Sustainable Design Guidelines to Support the Washington State Ferries Terminal Design Manual:

Design Guideline Application and Refinement

WA-RD 816.2

Michael Wolcott
Cara Poor
Liv Haselbach

August 2013



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WSDOT Research Report

Sustainable Design Guidelines to Support the Washington State Ferries Terminal Design Manual: Design Guideline Application and Refinement

Final Report: August 2013

Submitted by:

Michael P. Wolcott
Cara Poor
Liv Haselbach
Washington State University
Pullman, WA 99164

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16. ABSTRACT

The Sustainable Design Guidelines were developed in Phase I of this research program (WA-RD 816.1). Here we are reporting on the Phase II effort that "beta-tested" the Phase I Guidelines on example ferry terminal designs and refinements made to the tool. The specific objectives of this project are to:

1. Cite example WSF terminal projects that would serve as candidates for assessing the Sustainable Design Guidelines,
2. Compile and analyze site and resource attributes influencing the design needs,
3. Develop a "20% design" for each of the example terminals,
4. Refine the Draft Sustainable Design Guideline,
5. Develop preliminary data on the efficacy of sample stormwater design solutions,
6. Develop a database tool for GRIP, the proposed Green Rating Integration Platform for WSF.

This project represents the second phase in a three-part effort. The final component will develop and potentially demonstrate specific solutions that present unique opportunities will be deployed in Phase III.

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Introduction

This report presents the application and the refinement of the design guidelines developed in Phase I of this research program. This research is supporting a terminal design manual currently being developed by the Washington State Ferries (WSF) Terminal Engineering Division of the Washington State Department of Transportation (WSDOT) that will guide new projects towards meeting appropriate standards for terminals. The WSF Terminal Design manual is not expected to fully address sustainable design standards. However, WSDOT is challenged with two major initiatives that could potentially impact terminal design:

1. Governor Christine Gregoire issued Executive Order 09-05 (Washington's Leadership on Climate Change) that directed the WSDOT to coordinate with regional entities to develop a sustainable transportation plan. Although not explicitly called out in the Executive Order, sustainable design standards have a clear influence on Sustainable Transportation and are being investigated elsewhere within WSDOT (PCHB 2008).
2. The use of Low Impact Development (LID) techniques to control stormwater has recently become the preferred options in Washington State after two Pollution Control Board rulings (PCHB 2009).[1,2]

These initiatives address both the energy and water use of the facilities. Although WSF is not explicitly bound by either of these developments, it is prudent to investigate the likely sustainable design issues facing terminal development.

The Sustainable Design Guidelines were developed in Phase I of this research program. Here we are reporting on the Phase II effort that "beta-tested" the Phase I Guidelines on example ferry terminal designs and refinements made to the tool. The specific objectives of this project are to:

7. Cite example WSF terminal projects that would serve as candidates for assessing the Sustainable Design Guidelines.
8. Compile and analyze site and resource attributes influencing the design needs,
9. Develop a "20% design" for each of the example terminals,
10. Refine the Draft Sustainable Design Guideline
11. Develop preliminary data on the efficacy of sample stormwater design solutions,
12. Develop a database tool for GRIP, the proposed Green Rating Integration Platform for WSF.

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[1] Pollution Control Hearings Board. PSA vs. Ecology, Findings of Fact, Conclusions of Law, and Order Phase I August 2008. Accessed November 2008. www.eho.wa.gov/searchdocuments/2008%20archive/pchb%2007-021,07-026,07-027,07- 028,07-029,07-030,07-037%20phase%20i%20final.pdf

[2] Pollution Control Hearings Board. PSA vs. Ecology, Findings of Fact, Conclusions of Law, and Order Phase II February 2009. Accessed March 2009. www.eho.wa.gov/searchdocuments/2009%20archive/pchb%2007-022,07-023%20findings%20of%20fact%20conclusions%20of%20law%20and%20order.pdf

This project represents the second phase in a three-part effort. The final component will develop and potentially demonstrate specific solutions that present unique opportunities will be deployed in Phase III.

Phase II Report Format and Summary

This report delivers on three main components of the Phase II research. First, the Phase I Sustainable Design Guidelines were used to develop **IDX Design Concepts** for four WSF terminals in the Puget Sound: Seattle-Colman, Mukilteo, Friday Harbor, and Vachon. In this design process, two major concepts for metal removals from stormwater were developed and explored. The **Efficacy of Metals Removal** for both pervious concrete and a novel bioretention system (living filter) was evaluated and reported separately. Finally, the **Green Rating Integration Platform** was further developed to aid in developing efficiency for addressing multiple design goals across the myriad of design guidelines impacting integrated facilities such as a ferry terminal.

1. IDX Design Concepts: Washington State University undergraduate students in Architecture, Civil Engineering, Mechanical Engineering, and Construction Management collaborated as part of the Interdisciplinary Design Experience (IDX) to develop case studies of four WSF terminals in the Puget Sound.

As the client, the Washington State Ferries provided the majority of the data and valuable feedback to the students during the year. The primary output from the students were example design concepts for the four ferry terminals. Specifically, the students focused on stormwater treatment and a sustainable transportation plan. These include concepts for treating stormwater such as bioretention systems, pervious concrete, and filtration. This output was presented in a final review with WSF in May 2012. We believe these conceptual designs can be further developed into successful ferry terminal designs. Details of the designs for each terminal are located in Appendix A.

2. Efficacy of Metals Removal: Two stormwater handling concepts, pervious concrete and a shallow bioretention system (referred to as the "living filter" in the IDX Design) were prototyped and evaluated to assess the efficacy of metals removal. Both tests were conducted in a controlled laboratory setting. Summaries of these activities are provided below.

2.1 Pervious Concrete - Pervious concrete is a novel pavement material with many environmental benefits such as stormwater management and heat island mitigation. Pervious concrete pavement systems are emerging low impact development techniques capable of mitigating stormwater flows and potentially treating the water as well. It has been shown that permeable pavements may reduce stormwater metal pollutant loadings associated with filtered solids. This research demonstrates that the pervious concrete layer in a system is itself effective in removing dissolved zinc and copper contaminants from stormwater runoff. The research conducted was put into three categories: 1) removal efficacy of dissolved copper and zinc in pervious concrete with accelerated loading, 2) removal efficacy of pervious concrete under

enhanced loading conditions, and 3) removal efficacy of pervious concrete under typical loading conditions.

2.1.1 Removal efficacy of dissolved copper and zinc in pervious concrete with accelerated loading. To determine the removal efficacy of dissolved copper and zinc, pervious concrete cylinders made with ordinary portland cement were loaded in the laboratory with simulated runoff, and the influent and effluent concentrations and volumes measured. In one set of tests, stormwater was dispensed onto three cylinders at typical concentrations (100 µg/L Zn and 20 µg/L Cu) simulating ten consecutive storm events of 12 mm (0.5 inches) of rain. These cylinders removed at least 85% of zinc and copper. Another set of six concrete cylinders were used for accelerated long term exposure simulating many years and loaded at forty times the typical concentration. (They usually removed greater than 63% of the metals during the accelerated events.) Two of these cylinders were removed from the accelerated tests after 15 and 24 accelerated events respectively for further testing to determine performance during subsequent typical storm events, and the removal efficiencies were above 85%. Details of these tests are located in Appendix B.

2.1.2 Removal efficacy of pervious concrete under enhanced loading conditions. This study evaluated the ability of pervious concrete to sorb dissolved metals based on chemistry associated with pH, carbonate species, and hydroxide species in the hydrated cement. Portland cement based pervious concrete cylinders, which had been previously aged under ambient conditions in the laboratory for over three years to represent carbonated field conditions were used. Very high concentrations of dissolved zinc and copper based on typical roadway stormwater levels were applied to the cylinders and the exfiltrate analyzed. Removal rates for these elevated conditions initially exceeded 85%. Future long-term testing will provide information on the efficacy of pervious concrete systems for enhanced dissolved metal water quality treatment. Details of these tests are located in Appendix C.

2.1.3 Removal efficacy of pervious concrete under typical loading conditions. This study evaluated the ability of ordinary portland cement pervious concrete to sorb dissolved metals based on chemistry associated with pH, carbonate species, and hydroxide species in the hydrated cement. Portland cement based pervious concrete cylinders, which had been previously aged under ambient conditions in the laboratory for over three years to represent carbonated field conditions were used. Typical concentrations of dissolved zinc and copper based on typical roadway stormwater levels were applied to the cylinders. Removal rates for these conditions initially exceeded 82% for copper and 86% for zinc. In addition, two cylinders experienced a pre-loading of both zinc and copper equivalent to several years of use and were then subjected to a typical concentration. Removal rates exceeded 82% and 80% on individual cylinders for typical copper loadings, and 87% and 80% for typical zinc loadings after the two different accelerated loading scenarios. These preliminary results indicate that removal rates remained high, but additional long-term testing is needed to estimate life expectancies of pervious concrete applications for zinc and copper removal under various conditions. Details of these tests are located in Appendix D.

2.2 Bioretention System (Living Filter) - The "living filter," or shallow bioretention system, was a concept developed by one of the student groups in the IDX class. To test this concept, one of the students built several living filters based on their design and loaded them with stormwater. The systems consisted of a bottom layer of sandy loam, and top layer of compost, with geotextile fabric separating the layers. One system had 90% compost in the top layer by volume, with 10% vermiculite by volume. Another system had 90% compost in the top layer by volume, with 10% tree bark by volume. The living filter system contained live tufted hair grass, which is native to the Pacific Northwest to observe the effect of vegetation on the retention of heavy metals. Simulated storm events in urban areas were tested on various shallow bioretention systems to measure their efficiency of retaining zinc and copper. Each system was exposed to simulated stormwater with elevated levels of dissolved zinc and copper weekly for 4 simulated storm events, with the exception of the standard and living filter systems which were exposed to 10 simulated storm events. Volumes and concentrations were the same as what was applied to the pervious concrete. The mass of zinc removed was consistently greater than 90% for both the vermiculite and tree bark systems, and greater than 80% for all units in every test. Copper retention decreased with each simulated storm event, yet began effectively removing copper again (40% or higher) after the 6th storm event in the systems that were tested 10 separate occasions. Details of these tests are located in Appendix E.

3. Green Rating Integration Platform - To achieve sustainability goals and receive credit points for green certification, it is essential to understand the strategies to accomplish the sustainability objectives of a project. Sustainability rating systems come with project goals and strategies. However, among the multitude of sustainability rating systems and guidelines, it is difficult to decide which goals will earn more credit points and what methods need to be followed to achieve particular goals. In addition, multi-modal projects have different focal areas and associated rating systems related to each mode or other aspect of the project. Five green ratings systems representative of these aspects have been selected and analyzed through an analytical hierarchy process (AHP). Previous research resulted in synchronization of the rating system topical categories and synthesis of the credits. The Green Rating Integration Platform (GRIP) was first developed in Phase I of this project. Further development has occurred, including creating a website that enables users to search through different credits and categories.

This work focused on the water and material aspects, and the associated detailed goals and green methodologies. Key intents from the project goals and key strategies from the methodologies were identified. The lists of key intents and key strategies across the rating systems were then harmonized using an AHP and further cross-coded in an open database with the credit subcategories and corresponding rating systems. The database can filter the credit subcategories across the rating system for a specific key intent or key strategy. The harmonized lists and database may facilitate decision makers and sustainability practitioners in correlating intents and methodologies for a project across multiple rating systems. Details of the GRIP are located in Appendix F.

Appendices

Appendix A: Washington State Ferries Final IDX Design Report

Appendix B: Dissolved Zinc and Copper Retention from Stormwater Runoff in Ordinary Portland Cement Pervious Concrete (submitted to Environmental Science and Technology)

Appendix C: Dissolved Zinc and Copper Absorption in Pervious Concrete under Enhanced Loading Conditions

Appendix D: Summary of Dissolved Zinc and Copper Absorption in Pervious Concrete for Typical Loading Conditions

Appendix E: Retention of Zinc and Copper in Shallow Bioretention Systems in a Laboratory Setting

Appendix F: Green Rating Integration Platform – A Decision Making Tool for Multi-Modal Facilities: Sustainable Water & Material Practices (submitted to Journal of Infrastructure Systems)

Appendix A: Washington State Ferries Final IDX Design Report

WASHINGTON STATE FERRIES
FINAL IDeX DESIGN REPORT



IDeX
Integrated Design Experience

PROJECT ADVISORS

Prof. Todd Beyreuther
Dr. Cara Poor
Dr. Karl Olsen
Dr. Michael Wolcott

AUTHORS

Brad Albert
Kyle Billingsley
Eric Brandon
Emmanuel Diaz
Allison Dunn
James Frazier
Kelly Hayden
Holly Hicks
Timothy Ho
Jordan Jackson
Russell Lesieur
Nicholas Linton
Elise Markley
Kirsti McDaniel
Artur Mironchuk
Charlie Misner
Julia Mollner
Viral Patel
Lisa Reich
Matthew Sims
Nara Sin
Aaron Steele
Jonathan Talbott
Daniel Wagner
Jordan Williams
Victoria Wilson
Eric Winborne

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PREFACE

The Washington State Ferries (WSF) Sustainable Design Final Report was prepared by Washington State University undergraduate students in Architecture, Civil Engineering, Mechanical Engineering, and Construction Management as part of the Interdisciplinary Design Experience (IDeX) class. It is the result of a year-long effort to design four example ferry terminals for WSF. The IDeX class is organized to encourage innovative design across disciplines in a collaborative environment. This class was created in response to the need for practicing engineers, architects, and other disciplines to be able to communicate in an efficient manner and produce successful designs. Students have a unique, enriching experience that forms their way of approaching design. In addition, the client receives innovative design ideas that differ from the standard designs they would receive from a design firm. The benefit of university participation in a project in the conceptual phase is our students are free to explore all design ideas and options without being concerned with profit or competition. The class is taught in a studio setting; students work on projects while instructors circulate around and answer questions, provide feedback on student designs, and guide the design process. The studio mimics a design firm, with instructors as supervisors. Practicing engineers and architects also serve as mentors to the student groups. Students then present the final product to a paying client and their mentors. This year, the paying client was WSF. Washington State Ferries has provided the majority of the data and valuable feedback to the students during the year, as well as provided the funding for the class. As a result, the students developed four examples of how WSF could redesign their ferry terminals to incorporate sustainable design. Specifically, the students focused on stormwater treatment and a sustainable transportation plan. We believe these conceptual designs can be further developed into successful ferry terminal designs.

PREFACE

1. Introduction	1
2. Strategies	2
2.1 Stormwater	2
2.2 Queuing	3
2.3 Restraint	3
2.4 Structures	4
2.5 Construction	5
3. Sites	6
3.1 Seattle-Colman	6
3.2 Mukilteo	19
3.3 Friday Harbor	24
3.4 Vashon	28
4. Conclusions	31
Appendix: Drawing Sets	32
Seattle-Colman Drawings	
Mukilteo Drawings	
Friday Harbor Drawings	
Vashon Drawings	
Vessel Restraint Drawings	

1. INTRODUCTION

This final design report describes the design strategies for the WSF ferry terminal system and the site-specific designs of four WSF ferry terminals within the Puget Sound region. It is a culmination of a year-long design course at Washington State University. The Puget Sound is a large region of Washington State, which is bounded to the East by the Cascade Range and to the West by the Olympic Mountains. It reaches south to Olympia and north to Anacortes. Western Washington's Puget Sound region is home to the largest fjord-like estuary in the continental Unites States. This estuary is fed by numerous freshwater rivers and streams from the surrounding Olympic and Cascade mountain ranges. The marine climate prevalent in this region produces approximately 150 days of rain a year with a total precipitation average of 70 inches. The Washington State Ferries service provides transportation across the sound connecting the mainland with the various surrounding islands ***(Figure 1)***.

The four ferry terminals that were identified by WSF were Friday Harbor, Mukilteo, Seattle-Colman, and Vashon Island. The specific goals of the design, as identified by WSF and the IDeX class, were to:

- Develop a sustainable transportation plan
- To reduce vehicle traffic and increase pedestrian traffic
- Develop sustainable design standards for stormwater treatment and building materials
- Use Low Impact Development (LID) techniques to control and treat stormwater



Figure 1.
Puget Sound Region in Washington State and location of the four ferry terminals the class was tasked with redesigning.

Each student was assigned a specific site team and strategy team. The strategy teams, identified as stormwater, queuing,

restraint, structures, and construction, acted as consultants to the site teams. Each site had its own unique features which help inform the design interventions developed by each site team, identified as Friday Harbor, Mukilteo, Seattle-Colman, and Vashon Island teams. The report is divided into sections, one for each strategy and site team. Further details, including design concepts, unique site features, mapping that informed the design, and other information pertinent to design, of the design strategies as well as the specific site designs are described in their respective sections below.

2. STRATEGIES

Each strategy team was tasked with determining the best solutions and design strategies for the unique challenges at WSF ferry terminals. Strategy teams were formed to create a common design theme at the four sites chosen by WSF for a detailed design. The following sections describe the common design theme for stormwater, queuing, restraint, structures, and construction.

2.1 STORMWATER

Stormwater runoff must be addressed in any design that is either directly or indirectly exposed to precipitation. The majority of WSF ferry terminals currently have minimal stormwater storage or treatment designs in place to mitigate pollutants carried by stormwater. It is important to note that during a precipitation event, stormwater is immediately discharged into the Puget Sound via the four ferry terminals. Because the ferry terminals receive a relatively large amount of vehicular traffic, the concentrations of pollutants that stormwater can carry into the Puget Sound from these vehicles are high.

Typical pollutants of concern that each ferry terminal is potentially exposed to include:

- heavy metals
- hydrocarbons
- hydraulic oil
- sewage leaks

Ecosystems in the Puget Sound are not naturally accustomed to receiving large concentrations of any of the above pollutants. Exposing the Puget Sound to these contaminants instantaneously, or over long periods of time, decreases the biodiversity of the ecosystem and ultimately the quality of life for everyone living near the Puget Sound and its surrounding areas.

The most effective way of treating stormwater before it enters the Puget Sound is to use low impact design techniques. The design concepts presented in this report focus on filtration and/or storage of stormwater before it reaches each ferry terminal, or by filtering on the ferry terminals themselves.

Design flows used for designing stormwater treatment components were determined using the 25-year 30-minute design storm and the rational method at each site. Because the four ferry terminal sites had varying contributing watershed areas with unique site characteristics and constrictions to take into consideration, different design methods of stormwater filtration or storage were incorporated at each site.

2.2 QUEUING

Washington State Ferries applies a standard queuing system for the terminals they operate. This method allows for the terminal to function, but there are possibilities for improved queuing. An improved queuing system would help organize the traffic flow, working with vehicles and pedestrians to create an efficient and safe means of navigating a ferry terminal. Currently the queuing system at each terminal applies static traffic lines. Depending on the site, navigation can be confusing and the efficiency is not as high as it could be. Implementing a dynamic queuing system with signage or other notification for vehicles could greatly improve queuing at the ferry terminals. The design concepts presented for the four ferry terminals focus on dynamic queuing and vehicle notification to make loading and unloading of ferries a smoother process.

2.3 RESTRAINT

The current method that WSF uses for vessel restraint involves running the engines to maintain contact with the dock. This practice costs WSF approximately 12.5 million dollars each year,

which will rise as fuel prices increase. The boat buttress is intended to dramatically alleviate the economic strain associated with docking vessels in the Washington State Ferry System.

HOW THE BOAT BUTTRESS WORKS:

Step 1-Rotate Assembly *(Figure 2)*

Vessel approaches the dock and passes safely between each of the assemblies. When the vessel has made contact with the wing walls the boat buttress rotates into position.

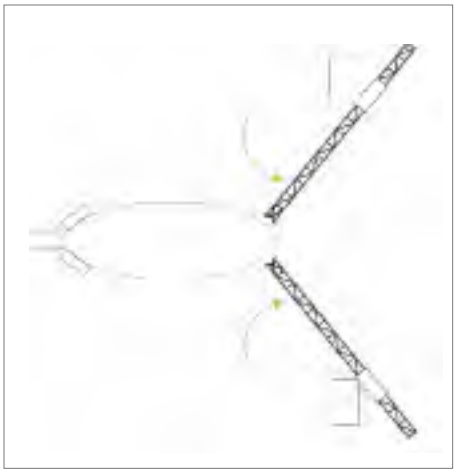


Figure 2.
Schematic showing the boat buttress rotating into position.

Step 2- Engage Vessel *(Figure 3)*

After the assembly has rotated into position the sea-draulic piston (a hydraulic piston using sea water) will push the truss forward and make contact with the vessel. The boat buttress provides adequate force to allow the vessel to maintain contact with the dock while also resisting lateral forces from wind and ocean currents.

The boat buttress will allow boat captains to completely throttle down the engines, and the boat buttress will operate in most weather conditions. This will significantly decrease fuel consumption and save millions of dollars for WSF.

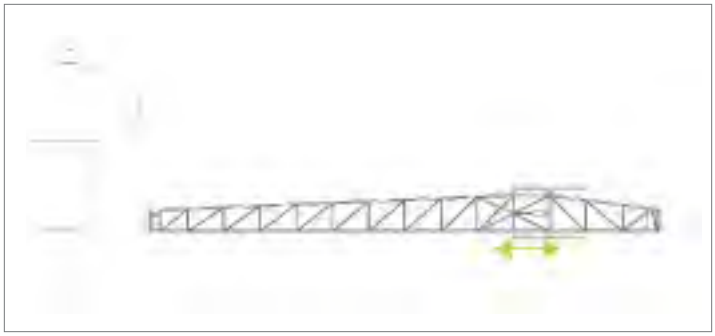


Figure 3.
Schematic showing the boat buttress engaging and securing the vessel.

2.4 STRUCTURES

All site designs included a structural design of the ferry terminals. This involved adding walkways, parking structures, and/or ferry terminal buildings. A description of each structural component is provided below. Load and Resistance Factor Design was used for all structures in this project, which determines the factored loads and size the structural elements. Concrete was the primary material used in design, with some steel framing. Concrete was chosen due to its durability in marine environments.

2.5 CONSTRUCTION

The project management group determined the construction schedule, construction plan, and cost estimates at the individual site projects. In addition to the aforementioned duties, project managers in each of the site groups also acted as a consultant to the designers and engineers, promoting constructability and sustainability within each site intervention.

All of the scheduling was done using Microsoft Project, and took into account the current IDeX contribution, design completion, construction, and payback periods. Individual site conditions dictated the phasing plans, and how detailed they were. For example, the Vashon site is located within a residential area, but has proposed a parking garage in town. The topography around Vashon is steep, causing large quantities of stormwater runoff to drain towards the terminal, which has been mitigated by the proposed "living wall." The phasing for this site requires movement of traffic flow, including road closures, to provide the best access and reduced time for construction. The goal of creating the schedule is to increase productivity, reduce time spent in construction, and alleviate problems before they occur.

Most of the estimating done was either done by hand or using Revit. Cost estimates were obtained using RS Means online, at www.meanscostworks.com. RS Means uses the new CSI master format, which expanded from 16 divisions to 50 divisions and provides easier access to a broad range of construction information. Since most of the projects are taking place over a number of years, the cost estimates should be in dollars of years of construction, or at least include expected inflation over the life of the project.

The common thread to each site that the project managers focused on were phasing issues. Each of the sites has their own individual challenges, and those challenges were solved almost always by meticulous planning and phasing. The Seattle Colman site, for example, is a large site at the heart of downtown Seattle. It is located wholly on Pier 52, with almost no room to work or place materials and equipment. WSF has also required 97,000 SF of queuing space at all times, including construction. Two means of egress from the site must be available at all times, meaning drivers must have two different ways to leave the site. The north portion of the trestle on Pier 52 must also be replaced. At the same time, there are other projects happening along the waterfront at time of construction. The best way to deal with all of these issues is to carefully plan and phase the project.

Another common thread for each site was limitations on space. Friday Harbor terminal is located on an island, but the town itself is also small and cramped. Vashon terminal is located at the end of a residential area, with storage space located off-site. Mukilteo also has the

same problem of having to store materials at a distance that is not conducive to productivity. Again, the solution to these issues is to carefully plan not only the utilization of the site during construction, but traffic flow as well. In addition to increasing productivity on site, proper planning will also increase safety on site and reduce the probability of accidents with riders and pedestrians.

3. SITES

The following sections describe the detailed design that students developed for Seattle-Colman, Mukilteo, Friday Harbor, and Vashon ferry terminals. Students used the common design theme developed in the strategy teams and customized them for each site. Additional design components may have been necessary (i.e., daylighting Japanese Creek at the new Mukilteo terminal) that were unique to a specific site. These additional design components are also described in the following sections.

3.1 SEATTLE-COLMAN

The Seattle Colman Ferry Terminal is an important icon and destination for Seattle's waterfront at the easternmost part of Elliot Bay. It is a gateway through the Puget Sound to the Olympic Peninsula. The Seattle Colman team's main goal was to provide WSF with a sustainable cohesive master plan with multiple components. The main components of the master plan include a sustainable stormwater solution, queuing/transportation solution, and the improvement of the pedestrian experience.

QUEUING

Pedestrian and vehicle interaction at the ferry terminal is a chaotic process, while queuing is often viewed as static. Applying a dynamic queuing system on the terminal could improve operations for the site, and would provide an interactive experience for both vehicles and pedestrians on the terminal while implementing a safer environment for all travelers. The dynamic queuing system would replace all painted vehicle lines on site with l.e.d. lights. These lights would cover the queuing surface like a pixel board (i.e. like the "Lite-Brite" toy). The idea is to turn the l.e.d. lights on and off (using various colors as well) to create a desired traveling path

for a vehicle and guide them from the point of entry on site to the proper queuing location. The queuing lanes would also be illuminated with l.e.d. lights. When the lane is not at capacity, the lane would have a green color and when the lane reached capacity it would turn red. The synchronization and coordination of the moving components of the terminal can be optimized, resulting in more efficient and fluid movement of ferry traffic ***(Figure 4)***. In addition to adding an interactive queuing system, designated oversized vehicle lanes would be made to allow semi-trucks and other large vehicles to navigate the terminal with ease. The redesigned layout, shown in Figure 19, gives the terminal an increased queuing capacity, incorporating turning radiuses for large vehicles. The queuing process would be dynamic in that the guided path for each car would be dependent on vehicle type and the current queuing status on site. The tolling for a vehicle would use a photographic system. Each vehicle would have the license plate photographed and billed to the registered owner's address. This would replace the current toll booth system which takes a considerable amount of time.

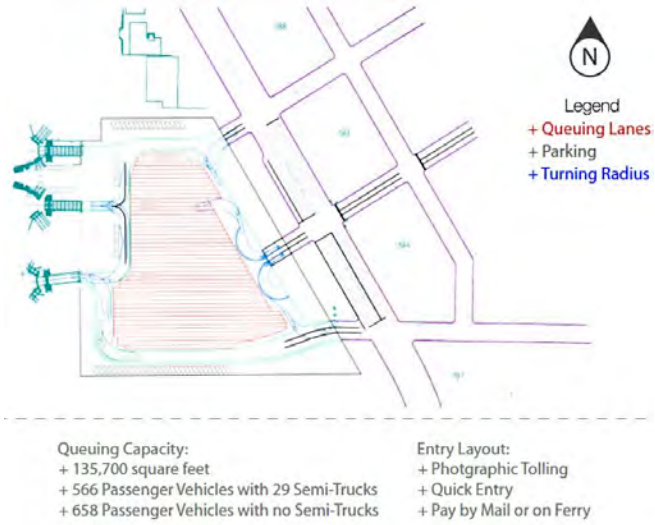


Figure 4. *Seattle-Colman Queuing Plan*

STORMWATER TREATMENT

The Seattle Colman Ferry Terminal (Pier 52), as well as Pier 48 directly to the South are only exposed to precipitation that falls directly on each of the respective piers. This ultimately resulted in designs that focused solely on the volume of stormwater each pier was exposed to during a 25-year 30-minute storm. A major limitation on the design options that could be implemented at both Pier 52 and Pier 48 was that no additional overwater coverage could be added. Another limitation was that treatment had to occur on the terminals themselves, with the waters of Elliot Bay directly underneath.

Figure 5 shows the areas on Pier 52 and the proposed Pier 48 that were taken into consideration during design of stormwater treatment.

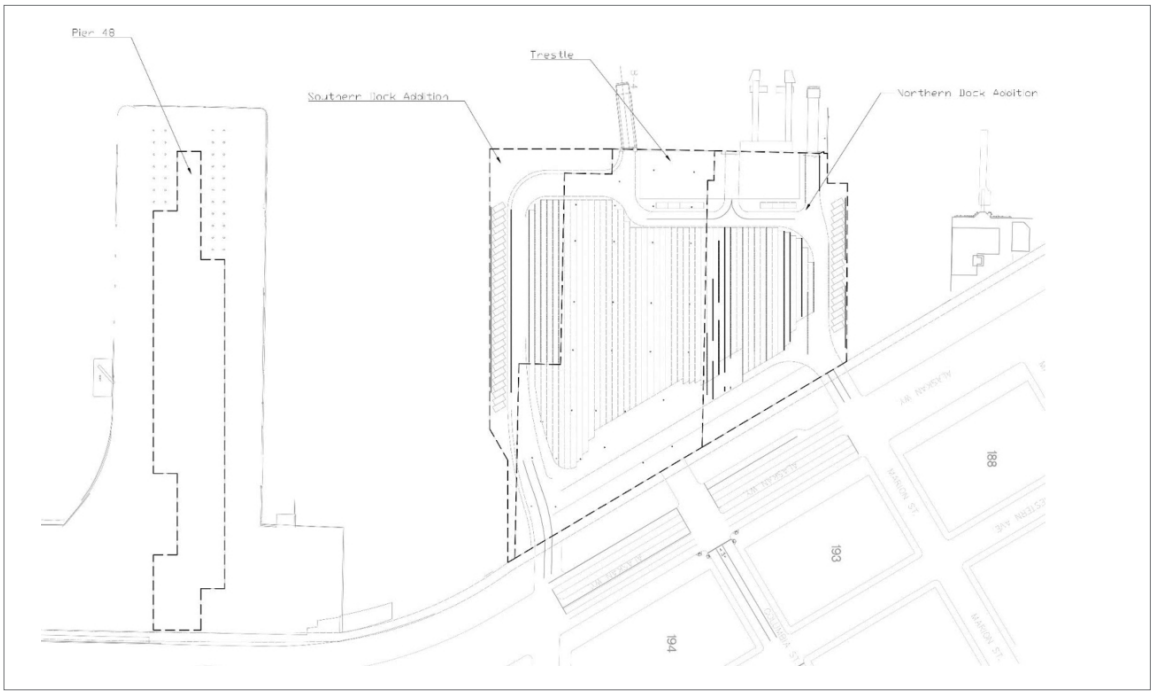


Figure 5. *Areas at the Seattle-Colman ferry terminal taken into consideration during design of stormwater treatment*

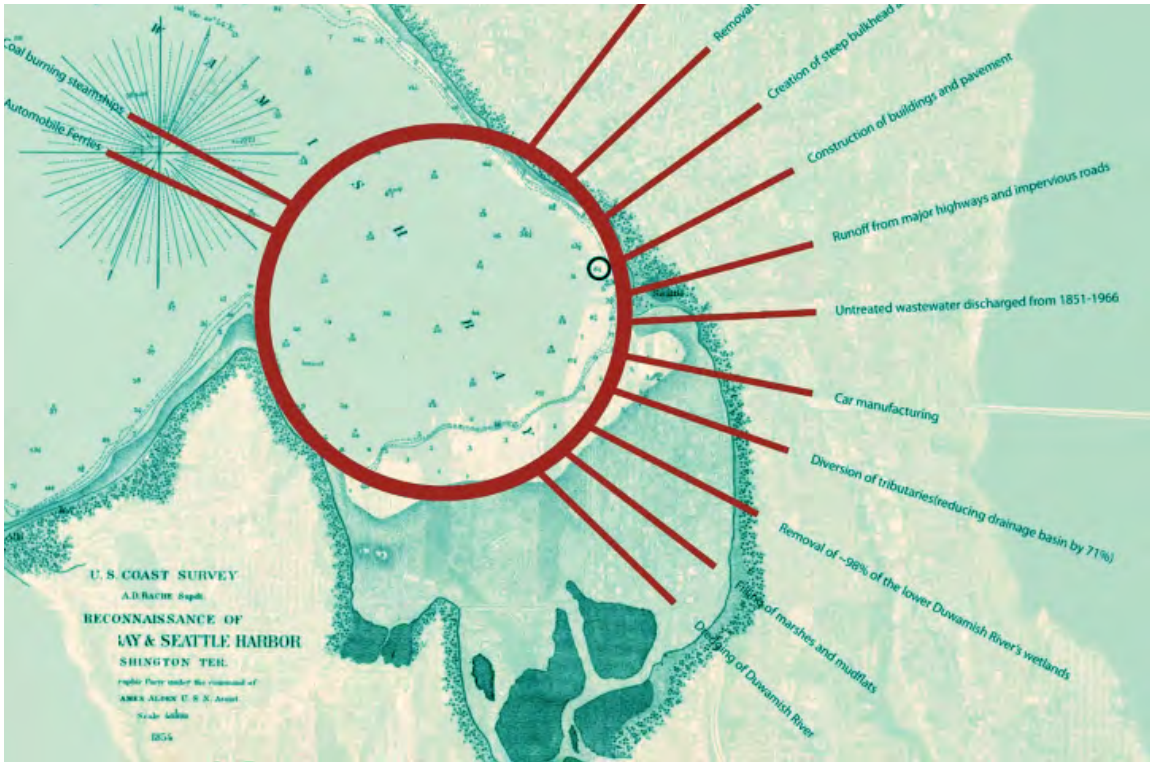


Figure 6. *Trends in degradation of Elliot Bay since 1851.*

Figure 6 shows an image that represents Ecologically damaging trends that have occurred in Elliot Bay since 1851 that highlight the importance of continued sustainable stormwater treatment design in the Puget Sound.

Figure 7 addresses the importance of considering the detrimental effects large concentrations of heavy metals have on ecosystems when transported by stormwater into receiving waters.

HEAVY METAL CONTAINERS

	EXISTING ESTIMATE		MINIMUM REQUIREMENTS		DESIGN	
	Concentrations	Removed	Concentrations	Removed	Concentrations	Removed
Lead	400 µgl/L	0%	210 µgl/L	47.5%	20 µgl/L	95%
Copper	54 µgl/L	0%	4.8 µgl/L	91.1%	2.7 µgl/L	95%
Zinc	329 µgl/L	0%	210 µgl/L	72.6%	17 µgl/L	95%

LEAD - Pb



Vehicle Batteries



Decreases Photosynthesis

COPPER - Cu



Brake Oads



Sakmon Lose Sense of Smell

ZINC - Zn



Tire Debris



Decreases Fish Growth

Figure 7. *Existing, minimum, and design concentrations of the metals of concern to WSF, as well as the sources and effects of these metals.*

Vehicles continually move on and off the ferry terminal, increasing the amount of heavy metals such as zinc and copper along with other pollutants that will eventually be transferred into Elliott Bay via stormwater runoff. Mitigating vehicle contaminants before they enter Puget Sound is essential, and can be implemented directly on the terminal using existing design plans. A filtration system was chosen for the Seattle Colman ferry terminal site as the most sustainable design. Several replaceable design features throughout the terminal that rely on filtration processes to reduce pollutants can filter these contaminants from their non-point sources which deteriorate the local marine ecology. This filtration system is called a "living filter" because the topsoil and loam in the filter promote microbial growth and can also support vegetation. The Living Filter ***(Figure 8)*** is a replaceable box that was designed to filter water effectively from a 25 year 30 minute storm, while also minimizing contaminants from the terminal that enter Elliot Bay.



Figure 8. *Living Filter Conceptual Diagram*

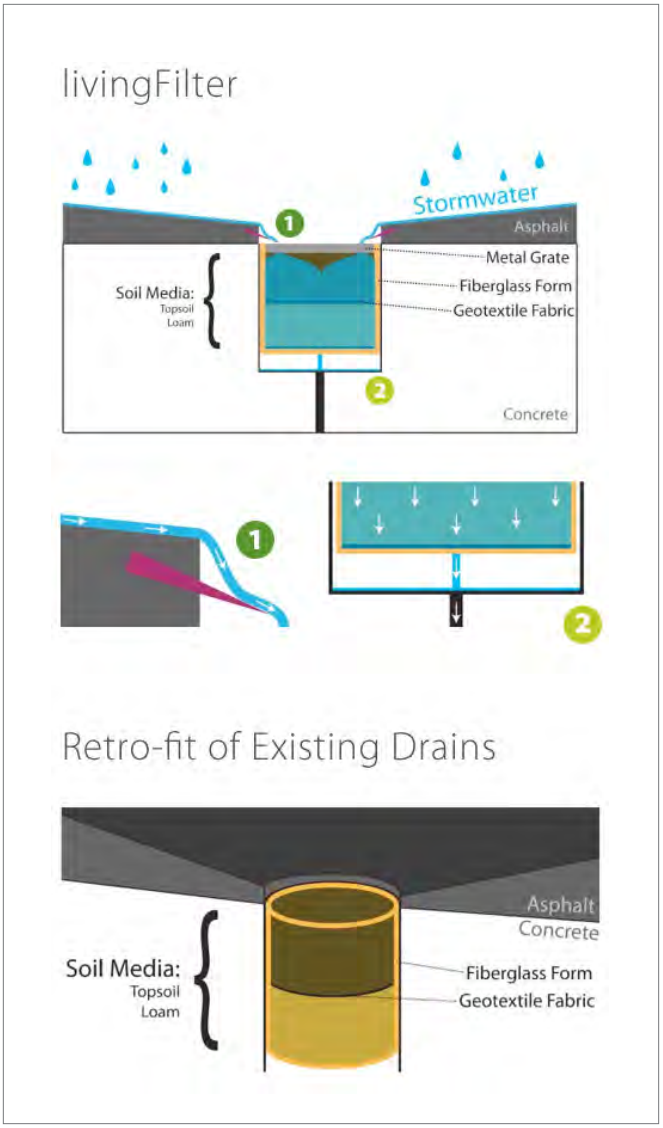


Figure 9. *Conceptual representation of filtration system for Seattle-Colman ferry terminal.*

Figure 10 shows a detail drawing with dimensions of the Living Filter. This design can be used in the areas where the dock will be replaced, and the filters can be incorporated into the new design.

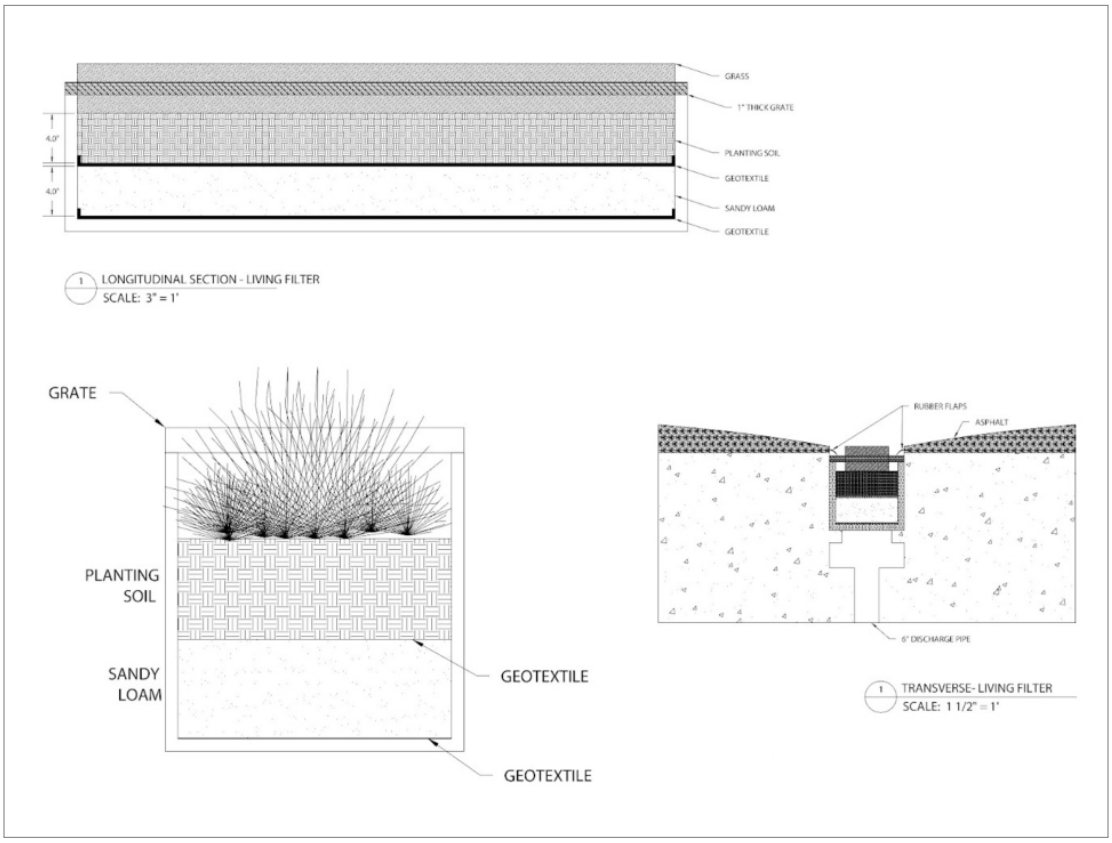


Figure 10. *Detail of Living Filter design.*

Figure 11 shows a detail drawing of the retrofit filters. This design can be used in the existing dock, and be placed in the same location as the existing drains. Because of the small diameter and the necessity of installing a grate to protect it from vehicles, there will be no vegetation in the retrofit filters.

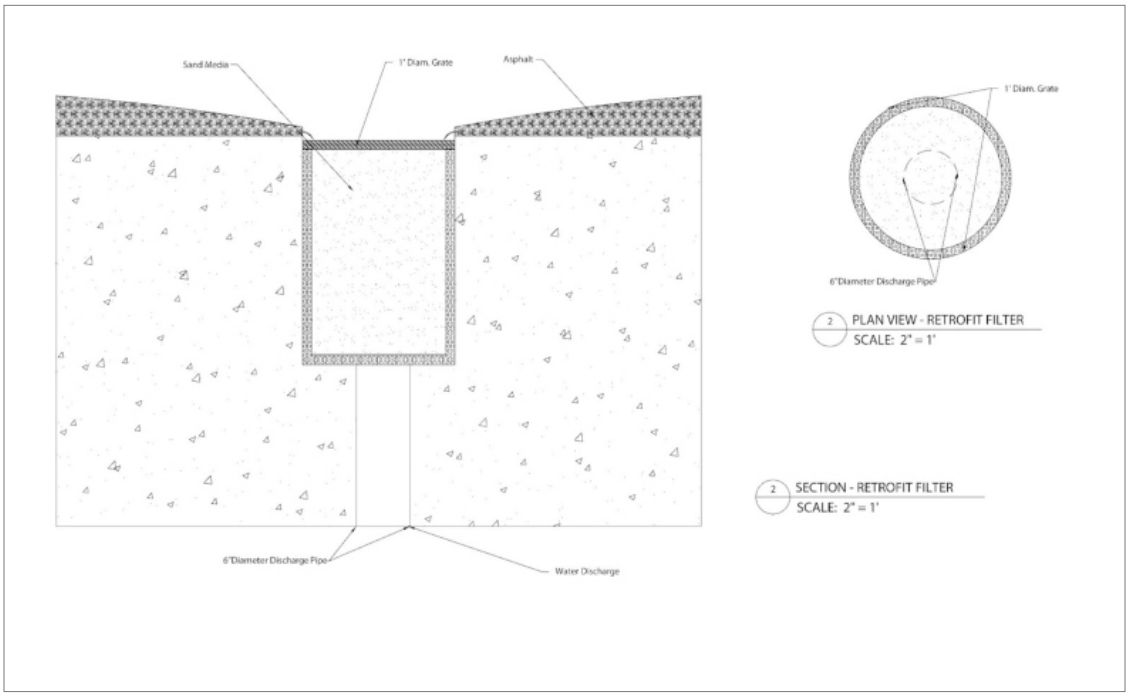


Figure 11. *Detail drawing of the retrofit filters.*

Figure 12 shows the locations of the designed Living Filters and retrofit filters to treat stormwater and remove the majority of pollutants before entering Elliot Bay on Pier 52.

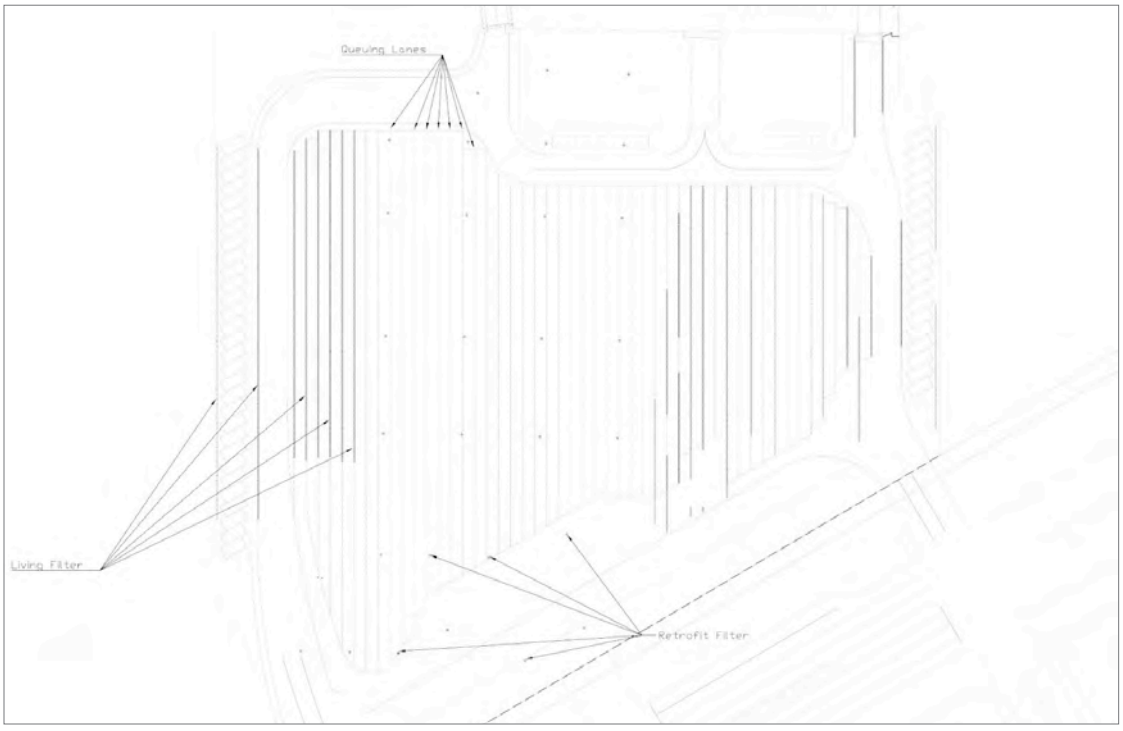


Figure 12. *Location of Living Filters and Retrofit Filters at the Seattle-Colman ferry terminal*

PHASING

One of the more challenging aspects of the Seattle Colman site is phasing the construction. Not only are there challenges specific to the site, but there are other projects taking place all around Pier 52 during construction. Between 2012 and 2020, the Seattle waterfront will experience a complete revitalization.

Currently, the Alaskan Way Viaduct is under construction, changing the way drivers get to and from the Colman Dock. The construction of Alaskan Way and the SR 99 Tunnel is already congesting traffic and is expected to do so throughout the duration of the project, which is scheduled for completion at the end of 2016.

The Elliott Bay Seawall project will also be taking place for a short time during the Colman Dock construction. Preliminary engineering and environmental review is scheduled to take place from January of 2012 until the Fall of 2013. Construction will promptly commence and is expected to reach completion in the early months of 2016. According to the City of Seattle, "the Elliott Bay Seawall Project is a critical public safety project. Failure of the seawall would have significant impacts to the public, the City of Seattle, the Puget Sound region, Washington State, and the nation. Protection from coastal storm damage and shoreline erosion is vital to preserving Seattle's downtown, the economy, and the region's quality of life and economic competitiveness. The Elliott Bay seawall has multiple functions, including:

- Protects Seattle's downtown waterfront from wind-driven storm waves and the erosive tidal forces of Puget Sound and Elliott Bay
- Supports and protects major public and private utilities, including power for downtown Seattle and the western seaboard, natural gas, and telecommunications
- Supports State Route 99, the ferry terminal, and rail lines, all of which transport local commuters and visitors as well as local, regional, and international freight" (http://www.seattle.gov/transportation/seawall.htm).

The project will replace deteriorated sections of the seawall, including the area along the Seattle Colman dock. It is expected that the shoreline will be moved east about15 feet, providing more space for queuing.

Finally, the Waterfront Seattle project is a community revitalization of the waterfront. The core project area will take place along the Colman Dock and Pier 48. The goals of the project are to:

- Create a waterfront for all
- Prioritize the shoreline and innovative, sustainable design
- Reconnect the city to its waterfront
- Embrace and celebrate Seattle's past, present and future
- Improve access and mobility (for people and goods)
- Create a bold vision that is adaptable over time
- Develop consistent leadership–from concept to construction to operations

The key project elements include:

- Replacing and re-configuring the timber trestle portion of the dock
- Replacing the main terminal building
- Reconfiguring the dock layout to provide safer and more efficient operations *(note: while the project would reconfigure the dock, the vehicle holding capacity and overwater coverage would remain the same as today)*
- Replacing the vehicle transfer span and the overhead loading structures of the northern slip
- Replacing vessel landing aids
- Maintaining a connection to the Marion Street pedestrian overpass

To mitigate some of the issues surrounding the phasing of the dock construction, a specific set of plans have been developed. The following plans describe the sequencing issue that WSF requested be solved, and not the full schedule of the project. The first step shows the first half or so of the new terminal being built on the part of the trestle that won't be replaced. The goal of this is to make sure there is a building in place for pedestrian use during construction.

The next phase of construction includes the removal of the old terminal. This will provide ample queuing space for the next three phases of construction. It is imperative to remove the whole terminal at once, due to the complicated process of replacing the North trestle. The

third phase of construction includes the first of three sets of replacement for the North trestle. Section 1 is the largest area of trestle to be replaced. It is an area closest to Alaskan Way, and is being done first to preserve the existing loading docks and provide a means of egress for traffic. Sections 2 and 3 subsequently follow and are only separated to keep the minimum required two loading docks open during construction. Following these phases fulfills the requirements set forth by WSF. The final phase of construction includes finishing the new terminal. The modular design of this building makes multiple building phases possible.

Utilizing multiple phases and alternating between construction on the terminal and the trestle is the best way to make construction work on this site. Given that this site has a limited amount of space, there is no other way to go about construction without implementing this type of idea. Granted that there is excellent communication between designers, constructors, WSF, and the builders, there should be no problem executing this plan.

STRUCTURAL AND ARCHITECTURAL

The redesign of the Seattle Colman Terminal requires structural analysis and design of numerous elements throughout the entire site. The terminal building, SkyTerrace, Pier 48, and the Boardwalk space are all added components that required structural analysis. For this project, the main focus was on the terminal building as well as small elements of Pier 48 and the SkyTerrace. Steel and concrete were the primary materials utilized for design. Both the "stitch" and the "fold" were common architectural elements that were taken into consideration for the structural design and seen across the entire site.

Boardwalk and Entrance.

The Seattle-Colman Ferry terminal has a unique location compared to the other terminals in the WSF system. The Colman terminal is set in an urban location and must play a part within the inner workings of the City of Seattle, especially in the downtown core. As the city plans to revamp the waterfront area, the Seattle-Colman terminal must also play a role in the new waterfront and integrate itself in the new waterfront, utilizing a boardwalk such as that shown in Figure 13. Three projects will take place during the design and construction of the new Seattle-Colman Ferry Terminal: demolition of the Alaskan Way Viaduct, Waterfront Seattle, and the replacement of the seawall. The new entrance and boardwalk area of the Seattle-Colman dock must serve two prime functions: be the entry point for the pier and public interface, and provide the human experience between ferry and city. We want to create a human experience, turn Pier 52 into a destination where the public wants to come and feels welcome, instead of a means to an end as it is now.

As the waterfront is revitalized through the Waterfront Seattle Project, the new terminal should incorporate itself into the new waterfront, effectively becoming part of the waterfront as a whole and not just an entity on the waterfront. Our design incorporates some retail spaces to go along with the revitalization of the waterfront (Figure 14). The design features a restaurant at the north end with a storefront window to peer into the kitchen to see the food the chefs are dishing up. This entices the public to dine at Pier 52 and patrons can see what else is happening at Pier 52 while dining. Another retail space could be a bike rental shop. With a planned bike lane for the new waterfront, a bike rental shop would be an easy means to travel the full length of the new waterfront. The southern anchor spot would be a coffee shop run by the local barista. With the Seattle terminal being WSF's only revenue generating terminal, the retail spaces would generate additional revenue for the terminal and WSF.



Figure 13. *Boardwalk area of the Seattle-Colman terminal*

The Seattle-Colman terminal is concerned with overwater coverage and security measures in the event of a possible terrorist attack. Currently for basic security measures, the Seattle terminal utilizes a system of metal bar and chain link fences in combination with the end of the current terminal building. What this communicates to the public is that unless you are riding the ferries, you are not welcome and are otherwise trespassing. What we propose to do is implement a series of punch-throughs in the dock. What this does, in association with removing the metal fencing, is create a boardwalk that pushes and pulls people into different areas of the Colman dock boardwalk, while at the same time providing an architectural solution to security. People will feel welcome at Pier 52 while at the same time the terminal's security concerns will be satisfied. Also the punch-throughs will remove sections of Pier 52, taking care of the overwater coverage concern. The public would then be able to see parts under the dock and see the sea ecology under Pier 52 while letting in sunlight to those areas.

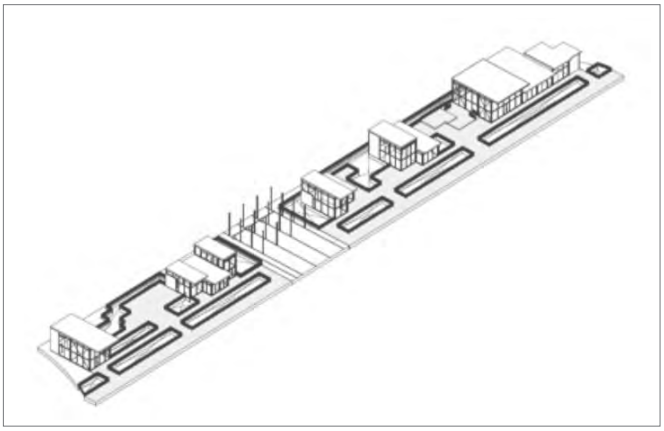


Figure 14. *Retail spaces at the Seattle-Colman terminal*

The demolition of the Alaskan Way Viaduct provides a prime opportunity to relocate Pier 52's current entrance at Yesler and Alaskan Way to Columbia. The current entrance requires all visitors to Pier 52 to navigate to the southern end of the pier. If a driver

was to come from the south this would not present an issue, however those coming from the downtown core and the north must circumnavigate around to the southern tip. Moving the entrance to Columbia reduces the congestion as vehicle traffic now has easy access from the north, downtown, and the south. This spreads the traffic into three flows of traffic instead of one.

Sky Terrace

The Sky Terrace was one of the main components of the Seattle Colman masterplan as it connected other components and improved the overall Ferry experience ***(Figure 15)***. The Sky Terrace served as an elevated greenscape path. The walkway served as an extension of the waterfront and was designed to give a park like experience as well as be efficient for commuters.



Figure 15. *Sky Terrace at Seattle-Colman terminal*

Terminal

The Seattle Colman Terminal is the epicenter of the masterplan as everything connects to it and goes through it. It serves as a multi-modal transit hub receiving people and goods from the water and from the city. The driving language for the terminal is the integration with the rest of the site through pulling the Sky Terrace into clear, double story roofs. Another element is the ribs that compose the terminal, which serve to meter light and interaction between downtown and the water, giving the terminal transparency and connection ***(Figure 16)***. The structural framing of the terminal building is shown in Figure 17. The terminal's design also incorporates auxiliary functions such as V-pak, which is vendor-loading space for the ferry system. The design proposes the terminal touch the ground, receiving passengers in their cars at the deck level as to give all pedestrians the possibility to experience the terminal.

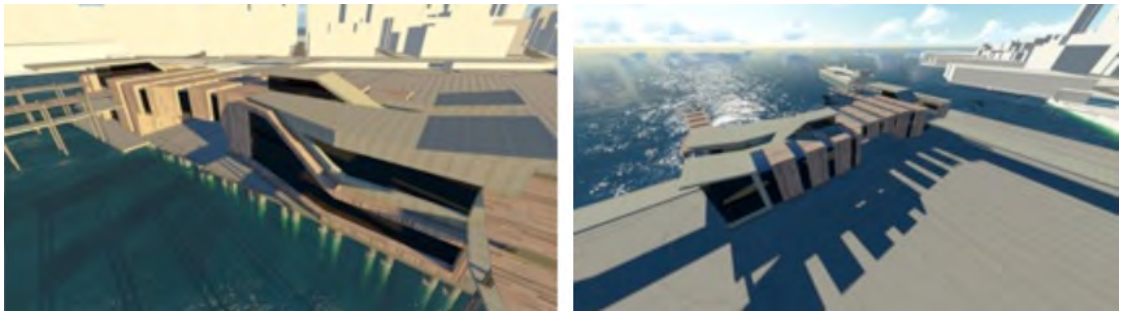


Figure 16. *Loading area of Seattle-Colman terminal*

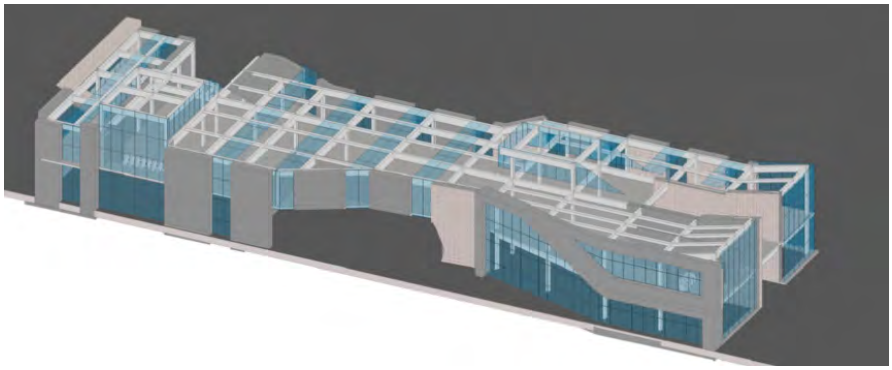


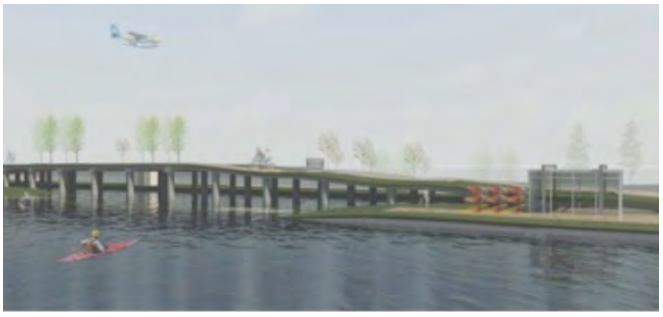
Figure 17. *Structural framing of terminal building*

Pier 48

Pier 48 is located directly south of the Seattle Colman ferry terminal, and is owned by WSDOT. It is not a structurally sound pier, and any plans to renovate it would involve a complete demolition of the current structure. Its original purpose was to allow the southern addition of Pier 52 to have a larger overwater coverage area. With the plans to remove a northern area of Pier 52 approximately equal to that of the added southern addition, Pier 48 has been largely overlooked in terms of ferry terminal activity.

With sustainability and the community's interests in mind, the design for Pier 48 incorporates passenger movement throughout the Puget Sound with a proposed water taxi docking area located at the end of the terminal. Public interaction and educational booths could be placed along the terminal to educate the public about conserving environmental resources. Another purpose the terminal would have would be a park-like experience in a traditionally industrial area ***(Figures 18, 19, and 20)***. The Living Filter system that will be incorporated on Pier 52 would be grown on Pier 48 as well to encourage sustainable design. The movement of the Pier up and down allows for the public to be

Figure 18. *View of Pier 48 design*



able to walk directly into the water, with easy access for kayaks or just to cool off. Other areas move up creating viewpoints throughout the Pier back at downtown Seattle. The structural framing of Pier 48 is shown in ***Figure 21***.

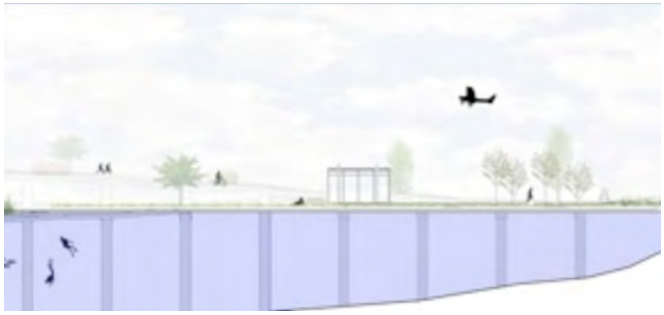


Figure 19. *Elevation of Pier 48 design*





Figure 2Ø. *Renderings of Pier 48 design*

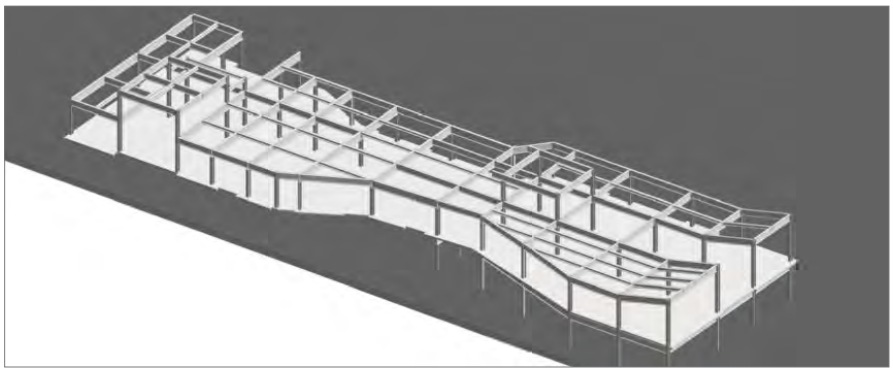


Figure 17. *Structural framing of Pier 48*

3.2 MUKILTEO

The Mukilteo Terminal is located in the City of Mukilteo at the northern end of SR-525. The ferry route connects Mukilteo to the Clinton dock on Whidbey Island. Due to the isolated nature of Whidbey Island, this is a critical transportation artery for the community. The projected population increase is 73% in the communities surrounding Mukilteo Ferry terminal; for this reason significant changes need to be made at this terminal.

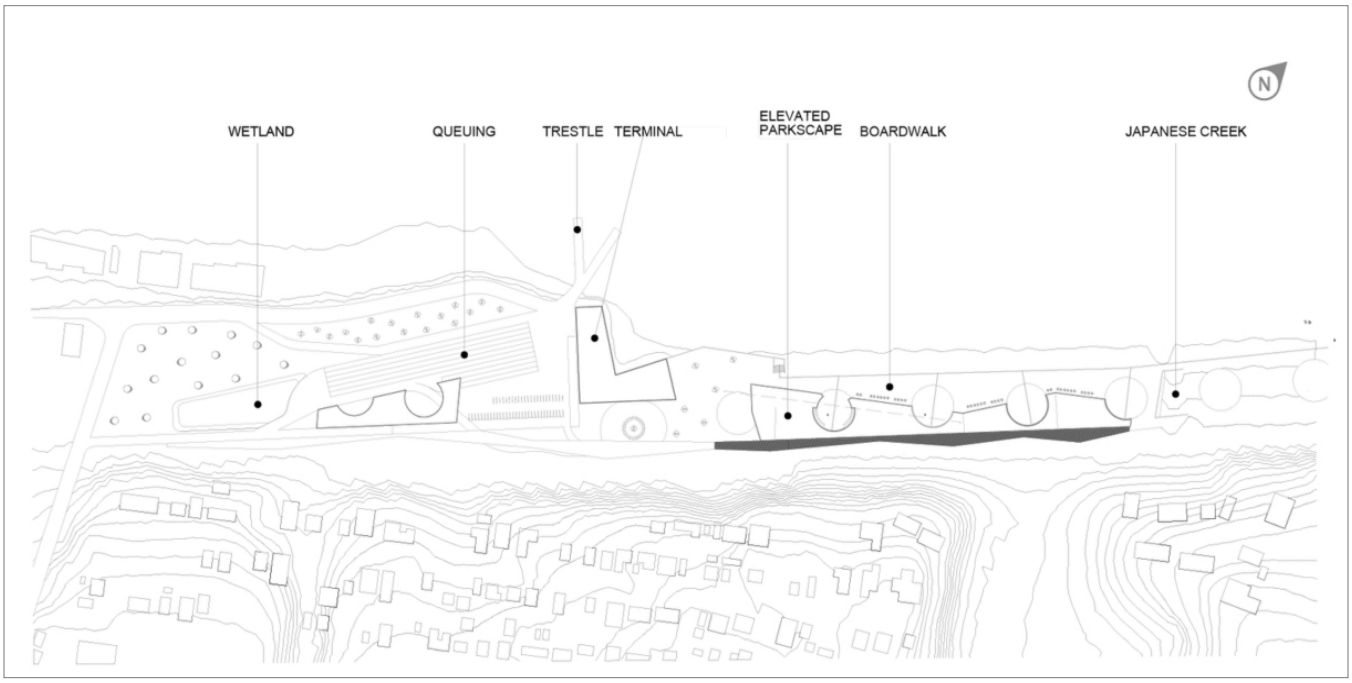
The current terminal and dock does not meet the needs of Washington State Ferries. The queuing area holds 206 cars, which does not meet the required minimum capacity of 216 cars. During high volume days the queuing area fills up and cars begin to line up on the side of SR-525. This line can reach over a mile long and is considered a safety hazard. The majority of the stormwater on or near the Mukilteo dock is discharged without any treatment. A small portion of the runoff is treated at a facility to the east of the current queuing area.

WSF has proposed moving the Mukilteo Ferry Terminal to a tank farm located ¼ mile to the east of the current site. This tank farm was owned and operated by the United States Air Force since the 1950's and was predominantly used as a storage facility for various types of jet fuel. The EPA has declared the site clean and will permit monitored natural attenuation of any remaining pollutants.

Washington State Ferries has expressed the desire for a sustainable stormwater treatment plan and a sustainable transportation plan. The interventions proposed address the issues of congestion and stormwater treatment.

Due to the size of the proposed site, Mukilteo Ferry dock represents a great opportunity to set a precedent for sustainable stormwater treatment throughout the Washington State Ferry system. The proposed design includes an area for queuing lanes and parking, a new terminal building and trestle, and an elevated parkskape and boardwalk adjacent to the terminal building ***(Figures 22 and 23)***.

Figure 22. *Site Plan for new Mukilteo terminal*



On the Mukilteo terminal, the structural design process focused on the terminal building, parking structure/covered queuing area, and the trestle. The terminal building (Figure 24) and parking structure (Figure 25) both were steel framed with braced bays spanning both directions. The trestle was designed as a one-way prestressed concrete slab that sat on prestressed concrete beams and piles.



Figure 23.
Parkscape adjacent to the new Mukilteo terminal

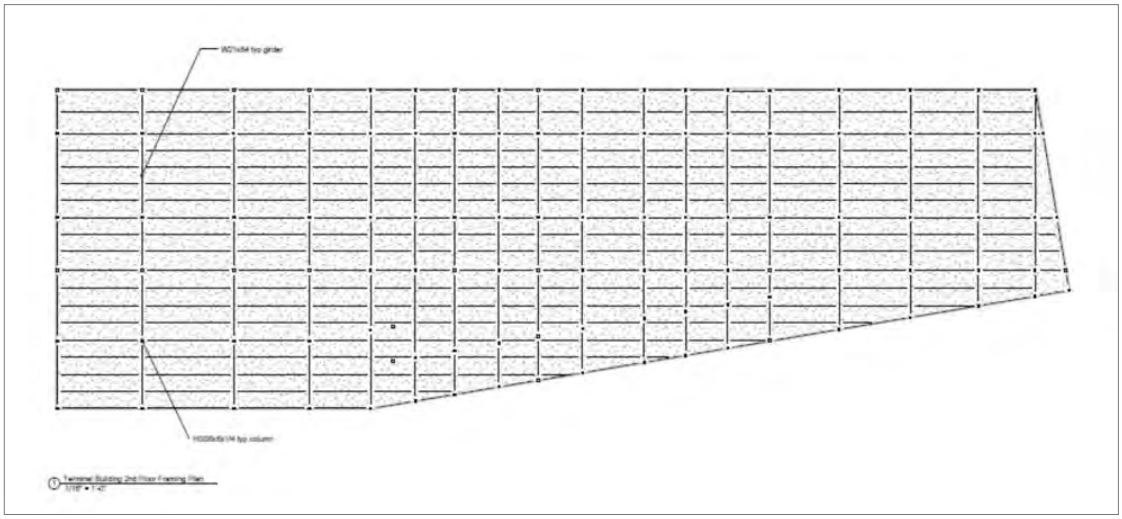


Figure 23.
Mukilteo Terminal Building Framing Plan

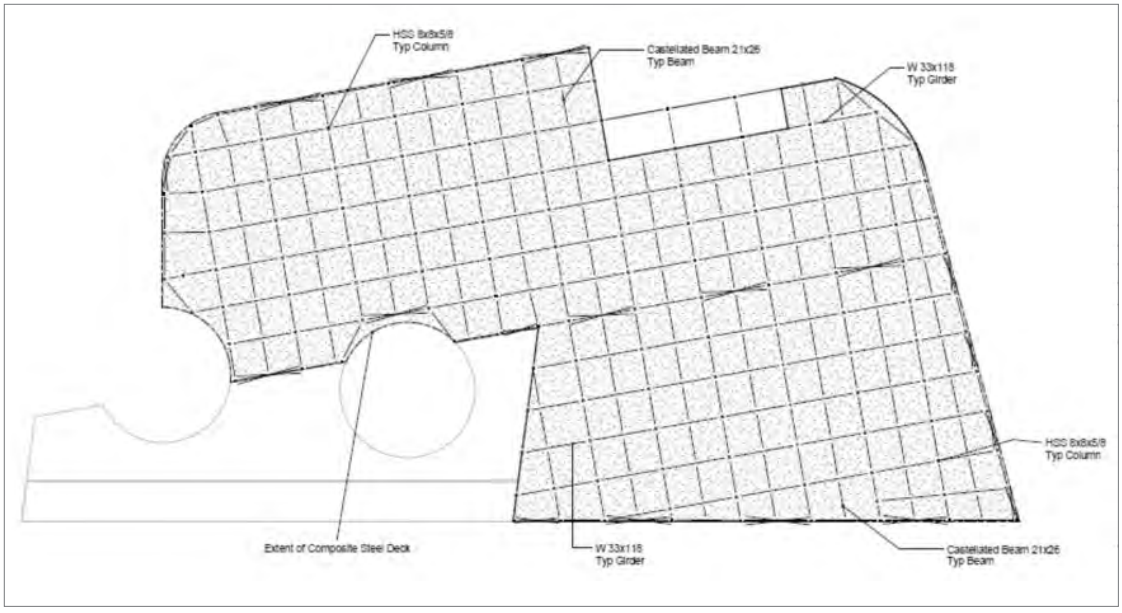


Figure 24.
Mukilteo Parking Garage Framing Plan

An innovative multi-tiered transportation plan was created for the proposed site (Figure 26). Departing ferry traffic will enter the site by taking a right off of SR-525 onto 1st St., travel through the queuing area, and then onto the ferry. Arriving ferry traffic will take an immediate right onto Front St., and then take a left onto SR-525. Through traffic will take a right off of SR-525 onto 1st St., travel up an inclined ramp, travel over the queuing area via an overpass, then take a left onto a declined ramp, move onto Front St. and then take a left onto SR-525. This transportation plan minimizes the interference between through traffic and ferry traffic. There will also be a parking structure located above the queuing area, which will increase the number of parking spots by 80%.

Another key design intervention is the implementation of a Transit Hub. This concept is the combination of the terminal building, the parking structure, the vessels themselves, and the overhead walkways which connect the first three components with one another. The goal of the Transit Hub is to encourage pedestrian ridership by creating an environment which is much more conducive to bicycle and foot traffic.

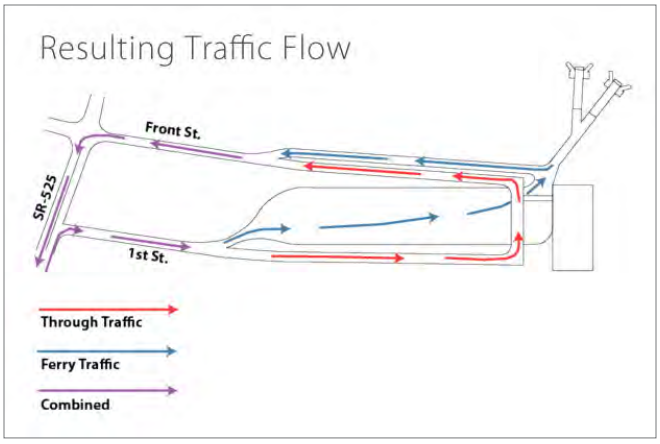


Figure 26. *Flow of traffic at the Mukilteo terminal*

Current queuing at the Mukilteo terminal is problematic. After queuing, the cars must then pass through a busy intersection. The cars stop and wait for pedestrians to load onto the ferry. Then the cars drive onto the ferry while the remaining pedestrians wait. Current queuing capacity is at 206 cars. For our proposed redesign we placed the queuing under the parking garage ***(Figure 27)***. To access it, cars simple need to turn right off SR-525 then take a left off the one-way road. Once the ferry has arrived and offloaded, the cars have a clear, unobstructed drive onto the ferry. Pedestrians will load via an overhead walkway. To facilitate the quick movement of traffic, a dynamic queuing system would be used. The overhead beams would have holes in them to allow for the mounting of lane markers and lighted signs. Path lights could also be built in on the sides of each lane to direct traffic. With the exception of one lane, the lanes would have a sensor and camera. Similarly to the current SR 520 bridge tolling, the sensors would look for a Good To Go! pass to charge. If none was found, the cameras would take a picture of the driver's license plate and bill them later. One lane would retain a traditional toll booth. The new proposed queuing capacity would be 220 cars.

The Mukilteo ferry terminal runs along the waterfront of the downtown Mukilteo area. There are four major considerations of stormwater on the site. The first is Japanese Creek, which runs

through the site on the east side. It is a fairly large creek with a flow rate of 92 cfs for a 25-year storm event. The next is Brewery Creek, which runs directly under the proposed parking and queuing area. This creek runs through a culvert. The next consideration is the rainwater that hits the site and our final consideration is the rainwater that runs off of the trestle.

A very important aspect to WSF was the salmon that travel up Japanese Creek. The best way to encourage salmon spawning up Japanese Creek is to daylight the creek. We propose an open channel through the site after running through a short culvert under the railroad tracks. Daylighting the creek can also help with water quality; the aquatic organisms can help remove nutrients, metals, and other pollutants before the creek reaches the Puget Sound. From the railroad tracks to Puget Sound, the creek is designed to have a bottom width of 5 feet, a top width of 13 feet, and a side slope of 2.5:1. We calculated the rock riprap to be a maximum of 13 inches and have varying grade. The area surrounding the creek will have local native vegetation to increase aesthetic appeal and support a healthy riparian area.

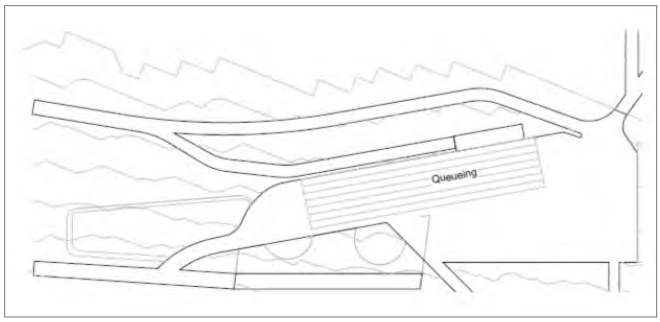


Figure 27. *New Queuing Location for Mukilteo Terminal*

Brewery Creek is a small creek that does not have any salmon spawning potential. We decided to keep this creek in the culvert that runs under the site. We looked at the watershed area and it is mostly forest with few residential homes. We think that this water will be fairly clean coming through the site and does not need to be treated.

Because of the large area of the site, approximately 22 acres, there is a lot of stormwater runoff to manage. The areas with the most potential to pick up contaminants are the parking, queuing, and roads, which are all located on the west end of the site. A constructed treatment wetland was designed to treat all of the stormwater runoff from these areas. To size the wetland, we used the 6-month, 24-hour storm and the rational formula, which produced a runoff of 0.18 cfs from the parking and roads. All of the water will be collected and piped to the wetland. Treatment wetlands are cost effective, sustainable, and efficient at removal of suspended solids and heavy metals. This wetland will be about 1.2 acres in area. There is a pre-settling cell which removes most of the suspended solids and is 4 feet in depth with an area of 0.4 acres. The rest of the wetland cell has a depth of 1.5 feet and an area of 0.8 acres. The total time the water spends in the wetland will be about 5 days. The longer the water remains in the wetland, the more pollutants will be removed before entering Puget Sound. The outflow will be controlled by a weir and piped to the Puget Sound once the water is treated. The wetland plants will include cattail, bulrush, water lilies, and other native plants.

The last consideration is the stormwater runoff from the trestle. We designed living filters to hang from the trestle. The same living filter design described in the Seattle-Colman description above will be used, but since the dock has a different configuration, the filters span the entire side of the dock. The dock will be sloped to the east and the living filters will be off the side to the east so all stormwater runs off to the filter, infiltrates, and discharges to the Puget Sound. They will be 1 foot in width and will run along the entire length. The details of the filter design and the mechanisms are described in the Seattle-Colman description above.

3.3 FRIDAY HARBOR

The Friday Harbor Ferry Terminal is located in the Puget Sound on the San Juan Islands (Figure 28). Friday Harbor is part of the ferry service that leaves out of Anacortes, WA and serves Lopez Island, Shaw Island, Orcas Island, and Sidney, B.C. The ferry transports pedestrians, bicyclists, and motor vehicles, which include motorcycles, passenger cars, and trucks.



Figure 28. *Location of Friday Harbor terminal and area considered for the design*

The two main issues that were addressed with the design interventions dealt with transportation and stormwater treatment. The town of Friday Harbor is small and because of its attraction as a tourist destination, its surface streets are not well equipped to deal with the large increase in visitors during the summer season. The ferry terminal location downtown further compounds this problem during loading and unloading times. In addition, there is no treatment of the stormwater runoff from the trestle or queuing areas. Surface runoff flows off the surface, into drains and eventually into pipes which terminate at the shoreline.

The interventions proposed include increasing queuing efficiency, a new terminal building, using Sunken Park to treat stormwater, a tidal park to provide water access, and living filters on the trestle to provide stormwater treatment ***(Figure 29)***. The designs were developed with the goal of not only solving the main issues, but to create a more unified community in the downtown area. Because of its location in a high-density, urban community vacant land was scarce. The interventions sought to make use of existing features or enhance underutilized elements.

The first intervention proposed would solve the congestion issues during queuing, loadings and offloading. To make the loading and unloading time more efficient it is necessary that the flow of traffic into and out of the town be streamlined. This is where traffic rerouting and organized flow of queuing traffic plays an important role. Friday Harbor does have broad and well-maintained streets, but the flow of traffic can be improved by putting into effect a traffic re-routing plan. This rerouting plan would make one-way inflow of traffic and one-way outflow of traffic. Using this type of traffic flow system would help eliminate waiting time at traffic signals and provide more vehicle outflow and inflow with respect to time. With dedicated ferry traffic lanes, it will be easier for the tourists to travel around the town without conflicting with the town traffic. Another reason for having dedicated lanes is to help ferry traffic flow into and out of the ferry without any guidance from WSF or confusion. The ferry queuing lots at Friday Harbor are disconnected and so it is necessary to make use of effective queuing system like dedicated lanes, connecting lots B&C and digital signage boards to communicate ferry schedules and lot space availability. The signage boards and dedicated ferry lanes will minimize the manpower needed to help with queuing at Friday Harbor, in addition to making the flow of traffic on and off the ferry smoother.

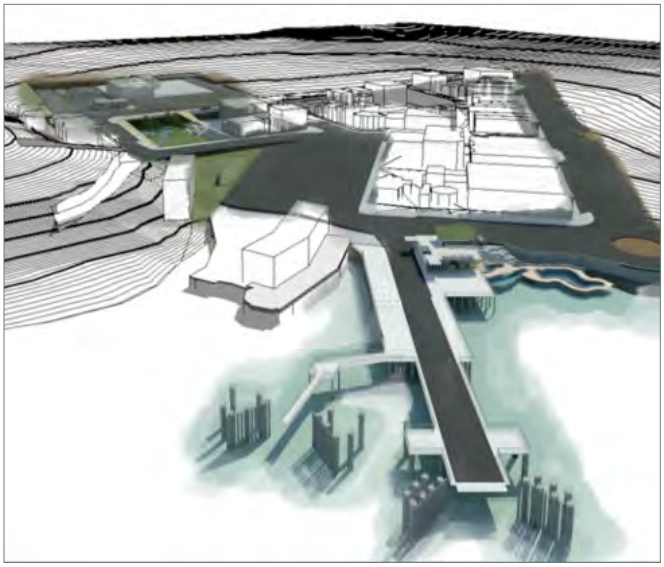


Figure 29. *Rendering of Friday Harbor terminal and queuing lots*

The new terminal building (Figure 30) is intended to be a location where visitors and community members can overlook the harbor and interact with the water. The indoor ground floor serves as a viewpoint to the water and provides seating and ticketing information. A Nana Wall on the north side fully opens up to the deck and the water below. Staff office space and public restrooms are also located on the ground floor. Stairs and an elevator take patrons to the upper deck where they can further appreciate the view of the harbor and incoming ferries under the shade of photovoltaic panels that provide power to the building. Rainwater is captured on the upper vegetative roof and falls into the bent plate gutter which channels within the main deck. This gutter serves as the drain for the entire roof and results in a waterfall into the tidal park. The glass walls of the vegetative roof allow light into the ground floor area, which also heats up the concrete trombe wall in the center. The building is intended to function more efficiently than the existing terminal building and will be a more interactive center for visitors.

The proposed structural design of the terminal building is a two-story steel moment frame resisting structure with four reinforced concrete shear walls (Figure 31). Steel bracing is provided in the building as well. When framing the terminal building, many architectural elements had to be considered and therefore changed a basic framing plan into a more complex design. The main shear wall is the connecting element of the building and supports the bent plate gutter. The current timber piles under the terminal need to be replaced since the size of the building is at least doubled and significantly increases the loads.

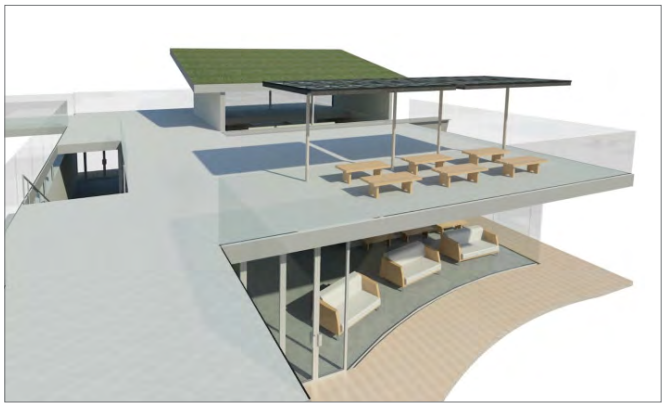


Figure 29. *Rendering of Friday Harbor terminal and queuing lots*

Located in the heart of downtown Friday Harbor, the Friday Harbor ferry terminal presents many opportunities for design innovations. This location also presents several challenges, however, due to the surrounding retail and restaurant businesses in the area, which limit space for stormwater treatment/storage and equate to a large amount of impervious surfaces, increasing runoff to the site. These challenges meant that all design interventions had to be space efficient and serve multiple purposes. Although relatively moderate to light rainfall occurs at Friday Harbor throughout the year, the high imperviousness of the site causes substantial runoff during storm events. Currently, any stormwater runoff picks up contaminants from the roadways and terminals then empties directly into the Puget Sound, which is a sensitive marine environment. Stormwater interventions at the Friday Harbor ferry terminal were designed to remove a large portion of pollutants as well as reduce the amount of water going into the Puget Sound.

The designed stormwater system consists of several infiltration, retention, and detention components to slow down water and remove pollutants before the stormwater enters the Puget Sound. The system starts at Lots B and C, which would both have storage basins below the pavement to store water as well as provide some infiltration. From the storage area, water would be released at a constant rate into a pipe that would transport water from the sub-lots to Sunken Park, where the water would then pass through a terraced rain garden, providing some bioremediation and phytoremediation to remove as many pollutants as possible. From there, the water would then flow into a bioretention cell, followed by a daylighted

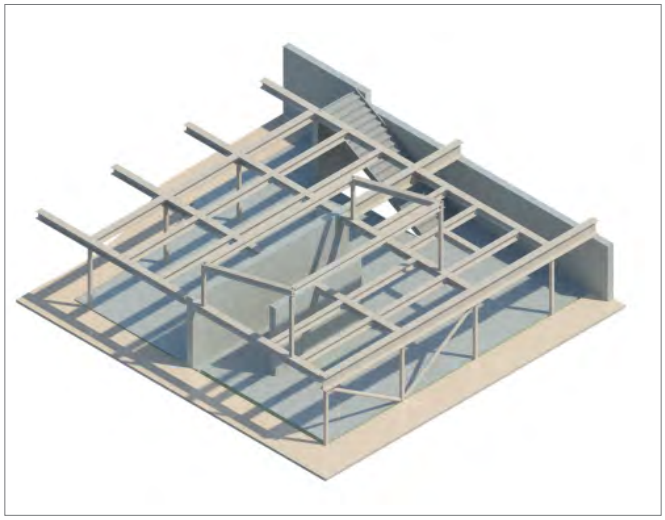


Figure 31. *Framing plan for Friday Harbor terminal building*

stream, which would be lined with large rocks and native plants to slow water down and allow infiltration and additional phyto-remediation. The daylighted stream would flow through Sunken Park, exiting through a corrugated metal culvert, which would pass the water under Harrison Street. The daylighted stream would then continue on the other side of Harrison Street in an area that would be restored with native vegetation. Because there is no space downgradient of the main queuing lot to continue the daylighted stream, water would need to be piped under the surface to two end-of-pipe treatment areas, one located on the west side of the terminal building, and one located on the east side of the trestle. Currently these two locations are bare earth areas leading to the shore, with no access. Terraced raingardens would replace these two bare-earth areas to incorporate stormwater treatment. The water would then exit into the Tidal Park. The water runoff from the main queuing lot and Front Street is designed to be treated in the two terraced raingardens near the terminal; however, in large storm events, excess water would be pumped into the cistern designed to capture, store, and slowly release stormwater from Spring Street into an additional terraced raingarden near the marina.

The enhancements of the Sunken Park ***(Figure 32)*** will provide an enjoyable experience for all passengers of the Friday Harbor Terminal. Its location between the overflow queuing lots and the ferry terminal make it a logical choice to serve as a path for ferry riders in cars, bicycles, or on foot. The park will also serve as the first point of treatment for the stormwater system. The daylighted stream will provide habitat for the abundant wildlife in the area as well as incorporating a natural path towards the ferry terminal. Its termination at the tidal park also serves as a cohesive element connecting the queuing areas, the intermediate park area, and the waterfront.

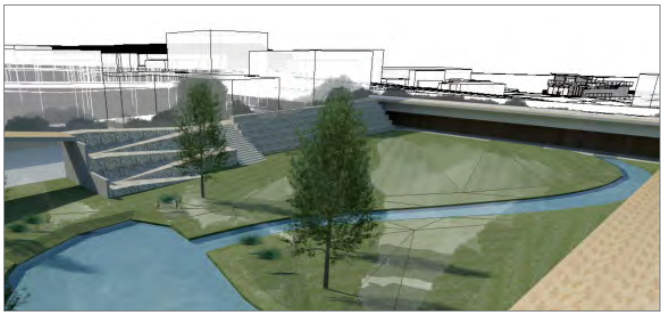


Figure 32. *Rendering of Sunken Park improvements*

The waterfront tidal park ***(Figure 33)*** provides a vital link between the town of Friday Harbor and the sea that surrounds it. Providing access to the waterfront, which is currently lacking, would highlight the ecology of the area as an asset. The park is composed of four tiered basins and a series of boardwalks. The basins retain water as the tide recedes and contain habitat for local ecology. The boardwalk winds its way between the basins and allows the users to view the local wildlife in their natural habitat. In addition to being aesthetically pleasing, the park , is also an interactive and educational experience which will heighten the user's awareness of this vibrant ecosystem.



Figure 33. *Rendering of waterfront tidal park*

3.4 VASHON

The North Vashon Island ferry terminal is located in the Puget Sound on the Northern tip of Vashon Island ***(Figure 34)***. This terminal services commuters looking to go to Fauntelroy and Southworth as well as a pedestrian only ferry that operates during peak hours between Seattle and Vashon.



Figure 34. *Location of Vashon terminal*

We focused on stormwater, ecology, and transportation/ridership during the design process. Stormwater at Vashon was very large factor in design due to the fact that the terminal is located at the apex of a very large watershed. The Vashon Island terminal has stormwater running onto the site from upland sources. Two main flow paths of stormwater converge right beneath the trestle (Figure 35). Currently there is no treatment of any of the stormwater runoff from the trestle or the watershed. Lack of stormwater treatment before discharge to the Puget Sound can potentially affect local ecology.

We primarily looked at the stormwater in our immediate vicinity: is the parking lot, the road, and the trestle itself. One of our design interventions is a parking garage that will replace the existing parking lot. The parking garage, during a 25-year, 10-minute storm, would produce runoff with a peak flow of 4 cfs. To treat this runoff we designed a terraced slow sand filtration system along the road underneath the sidewalk. The filter will also treat water coming off of the road. On the opposite side of the road, we designed a pervious pavement bike lane that will also filter the stormwater coming from the road. After the stormwater has been treated it will flow into the Puget Sound.

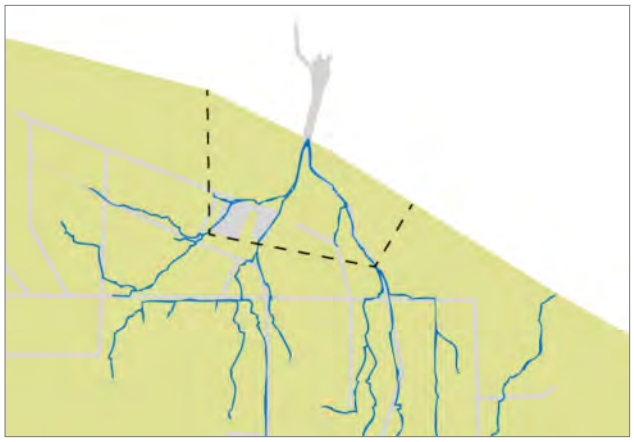


Figure 35. *Contributing watersheds that discharge beneath the trestle at Vashon terminal*

The tressel currently has 27 open drains that allow for stormwater on the deck to drain uninhibited into the Puget Sound. Our treatment design is similar to that of the parking

garage. Next to the sidewalk is a slow sand filter with the same design as the upland sidewalk. The trestle is set to be rebuilt in the future; so to channel the water into the filter we assumed the deck will be sloped towards the filter.

We also looked at increasing pedestrian ridership. More vehicles are using the ferries each year ***(Figure 36)***. The ferry has limited capacity and thus some cars may not be able to board the ferry when they wish. Another problem is the increase in the queue length that extends up Vashon Highway as well as the emissions from the waiting vehicles. A full parking lot is also contributing to the increase in queue length and a decrease in pedestrian ridership.

	JAN.-MAR	APR-JUN	JUL-SEP	OCT-DEC
2009	88,022	114.132	77.572	63,652
2010	56,644	60,066	68.090	61,788
2011	58,88	65,102	68,740	--
2009	14,564	15,836	18,548	15,874
2010	14,244	16,026	22,912	18,848
2011	16,462	16,460	18,984	--
2009	88,022	114.132	77.572	63,652
2010	56,644	60,066	68.090	61,788
2011	58,88	65,102	68,740	--
2009	14,564	15,836	18,548	15,874
2010	14,244	16,026	22,912	18,848
2011	16,462	16,460	18,984	--
2009	88,022	114.132	77.572	63,652
2010	56,644	60,066	68.090	61,788
2011	58,88	65,102	68,740	--
2009	14,564	15,836	18,548	15,874
2010	14,244	16,026	22,912	18,848
2011	16,462	16,460	18,984	--
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2010	56,644	60,066	68.090	61,788
2011	58,88	65,102	68,740	--
2009	14,564	15,836	18,548	15,874
2010	14,244	16,026	22,912	18,848
2011	16,462	16,460	18,984	--

Figure 36. *Ridership for Vashon Ferries, 2009-2011*

Fauntleroy-Vashon

Southworth-Vashon

To address these problems we looked at many possible solutions. Ultimately we decided upon three main design interventions that would help to reduce the impact of stormwater runoff and increase pedestrian ridership. The first solution is a parking structure that will increase the amount of WSF parking by almost 100%. This intervention would allow for more passengers to park their cars in order to increase pedestrian ridership. A low profile design was implemented in order to allow for surrounding residents to retain any views that they have, and to not disrupt the community with an unsightly structure ***(Figure 37)***. The use of the existing slope was capitalized on and allows for three separate levels of parking.



Figure 37. *Rendering of proposed parking garage*

Next we looked at how pedestrians would get from the parking structure to the ferry terminal. In order to make this experience delightful we proposed a sidewalk with an integrated filtration system. This would filter out most of the stormwater pollutants while a pervious pavement bike lane on the opposite side of the road would filter out the remaining pollutants.

Finally we looked at the ergonomics of a new terminal building in order to make the flow of both pedestrian and vehicular paths more usable. In order to provide adequate bus turn around area the proposed shape of the new terminal building would have a "kinked" floorplan ***(Figure 38)***. This would allow enough room for a bus to safely turn around and drop passengers off right at the front door of the terminal. Within the proposed terminal there is a rampway that leads to the rooftop waiting area. It is here where passengers will use overhead loading to board the ferry. This allows for pedestrian traffic to be separated from vehicular traffic, which is safer and provides for safer loading and unloading.



Figure 35. *Contributing watersheds that discharge beneath the trestle at Vashon terminal*

The Vashon Ferry terminal structural design consisted of creating a framing plan for the terminal building, followed by an initial design analysis. The terminal building consists of a steel frame moment resisting structure ***(Figure 39)***. Bracing was provided throughout the building in various directions to provide support against lateral forces. Various steel shapes were used throughout the structure including W shapes, MC shapes and Square HSS shapes.

The biggest challenge structurally involved connecting the cantilevered ramped walkway to the main diaphragm.

With each of these design interventions the Vashon Island Ferry Terminal would be much more pedestrian, traffic, and environmentally friendly. Pedestrians would feel more invited due to the natural flow of the system and its amenities. In turn the length of queuing would decrease because less people would be taking their cars and more would be inclined to walk onto the ferry. The local Puget Sound ecology would also greatly benefit from the reduced stormwater pollutants discharging into the Sound.



Figure 39. *Framing Plan for Vashon Terminal Building*

4. CONCLUSIONS

This report provides several design concepts that can address stormwater treatment and a sustainable transportation plan. Although each site is unique and requires specific designs, there was a common thread of stormwater filtration, improved queuing and parking, and encouraging pedestrian ridership through raised boardwalks, park areas, etc. Some sites were limited on space, which required modifications of the common design thread. At all sites, the vessel restraint system can potentially save WSF millions of dollars each year. We hope that WSF can implement some of the design concepts developed by the class, or modify the concept so it can be more practically applied. Our students have developed unique, innovative designs that will help WSF create terminals that are more sustainable and attract more ridership.

APPENDIX: DRAWING SETS

SEATTLE-COLMAN DRAWINGS

MUKILTEO DRAWINGS

FRIDAY HARBOR DRAWINGS

VASHON DRAWINGS

APPENDIX: DRAWING SETS

SEATTLE-COLMAN DRAWINGS

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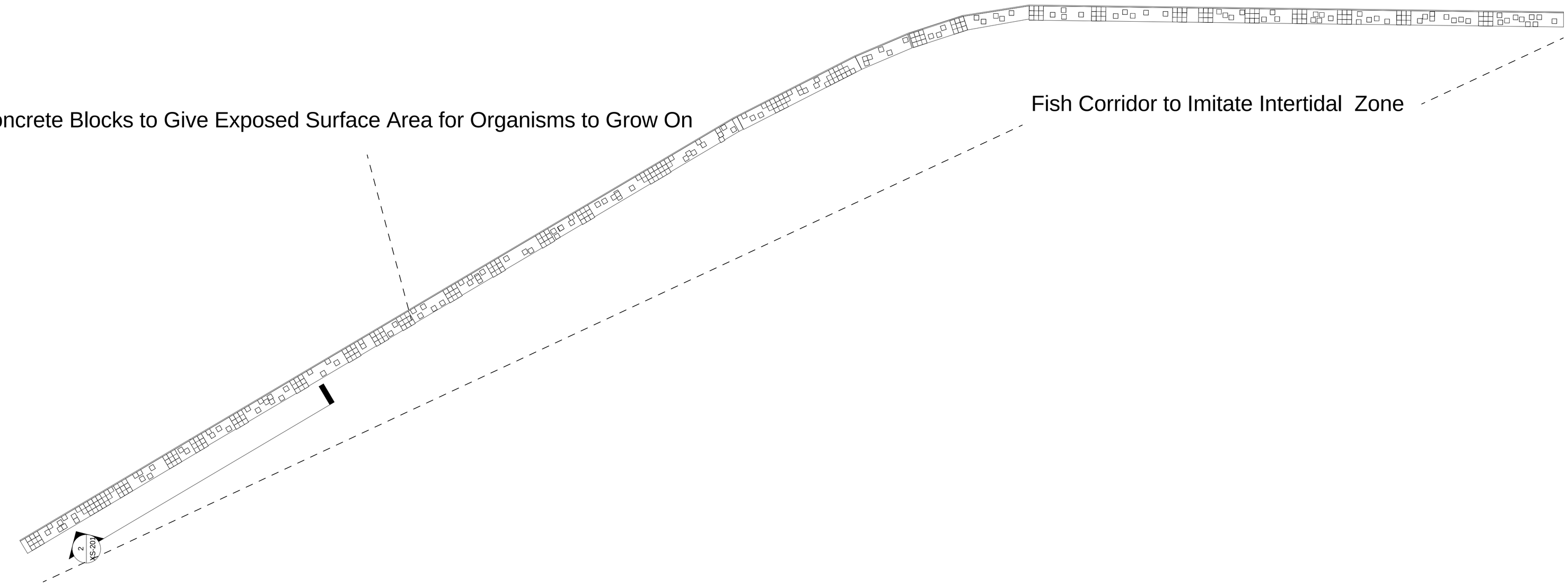
Concrete Blocks to Give Exposed Surface Area for Organisms to Grow On

Fish Corridor to Imitate Intertidal Zone



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Daniel Wagner/CE

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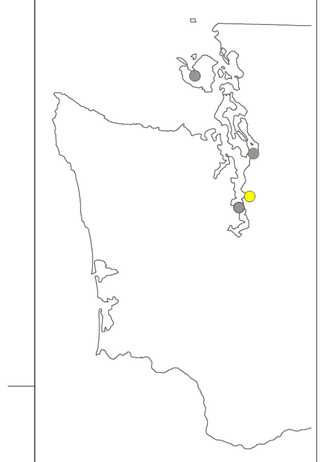

Seattle Colman Terminal

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Seawall Plan View

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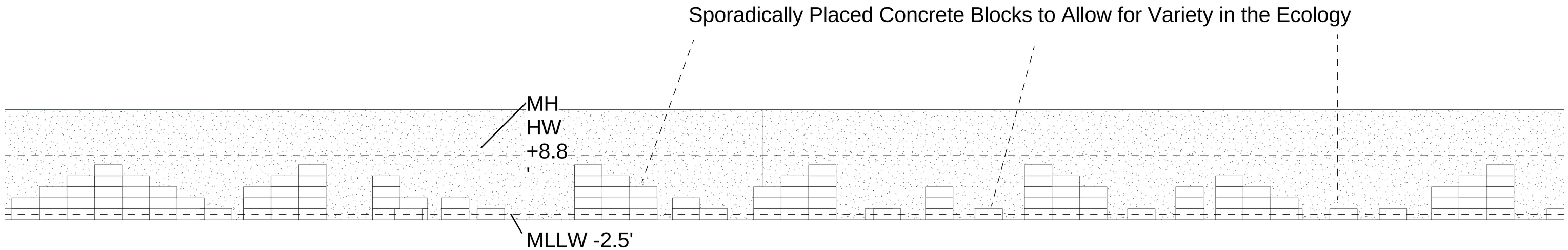

2 Elevation
1" = 10'-0"

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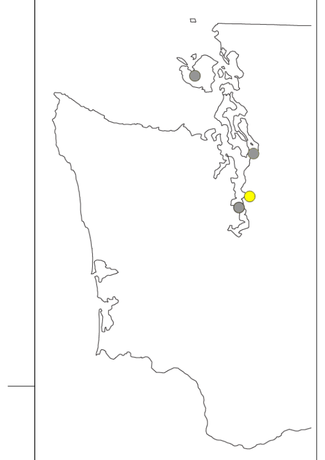
LOCATION



Seattle Colman Terminal

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Seawall Elevation

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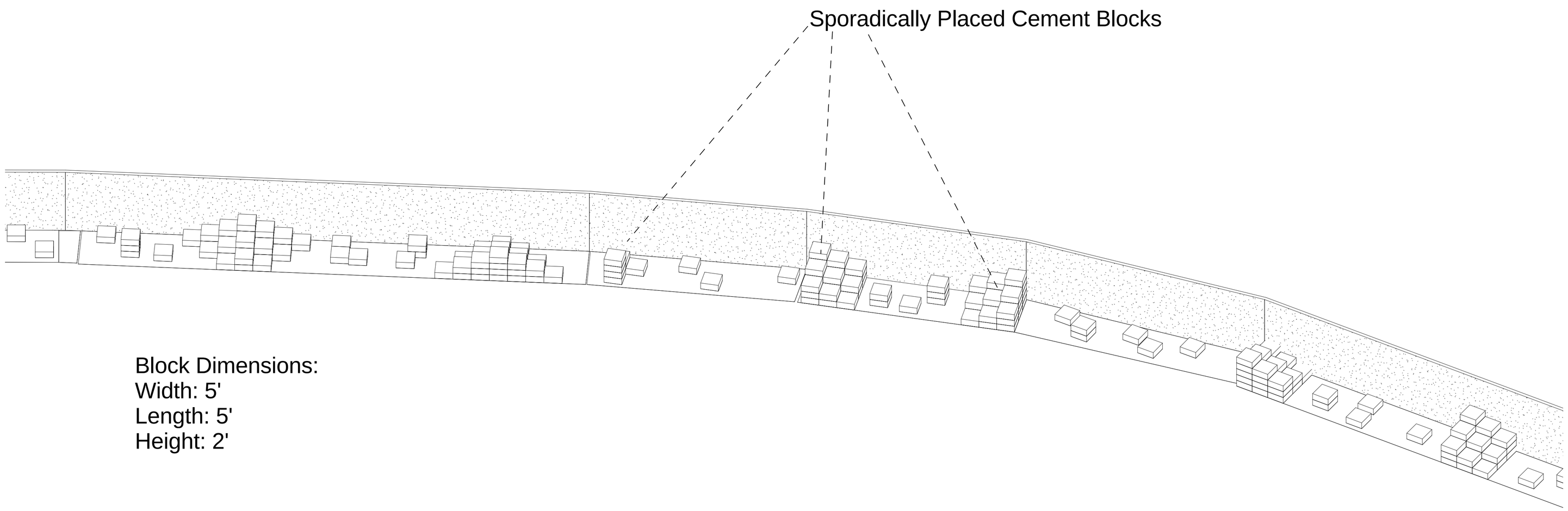

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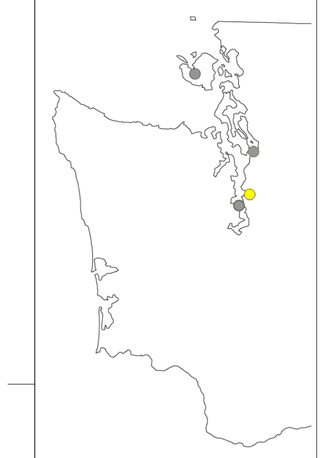

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SCALE

Seawall Axon

XS-701

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SEATTLE COLMAN FERRY TERMINAL

Drawing Index

General
Cover Sheet

Civil
C-102 Queuing Lanes and Stormwater Filter
C-501 Living Filter/Retrofit Filter Details

Architecture
A-102 Level 1 Plan View
A-103 Roof Level Plan View
A-201 North Elevation
A-202 South Elevation
A-203 East Elevation
A-204 West Elevation
A-303 North Fold Section
A-304 South Fold Section
A-305 South Building Section
A-401 Pier 48-Site
A-501 Pier 48-Callout
A-502 Pier 48-Callout East Elevation
A-701 Pier 48-Axon
A-901 Perspective

Structural
S-101A Pile Plan
S-101B Level 0 Framing Plan
S-201 Roof Framing Plan
S-901 Structural Perspective

Transportation
T-101 Example

Stormwater
XS-101 Seawall Plan View
XS-201 Seawall Elevation
XS-701 Seawall Axon

Seattle Colman Ferry Terminal
Pier 52, 801 Alaskan Way
Seattle, WA 98104

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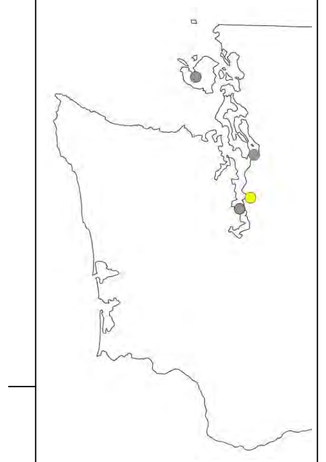
DESIGNED BY
Eric Brandon
Nick Linton
Dan Wagner
Arthur Mironchuk
Matt Sims
Victoria Wilson
Jordan Williams

LOCATION



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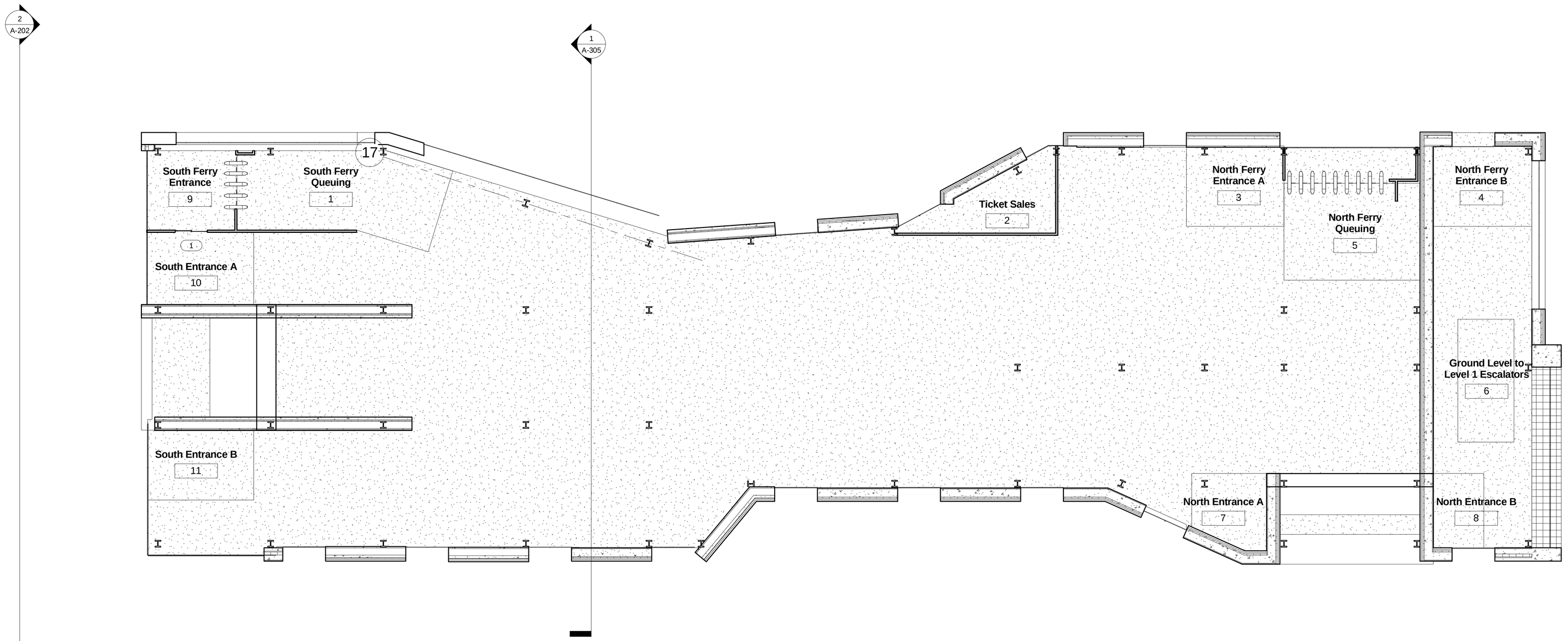

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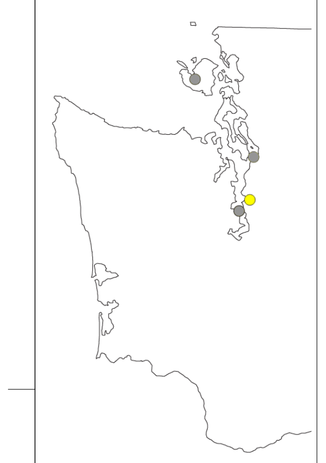

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Level 1 Plan

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Roof Level Plan

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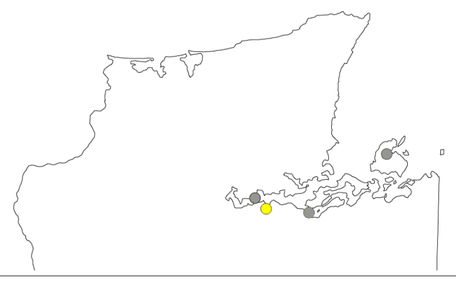

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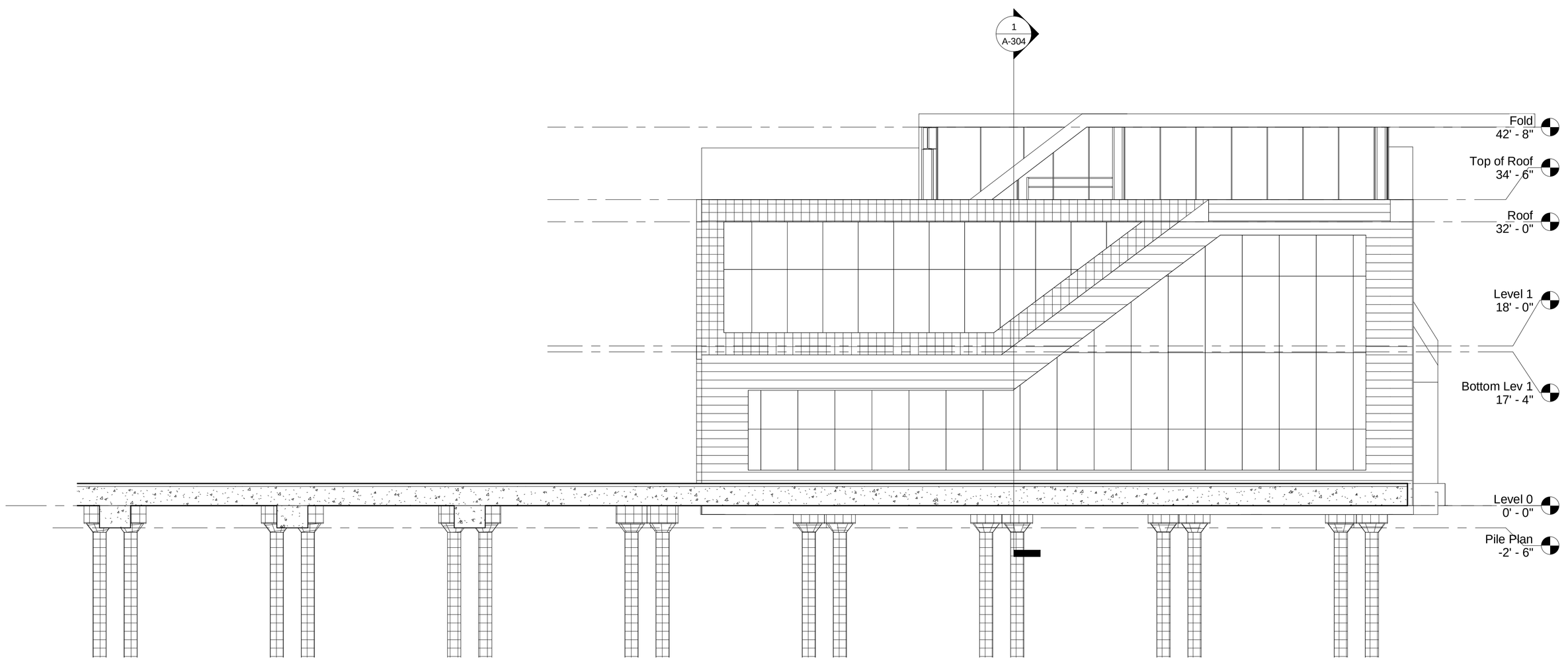

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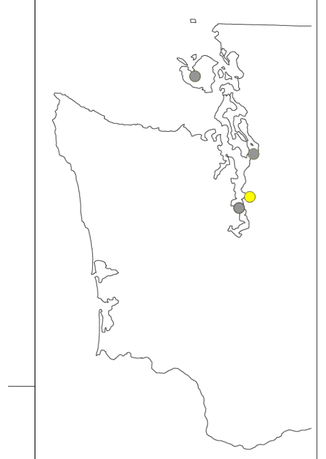

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North Elevation

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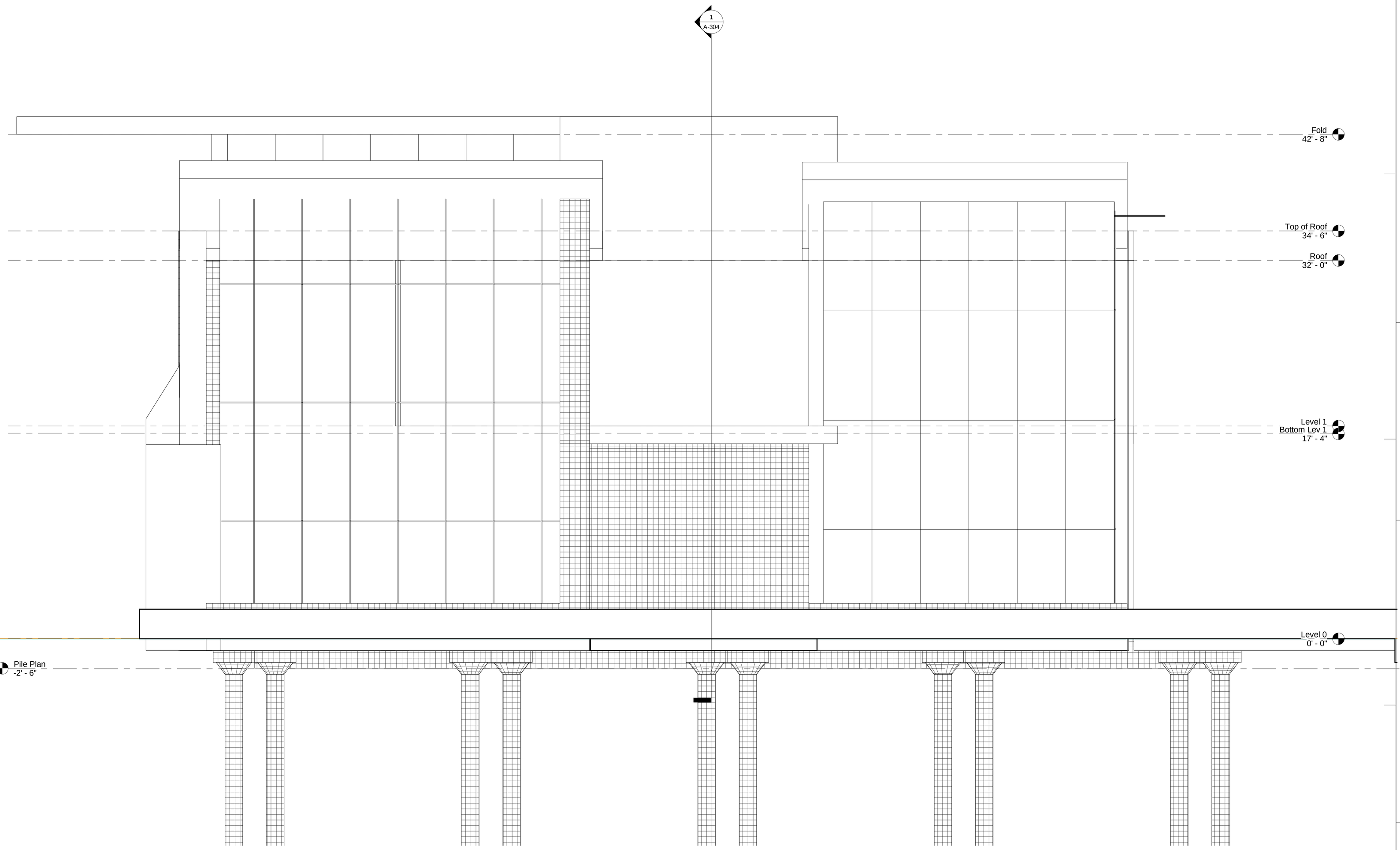

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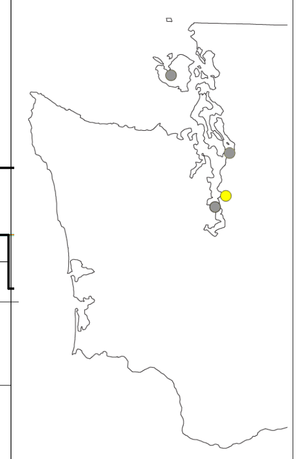

Seattle Colman Terminal

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South Elevation

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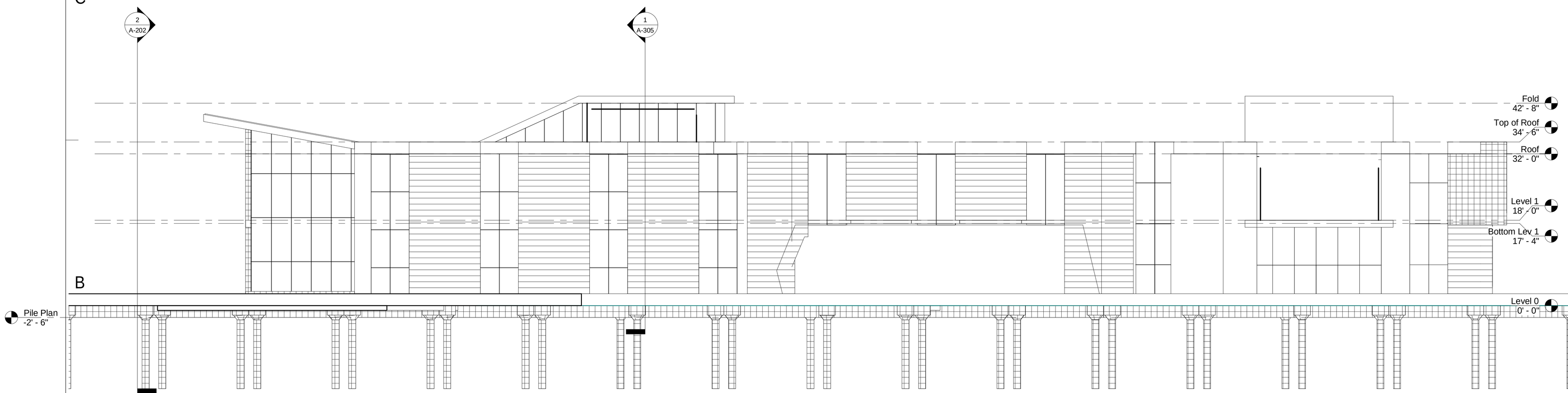

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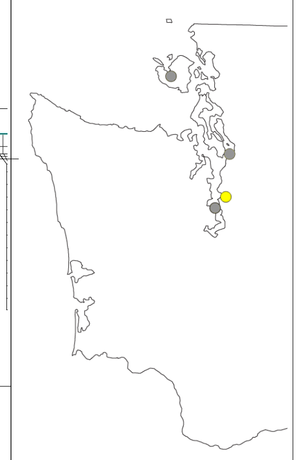

Seattle Colman Terminal

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East Elevation

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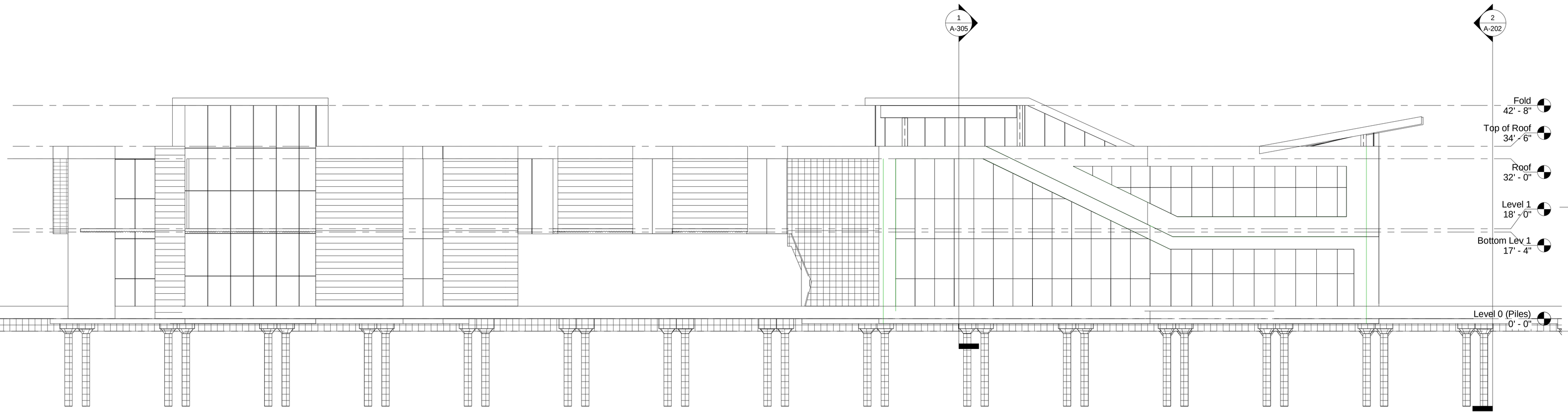

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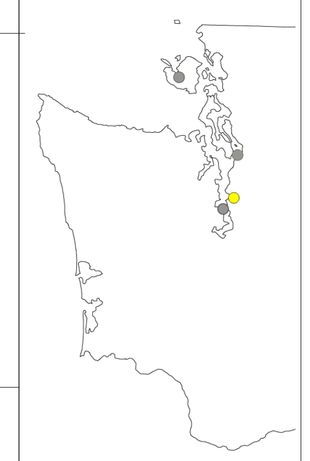

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West Elevation

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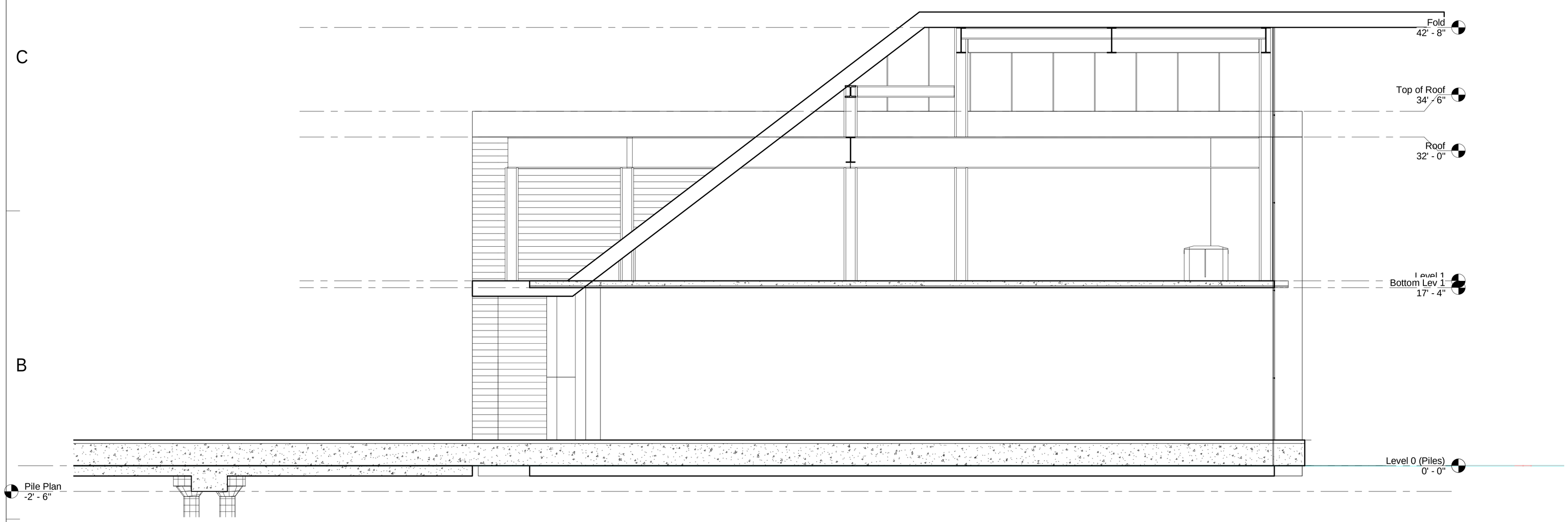

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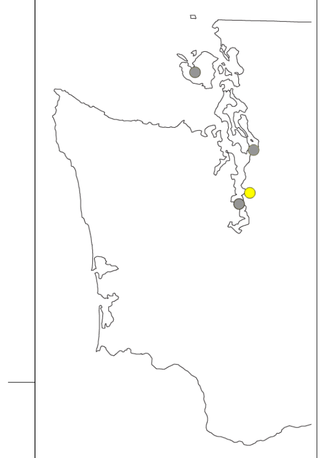

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North Fold Section

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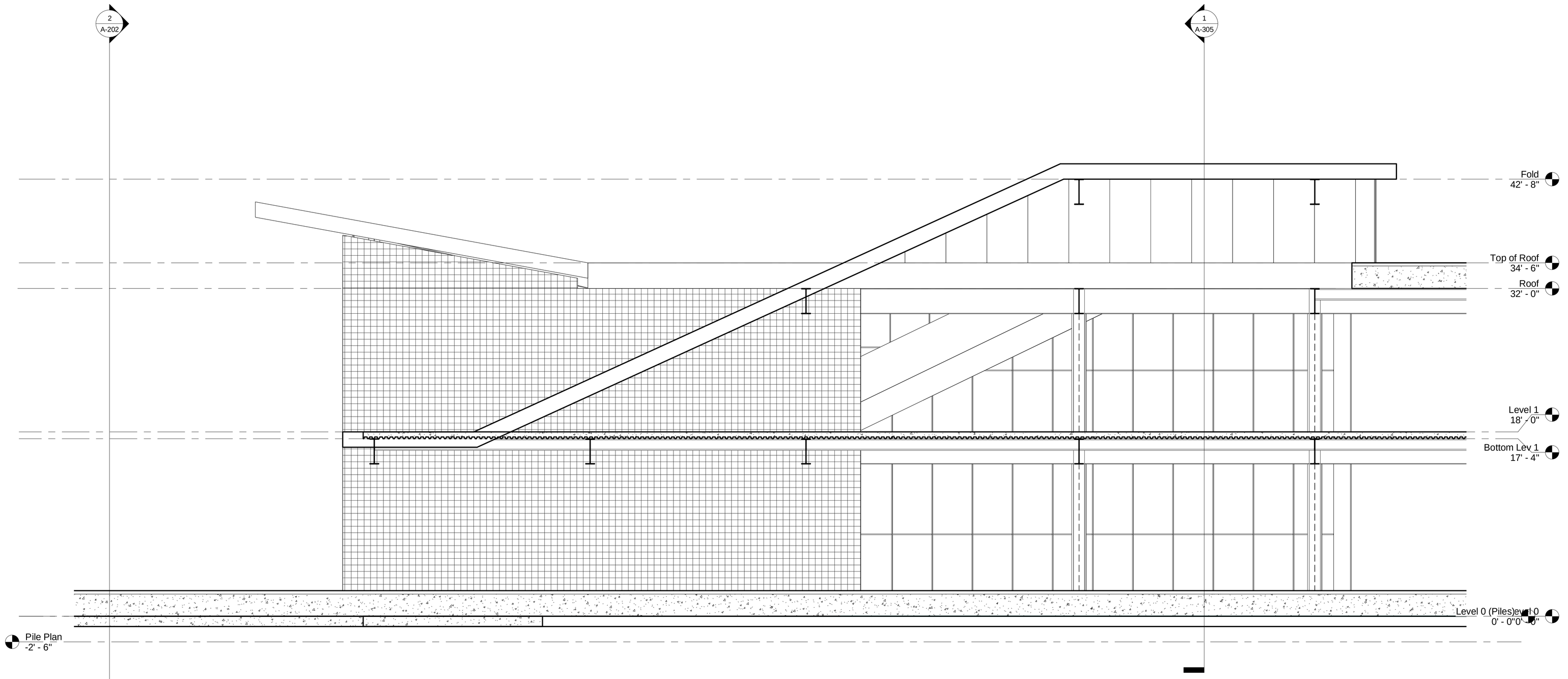
C

B

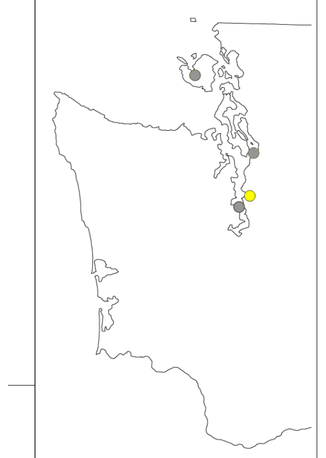
A



IDeX Integrated Design Experience

DESIGNED BY

LOCATION



Seattle Colman Terminal

DATE 4/25/2012- DD4

SCALE 3/16" = 1'-0"

South Fold Section

A-304

4/26/2012 4:00:01 PM
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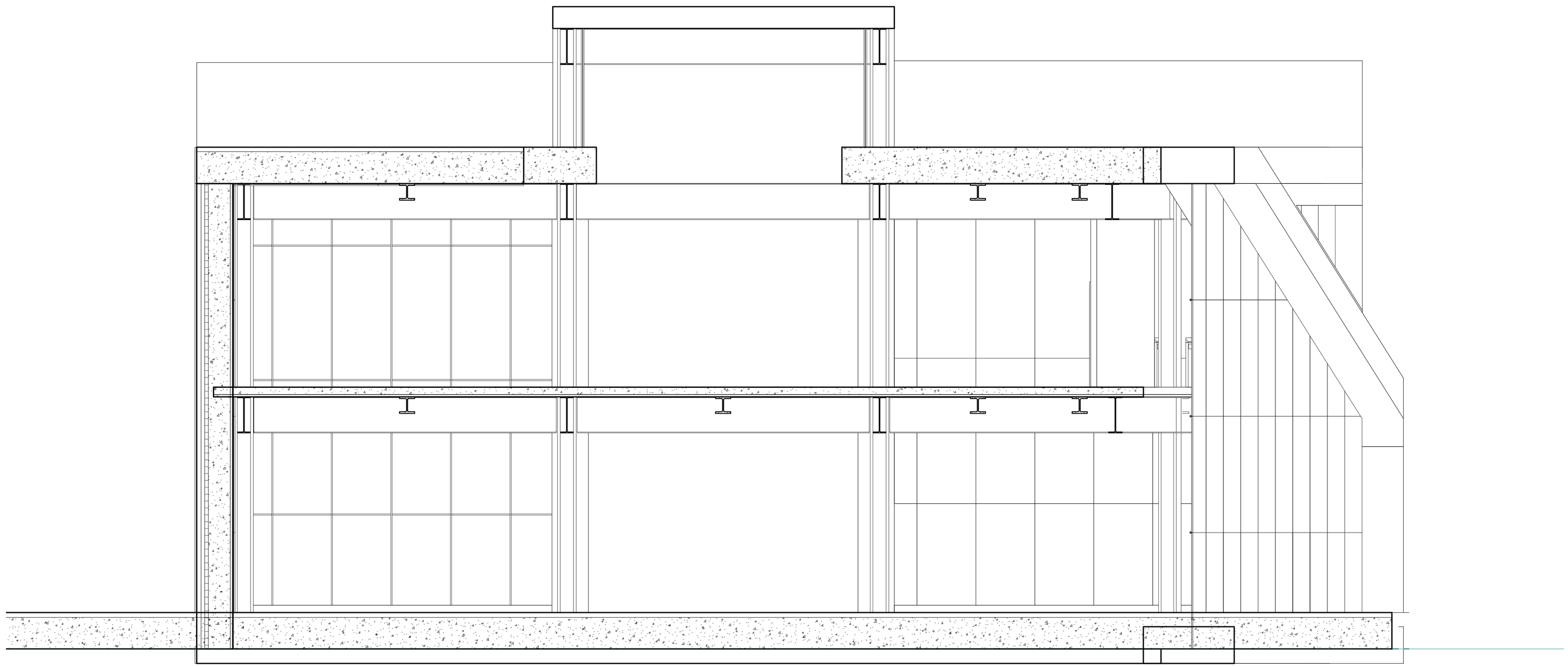
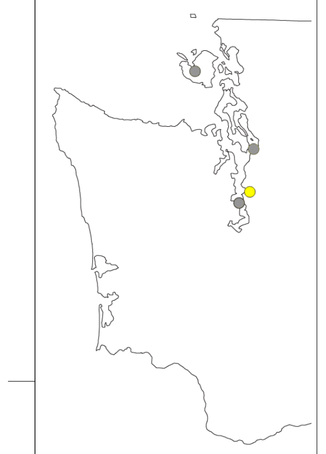


IDeX
Integrated Design Experience

DESIGNED BY

LOCATION



Seattle Colman Terminal

DATE 4/25/2012- DD4

SCALE 1/4" = 1'-0"

South Building Section

A-305

4/26/2012 4:00:02 PM
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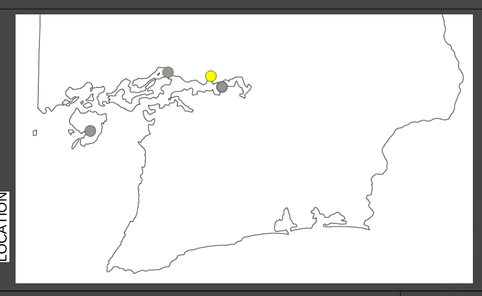
IDeX
Integrated Design
Experience

DESIGNED BY

LOCATION



Seattle Colman Terminal

DATE 4/25/2012- DD4

SCALE

Perspective

A-901

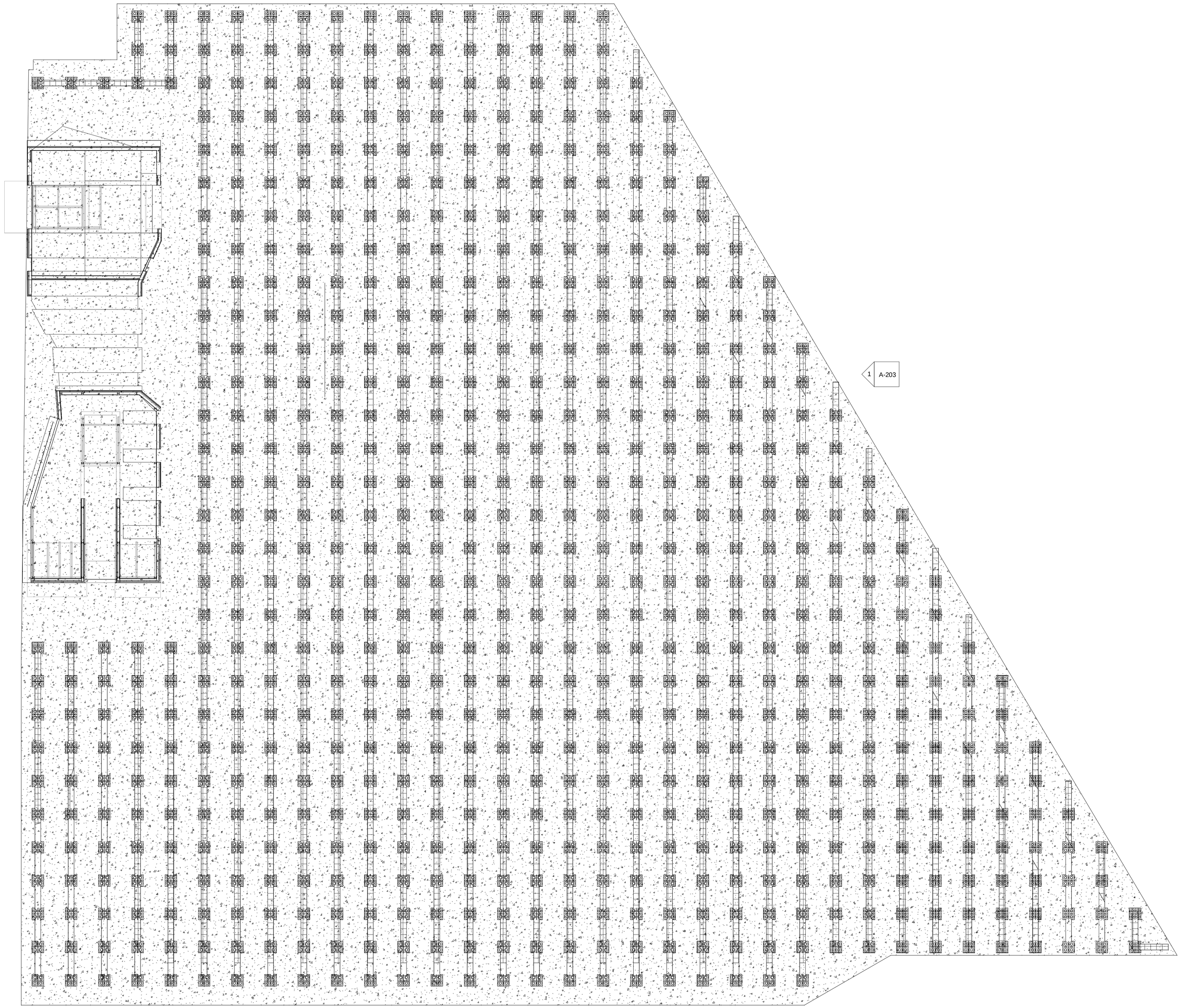
1 2 3 4 5

D

C

B

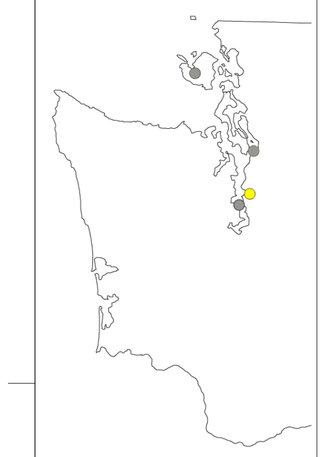
A



IDeX
Integrated Design Experience

DESIGNED BY

LOCATION



Seattle Colman Terminal

DATE 4/25/2012- DD4

SCALE 1" = 30'-0"

Pile Plan

S-101A

4/26/2012 4:00:25 PM
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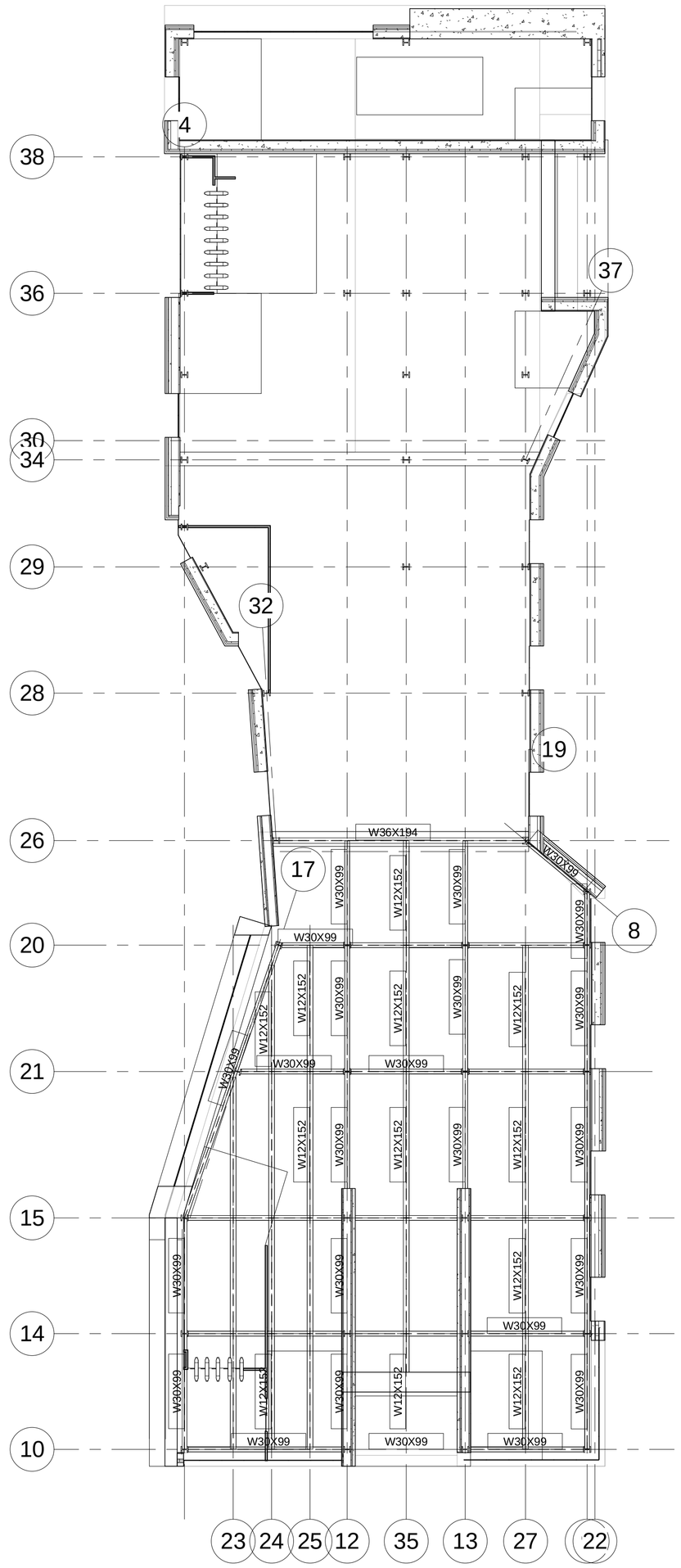
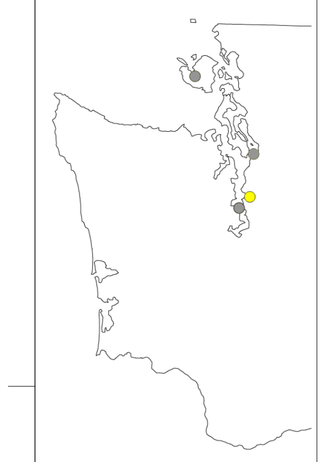


IDeX Integrated Design Experience

DESIGNED BY

LOCATION



Seattle Colman Terminal

DATE	4/25/2012- DD4
SCALE	1/16" = 1'-0"

Level 0 Framing Plan

S-101B

4/26/2012 4:00:26 PM
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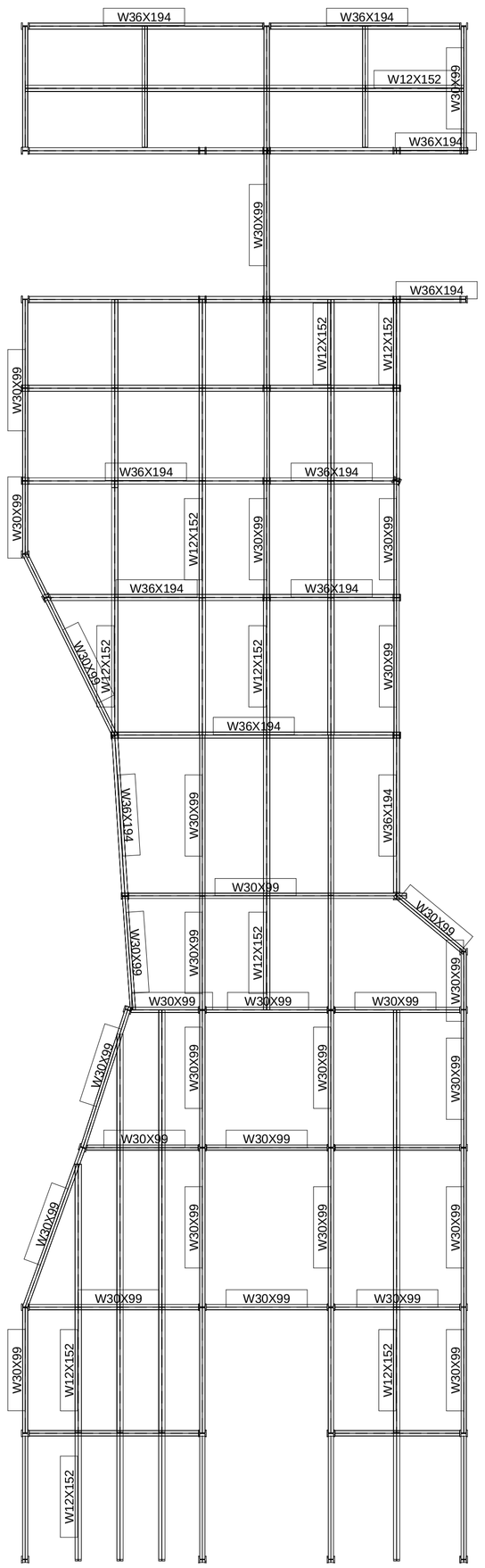
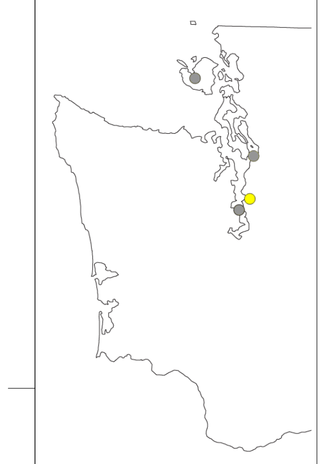


DESIGNED BY

LOCATION



Seattle Colman Terminal

DATE 4/25/2012- DD4

SCALE 1/16" = 1'-0"

Roof Framing Plan

S-102

4/26/2012 4:00:27 PM
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4/26/2012 4:00:46 PM
E:\Terminal DD3 - 9 - Structural Design 1- Site 1- Terminal and Trestle.rvt

A B C D

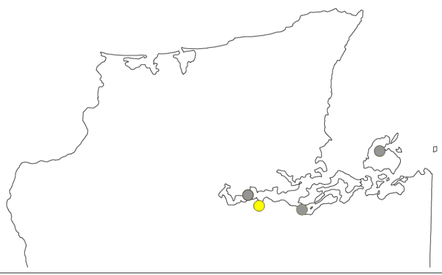
1 2 3 4 5

Structural Perspective

S-901

DATE 4/25/2012- DD4
SCALE

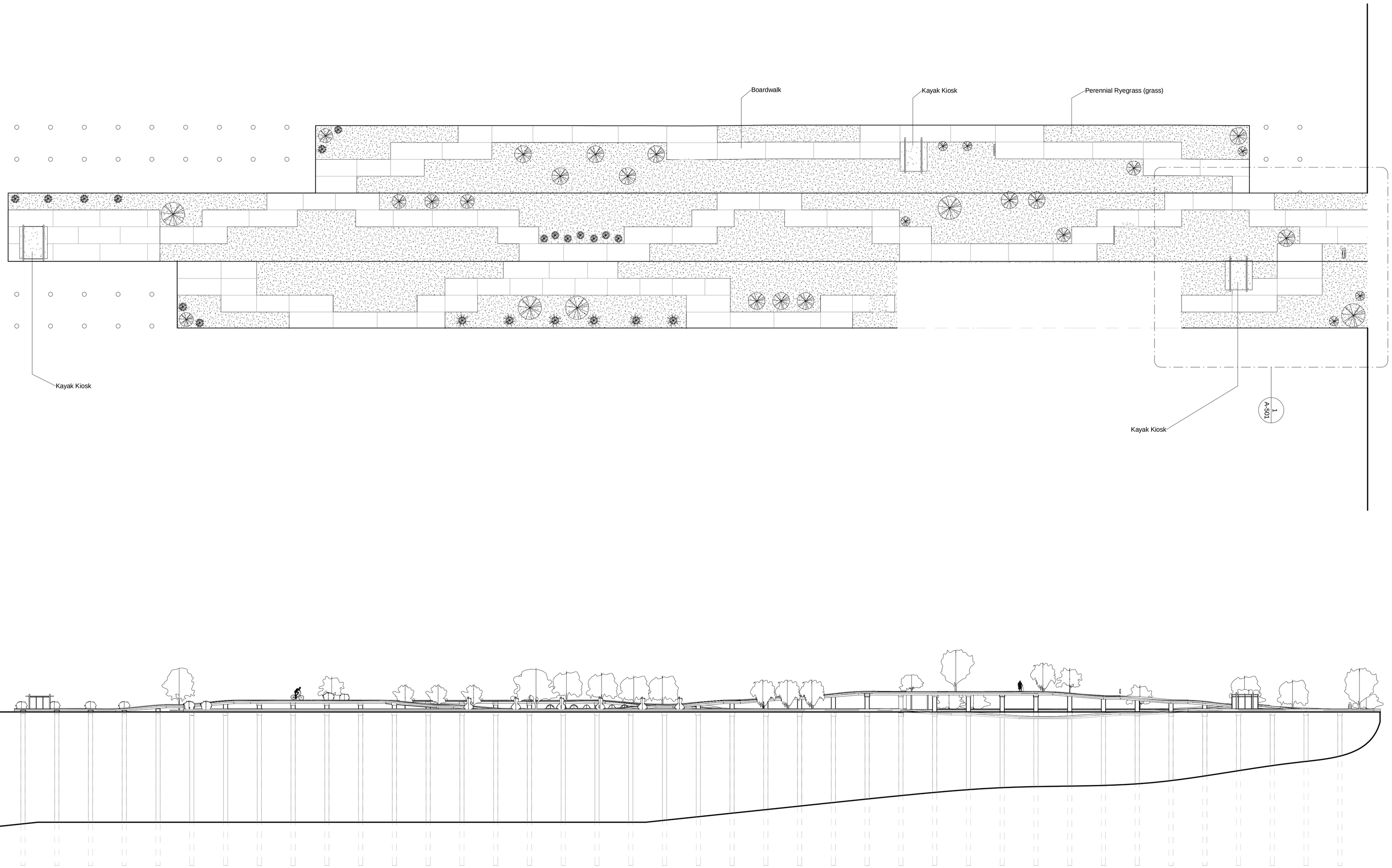
LOCATION



Seattle Colman Terminal

DESIGNED BY

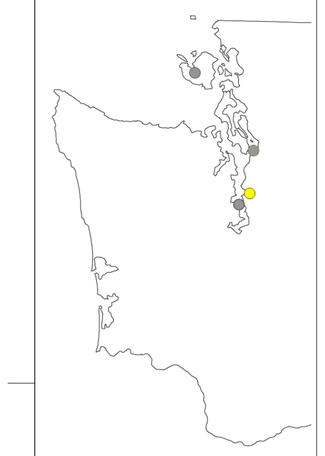
IDeX
Integrated Design Experience



IDeX
Integrated Design Experience

DESIGNED BY
Arthur Mironchuk

LOCATION

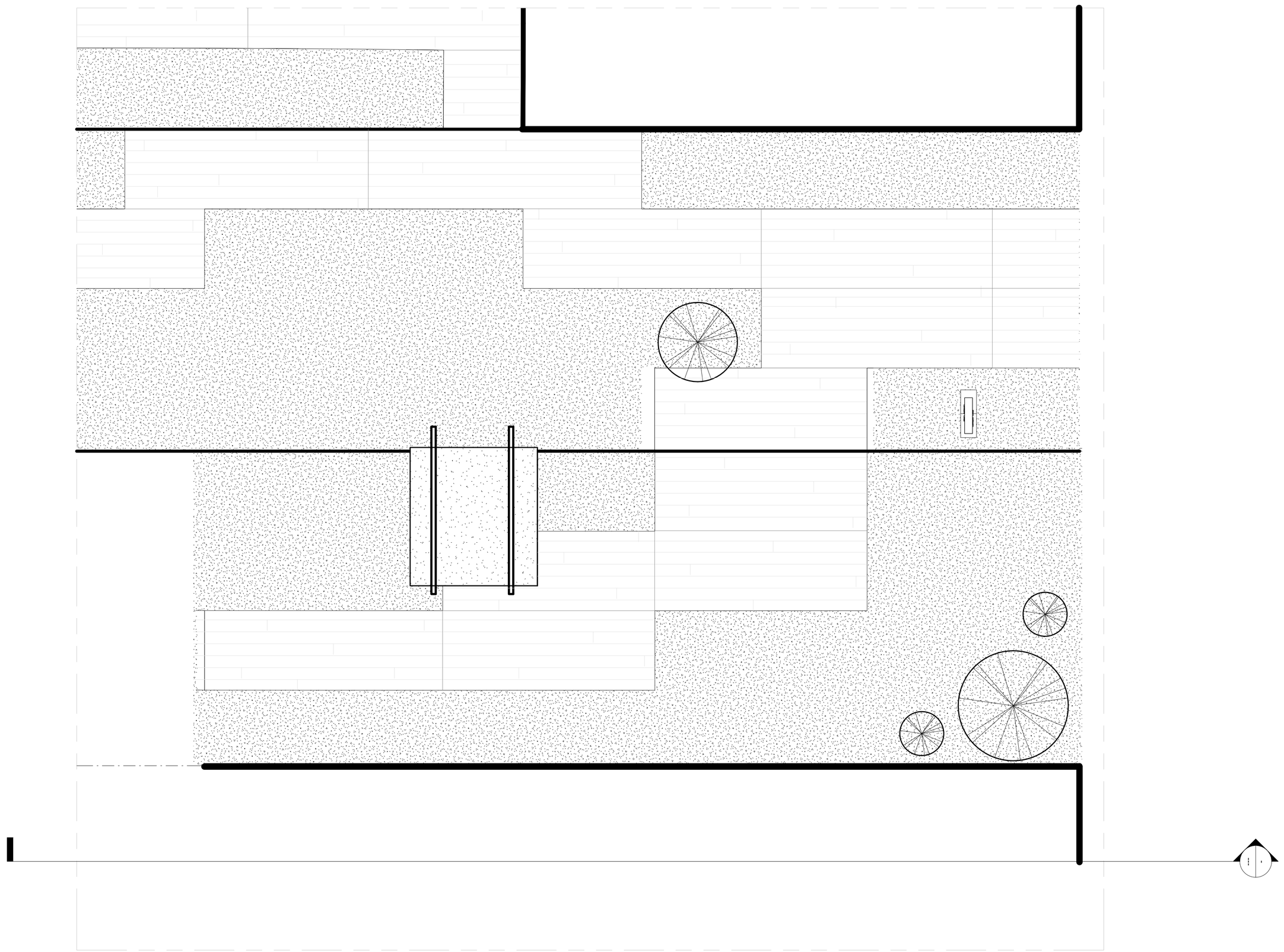


Seattle Colman Terminal

DATE 4/25/2012- DD4
SCALE 1" = 30'-0"

PIER 48 - SITE
A-401

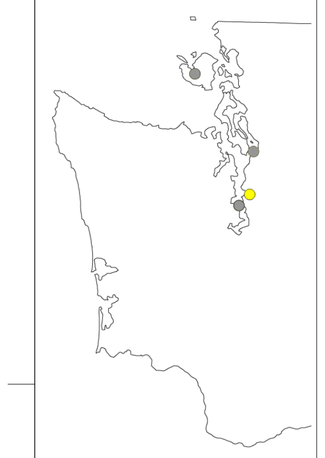
4/26/2012 3:23:22 PM
Z:\IDeX - VS\FTeam Folders\Seattle Colman\Pier 48\Final Pier 48.rvt



IDeX
Integrated Design Experience

DESIGNED BY
Arthur Mironchuk

LOCATION



Seattle Colman Terminal

DATE 4/25/2012- DD4
SCALE 1/8" = 1'-0"

PIER 48 - CALLOUT

A-501

4/26/2012 3:23:27 PM
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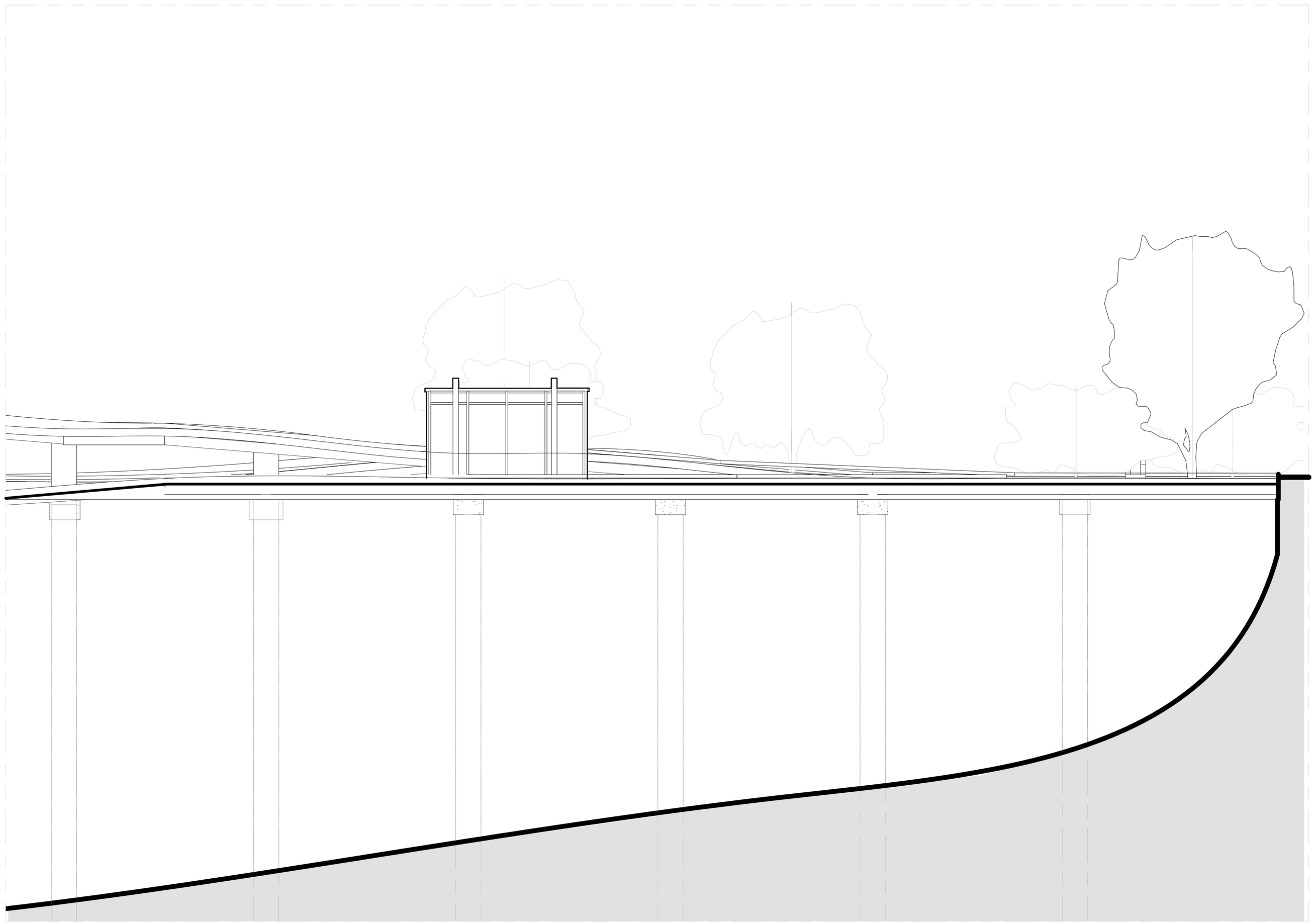
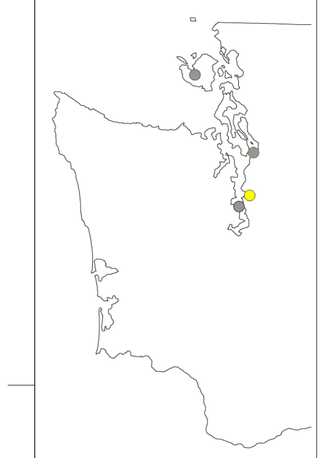


IDeX
Integrated Design Experience

DESIGNED BY
Arthur Mironchuk

LOCATION



Seattle Colman Terminal

DATE	4/25/2012- DD4
SCALE	3/16" = 1'-0"

PIER 48 - CALLOUT EAST ELEVATION

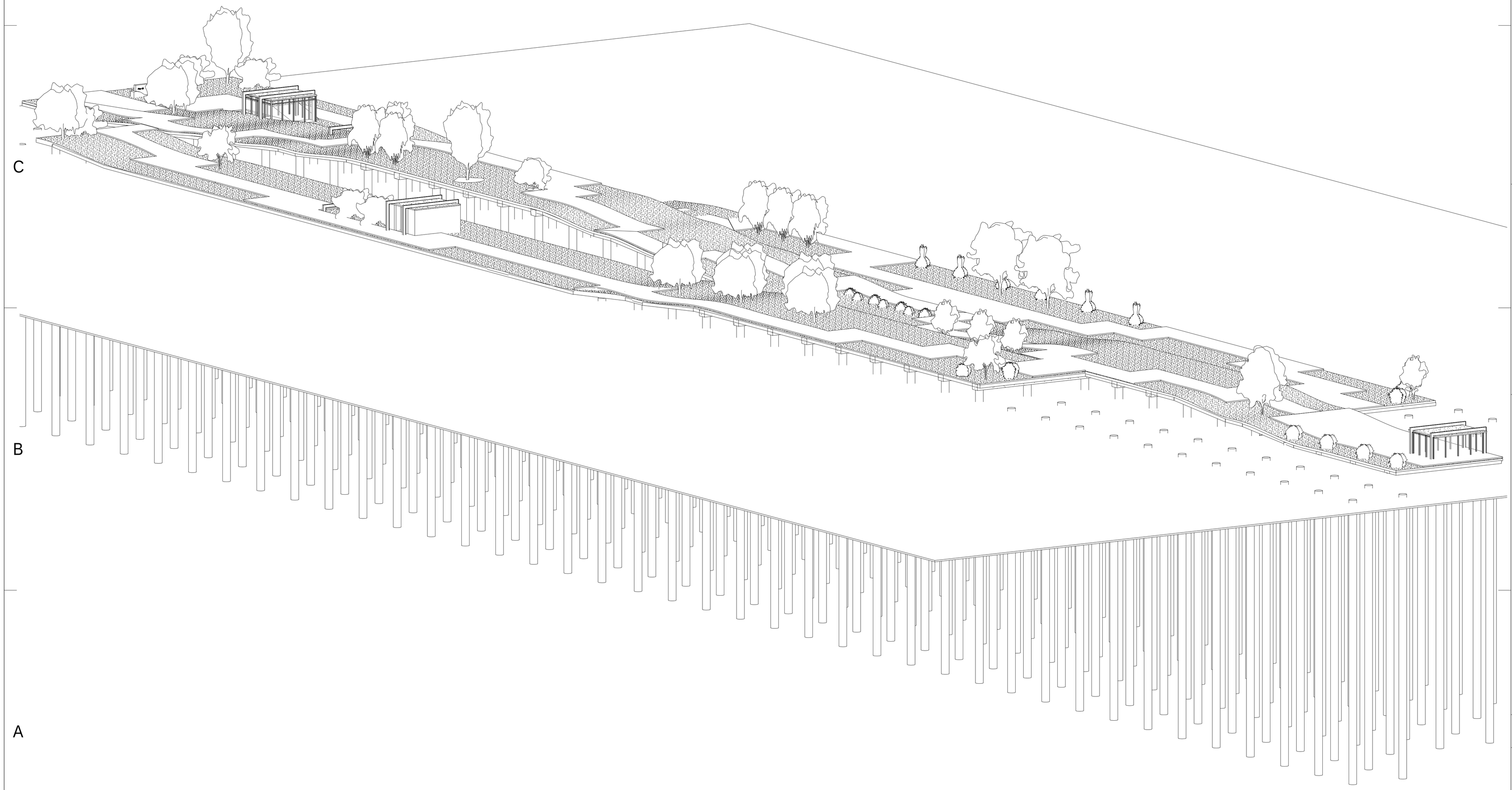
A-502

4/26/2012 3:23:36 PM
Z:\IDeX - WSF\Team Folders\Seattle Colman\Pier 48\Final Pier 48.rvt

1 2 3 4 5

D

C



B

A

IDeX
Integrated Design Experience

DESIGNED BY
Arthur Mironchuk

LOCATION



Seattle Colman Terminal

DATE 4/25/2012- DD4

SCALE

PIER 48 - AXON

A-701

4/26/2012 2:23:43 PM
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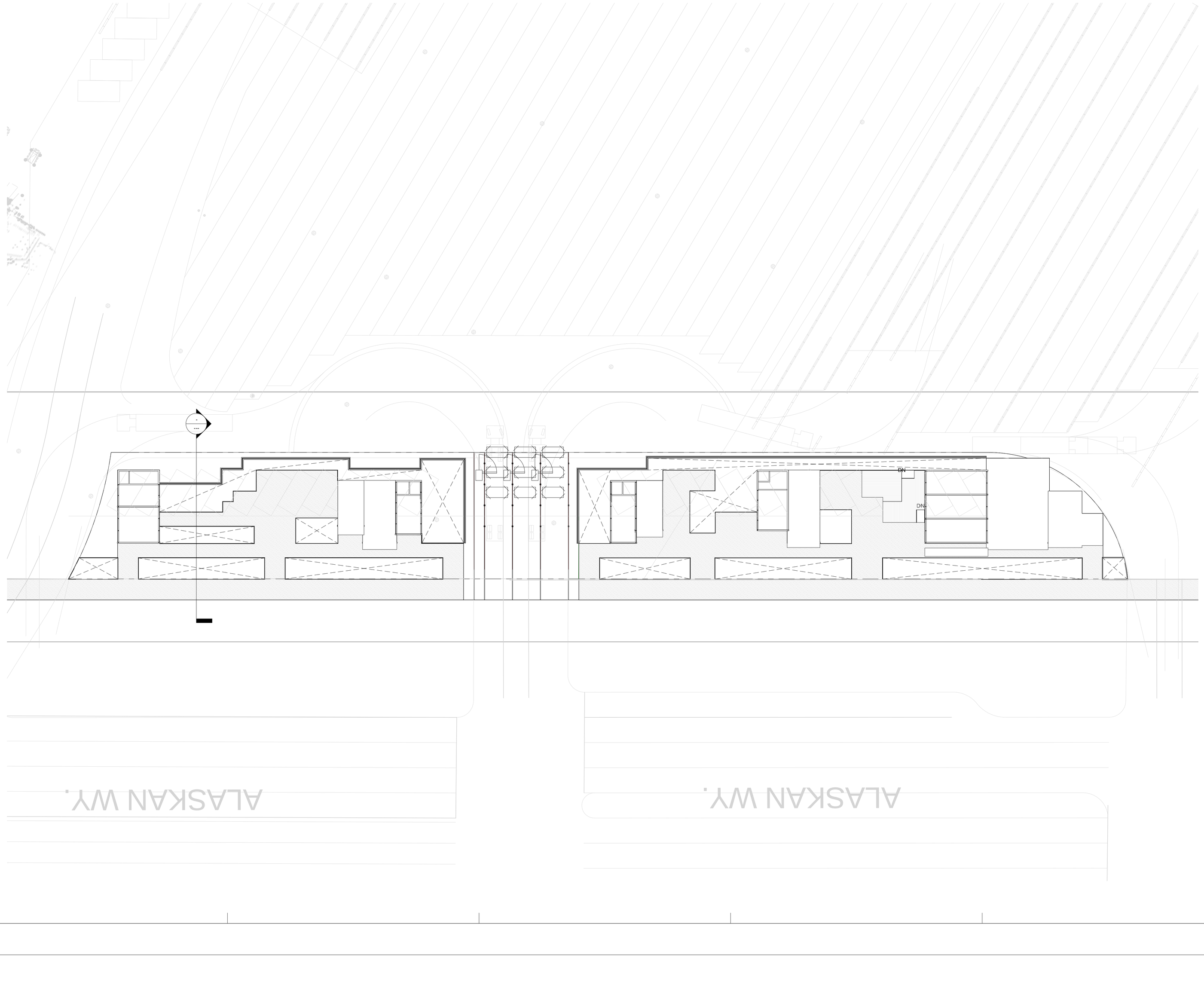
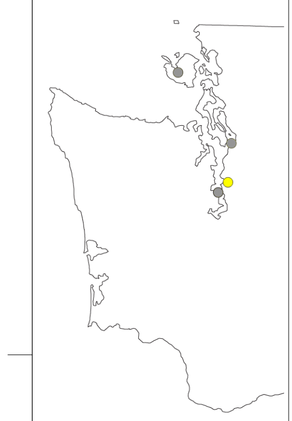


IDeX
Integrated Design Experience

DESIGNED BY
Jordan Williams

LOCATION



Seattle Colman Terminal

DATE 4/25/2012- DD4
SCALE 1" = 20'-0"

Boardwalk - Site

A-100

4/26/2012 2:41:07 PM
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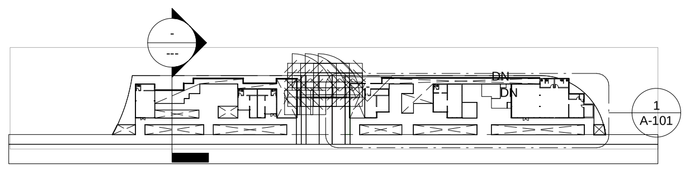
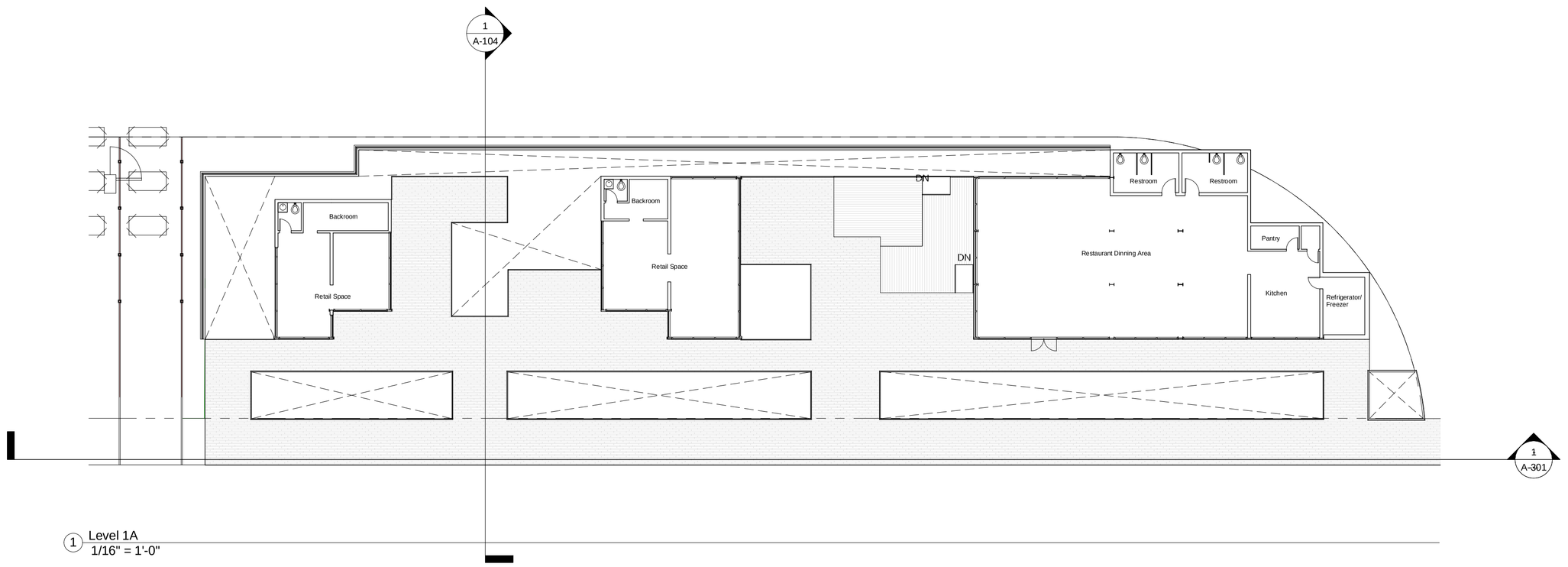
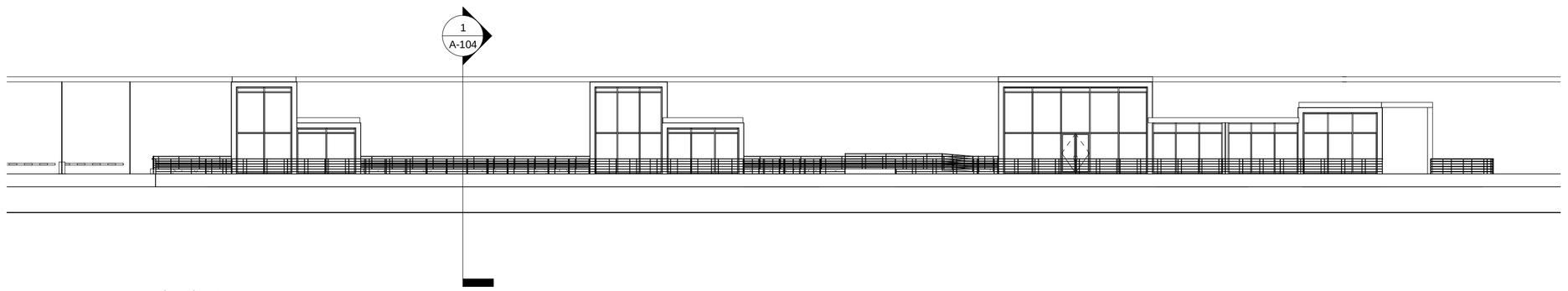


2 Level 1
1" = 100'-0"



1 Level 1A
1/16" = 1'-0"



3 Elevation 1A
1/16" = 1'-0"

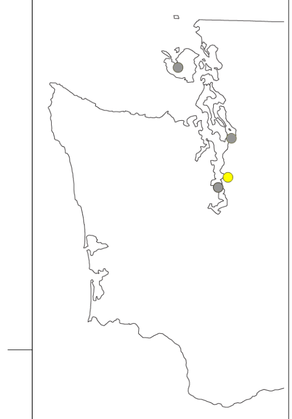
Open to Water

4/26/2012 2:41:12 PM
Z:\IDeX - WSF\Team Folders\Seattle Colman\Spring Semester\Jordan's Final Files\Park 52.rvt

IDeX
Integrated Design Experience

DESIGNED BY
Jordan Williams

LOCATION

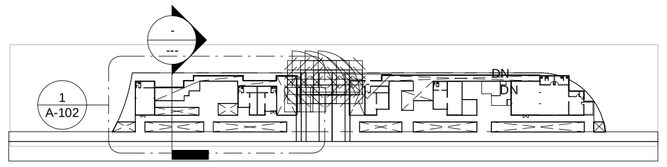


Seattle Colman Terminal

DATE 4/25/2012- DD4
SCALE As indicated

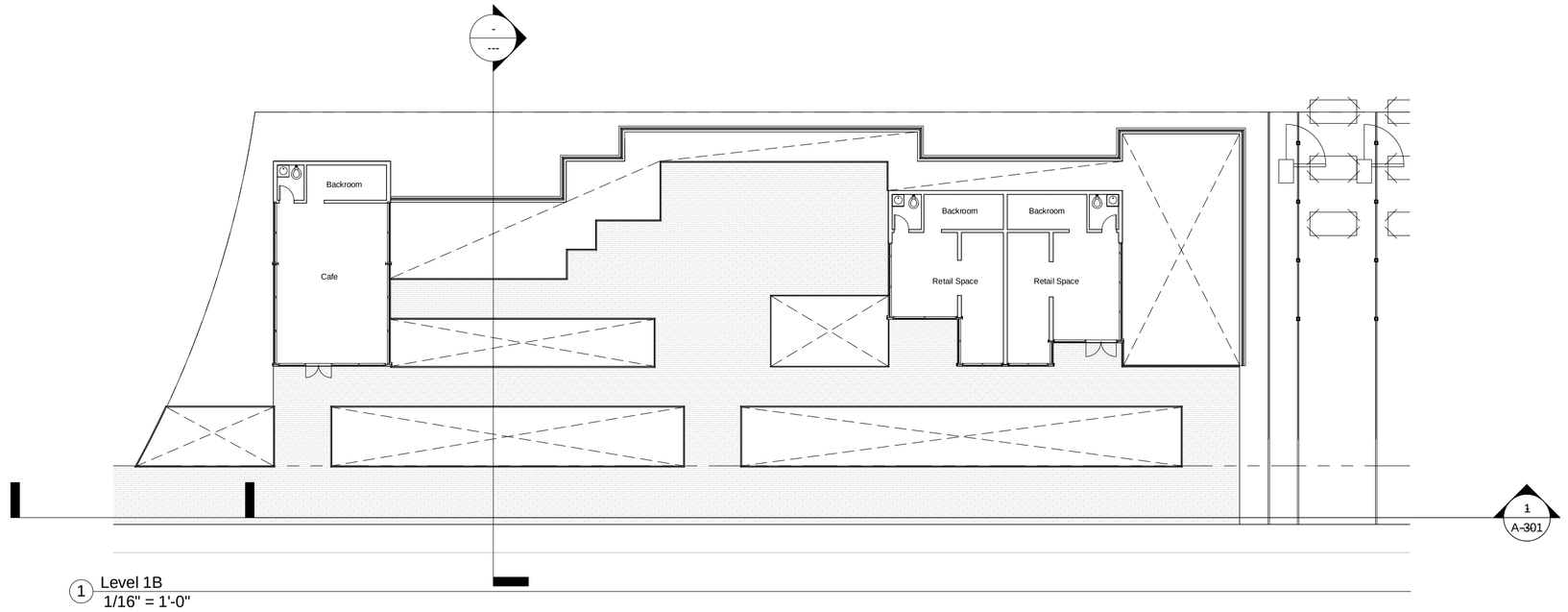
Level 1A
A-101

D



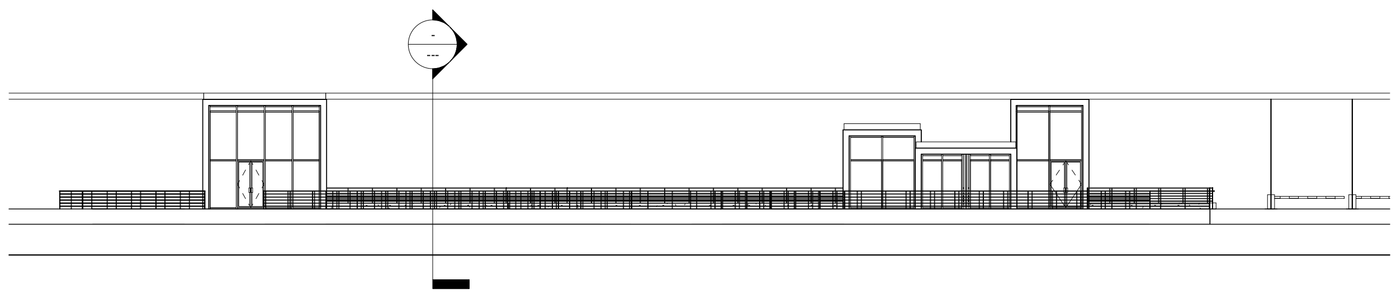
2 Copy of Level 1
1" = 100'-0"

C



1 Level 1B
1/16" = 1'-0"

B



3 Elevation 1B
1/16" = 1'-0"

A

Opening to Water

4/26/2012 2:41:19 PM
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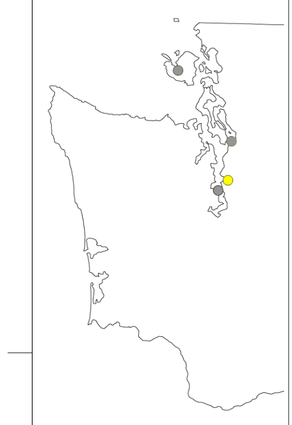
IDeX Integrated Design Experience

DESIGNED BY

Jordan Williams

LOCATION



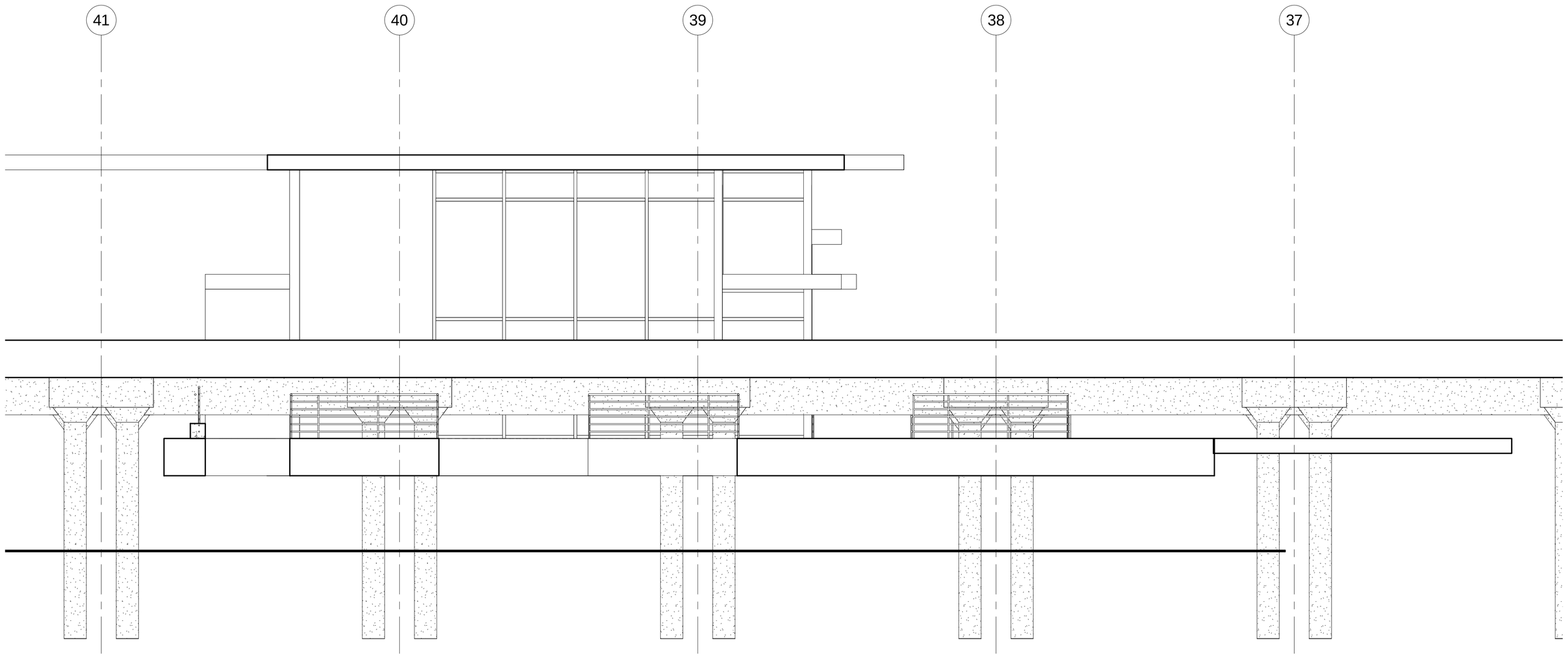
Seattle Colman Terminal

DATE 4/25/2012- DD4

SCALE As indicated

Level 1B

A-102



1 Section A-A
1/4" = 1'-0"

IDeX
Integrated Design Experience

DESIGNED BY

Jordan Williams

LOCATION



Seattle Colman Terminal

DATE 4/25/2012- DD4

SCALE 1/4" = 1'-0"

Section

A-104

4/26/2012 2:52:39 PM
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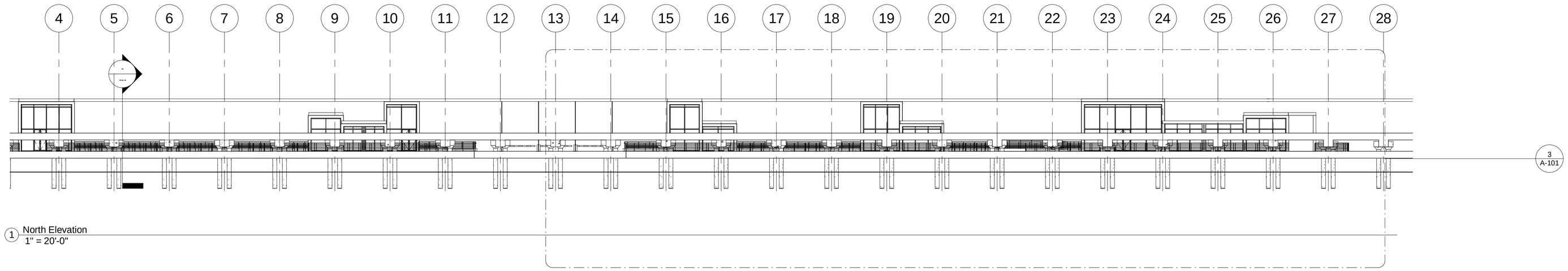


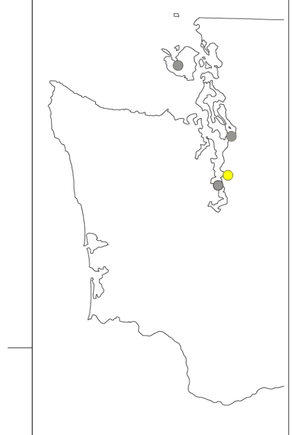
1 North Elevation
1" = 20'-0"

IDeX
Integrated Design Experience

DESIGNED BY

Jordan Williams

LOCATION



Seattle Colman Terminal

DATE	4/25/2012- DD4
SCALE	1" = 20'-0"

Eleveations

A-301

4/26/2012 2:52:45 PM
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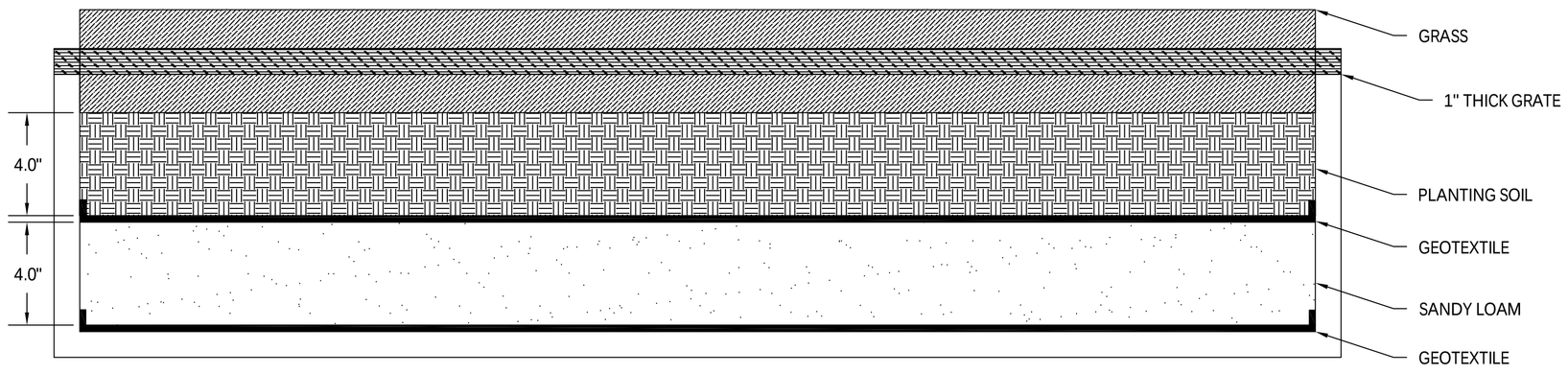
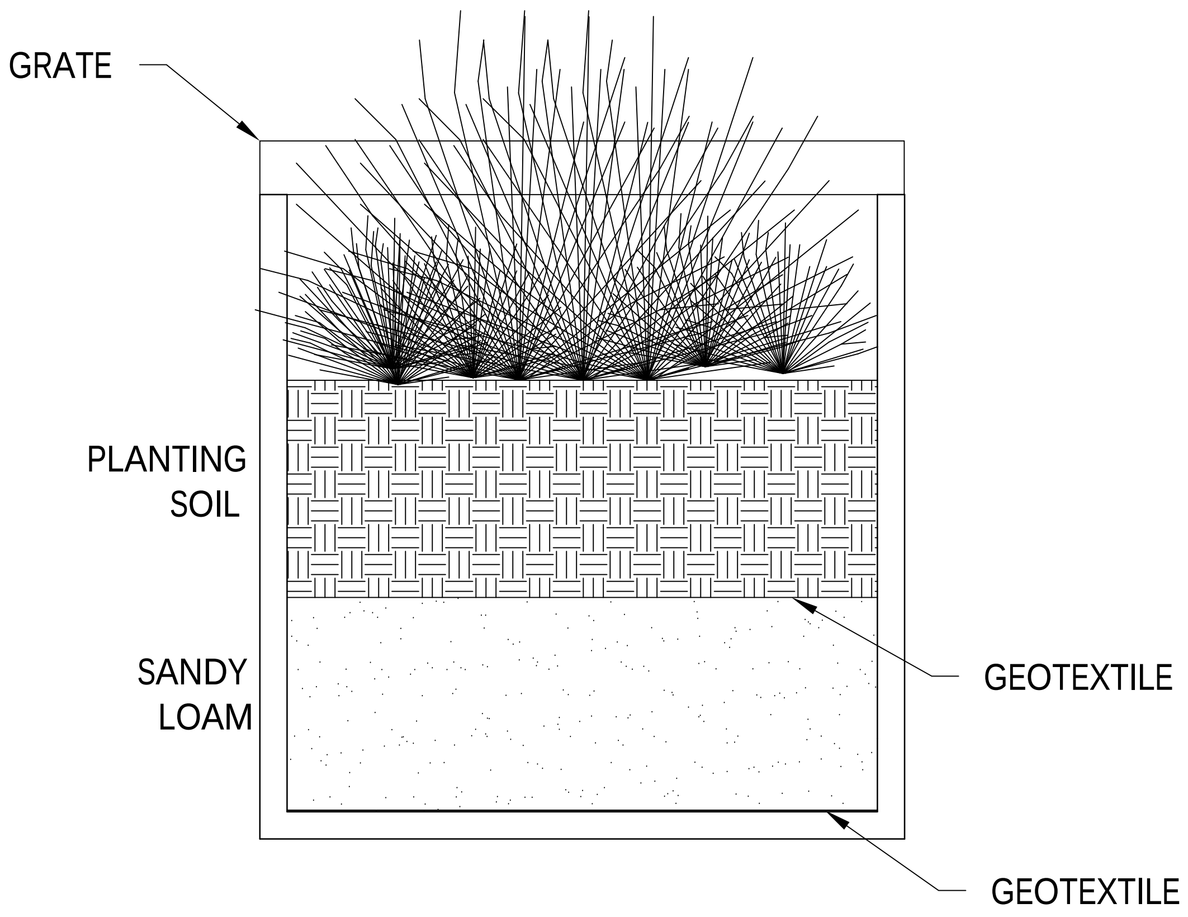
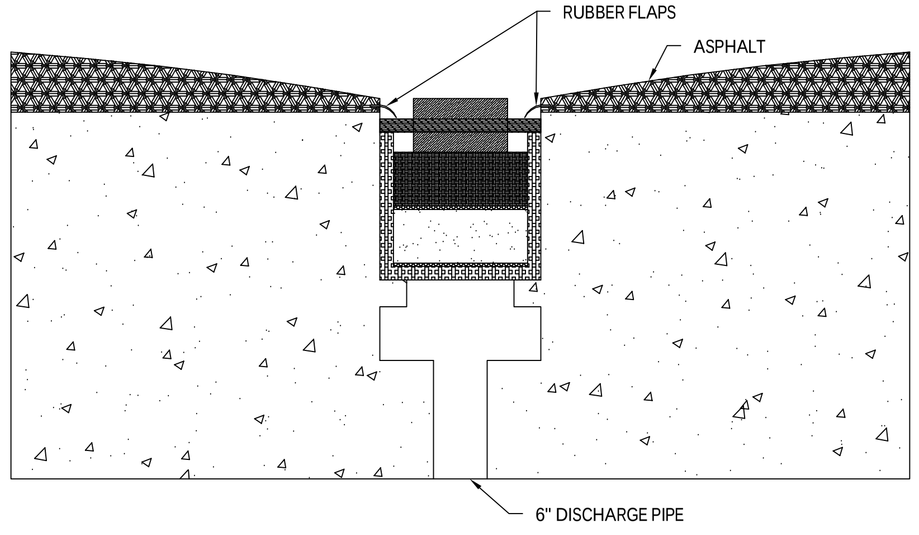


1 LONGITUDINAL SECTION - LIVING FILTER
SCALE: 3" = 1'



1 SECTION - LIVING FILTER
SCALE: 6" = 1'

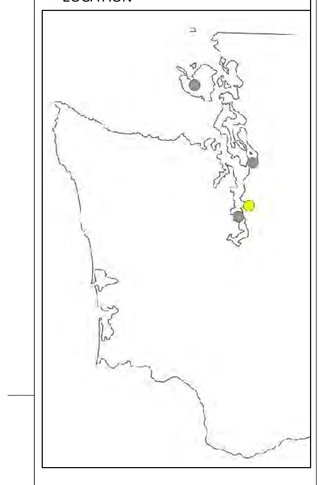


1 TRANSVERSE- LIVING FILTER
SCALE: 1 1/2" = 1'

IDeX Integrated Design Experience

DESIGNED BY
Daniel Wagner | CE

LOCATION

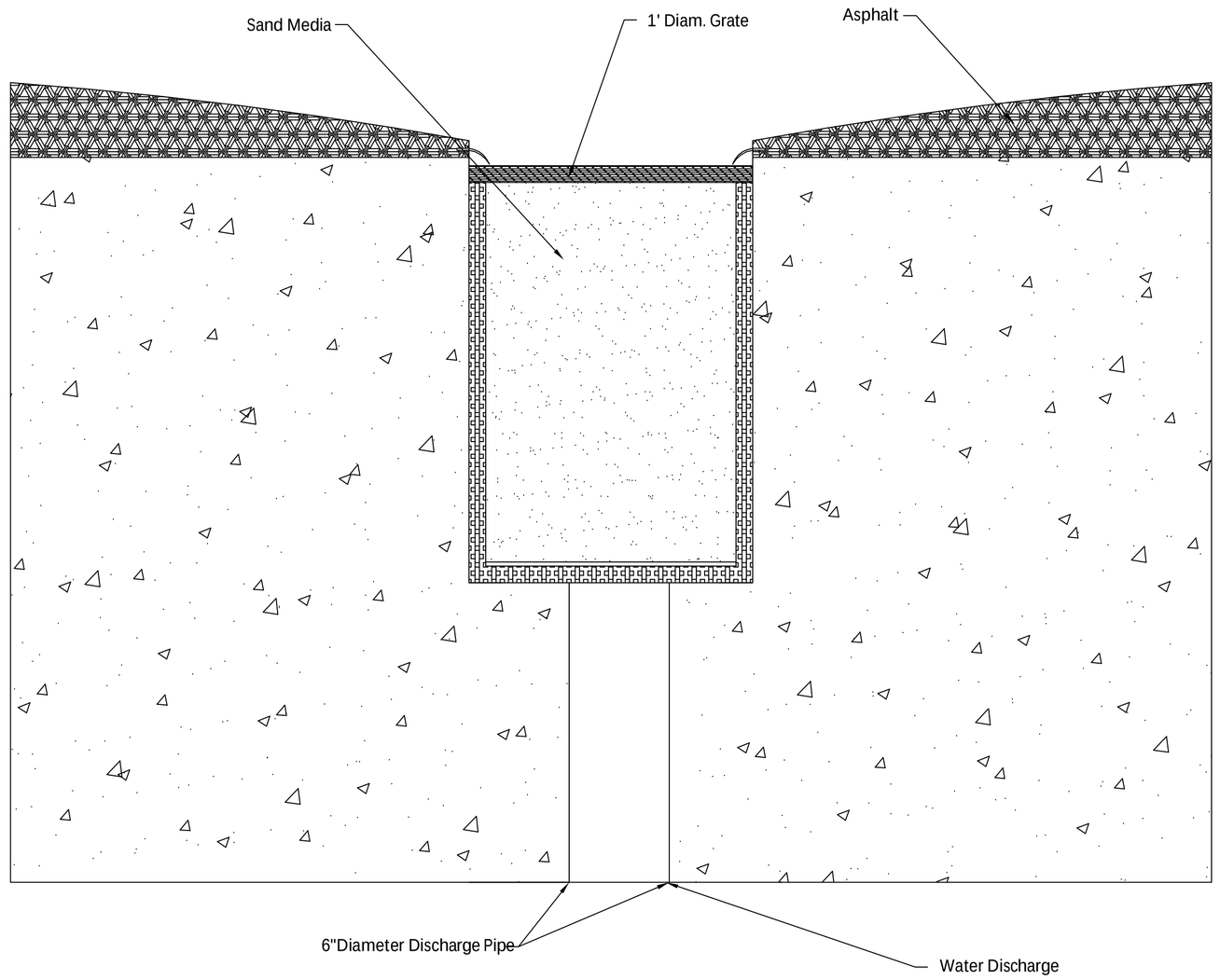


Seattle Colman Terminal

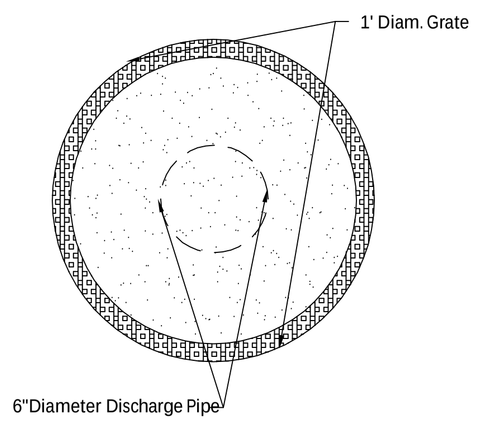
DATE **4/25/2012 - DD4**
SCALE **AS SPECIFIED**

Living Filter Details

C-501



2 SECTION - RETROFIT FILTER
SCALE: 2" = 1'



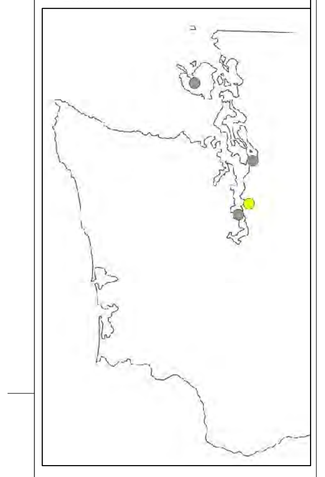
2 PLAN VIEW - RETROFIT FILTER
SCALE: 2" = 1'

IDeX Integrated Design Experience

DESIGNED BY

Daniel Wagner | CE

LOCATION



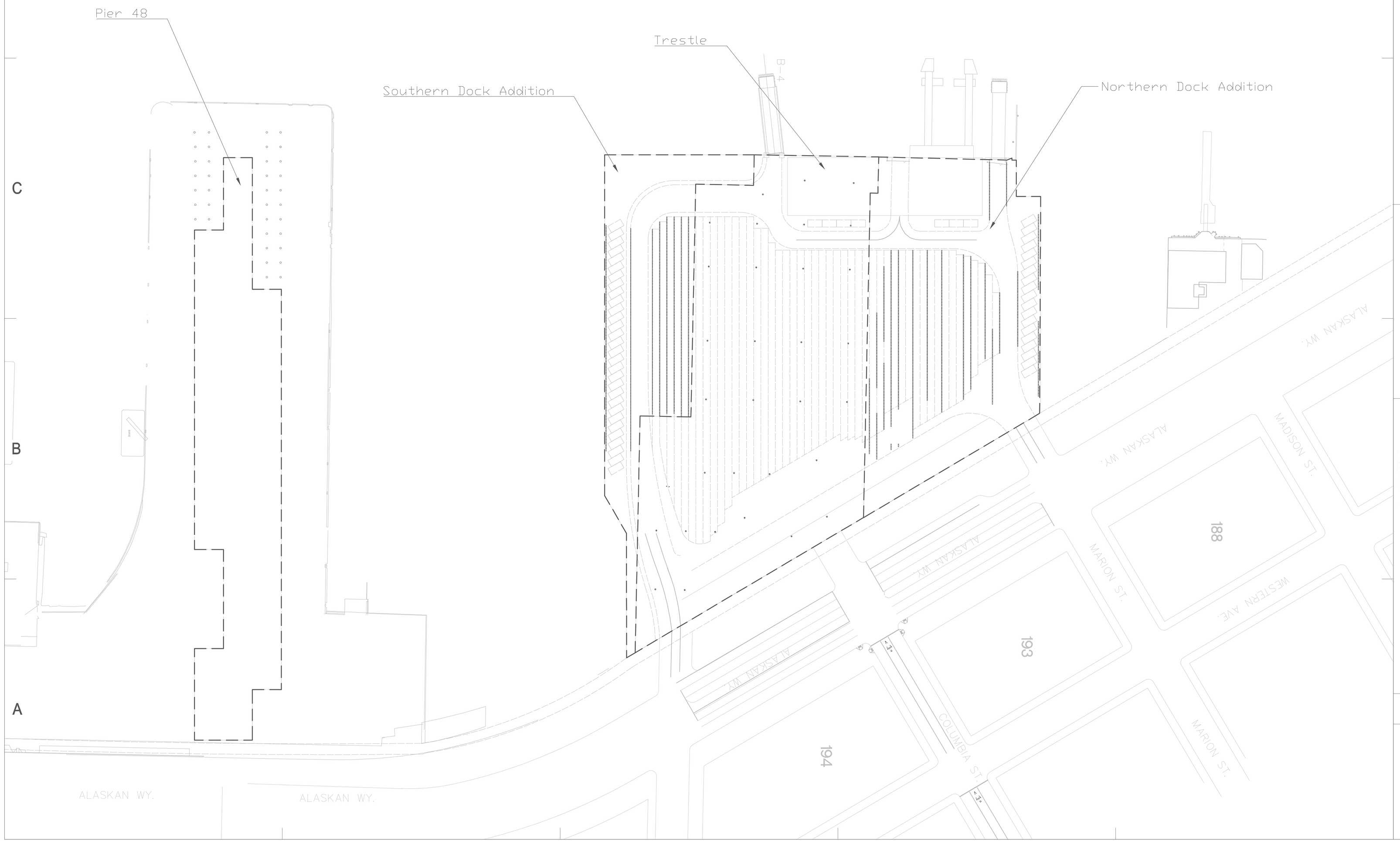
Seattle Colman Terminal

DATE **4/25/2012 - DD4**
SCALE **AS SPECIFIED**

Retrofit Filter Details

C-502

Watershed Boundaries

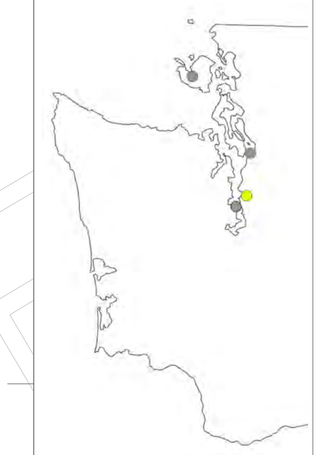


IDeX Integrated Design Experience

DESIGNED BY

Daniel Wagner | CE

LOCATION



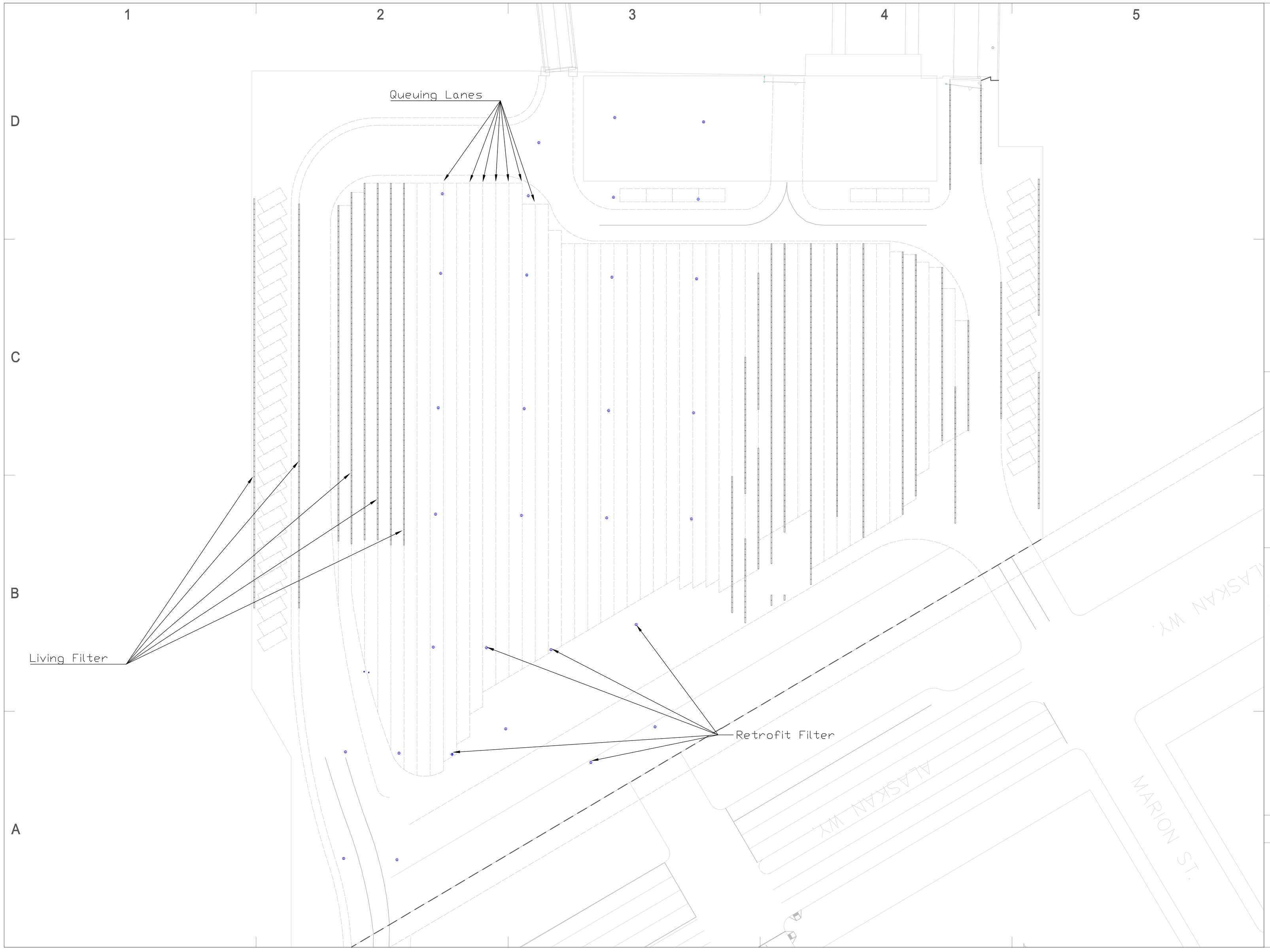
Seattle Colman Terminal

DATE 4/25 /2012 - DD4

SCALE 1/64" = 1'-0"

Sheet Name

C-103

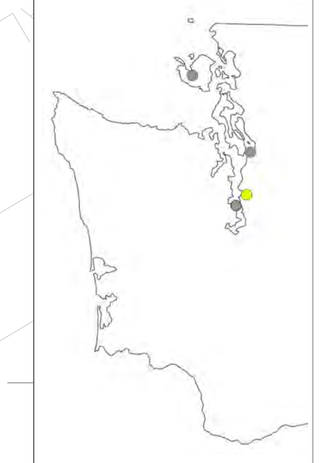


IDeX
Integrated Design Experience

DESIGNED BY

Daniel Wagner | CE

LOCATION



Seattle Colman Terminal

DATE **4/25/2012- DD4**

SCALE **1/32 " = 1' 0"**

Queuing Lanes and Stormwater Filtration System

C-102

APPENDIX: DRAWING SETS

MUKILTEO DRAWINGS

MUKILTEO MULTIMODAL TRANSIT HUB

APRIL 27, 2012

WATERSHED

614 FRONT STREET, MUKILTEO, WA 98204

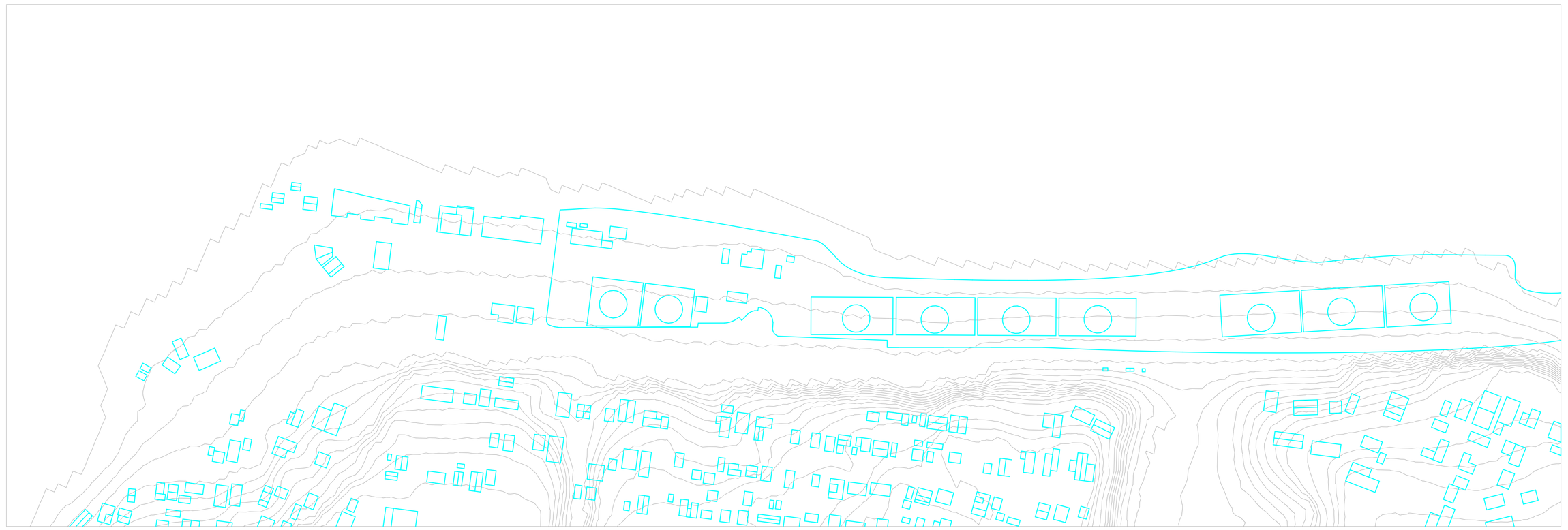


Table of Contents

GENERAL

G-001	Cover Sheet

CIVIL

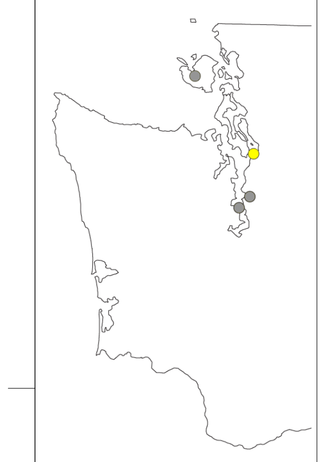
C-101	Site Plan
C-102	Wetland Plan
C-103	Japanese Creek
C-201	Wetland Profile
C-501	Japanese Creek, Living Filter Details

IDeX Integrated Design Experience

DESIGNED BY

Brad Albert | Architecture
Russell LeSieur | Architecture
Eric Winborne | Architecture
Charlie Misner | Civil Engineering
Aaron Steele | Civil Engineering
Kelly Hayden | Civil Engineering
Matt Frazier | Construction Management

LOCATION



Mukilteo Multimodal Transit Hub

DATE **4/27/2012- 20% CD**

SCALE

Cover Sheet

G-001

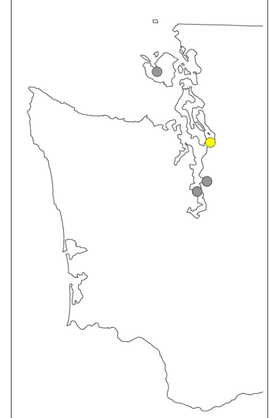


IDeX
Integrated Design Experience

DESIGNED BY

Brad Albert | Architecture
Russell LeSieur | Architecture
Eric Winborne | Architecture
Charlie Misner | Civil Engineer
Aaron Steele | Civil Engineer
Kelly Hayden | Civil Engineer
Matt Frazier | Construction Management

LOCATION



Mukilteo Multimodal Transit Hub

DATE **04/27/2012- 20% CD**
SCALE **1" - 200'**

Site Plan

C-101

1 2 3 4 5

D

C

B

A



IDeX
Integrated Design Experience

DESIGNED BY

Brad Albert | Architecture
Russell LeSieur | Architecture
Eric Winborne | Architecture
Charlie Misner | Civil Engineering
Aaron Steele | Civil Engineering
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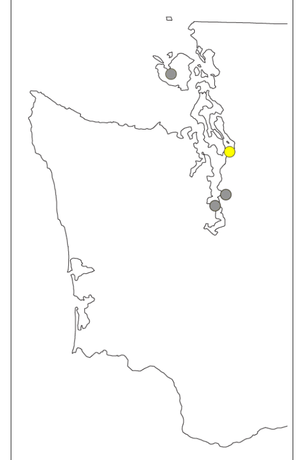
Matt Frazier | Construction Management

LOCATION



Mukilteo Multimodal Transit Hub

DATE **04/27/2012- 20% CD**
SCALE **1" = 50'-0"**

Wetland Plan

C-102

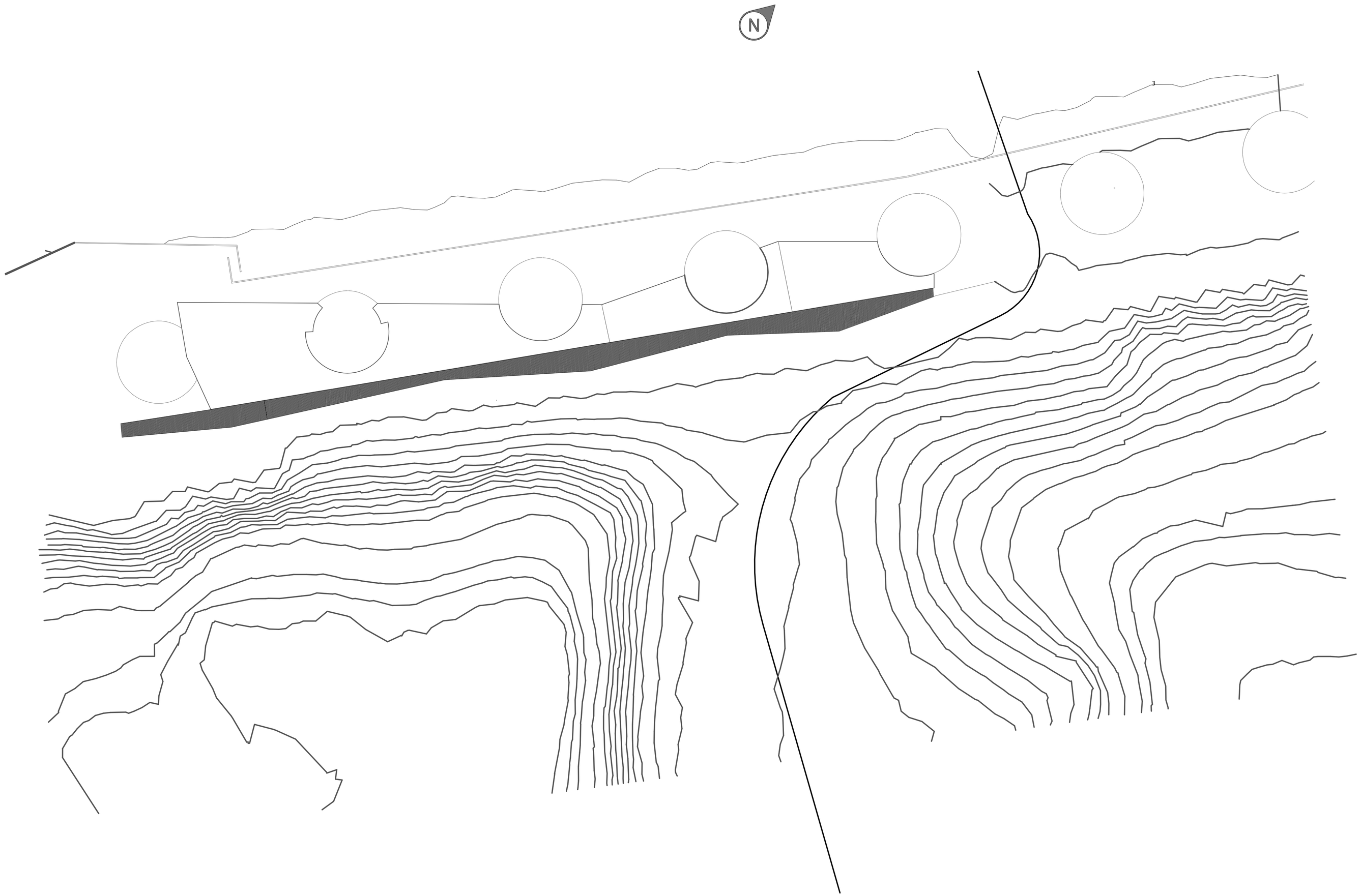
1 2 3 4 5

D

C

B

A



IDeX Integrated Design Experience

DESIGNED BY

Brad Albert | Architecture
Russell LeSieur | Architecture
Eric Winborne | Architecture
Charlie Misner | Civil Engineering
Aaron Steele | Civil Engineering
Kelly Hayden | Civil Engineering
Matt Frazier | Construction Management

LOCATION

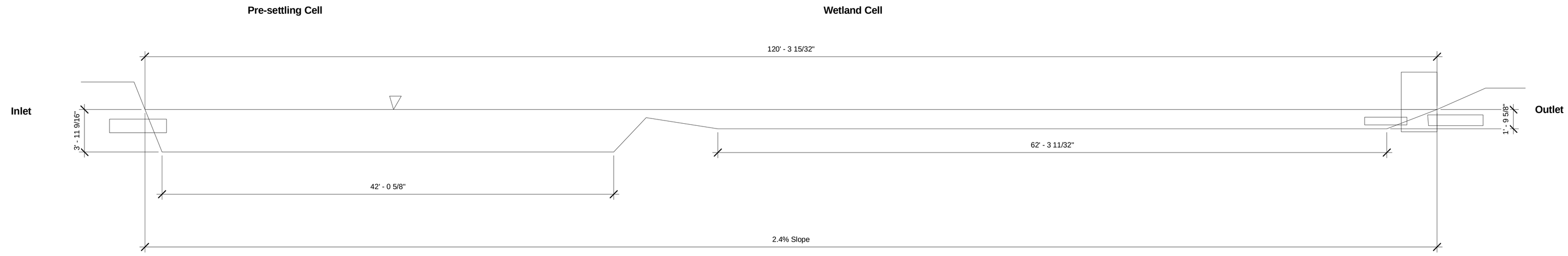


Mukilteo Multimodal Transit Hub

DATE **04/27/2012- 20% CD**
SCALE **1" = 90'-0"**

Japanese Creek Plan

C-103



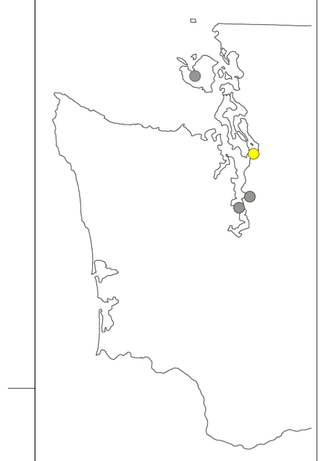
1 Wetland Profile
3/16" = 1'-0"

IDeX Integrated Design Experience

DESIGNED BY

Brad Albert | Architecture
Russell LeSieur | Architecture
Erin Winborne | Architecture
Charlie Misner | Civil Engineering
Aaron Steele | Civil Engineering
Kelly Hayden | Civil Engineering
Matt Frazier | Construction Management

LOCATION

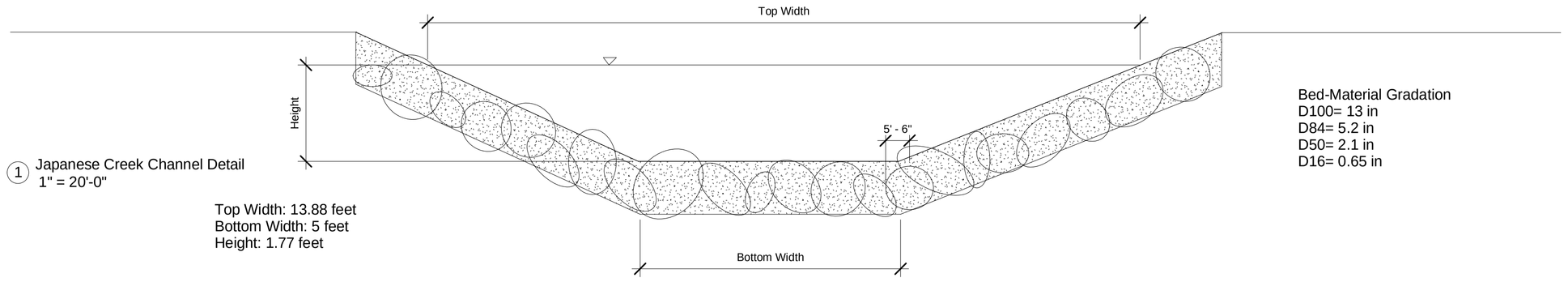


Mukilteo Multimodal Transit Hub

DATE **04/27/2012- 20% CD**
SCALE **3/16" = 1'-0"**

Wetland Profile

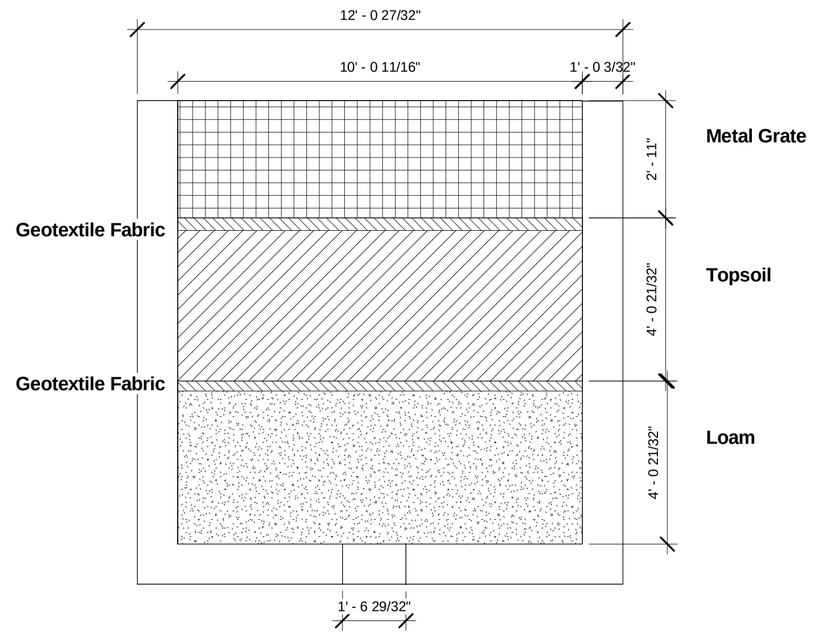
C-201



① Japanese Creek Channel Detail
1" = 20'-0"

Top Width: 13.88 feet
Bottom Width: 5 feet
Height: 1.77 feet

Bed-Material Gradation
D100= 13 in
D84= 5.2 in
D50= 2.1 in
D16= 0.65 in



Circular Drainage Outlet

② Living Filter Detail
3/8" = 1'-0"

IDeX Integrated Design Experience

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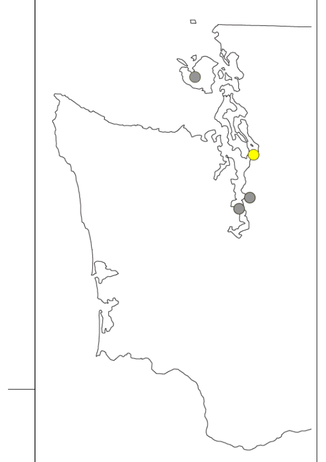
LOCATION



Mukilteo Multimodal Transit Hub

DATE **04/27/2012- 20% CD**
SCALE **As indicated**

Detail
C-501

MUKILTEO MULTIMODAL TRANSIT HUB

APRIL 27, 2012

TERMINAL BUILDING

614 FRONT STREET, MUKILTEO, WA 98204



Table of Contents

GENERAL

G-001	Cover Sheet

CIVIL

C-101	Site Plan
C-102	Site Plan Transit Hub

STRUCTURAL

S-101	Terminal Building 2nd Floor Framing Plan
S-102	Terminal Building Roof Framing Plan
S-201	Terminal Building North and South Framing Plan
S-202	Terminal Building East and West Framing Plan

ARCHITECTURAL

A-101	Building A 1 Floor
A-102	Building A 2 Floor
A-103	Building B 1 Floor
A-104	Building B 2 Floor
A-201	Building A North Elevation
A-202	Building A East Elevation
A-203	Building A West Elevation
A-204	Building A & B South Elevation
A-205	Building B North Elevation
A-206	Building B West Elevation
A-301	Building A Section A
A-302	Building A Section B
A-303	Building B Section C

IDeX Integrated Design Experience

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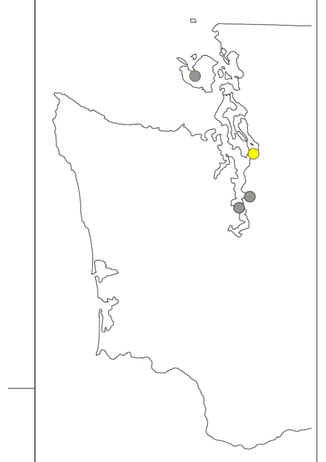


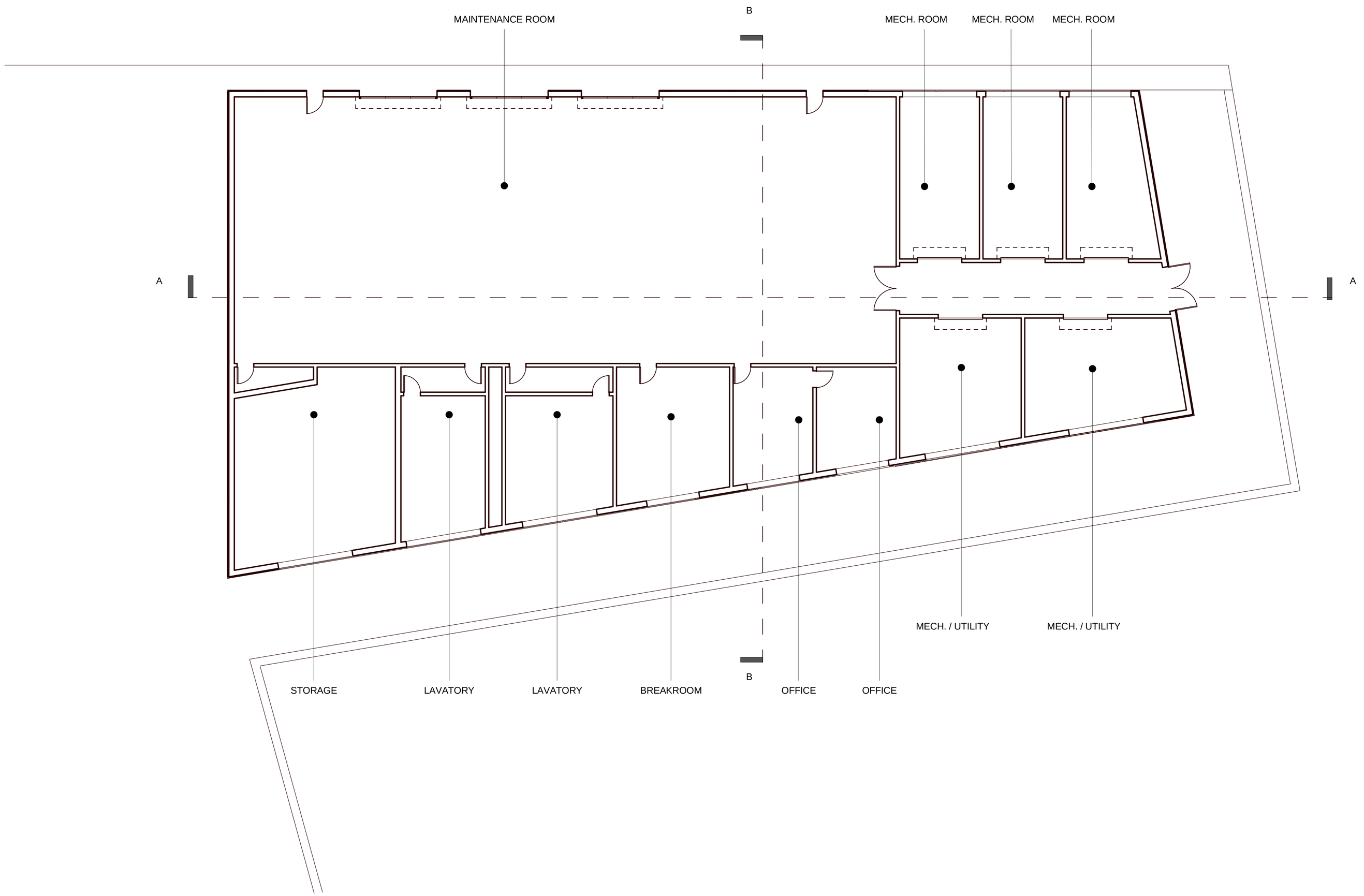
Mukilteo Multimodal Transit Hub

DATE **4/27/2012- 20% CD**

SCALE

Cover Sheet

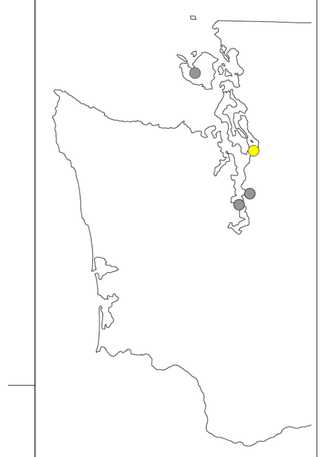
G-001



IDeX Integrated Design Experience

DESIGNED BY

LOCATION



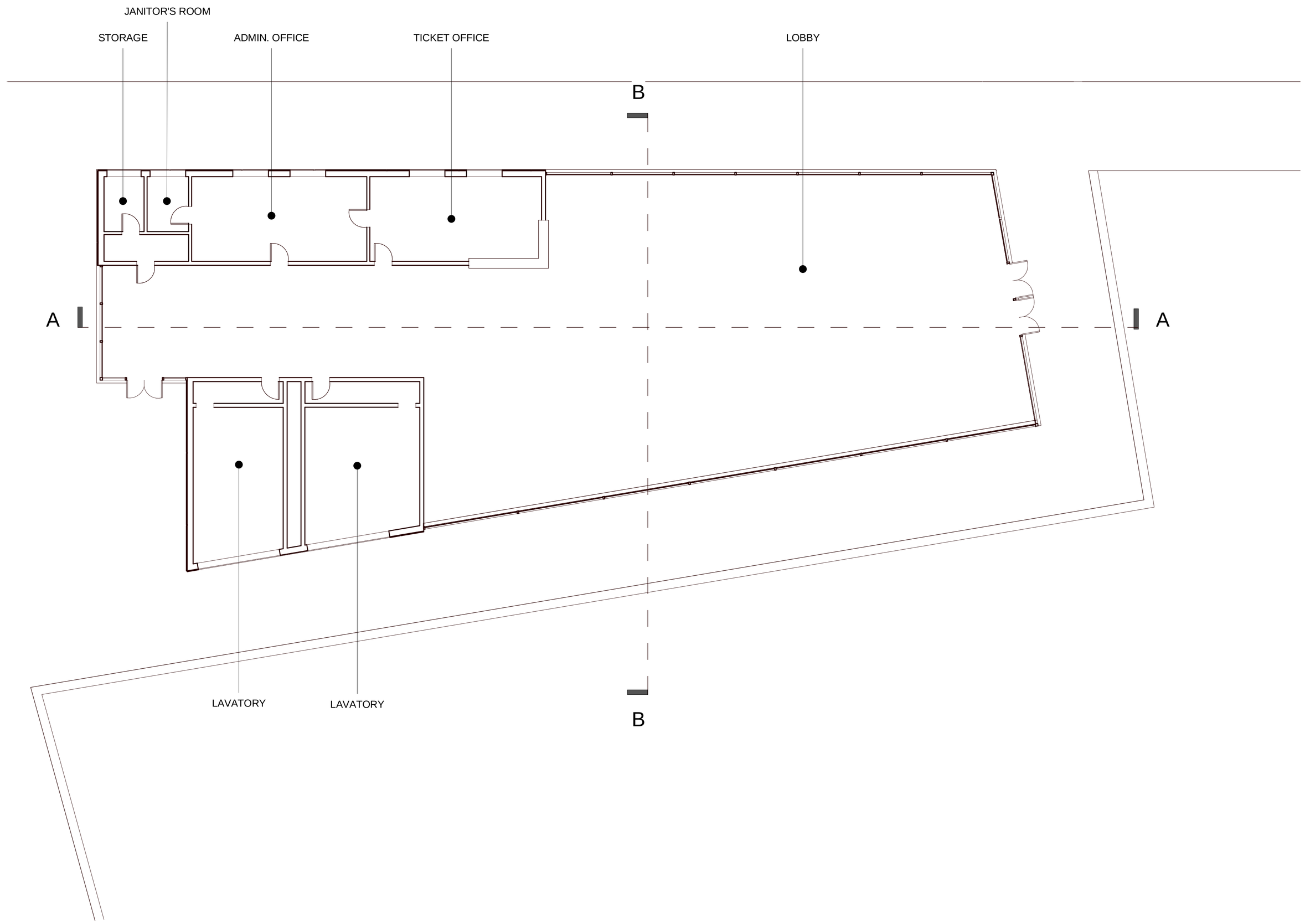
Mukilteo Multimodal Transit Hub

DATE 04/27/2012- 20% CD

SCALE 1" = 10'-0"

Bldg.A 1Floor

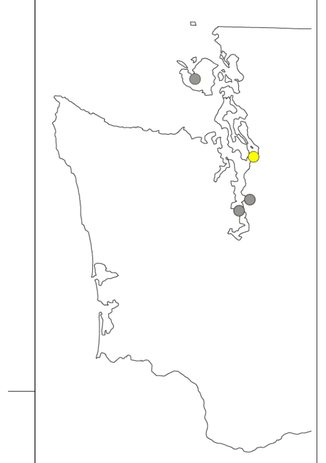
A-101



IDeX
Integrated Design Experience

DESIGNED BY

LOCATION



Mukilteo Multimodal Transit Hub

DATE 04/27/2012- 20% CD

SCALE 1" = 10'-0"

Bldg.A 2Floor

A-102

1 2 3 4 5

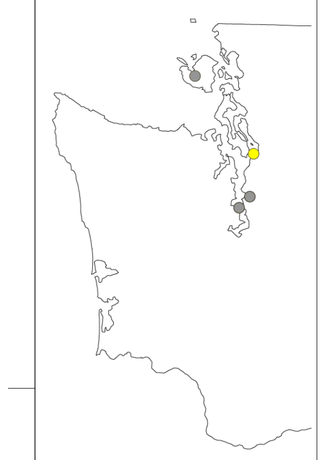
D C B A



IDeX Integrated Design Experience

DESIGNED BY

LOCATION



Mukilteo Multimodal Transit Hub

DATE 04/27/2012- 20% CD

SCALE 1" = 10'-0"

Bldg.B1Floor

A-103

Bldg.B 2Floor

A-104

DATE 04/27/2012- 20% CD

SCALE 1" = 10'-0"

LOCATION

Mukilteo Multimodal Transit Hub

DESIGNED BY

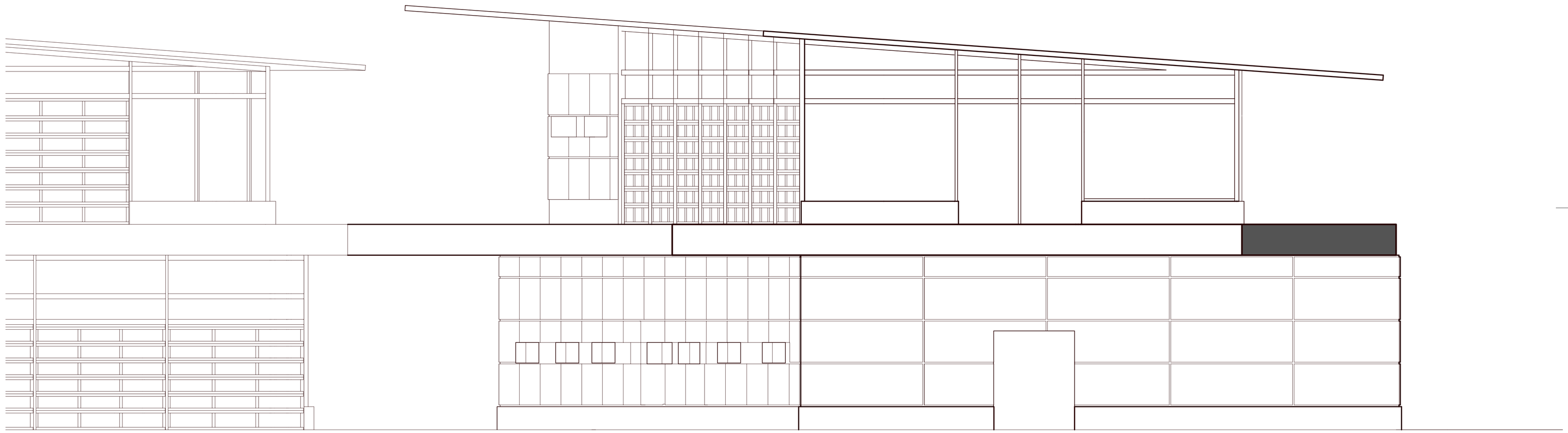
IDeX

Integrated Design Experience

1 2 3 4 5

D

C



B

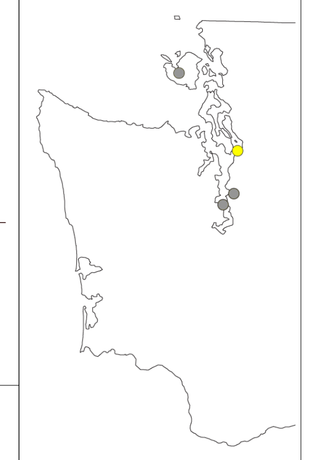
A

IDeX

Integrated Design Experience

DESIGNED BY

LOCATION



Mukilteo Multimodal Transit Hub

DATE 04/27/2012- 20% CD

SCALE 3/16" = 1'-0"

Bldg.A North Elev.

A-201

1 2 3 4 5

D

C



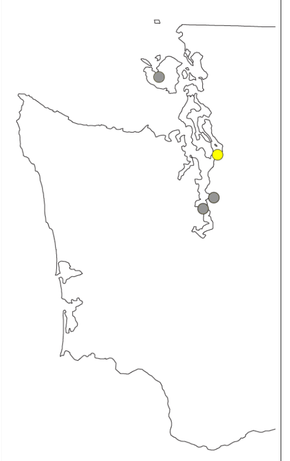
B

A

IDeX
Integrated Design Experience

DESIGNED BY

LOCATION



Mukilteo Multimodal Transit Hub

DATE 04/27/2012- 20% CD

SCALE 1" = 10'-0"

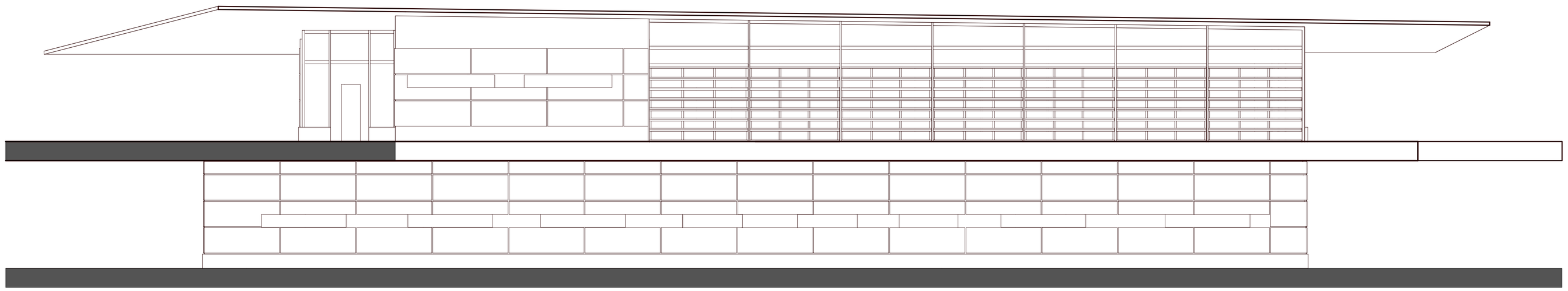
Bldg.A East Elev

A-202

1 2 3 4 5

D

C



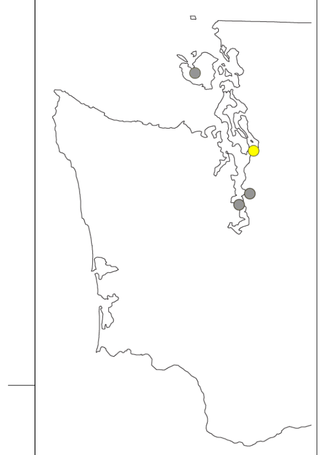
B

A

IDeX
Integrated Design Experience

DESIGNED BY

LOCATION



Mukilteo Multimodal Transit Hub

DATE 04/27/2012- 20% CD

SCALE 1" = 10'-0"

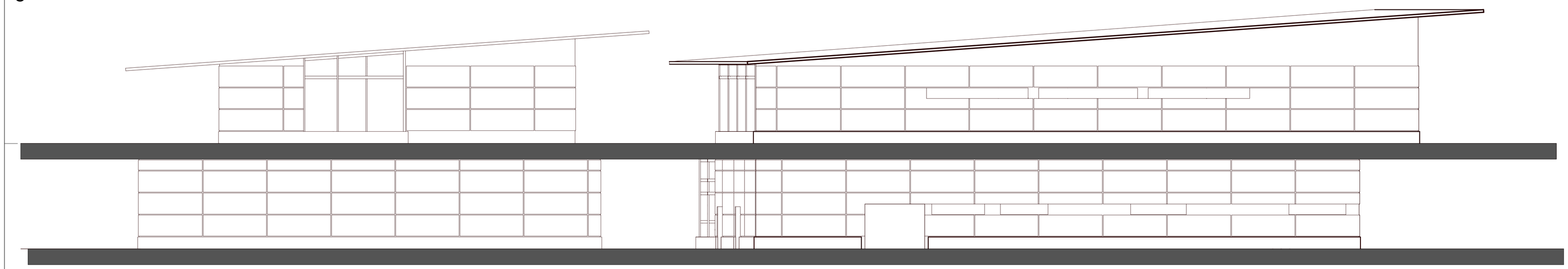
Bldg.A West Elev.

A-203

1 2 3 4 5

D

C



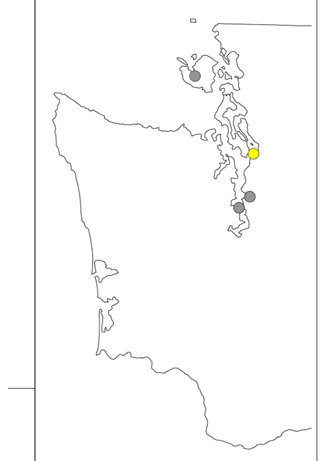
B

A

IDeX
Integrated Design Experience

DESIGNED BY

LOCATION



Mukilteo Multimodal Transit Hub

DATE 04/27/2012- 20% CD

SCALE 1" = 10'-0"

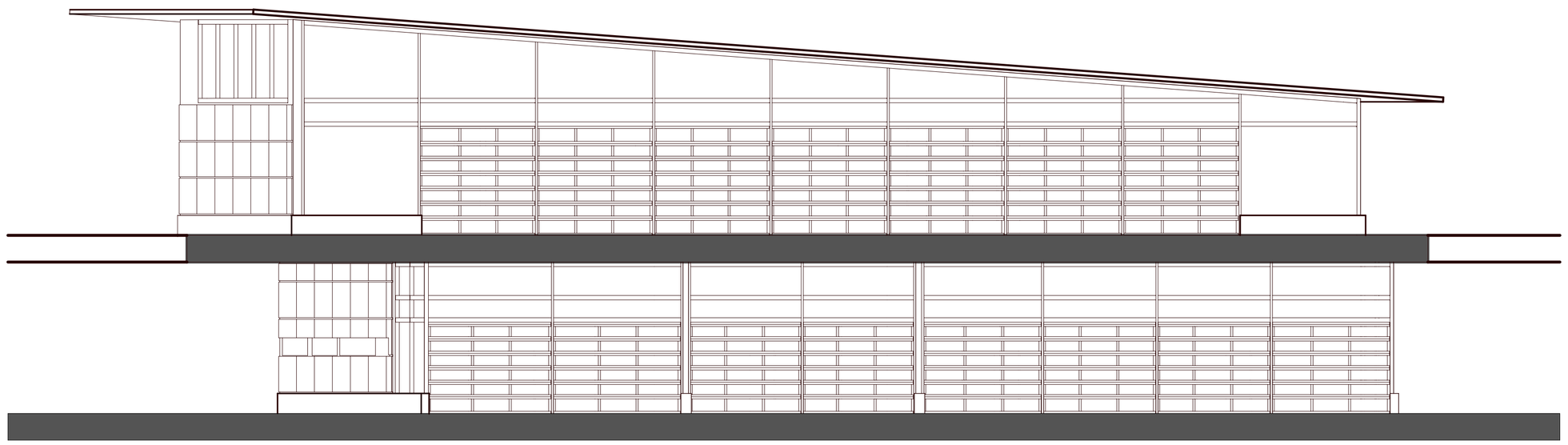
Bldg.A&B South Elev.s

A-204

1 2 3 4 5

D

C



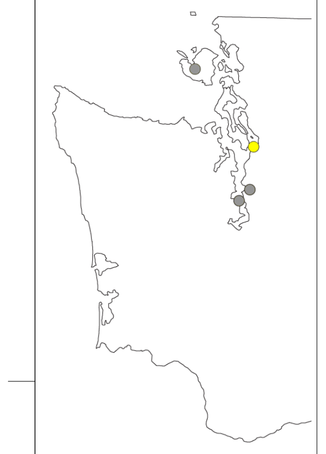
B

A

IDeX
Integrated Design Experience

DESIGNED BY

LOCATION



Mukilteo Multimodal Transit Hub

DATE 04/27/2012- 20% CD

SCALE 1" = 10'-0"

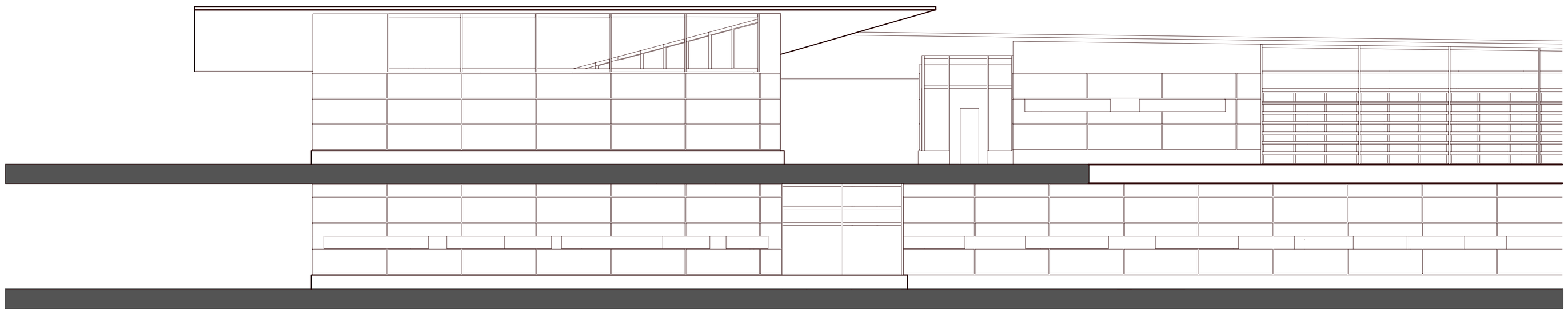
Bldg.B North Elev.

A-205

1 2 3 4 5

D

C



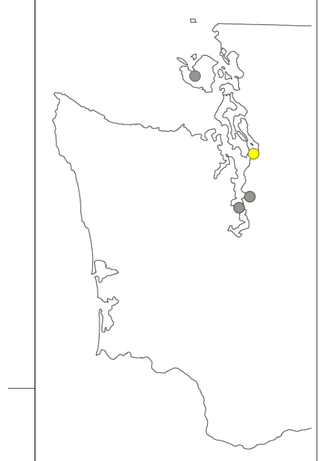
B

A

IDeX
Integrated Design Experience

DESIGNED BY

LOCATION



Mukilteo Multimodal Transit Hub

DATE 04/27/2012- 20% CD

SCALE 1" = 10'-0"

Bldg.B West Elev.

A-206

1 2 3 4 5

D

C



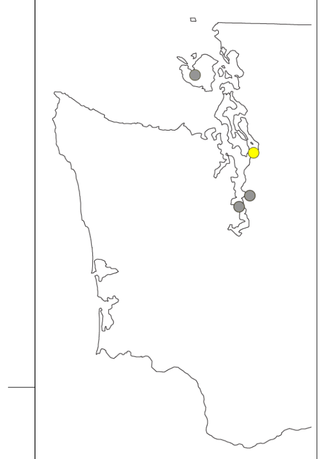
B

A

IDeX Integrated Design Experience

DESIGNED BY

LOCATION



Mukilteo Multimodal Transit Hub

DATE 04/27/2012- 20% CD

SCALE 1" = 10'-0"

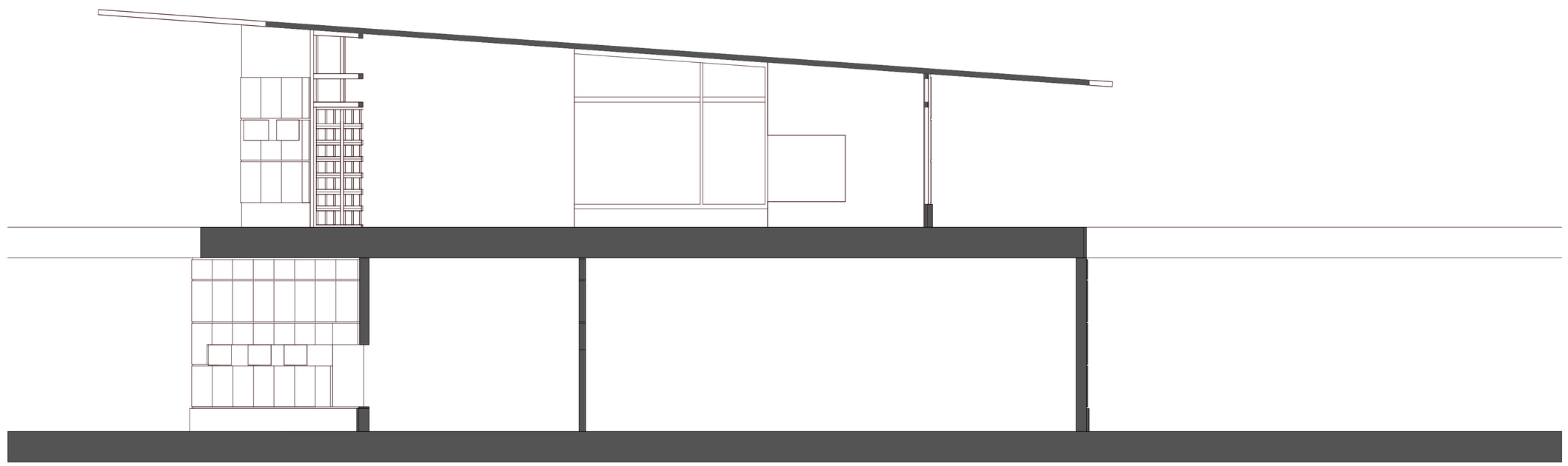
Bldg.A Sec.A

A-301

1 2 3 4 5

D

C



B

A

IDeX Integrated Design Experience

DESIGNED BY

LOCATION



Mukilteo Multimodal Transit Hub

DATE 04/27/2012- 20% CD

SCALE 1" = 10'-0"

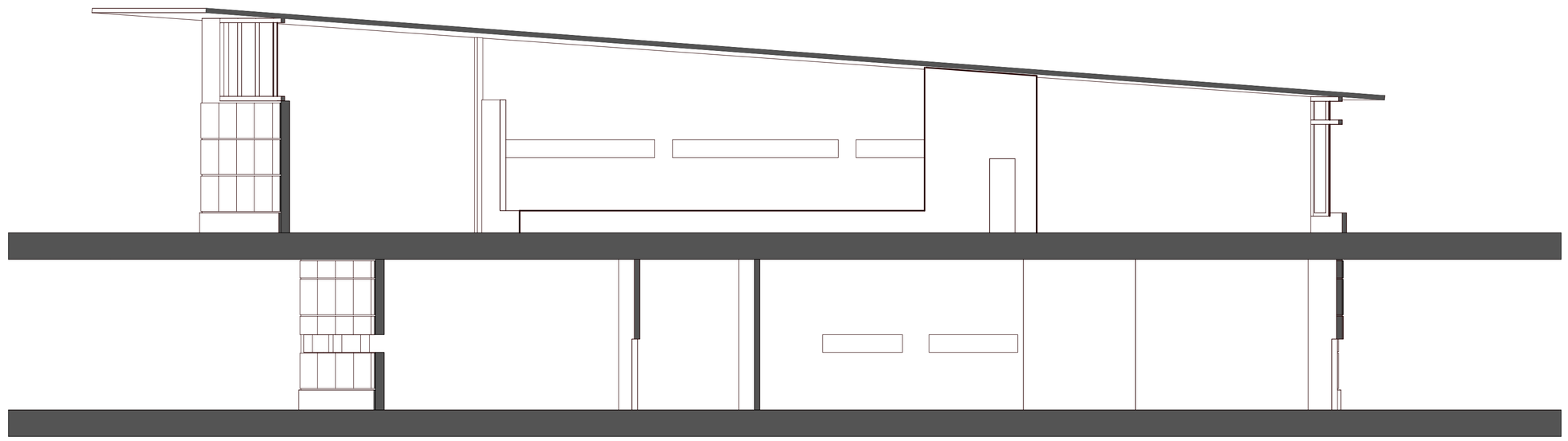
Bldg.A Sec.B

A-302

1 2 3 4 5

D

C



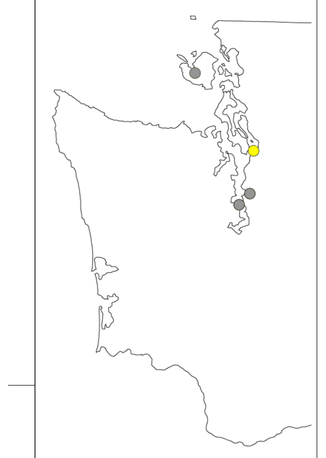
B

A

IDeX
Integrated Design Experience

DESIGNED BY

LOCATION



Mukilteo Multimodal Transit Hub

DATE 04/27/2012- 20% CD

SCALE 1" = 10'-0"

Bldg.B Sec.C

A-303



IDeX
Integrated Design Experience

DESIGNED BY

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Russell LeSieur | Architecture
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Kelly Hayden | Civil Engineer
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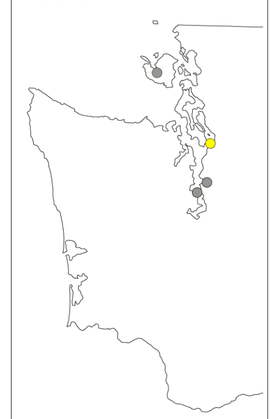


Mukilteo Multimodal Transit Hub

DATE **04/27/2012- 20% CD**
SCALE **1" - 200'**

Site Plan

C-101



IDeX
Integrated Design Experience

DESIGNED BY

Brad Albert | Architecture
Russell LeSieur | Architecture
Eric Winborne | Architecture
Charlie Misner | Civil Engineer
Aaron Steele | Civil Engineer
Kelly Hayden | Civil Engineer
Matt Frazier | Construction Management

LOCATION



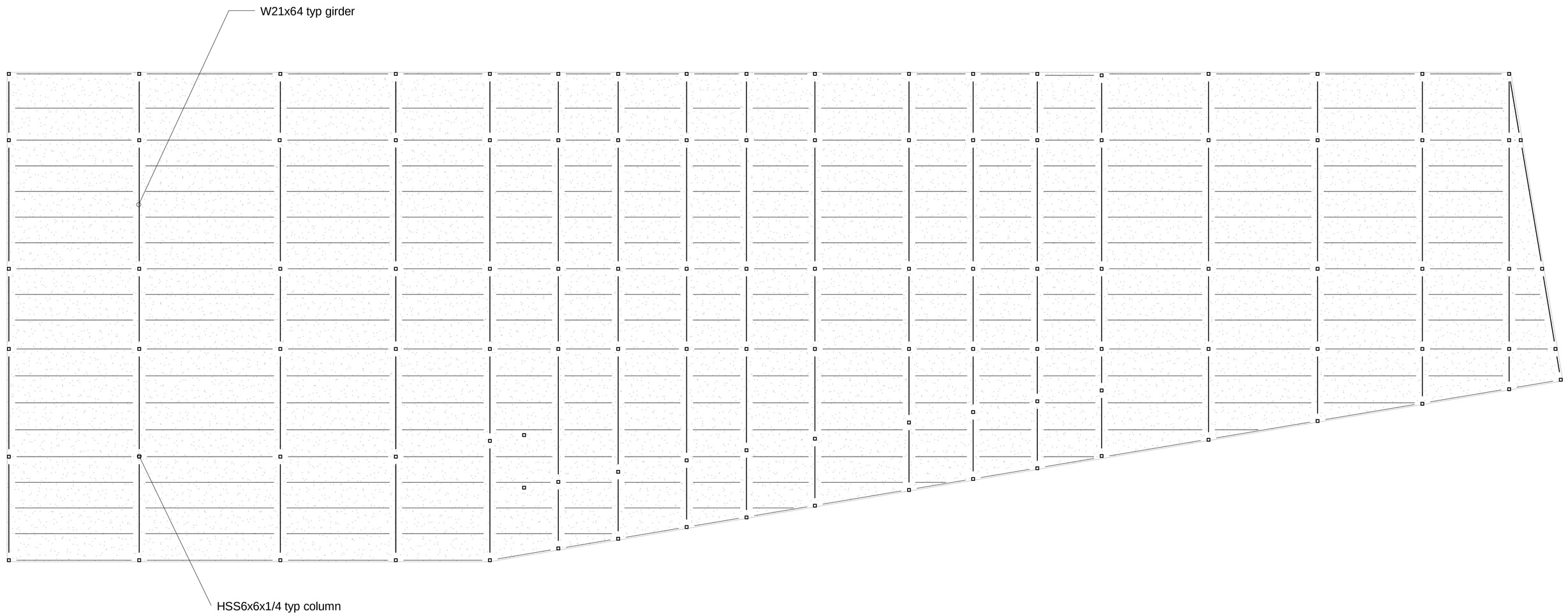
Mukilteo Multimodal Transit Hub

DATE **04/27/2012- 20% CD**

SCALE **1" - 100'**

Site Plan - Transit Hub

C-102

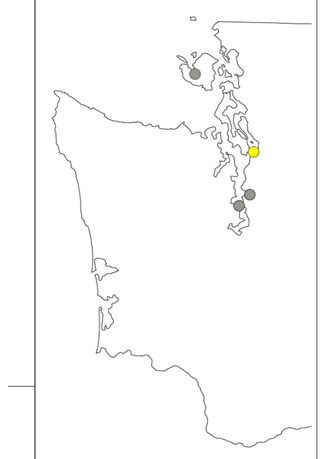


1 Terminal Building 2nd Floor Framing Plan
1/16" = 1'-0"

IDeX
Integrated Design Experience

DESIGNED BY
Brad Albert | Architecture
Russell LeSieur | Architecture
Eric Winborne | Architecture
Charlie Misner | Civil Engineer
Aaron Steele | Civil Engineer
Kelly Hayden | Civil Engineer
Matt Frazier | Construction Management

LOCATION



Mukilteo Multimodal Transit Hub

DATE **04/27/2012- 20% CD**
SCALE **1/16" = 1'-0"**

Terminal Building Second Floor Framing Plan

S-101

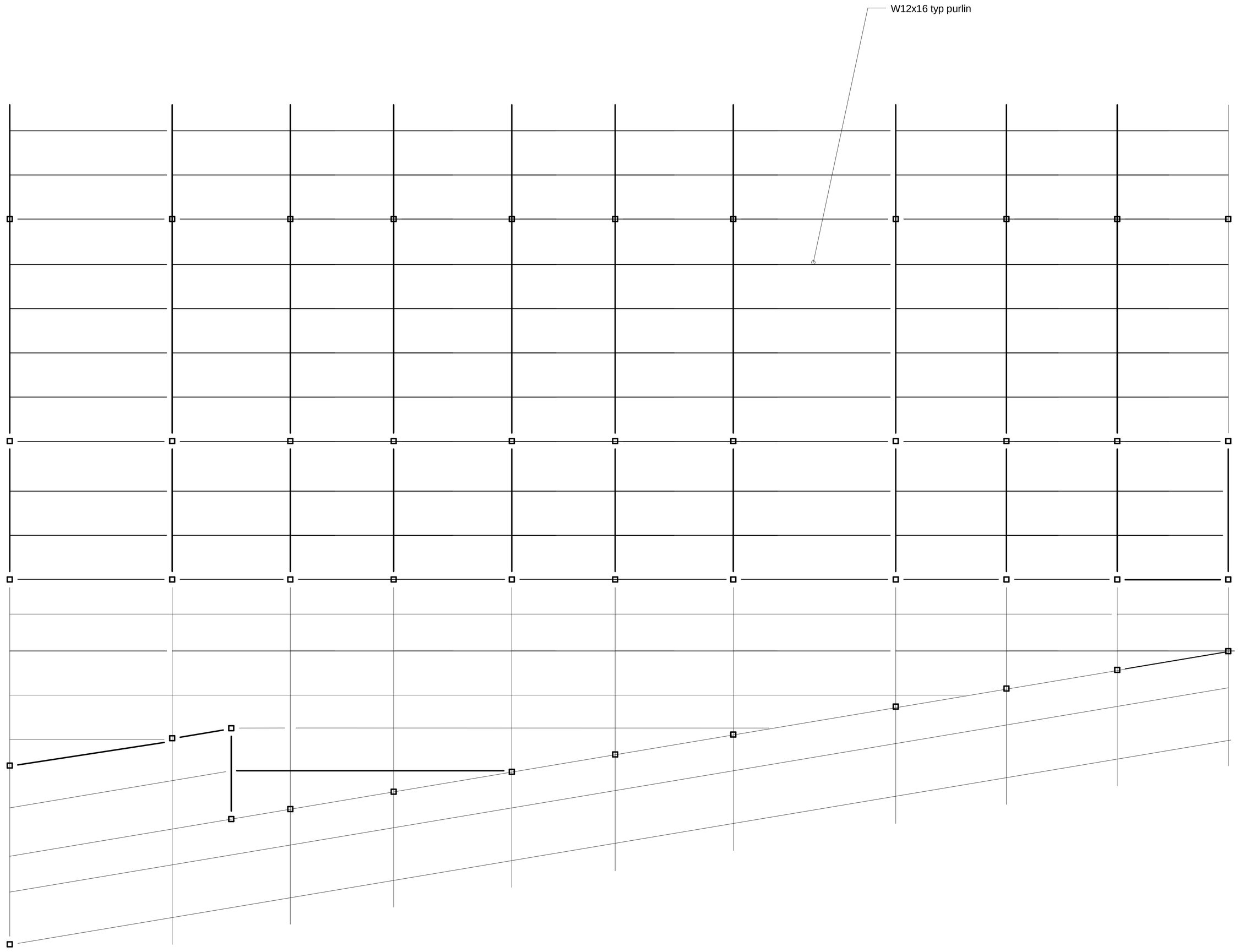
1 2 3 4 5

D

C

B

A



1 Terminal Building Roof Framing Plan
1/8" = 1'-0"

IDeX
Integrated Design Experience

DESIGNED BY

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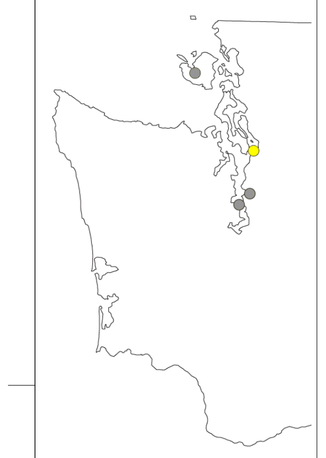
Russell LeSieur | Architecture
Eric Winborne | Architecture
Charlie Misner | Civil Engineer
Aaron Steele | Civil Engineer
Kelly Hayden | Civil Engineer
Matt Frazier | Construction Management

LOCATION

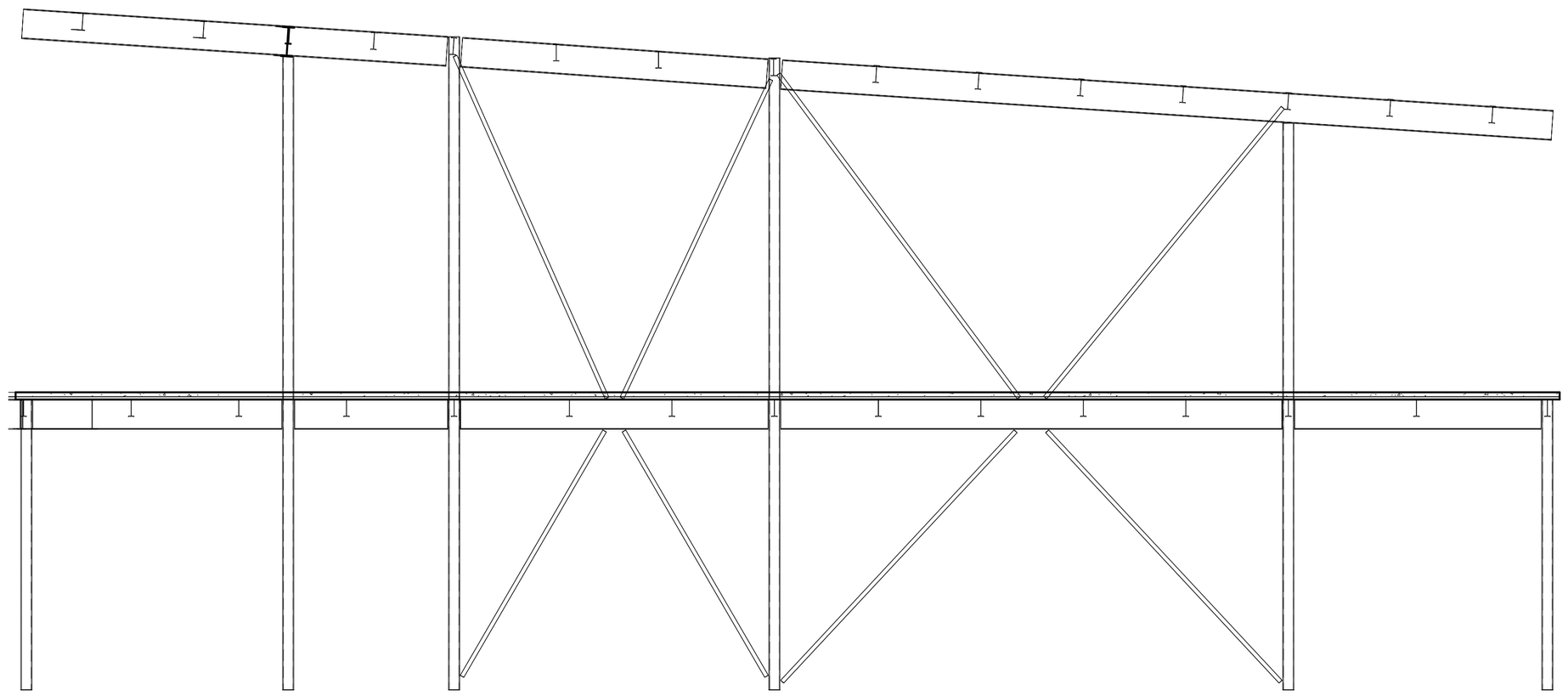


Mukilteo Multimodal Transit Hub

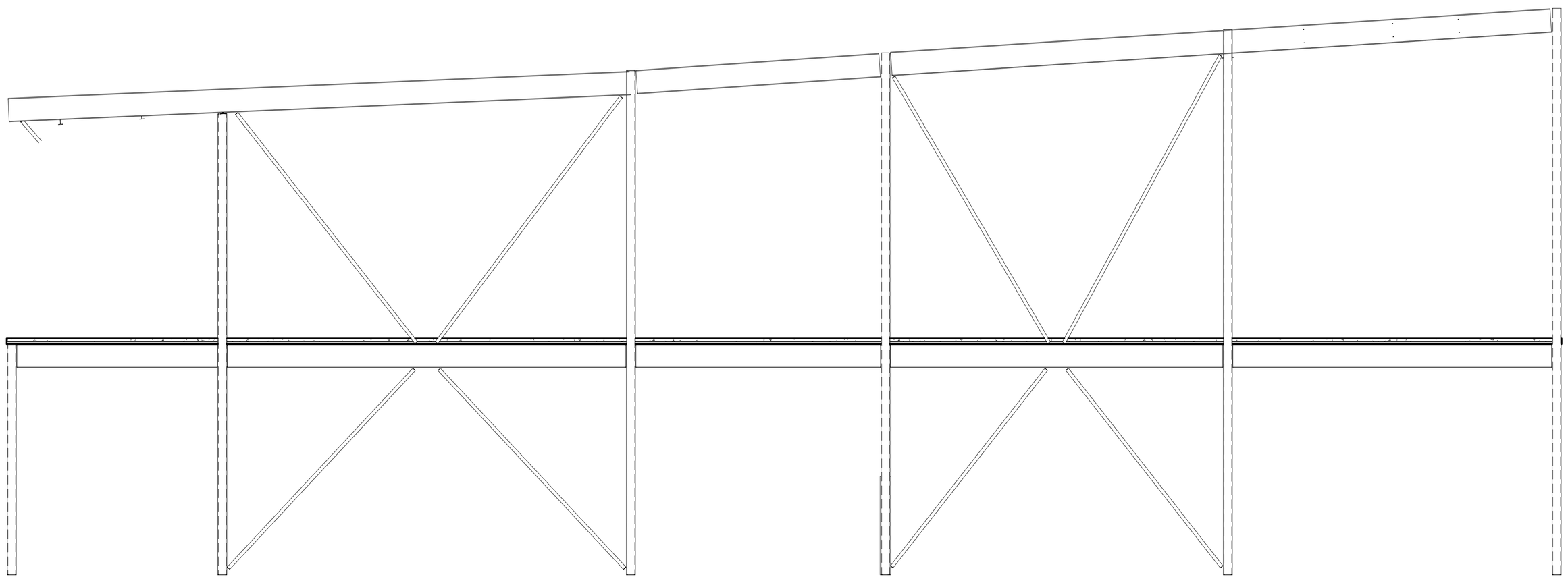
DATE **04/27/2012- 20% CD**
SCALE **1/8" = 1'-0"**

Terminal Building Roof Framing Plan

S-102



1 Terminal Building North Framing Elevation
3/16" = 1'-0"



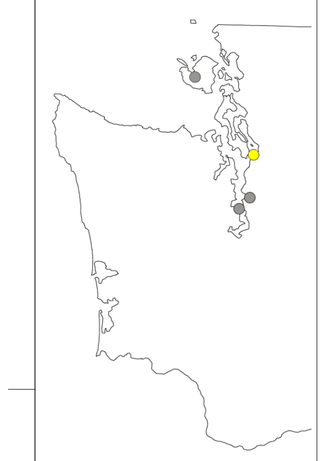
2 Terminal Building South Framing Elevation
3/16" = 1'-0"

IDeX
Integrated Design Experience

DESIGNED BY

Brad Albert | Architecture
Russell LeSieur | Architecture
Eric Winborne | Architecture
Charlie Misner | Civil Engineer
Aaron Steele | Civil Engineer
Kelly Hayden | Civil Engineer
Matt Frazier | Construction Management

LOCATION



Mukilteo Multimodal Transit Hub

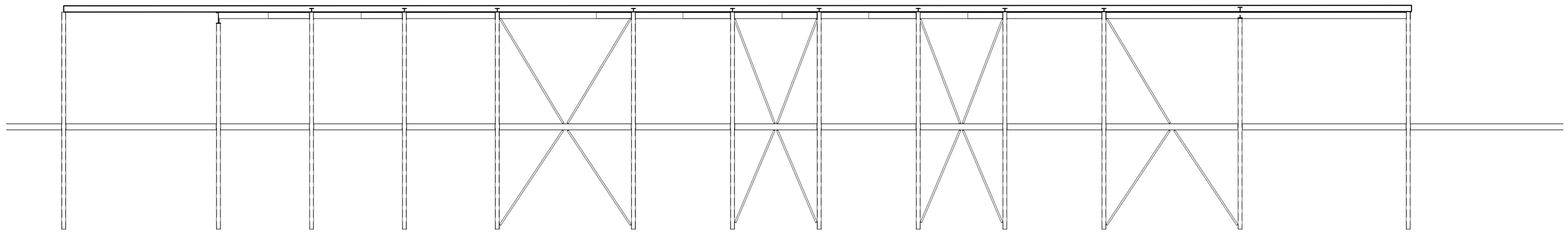
DATE **04/27/2012- 20% CD**
SCALE **3/16" = 1'-0"**

Terminal Building North and South Framing Elevation

S-201

1 2 3 4 5

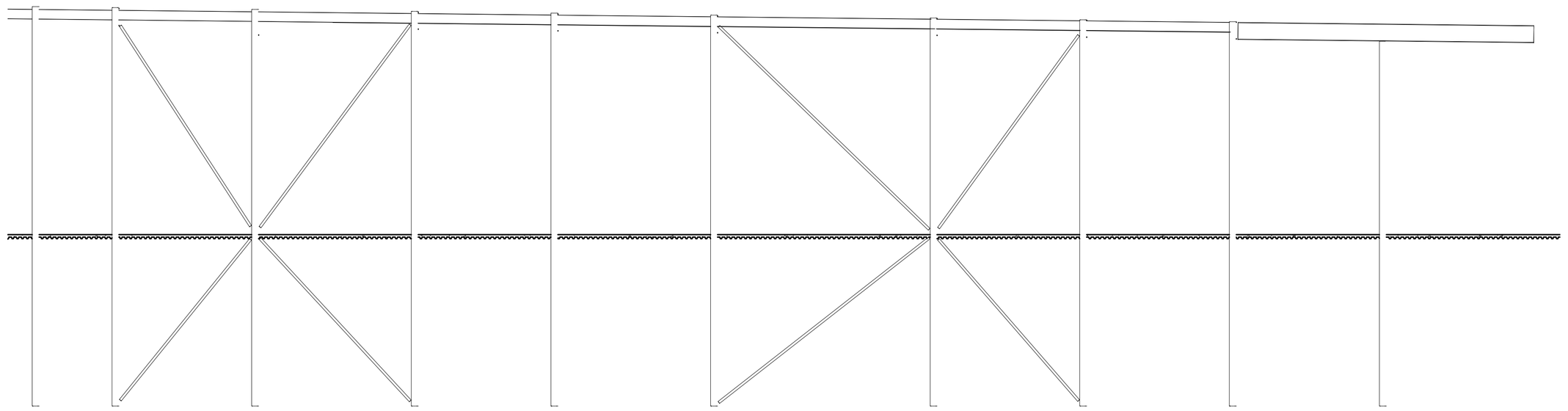
D



1 Terminal Building East Framing Elevation
1" = 10'-0"

C

B



2 Terminal Building West Framing Elevation
1/8" = 1'-0"

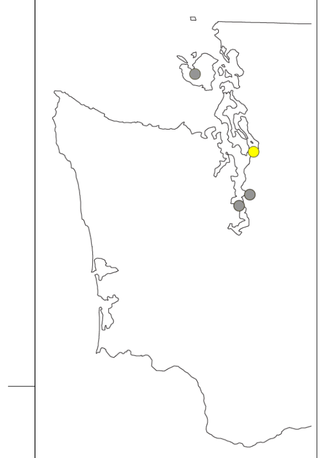
A

IDeX Integrated Design Experience

DESIGNED BY

Brad Albert | Architecture
Russell LeSieur | Architecture
Eric Winborne | Architecture
Charlie Misner | Civil Engineer
Aaron Steele | Civil Engineer
Kelly Hayden | Civil Engineer
Matt Frazier | Construction Management

LOCATION



Mukilteo Multimodal Transit Hub

DATE **04/27/2012- 20% CD**
SCALE **As indicated**

Terminal Building East and West Framing Elevation

S-202

MUKILTEO MULTIMODAL TRANSIT HUB

APRIL 27, 2012

PARKSCAPE

614 FRONT STREET, MUKILTEO, WA 98204

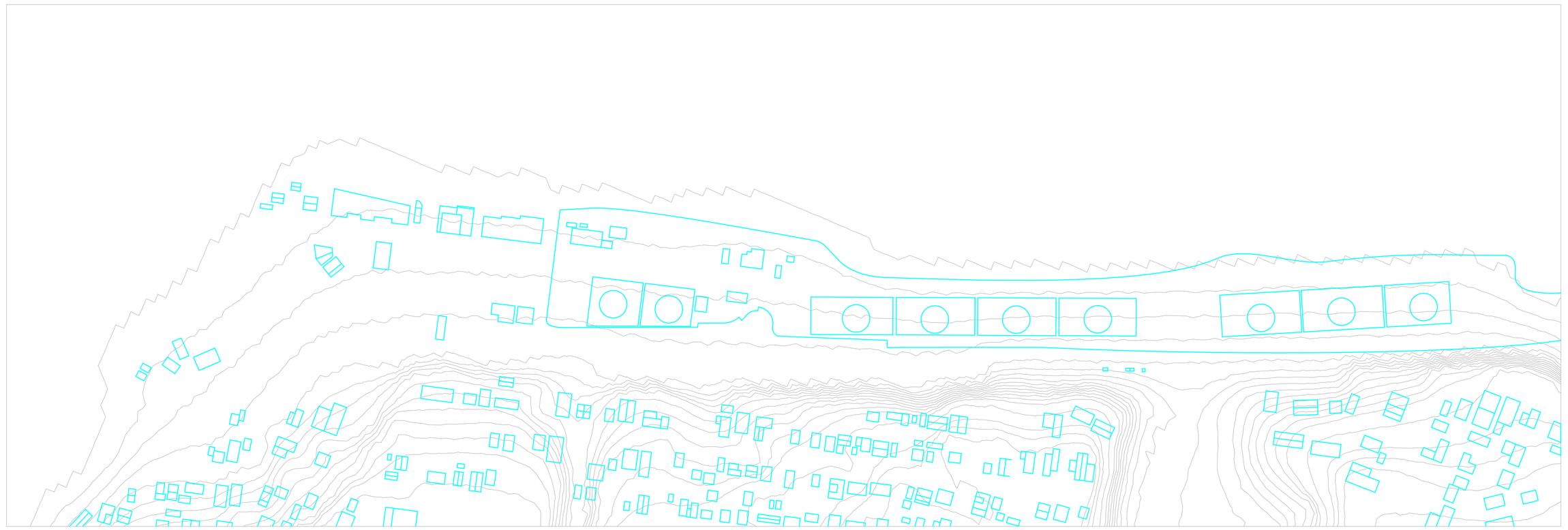


Table of Contents

GENERAL

G-001	Cover Sheet

CIVIL

C-101	Site Plan
C-102	Site Plan Park

ARCHITECTURAL

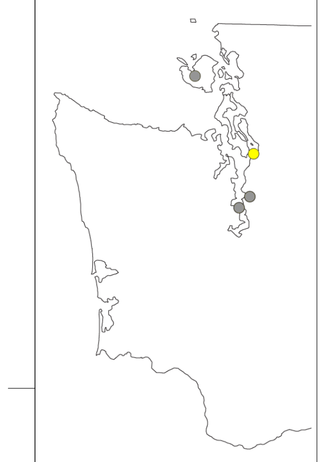
A-301	MSE Section
A-302	Sea Wall Section
A-401	Archtiectural Site Plan
A-501	Details & Perspectives

IDeX Integrated Design Experience

DESIGNED BY

Brad Albert | Architecture
Russell LeSieur | Architecture
Eric Winborne | Architecture
Charlie Misner | Civil Engineering
Aaron Steele | Civil Engineering
Kelly Hayden | Civil Engineering
Matt Frazier | Construction Management

LOCATION



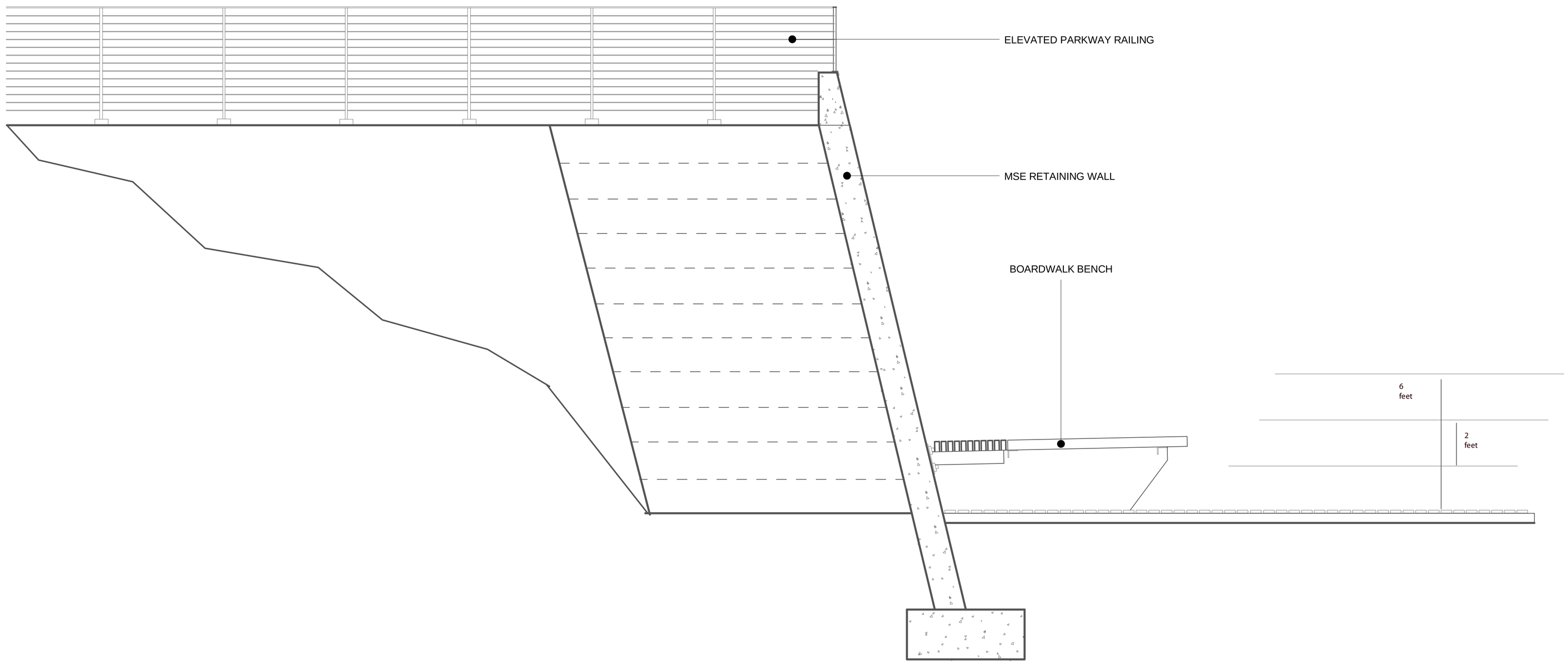
Mukilteo Multimodal Transit Hub

DATE **4/27/2012- 20% CD**

SCALE

Cover Sheet

G-001



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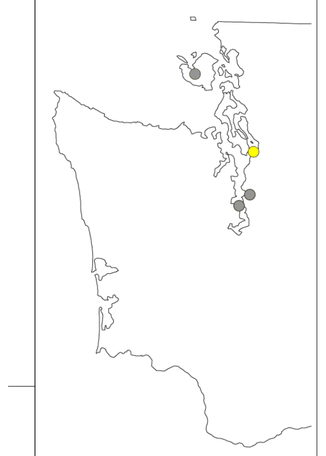
Integrated Design Experience

DESIGNED BY

LOCATION



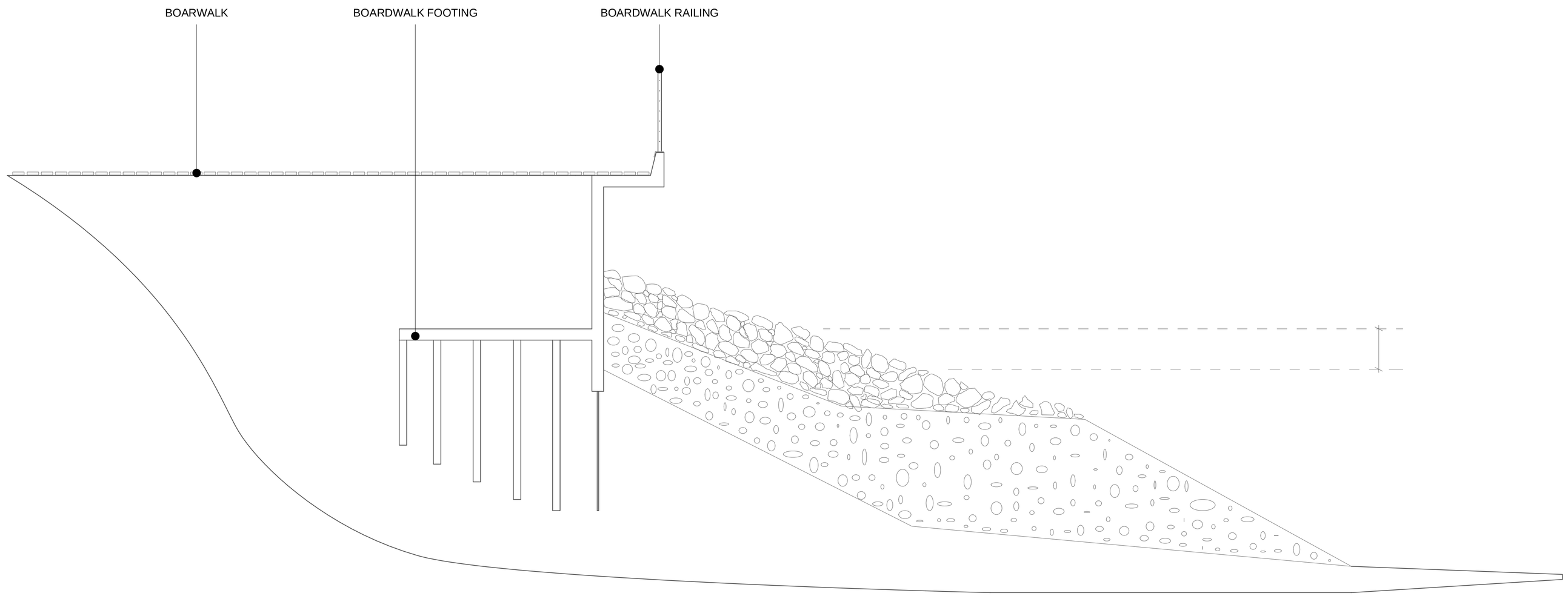
Mukilteo Multimodal Transit Hub

DATE 04/27/2012- 20% CD

SCALE 3/8" = 1'-0"

MSE Section

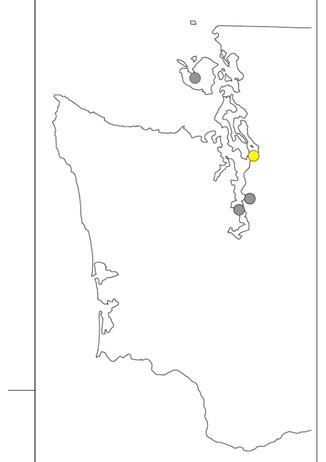
A-301.1



IDeX
Integrated Design Experience

DESIGNED BY

LOCATION



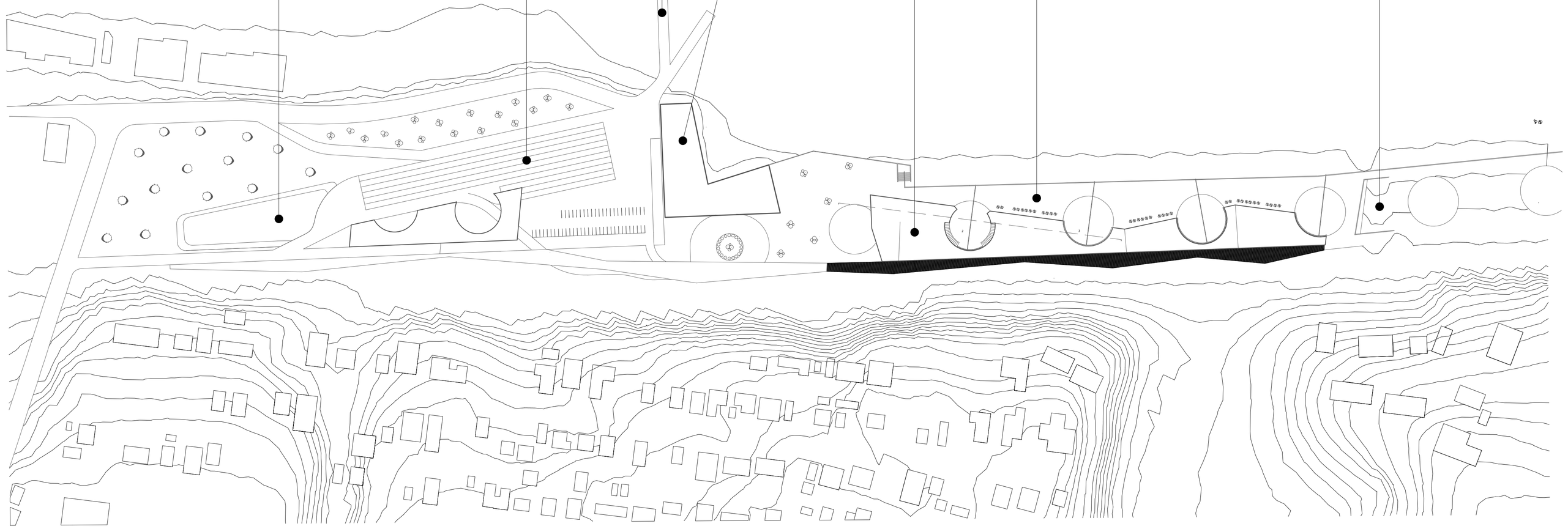
Mukilteo Multimodal Transit Hub

DATE 04/27/2012- 20% CD

SCALE 1/2" = 1'-0"

Seawall Section

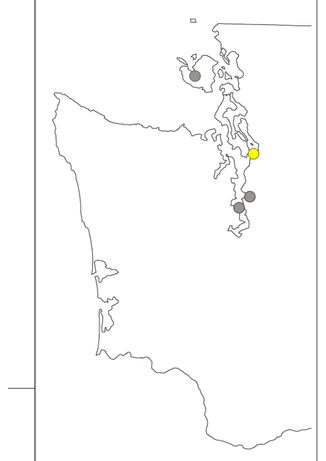
A-302.1



IDeX Integrated Design Experience

DESIGNED BY

LOCATION



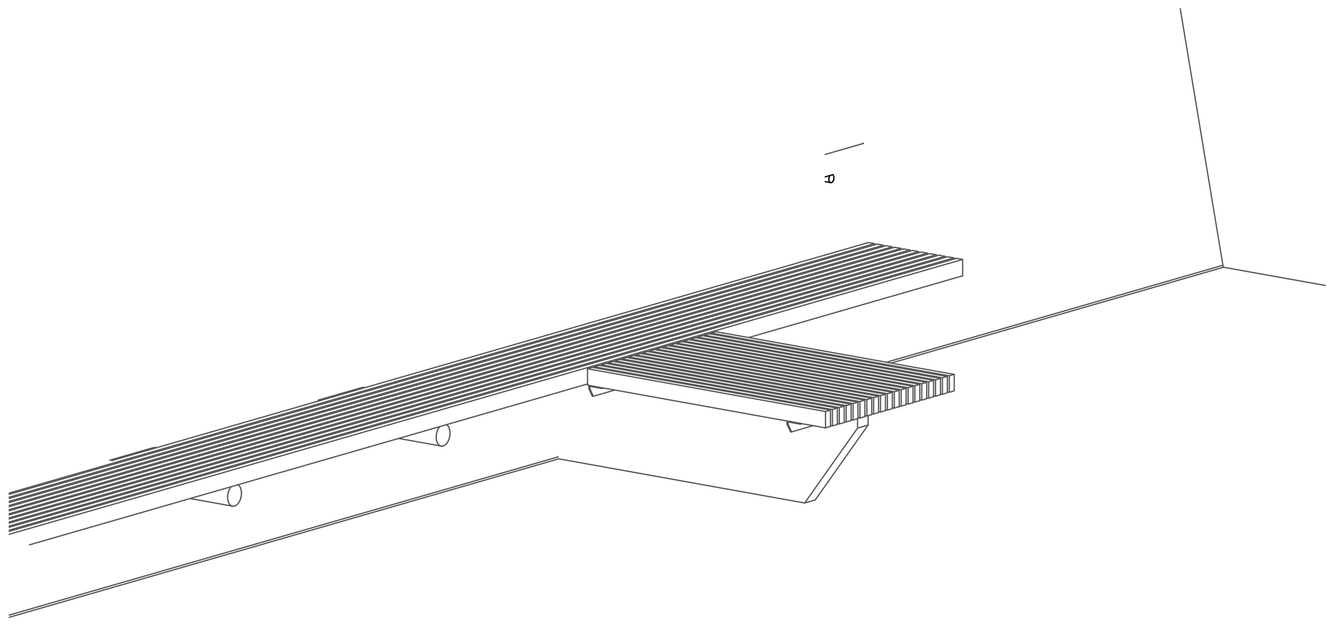
Mukilteo Multimodal Transit Hub

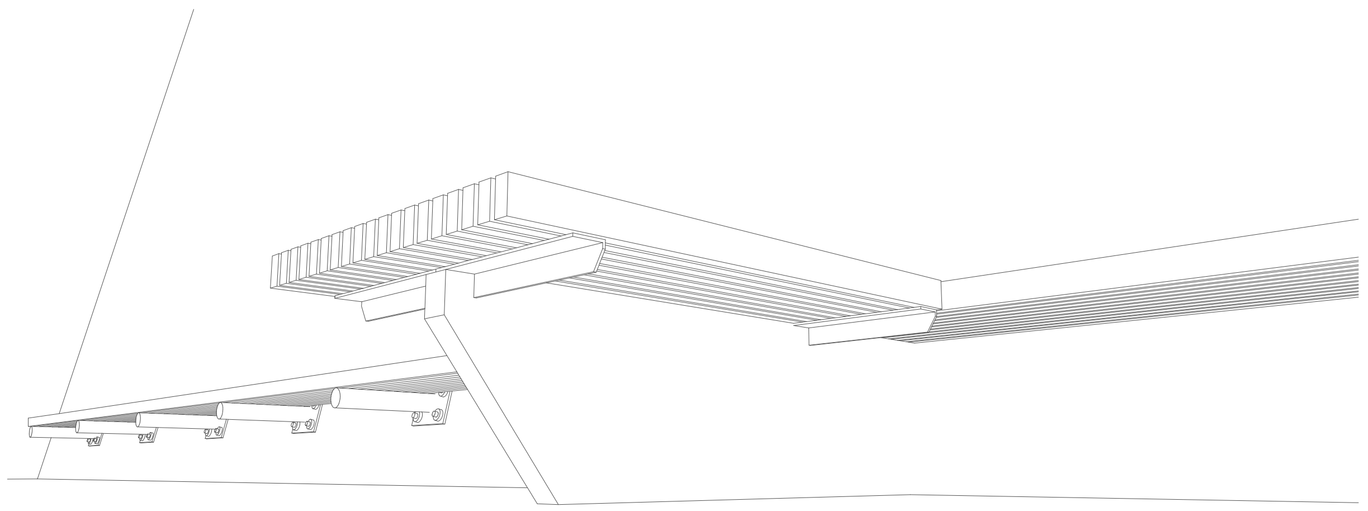
DATE 04/27/2012- 20% CD

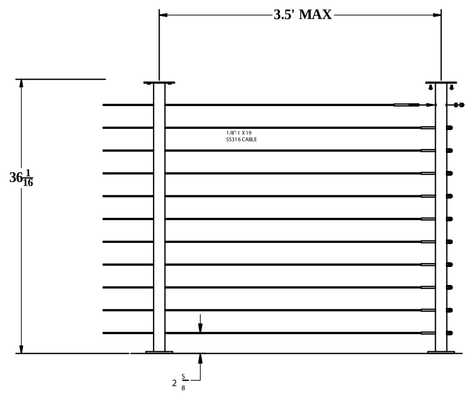
SCALE 1" = 160'-0"

Site Plan

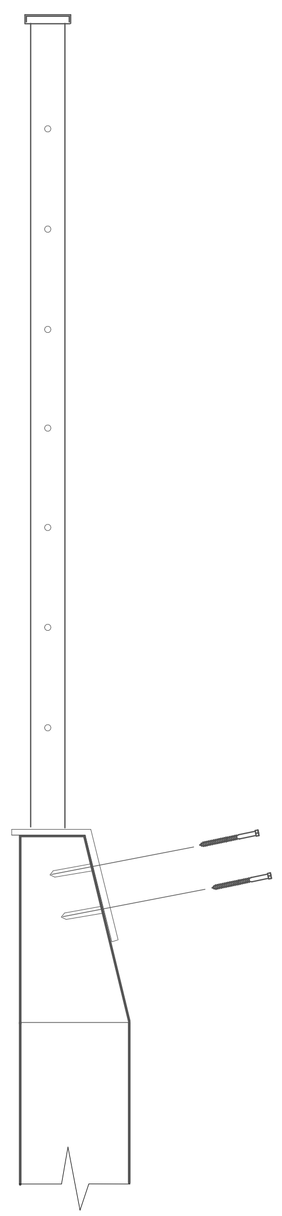
A-401

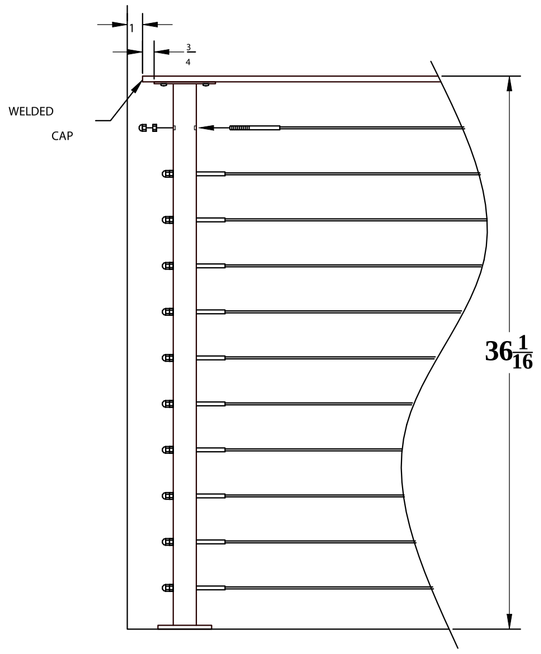




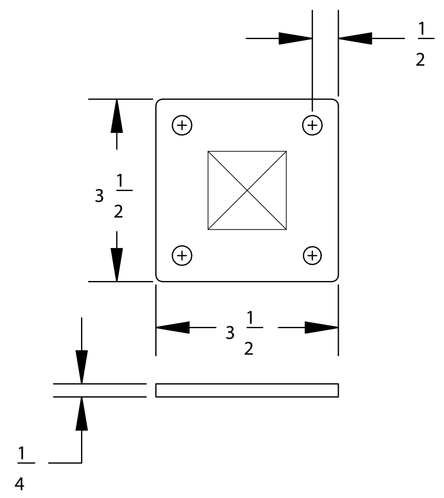


ELEVATION B





PART#
AG-105
BASE
PLATE



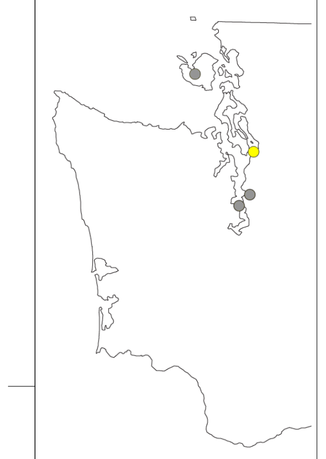
DESIGNED BY:

Brad Albert / Architecture
Aaron Steele / Civil Engineering
Kelly Hayden / Civil Engineering
Charlie Misner / Civil Engineering
Russell LeSieur / Architecture
Eric Winborne / Architecture

IDeX
Integrated Design Experience

DESIGNED BY

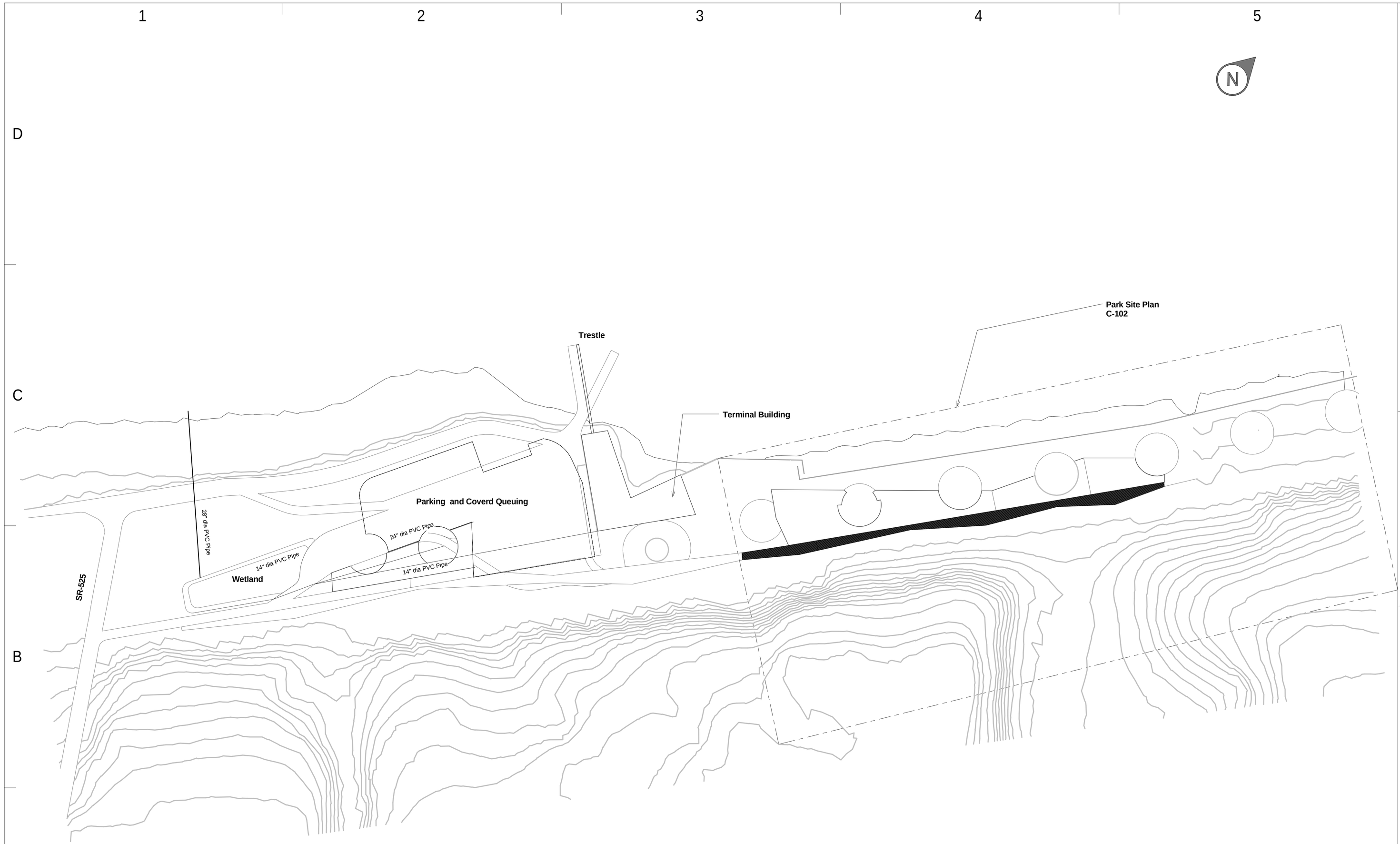
LOCATION



Mukilteo Multimodal Transit Hub

DATE 04/27/2012- 20% CD
SCALE 3/8" = 1'-0"

Details
A-501

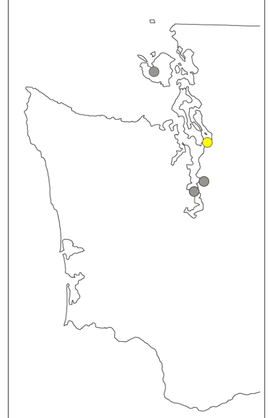


IDeX Integrated Design Experience

DESIGNED BY

Brad Albert | Architecture
Russell LeSieur | Architecture
Eric Winborne | Architecture
Charlie Misner | Civil Engineer
Aaron Steele | Civil Engineer
Kelly Hayden | Civil Engineer
Matt Frazier | Construction Management

LOCATION



Mukilteo Multimodal Transit Hub

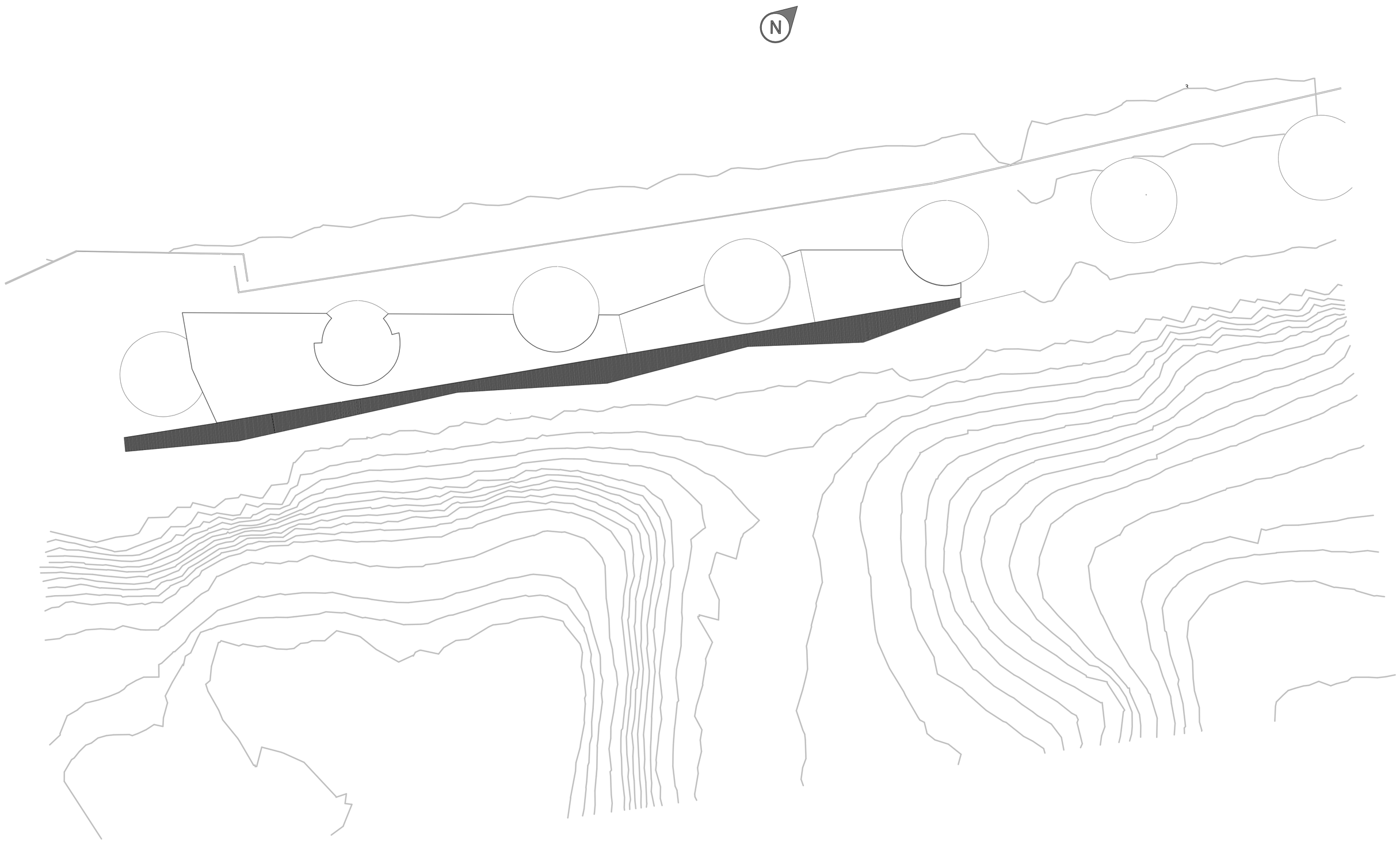
DATE **04/27/2012- 20% CD**
SCALE **1" - 200'**

Site Plan

C-101

1 2 3 4 5

D C B A



IDeX
Integrated Design Experience

DESIGNED BY
Brad Albert | Architecture
Russell LeSieur | Architecture
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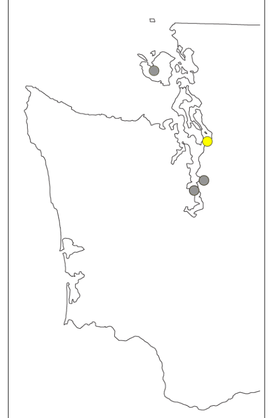
Aaron Steele | Civil Engineer
Kelly Hayden | Civil Engineer
Matt Frazier | Construction Management

LOCATION



Mukilteo Multimodal Transit Hub

DATE **04/27/2012- 20% CD**
SCALE **1" - 80'**

Site Plan - Park

C-102

MUKILTEO MULTIMODAL TRANSIT HUB

APRIL 27, 2012

INFRASTRUCTURE

614 FRONT STREET, MUKILTEO, WA 98204

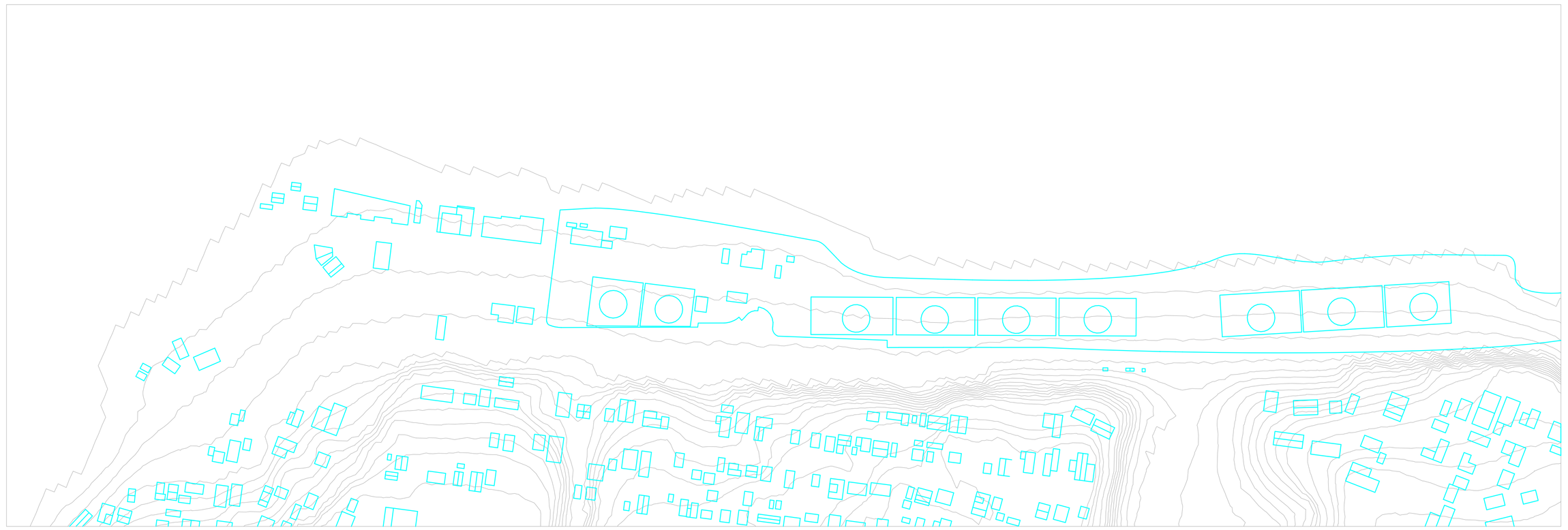


Table of Contents

GENERAL

G-001	Cover Sheet

CIVIL

C-101	Site Plan
C-102	Transit Hub
C-103	Transportation Plan
C-104	Transportation Plan 1st Level
C-105	Transportation Plan 2nd Level

STRUCTURAL

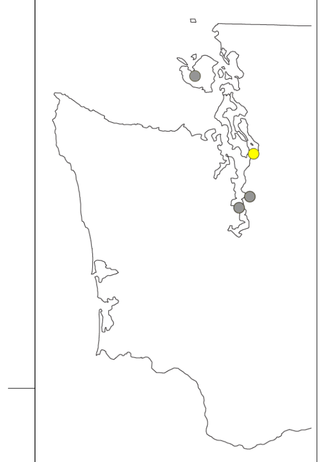
S-101	Parking Garage Framing Plan
S-102	Parking Garage Elevations
S-201	Trestle Framing Plan

IDeX Integrated Design Experience

DESIGNED BY

Brad Albert | Architecture
Russell LeSieur | Architecture
Eric Winborne | Architecture
Charlie Misner | Civil Engineering
Aaron Steele | Civil Engineering
Kelly Hayden | Civil Engineering
Matt Frazier | Construction Management

LOCATION



Mukilteo Multimodal Transit Hub

DATE **4/27/2012- 20% CD**

SCALE

Cover Sheet

G-001

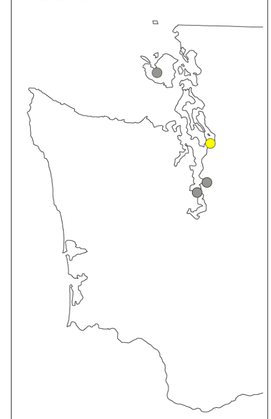


IDeX
Integrated Design Experience

DESIGNED BY

Brad Albert | Architecture
Russell LeSieur | Architecture
Eric Winborne | Architecture
Charlie Misner | Civil Engineer
Aaron Steele | Civil Engineer
Kelly Hayden | Civil Engineer
Matt Frazier | Construction Management

LOCATION



Mukilteo Multimodal Transit Hub

DATE **04/27/2012- 20% CD**
SCALE **1" - 200'**

Site Plan

C-101



IDeX
Integrated Design Experience

DESIGNED BY

Brad Albert | Architecture
Russell LeSieur | Architecture
Eric Winborne | Architecture
Charlie Misner | Civil Engineer
Aaron Steele | Civil Engineer
Kelly Hayden | Civil Engineer
Matt Frazier | Construction Management

LOCATION



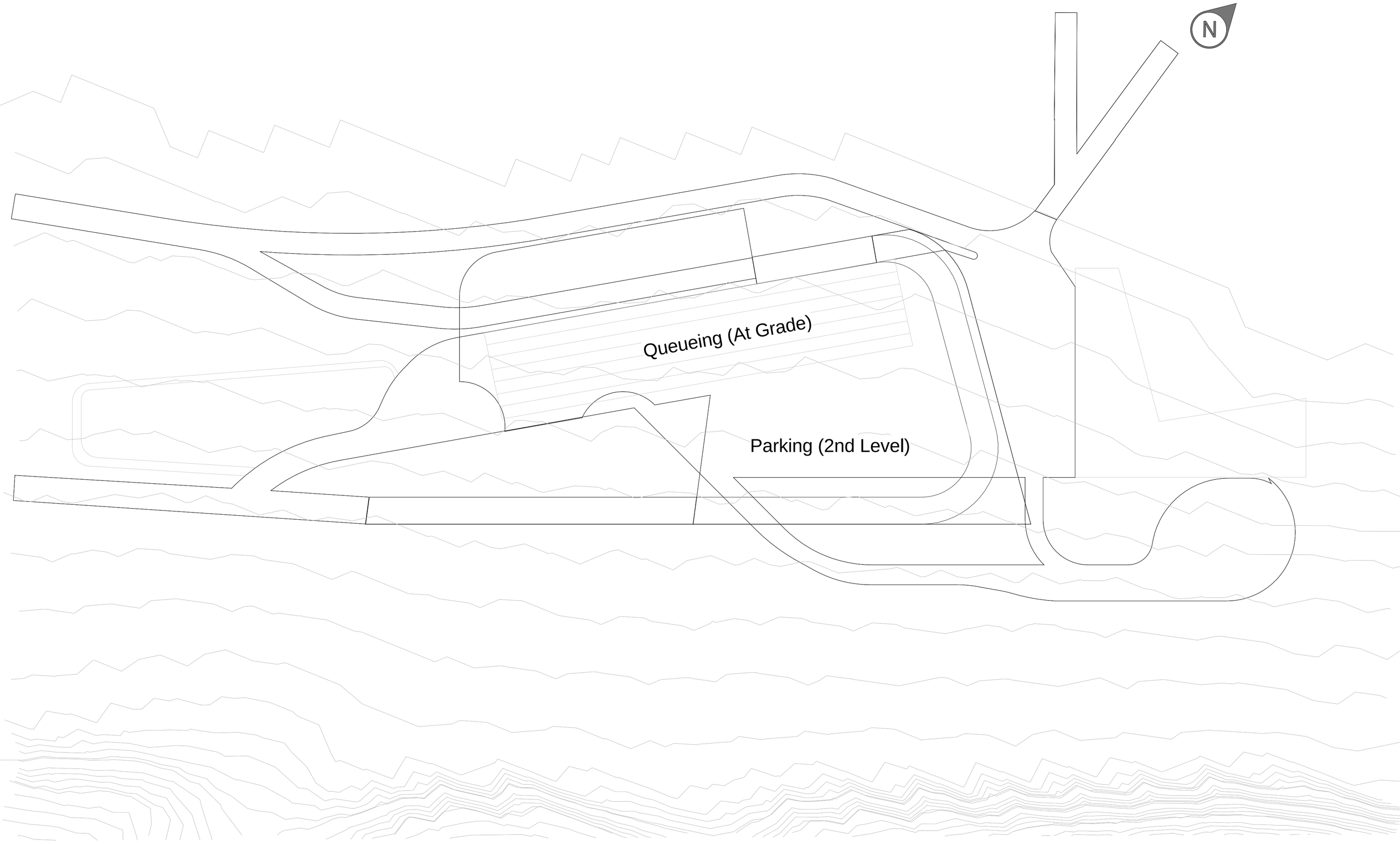
Mukilteo Multimodal Transit Hub

DATE **04/27/2012- 20% CD**

SCALE **1" - 100'**

Site Plan - Transit Hub

C-102



IDeX
Integrated Design Experience

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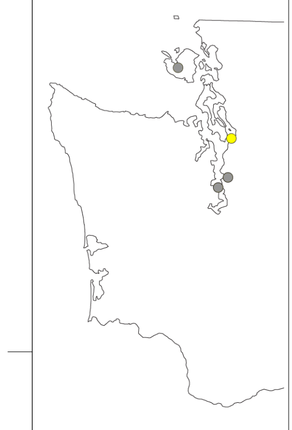
Aaron Steele | Civil Engineer
Kelly Hayden | Civil Engineer
Matt Frazier | Construction Management

LOCATION



Mukilteo Multimodal Hub

DATE **04/27/2012- 20% CD**
SCALE **1" = 60'-0"**

Transporation Plan

C-103

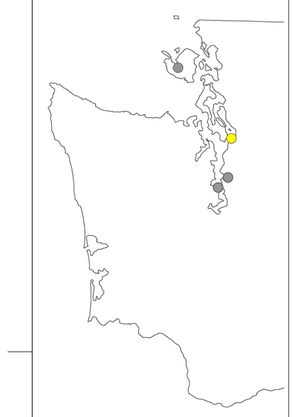


IDeX
Integrated Design Experience

DESIGNED BY

Brad Albert | Architecture
Russell LeSieur | Architecture
Eric Winborne | Architecture
Charlie Misner | Civil Engineer
Aaron Steele | Civil Engineer
Kelly Hayden | Civil Engineer
Matt Frazier | Construction Management

LOCATION

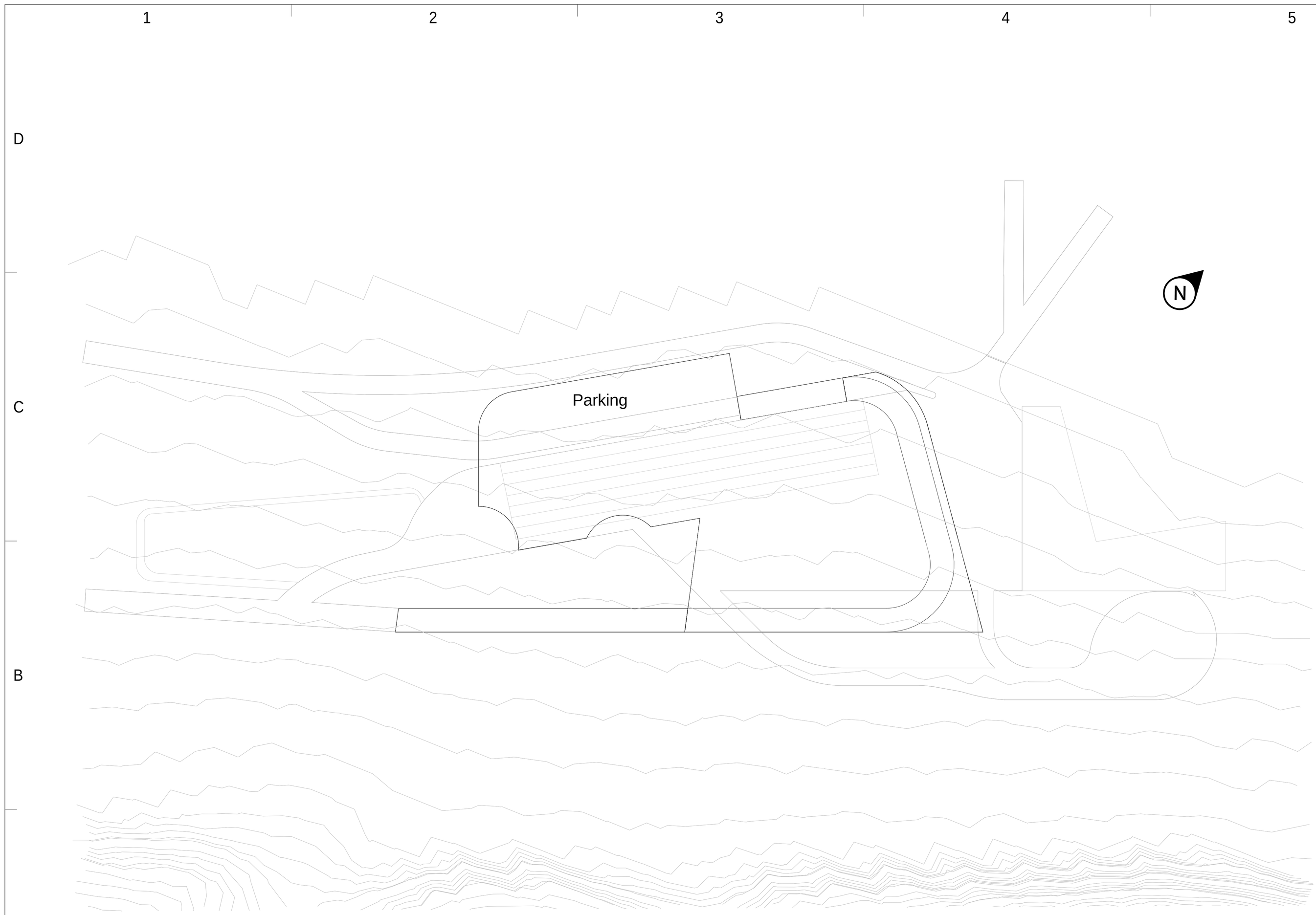


Mukilteo Multimodal Hub

DATE **04/27/2012- 20% CD**
SCALE **1" = 60'-0"**

Transporation Plan - 1st Level

C-104

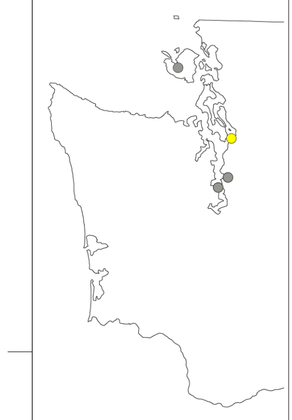


IDeX
Integrated Design Experience

DESIGNED BY

Brad Albert | Architecture
Russell LeSieur | Architecture
Eric Winborne | Architecture
Charlie Misner | Civil Engineer
Aaron Steele | Civil Engineer
Kelly Hayden | Civil Engineer
Matt Frazier | Construction Management

LOCATION



Mukilteo Multimodal Hub

DATE **04/27/2012- 20% CD**
SCALE **1" = 60'-0"**

Transportation Plan - 2nd Level

C-105

1 2 3 4 5

D

C

B

A



N

IDeX Integrated Design Experience

DESIGNED BY

Brad Albert | Architecture
Russell LeSieur | Architecture
Eric Winborne | Architecture
Charlie Misner | Civil Engineer
Aaron Steele | Civil Engineer
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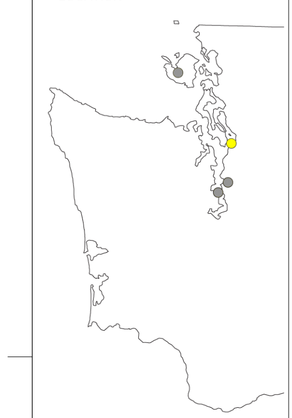
LOCATION



Mukilteo Multimodal Transit Hub

DATE **04/27/2012- 20% CD**

SCALE **1" = 30'-0"**

Parking Garage
Framing Plan

S-101

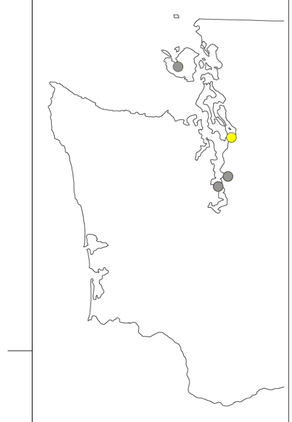


IDeX
Integrated Design Experience

DESIGNED BY

Brad Albert | Architecture
Russell LeSieur | Architecture
Eric Winborne | Architecture
Charlie Misner | Civil Engineer
Aaron Steele | Civil Engineer
Kelly Hayden | Civil Engineer
Matt Frazier | Construction Management

LOCATION



Mukilteo Multimodal Transit Hub

DATE **04/27/2012- 20% CD**
SCALE **1" = 10'-0"**

Trestle Framing Plan

S-102

4/26/2012 12:14:26 PM
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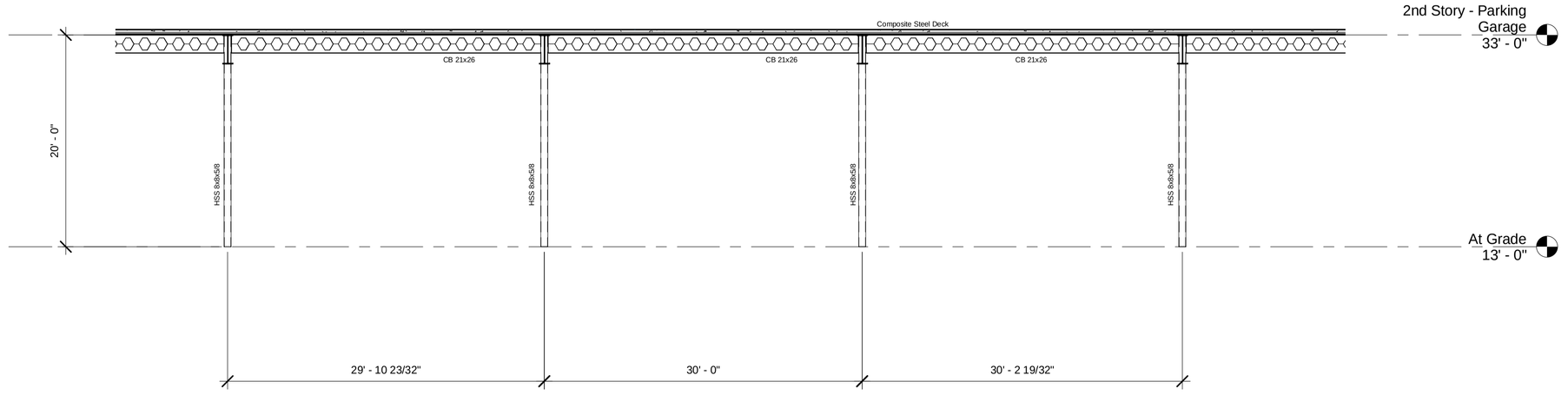
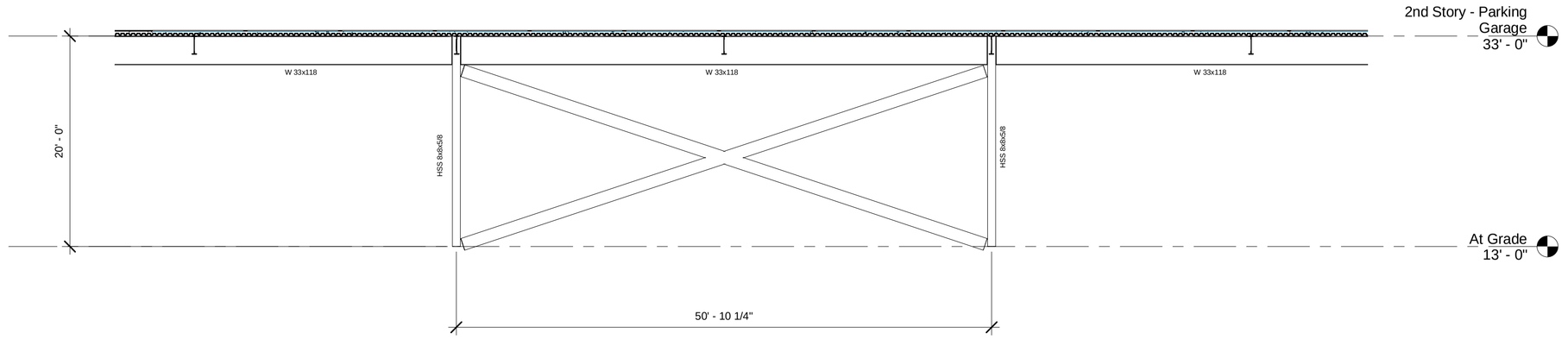


1 Parking Structure East Elevation
1/8" = 1'-0"



2 Parking Structure North Elevation
1/8" = 1'-0"

IDeX
Integrated Design Experience

DESIGNED BY

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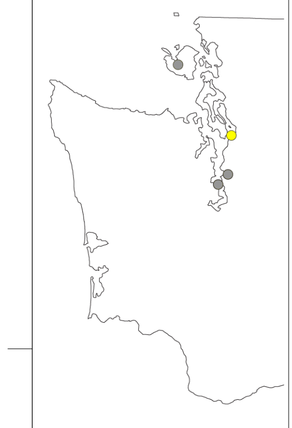
Russell LeSieur | Architecture
Eric Winborne | Architecture
Charlie Misner | Civil Engineer
Aaron Steele | Civil Engineer
Kelly Hayden | Civil Engineer
Matt Frazier | Construction Management

LOCATION



Mukilteo Multimodal Transit Hub

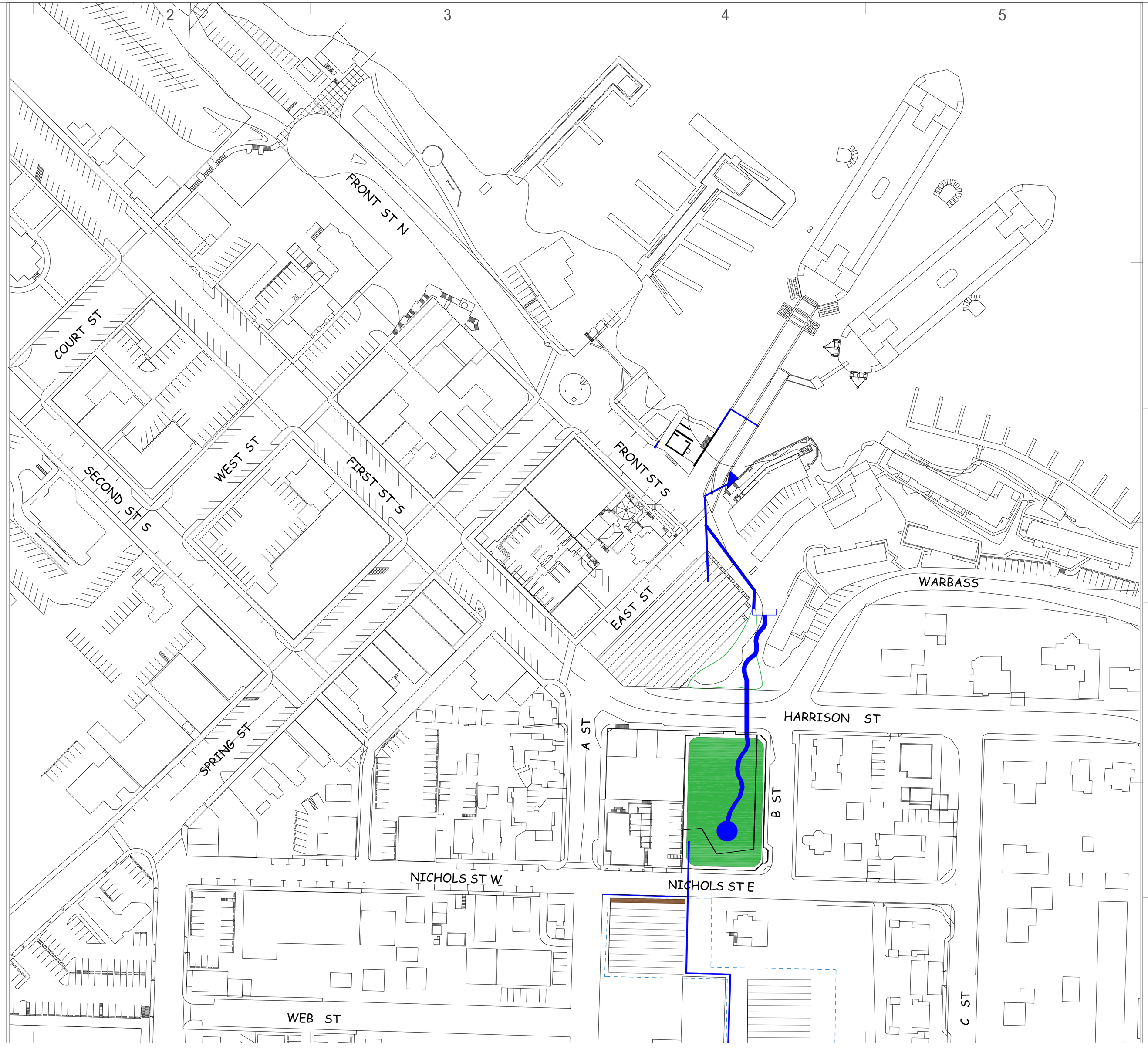
DATE **04/27/2012- 20% CD**
SCALE **1/8" = 1'-0"**

Parking Garage North and East Elevatons

S-201

APPENDIX: DRAWING SETS

FRIDAY HARBOR DRAWINGS

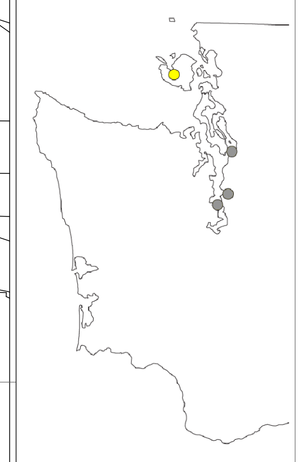


IDeX
Integrated Design Experience

DESIGNED BY

Nara Sin | Civil Engineering
Kirsti McDaniel | Civil Engineering
Jon Talbott | Architecture
Allison Dunn | Architecture
Viral Patel | Civil Engineering
Holly Hicks | Civil Engineering
Jordan Jackson | Construction Management
-

LOCATION



FRIDAY HARBOR

DATE

SCALE

W-101

1 2 3 4 5

D

C

B

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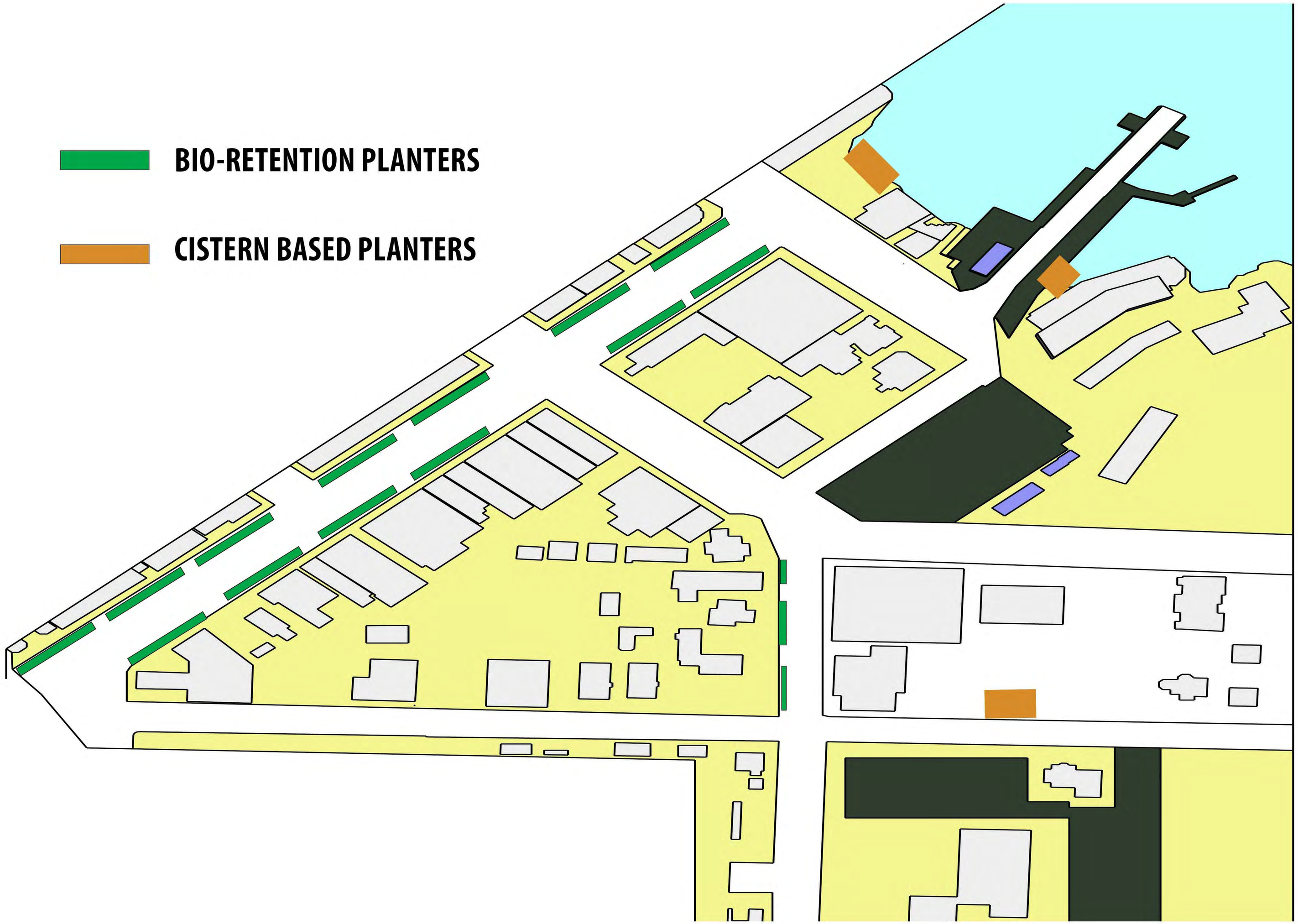
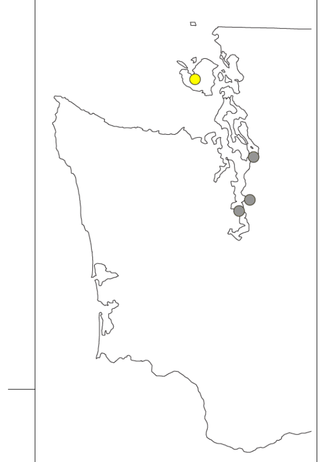


IDeX
Integrated Design Experience

DESIGNED BY

LOCATION



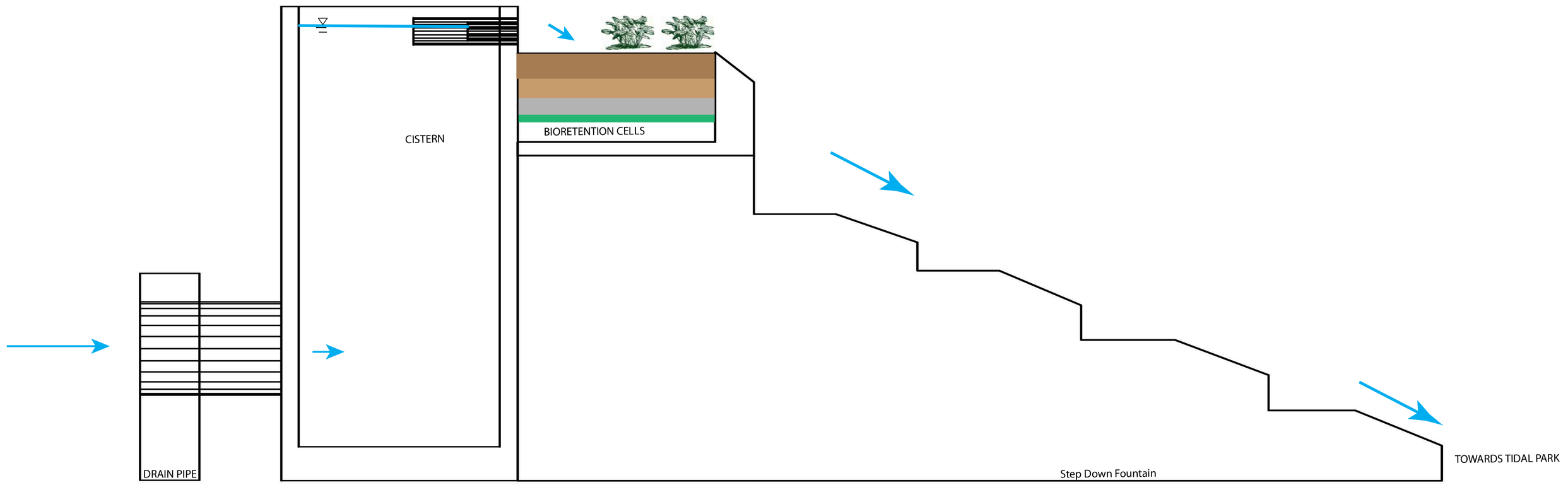
FRIDAY HARBOR

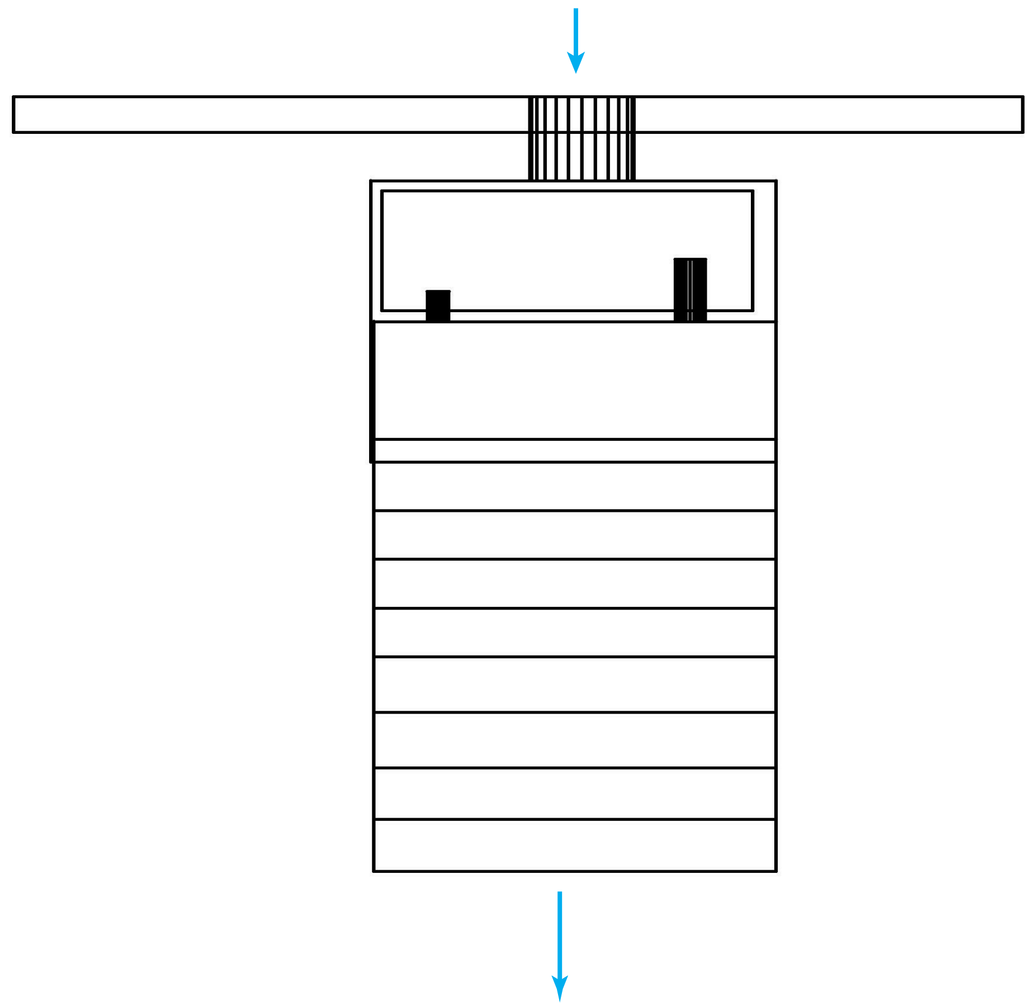
DATE

SCALE

Plan-Bioretenetion

W-102

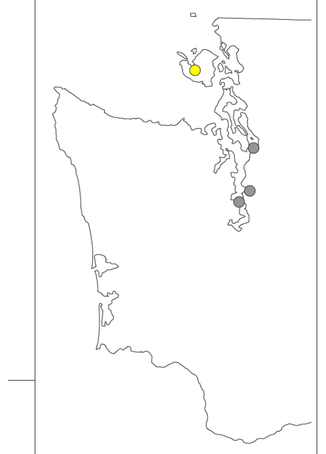




IDeX | Integrated Design Experience

DESIGNED BY

LOCATION



FRIDAY HARBOR

DATE

SCALE

Section-Cistern

W-401

1 2 3 4 5

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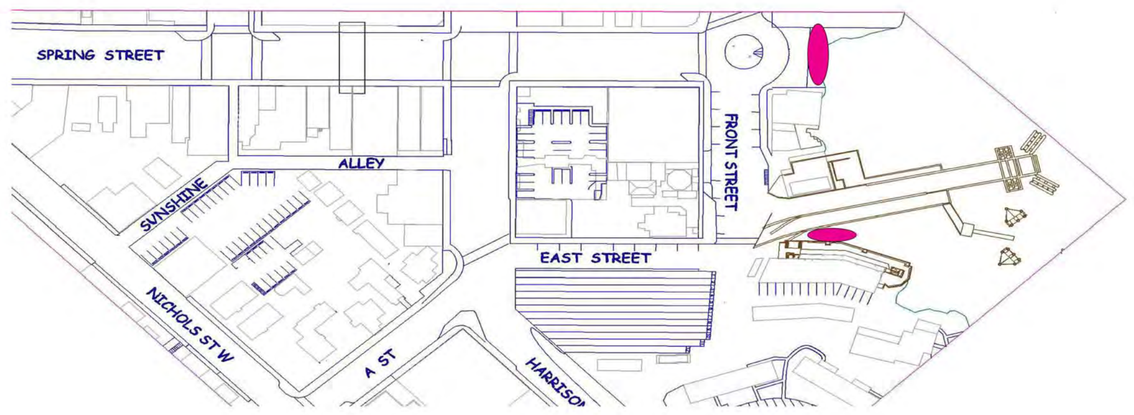

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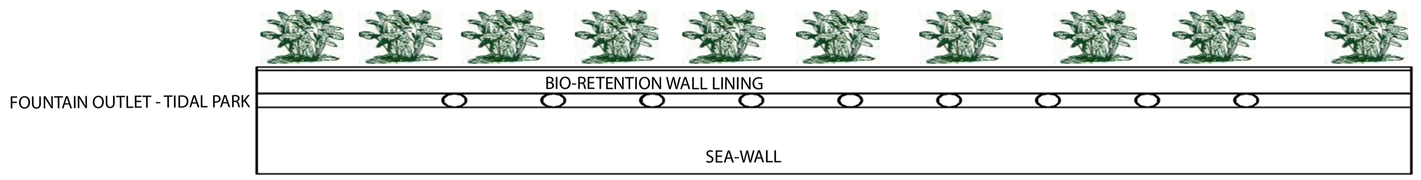

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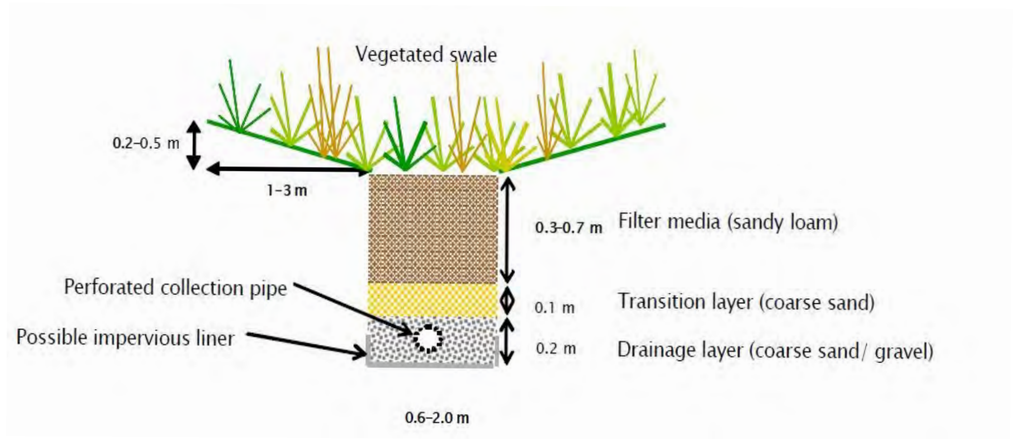
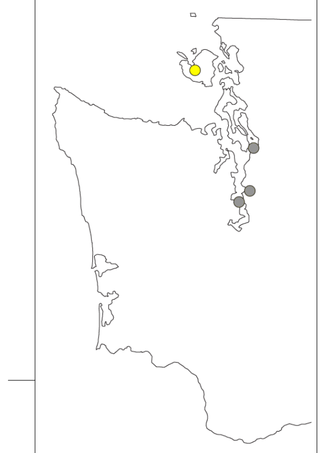




IDeX
Integrated Design Experience

DESIGNED BY

LOCATION



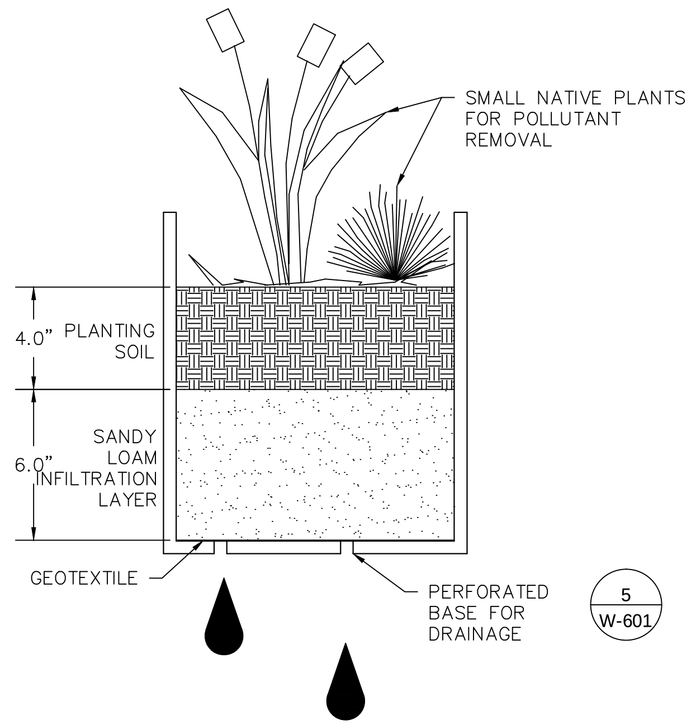
FRIDAY HARBOR

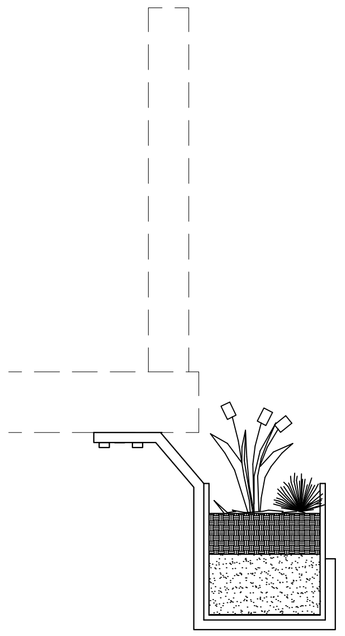
DATE

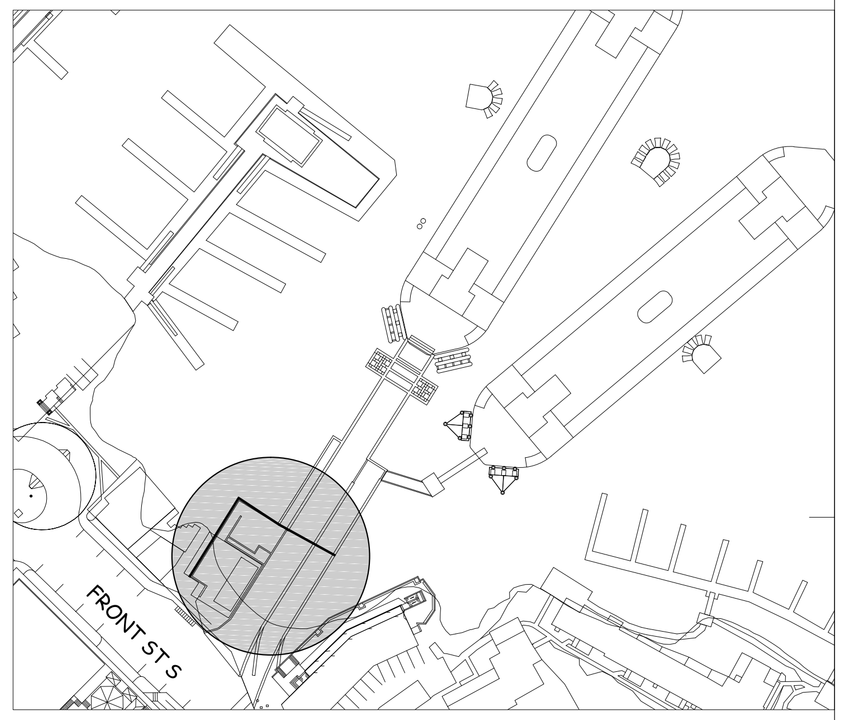
SCALE

Section-Bioretention Wall

W-402







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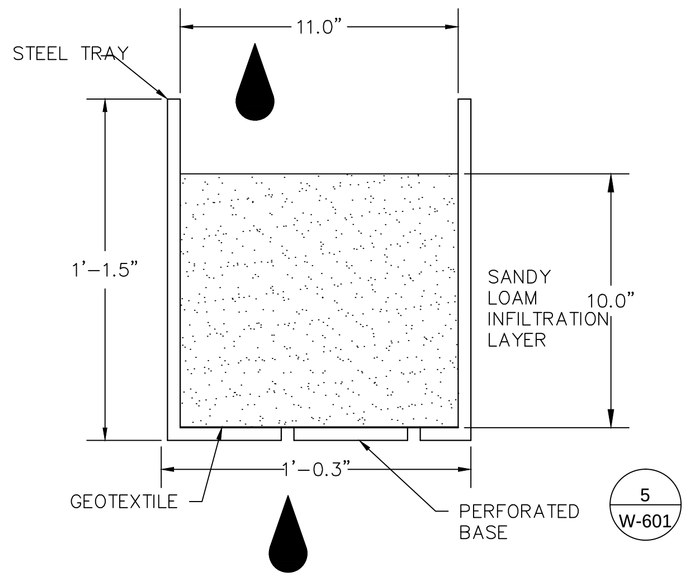
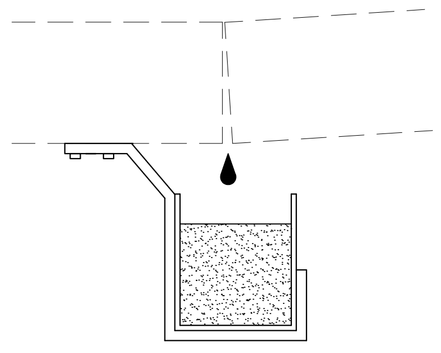
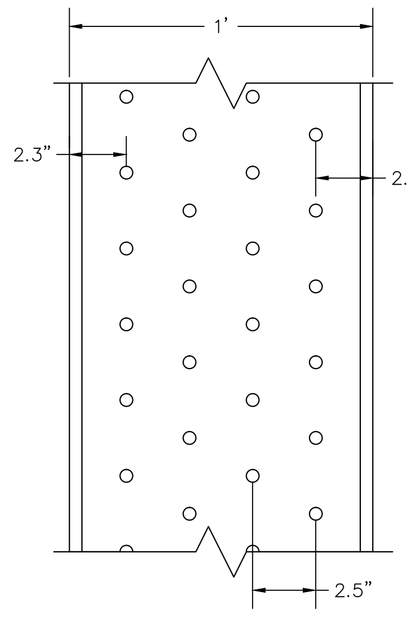
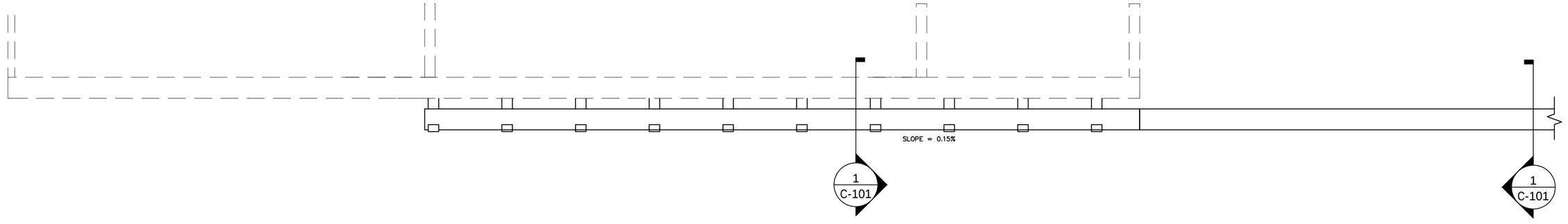








1 W-601 SECTION
SCALE: 1" = 40'

IDeX Integrated Design Experience

DESIGNED BY

Nara Sin | Civil Engineering
Kirsti McDaniel | Civil Engineering
Jon Talbott | Architecture
Allison Dunn | Architecture
Viral Patel | Civil Engineering
Holly Hicks | Civil Engineering
Jordan Jackson | Construction Management
-

LOCATION



FRIDAY HARBOR

DATE 4-27-2012 - 20%
SCALE AS SPECIFIED

LIVING FILTER
W-601

IDEX FRIDAY HARBOR

91 FRONT STREET S.
FRIDAY HARBOR, WA 98250

APRIL 27, 2012

FRIDAY HARBOR, WASHINGTON



DRAWING INDEX

GENERAL
COVERSHEET

CIVIL

C101	SITE PLAN
C102	CULVERT
C103	SUNKEN PARK
C601	LIVING FILTER
L101	LANDSCAPE

ARCHITECTURAL

A101	BUILDING PLAN
A102	TIDAL PARK PLAN
A201	BUILDING ELEVATIONS
A401	BUILDING SECTIONS

STRUCTURAL

S101	STRUCURAL PLAN
S401	STRUC SECTION 1
S402	STRUC SECTION 2
S403	STRUC SECTION 3

STORMWATER

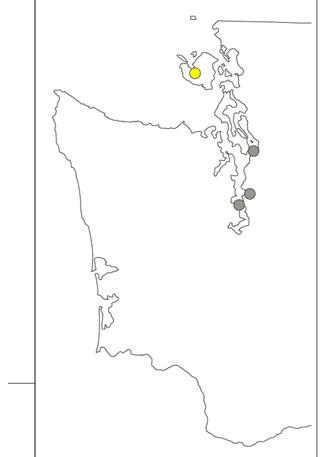
W101	SW PLAN
W102	BIORETENTION
W401	CISTERN
W402	BIORET WALL

TRANSPORTATION
T101TRAFFIC FLOW
T401SPRING ST SECTION I
T402SPRING ST SECTION II
T403A STREET SECTION

IDeX Integrated Design Experience

DESIGNED BY
NARA SIN | CIVIL ENGINEERING
KIRSTI MCDANIEL | CIVIL ENGINEERING
JON TALBOTT | ARCHITEXTURE
ALLISON DUNN | ARCHITECTURE
VIRAL PATEL |CIVIL ENGINEERING
HOLLY HICKS | CIVIL ENGINEERING
JORDAN JACKSON | CONSTRUTION MANAGEMENT

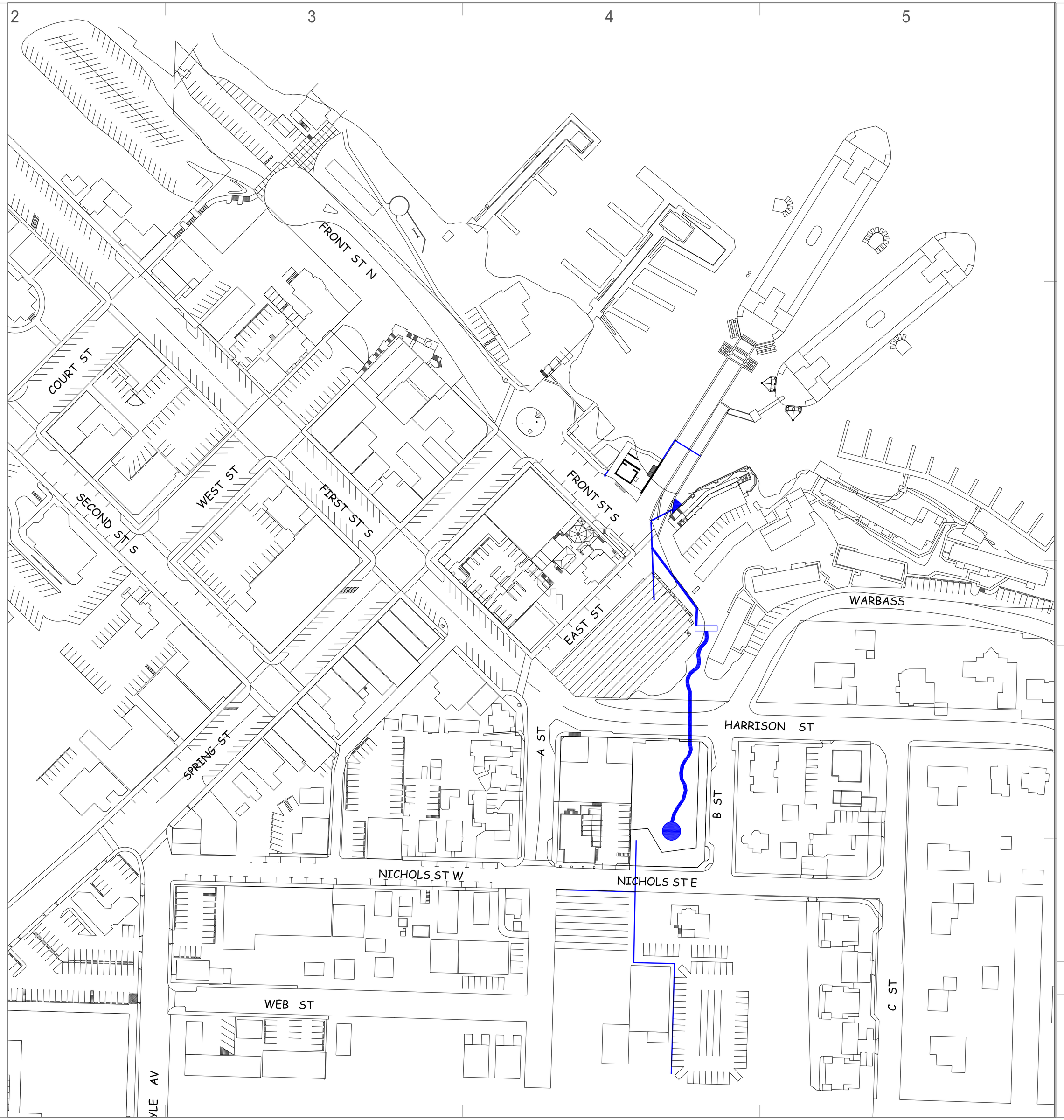
LOCATION



FRIDAY HARBOR

DATE **Issue Date- Project Status**
SCALE

FRIDAY HARBOR
COVER SHEET
G-101

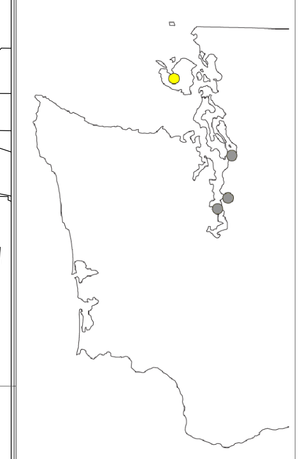


IDeX
Integrated Design Experience

DESIGNED BY

Nara Sin | Civil Engineering
Kirsti McDaniel | Civil Engineering
Jon Talbott | Architecture
Allison Dunn | Architecture
Viral Patel | Civil Engineering
Holly Hicks | Civil Engineering
Jordan Jackson | Construction Management
-

LOCATION

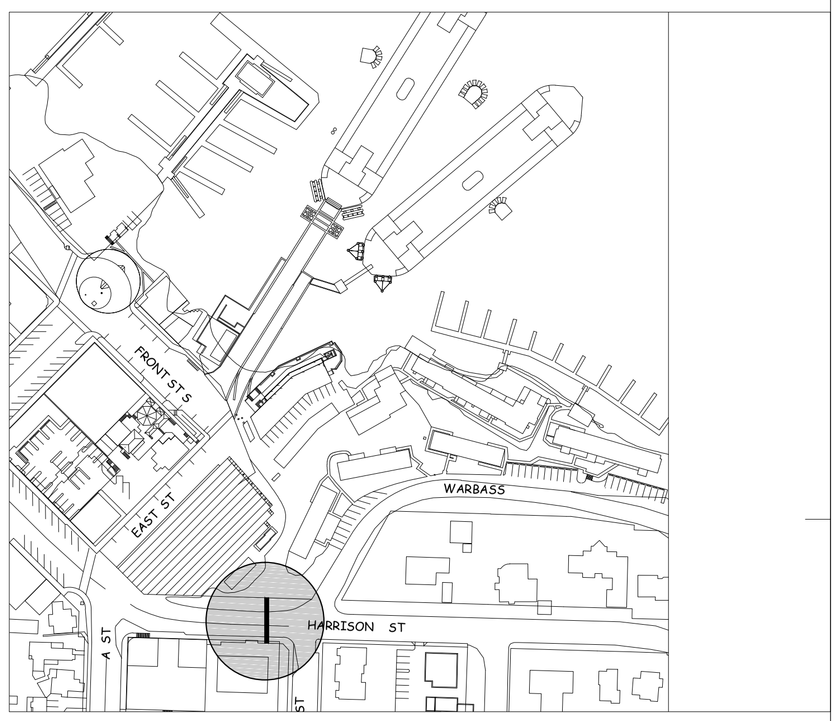


FRIDAY HARBOR

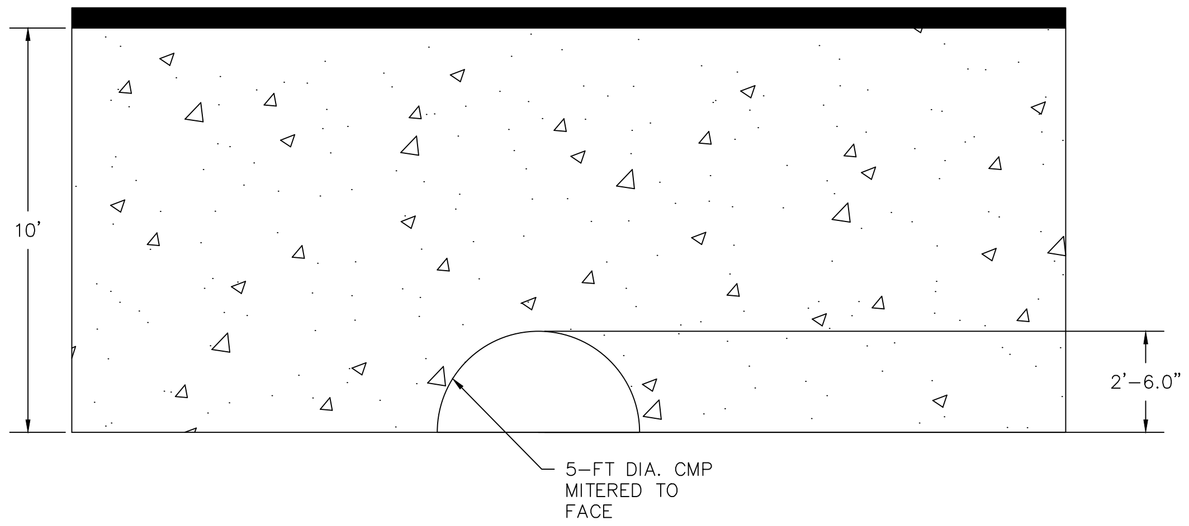
DATE 2/14/11- Project Status
SCALE 1/8" = 1'-0"

CIVIL SITE PLAN

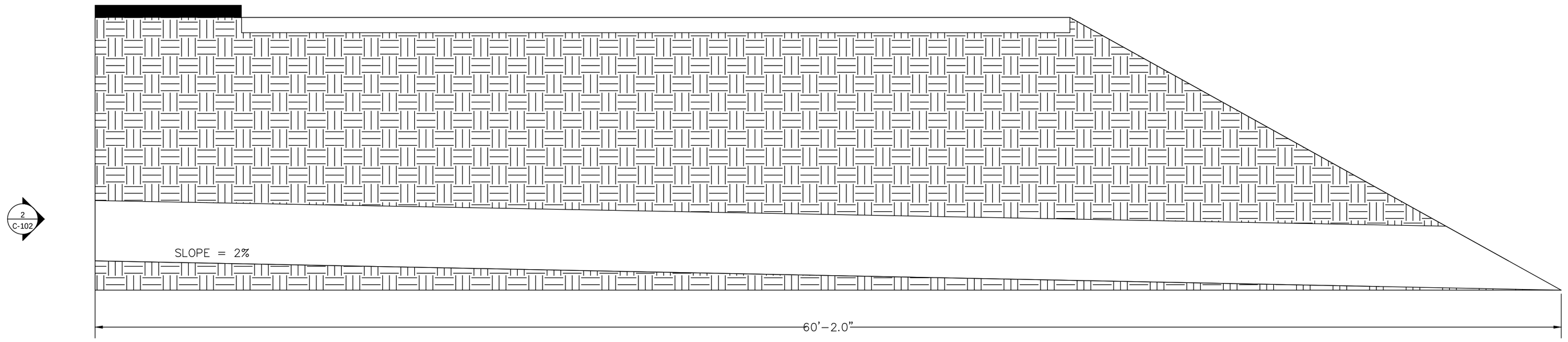
C-101



CULVERT LOCATION



2 / C-102 ELEVATION
SCALE: 1" = 30'



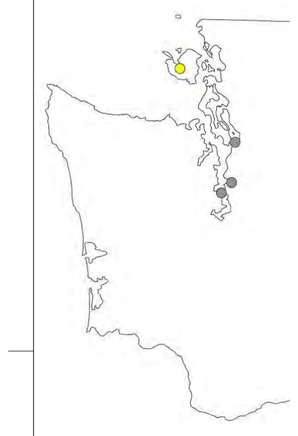
1 / C-102 ELEVATION
SCALE: 1" = 30'

IDeX
Integrated Design Experience

DESIGNED BY

Nara Sin | Civil Engineering
Kirsti McDaniel | Civil Engineering
Jon Talbott | Architecture
Allison Dunn | Architecture
Viral Patel | Civil Engineering
Holly Hicks | Civil Engineering
Jordan Jackson | Construction Management
-

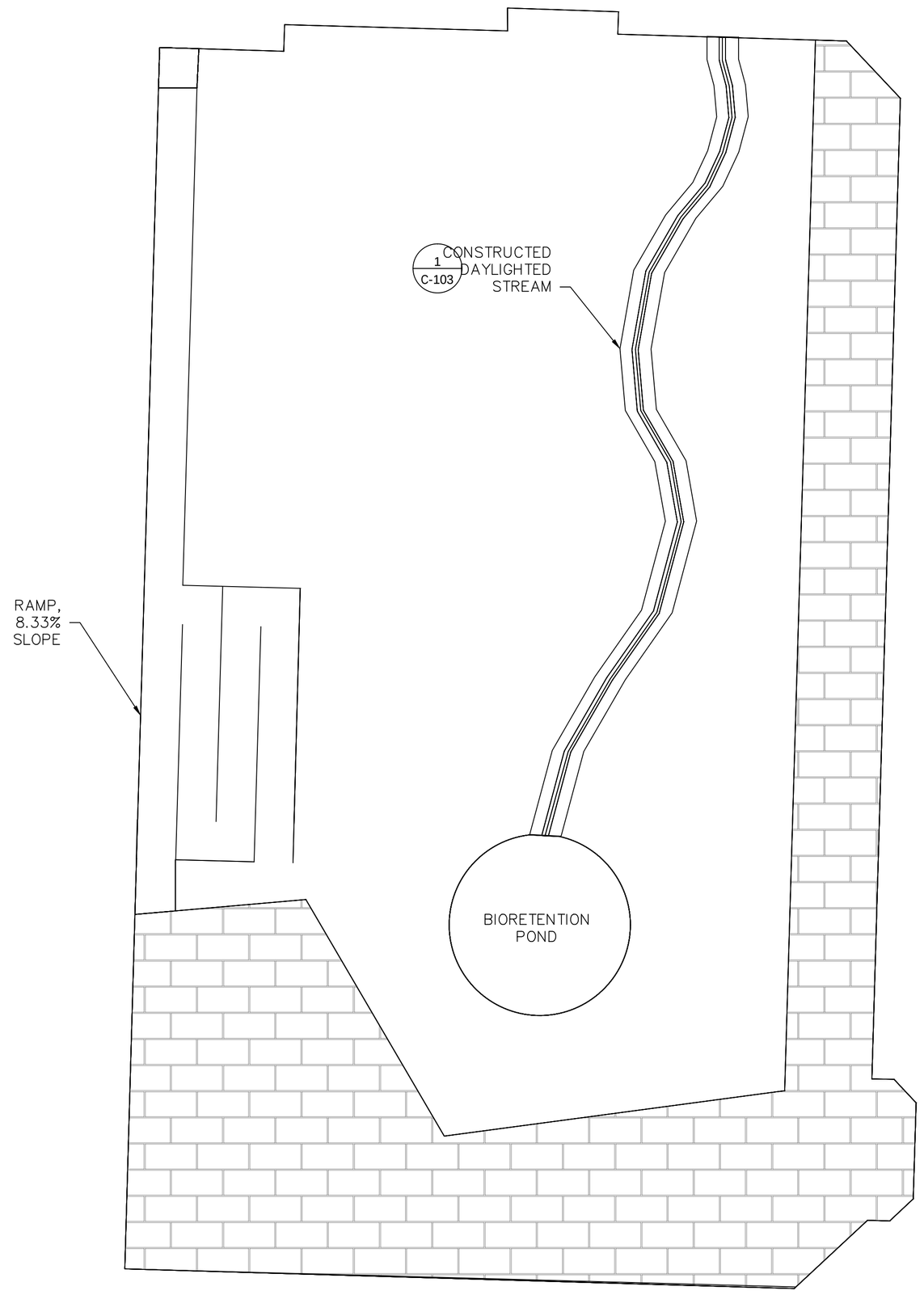
LOCATION



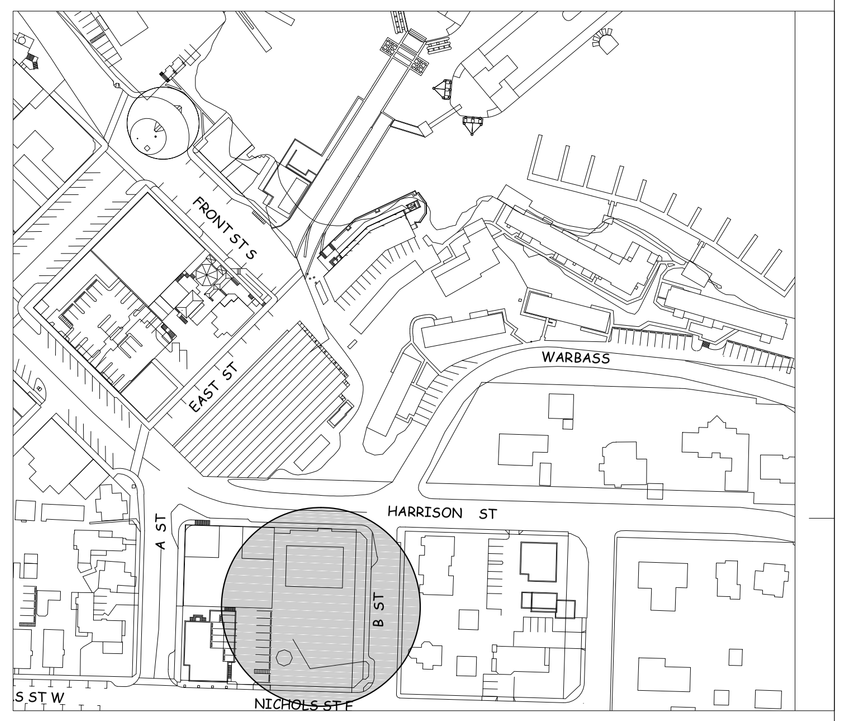
FRIDAY HARBOR

DATE **4-27-2012 - 20%**
SCALE **AS SPECIFIED**

CULVERT
C-102



PLAN VIEW
SCALE: 1" = 150'



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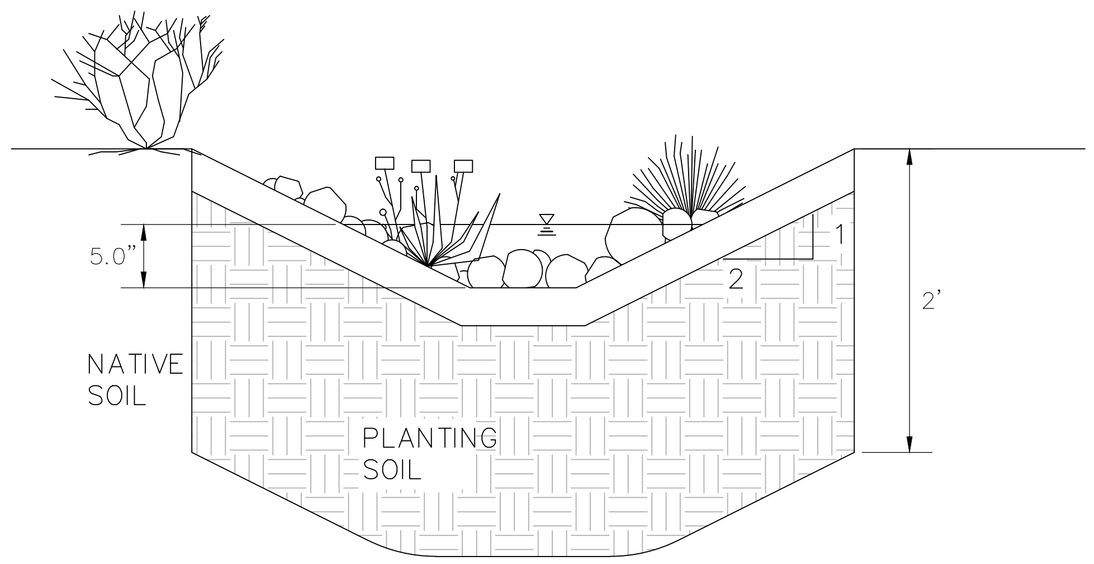


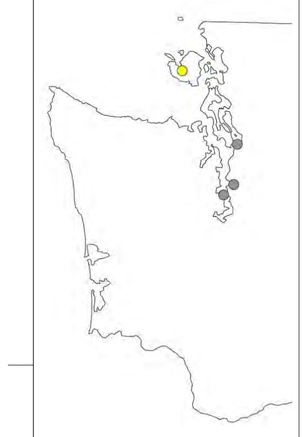
1 C-103 SECTION
SCALE: 1 1/2" = 1'

IDeX
Integrated Design Experience

DESIGNED BY

Nara Sin | Civil Engineering
Kirsti McDaniel | Civil Engineering
Jon Talbott | Architecture
Allison Dunn | Architecture
Viral Patel | Civil Engineering
Holly Hicks | Civil Engineering
Jordan Jackson | Construction Management
-

LOCATION

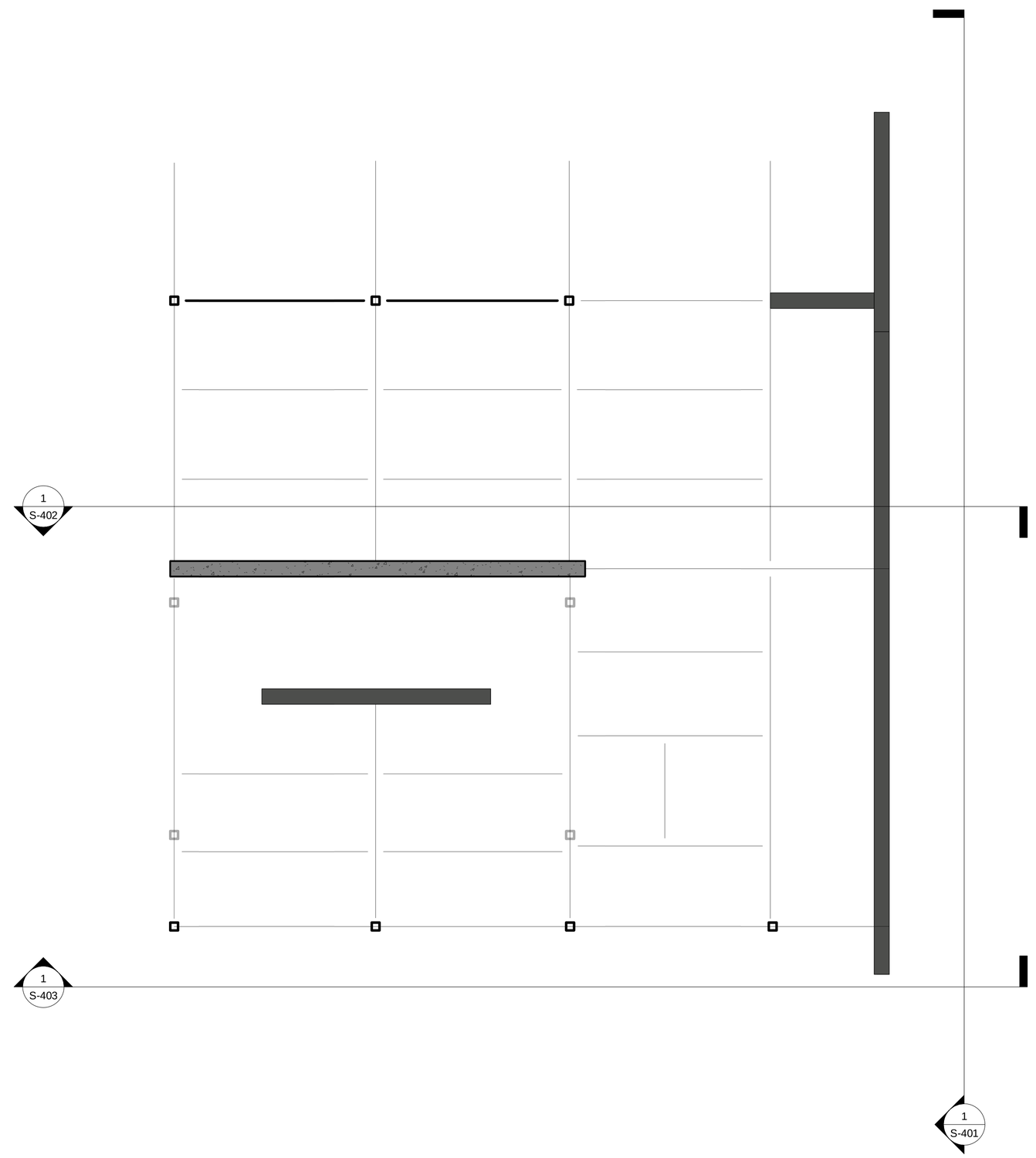


FRIDAY HARBOR

DATE 4-27-2012 - 20%
SCALE AS SPECIFIED

SUNKEN PARK

C-103

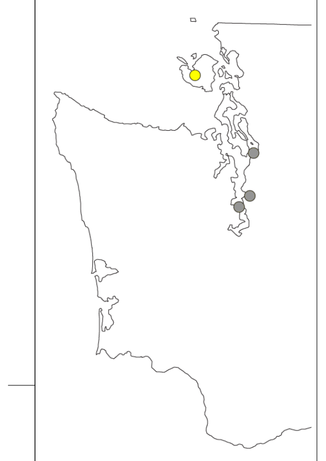


1 Roof Level
3/16" = 1'-0"

IDeX
Integrated Design Experience

DESIGNED BY

LOCATION

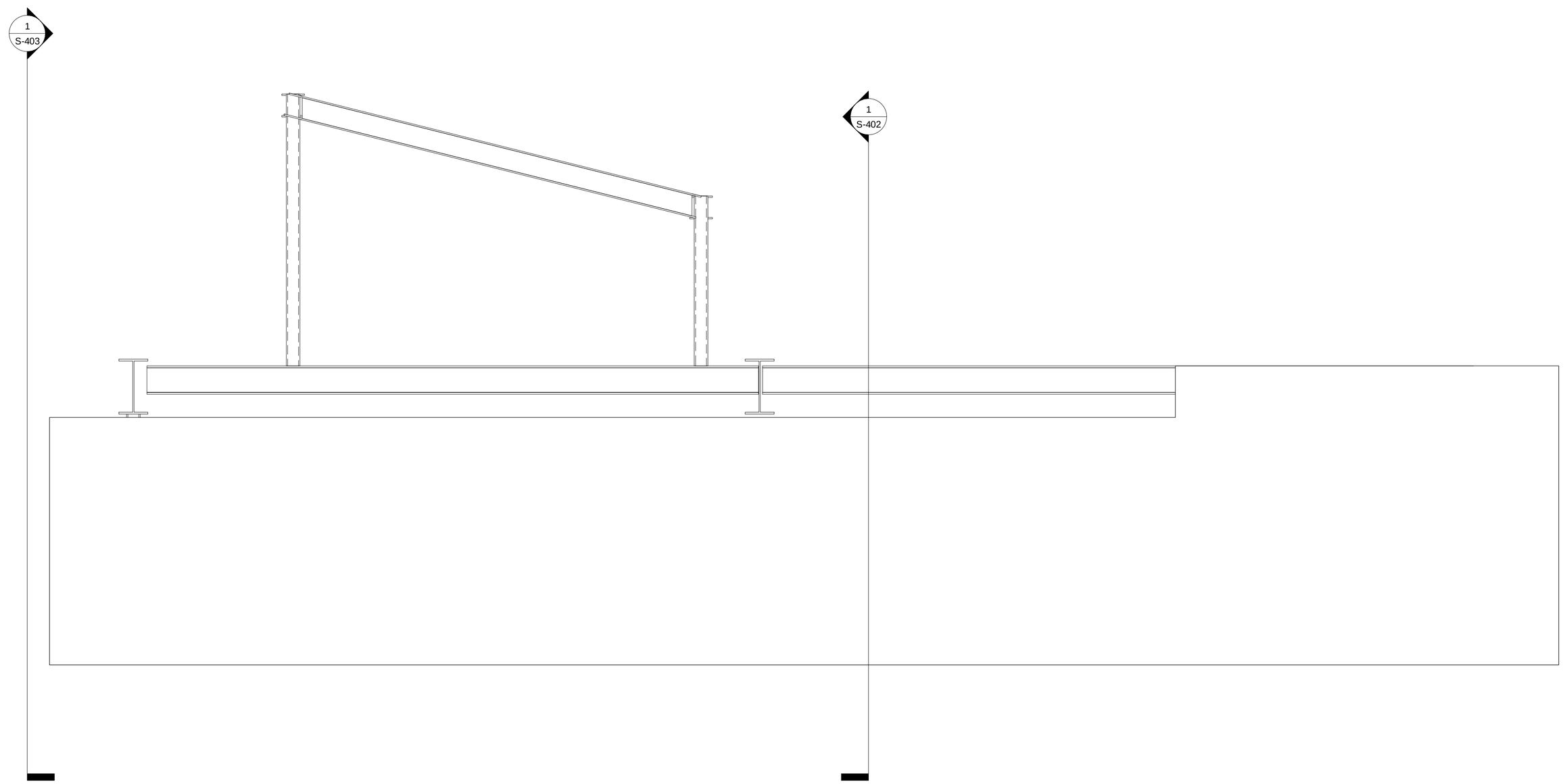


FRIDAY HARBOR

DATE Issue Date- Project Status
SCALE 3/16" = 1'-0"

STRUCTURAL FRAMING PLAN

S-101

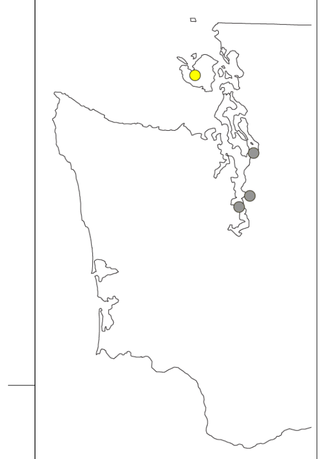


1 Girders on Exterior Concrete Wall
3/8" = 1'-0"

IDeX
Integrated Design Experience

DESIGNED BY

LOCATION



FRIDAY HARBOR

DATE Issue Date- Project Status
SCALE 3/8" = 1'-0"

GIRDERS ON EXTERIOR CONCRETE SECTION

S-401

1 2 3 4 5

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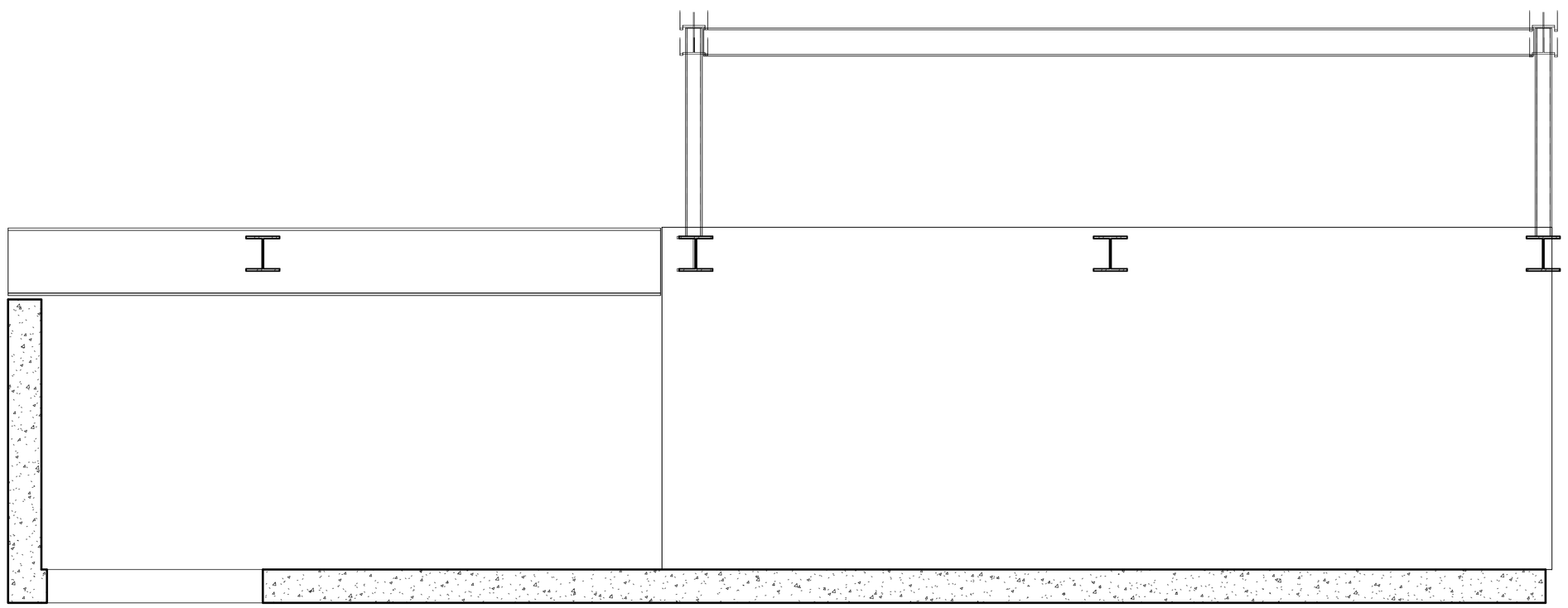
S-401



1 Main Shear Wall and Girder
3/8" = 1'-0"

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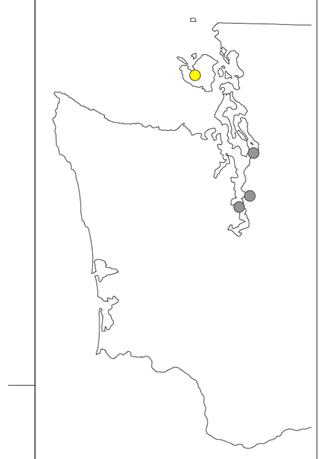
Integrated Design Experience

DESIGNED BY

LOCATION

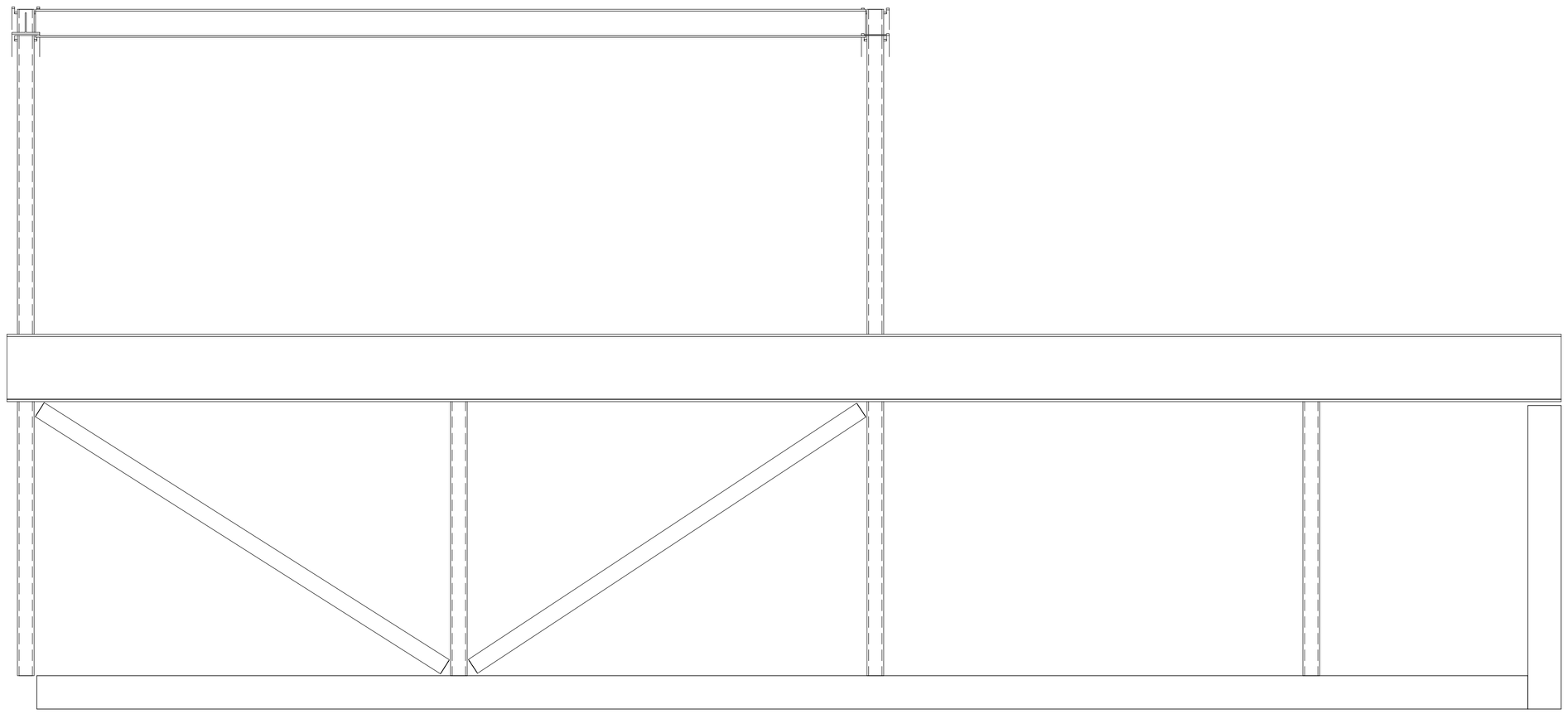


FRIDAY HARBOR

DATE Issue Date- Project Status
SCALE 3/8" = 1'-0"

MAIN SHEAR WALL AND GIRDER SECTION

S-402



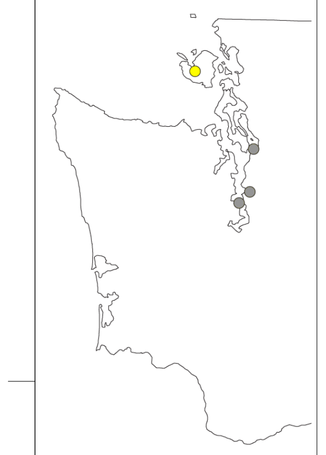
1 S-401

1 Cross Braces
3/8" = 1'-0"

IDeX Integrated Design Experience

DESIGNED BY

LOCATION

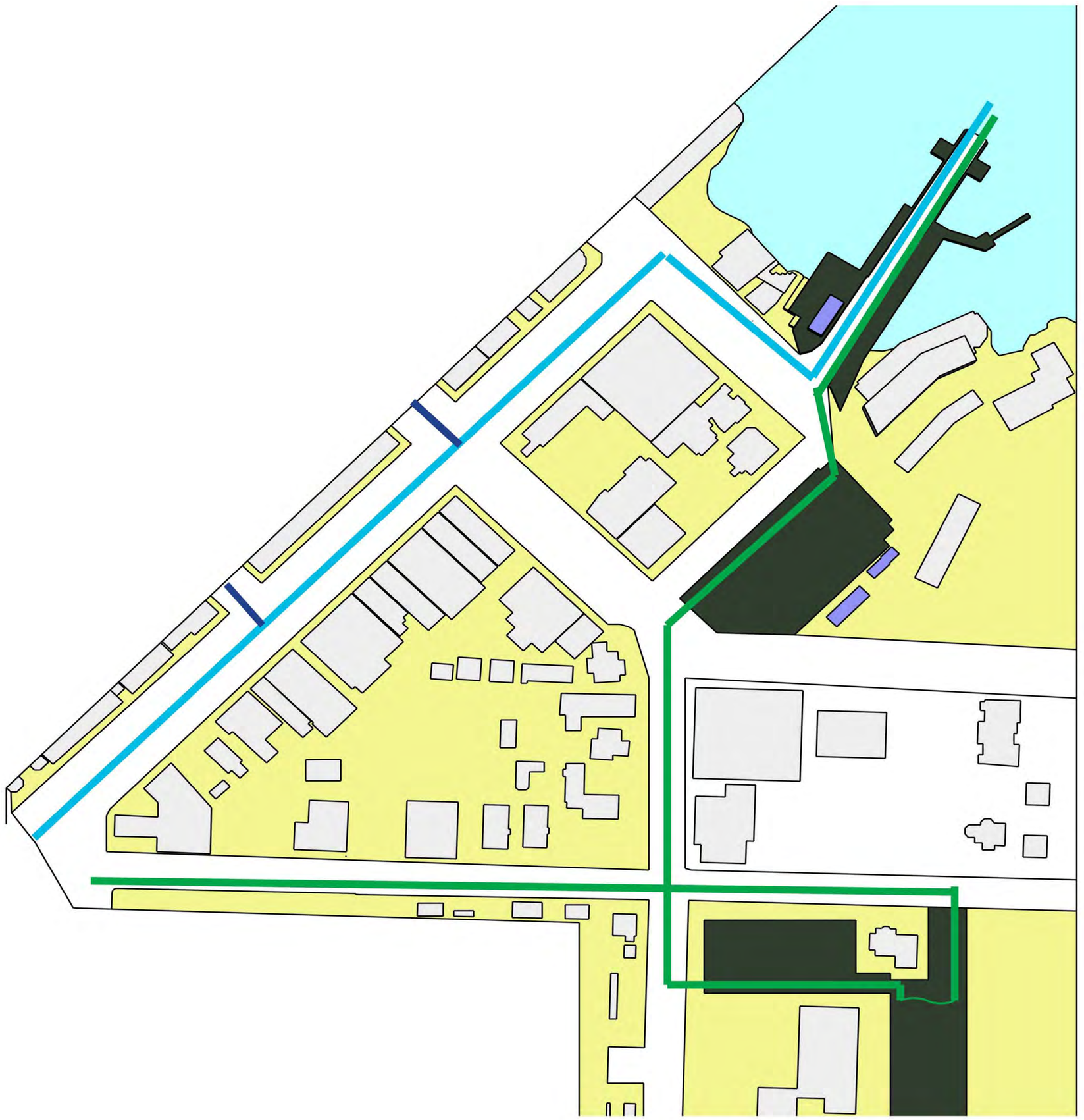


FRIDAY HARBOR

DATE Issue Date- Project Status
SCALE 3/8" = 1'-0"

CROSS BRACE SECTION

S-403



TRAFFIC FLOW

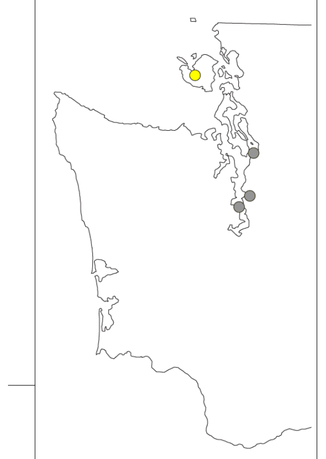
OUTWARD FLOW

INWARD FLOW

IDeX Integrated Design Experience

DESIGNED BY

LOCATION



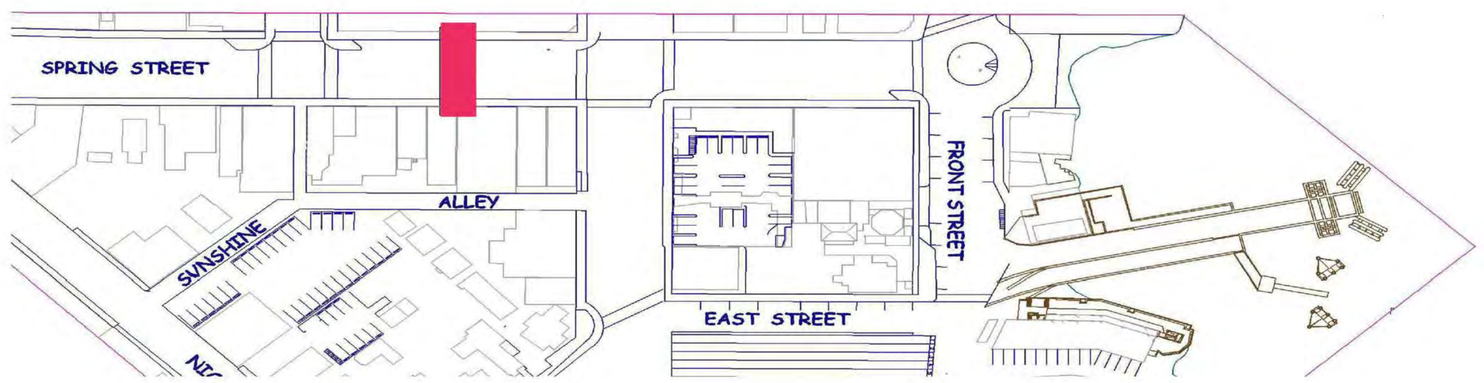
FRIDAY HARBOR

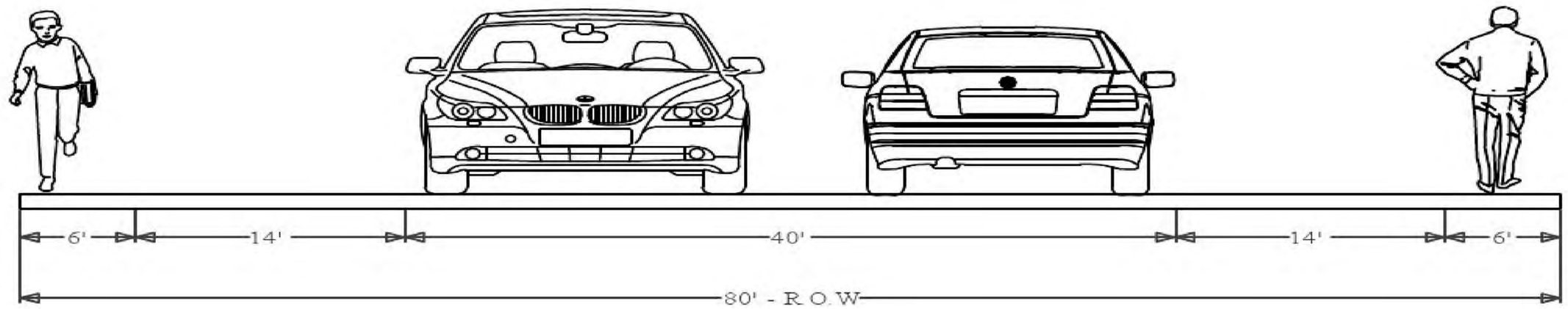
DATE

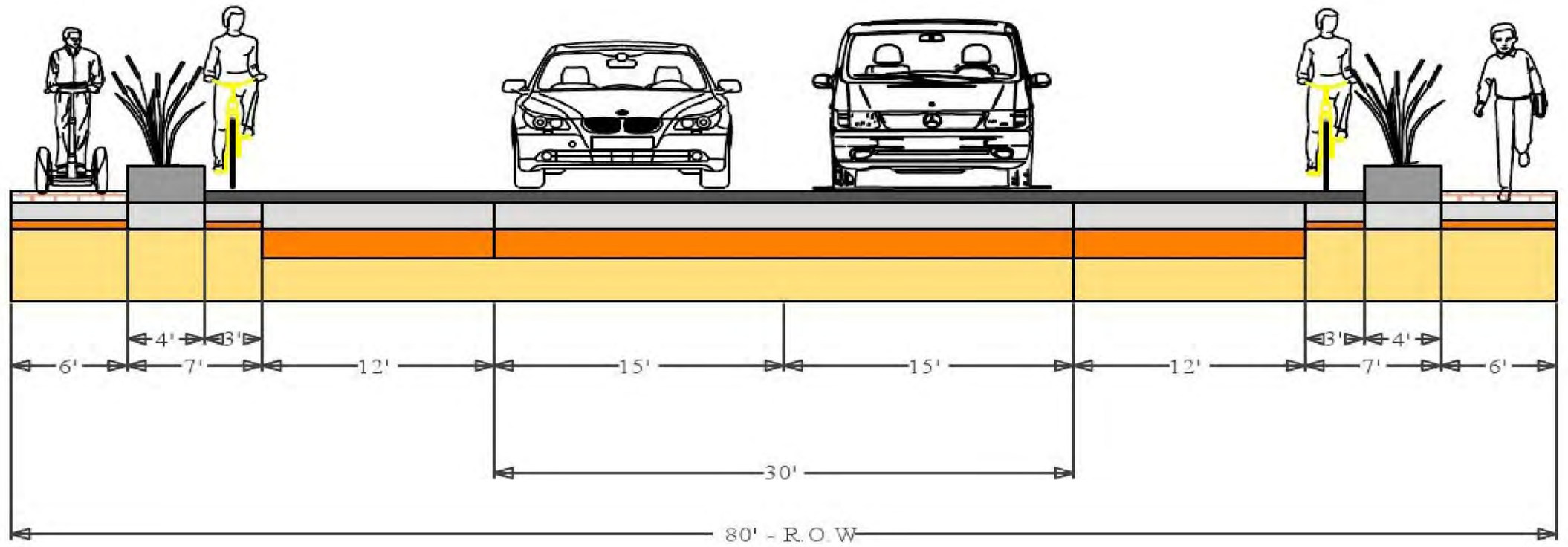
SCALE

TRAFFIC FLOW

T-101



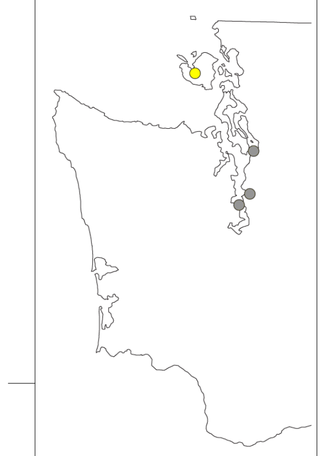




IDeX
Integrated Design Experience

DESIGNED BY

LOCATION



FRIDAY HARBOR

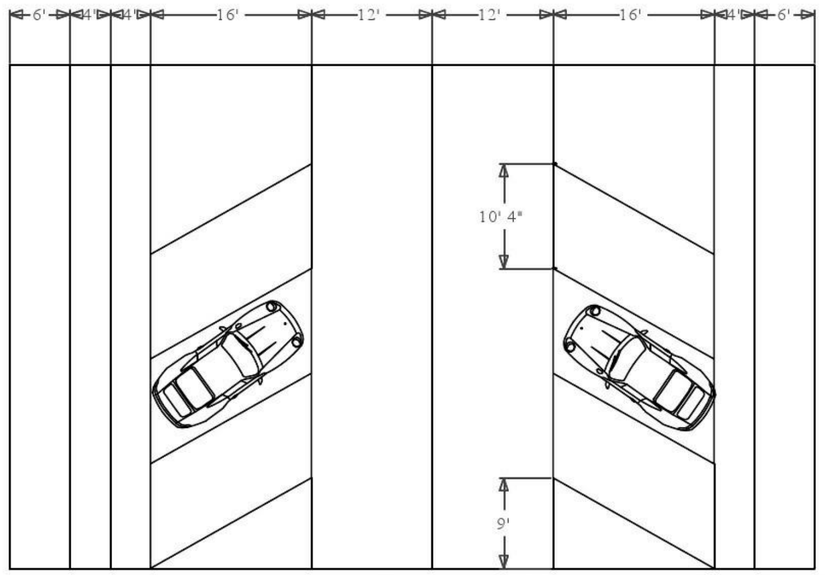
DATE

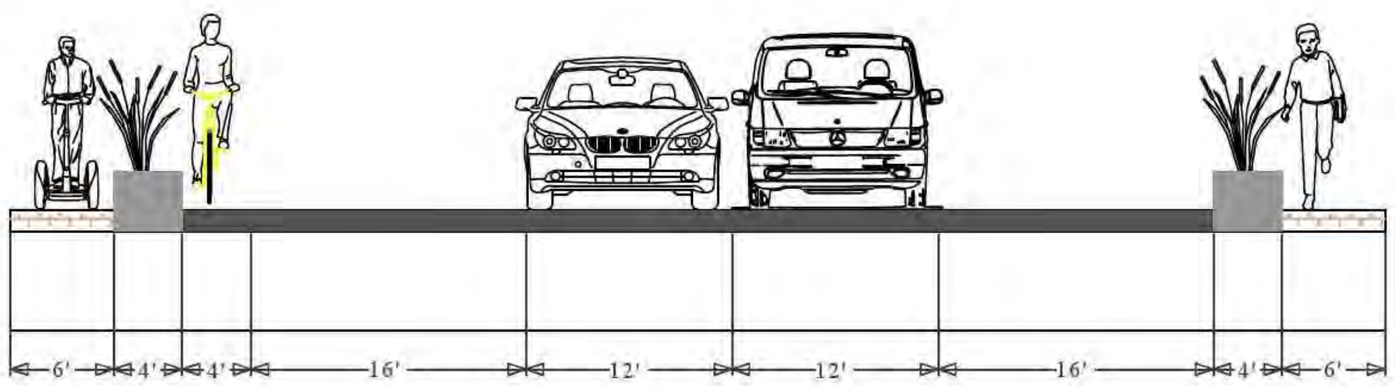
SCALE

Section-Spring Street I

T-401



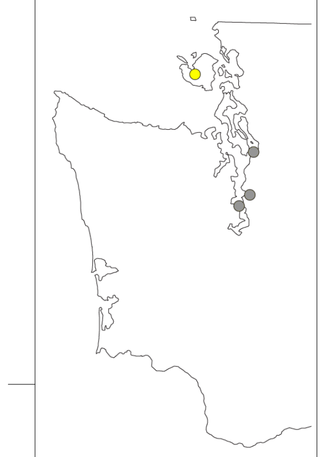




IDeX
Integrated Design Experience

DESIGNED BY

LOCATION



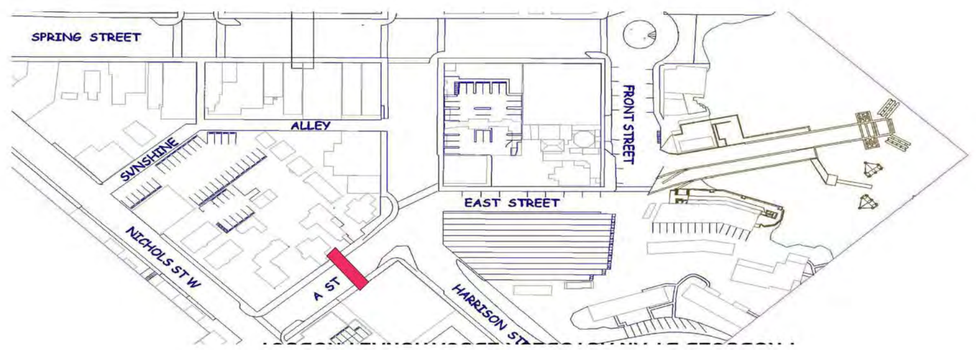
FRIDAY HARBOR

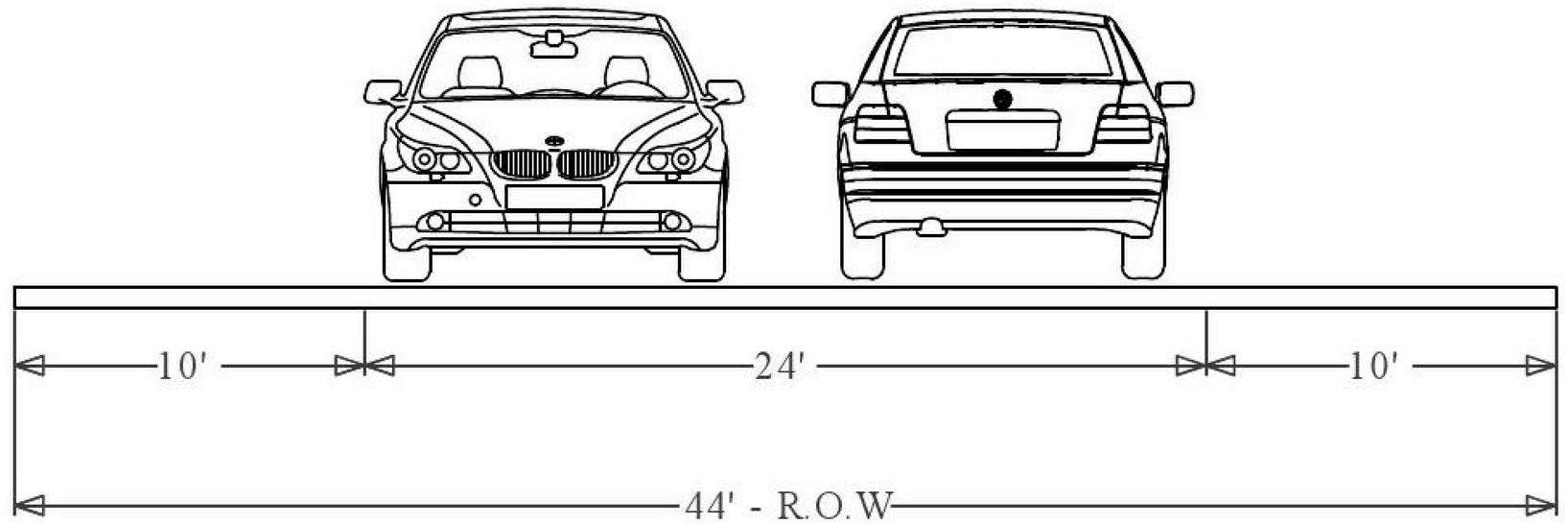
DATE

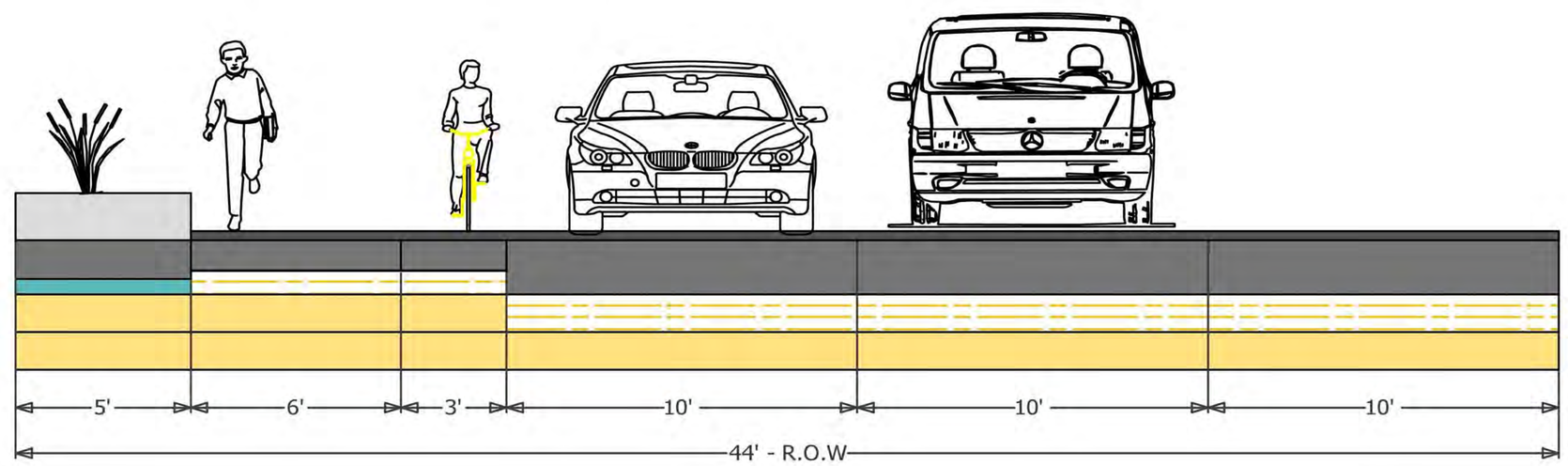
SCALE

Section-Spring Street II

T-402







IDeX
Integrated Design Experience

DESIGNED BY

LOCATION



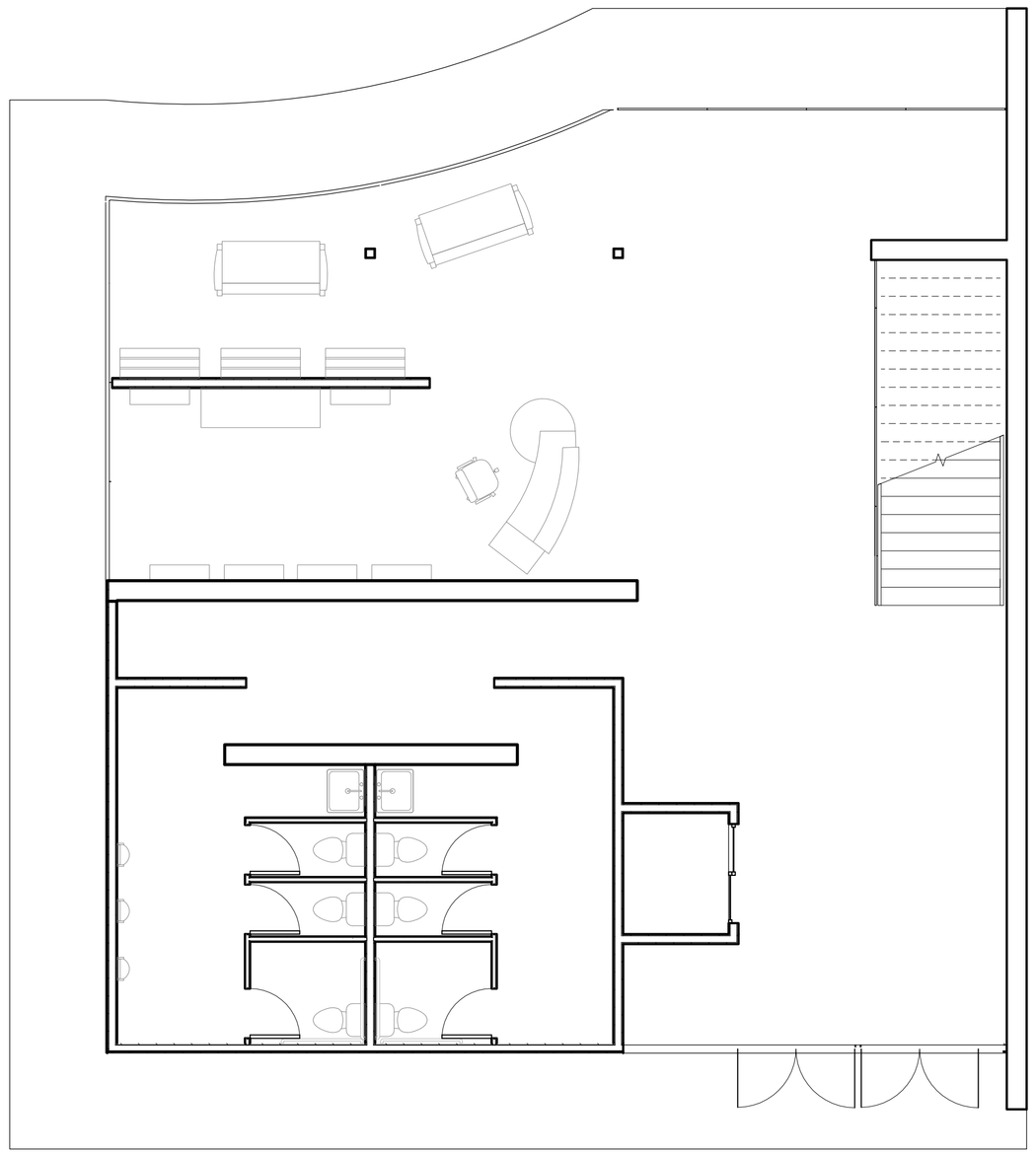
FRIDAY HARBOR

DATE
SCALE

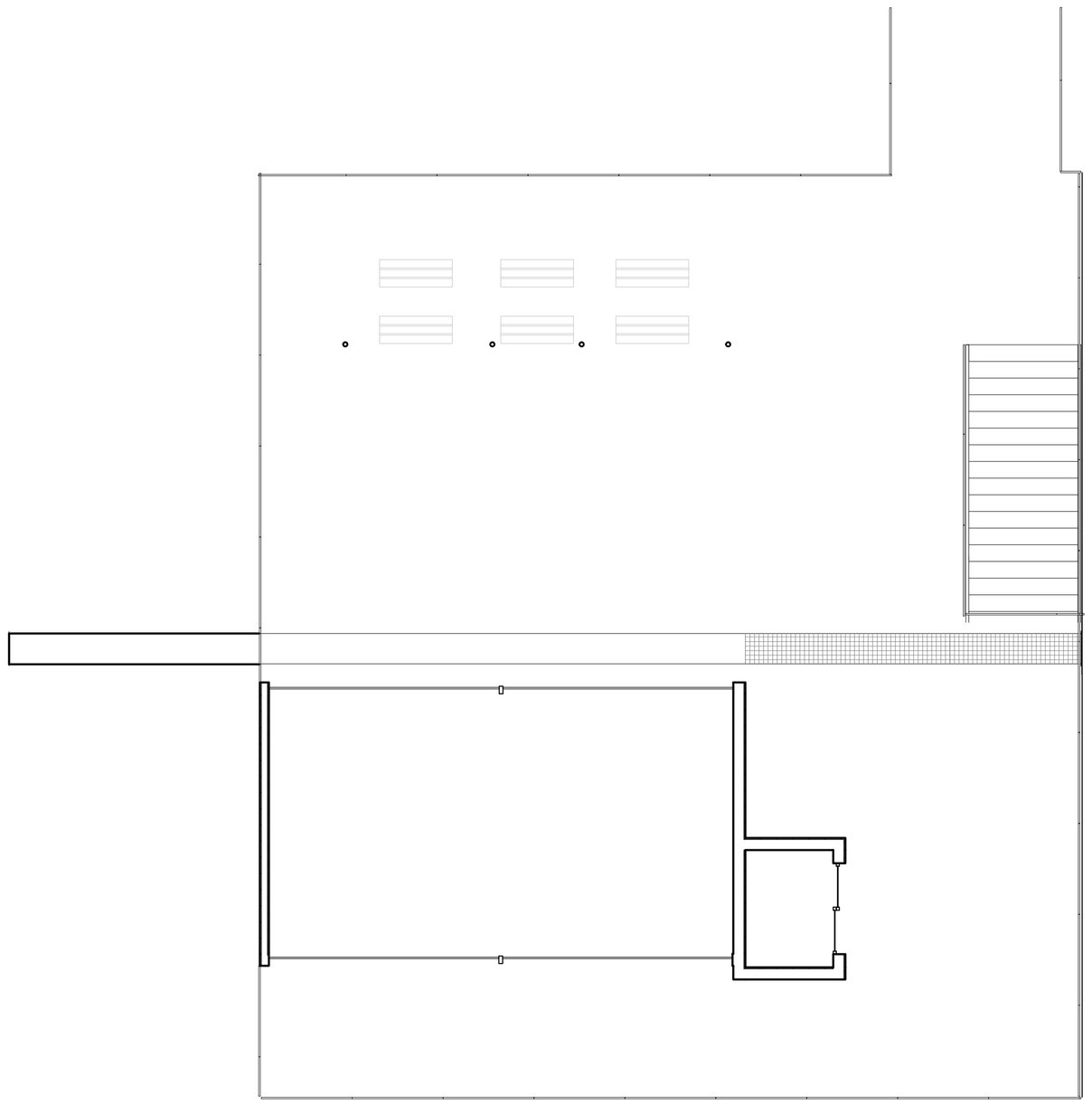
Issue Date- Project Status

Section-A Street

T-403



1 Ground Level Floor Plan
3/16" = 1'-0"

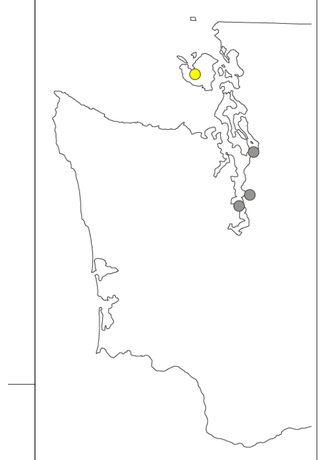


2 Roof Level
3/16" = 1'-0"

IDeX
Integrated Design Experience

DESIGNED BY

LOCATION



FRIDAY HARBOR

DATE Issue Date- Project Status
SCALE 3/16" = 1'-0"

Ferry Building Plans

A-101

4/26/2012 5:55:04 PM
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1 2 3 4 5

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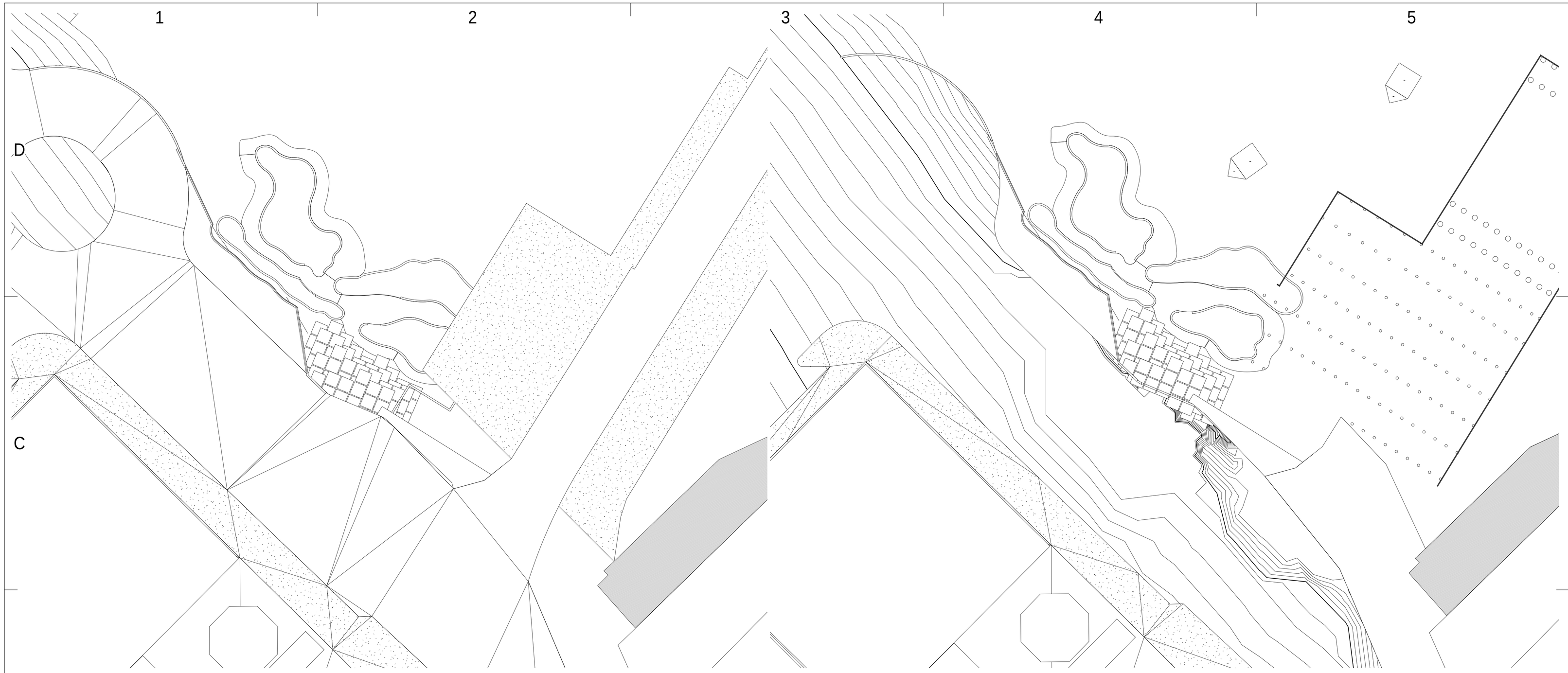


IDeX
Integrated Design Experience

DESIGNED BY

LOCATION



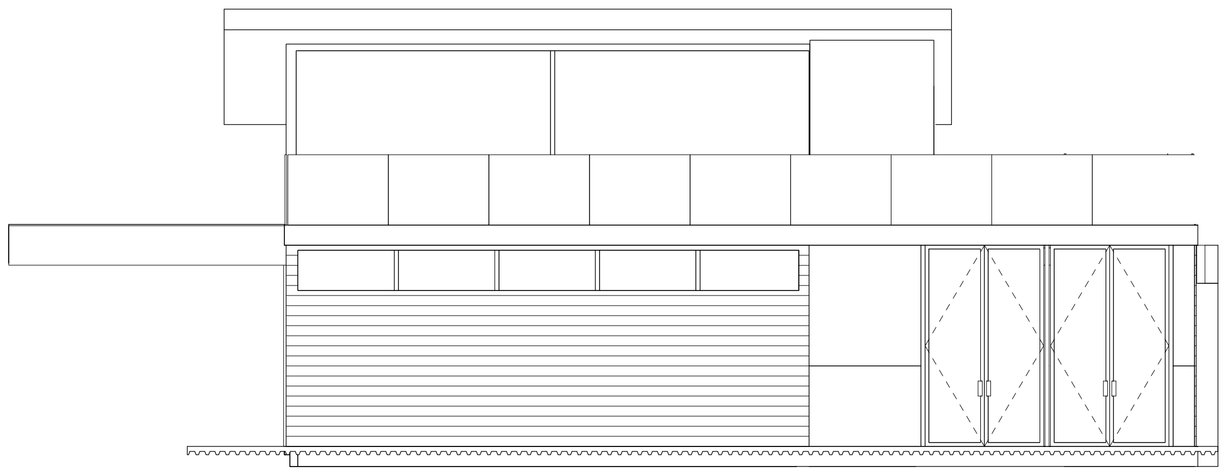
FRIDAY HARBOR

DATE Issue Date- Project Status

SCALE 1" = 20'-0"

TIDAL PARK PLAN

A-102



1 South
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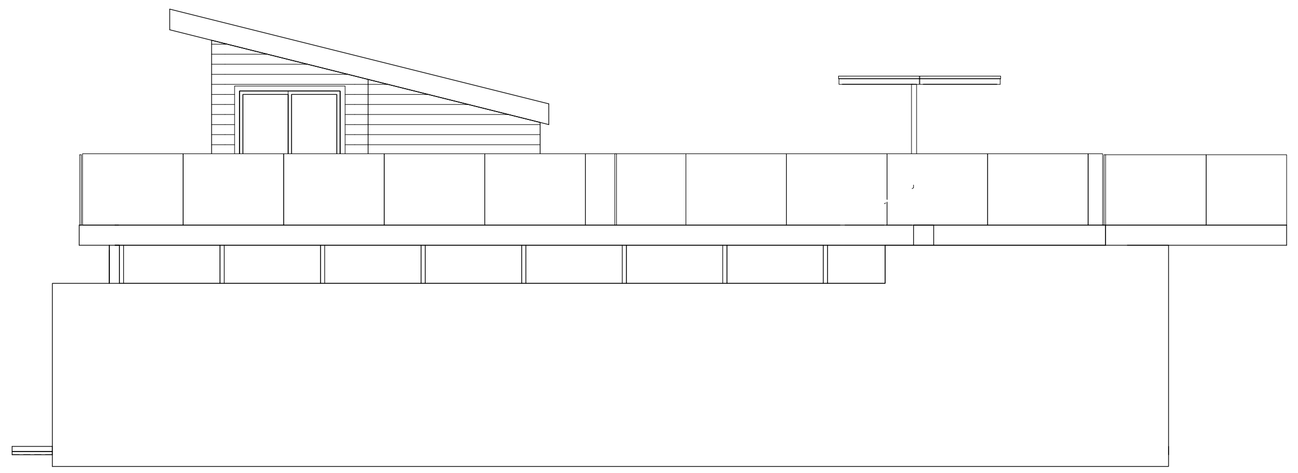

3 East
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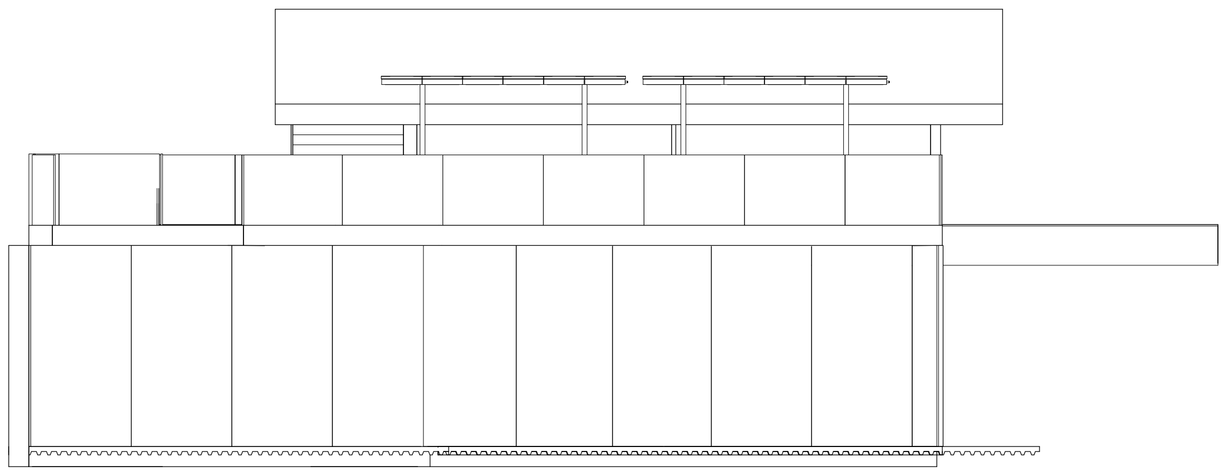

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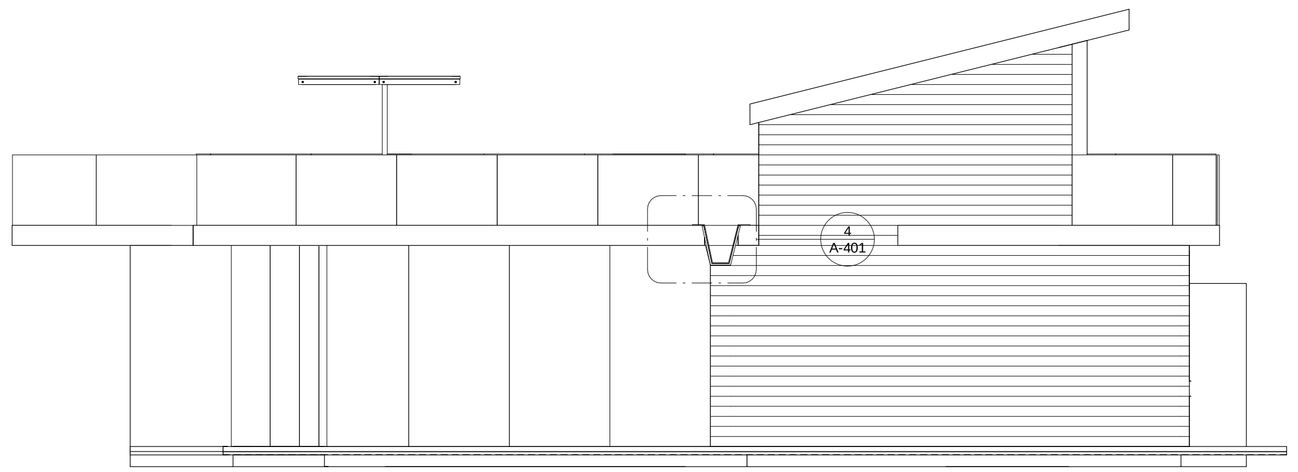
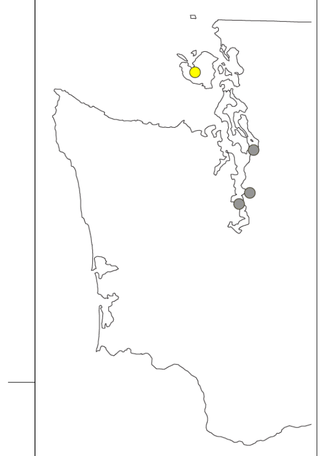


4 West
3/16" = 1'-0"

IDeX
Integrated Design Experience

DESIGNED BY

LOCATION

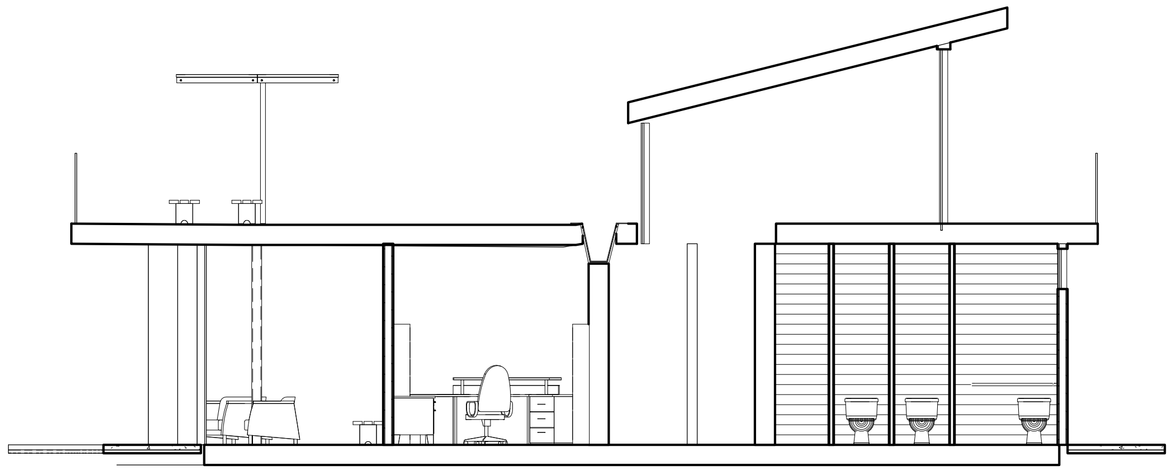


FRIDAY HARBOR

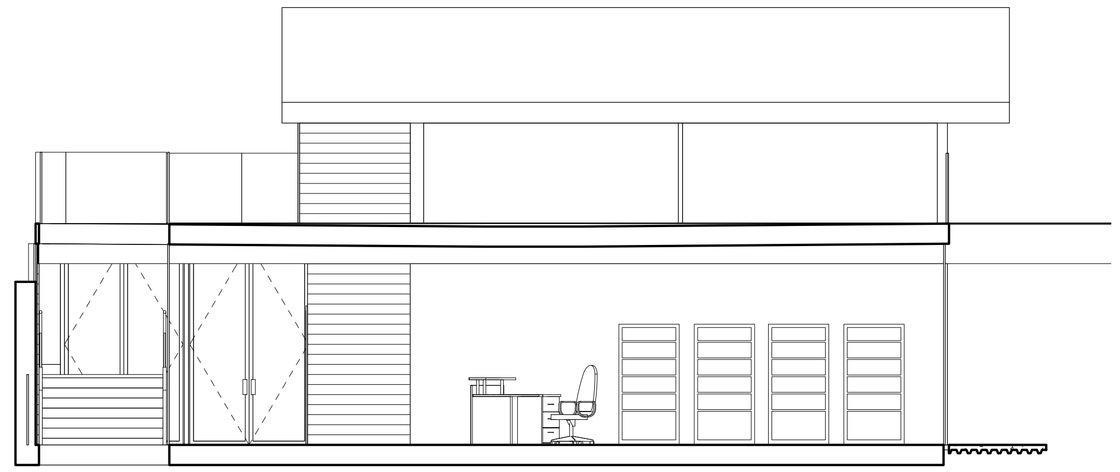
DATE Issue Date- Project Status
SCALE 3/16" = 1'-0"

Ferry Building
Elevations

A-201



2 Section 1
3/16" = 1'-0"



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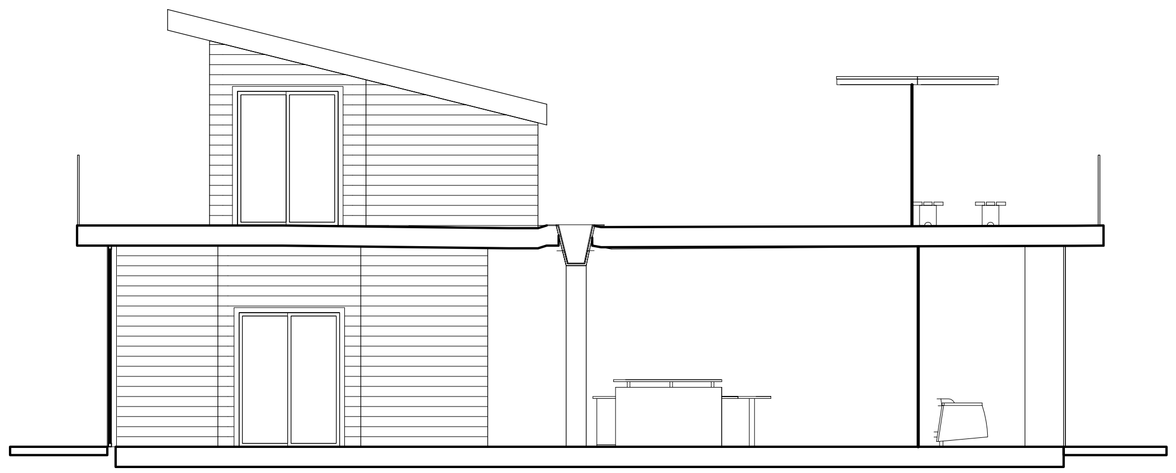
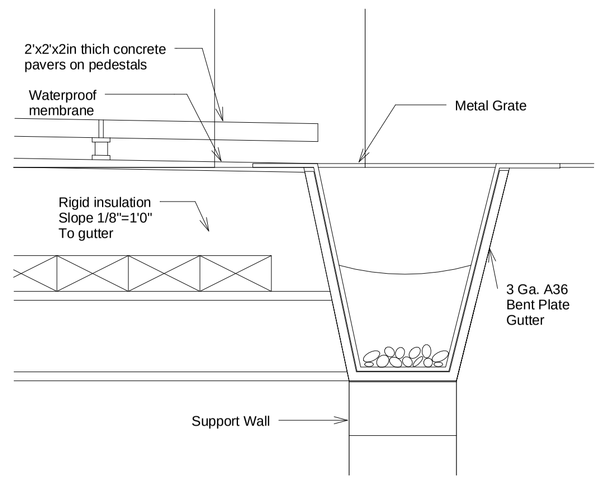


3 Section 2
3/16" = 1'-0"

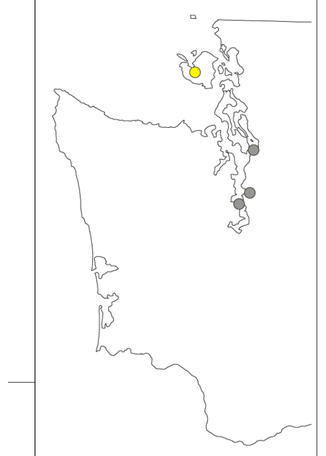


4 Bent Plate Gutter
1" = 1'-0"

IDeX | Integrated Design Experience

DESIGNED BY

LOCATION



FRIDAY HARBOR

DATE Issue Date- Project Status

SCALE As indicated

Ferry Building Sections

A-401

4/26/2012 5:58:28 PM
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APPENDIX: DRAWING SETS

VASHON DRAWINGS

2/13/2011 3:10:02 PM
File Path

A B C D

1 2 3 4 5

a a

b b

Wall - Walkway Land

Vashon Channel

LOCATION



DESIGNED BY

Emmanuel Diaz | Architecture
Kyle Billingsley | Civil Engineering
Tim Ho | Civil Engineering

DATE 4/27/12 - Project Status
SCALE 1/8" = 1'-0"

Plan

A-102

IDeX
Integrated Design Experience

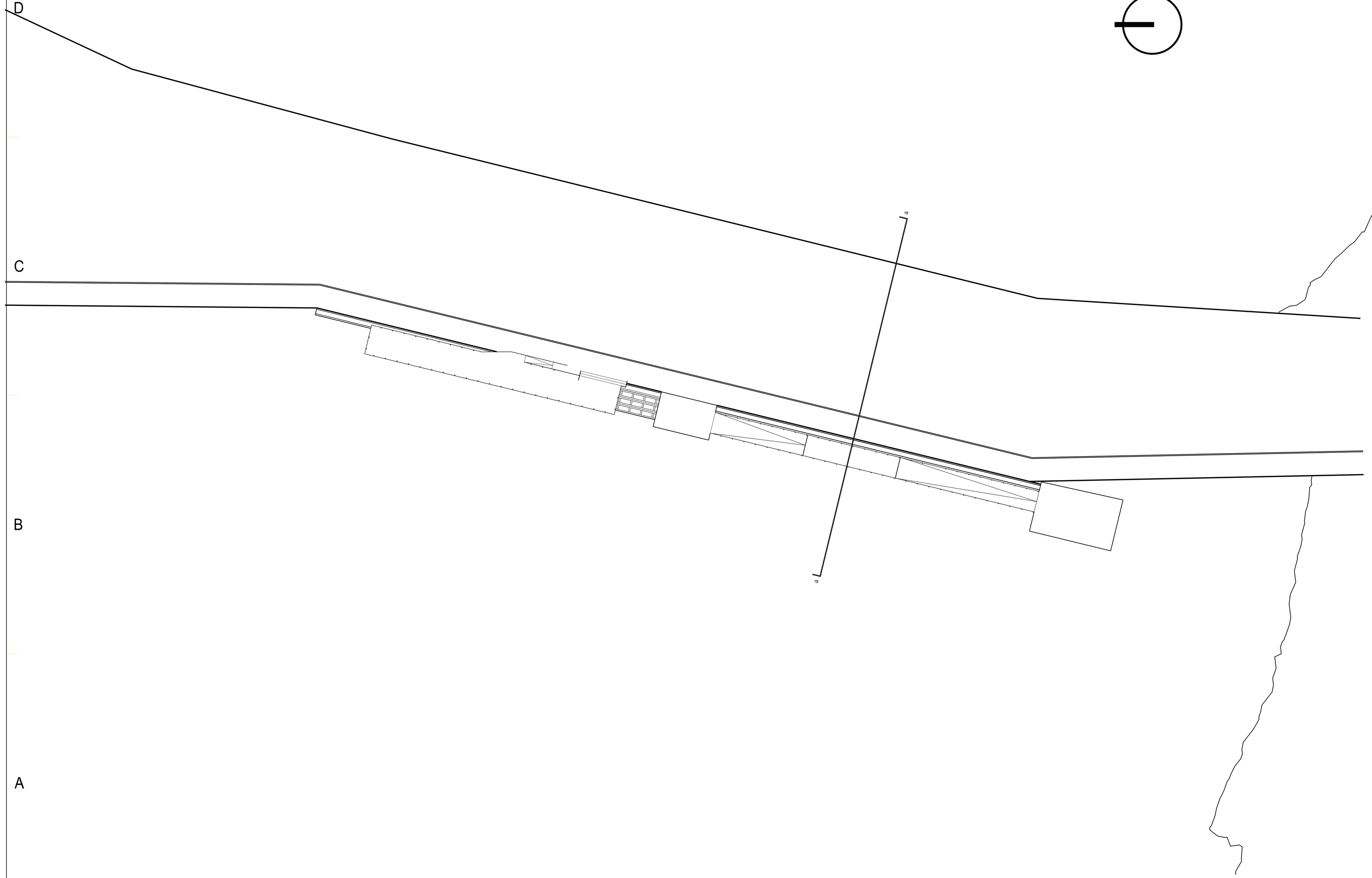
1 2 3 4 5

D

C

B

A



IDeX
Integrated Design Experience

DESIGNED BY

Emmanuel Diaz	Architecture
Kyle Billingsley	Civil Engineering
Tim Ho	Civil Engineering

LOCATION



Wall - Walkway Sea
Vashon Channel

DATE **4/27/12 - Project Status**
SCALE **1/8" = 1'-0"**

Plan

A-303

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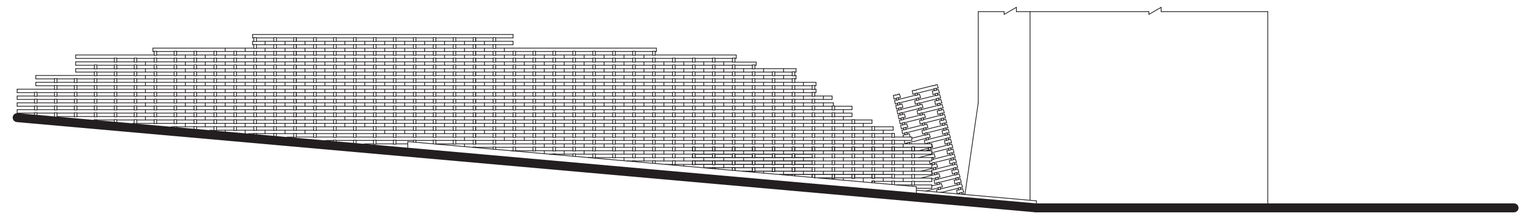
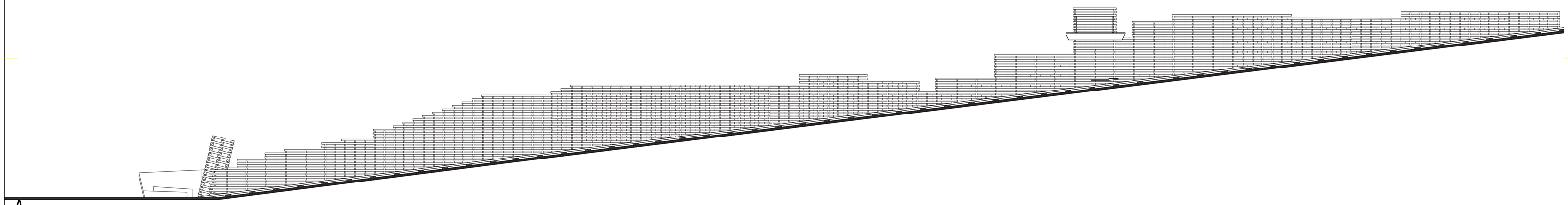
File Path



Northeast Elevation



West Elevation

IDeX
Integrated Design Experience

DESIGNED BY

Emmanuel Diaz	Architecture
Kyle Billingsley	Civil Engineering
Tim Ho	Civil Engineering

LOCATION



Wall - Walkway Land

Vashon Channel

DATE	**4/27/12 - Project Status**
SCALE	**1/16" = 1'-0"**

Elevation

A-202

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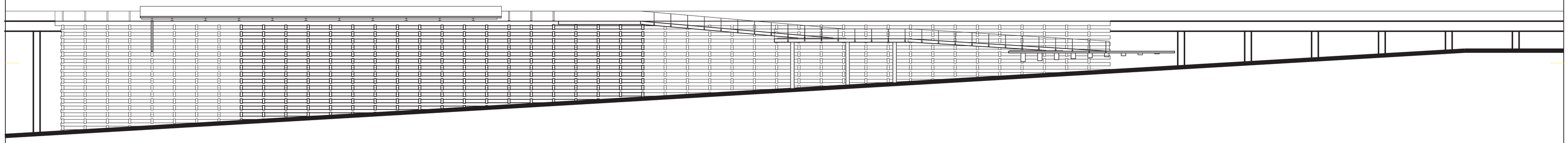
D

C



B

West Elevation

A

IDeX
Integrated Design Experience

DESIGNED BY

Emmanuel Diaz	Architecture
Kyle Billingsley	Civil Engineering
Tim Ho	Civil Engineering

LOCATION



Wall - Walkway Sea
Vashon Channel

DATE 4/27/12 - Project Status
SCALE 1/16" = 1'-0"

Elevation

A-203

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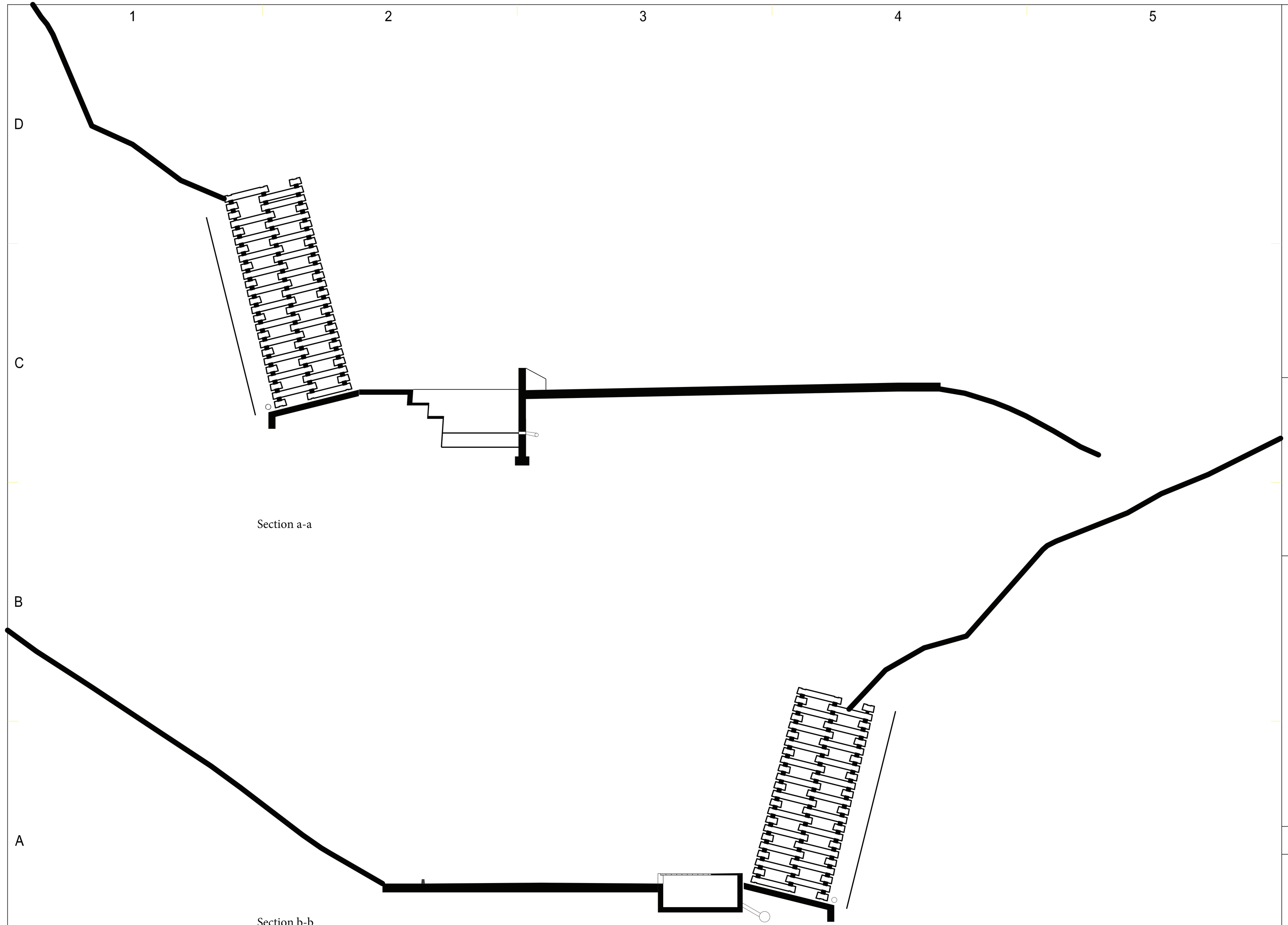
File Path

1 2 3 4 5

D

C



Section a-a

B

A

Section b-b

2/13/2011 3:10:02 PM
Plot Path

IDeX
Integrated Design Experience

DESIGNED BY

Emmanuel Diaz	Architecture
Kyle Billingsley	Civil Engineering
Tim Ho	Civil Engineering

LOCATION



Wall - Walkway Land

Vashon Channel

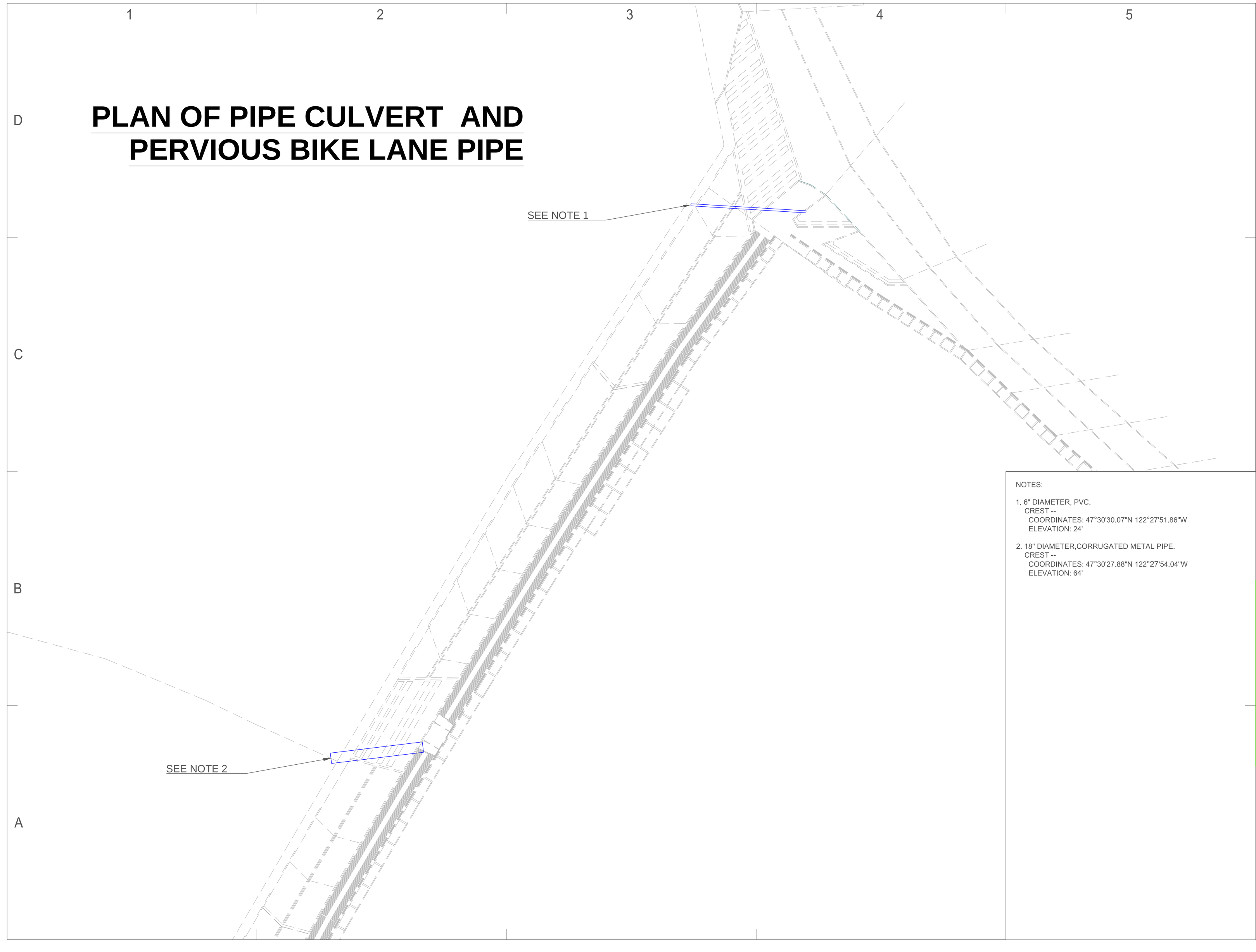
DATE 4/27/12 - Project Status

SCALE 1/8" = 1'-0"

Section

A-302

PLAN OF PIPE CULVERT AND PERVIOUS BIKE LANE PIPE



NOTES:

1. 6" DIAMETER, PVC.
   CREST --
   COORDINATES: 47°30'30.07"N 122°27'51.86"W
   ELEVATION: 24'

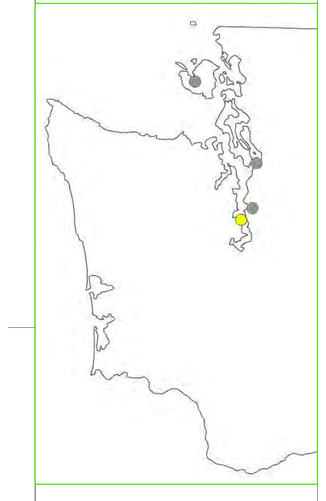
2. 18" DIAMETER,CORRUGATED METAL PIPE.
   CREST --
   COORDINATES: 47°30'27.88"N 122°27'54.04"W
   ELEVATION: 64'

IDeX Integrated Design Experience

DESIGNED BY

KYLE BILLINGSLEY
EMMANUEL DIAZ
TIM HO
ELISE MARKLEY
JULIA MOLLNER
BEN PIERCE
LISA REICH

LOCATION

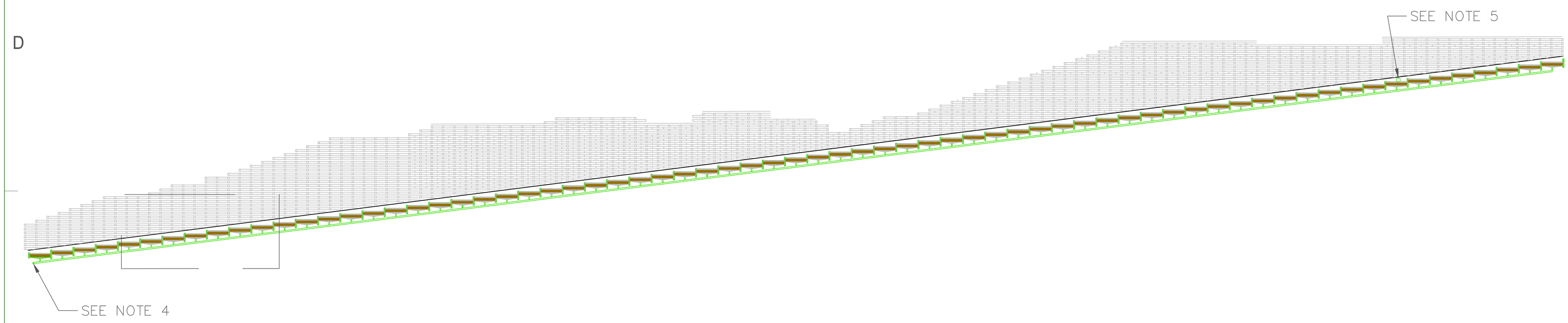


VASHON FERRY TERMINAL

DATE 2/25/11- FINAL DESIGN
SCALE NOT TO SCALE

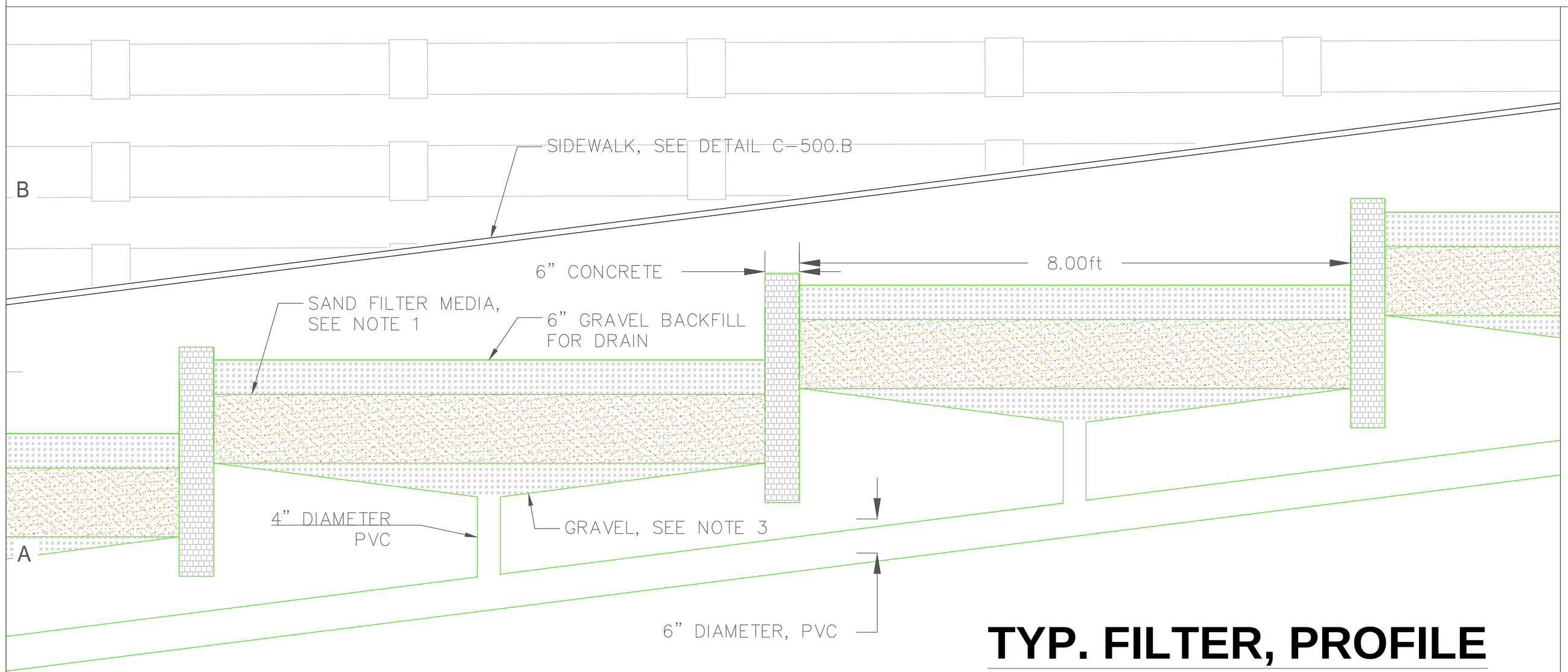
STORMWATER

C.220



PROFILE OF CRIBWALL WITH FILTERS

50 FEET



TYP. FILTER, PROFILE

NOTES:

1. SAND FILTRATION MEDIA, USE A SINGLE 8" LAYER MADE UP OF 10% COARSE SAND, 60% FINE SAND, 30% MULCH (PERCENTAGE BY WEIGHT.

2. GRAVEL AND SAND FILTRATION MEDIA SEPARATED BY PERMEABLE FABRIC.

3. BOTTOM OF FILTERS SLOPED TOWARDS PIPE DRAIN. FILLED WITH GRAVEL BACKFILL FOR DRAIN UNTIL SURFACE IS LEVEL.

4. 6" DIAMETER, PVC.
   CREST --
   COORDINATES: 47°30'30.07"N 122°27'51.86"W
   ELEVATION: 24'

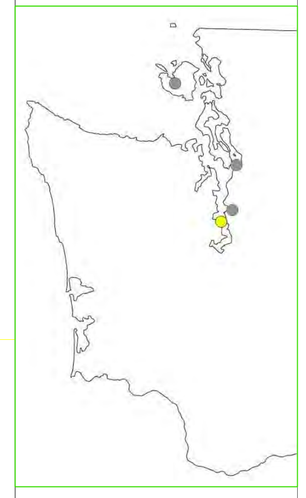
5. 18" DIAMETER,CORRUGATED METAL PIPE.
   CREST --
   COORDINATES: 47°30'27.88"N 122°27'54.04"W
   ELEVATION: 64'

IDeX Integrated Design Experience

DESIGNED BY

KYLE BILLINGSLEY
EMMANUEL DIAZ
TIM HO
ELISE MARKLEY
JULIA MOLLNER
BEN PIERCE
LISA REICH

LOCATION



VASHON FERRY TERMINAL

DATE 2/25/11- FINAL DESIGN
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STORMWATER

C.221

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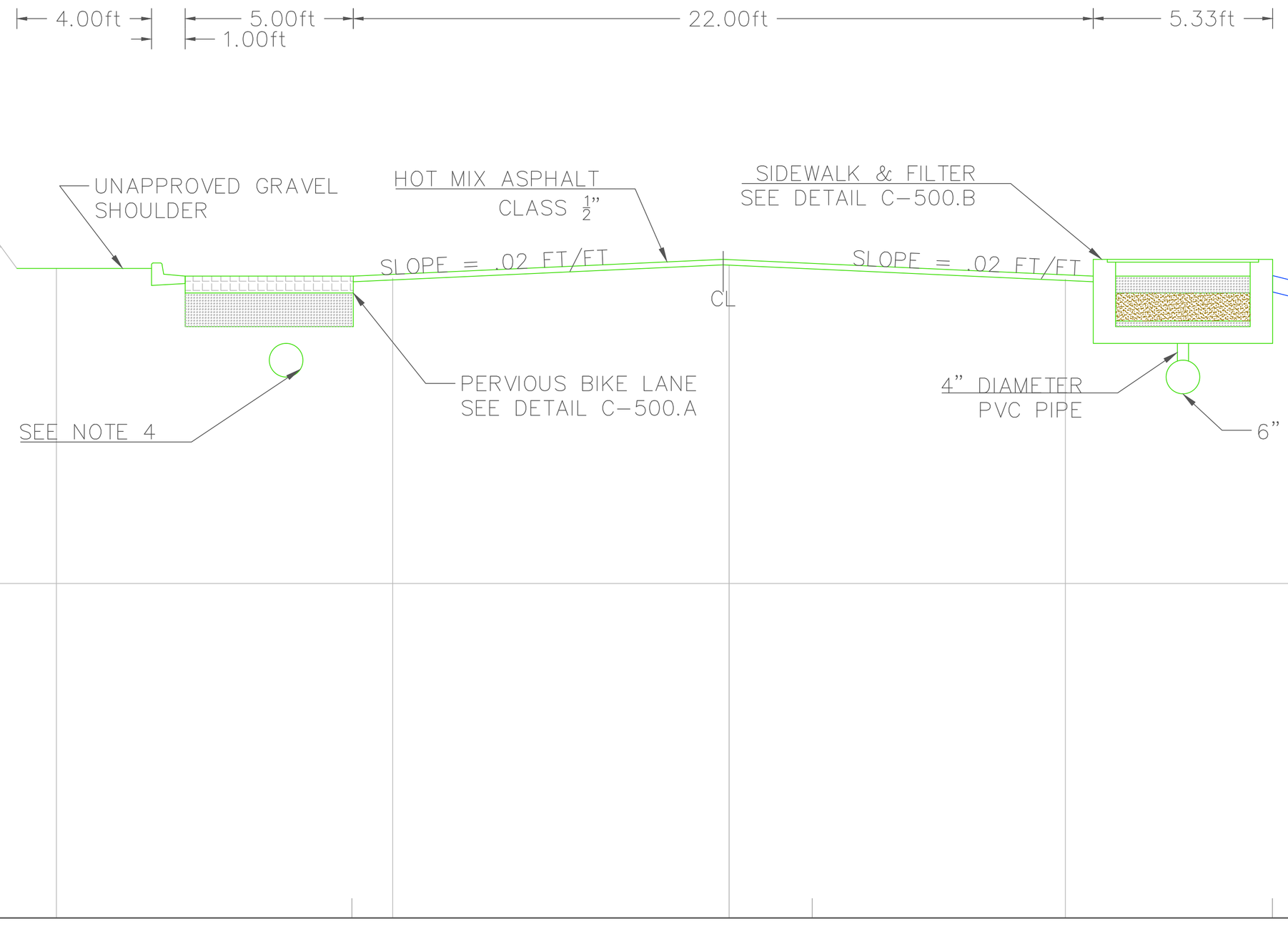
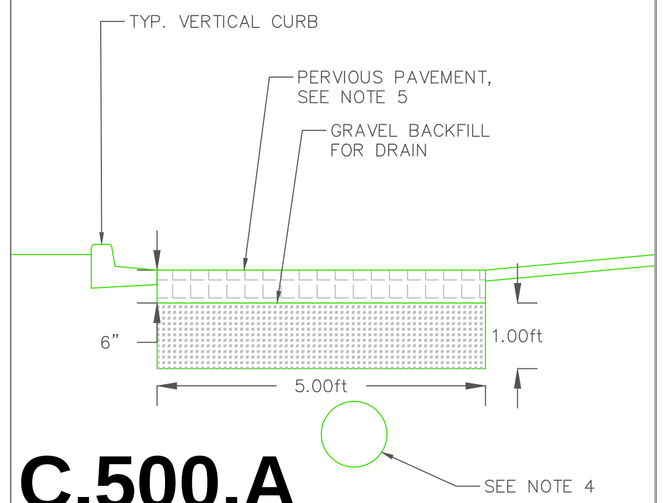
File Path

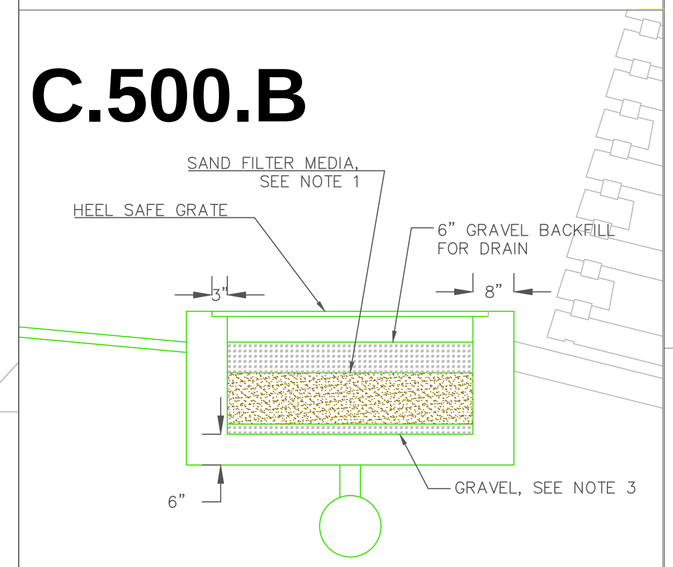
TYP. CROSS-SECTION OF 103RD AVE





C.500.A

C.500.B



NOTES:

1. SAND FILTRATION MEDIA, USE A SINGLE 8" LAYER MADE UP OF 10% COARSE SAND, 60% FINE SAND, 30% MULCH (PERCENTAGE BY WEIGHT.

2. GRAVEL AND SAND FILTRATION MEDIA SEPARATED BY PERMEABLE FABRIC.

3. BOTTOM OF FILTERS SLOPED TOWARDS PIPE DRAIN. FILLED WITH GRAVEL BACKFILL FOR DRAIN UNTIL SURFACE IS LEVEL.

4. 6" PVC PIPE WITH PERFORATED CREST.

5. PERVIOUS PAVEMENT, MUST MEET SPECIFICATIONS AS OUTLINED BY THE KING COUNTY PERVIOUS PAVEMENT DESIGN MANUAL.

6. SIDEWALK AND FILTER FOUNDATION IS MADE OF CONCRETE.

IDeX Integrated Design Experience

DESIGNED BY

KYLE BILLINGSLEY
EMMANUEL DIAZ
TIM HO
ELISE MARKLEY
JULIA MOLLNER
BEN PIERCE
LISA REICH

LOCATION



VASHON FERRY TERMINAL

DATE 2/25/11- FINAL DESIGN
SCALE NOT TO SCALE

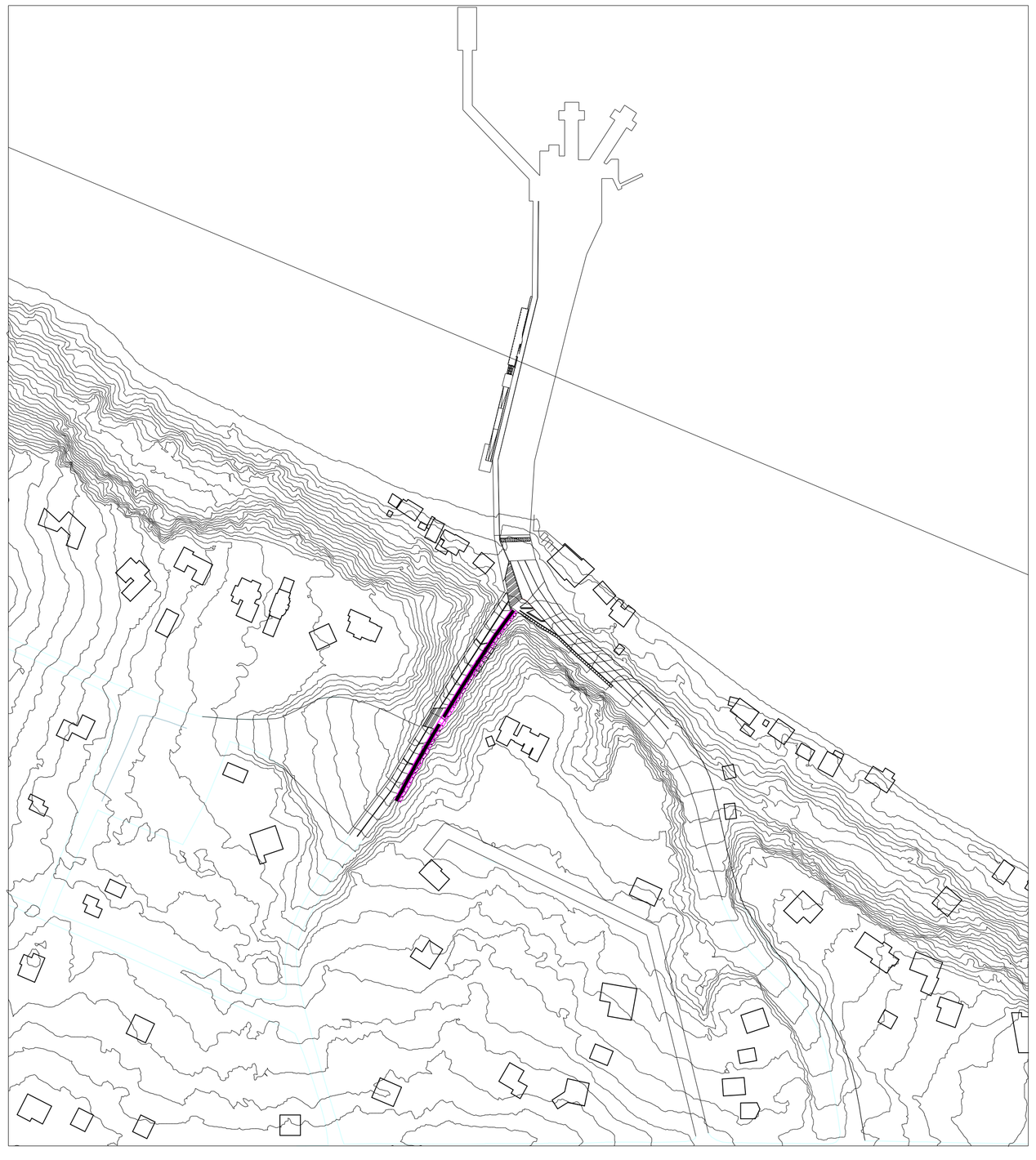
DETAILS
C.500

2/13/2011 3:10:02 PM
File Path

TERMINAL BUILDING

APRIL 27, 2012

10800 NORTH VASHON HIGHWAY
VASHON, WA 98070



DRAWING INDEX

GENERAL

COVER SHEET

ARCHITECTURAL

A104 GROUND FLOOR PLAN
A104.1 ROOF PLAN
A204 ELEVATIONS
A304 SECTIONS
A501 DETAILS

STRUCTURAL

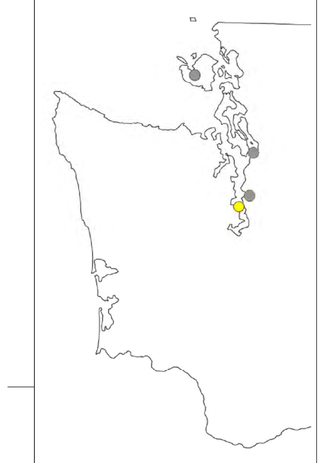
S104 FRAMING PLAN
S304.1 RAMP SECTION
S304.2 LATERAL BRACING

IDeX Integrated Design Experience

DESIGNED BY

Kyle Billingsley
Emmanuel Diaz
Tim Ho
Elise Markley
Julia Mollner
Ben Pierce
Lisa Reich
-

LOCATION



Terminal Building
IDeX Team Name

DATE 4/27/12- Project Status
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Sheet Name
G-01.1

2/13/2011 3:10:02 PM
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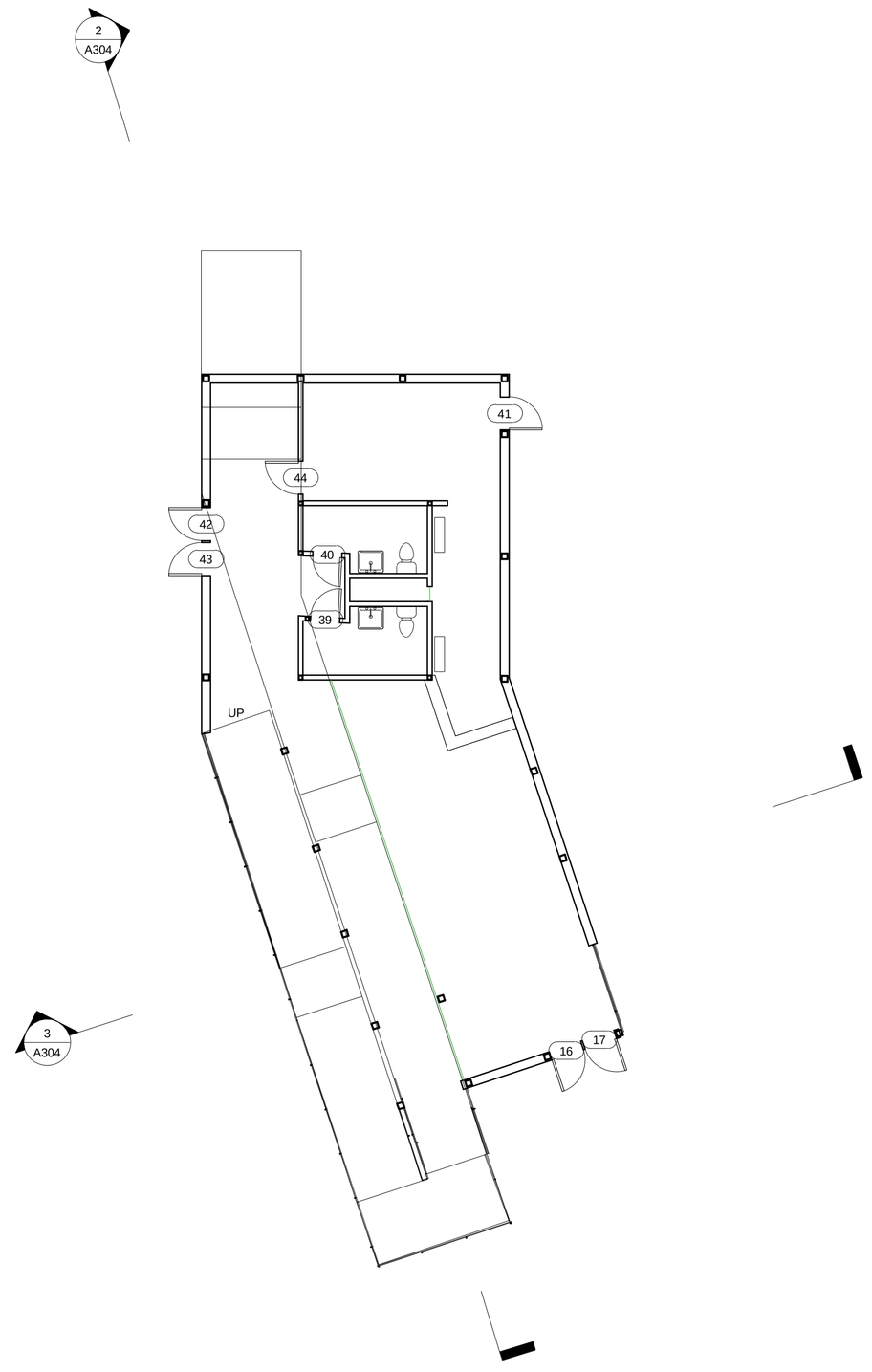
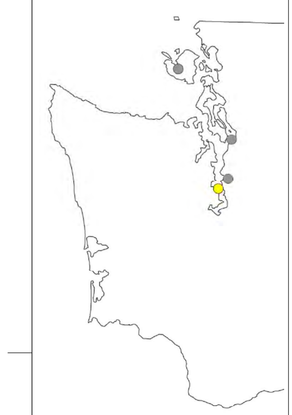


IDeX
Integrated Design Experience

DESIGNED BY

Julia Mollner I Architecture
Lisa Reich I Structural Engineering

LOCATION



Terminal Building

DATE Issue Date- Project Status

SCALE 1/8" = 1'-0"

Ground Floor Plan

A104

4/25/2012 3:36:48 AM
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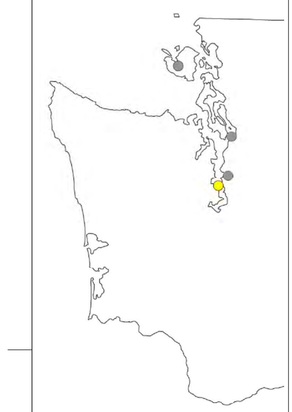
IDeX
Integrated Design Experience

DESIGNED BY

Julia Mollner I Architecture
Lisa Reich I Structural Engineering

LOCATION



Terminal Building

DATE Issue Date- Project Status

SCALE 1/8" = 1'-0"

Roof Plan

A104.1

4/25/2012 3:36:49 AM
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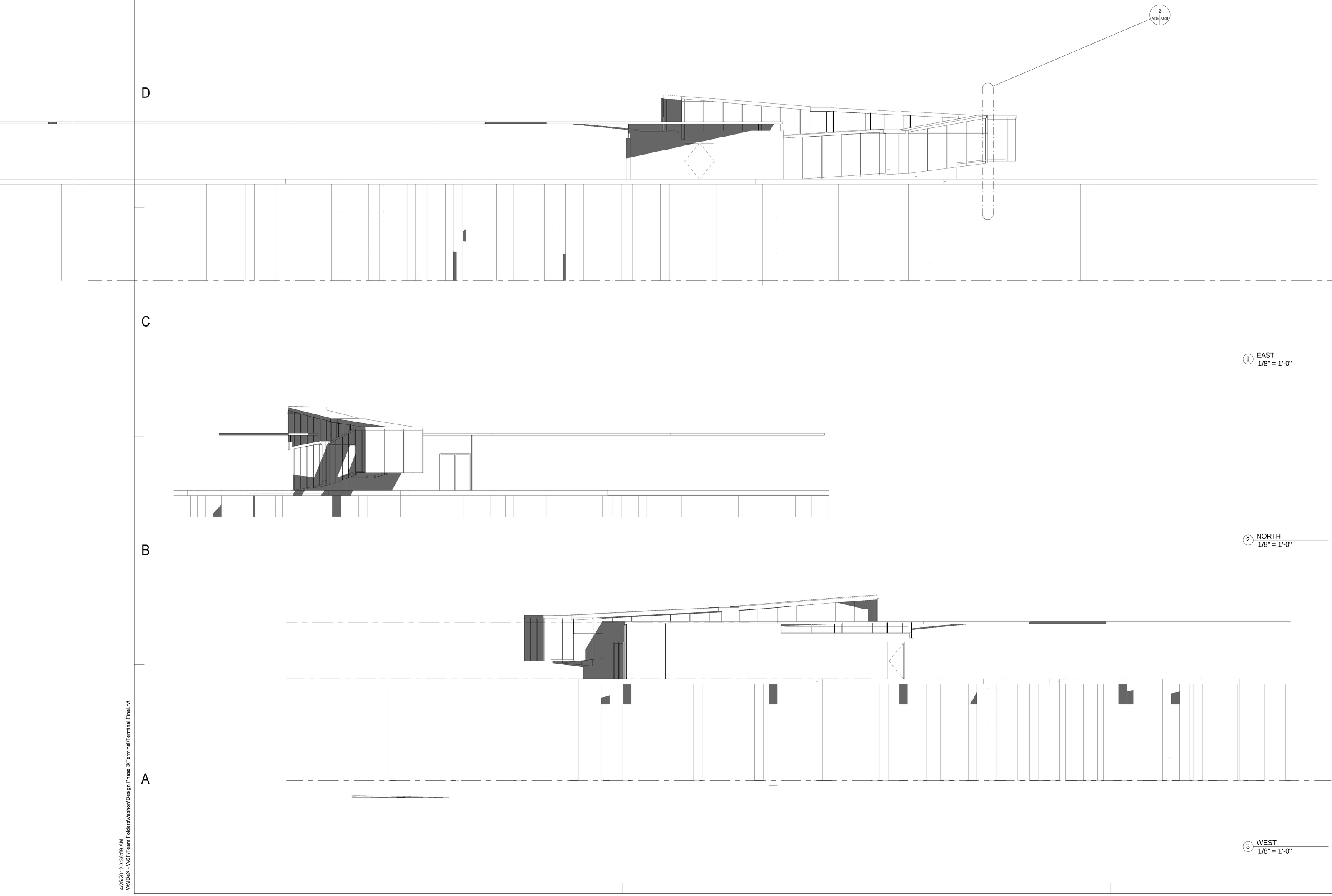


1 EAST
1/8" = 1'-0"

2 NORTH
1/8" = 1'-0"

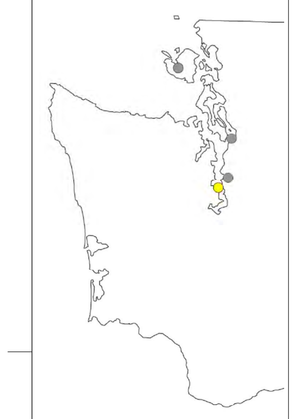
3 WEST
1/8" = 1'-0"

IDeX
Integrated Design Experience

DESIGNED BY

Julia Mollner I Architecture
Lisa Reich I Structural Engineering

LOCATION



Terminal Building

DATE Issue Date- Project Status
SCALE 1/8" = 1'-0"

Elevations

A204

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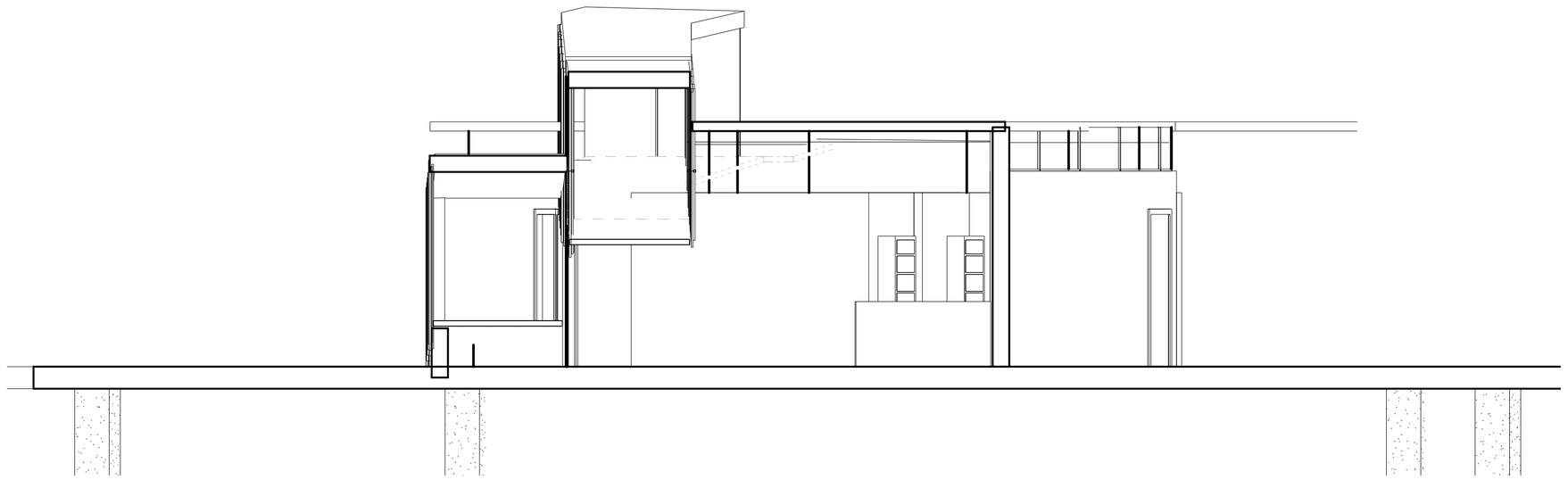
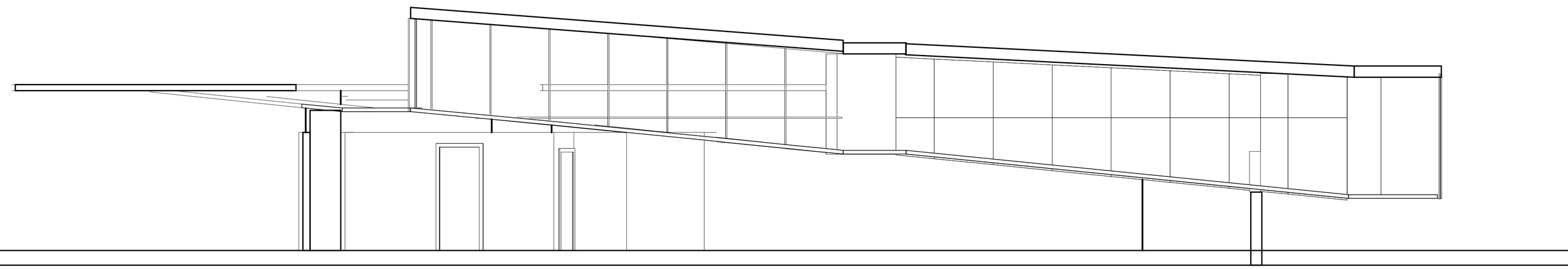
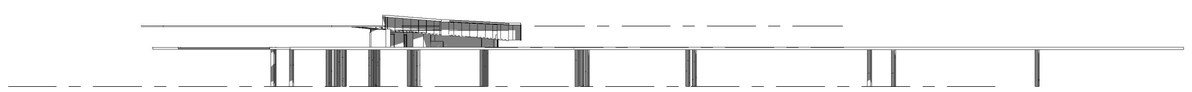


3 Section 5
1/4" = 1'-0"



2 Section 4
1/4" = 1'-0"



1 Section 2
1" = 50'-0"



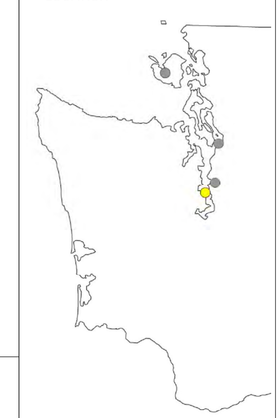
4/25/2012 3:37:12 AM
V:\IDeX - WSF\Team Folders\Vashon\Design Phase 3\Terminal\Terminal Final.rvt

IDeX
Integrated Design Experience

DESIGNED BY

Julia Mollner I Architecture
Lisa Reich I Structural Engineering

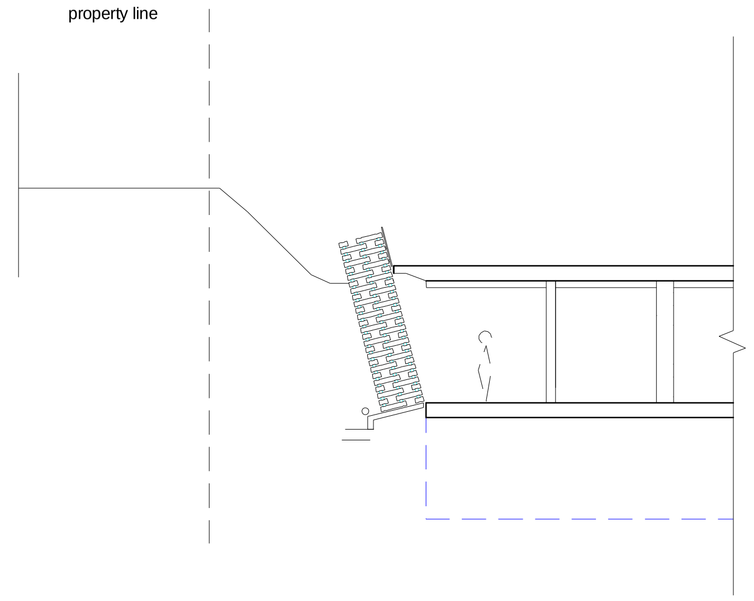
LOCATION

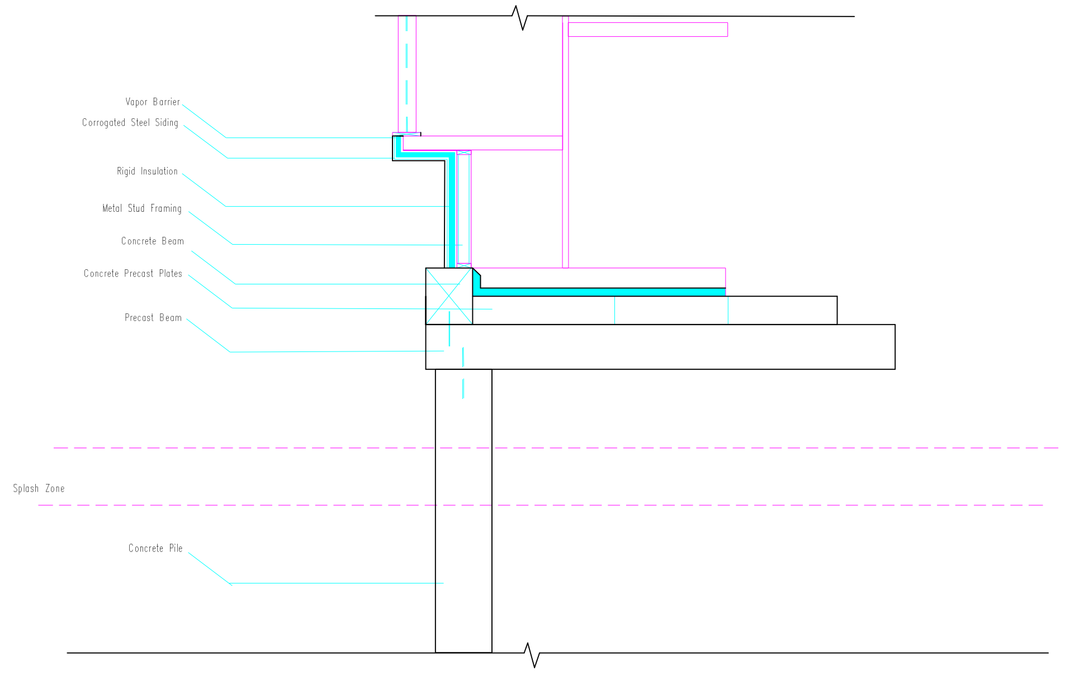


Terminal Building

DATE Issue Date- Project Status
SCALE As indicated

Sections
A304





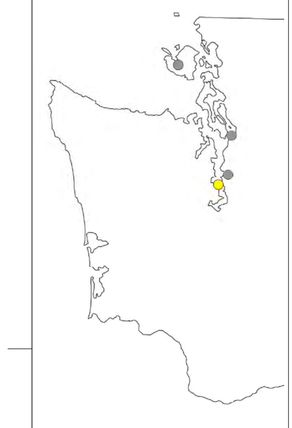
2 Callout of West
1/2" = 1'-0"

IDeX
Integrated Design Experience

DESIGNED BY

Julia Mollner I Architecture
Lisa Reich I Structural Engineering

LOCATION



Terminal Building

DATE Issue Date- Project Status
SCALE 1/2" = 1'-0"

Details
A501

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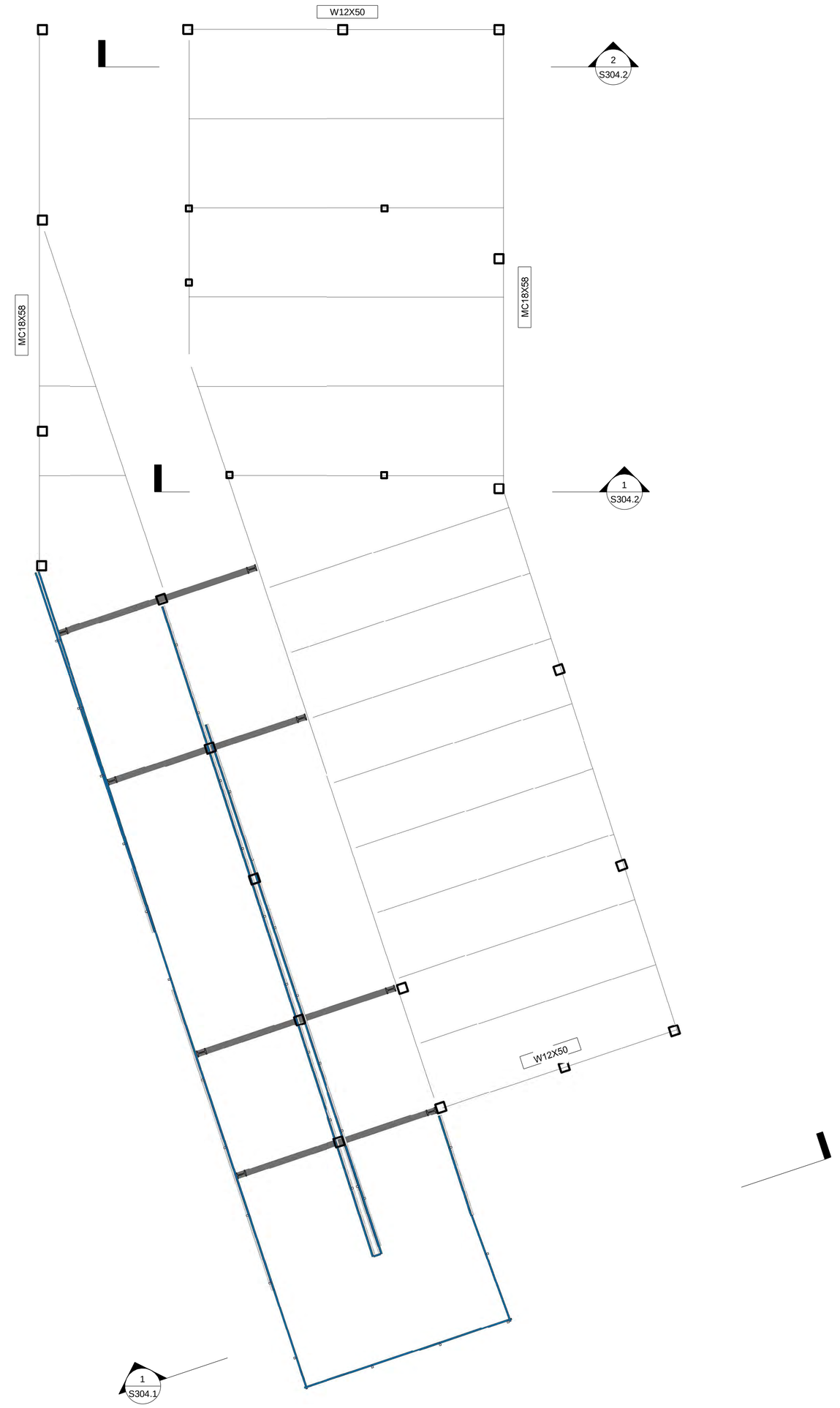

1 2 3 4 5

D C B A

IDeX Integrated Design Experience

DESIGNED BY

Lisa Reich I Structural Engineering

LOCATION



Terminal Building

DATE Issue Date- Project Status

SCALE 1/4" = 1'-0"

Framing Plan

S104

4/25/2012 3:32:40 AM
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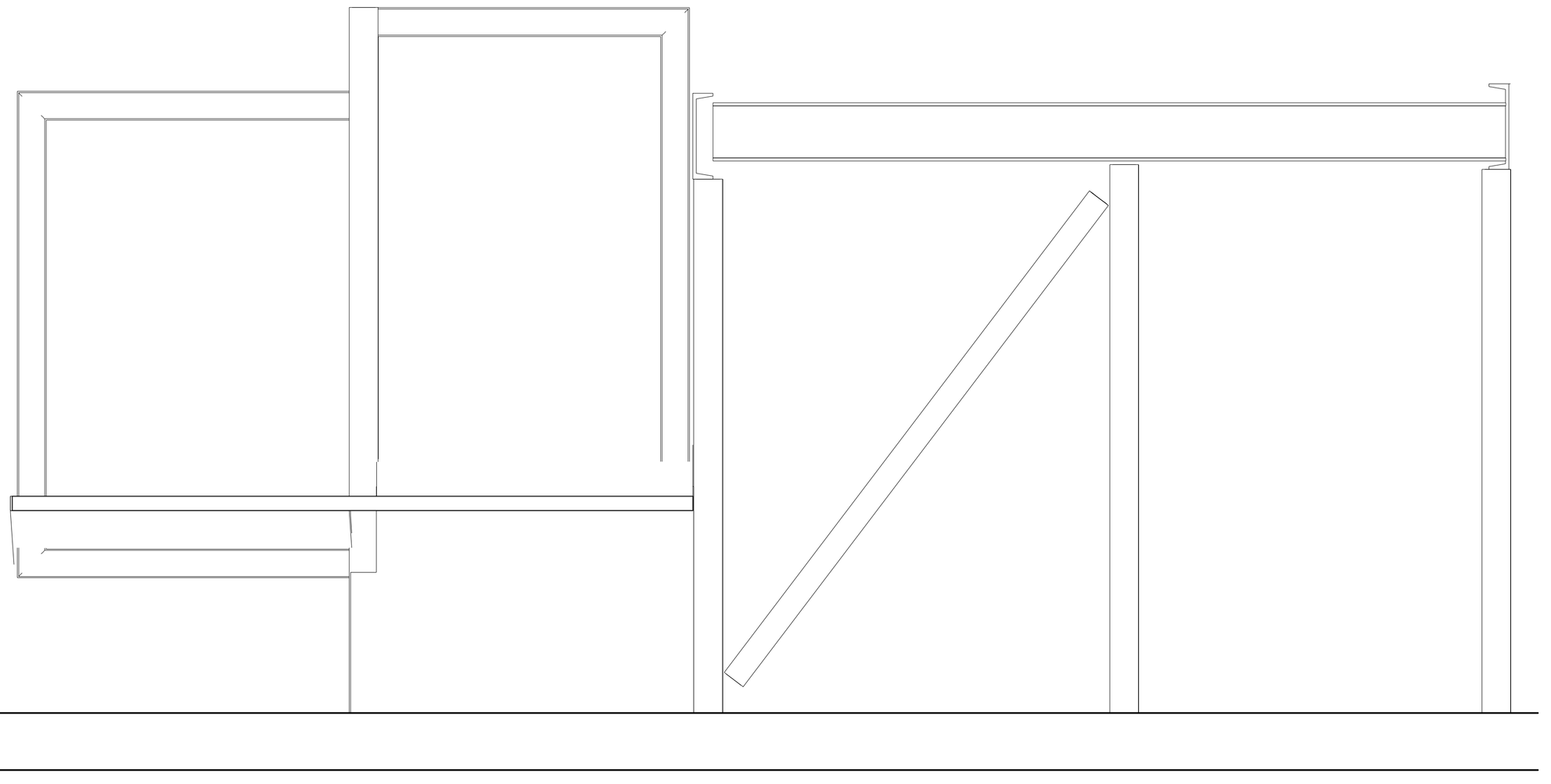
1 2 3 4 5

D

C

B

A



1 End of Ramp
3/4" = 1'-0"

IDeX Integrated Design Experience

DESIGNED BY

Lisa Reich I Structural Engineering

LOCATION



Terminal Building

DATE Issue Date- Project Status

SCALE 3/4" = 1'-0"

Ramp Section

S304.1

4/25/2012 3:32:43 AM
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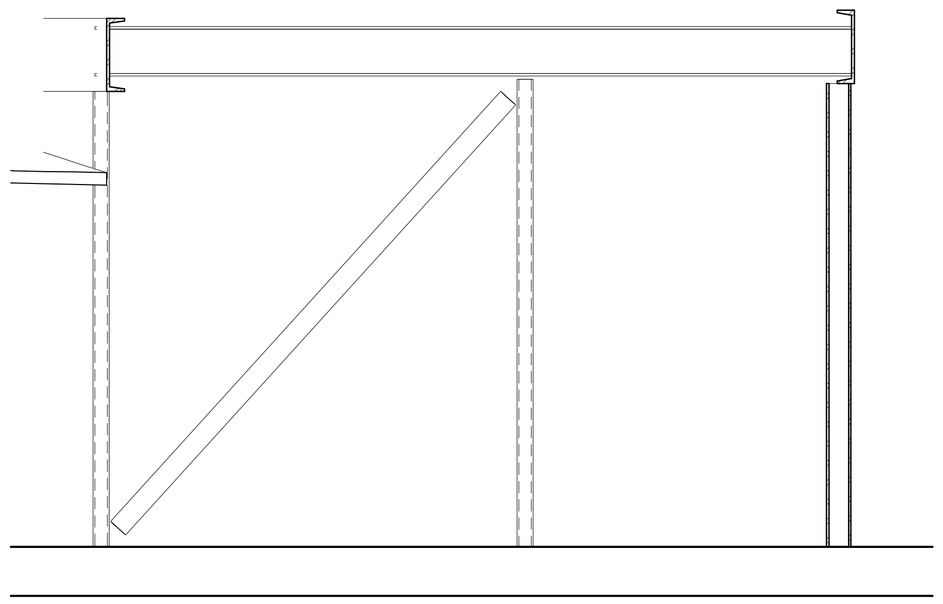
1 2 3 4 5

D

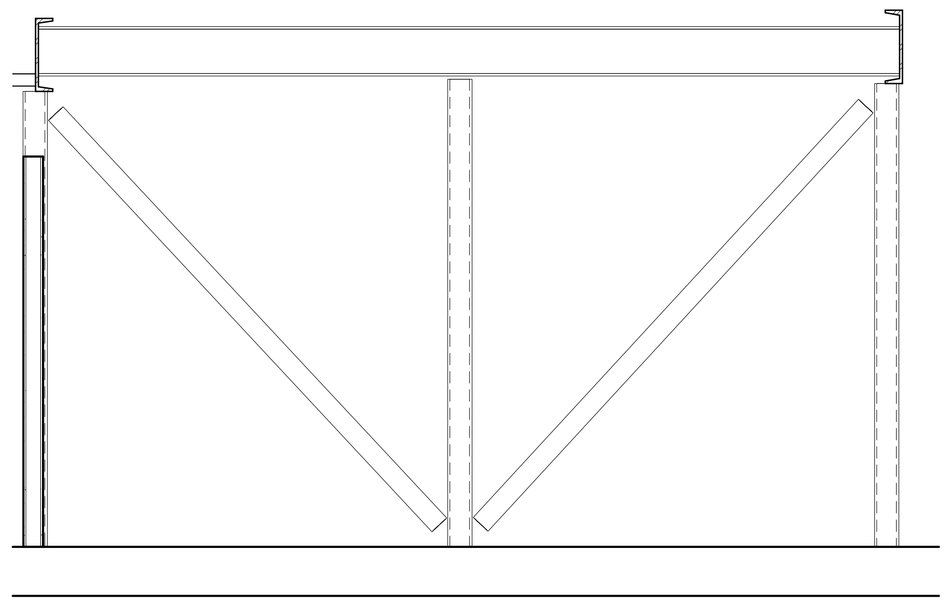
C

B

A



1 Single Brace Section
1/2" = 1'-0"



2 Double Brace Section
1/2" = 1'-0"

IDeX
Integrated Design Experience

DESIGNED BY

Lisa Reich I Structural Engineering

LOCATION



Terminal Building

DATE Issue Date- Project Status

SCALE 1/2" = 1'-0"

Lateral Bracing

S304.2

4/25/2012 3:32:44 AM
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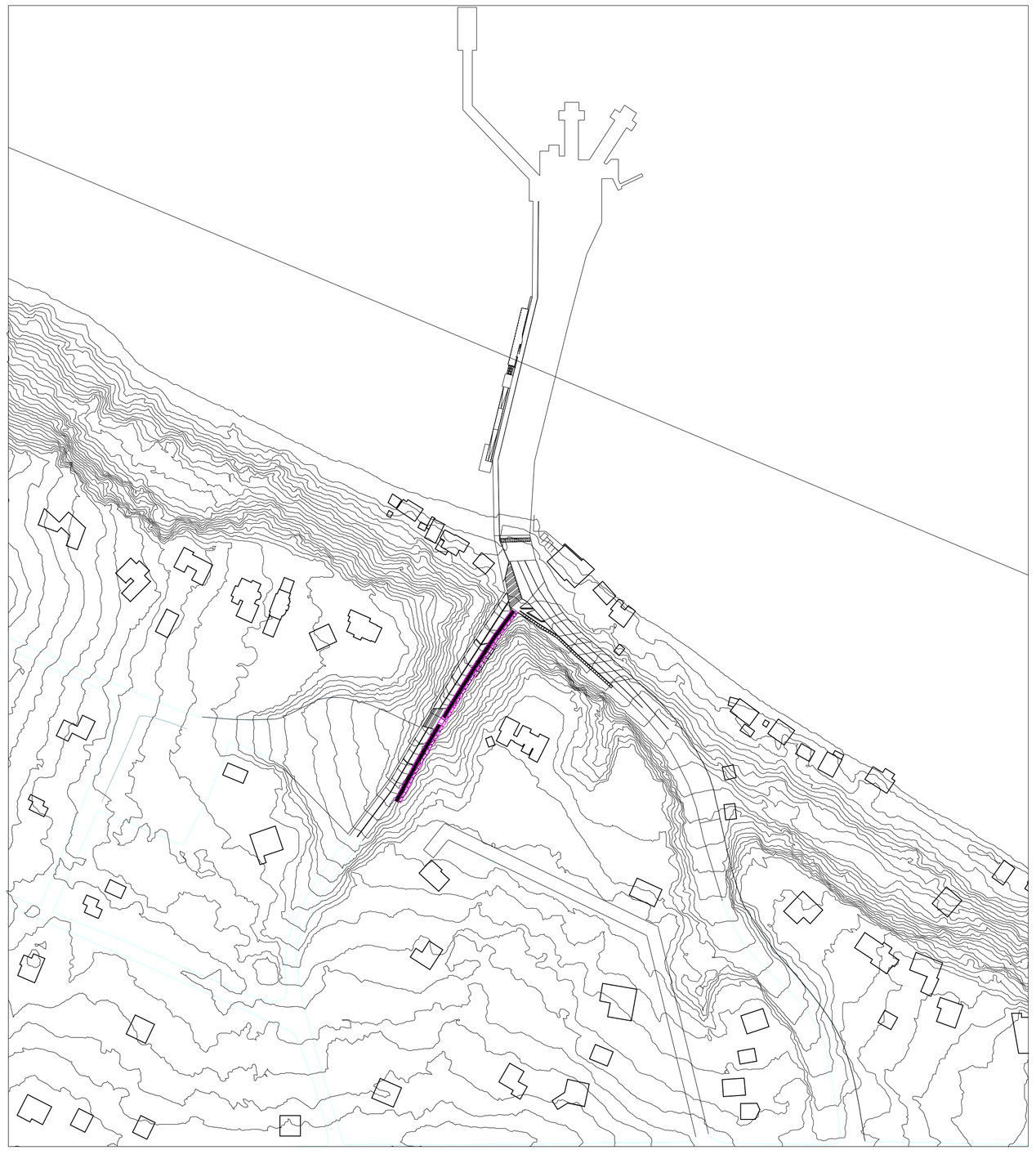
PARKING GARAGE

APRIL 27, 2012

10800 NORTH VASHON HIGHWAY
VASHON, WA 98070



DRAWING INDEX

GENERAL

COVER SHEET

ARCHITECTURAL

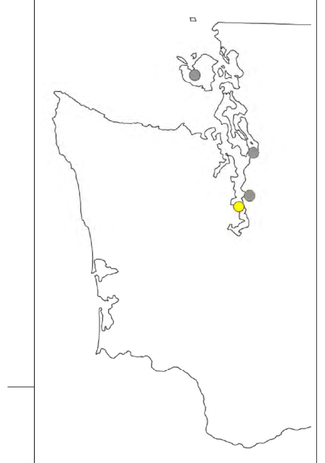
A101	SUBLEVEL PLAN
A101.1	MAIN LEVEL
A101.2	UPPER LEVEL
A201	ELEVATIONS
A301	SECTIONS

IDeX Integrated Design Experience

DESIGNED BY

Kyle Billingsley
Emmanuel Diaz
Tim Ho
Elise Markley
Julia Mollner
Ben Pierce
Lisa Reich
-

LOCATION



Parking Garage

IDeX Team Name

DATE 4/27/12- Project Status

SCALE 1/8" = 1'-0"

Sheet Name

G-01.1

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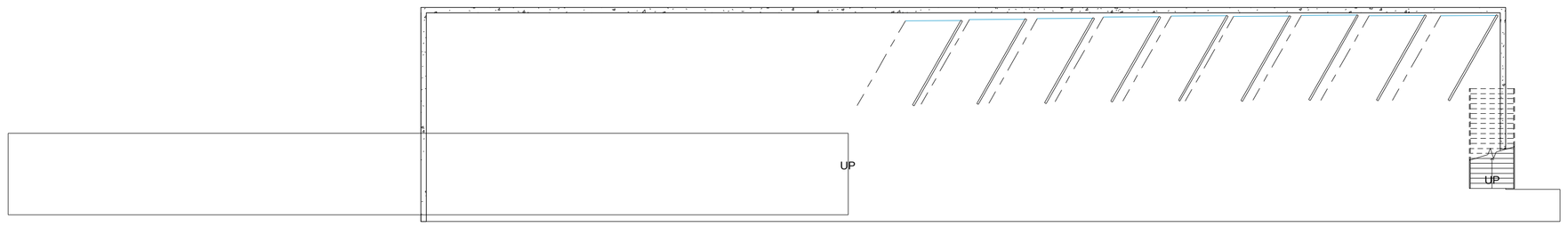
ile Path

1 2 3 4 5

D

C



B

A

4/25/2012 3:30:13 AM
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IDeX
Integrated Design Experience

DESIGNED BY

Julia Mollner I Architecture
Lisa Reich I Structural Engineering

LOCATION



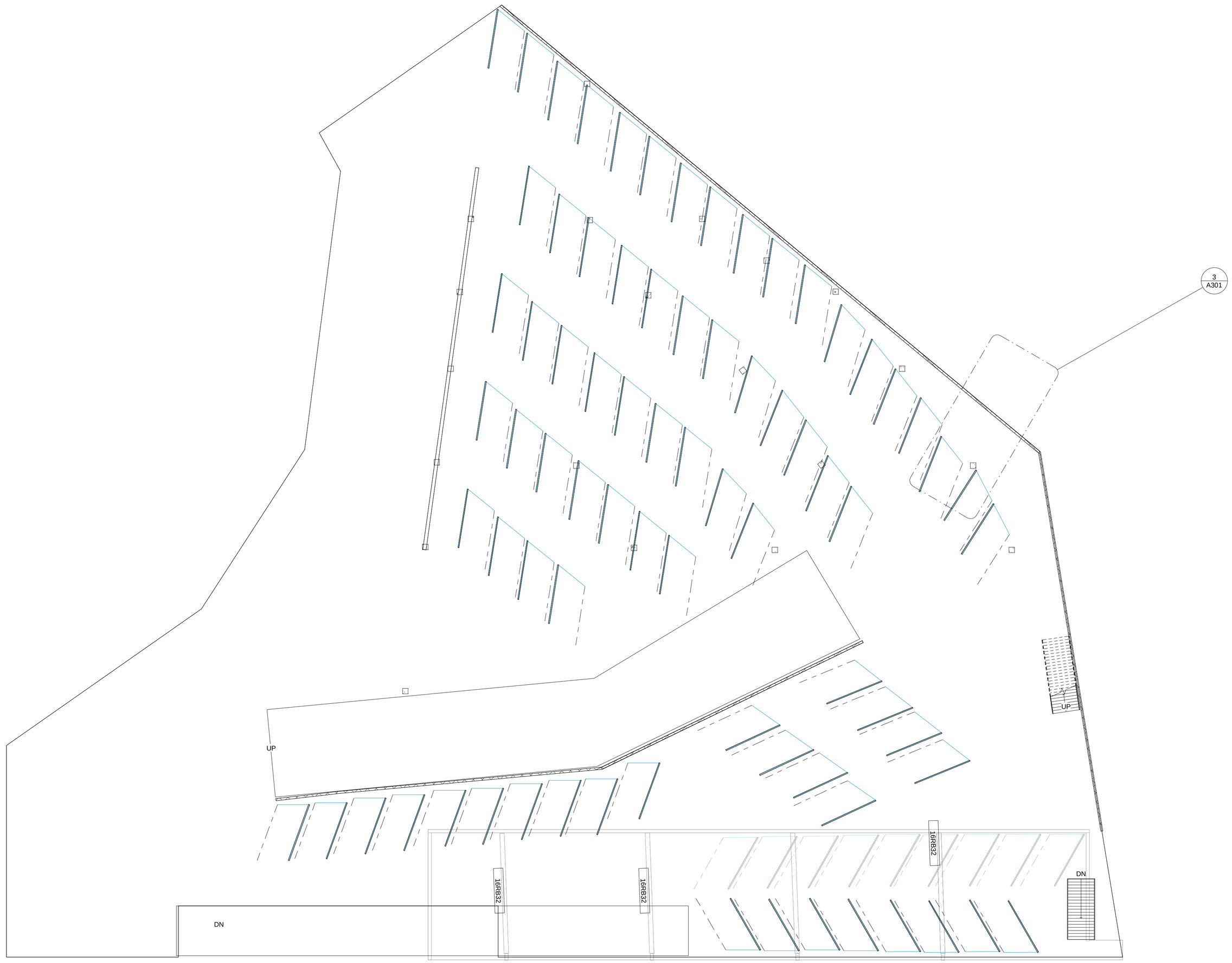
Parking Structure

DATE Issue Date- Project Status

SCALE 1/16" = 1'-0"

Sublevel Plan

A101

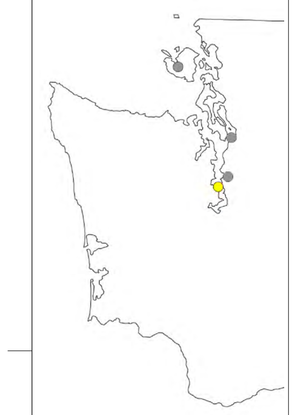


IDeX
Integrated Design Experience

DESIGNED BY

Julia Mollner I Architecture
Lisa Reich I Structural Engineering

LOCATION



Parking Structure

DATE Issue Date- Project Status
SCALE 1/16" = 1'-0"

Main Level

A101.1

4/25/2012 3:30:13 AM
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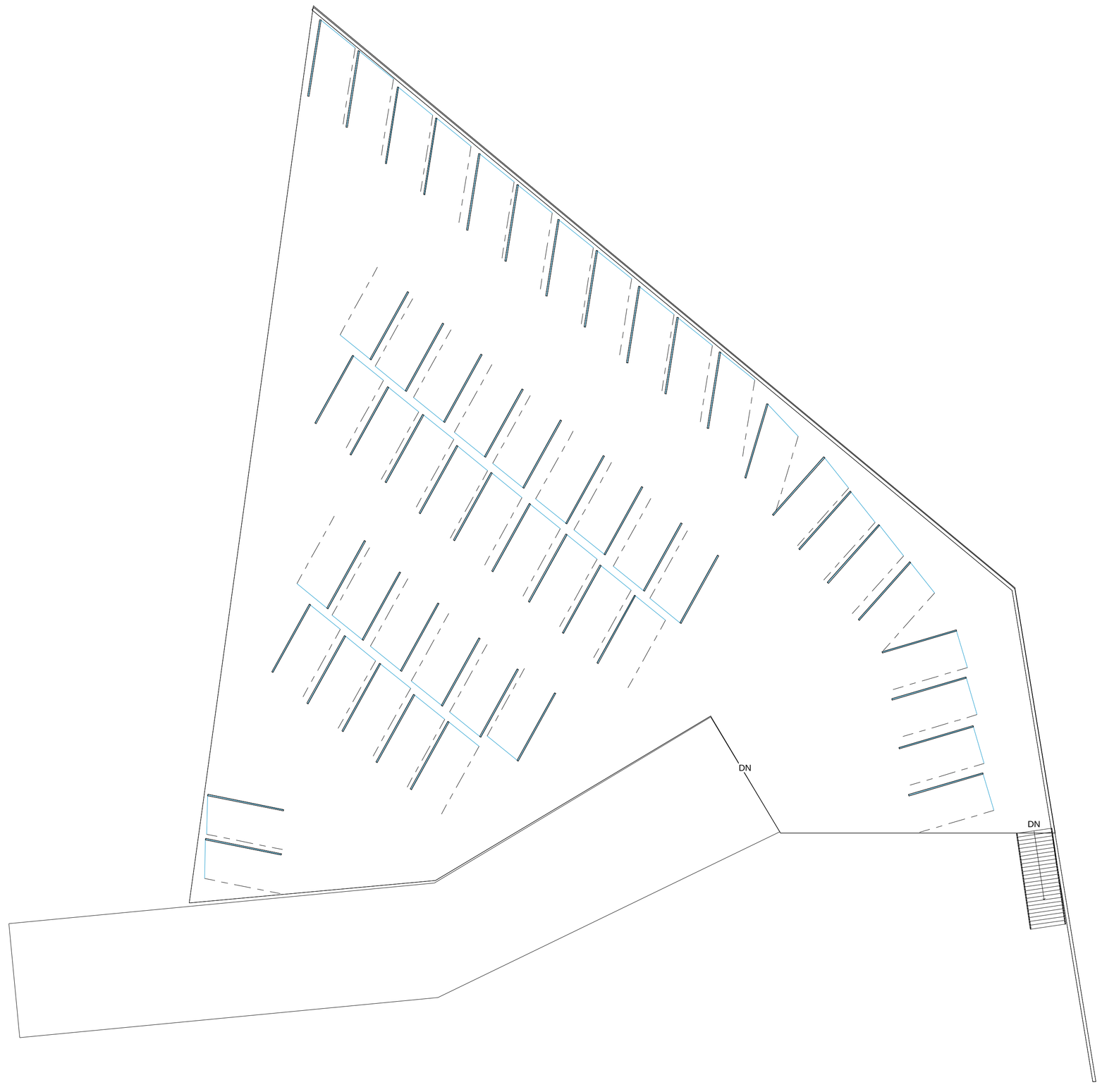
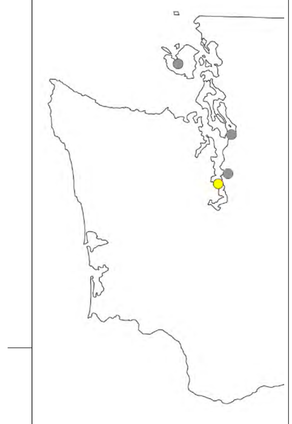


IDeX Integrated Design Experience

DESIGNED BY

Julia Mollner I Architecture
Lisa Reich I Structural Engineering

LOCATION



Parking Structure

DATE	Issue Date- Project Status
SCALE	1/16" = 1'-0"

Upper Level

A101.2

4/25/2012 3:30:14 AM
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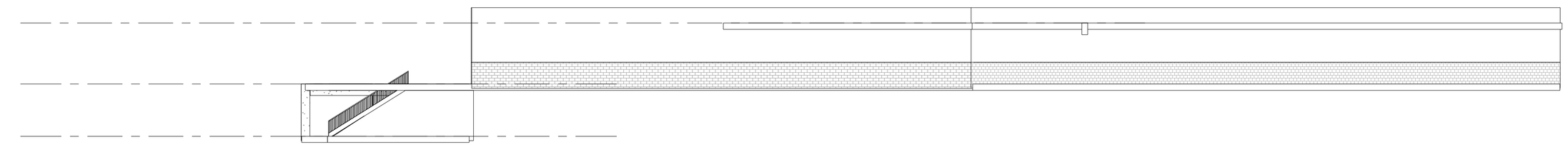

1 East
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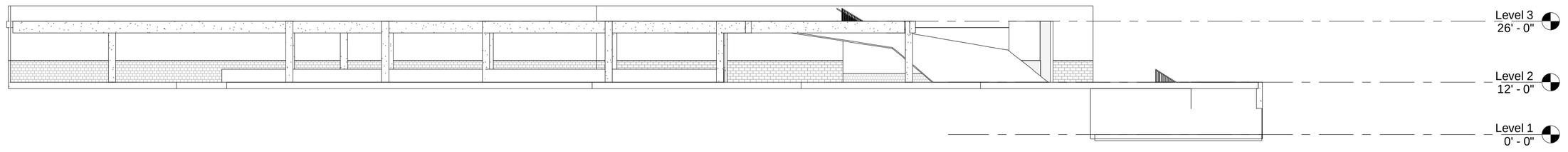

3 West
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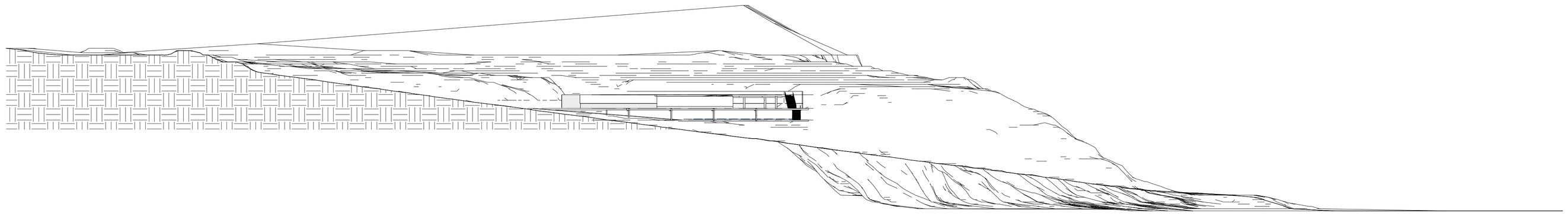

2 South
1" = 60'-0"

4/25/2012 3:30:17 AM
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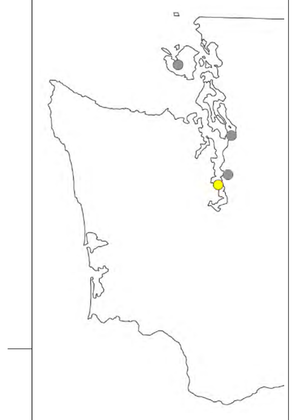
Integrated Design Experience

DESIGNED BY

Julia Mollner I Architecture
Lisa Reich I Structural Engineering

LOCATION



Parking Structure

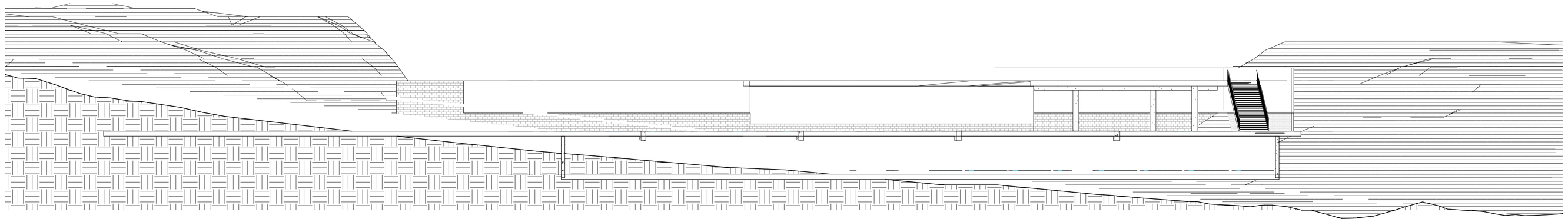
DATE Issue Date- Project Status
SCALE As indicated

Elevations

A201

1 2 3 4 5

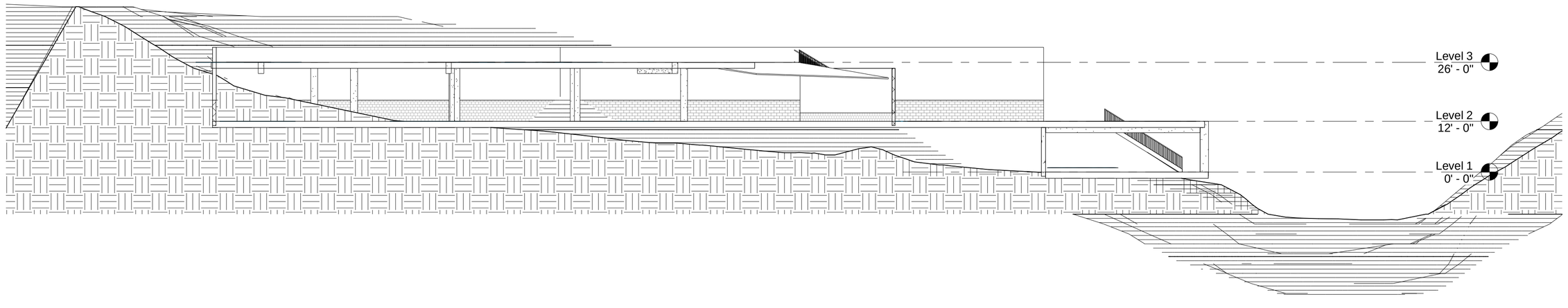
D



1 Section 1
1/16" = 1'-0"

C

B



A

2 Section 3
1/16" = 1'-0"

4/25/2012 3:30:25 AM
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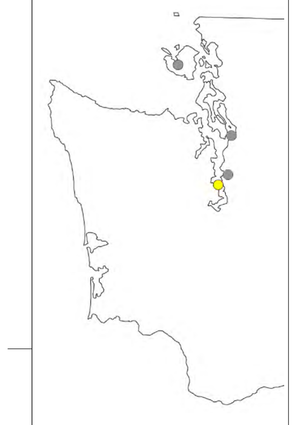
IDeX Integrated Design Experience

DESIGNED BY

Julia Mollner I Architecture
Lisa Reich I Structural Engineering

LOCATION



Parking Structure

DATE Issue Date- Project Status
SCALE As indicated

Sections

A301

APPENDIX: DRAWING SETS

VESSEL RESTRAINT DRAWINGS

The Boat Buttress

Drawing Index:

Civil:

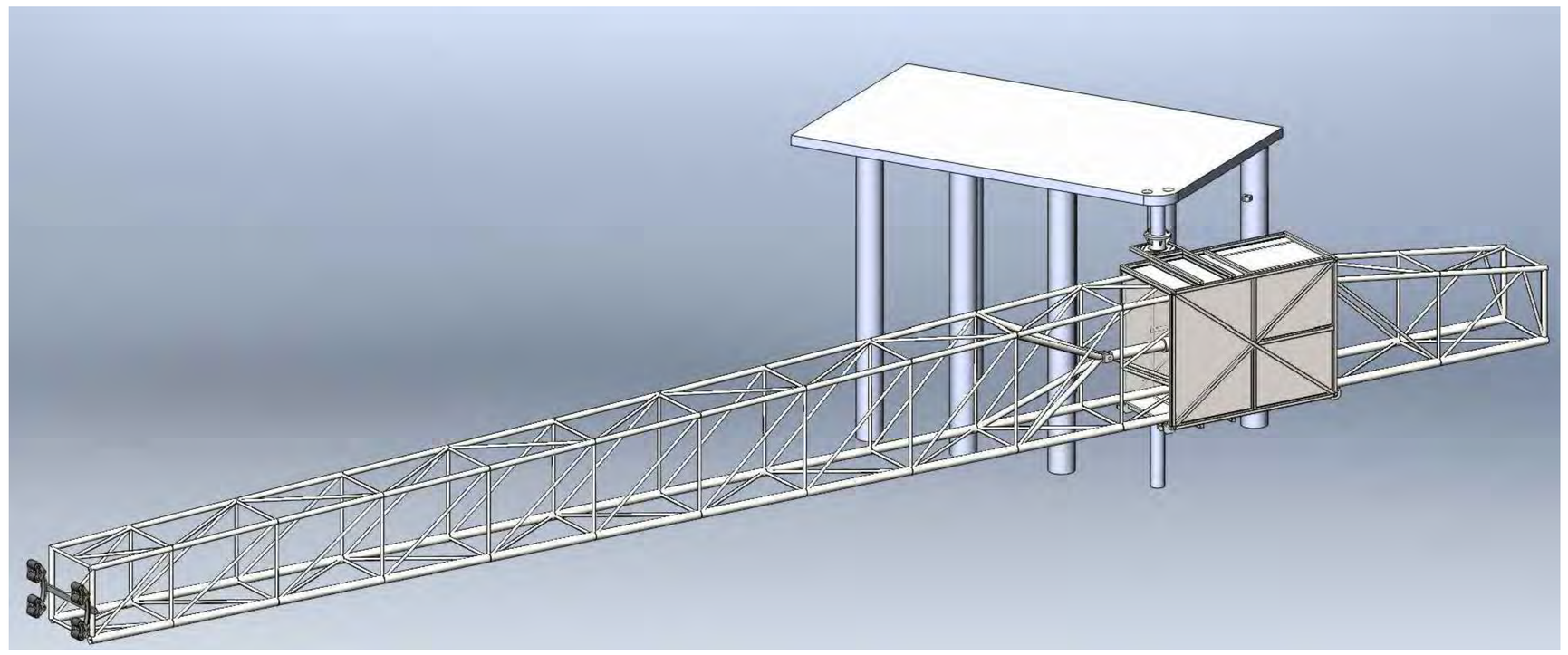
C-101	Plan

Structural:

S-201	Truss Plan and Elevation
S-202	Truss Framing Plan and Elevation
S-401	Hydraulic Assembly Framing
S-402	Hydraulic Assembly Section

Mechanical:

M-401	Contact Detail
M-402	Roller Detail
M-403	Truss Guide
M-404	Nested Pivot

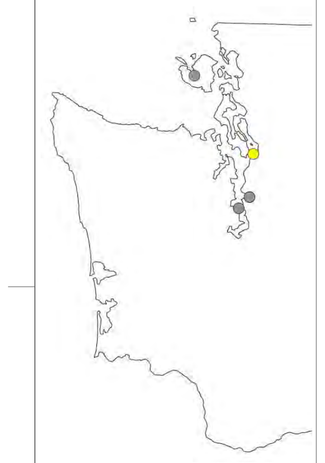


IDeX
Integrated Design Experience

DESIGNED BY

Brandyn Giroux | Mechanical Engineer
Ryan Evans | Mechanical Engineer
Peter Gray | Economist
Charlie Misner | Structural Engineer

LOCATION



Vessel Restraint

DATE 4/24/2012

SCALE

General Cover Sheet

G-101

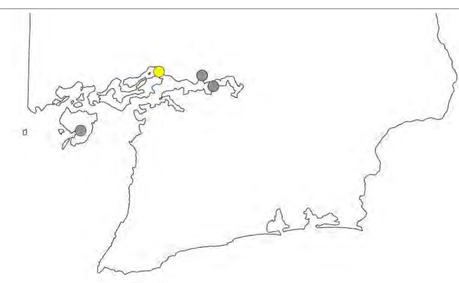
IDeX

Integrated Design Experience

DESIGNED BY

Brandyn Giroux | Mechanical Engineer
Ryan Evans | Mechanical Engineer
Peter Gray | Economist
Charlie Misner | Structural Engineer

LOCATION



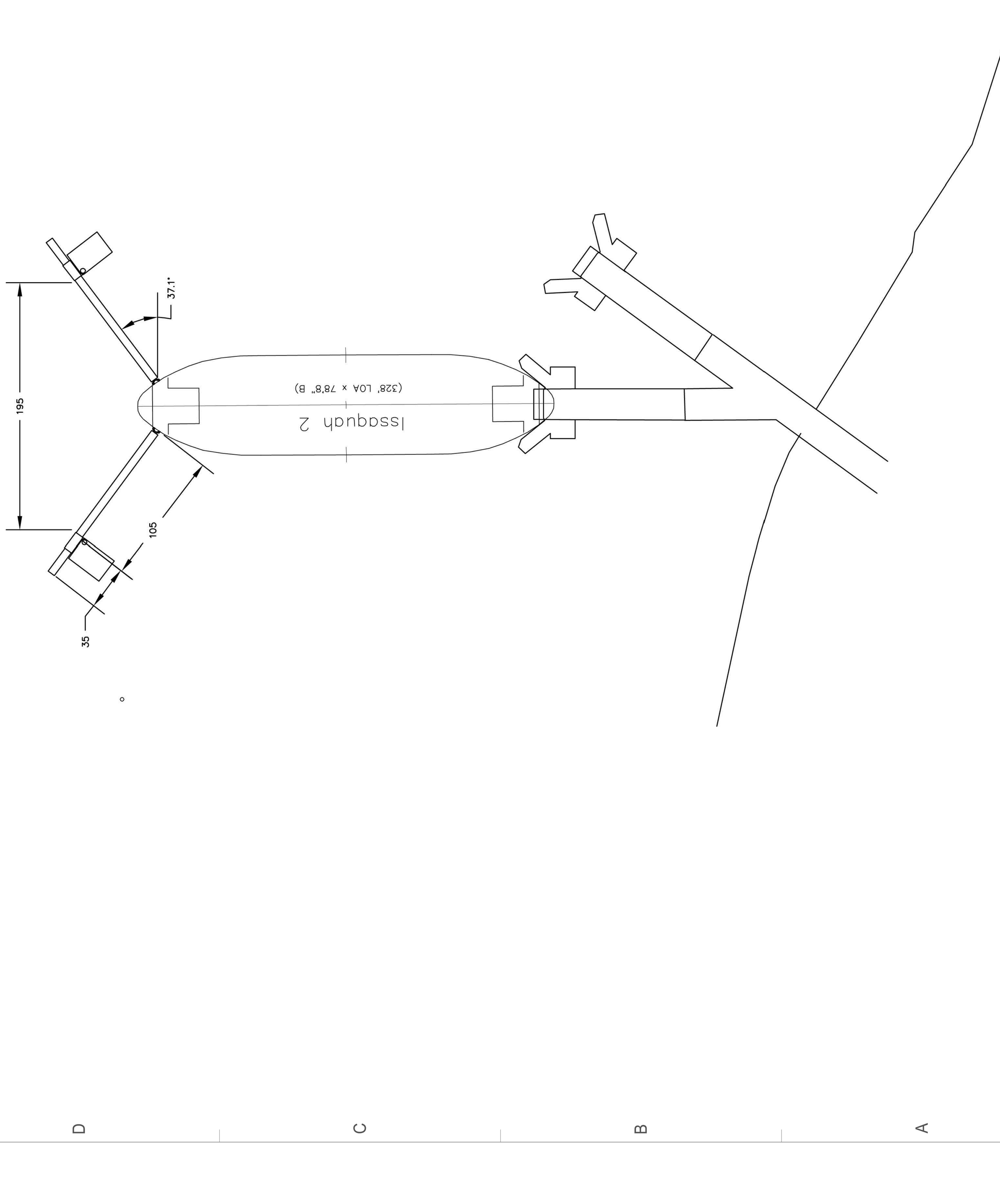
Vessel Restraint

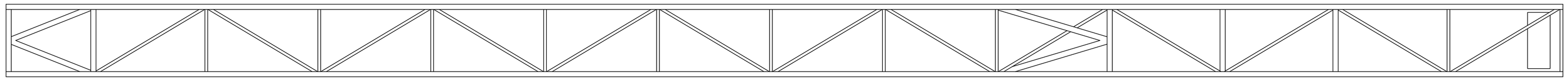
DATE 4/24/2012

SCALE

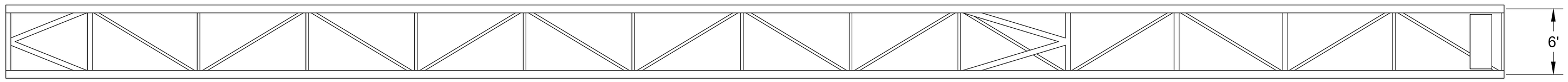
Plan

C-101

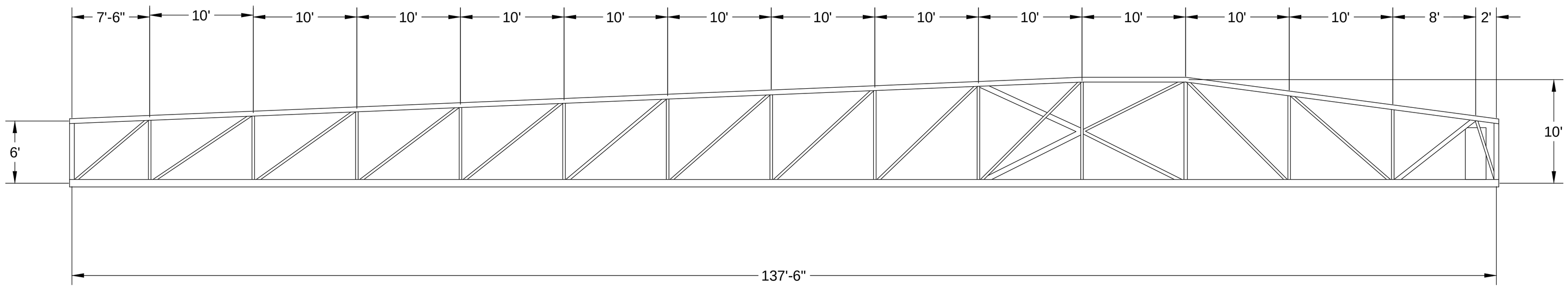




Truss Top Plan



Truss Bottom Plan



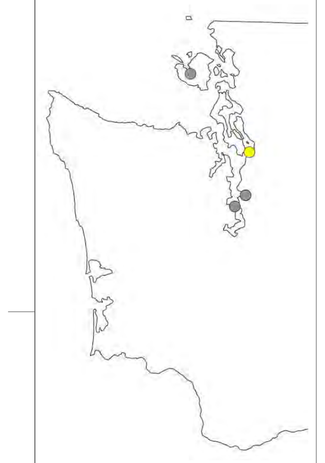
Truss Elevation

IDeX
Integrated Design Experience

DESIGNED BY

Brandyn Giroux | Mechanical Engineer
Ryan Evans | Mechanical Engineer
Peter Gray | Economist
Charlie Misner | Structural Engineer

LOCATION

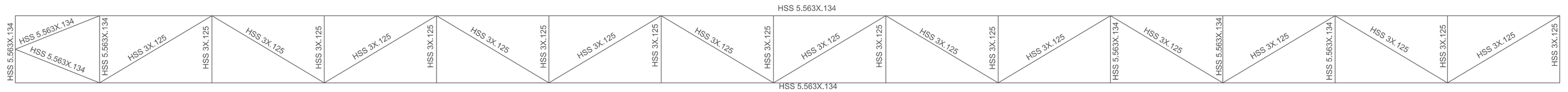


Vessel Restraint

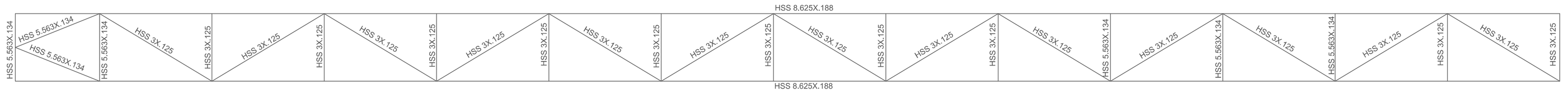
DATE 4/24/2012
SCALE 3/16" = 1'-0"

Truss Plan and Elevation

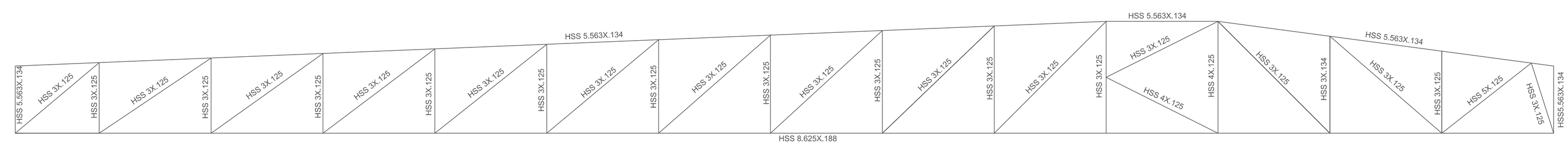
S-201



Truss Top Framing Plan



Truss Bottom Framing Plan



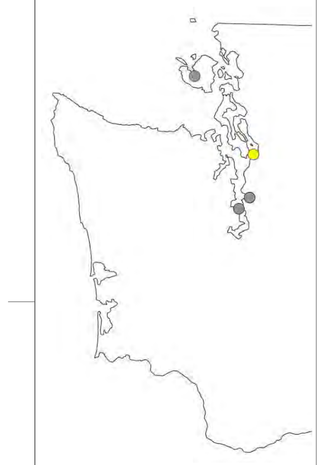
Truss Framing Elevation

IDeX
Integrated Design Experience

DESIGNED BY

Brandyn Giroux | Mechanical Engineer
Ryan Evans | Mechanical Engineer
Peter Gray | Economist
Charlie Misner | Structural Engineer

LOCATION

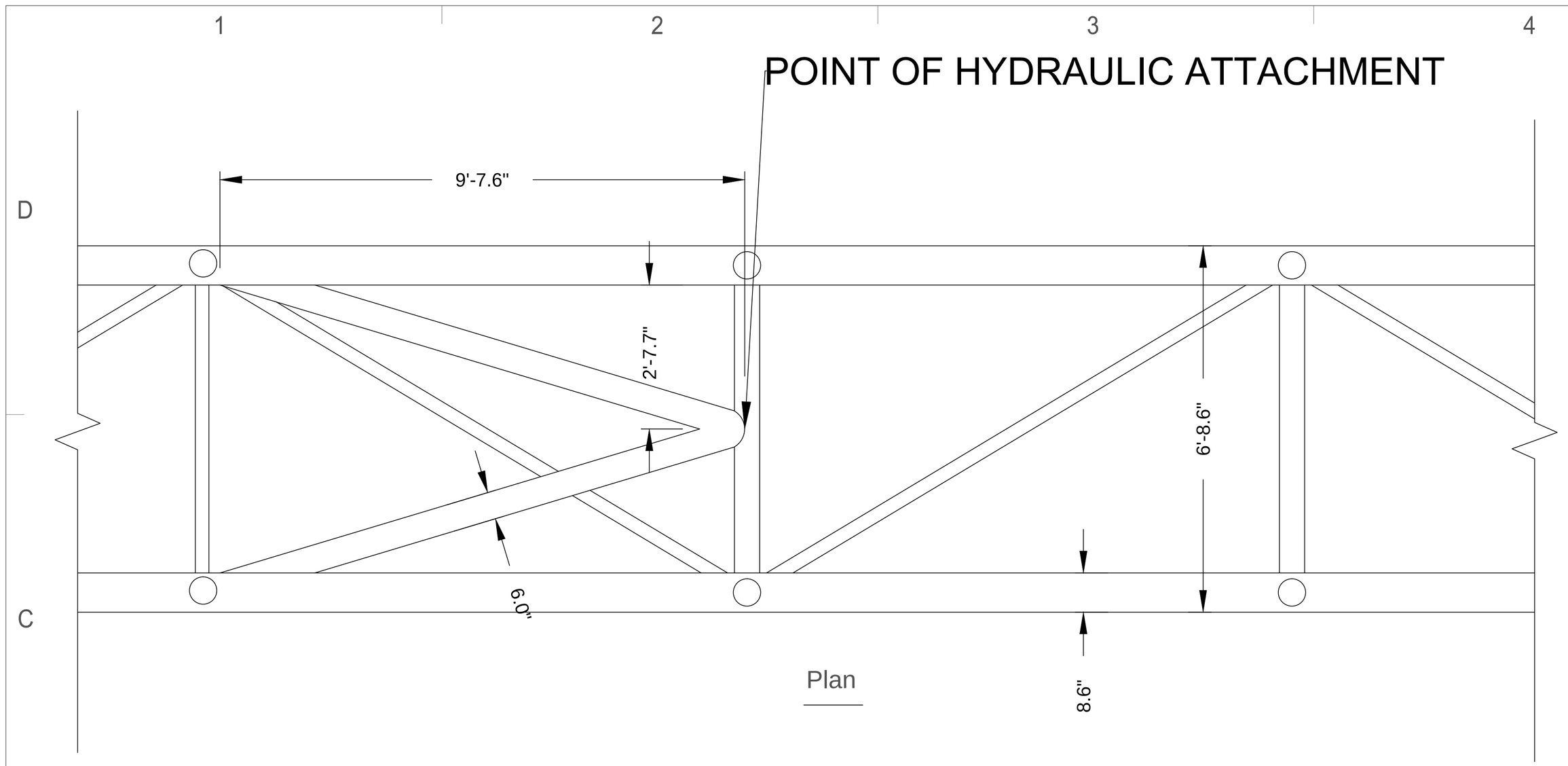


Vessel Restraint

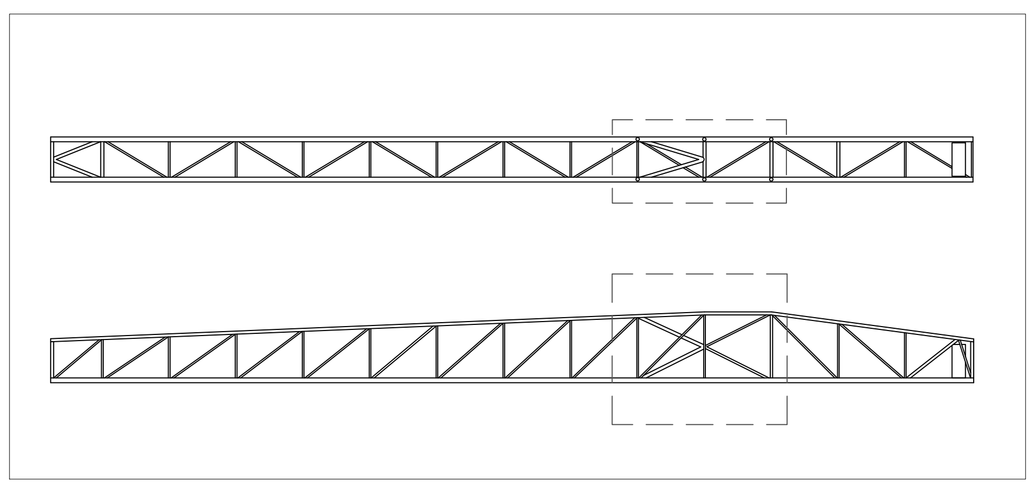
DATE 4/24/2012
SCALE 3/16" = 1'-0"

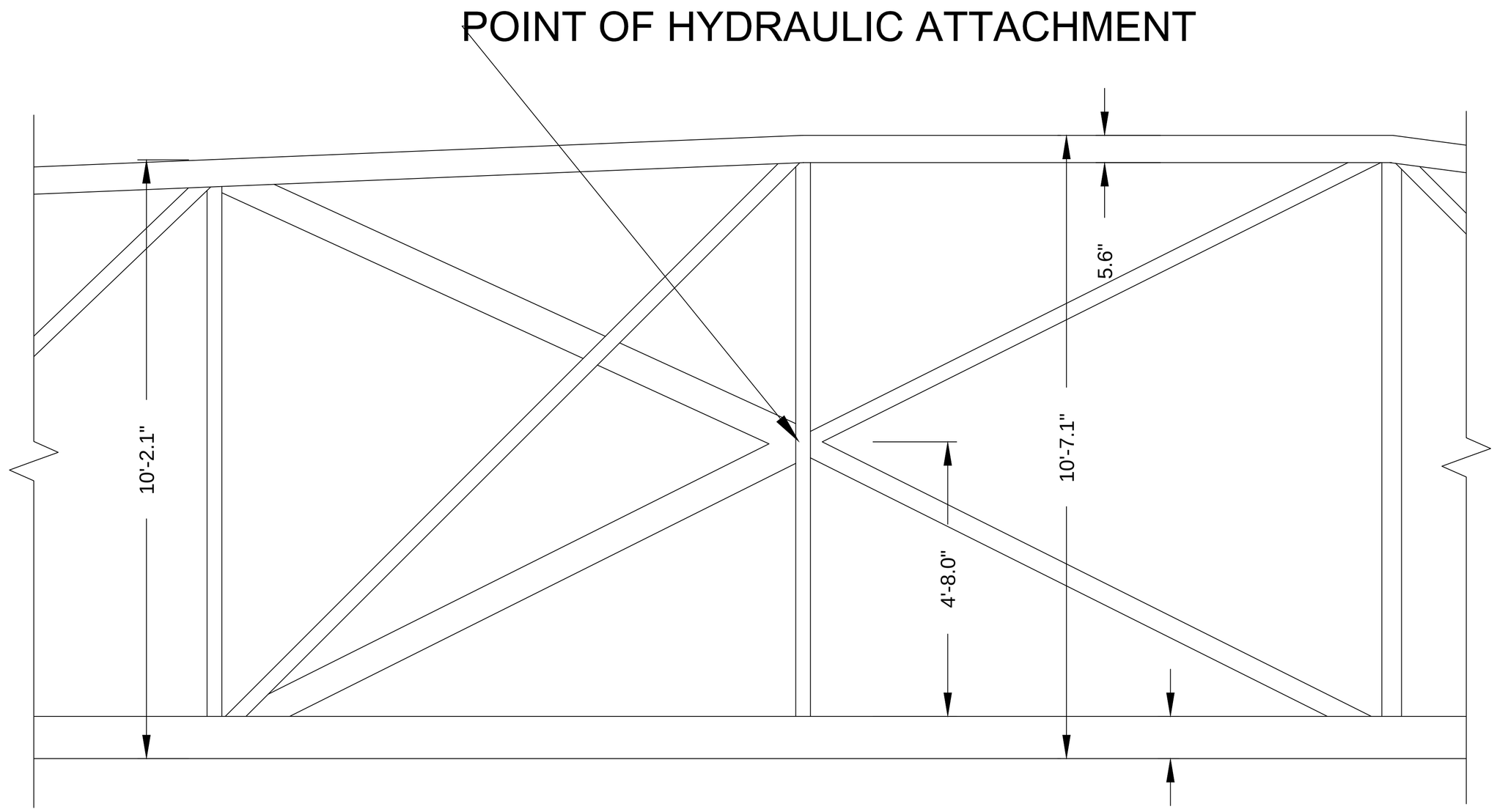
Truss Framing

S-202



Plan





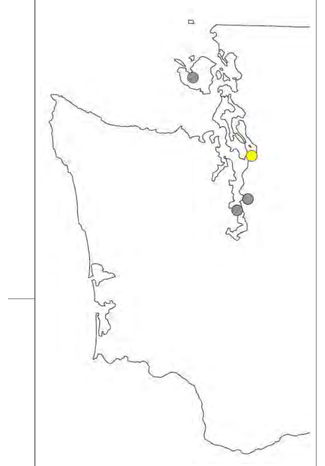
Elevation

IDeX
Integrated Design Experience

DESIGNED BY

Brandyn Giroux | Mechanical Engineer
Ryan Evans | Mechanical Engineer
Peter Gray | Economist
Charlie Misner | Structural Engineer

LOCATION

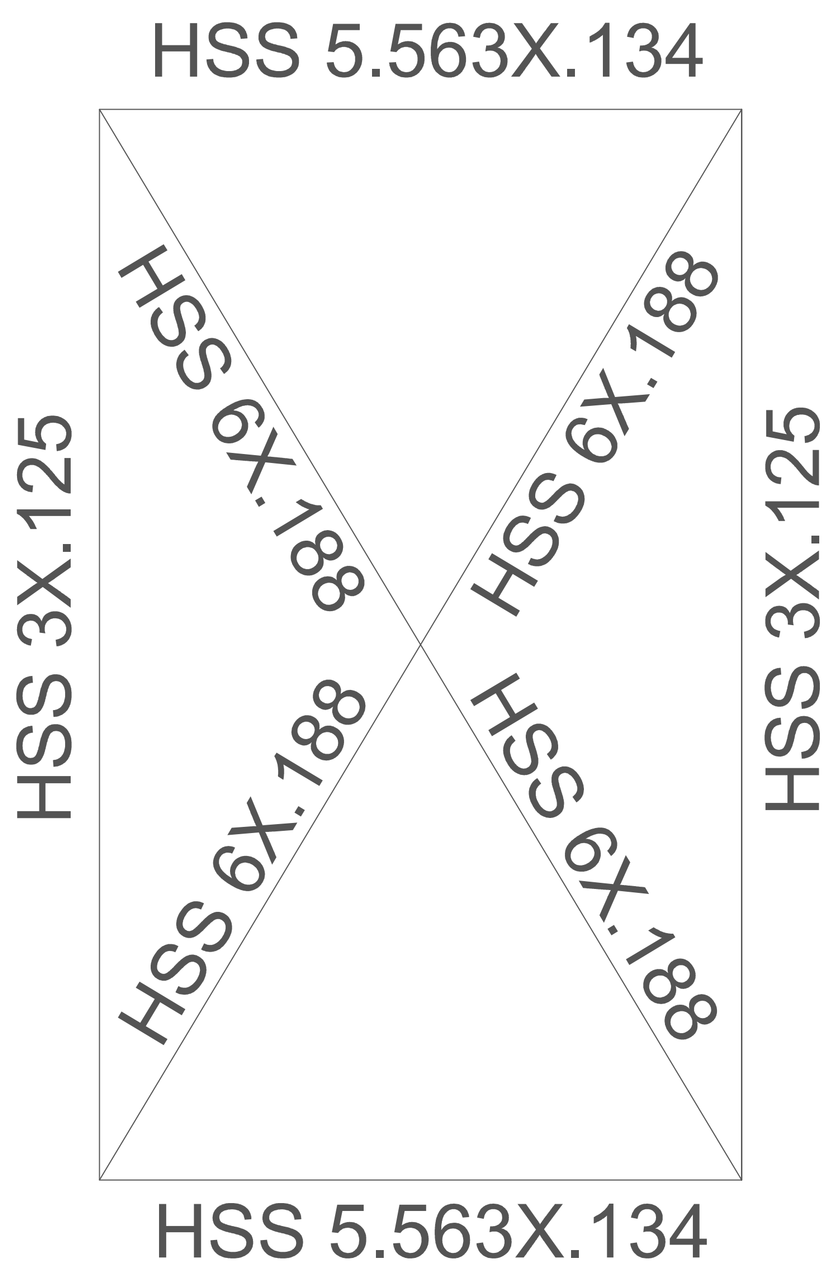


DATE 4/24/2012
SCALE 1/4" = 1'-0"

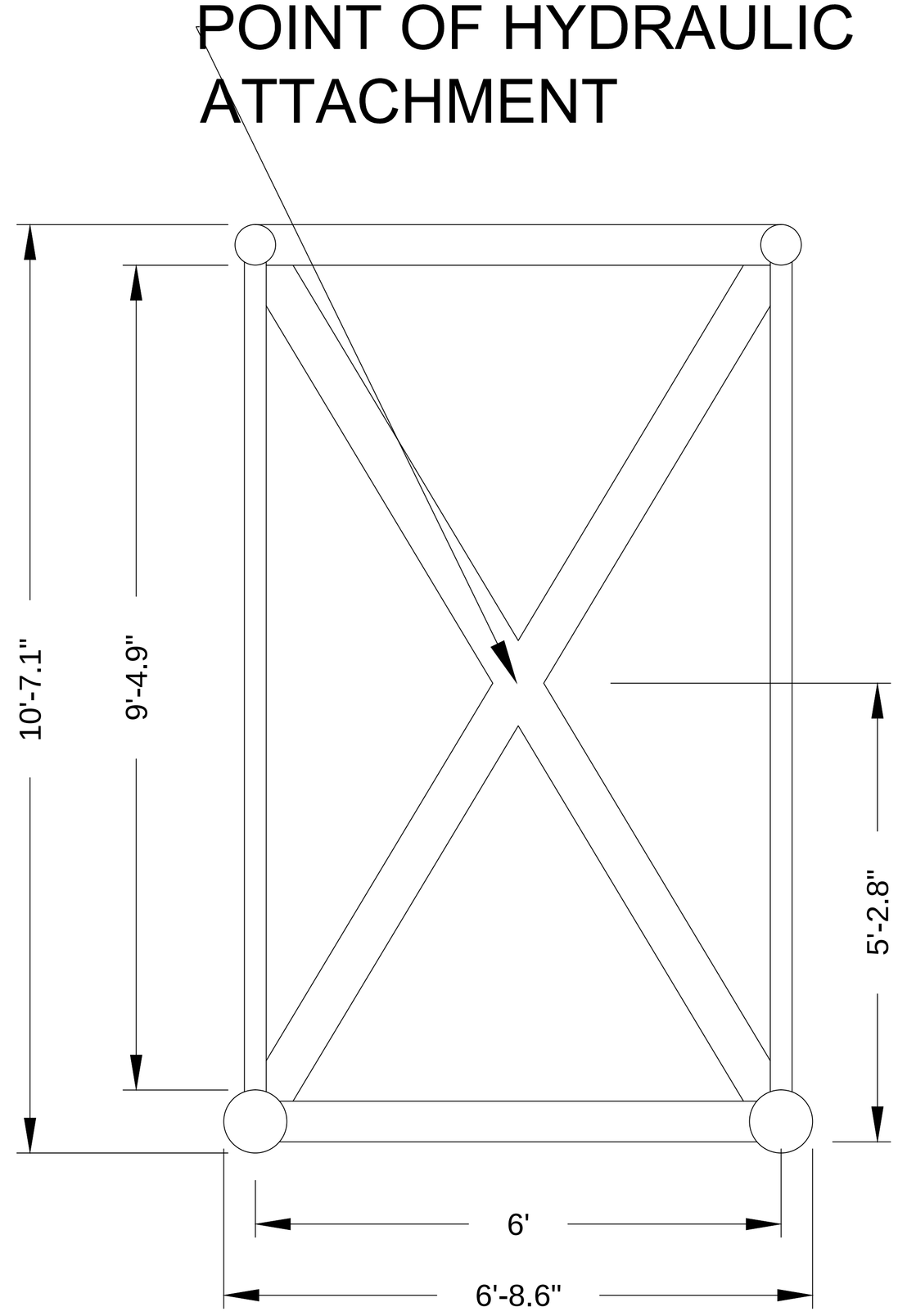
Vessel Restraint

Hydraulic Assembly Framing

S-401



A-A Hydraulic Attachment Framing



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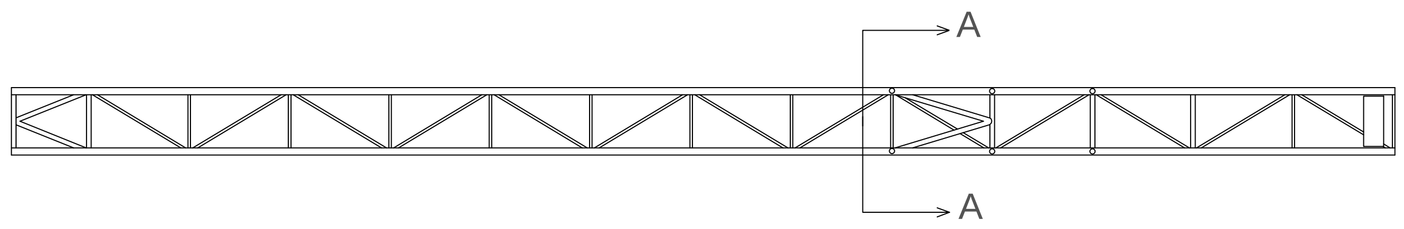
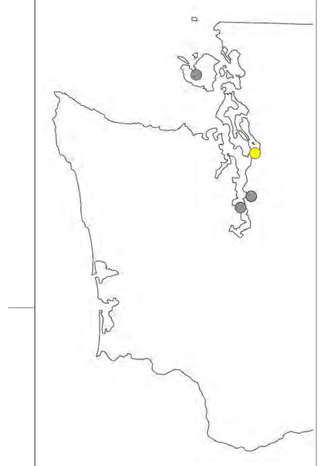


IDeX
Integrated Design Experience

DESIGNED BY

Brandyn Giroux | Mechanical Engineer
Ryan Evans | Mechanical Engineer
Peter Gray | Economist
Charlie Misner | Structural Engineer

LOCATION

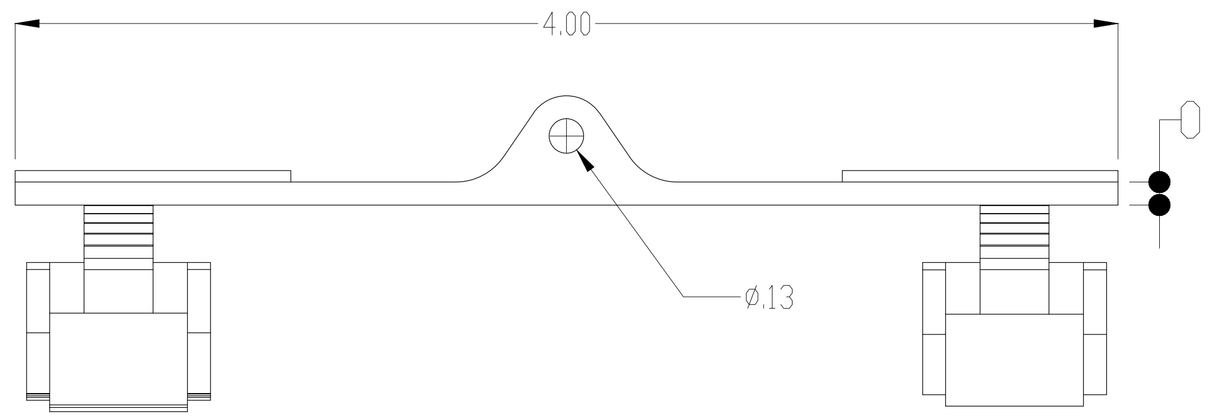


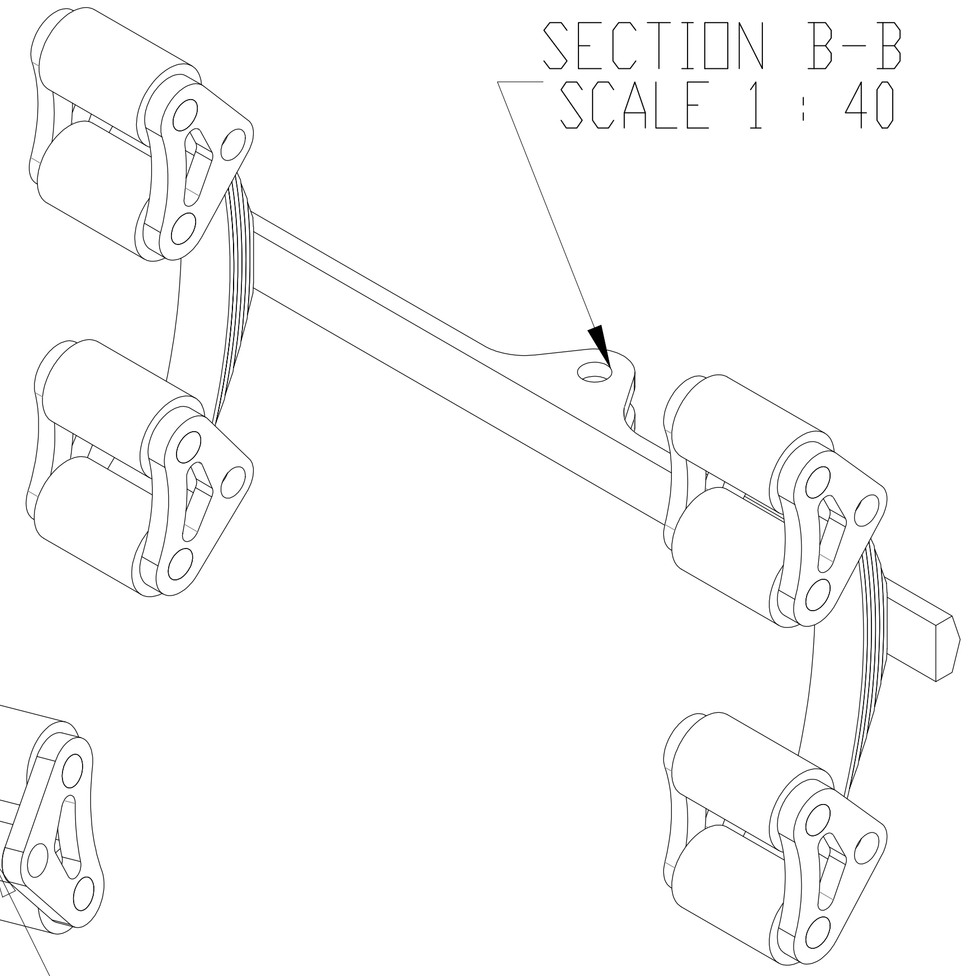
Vessel Restraint

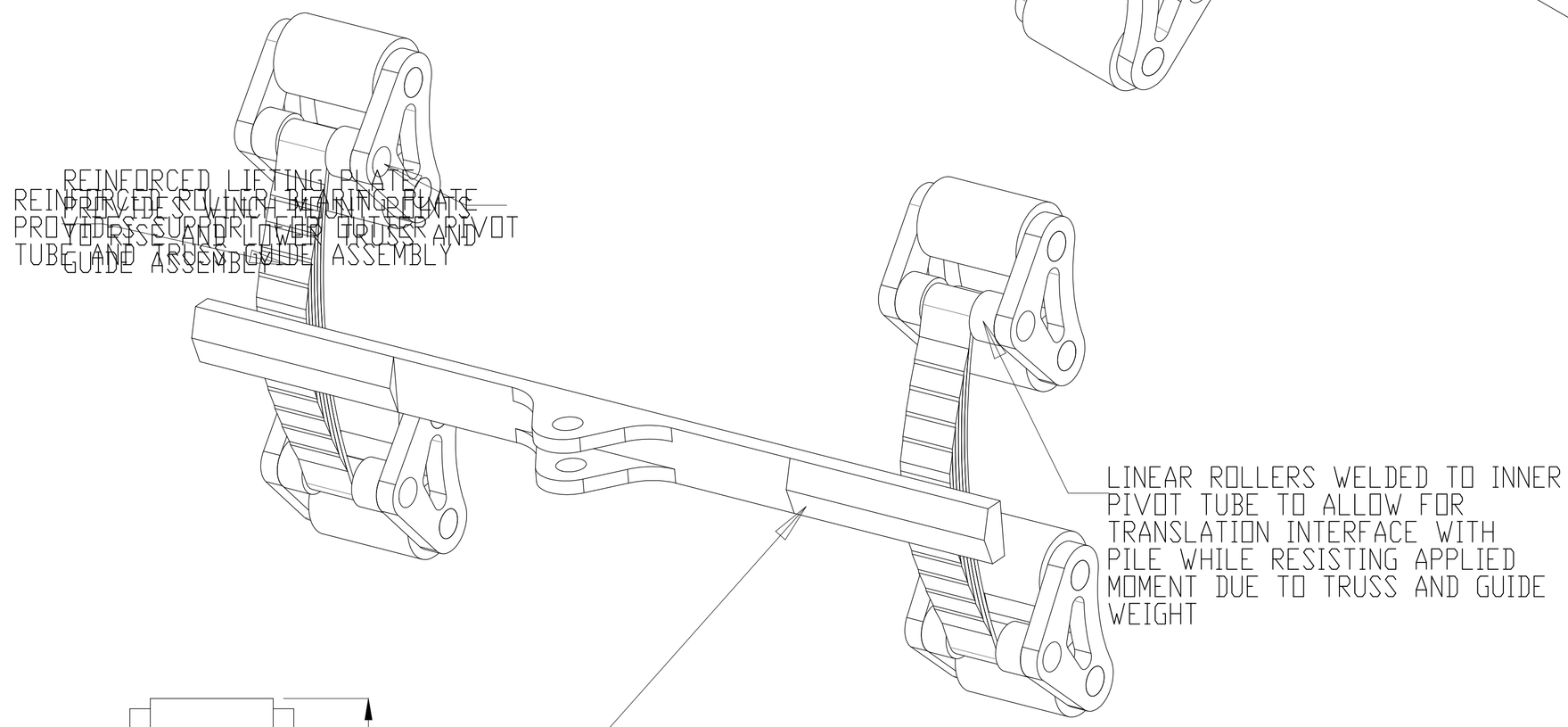
DATE 4/24/2012
SCALE 1" = 1'-0"

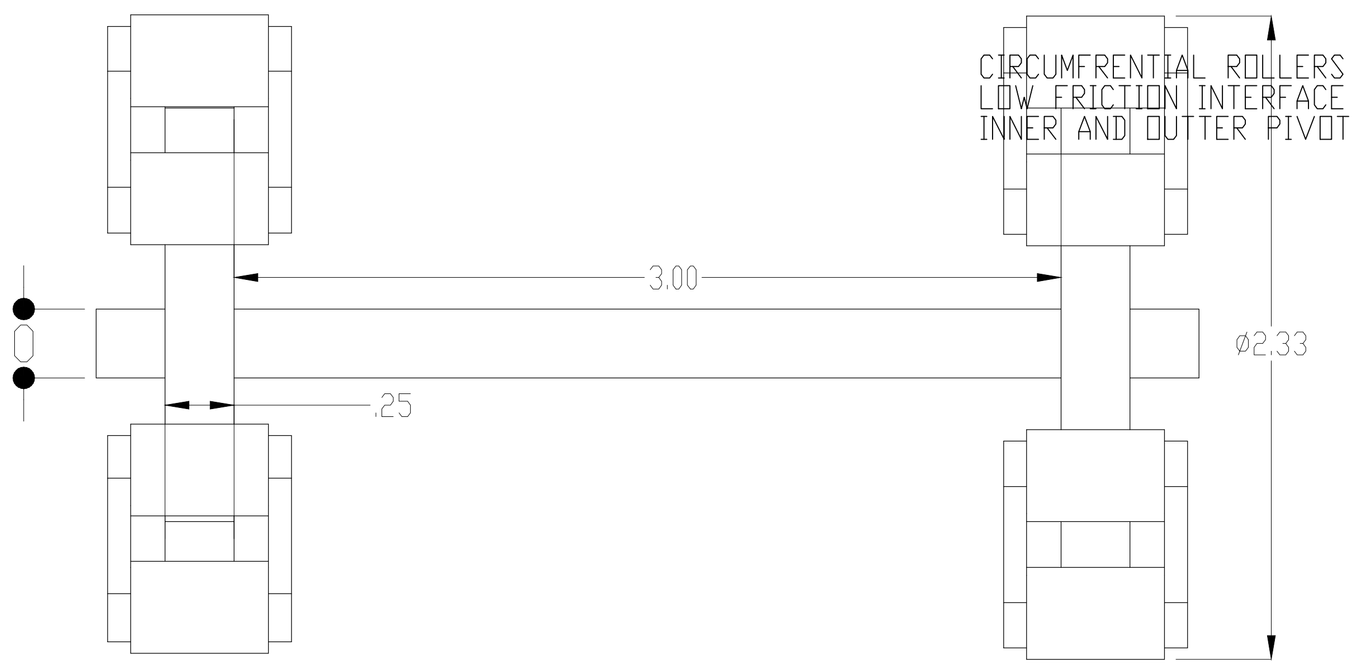
Hydraulic Assembly Framing

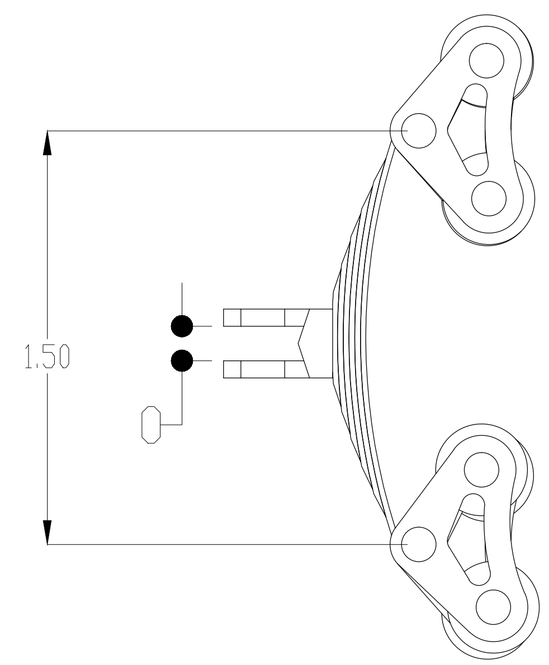
S-402











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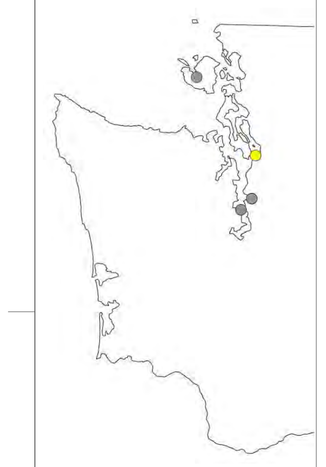
Ryan Evans | Mechanical Engineer
Peter Gray | Economist
Charlie Misner | Structural Engineer

LOCATION



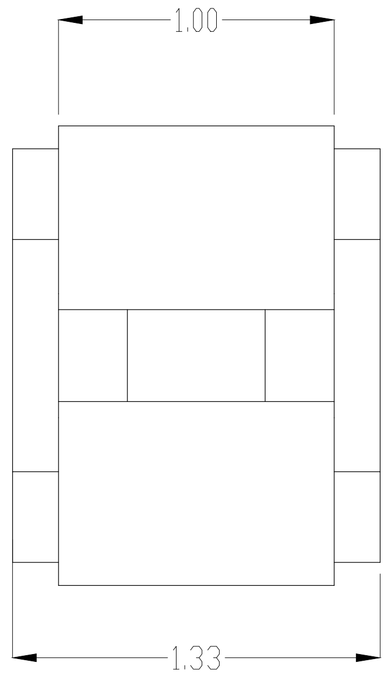
Vessel Restraint

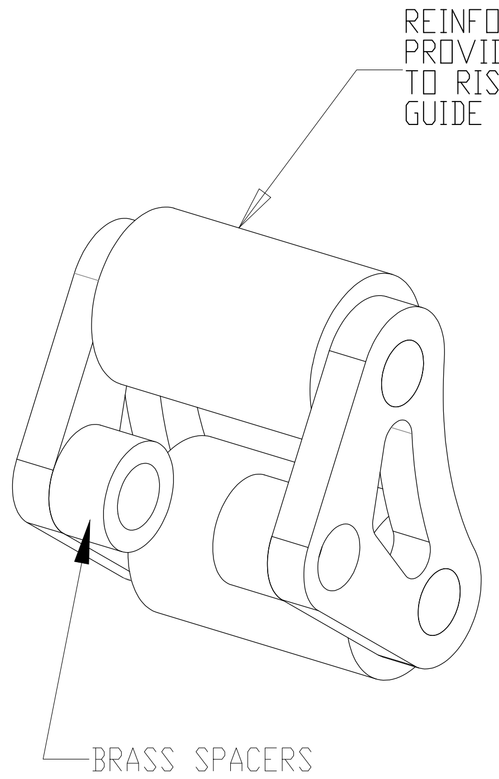
DATE 4/24/2012

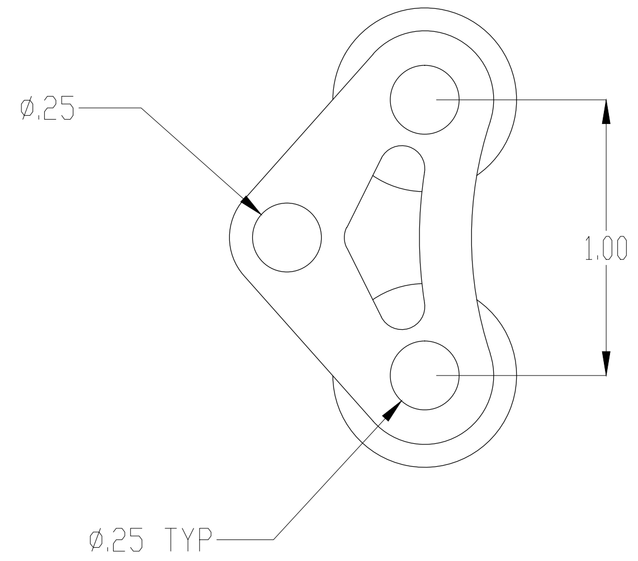
SCALE

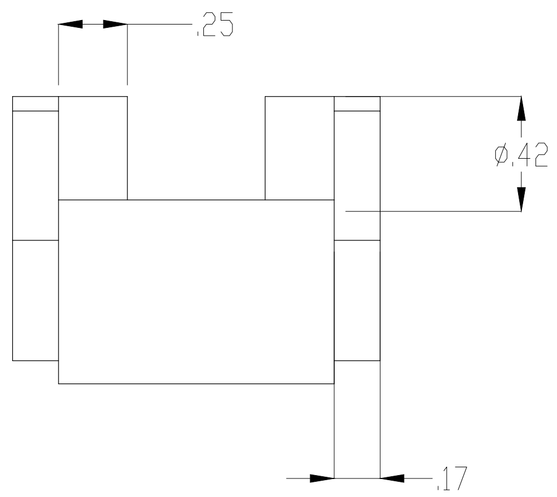
Contact Assembly

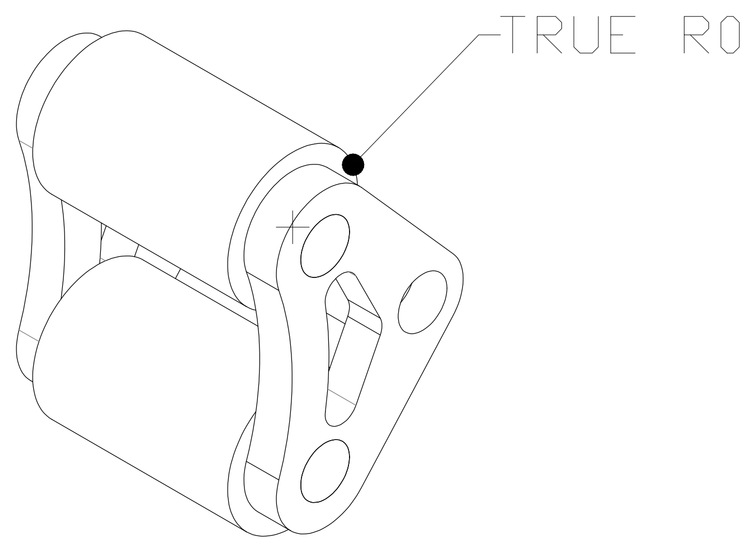
M-401











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DESIGNED BY

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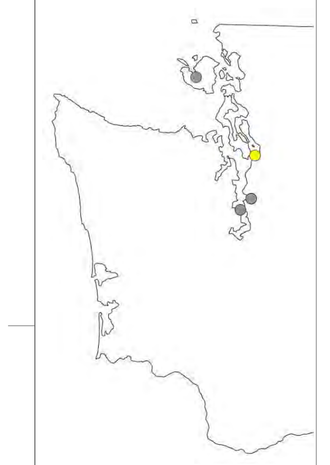
LOCATION

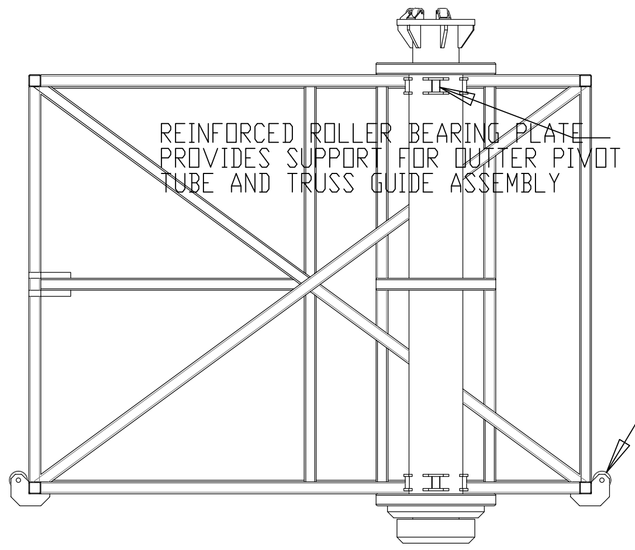


Vessel Restraint

DATE **4/24/2012**
SCALE **3/16" = 1'-0"**

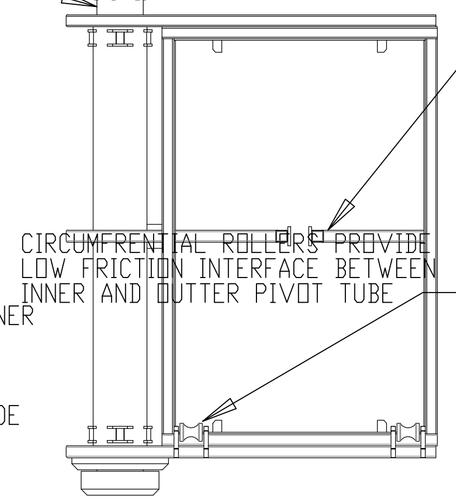
Contact Rollers

M-402

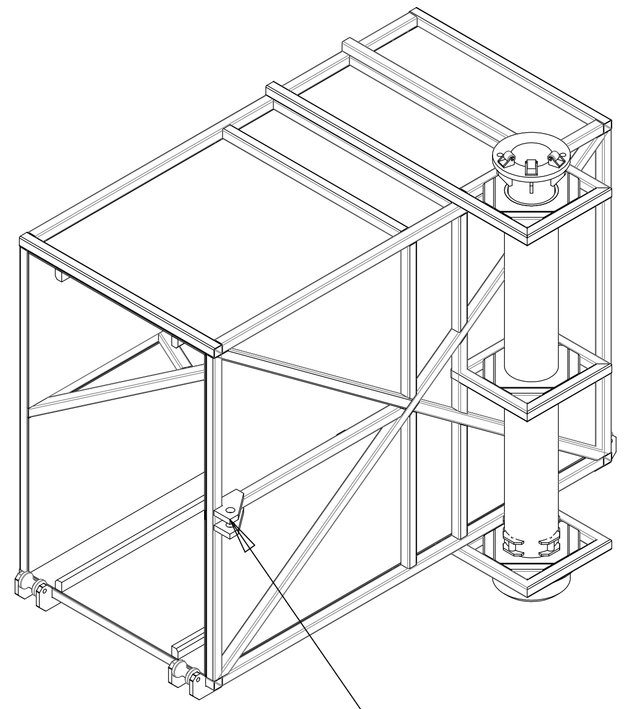


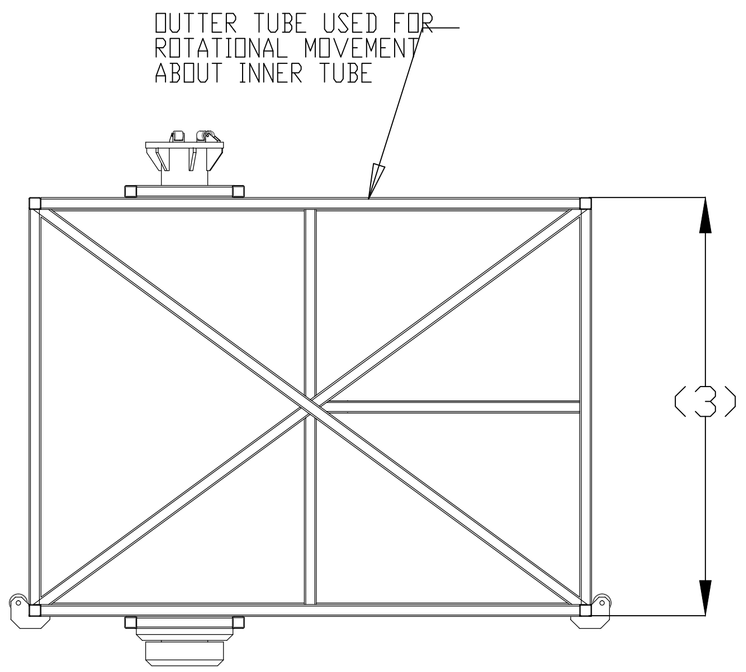
PIER SIDE VIEW

SECTION B-B
SCALE 1 : 40

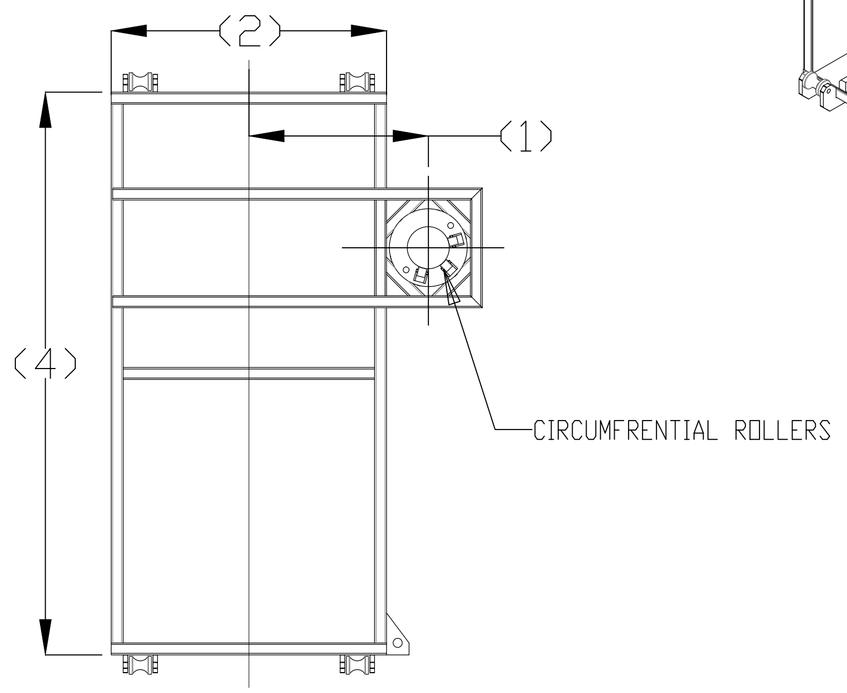


FRONT VIEW





NON PIER SIDE VIEW



TOP VIEW

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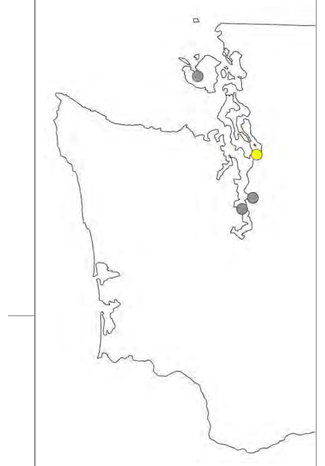
DESIGNED BY

Brandyn Giroux | Mechanical Engineer
Ryan Evans | Mechanical Engineer
Peter Gray | Economist
Charlie Misner | Structural Engineer

LOCATION

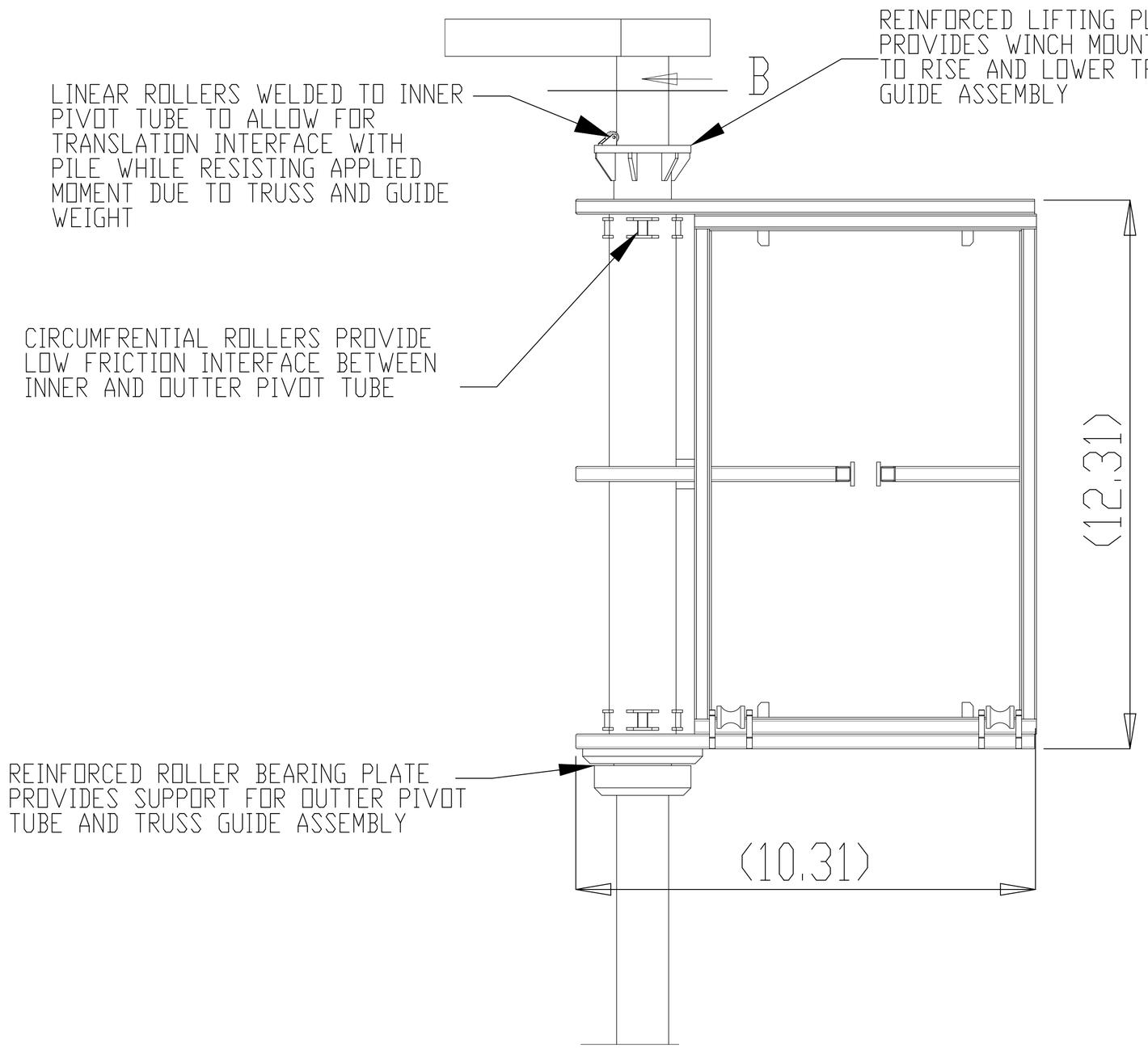


Vessel Restraint

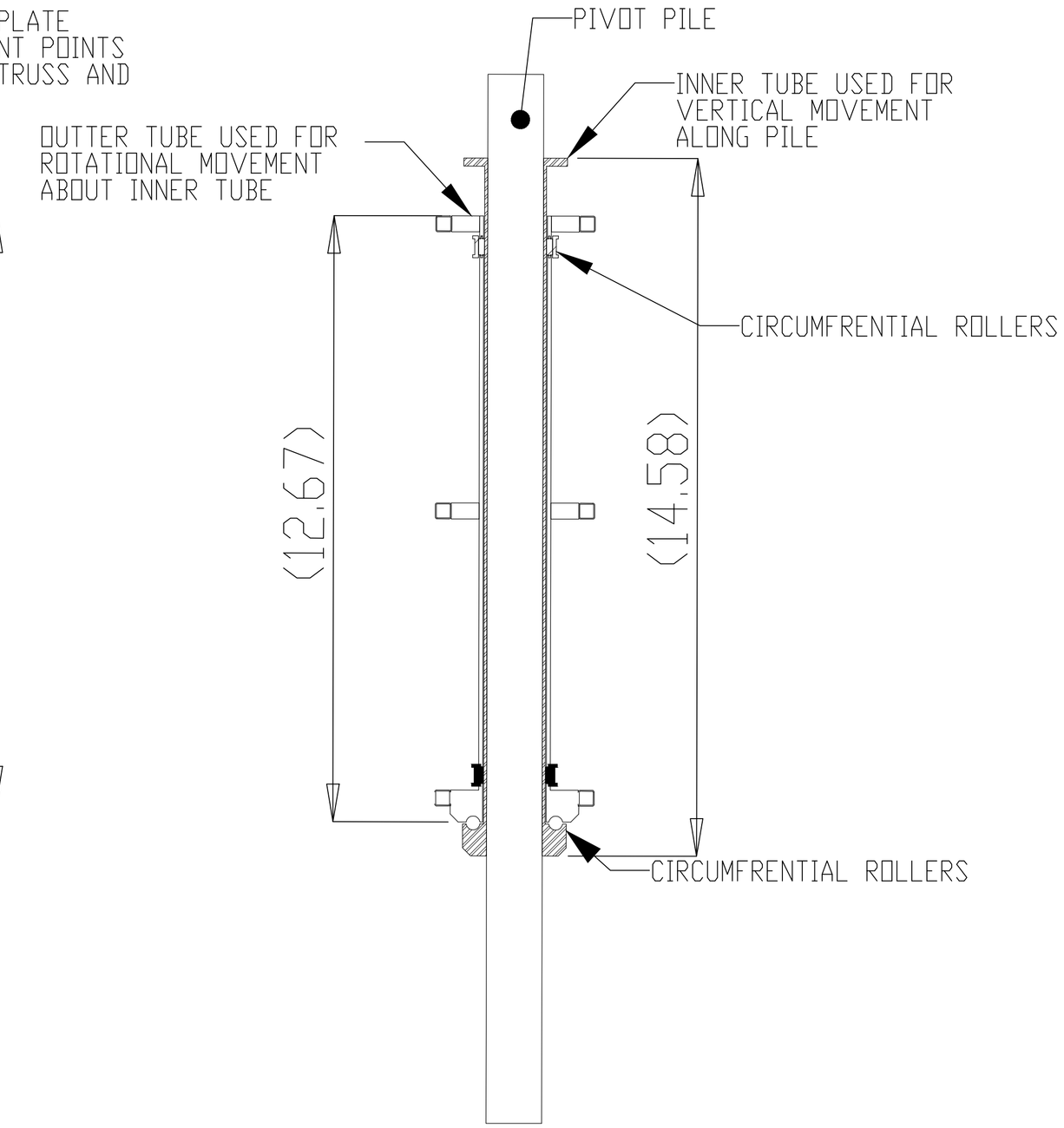
DATE 4/24/2012
SCALE

Truss Guide

M-403



DETAIL: NESTED PIVOT STRUCTURE



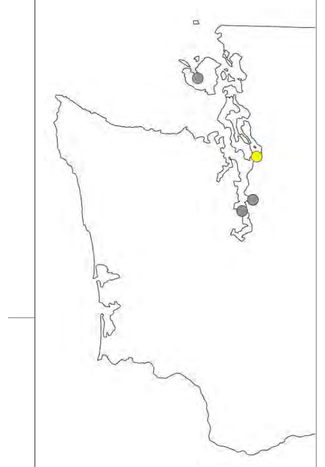
SECTION B-B
SCALE 1 : 40

IDeX
Integrated Design Experience

DESIGNED BY

Brandyn Giroux | Mechanical Engineer
Ryan Evans | Mechanical Engineer
Peter Gray | Economist
Charlie Misner | Structural Engineer

LOCATION

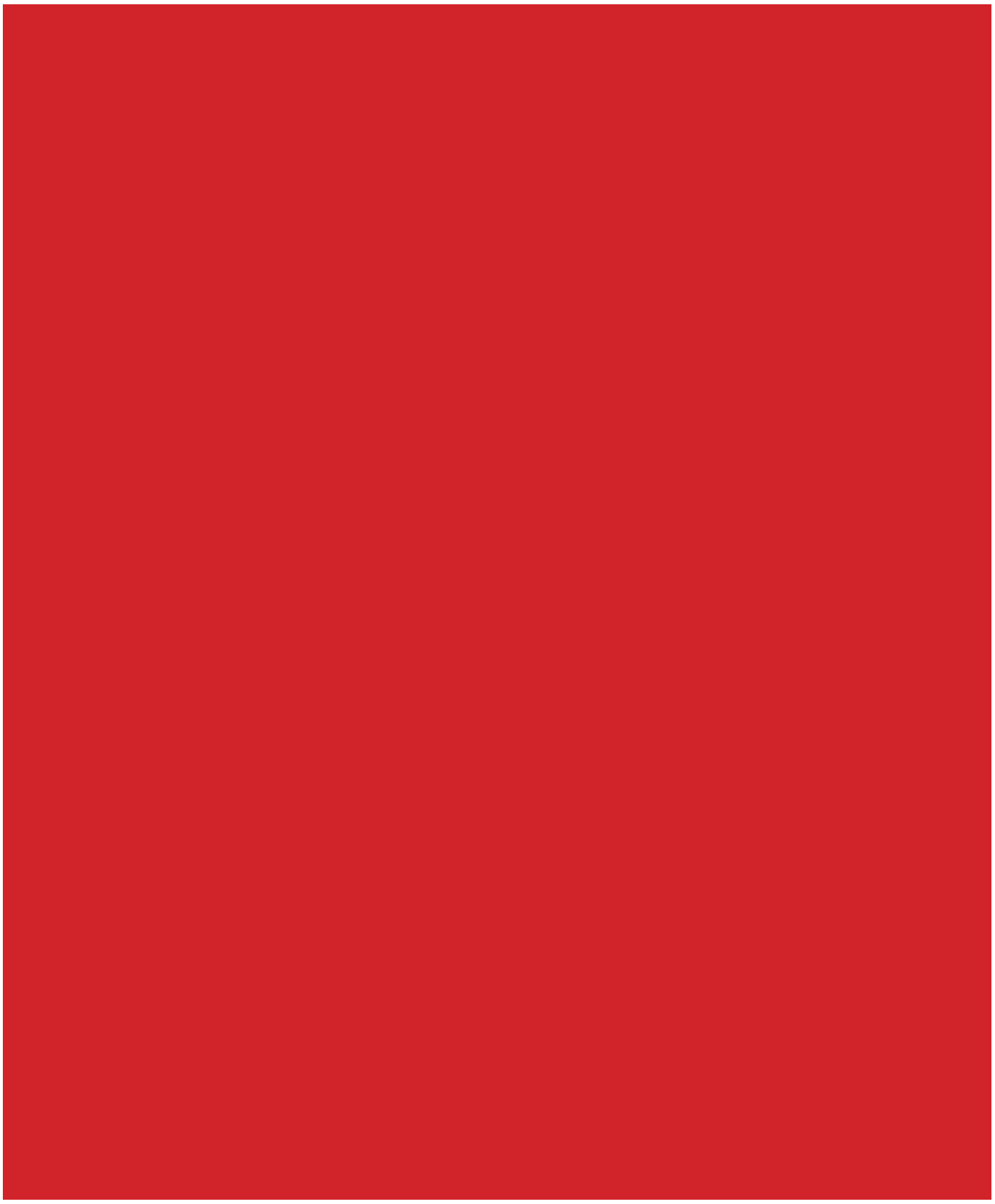


Vessel Restraint

DATE 4/24/2012
SCALE

Nested Pivot

M-404



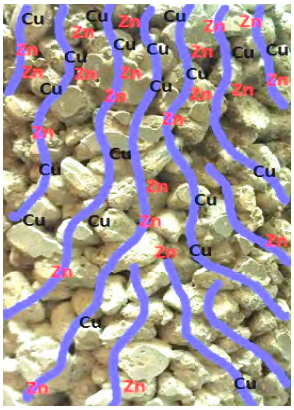
Appendix B: Dissolved Zinc and Copper Retention from Stormwater Runoff in Ordinary Portland Cement Pervious Concrete (submitted to Environmental Science and Technology)

Dissolved Zinc and Copper Retention from Stormwater Runoff in Ordinary Portland Cement Pervious Concrete

Liv M. Haselbach*, Cara Poor and Jerin Tilson
Washington State University, Pullman, WA 99164-2910
*Correspondence: haselbach@wsu.edu, 509 335 4874, Fax: 509 335 7632

Abstract

Pervious concrete pavement systems are emerging low impact development techniques capable of mitigating stormwater flows and potentially treating the water as well. This research demonstrates that the pervious concrete layer in a system is itself effective in removing dissolved zinc and copper contaminants from stormwater runoff. Pervious concrete cylinders made with ordinary portland cement were loaded in the laboratory with simulated runoff, and the influent and effluent concentrations and volumes measured. In one set of tests, stormwater was dispensed onto three cylinders at typical concentrations (100 µg/L Zn and 20 µg/L Cu) simulating ten consecutive storm events of 12 mm (0.5 inches) of rain. These cylinders removed at least 85% of zinc and copper. Another set of six concrete cylinders were used for accelerated long term exposure simulating many years and loaded at forty times the typical concentration. (They usually removed greater than 63% of the metals during the accelerated events.) Two of these cylinders were removed from the accelerated tests after 15 and 24 accelerated events respectively for further testing to determine performance during subsequent typical storm events, and the removal efficiencies were above 85%.



Introduction

Urbanization may negatively affect stormwater quantity and quality. Runoff from parking lots, roadways, and roofs causes excessive volumes of water and contamination to reach water bodies because the stormwater that may carry the contaminants does not return to the soil or air via infiltration or evaporation. Many of the roadway associated waters contain elevated levels of zinc and copper (Barrett et al., 1998). These metal contaminants may pose a significant threat to many aquatic environments (Eisler, 1993; Horne and Dunson, 1995; U.S. EPA, 1993).

Some studies have indicated that permeable pavements are effective in removing metals from stormwater, especially particulate bound metals. Most of these studies focused on full permeable pavement systems, consisting of the pavement layer (pervious concrete, porous asphalt or permeable pavers), the aggregate storage bed below and other attributes of the system in actual field studies. Mechanisms may have included filtration of particulate bound metals and sorption to soils and other particles in the systems (Ahiablame *et al.,* 2012; Rushton, 2001). This study is based on the hypothesis that the pervious concrete layer itself in a permeable pavement system may effectively remove some dissolved metals, especially zinc and copper due to the chemical and physical characteristics of the concrete.

When ordinary portland cement (OPC) is used to make concrete, the compounds that result include many hydroxide species, including substantial amounts of calcium hydroxide. In the tortuous interconnected flow channels throughout pervious concrete, there are many carbonate species, in addition to the hydroxide species, on the surface due to carbonation from the carbon dioxide in the atmosphere. In fact, XPS analyses have indicated that on cement surfaces there may be up to three carbon atoms for every calcium ion (Haselbach and Ma, 2008). Dissolved metals are likely removed from solution while passing through these tortuous flow channels within a pervious concrete layer due to complexation and solids formation with the hydroxides (OH^-) and carbonates (CO_3^{2}) that are attached to calcium in the concrete. In aqueous systems, many complexes form between carbonate and hydroxide ligands, and metals such as calcium, zinc and copper. Formation is also enhanced at higher pH which is typically found in OPC concrete. These complexes can also form on surface species of the carbonates and hydroxides (Stumm and Morgan, 1996). Thus, there is a high affinity for surface complexation of the dissolved zinc and copper ions with both ligands. After complexation during a storm event, there is then the opportunity for diffusion into the microporous structure of the interior pervious concrete matrix. As in any ordinary portland cement concrete specimen exposed to the atmosphere, beyond the highly carbonated surfaces, the concrete will be less carbonated and there will be more hydroxide species remaining (Pade and Guimaraes, 2007). These interior sites may also form many complexes with the zinc and copper ions, with the potential for formation of the solid complex species too. The logarithm of the stability constants for the formation of the solid hydroxide species for the three metals are 5.19, 19.3 and 16 for calcium, copper and zinc respectively, indicating a higher affinity for formation of the copper and zinc hydroxide solids than the calcium. The logarithm of the stability constants for the formation of the solid carbonate species for the three metals are 8.2, 9.6 and 10 for calcium, copper and zinc respectively, again indicating a higher affinity for copper and zinc than calcium. In addition to the solid phases, the stability constants for the various complexations generally tend to favor zinc and copper complexation over calcium (Stumm and Morgan, 1996).

Due to the large amounts of surface areas in the channels in pervious concrete, the likely processes for pervious concrete sorption of dissolved copper and zinc are rapid surface adsorption forming various complexation species during a storm event, and then diffusion and additional complexation species development in the interior of the concrete matrix. This three-step process would then allow for partial renewal of the complexation sites in the channels prior to subsequent storm events.

There are some previous studies which support the hypothesis that OPC concrete may have these sorption capabilities. Fach and Geiger (2005) developed metal adsorption equilibrium curves (isotherms) for the concrete in concrete pavers by pulverizing them and exposing crushed samples to aqueous dissolved metal solutions. Dyer et al. (2009) found that significant amounts of metal hydroxides precipitate on the concrete surface and within the concrete in a study on the impact of soil contaminated with zinc, lead and copper on freshly placed concrete.

The study reported upon herein was planned in three parts using laboratory testing to simulate field conditions. The intention of the first set of tests was to examine the initial removal of dissolved zinc and copper species by pervious concrete from simulated stormwater runoff with typical dissolved metal concentrations. The second part was planned to simulate longer term loading by accelerating many years of metal sorption by using very concentrated solutions of these two metals. In this second portion removal efficiencies were also determined. Although these efficiencies are not realistic of in-situ conditions, they are indicative of mass loadings and therefore years of service. The intention of the third part was to examine the effectiveness of the pervious concrete to remove typical concentrations of dissolved copper and zinc after the accelerated longer term loading, or perhaps to even begin leaching of the metals. Due to the high levels of the carbonate and hydroxide species in the pervious concrete layer, and the relatively low concentration of dissolved zinc and copper in typical runoff, the specimens in the third part were not expected to reach saturation and lose their sorptive capabilities even after many years of simulated loading.

Experimental Materials and Methods

Pervious Concrete Specimens

Pervious concrete cylinders were prepared in December 2008 using a mix of ordinary portland cement, narrowly graded number eight sized aggregate (nominal diameter of 9 to 10 mm), and water, in mass percentages of approximately 19%, 76% and 5% respectively. The cylinders were all 102 mm (4 inches) in diameter and ranged in volume from 0.00147 to 0.00151 m^3 (90 to 92 in^3). These pervious concrete cylinders were previously exposed to tap and deionized water for pH testing in 2009-2010 and then left open to the atmosphere in the laboratory. This allowed for carbonation to develop in the flow channels, typical of in-situ conditions. The porosity of each cylinder was measured in February 2012 using a modified ASTM C1754. All cylinders were then flushed with tap water before testing to remove miscellaneous material.

Simulated Rainwater, Stormwater and Influent/Effluent Sample Preparation

Simulated rainwater was made using the chemical makeup of rainwater in Southeast Washington State. It contained sodium chloride, calcium carbonate, potassium nitrate, sodium bicarbonate, and potassium bicarbonate. A highly concentrated stock solution of both zinc and copper in the form of zinc chloride and cupric chloride dihydrate was mixed. The solution was then diluted with the simulated rainwater to the desired metal concentration at the time of testing to simulate stormwater contaminated with metals at the specified concentrations.

Samples of both the simulated stormwater applied to the cylinders and the remaining effluent after passing through the pervious concrete cylinders were collected. All of the samples were acidified to a pH below 2 and stored in high density poly ethylene bottles (HDPE) at 4°C prior to metal analyses (Eaton *et al.,* 2005). The influent and effluent samples were then analyzed for total dissolved zinc and copper using an Agilent Technologies 7700 Series Inductive Coupled Plasma – Mass Spectrometer (ICP-MS) at the geoanalytical laboratories at Washington State University.

Metal Loading Tests

For all of the following tests, 100 mL (6.1 in^3) of simulated stormwater solution was dripped over each concrete cylinder at a rate of approximately 10 mL (0.61 in^3) per minute to represent a 12 mm (0.5 inch) storm event. Effluent was allowed to drip from the cylinder for 10 to 20 minutes after the simulated stormwater application. Influent and effluent samples were collected, and the effluent volumes measured for all tests. Note that a significant amount of influent remained in the cylinder and was either evaporated or remained in the pores of the cylinders in the subsequent events.

For the cylinders used in the accelerated loading cycles (Part 2), the effluent was consolidated into one sample after each event for testing. For the cylinders used in the typical loading experiments (Parts 1 and 3), effluent samples were individually collected and analyzed for each event.

For the typical loading events (Part 1), the stock solution of zinc and copper was diluted with simulated rainwater to concentrations of approximately 100 µg/L and 20 µg/L respectively for the simulated typical stormwater. A single influent sample analyzed for each event. (Actual concentrations as measured are given in the Results and Discussion Section.) The columns were then loaded with 100 mL (6.1 in^3) of the simulated stormwater solution. Individual effluent samples were taken from each cylinder for each event and separately prepared for analysis. The volume of effluent was also recorded for mass balance purposes. After each event the cylinders were allowed to dry for at least 12 hours in a warm oven prior to the next event (maximum temperature of 50°C). Three of the cylinders were used for the initial typical loading tests (Part 1) and they received ten consecutive events of simulated stormwater loading at these rates and concentrations. Two of the accelerated loading cylinders, labeled WB10 and WB11, also received three consecutive typical loading events (Part 3) after a series of accelerated loading as described in the following sections.

For the accelerated tests that simulated longer term loading (Part 2), the stock solution of zinc and copper was diluted with simulated rainwater to concentrations of approximately 4000 µg/L and 800 µg/L respectively producing a stormwater solution forty times more concentrated with metals than the typical concentrations. A single influent sample was analyzed for each event. (Actual concentrations as measured are given in the Results and Discussion Section.) For each simulated accelerated event, 100 mL (6.1 in^3) of the forty times concentrated metal solution was applied to each of the six pervious concrete cylinders and the effluent volumes were measured. In this case, the individual effluent samples collected for all of the cylinders tested

were combined into one consolidated effluent sample per event. After each event the cylinders were allowed to dry for at least 12 hours in a warm oven prior to the next event (maximum temperature of 50°C). All six cylinders received 15 accelerated loading events at which time one of the cylinders (WB10) was then sacrificed and subsequently received three typical loading events (Part 3). The remaining five cylinders in the second set of tests (Part 2) received 9 more accelerated loading events at which time cylinder WB11 was sacrificed and subsequently received three typical loading events (Part 3). The last four cylinders in Part 2 continued with the accelerated loading for a total of 30 events. The two sacrificial cylinders (WB10 and WB11) in Part 3 were investigated for long-term removal effectiveness and/or if leaching might occur from heavily loaded pervious concrete under typical conditions.

Results and Discussion

The identification label for each of the pervious cylinders and their measured porosity are given in Table 1. They were chosen from a larger group of specimens due to their similar porosities. This minimized experimental variability from porosity distributions. All the cylinders are labeled beginning with the letters WB to indicate that they all were prepared at the same time in the same batch of concrete using the same cement and aggregate source, further decreasing experimental variability.

Table 1: Material Characteristics of Pervious Concrete Cylinders and Representative Summary Results for Typical Loading Events (Both Initial and Post Accelerated Loading)

Loading Group	Cylinder ID	Porosity (%)	# of Accelerated Events	Metal Removal for Typical Loadings (%) (Parts 1 and 3)									
				Post Accelerated Event 1		Post Accelerated Event 2		Post Accelerated Event 3		No Accelerated Loading (Part 1)			
										Event 1		Event 10	
				Zn	Cu	Zn	Cu	Zn	Cu	Zn	Cu	Zn	Cu
Accelerated	WB01	24.7	30	--	--	--	--	--	--	--	--	--	--
	WB07	24.4	30	--	--	--	--	--	--	--	--	--	--
	WB10	24.8	15	92	90	95	93	92	87	--	--	--	--
	WB11	25.4	24	93	89	86	86	92	89	--	--	--	--
	WB12	25.4	30	--	--	--	--	--	--	--	--	--	--
	WB18	25.5	30	--	--	--	--	--	--	--	--	--	--
Typical	WB02	24.7	0	--	--	--	--	--	--	88	90	93	89
	WB05	24.4	0	--	--	--	--	--	--	94	93	96	90
	WB06	25.1	0	--	--	--	--	--	--	92	89	90	90
	Avg.	**24.7**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**91**	**91**	**93**	**90**

The influent and effluent volumes and concentrations for the typically loaded pervious concrete tests in Part 1 were used to determine the percent metals removed in each cylinder for each event. The average removal with standard deviation is presented in Figure 1. Retention of metals in the concrete was found to be no less than 85% for zinc and for copper, even after 10 consecutive events.

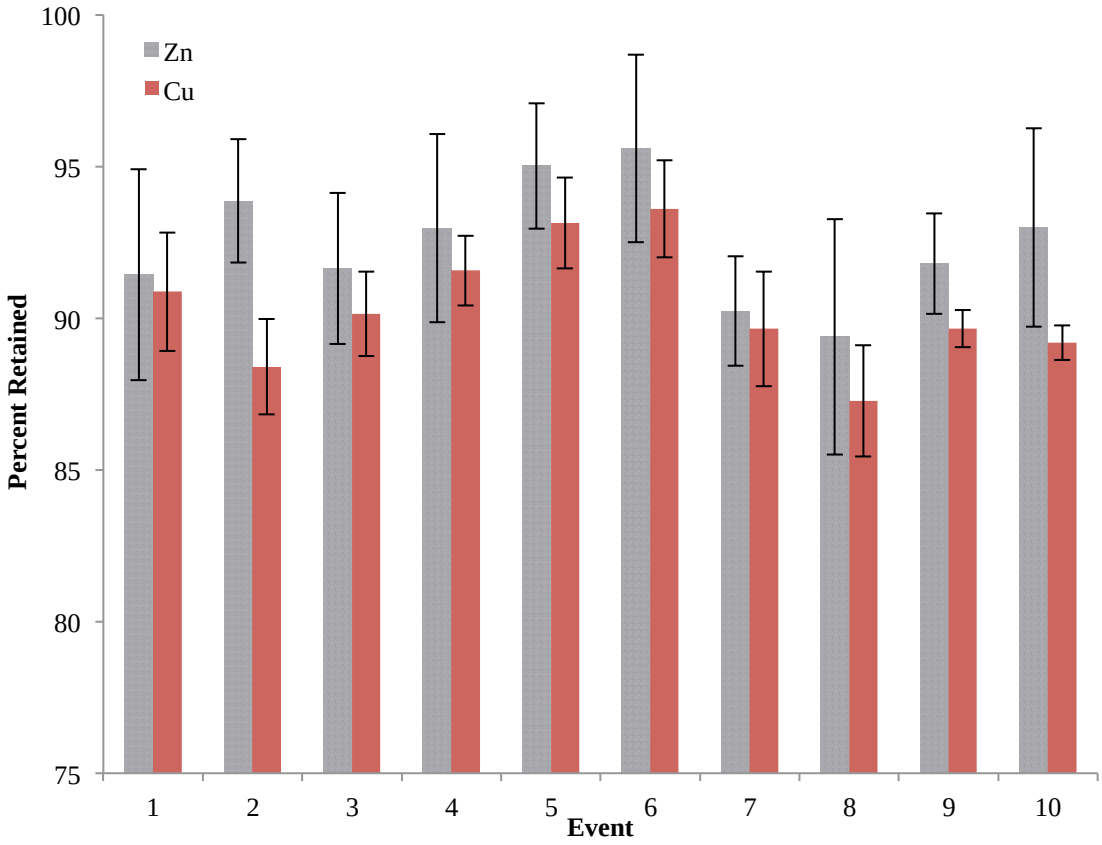


Figure 1: Average zinc and copper percent retained during typical concentration loading events in three pervious concrete cylinders (Part 1)

The influent concentrations of zinc for the accelerated events in Part 2 ranged between 4285 µg/L and 4901 µg/L with one at a higher concentration of 5722 µg/L. This was probably due to experimental variability and laboratory errors, but does not affect the overall results. The average composite effluent concentration was 2,200 µg/L. Figure 2 shows the influent and effluent concentrations for each event.

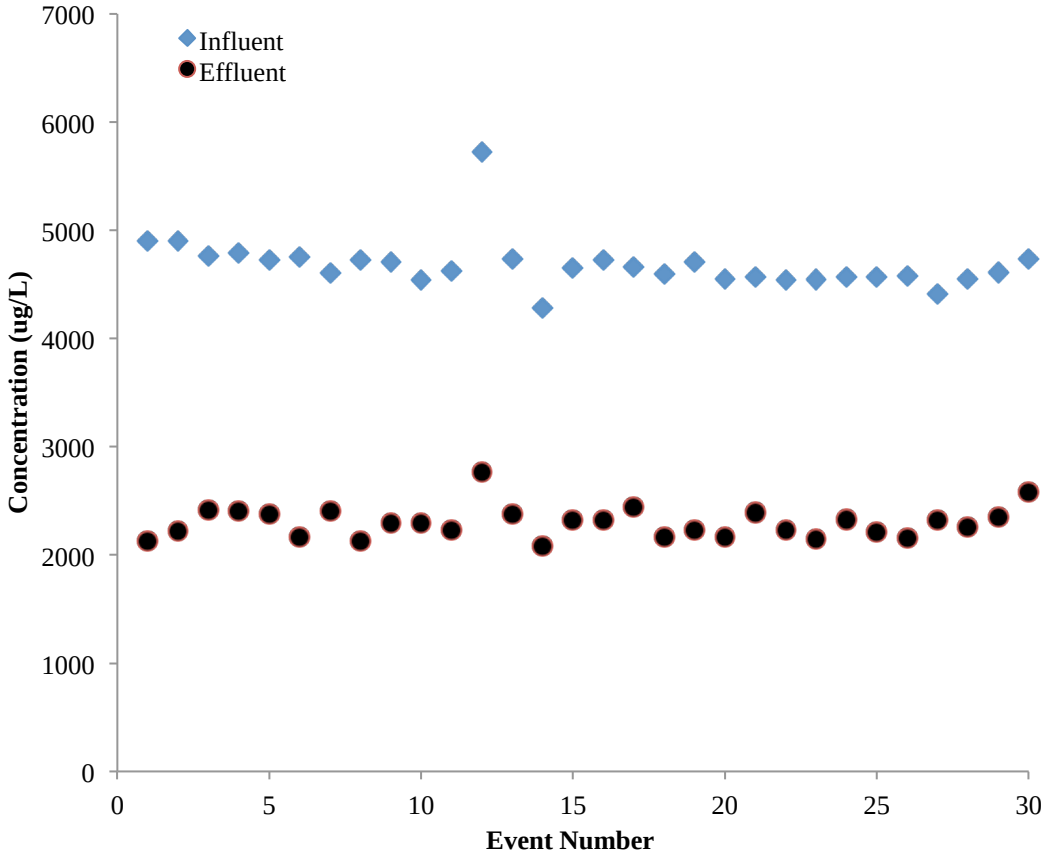


Figure 2: Average measured concentrations of zinc for accelerated events (Part 2)

In these same accelerated events the copper influent concentrations ranged from 745 µg/L to 814 µg/L with one high influent concentration of 937 µg/L and one low concentrated sample of 715 µg/L. These high and low values were probably due to experimental variability and laboratory errors, but do not affect the overall results. The copper concentrations for the accelerated events, shown in Figure 3, encountered an interesting phenomenon of lower effluent concentrations as the number of events increased.

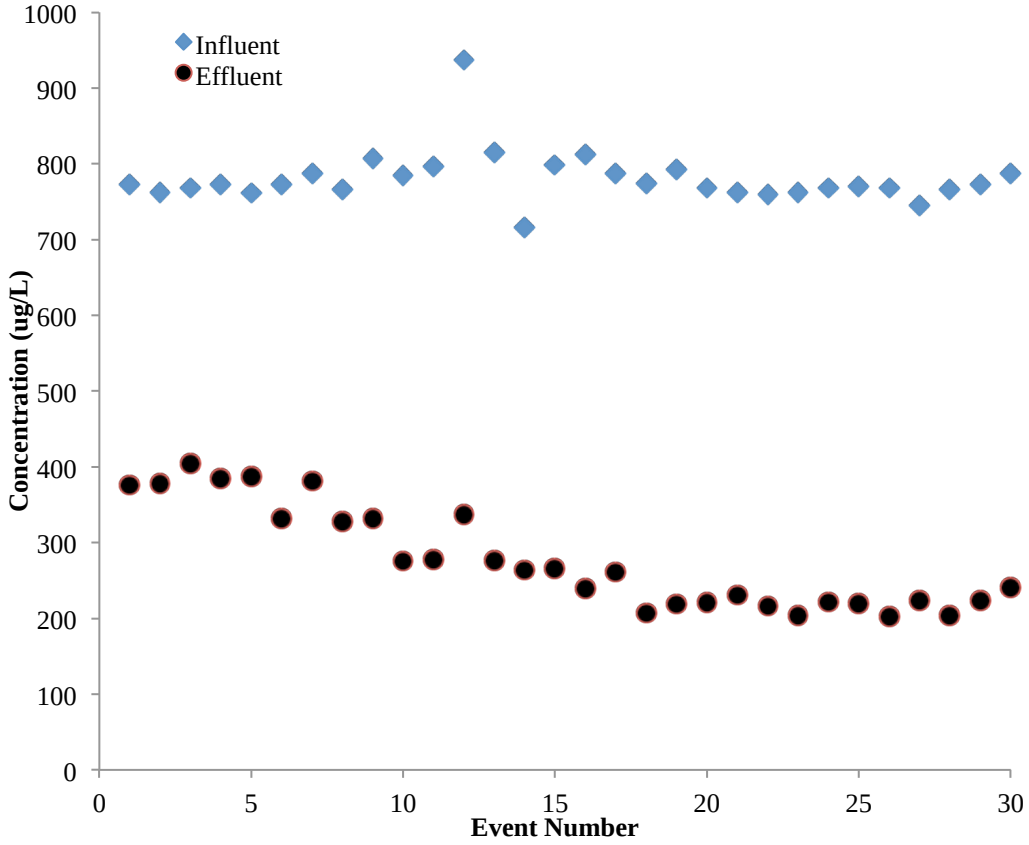


Figure 3: Average measured concentrations of copper for accelerated events (Part 2)

Decreasing concentrations of copper in the effluent may be due to the increase in temperature experienced during the March-August 2012 experimental period. However, the cylinders, stock solutions, and simulated rainwater were in a conditioned laboratory during this period, so the temperature difference is expected to be negligible.

Based on the individual event influent and effluent composite concentrations and volumes, the percent removal for copper and for zinc were calculated for each accelerated event. The averaged effluent volumes for the accelerated events are presented in Figure 4. (Note that the effluent volume recorded for Event 30 is an outlier and is assumed to be experimental error due to misreading of a graduated cylinder which had faint volume markings. This outlier is not included in any of the summaries.) The mass balances representing average percent metals removal for each accelerated event are presented in Figure 5. The zinc percent removal was never less than 64% except as noted for the last event. The copper retained in the concrete increased with storm events. Copper removal was 63% at first, slowly increasing to about 80%, except again for the final event.

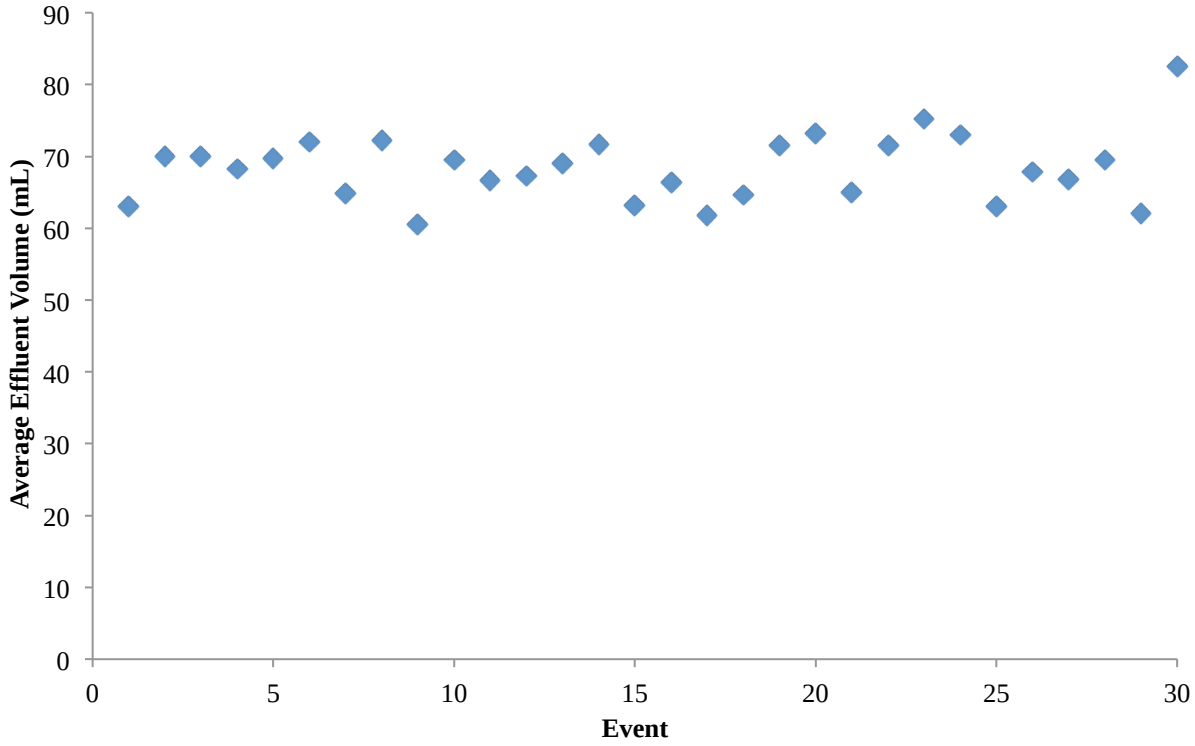


Figure 4: Average effluent volumes for each accelerated event (Part 2)

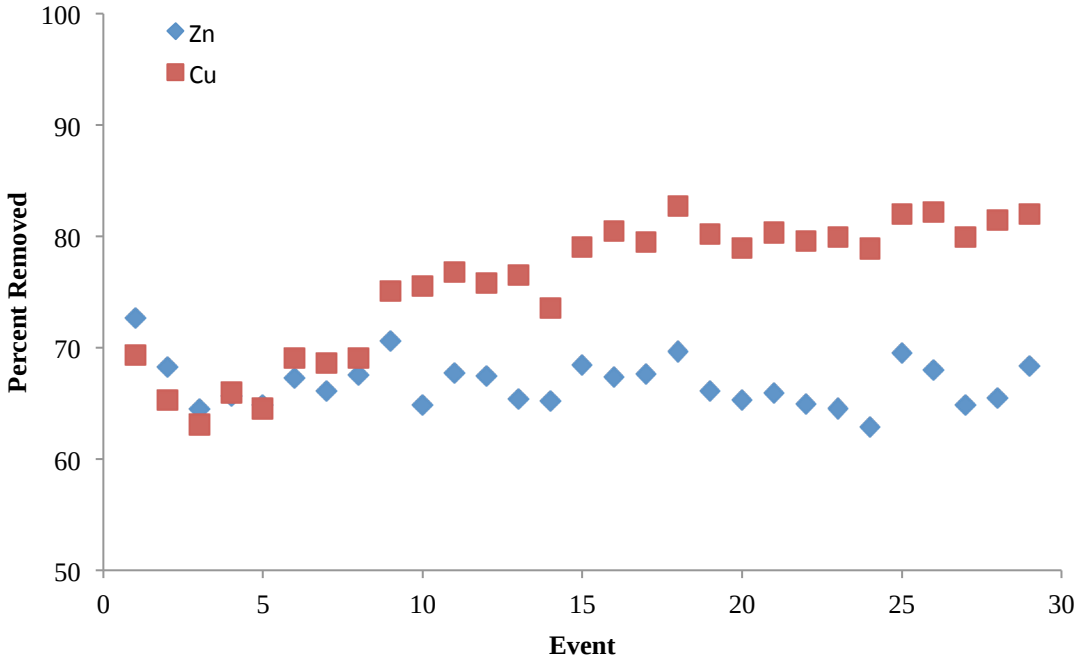


Figure 5: Percent of zinc and copper retained in cylinders during accelerated loading events (Part 2)

In Part 3 two of the cylinders were taken from Part 2 for further typical loading tests. One of the cylinders, WB10, was removed from the accelerated loading cycles after 15 events and received three consecutive typical loading events. The zinc and copper removal percentages for these three post-accelerated loading consecutive typical loading events were found to range from 92 to 95, and 87 to 93 respectively, with all values given in Table 1. Another cylinder, WB11, was removed from the accelerated loading tests after 24 events and received three consecutive typical loading events. Table 1 indicates that the removal percentages ranged from 86 to 93 and 86 to 89 for zinc and copper respectively for WB11 after the 24 accelerated loading events.

Table 1 also provides some of the removal percentages for the typically loaded cylinders without the long-term accelerated loading. Comparing the results of the initial typically concentrated storm events (Part 1) to the typical storm events after the accelerated loading (Part 3), the long-term loading did not significantly decrease the zinc and copper removal capacity of pervious concrete.

The removal efficiency of typical stormwater concentrations of dissolved zinc and copper through a layer of pervious concrete appear to be very high, even with influent concentrations well above any levels found in stormwater runoff from most roadway applications. The accelerated testing events included 30 applications of 12 mm (0.5 inches) of rain with 40 times the typical concentrations of dissolved zinc and copper, or assuming no runon from other surfaces, 15 years of rainfall in a region with 1.02 m (40 inches) annual rainfall. In a similar manner, the two cylinders which were sacrificed to perform the subsequent typical event trials were sacrificed at approximately 7.5 and 12 years of metal loading for similar rainfall averages with no runon. Estimates for applications that include runon from other surfaces can be similarly performed depending on the areas involved and the associated rainfall.

The increase in the affinity for copper sorption in the accelerated experiments modeling longer term exposure is an interesting phenomenon. The values of the logarithm of the stability constants for the copper carbonate and hydroxide solids versus the zinc carbonate and hydroxide solid species may provide some reason for this. The logarithm of the solid carbonate values for these constants are 9.6 for copper and 10.0 for zinc implying a small preference for the zinc species when the dissolved ion concentrations are the same. With the higher dissolved concentrations of zinc in the simulated runoff, surface sorption of the zinc is expected to occupy more surface sites. However, the logarithm of the stability constants for the solid copper and zinc hydroxide ligands respectively are 19.3 and 16, giving a small preference for the copper species when the dissolved ion concentrations are the same (Stumm and Morgan, 1996). This implies that the copper may have a preference for forming the interior hydroxide species. An alternate consideration is that, if competition between the two metal ions is not considered, the higher dissolved zinc concentrations in the simulated stormwater implies that over time the surface sites might have a larger concentration of zinc. However, if this was the governing process explaining changes in the affinity for the two metal ions, then the affinity for zinc should be decreasing with the number of storm events. After 30 events, this has not happened, implying that the affinity for zinc sorption in the channels has not yet reached saturation.

Continued testing well beyond the 30 event accelerated methodology would be useful in determining life expectancies, as would batch testing for absorption in equilibrium with allowable effluent levels. It is also recommended that similar experiments are performed using variable ratios of the two metals, and/or other metals to explore competition for adsorption sites. Factors such as temperature, pH of the rainwater, various pervious concrete mix designs with supplementary cementitious materials, and the introduction of solvents or other compounds in the stormwater, are subject to further investigation to gain a better understanding of the capacity of pervious concrete to sorb and retain metals. Finally, variable flow rate experiments would be useful in estimating removal efficiencies under design conditions with higher flowrates.

Acknowledgments

The authors are grateful for funding provided for this project by the Washington State Ferries and for assistance from Michael Wolcott, David Yonge and Kirsti McDaniel of Washington State University. The synthetic rainwater chemical composition was provided by Marcus Flury of Washington State University. Materials have been donated from Central Pre-Mix and Atlas Concrete Company.

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Appendix C: Dissolved Zinc and Copper Absorption in Pervious Concrete under Enhanced Loading Conditions

Dissolved Zinc and Copper Absorption in Pervious Concrete under Enhanced Loading Conditions

Liv M. Haselbach*, Cara J. Poor, Jerin W. Tilson
Washington State University, Pullman, Washington, USA
*Correspondence: haselbach@wsu.edu, 509 335 4874, Fax: 509 335 7632

Abstract

Pervious concrete is a novel pavement material with many environmental benefits such as stormwater management and heat island mitigation. It has been shown that permeable pavements may also reduce stormwater metal pollutant loadings associated with filtered solids. This study evaluated the ability of pervious concrete to sorb dissolved metals based on chemistry associated with pH, carbonate species, and hydroxide species in the hydrated cement. Portland cement based pervious concrete cylinders, which had been previously aged under ambient conditions in the laboratory for over three years to represent carbonated field conditions were used. Very high concentrations of dissolved zinc and copper based on typical roadway stormwater levels were applied to the cylinders and the exfiltrate analyzed. Removal rates for these elevated conditions initially exceeded 85%. Future long-term testing will provide information on the efficacy of pervious concrete systems for enhanced dissolved metal water quality treatment.

Introduction

Certain dissolved metals species in stormwater runoff may be of concern if high levels enter waterbodies where the biota are sensitive to these metals. It has been shown that many permeable pavement systems are effective in removing many metals from stormwater. In a study evaluating the performance of concrete media to filter pollutants from stormwater runoff, different types of paver stones were tested in the field to determine the effectiveness of the removal of contaminants (Brattebo and Booth, 2003). The minimum detection limits were 1.0 µg/L and 5.0 µg/L for copper and zinc, respectively. Results varied due to the different types of paver systems tested. 97% of influent samples contained metal concentrations that were considered toxic. After treatment, however, 31 of 36 samples tested for metals were below toxic levels. Furthermore, most of these samples were below the detectable limits. In another study by Dierkes et al. (2007) effluent collected from stormwater runoff containing zinc and copper infiltrated permeable pavers with a subbase containing limestone. The infiltrated stormwater through the limestone paver system experienced 88% and 94% removal for zinc and copper, respectively. In a field study in Pennsylvania, metals were removed from stormwater by infiltrating through a pervious concrete system (Barbis, 2009). Stormwater runoff containing 7.1 µg/L of copper infiltrated through a pervious concrete system. The effluent was collected and copper was measured below 2.8 µg/L. The influent concentration for zinc was 90.4 µg/L and it experienced significant removal flowing through the pervious concrete system.

However, much of the aforementioned removal effectiveness might be from filtering of metal laden particulates in the stormwater. In addition, there might be absorption or adsorption to other components in the systems such as retained sediments, or soils and

other materials in the underlying aggregate storage beds or soils. The hypothesis of this current research is that the pervious concrete itself can be used to remove various dissolved metal species from stormwater runoff, particularly in this case dissolved copper and zinc. This is due to the unique carbonate/hydroxide chemistry of concrete with a fairly high pH which may promote copper and zinc complexation along the flow channels, and then diffusion into the porous structure of the cement paste in the concrete itself.

The objective of this study is to test the removal effectiveness of pervious concrete for dissolved zinc and copper by applying specific known concentrations of these metals through pervious concrete cylinders in the laboratory, and collecting and testing the effluent for dissolved zinc and copper. The water volumes and flowrates used are based on typical larger storms such as 6 month to 5 year events, with the concentrations representative of first flush conditions in areas expected to receive higher levels of metal pollutants.

Experimental Methodology

Three similar pervious concrete cylinders were used in this experiment. All three were made with ordinary portland cement, water and #8 aggregate at the WSU civil engineering laboratories in December 2008. They were previously used for pH testing with deionized and/or tap water in 2010, and left exposed to ambient laboratory conditions before and after this previous pH testing. This implies that the cylinders were substantially surface carbonated under natural conditions, which was validated by the lower pH of the effluents in the previous tests. The three cylinders were then tested for porosity in June 2012 using a modified ASTM C1754 method. The pervious concrete cylinders were all approximately 7.3 inches (185 mm) in height.

The metal concentrations used in this experiment are based on reported results from several field investigations found in the literature. In Schueler and Holland (2002), water quality tests for zinc and copper were performed on water samples taken from an oil grit separator that was located at a gas station, which is considered to be a hot spot for metal pollutants. The elevated concentrations in the oil/grit separator were found to be 554 µg/L and 112.6 µg/L for zinc and copper respectively. Stormwater samples collected from surface runoff from a highway in Texas showed concentrations of 222 µg/ for zinc and 37 µg/L for copper (Barrett et al., 1998). In the Barbis study (2009), the influent runoff contained zinc and copper concentrations of 90.4 µg/L and 7.1 µg/L, respectively. Given these ranges, this experimental plan assumed typical concentrations of 100 µg/L and 20 µg/L for zinc and copper, respectively, and used high (hot spot) concentrations of five times the typical (approximately 500 µg/L for zinc and 100 µg/L for copper). Actual concentrations varied slightly and are given in the results.

A stormwater mixture was made using a synthetic rainwater, zinc chloride, and cupric chloride. The synthetic rainwater was made to conform with rainwater samples taken at the Hanford site in Washington (Flury, unpublished data). The component details for this synthetic rainwater are given in Table 1.

Table 1. Chemical composition of synthetic rainwater.

Major Constituents	Concentration (M)
Na^+	4.63E-05
K^+	4.17E-05
Ca^{2+}	3.00E-06
Cl^-	4.23E-05
NO_3^-	3.88E-05
TIC	1.00E-05
TIC : total inorganic carbon (HCO_3^- + CO_3^{2-}) pH(measured) : 6.4; Ionic strength (calculated) : 0.0001 M	

To simulate rainfall and stormwater runoff on pervious concrete, 100 mL of the hot spot stormwater mixture was dripped over each concrete cylinder over a time span of approximately 10 minutes to represent the enhanced loading that might be experienced in a first flush from a pavement in high traffic areas. The top surfaces of the pervious concrete cylinders used in the experiment were 4 inches (102 mm) in diameter. A rainfall rate of approximately 2.9 in/hr (74 mm/hr) was used to calculate application volume. Rainfall rates vary with regions and seasons, but this rate is frequently found for 2-5 year peak storms and can be related to intensity/duration/frequency curve values for any region. Using the area of the cylinder and this rainfall rate, the volume of applied stormwater was calculated to be 100 mL for one storm event.

For each event (application of 100 mL of stormwater mixture), the volume of effluent was measured for mass balances. Effluent samples were collected in a 30-mL HDPE sample bottle for each experiment. All samples were acidified and refrigerated according to standard methods (Eaton et al., 2005). Between each event, the cylinders were placed in a maximum 50°C oven for a minimum of 24 hours to facilitate drying of the cylinder prior to the next event. Ten events were applied to each cylinder. Influent and effluent samples were sent to the geoanalytical laboratories at Washington State University for analysis of total dissolved zinc and copper using an Agilent Technologies 7700 Series Inductive Coupled Plasma – Mass Spectrometer (ICP-MS).

Results

Table 2 shows the porosities for each cylinder, which were nearly identical. Measured influent and effluent volumes and concentrations for each event are also shown in Table 2. Approximately 20-40 mL of the stormwater mixture was retained in the cylinder during each event. Data from event 6 was omitted due to experimental error.

Using a mass balance, the amount of zinc and copper that was retained in each cylinder during events was determined, which is represented in Figure 1. At least 85% of the copper and 90% of the zinc was retained for all events. Figures 2 and 3 show influent and effluent concentrations for zinc and copper, respectively. As each cylinder is loaded, retention levels do not appear to change. Effluent concentrations for both zinc and copper stay relatively constant throughout the 10 loading events.

Table 2: Results for Specimens Loaded with High Concentrations of Zn and Cu

Specimen ID	Porosity (%)	Event	Influent Volume (mL)	Effluent Volume (mL)	Influent Concentration (µg/L)		Effluent Concentration (µg/L)	
					Zn	Cu	Zn	Cu
WB13	24.8	1	100	76	579	94	43	12
		2	100	80	562	92	18	9
		3	100	72	601	100	42	15
		4	100	73	556	90	33	10
		5	100	63	575	94	29	10
		6	100	68	Experimental Error			
		7	100	64	573	93	38	8
		8	100	66	560	92	47	10
		9	100	71	575	93	40	11
		10	100	64	626	101	19	9
WB15	24.7	1	100	72	579	94	34	11
		2	100	77	562	92	19	9
		3	100	72	601	100	44	14
		4	100	72	556	90	28	9
		5	100	59	575	94	21	8
		6	100	66	Experimental Error			
		7	100	60	573	93	20	7
		8	100	66	560	92	15	7
		9	100	70	575	93	25	9
		10	100	66	626	101	29	11
WB17	25.0	1	100	74	579	94	27	9
		2	100	74	562	92	22	9
		3	100	72	601	100	25	12
		4	100	74	556	90	21	8
		5	100	62	575	94	26	7
		6	100	72	Experimental Error			
		7	100	69	573	93	44	9
		8	100	70	560	92	21	8
		9	100	72	575	93	33	9
		10	100	70	626	101	29	10

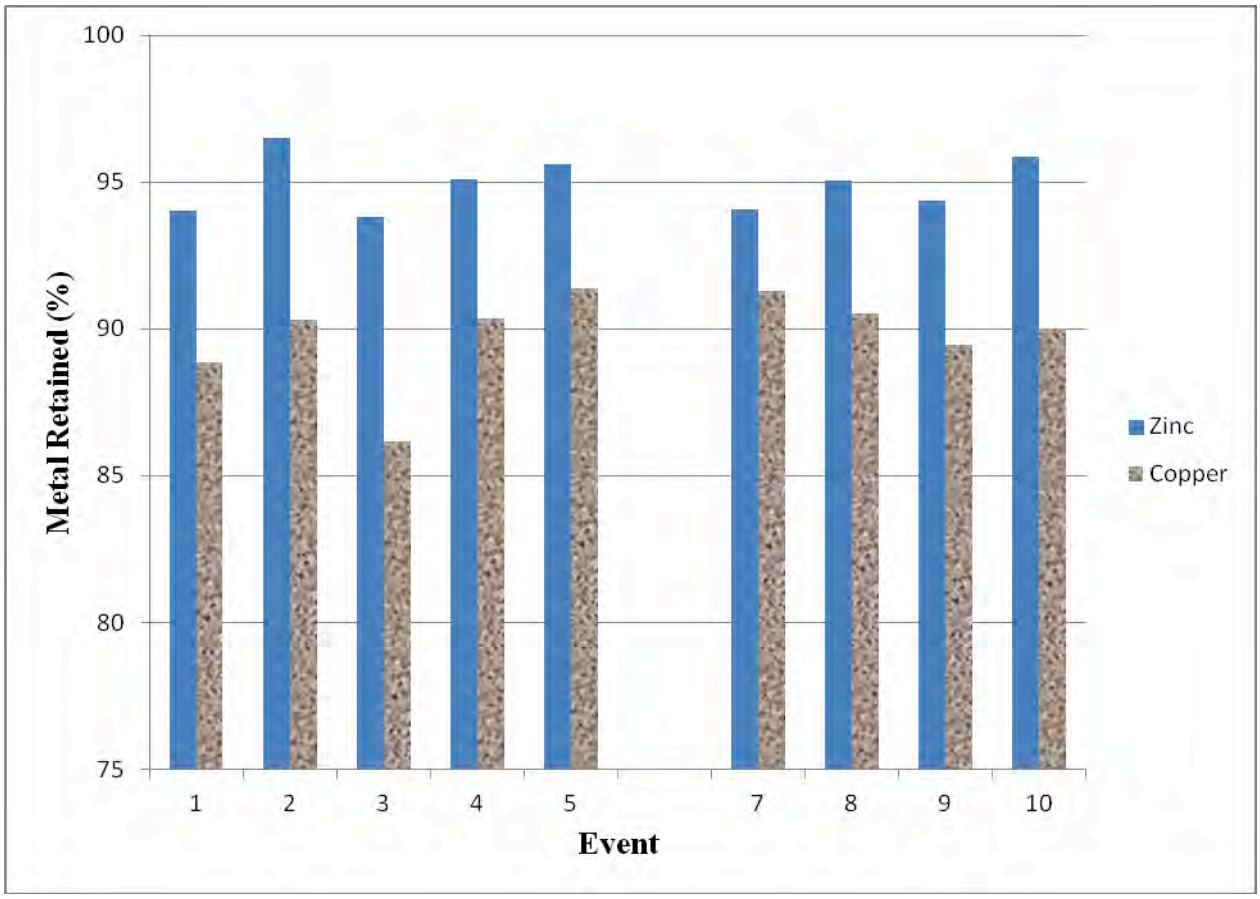

Figure 1: Percent metal retained averaged for the three cylinders.

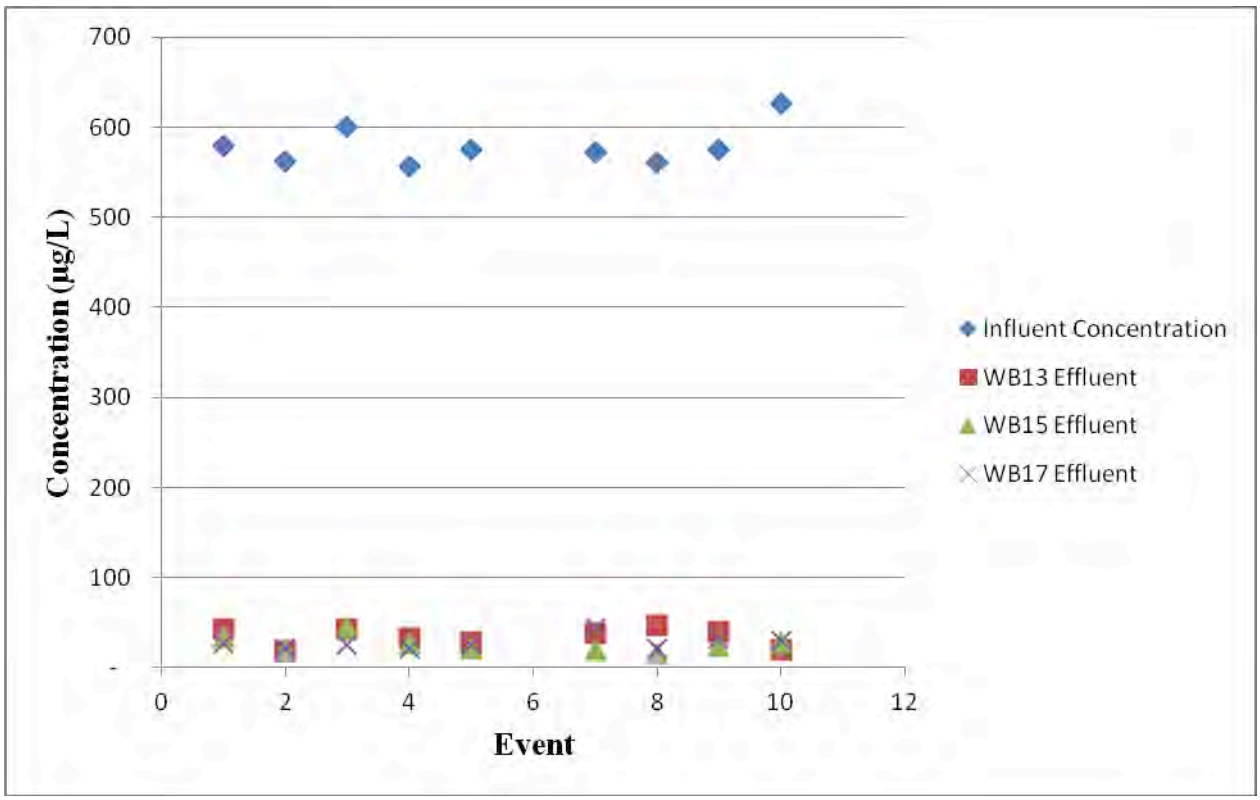

Figure 2: Influent and effluent concentrations of zinc for each cylinder.

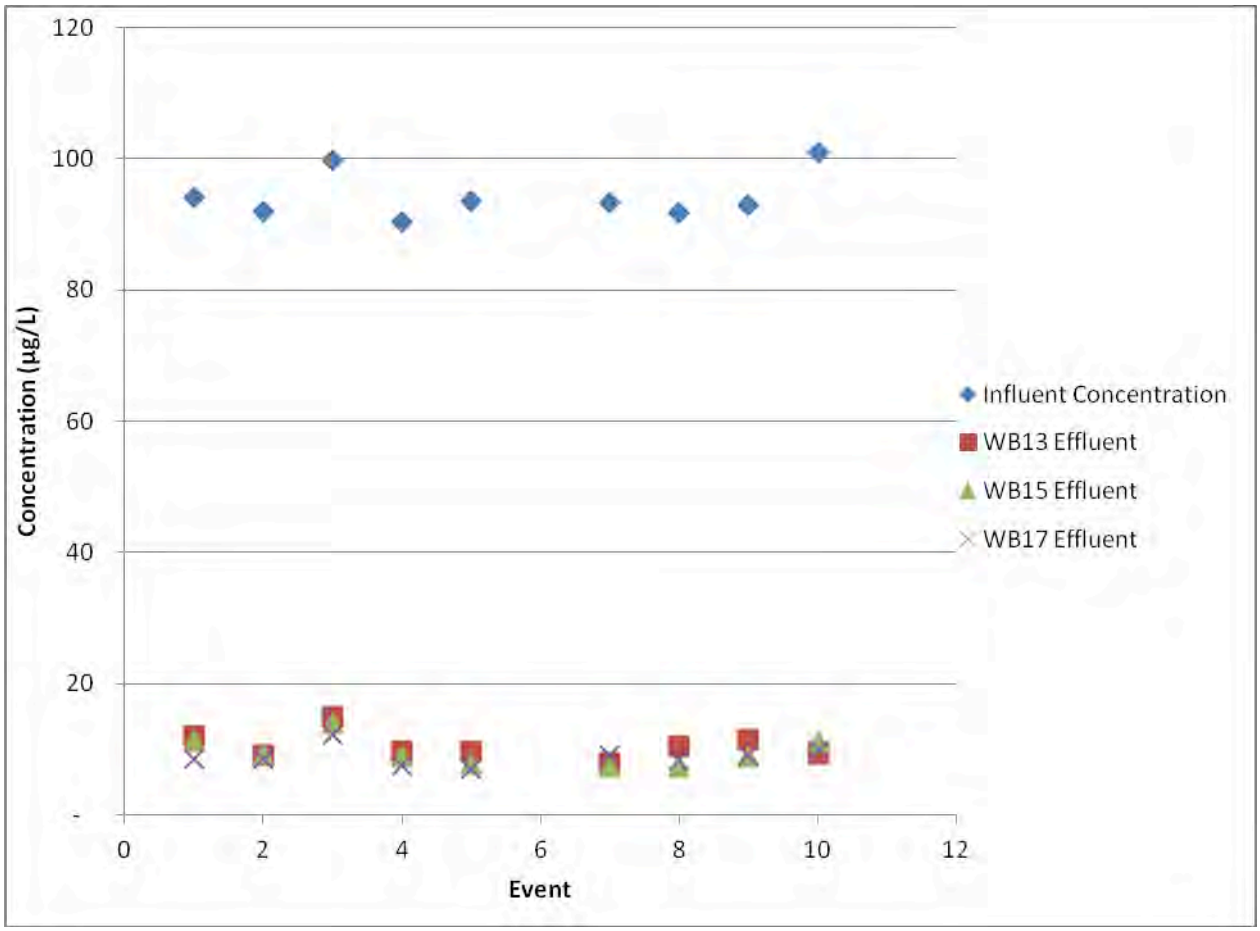

Figure 3: Influent and effluent concentrations of copper for each cylinder.

Conclusions

In all cases at least 85% of the copper and 90% of the zinc were removed from the stormwater mixture and sorbed to the pervious concrete, even after 10 events of consecutive loading. Pervious concrete is made of random, tortuous flow channels, various micropores, and both connected and disconnected macropores. Since the volumetric flow rates were fairly high, there was little chance for equilibrium partitioning to occur between the stormwater mixture and the pervious concrete cylinders. This indicates that pervious concrete has a high affinity for rapid surface sorption of dissolved zinc and copper in its flow channels. The retained metals might then more slowly diffuse into the pervious concrete matrix allowing for longer term retention and additional surface sorption sites in the flow channels. These removal rates achieve levels frequently found in specially designed water treatment media. This experiment indicates that pervious concrete has a high potential for enhanced dissolved zinc and copper removal from stormwater, even at hotspot concentrations and during fairly large storm events.

Future testing for extended times which might mimic decades of metals loading would aid in estimating the life of pervious concrete applications for enhanced metals removal. Other metals and different pervious concrete mix designs should also be tested to determine best practices under various field and material conditions.

Acknowledgements

The authors are grateful for funding provided for this project by the Washington State Ferries and for assistance from Michael Wolcott, David Yonge and Kirsti McDaniel of Washington State University.

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Appendix D: Summary of Dissolved Zinc and Copper Absorption in Pervious Concrete for Typical Loading Conditions

Summary of Dissolved Zinc and Copper Absorption in Pervious Concrete for Typical Loading Conditions

Liv M. Haselbach*, Cara J. Poor, Jerin W. Tilson
Washington State University, Pullman, Washington, USA
*Correspondence: haselbach@wsu.edu, 509 335 4874, Fax: 509 335 7632

Abstract

Pervious concrete is a novel pavement material with many environmental benefits such as stormwater management and heat island mitigation. Permeable pavements may also reduce stormwater metal pollutant loadings associated with filtered solids. This study evaluated the ability of ordinary portland cement pervious concrete to sorb dissolved metals based on chemistry associated with pH, carbonate species, and hydroxide species in the hydrated cement. Portland cement based pervious concrete cylinders, which had been previously aged under ambient conditions in the laboratory for over three years to represent carbonated field conditions were used. Typical concentrations of dissolved zinc and copper based on typical roadway stormwater levels were applied to the cylinders. Removal rates for these conditions initially exceeded 82% for copper and 86% for zinc. In addition, two cylinders experienced a pre-loading of both zinc and copper equivalent to several years of use and were then subjected to a typical concentration. Removal rates exceeded 82% and 80% on individual cylinders for typical copper loadings, and 87% and 80% for typical zinc loadings after the two different accelerated loading scenarios. These preliminary results indicate that removal rates remained high, but additional long-term testing is needed to estimate life expectancies of pervious concrete applications for zinc and copper removal under various conditions.

Experimental Methodology

Five similar pervious concrete cylinders were used in this experiment. All five were made with ordinary portland cement, water and #8 aggregate at the WSU civil engineering laboratories in December 2008. They were previously used for pH testing with deionized and/or tap water in 2010, and left exposed to ambient laboratory conditions before and after pH testing. This implies that the cylinders were substantially surface carbonated under natural conditions, which was validated by the lower pH of the effluents in the previous tests. The five cylinders were then tested for porosity in June 2012 using a modified ASTM C1754 method. The pervious concrete cylinders were all approximately 7.3 inches (185 mm) in height and four inches (102 mm) in diameter, and had average porosities of approximately 24 to 25%. They were all loaded with solutions containing dissolved zinc and copper at various concentrations several times (events). Both influent and effluent concentrations for both metals were analyzed for each event, and influent and effluent volumes recorded.

This experimental plan assumed typical concentrations of 100 µg/L and 20 µg/L for zinc and copper. (Actual concentrations varied slightly and are given in the detailed experimental results) The synthetic stormwater mixture was made using a synthetic rainwater, zinc

chloride, and cupric chloride. The synthetic rainwater was made to conform with rainwater samples taken at the Hanford site in Washington (Flury, unpublished data).

During the events some of the influent remained in the cylinders. Much of the stormwater runoff remains in the pervious concrete, allowing for evaporation and additional retention of metals. In between the events, the cylinders were placed in an oven with a maximum temperature of 50°C for a minimum of 24 hours to allow for significant evaporation.
The experiment included three parts. The first part represented typical concentration loading scenarios. The other two parts represented long-term accelerated loading scenarios after which the cylinders were exposed to typical loading events to determine if there was leaching or a reduction in sorptive capacity as compared to the initial typical loadings.

Part 1 consisted of loading three cylinders with a solution containing these typical concentrations of zinc and copper for ten storm events of 0.5 inches (12 mm) for 10 minutes (at a rate of approximately 2.9 in/hr or 74 mm/hr). Part 2 used one cylinder that was first loaded fifteen times at concentrations that were 40 times the typical concentration of zinc and copper. These loadings were applied at the same volumetric rates as Part 1. Afterwards, the cylinder was loaded three times with typical concentrations of zinc and copper. Part 3 consisted of 24 accelerated (40 times the typical loading) events, then three typical events applied to the cylinder.

Results

Figure 1 portrays the copper removal rates (percent) for the typical loading events in all three portions of the experiment. The values given in Figure 1 are averaged for all three of the cylinders used in Part 1. In Part 1, the individual cylinder removal rate for copper always exceeded 82%. In Parts 2 and 3, the individual cylinder removal rates for copper for the typical loadings experienced after the 15 and 24 accelerated events exceeded 82% and 80% respectively.

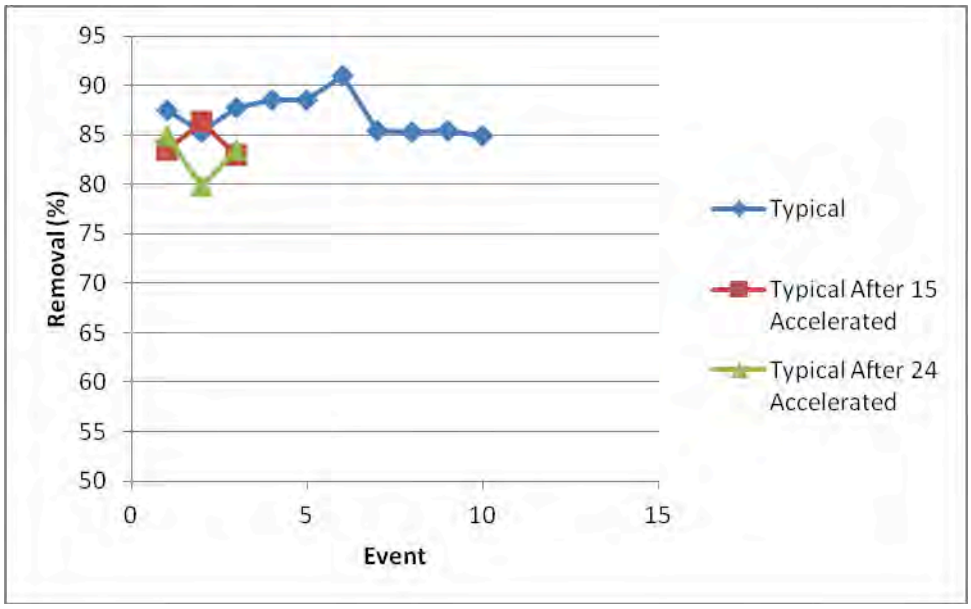

Figure 1: Average removal rates of copper for typical loading events for Part 1 (Typical), Part 2 (Typical after 15 Accelerated Events) and Part 3 (Typical after 24 Accelerated Events)

Figure 2 portrays the zinc removal rates (percent) for the typical loading events in all three portions of the experiment. The values given in Figure 2 are averaged for the three cylinders used in Part 1. In Part 1, the individual cylinder removal rate for zinc always exceeded 86%. In Parts 2 and 3, the individual cylinder removal rates for zinc for the typical loadings experienced after the 15 and 24 accelerated events exceeded 87% and 80% respectively.

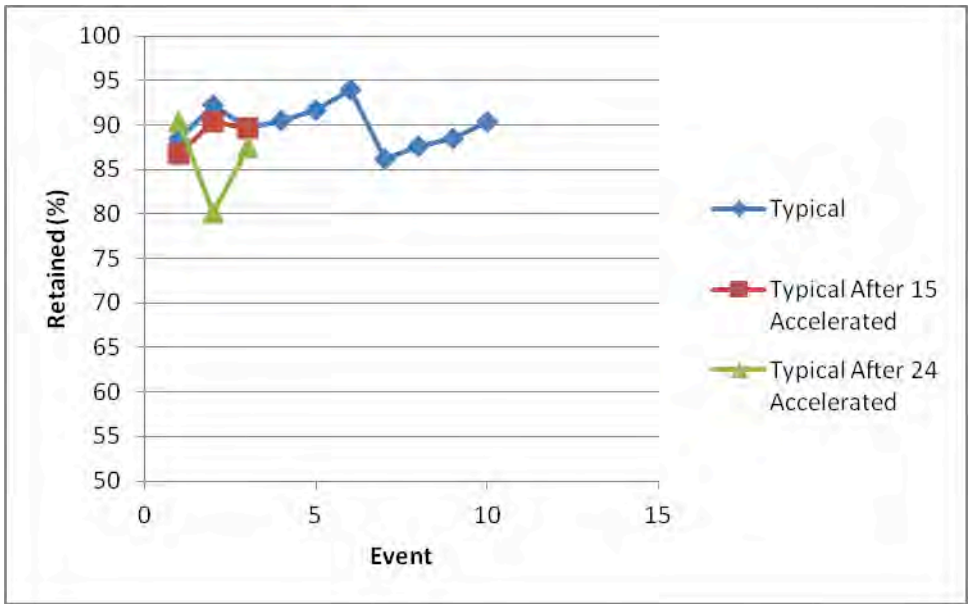

Figure 2: Average removal rates of zinc for typical loading events for Part 1 (Typical), Part 2 (Typical after 15 Accelerated Events) and Part 3 (Typical after 24 Accelerated Events)

Additional calculations were performed on the results from the accelerated events in Parts 2 and 3 to estimate the possible years of service these loadings represented. Using the volumes and concentrations in the influent and the effluent, the actual masses of zinc and

copper retained on each cylinder was estimated. Precipitation levels vary from region to region, but using an annual average of 40 inches (1020 mm) of rain per year, and the total typical concentrations in Part 1, maximum availability of metal infiltrating into the pervious concrete was estimated annually. Dividing the retained masses in the accelerated events and the metal availability per year then provides a conservative estimate of lifespans prior to the final typical loadings in Parts 2 and 3. These resulted in Parts 2 and 3 representing approximately 5 to 6 years, and 9 years of use respectively.

Conclusions

Copper and zinc were substantially removed from the stormwater mixtures and sorbed to the pervious concrete, even after multiple events of consecutive loading. Pervious concrete is made of random, tortuous flow channels, micropores, and both connected and disconnected macropores. Since the volumetric flow rates were fairly high, there was little chance for equilibrium partitioning to occur between the stormwater mixture and the pervious concrete cylinders. This indicates that pervious concrete has a high affinity for rapid surface sorption of dissolved zinc and copper in its flow channels. The retained metals might then more slowly diffuse into the pervious concrete matrix allowing for longer term retention. This experiment indicates that pervious concrete has a high potential for dissolved zinc and copper removal from stormwater, even after multiple years of use and during fairly large storm events. Additional testing was also initiated on cylinders which contained 25% supplementary fly ash for the cementitious material and preliminary results look promising.

Acknowledgements

The authors are grateful for funding provided by the Washington State Ferries and for assistance from Michael Wolcott, David Yonge and Kirsti McDaniel of Washington State University.

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Flury, M. Washington State University, Unpublished data.

Appendix E: Retention of Zinc and Copper in Shallow Bioretention Systems in a Laboratory Setting

Retention of Zinc and Copper in Shallow Bioretention Systems in a Laboratory Setting

Daniel M Wagner
Washington State University, Pullman, Washington

Abstract

Simulated storm events in urban areas were tested on various shallow bioretention systems to measure their efficiency of retaining zinc and copper. The systems consisted of a bottom layer of sandy loam, and top layer of compost, with geotextile fabric separating the layers. One system had 90% compost in the top layer by volume, with 10% vermiculite by volume. Another system had 90% compost in the top layer by volume, with 10% tree bark by volume. The living filter system contained live tufted hair grass, which is native to the Pacific Northwest to observe what effect vegetation had on the retention of heavy metals. Each system was exposed to simulated stormwater with elevated levels of dissolved zinc and copper weekly for 4 simulated storm events, with the exception of the standard and living filter systems which were exposed to 10 simulated storm events. The mass of zinc removed was consistently greater than 90% for both the vermiculite and tree bark systems, and greater than 80% for all units in every test. Copper retention decreased with each simulated storm event, yet began effectively removing copper again after the 6th storm event in the systems that were tested 10 separate occasions.

Introduction

Zinc and copper are heavy metals of concern in stormwater runoff, and can negatively impact aquatic ecosystems if the influent concentrations to large bodies of water are too high. Stormwater in urban areas threatens the biodiversity of natural systems in the environment, particularly bodies of water that receive large volumes of this runoff during a storm event. Non-point sources in urban areas such as vehicles in parking lots, highways, and roadways contribute large concentrations of heavy metals to stormwater during a storm event (Davis et al., 2001). Bioretention systems have the potential to mitigate the impact of contaminants carried in stormwater runoff during storm events (Davis et al, 1993; Roy-Poirier et al., 2010; Davis et al., 2003). Variations in the composition of media used within bioretention systems are known to greatly impact infiltration rates, as well as the removal efficiency of zinc and copper (Hsieh and Davis, 2005; Seelsaen, 2006).

Methods

Separate fiberglass boxes with a length of 3', depth of 12", and a width of 10" had three equally spaced holes drilled through the underside of the box for filtration purposes. Geotextile fiber was then placed on the bottom of these boxes to prevent soil media losses. Sandy loam was then placed on the geotextile fabric measuring approximately 4" in depth. Another geotextile fiber layer was placed on top of the sandy loam. Compost was then placed on this geotextile fabric which also measured approximately 4" in depth. All boxes had the same soil composition, with the only difference being one unit had 10% vermiculite by volume added to

the compost, one unit had 10% tree bark added to the compost by volume, and one unit had 4 tufted hair grass plants evenly placed within the compost and allowed to establish itself in the soil for 6 weeks.

Artificial rainwater was created in a laboratory setting and spiked with dissolved zinc and copper to simulate highly contaminated stormwater. The total volume of each stormwater batch was 11.375 L, with desired zinc concentrations of 580 µg/L and copper concentrations of 100 µg/L.

A sample of water was taken from the stormwater batch before coming into contact with the soil media. Each stormwater batch was then poured into a bioretention box and the effluent volumes were measured at each exit point before a sample was taken. This process occurred weekly for 10 weeks for each box.

The samples were then sent to the Geoanalytical Laboratory on the WSU campus where an ICP/MS was used to analyze the samples for concentrations of dissolved zinc and copper present in the solution. The effluent concentrations were averaged based on volume for each test. A mass balance was performed for each simulated storm event to determine the total percentage of zinc and copper removed by mass.

Results

Figures 1-8 show zinc and copper trend lines associated with the influent concentration and average effluent concentrations for each test and system (Standard Bioretention Mix, Standard Bioretention Mix with Vermiculite, Standard Bioretention Mix with Tree Bark, and Standard Bioretention Mix with Tufted Hair Grass).

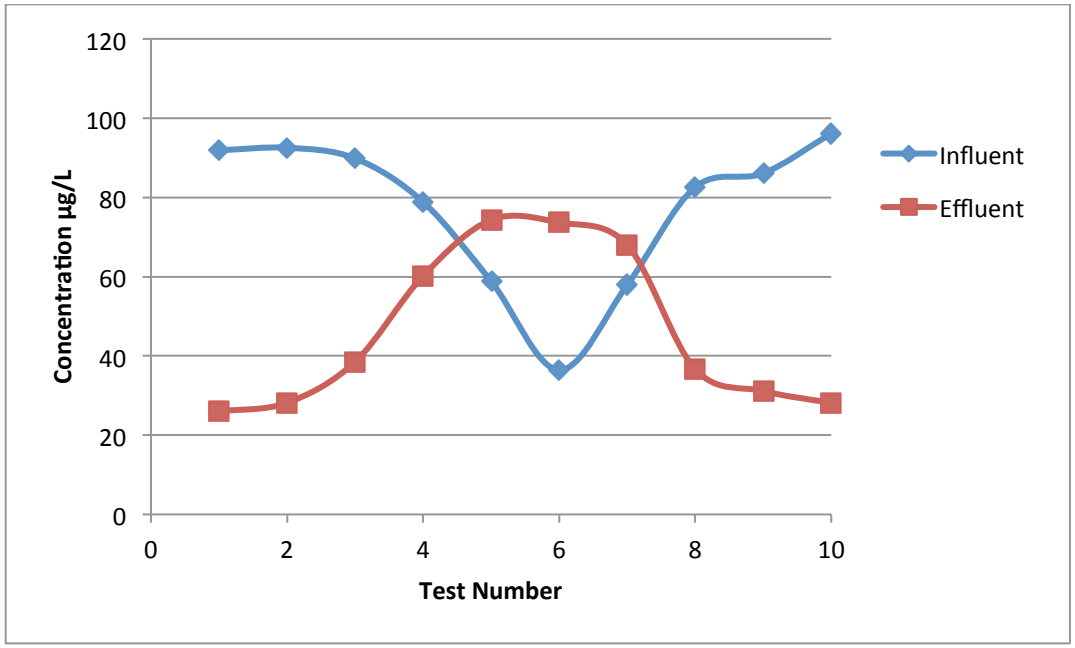

Figure 1. Copper Concentrations for the Standard System

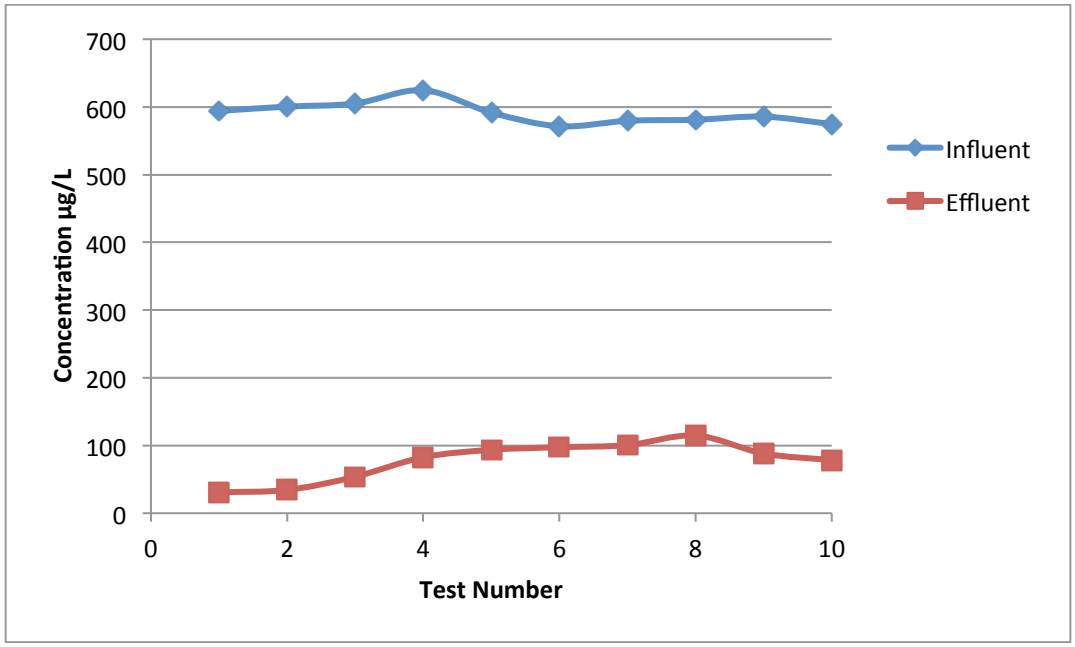

Figure 2. Zinc Concentrations for the Standard System

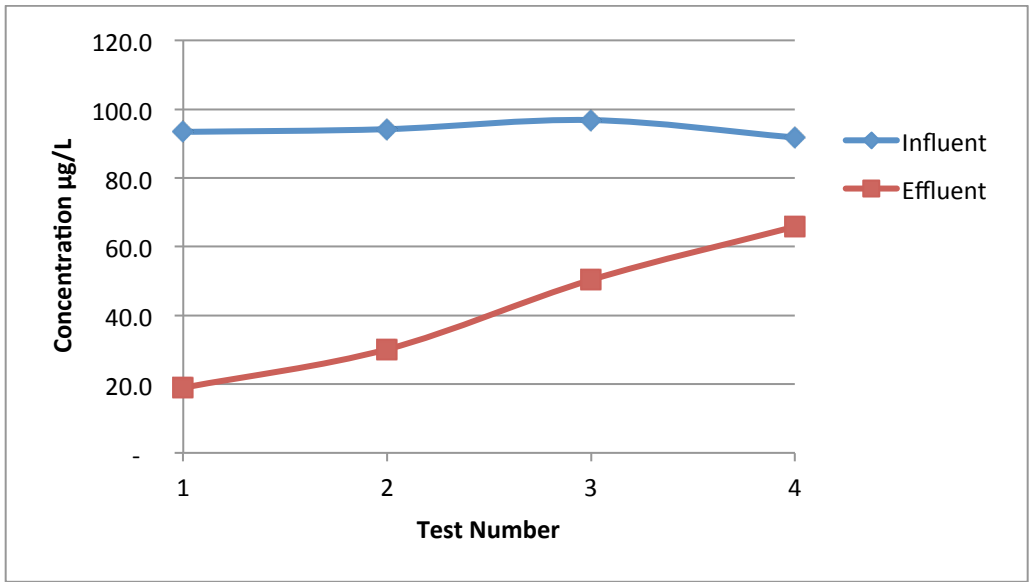

Figure 3. Copper Concentrations for the Vermiculite System

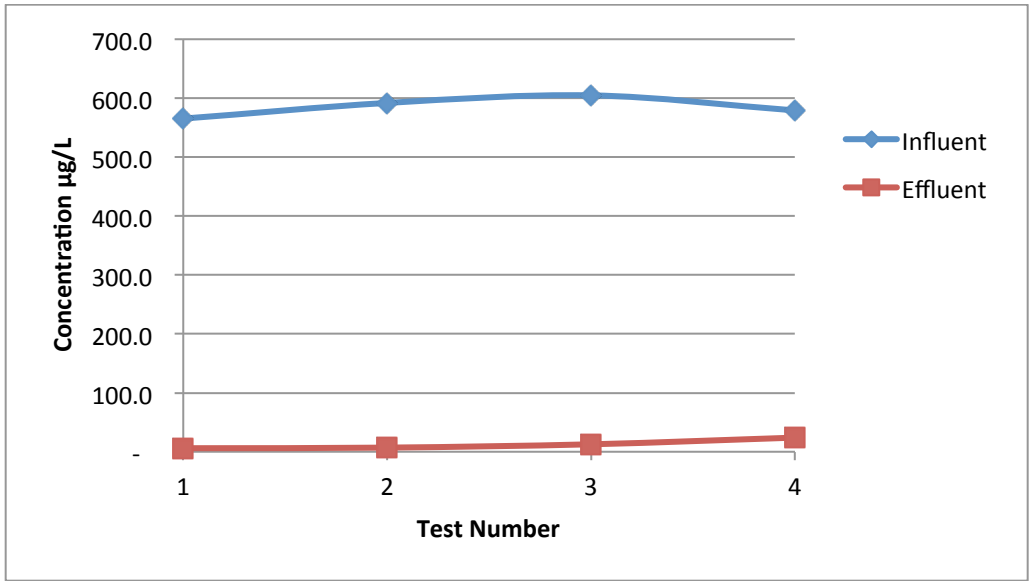

Figure 4. Zinc Concentrations for the Vermiculite System

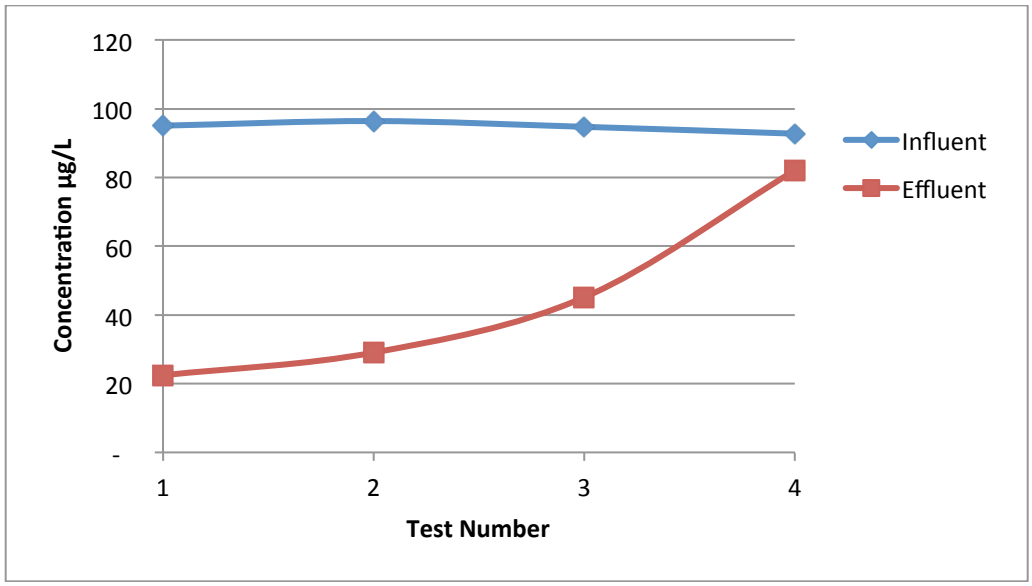

Figure 5. Copper Concentrations for the Tree Bark System

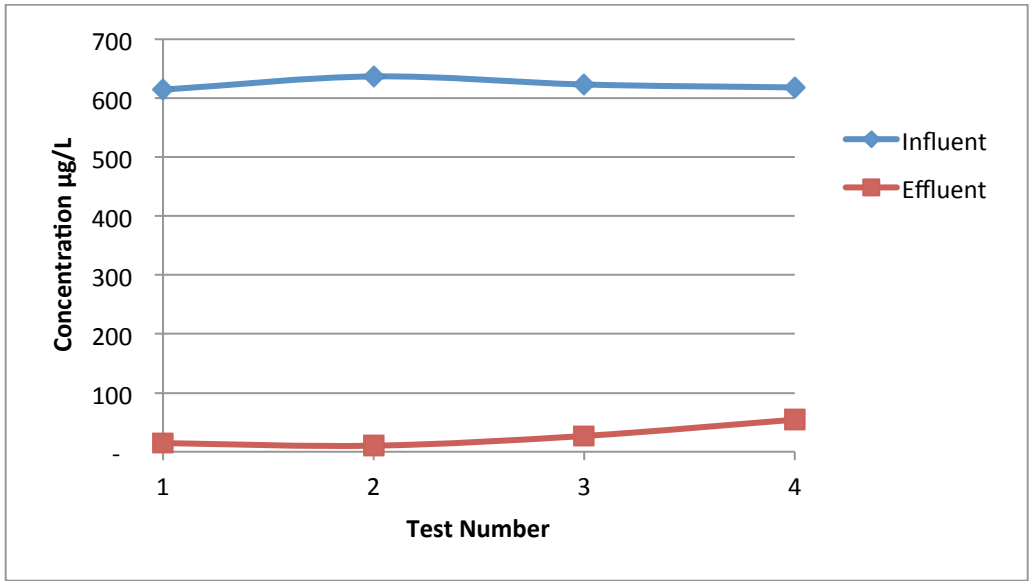

Figure 6. Zinc Concentrations for the Tree Bark System

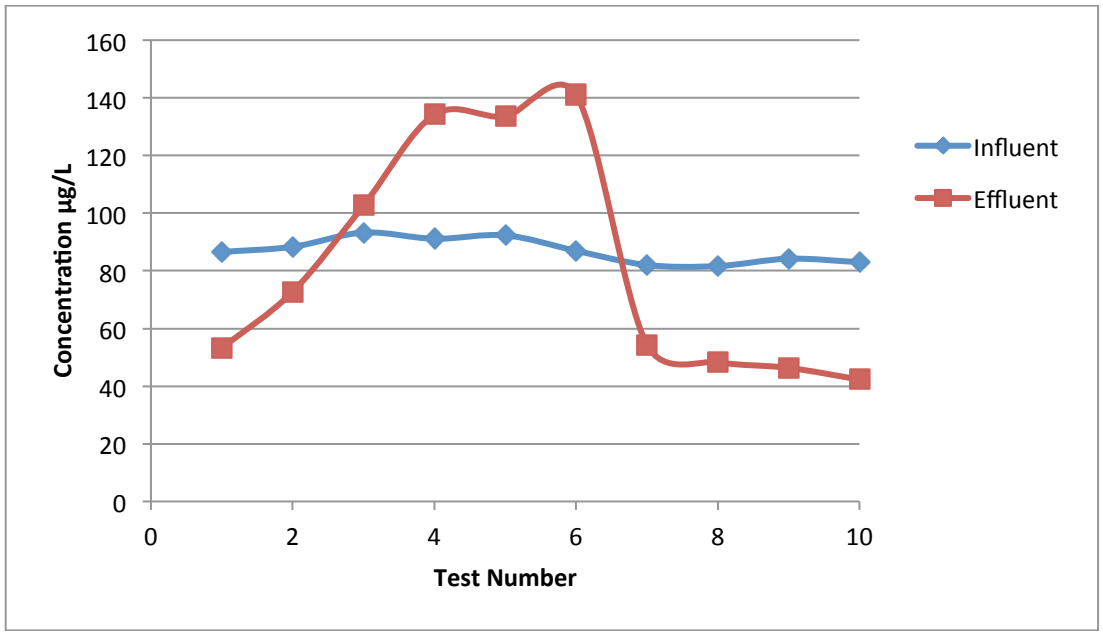

Figure 7. Copper Concentrations for the Living Filter System

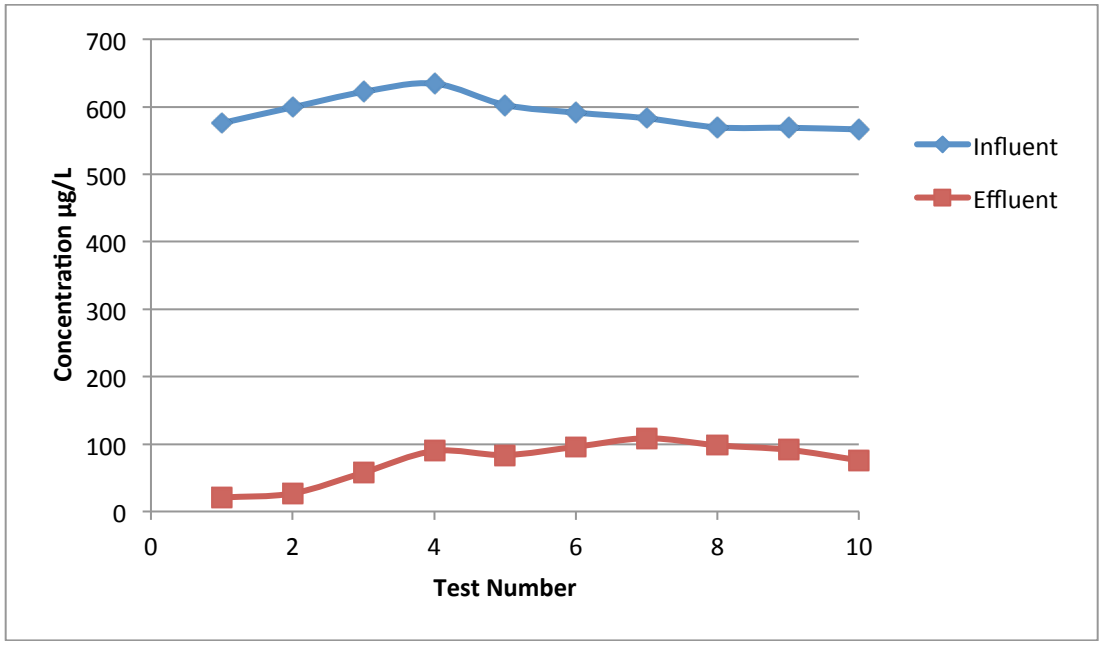

Figure 8. Zinc Concentrations for the Living Filter System

Table 1. Influent and Effluent Copper and Zinc Concentrations for Vermiculite and Tree Bark Systems

Vermiculite	Influent(µg/L)		Effluent(µg/L)		Tree Bark	Influent(µg/L)		Effluent(µg/L)	
Test	Cu	Zn	Cu	Zn	Test	Cu	Zn	Cu	Zn
1	93.4	565.0	18.94	6.01	1	95	615	22.41	14.23
2	94	592	30.14	7.03	2	96	637	29.05	10.31
3	97	605	50.34	12.66	3	95	623	45.13	26.82
4	92	579	65.82	24.00	4	93	618	82.07	54.43

Table 2. Influent and Effluent Copper and Zinc Concentrations for Standard and Living Filter Systems

Standard	Influent(µg/L)		Effluent(µg/L)		Living Filter	Influent(µg/L)		Effluent(µg/L)	
Test	Cu	Zn	Cu	Zn	Test	Cu	Zn	Cu	Zn
1	92	594	26	31	1	87	576	53	21
2	93	601	28	34	2	88	599	73	27
3	90	605	39	54	3	93	622	103	58
4	79	625	60	83	4	91	634	134	90
5	59	592	74	94	5	92	603	134	84
6	36	572	74	98	6	87	591	141	96
7	58	580	68	101	7	82	583	54	108
8	83	581	37	115	8	82	569	48	98
9	86	586	31	88	9	84	569	46	92
10	96	575	28	78	10	83	567	42	76

Tables 3 and 4 and Figures 9-12 show the percentage of copper and zinc removed by mass for all of the treatments.

Table 3.Percentage of Mass Removed in Media for Vermiculite and Tree Bark Systems

Vermiculite			Tree Bark		
Test	Cu	Zn	Test	Cu	Zn
1	99.4	100.0	1	97.7	99.8
2	83.2	99.4	2	82.9	99.1
3	57.4	98.3	3	58.6	96.3
4	39.0	96.5	4	25.6	92.6

Table 4.Percentage of Mass Removed in Media for Standard and Living Filter Systems

Standard			Living Filter		
Test	Cu	Zn	Test	Cu	Zn
1	94.9	99.1	1	71.1	98.3
2	83.1	96.8	2	39.8	96.7
3	61.2	91.9	3	27.6	93.9
4	33.0	88.4	4	3.2	90.7
5	-4.6	86.9	5	-3.1	90.1
6	-70.2	85.6	6	-22.5	87.8
7	4.5	85.9	7	53.9	87.0
8	64.0	84.0	8	54.3	86.7
9	69.5	87.3	9	57.8	87.7
10	75.7	88.7	10	64.1	89.8

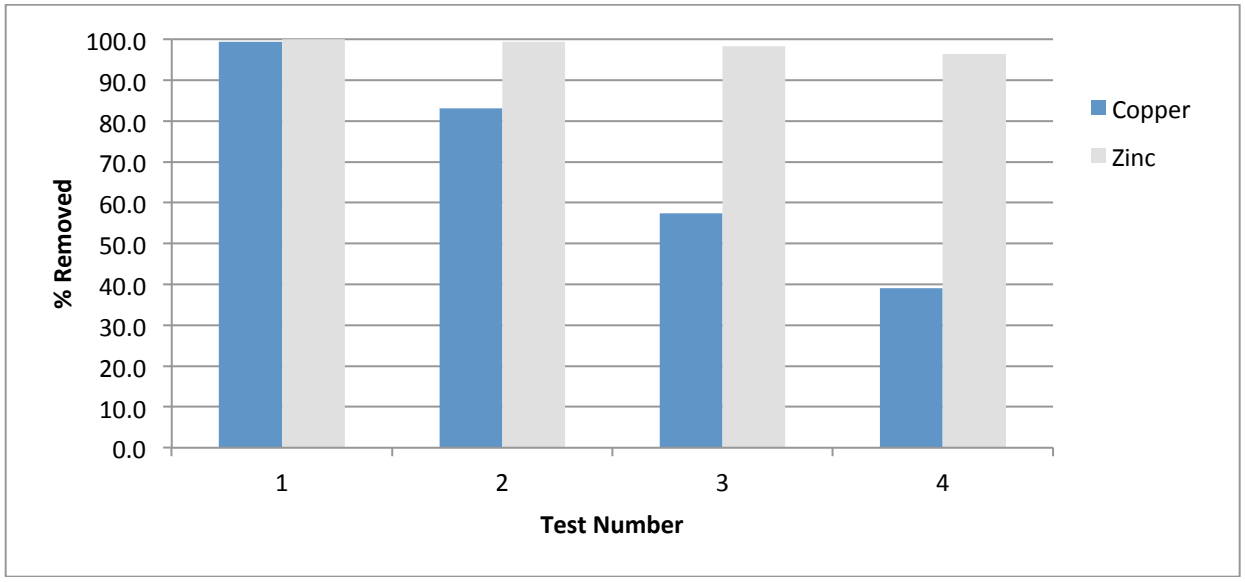

Figure 9. Percentage of Mass Removed in the Vermiculite System

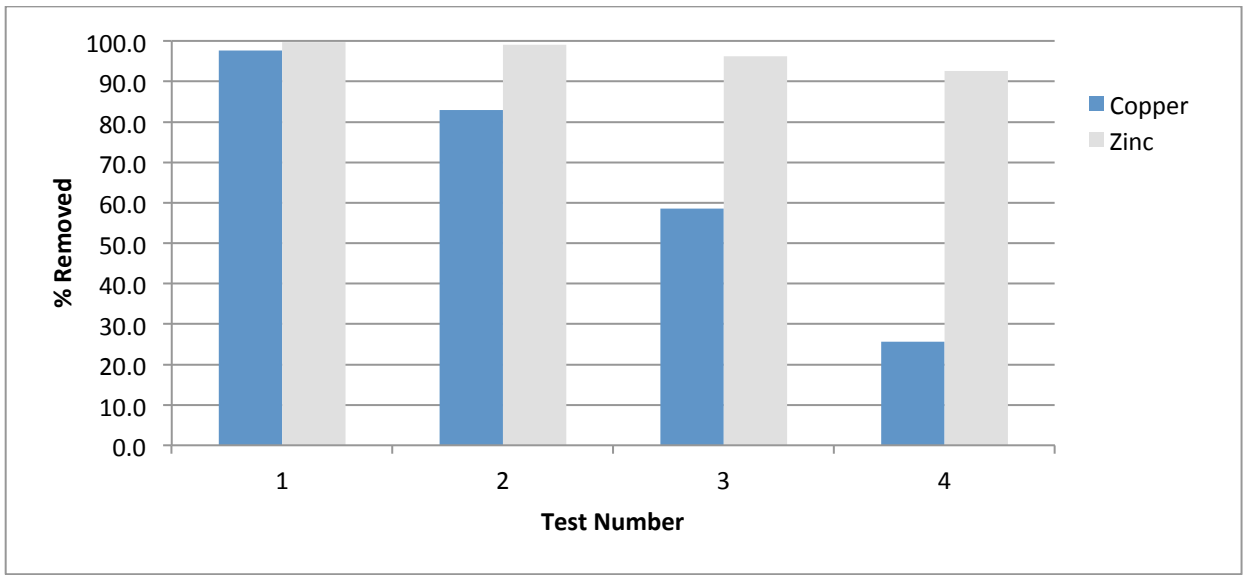

Figure 10. Percentage of Mass Removed in the Tree Bark System

The vermiculite system retained zinc consistently with an efficiency greater than 90%. Copper was retained with an efficiency of 99.4% during the first simulated storm event, yet dropped to a 39% efficiency by the 4th test (Table 3 and Figure 9).

The tree bark system retained zinc consistently with an efficiency greater than 90%. Copper was retained with an efficiency of 97.7% during the first simulated storm event, yet dropped to a 25.6% efficiency by the 4th test (Table 3 and Figure 10).

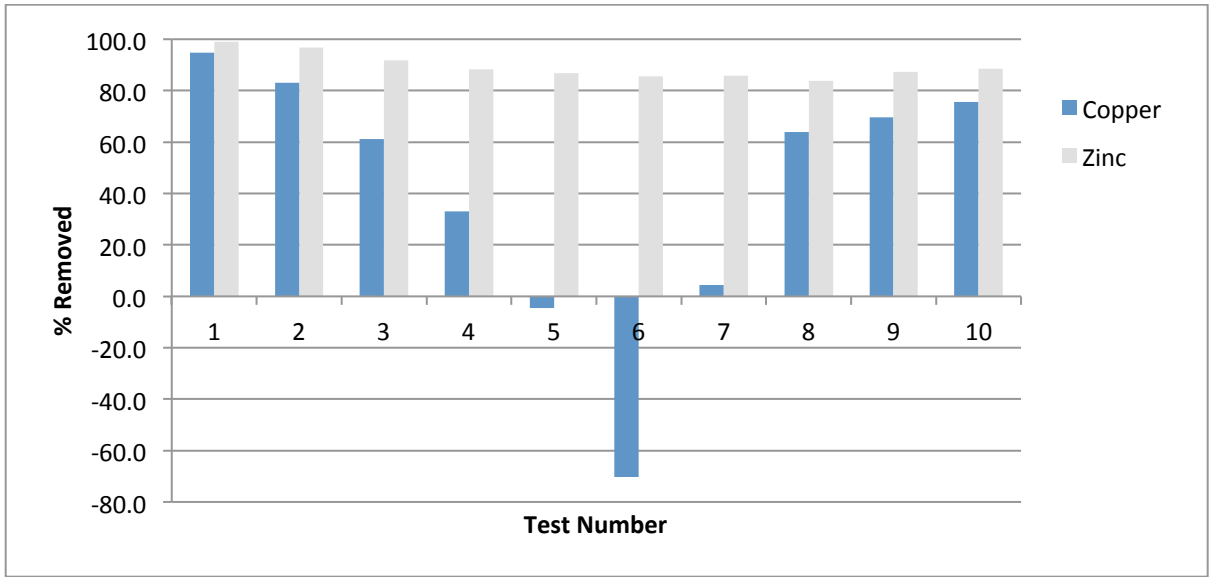

Figure 11. Percentage of Mass Removed in the Standard Bioretention System

The standard bioretention system initially retained dissolved copper and zinc very efficiently, with removal rates of approximately 95% and greater for the initial simulated storm event. The effectiveness of zinc removal remained above 90% until the 4th test (Figure 11). Zinc removal rates remained above 84% consistently, with the lowest retention percentage occurring on the 8th test. The dissolved copper in the standard bioretention system was not retained as efficiently as zinc, with the effective removal of copper being only 33% by the 4th test, and releasing more copper by mass in the effluent on the 5th and 6th test. In tests 7 through 10, the copper retention begins to increase again, with a removal rate of 75.7% by the 10th test (Table 4).

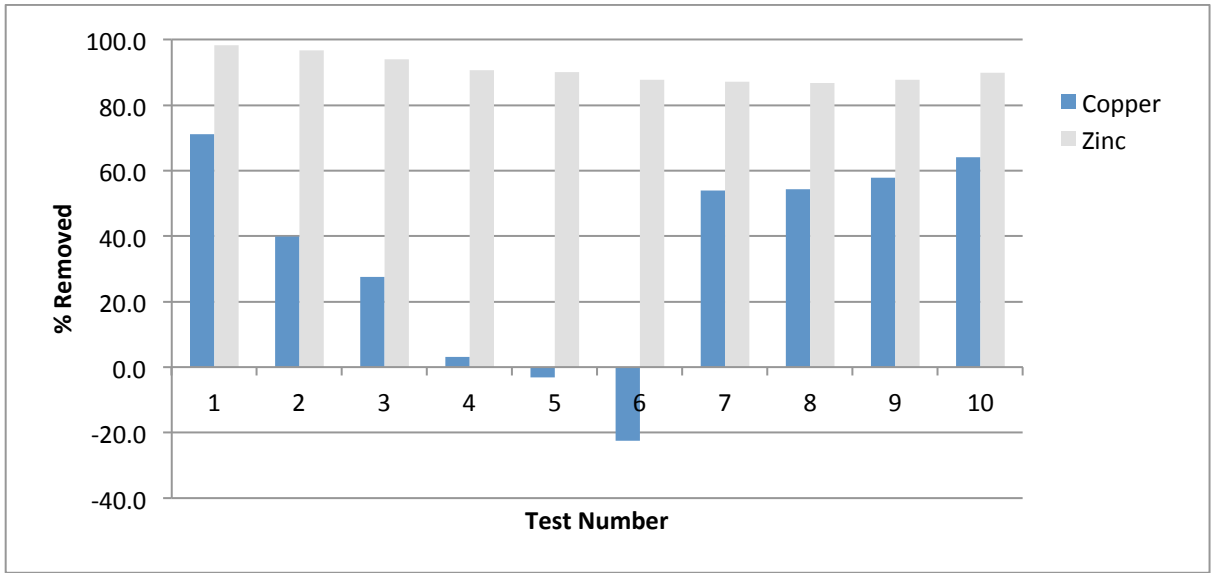

Figure 12. Percentage of Mass Removed in the Living Filter System

The living filter retained less copper initially, with the 5th and 6th tests releasing more copper by mass in the effluent than what was added in the influent. Tests 7-10 consistently retained more copper with each test, starting with 53.9% retention, and ending with 64.1% retention by the 10th test. Zinc retention was consistently above 86.7% with the lowest retention percentage occurring on the 8th test (Table 4 & Figure 12).

Discussion

When comparing the influent and effluent zinc concentrations for all bioretention systems, it is clear that they are all efficient at retaining high concentrations of zinc (Figures 9-12). Copper retention was not as efficient as the zinc in the shallow bioretention systems, and the effluent concentrations exceeded the influent concentrations in the experiments involving 10 simulated storm events (Figures 11 and 12). A mass balance was performed on the systems to account for evapotranspiration, soil saturation, and when applicable, plant intake of water. After a mass balance, it was found that the bioretention systems did retain more dissolved copper and zinc than was put into the system. The standard and living filter systems consistently retained more than 84% of zinc in all 10 tests, with the vermiculite and tree bark experiments retaining greater than 90% of zinc in the 4 tests. The standard and living filter systems retained copper by mass until the 4th test. The 5th and 6th tests in both systems had a greater copper effluent concentration by mass than the initial addition of copper in the simulated storm event. In tests 7-10, the standard and living filter systems showed a progressive increase in copper retention by mass again. While the living filter did not effectively retain copper as well as the standard system in the first 4 tests, total copper retention was greater overall in later tests. The living filter consistently retained a greater percentage of zinc by mass after the first two tests when compared to the standard system (Table 2). All of the systems were expected to remove copper and zinc. With decreasing copper retention rates in tests 1-4 for all systems, negative values were expected in tests 5 and 6 with the systems that were exposed to a greater number of storm events. It was unexpected when tests 7-10 in the standard and living filter systems showed effective removal of copper again, with an increased retention after each test. Further research is necessary to understand what mechanisms caused the shallow bioretention systems to retain copper in tests 7-10 in both the standard and living filter systems.

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Appendix F: Green Rating Integration Platform – A Decision Making Tool for Multi-Modal Facilities: Sustainable Water & Material Practices (submitted to Journal of Infrastructure Systems)

Green Rating Integration Platform – A Decision Making Tool for Multi-Modal Facilities: Sustainable Water & Material Practices

Ashraful Alam, Liv Haselbach*, Garrett DeRooy, Cara Poor, and Michael Wolcott
Washington State University, Pullman, Washington, USA
*Correspondence: haselbach@wsu.edu, 509 335 4874, Fax: 509 335 7632

Abstract

To achieve sustainability goals and receive credit points for green certification, it is essential to understand the strategies to accomplish the sustainability objectives of a project. Sustainability rating systems come with project goals and strategies. However, among the multitude of sustainability rating systems and guidelines, it is difficult to decide which goals will earn more credit points and what methods need to be followed to achieve particular goals. In addition, multi-modal projects have different focal areas and associated rating systems related to each mode or other aspect of the project. Five green ratings systems representative of these aspects have been selected and analyzed through an analytical hierarchy process (AHP). Previous research resulted in synchronization of the rating system topical categories and synthesis of the credits. This work focused on the water and material aspects, and the associated detailed goals and green methodologies. Key intents from the project goals and key strategies from the methodologies were identified. The lists of key intents and key strategies across the rating systems were then harmonized using an AHP and further cross-coded in an open database with the credit subcategories and corresponding rating systems. The database can filter the credit subcategories across the rating system for a specific key intent or key strategy. The harmonized lists and database may facilitate decision makers and sustainability practitioners in correlating intents and methodologies for a project across multiple rating systems.

Introduction

Sustainable design has become more common with the development of any kind of infrastructure or system (Curwell and Deakin, 2002). Global climate variability and increased urbanization, together with associated environmental problems have activated the growing interest in sustainable development. As a result, numerous sustainability rating systems and guidelines have evolved around the world.

Recent research has compared different rating systems to analyze the specific requirements to attain sustainability for individual projects. Retzlaff (2008) analyzed nine different green building rating systems to assess building requirements during the planning phase. The different rating systems that were analyzed are EarthCraft Communities, EarthCraft House, Enterprise Communities, Green Globes, Health House, LEED-H, LEED-ND, LEED-NC, and NAHB. LEED NC 2.2 was incorporated in the building information modeling (BIM) software to enhance awareness among the designers about the different sustainable design aspects in the early design phases (Biswas *et al.,* 2008). A Sustainable Systems Integration Model (SSIM) model has been developed for the city of Tanggu-Baitang in China (Georgoulias *et al.,* 2009). This

integration software evaluates the efficacy of the sustainable design concepts in terms of cost, and provides alternative development scenarios and design options. Instead of considering any specific green rating system, the model requires the input of the alternative concepts of sustainable design, and the software then analyzes the different concepts and ranks them.

This study builds upon previous research where topical categories across five different green rating systems were synchronized to develop a green rating integration platform (D'Agneaux, 2009; Thompson *et al.,* 2013). Although, the integration platform was developed with a focus on ferry facilities, it is applicable to most multi-modal projects. Seven topical categories were designated based on project functionality; site selection, materials, energy, water, air quality, traffic and parking, and integration in the community. The various credit subcategories were then synthesized across the topical categories to make the comparison of the rating systems easier for achieving the green building and construction goals. However, each of the credit subcategories has various defined intents or objective, and strategies or methods to accomplish the sustainability goals. There remains a need to develop an inter-relationship between these credit subcategories in terms of their objectives and strategies. The objective of this paper is to facilitate green or sustainability practicing users (engineers, researchers, developers, contractors, and others) to correlate their particular project goals and technologies within a common and harmonized platform containing a set of applicable green rating systems. For this case study, five rating systems previously identified as possibly applicable to a ferry terminal and other multi-modal marine facilities, and the water and materials topical categories within them were used.

Green Rating Systems

The growing interest toward sustainable development has led to the development of numerous sustainable rating guidelines around the world. These rating systems are constantly evolving. Various rating systems focus on different aspects of sustainable development. Although there are some commonalities in these rating categories, they vary for each country reflecting the climate and socio-economic condition of the country (Gomes *et al.,* 2008; Reed *et al*., 2009, Haselbach 2010).

The sustainability rating systems may vary within the regions of one country to satisfy particular regional requirements to achieve the intended sustainability. In addition, there is variability in rating systems as to the main type of project that is its focus, i.e., a building, a transportation system, or marine infrastructure. Credit categories in these rating systems usually cover a wide range of subject matter. Typical categories include site selection, water and wastewater management, material selection, energy conservation, and operations and maintenance. Another important variability for sustainability rating systems is the application area of the project, i.e. is the infrastructure an upland, landside, marine-side, or intermodal project. While the project goals or objectives may be the same for an upland or marine side project, their strategy for accomplishing the same goal may be entirely different.

Selection of Rating System

In the previous study, five different rating systems were synchronized (Thompson *et al.,* 2013). The initial criterion of selecting these rating systems was their focus on a ferry terminal with expanded application to multi-modal infrastructure facilities. The decisions to use these five specific ones were mainly based on availability for the marine and port systems, the inter-relationship of the port system to a highway rating system due to their use in one particular state, and finally the wide national exposure of the building and the site focus rating systems. Other similar rating systems could have been just as readily been used in this or other case studies. Two of the rating systems have landside focus at the terminal, while the other three rating systems are applicable for upland, marine-side, and intermodal aspects of a project. The rating systems and their focus areas are – a) GreenLITES – Upland (NYDOT, 2011), b) LEED New Construction– Landside (USGBC, 2009), c) Sustainable Sites Initiative (SSI) – Landside (SSI, 2009), d) draft Sustainable Infrastructure Guidelines by the Port Authority of New York and New Jersey (SIG) – Intermodal (TPA, 2010), and e) draft Marine Vessel Environmental Performance Guidelines (MVeP) – Marine-Side (SNAME, 2010).

After synchronization of these five rating systems into a selected set of seven topical categories (site selection, materials, energy, water, air quality, traffic and parking, and integration in the community), the credits in each were then synthesized into the single ***green rating integration platform*** (GRIP) in the previous work. Figure1 provides the resulting platform in a simple spreadsheet format, which is intended to be a tool for strategic decision making (Thompson *et al.,* 2013). However, further harmonization is needed for detailed decision making, correlation, and analysis.

Methodology

For most problems, the decision making process is a two way approach: take a decision from a holistic point of view in which it is assumed that the adopted decision is best, or decompose the decision into components to better understand the problem (Golden *et al.*, 1989). This technique of decision making by decomposing the problem is known as an analytical hierarchy process (AHP). The first step of AHP is to decompose the problem into a goal, criteria, sub-criteria, and alternatives (Bhushan and Rai, 2004).

The objective of this research is the harmonization of project goals and design strategies across the different green rating systems. Another objective is to develop a relationship between the project goals across the credit categories for different rating systems. Design strategies are the procedures for accomplishing a particular goal. An AHP flow diagram for the interrelationship between the project goals and strategies is shown in Figure 2.

	Upland GreenLITES	Land Side LEED retail	Land Side Sustainable Sites Initiative	Intermodal Port Authority	Intermodal WSU Ferry Guidelines	Marine Side MVeP
Traffic/Parking	☐ E-1: Improve Traffic Flow	☐ SSc4-Alternative Transportation		☐ IS-17: Optimize Traffic Safety	☐ Promote HOV	
	☐ E-4:Bicycle/Pedestrian Facilities			☐ IS-19:Enhance Intermodal Connectivity	☐ Encourage walk-ons	
				☐ IS-20:Transportation System Management	☐ Encourage bicycle use	
				☐ IS-21:Transportation Technologies	☐ Facilitate drop-off	
					☐ Park-and-ride program	
					☐ Shared-car program	
					☐ Optimize traffic flow	
					☐ Reservation system	
					☐ Peak periods prices	
					☐ Allow future growth	
Community/Social	☐ S-2: Context Sensitive Solutions	☐ SSc2-Community Connectivity	☐ SSp1.2-Protect floodplain functions	☐ IS-5: Protect Ecological Health	☐ Architecturally blend	☐ GM3.1-Aquatic Life Impact
	☐ S-3: Land Use Planning	☐ SSc5.1-Protect or Restore Habitat	☐ SSp1.3-Preserve wetlands	☐ IS-6:Maintain Absorbent Landscapes	☐ Visitor center	☐ GM3.2-Shore Protection
	☐ S-4: Protect Wildlife Habitat	☐ SSc5.2-Maximize Open Space	☐ SSp1.4-Preserve endangered species	☐ IS-8:Utilize Appropriate Vegetation	☐ Include guided tours	☐ AE6-Ozone-Depleting
	☐ S-5: Protect Plant Communities	☐ SSc7-Heat Island Effect	☐ SSc1.6-Select sites in communities	☐ IS-14: Mitigate Heat Island Effect	☐ Prevent flood damage	
	☐ E-5: Noise Abatement	☐ SSc8-Light Pollution Reduction	☐ SSc1.7-Accessible to public transit	☐ IS-15:Minimize Light Pollution	☐ Allow change in activity	
	☐ E-6: Stray Light Reduction	☐ EAp3-Refrigerant Management	☐ SVp4.1-Control invasive plants	☐ IS-16: Optimize Public Environments	☐ No ozone depleting substances	
		☐ EAc4-Refrigerant Management	☐ SVp4.2-Use non-invasive plants		☐ Light Pollution Prevention	
		☐ IEQc6-Controllability of Systems	☐ SVp4.3-Soil management plan		☐ Noise Pollution Prevention	
		☐ IEQc7-Thermal Comfort	☐ SVc4.5-Preserve special status veg.		☐ Wildlife Considerations	
		☐ IEQc8-Daylighting and Views	☐ SVc4.6-Daylighting and Views			
			☐ SVc4.7-Use native plants			
			☐ SVc4.8-Preserve native plants			
			☐ SVc4.9-Restore native plants			
			☐ SVc4.12-Reduce heat island effect			
			☐ SVc4.13-Reduce wildfire risk			
			☐ HHc6.1-Equitable site development			
			☐ HHc6.2-Equitable site use			
			☐ HHc6.3-Sustainability education			
			☐ HHc6.4-Protect historical places			
			☐ HHc6.5-Optimum site accessibility			
			☐ HHc6.6-Outdoor physical activity			
			☐ HHc6.7-Views of vegetation			
			☐ HHc6.8-Outdoor spaces			
			☐ HHc6.9-Reduce light pollution			
Energy	☐ E-2: Reduce Electrical	☐ EAp2-Minimum Energy Performance	☐ SVc4.10-Minimize heating	☐ IE-1: Optimize Energy Performance	☐ Produce renewable energy	☐ EE1.1-Lighting
	☐ E-3: Reduce Petroleum	☐ EAc1-Optimize Energy	☐ SVc4.11-Minimize cooling	☐ IE-2:Electrical and Mechanical Systems	☐ Use waste heat from engine	☐ EE1.2-HVAC
		☐ EAc2-On-site Renewable Energy	☐ OMc8.4-Reduce energy consumption	☐ IE-3: Utilize End Use Metering	☐ Use local material	☐ EE1.3-Pump Systems
		☐ EAc5-Measurement and Verification	☐ OMc8.5-Use renewable energy	☐ IE-4: Use On-Site Renewable Energy	☐ Minimal embodied energy	☐ EE1.4-Mechanical Equipment
		☐ EAc6-Green Power		☐ IE-5: Protect Ozone Layer	☐ Daylight harvesting	☐ EE1.5-Hull/Propeller
				☐ IE-6: Provide Alternative Fueling Stations	☐ High-efficiency systems	☐ EE1.6-Route Optimization
					☐ Individual control in offices	☐ EE1.7-Vessel Speed
					☐ Automatic control in public	☐ EE1.8-Energy Recovery
					☐ Automatically turn off lights	☐ EE1.9-Hull Optimization
					☐ High reflectance	☐ EE2.1-Other Fuels
						☐ EE2.2-Renewable Energies
						☐ EE3-Carbon Footprint
Water	☐ W-1: Stormwater Management	☐ SSc6.1-Stormwater Quantity Control	☐ Wp3.1-Reduce landscape irrigation	☐ IS-7: Utilize Pervious Pavement	☐ Emergency plan for spills	☐ WE1-Oily Water
	☐ W-2:BMPSs	☐ SSC6.2-Stormwater Quality Control	☐ Wc3.2-Reduce landscape irrigation	☐ IS-9: Use Turfgrass Appropriately	☐ Oil separation equipment	☐ WE2-Non-Indigenous Species
		☐ WEp1-Water Use Reduction	☐ Wc3.3-Protect/Restore buffers	☐ IW-1: Implement Stormwater BMPs	☐ Non toxic paint	☐ WE2.1-Ballast Water/Sediment
		☐ WEc1-Water Efficient Landscaping	☐ Wc3.4-Rehabilitate streams	☐ IW-2: Implement Rainwater Neutrality	☐ High-efficiency fixtures	☐ WE2.2-Hull Fouling
		☐ WEc2-Innovative Technologies	☐ Wc3.5-Manage stormwater on site	☐ IW-3: Reduce Use of Potable Water	☐ Prevent leaks	☐ WE3-Sanitary Systems
		☐ WEc3-Water Use Reduction	☐ Wc3.6-On-site water resources	☐ IW-4: Utilize End Use Metering	☐ Reduce potable water	☐ WE4-Solid Waste
			☐ Wc3.7-Use stormwater for landscape	☐ IO-1:Sustainable Landscape Maintenance	☐ Reduce city water	☐ WE5-Incidental Discharges
			☐ Wc3.8-Maintain water features	☐ IO-2: Maintain Soil Quality	☐ Treat wastewater on-site	☐ WE6-Protection of Oil
			☐ OMp8.1-Sustainable maintenance		☐ Implement LIDs	☐ GM2-Hotel Water Use
					☐ Collect runoff/rainwater	
					☐ Treat water on boat	
					☐ Maintain ballast tanks	
					☐ Exchanges off-shore	
Materials	☐ M-1: Reuse of Materials	☐ MRp1-Recyclables	☐ MSp5.1-Eliminate threatened wood	☐ IS-10: Amend and Reuse Existing Soils	☐ Reduce waste due to activity	☐ GM1-Materials
	☐ M-2: Recycle content	☐ MRc1.1-Building Reuse-Exterior	☐ MSc5.2-Maintain often	☐ IS-11: Balance Earthwork	☐ Recycling dumpsters	☐ GM4-Inventory Program
	☐ M-3: Locally Provided Material	☐ MRc1.2-Building Reuse-Interior	☐ MSc5.3-Design for deconstruction	☐ IM-1: Use Recycled Materials	☐ Sort waste for recycling	☐ GM5-Ship Recycling
	☐ M-4: Bioengineering Techniques	☐ MRc2-Waste Management	☐ MSc5.4-Reuse salvaged materials	☐ IM-2: Use Local/Regional Materials	☐ Recycle bins	
	☐ M-5: Hazardous Minimization	☐ MRc3-Materials Reuse	☐ MSc5.5-Recycled content materials	☐ IM-3: Reuse Materials	☐ High-recyclable materials	
		☐ MRc4-Recycled Content	☐ MSc5.6-Use certified wood	☐ IM-4: Use Durable Materials	☐ Hazardous waste plan	
		☐ MRc5-Regional Materials	☐ MSc5.7-Use regional materials	☐ IM-5:Sustainably Harvested Wood	☐ Sustainable materials	
		☐ MRc6-Rapidly Renewable Materials	☐ MSc5.8-Reduce VOC emissions	☐ IM-6: Minimize Toxic Materials	☐ Low-emitting materials	
		☐ MRc7-Certified Wood	☐ MSc5.9-Sustainable plant production	☐ IM-7: Enhance Pavement Lifecycle		
		☐ IEQc4-Low-Emitting Materials	☐ MSc5.10-Sustainable manufacturing	☐ IM-8: Utilize Thin Surface Paving		
			☐ OMp8.2-Collect recyclables	☐ IM-9: Utilize WMA Technology		
			☐ OMc8.3-Recycle organic matter			
Air Quality		☐ IEQp1-Minimum IAQ	☐ OMc8.6-Minimize tobacco smoke		☐ Outside air intake	☐ AE1-NOx Reductions
		☐ IEQp2-ETS control	☐ OMc8.7-Minimize greenhouse gases		☐ Natural ventilation	☐ AE2-Sox Reductions
		☐ IEQc1-Outdoor Air Monitoring	☐ OMc8.8-Reduce emissions		☐ Minimize chemical use	☐ AE3-PM Reductions
		☐ IEQc2-Increased Ventilation			☐ Reduce flying dirt	☐ AE4-VOC
		☐ IEQc5-Indoor Pollutant Control			☐ Limit engines running	☐ AE5-GHGs
					☐ Avoid fossil fuel engines	☐ AE7-Port Air Emissions
Construction Phase	☐ S-1: Alignment Selection	☐ SSp1-Pollution Prevention	☐ SSp1.1-Limit farmland development	☐ IS-1:Integrated Team Approach	☐ Brownfield site	
		☐ SSc1-Site Selection	☐ SSc1.5-Select brownfields	☐ IS-2: Prepare a Site Assessment	☐ Clean polluted water	
		☐ SSc3-Brownfield Redevelopment	☐ PDp2.1-Pre-design assessment	☐ IS-3:Previously Developed Sites	☐ Reduce construction waste	
		☐ EAp1-Fundamental Commissioning	☐ PDp2.2-Integrated site development	☐ IS-4:Known Contaminated Sites	☐ Dredging	
		☐ EAc3-Enhanced Commissioning	☐ PDc2.3-Engage users in site design	☐ IS-12: Coordinate Utility Work		
		☐ IEQc3-Construction IAQ	☐ SVp4.4-Minimize soil disturbance	☐ IS-13: Utilize Trenchless Technology		
			☐ Cp7.1-Control construction pollutants	☐ IS-18:Roadway Alignment Section		
			☐ Cp7.2-Restore disturbed soils	☐ IC-1: Minimize Pollution		
			☐ Cc7.3-Restore disturbed soils	☐ IC-2: Protect Existing Natural Systems		
			☐ Cp7.4-Divert materials from disposal	☐ IC-3:Transportation Management		
			☐ Cp7.5-Reuse soil	☐ IC-4:Green Construction Equipment		
			☐ Cp7.6-Minimize emissions	☐ IC-5: Reduce Noise and Vibration		
				☐ IC-6:Waste Management		
				☐ IC-7:Integrated Pest Management		

Figure 1: Integrated green rating systems and credit subcategories (Courtesy J. of Green Building) (*6*)

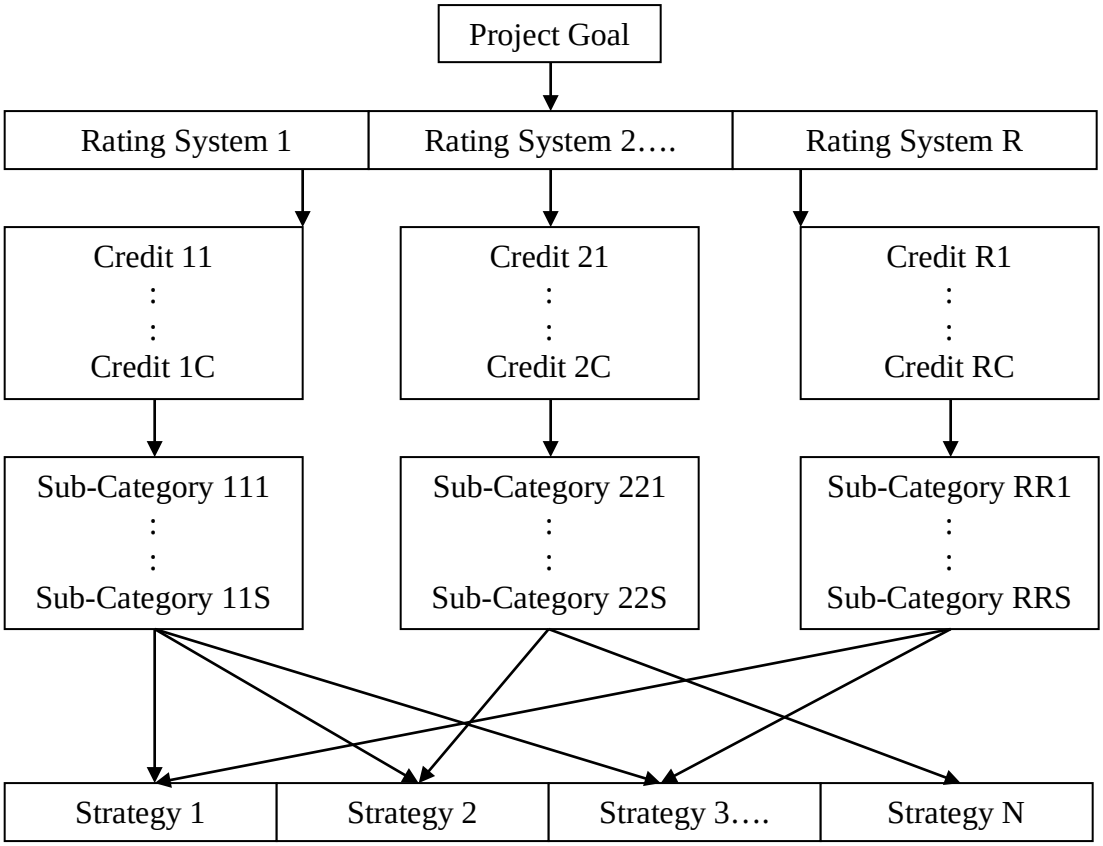

Figure 2: AHP for harmonizing project goals with strategies within the subcategories

As previously stated, the rating systems were first synthesized into different topical categories such as water, and then the categories were further subdivided into credit subcategories. This synthesis adopted from two previous studies by D'Agneaux (2009) and Thompson (2011).
In this manuscript, the credit subcategories of the topical categories *'Water'* and *'Materials'* within the five rating systems were analyzed. Each of the rating systems has specific formats for its subcategories to achieve the sustainability credits. The numerous variables that the credit formats might include are intent, requirements, potential technologies and strategies, approach and implementation, calculations, examples, numerical credit points, exemplary performance, definitions, etc. Intents, strategies, and credit point details are the most common recurrence in the credit format for most of the rating systems. The credit formats of the rating systems that have been considered in this research are listed in Table 1. Only the fundamental variables were listed for correlating the credit format across the rating systems.

Table 1: Credit formats of the rating systems

Credit Format Variables	Rating Systems				
	GreenLITES	LEED	SSI	SIG	MVeP
Intents	√	√	√	√	--
Requirements	--	√	√	√	--
Strategies/ Methods	--	√	√	--	√
Calculations	--	√	√	--	--
Credit Points	√	√	√	√	--
Credit Point Details	√	√	√	√	√

In some rating systems, credit intent was designated as purpose or objective. While GreenLITES and SIG do not specifically describe the strategy, the credit point details contain specific methodologies to obtain certain credit points. LEED and SSI provide equation/calculations to calculate the credit points; however, not all of the credit subcategories have explicit calculations or estimation tools to achieve credit points. Although, MVeP does not have numerical value for credit points, it defines its sustainability goals by prerequisite followed by good, best, and zero impact methodology as Level 1 to Level 4, sustainability credits.

The intent, strategies, and credit point details were analyzed to list the key intents and key strategies for each credit subcategory. This was done in a very cursory expert analysis using team members in the research group at Washington State University. Future research intends to extend this process to using a more detailed expert analysis tool with a larger pool of experts as the GRIP is refined and expanded.

After this cursory analysis, the key intents were cross-listed with the key strategies required to accomplish certain sustainability intents. Tabular cross-referencing of the key intents and key strategies has been developed to facilitate use for not just this case study, but for extension to other rating systems and project types. Additionally, a web-based database has been developed to data mine for key intents and key strategies for both this *'Water'* category and the *'Material*' category for ferry and similar multi-modal facilities.

Key Intents and Key Strategies

The following summarizes how the project goals and technologies for the topical categories of *'Water'* and *'Materials'* were analyzed across the five rating systems. The topical categories of *'Water'* and *'Materials'* have 22 and 38 subcategories, respectively, within these five rating systems. The minimum number of subcategories is two for a rating system and the maximum number of subcategories for a rating system is twelve. Each of these subcategories has different goals, which are also known as intents, and they adopt different technologies to accomplish these goals and they are also sometimes referred to as credit strategies or methods.

The intents and strategies of the 22 credit subcategories of *'Water'* were analyzed using the cursory expert method and these 22 subcategories could be defined through 13 intents and 53

strategies. The analysis was based upon the provided description, intents, and strategies of the credit subcategories associated with the rating systems. These listings of intents and strategies may not be totally inclusive, and they are subject to modification and addition as, rating systems are modified and re-evaluated and as additional expert input is provided to the process. These 13 intents were classified as key intents and the 53 strategies were named as key strategies. The analysis reveals that some subcategories have only one key intent, while some subcategories have as many as six key intents. While the number of key strategies to accomplish the goals or intents of several credit subcategories was one, 13 key strategies were required to accomplish the goals of credit subcategory *'On-site Water Resources'* under the rating system Sustainable Sites Initiative. An example of the key intents and key strategies for the corresponding credit subcategories for the GreenLITES rating system are listed in Table 2. This process was repeated for the *'Material'* categories.

Table 2: List of GreenLITES – water key intents and key strategies

Rating System	Credit Subcategories	Key Intents	Key Strategies
GreenLITES	W-1: Stormwater management (Quality and Volume)	• Reduce runoff • Reduce runoff pollutants • Protect wetlands/ waterbodies • Water body restoration • Reduce non-stormwater discharge to waters • Reduce impervious area	• Stormwater retrofitting • Stream restoration • Wetland protection • Erosion and sediment control
	W-2: Best Management Practices (BMPs)	• Manage stormwater • Treat stormwater pollutants	• Strategic use of soils • Use of bio-retention • Use wet or dry swales • Use filters, i.e. sand filters • Use oil/grit separators • Use detention basin • Use retention basin • Use permeable pavements

Key Strategies for the Key Intents

The analysis of key intents and key strategies for the credit subcategories shows that, for some subcategories the number of key intents is higher than the number of key strategies and vice versa. For example, the credit subcategory *W-1: Stormwater Management* was analyzed to have six key intents and the number of key strategies for these key intents is four and in contrast, the subcategory *W-2: Best Management Practices* has two key intents but may use eight key strategies to accomplish these two sustainability goals. Thus, a harmonization between the key intents and key strategies is very essential for an interactive sustainable rating system. Using the AHP by reviewing which strategies were correlated with various intents in each credit, the key strategies were correlated against the key intents to develop their inter-

relationship. The full checklist of key strategy with key intent is available on the website (https://greenintegration.cee.wsu.edu/), with a few examples of the strategies given in Table 3. (In developing the relationship, emphasis was given to the definition of the key intent and the details of the subcategory associated with that key intent.)

Table 3: Checklist example of some key strategies to accomplish key intents

GRIP Intent/Strategy Interaction Chart

This chart demonstrates which key intents are accomplished when a specific key strategy is implemented. Intents are grouped into materials and water categories at this time.

KEY STRATEGY	Credit: Materials													Credit: Water													
	KI 1: Reduce waste	KI 2: Recycle	KI 3: Reuse materials off-site	KI 4: Reuse materials on-site	KI 5: Conserve resources	KI 6: Retain cultural resources	KI 7: Reduce haul distances	KI 8: Support local businesses	KI 9: Use rapidly renewable materials	KI 10: Support responsible forest mgt	KI 11: Reduce indoor air contaminants	KI 12: Minimize hazardous materials	KI 13: Support sustainable businesses	KI 14: Increase natural hydrological features	KI 15: Manage stormwater	KI 16: Protect wetlands/water bodies	KI 17: Reduce heat island impact	KI 18: Reduce impervious area	KI 19: Reduce non-indigenous species	KI 20: Reduce non-stormwater discharge	KI 21: Reduce runoff	KI 22: Reduce runoff pollutants	KI 23: Reduce water usage	KI 24: Treat stormwater pollutants	KI 25: Water body restoration	KI 26: Water reuse onsite
Adopt construction waste management plan	√																									
Balance "cut-and-fills"				√	√	√																				
Size and functionality of recycling areas		√	√																							
Crush on-site pavement for aggregate				√	√																					
Limit certain metal use near water bodies											√	√														
Avoid pollutant potential materials											√	√					√					√				
Ballast water treatment system																√				√						
Biologically-based water treatment system														√												
Buy in bulk																√										
Clean vessel exterior																				√						
Constructed wetland																			√		√	√		√		
Stormwater harvesting														√							√			√		√

Harmonization of the key intents and strategies also produced several strategies that could be connected with key intents from both of the *'Water'* and *'Materials'* categories These unique strategies could be sought after by decision makers who want to incorporate a single key strategy in order to accomplish several intents across different rating systems and topical categories. These strategies can become even more valuable as further categories are added to the GRIP allowing for more key intents to be connected with current and new strategies.

Database Development

As sustainability is becoming a key element in infrastructure design and construction, there is a need for interconnected tools to more readily identify and cross-reference sustainability practice methods. From that perspective, an open database has been developed so that sustainability practitioners and others can access the information and receive simplified summary outputs. The database platform is based upon an open content management system named Drupal (http://drupal.org/). This database has been launched in the virtual world (https://greenintegration.cee.wsu.edu/). Currently, the database contains the details of the topical categories of *'Water'* and *'Materials'*. The database has the capability of data mining for key intents and key strategies. This is also an open database so that users can add content and modify or update the analysis that has been performed to synthesize and harmonize the intents and strategies of these and other credit subcategories of various rating systems.

Data Mining

The objective of this database is to facilitate data mining for the key intents and key strategies and provide the user with a simplified output across the rating systems for impact analysis. The key intents and key strategies of different credit subcategories were programmed and scripted in such a way that, when a key intent or key strategy is selected, the database filters the credit subcategories, and returns with the list of credit subcategories associated with that specific key intent or key strategy. The credit subcategories in the database were denoted to represent the rating systems the credit subcategories belong to.

There are various ways to data mine for key intents or key strategies. One way is to select a key intent or key strategy from inside the credit subcategories located in the dropdowns of the right sidebar under Rating Categories. The pointers 1, 2, 3, and 4 in Figure 3 represent right sidebar, topical categories menu, credit subcategories for LEED, and content area, respectively. The right sidebar dropdown contains the list of the five rating systems under each topical category while an additional dropdown lists the subcategories under specific topical category. Once the credit subcategory is selected, the detail description of the credit subcategory pops out in the content area. The details include the list of key intents and key strategies for the specific credit subcategory along with their details and credit points. Selection of a key intent or key strategy from this content area will list the credit subcategories associated with that specific key intent or key strategy.

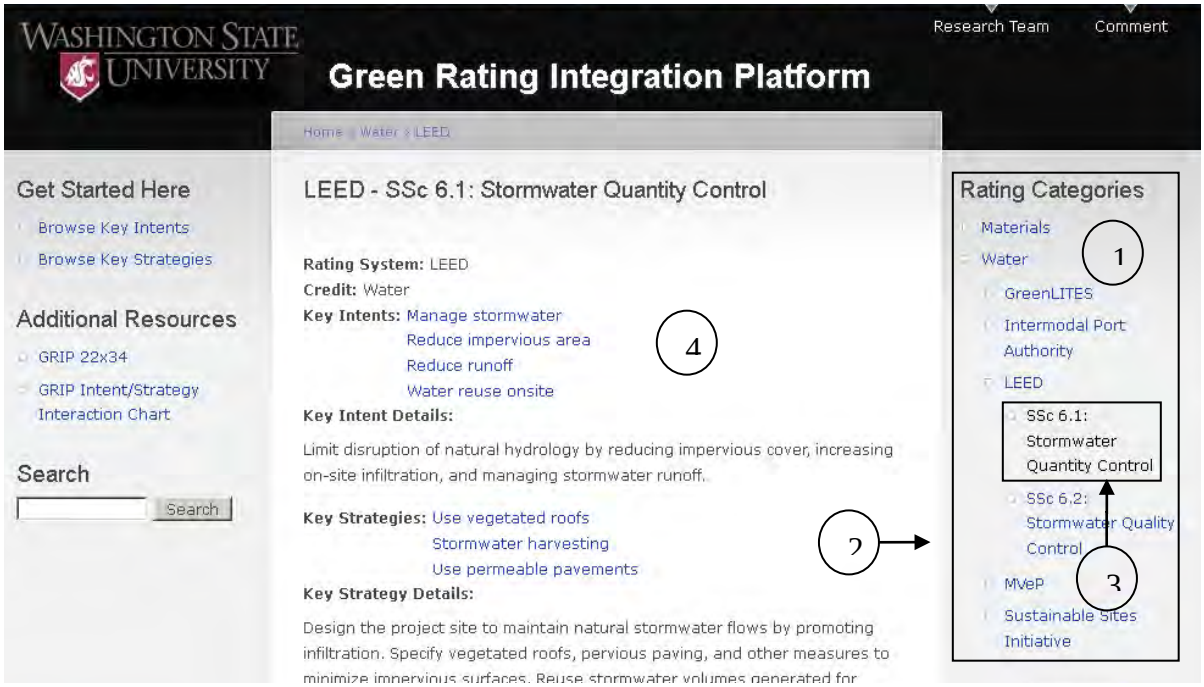

Figure 3: List of key intents and key strategies for a credit sub-category

Another way to select a key intent or key strategy is from the list of key intents (Fig. 4) or key strategies that appear under the topical category dropdown in the left sidebar. The Legends 5, 6, 7, and 8 in Figure 4 are for the left sidebar, key intents and key strategies tag menu, topical categories, and list of key intents for the five rating systems, respectively. The credit categories are listed under key intents and key strategies. Each topical category can have its own key intents and key strategies that have been obtained by analyzing the credit subcategories for different rating systems. As previously stated, these have been input in the database for the *'Water'* and *'Material'* topical categories.

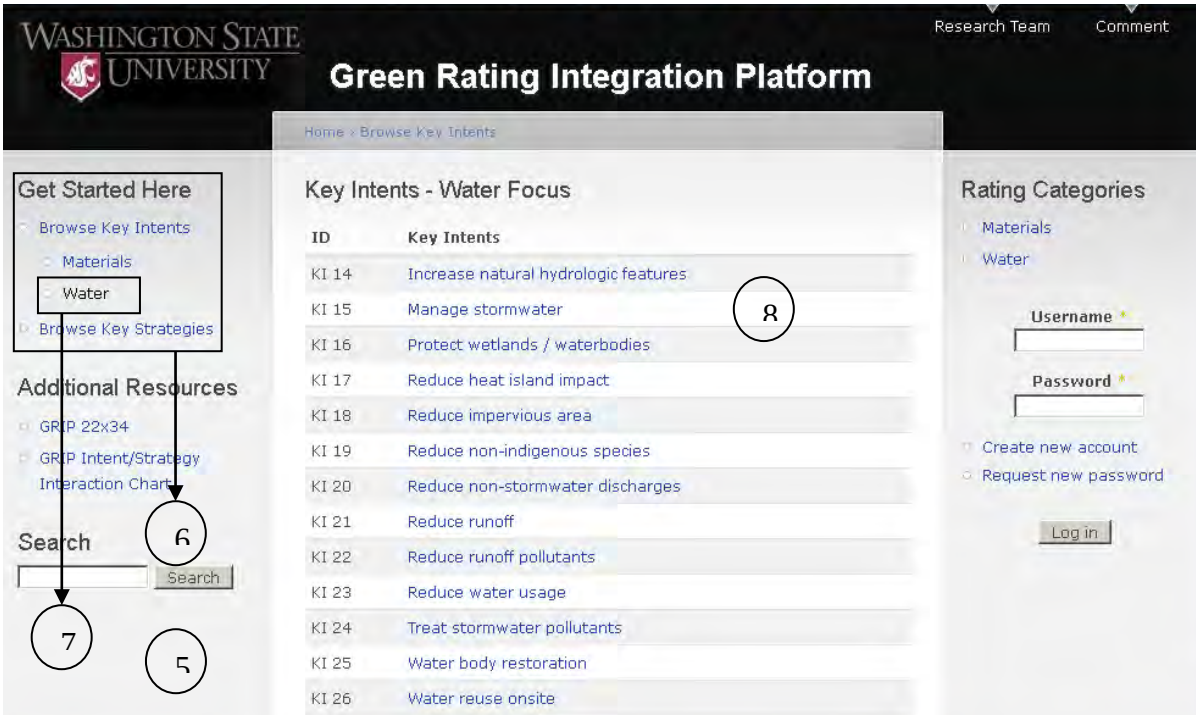

Figure 4: List of key intents for a specific credit category

An example from the water topical category is as follows. The selection of a key intent named *"Reduce runoff"*, either from the left sidebar of *"Browse Key Intents – Water"* or from the right sidebar *"Water – GreenLITES- GreenLITES - W1: Stormwater management (Quality and Volume)"* returns the list of credit subcategories associated with reduce runoff (Fig. 5). The acronym at the beginning of the subcategory represents the corresponding rating systems of that subcategory.

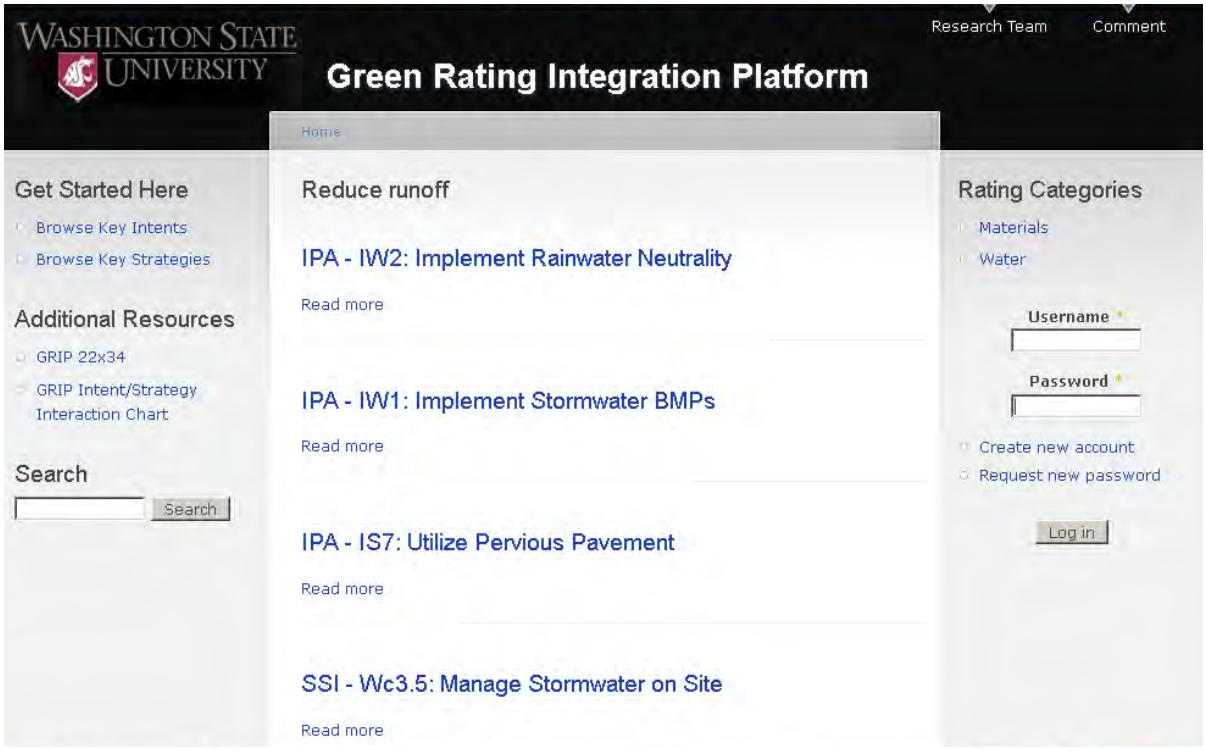

Figure 5: List of credit sub-categories for reduce runoff key intent

In summary, if the 22 credit subcategories of *'Water'* are designated by WC1 to WC22 (Table 4), and the intents that were designated by KI13 to KI26 in the expanded Table 3 available on the website, the credit subcategory for each of the intents obtained from the database can be listed as shown in Table 5. The highest recurring key intent is "*Reduce non-stormwater discharge"*, mainly for marine side facilities. The other most appearing key intents are "*Reduce runoff"* and "*Reduce runoff pollutants"*.

Table 4: Designation for water credit sub-categories

Designation	Credit Subcategory
WC1	W-1: Stormwater management (Quality and Volume)
WC2	W-2: Best Management Practices (BMPs)
WC3	SSc 6.1: Stormwater Quantity Control
WC4	SSc 6.2: Stormwater Quality Control
WC5	Wc3.3: Protect/Restore buffers
WC6	Wc3.4: Rehabilitate Streams
WC7	Wc3.5: Manage Stormwater on Site
WC8	Wc3.6: On-site Water Resources
WC9	Wc3.7: Use Stormwater for Landscape
WC10	Wc3.8: Maintain Water Features
WC11	IS-7: Utilize Pervious Pavement
WC12	IS-9: Use Turfgrass Appropriately
WC13	IW-1: Implement Stormwater BMPs
WC14	IW-2: Implement Rainwater Neutrality
WC15	IO-2: Maintain Soil Quality
WC16	WE1: Oily Water
WC17	WE2.1: Ballast Water/ Sediment
WC18	WE2.2: Hull Fouling
WC19	WE3: Sanitary Systems
WC20	WE4: Solid Waste
WC21	WE5: Incidental Discharges
WC22	WE6: Protection of Oil

Table 5: Water credit subcategories for the key intents

Key Intents	Credit Sub-categories
Increase natural hydrologic features	WC10 WC15
Manage stormwater	WC2 WC3 WC7 WC11 WC14
Protect wetlands/ waterbodies	WC1 WC5 WC6
Reduce heat island impact	WC11
Reduce impervious area	WC1 WC3 WC8 WC11
Reduce non-indigenous species	WC1 WC17 WC18
Reduce non-stormwater discharge	WC6 WC16 WC17 WC19 WC20 WC21 WC22
Reduce runoff	WC1 WC3 WC7 WC11 WC13 WC14
Reduce runoff pollutants	WC1 WC4 WC5 WC8 WC11 WC13 WC14
Reduce water usage	WC12
Treat stormwater pollutants	WC2 WC4 WC6 WC8
Water body restoration	WC1 WC5 WC6
Water reuse onsite	WC3 WC9

Difference in Outputs between Search Bar and Data Mining

In addition to data mining, a search bar located at the left sidebar of the website can be used. There are significant differences in the outputs from the search bar and tag search or data mining from the list of key intents and key strategies or from inside the credit subcategories. *"Reduce runoff"*, a key intent selection, screens the credit subcategories and returns the list of credit subcategories which have *"Reduce runoff"* as a key intent as shown in Fig. 5, while the reduce runoff search using the search bar returns a list of all items which includes these terms.

Open Database

The key intents and key strategies are listed based on the analysis of intents or objective, general strategies, methodology, credit point details, and sustainability judgment. Since the analysis is open ended, the database is open for the users to write additional content for the analysis of key intents and key strategies. The database then can be updated reflecting the analysis.

Conclusion

An analytical hierarchy process method together with an example expert analysis were adopted to develop a spreadsheet for key intents and key strategies for water and material sustainability issues across multiple rating systems related to a multi-modal facility. Efforts to harmonize the key intents and key strategies have resulted in a preliminary cross-listing for further harmonization and synchronization in these topical categories (Table 3). In addition, an open database has been developed to filter key intents and key strategies. Selection of a key intent or a key strategy from the database lists the credit subcategories across the rating systems, thus enabling practitioners to decide which key intents or key strategies might be the most appropriate for the green certification of their facility for multiple aspects of a project. The green rating integration platform, together with the harmonized key intent and key strategy cross-listings create a more detailed decision making tool for evaluating which key strategy might accomplish the maximum number or extent of sustainability goals. The open database will further facilitate this decision process.

Future research requires using expanded expert analysis methods for these and topical categories and the associated credit subcategories to refine and list their key intents and key strategies. Another important aspect may be the inclusion of credit point analyses and then normalization of the credit points across the rating systems, since the different rating systems have different credit point options. In addition, sustainability includes not only environmental considerations, but economic and social ones as well. Decision makers will need to include these other impact aspects in their final decisions. Enhanced access might also be provided with the establishment of an app application.

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