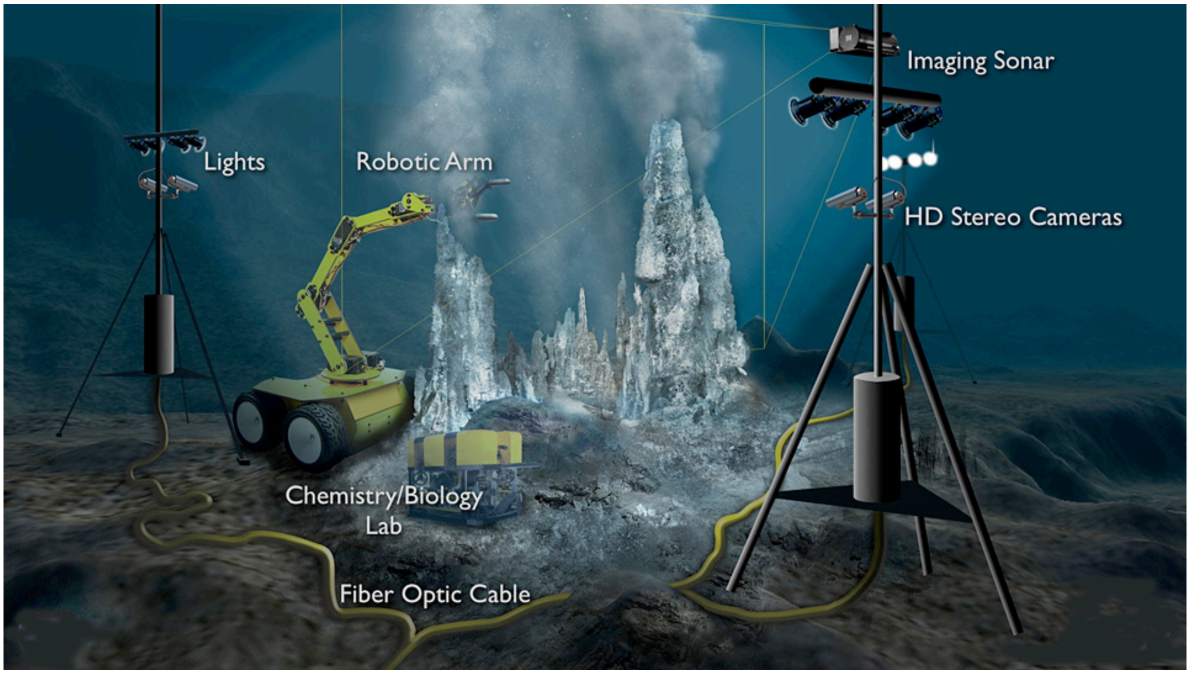
Regional Scale Nodes
Shore Station Options
White Paper



Prepared by
University of Washington for the
Joint Oceanographic Institutions, Inc.

June 15, 2007

Document Control Sheet

Version	**Date**	**Description**	**By**
1.0	June 15, 2007	Initial release	Kelly, McGinnis, Barletto, Harkins
1.1	July 17, 2007	Comments from R. Lunde (JOI)	Kelly, McGinnis, Barletto, Harkins
1.2	July 19, 2007	Cost Indexed	Kelly

Table of Contents

Figures

Tables

1.0 Executive Summary

This White Paper presents a technical trade-off study conducted by the University of Washington of Submarine Cable Landing Stations for the Regional Scale Cabled Nodes (RSN) component of the Ocean Observatories Initiative (OOI), a program overseen by the Joint Oceanographic Institutions, Inc., for the National Science Foundation.

Based on the recommendation in the Regional Scale Nodes (RSN) Wet Plant Primary Infrastructure White Paper (OOI-RSN WP#1), a preliminary study was undertaken to review possible cable landing sites in Oregon and Washington. The study determined that there are significant cost savings to be derived from using existing commercial cable stations facilities on the Oregon coast rather than constructing and maintaining new facilities. Savings would be better applied directly to regional-scale observatory ocean science.

Table 1 identifies the existing commercial landing stations considered in this study. The two cable stations located within Washington were immediately eliminated from consideration based on distance from the RSN and on permitting issues associated with crossing a National Marine Sanctuary. Existing commercial cables permitted in the late 1990s to cross the Sanctuary are now facing possible permit modifications that would require re-routing outside the Sanctuary boundaries, a substantial financial and operational burden. The cable landing at Bandon, Oregon was also immediately removed from consideration based on the distance from the RSN and on the high cable fault history associated with the poor inshore bottom conditions that preclude burial for at least the first 12 miles seaward of the beach manhole.

Table 1. Existing Commercial Cable Stations in Oregon and Washington

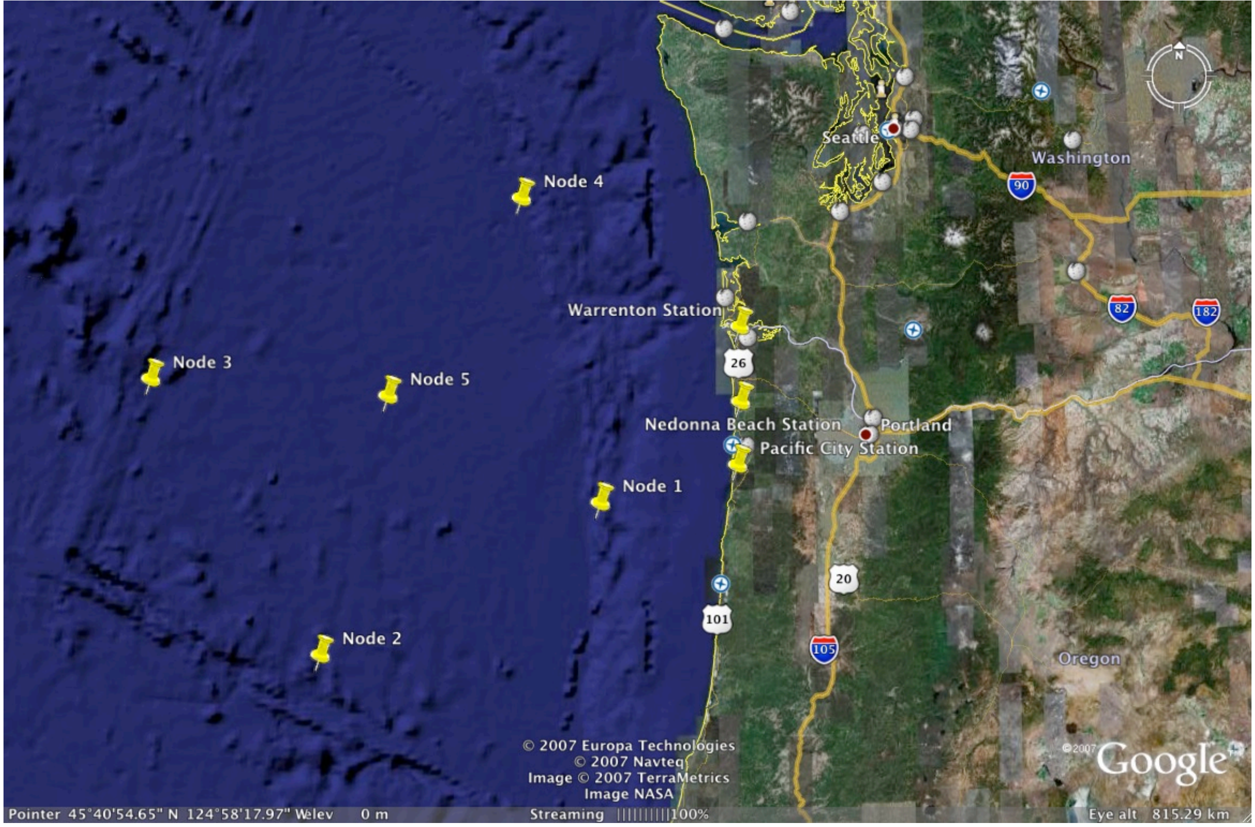
Landing Point	**Owner**	**Existing Cables**	**Comments**
Bandon, OR	AT&T	TPC-5 China-US	Not considered, due to distance from nodes and high fault rate associated with poor bottom conditions and no burial
Harbor Pointe, WA	Pacific Crossing	PC-1	Not considered, due to distance from nodes and Marine Sanctuary issues
Nedonna Beach, OR	WCI Cable	Northstar S. Cross VSNL-P (3) TPE (2008)	Candidate
Norma Beach, WA	GCI	AUFS I	Not considered, due to distance from nodes and Marine Sanctuary issues
Pacific City, OR	MetLife	NPC	Candidate. NPC is no longer in service
Warrenton, OR	GCI	AUFS II	Candidate

At the suggestion of the interim Observatories Steering Committee (*i*OSC), consideration was given to the use of Oregon State University's, Hatfield Marine Science Center as a cable landing station. Section 4.4 provides some information on this facility, initial analysis dictates that this site not be considered unless a technical solution could be achieved enabling a single cable to support multiple cabled instruments of the Coastal Newport Line without compromising the backbone power and bandwidth of Node 1 at Hydrate Ridge. Risk factors associated with a non-purpose built facility, as well as permitting a new landing station were considered prohibitive.

Our recommendation presented in this White Paper is based on three key criteria: 1) minimize cable segment lengths to individual nodes; 2) availability of power; and 3) availability of backhaul. In evaluating these criteria, consideration was given to cost, risk, schedule, and long-term ease of operation. We also conducted an analysis on the incremental costs related to dividing the cable landings between two stations.

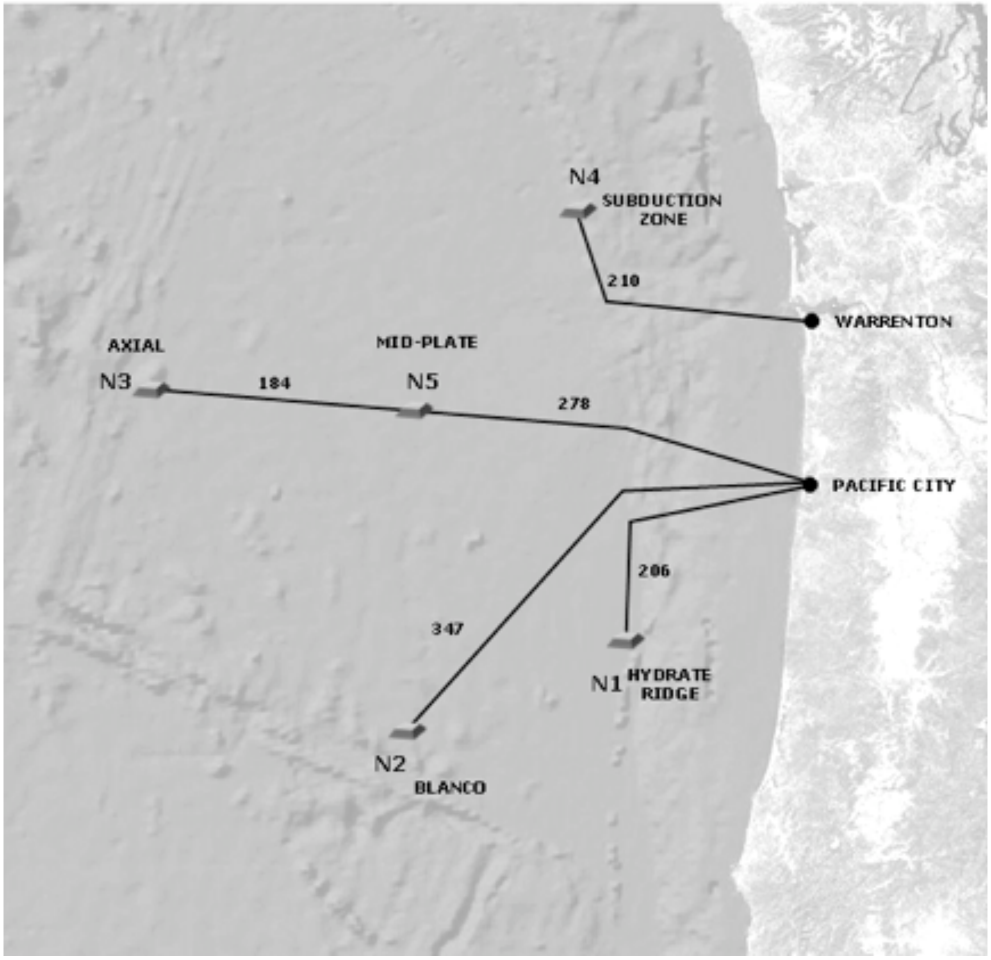
Figure 1 provides a graphic representation of the geographic relationship among the five nodes of the Star configuration and the candidate cable landing stations. The Star configuration is the network configuration recommended and fully described in RSN Wet Plant Primary Infrastructure White Paper and is depicted in Figure 2.

Figure 1. Locations of Possible Landing Stations and Nodes



Further cost analysis was conducted in this White Paper study to validate the recommendation of the RSN Wet Plant Primary Infrastructure White Paper in relation to the shore station and backhaul solutions. Table 12 provides a summary of the total costs of each configuration from wet plant and shore station/backhaul perspectives. Details of the shore station and backhaul costs for the Ring can be found in Tables 10 and 11 of this White Paper. As annual recurring costs of each solution were the same, this component was not included in the analysis for simplicity. Because the Star and Ring are quite different technical solutions, it is important to review the shore station and backhaul costs in the overall context of the system cost. The Primary Infrastructure White Paper documents the risk mitigation inherent in the simplicity of the Star configuration.

Figure 2. Recommended Star Configuration



Shore Station Recommendation

Our conclusion is that we favor landing one segment in Warrenton and three segments in Pacific City. This is our best effort at developing an affordable solution in support of the Star configuration. The two proposed shore stations minimize segment distances while maximizing the power and bandwidth available at each node in order to satisfy primary science goals. Compared to the Nedonna landing, stations at Warrenton and Pacific City have the added benefit of minimizing the number of commercial cable crossings. As documented in a preliminary desktop study of a Ring configuration, thirty-five commercial cable crossings would be expected. A STAR configuration landing at single cable station would require at least sixteen commercial cable crossings, where the proposed Warrenton and Pacific City landings would only require seven. Fewer cable crossings translate to fewer crossing agreements, but more importantly reduce the number of plow flyovers. Plow flyovers are areas where the plow is removed from the seabed and, at a later time, the less capable method of remotely operated vehicle jetting is employed for burial.

This White Paper identifies key technical considerations and summarizes our findings of the conditions and capabilities of each of the cable landing stations. Most importantly, the simplicity and reliance on existing technology of our recommendation offer what we believe to be the highest level of network availability. Table 2 presents a summary of costs for our shore station recommendation.

Table 2. Summary of Costs for Recommended Solution

Station (#Landings)	**STATION COST**	**RISK FACTOR**	**CONTINGENCY**	**TOTAL COST**
Warrenton (1)		23%		
Pacific City (3)		30%		
TOTAL				

DETAILS on file with JOI

Cost For Recommended Solution					
Warrenton, OR Cable Station					
Single Landing					
	Unit		**Unit Price**	**Full Price**	
				One Time	**Annual Recurring**
Equipment Cost					
PFE*	1	ea			
SLTE**	1	ea			
Terrestrial WDM***	2	ea			
Infrastructure Cost					
Cable Station Colocation					
pfe	3	cabinet			
slte	1	cabinet			
terrestrial wdm	1	cabinet			
Power install	400	Amp			
Duct (Station-Beach Manhole)	1	ea			
install 3 sub-duct	1	ea			
Beach Manhole	1	ea			
Land Cable BMH-Station	1	ea			
Ocean Ground Bed	1	ea			
Dark fiber (Station-Portland)	1	ea			
SUB-TOTAL					
* Power Feed Equipment					
** Submarine Line Terminating Equipment					
*** Wave Division Multiplexing					

Cost For Recommended Solution *(cont.)*

Pacific City, OR Cable Station					
Three Landings					
	Unit		**Unit Price**	**Full Price**	
				One Time	**Annual Recurring**
Equipment Cost					
PFE	3	ea			
SLTE	3	ea			
Terrestrial WDM	2	ea			
Infrastructure Cost					
Cable Station Colocation					
pfe	9	cabinet			
slte	3	cabinet			
terrestrial wdm	1	cabinet			
Power install	1100	Amp			
Duct (Station-Beach Manhole)	3	ea			
install 3 sub-duct	3	ea			
Beach Manhole	1	ea			
Land Cable BMH-Station	3	ea			
Ocean Ground Bed	2	ea			
Dark fiber (Station-Portland)	1	ea			
SUB-TOTAL					
				One Time	**Annual Recurring**
GRAND TOTAL					

The voyage of discovery is not in seeking new landscapes but in having new eyes.
Marcel Proust

2.0 Introduction

Over the coming months there will be a series of White Papers and Trade-off Studies that deal with components of the Regional Scale (Cabled) Nodes (RSN) or the Regional Cabled Observatory (RCO) as it is referred to in the NSF-JOI-supported Conceptual Network Design documents that have been generated over the past 3 years within the Ocean Observatories Initiative (OOI). The OOI-RSN White Paper documents are being generated by the University of Washington for the Joint Oceanographic Institutions (JOI)., in part, as preparation for the programmatic Preliminary Design Review (PDR) to be held for the OOI in December of 2007 as called for in the Major Research Equipment and Facilities Construction Fund within NSF. It is our intent that each White Paper will become part of a more comprehensive RSN-oriented set of evaluation documents that will be accessible as the program evolves. Presently planned topical materials include the following: OOI-RSN WP #1 – The Wet Plant Primary Infrastructure; OOI-RSN WP #2 –Shore Station Options; and OOI-RSN WP#3 – Wet Plant Secondary Infrastructure. Additional documents will be completed during the year on topics that include Backhaul, Instrument Availability, Science Requirements, and Engineering Requirements.

One of the most transformational characteristics of the Ocean Observatories Initiative involves the delivery, throughout the ocean, the seafloor, and the sub-seafloor, of unprecedented, sustained levels of electrical power and high bandwidth communications over a volume the size of meso-scale ocean processes, or a tectonic plate (100's of km on a side). Next generation ocean scientists will continually capitalize on the existence of this novel infrastructure to design evolving and innovative sensing modalities, real-time, interactive experiments, and improved approaches to quantifying previously inaccessible processes that unfold rapidly or take decades to occur. Both the ocean and the sea floor are highly dynamic and poorly sampled systems because they are so remote and so difficult to study. The capability envisioned for the RSN system will allow breakthrough discoveries to take place of time and spatial scales that have not been possible. Dependable power, bandwidth and real-time, interactive access to the ocean 24/7/365 for decades will fundamentally revolutionize the ocean sciences.

This White Paper presents a technical trade-off study of Submarine Cable Landing Stations for the Regional Scale Cabled Nodes (RSN) component of the Ocean Observatories Initiative (OOI), a program overseen by the Joint Oceanographic Institutions, Inc., for the National Science Foundation. The system will be installed off the coast of Washington and Oregon at locations spatially coincident with the Juan de Fuca Plate and a suite of meso-scale oceanographic processes that operate in a 300- to 400-km wide swath that extends from south of Vancouver Island to southern Oregon. The conceptual evolution of this novel ocean research facility over many years has involved numerous scientific reports from community workshops and a number of Conceptual Network Design (CND) efforts. The current Conceptual Network Design is accessible at: http://www.orionprogram.org/PDFs/RevisedOOICND08Mar07.pdf .

The recommended submarine cable system configuration, presented in Figure 2 in this White Paper and fully described in the RSN Wet Plant Primary Infrastructure White Paper, will deliver unprecedented power and bandwidth to a full ocean environment, a capability that is one of the truly transformative components of the OOI. The approach developed over the past four years of work has been to configure a network of electro-optical cables that will provide multiple Gb/sec bandwidth and considerable, continuous electrical power to the ocean environment in the Northeast Pacific, from boreholes in the seafloor to the air-sea interface.

As part of this shore landing options study, we conducted a high-level analysis on the viability of constructing dedicated cable landing stations. We contemplated the option of constructing robust, seismic-hardened buildings as well as deploying small huts similar to a 20- or 40-foot shipping container. Both of these solutions would add considerable cost in the construction and operational phases of the project. By using one or more of the considerable number of existing commercial cable stations available on the Oregon coast, we could reduce construction cost, schedule risk, and long-term maintenance costs associated with owning infrastructure.

Toward these goals we have evaluated three existing cable stations on the Oregon coast. In an effort to better quantify the results of this study we made several assumptions. A key assumption, based on the recommendation of the Regional Scale Nodes Wet Plant Primary Infrastructure White Paper, is that the network will be in the Star configuration. From a shore station perspective, the key issue associated with the Star is that the cable lengths are minimized between shore cable station and individual nodes. We have also created a baseline for required space within the shore station, assuming that each cable segment will require 3 cabinets for Power Feed Equipment (PFE) and 1 cabinet for Submarine Line Terminating Equipment (SLTE). Each shore station would also require 1 cabinet for terrestrial Wave Division Multiplexing (WDM) equipment in support of a dark-fiber backhaul solution.

Of paramount importance in evaluating the various cable stations is the availability of commercial power and associated backup power. RSN power demands are considerable compared to commercial systems: a commercial trans-Pacific cable system operates at approximately 10,000V and current of less than 1A; we expect to run each segment of our network at 10,000V and dynamic currents up to 10A. This power demand clearly becomes a controlling factor in station selection. The magnitude of power required for this project is difficult for commercial undersea network operators to comprehend, and they are planning power audits to understand how their infrastructure can support this transformational research network.

A key challenge in researching this report was obtaining pricing information from commercial cable station owners. Commercial operators are reluctant to provide pricing for a project that they perceive as relatively distant in their future. This reluctance stems from the uncertainty of market conditions in the current mini-boom in the undersea communications market. Costs were estimated based on unit costs gathered from reliable sources. These cost estimates were modulated from a risk assessment based on the OOI Cost Estimating Plan (CEP). Risk assessments were assigned for each case based on technical, schedule, and cost.

Section 3.0 of this White Paper provides the key technical considerations for the evaluation of the cable landing stations. These Technical Considerations include discussions on Power Feed Equipment, types of power supplies, and Ocean Ground Beds. Section 4.0 presents narrative details, photographs, maps and tables listing positive and negative attributes, total cost, risk factor, and budget contingency for each cable landing station studied. Detailed cost tables have been difficult to obtain for the reasons provided above. Section 5.0 analyzes the shore station costs for a Ring configuration as part of the comparison of overall system costs between the Star and Ring configuration. Section 6.0 summarizes our recommendations based on the detailed analysis in this paper.

3.0 Key Technical Considerations

3.1 Introduction

The technologies used in the shore stations to provide power and communications to the wet plant have many functions and features that are shared with traditional submarine telecom shore stations, and some that are not. The differences are shown in Table 3, below.

Table 3. Comparisons between Submarine Telecom and RSN Requirements

	Submarine Telecom Shore Station	**RSN Cable Station**
SLTE Equipment	SDH/SONET or IP Submarine Telecom Grade, repeatered, wdm	IP Submarine Telecom Grade, unrepeatered, non-wdm
Total Wet Plant Power	10-20kW	50-100kW
Ocean Ground Bed	25 year, <1A	25 year, 5-10A
Reliability	Ultra high reliability/ availability is required	High reliability/availability is required, low time-to-repair required
Cost Considerations	Dollar cost of component failure is extremely high, cost of equipment is secondary consideration	Cost of component failure is interruption of data time-series, cost of equipment is a primary consideration

In this section, several of these key technologies are discussed and in some cases preliminary recommendations are made. All of the technology choices have cost, performance, schedule, and other considerations. More information is necessary before the final decisions are made.

3.2 Power Feed Equipment (PFE) Capacity and Quantity

Each of the primary and secondary nodes in the wet plant will have a nominal power capacity of 10kW. With the assumed initial configuration of the wet plant, there will be one primary and one secondary node (Subduction Zone) connected to the Warrenton Shore Station and four primary and three secondary nodes (Hydrate Ridge, Blanco, Node 5 and Axial) connected to the Pacific City Shore Station.

In addition to the power required to operate the initial configuration of the wet plant, some capacity should be added for future growth. In order to have some margin for transients, cable losses, etc., the PFE should have 20-50% excess capacity beyond the minimum requirement. Table 4 provides recommended PFE capacities.

The multiple PFEs at Pacific City/Nedonna could either be connected to each cable segment independently or could be combined in parallel to make a higher-capacity single bus. There are challenges with paralleling multiple PFEs so the basic design would be to power the cable segments independently. This would provide isolation between segments so a fault to a PFE would impact only a single cable segment.

Table 4. Recommended PFE Capacities as detailed in WP#1 Appendix B

	Initial Maximum Wet Plant Load	**Future Expansion Capacity**	**Maximum Wet Plant Load**	**Recommended PFE Capacity**
Warrenton				20-40kW
Subduction Zone	20kW	10kW	30kW	
Pacific City				60-100kW
Hydrate Ridge	30kW	10kW	40kW	
Blanco	10kW	10kW	20kW	
Axial	20kW	10kW	30kW	
Node 5	10kW	10kW	20kW	

PFE Testing/Troubleshooting Load

For testing and troubleshooting purposes, it is typical for submarine telecom shore stations to have a PFE dummy load with a capacity of at least the worst-case wet plant load and preferably the maximum capacity of the PFE. For a typical trans-Pacific submarine telecom system these loads would be on the order of 20kW.

For the RSN, it is recommended that each PFE have an independent dummy load able to dissipate its capacity.

Recommendation

Use independent PFEs for each cable segment. Include a dummy load with a capacity equal to the capacity of the PFE units.

3.3 Power Feed Equipment (PFE) Type

Submarine Telecom Class PFE

There is a class of “ultra-high voltage” submarine telecom grade PFE that is 12.5kV/1.6A/20kW. At 10kV, the maximum power capacity would be 16kW. This type of PFE is powered from a 48V battery bank.

These PFEs are built to a very high standard and require special components and design to allow conversion of 48V battery power to 12kV. The input low voltage results in high current draw from the batteries – 20kW/48V = 416A. Designing the PFE to handle 400A with minimal voltage drop results in a larger size and higher cost. A nominal 20kW submarine telecom PFE has a cost of approximately $1-2M.

Shipboard/Commercial Class PFE

There is also a class of PFE that has been used on cable installation ships to power submarine telecoms cables during installation that is 10kV/2A/20kW. This class is built to commercial quality/reliability, is AC powered and has a significantly lower cost. They are built using commercial off-the-shelf (COTS) 5kW modules and can be built with a capacity of up to 40kW. It is possible that the various cable segments could be equipped with a different number of 5kW modules to match the load requirement of the segment. A 20kW shipboard PFE is shown below in Figure 3.

Figure 3. Typical Cable Ship 20kW PFE

A 20kW PFE that is powered from 480VAC has a lower input current of only 24A and the losses (and the resulting engineering challenges) are much smaller. A nominal 20kW commercial PFE would have a cost of approximately $50-100k.

There also is the potential for a single large PFE with a capacity of 80-100kW or higher. This option would only be applicable to the cable station with three cable landings. A single PFE was dropped from consideration based on development of a shared power bus, as well as operational troubleshooting complexity.

NEPTUNE Canada will use two 80kW PFEs to power its wet plant – initially a single 80kW PFE will be used to power the cable from one end and as the number of users and the load increase, both PFEs can be used to power it from both ends.

Recommendation

Collect more information on commercial grade PFEs to get a better understanding of the risks associated with using commercial AC type of PFE as opposed to the traditional approach of using 48VDC submarine telecom type.

3.4 Utility Power

All of the existing shore stations that are being considered are currently supplied with 480VAC, 3 phase power. The exact utility power capacity of the stations is not known but is typically 300kW. In cases where the current tenant's power requirements are approaching the limit, it may be necessary to add an additional 300kW service panel.

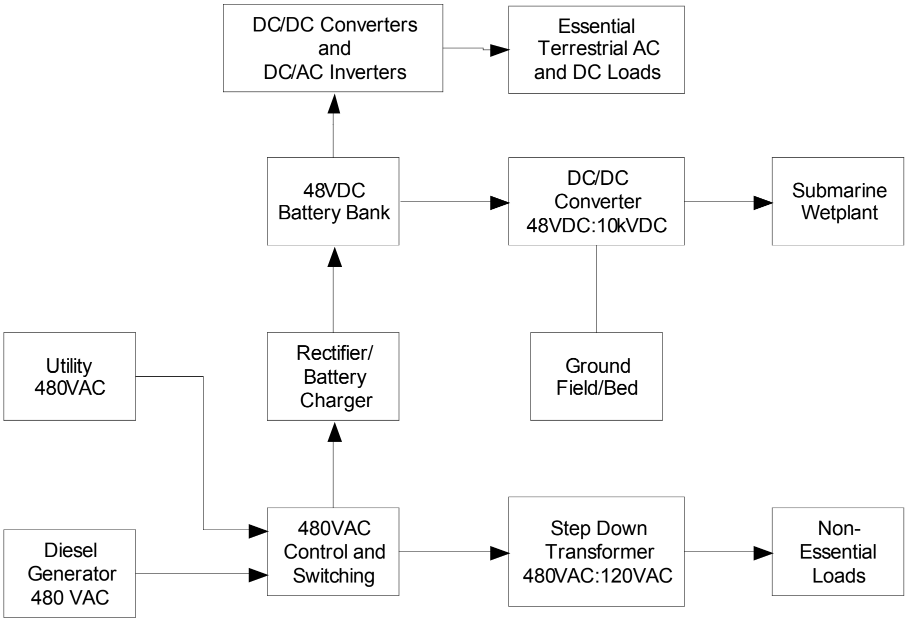
3.5 AC vs. DC Power Supply

DC Power

Traditional telecommunications equipment generally consists of multiple rectifiers that convert utility AC power to -48VDC power to charge lead-acid storage batteries that in turn supply power to the critical load equipment. When other voltages are required, DC-DC converters or DC-AC inverters are used to derive the other required voltages from the -48 VDC power plant. Long battery support times or engine-generator systems are required to support the critical load equipment in case of utility AC power failure. Traditional telecommunications battery support times range from a minimum of 1 hour to over 24 hours, with typical battery support times being 3 to 8 hours. Figure 4 is a block diagram of a typical traditional telecommunications power system using rectifiers and a -48VDC battery bank to support the critical load equipment.

Non-essential building power is fed off the main AC bus via a transformer. All essential loads are supplied from the batteries. With this type of system, only simple switching is required: the DC bus is fed by the batteries whether the AC feed is there or not and there is no need for generator synchronization with utility AC or DC-AC inverters.

Figure 4. Traditional Submarine Telecom DC Power System



A position paper describing and recommending DC power systems for telecom equipment has been written by the *Technical Subgroup on Telecommunications Energy Systems of the Power Electronics Society of the Institute of Electrical and Electronics Engineers, Inc.* and can be found at http://www.pels.org/Comm/Telecom/WhitePaper1_1/WHPAP11.pdf

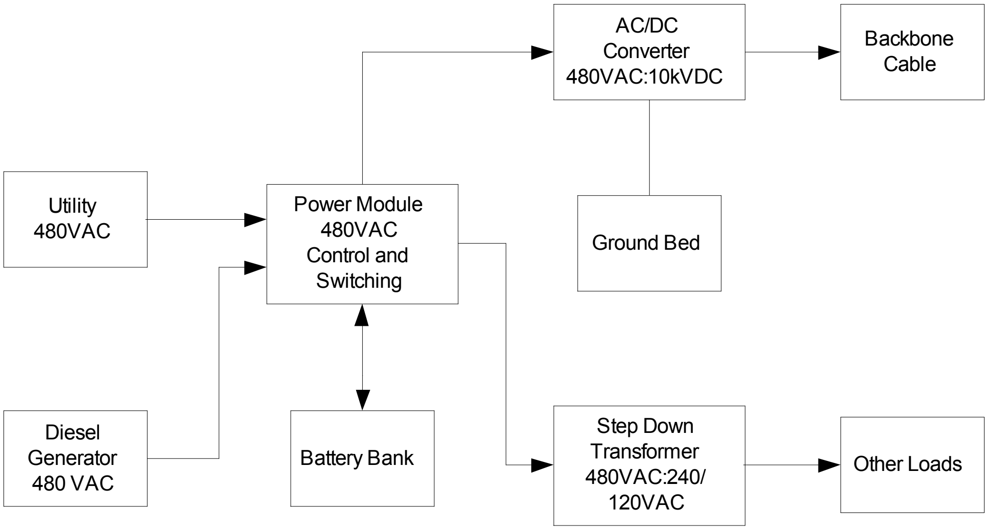
Due to the high power requirements of the RSN, an existing battery plant might not be able to supply the requred power, in which case the RSN may need to install a battery plant.

AC Power

Traditional information technology (IT) equipment generally uses AC input power, typically 120 or 240 VAC, single phase 60 Hz (in North America). Traditional IT power systems include AC UPS systems with battery systems sized to provide either the necessary time for an orderly shutdown or time to reliably get standby engine-generator power systems on line, typically 10-15 minutes. Figure 5 is an example of an implementation of a submarine telecom system using an AC UPS to support the critical load equipment. A paper written by a suppler of AC UPS equipment (partially in response to the DC paper mentioned above) can be found at http://www.liebert.com/support/whitepapers/documents/Intelec.pdf

AC power is readily available and a suitable size UPS would need to be procured for the RSN.

Figure 5. Submarine Telecom AC Power System



AC vs. DC Selection Criteria

<u>Reliability</u> The unavailability of AC vs. DC power systems has been calculated, with results as follow:

AC UPS, 10-minute battery =	3.5×10^{-10}
DC System with 8-hour battery =	9×10^{-10}

The AC UPS is relatively unaffected by battery size. Increasing the battery backup time to 3 hours yields approximately the same unavailability as the 10-minute battery. These calculations do not include many real-world issues like human error, maintenance, distribution failures, and other factors but do point out the relative dependencies on the various subcomponents.

In the case of DC power systems, the mitigating factor for reliability is the battery being directly connected to the load bus. For AC UPS systems, the mitigating factor for reliability and availability is the ability to provide an alternate source of power with the UPS bypass circuit. Despite the philosophical differences in powering perspectives, both the AC and DC powering approaches are feasible and both, when implemented properly, have been demonstrated to be very reliable**.**

Power Requirements of Load Equipment Another consideration is the total power requirement. The total shore station power requirement is unknown but the baseline estimate for the wet plant is 80kW. The preliminary estimate for the critical terrestrial equipment, including PFE is 100kW.

With 480VAC, 3 phase, this results in a high but manageable 120A. At -48VDC, this results in 2,100A, which would be difficult and expensive to manage and distribute without very large gauge wires, significant resistive losses, and/or voltage drops. Larger power systems requirements are better served by the higher voltage 3 phase AC power system.

The suggested criteria for selecting a RSN Power System UPS are provided in Table 5.

Table 5. Criteria for selecting a UPS System

Item	**AC System**	**DC System**
PFE Cost	X	
Cost of UPS vs. Battery Plant	X	
Legacy of use in submarine telecom systems		X
Simplicity		X
Reliability	X	X
Large Load Power Requirement – 100kW	X	

Recommendation

Further research is required to better understand the risks with using an AC-type UPS instead of the traditional submarine telecom approach of using a large 48VDC battery bank.

3.6 Generator Backup

Backup power systems generally include a generator capable of providing power to all loads during an extended failure of the utility source. The backup generator set includes a diesel engine generator capable of accepting the full system load–including the requirements of the shore station–with some overhead capacity for loads with start-up surges like HVAC pumps and compressors.

Upon sensing a power disturbance on the utility source in excess of two seconds duration (typical), the system control initiates startup of the generator. Once the generator is at operating voltage and frequency, the system control senses the voltage and frequency of the generator output, synchronizes the battery-powered inverter output with that of the generator, and switches the generator output to the load. Once the generator is switched to the load, the system control will smoothly ramp load current to the generator output. The rate of change of the current is maintained within the dynamic loading capability of the generator to ensure that proper voltage and frequency are maintained to the critical load. Once load transfer to the generator has been affected, the system draws additional energy from the generator to permit recharging of the batteries. After recharging has been completed, the system control initiates a return to the standby ready state. Upon return of the utility source, the system automatically transfers back the utility source.

Due to the large power requirement of the RSN, an existing generator at a co-location space may not be able to handle the increased load of the RSN and it may be necessary for the RSN to install a generator, even if there is an existing one.

Recommendation

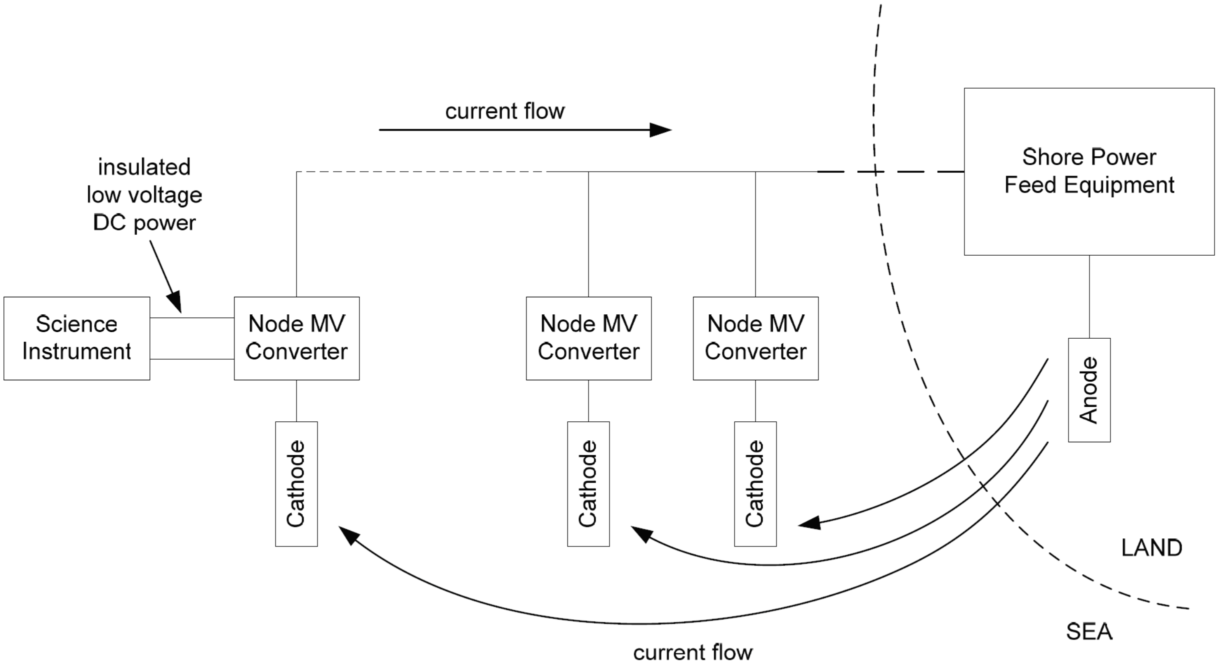
A backup generator of sufficient capacity is required at all shore station locations.

3.7 Ocean Ground Bed

Introduction

Because of the fact that the backbone cable only has a single copper power conductor, it is necessary to use the ocean as the return conductor to complete the electrical circuit. Figure 6 illustrates a typical ocean ground bed.

Figure 6. Typical Ocean Ground Bed



Beach Ground Bed Anode

Some submarine telecom systems use beach ground beds, which consist of a metallic plate located at the beach, either buried or laying on the seafloor in shallow water. The anode will be consumed during operation and needs to be sized appropriately. A cable from the anode would need to be trenched to the beach manhole and connected to the high side of the shore station PFE through the shore duct.

On-Shore Ground Bed Anode

Another technique that is used with telecom systems is to bury metallic rods (typically high-silicon iron) in the soil near the shore station. These rods would be electrically connected to each other and to the high side of the PFE output.

Both of these shore-side anodes will be consumed during operation and must be monitored, periodically tested, and possibly replaced if the rate of consumption is excessive. Some of the issues with onshore and beach ground beds are shown in the Table 6 below.

Table 6. Comparison of Deep, Shallow, and Seawater Anode Beds

Deep Onshore Ground Bed	**Advantages**	**Disadvantages**
	Very low resistance	Not maintainable
	Little seasonal variation	High cost
	Reduced interference	May fail completely – may need redundant bed
	Small surface expression	Long construction time
Shallow Onshore Ground Bed	Low cost	High cost to achieve very low resistance
	Proven design	Seasonal variations
	Maintainable	May fail completely – can be quickly repaired
		Large surface expression
Beach Ground Bed	Low cost	Difficult to install if buried
	No seasonal variance	Difficult to maintain
	Low resistance to seawater	May require special permitting

Science Node Cathode

The input of the MV converter in the primary and secondary Nodes would connect to the backbone cable conductor and to a metallic electrode (cathode) that is in contact with the seawater. A reasonable material for this cathode is platinized titanium. The cathode is not consumed during operation and should not require maintenance or replacement.

Recommendation

Continue researching the options for electrode materials and configurations.

4.0 Comparison of Landing Stations

4.1 Warrenton, Oregon Cable Station

General

The Warrenton Cable Station is owned by GCI – a publicly traded, full service, commercial and residential communications company serving the major metropolitan areas of Alaska. In 1999, GCI completed construction of its first undersea cable linking Washington and Alaska. As GCI and the Alaskan market grew, construction of a diverse undersea cable was undertaken and the link between Oregon and Alaska was completed in 2005. The Warrenton Cable Station was specifically constructed by GCI as the landing point for this cable. These two undersea cables comprise the Alaska United Fiber System (AUFS), providing redundant communications links between Alaska and the mainland United States with onward connectivity to the rest of the world.

The Station is located within a residential area and is of wood-frame construction so as to provide an aesthetically pleasing mix with existing homes. A second structure is located on the property and is used for the storage of outside plant and other equipment not requiring a controlled environment. Figure 7 shows the exterior.

Figure 7. Warrenton Station, Exterior

Space

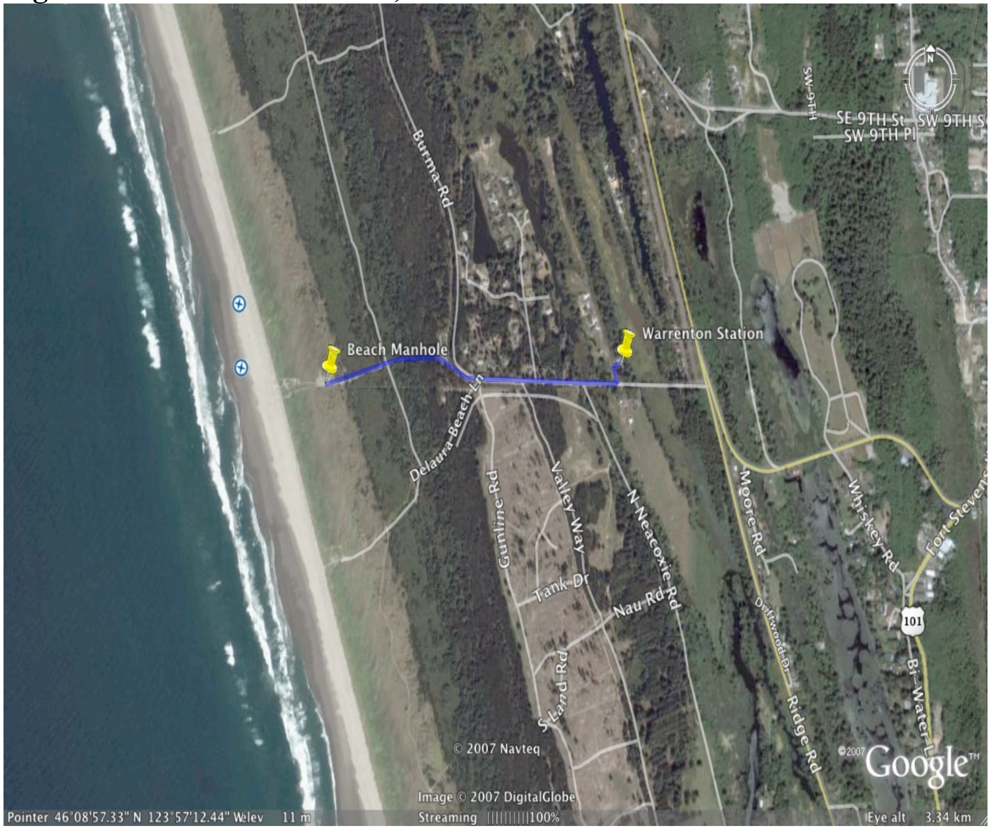
The main drawback to Warrenton is that the existing cable station structure is space limited. Although ample space is available on the property, expansion would require construction of an addition to the existing building. We expect that Warrenton can easily support one additional cable and depending on the configuration may support a second. Figure 8 shows the available co-location space.

GCI has confirmed that duct is available for at least one cable between the beach manhole and the station. Although expensive, installation of additional duct would not be a problem as the route to the beach is along tertiary roads.

The existing beach manhole is large enough to land multiple additional undersea cables. AUFS has installed an ocean ground bed in close proximity to the beach manhole. Figure 9 shows the route to the beach manhole. No bore pipes are available to land new cables across the beach. Directional drilling would be required from the beach manhole to a water depth of approximately 15 meters. As long as drilling were undertaken during winter months, no significant obstacles to permitting would be anticipated.

Figure 8. Warrenton Station, Available Colocation Space

Figure 9. Warrenton Station, Route to Beach Manhole



Building Management

Warrenton is an unmanned station. A local electronics company is contracted to provide on-call technicians available for remote-hands work, on a pay per use basis. On-call technicians can be onsite within 30 minutes. Through the building management system, the GCI Network Operations Center in Alaska provides 24/7/365 monitoring of the facility. The building management system monitors power, environmental conditions, security and fire. Security features include fenced property, internal/external closed circuit television cameras, and intrusion detection system. The facility is fitted with state of the art fire detection and primary suppression systems.

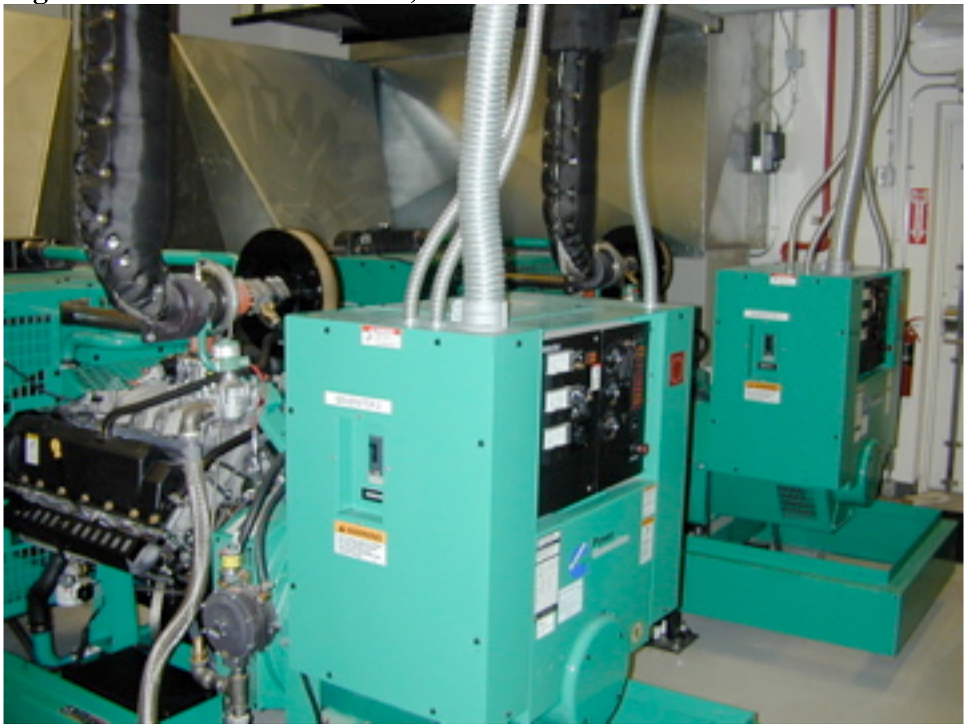
Electrical

The facility is provided commercial AC power from two separate grids, but due to the rugged nature of the Oregon coast has experienced power outages lasting up to 8 hours. Back up power is provided through a redundant 48V DC battery plant (Figure 10), as well as an UPS unit for limited AC power. Redundant 100kW generators (Figure 11), fueled by 4800 pounds of natural gas, augment the battery plants.

GCI has not yet been able to provide figures on the capacity of their commercial AC power feeds, or how much protected power that they would contractually commit to the RSN. Because only one commercial undersea cable currently lands in the building, we suspect that sufficient electrical capacity is available to support at least 1 landing of the RSN.

Figure 10. Warrenton Station, Battery Plant

Figure 11. Warrenton Station, 2x100kW Generator Sets



Backhaul

Dark fiber is not currently available for a backhaul solution. Dark fiber to Hillsboro/Portland is available nearby, and GCI has indicated that they would be interested in a joint build. GCI accomplishes their backhaul using managed bandwidth from Northwest Open Access Network (NoaNet). NoaNet represents Public Utility Districts that have linked their fiber optic networks together to provide wholesale long haul and last-mile bandwidth throughout the Pacific Northwest. Insufficient data are available to accurately analyze the financial impacts of either of these solutions.

Table 7 provides a summary of the Warrenton attributes and costs.

Table 7. WARRENTON CABLE STATION	
POSITIVE ATTRIBUTES	**NEGATIVE ATTRIBUTES**
No improvements required for single cable	**Limited expansion capability**
Reduced cable distance to N4	
Uncongested cable landing	

STATION COST	**RISK FACTOR**	**CONTINGENCY**	**TOTAL COST**
	23%		

Details on file with JOI

Warrenton, OR Cable Station					
single landing					
	Unit		**Unit Price**	**Full Price**	
				One Time	**Annual Recurring**
Equipment Cost					
PFE	1	ea			
SLTE	1	ea			
Terrestrial WDM	2	ea			
Infrastructure Cost					
Cable Station Colocation					
pfe	3	cabinet			
slte	1	cabinet			
terrestrial wdm	1	cabinet			
Power install	400	Amp			
Duct (Station-Beach Manhole)	1	ea			
install 3 sub-duct	1	ea			
Beach Manhole	1	ea			
Land Cable BMH-Station	1	ea			
Ocean Ground Bed	1	ea			
Dark fiber (Station-Portland)	1	ea			
TOTAL					
Assumption: Includes all equipment and installation shoreward of beach manhole.					

4.2 Nedonna Beach, Oregon, Cable Station

General

The Nedonna Beach cable station is owned by WCI Cable, which is owned by an investment vehicle of the Carlyle Group. WCI provides mostly wholesale communications services between Alaska and Oregon. In 1999, WCI completed construction of their undersea cable named Northstar including the cable station at Nedonna Beach. The cable station was constructed with the vision that Oregon would become a key, west coast, landing point for future undersea cables. Nedonna currently supports five undersea cable segments with a sixth segment to be installed by the spring of 2008.

The Station is located along a sparsely populated area, on a major north-south highway. Construction reflects the robust nature of the Oregon coast, with commercial grade cinder block construction, reinforced for Seismic Zone 4 conditions (Figure 12). Ample storage yards adjacent to the property are owned by WCI.

Figure 12. Nedonna Station, Exterior

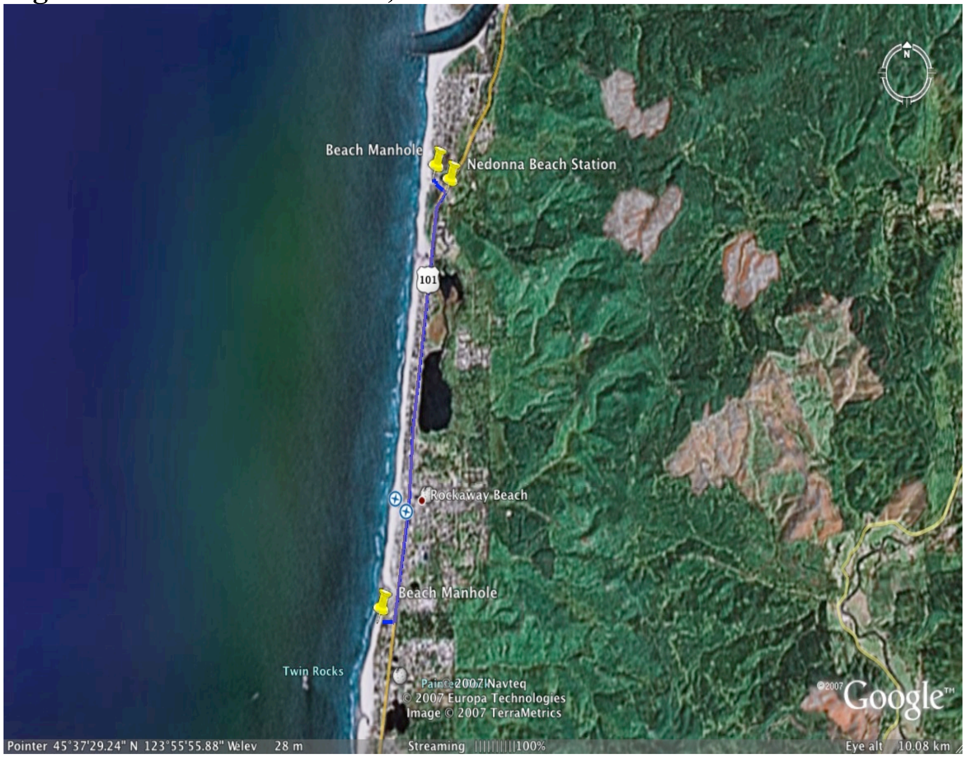
Space

Nedonna has sufficient space to support all possible configurations of the RSN. The main drawback to Nedonna is that the only remaining available space has not yet been fit out for use as colocation space. The existing core and shell state of the colocation room (Figure 13) require the installation of internal walls, overhead ladder racking, power, heating ventilation air conditioning (HVAC), security, fire detection/suppression, and fiber patch panels.

Nedonna supports two diverse cable landings, located at Nedonna Beach and Rockaway Beach. Multiple beach manholes exist at each landing, but space may not support more than two additional undersea cables at each landing (Figure 14).

Figure 13. Nedonna Station, Available Colocation Space

Figure 14. Nedonna Station, Route to Both Beach Manholes



Building Management

Nedonna is manned during normal business hours with an employee of WCI. On a contract basis, WCI provides remote-hands technicians immediately available during business hours or after hours on a 2-hour response. Through the building management system, the WCI Network Operations Center in Hillsboro, Oregon provides 24/7/365 monitoring of the facility. The building management system monitors power, environmental conditions, security and fire. Security features include fenced property, internal/external closed circuit television cameras, proximity card reader access on all doors, and intrusion detection system. The facility is fitted with state of the art fire detection and primary/secondary fire suppression systems.

Electrical

The facility is provided commercial AC power from a single grid. WCI has identified and priced a dual-grid solution but has not been able to substantiate a business case for execution. During this past winter's windstorms the facility was without commercial power for 4 days. WCI indicated that this 4-day outage would not have been reduced by implementation of a dual grid commercial feed.

Back up power is provided through a redundant 48V DC battery plant (Figure 15), as well as a UPS unit for limited AC power. Redundant 450kW generators (Figure 16), fueled by 10,000 gallons of diesel fuel, augment the battery plants. It was noted that the 48V DC battery plant consisted of dry cell batteries, which are maintenance intensive and require replacement every 5-7 years.

WCI has not yet been able to provide figures on the capacity of their commercial AC power feed, or how much protected power that they would contractually commit to the RSN. By 2008 when six commercial undersea cable systems land in the building, it is difficult to estimate the available capacity without additional information from WCI. This section will be updated as soon as the information becomes available.

Figure 15. Nedonna Station, Battery Plant

Figure 16. Nedonna Station, 2x450kW Generator Sets

Backhaul

Ample diverse backhaul solutions are available from this facility back to Hillsboro/Portland. Dark fiber and terrestrial repeater colocation space can be obtained directly from either WCI or VSNL. Similarly, managed bandwidth can be obtained from multiple parties. Insufficient data is available to analyze the financial impacts of either of these solutions.

Table 8 provides a summary of Nedonna attributes and cost.

Table 8. NEDONNA BEACH CABLE STATION

POSITIVE ATTRIBUTES	NEGATIVE ATTRIBUTES
First class communications facility	**Colocation space needs to be fit out**
Two diverse landings available	**Congested landing, many cable crossings**
Ample expansion space	

STATION COST	RISK FACTOR	CONTINGENCY	TOTAL COST
	30%		

Details on file with JOI

Nedonna Beach, OR Cable Station					
single landing					
	Unit		**Unit Price**	**Full Price**	
				One Time	**Annual Recurring**
Equipment Cost					
PFE	1	ea			
SLTE	1	ea			
Terrestrial WDM	2	ea			
Infrastructure Cost					
Cable Station Colocation					
pfe	3	cabinet			
slte	1	cabinet			
terrestrial wdm	1	cabinet			
Power install	400	Amp			
Duct (Station-Beach Manhole)	1	ea			
install 3 sub-duct	1	ea			
Beach Manhole	1	ea			
Land Cable BMH-Station	1	ea			
Ocean Ground Bed	1	ea			
Dark fiber (Station-Portland)	1	ea			
TOTAL					
Assumption: Includes all equipment and installation shoreward of beach manhole.					

4.3 Pacific City, Oregon Cable Station

General

MetLife, as the debt holder of the bankrupt North Pacific Cable (NPC), owns the Pacific City Cable Station. NPC was constructed in 1991 as the first private undersea cable in the Pacific Ocean and provided connectivity between Oregon, Alaska and Japan. By 2005 NPC's relatively low capacity was no match for the new high-capacity systems and was forced into bankruptcy. The Station was closed on short notice in 2005 at the time of bankruptcy and little was done to mothball the infrastructure. However as the below photos indicate, the building appears to be in surprisingly good condition both inside and out. Currently, at least one party is looking to purchase the asset and refurbish the facility as an alternative landing to Nedonna Beach. With only one out-of-service undersea cable landing at the Station, this is a unique opportunity for an anchor tenant to enter the facility. The expected deployment date of the RSN provides sufficient time for the refurbishment of the facility.

The Station is located in a densely populated expanding beach vacation community. Construction reflects the robust nature of the Oregon coast, with commercial-grade cinder block construction (Figure 17). Reinforcement for Seismic Zone conditions could not be verified at the time of inspection. Ample storage yard space is available on the 5-acre property.

Figure 17. Pacific City Station, Exterior

Space

Pacific City has sufficient space to support all possible configurations of the RSN. The main drawback to Pacific City is that early commitment to the facility may be necessary for an investor to support a business plan to refurbish the property. Aside from the refurbishment of infrastructure, the transmission rooms (Figure 18) require only the removal of the old NPC equipment.

Drawings onsite confirm that in addition to the duct for the out-of-service cable, at least one additional duct is available between the station and the beach manhole. Although expensive, installation of additional duct would be possible.

The existing beach manhole was covered by sand and could not be observed, but pictures onsite indicated that at least 1 additional cable could be landed. Figure 19 depicts the route between the cable station and the beach manhole.

The location of the ocean ground bed could not be determined but the Station property was large enough that it should be able to be supported.

The original cable was installed before bore pipe was required from the beach manhole to a water depth of 15 meters. As long as drilling is undertaken during winter months, no significant obstacles to permitting are anticipated.

Figure 18. Pacific City Station, Portion of Transmission Room

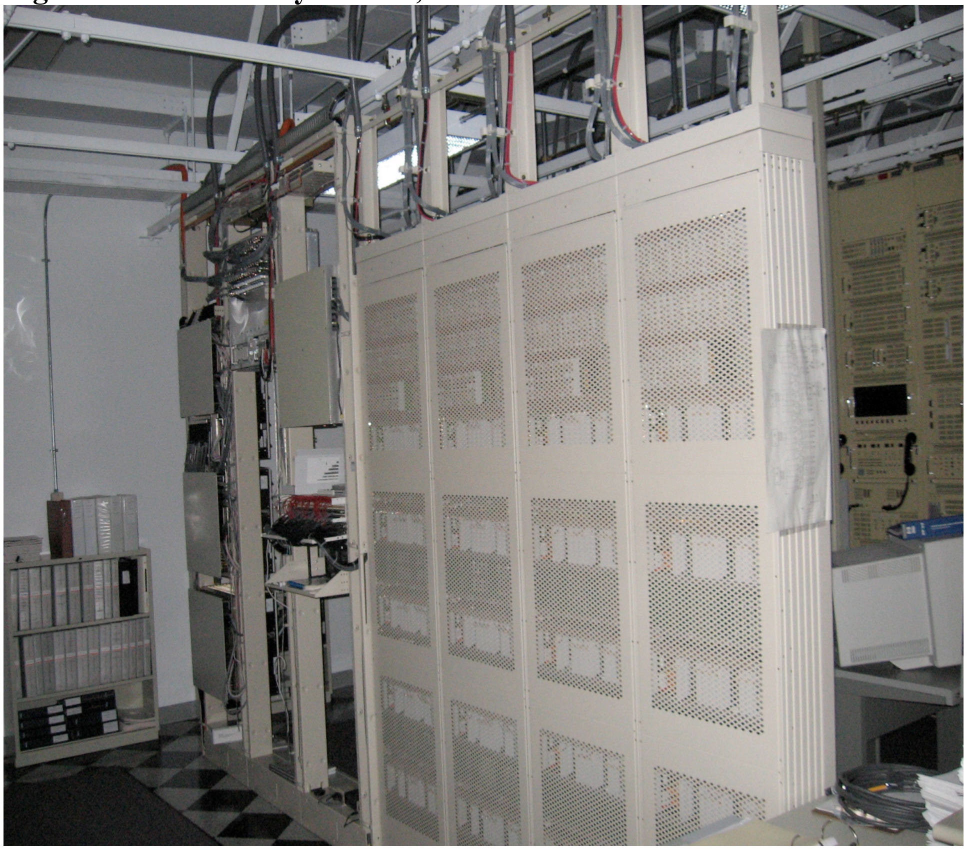
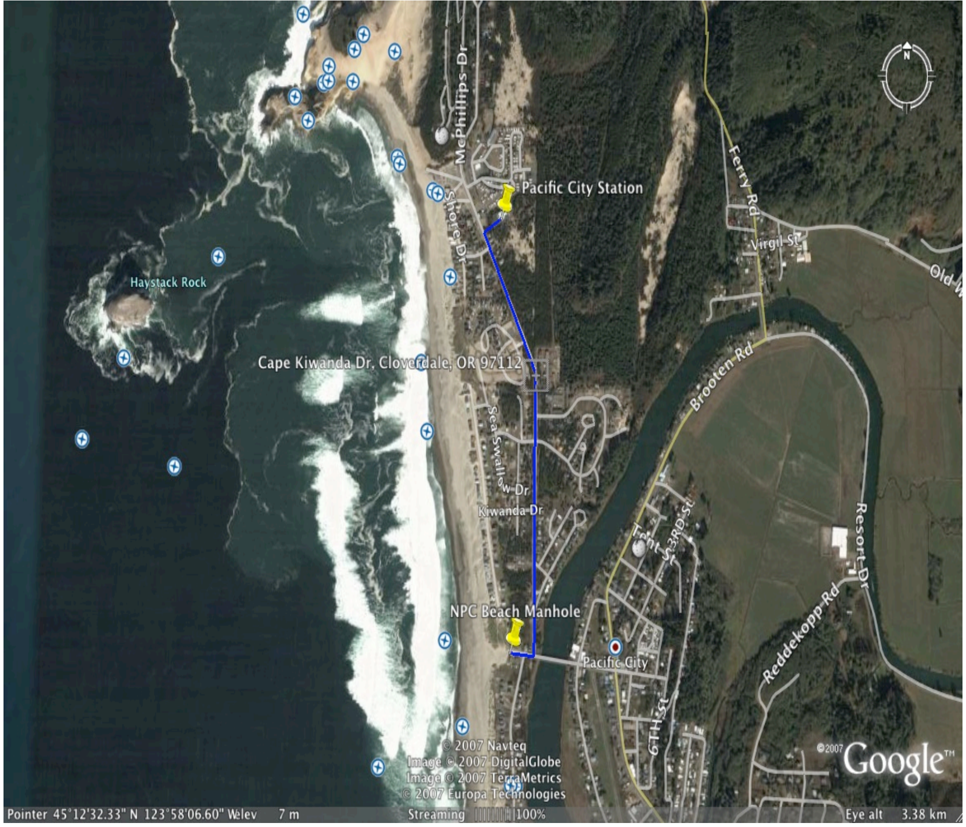


Figure 19. Pacific City Station, Route to Beach Manhole



Building Management

Pacific City has been shutdown for approximately two years with no caretaker. The facility was initially fitted with a building management system that was monitored from the NPC Network Operations Center in Portland. The building management system appears to have the capability to monitor power, environmental conditions, security and fire. Security features include fenced property, internal/external closed circuit television cameras, and intrusion detection systems. The facility is fitted with fire detection and primary suppression systems. It must be expected that any new owner will need to refurbish and updated these systems.

Electrical

The facility is provided commercial AC power from a single grid. Commercial power to the building was shut off shortly after the bankruptcy and the generators ran for almost a week till the neighbors called to complain about the noise.

Back up power is provided through a redundant 48V DC battery plant (Figure 20), as well as a UPS unit for limited AC power. With no charge for almost 2 years, it is expected that the battery strings will need to be replaced. Redundant 300kW generators (Figure 21), fueled by 10,000 gallons of diesel fuel, augment the battery plants.

The representative for MetLife was unable to provide figures on the capacity of the commercial AC power feeds, or how much protected power the battery plant was capable of supporting. However as anchor tenant we would expect to have access to all available power.

Figure 20. Pacific City Station, Battery Plant

Figure 21. Pacific City Station, 2x300kW Generator Sets

Backhaul

Diverse backhaul solutions are available from this facility to Portland. One of the bankruptcy assets is a dark-fiber pair between Pacific City and the Pittock Building in Portland. Previously the route had a terrestrial repeater halfway along the route at a satellite earth station owned by NPC. The earth station was sold off but the new owner is not using the property and a lease for a small repeater hut could most likely be obtained. Qwest also has a diverse route to Portland available within the building, but it was not clear from the MetLife representative whether at one point NPC had a lease on the dark fiber or whether Qwest was offering managed bandwidth. Insufficient data are available to analyze financial impacts of either of these solutions.

Table 9 provides a summary of Pacific City attributes and costs.

Table 9. PACIFIC CITY CABLE STATION	
POSITIVE ATTRIBUTES	**NEGATIVE ATTRIBUTES**
1st tenant so access to all available power	Landlord must obtain property
Uncongested cable landing	Overhaul/update of infrastructure
Reduced cable distances to N1 & N2	
Colocation space ready for service	
Ample expansion space	

STATION COST	**RISK FACTOR**	**CONTINGENCY**	**TOTAL COST**
	30%		

Details on file with JOI

Pacific City, OR Cable Station					
single landing					
	Unit		**Unit Price**	**Full Price**	
				One Time	**Annual Recurring**
Equipment Cost					
PFE	1	ea			
SLTE	1	ea			
Terrestrial WDM	2	ea			
Infrastructure Cost					
Cable Station Colocation					
pfe	3	cabinet			
slte	1	cabinet			
terrestrial wdm	1	cabinet			
Power install	400	Amp			
Duct (Station-Beach Manhole)	1	ea			
install 3 sub-duct	1	ea			
Beach Manhole	1	ea			
Land Cable BMH-Station	1	ea			
Ocean Ground Bed	2	ea			
Dark fiber (Station-Portland)	1	ea			
TOTAL					
Assumption: Includes all equipment and installation shoreward of beach manhole.					

4.3 Newport, Oregon

General

During the *i*OSC meeting held in Washington DC the week of 18 June 2007 a request was made to review the possible use of Oregon State University's, Hatfield Marine Sciences Center as a possible landing for segments of the RSN. The University of Washington Cable Station Team has not had an opportunity to visit HMSC but have been provided with preliminary information and awaiting responses to clarification questions.

In the time frames of this report, it is not feasible to appropriately investigate and address the financial, operational and technical risks involved with using a site that has never landed an undersea cable.

Space

Although not purpose built as a cable station, reports from the site indicate that sufficient space is available to support three segments of the RSN. An existing 600 ft^2 datacenter is approximately 25% occupied with IT infrastructure and an additional previously fit datacenter of 180 ft^2 is available.

Building Management

Newport is manned during normal business hours by Oregon State University (OSU) Network Analysts. No discussions have taken place on the ability, required training, or response times, for OSU to provide remote hands services. The existing datacenter is fitted with an APC system for monitoring power and environmental conditions. Additional discussions are required to understand how alarms are reported and responded to outside of normal business hours. Security features include cameras and proximity card reader access on main doors. The facility is fitted with a fire detection system.

Electrical

The facility is provided commercial AC power from a single grid. Depending on the number of segments landed at this site, additional commercial power may be required.

Back up power for the existing datacenter is provided by several standalone UPS systems. The facility also has one 60kW generator with a 50 gallon fuel tank, and one 225kW generator with a 200 gallon fuel tank. The configuration and switching gear for the generators are unknown at this time. A 48V DC battery plant is not available.

Backhaul

The facility currently has fiber optic connectivity and is provided with a 100mb/s Ethernet circuit from CoastCom. CoastCom was founded as a Competitive Local Exchange Carrier in the Newport area, and now operates two fiber optic networks. One of these networks is a public/not for profit entity led by the Economic Development Alliance of Lincoln County, and the other network is for a Tillamook County intergovernmental agency. Details of managed bandwidth at the 10Gb/s or dark fiber to Hillsboro/Portland area are not immediately available.

5.0 Ring Configuration Landings

As a benchmark for the recommendation to proceed with a Star configuration, analysis was done of the shore station and backhaul costs for construction of a Ring configuration with two different landing stations. The two generic stations differ only in the added cost of colocation for one versus no colocations costs in the other. Although it would be inappropriate to directly compare the shore station and backhaul costs of the two configurations, the costs provide additional data points that, when combined with the wet plant costs, are a preliminary comparison of the overall construction costs for Ring vs. Star. The two-station choice ensures redundancy in that wholesale failure in one station could not cause the entire network to fail.

Table 10 provides the detailed costs associated with the shore station and backhaul costs of a Ring configuration with a single shore station, while Table 11 represents a Ring configuration with two physically diverse cable stations. Comparison of total system cost for the Star and both Rings are summarized in Table 12.

Details on file with JOI

Table 10. Ring Configuration Landing Costs, One Cable Station

Station #1					
Double landing					
	Unit		**Unit Price**	**Full Price**	
				One Time	**Annual Recurring**
Equipment Cost					
PFE	2	ea			
SLTE	2	ea			
Terrestrial WDM	2	ea			
Infrastructure Cost					
Cable Station Colocation					
pfe	6	cabinet			
slte	2	cabinet			
terrestrial wdm	1	cabinet			
Power install	800	Amp			
Duct (Station-Beach Manhole)	2	ea			
install 3 sub-duct	2	ea			
Beach Manhole	2	ea			
Land Cable BMH-Station	2	ea			
Ocean Ground Bed	2	ea			
Dark fiber (Station-Portland)	1	ea			
GRAND TOTAL					

Details on file with JOI

Table 11. Ring Configuration Landing Costs, Two Cable Stations

Station #1					
single landing					
	Unit		**Unit Price**	**Full Price**	
				One Time	**Annual Recurring**
Equipment Cost					
PFE	1	ea			
SLTE	1	ea			
Terrestrial WDM	2	ea			
Infrastructure Cost					
Cable Station Colocation					
pfe	3	cabinet			
slte	1	cabinet			
terrestrial wdm	1	cabinet			
Power install	400	Amp			
Duct (Station-Beach Manhole)	1	ea			
install 3 sub-duct	1	ea			
Beach Manhole	1	ea			
Land Cable BMH-Station	1	ea			
Ocean Ground Bed	1	ea			
Dark fiber (Station-Portland)	1	ea			
SUB-TOTAL					

Table 11. Ring Configuration Landing Costs, Two Cable Stations (*cont.*)

Station #2					
single landing					
	Unit		**Unit Price**	**Full Price**	
				One Time	**Annual Recurring**
Equipment Cost					
PFE	1	ea			
SLTE	1	ea			
Terrestrial WDM	2	ea			
Infrastructure Cost					
Cable Station Colocation					
pfe	3	cabinet			
slte	1	cabinet			
terrestrial wdm	1	cabinet			
Power install	400	Amp			
Duct (Station-Beach Manhole)	1	ea			
install 3 sub-duct	1	ea			
Beach Manhole	1	ea			
Land Cable BMH-Station	1	ea			
Ocean Ground Bed	1	ea			
Dark fiber (Station-Portland)	1	ea			
SUB-TOTAL					
				One Time	**Annual Recurring**
GRAND TOTAL					

Technical analysis of the risk mitigation factors associated with the Star configuration can be found in OOI-RSN WP #1 – Wet Plant Primary Infrastructure.

Table 12. System Cost - Star vs. Ring

Configuration	**Wet Plant Index**	**Shore Station/Backhaul Index**	**TOTAL SYSTEM COST**
Star	110	124	$57.192M
Ring (1 cable station)	127	100	$59.237M
Ring (2 cable stations)	127	108	$60.287M

The data in Table 12 depicts the overall cost of the STAR configuration against the Ring configurations of a single cable station as well as two physically diverse stations. Both configurations of the Ring were included to show comparison with the single station model presented at CND, as well as a two station model which would be more consistent with the philosophy of a physically diverse Ring.

6.0 Recommendations

6.1 Discussion

In response to the recommendation of the Regional Scale Nodes (RSN) Wet Plant Primary Infrastructure White Paper, a preliminary study was undertaken to review possible landing sites within the Pacific Northwest. This paper has identified three possible cable landing sites along the Oregon coast. Each site was visited by a Team from the University of Washington to evaluate the condition and suitability to support the RSN.

Three key criteria were identified for site selection that would optimize the cost, installation and future maintenance of the RSN. The criteria are 1) minimize cable segment lengths to individual nodes; 2) availability of power; and 3) availability of backhaul connectivity.

In minimizing cable lengths to individual nodes, it was determined that the optimal configuration would involve landing at two physically diverse cable stations. Incremental costs for choosing two cable stations were identified to reside in cable landing permits, mobilization of the bore pipe drill rig and the additional backhaul. These increased costs are offset by elimination of the need for repeaters in the wet plant, as well as the virtual elimination of thirty-six undersea cable crossings.

Delivering sufficient electrical power to the ocean floor is one of the key transformational qualities of the RSN project. The RSN power requirements significantly surpass those of a commercial undersea cable. It is clear that sufficient power could be obtained at all sites, but levels of effort and cost to upgrade commercial power feed, battery plants, and generators vary. Our selection optimizes the use of immediately available power.

Our evaluation of backhaul connectivity focused on the ability to obtain dark fiber from the cable landing station to major communications Points of Presence within the Portland/Hillsboro area. We chose to focus primarily on dark-fiber solutions as they provided the most bandwidth flexibility. The procurement of managed bandwidth, up to the 10Gb/s level, is available for both lease and purchase. Further analysis of this issue will be undertaken as the long-term bandwidth forecasts and final network architecture are solidified.

6.2 Capability Matrix

To assist in quantifying the suitability of the various cable stations, a simple matrix was developed to rank the key attributes associated with the RSN project. Individual rankings for each station were totaled to provide a relative score of suitability (Table 13).

Table 13. Station Capability, Ranking by Category (1 = high rank; 4 = low rank)

Station	Power	Space	Segment Length	Backhaul	Schedule	TOTAL
Newport	4	4	1	4	3	16
Warrenton	2	3	1	3	1	10
Nedonna Beach	3	2	2	1	2	10
Pacific City	1	1	1	2	2	7

The table is meant to be a simple representation of the ordinal rankings of each site, based on five cable station infrastructure requirements. The higher the score the less desirable a site is ranked based on the three risk factors of Technical, Cost and Schedule.

6.3 Risk Summary

Table 14, Risk Summary, presents the percentages used to calculate the risk factor for each of the cable landing stations. Details on how the factors and contingencies were calculated are included in OOI-RSN WP#1 Appendix A.

Table 14. Risk Summary

STATION	TECHNICAL	COST	SCHEDULE	RISK
WARRENTON	6*2%	3*1%	8*1%	23%
NEDONNA BEACH	8*2%	6*1%	8*1%	30%
PACIFIC CITY	8*2%	6*1%	8*1%	30%

Overall, Warrenton has a lower risk rating compared to the other two landing sights. The key issues working in Warrenton’s favor are immediately available electrical infrastructure and connectivity between the beach manhole and cable station. The risks for Pacific City are associated with a third party obtaining title to the property, refurbishment of the station infrastructure, and additional construction work between the beach manhole and cable station. Nedonna is considered to be on a similar risk level as Pacific City based on the fact that there is currently no available fit out colocation space, additional commercial power may need to be built into the facility, and partial construction requirements between beach manhole and cable station. All the facilities received a high Schedule risk, since they are critical path items that control the completion of the project.

6.4 Conclusion

Our recommendation is for planning cable terminations in both the Warrenton and Pacific City cable landing stations. Warrenton would have a single cable landing for connectivity to Node 4, and Pacific City would have three cable landings for connectivity to Nodes 1, 2, 3 and 5.

As Warrenton is an existing cable station with infrastructure immediately available to support one cable landing, this segment could be a candidate for early installation. Early installation could enable quicker time to science, and provide insight to the richness of data that full plate array sensors will provide. Further analysis of schedule and cost are required to evaluate this opportunity.