Washington State Department of Transportation

SR 520 Bridge Replacement and HOV Project

Assessment of Nighttime Roadway Lighting Effect on Lake Washington Fish Habitat

Technical Memorandum

Prepared for

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Acronyms and Abbreviations

ANSI	American National Standard Institute
ASSHTO	American Association of State Highway and Transportation Officials
cd/m^2	candela per meter square (measure of luminance)
COS	City of Seattle
EB	eastbound
fc	foot candle (measure of illuminance, $lumens/ft^2$)
HOV	high occupancy vehicle
HPS	high-pressure sodium
IES	Illumination Engineering Society
IESNA	Illumination Engineering Society of North America
LED	light-emitting diode
LDD	Luminaire Dirt Depreciation
LLD	Lamp Lumen Depreciation
LLF	Light Loss Factor
LPS	low-pressure sodium
MOE	measure of effectiveness
NB	northbound
SB	southbound
SCL	Seattle City Light
SDOT	Seattle Department of Transportation
SDEIS	Supplemental Draft Environmental Impact Statement
UCO	Urban Corridors Office
W	watts
WB	westbound
WSDOT	Washington State Department of Transportation

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1. Introduction

1.1 Purpose of the Document

This technical memorandum serves as a project deliverable prepared by the SR 520 Traffic/Illumination Design Team under Contract Y-9761, Task Order BX Study#2 - Westside Conceptual Design and Floating Bridge Support, Task 3.2.2 - AGI32 Photometric Isoline and Memorandum. The purpose of this document is to assess nighttime roadway lighting effect on Lake Washington fish habitat adjacent to the proposed SR 520 roadway (Options A, K, L, and the new Floating Bridge) in support of the Supplemental Draft Environmental Impact Statement (SDEIS).

1.2 Study Objectives

The objectives of this study consist of the following:

- Review relevant illumination design standards and guidelines that have been adopted by Washington State Department of Transportation (WSDOT) and City of Seattle (COS) in roadway illumination design.
- Review WSDOT and other agencies' current practices in roadway illumination design for reducing lighting impacts.
- Assess current nighttime light levels in water areas adjacent to the existing SR 520 roadway including Portage Bay Bridge, Foster Island area, and Montlake Bridge over Montlake Cut.
- Identify an appropriate design approach that both meets required light levels and uniformity ratios for the proposed roadways, but at the same time reduces light spillage onto adjacent waterways.
- Perform design calculations using AGI32 lighting design software based on the identified design approach for Options A, K, L, and the new Floating Bridge.
- Identify levels of light spill and areas of impact for water areas adjacent to the proposed roadway.
- Develop photometric isoline maps for water areas adjacent to the proposed roadway where roadway illumination is provided in support of SDEIS.

1.3 Organization of the Document

This technical memorandum is organized into the following six sections:

- Section 1 (Introduction) provides a brief introduction to the project and this document.
- Section 2 (Background) provides a summary of current practices and design approaches adopted by WSDOT and other agencies for roadway lighting design and reducing lighting impacts, as well as a discussion regarding acceptable light levels for the fish habitat in Lake Washington.
- Section 3 (Assessment of Existing Illumination System) documents the existing illumination system on the SR 520 Westside corridor and current light level readings at various locations adjacent to the existing roadways including Portage Bay Bridge, Foster Island area, and the Montlake Bridge over the Montlake Cut.

- Section 4 (Design Approach for Reducing Lighting Impacts) describes roadway illumination design requirements, assumptions, acceptable light levels and light standards, and identifies a proper design approach that will reduce light spillage onto the water areas adjacent to the proposed roadways for Options A, K, L, and the new Floating Bridge.
- Section 5 (AGI32 Photometric Analysis) describes the photometric analysis in detail using AGI32 lighting design software.
- Section 6 (Summary and Future Considerations) summarizes the findings and discusses the possible design options for future consideration.
- Appendix I - References
- Appendix II - Nighttime Light Level Readings in Water Areas Adjacent to the Existing Roadway
- Appendix III - AGI32 Photometric Isolines in Water Areas Adjacent to the Proposed Roadway (Option A)
- Appendix IV - AGI32 Photometric Isolines in Water Areas Adjacent to the Proposed Roadway (Option K)
- Appendix V - AGI32 Photometric Isolines in Water Areas Adjacent to the Proposed Roadway (Option L)
- Appendix VI - AGI32 Photometric Isolines in Water Areas Adjacent to the Proposed Roadway (East High Rise)

2. Background

2.1 Current Practices in Reducing Lighting Impacts

Few studies have been performed in recent years to evaluate and resolve roadway light-pollution problems on adjacent sensitive water environment such as coastal beaches, lakes or rivers. The design team performed extensive literary research and was able to find only one study that evaluated the roadway lighting impacts in any significant detail and included recommendations for effectively minimizing such impacts.

Florida Department of Environmental Protection (Reference 1) conducted a detailed study in 1996 to assess and resolve light-pollution problems on sea turtle nesting beaches due to the artificial lighting at the beaches during nighttime. In this study, several approaches were discussed extensively to reduce the roadway lighting impacts. In 2002, based on the previous studies, Florida Department of Environmental Protection issued a Coastal Roadway Lighting Manual (Reference 2) to provide practical guidelines for managing street lighting to minimize impacts to sea turtles. Some of the recommended approaches in this manual are summarized as follows:

- Realign the fixture (change angle of mounting arm or rotate fixture head) so the source of light is not directly visible from the beach.
- Apply a shield to a drop globe fixture.
- Change an open bottom or drop globe fixture to a cutoff fixture.
- Apply a shield to a cutoff fixture.
- Reduce the mounting height of the fixture.
- Reduce the lamp wattage.
- Change the lamp socket position in the fixture to compress the lighting footprint.
- Change to a fixture with a different type of reflector providing a more favorable lighting footprint.
- Install a flat 2422 acrylic amber lens in a cutoff fixture with a high-pressure sodium (HPS) lamp of 70 watts or less (e.g., GELS 70W M250). This option should only be used in addition to keeping light off the beach and reducing total luminance.
- Turn the light off.
- Remove the fixture.
- Relocate the fixture to block light from beach view.
- Move the fixture to the ocean side of the roadway so that light is broadcast away from the beach.
- Change to a low-pressure sodium (LPS) fixture if the light is customer-owned (turtles have an aversion to the light generated by LPS light fixtures).
- Create a vegetated dune buffer.
- Erect an artificial light shield between the light and the beach.

Although many of the above recommendations are intended only to manage existing coastal street lighting systems that are not transferable to this project, some of these approaches are applicable in reducing light spillage onto adjacent water areas. Some examples include utilizing a cutoff fixture with a proper shield, lowering luminaire mounting height, reducing lamp wattage, arranging the light fixture to shine away from water, and creating a vegetated dune buffer. However, due to the reduction of mounting height and lamp wattage, these approaches typically require a greater number of luminaires to be installed to maintain necessary light levels for roadway safety and security. Therefore, a balanced approach must be considered to evaluate the tradeoff between maintaining necessary roadway lighting and reducing any potential negative impacts on the environment.

In another case, WSDOT Northwest Region in 2001 (Reference 3) installed shields on the Cedar River Trail lighting fixtures to reduce the lighting impact on an adjacent salmon migratory route in Cedar River. According to this study, the results of installing the retrofitted shields were remarkable and the salmon fry could move through the area quickly without being impacted by the lights.

2.2 Acceptable Light Levels for Lake Washington Fish Habitat

Several research studies have been performed to evaluate the effect of light intensity on salmon habitat along Puget Sound shorelines and in Lake Washington. Many of these studies either collected actual light level readings or performed literature review to identify a threshold or a range of light levels that has a negligible impact on salmon. For ease of reference, light levels described below in lumens/ft^2 and lumens/m^2 are converted to foot candles (fc), that are commonly used in lighting calculations.

According to the literature review performed by U.S. Fish and Wildlife Service in 1998 (Reference 4), sockeye fry moved through experimental streams at a faster rate under complete darkness than under bright lights, and increased ambient light appeared to inhibit the migratory movement of the salmon fry. The same study also stated that based on a previous study conducted by Fraser in 1994 that salmon fry's movements were significantly reduced at 2.0 lumens/ft^2 (2.0 fc).

U.S. Fish and Wildlife Service conducted another study in 2001 (Reference 5) to evaluate the near shore habitat used by juvenile Chinook salmon in the Lake Washington basin. In this study, actual light levels were measured at the Gene Coulon swim beach by snorkelers from 5:40 AM to 6:30 AM in very shallow water, approximately 0.4 m deep for three days. It was documented that Chinook salmon became active when light intensity levels were 0.8 to 2.1 lumens/m^2 (0.08 to 0.21 fc); however, as light intensity increased between 22 and 65 lumens/m^2 (2.2 to 6.5 fc), it was difficult finding Chinook salmon.

Another study performed by Washington State Transportation Center (TRAC), University of Washington in 1999 (Reference 6) to investigate the impacts of ferry terminals on juvenile salmon migrating along Puget Sound shorelines. It was documented in the study report that light has tremendous importance in the life of salmon for spatial orientation, prey capture, schooling, predator avoidance, and migration navigation. This study report referenced several studies previously performed by Ali (1958, 1959, 1962) that revealed threshold light intensities for different behaviors of juvenile chum, coho, sockeye and pink salmon. In Ali's studies, he stated that juvenile salmon's feeding, minimum prey capture, and schooling are dependent upon specific light intensities of no lower than 10^{-4} fc (this light level is nearly equivalent to a clear night with a new moon) and maximum prey capture for chum and pink fry occurs at 1.0 fc (equivalent to the light range of dawn and dusk).

Based on the above studies, it may be safe to assume that 2.0 fc is the maximum light level that has no adverse effect on salmon behavior during nighttime. The roadway lighting should be designed such that light spillage into adjacent water surfaces is less than 2.0 fc, even though it is desirable to reduce light spillage to the minimum level - the lower, the better. Note that the design team asked WSDOT and the SR 520 Environmental Team for an acceptable light level threshold that could be used in the roadway illumination design; however, such information was not available at the time of this writing.

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3. Assessment of Existing Illumination System

3.1 Existing Illumination System

Continuous lighting is currently provided on the existing SR 520 westside corridor from the I-5 interchange to the East High Rise of the Evergreen Point Floating Bridge. The entire electrical system including illumination and Intelligent Transportation Systems (ITS) was rebuilt by Washington State Department of Transportation (WSDOT) in 2003 for the SR 520 mainline roadway and ramps between I-5 interchange and the mid-span of the floating bridge. As part of this project, the old illumination system installed prior to 2003 including luminaires, poles, foundations, and electrical wiring was completely removed and re-constructed. The construction was completed in early 2004. All newly-installed luminaire standards are WSDOT standard cobra-head flat glass high-pressure sodium (HPS) light fixtures with Type III, medium cut-off and 250W, staggered on both sides of the mainline roadway with additional luminaires provided on the ramps and at the ramp terminals. Typical luminare mounting height is 40 feet from the roadway surface. Furthermore, 6 inches (height) by 13.5 inches (width) house/water-side shields are installed on the luminaires wherever the luminaire standards are located adjacent to residential or water areas to reduce light spillage into the residential properties or water areas.

The illumination system on Montlake Boulevard and other arterial streets appears to follow City of Seattle (COS) street lighting standards and appear to be operated and maintained by Seattle City Light (SCL). The age of the system is unknown at the time of writing. COS standard cobra-head flat lens HPS light fixtures with Type III, Medium cut-off and 250W are typically seen in the field. Mounting height is approximately 30 to 35 feet with a 10-foot mast arm.

For the over-water roadway segments including Portage Bay Bridge, Foster Island area, West High Rise, and the Floating Bridge (west of the mid-span), as illustrated in Figure 1, standard WSDOT cobra head luminaire standards are mounted on the outside concrete barriers with a 40-foot mounting height, a 6-foot luminaire mast arm, and approximately 350-foot spacing between two adjacent luminaires on the same side of the roadway. Water-side shields are installed on the light fixtures wherever they are located adjacent to the water areas.

From the mid-span of the Floating Bridge to the East High Rise, it appears that the existing illumination system was constructed in a very early stage of the bridge and has not been rebuilt or upgraded for many years; the exact age of the system is unknown. All electrical services for this bridge segment appear to originate from the east side of the floating bridge. The HPS luminaire fixtures (type, distribution, and wattage) are unknown and are not in accordance with the current WSDOT standards. As shown in Exhibit 2, the luminaires are only mounted at 30 feet high without any shields to prevent the light from spilling into the adjacent water area. The continual illumination then terminates at the East High Rise, at which point only illumination is provided for safety and security purposes at transit flyer stops, ramps, and merge and diverge areas through the 108th Avenue interchange in Bellevue.

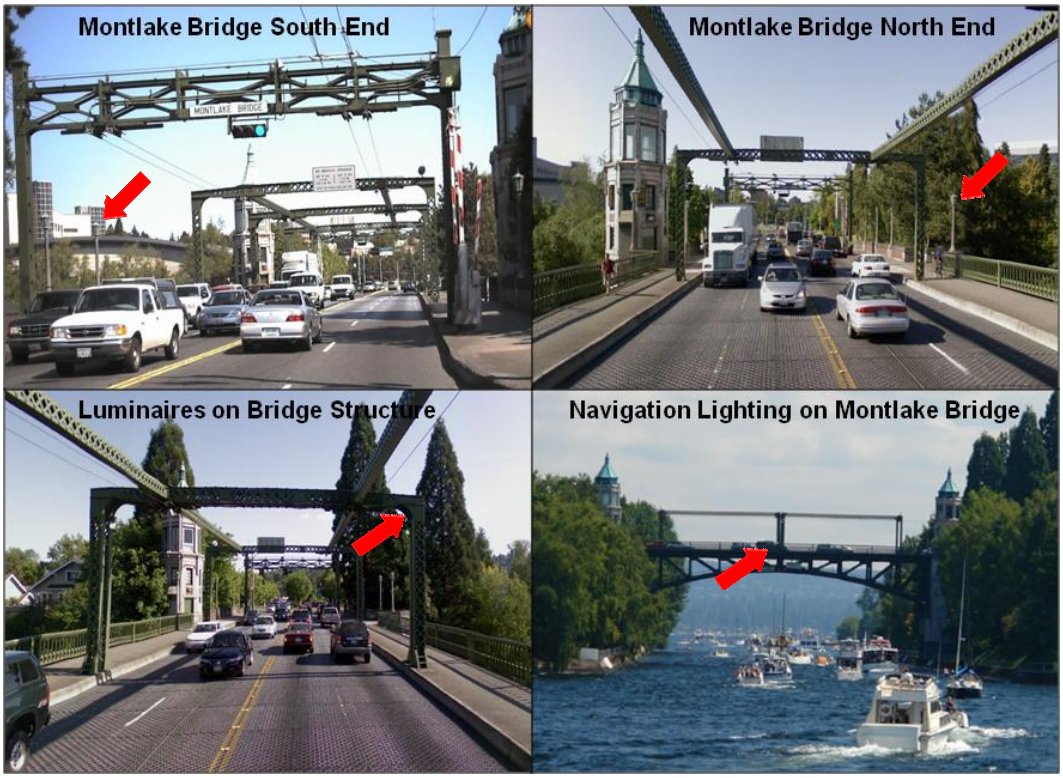
Navigation lights are provided on both sides of the Floating Bridge to prevent the boats from colliding into the bridge structure during nighttime. No photos were obtained for the navigation lights. It is estimated that these navigation lights have negligible impacts on water in comparison to the roadway lighting.

EXHIBIT 1 - EXISTING LIGHT STANDARDS FROM PORTAGE BAY BRIDGE TO FLOATING BRIDGE MID-SPAN

EXHIBIT 2 - EXISTING LIGHT STANDARDS FROM FLOATING BRIDGE MID-SPAN TO EAST HIGH RISE

In addition to the SR 520 corridor mainline and ramp segments, the only other over-water roadway segment within the SR 520 project limits is the Montlake Bridge over the Montlake Cut. The Montlake Cut is the only fish migration route in and out of Lake Washington. As shown in Exhibit 3, there are no luminaires on the bridge except two small wall-pack lights mounted on the bridge's mid-span structure facing away from the water. Decorative pedestrian light fixtures are post top mounted on each end of the bridge and are blocked by the surrounding vegetation, therefore having very low light spillage into the water underneath the bridge during nighttime. In contrast to the roadway lighting, the navigation lights, which are mounted underneath both sides of the bridge structure to alert tall vessels about the bridge, appear to shine more light into the water during nighttime.

EXHIBIT 3 - EXISTING LIGHT STANDARDS AT MONTLAKE BRIDGE



3.2 Light Level Readings in Water Areas near the Existing Roadway

In order to investigate the existing nighttime artificial lighting effect in the water areas, the design team took a field trip from 7:30 PM to 10:20 PM on October 29, 2008, to measure the actual light levels using Extech Instruments LT300 Light Meter at various accessible locations near the existing SR 520 roadway. The field crew collected baseline readings at twenty-four sites. These readings were taken close to the water surface at the edge of water areas or on the pedestrian trail bridges.

Appendix II includes these light level readings at the following locations. Note that each data site shown on the map is based on its approximate location observed in the field and may not represent the exact distance from the edge of roadway.

- ***South side of Portage Bay Bridge*** – light levels range from 0.01 foot candles (fc) to 0.11 fc at four sites, 50 to 300 feet away from the edge of the bridge.
- ***North side of SR 520 near McCurdy Park*** – light levels range from 0.02 fc to 0.13 fc at three sites, 120 feet to 300 feet away from the edge of the roadway. The high light level reading of 0.13 fc (300 feet from the edge of the roadway) was due to the light coming from Husky Stadium.
- ***West side of Foster Island near Pedestrian Underpass*** – light levels range from 0.45 fc to 0.03 fc at six sites, 5 feet to 200 feet away from the edge of the roadway.
- ***Both sides of Montlake Bridge*** – light levels range from 0.03 fc to 0.13 fc at seven sites, 60 feet to 200 feet away from the edge of the bridge.
- ***Montlake Cut near Husky Stadium Parking Lot*** – light levels range from 0.02 fc to 3.4 fc at three sites. Note that this area is not adjacent to the existing SR 520 roadway; the light level readings were taken for comparison with the proposed lighting on the new bascule bridge at this area (Option L).

The existing light levels are relatively low in the water areas adjacent to the existing roadway during nighttime. The highest reading is only 0.45 fc at the edge of the water near Foster Island and 5 feet from the edge of roadway, where the roadway surface is about 10 feet above the pedestrian underpass. The light levels are typically higher at the edge of the roadway and gradually diminish to the full moonlight level (0.03 fc) about 200 feet away from the roadway. It is also worth noting that the stadium parking lot and adjacent ship dock appear to spill more light into the adjacent water surface (up to 3.4 fc) than the roadway lighting.

4. Design Approach for Reducing Lighting Impact

4.1 Design Standards for Roadway Lighting

The design team reviewed relevant roadway lighting design standards and identified the following applicable standards and design guides to ensure that the proposed roadway illumination design meets the illumination design criteria required by the Washington State Department of Transportation (WSDOT) and the City of Seattle (COS).

- WSDOT Design Manual Chapter 840, M 22-01.03, May 2008.
- Roadway Lighting Design Guide, AASHTO, October 2005.
- American National Standard Practice for Roadway Lighting (ANSI/IESNA-RP-8-00), 2000.
- Seattle Right-of-Way Improvements Manual, Version 2.0, Chapter 4, City of Seattle, 2008.
- Standard Plans for Municipal Construction, Section 500, City of Seattle, 2008.
- Standard Specifications for Municipal Construction, Section 8-30, City of Seattle, 2008.

Based on the above standards, both illuminance and luminance methods are required to calculate the proper light level and uniformity ratio for the proposed SR 520 roadway. Each of the design methods utilizes the following measures of effectiveness (MOE) to calculate the design results.

Illuminance Method

- Minimum Average maintained Horizontal Light level (foot candle).
- Maximum Uniformity Ratio.

Luminance Method

- Maximum Veiling Luminance Ratio.

4.2 Design Assumptions

The following design assumptions are based on the input from the WSDOT Urban Corridors Office (UCO) and the Northwest Region Traffic Design Office:

- Same as the existing illumination system, a continuous illumination system is required from I-5 interchange to Foster Island area including all arterial streets within the construction foot print. This includes the following over-water roadway segments:
    - Portage Bay Bridge (Options A, K, and L)
    - Union Bay Bridge in Forster Island area (Options A, K, and L)
    - Montlake Bridge (Option A only)
    - New bascule bridge over Montlake Cut (Option L only)
- To reduce the lighting impact to the Lake Washington fish habitat, continuous roadway illumination will not be provided for the following mainline roadway segments. These segments also represent mainline sections where there are no vehicular conflict points such as add lanes, drop lanes, merges, diverges, auxiliary lanes, or weaving sections:
    - From Station 104 (Options A, K and L - where additional lanes begins around Foster Island area) to Station 201 - where the Evergreen Point Flyer stop merges

(westbound) back into the westbound high-occupancy vehicle (HOV) lane on the Floating Bridge.

- A continuous illumination system is required starting from Station 201 to the eastside project limit prior to the 84th Avenue NE interchange (Station 249) to accommodate the illumination needs at the HOV lane merging and diverging areas on the East High Rise. The illumination system should be designed to integrate with the Eastside illumination system as an integrated electrical system. This may cause light spillage into the water under the East High Rise (approximately 1,900 feet long).
- Continuous pedestrian lighting is required for the proposed pedestrian/bike path on the Floating Bridge and is still being considered throughout the remainder of the SR 520 corridor.
- Inquiries to clarify the lighting levels at which fish may be affected, have been unsuccessful. The only practical light level that can be referenced is that produced by moonlight, which is generally accepted to be approximately 0.03 foot candles (fc) when a full moon occurs on a clear night. The area of impact that light spills off the roadway can be measured from the edge of the roadway to where the light diminishes to the moonlight level (0.03 fc). It is worth noting that moonlight spreads evenly over a large area of the water surface; however, problems may arise where a bright band of light spilled off from the roadway may form a barrier through which fish may not pass.
- Pavement reflection factor is assumed to be 0.38 for concrete pavement type.
- Design data for noise walls are not available at the time of writing and therefore they are not considered in the lighting calculations.
- Only WSDOT and COS standard light standards and luminaire types are considered in the design calculation for roadway lighting.
- Additional pedestrian lighting on Montlake Boulevard including Montlake Bridge is not considered at this stage of design. It is assumed that the continuous roadway lighting will provide sufficient lighting in conformance to COS pedestrian lighting requirements.

4.3 Light Level

The illuminated facilities and associated lighting design requirements are listed below.

1. Freeway Mainline and Ramps

The proposed freeway mainline has two general purpose lanes, one HOV lane, and two shoulders for each direction. Additional lanes occur at many of the interchanges. The required light level and uniformity ratio per WSDOT Design Manual Chapter 840 for providing sufficient lighting to illuminate all six lanes and both inside and outside shoulders between the edges of roadway pavement are:

- Minimum Average Maintained Horizontal Light Level - 0.6 fc.
- Maximum Uniformity Ratio - 4:1.
- Maximum Veiling Luminance Ratio - 0.3:1.

2. Pedestrian/Bike Path on Floating Bridge

The proposed pedestrian/bike path is 14 feet wide along the north side of the new Floating Bridge connecting the pedestrian trails on both sides of the bridge. The pathway surface at the lowest point

of the floating bridge is about 29 feet above water level. The lighting design requirements per WSDOT Design Manual Chapter 840 are:

- Minimum Average Maintained Horizontal Light Level - 0.8 fc.
- Maximum Uniformity Ratio - 3:1.
- Maximum Veiling Luminance Ratio - 0.3:1.

3. Principal Arterial

The proposed Montlake Bridge (Option A) and new Bascule Bridge over Montlake Cut (Option L) are the principal arterial streets over the water areas. Per COS street lighting requirements, Seattle Department of Transportation (SDOT) requires street lighting to meet or exceed the requirements set forth by the recommended Illuminating Engineering Society (IES) guidelines where applicable. The required light level and uniformity ratio per IESNA-RP-8-00 for these two bridges are described below:

Montlake Bridge (Option A)

- Minimum Average Maintained Horizontal Light Level – 1.2 fc for medium pedestrian activity.
- Maximum Uniformity Ratio - 3:1.
- Maximum Veiling Luminance Ratio - 0.3:1.

New Bascule Bridge over Montlake Cut (Option L)

- Minimum Average Maintained Horizontal Light Level – 0.6 fc for low pedestrian activity.
- Maximum Uniformity Ratio - 3:1.
- Maximum Veiling Luminance Ratio - 0.3:1.

4.4 Light Standards

WSDOT Current Practice

- 40- and 50-foot-high light standards with slip bases and Type 1 mast arms are predominantly used on state highways. The 50-foot-high light standard is preferable if environment impact is not a concern.
- The typical location for a light standard is on the right shoulder, while design for light standards mounted on a concrete barrier in the median is allowed; however, a total life cycle cost of the system, including the user costs resulting from lane closures required for relamping and repair operations, should be considered.
- The preferred position for the luminaire is directly over the edge (fog) line. On Type III light standards, luminaires may be placed more than 4 feet from the edge line. Standard mast arm lengths are available in 2-foot increments between 6 and 16 feet.
- The preferred design for a single-arm light standard is a 16-foot mast arm installed on a 40- or 50-foot standard. The maximum allowable mast arm length for a single-arm light standard is 16 feet.

- The preferred design for a double mast arm light standard has mast arms between 6 feet and 12 feet in length, installed on a 40- or 50-foot standard. The maximum allowable mast arm length for a double luminaire light standard is 12 feet.
- The cobra head-style, high-pressure sodium (HPS) vapor luminaire with flat glass, Type III, medium cut-off light distribution is the normal light source used for state highway lighting. Typical wattage is 200W, 250W, or 400 W with 22,000, 28,000, and 51,000 lumens, respectively. The 400W luminaire is preferable if environment impact is not a concern.
- A Light Loss Factor (LLF) of 0.62 is typically used for lighting calculations based on a Luminaire Dirt Depreciation Factor (LDD) factor of 0.85 and a Lamp Lumen Depreciation (LLD) factor of 0.73 at the end of the luminaire life cycle (a total of 24,000 hours).
- If required, external house-side, street-side or 360° shields should be used to reduce the light trespass on adjacent sensitive areas such at waterways or residential areas.

City of Seattle Current Practice

- Luminaires shall be "cobrahead" style and shall consist of a luminaire housing, lamp, ballast, and photoelectric control.
- Luminaire light distribution patterns shall conform to the IES classification system for Type III medium cutoff for less than 200 watts and Type II short cutoff for 200 watts and more.
- Glare control shall be accomplished by use of a flat lens. Minimum streetside utilization shall be 39 percent at 1.5 transverse mounting height. Distribution shall be free from striations and hotspots.
- HPS lamps shall be clear lamps suitable for operation in any position and meet the minimum ratings for 150W, 250W and 400W lamps with 16,000, 28,800, and 50,000 initial lumens, respectively, and a minimum of 24,000 hours life for each lamp type.
- The typical location for a light standard is 3 feet (5 feet is desirable for an unobstructed walking path) behind the curb.
- Standard luminaire mounting height should be 35± feet on a standard 33.5-foot-high light pole.
- The luminaire should extend approximately 2 feet beyond the projection of the curb above the roadway.
- A LLF of 0.69 is typically used for lighting calculations.

4.5 Design Approach for Reducing Lighting Impacts

An iterative design approach was utilized for the proposed illumination system occurring over-water roadway segments. The design philosophy is to first calculate the roadway lighting to meet the minimum roadway lighting design requirements outlined in Section 4.3, and then take a further step to reduce the light level and impact areas where light spills into the water areas without compromising the roadway lighting requirements. Iterations of design calculations were required during this design process to verify the roadway light level and uniformity ratio each time certain design factors were modified to reduce light spillage. These factors include luminaire standard arrangement, spacing, pole height, lamp wattage, shielding, and mast arm length. The detailed design approach is described as follows:

First, various design scenarios were defined for small sections (600 to 1400 feet) of the most critical areas for the following over-water roadway segments:

- Portage Bay Bridge (Options A, K, and L).
- Union Bay Bridge in Foster Island area (Options A, K, and L).
- Montlake Bridge (Option A only).
- New Bascule Bridge over Montlake Cut (Option L only).
- East High Rise.
- Pedestrian/bike Path on the floating bridge.

The design scenarios include various luminaire standard arrangements such as central twin, two-side opposite, and two-side staggered for a six-lane roadway and combination of these arrangements for a wider-than-six-lane area such as Union Bay Bridge near Foster Island. The AGI32 lighting design software (Version 2.02) was used to calculate the light level and uniformity ratio based on various combinations of luminaire arrangement, spacing, pole height, lamp wattage, shielding, and mast arm length. 3-D roadway surface triangles produced from AutoCAD were imported into AGI32 as opaque objects and all these objects were tagged together and defined as one single roadway surface. The roadway surface is assumed to be concrete with R1 roadway surface classification as defined in IESNA RP-8-00. The design team used 5 foot by 5 foot calculation grids to simulate the roadway and water surfaces based on the 3-D contour plans with 1 foot incremental in elevation. Upon completion of the calculations, acceptable design scenarios were noted for further lighting impact analysis.

Second, a photometric analysis was performed for the water areas adjacent to the proposed roadway using the luminaire's initial lumen output (LLF is set to 1) to simulate the worst condition at the initial installation (See Section 5 for details). The maximum light level and size of the impact areas were calculated using AGI32 and compared for each design scenario. The best design scenario with the least lighting impact among all scenarios was then selected.

Third, based on the selected best scenario, final lighting calculations were performed for all the over-water roadway segments to verify whether the roadway light level and uniformity ratio meet the requirements. Where the light level and uniformity ratio did not meet the requirements, minor adjustments were made and the calculation was repeated until the roadway lighting met the requirements.

Finally, upon completion of the roadway lighting calculation, the light levels and sizes of impact areas were recorded (Exhibit 7) and photometric isolines were generated (Appendix III thru VI) using AGI32 for all water areas.

The following design elements were determined in the design based on the input from WSDOT's Northwest Region Traffic Design Office and the AGI32 light calculation.

1. Freeway Mainline and Ramps

- WSDOT standard cobra-head luminaire with Type III, medium cutoff distribution.
- 250W HPS, reduced from 400 W typically used by WSDOT for highway lighting.
- 40-foot luminaire mounting height, reduced from the 50-foot height typically used by WSDOT for highway lighting.

- 10-foot mast arm length for right-shoulder mount luminaries, increased from the 6-foot length typically used on bridges, so that the luminaires are placed directly over the fog line.
- Luminaire spacing is approximately 200 feet based on the design calculation.
- For a six-lane roadway, two-side opposite shoulder mount luminaire arrangement is used instead of the central twin arrangement. Central twin arrangement generally has more light spillage into the adjacent water areas based on the design calculation. The two-side staggered arrangement is not able to meet the roadway lighting requirements with the same luminaire spacing and mounting height; therefore, it is not considered.
- A house/water side non-reflective shield is required on all luminaires above or adjacent to the water areas.

2. Pedestrian/Bike Path on Floating Bridge

For the design approach for the pedestrian lighting on the bridge, the initial design utilizes a similar design currently in place for the pedestrian lighting on the I-90 floating bridge. In both cases, recessed pedestrian lighting fixtures are mounted in the concrete barrier. This design approach was taken, rather than using WSDOT standard post mount luminaires, to reduce lighting spillage into the water. However, WSDOT does not currently have any design guidelines for recessed pedestrian lighting. The design team selected the following light fixture based on its low wattage and the design calculation.

- For pedestrian lighting on the Floating Bridge, recessed 50W Metal Halide luminaires at 17.5-foot spacing are proposed to be installed in the concrete barrier between the pedestrian/bike path and the outside shoulder, approximately 2.1 feet above the traveled surface.
- No light spillage was found in water based on this design.

3. Principal Arterial

- COS standard Type II, medium cutoff, 250W HPS cobra-head luminaire.
- Standard 35-foot luminaire mounting height.
- 10-foot mast arm length for right-shoulder mount luminaries, increased from the 6-foot length typically used on bridges.
- Two side opposite luminaire arrangement.
- Luminaire spacing is approximately 200 feet based on the design calculation.
- Luminaires are located as close to the end of bridge as possible.
- A house/water side non-reflective shield is required on all luminaires above or adjacent to the water areas.

5. AGI32 Photometric Analysis

A detailed photometric analysis was performed using AGI32 lighting design software (Version 2.02) on the water surfaces based on the lighting fixture and design approach identified in Section 4. The water in Lake Washington remains almost at a constant level - approximately 18.75 feet from the sea level. The elevations of the proposed over-water roadway surfaces (lowest point) range from 25 feet to 74 feet based on the 3-D roadway surface contour plans:

- Montlake Bridge - approximately 70 feet (Option A).
- New Bascule Bridge over Montlake Cut - approximately 74 feet (Option L).
- Floating Bridge - approximately 47 feet.
- Union Bay Bridge at Foster Island area.
    - Approximately 50 feet (Option A)
    - Approximately 25 feet (Option K)
    - Approximately 44 feet (Option L)
- Portage Bay Bridge.
    - Approximately 44 feet (Option A)
    - Approximately 35 feet (Option K)
    - Approximately 38 feet (Option L)

The design team developed 5 foot by 5 foot calculation grids at the water level to simulate the water surfaces in AGI32 software. However, the design team encountered a difficulty in finding a proper photometric file for the shielded luminaire.

WSDOT uses a photometric file (GE1002.ies) provided by General Electric (GE) to perform roadway lighting calculations for the standard unshielded luminaire (250W HPS, Type III, Medium, Cutoff with Flat Glass). To perform the analysis more accurately, the design team inquired GE for a photometric file for this specific shielded luminaire. Unfortunately, such photometric file was not available at the time of writing. Instead, GE provided a photometric file for a similar Type II luminaire with and without a shield. The design team performed an experimental analysis and carefully compared these two unshielded luminaires based on their photometric files and light spillage in the water surface with an 18.75-foot elevation from a roadway surface with a 35-foot elevation. As illustrated in Exhibits 4 and 5, the maximum and average light levels are the same; the only marginal difference is the size of the impact area on water - 127 feet vs. 124 feet from the edge of roadway. The design team further analyzed the shielded Type II luminaire using the provided photometric file and the results are illustrated in Exhibit 6, which also shows the difference of the light levels and sizes of impact areas at the initial installation vs. at end of the luminaire life cycle. In this comparative analysis, Light Loss Factor (LLF) was set to 1 and 0.62 at the initial installation and at end of the luminaire life cycle (a typical 6-year life span based on 24,000-hour design life for 10-hour daily use), respectively.

EXHIBIT 4 - WSDOT STANDARD TYPE III UNSHIELDED LUMINAIRE - AGI32 PHOTEMETRIC FILE (LEFT) AND LIGHT SPILLAGE ON WATER BASED ON INITIAL LUMEN OUTPUT (RIGHT)

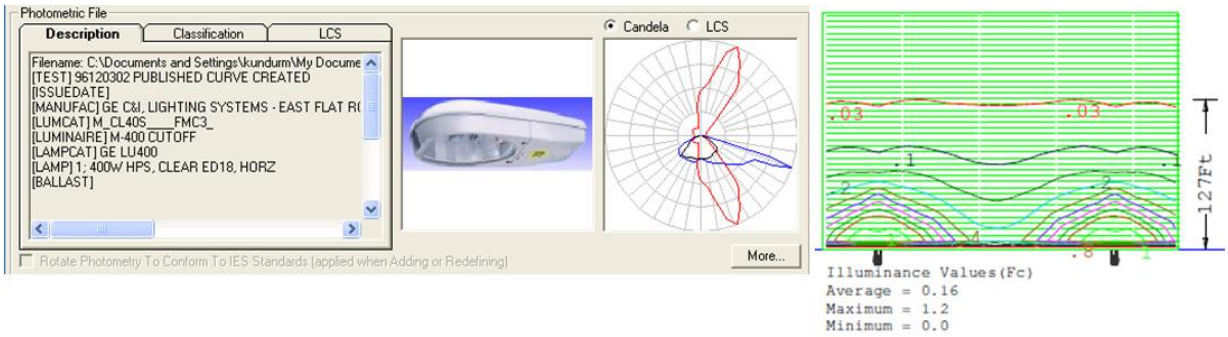


EXHIBIT 5 - GE TYPE II UNSHIELDED LUMINAIRE - AGI32 PHOTEMETRIC FILE (LEFT) AND LIGHT SPILLAGE ON WATER BASED ON INITIAL LUMEN OUTPUT (RIGHT)

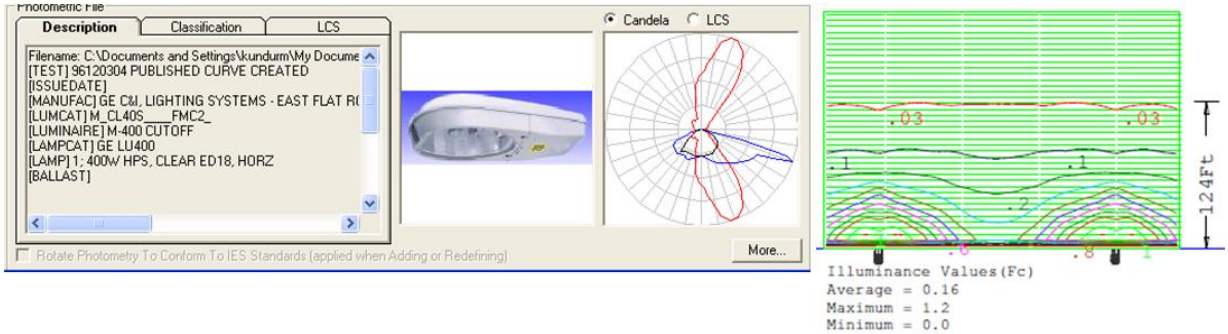
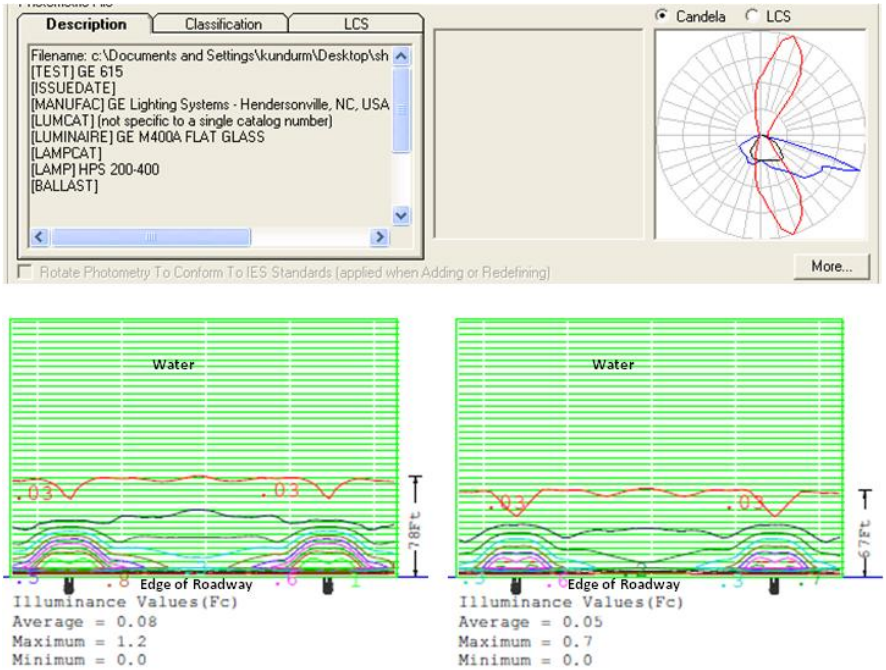


EXHIBIT 6 - GE TYPE II SHIELDED LUMINAIRE - AGI32 PHOTEMETRIC FILE (TOP) AND LIGHT SPILLAGE ON WATER BASED ON INITIAL LUMEN OUTPUT (BOTTOM LEFT) VS. END OF LIFE CYCLE (BOTTOM RIGHT)



The following were also found from the comparison analysis:

- As illustrated in Exhibits 5 and 6, the maximum light level between the shielded and unshielded luminaire at the initial installation is the same, but the impact area could be reduced by approximately 40 percent. This indicates that applying shields is always the most effective way of reducing roadway lighting impacts to adjacent water areas or residential properties.
- As illustrated in Exhibit 6, the maximum light level at the end of life cycle of the shielded luminaire could be approximately 40 percent less than that at the initial installation, and the impact area could also be reduced by approximately 14 percent.

Based on the above analysis, it was decided to use the shielded Type II luminaire in development of the photometric isolines for the water areas, while the standard Type III luminaire was still used in roadway lighting calculation to ensure the roadway lighting meets the requirements. The maximum light levels and sizes of impact area are showed in Exhibit 7 for all water areas adjacent to the proposed roadway. In the AGI32 lighting calculation, the initial lumen output was used to simulate the worst condition at the initial installation. The design team has made every effort to reduce the maximum light levels to a level below the acceptable threshold – 2.0 foot candles (fc) as noted in Section 2.2. Although the maximum light levels seem to be slightly higher than the current nighttime light level readings, they would reduce by up to 40 percent when the luminaires depreciate during their life cycle. All impact areas are within 160 feet from the proposed roadway, which is equivalent to the existing condition based on the light level readings in Section 3.2.

EXHIBIT 7 - MAXIMUM LIGHT LEVELS AND SIZES OF IMPACT AREA FOR VARIOUS WATER AREAS

Proposed Roadway		Maximum Light Level (fc)[1]		Distance (feet)[2]		Photometric Isolines Generated
		EB (NB)	WB (SB)	EB (NB)	WB (SB)	
Option A	Portage Bay Bridge	0.9	1.0	157	137	Yes
	Foster Island	1.1	0.5	103	90	Yes
	Montlake Bridge	1.1	1.1	130	135	Yes
Option K	Portage Bay Bridge	1.0	1.0	150	135	Yes
	Foster Island	1.7	1.0	79	70	Yes
Option L	Portage Bay Bridge	0.9	1.0	140	140	Yes
	Foster Island	1.6	0.6	86	81	Yes
	New Bascule Bridge over Montlake Cut	0.5	0.5	155	159	Yes
Floating Bridge	Floating Bridge	0	0	N/A	N/A	No
	East High Rise	0.9	0.4	154	140	Yes

[1] The maximum light levels are calculated based on AGI32 calculations without considering any other artificial lighting.

[2] The distance from the edge of the proposed roadway to where light diminishes to the full moonlight level (0.03 fc)

Appendix III, IV, V, and VI include the photometric isolines for all the above water areas:

- Appendix III - Photometric Isolines for Option A.
- Appendix IV - Photometric Isolines for Option K.
- Appendix V - Photometric Isolines for Option L.
- Appendix VI - Photometric Isolines for East High Rise.

6. Summary and Future Considerations

The design team has attempted to utilize the current Washington State Department of Transportation (WSDOT) and City of Seattle (COS) lighting design standards, based on their most current practices, to design a roadway lighting system that both conforms to the roadway lighting requirements for safety and security purposes, and reduces light spillage onto the adjacent water areas.

The study has met the objectives set forth in Section 1.2 and the scope requirement for Contract Y-9761, Task Order BX Study #2 - Westside Conceptual Design and Floating Bridge Support, Task 3.2.2 - AGI32 Photometric Isolines and Memorandum. The outcomes of this study are summarized below:

- WSDOT standard luminaires could be used in the design of the illumination system on freeway mainline and ramps; however, adjustments would be necessary to reduce the lighting impact. These adjustments include:
    - Reducing pole height from 50 feet to 40 feet.
    - Reducing lamp wattage from 400W to 250W.
    - Increasing mast arm length from 6 feet to 10 feet.
    - Applying non-reflective shields to the luminaires.
- COS standard luminaires could be used in the design of the illumination system on bridges for the principal arterial streets; however, luminaires should be placed outside of the bridge area away from the water surface or close to the ends of the bridge, if applicable.
- With the proper adjustments to the light standard, the maximum light levels on the water surface could be reduced to a level below the acceptable threshold – 2.0 foot candles (fc) as noted in Section 2.2. Although the maximum light levels seem to be slightly higher than the current nighttime light level readings, they would reduce by up to 40 percent when the luminaires depreciate during their life cycle.
- All impact areas are within 160 feet from the proposed roadway, which is equivalent to the existing condition based on the light level readings in Section 3.2.
- Recessed pedestrian lighting fixture could be used in the design of pedestrian lighting on the floating bridge where roadway lighting is not provided. No light spillage was found in water based on this design approach.

Some options should be considered in the future design:

- Photometric Isolines on the water area and roadway calculation could be repeated once the photometric file for the shielded standard luminaire is available.
- A vegetated dune buffer or an artificial light shield could be created at each end of Montlake Bridge to further reduce the lighting impact. This study does not consider the vegetation effect in blocking the light source.
- Light-emitting diode (LED) lighting could be considered and analyzed for use on the over-water roadway segments. LED lighting provides more directional light in comparison to the high-pressure sodium (HPS) light source, which produces a relatively smaller footprint on the roadway surface and could be even more effective in reducing light spillage onto waterways. However, the use of LED light source for roadway lighting is not currently approved by

WSDOT and COS at this time. Therefore, further evaluation of the feasibility of LED lighting requirements and cost-benefit life cycle analysis would be required.

Appendix I - References

1. Witherington, B.E., and Martin, R.E. *Understanding, Assessing, and Resolving Light-Pollution Problems on Sea Turtle Nesting Beaches*. FMRI Technical Report TR-2, Florida Marine Research Institute, St. Petersburg, Florida, 1996.
2. *Coastal Roadway Lighting Manual - A Handbook of Practical Guidelines for Managing Street Lighting to Minimizing Impacts to Sea Turtles*, Revised by Florida Power & Light Company in consultation with Ecological Associates, Inc., Florida Fish and Wildlife Conservation Commission, US Fish and Wildlife Service, Florida Department of Transportation, and the Florida Department of Environmental Protection, May 2002.
3. *Signals Maintenance Shapes Salmon Solution*, Northwest Region, Bulletin No. 01-12, WSDOT, March 23, 2001.
4. Tabor, R.A., G. Brown, and V. Luiting. *The Effect of Light Intensity on Predation of Sockeye Salmon Fry by Prickly Sculpin and Torrent Sculpin*. U.S. Fish and Wildlife Service, Western Washington Office, Lacey, Washington. May 1998.
5. Tabor, R.A., and Piaskowski, Richard M., *Nearshore Habitat Use by Juvenile Chinook Salmon in Lenticd Systems of the Lake Washington Basin*, Annual Report, U.S. Fish and Wildlife Service, Western Washington Office, Lacey, Washington, 2001.
6. *Impacts of Ferry Terminals on Juvenile Salmon Migrating along Puget Sound Shorelines Phase I: Synthesis of State of Knowledge*, Research Report, Washington State Transportation Center, University of Washington, June 1999.

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Appendix II - Nighttime Light Level Readings in Water Areas Adjacent to the Existing Roadway

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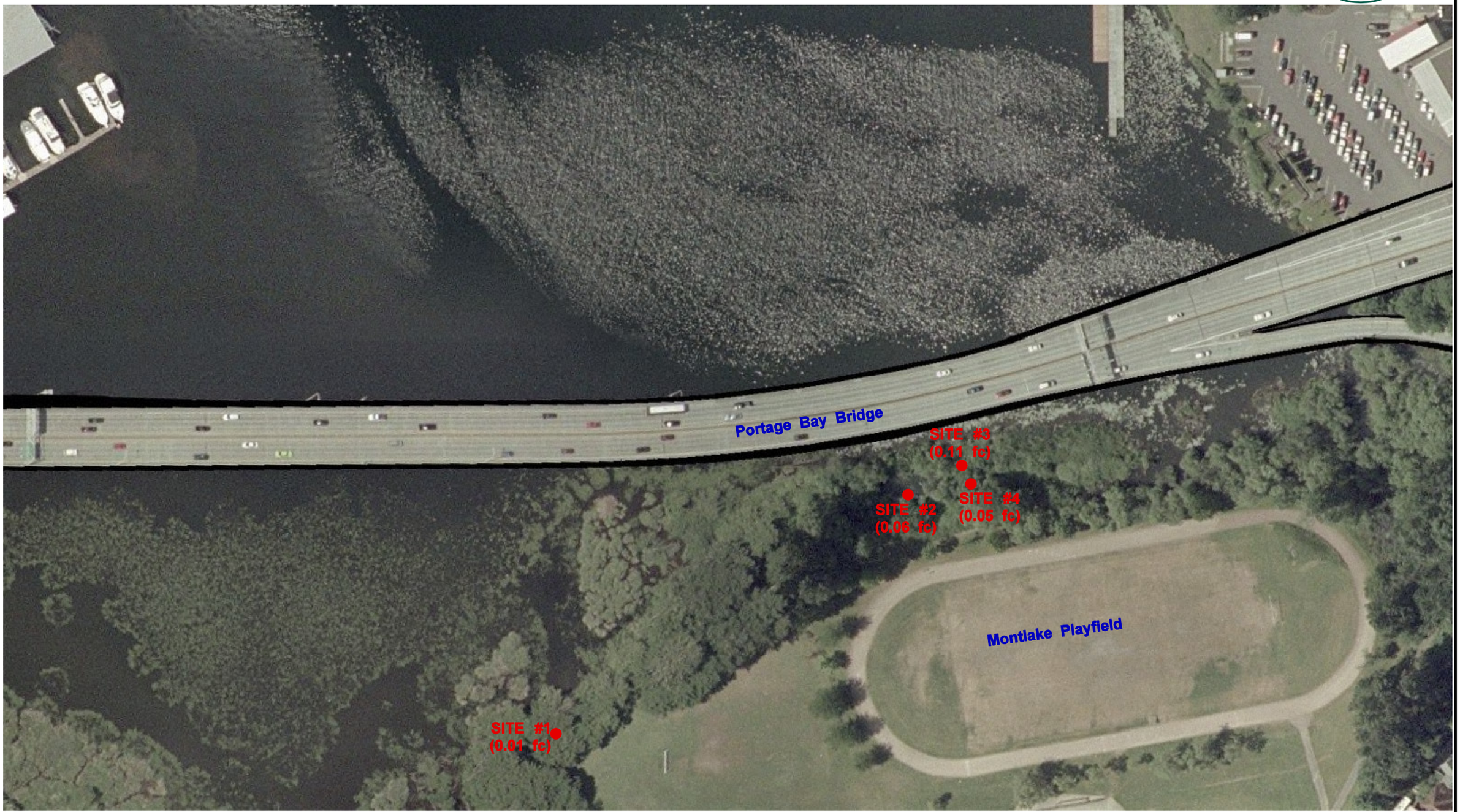
Washington State
Department of Transportation

SR 520 Bridge Replacement and HOV Project

STATE ROUTE 520



CONCEPTUAL

DRAFT - THIS SKETCH ONLY DEPICTS THE IDEA. ENGINEERING, OPERATIONS AND ENVIRONMENTAL ANALYSIS REQUIRED.

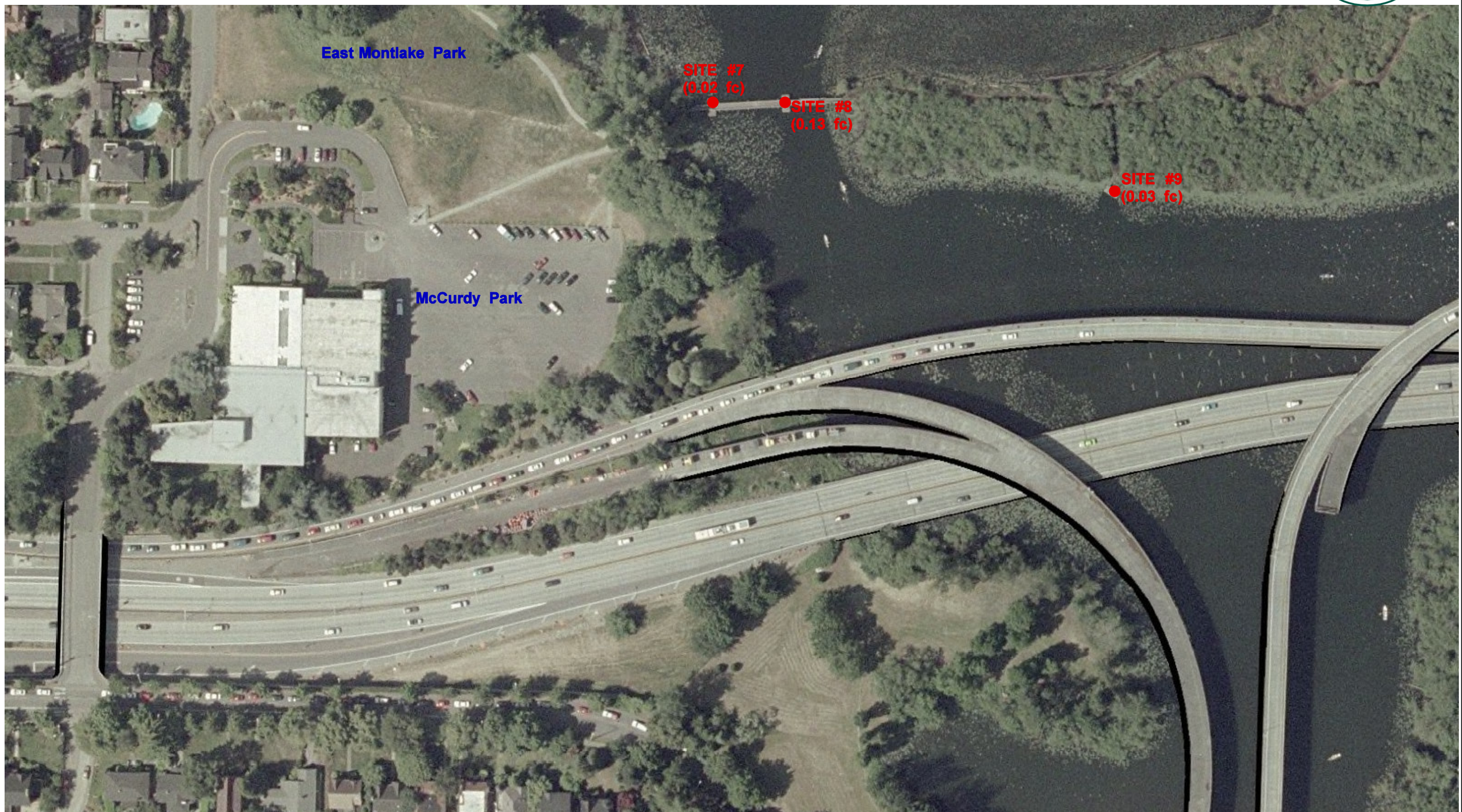
0 50 100
SCALE IN FEET

Nighttime Light Level Readings near Portage Bay Bridge

Washington State
Department of Transportation

SR 520 Bridge Replacement and HOV Project

STATE ROUTE 520



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Nighttime Light Level Readings near McCurdy Park

Washington State
Department of Transportation

SR 520 Bridge Replacement and HOV Project

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CONCEPTUAL

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0 50 100
SCALE IN FEET

Nighttime Light Level Readings near Foster Island

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Department of Transportation

SR 520 Bridge Replacement and HOV Project

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CONCEPTUAL

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0 50 100
SCALE IN FEET

Nighttime Light Level Readings near Montlake Bridge

Washington State
Department of Transportation

SR 520 Bridge Replacement and HOV Project

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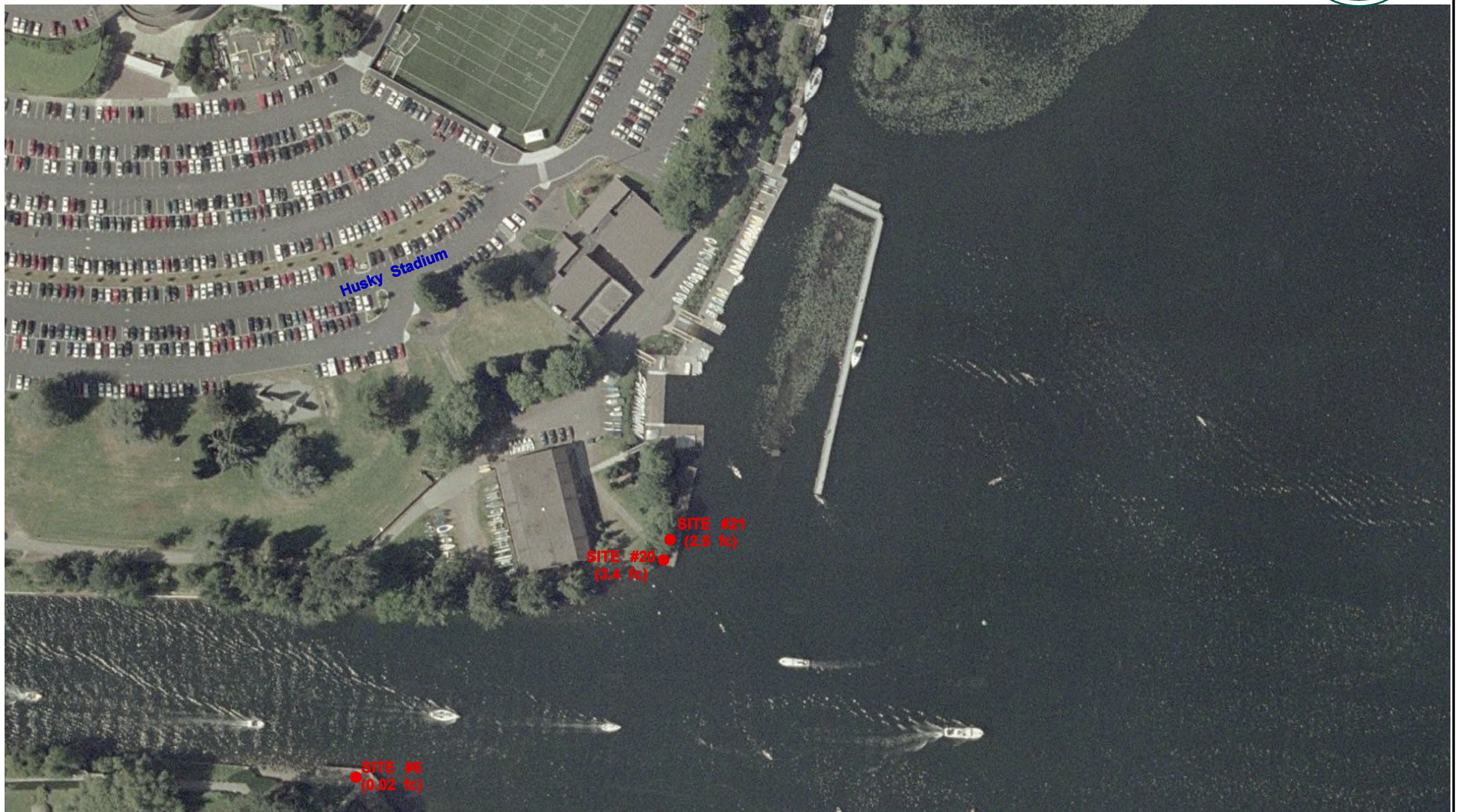

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SCALE IN FEET

Nighttime Light Level Readings near Husky Stadium

Appendix III - AGI32 Photometric Isolines in Water Areas Adjacent to the Proposed Roadway (Option A)

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SR 520 Bridge Replacement and HOV Project

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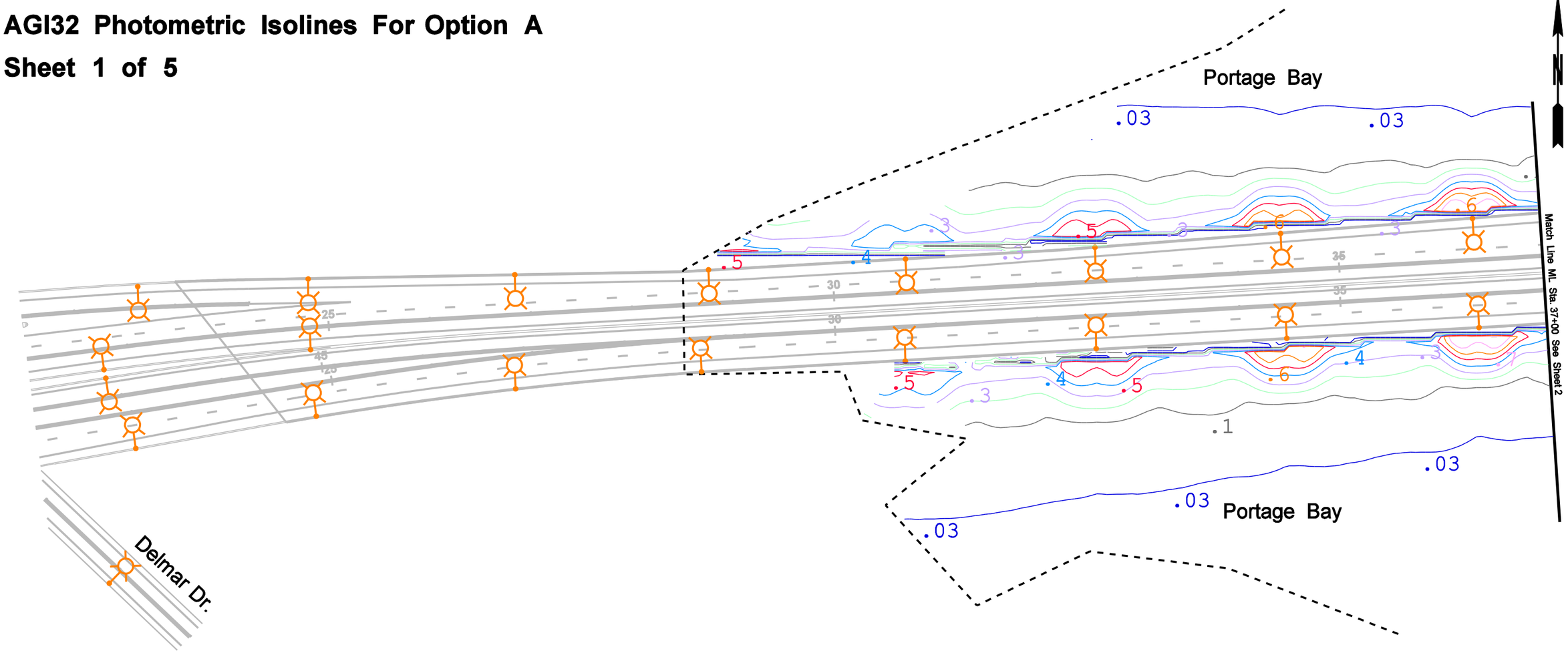
AGI32 Photometric Isolines For Option A

Sheet 1 of 5



Legend

- - - - - Approximate Border Line Between Land and Water

X.XX Foot-Candle

Luminaire Standard

0 50 100
SCALE IN FEET

CONCEPTUAL

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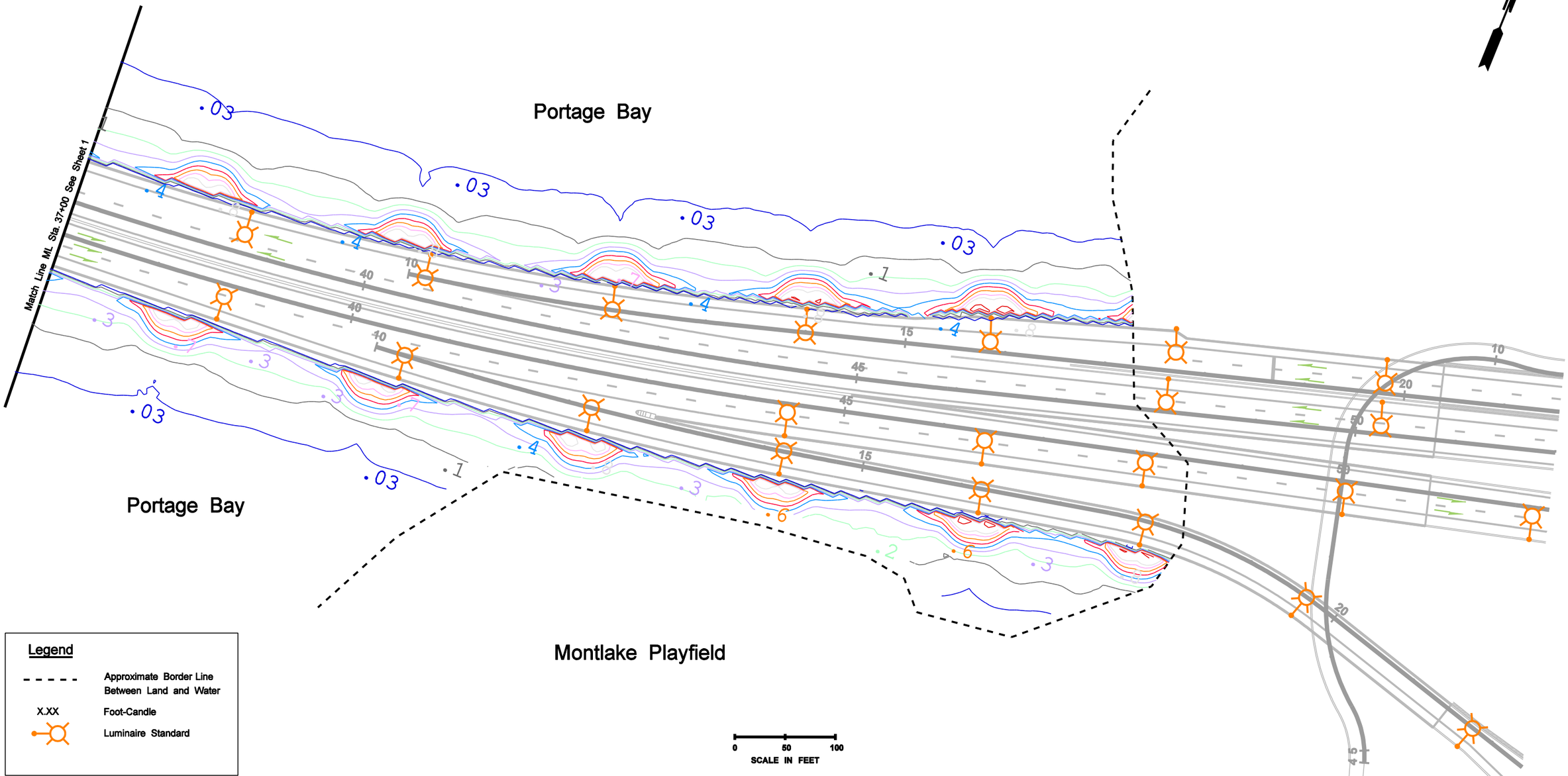
Washington State Department of Transportation

SR 520 Bridge Replacement and HOV Project

STATE ROUTE 520

AGI32 Photometric Isolines For Option A

Sheet 2 of 5



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SR 520 Bridge Replacement and HOV Project

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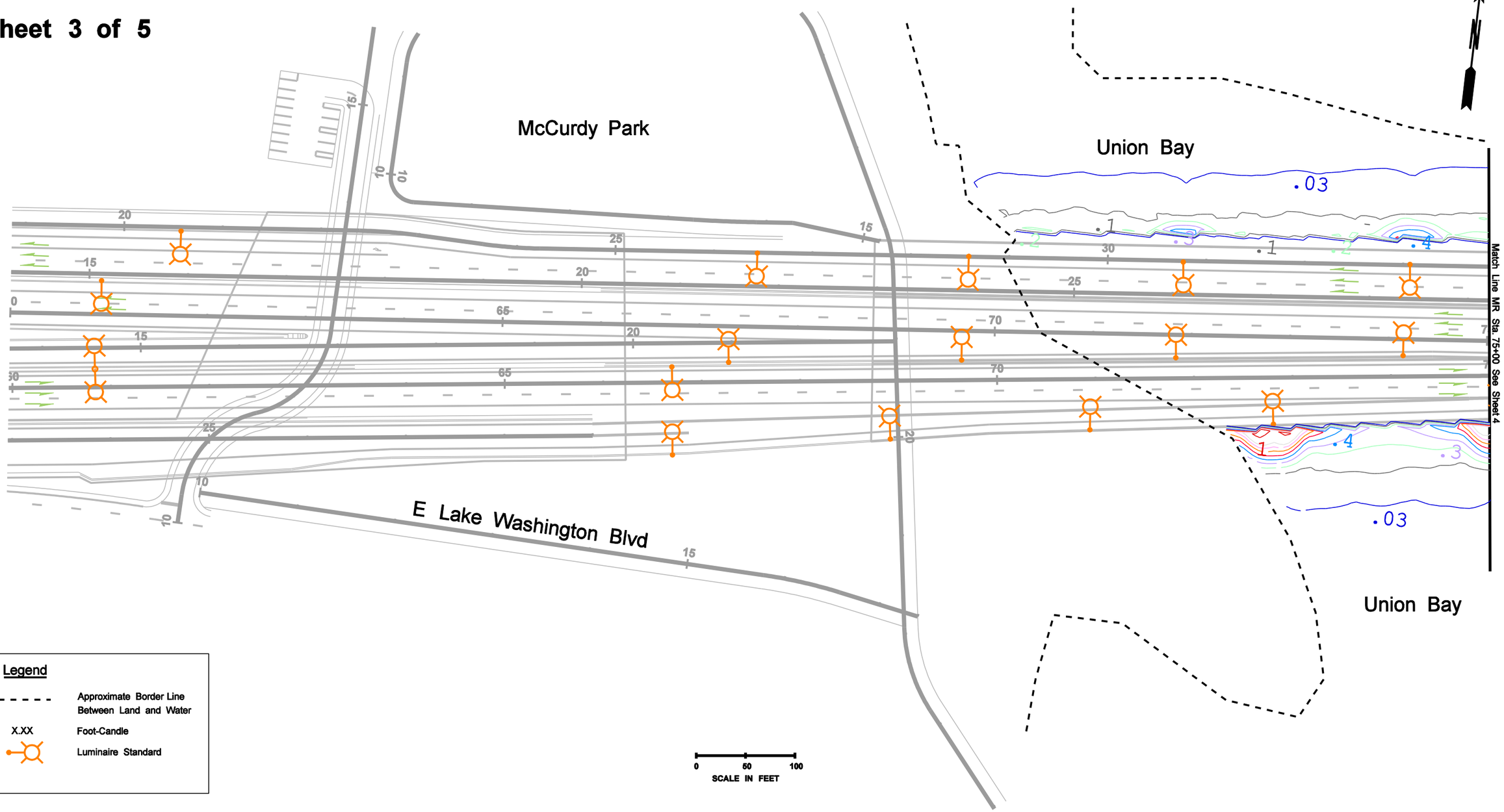
AGI32 Photometric Isolines For Option A

Sheet 3 of 5



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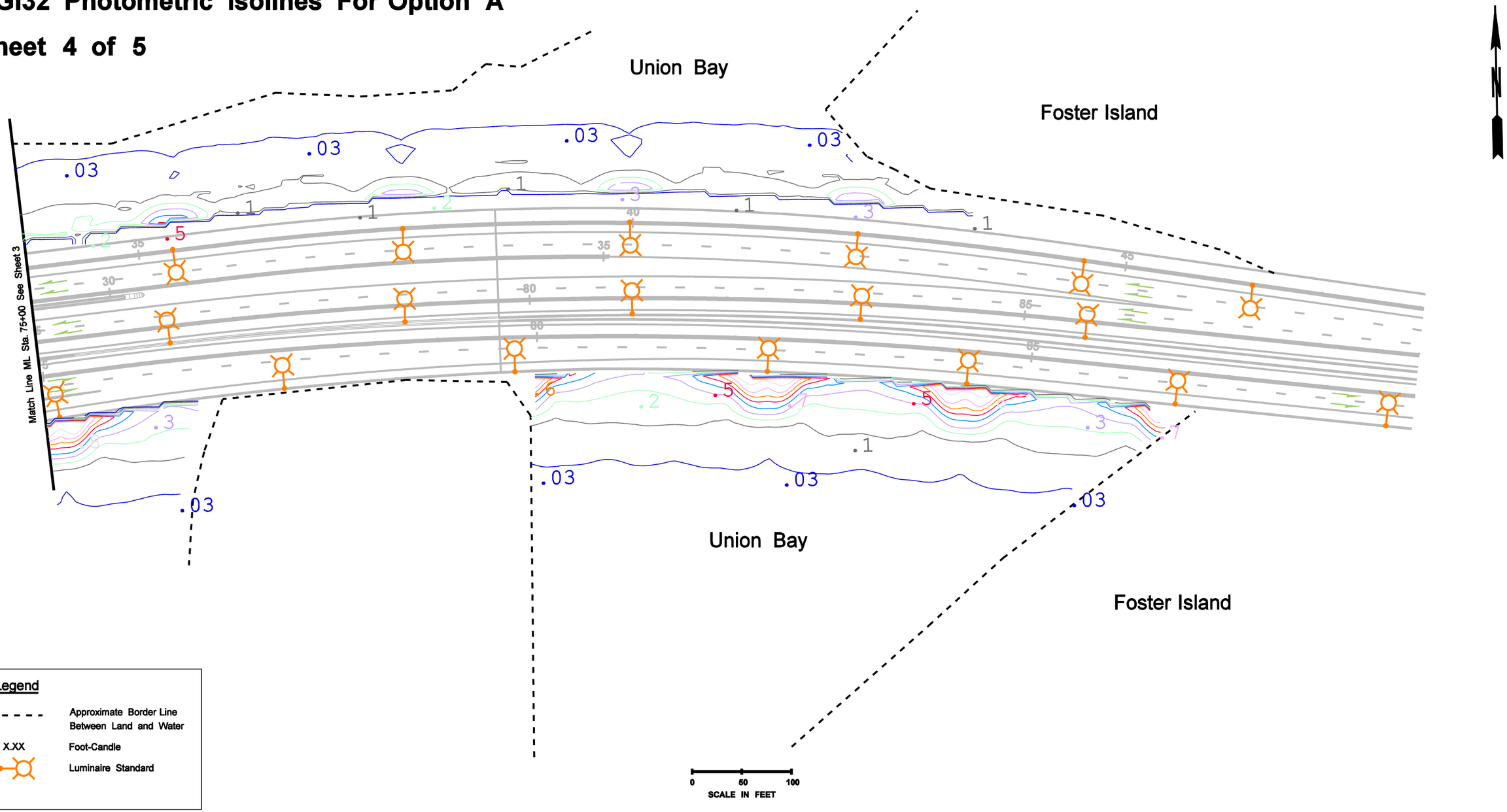
Washington State Department of Transportation

SR 520 Bridge Replacement and HOV Project

STATE ROUTE 520

AGI32 Photometric Isolines For Option A

Sheet 4 of 5



Legend

- - - - - Approximate Border Line Between Land and Water

X.XX Foot-Candle

Luminaire Standard

CONCEPTUAL

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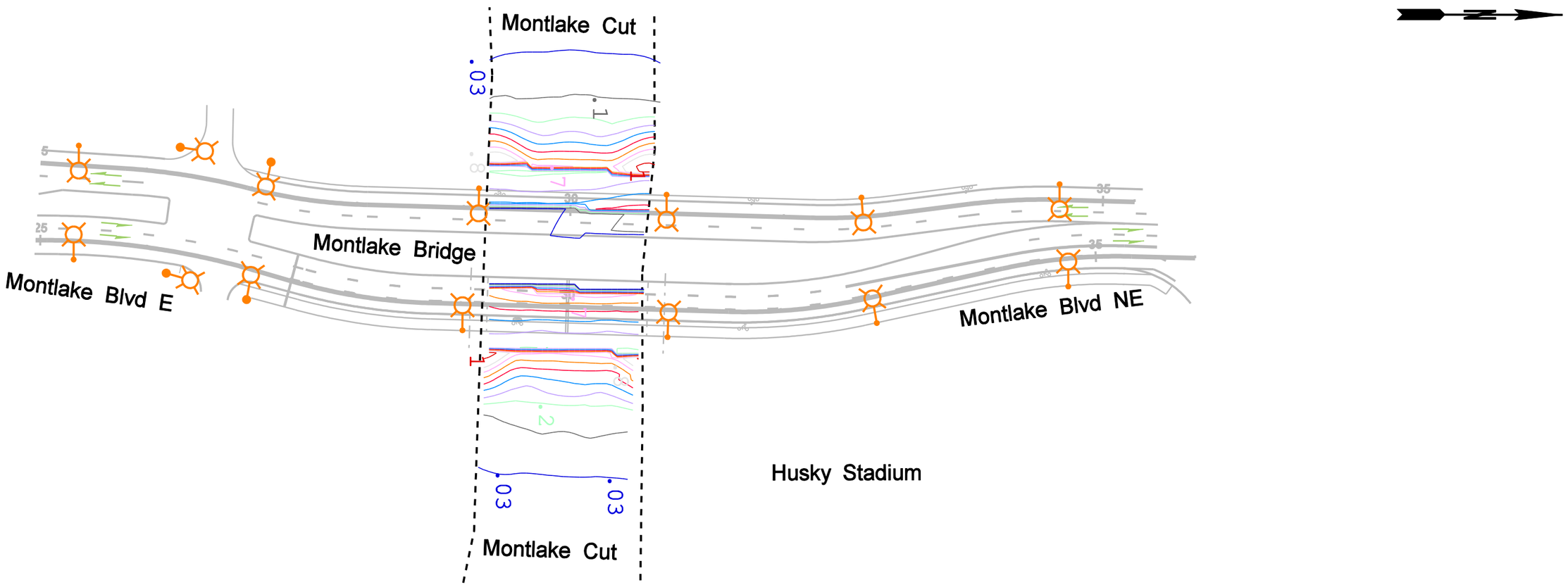
SR 520 Bridge Replacement and HOV Project

STATE ROUTE 520

AGI32 Photometric Isolines For Option A

Sheet 5 of 5



Legend

- - - - - Approximate Border Line Between Land and Water

X.XX Foot-Candle

Luminaire Standard

0 50 100
SCALE IN FEET

CONCEPTUAL

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Appendix IV - AGI32 Photometric Isolines in Water Areas Adjacent to the Proposed Roadway (Option K)

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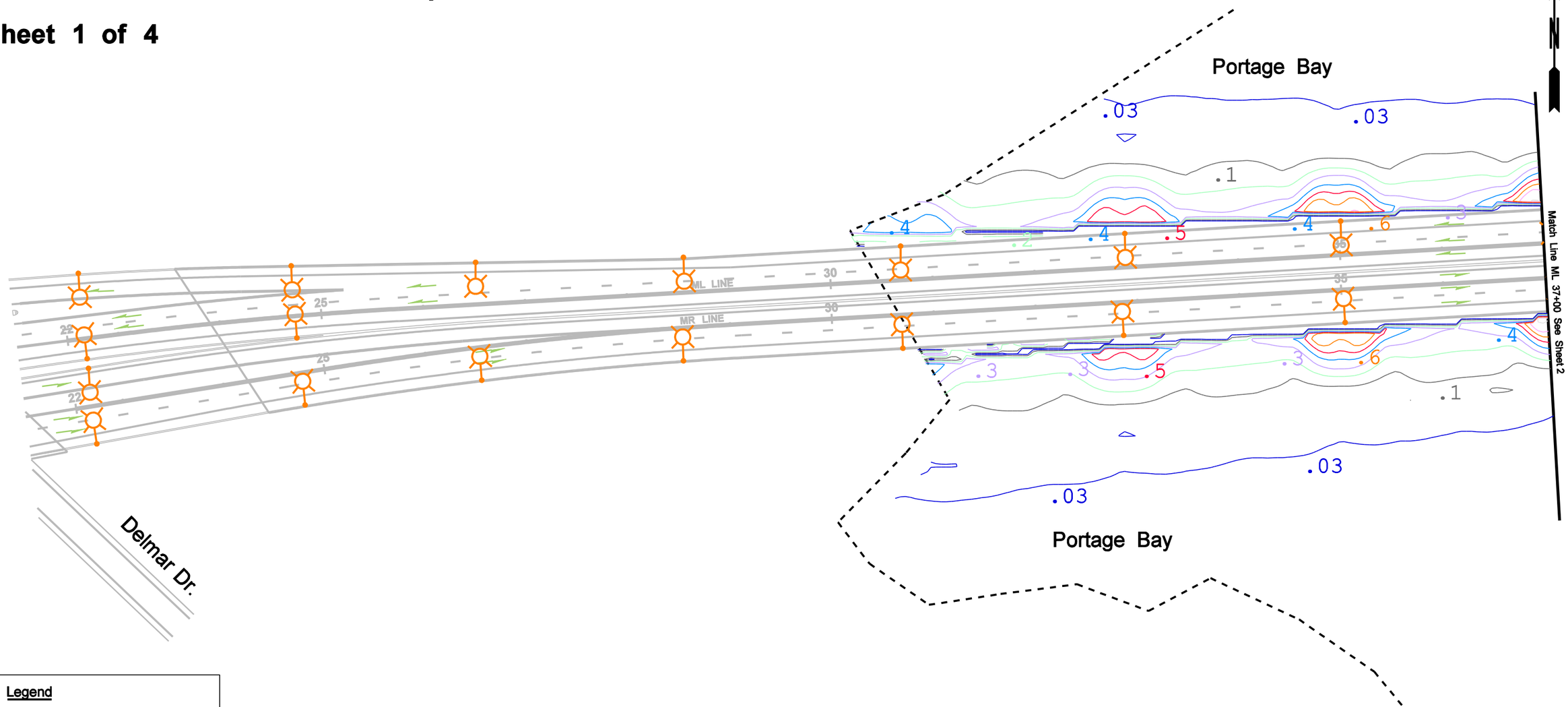
Washington State Department of Transportation

SR 520 Bridge Replacement and HOV Project

STATE ROUTE 520

AGI32 Photometric Isolines For Option K

Sheet 1 of 4



Legend

- - - - -	Approximate Border Line Between Land and Water
X.XX	Foot-Candle
	Luminaire Standard

0 50 100
SCALE IN FEET

CONCEPTUAL

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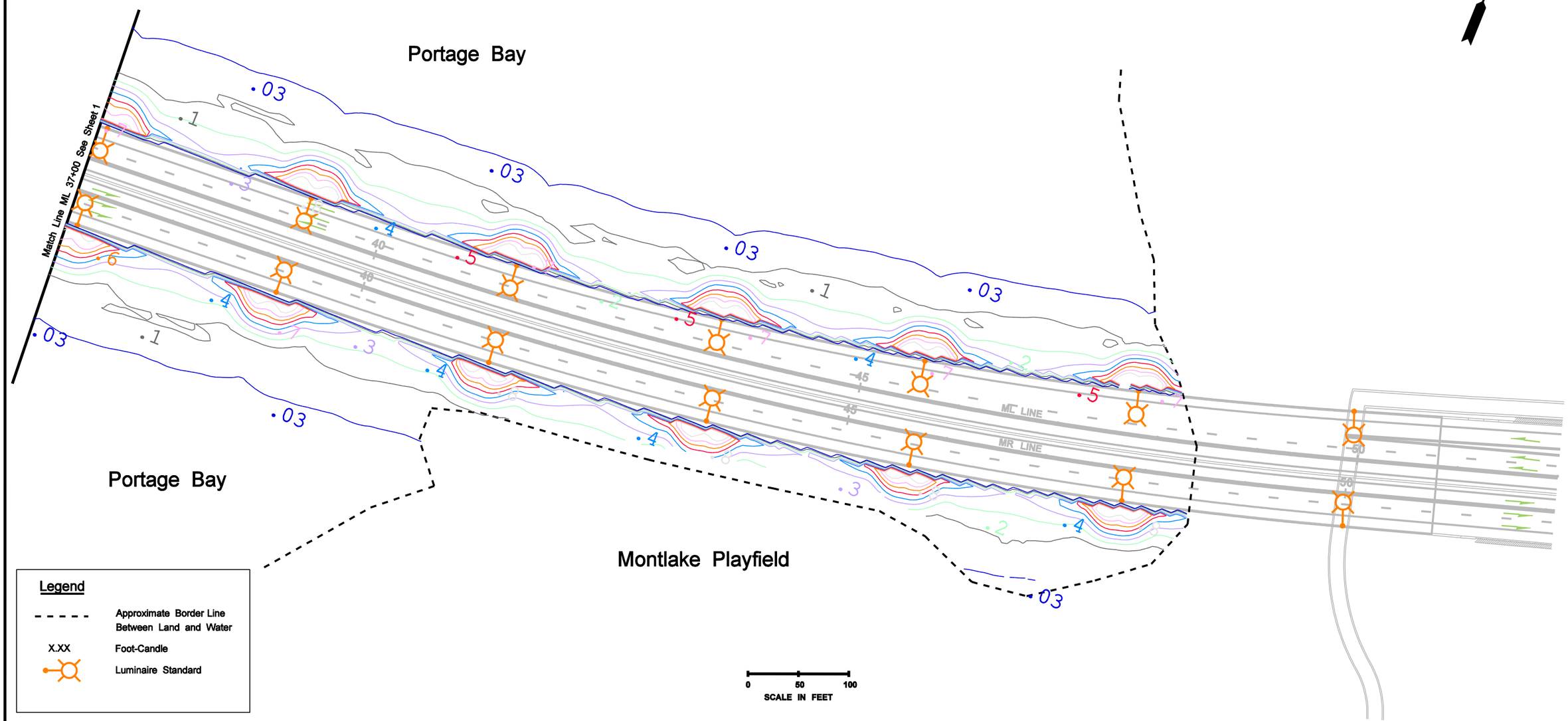
Washington State Department of Transportation

SR 520 Bridge Replacement and HOV Project

STATE ROUTE 520

AGI32 Photometric Isolines For Option K

Sheet 2 of 4



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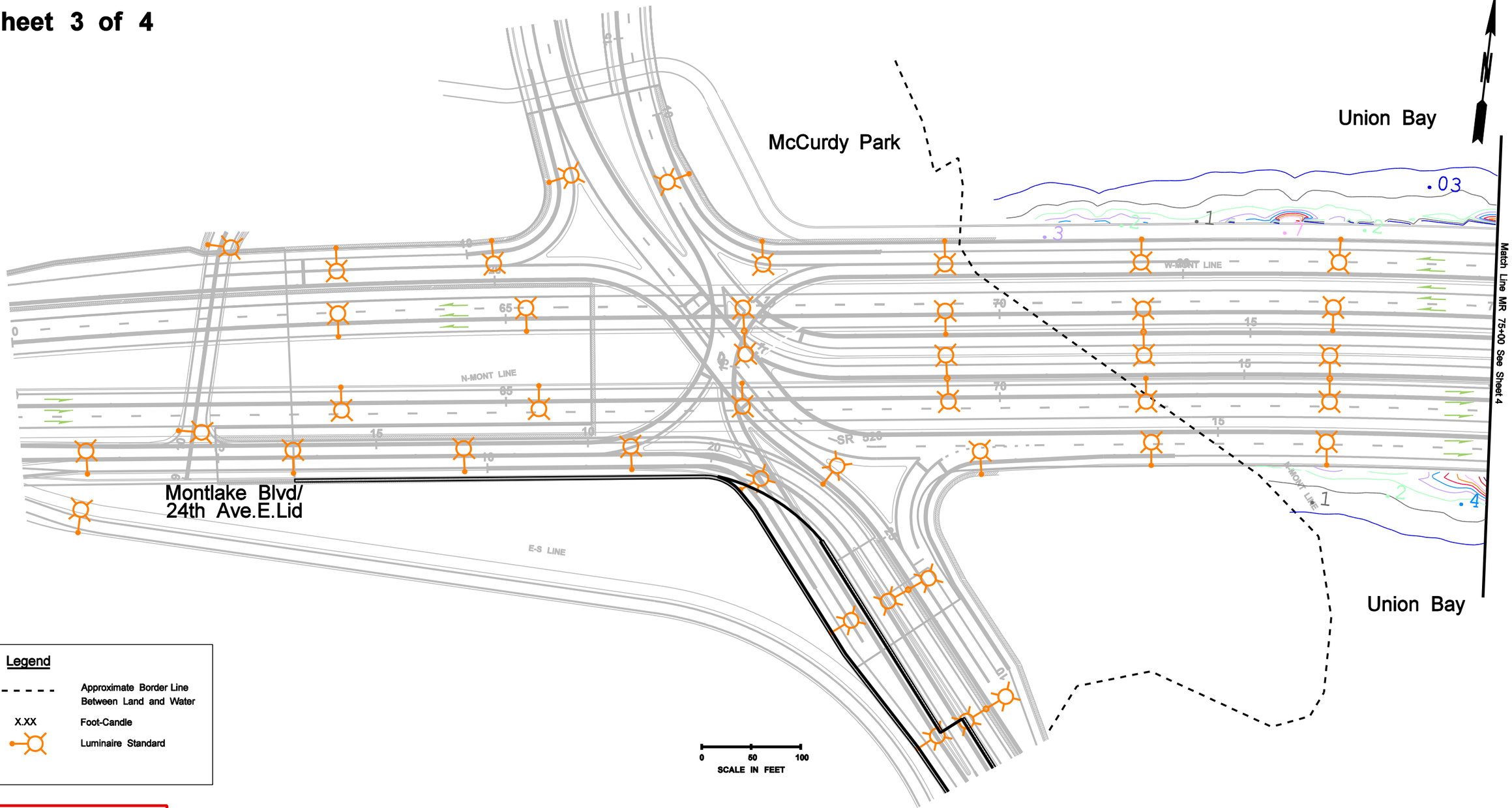
Washington State Department of Transportation

SR 520 Bridge Replacement and HOV Project

STATE ROUTE 520

AGI32 Photometric Isolines For Option K

Sheet 3 of 4



Legend

- - - - - Approximate Border Line Between Land and Water
- X.XX Foot-Candle
- Luminaire Standard

CONCEPTUAL

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SR 520 Bridge Replacement and HOV Project

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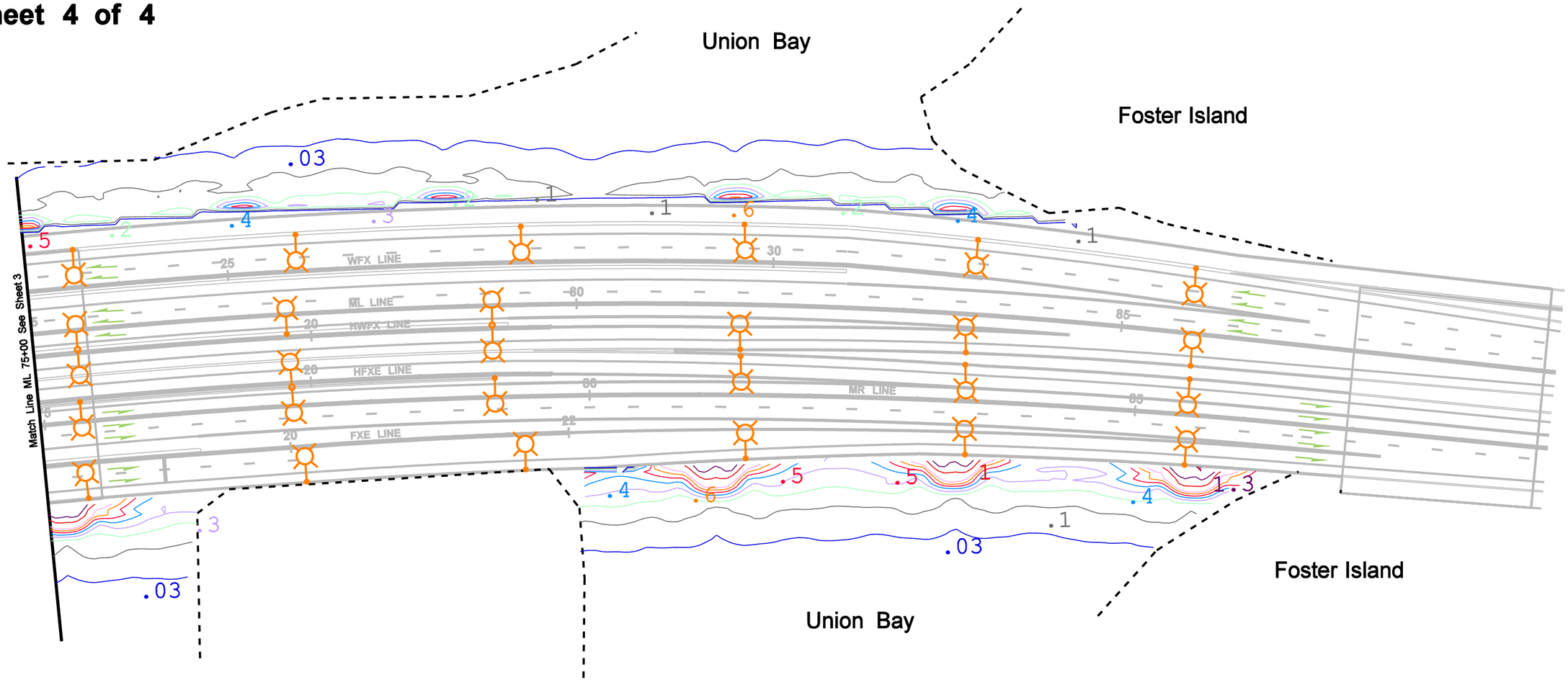
AGI32 Photometric Isolines For Option K

Sheet 4 of 4



Legend

- - - - - Approximate Border Line Between Land and Water

X.XX Foot-Candle

Luminaire Standard

0 50 100
SCALE IN FEET

CONCEPTUAL

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Appendix V - AGI32 Photometric Isolines in Water Areas Adjacent to the Proposed Roadway (Option L)

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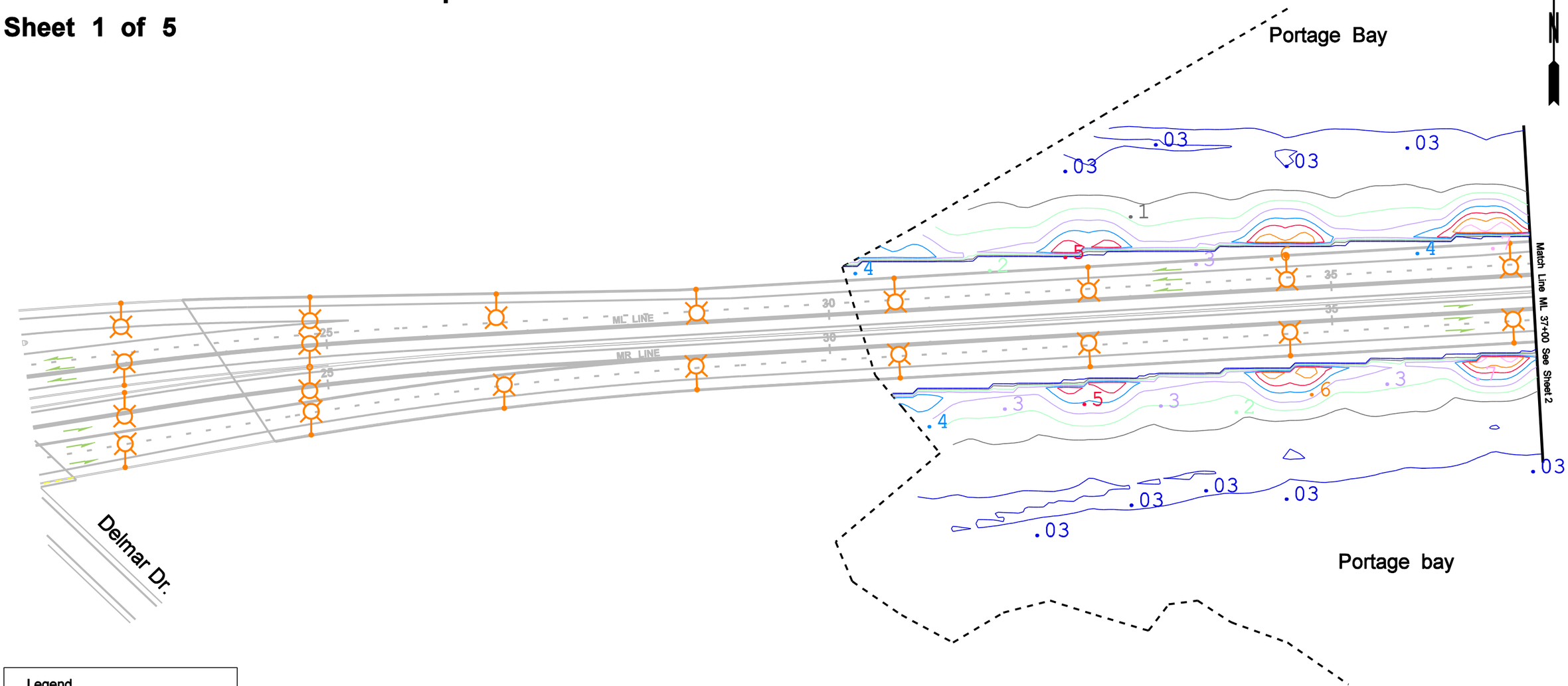
SR 520 Bridge Replacement and HOV Project

STATE ROUTE 520

AGI32 Photometric Isolines For Option L

Sheet 1 of 5



Legend

- - - - -	Approximate Border Line Between Land and Water
X.XX	Foot-Candle
	Luminaire Standard

0 50 100
SCALE IN FEET

CONCEPTUAL

DRAFT - THIS SKETCH ONLY DEPICTS THE IDEA. ENGINEERING, OPERATIONS AND ENVIRONMENTAL ANALYSIS REQUIRED.

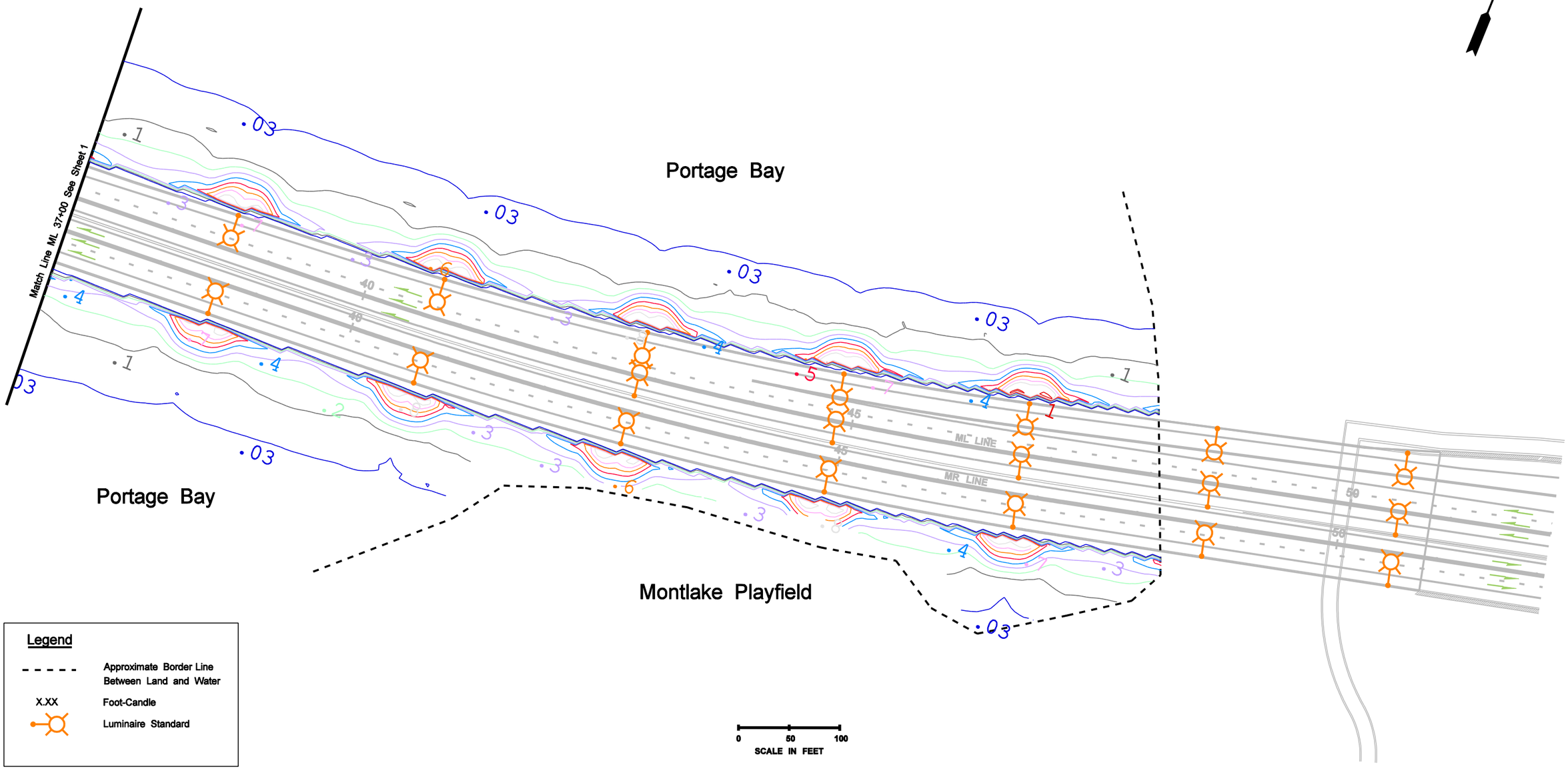
Washington State Department of Transportation

SR 520 Bridge Replacement and HOV Project

STATE ROUTE 520

AGI32 Photometric Isolines For Option L

Sheet 2 of 5



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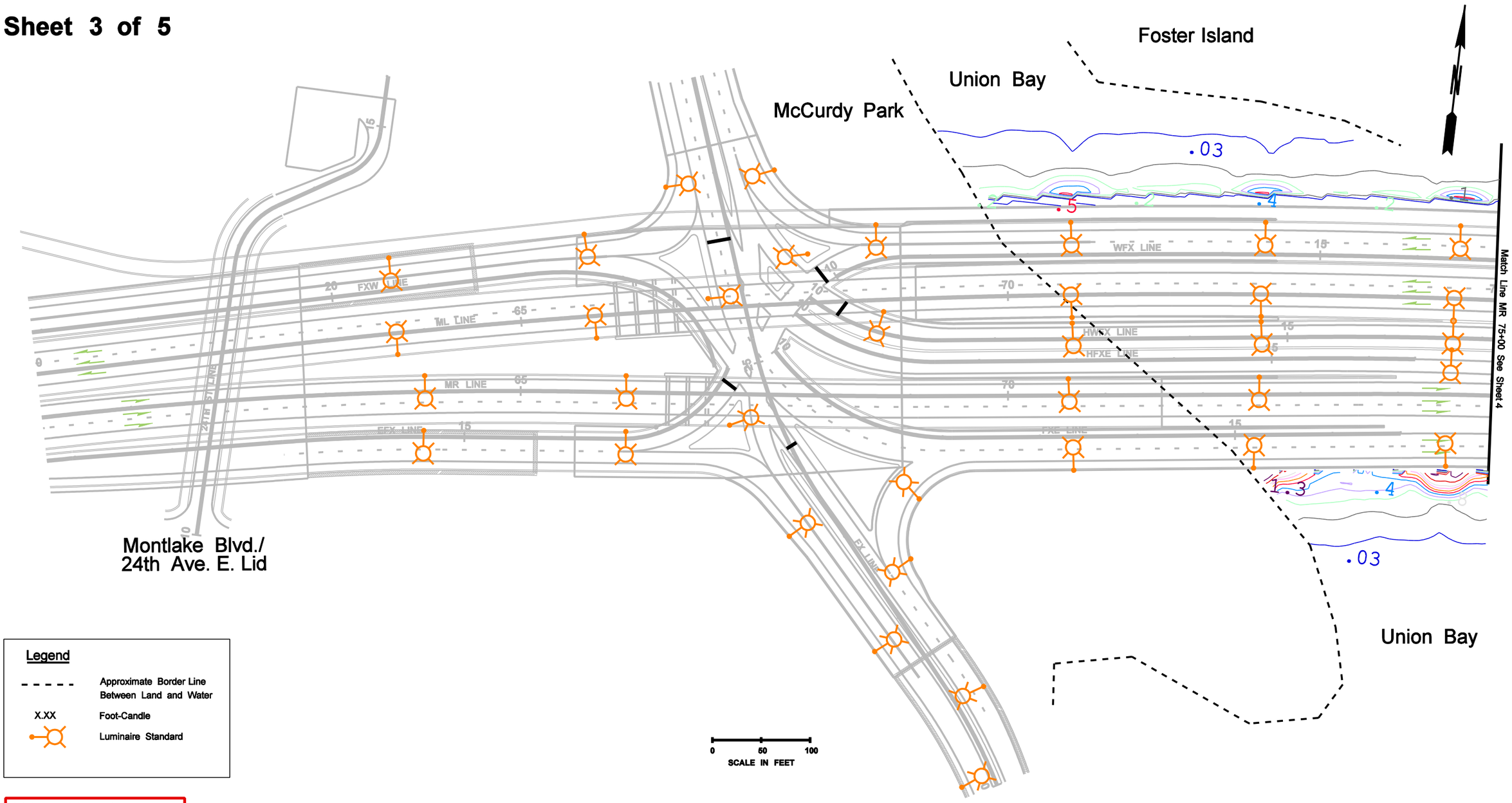
Washington State Department of Transportation

SR 520 Bridge Replacement and HOV Project

STATE ROUTE 520

AGI32 Photometric Isolines For Option L

Sheet 3 of 5



Legend

- - - - - Approximate Border Line Between Land and Water

X.XX Foot-Candle

Luminaire Standard

CONCEPTUAL

DRAFT - THIS SKETCH ONLY DEPICTS THE IDEA. ENGINEERING, OPERATIONS AND ENVIRONMENTAL ANALYSIS REQUIRED.

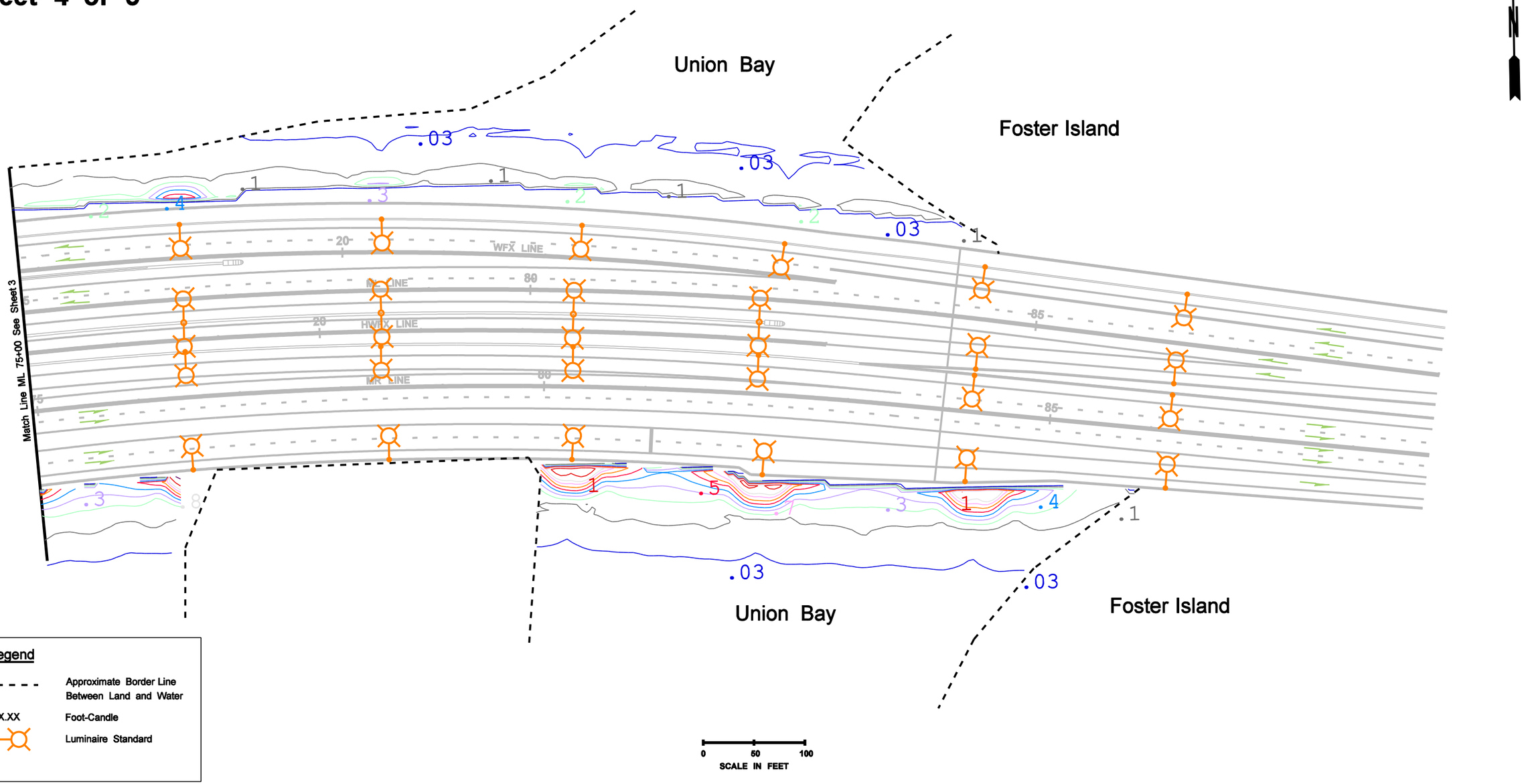
Washington State Department of Transportation

SR 520 Bridge Replacement and HOV Project

STATE ROUTE 520

AGI32 Photometric Isolines For Option L

Sheet 4 of 5



Legend

- - - - - Approximate Border Line Between Land and Water
- X.XX Foot-Candle
- Luminaire Standard

CONCEPTUAL

DRAFT - THIS SKETCH ONLY DEPICTS THE IDEA. ENGINEERING, OPERATIONS AND ENVIRONMENTAL ANALYSIS REQUIRED.

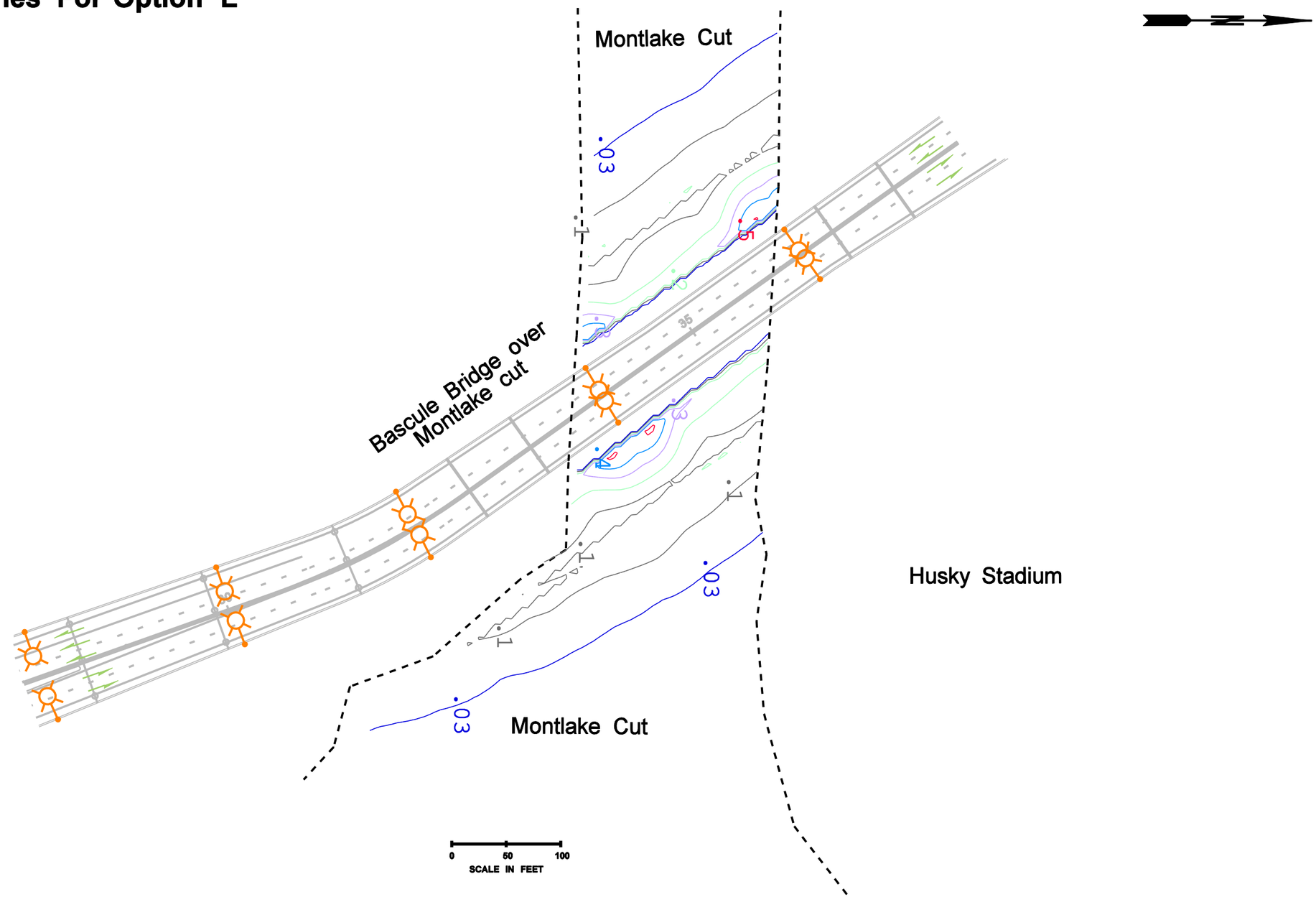
Washington State Department of Transportation

SR 520 Bridge Replacement and HOV Project

STATE ROUTE 520

AGI32 Photometric Isolines For Option L

Sheet 5 of 5



Legend

- - - - -	Approximate Border Line Between Land and Water
X.XX	Foot-Candle
	Luminaire Standard

CONCEPTUAL

DRAFT - THIS SKETCH ONLY DEPICTS THE IDEA. ENGINEERING, OPERATIONS AND ENVIRONMENTAL ANALYSIS REQUIRED.

Appendix VI - AGI32 Photometric Isolines in Water Areas Adjacent to the Proposed Roadway (East High Rise)

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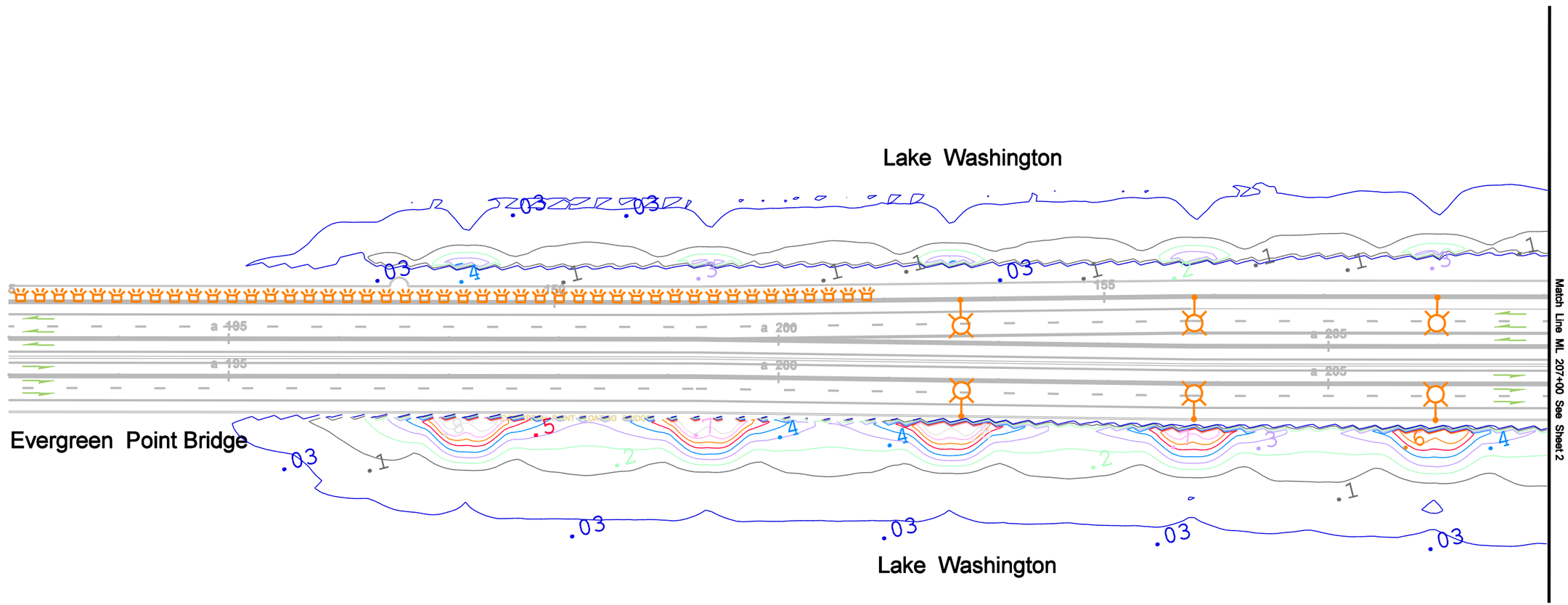
SR 520 Bridge Replacement and HOV Project

STATE ROUTE 520

AGI32 Photometric Isolines For East High Rise

Sheet 1 of 2



Legend

- - - - - Approximate Border Line Between Land and Water

X.XX Foot-Candle

Luminaire Standard

0 50 100
SCALE IN FEET

CONCEPTUAL

DRAFT - THIS SKETCH ONLY DEPICTS THE IDEA. ENGINEERING, OPERATIONS AND ENVIRONMENTAL ANALYSIS REQUIRED.

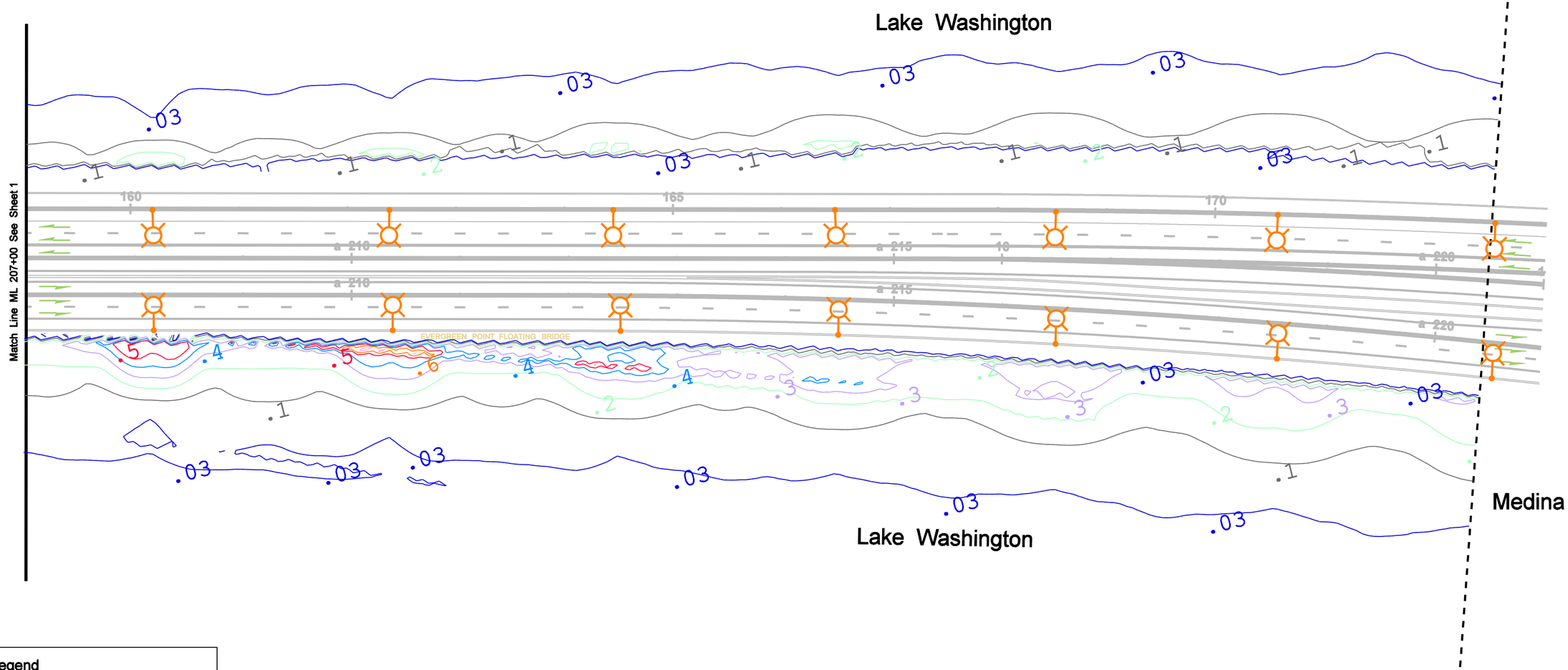
Washington State Department of Transportation

SR 520 Bridge Replacement and HOV Project

STATE ROUTE 520

AGI32 Isolines For East High Rise

Sheet 2 of 2



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