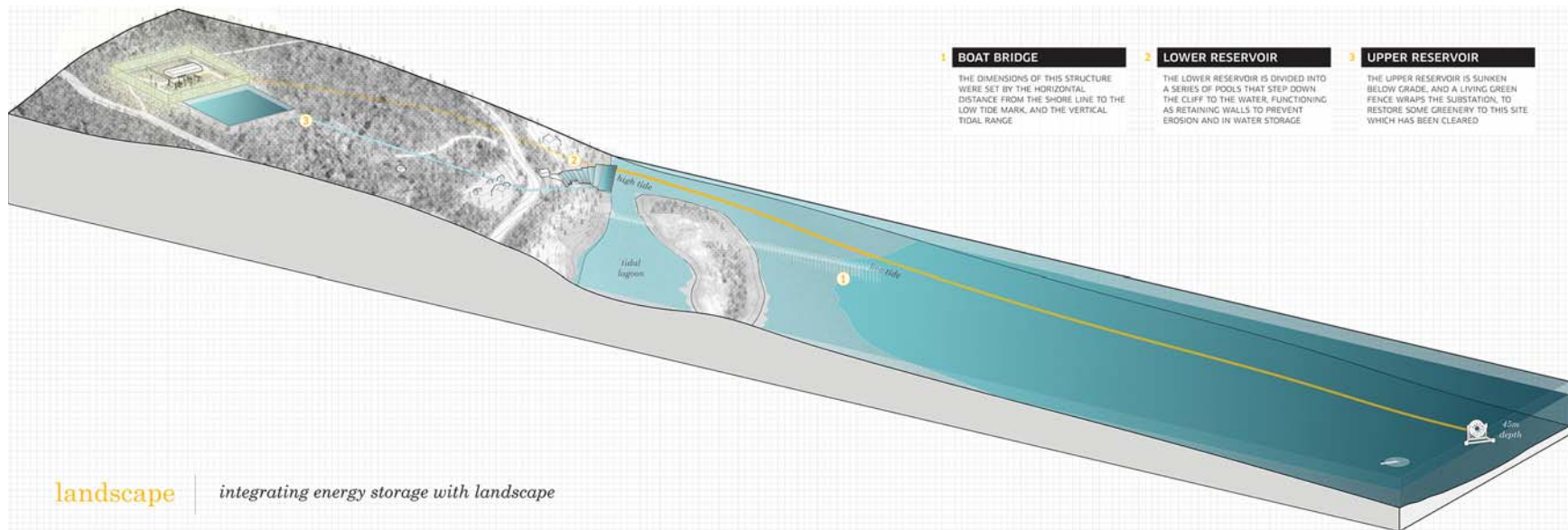
A series of axonometric drawings describe energy processes occurring on site. The first drawing shows the existing renewable energy infrastructure on site: the OpenHydro turbine, subsea cables, and the electrical substation. The second drawing shows the application of pumped hydro energy storage on site, with the upper reservoir at the highest point and the lower reservoir along the shoreline. The third drawing shows the proposed pumped hydro energy infrastructure integrated with the landscape.



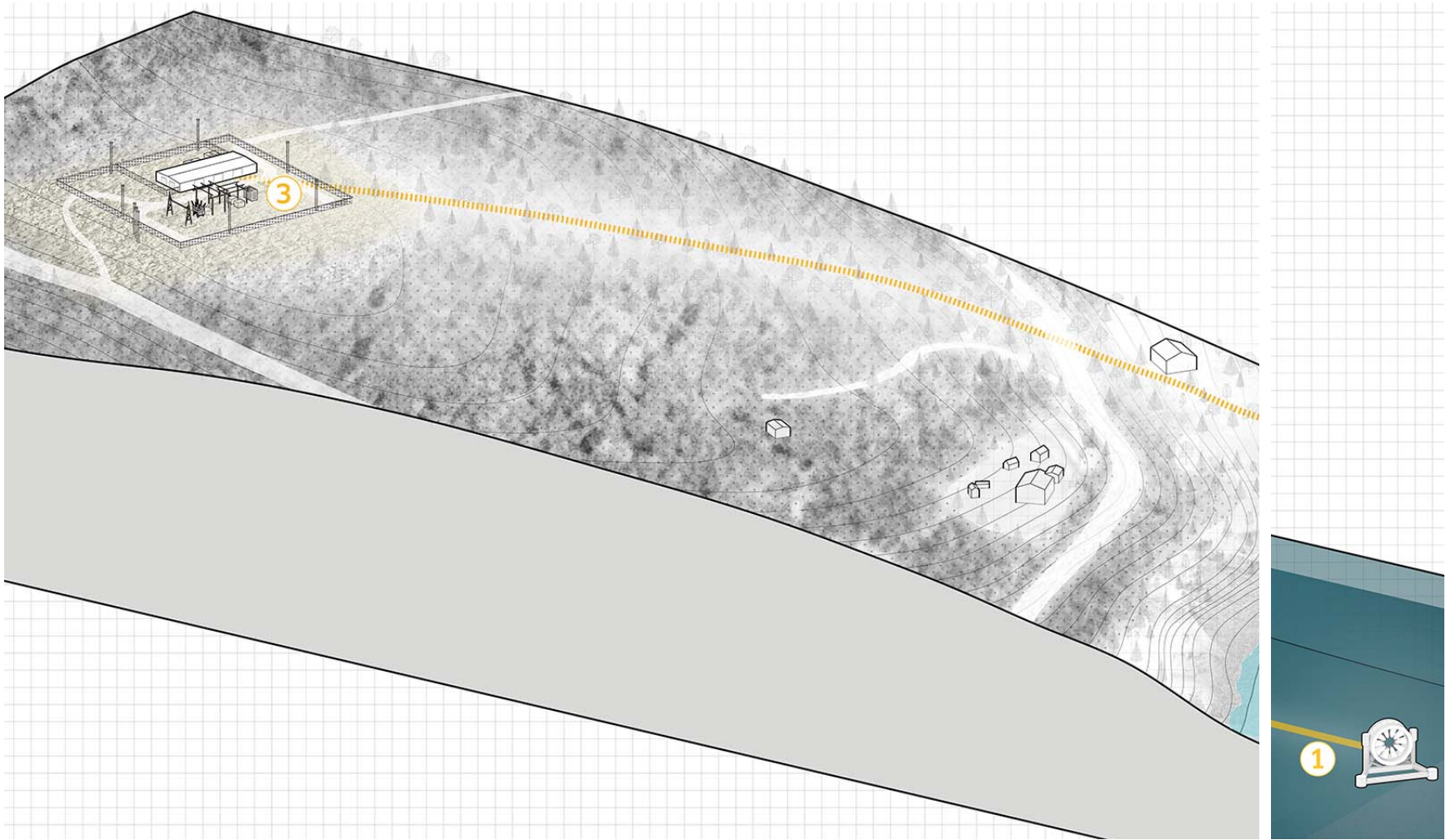
This drawing shows the existing renewable energy infrastructure on site: the tidal turbine, a subsea cable that travels along the ocean floor and underground, carrying tidal power to the electrical substation, which converts this energy to electricity for the Nova Scotia power grid.



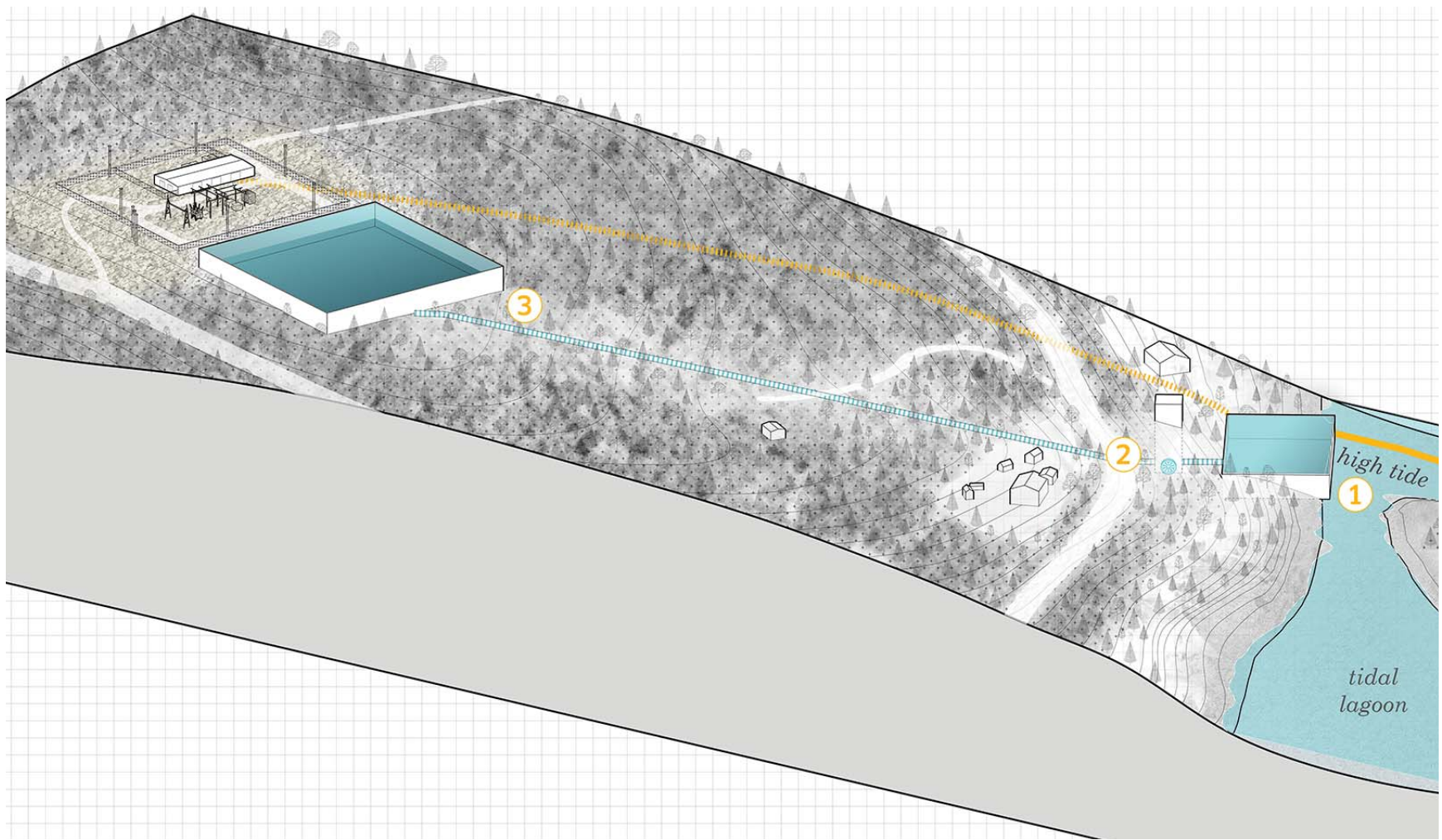
This drawing shows the application of pumped hydro energy storage on site. The upper reservoir is located at the highest point of the site, next to the existing sub-station. The lower reservoir is located along the shoreline, between two barrier beaches. A turbine and pump sit below grade, in line with the lower reservoir. This location maximizes the head between reservoirs, to provide greater storage potential.



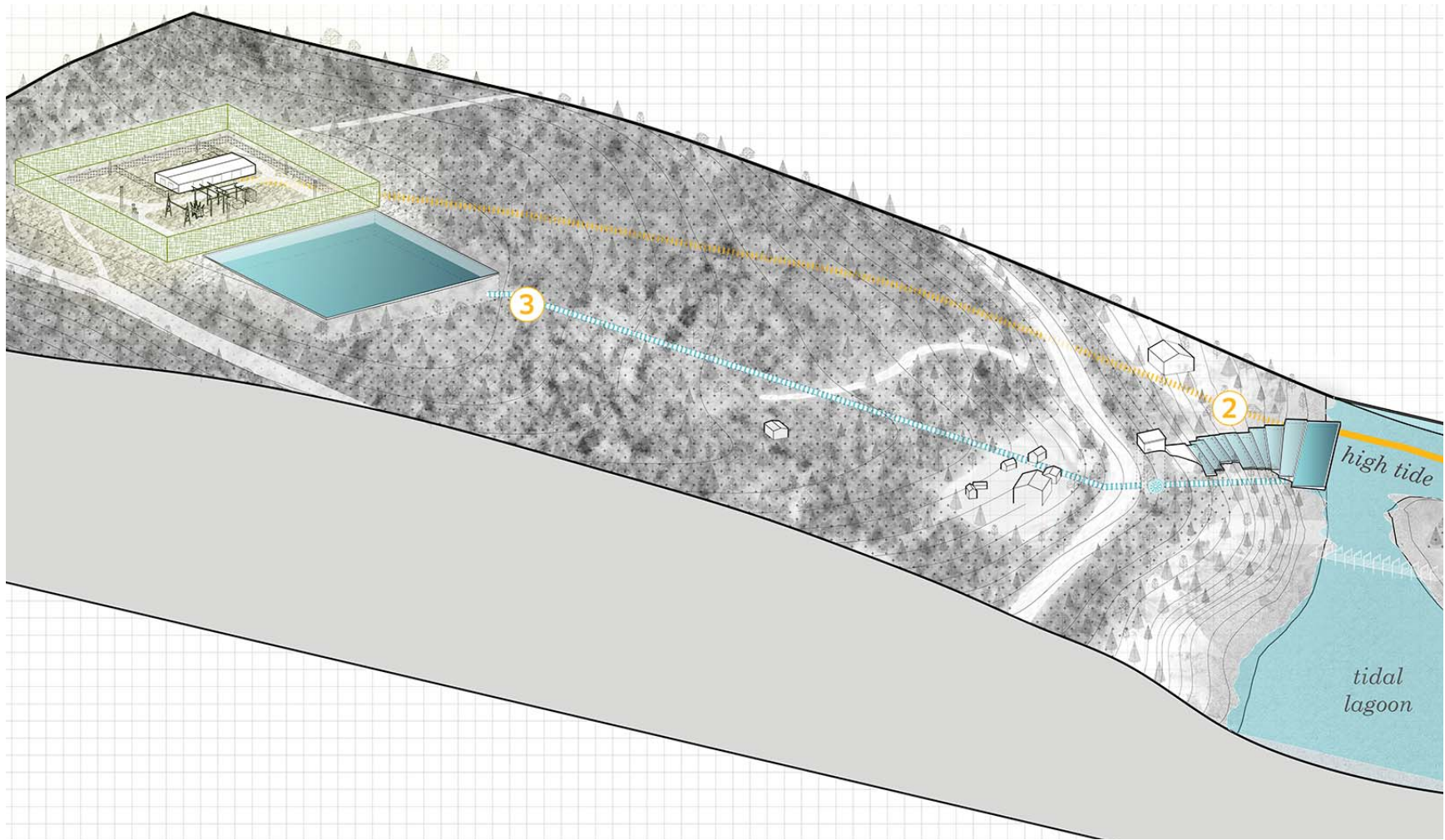
This drawing shows the pumped hydro energy infrastructure integrated with the landscape. The upper reservoir is sunken below grade. The lower reservoir is divided into a series of smaller pools that conform with the steep cliff.



Closer view of the site axo showing existing renewable energy infrastructure on site: the electrical substation, and the turbine.



Closer view of the site axo showing the introduction of pumped hydro energy storage on site.



Closer view of the site axo showing pumped hydro energy storage on site that is integrated with the landscape.

Integrating Renewable Energy Infrastructure with Community Program

Currently, indoor recreation in Parrsborro and surrounding communities takes place in a variety of public buildings, including the high school gym, the fire hall, and the town hall (Municipality of Cumberland 2018). Cumberland County has an initiative to increase opportunities for recreation, to improve health and quality of life for their residents. The county has emphasized a desire for water-based recreation and tourism in the region (Municipality of the County of Cumberland 2009).

Health statistics in Cumberland County are lower than provincial and national standards when looking at diabetes, respiratory disease, and high blood pressure. Residents also reported high limitations in accessing recreation activities. However, the region ranks higher than provincial and national statistics in life satisfaction, and sense of belonging, which speaks to the positive character of this community (Statistics Canada 2017).

Based on this application of renewable energy infrastructure, three sites have been identified for this thesis. The hilltop upper reservoir, the cliff lower reservoir, and the water. This proposal integrates renewable energy infrastructure with landscape while incorporating water-based community programs geared towards wellness.



Map showing the existing renewable energy infrastructure on site, and the location of the three sites developed in this thesis. Overlaid are solar and wind charts.



Site model showing the three sites in relation to FORCE and the turbine; as well as topography, bathymetry, tree cover, the wildlife preservation area, barrier beaches and the tidal lagoon.



Closer view of the site model showing FORCE, the substation, and the upper and lower reservoir.



- LANDSCAPE
 - 1 BARRIER BEACH
 - 2 TIDAL LAGOON
 - 3 WILDLIFE PRESERVATION
- EXISTING
 - 4 FORCE
 - 5 SEASONAL COTTAGES
 - 6 ELECTRICAL SUBSTATION
 - 7 TURBINE
- PROPOSED
 - 8 UPPER RESERVOIR
 - 9 LOWER RESERVOIR
 - 10 BOAT BRIDGE

Closer view of the site model showing the lower reservoir, the boat bridge, and the turbines.



- LANDSCAPE
 - 1 BARRIER BEACH
 - 2 TIDAL LAGOON
 - 3 WILDLIFE PRESERVATION
- EXISTING
 - 4 FORCE
 - 5 SEASONAL COTTAGES
 - 6 ELECTRICAL SUBSTATION
 - 7 TURBINE
- PROPOSED
 - 8 UPPER RESERVOIR
 - 9 LOWER RESERVOIR
 - 10 BOAT BRIDGE

Closer view of the site model showing the three sites in relation to one another and the shoreline.

CHAPTER 4: DESIGN FRAMEWORK

Guiding Principles

The interventions in this proposal integrate renewable energy infrastructure with landscape and community. Built form is informed by the natural and energy processes that sustain it. The following design principles guide program and formal development across three sites:



Icons representing guiding principles for developing program and design.

Integrate Energy and Community Program

The tidal industry in Nova Scotia is developing in isolation from its surrounding community. The primary goal for this thesis is to integrate renewable energy infrastructure and community program, to establish a mutually beneficial relationship between community and industry that is environmentally and socially sustainable. Each of the three proposed sites incorporates energy program and community program, with a strong connection between the two.

Incorporate Water

Water is a defining quality of this region, as the tides are what distinguish this landscape. Cumberland County has a mandate to increase water-based tourism and recreation, to foster a local sense of identity and pride that is rooted in the defining characteristic of this landscape. Each site incorporates water as a source of energy, recreation, or sustenance.

Make Natural Processes Evident

The natural process of the tides defines the dynamic landscape surrounding the Bay of Fundy while providing immense potential for renewable energy. This natural phenomenon is what makes this landscape so unique, and so should be celebrated. The architecture of this work aims to respond to the natural process of the tides, giving the community a new way to experience the dramatic tidal range unique to this landscape.

Make Energy Processes Evident

Making energy processes evident provides an opportunity for educating the public, in a way that is much more engaging than a typical visitor's centre. This work aims to develop architecture that provides the community with an opportunity to understand and engage with the processes that generate renewable energy on site.

Integrate Built Form with Landscape

Built form in this thesis is integrated with landscape and informed by natural processes, using locally sourced building materials and methods. Buildings accommodate existing landscape conditions, such as topography, tree cover, and waterways.

Architectural Strategies

Local Building Materials and Methods

A consistent material palette is used to unify the three sites, with contrasting stereotomic and tectonic structures. Stereotomic concrete structures hold water and retain earth. The concrete uses a large aggregate from Debert, Nova Scotia, along the northern Bay of Fundy. The aggregate displays the natural colours found along this shoreline. Wood elements provide a tectonic structure which perches atop concrete or water, taking precedent from fishing weirs used in the area. These fishing structures were developed to take advantage of the dramatic tidal range (Bleakney 2004, 7).

Buildings are clad in cedar wood slats, as is common in vernacular architecture in this region. Exterior cedar weathers and becomes silver, while interior cedar provides a warm tone and tactile experience. Wood slat screens filter natural light to interior spaces. Copper is used as a grounding element in the existing substation as it is highly conductive of electricity and heat. The proposed sites incorporate copper hardware, which patinas over time.



Material Palette: large aggregate concrete, cedar, copper, and water. Concrete image from Strescon Corp Brochure, subsequent images from Textures.

Integrate Built Form with Landscape

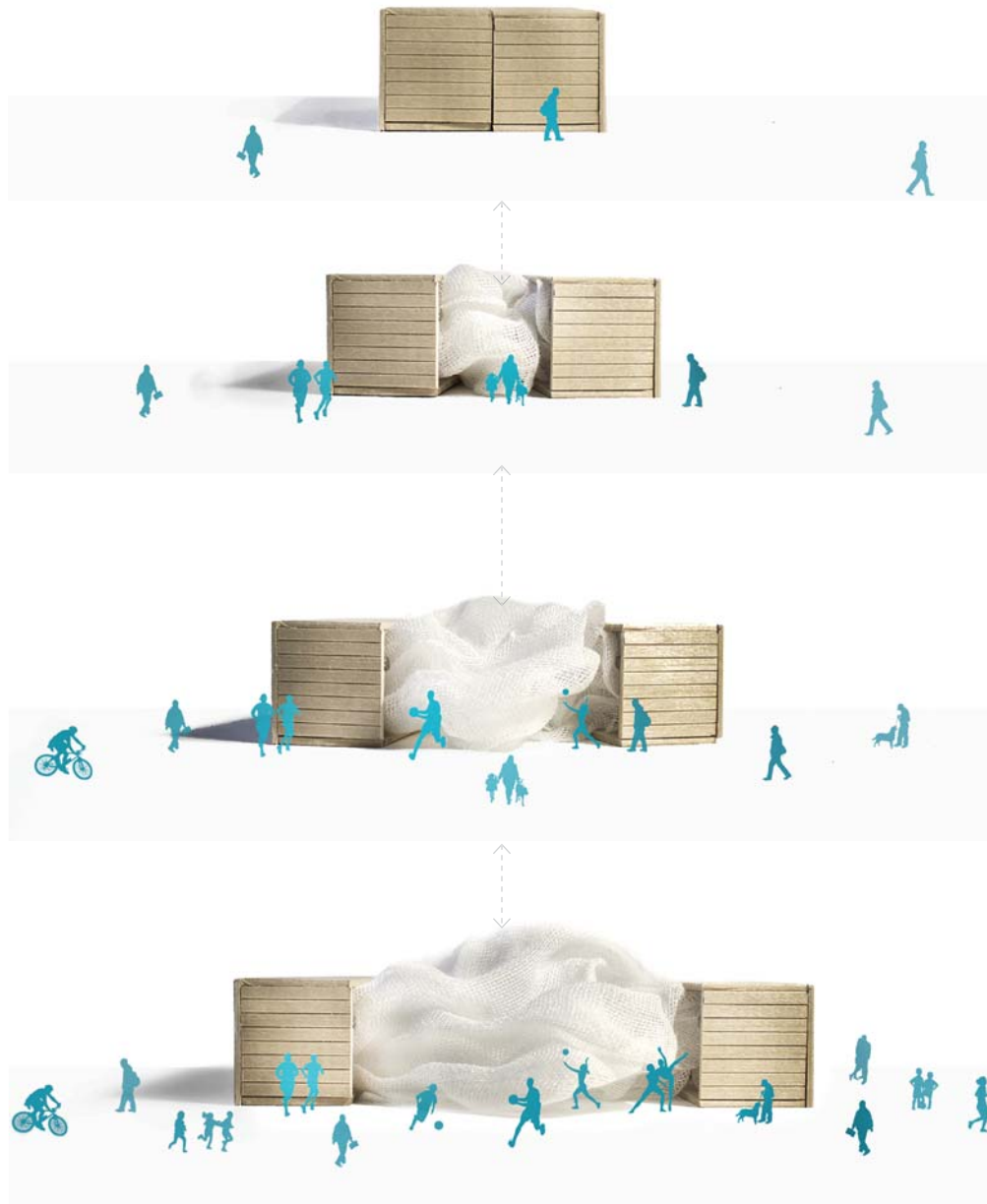
This common material palette links the three sites, while the structural composition at each site adapts to building program and landscape conditions. The way buildings meet the ground varies with the topography and geology of a given site, as explored in these early sketch models.



Early sketch models demonstrating ways structure may adapt to various landscape conditions.

Integrate Dynamic Processes

This thesis proposes an architecture that adapts to the rhythmic natural and energy processes of the landscape. This early concept model depicts a form of flexible architecture, one that could adapt to a dynamic environment, such as the Fundy landscape. This adaptable architecture aims to make evident the natural rhythms and energy processes that characterize this region.



Early concept model depicting a form of flexible architecture, one that could adapt to a dynamic environment, such as the Fundy landscape.

Precedents

Länsisalmi Power Station, Parviainen Architects

This power station is located in a highly visible area in the city of Vanda, Finland. A main goal for the architects was expressing the visual manifestation of electricity, which is light. The façade becomes a lantern at night, as an interstitial glass space is illuminated. The building acts as a beacon which symbolizes the energy being processed on site. The glass also provides a material connection to the glass used in glazed insulators in the electrical distribution industry. This served as inspiration for architecture as a vehicle for making energy processes evident.



This power station displays the visual manifestation of electricity: light. Above: The entirety of the substation showing the buildings as lanterns. Below: A closer view of the illuminated façade with the electrical infrastructure behind. Original image from: ArchDaily.

Leça Swimming Pools, Álvaro Siza Vieira

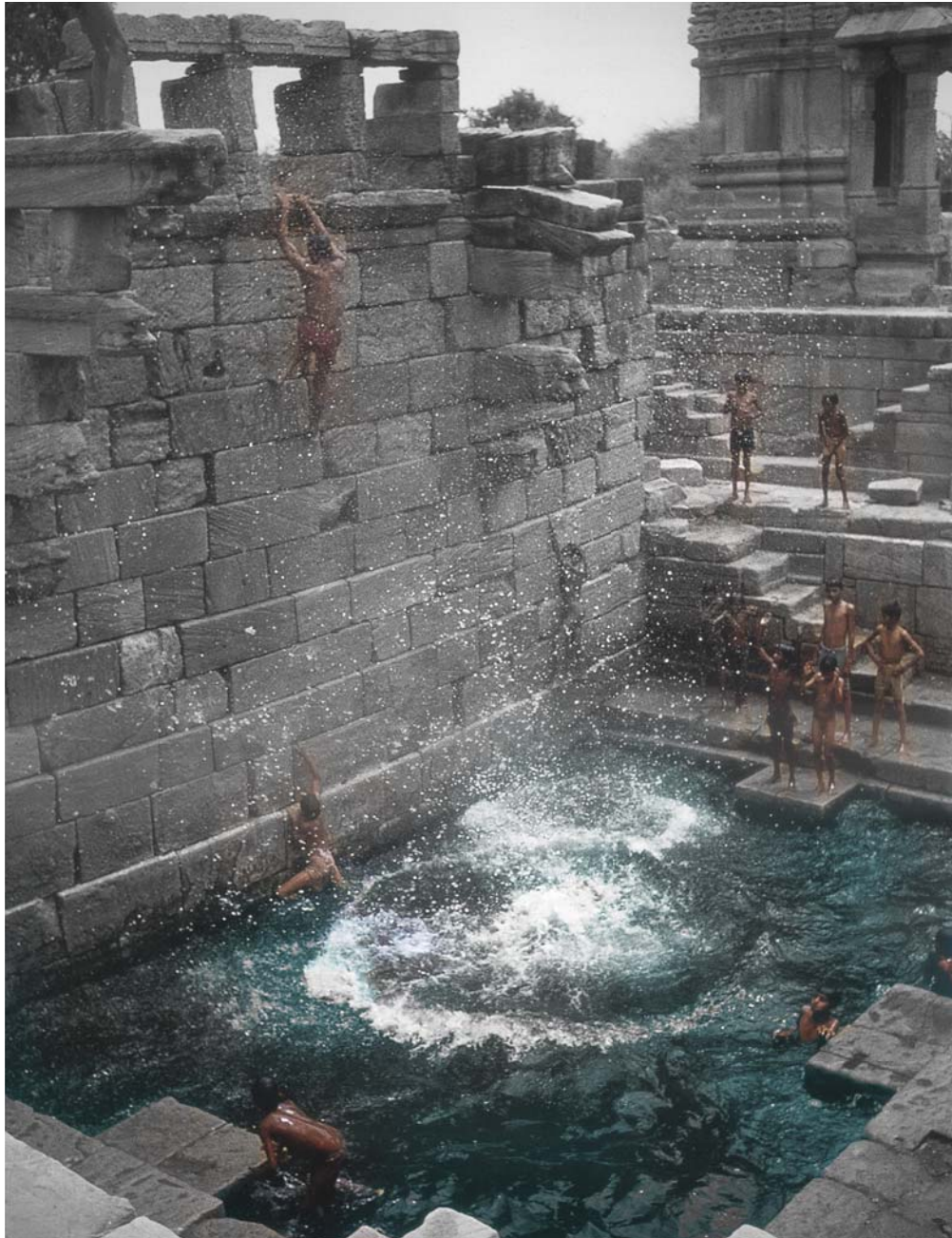
Álvaro Siza's swimming pools in Leça, Portugal are a useful precedent for integrating built form with landscape. This project shows a 'careful reconciliation between nature and...design' (Balters 2011). A quiet building is sunken below the road, to create a disconnect from the infrastructure of the city, while preserving ocean views from the road. The building contains a café, change rooms, and two pools. The pools are a careful intervention in the landscape, sited in a way that preserves existing rock formations. Pools reach out to the ocean, visually blurring the edge between built form and nature.



Álvaro Siza blurs the edge between built form and nature. Above: Stairs fit within natural rock formations. Below: Pools extend from the land to the sea. Original image from: Balters 2011.

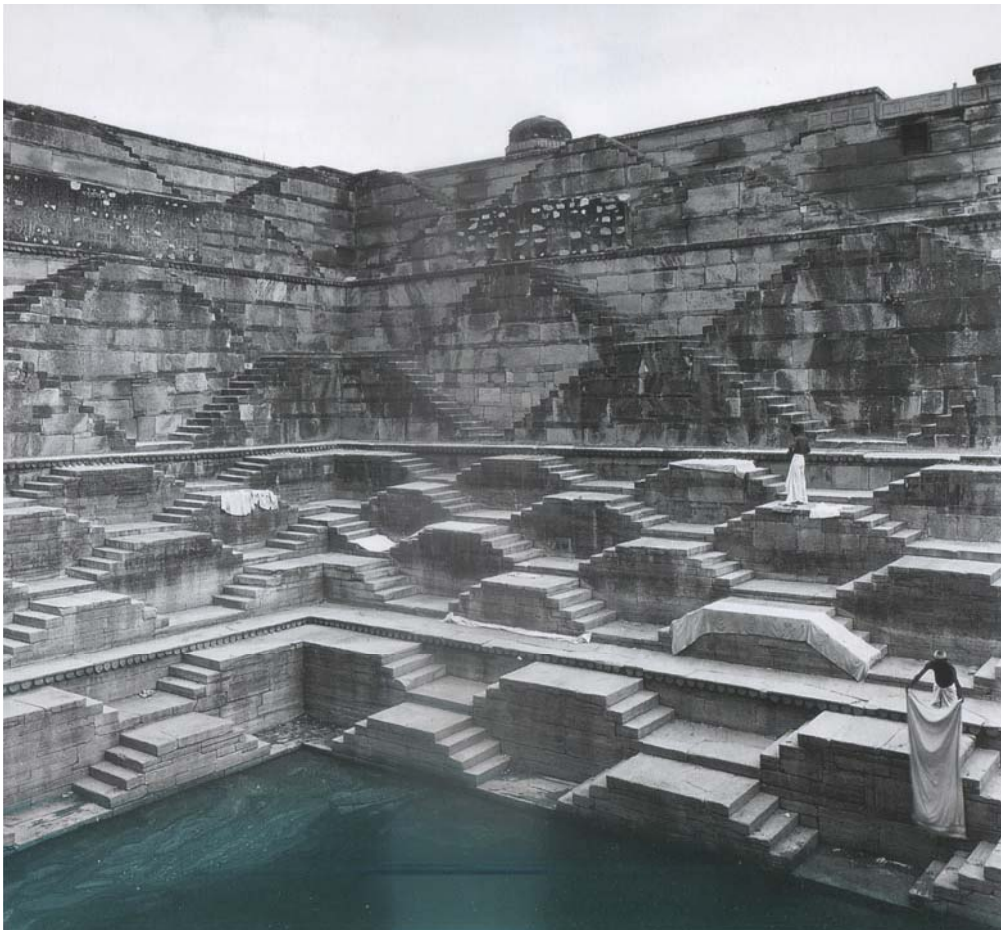
Ancient Stepwells of India

The stepping wells of ancient India inspire the pools of the lower reservoir swimming facility. These structures serve as a useful precedent as they provide the practical function of accessing water at variable depths, which is appropriate on this site as water levels change with the tides and energy demand. The step wells also act as an important social gathering place.



The step wells of Ancient India incorporates necessary infrastructure with a community meeting place. Original image from: Livingston 2002, 16.

The stepwells and stepping ponds of ancient India display bold patterns as the sun passes over them illuminating their stepped form (Livingston, 11).



The stepwells of Ancient India incorporate necessary infrastructure with a community meeting place. Above: Step well in Rajasthan. Below: Cistern in Jaipur. Original image from: Livingston 2002, 11-127.

Monumento alla Partigiana, Carlo Scarpa

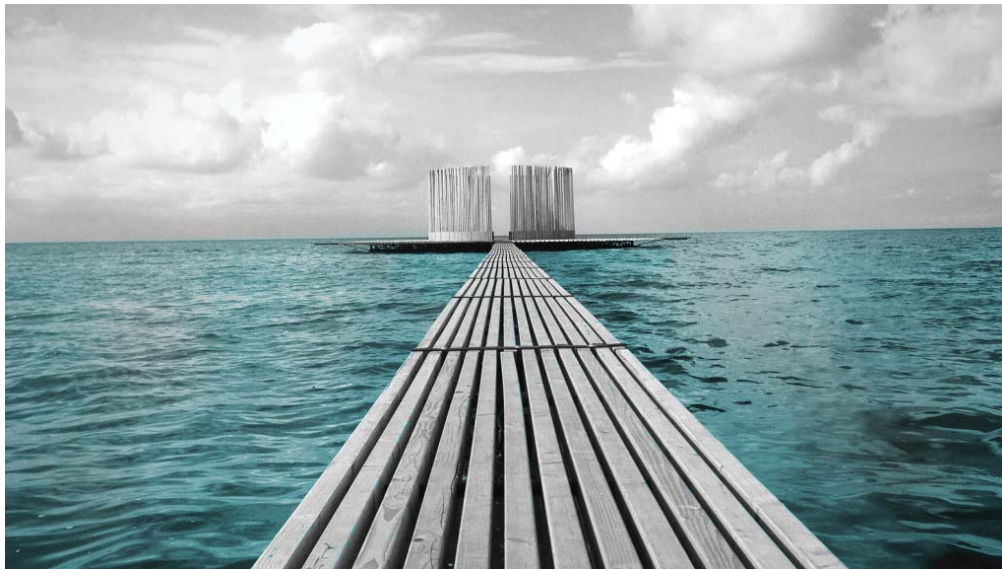
Carlos Scarpa blurs the edge between built form and the sea beyond, in a sensitive way. This pixelated structure becomes hidden and then revealed as the water level in the river changes, providing a gradual transition between the public path and the waterway. Water is a primary element in the composition of this structure. Changing water levels impact the way we experience and engage with the built form. These ideas are carried through in the design of the reservoirs in this proposal.



Carlos Scarpa blurs the edge between built form and the river in a pixelated way. Above: View from the waters edge. Below: View from the path. Original image from: De Cal 2016.

Floating Observatory, Marc Van Vliet

This floating observatory by Marc Van Vliet on the Dutch flat sands serves as a useful precedent for architecture that is activated by the shifting tides. The experience of the observatory varies with the tides, as water floods in and out of the flatlands. The form of the observatory shifts with the tides, as the wooden slats of the enclosure open and close with tidal ebb and flood (Neira 2016).



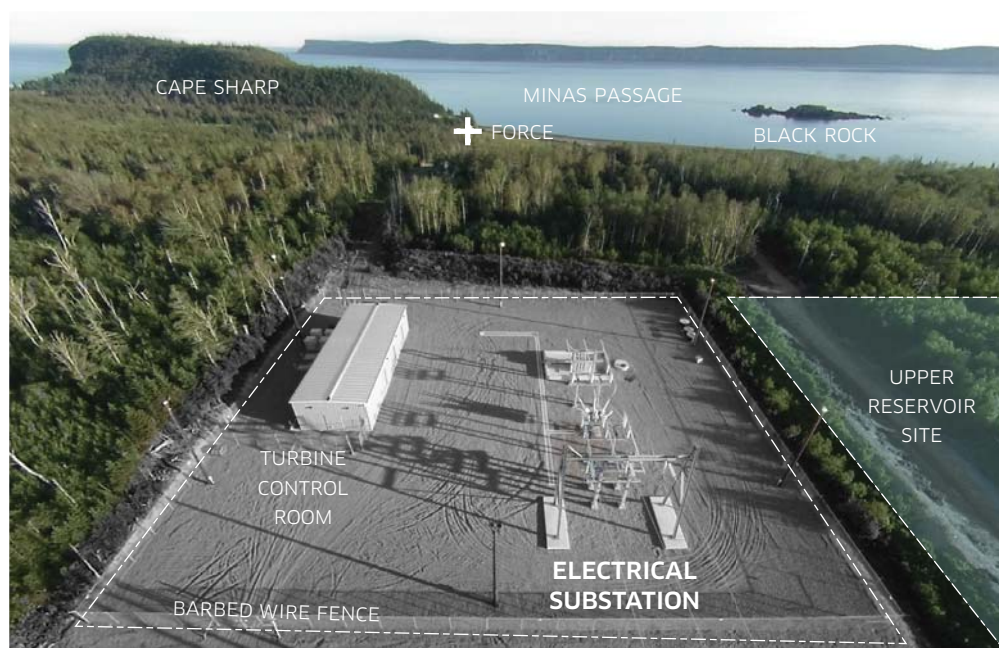
This floating pavilion moves with the shifting tides. Above: View from the path at high tide with the platform fins are pushed open by the tide. Below: Aerial view during low tide when the platform remains closed. Original image from: Neira 2016.

CHAPTER 5: DESIGN

Site 1: The Hilltop

Upper Reservoir Community Aquaculture

The upper reservoir is located at the highest point of the site, adjacent to the existing substation. It sits 64 metres above the lower reservoir, providing enough vertical height to make pumped hydro a viable option for energy storage (Rogean, Girard, Kariniotakis 2017, 241-53). The substation is surrounded by a barbed wire fence to ensure user and wildlife safety, which is common in substation design. All vegetation is cleared from the site, to prevent attracting wildlife inside the substation fence, as they could be harmed if an electrical shock were to occur. Gravel covers the ground to prevent any regrowth and to provide even footing. A grid of copper rods sits half a metre below ground, with vertical copper rods at the corners of the substation, and beneath major equipment. As copper is highly conductive, it easily distributes electrical currents, providing grounding for the substation (United States Department of Agriculture 2001, 42-52).



Existing condition at FORCE's substation, showing the lifeless fenced area and the surrounding lush landscape, with views across the Minas Passage beyond. Image: FORCE Annual Report.

Restoring vegetation to the site is a primary goal with this intervention. A 'living willow fence' wraps around the substation's barbed wire fence to return greenery to the site. This provides an approachable backdrop for the adjacent public spaces while maintaining user and wildlife safety. The green fence acts as a new threshold between the lifeless substation and the surrounding landscape and public space.

As a further attempt to bring life back to this scar in the landscape, the upper reservoir incorporates a community greenhouse and garden centre. Greenhouses shift across the reservoir and contain sites of aquaculture, and a meeting space shared by the garden centre and substation, which protrudes through the green fence.

Water levels are continuously changing within the reservoir, shifting with the tides and energy demand. Fifty percent of the volume of water travels between this reservoir and the one below to generate energy. The reservoir is comprised of a concrete structure that is sunken into the earth, to sit quietly within the hilltop. Concrete fins support a lighter wood structure that is wrapped in polycarbonate, to create diffuse lighting conditions for growing. Grow beds sit within the wood structure, and fish beds dip into the reservoir.



Isometric view of the upper reservoir and community greenhouse at the low water level, in relation to the existing substation.

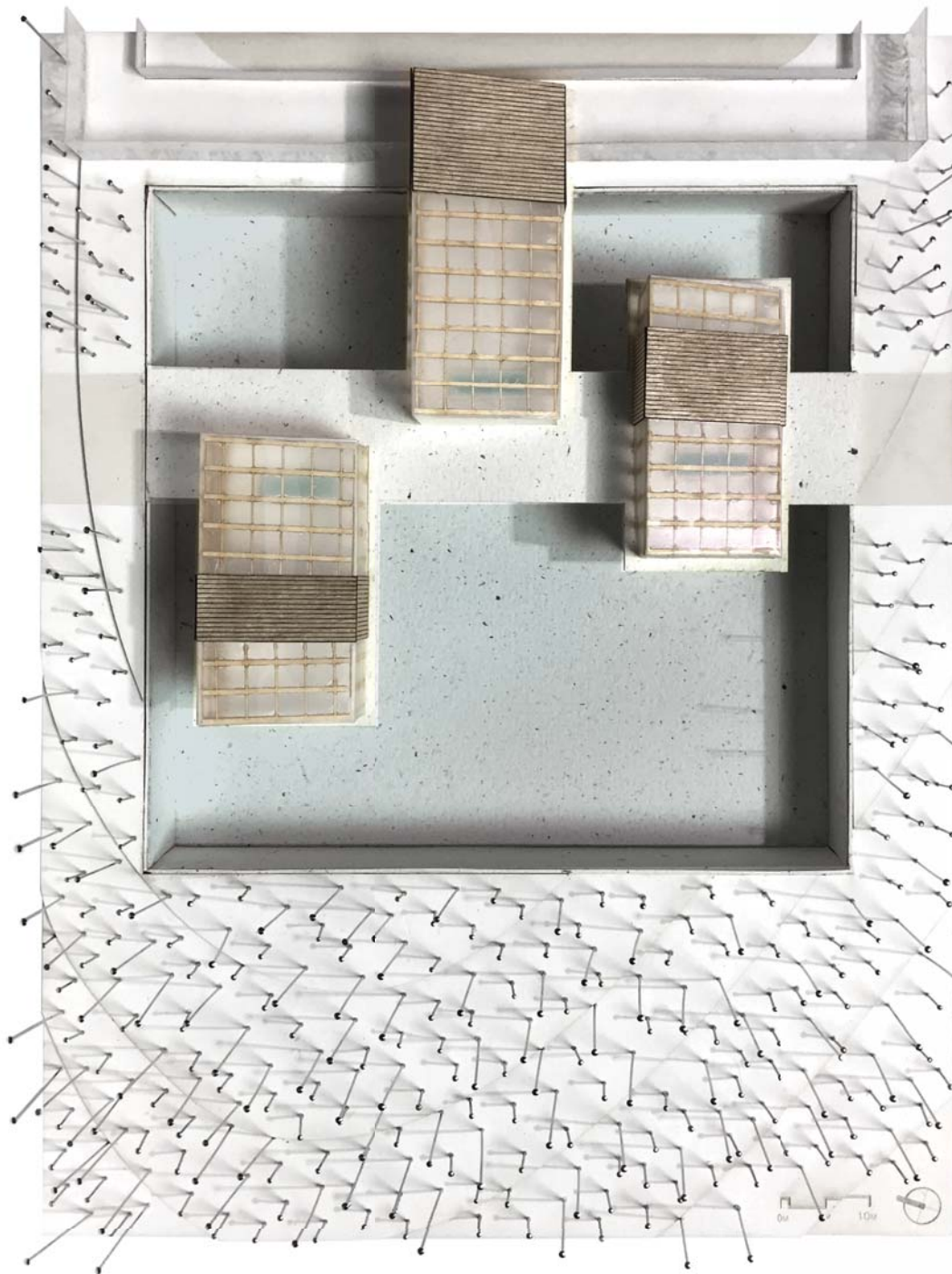
Greenhouse roofs face South and collect rainwater which is used to water the plants. Fish waste provides nutrient-rich fertilizer for plant grow beds. Fish beds dip down into the salt water of the reservoir, growing bivalves such as mussels and oysters, in the ocean water that pumps through the reservoir as a source of energy (EFFEKT 2017).

This type of agriculture is well suited to this landscape, as the soil is nutrient deficient and not suitable for typical methods of agriculture. Aquaculture is ideal for growing leafy greens, and herbs, but can also produce root vegetables and decorative plants. In terms of fish, invertebrates such as mussels and oysters are preferable over vertebrates such as salmon, as they do not require fish feed. Supplying farmed fish with feed from the ocean disrupts the natural balance of the ecosystem (Goddek, Delaide, Mankasing, Ragnarsdottir, Jijakli, Thorarinsdottir 2015, 4208).

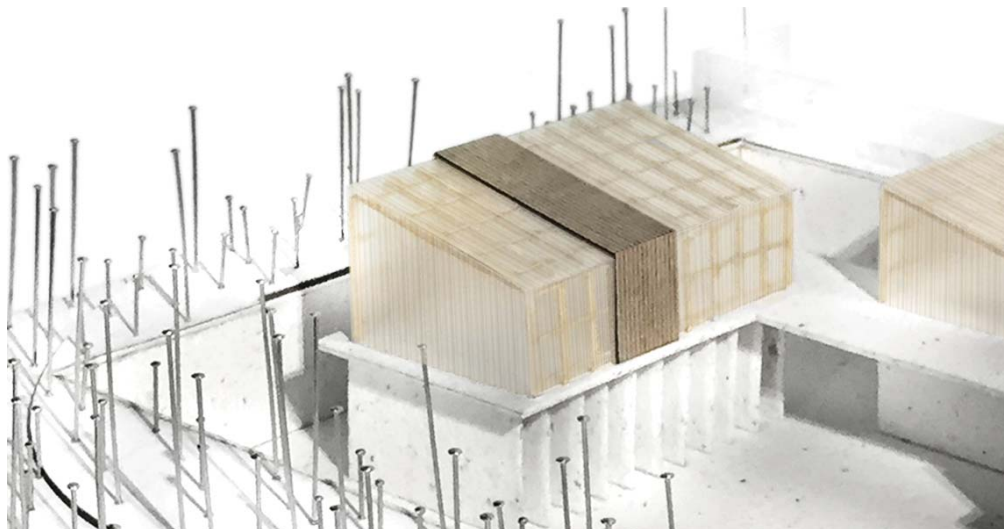
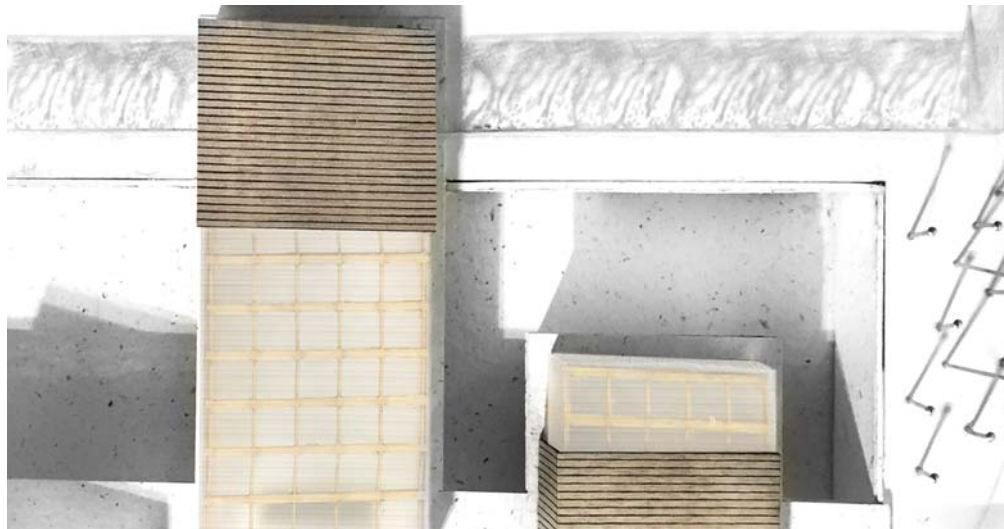
Together, this site provides a modest supply of local produce, seafood and renewable energy. While working in the greenhouse or purchasing produce in the garden centre, water levels change drastically throughout the day based on energy supply and demand, bringing the dynamic tidal processes to the peak of the hill.



Isometric view of the upper reservoir and community greenhouse at the high water level, in relation to the existing substation.



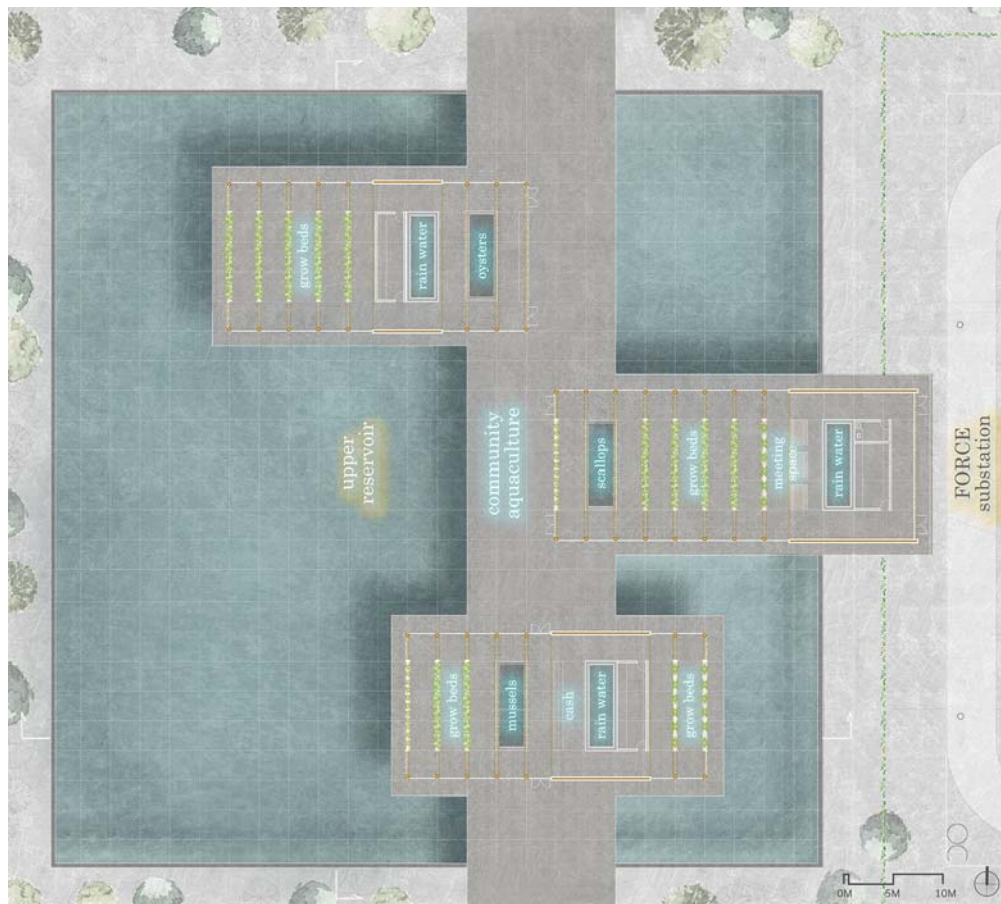
Physical model of the upper reservoir and community aquaculture, showing stereotomic and tectonic elements, and how they adapt to the hilltop site.



Above: Alignment of concrete fins and wood frame structure above, and the meeting space that protrudes through the green fence. Middle: Polycarbonate wraps wood structure in the growing areas to allow diffuse daylighting, cedar wood slats wrap the solid portions of the building. Below: The greenhouse as it sits atop concrete fins in the reservoir.



Roof plan of greenhouse and upper reservoir in relation to the adjacent existing substation and the living willow fence.



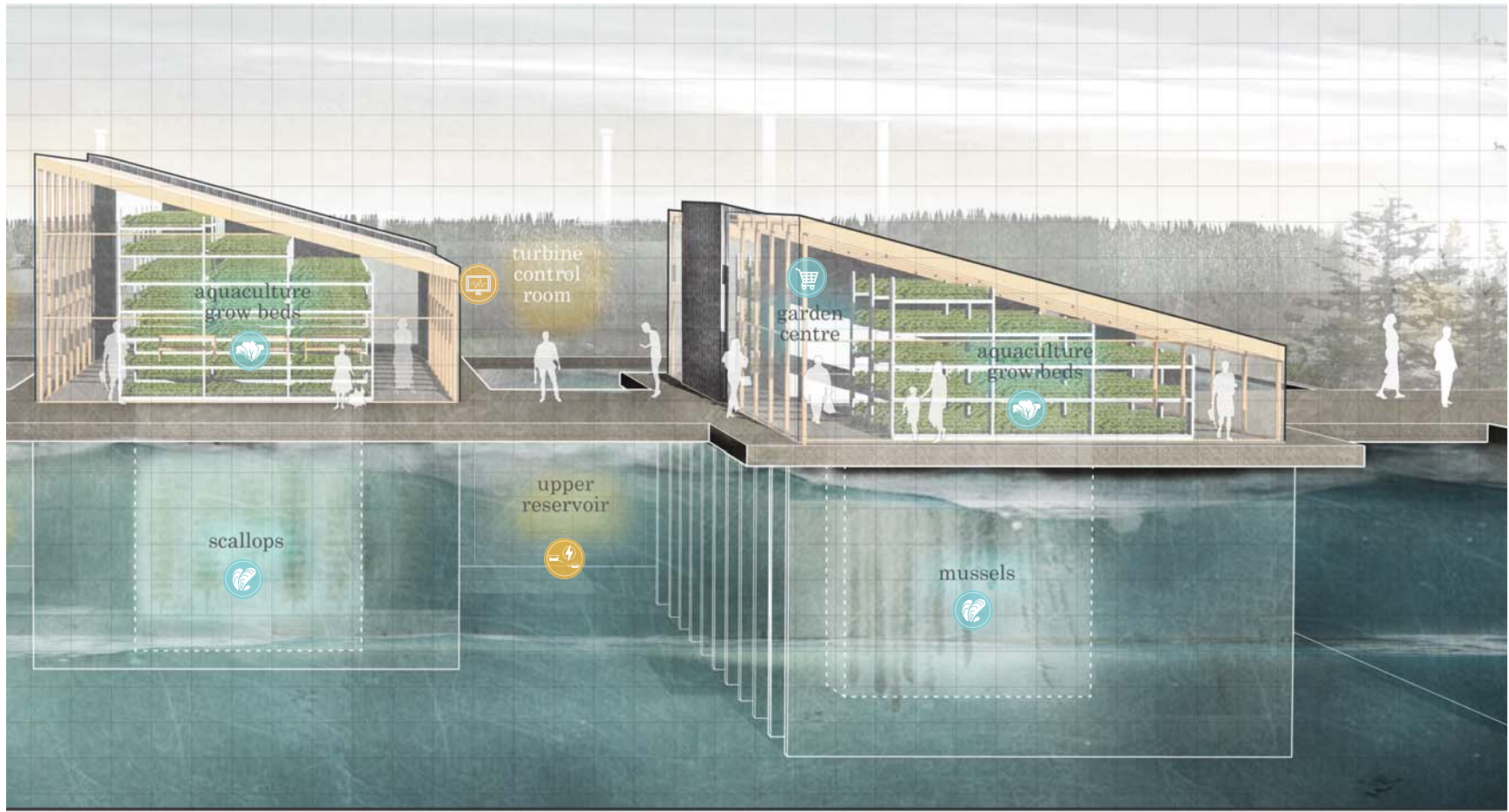
Plan of the upper reservoir and community greenhouses. The 3 metre spacing of the copper grounding rods of the substation inform the structural grid of the greenhouses.



Short section through the upper reservoir and community greenhouse, showing the green fence and substation behind.



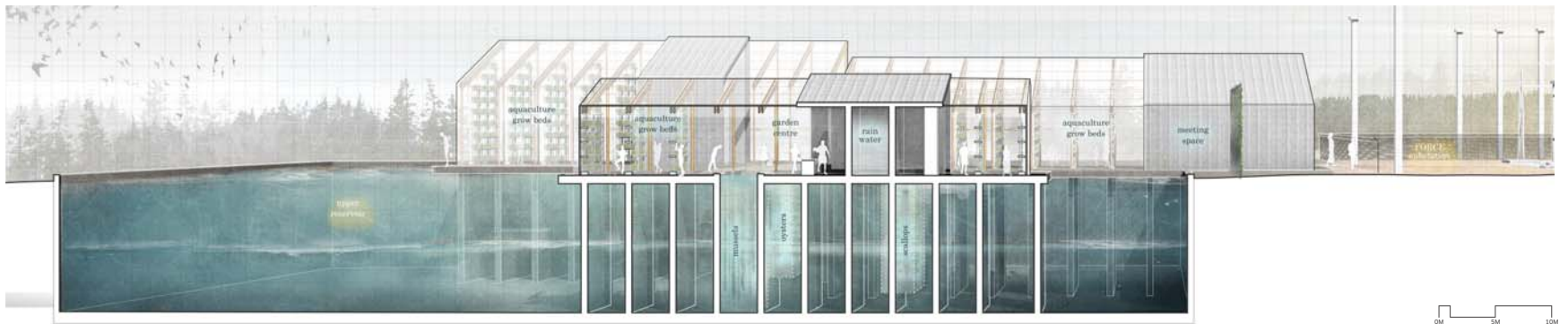
Closer view of the upper reservoir short section, showing inhabitation of the greenhouse, with the fish beds ghosted in the reservoir. Polycarbonate roofs face South to maximize natural light penetration



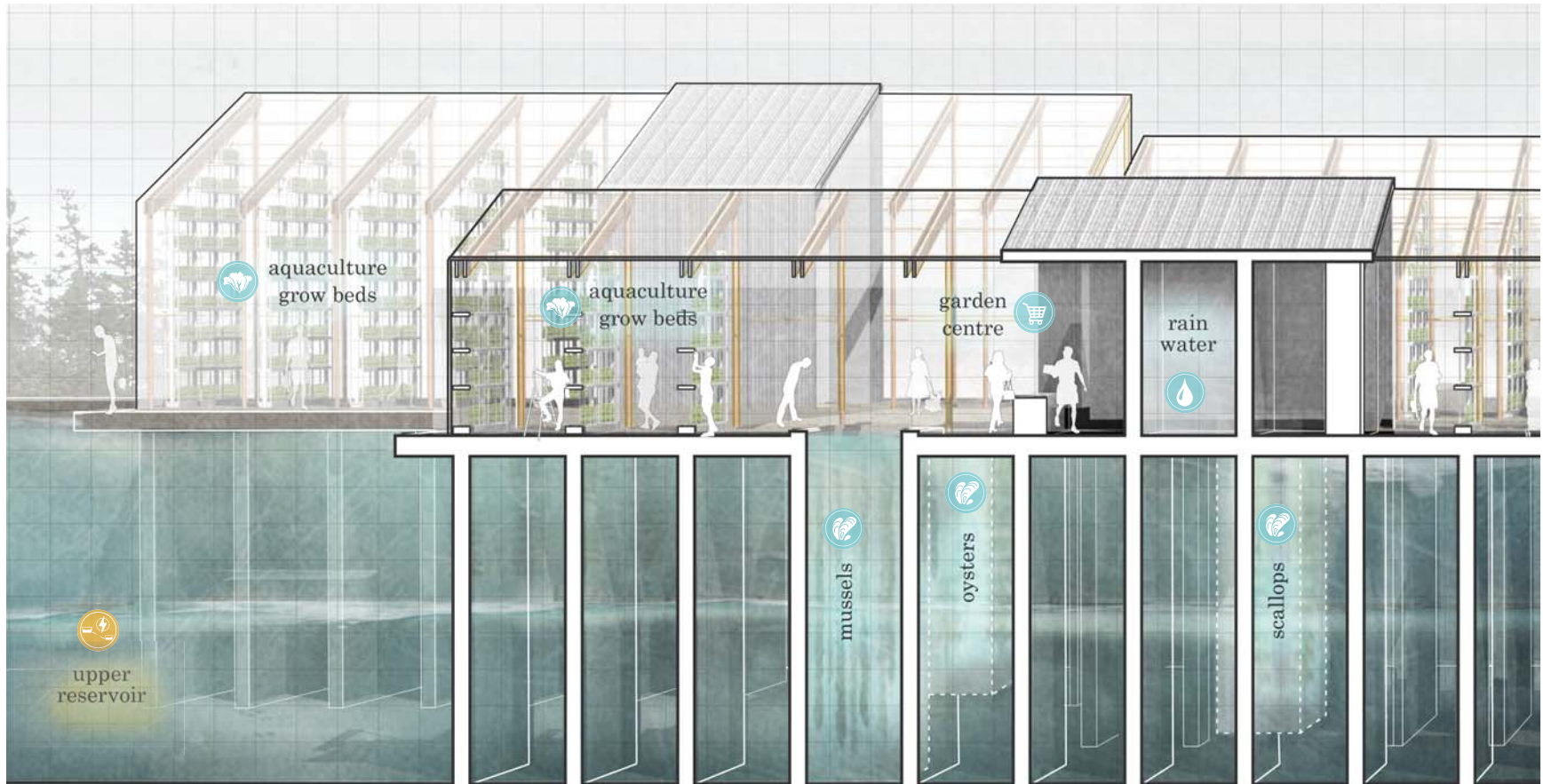
Closer view of the upper reservoir short section, showing inhabitation of the greenhouse, and the concrete path that leads you across the reservoir and through the three buildings.



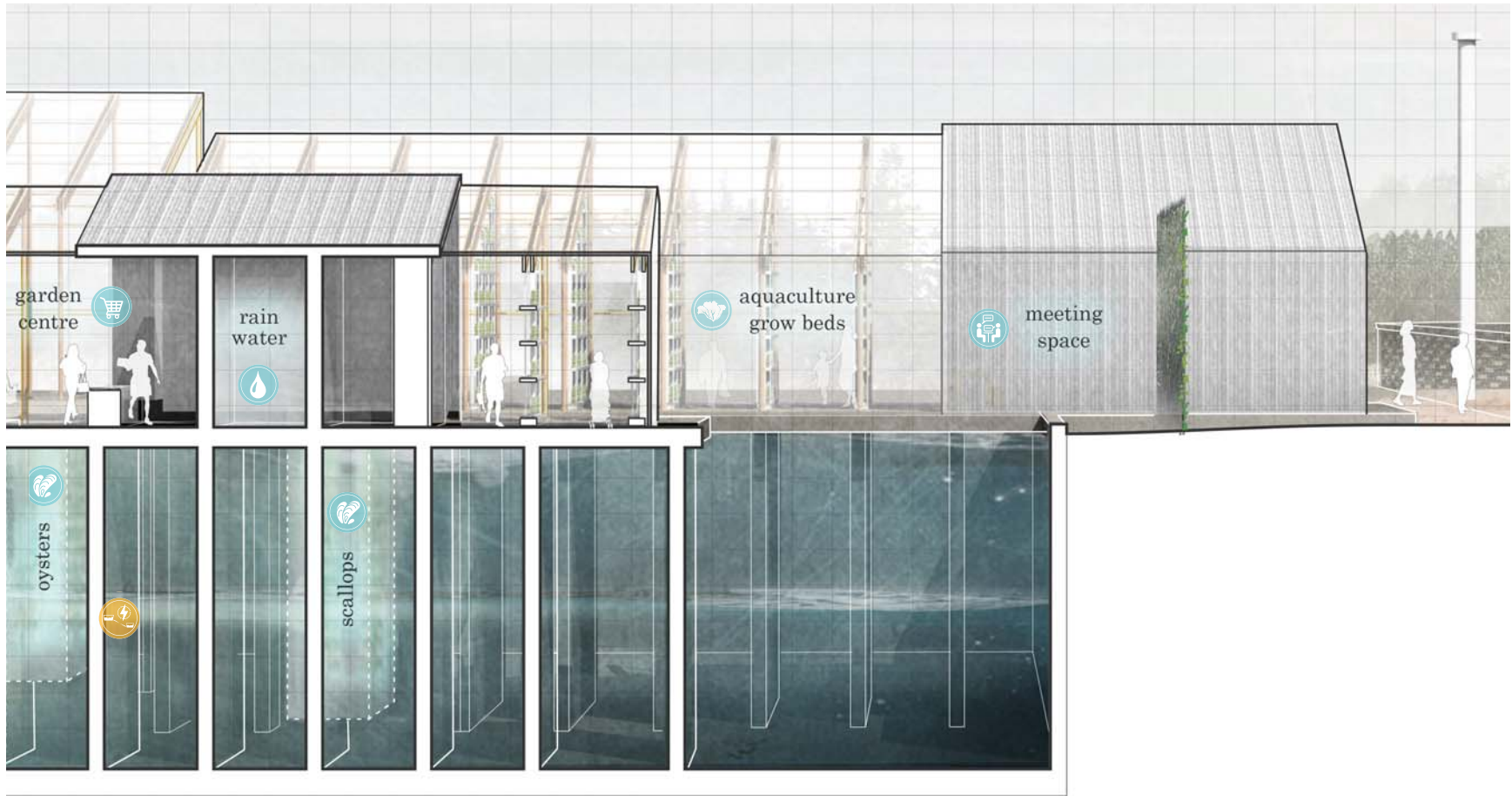
Long section through the upper reservoir, community greenhouses, and the adjacent electrical substation. This drawing shows the contrast between the dry lifeless substation and the wet and dry columns of growth in the site of community aquaculture.



Closer view of the long section through the upper reservoir and community greenhouses, showing the meeting space which protrudes through the green fence on the right. Fish beds are ghosted in the reservoir, as is the low water level, and the rain water collection drum in the nearest greenhouse.



Closer view of the long section through the upper reservoir and greenhouse. Concrete fins support wooden frames. Plant grow beds sit within the wooden frames, and fish beds fit between concrete fins in the reservoir. Rain water is collected and stored in the solid portions of the buildings.



Closer view of the long section through the upper reservoir and greenhouse, showing the meeting space beyond protruding through the green fence to the substation.



Closer view of the long section, showing the dry gravel ground cover in the substation, the transformers, the barbed wire fence and the green fence that surrounds it.



View showing inhabitation of the upper reservoir at the low water level, with the fish beds raised in the greenhouse.



View showing inhabitation of the upper reservoir at the high water level, with the fish beds submerged in the greenhouse.

Site 2: The Cliff

Lower Reservoir Swimming Facility

The volume of the lower reservoir is divided into a series of smaller pools that conform with the slope of the land. The pools cascade down the cliff towards the ocean, blurring the boundary between built form and landscape, with the lowest pool fully submerged at high tide. Pools shift along the slope to fit within an existing tree clearing where the cliff is eroding. A series of concrete retaining walls align with the contours of the land to act as retaining walls that prevent erosion and form the pools that hold water as potential energy for the lower reservoir. Like the upper reservoir, water levels change with the shifting tides and energy demand. The dramatic change in water levels provides a distinct experience each time you visit the pools, as well as a changing experience throughout each visit.

To integrate community program, the pools incorporate a public swimming facility. Ocean water pumps through the pools, for both energy storage and recreation. Pools are heated to varying temperatures using the energy generated on site, to heighten the bathing experience and be enjoyed year-round. This heightens the restorative health benefits of hydrotherapy, helping the body to energize and relax, through a series of hot, cold and rest cycles.



The lower reservoir swimming facility at low tide with the pools at low water. Unlike typical low reservoirs, this one never completely empties, to allow continual access to the full bathing cycle.

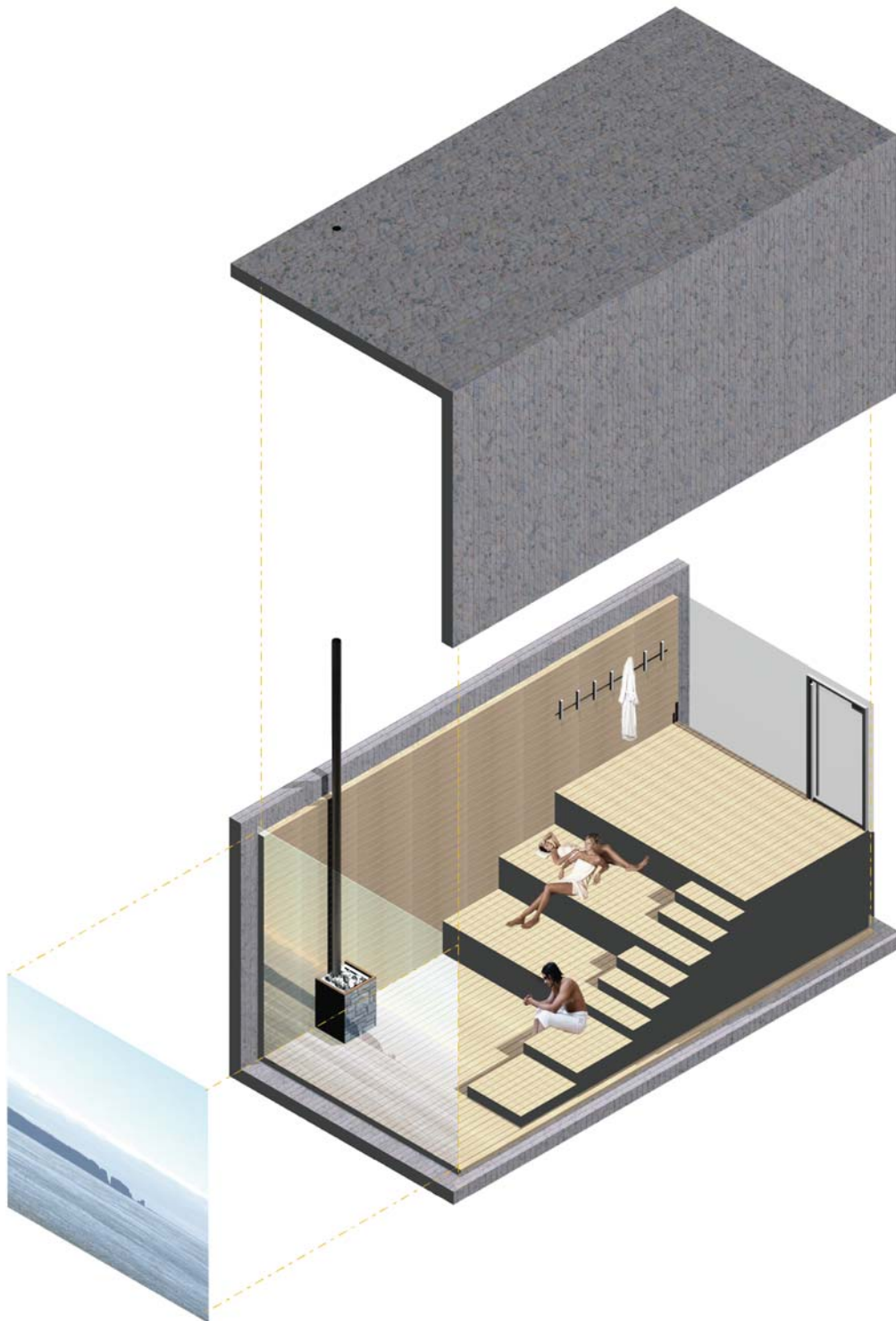
The ideal hydrotherapy cycle involves 10-15 minutes of heat, followed by seconds of cold, then 10-15 minutes of rest, and repeat. Heating the body dilates blood vessels on the surface of the skin, reduces blood pressure, and increases blood flow, inducing a feeling of calmness. Hot pools are followed by cold plunges; which close pores, trapping in heat. This temperature change causes a shift in blood pressure, which helps the body to flush toxins and release muscle tension. During the rest period, the cardiovascular system regulates itself, and the body has a chance to stabilize blood flow and heart rate (Scandinave Spa 2017).



Pools are heated to various temperatures using energy generated on site, to be enjoyed year-round.



The lower reservoir swimming facility at high tide with the pools at high water. where the lowest pool is fully submerged in the ocean water.



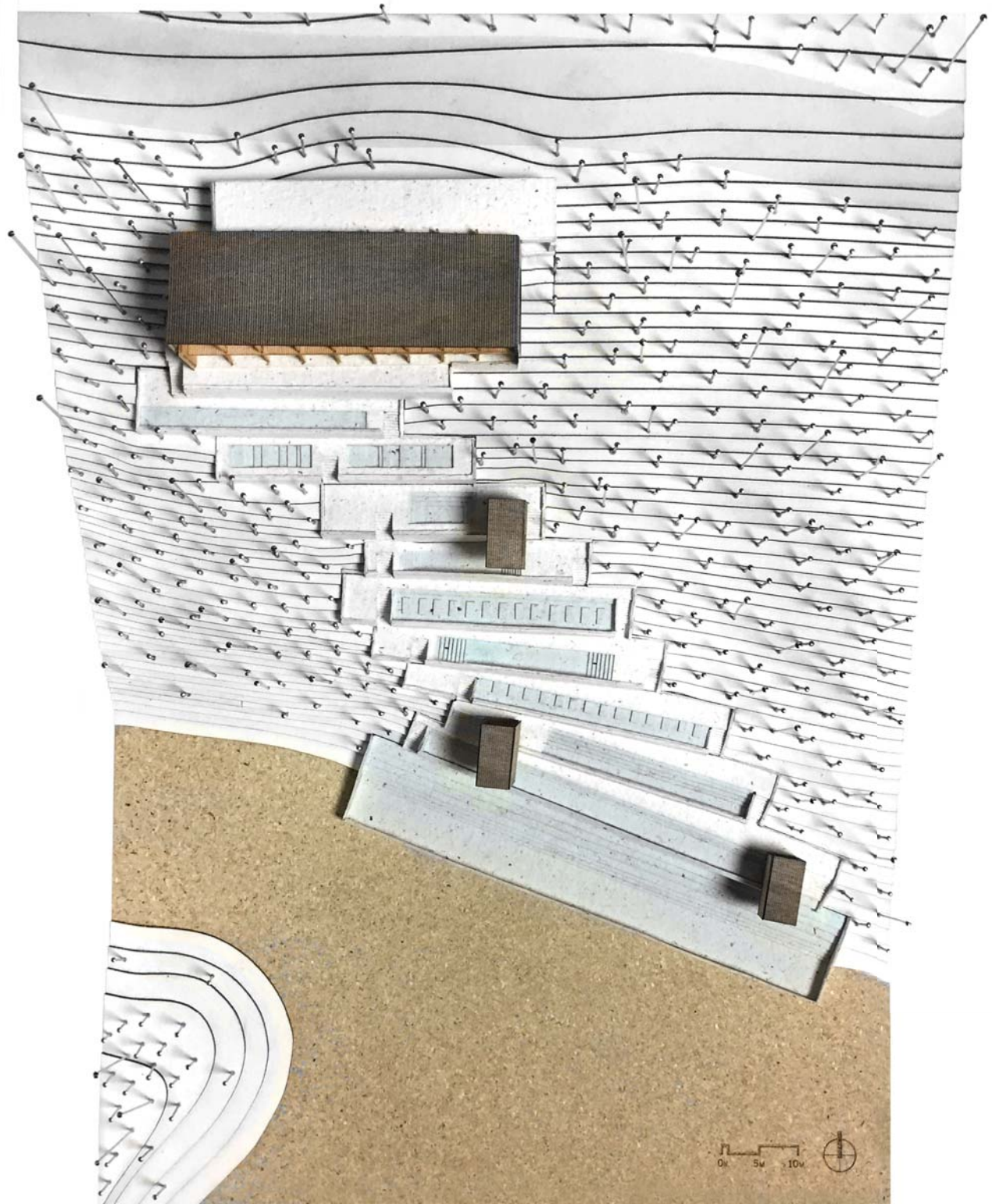
A series of sauna boxes protrude from the pools to provide moments of refuge, framing views of Cape Split in the distance. Sauna boxes are clad in cedar, with a warm wood slat interior.



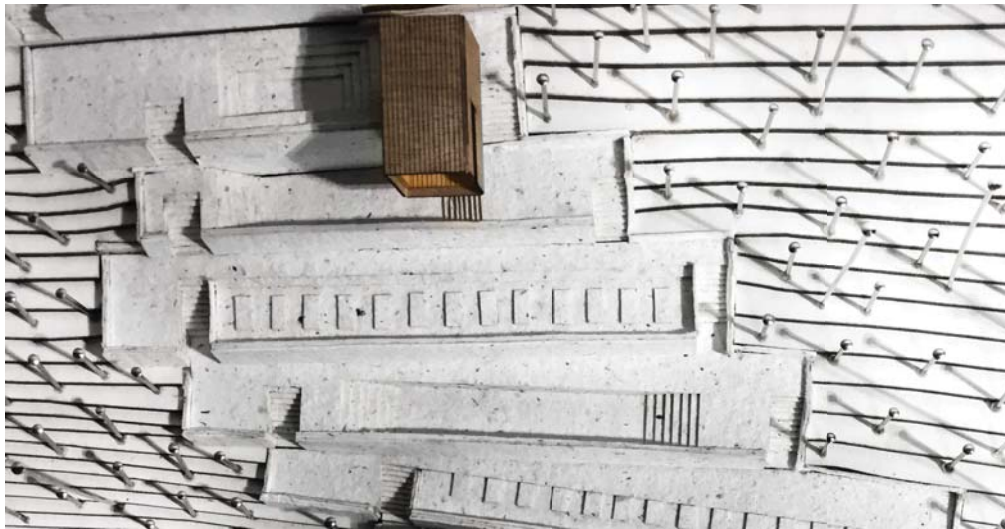
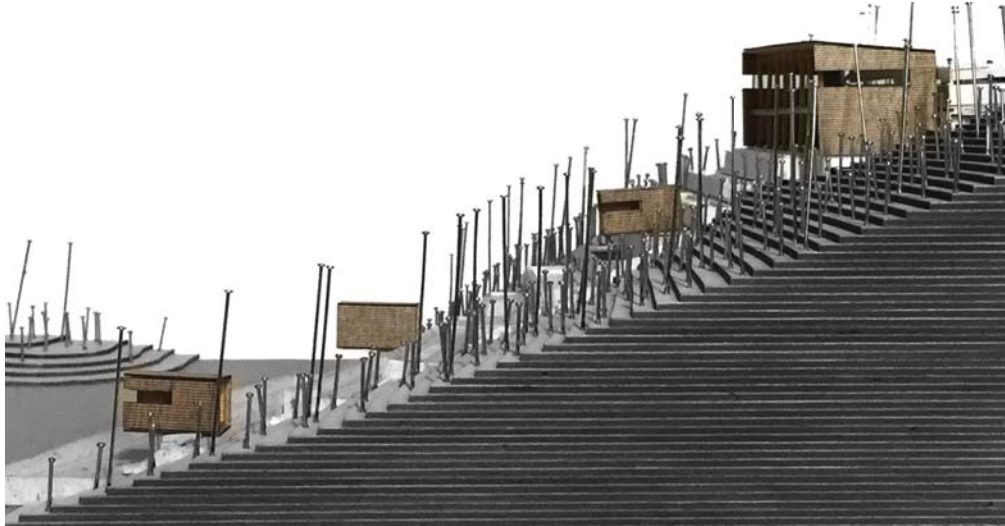
View from the low pool near the high water level, showing the sauna box protruding out and over the pool, with Cape Sharp in the distance, a protected habitat for endangered bird species.

The pools concrete structure makes it's way from the ocean to the road above and become the service core of the building. A lighter wood structure wraps out and over the concrete, to enclose the public portions of the building. On the main level, there is a café, with a warming lounge below. The service core contains the café kitchen, and turbine control room on the main level, with visual connections to the adjacent public space. Changing facilities are below, and the turbine is far below grade, in line with the lowest pool.

The following views show the pools at low and high-water levels. Copper downspouts allow water to flow between pools as water levels rise and fall with the shifting tides and energy demand, further amplifying these processes. By integrating swimming facilities within the reservoir, users have a physical connection to the movement of water that generates energy and heats the pools.



Physical model of the lower reservoir and swimming facility, showing stereotomic and tectonic elements, and how they adapt to the steep topography.



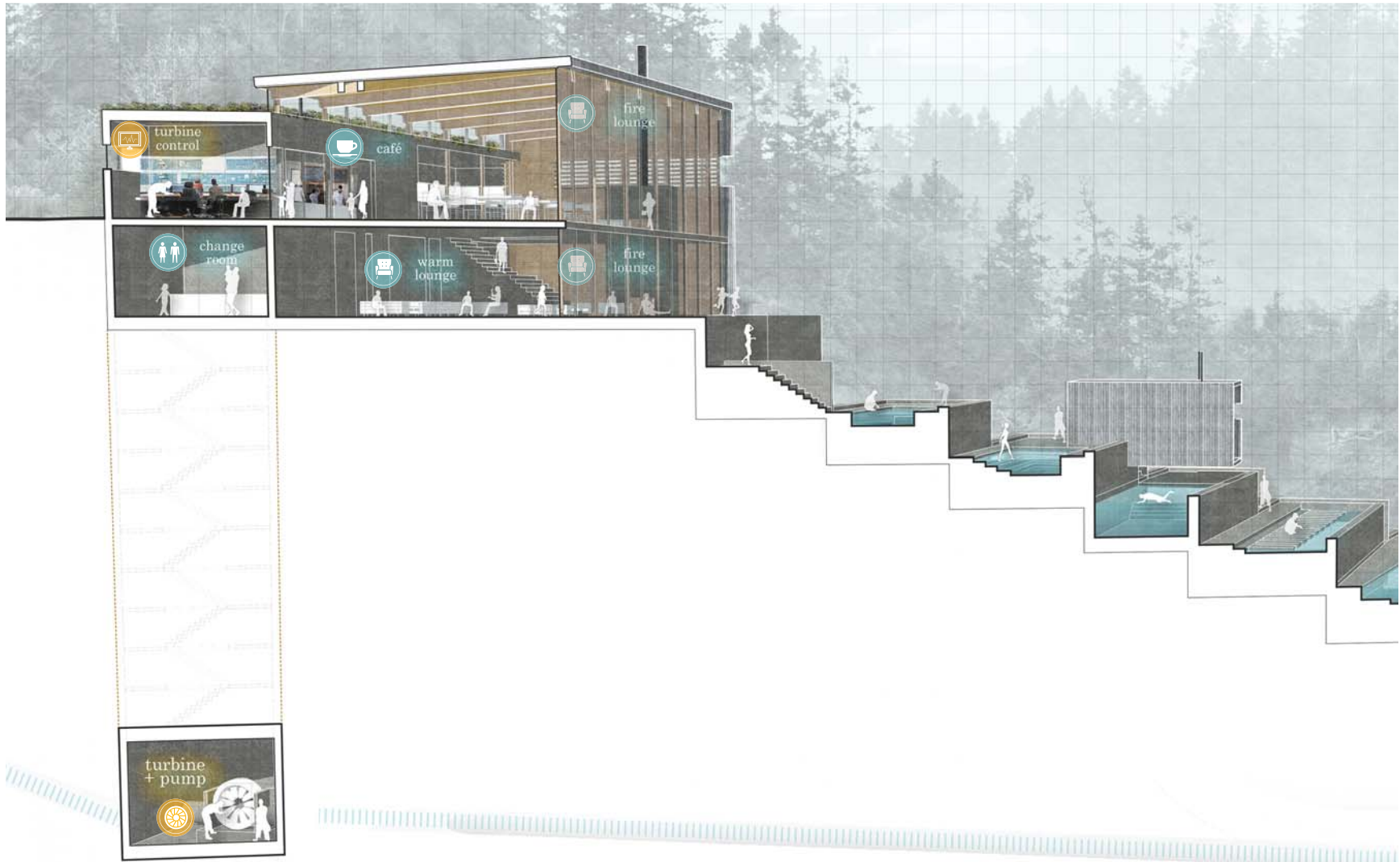
Above: Eastern elevation of the pools as they sit within the landscape, with the lighter wood enclosed spaces perched atop the pools. Middle: The pools step down the slope and fit within an existing tree clearing. Below: Detailed view of the variations in pool depths and processions, which vary based on water temperature.



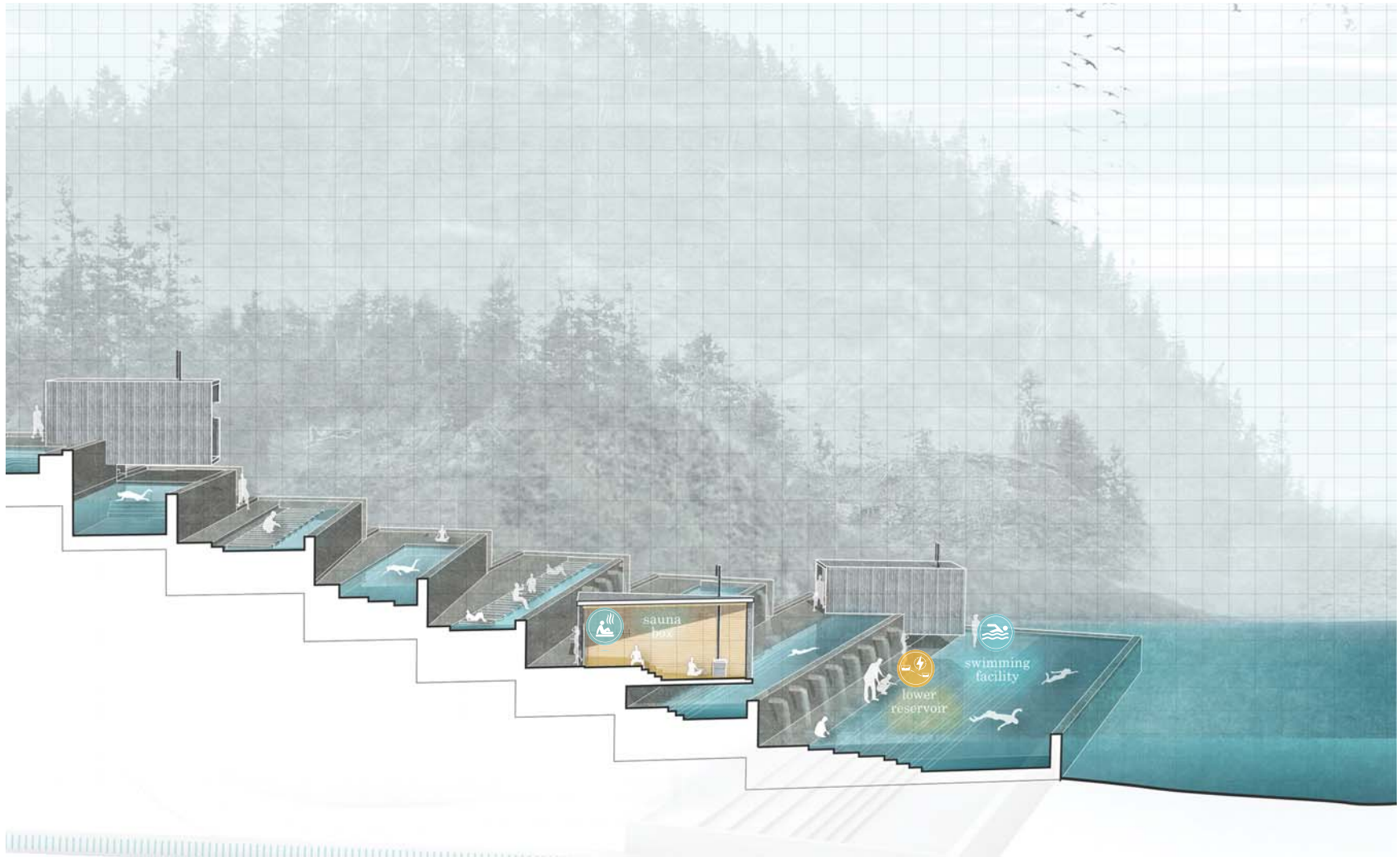
Lower reservoir swimming facility plan. The reservoir is divided into a series of smaller pools, to conform with the steep cliff, and shift along the slope to fit within an existing tree clearing.



Long section through the lower reservoir swimming facility, showing the relationship of stereotomic concrete elements and tectonic wood elements, and the adjacencies between energy and community program.



Closer view of the long section through the swimming facility, showing the stereotomic concrete structure that forms the pools then becomes the service core of the building, and the lighter wood structure that wraps over to contain the public gathering spaces.



Closer view of the long section through the swimming facility, showing the interior of a sauna box, with the lowest pool fully submerged at low tide, and the copper downspouts fully active as the pools are filling with ocean water.



View of the minimum water level in the lower reservoir, during low tide. Water remains in the three pools closest to the shoreline at the low water level to allow continuous access to the full bathing cycle of hot, cold, and rest.



View of the high water level in the lower reservoir, during high tide. The lowest pool is fully submerged by the tide, and the copper downspouts allow water to overflow between levels, cascading water as the pool above it fills, making evident the movement of water that generates energy.

Site 3: The Water

Boat Bridge

The primary goal for this site is to provide direct water access throughout the tide cycle. Typical wharves in this area only provide water access by boat when the water is near high tide, as pictured in the tidal study in Chapter 2. On this site, the horizontal distance from the low tide mark to the shoreline is 115 metres, with a vertical tidal range of 13 metres (Acadia Tidal Energy Institute, 2017). This makes accessing water by boat at low and high tide a vastly different task. These measurements set the initial dimensions of this structure.

A series of stationary wood frames define a path from the shoreline to the low tide mark. The structure uses tension ropes to prevent wracking, inspired by the fishing weirs used in the area.

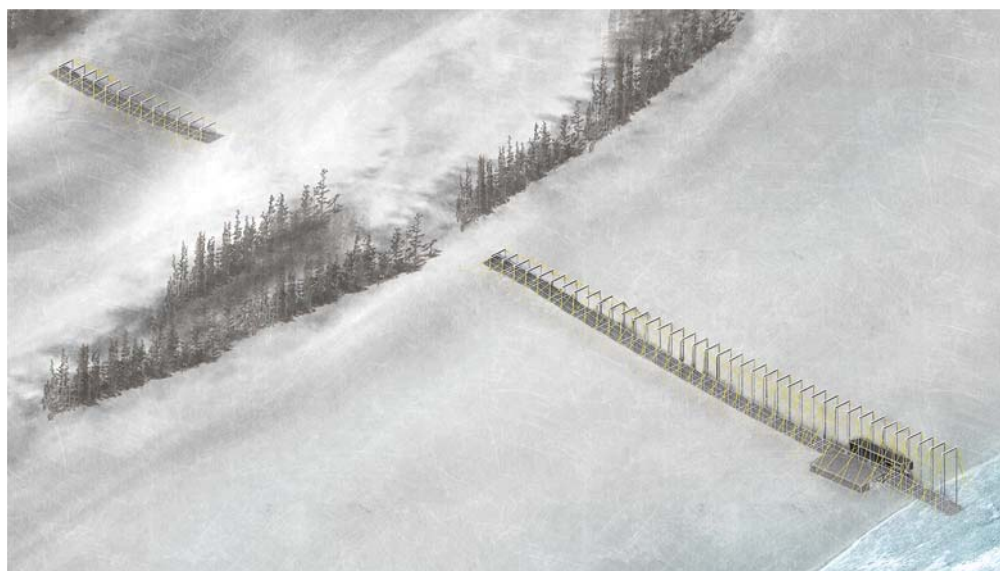


Below: Fishing weir at Partridge Island, shown at low tide, with Cape Split in the background. These vernacular structures serve as a precedent for the structure of the proposed boat bridge. Right: Detail of the fishing weir ground connection.

Fishing weirs are comprised of a series of birch poles erected in the firm tidal flats, perpendicular to the shoreline. The Acadians developed these structures in the early 1900s as an adaptation to traditional fishing nets. Rather than bringing nets out into the water, the nets could be set at low tide, allowing fish to come in with the tide and become caught in the weirs as the tide went out. The nets could be retrieved at low tide using the same wagons the Acadians used on their farms, providing a much more efficient fishing method (Bleakney 2004, 6).

In the proposed design, wooden frames support a buoyant wood structure and boat shed, that rise and fall with the shifting tides. The physical experience of walking through the structure, varies with the tides, providing users with an embodied experience of the dramatic tidal range. The boat shed is located at the low tide mark to allow continuous water access by boat. By framing the height of the tidal range, this structure provides direct water access throughout the tide cycle, while making evident this natural phenomenon.

In terms of energy program, environmental monitoring is a crucial aspect of the tidal industry. Monitoring platforms have been custom designed, to withstand the powerful Fundy tides, recording data on fish density, currents, sediment and acoustics surrounding the turbine (FORCE: Subsea Equipment).



The boat bridge at low tide, resting on the ocean floor.

Some monitoring takes place with platforms in the water, but onshore assessment occurs as well. Currently, monitoring platforms ship to Parrsboro for onshore assessment, as there is no facility on site. The boat shed provides a space for on-site environmental monitoring to occur.

This intervention focuses on accessing the water, learning from the land, and returning to shore. The proposed community program for this site is a kayak rental facility, in a shared space with the environmental monitoring platforms. This mixed-programming allows locals and visitors taking kayaking tours from the site to view environmental monitoring equipment, and scientists at work when on-shore assessment is taking place. It also provides an amenity for those working in the tidal industry, to enjoy at the end of their shift.

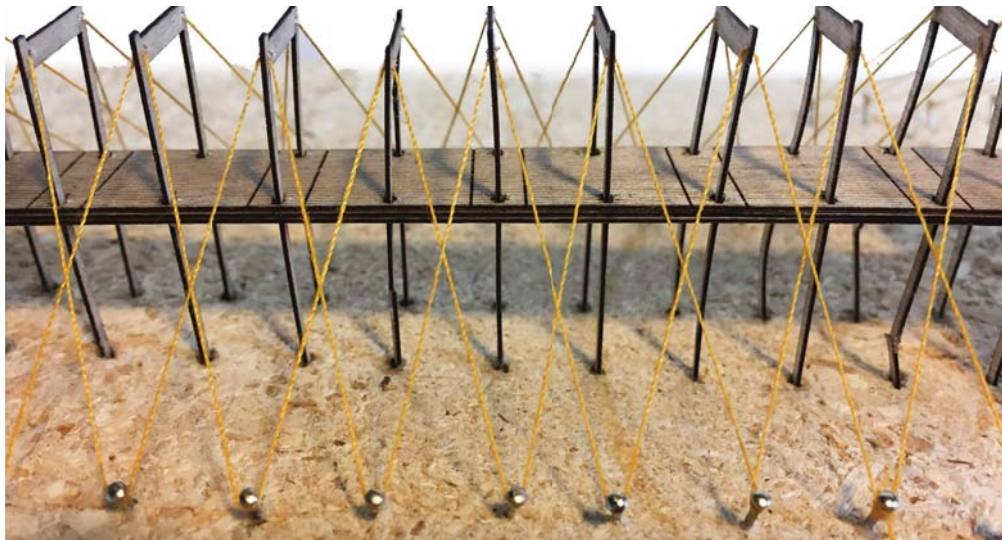
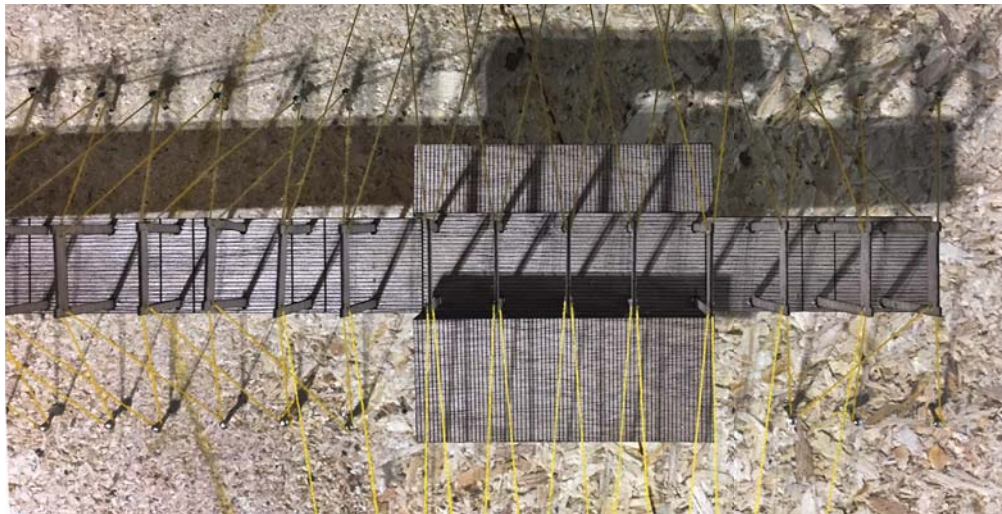
To ensure safety, all kayakers enjoy guided tours led in small groups by experienced kayakers. Tour routes vary based on the tides, wind and wave conditions, and the fitness level of participants, with a variety of tours available for different skill levels and durations. All rentals are tandem kayaks, as they are more stable. These safety precautions are based on Nova Shores Sea Kayaking, a successful kayaking tour operator located along the Bay of Fundy, in Advocate Harbour, 55 kilometres West of Black Rock (Nova Shores 2017).



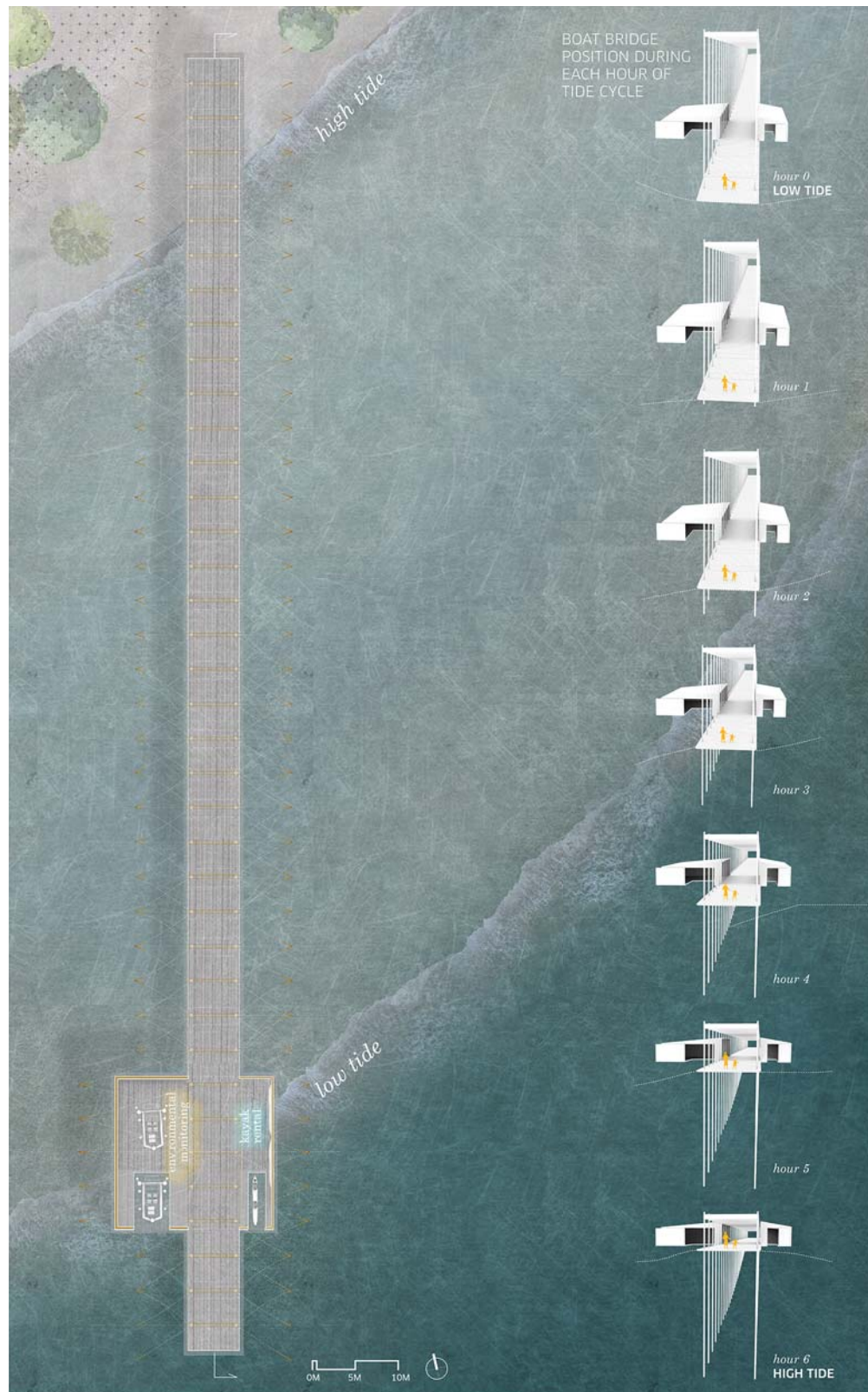
The boat bridge at high tide, floating on the surface of the water.



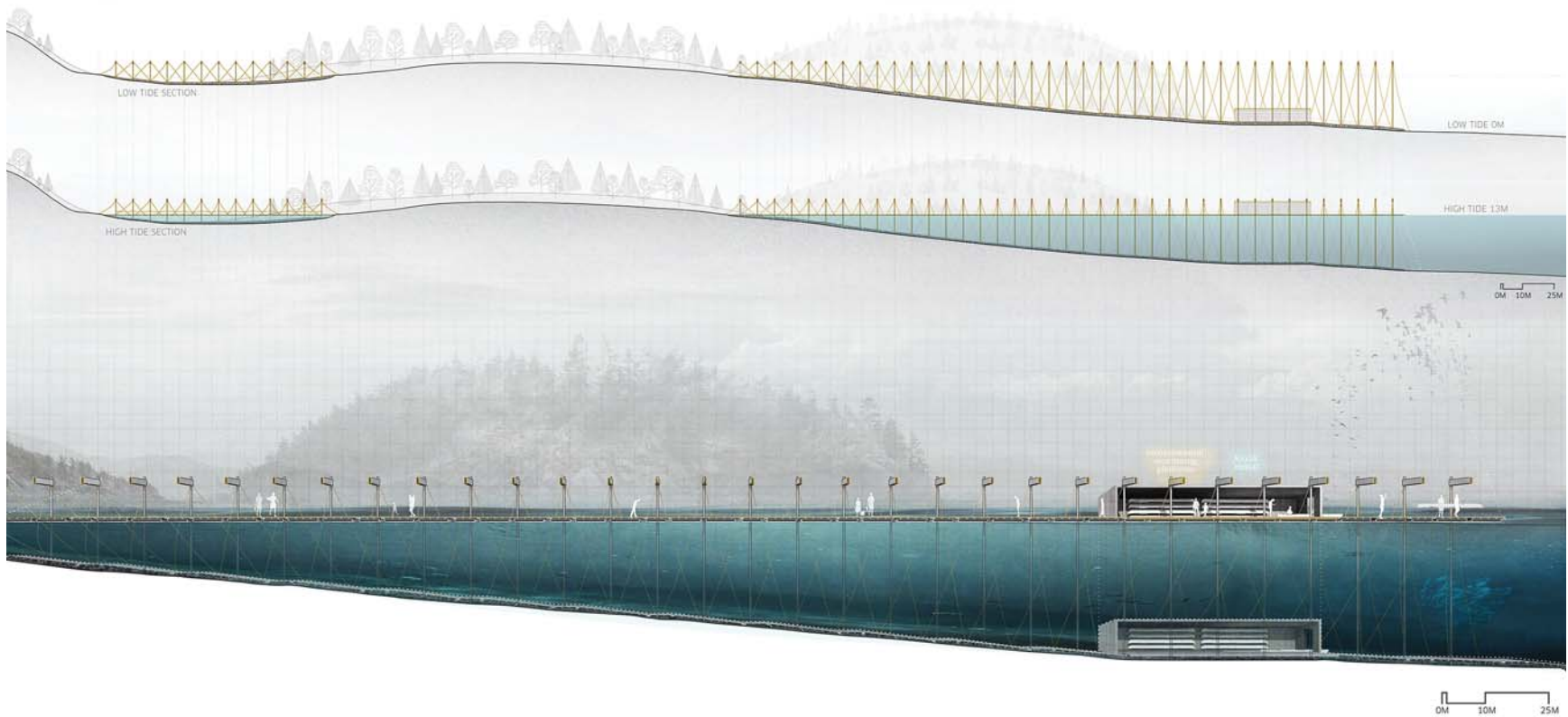
Physical model of the boat bridge, showing the tectonic wood structure and tension ropes, inspired by local fishing weirs. This structure supports the buoyant boat shed and boardwalk.



Above: View of the boat bridge from the water at mid tide level, showing the repetitive wood structure and tension ropes, inspired by fishing weirs used in the area. Middle; Top view of wood structure and tension ropes over the boat shed. Bottom. Detailed view of tension ropes securing the wood structure to the ocean floor.



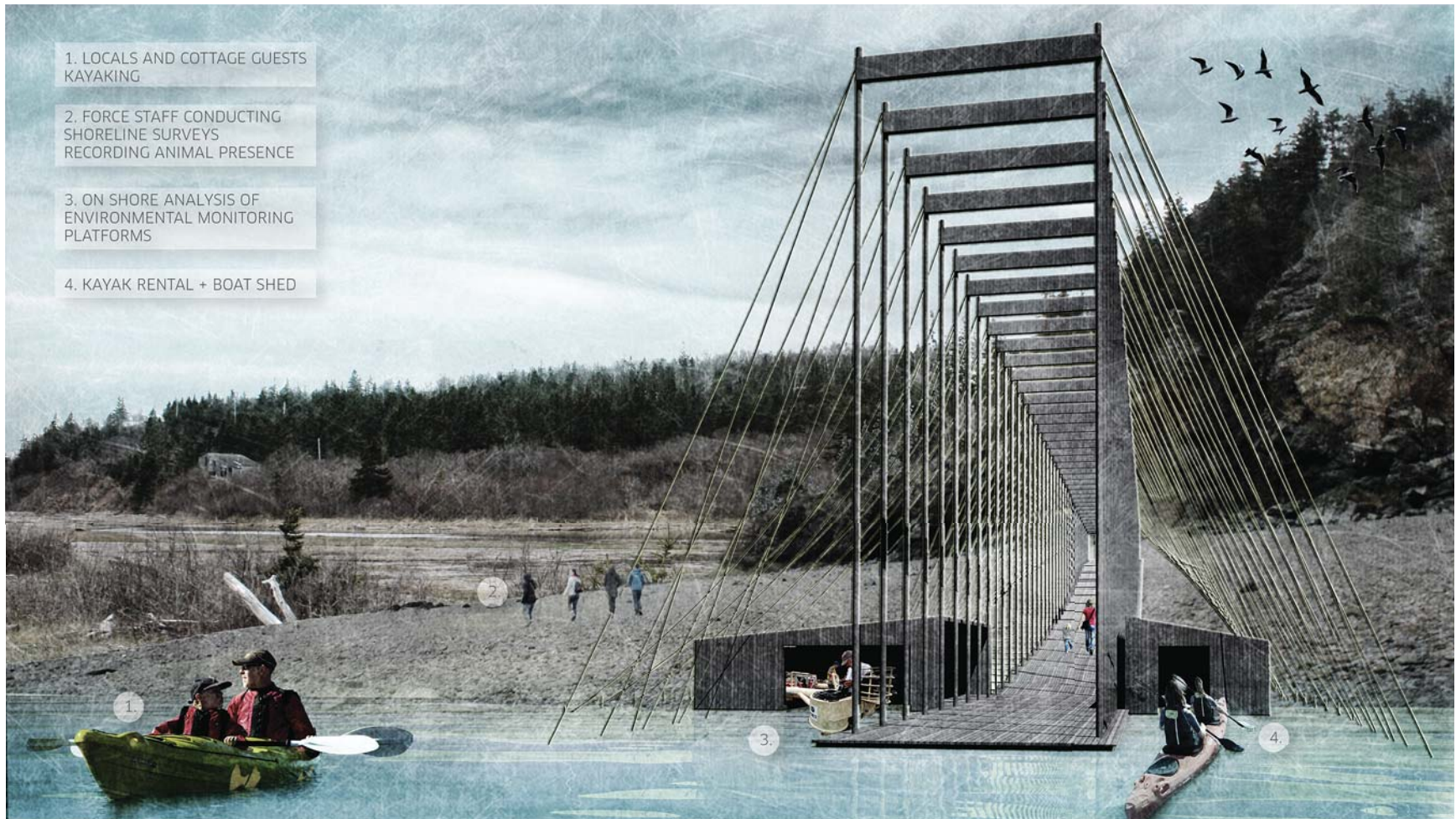
Plan of the boat bridge showing the connection from the barrier beach to the low tide mark. The diagram on the right shows the position of the buoyant boardwalk and boat shed at each hour of the tide cycle, as it rises and falls with the movement of water.



Long landscape sections above show the position of the boat bridge at low tide, resting on the ocean floor, and at high tide, elevated to the water's surface. The detailed section below shows a closer view of the boat bridge at high tide, with the low tide position ghosted in.



Closer view of the inhabited boat bridge section shown at high tide, with the low tide position ghosted in. The boat shed houses kayaks and environmental monitoring equipment, combining energy and community program related to the tides.



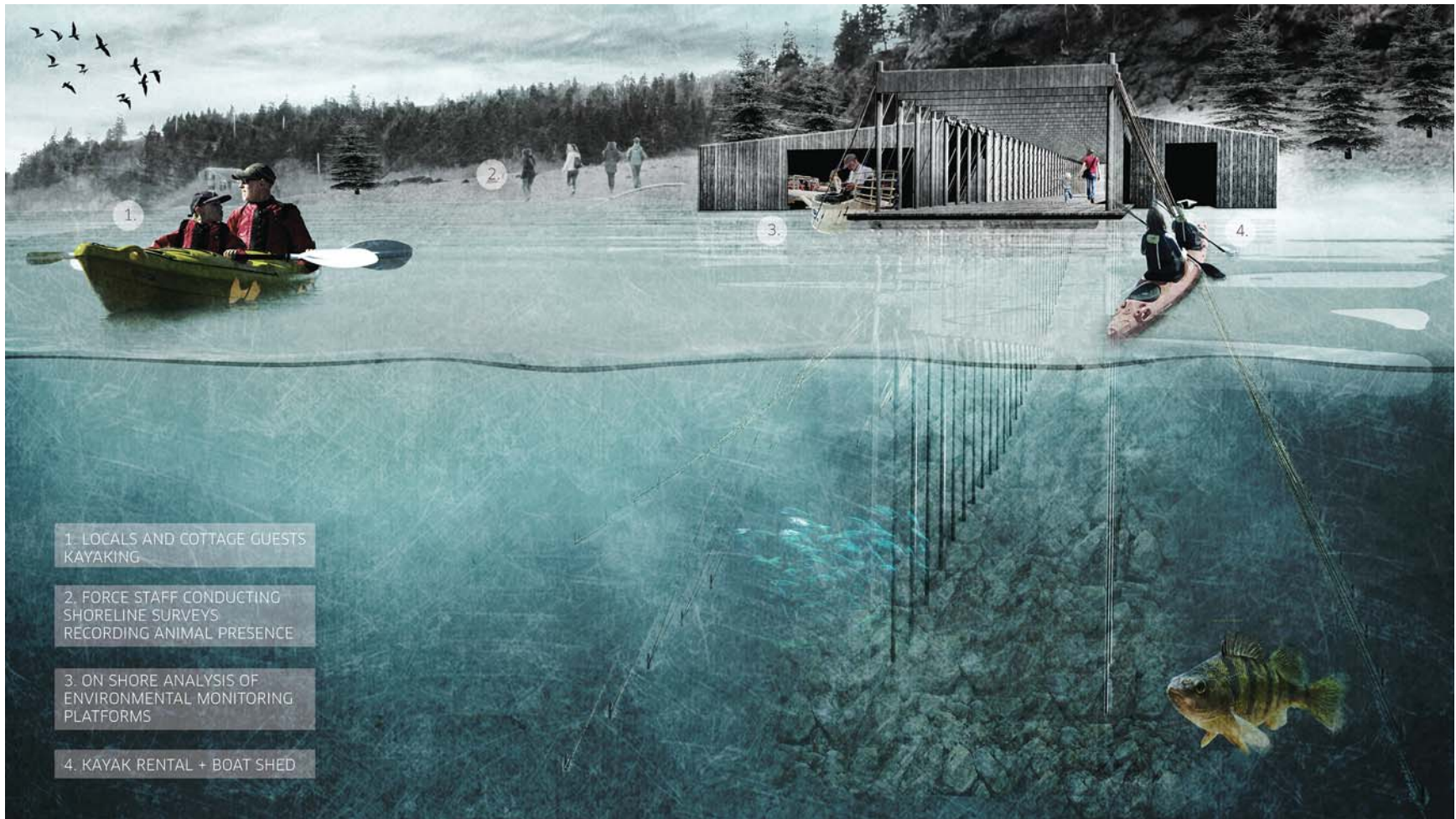
1. LOCALS AND COTTAGE GUESTS
KAYAKING

2. FORCE STAFF CONDUCTING
SHORELINE SURVEYS
RECORDING ANIMAL PRESENCE

3. ON SHORE ANALYSIS OF
ENVIRONMENTAL MONITORING
PLATFORMS

4. KAYAK RENTAL + BOAT SHED

The boat bridge resting on the ocean floor at low tide, providing direct water access 115 metres from the shoreline.



The boat bridge floating 13 metres above the ocean floor, at high tide.

CHAPTER 6: CONCLUSION

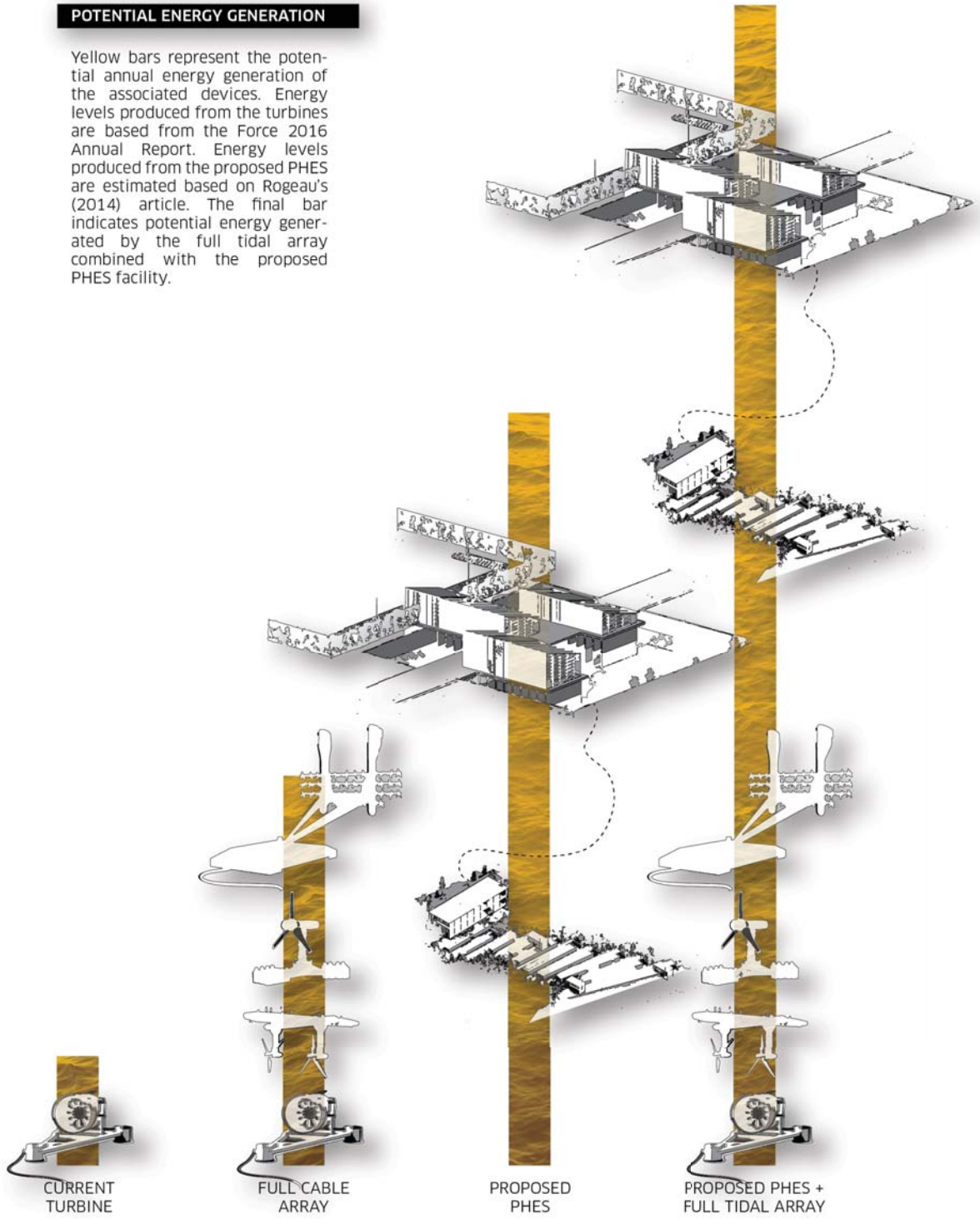
The landscape of the Fundy coast presents a valuable natural resource that gives Nova Scotia immense potential for a sustainable industry. The dramatic tides and currents, and accessible depths of the Minas Passage make for an ideal location for tidal energy. The steep cliffs and topography surrounding the passage provide a suitable landscape for pumped hydro energy storage. Combined, tidal energy and pumped-hydro energy storage can provide Nova Scotia with a continuous supply of renewable energy, with sufficient energy to power much of the province.

The current turbine installed at FORCE has the potential to generate enough energy to power over 650 homes. With the full turbine array installed, the site could capture enough energy to power over 21,000 homes (FORCE 2016). Based on Rogeau's method for determining small-scale PHES efficiency, it is estimated that the proposed pumped hydro facility has potential to generate enough energy to power twice the number of homes as the full turbine array (Rogeau, Girard, Kariniotakis 2017, 244). Combined with the full tidal cable array, this site could provide a significant source of local renewable energy for Nova Scotia.

Currently, FORCE hosts 5,000 visitors each summer, from across Canada, and the world. According to Nova Scotia Energy Minister, Geoff MacLellan, the tidal energy industry has the potential to generate 22,000 jobs and generate \$1.7 billion for the Nova Scotia economy (MacDonald 2018). Black Rock is currently unequipped to support the population influx that will arise with the anticipated expansion of the tidal industry. If the tidal industry continues to develop, it is important to do so in a way that is sustainable for the environment and for community members impacted by such development.

POTENTIAL ENERGY GENERATION

Yellow bars represent the potential annual energy generation of the associated devices. Energy levels produced from the turbines are based from the Force 2016 Annual Report. Energy levels produced from the proposed PHES are estimated based on Rogeau's (2014) article. The final bar indicates potential energy generated by the full tidal array combined with the proposed PHES facility.



Potential energy generation associated with the FORCE turbine array and the proposed PHES facility.

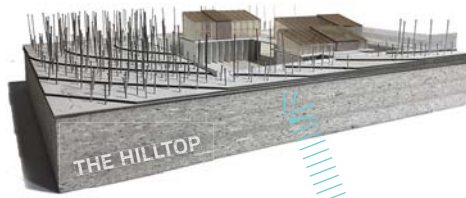
Future Developments

Future developments surrounding this industry should incorporate energy and community programs, providing users with an engaging experience that makes evident the processes occurring on site. Using local building materials and methods can help to develop an architecture rooted in landscape and culture, providing an interactive architecture that is activated by the natural and energy processes that sustain it. The following image shows the three design proposals as they sit in elevation relative to one another. The models show how the stereotomic and tectonic structural elements adapt to changes in program and topography across the three sites.

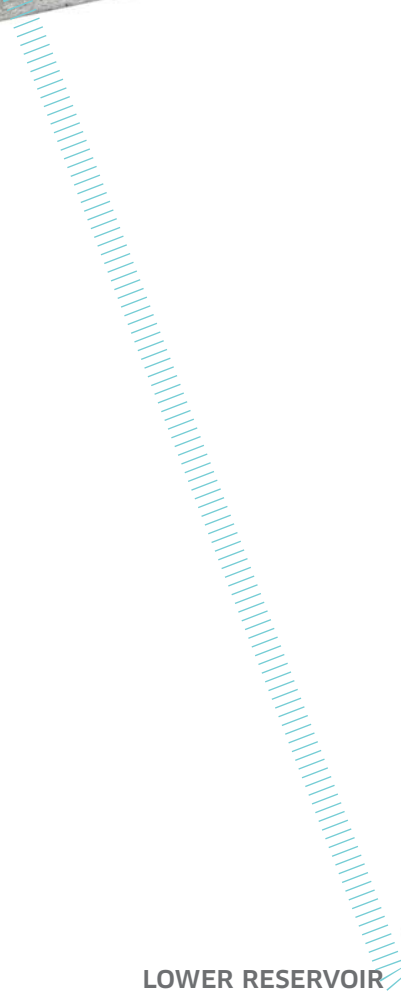
An additional community program that would complement the developing renewable energy infrastructure on site would be a dark sky preserve. This public program promotes year-round recreation, as viewing conditions are best in winter when skies are dry and clear. Cumberland County has identified a dark sky preserve as a potential attraction for this area, as the number of truly dark skies left in the world is decreasing (UPLAND 2018, 80). This activity links star gazing and full moon gazing, providing a connection to the source of the great tidal range, attracting potential visitors during times of the greatest natural phenomenon.

Broader Implications

Through the duration of this thesis interest in tidal energy has increased in Nova Scotia, and globally. The province has recently approved the development of a second tidal facility on the Southern Coast of the Minas Basin. The proposal for this thesis would be well suited to this site, as the steep topography lends itself to pumped-hydro energy storage. Integrating bathing with the energy storage facility could provide additional recreation amenities for Cape Split and Blomidon provincial park, an area popular for landscape-based tourism and recreation. This could increase opportunities for locals and visitors to engage with the landscape while gaining an understanding of the natural and energy processes unique to the Bay of Fundy.



UPPER RESERVOIR
AQUACULTURE

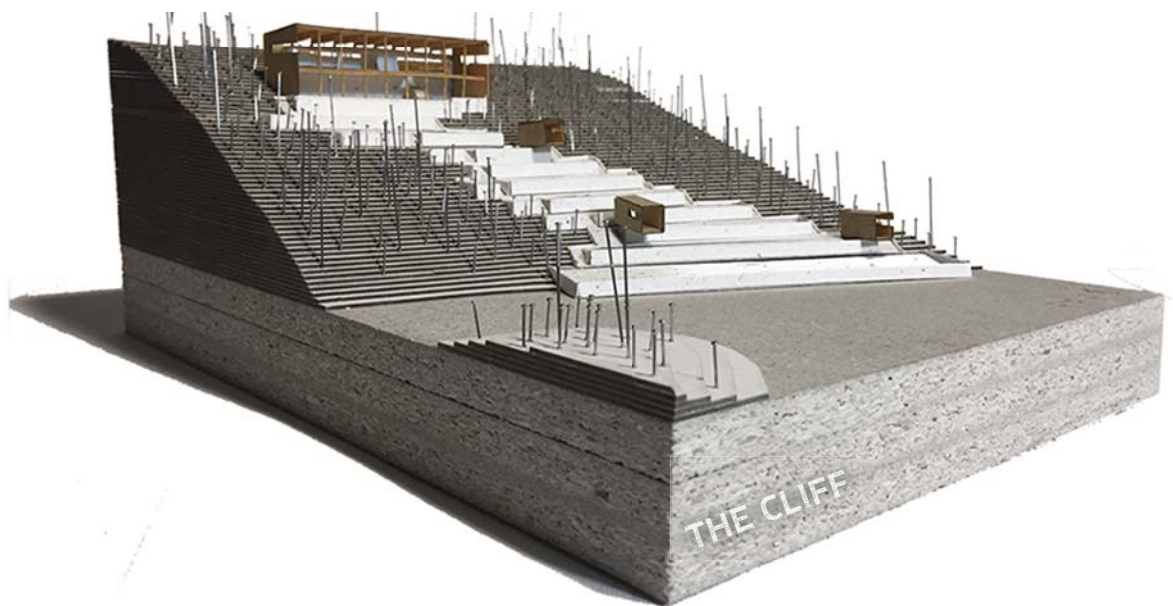
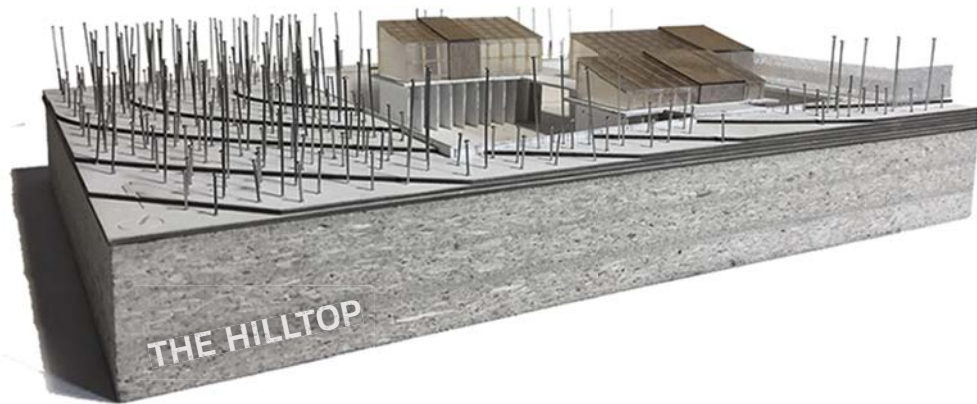


LOWER RESERVOIR
SWIMMING FACILITY



ENVIRONMENTAL MONITORING
KAYAK RENTAL

This page shows the three sites in relation to one another, and the pipe between reservoirs. The stereotomic and tectonic structure of each site adapts to accommodate various programs and landscape conditions.



A closer view of each of the three models, showing how the structure of each site adapts to conform to the changes in program and landscape conditions for each site.

Developing renewable energy has the potential to revitalize declining rural communities in Nova Scotia by reducing energy dependence on imports, stimulating economic growth, and providing job opportunities in ‘research, training, mechanics, installation, maintenance, and interpretation.’ (UPLAND 2018, 39-41). Integrating community programs with energy production could increase community buy-in by improving job opportunities and access to amenities.

Natural Resources Canada has identified numerous sites in Cumberland County with renewable energy potential (Government of Canada 2017). Amherst has been identified as the most suitable area in Nova Scotia for solar energy, with three organizations in Cumberland County currently using solar energy for commercial and residential use. Wind power currently generates 5.8MW of power in the municipality, with an expected increase. The highest wind speeds are in Advocate Harbour, Cape Chignecto, and throughout the Cobequid Mountains. An abandoned mine in Springhill has the potential to extract geothermal energy from flooded mine water, with ten organizations currently extracting geothermal energy in Springhill. Abandoned coal mines near Joggins and surrounding areas also have geothermal energy potential. Community meetings have identified the municipality as a future “green energy hub” that positively contributes to a reduction in greenhouse gas emissions (Merrill, Bruce, Zwicker 2018, 22).

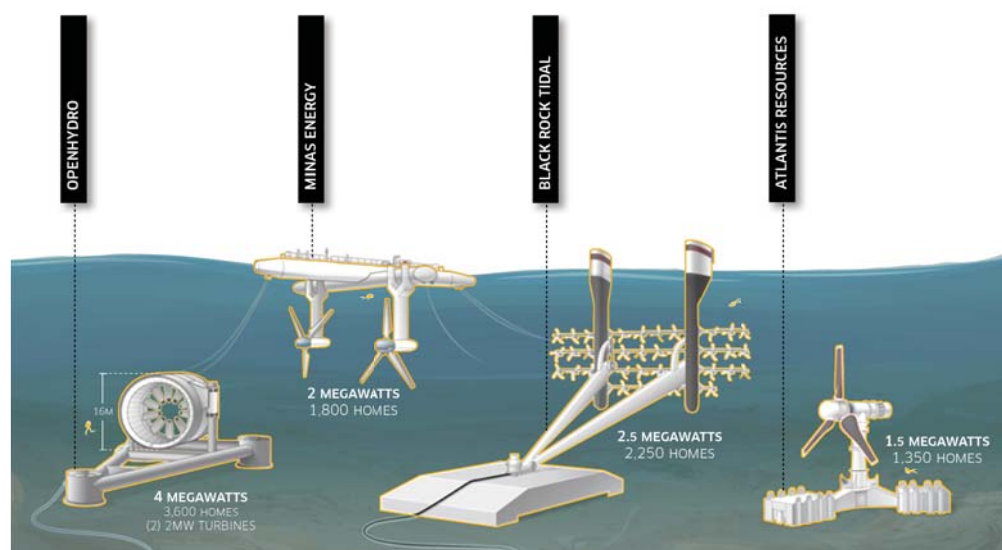
This framework for developing renewable energy infrastructure that integrates landscape and community can apply to various forms of renewable energy. This approach could apply to community solar energy production using architecture that emphasizes natural light, or wind energy production using architecture that emphasizes sound and movement, to emphasize natural and energy processes. Designing renewable energy infrastructure that is informed by the natural and energy processes that sustain it, gives locals and visitors an interactive means of understanding of the processes unique to this landscape while providing a cleaner energy future for Nova Scotia.

APPENDIX A: TIDAL TURBINES AT FORCE

Turbine Berth Holders

OpenHydro has deployed tidal turbines at multiple sites in Scotland, and France, and has current developments for turbine deployment in Ireland and Japan. The turbine deployed in Nova Scotia is their strongest and most powerful design, to withstand the powerful Fundy tides. Two OpenHydro turbines have been deployed and tested on site, connected to the Nova Scotia Power grid. Currently, one is currently installed and connected to the provincial power grid; the other is undergoing upgrades in the Port of Saint John. Once both turbines are operating at their full potential, they will carry a 4MW capacity, generating enough energy to power 3,600 homes (FORCE: Technology 2017).

Minas Energy, of Bedford Nova Scotia, has paired with Marine Current Turbines, and Bluewater Energy Services, of the United Kingdom. Together they have developed a floating tidal energy converter, known as ‘SeaGen F’. This turbine design was deployed in Strangford Lough, UK, in 2008, as the first commercial-scale tidal turbine in the world. The turbine they will be installing at FORCE has a 2MW capacity, generating enough energy to power 1,800 homes.



The four turbine berth holders at FORCE, and the tidal devices they will be testing on site. Image adapted from: Rosano 2016.

Black Rock Tidal, and Allswater, of Halifax, have paired with Schottell, of Dorth, Germany, and Tidal Steam, of Southam UK. They will be installing tidal stream tidal platforms with an array of 'Schottell STG' tidal turbines. These semi-submerged floating units house 36 independent turbines. This 2.5MW turbine will generate enough electricity to power 2,250 homes.

Atlantis Resources, of Eninburgh, UK, has paired with local engineering firm Lockheed Martin and Irving Shipbuilding, in their development of the Atlantic AR1500 turbine. This 1.5MW turbine will generate enough energy to power 1,350 homes. Atlantis Resources owns MeyGen, the world's largest planned tidal stream energy project, located in Pentland Firth, Scotland, which has the potential for 398MW of energy. With all four turbine berths occupied and functioning fully, they would generate the combined energy to power 9,000 Nova Scotian homes. This would significantly reduce our reliance on fossil fuels while advancing the innovative technology behind local renewable energy production (FORCE: Technology 2017).

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