Last Chance Grade

Geotechnical Risk Assessment

Prepared by BGC Engineering USA Inc. and WSP USA for:

California Department of Transportation

July 25, 2024

Project 03A3157

Pioneering responsible solutions to complex earth science challenges

July 25, 2024

Caltrans Project 03A3157

Charlie Narwold, CEG
California Department of Transportation
Geotechnical Services
1835 6th Street
Eureka, CA 95501

Attention: Mr. Narwold, Senior Engineering Geologist

Geotechnical Risk Assessment

This report presents the methodology and findings of the geotechnical risk assessment conducted by BGC and WSP Engineering for the Last Chance Grade portion of US 101 in Del Norte County. The work was completed by BGC Engineering USA, Inc. (BGC) and WSP USA, Inc. (WSP).

We are pleased to have been able to assist Caltrans in this way. If we can be of further assistance, please let us know.

Yours sincerely,

BGC ENGINEERING INC.
per:

Scott A. Anderson, Ph.D.
Principal Consultant

WSP USA INC.
per:

Kenneth A. Johnson, Ph.D., CEG, PE
Senior Technical Principal Geological Engineer

EXECUTIVE SUMMARY

To support Caltrans' alternative selection process, a geotechnical risk assessment (GRA) was performed in 2024 to help characterize geotechnical risks. This step was taken for two primary reasons. First, the difficult site access, varied land ownership and cultural and environmental significance of the project environment have meant geotechnical data collection is and has been challenging. Second, considerable additional data has been collected for the project since the prior Expert-Based Risk Assessment in 2018 and a re-evaluation is appropriate at this time. Two types of geotechnically-related risks were evaluated: delivery risks and performance risks. Delivery risks are related to the geotechnical factors that impact the steps to program, design and construct a selected alternative. Performance risks are related to how the proposed alternative will serve mobility post-construction and how the geotechnical factors within the project area might impact mobility.

Both Alternative X (re-engineered on-alignment with deep groundwater depressurization) and F (highway bypass tunnel with south portal approach in earthflow) involve constructing new highway infrastructure within active landslides (ground that is currently moving) and the alignment for each connects to stationary ground, beyond active landslides, making the maintenance of performance difficult. The alternative approaches are different and geotechnical threats to performance are unique for each alternative, yet they are similar in that the risks attributed to them threaten how well the completed project performs. Thus, the GRA is intended to provide Caltrans with an expanded evaluation of geotechnical risks for both project delivery and performance that can be incorporated into the alternative selection process for the project.

A key element of the geotechnical risk assessment was an onsite workshop. The geotechnical workshop involved a panel of six experts, with facilitation by BGC and WSP staff who also have relevant technical experience. Prior to the workshop, the panel received an information package to help establish consistency in their understanding of the project and geotechnical data collected for the project. Additional tools prepared for the workshop included augmented reality visualizations and other data integration tools, a field trip, and brief presentations by Caltrans, WSP and BGC. After the workshop there were two follow up meetings attended by the full panel along with email updates and assignments to refine the panel work and consolidate and summarize results and to advance the GRA.

The work presented here includes opinions and estimates made by BGC and WSP that were based on the input and judgement of the panel members as well as the WSP/BGC team. The panel's observations and estimates of risk, and the associated work products of BGC and WSP, are based only on the level of information conveyed through this process. This is believed to be sufficient to assist Caltrans with their project development and alternative selection process, but not for other purposes.

General Approach to Geotechnical Risk Assessment

Delivery risk was evaluated beginning with the Caltrans standard project delivery risk register and process, including geotechnical risks that were previously included in the project risk register. The panel's scope was to identify additional geotechnical risks and to provide recommendations for the fields in the risk register where their expertise and independence is relevant and helpful. As captured here, they identified new delivery risks and estimated probabilities of their occurrence.

Performance risk was characterized with respect to maintenance-of-traffic-criteria that describe mobility impacts from geotechnical threats to the design and constructed works. In discussions and reviews with Caltrans District 01 (D01) senior staff, it was decided that this performance attribute was one of primary importance and that other performance attributes are negatively correlated with it, such that if the need for traffic impacts was low, performance of the highway would be high.

The two risk types were addressed separately. A structured approach was then used to develop an understandable and repeatable framework for comparing and contrasting the risks associated with each alternative. The panel assumed that for projects of this scale, at a minimum, value analysis will be conducted wherein value, as measured by cost, schedule and other attributes will be optimized by making value modifications to the project design. This was one of several assumptions agreed to by the panel to help assure that their assessments were consistent with one another, and they represent a reasonable consideration of the current design and its likely final configuration.

Delivery Risk Evaluation

During the workshop, the panel discussed seed risks from the current risk register and then identified additional geotechnically-based risks for each of the alternatives. A total of 24 geotechnical risks were identified for Alternative X, and 17 were identified for Alternative F. The WSP/BGC team consolidated the risks into seven risk categories that allowed the panel to develop a risk profile useful for alternative comparison. The seven risk categories were then evaluated by the panel in terms of the probability of occurrence using the qualitative criteria established in the Caltrans risk assessment tool. The WSP/BGC team consolidated the panel responses into representative probabilities of occurrence for each risk.

As is typical for a project delivery risk evaluation, the consequence of a risk is assessed here in terms of cost and schedule impacts. The WSP/BGC team developed an initial evaluation of the consequences to allow the project impacts to be more fully conveyed for each alternative. This semi-quantitative assessment of consequences is interim, and it should receive further consideration. Nevertheless, these results show that the delivery risks are generally high and that Alternative F may have project delivery impacts almost three times as high as those for Alternative X. Mitigation strategies were proposed by the panel for both alternatives, generally tied to collecting more geotechnical data to improve understanding and reduce risk. The high probabilities assigned to the unmitigated risks emphasize the value of additional site investigation as an important strategy to reduce the risks to an acceptable level.

Performance Risk Evaluation

Five different levels of traffic impacts were identified and characterized as "Condition States" A, B, C, D, and F, representing decreasing level of performance due to impact on mobility. This condition state structure enabled the panel to evaluate the probability of occurrence that the highway would experience different levels of mobility impacts over near-term (years 0-10 of operation) and long-term (years 50-75 of operation) in a structured manner. The panel considered what significant geotechnical threats to this measure of performance were present with each alternative, how likely they were to occur, and how likely it is that the design, informed by the anticipated site investigation and analysis, would be robust enough to fully mitigate the threat. Finally, the panel assessed what impacts to mobility would most likely be present if the threat was not fully mitigated. The panel identified seven primary threats for Alternative F and five for Alternative X. These were assessed individually and, using statistical assumptions, combined so that the alternatives could be compared.

Based on the risk elicitation from the panel members and the process and assumptions stated herein, the interpretation of combined results is that Alternative F is about twice as likely to remain in its initial condition (requiring only average maintenance) as Alternative X. This observation is generally consistent for both the near-term and long-term assessments.

Performance risk mitigation, to the extent it is possible, occurs in the delivery stage of the project through delivery risk mitigation. No alternate or additional strategies for performance risk mitigation were proposed as part of this risk assessment.

TABLE OF REVISIONS

Date	Revision	Remarks
June 12, 2024	A	Draft submitted to Caltrans for review.
July 25, 2024	0	Final

CREDITS AND ACKNOWLEDGEMENTS

The summaries and conclusions presented herein are the responsibilities of the WSP/BGC team, but WSP/BGC team would like to express its appreciation to the panelists listed here for their expert opinion, ideas and debate, and for their review of this report:

- George Machan, PE, Cornforth Consultants
- Matt Fowler, PE, WSP
- Mike Porter, M.Eng., P.Eng., LEG, BGC Engineering
- Steve Klein, PE, GE, WSP
- Tom Badger, LEH, LHG, PE, Cornforth Consultants
- Warren Newcomen, P.Eng., BGC Engineering.

The signatory authors would also like to acknowledge the contributions of Seamus Millet and Molly Winston of BGC, and Emma O'Hara of WSP for their contributions in planning the workshop, preparing materials and recording proceedings, as well as their help in completing this report.

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1.0 INTRODUCTION

US 101 crosses landslides along Last Chance Grade (LCG) that have been actively moving and impacting the highway for decades. Despite ongoing efforts and substantial investment, including over $85 million in landslide mitigation measures, the route has faced continuous challenges, necessitating costly repairs. Recent reopening after years of restricted traffic underscores the urgency of finding a sustainable, long-term and resilient solution.

As part of this project, Caltrans has been considering a major capital investment and working on a long-term solution since March of 2014. The preliminary alternative selection process ended in April 2021 with the final two alternatives, F and X, that were considered for further study. Alternative X is near the existing U.S. 101 alignment with inboard retreat and realignment using new retaining walls and it has, as a major component, an underground groundwater depressurization system of tunnels and drains beneath the landslide failure surfaces. Alternative F consists of a 6,000-ft-long tunnel east of the existing highway. The tunnel is aligned behind the landslide failure surfaces, and it carries two-way traffic and bicycle access. A tunnel operation and control center would be built south of the tunnel.

To support Caltrans' alternative selection process, a geotechnical risk assessment (GRA) was performed to help characterize geotechnical risks during the project delivery and design life time frames. This step was taken for two primary reasons. First, the difficult site access, varied land ownership and cultural and environmental significance of the project environment have meant that geotechnical data collection, as a basis for design, has been challenging. The result is that some data collection has been deferred and that prioritization of future data collection, and to what extent it is performed in advance of construction or concurrent with construction, will be needed. This prioritization will be informed by the geotechnical risks assessed here. These risks are geotechnical in nature and are referred to herein as delivery risks because they are related to the steps needed to deliver a selected alternative through design and construction phases.

The second reason for the GRA is related to performance after the project has been delivered. Both Alternative X and F involve new highway infrastructure built on ground that is moving currently and ground that is expected to continue to move after the project is delivered because, to do otherwise, through complete avoidance or stabilization, would be considerably more impactful and expensive. As a result, there are geotechnical, ground movement risks to the new infrastructure, and each alternative is different. These risks, referred to herein as performance risks, threaten how well the completed project delivers uninterrupted service into the future.

A key element of the GRA was an onsite workshop. The workshop consisted of a panel of six experts, with facilitation by BGC and WSP staff who also have relevant technical experience. There was some pre-read material provided to the panel to help with understanding, augmented reality visualizations and other data integration tools while onsite, a field trip, and brief presentations by Caltrans, WSP and BGC. After the workshop there were follow up meetings attended by the full panel and email interchanges to complete transfer of understanding and receipt of panelist input.

The work presented here includes opinions and estimates made by the WSP/BGC team. The panel's observations and estimates of risk, and the associated work products of BGC and WSP, are based only on the level of information conveyed through this process. This is believed to be sufficient to assist Caltrans with their project planning process, but not for other purposes that follow in project delivery.

BGC and WSP were contracted by Caltrans to design, facilitate, report, and communicate the findings of this risk assessment. This scope of services is consistent with the scope of Contract No. 03A3157 Task Order No. 2 Amendments 7 (dated November 21, 2023) and 8 (dated May 16, 2024).

2.0 GEOTECHNICAL RISK ASSESSMENT APPROACH AND SCOPE

2.1 Context

The LCG Permanent Restoration Project is located on a section of U.S. 101 known as Last Chance Grade in Del Norte County between Wilson Creek to the south and Crescent City to the north. The LCG has been experiencing ongoing geologic instability since its construction in the 1930s and has recently just fully reopened after years of one-way controlled traffic and ongoing structural repairs. Between 1997 and 2021, Caltrans estimates the direct cost of landslide mitigation efforts, including retaining walls, drainage improvements, and roadway repairs have been more than $85 million (Caltrans, 2023a). The costs are expected to continue to increase, and this trajectory of repair costs is not an acceptable long-term solution.

The purpose of the project is to develop a long-term solution to the instability and potential roadway failure at LCG. The project considers alternatives that provide a more reliable connection, reduce maintenance costs of the type that have been experienced, and serves to protect the economy, natural resources, and cultural landscapes present.

In summary, a long-term sustainable solution at LCG is needed to address:

- Economic ramifications of a potential longer-term failure and closure
- Risk of delay/detour to traveling public
- Increase in maintenance and emergency project costs
- Increase in frequency and severity of large storm events caused by climate change (Caltrans, 2023a).

The preliminary alternative selection process for developing a long-term solution began in March of 2014 and ended in April 2021 with the final two alternatives, F and X, that are being considered for further study. Through the alternative selection process, approximately twenty different alternatives were considered and evaluated against various criteria, such as cost, environmental impact, geotechnical risk, and operational factors (Caltrans, 2021).

The previous GRA, which has been referred to as an Expert Based Risk Assessment (EBRA), completed in early 2018, considered six alternatives against Caltrans' long-term performance objectives assuming a 50-year lifecycle. The project approach at the time of the 2018 risk assessment assumed that Caltrans would follow its standard practice in the design and construction of any alternative in such a way to deliver essentially equivalent safety and highway design standard across its roadways. In addition to safety, other performance objectives include (a) maintaining low lifecycle ownership cost and (b) providing a certain level of mobility, for example by keeping lanes open in both directions, and at posted travel speeds (BGC, June 14, 2018).

As the project has progressed beyond the initial GRA, including the collection and analysis of additional data and the narrowing of alternatives down to two, it has become apparent that an updated risk assessment is desirable. California and AASHTO guidance documents are written to address most projects, but they are not written to address projects like this. The project is unique for three reasons:

- The complex geology and hydrogeology which has led to the project need.
- The two alternatives involve building complex new infrastructure in ground that is currently moving and will continue to move, perhaps throughout the design life.
- The cultural and environmental constraints are such that geotechnical site characterization will be less than normally achieved, and uncertainty will be greater.

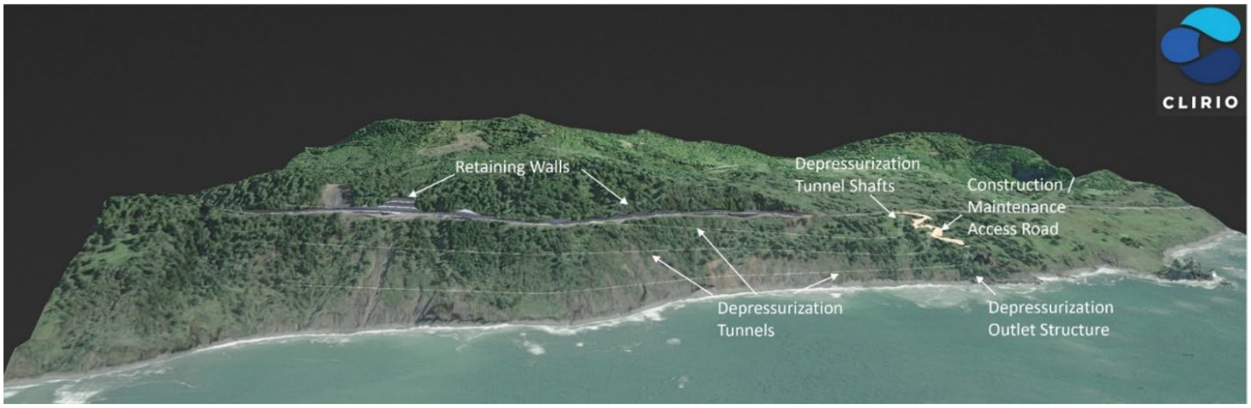
In the absence of specific applicability of guidance documents, this GRA is proposed to characterize and help manage risk through the risk-informed selection of a preferred alternative. The risks will be different for each alternative, and the risk assessment will identify how and why these risks are different to enable risk-informed decision. The assessment will hold separate two types of risk: delivery risk and performance risk, as described in the following section. In summary, the objective of this risk assessment is to support Caltrans' alternative selection process by assessing geotechnical risks in design and construction (delivery risk), and performance (performance risk).

2.2 Alternative Alignments

Two alternative alignments are currently being considered: Alternatives X and F, as presented within the Draft Environmental Document. Each alternative is summarized below in language excerpted from the Caltrans Preliminary Geotechnical Report (Caltrans, 2023b). Plan views of each alternative can be found in Plates 2 and 3 of the Caltrans Preliminary Geotechnical Report, Appendix D, and are shown conceptually here in Schematic 2-1 and Schematic 2-2. Potential optimizations to these designs are expected during the advancement of site investigation and design, and through value analysis. The scope of this risk evaluation is limited to the concepts presented in the environmental document as amended by these expected optimizations. No other alternatives were evaluated.

2.2.1 Alternative X

Alternative X maintains the existing U.S. 101 alignment with segments of slight realignment to improve roadway geometry and to shift away from the downslope failing areas. The area of improvement begins at current post mile (PM) 14.3 and ends at PM 15.9. The alignment extends into the hillside at some locations requiring six new retaining walls to be constructed, totaling approximately 1.2 miles of new walls. In addition to the roadway realignment, Alternative X also includes an underground groundwater depressurization system designed to reduce landslide movement across the site through depressurization of the groundwater below landslide failure surfaces. The underground drainage system currently considers three Tunnel Boring Machine (TBM) bored drainage gallery tunnels with radial drains drilled upward toward and into the slide mass, three interconnected vertical shafts, and an outfall structure.



Schematic 2-1 Alternative X.

2.2.2 Alternative F

Alternative F would involve constructing a 6,000-foot-long (1.1-mile) tunnel east of the existing highway to avoid the most intense areas of known deep-seated landslides and instability. Main components of the alternative would include a sequentially excavated tunnel, associated north and south portals and approaches, a bridge from the north portal to connect to existing U.S. 101, and an Operations and Maintenance Center (OMC). The south portal approach structure would include an Engineered Deformation Absorption System (EDAS) designed to allow for continued ground movement around the portal structure, while the structure remains in place.

Schematic 2-2 Alternative F.

2.3 Geotechnical Risk Understanding

There are two geotechnical risk types to be evaluated in a way that provides for comparison and contrast between alternatives: delivery risk and performance risk. This distinction is emphasized here and throughout the approach, and the evaluation is only from a geotechnical perspective and only for Alternatives X and F, as identified in the Draft Environmental Impact Report/Environmental Impact Statement and Draft Section 4(f) Evaluation and supporting documentation.

Delivery risk pertains to the challenges associated with successfully *delivering* the preferred alternative through its construction and opening to the public. This encompasses various aspects including programming, site investigation, design, procurement, and construction. Despite the numerous risks inherent in project delivery, geotechnical delivery risk is specifically highlighted due to its direct relation to the geological complexities of the site. This risk factor can be thoroughly examined by the panel in conjunction with the performance risk.

Alternatives X and F have been identified to substantially meet the project purpose and need but the extent to which they do so may be different because both alternatives have considerable uncertainty in *performance*. This uncertainty arises from the necessity of maintaining service in ground that is moving and alignments that traverse from moving ground into stable ground. This threat to performance, generally, and the uncertainty with it, are geotechnical in nature and they result in geotechnical performance risk.

The GRA presents an objective assessment framework to identify, articulate and compare specific risks across both alternatives. Caltrans will consider these geotechnical delivery and performance risks, along with various other factors, in their decision-making process for selecting the preferred alternative. Because delivery risk and performance risk are distinct from one another they are covered separately in this report.

2.4 Approach

To evaluate the geotechnical risks associated with Alternatives X and F, a structured approach was followed, as summarized in 10 steps to achieve an objective and impartial evaluation:

1. Convene a panel of experienced practitioners with complimentary and diverse backgrounds.
2. Convey a summary of the project purpose and need, including the site history and characteristics.
3. Convey a summary of the conceptual designs for Alternative F and Alternative X.
4. Review the performance objectives and definitions of condition states.
5. Compile a list of threats including threats to successful design, procurement and construction (delivery) and threats to the longer-term performance objectives. These two types of threats will be treated differently, as discussed above.
6. For threats to project delivery, describe in terms consistent with Caltrans project risk management and provide a qualitative likelihood assessment and an initial risk management entry for Caltrans consideration.
7. Document assumptions needed for this process.
8. Using the documented assumptions for the delivery risk assessment and the established objectives, evaluate the performance risk in terms of the likelihood of falling into less desirable condition states.
9. Cross-check the work with different strategies to help confirm internally consistent assessments and correlations.
10. Summarize the work and present findings for review by the panel and by Caltrans.

An important consideration at this level of project development is that the design will most likely change once the preferred alternative is selected, the associated design has further site investigation and is advanced. For projects of this scale, at a minimum, value analysis will be performed wherein value, as measured by cost, schedule and other attributes will be optimized. The value analysis process often involves a panel similar to that convened here, for the risk assessment, and would last a week or more. The panel was asked to consider the concepts as outlined in the environmental document while understanding that optimizations will occur. Significant assumptions by the panel have been recorded, as reported in Section 3.2.3.

2.5 Panelist Engagement

A panel of six experts was assembled of individuals, each possessing valuable insights and relevant experiences crucial for the risk assessment. All panelists are leading geological or geotechnical experts, and each person brought a unique and complementary perspective to the group. The panel members and key words to emphasize their importance to the panel are:

- George Machan, PE, Cornforth Consultants: Landslide Characterization and Mitigation
- Matt Fowler, PE, WSP: Tunneling and Structures
- Mike Porter, M.Eng., P.Eng., LEG, BGC Engineering: Landslide Risk and Mitigation
- Steve Klein, PE, GE, WSP: Tunnels and Landslides
- Tom Badger, LEH, LHG, PE, Cornforth Consultants: State Agency Perspective
- Warren Newcomen, P.Eng., BGC Engineering: Rock Slope Engineering/Mining.

The panel represents collectively more than 150 years of experience with highway, bridge and tunnel construction, and landslide study, on the Pacific coast of the US as well as in other countries and settings. There is a balance of geologists and engineers, former DOT employees, and consultants, and a mutual respect for the experience that each brought to the panel. As explained further below, Caltrans expertise was shared with the panel, but Caltrans experts were not part of the panel, nor were they providing risk characterizations as part of the panel deliberations.

The panel of experts convened in Crescent City, California, from February 13-15, 2024. Each panelist received a workbook outlining the objectives, process, and background of the project a few days prior to the meeting. The approximate total time commitment from each panelist was 50-60 professional hours per person, for review, meeting, assessment, and summary. This time allotment means that significant project understanding was transferred but not all available project material was reviewed, and additional research was not expected by panelists.

The first day of the in-person workshop focused on familiarizing the panel with the site and alternative designs, and included a site visit. The following two days continued with the delivery and performance risk assessments as described in Section 3.0.

Subsequently, two virtual follow-up meetings were conducted, on March 21 and 27, 2024, to discuss the outcomes of the panel session. Each meeting was approximately 2-hours long and all panelists were able to attend both meetings. The first virtual follow-up meeting focused on the results of the performance risk assessment while the second meeting focused on the consolidation of the delivery risk assessment. Following each meeting, panelists were asked to give their final input on items discussed in each meeting via email.

2.6 Final Product

This is the final product of the GRA. It includes the statement of purpose, method and approach, aggregated results from the panelists, conclusions and recommendations for Caltrans to consider related to this work. The time allocated for the process was limited and yet acceptable for the purpose of helping facilitate a decision that has many other considerations. Individual panelist results and results from interim stages of debate are not presented. Furthermore, the final compilations and distillations of results have been performed by BGC and WSP facilitators and not by the panel itself. This was needed to meet the project schedule. The final compilations of results and this report have been reviewed by the panelists.

In addition to this final report, a presentation was prepared and delivered at the stakeholder engagement meeting held in Crescent City on May 16, 2024. The content prepared and its presentation were part of a project update and solicitation of input that had broader, multidisciplinary scope.

3.0 METHODS

3.1 Delivery Risk Methods

3.1.1 Caltrans Project Risk Register Adaptation and Identification of Risks

The Caltrans Project Risk Management Handbook (PRMH) (Caltrans, 2022) provides a framework for developing a project risk register, typically in the format of a large table, which is used by the project team to assess and manage project delivery risks from the project's initiation through to its closeout activities. The risk register table template provided in the Caltrans PRMH can generally be broken into three categories, risk identification, risk assessment, and risk response. Within each category are numerous subcategories and inputs required to complete the register, and this is often a task completed by a project team, instead of specialized expert groups like the one convened for the GRA. With this in mind and due to the limited time and scope of the of the GRA workshop, the WSP/BGC team reduced the Caltrans Project Risk Register into a simpler form that was focused on gathering three inputs from the expert panel for the geotechnical delivery risks identified for either alternative:

1. Risk statement, written in the Caltrans three-part structure: definite cause, uncertain event, and effect on project.
2. Probability of occurrence, estimated using the bounds provided in the risk register.
3. Recommended response strategies and actions, written in the Caltrans standard language.

A review of the current LCG project risk registers provided by Caltrans to the WSP/BGC team, dated March 1, 2023, indicated a number of geotechnical related delivery risks had already been identified for each alternative. These risks were included into the simplified table presented to the panel during the risk workshop to initiate panel discussion and risk identification. The panel was asked to update the information provided for the existing risks where they felt necessary and provide additional risks they felt were not already captured in the register. For example, the panel evaluated, from their perspectives in similar investigation, design, and construction projects, what types of risks could be present, how likely they are, and what differences exist between the two alternatives. Given time limitations, this process was completed both during the workshop and by panelists individually following the workshop. After a compilation of the preliminary individual delivery risk assessment results by the WSP/BGC team, a total of 17 and 24 different risks had been identified for Alterative F and Alternative X, respectively.

3.1.2 Consolidation of Delivery Risks and Risk Assessment Process

While comprehensive and useful for understanding the geotechnical complexity and risks associated with the delivery of either alternative, the WSP/BGC team determined that presenting a list of 41 risks would not be easily synthesized or useful in the alternative selection process. A review of the risks identified by the panel indicated that across and within the two alternatives, the risks were similar, such as securing funding given the geotechnical uncertainty or finding qualified contractors/designers for the same reason. Some of the initial listed risks were very specific to each alternative, such as uncertainty in wall quantities for Alternative X or tunnel configuration concerns for Alternative F, but these are both uncertainties related to the design because of geotechnical unknowns, and in that sense, they are similar in theme.

The panelists generated more procurement-based risks (earlier in delivery) for Alternative F and more construction-based risks (later in delivery) for Alternative X. As implied by this observation, there is a rough chronology to delivery risks and, by the prior observation, there are themes. Seven themes were identified in the panelist's risk statements and they are listed in an approximately chronological order in Table 3-1. The consolidation was done by the WSP/BGC team for the panelist to review, and all panelists concurred that the specific risks they identified could be placed in these themed categories.

Following the consolidation and review, the WSP/BGC team ask the panelists to independently provide the probability of occurrence for each of the risks for both alternatives using the Caltrans Risk Register probability of occurrence scale between 1 and 5 wherein:

- 1 = Very Low (1-10%)
- 2 = Low (11-30%)
- 3 = Moderate (31-50%)
- 4 = High (51-70%)
- 5 = Very High (>70%).

Also, during this time, the panel was invited to suggest recommendations to Caltrans for risk response strategies and actions. While the panel's collective expertise is useful in suggesting risk response strategies and actions based on their experience, these recommendations need to be considered by Caltrans in light of other objectives for which the panel does not have responsibility for and was not tasked. The WSP/BGC team combined the panelist responses to the probabilities and response strategy recommendations and then identified the need to include an evaluation of consequences to more fully inform the potential project impacts of the risks. Following a meeting with Caltrans D01 construction, geotechnical, and maintenance staff to discuss consequences, the WSP/BGC team reviewed each risk category to assess the potential schedule and cost consequences for each. The consequences assigned were developed using incremental levels of impact that are judged to be significant for a project similar to the Last Chance Grade Project. Schedule (Time) consequences were assigned in 6-month increments and Cost consequences were assigned in increments of $50 Million. The overall project impact of the delivery risks evaluated were then tabulated by multiplying the probability of occurrence category number by the consequence totals assigned for each resulting in a product that is considered representative of the overall project impact potential for each risk. The sum of these populated risk impacts represents a gross geotechnical delivery risk rating for each alternative as described in Section 4.0.

It should be noted that the quantified delivery risks presented in this geotechnical risk assessment report should be considered preliminary in the sense that they have been developed by the expert panel and the WSP/BGC team and that ultimately Caltrans will require a more fully developed risk register for geotechnical as well as other delivery risk types.

Individual risks will need to be identified clearly and rated for probability of occurrence and a variety of consequences relevant to the project. It should be expected that Caltrans staff will retain primary responsibility for the actual project delivery risk management process; however, the initial evaluation described in this report is useful for the purpose of comparing geotechnically-based delivery risks between the two alternatives.

Table 3-1 Consolidated list of delivery risks.

ID	Name	Risk Statement and Explanation
1	Project Programming and Award	Geotechnical complexity and uncertainty too great to secure federal funding or multiple responsible bids, resulting in delay from the inability to program the work on schedule or the need for readvertisement and associated delay.
2	Qualified Design Professionals	Geotechnical complexity and uncertainty limit the commercial appetite and/or quality of design professionals willing to engage in the design phase, resulting in outcomes such as delay of design, construction contract escalation and poor long-term performance.
3	Evolving Site Understanding	Site investigation as first scoped generates questions that need resolution, and more investigation is needed that is not covered in the environmental document, thereby resulting in project delay.
4	Unplanned Highway Closure	Construction activities directly or indirectly cause a failure that temporarily, yet substantially closes the road, interrupting public mobility, contractor access and project schedule.
5	Construction Contract Escalation	The risk of Differing Site Condition claims is realized in a significant way because of real or contested claims, resulting in contract escalation, delays and/or costs during construction.
6	Changed Environmental Impacts	Site investigation and analysis lead to a need for modifications to design that result in additional environmental studies and a need to manage changes and accept delays or other impacts.[1, 2]
7	Changing Site Conditions	Given the anticipated length of time required for all delivery activities and the active or anticipated ground movement, site conditions change between alternative selection (now) and the end of delivery and construction activities, resulting in need to update designs and construction contracts, and possibly extra effort to maintain access between north and south ends of the project.

Notes:

1. For Alternative F: This could include, but is not limited to: the EDAS system, the approach work in the earthflow, the tunneling method or the North portal slope and potential relocation.
2. For Alternative X: This could include, but is not limited to: the upslope walls, the need for downslope walls to be included, surface impacts to vegetation and topography on nested landslides below the road, drilling horizontal drains from within or outside the ESL, or work to slow gully development.

3.1.3 Additional Considerations

As a part of the GRA workshop WSP and BGC moderators asked the expert panel to record their considerations for Caltrans on the project that went beyond the scope of the GRA goals. The exact prompt was, “Considerations for Caltrans on Last Chance Grade (separate from the risk assessment tasks)”. The contributions to this list also include comments and thoughts from the panelists generated during the two, two-hour-long follow-up videocalls and comments recorded by panelists during individual submissions. Recommendations range from design changes for either alternative to construction safety concerns to existing road improvements. Appendix A lists those considerations, some of which have already been considered by Caltrans. This record of data was not edited for clarity, better understanding of site conditions or project history by the WSP/BGC team. The WSP/BGC team did group these considerations in Appendix A for easier readability.

3.2 Performance Risk Methods

Performance risks were assessed through a process of elicitation as in the EBRA (BGC, June 14, 2018). Panelists offer judgments on expectation of performance based on their prior experience with similar work or similar environments. They did this after a period of introduction to the project including reading background documents, viewing 3D augmented reality models together in a conference room, visiting the site, and participating in presentations by the WSP/BGC team and Caltrans. They made judgments independently and then shared and debated them within a panel setting, ultimately arriving at a consensus, which was often represented by an average of their opinions.

Important steps to achieving a valuable outcome include establishing clear definitions of performance and how it can be recognized and measured, and decomposing the project into smaller assessments that can be more accurately evaluated independently, and then recomposed in a meaningful way. As described in the following sections, operational performance was defined in terms of specified condition states and the project was decomposed by considering geotechnical threats individually and by considering a series of three events, as presented in an event tree. Once these individual assessments were made, the elicited, consensus probabilities were recomposed to give an indication of expected performance for Alternative X and Alternative F. Further explanation is provided in the following sections.

Additionally, performance of the alternatives following a notable seismic event was assessed through a single question to the panel, “With specific consideration of the performance threats identified for each alternative, is one alternative more vulnerable to strong seismic ground motions than the other?” Attempts to quantify beyond a simplified seismic scenario would be limited in value without further design development and seismic hazard analyses that are not available currently. Furthermore, this directs the assessment to performance as we have measured it in terms of mobility.

3.2.1 Condition States

The condition of the subject highway can be measured in many ways and there would be an expected continuum of values, varying from one part of the project to another. A common metric is needed for the purpose of the risk assessment so that all panelists are evaluating against the same criteria. To simplify the variation through space, it was assumed that the worst condition that develops anywhere can be assigned to the whole project alignment under consideration. Given that the roadway acts as a number of elements in series, this assumption is deemed reasonable. To discretize the continuous range of possible condition, five different condition states were defined, A through F, ranging from good to poor. A similar approach was taken for the EBRA (BGC, June 14, 2018).

Condition was defined using criteria derived from discussions and reviews with Caltrans D01 senior staff. While alternative metrics for performance exist, the focus was placed on consequences aligned with maintenance of traffic requirements, given their direct impact on public satisfaction and usage, and that they can be a surrogate to other potential measures. For example, if only occasional repairs are needed and they only require a short blocking of the shoulder, not travel lanes, cost is probably lower and safety better than if frequent full closures were needed to do repairs. These condition states are defined by the descriptions and characteristics of the impact and the characteristic traffic control measures, as outlined in Table 3-2.

An example outcome of this measure of performance is that elements that are not within or adjacent to the travel lanes have little influence on the stated performance. This influences the selection of the most important geotechnical threats, as discussed next.

Table 3-2 Condition State definitions.

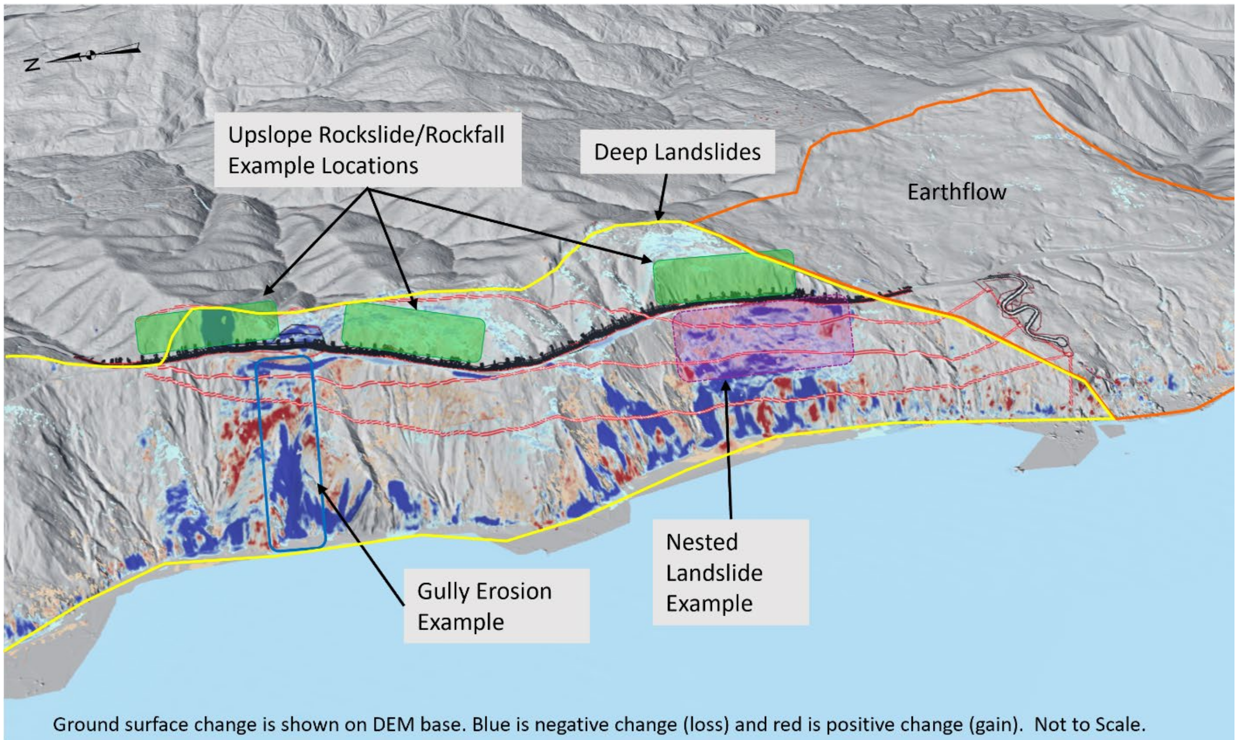
Condition State	Characteristic Impacts	Characteristic Actions	Characteristic Traffic Control
A	• Starting condition for newly constructed assets • Landslide/rockfall volumes, velocities, and frequencies are small enough to be characteristic of other Caltrans highways • No recognizable maintenance needs.	• No more than average maintenance effort.	• Public is unaware of any needs.
B	• Pavement cracking or structural stress related to slope movement is evident but generally not impactful to highway users • Walls, tunnel elements and appurtenant features appear to be in good condition to highway users • Typically, one-off natural events cleanup of limited size.	• Routine maintenance activities but above-average effort • Increase in the frequency of pavement repair as compared to A • Walls, tunnel elements and appurtenant features require occasional recognizable maintenance (face, liner, anchor, concrete, lagging, drainage, etc.).	• 1 week of shoulder closure per month or 1 week of lane closure per year • Requiring single lane closures.
C	• Drivers notice. Episodic events and maintenance interventions impact the road. • Pavement cracking is associated with settlement • Walls, tunnel elements and appurtenant features have cracks and evidence of distress recognizable to highway users or Caltrans. • An event that causes the need for a new or modified structure is possible (tunnel or slide movement, gully or rockslide, for example).	• Geotechnical input needed: above-average effort requiring some rehabilitation of project elements • Ditches and shoulders have common cleanup needs • Walls, tunnel elements and appurtenant features require common maintenance to the elements in place (face, liner, anchor, concrete, lagging, drainage, etc.) • Occasional need for new or larger structure elements and resetting of guardrail and surface drainage.	• Increased impacts that expand traffic control such that single lane closures are needed for longer than B • Typically, a stable but recurring maintenance need.
D	• Urgent/emergency response actions required to keep corridor open. Adverse community impact. Increased potential for vehicle damages. • Roadway grade is impacted, existing structures are insufficient and warrant repairs. • Speeds are reduced and reliability of connection is uncertain.	• An escalating need for recurring actions • New or modified structures and tunnel elements are needed.	• Frequent lane or full road closures • Typically, a closure of a shoulder for more than a month per year, lane closure of up to a month per year, or full closure for a week per year.
F	• Impractical to keep road open; the traveling public faces detours or loss of access, and any first vehicle encounters following new movement face increased accident potential.	• Emergency declarations, new project, etc.	• Full closures last more than 1 week.

3.2.2 Threats

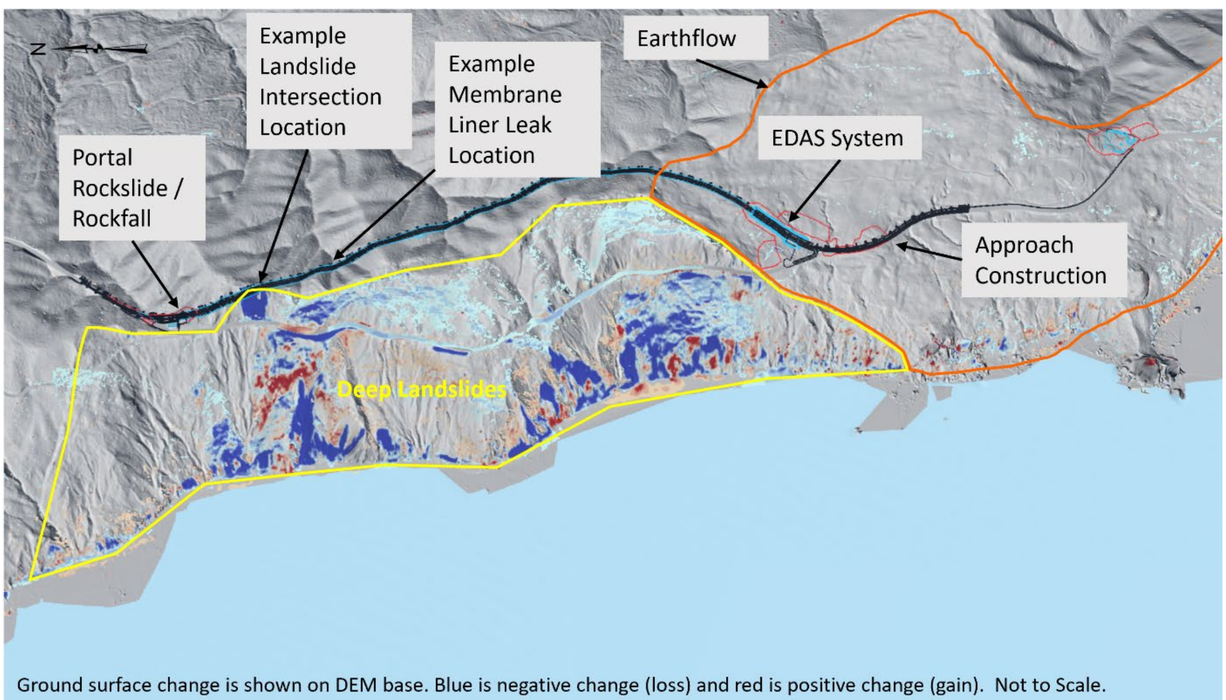
Threats are uncertain geotechnical events with a probability of occurrence less than 1.0; if these events do occur, they have adverse consequences. The combination of the threat and its consequence constitutes a geotechnical risk to performance. Threats can be considered as potential failure modes if failure is defined in the statement of consequence. Some threats may be spatially present throughout the alignment. Others may only exist at one place or another, but with the assumption stated previously, if a threat is realized anywhere, it is assumed to be realized everywhere. Therefore, the specific spatial location of threats is not important. Another consideration is that threats that may impact the project away from the travel lanes will not have much impact on performance as measured, and thus, they are not as significant.

The panel was presented with an initial list of threats to each alternative. The threats for each are different because of the types of elements designed and how the alternatives intersect, or potentially intersect, the geotechnical source of the threat. Examples include a tunnel entering a portal beneath a rock slope that could produce rockfall or a paved lane crossing a landslide scarp that may be active.

The panel was presented with a list of many conceivable threats for each alternative and a graphic of where they might intersect with the alignments to help with understanding, shown in Schematic 3-1 and Schematic 3-2. As stated before, it was assumed that any intersection (as shown conceptually in the schematics) is of equal significance. After review, some threats were found to be primarily responsible for risk to performance as we are measuring it. These primary threats are potential geotechnical failure modes, with failure defined specifically as entering a condition state less desirable than A. The panel retained 7 primary threats for Alternative F and 5 for Alternative X and these threats, written in a form consistent with Caltrans risk management, are presented in Table 3-3 and Table 3-4. The number of performance threats for the two alternatives reflects distinct differences in the design elements and distinct geotechnical risks associated with these elements. It is not otherwise important in the way the results are calculated or aggregated.



Schematic 3-1 Intersections with Alternative X.



Schematic 3-2 Schematic showing terminology and some threat intersections with Alternative F, including off-alignment elements.

Table 3-3 Alternative X geotechnical threats.

Threat ID	Cause	Uncertain Event	Effect
Deep Landslide	Deep-seated landslides extend beneath the highway.	Deep-seated landslides move and intersect the roadway prism.	Distress to the road surface or retaining wall structures at the margins exceeds serviceability requirements, requiring intervention.
Nested Landslide	Nested landslides are present downslope of the roadway.	Movement of nested landslides intersects the roadway prism.	The roadway section and/or retaining walls are undermined and impacted, requiring interventions.
Upslope Rockslide	Landslide or rockslide risk is present above the highway.	Landslides or rockslides upslope of the roadway intersect the roadway prism.	The roadway and/or upslope structures are impacted, requiring intervention (debris clean-up, modifications).
Gully Erosion	Debris slides and gully erosion are present downslope of the roadway.	Debris slides and gully erosion intersect the roadway prism.	The roadway section and/or downslope retaining walls are undermined and impacted, requiring interventions.
Upslope Rockfall	Small-scale rockfalls are present above the highway.	Small-scale rockfalls occur and reach the roadway prism.	Rock and debris block the highway or impact safety, requiring intervention (clean-up or repair/mitigation).

Table 3-4 Alternative F geotechnical threats.

Threat ID	Cause	Uncertain Event	Effect
Approach Construction	The tunnel approach is in an active earthflow.	Approach construction and earthwork causes additional earthflow movement.	Distress to the approach roadway exceeds serviceability requirements, requiring interventions.
EDAS System	The south portal approach structure is in an active earthflow.	Earthflow forces on the south portal approach structure are not effectively eliminated by the EDAS system.	Distress to the south portal approach structure exceeds serviceability requirements, requiring interventions.
Earthflow	There is active earth movement in the area of the south portal approach structure.	Landslide movement occurs beneath all or part of the south portal approach structure.	Differential movements between the south portal approach structure and the tunnel exceed serviceability requirements, requiring interventions.
Intersects Landslide	The ground conditions along the tunnel alignment have not been fully explored.	The tunnel is constructed through an unidentified, active, deep-seated landslide.	The tunnel is distressed beyond serviceability, requiring interventions.
Membrane Liner	Groundwater is present in areas along the tunnel alignment.	The tunnel liner leaks.	The tunnel drainage system design is insufficient, requiring intervention.
Portal Rockslide	Debris/rockslide risk is present above the north portal.	Debris/rockslides intersect the roadway prism around the north portal.	Rock debris reaches the roadway, requiring interventions (clean-up or maintenance response, possibly modifications to the slopes).
Portal Rockfall	Small-scale rockfall risk is present above the north portal.	Rockfalls occur upslope of the roadway and intersect the roadway prism.	The roadway is impacted, requiring interventions.

3.2.3 Assumptions

Additional assumptions were needed to facilitate the work. After the presentation of how performance will be measured and after the primary threats were identified, there was still some ambiguity that needed to be removed. This was addressed by discussion and statement of some key assumptions. These discussions helped ensure that all panelists were considering the same factors and allowed for the sharing of expertise among panelists (e.g. tunnels to landslides, etc.). Through these discussions, the following assumptions were discussed and agreed upon and posted in the room for reference:

1. Future site investigation will occur, although the scope will likely be restricted by site constraints.
2. Design revisions will be implemented following Value Analysis.

3. Alternative X effectively has an additional lane in the shoulder throughout its alignment, and this can be relied upon to maintain condition state.
4. Horizontal drains will generally be drilled upslope and downslope of the Alternative X alignment, through existing and planned walls.
5. Downslope walls and other roadway prism mitigation will be added to Alternative X through Value Analysis or constructed prior to this contract being awarded based on changing site conditions and their potential need in the near-term.
6. Tunneling through the Franciscan Complex rock, specifically in the Franciscan mélange, Alternative F is very likely to encounter areas with squeezing ground along alignment. The panel agreed on this as an assumption because panelist experience with tunneling in Franciscan varied widely.
7. To keep the Alternative X drainage tunnels functioning well, tunnel maintenance will be funded and will occur as necessary.
8. Upslope walls for Alternative X or for Alternative F portals will be designed to have a catchment or a fence.
9. The terminology “road/highway prism” was defined as “the volume of ground that supports the roadway and shoulders, including embankments and retaining structures.”

3.2.4 Elicitation of Probabilities and Event Trees

After identifying the threats, the expert panel estimated the threat probabilities. Considering the potential evolution of highway conditions over time, performance risk was evaluated at two distinct periods: 0-10 years after construction completion and 50-75 years post-construction. This evaluation takes into account the increasing likelihood of encountering a degraded condition state and, perhaps, the evolving tolerance for such conditions as highways age, from initial construction to nearing the end of their design life. Additionally, it was taken into consideration that for the existing 50-year-old highways nearby in Caltrans D01, none in similar settings are currently in Condition State A. Thus, it was assumed that when the Last Chance Grade is 50 years old, it will be in Condition State B, like other similar highways presently maintained by Caltrans D01.

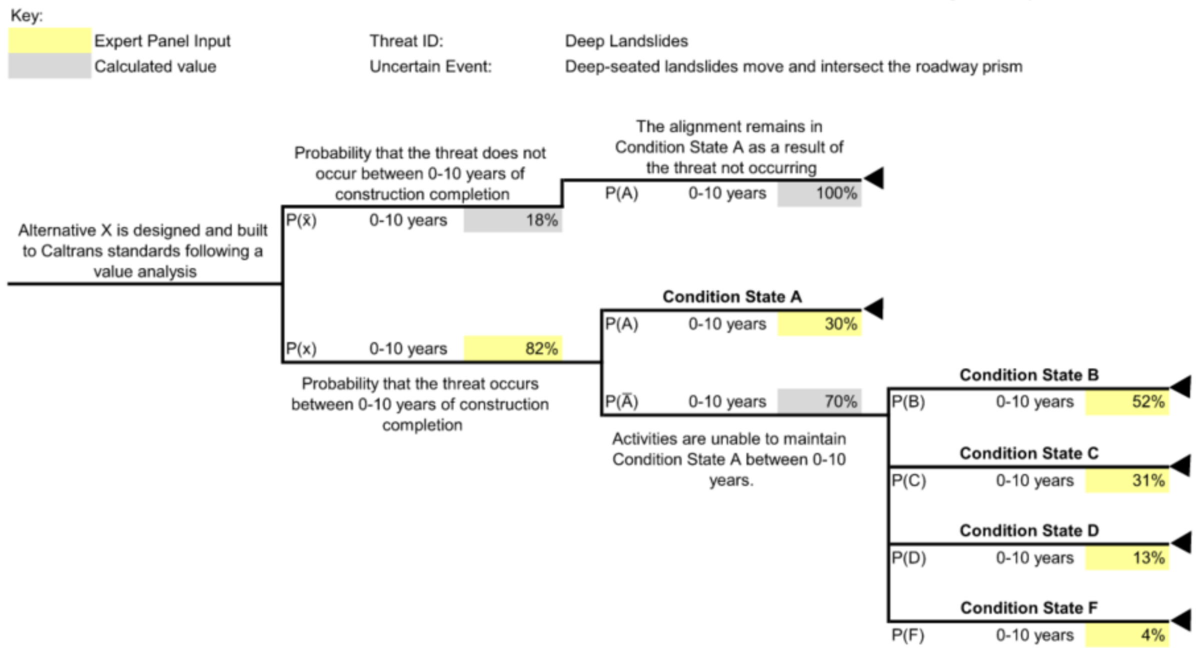
The likelihood of being in one of the four Condition States B to F and being in Condition State A (the initial, like-new condition) was estimated at two time periods. This step was applied to the seven threats for Alternative F and five threats for Alternative X. Since it is generally easier to accurately estimate higher probability events that are direct in nature than lower ones that are indirect, the problem was decomposed into conditional probabilities. The decomposition process was facilitated using event trees, with two event trees being built for each identified threat to an alternative, one for each time-period. Example event trees for both time periods for a given threat are shown in Schematic 3-3 and Schematic 3-4 and on the following pages. The probabilities highlighted in yellow are the averaged conditional probability values elicited from the panel, as discussed above. Calculated values, shown in grey, are values that could be calculated from the probabilities given by the panel. For individual threats, condition states are created to be mutually exclusive and collectively exhaustive, and the probabilities for each condition state sum to 100%.

Furthermore, each branching in the event tree represents a different type of uncertainty, informed with emphasis on different data and judgments, as described here:

- **Will threat be realized?** Judgement was based at least partly on panelist experience including reference to the project's history regarding the threat, current site observations, and expectations for the future. This relies on experience and judgment regarding geology, geohazards, and climate, rather than solely on engineering. It represents the intersection of the hazard and the alignment.
- **Will designers be able to mitigate the consequence of threat so that the road remains in Condition State A if the threat is realized?** Judgment was based at least partly on panelist experience including reference to the ability to gain understanding of the threat through site characterization, project history, the maturity of mitigation approaches, and the capability to maintain and adapt without impacting traffic. This relies on experience and judgment regarding engineering, rather than emphasizing geology or geohazards, as it concerns the ability to develop and construct the necessary designs. The limited access for site characterization could be reflected in this judgment.
- **If design fails to mitigate the threat, how large will the consequence be in terms of impact to traffic?** Judgment was based at least partly on panelist experience including reference to how impactful the failure would likely be in the terms of condition state definitions. This assessment draws upon experience and judgment in construction, as it would be necessary to adapt designs and construction that were insufficient to mitigate the geotechnical threats.

Using the questions provided above, each panelist verbally provided a conditional probability estimate for every branch of the event tree, eventually allowing for calculation of the likelihood of experiencing a specific condition state resulting from the threat. Whenever there was a significant difference in values, discussions were held to ensure clarity and mutual understanding. The values were found to be sufficiently close that taking average of the panelist's inputs was deemed a reasonable input in the calculations described below. This process was completed for each threat, for both alternatives, and for each analysis time period (0-10 years and 50-75 years).

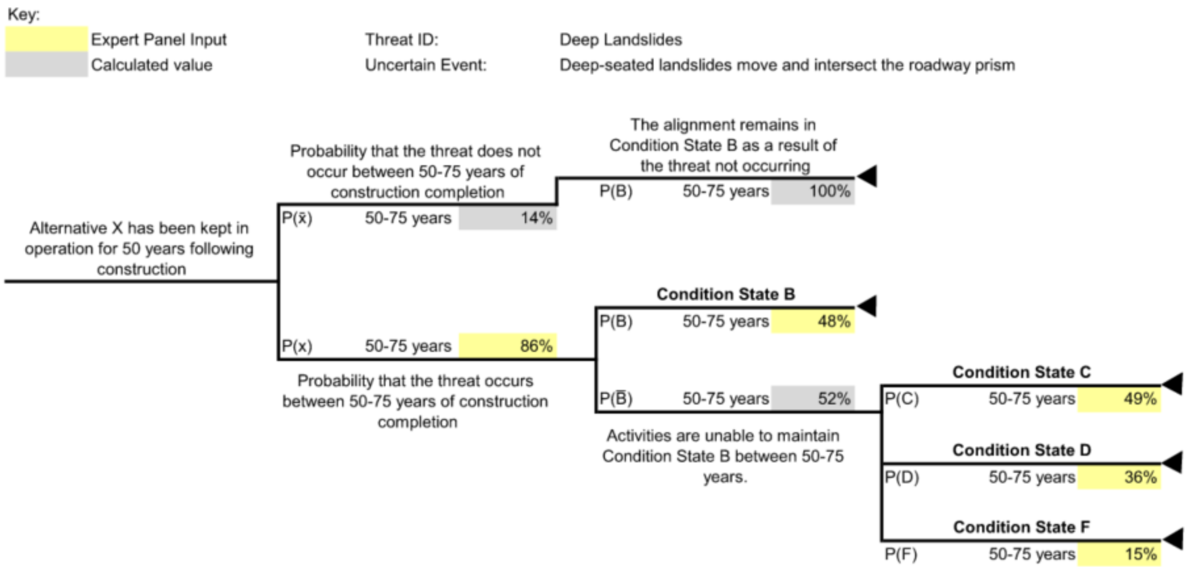
Last Chance Grade Geotechnical Risk Assessment Event Tree Calculations
Alternative X - 0 to 10 year time period



Probability Results	0 - 10 years
P(Condition State A) = P(x̄ | A) + P(x | A)	42.6%
P(Condition State B = P(x | Ā | B)	29.8%
P(Condition State C) = P(x | Ā | C)	17.8%
P(Condition State D) = P(x | Ā | D)	7.5%
P(Condition State F) = P(x | Ā | F)	2.3%
Sum of all end nodes	100.0%

Schematic 3-3 Representative event tree showing the estimated probability of experiencing a given condition state in years 0-10. Threat ID: Deep Landslides is shown here.

Last Chance Grade Geotechnical Risk Assessment Event Tree Calculations
Alternative X - 50 to 75 year time period



Probability Results	50 - 75 years
P(Condition State B) = $P(\bar{x}$│B) + P(x│B)	55.3%
P(Condition State C) = P(x│$\bar{B}$│C)	21.9%
P(Condition State D) = P(x│$\bar{B}$│D)	16.1%
P(Condition State F) = P(x│$\bar{B}$│F)	6.7%
Sum of all end nodes	100.0%

Schematic 3-4 Representative event tree showing the estimated probability of experiencing a given condition state in years 50-75. Threat ID: Deep Landslides is shown here.

4.0 DELIVERY RISK RESULTS

As stated earlier, delivery risks are the challenges, including but not limited to, programming, site investigation, design, procurement, and construction associated with delivering the preferred alternative through its construction and opening to the public. The delivery risks were assessed individually by the panelists and collectively discussed to arrive at a consensus on the probability of occurrence.

4.1 Probability of Occurrence

Consolidated panelist responses to the probability of occurrence and risk response prompts are presented in Table 4-1. Consolidated panelist responses to the probability of occurrence and risk response prompts were compiled using averages and some interpretation for split opinions or discrepancies. The Probability of Occurrence ratings in the table represent unmitigated risk levels, and the panel understood that the recommended response actions provide a means for reducing the risk levels. As can be seen in the table the overall level of delivery risk probability of occurrence is generally high. The expert panel specifically advocated for the project to include sufficient subsurface investigation to characterize the geologic conditions that could impact the project.

In addition to the probability of occurrence, the panelists also recommended response strategies and generated some alternative-specific response actions for Caltrans. These response strategies were discussed as part of the panel's brainstorming session for geotechnical threats as well as in discussions following the compilation of threats. The risk responses and alternative specific risk response actions are also included in Table 4-1.

4.2 WSP/BGC Initial Delivery Risk Consequences

To understand the implications of delivery risks, it is typical to quantify consequences of a particular threat to the project. Typically, with Risk Registers this is done by estimating consequences in terms of schedule impacts (time) or budget impacts (cost). Including the consequences allows a more complete characterization of the potential impact of a given risk to project delivery if the risk is realized.

The expert panel sessions were used to develop a broad array of delivery risks for each alternative, worked to consolidate these risks into the seven risk categories presented herein, and weighed in on the probability of occurrence for each of the delivery risks. Due to constraints of time, the consequences of these risks were not developed or addressed by the panel, but rather consequences were developed by the WSP/BGC team based on our understanding of the specific risks as well as incorporating our professional experience and judgment from other similar projects.

As such the consequences presented in this document represent the judgement of the geotechnical risks at this time and is intended to serve as a means for comparing the alternatives. Given the approximate nature of this work, increments of $50 million dollars and/or 6 months were used to reflect anticipated cost and schedule impacts, respectively, if the risk was realized fully. The outcome of this work should be considered a work in progress that will be further developed and advanced by the Caltrans Project team as the project proceeds.

Table 4-2 summarizes the delivery risks with the WSP/BGC consequences included. These consequences are proposed by WSP and BGC as an initial evaluation of the potential impacts posed by the risk categories should they become realized. The project impact was computed by multiplying the probability of occurrence category value by the number of cost or schedule consequences and were then summed. Future risk register work for this project will involve more sophisticated consideration of the risks as well as the consequences and should include a Monte Carlo analysis step to arrive at probabilistic distribution of the risk impacts, as appropriate. The future analysis may also elect to include weighting factors to help better characterize the overall risk profile. The compilation presented in Table 4-2 should be considered preliminary and was developed to allow a comparison of the alternatives for the purpose of including geotechnical risks in the alternative selection process.

4.3 Discussion

As summarized in Table 4-1, Alternatives F and X are quite similar in terms of the delivery risk probability of occurrences—each risk category for either alternative never differs by more than one probability of occurrence on the probability scale presented in Section 3.1.2. Including the consequence consideration for each threat, the alternatives become more distinct with the project impact scores for each alternative. Thus, by considering the geotechnical risks identified, their probability of occurrence and the initial evaluation of potential consequences for each threat, the geotechnical delivery risk realized are very different for Alternatives F and X, with corresponding geotechnical delivery risk impact scores of 162 and 67, respectively. Alternative F is perceived to have two to three times the geotechnical delivery risk as Alternative X.

Table 4-1 Project delivery risk categories and expert panel considerations.

ID	Name	Risk Statement	Alternative F Probability of Occurrence[1,2]	Alternative X Probability of Occurrence[1,2]	Recommended Response Strategy[3]	Recommended Response Actions[3]
1	Project Programming and Award	Geotechnical complexity and uncertainty too great to secure federal funding or multiple responsible bids, resulting in delay from the inability to program the work on schedule or the need for readvertisement and associated delay.	4 - High (51-70%)	3 - Moderate (31-50%)	Mitigate	Commit to sufficient site investigation and study.
2	Qualified Design Professionals	Geotechnical complexity and uncertainty limit the commercial appetite and/or quality of design professionals willing to engage in the design phase, resulting in outcomes such as delay of design, construction contract escalation and poor long-term performance.	3 - Moderate (31-50%)	3 - Moderate (31-50%)	Mitigate	Commit to sufficient site investigation and study and establish design basis expectations and contract protections (limits on liability).
3	Evolving Site Understanding	Site investigation as first scoped generates questions that need resolution, and more investigation is needed that is not covered in the environmental document, thereby resulting in project delay.	4 - High (51-70%)	3 - Moderate (31-50%)	Mitigate	Good communication and a practiced permitting resolution approach.
4	Unplanned Highway Closure	Construction activities directly or indirectly cause a failure that temporarily, yet substantially closes the road, interrupting public mobility, contractor access and project schedule.	2 - Low (11-30%)	3 - Moderate (31-50%)	Mitigate	Ensure that construction contract includes extensive monitoring and an Alert and Trigger Action Response Plan.
5	Construction Contract Escalation	Contract leads to Differing Site Condition claims, resulting in contract escalation, delays and costs during construction.	4 - High (51-70%)	4 - High (51-70%)	Mitigate	Commit to sufficient site investigation and study, and develop a design basis report, geotechnical baseline report, and contract language with this risk in mind.

ID	Name	Risk Statement	Alternative F Probability of Occurrence[1,2]	Alternative X Probability of Occurrence[1,2]	Recommended Response Strategy[3]	Recommended Response Actions[3]
6	Changed Environmental Impacts	Site investigation and analysis lead to a need for modifications to design that result in additional environmental studies and a need to manage changes and accept delays or other impacts.[4,5]	3 - Moderate (31-50%)	3 - Moderate (31-50%)	Accept	Balance the need for site investigation and DED requirements to effectively deliver the project, while striving to minimize the delay
7	Changing Site Conditions	Given the anticipated length of time required for all delivery activities and the active or anticipated ground movement, site conditions change between alternative selection (now) and the end of delivery and construction activities, resulting in need to update designs and construction contracts, and possibly extra effort to maintain access between north and south ends of the project.	3 - Moderate (31-50%)	2 - Low (11-30%)	Accept	Deliver the project quickly, reducing the time for such events to occur and write contract language in advance to anticipate the possibility.

Notes:

1. Probability of Occurrence is evaluated for unmitigated risks.
2. Estimated as part of Geotechnical Risk Assessment. This is a panel judgment.
3. Geotechnical Risk Assessment Panel recommendation to Caltrans.
4. For Alternative F: This could include, but is not limited to: the EDAS system, the approach work in the earthflow, the tunneling method or the North portal slope and potential relocation.
5. For Alternative X: This could include, but is not limited to: the upslope walls, the need for downslope walls to be included, surface impacts to vegetation and topography on nested landslides below the road, drilling horizontal drains from within or outside the Environmental Study Limits (ESL), or work to slow gully development.

Table 4-2 Summary of geotechnical project delivery risk results.

		Alternative F			Alternative X		
ID	**Name**	**Probability Of Occurrence**	**Consequences**	**Project Impact**	**Probability Of Occurrence**	**Consequences**	**Project Impact**
1	Project Programming and Award	4 - High (51-70%)	6T	24	3 - Moderate (31-50%)	4T	12
			4C	16		1C	3
2	Qualified Design Professionals	3 - Moderate (31-50%)	1T	3	3 - Moderate (31-50%)	1T	3
			1C	3		1C	3
3	Evolving Site Understanding	4 - High (51-70%)	6T	24	3 - Moderate (31-50%)	4T	12
			2C	8		1C	3
4	Unplanned Highway Closure	2 - Low (11-30%)	1T	2	3 - Moderate (31-50%)	1T	3
			1C	2		1C	3
5	Construction Contract Escalation	4 - High (51-70%)	2T	8	4 - High (51-70%)	1T	4
			12C	48		1C	4
6	Changed Environmental Impacts	3 - Moderate (31-50%)	4T	12	3 - Moderate (31-50%)	2T	6
			2C	6		1C	3
7	Changing Site Conditions	3 - Moderate (31-50%)	1T	3	2 - Low (11-30%)	2T	4
			1C	3		2C	4
			TOTAL	**162**			**67**

Notes:

1. Consequences are defined as either Cost (C) or Time (T) (Schedule) increments of $50M or 6 months, respectively.
2. Characterization of risk probabilities and consequences are for unmitigated risks.
3. Project Impact is a product of the probability of occurrence and the consequence. For example, the Project Programming and Award project impact is equal to 4 (High Probability of Occurrence) x 6T Consequence = 24.

5.0 PERFORMANCE RISK RESULTS

5.1 Individual Threat Results for the Alternatives

The results provided below are calculated conditional probabilities for experiencing a given condition state as a result of each individual threat. The individual threat results were calculated using the Bernoulli Trials statistical method and assume statistical independence, meaning that the outcome of one threat is independent from any other threat. The event tree logic also assumes that the threat either occurs or does not, there are no other outcomes, and if it does not occur, the alternative will remain in the starting condition state.

5.1.1 Beginning of Operational Lifecycle

Results for the likelihood of experiencing a given condition state at the beginning of the operational lifecycle for each alternative, assumed to be the first 10 years of use, are shown in Table 5-1. The results are separated by individual threats to each alternative. The results shown are calculated using the logic in event trees, as represented in Schematic 3-3.

Table 5-1 Probability of experiencing a given condition state as a result of each individual threat in years 0 to 10 of service.

Alternative	Threat ID	Condition State				
		A	B	C	D	F
Alternative X	Deep Landslide	50%	21%	15%	9%	5%
	Nested Landslide	38%	22%	20%	15%	5%
	Upslope Rockslide	62%	16%	14%	6%	2%
	Gully Erosion	61%	15%	19%	4%	1%
	Upslope Rockfall	67%	20%	7%	5%	0%
Alternative F	Approach Construction	61%	22%	11%	5%	1%
	EDAS System	98%	2%	0%	0%	0%
	Earth Flow	95%	1%	1%	1%	2%
	Intersects Landslide	79%	7%	5%	5%	3%
	Membrane Liner	68%	22%	8%	2%	1%
	Portal Rockslide	97%	2%	1%	0%	0%
	Portal Rockfall	99%	1%	0%	0%	0%

The results from Table 5-1 are plotted in Figure 1 using abbreviated condition state labels to represent the full explanation of each. The precise values in the table are useful within the panel for understanding how the results were obtained but the relative scale of bars in the figure is a more appropriate way of comparing results within and across alternatives. Given the limitations of the process and in understanding the geotechnical conditions and conceptual designs, small differences in calculated values are not particularly meaningful. Thus, the later discussion of results is based on the general trends recognizable in the bar charts of the figures.

Some important considerations for reading Figure 1 are that a high value for Condition State A is "good" whereas a high value for the other condition states is "undesirable". Condition State A is the initial, as built, or like new condition and a high probability of experiencing that condition state is equivalent to remaining in that condition state, which is a favorable outcome. Other condition states are all less desirable, with a range of perceived acceptance, and a high probability of experiencing one of those states is therefore also not desirable.

Considering how each threat can influence the road's condition, it's essential for the road to be categorized under a single condition state in this assessment. This is the logic within the event tree (Schematic 3-3) and it means that the sum across all columns of Table 5-1 for each row is 100% (values may be slightly more or less than 100% due to rounding) and all the bars total 100% probability. Condition State A represents the initial condition, indicating the probability of remaining in that state by subtracting from the probabilities of other condition states. To enhance clarity, Figure 2 omits the display of the Condition State A results, focusing instead on the comparison of the probability of experiencing condition state following the initial condition. Thus, the figure can be interpreted to inform "either/or" types of questions – either the initial condition is retained or a lesser condition is experienced and the lower the bars, the more likely that the initial condition is retained.

The relative heights of the bars in Figure 2 can be used to compare the results of each threat specifically within an alternative and more generally (because the threats are different) across alternatives. This method of interpretation helps to develop a sense for which threats are influencing the risk to the alternative, and which ones may be less consequential to long-term performance as defined. A few example observations from comparison of these results are:

- The Approach Construction and Membrane Liner threats for Alternative F are approximately 10 times as likely to result in Alternative F experiencing Condition State B in years 0 to 10 than the other threats to Alternative F.
- The Nested Landslides and Gully Erosion threats to Alternative X result in the highest probability of the alternative experiencing Condition State C in years 0 to 10.
- With the exception of the Upslope Rockfall, Approach Construction, and Membrane Liner threats, on average, the threats to Alternative X result in higher likelihoods of experiencing Condition States B and C in years 0 to 10 than the threats to Alternative F.

The way the results were derived, by eliciting judgment on whether the threat would be realized, whether the design would be robust enough to mitigate it with no impact if it was realized, and what types of actions would be required if the design was not robust enough has no explicit consideration of time or space. This is consistent with a Bernoulli trial, and it is why the verb is 'experiencing'. Time is covered implicitly in the 10-year interval that is being assessed and in the definitions of condition states (Table 3-2). The spatial relevance of threats is addressed by the assumption treating the entire alternative as one location and implicitly, again, with the types of actions that would be required in the condition state definitions.

There is a tendency to want to average the probabilities tied to each individual threat, meaning the heights of the bars in Figures 1 and 2. Doing so is not advised, however because of what is known as common cause, and the suggested way of combining the threats into an overall probability of experiencing a condition state is presented in Section 5.2.

5.1.2 End of Operational Lifecycle

The same process and representation of results was repeated with elicited judgments for a later and longer time period. Results for the probabilities of experiencing a given condition state at the end of service life (50-75 years) for each alternative, are shown in Table 5-2 and Figures 3 and 4. The results are categorized by individual threats to each alternative. The results shown are calculated using the logic in the event trees, as represented in Schematic 3-4.

For the end of lifecycle probabilities, each alternative is expected to begin in Condition State B due to the likelihood of degradation over time and comparisons with existing 50-year-old highways nearby managed by Caltrans, none of which are currently in Condition State A.

As discussed for the beginning of the lifecycle, a simplified representation of the data is presented in Figure 4. This figure replaces Condition State B values with an indication of the initial condition to facilitate communication of the probabilities involved.

Table 5-2 Probability of experiencing a given condition state as a result of each individual threat in years 50 to 75.

Alternative	Threat ID	Condition State			
		B	C	D	F
Alternative X	Deep Landslide	38%	28%	24%	10%
	Nested Landslide	32%	26%	32%	10%
	Upslope Rockslide	62%	20%	14%	3%
	Gully Erosion	57%	26%	14%	3%
	Upslope Rockfall	76%	18%	6%	1%
Alternative F	Approach Construction	82%	11%	5%	1%
	EDAS System	85%	10%	4%	2%
	Earth Flow	90%	5%	2%	2%
	Intersects Landslide	80%	8%	7%	6%
	Membrane Liner	74%	18%	7%	1%
	Portal Rockslide	99%	1%	0%	0%
	Portal Rockfall	100%	0%	0%	0%

5.2 Comparing Alternative Alignments

The results presented in Section 5.1 are for calculated probabilities for experiencing a given condition state as a result of each individual threat, and there are ways for combining these probabilities to evaluate each alternative as a whole. Given the assumption that each threat acts on the entire alternative and is statistically independent from any other threat, the probabilities for either alternative to experience a given condition state can be calculated using Equation 5-1, where p_i is the probability of experiencing a given condition state from an individual threat.

$$P(Condition\ State) = 1 - (1 - p_1) \times (1 - p_2) \ldots \times (1 - p_i) \qquad \text{Equation 5-1}$$

Combining the probabilities using Equation 5-1 considers a common cause adjustment, which here accounts for the simultaneous (in time period) occurrence of statistically independent threats at different locations, more than cause. For example, something could happen to change condition state at a tunnel portal and something could happen in the pavement as the result of landsliding in the time period. There is some probability that they both occur, instead of one precluding the other. This method has been used to estimate the probability of experiencing a given condition state as a result of any of the threats identified.

The sum of all condition state probabilities across an alternative (e.g., P(A)+P(B)+P(C)+P(D)+P(F)) is greater than 1.0 when this combination is made. This is acceptable because each of the threats to the alternatives themselves are not mutually exclusive. This is in contrast to the results for the individual threats, where the condition states are mutually exclusive and collectively exhaustive, and the probabilities for each condition state sum to 100%.

An additional consideration is the assumption of statistical independence of the threats occurring, the designs being robust enough, and the interventions needed to restore distressed elements. Statistical independence is a convenient assumption because it allows for this combination, but it is not likely accurate. There is likely some correlation between threats, designs, and actions, though the precise relationships are difficult to assess in this framework and scope. The opposite of statistical independence is perfect correlation, wherein if one thing were to happen, another would be sure to happen. These two assumptions represent the end members of how the threats and events could be correlated and they allow the problem to be bracketed.

The statistical independence assumption is conservative and leads to the highest probability estimates, and these are what are shown in Figures 5 to 8. Perfect correlation would lead to the lowest combined estimate, and it would be equal to the probability of the threat outcome that was most likely. Other events being correlated, they would occur simultaneously. The consideration of the WSP/BGC team is that statistical independence is a better assumption than correlation. This is because the purpose of the combined threat estimate is for comparison between alternatives and not absolute values. It is likely that if the degree of correlation was determinable, the relative outcome would change somewhat, but the conclusions would remain the same. The results assuming statistical independence and a common cause adjustment, as described here, are presented in the following subsections.

5.2.1 Beginning of Lifecycle

The combined probabilities for each alternative experiencing a condition state in years 0 to 10 are shown in Table 5-3 and plotted in Figures 5 and 6.

Table 5-3 Probabilities of an Alternative experiencing a condition state in years 0 to 10.

Alternative	Condition State				
	A	B	C	D	F
Alternative X	99%	65%	56%	33%	12%
Alternative F	100%	46%	24%	13%	6%

A few example observations from the results are:

- As a result of the threats to the alternative, Alternative F is as likely as not to experience Condition State B between years 0 and 10 of construction.
- As a result of the identified threats to Alternative X and F respectively, both alternatives are least likely to experience Condition State F between years 0 and 10 of construction.

As for the results presented for each threat, the numbers presented in Figures 5 and 6 are useful for understanding the calculations and how the panelists inputs were used, but they imply a precision in findings that is not appropriate given the uncertainties incorporated. Bar graphs are used to also convey the results, and comparison of the relative scale of the bars offers a more appropriate way of comparing the results. Bar graphs for the combined probability of experiencing a condition state between years 0 and 10 are shown in Figures 5 and 6. Figure 6 has the probabilities of experiencing an initial condition state blocked so the viewer can focus on the probabilities of being in less desirable states.

5.2.2 End of Lifecycle

Results for the probabilities of experiencing a given condition state at the End of Lifecycle (50-75 years) for each alternative are shown in Table 5-4. Bar graphs for the combined probability of experiencing a condition state between years 50 and 75 are shown in Figures 7 and 8. Figure 8 has the probabilities of experiencing an initial condition state blocked so the viewer can focus on the probabilities of being in less desirable states. As previously discussed in the individual threat results, the end of lifecycle probabilities, each alternative is expected to begin in Condition State B due to the likelihood of degradation over time and comparisons with existing 50-year-old highways nearby managed by Caltrans, none of which are currently in Condition State A.

Table 5-4 Probabilities of an alternative experiencing a condition state in years 50 to 75.

Alternative	Condition State			
	B	C	D	F
Alternative X	98%	75%	64%	24%
Alternative F	100%	43%	23%	11%

5.2.3 Seismic Event Performance

The expert panel was also asked to provide an opinion on the relative performance of the alternatives when experiencing a seismic event. The panel was asked, “With specific consideration of the performance threats identified for each alternative, is one alternative more vulnerable to strong seismic ground motions than the other?”. No specific level, type, or duration of ground motions accompanied this request. Each of the panel members replied that they expected Alternative F to perform better than Alternative X.

5.3 Discussion

Looking at the estimated probabilities for the individual threats and the combined results for the alternatives, there are a number of observations that can be made. Some of the observations relevant to discerning where the risks lie and for comparing the alternatives are as follows:

- There were more long-term geotechnical threats to performance identified and assessed for Alternative F than for Alternative X.
- For Alternative X, 0-10 years, the “Nested Landslide” threat was judged to have the lowest probability of “not occurring or occurring and remaining in Condition State A”, and the highest probability of resulting in Condition States B, C, D, and F.
- For Alternative F, 0-10 years, the “Approach Construction” threat was judged to have the lowest probability of “not occurring or occurring and remaining in Condition State A”, and among the highest probabilities of resulting in Condition State B, C, and D. The “Intersects Landslide” threat was judged to have the highest probability of resulting in Condition State F.
- For 0-10 years, Alternative X is approximately 1.5 to 2 times more likely to experience Condition States B, C, D, and F than Alternative F.
- For 0-10 years, Alternative X and F are approximately equally likely to experience Condition States A.
- For Alternative X, 50-75 years, the “Deep Landslide” and “Nested Landslide” threats were judged to have the lowest probabilities of “not occurring or occurring and remaining in Condition State B”, and approximately the highest probabilities of resulting in Condition State C, D, and F.
- For Alternative F, 50-75 years, the “Membrane Liner” threat was judged to have the lowest probability of “not occurring or occurring and remaining in Condition State B”, and among the highest probabilities of resulting in Condition States C and D. The “Intersects

Landslide" threat was judged to have the highest probability of Experiencing Condition State F.

- For 50-75 years, Alternative X and F are approximately equally likely to experience Condition State B.
- For 50-75 years, Alternative X is approximately 1.5 to 2 times more likely to experience Condition States C, D, and F than Alternative F.

6.0 CONCLUSIONS

Alternative X and F involve constructing new highway infrastructure within active landslides (ground that is currently moving) and the alignment for each connects to stationary ground, beyond active landslides, making the maintenance of a reliable highway connection difficult. The alternative approaches are different and geotechnical threats to performance are unique for each alternative, yet they are similar in that the risks attributed to them threaten how well the completed project performs. There are also significant risks with the delivery of either alternative from selection through construction and these are generally tied to the scale of the project at a remote location with geologic complexity and environmental and cultural interests. In part, this risk is that site understanding and construction methods might be limited because of the need to protect environmental and cultural resources. The GRA has provided an objective evaluation of geotechnical risks for both project delivery and performance that can be incorporated into the alternative selection process for the project.

A total of 24 geotechnical delivery risks were identified for Alternative X, and 17 were identified for Alternative F. The WSP/BGC team consolidated the risks into seven delivery risk categories that allowed an expert panel to develop a risk profile useful for alternative comparison. The WSP/BGC team developed an initial evaluation of the consequences to allow the project impacts to be more fully conveyed for each alternative. This semi-quantitative assessment of consequences is interim, and it should receive further consideration as the preferred alternative is selected. Nevertheless, these results show that the delivery risks are generally high, and that Alternative F may have project delivery impacts two to three times as high as those for Alternative X. Mitigation strategies were proposed by the panel for both alternatives, generally tied to collecting more geotechnical data to improve understanding and reduce risk. The high probabilities assigned to the unmitigated risks emphasize the importance of additional site investigation and study as an important strategy to reduce the risks to an acceptable level.

Five different levels of traffic impacts were identified and characterized as Condition States A, B, C, D, and F, representing decreasing level of performance due to impact on reliable mobility. This condition state structure enabled the panel to evaluate the probability of occurrence that the highway would experience different levels of mobility impacts over near-term (years 0-10 of operation) and long-term (years 50-75 of operation) in a structured manner.

The panel considered what significant geotechnical threats to this measure of performance were present with each alternative, how likely they were to occur, and how likely it is that the design, informed by the anticipated site investigation and analysis, would be robust enough to fully mitigate the threat. The panel identified seven primary threats for Alternative F and five for Alternative X. Finally, the panel assessed what impacts to mobility would most likely be present if the threat was not fully mitigated. Comparison of the individual risks from threats for the two alternatives indicates a range of performance by correlating to the probability of experiencing a less desirable condition state.

Performance was evaluated gradationally, with progressively less desirable condition states being associated with higher maintenance interruptions, programmed repair-project interruptions, escalation on frequency of interruptions, and full closure for one week or more. These threats were assessed individually and then combined using statistical assumptions to compare the alternatives.

The most notable finding of the objective performance risk assessment, wherein the problem was decomposed and then recomposed, and the result was unknown a priori, is the consistency of results. In both time periods, Alternative X is approximately twice as likely as Alternative F to experience each condition state other than the initial one. This will lead to the conclusion, as discussed more below, that Alternative F is about twice as likely to perform well as Alternative X. It is also readily observable that for both alternatives the probability of experiencing progressively worse condition states is progressively less: the bars decrease in height to the right on Figures 6 and 8. In fact, this may lead to an interpretation, which would be incorrect, that there is a progression from left to right on these figures. The only progression calculated is the probability of departing from the initial condition and experiencing another condition. The worst condition states are simply less likely to occur than the better ones.

It is also notable that the estimated probability of less desirable condition and the associated impacts to mobility are relatively high. In part this is due to the complexity of the geologic setting and the engineered works that would be included in either alternative, and the assumptions made here, including of statistical independence of threats and impacts. However, it is also partly due to uncertainties at this stage of design. It could be expected that as the site is studied more and the designs are developed to mitigate the individual threats, that estimates of the probability of being in less desirable condition states would lower.

The conclusion that Alternative F is about twice as likely as Alternative X to perform well stems from some key interpretive steps which the WSP/BGC team sees as appropriate. First, there is no unique definition of failure, such as complete closure of the highway, but rather a number of ways to judge undesired performance, which means that each condition state contributes to the assessment in a roughly equal way. No weighting was applied to give more significance to worse condition states, for example. Additionally, it is assumed that the probability of poor performance, which is what was estimated, is inversely proportional to the probability of good performance so that the ratios of poor performance between alternatives are equal to the ratios of good performance. This is intuitive based on the approach described here, but it was not directly calculated. In summary, based on the risk elicitation from the panel members and the process and assumptions stated herein, the interpretation of combined results is that Alternative F is about twice as likely to remain in its initial condition, requiring only average maintenance for a highway of its type, as Alternative X.

Strategies for mitigating delivery risk have been presented. Performance risk mitigation, to the extent it is possible, occurs in the delivery stage of the project through delivery risk mitigation (e.g. quality investigation, design and construction), and no alternate or additional strategies for performance risk mitigation were proposed as part of this risk assessment.

7.0 RECOMMENDATIONS

During the process of developing, conducting, and documenting the geotechnical risk assessment for the Last Chance Grade project, the expert panel and the WSP/BGC team have developed a number of recommendations for the project going forward.

The WSP/BGC team recommend that the delivery risks be reduced to an acceptable level by mitigation and acceptance, with actions as outlined in Section 4. Specifically, many of the delivery risks are thought to be best mitigated by performing sufficient site investigation to characterize the geology, limits of moving ground, groundwater conditions and ground characterization for tunneling either for the highway tunnel for Alternative F or the drainage tunnels for Alternative X. Developing and implementing appropriate mitigation measures to address these risks will be crucial regardless of the alternative selected. Characterization of the landslides and proposed alignments using geologic models based on measured stratigraphy and measured hydrogeologic conditions are critical. It is important for reliable stability analyses and for predicting stability improvements of the landslides, designing tunnels and drainage systems, and understanding potential impacts to vegetation.

With this investigation, characterization, and modeling, the basis of design for the selected alternative would be developed such that the geotechnical risks are reduced. Some level of uncertainty in subsurface conditions is inherent in all underground work, and beyond the degree to which site characterization is judged to be adequate, the project owner is typically responsible for undiscovered subsurface conditions that may impact the project. This underscores the importance of subsurface investigation work to reduce that risk to an acceptable level.

Given the nature of the site and the competing interests for building knowledge through investigation and study without making impacts to an environmentally and culturally significant area, site characterization work will be challenging. To that end, key elements of a successful approach to site investigation will require innovation and commitment. Innovations for this effort will likely include measures beyond typical borehole investigations with typical exploration spacing. Additional methods include directionally drilled horizontal borings to the maximum length, explorations using exploratory adits to explore ground behavior for tunneling, geophysical methods, test programs (i.e. horizontal drains) and statistical characterization of rock mass properties.

The WSP/BGC team further recommend that Caltrans advance the project delivery risk register to expand and refine the definition of probabilities of occurrence and consequences for the preferred alternative. This work should be performed by a multidisciplinary team knowledgeable about design and construction of large infrastructure projects and underground construction. The interim values presented here, along with an interim approach to calculate risk given those consequences, are not meant to directly assist with long-term project delivery. Rather the interim results presented herein are meant to characterize the geotechnical risks sufficiently to provide a comparison between the two existing alternatives to support Caltrans' selection of a preferred alternative.

8.0 CLOSURE

We trust the above satisfies your requirements. Should you have any questions or comments, please do not hesitate to contact us.

Yours sincerely,

BGC Engineering USA Inc.
per:

Scott A. Anderson, Ph.D.
Principal Consultant

07/25/2024

Cole Christiansen, PE
Senior Civil Engineer

WSP USA INC.
per:

Kenneth A. Johnson, Ph.D., CEG, PE
Senior Technical Principal Geological Engineer

Reviewed by:

Mark Vessely
Principal Consultant

CC/MV/mp/mm

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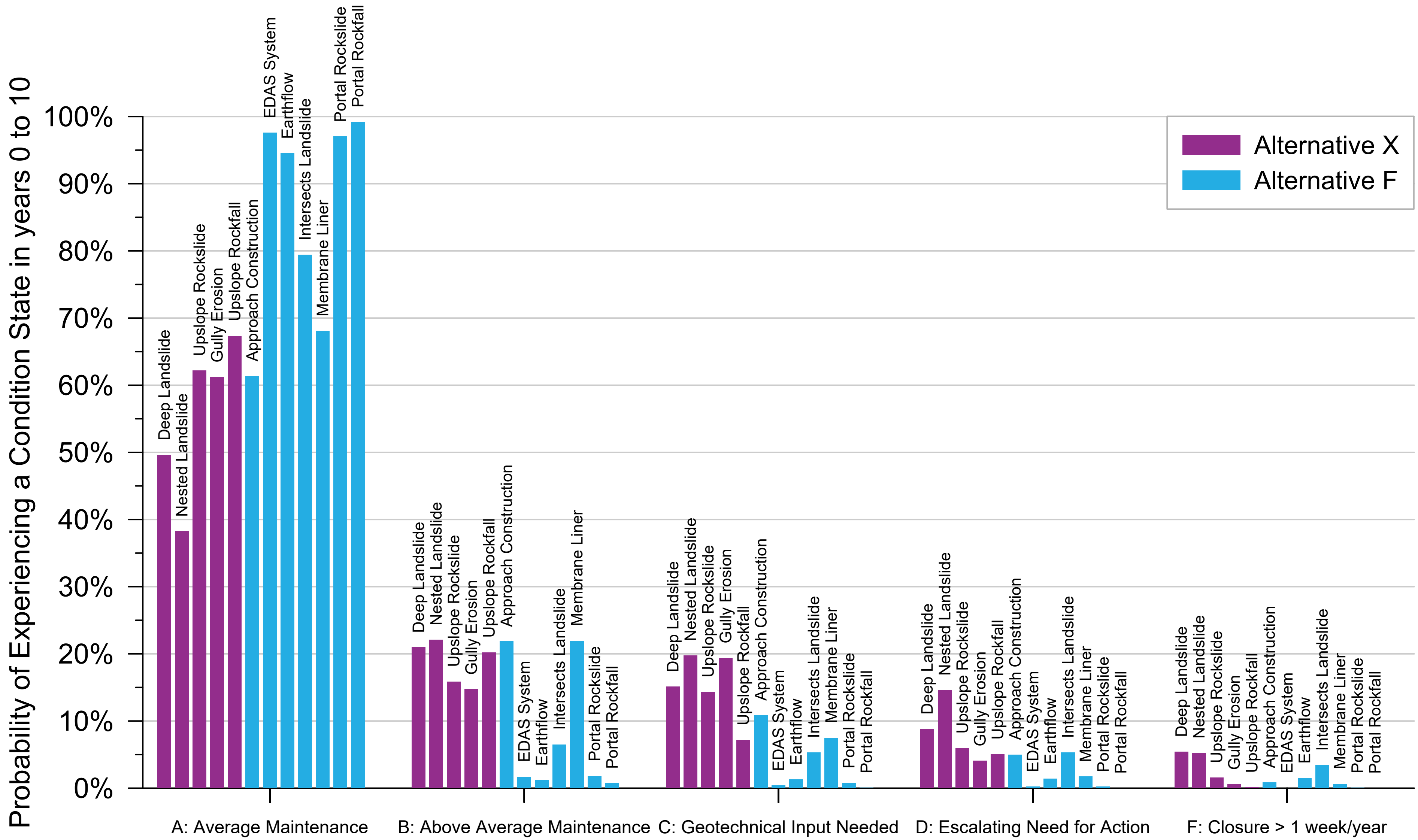
FIGURES

07-2024



NOTES:

1. This figure should be read in conjunction with BGC/WSP's report titled "Geotechnical Risk Assessment", and dated July 2024.
2. Condition States A through F are defined more completely in Table 3.2 of the report.
3. Threats are listed on the figure by Thread ID and are defined in Tables 3.3 and 3.4 of the report.

PREPARED BY: STM	FIGURE TITLE: CONDITION STATE PROBABILITIES BY THREAT - 0 TO 10 YEARS		
CHECKED BY: MAW	CLIENT: CALIFORNIA DEPARTMENT OF TRANSPORTATION		
APPROVED BY: SAA	SCALE: NTS	PROJECT NO: 1716009/ 30901047	FIGURE NO: 1

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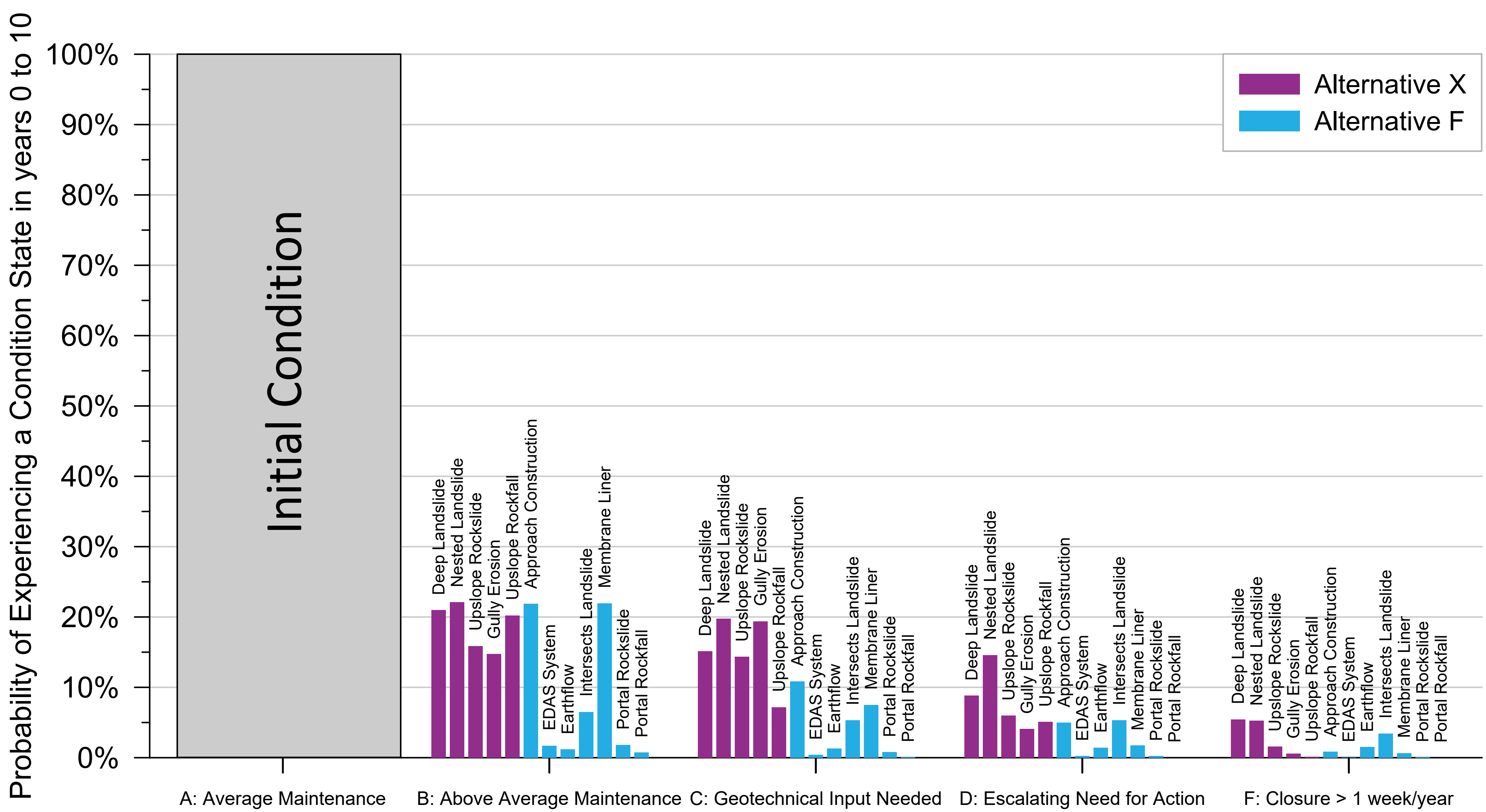

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2. Condition States A through F are defined more completely in Table 3.2 of the report.
3. Threats are listed on the figure by Thread ID and are defined in Tables 3.3 and 3.4 of the report.

PREPARED BY: STM	FIGURE TITLE: PROBABILTIES OF EXPERIENCING A CHANGED CONDITION STATE BY THREAT – 0 TO 10 YEARS		
CHECKED BY: MAW	CLIENT: CALIFORNIA DEPARTMENT OF TRANSPORTATION		
APPROVED BY: SAA	SCALE: NTS	PROJECT NO: 1716009/ 30901047	FIGURE NO: 2

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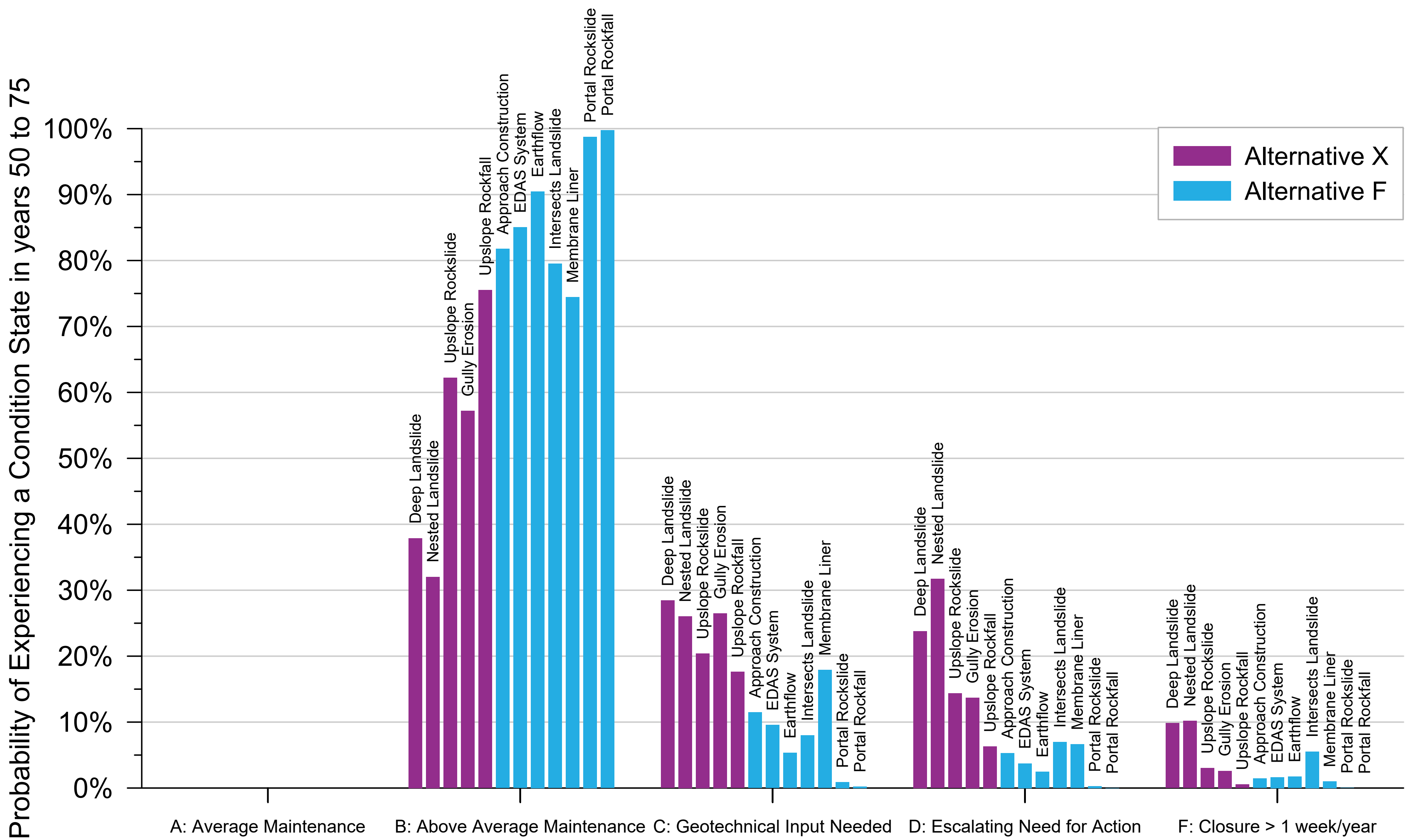

NOTES:

1. This figure should be read in conjunction with BGC/WSP's report titled "Geotechnical Risk Assessment", and dated July 2024.
2. Condition States A through F are defined more completely in Table 3.2 of the report.
3. Threats are listed on the figure by Thread ID and are defined in Tables 3.3 and 3.4 of the report.

PREPARED BY: STM	FIGURE TITLE: CONDITION STATE PROBABILITIES BY THREAT - 50 TO 75 YEARS		
CHECKED BY: MAW	CLIENT: CALIFORNIA DEPARTMENT OF TRANSPORTATION		
APPROVED BY: SAA	SCALE: NTS	PROJECT NO: 1716009/ 30901047	FIGURE NO: 3

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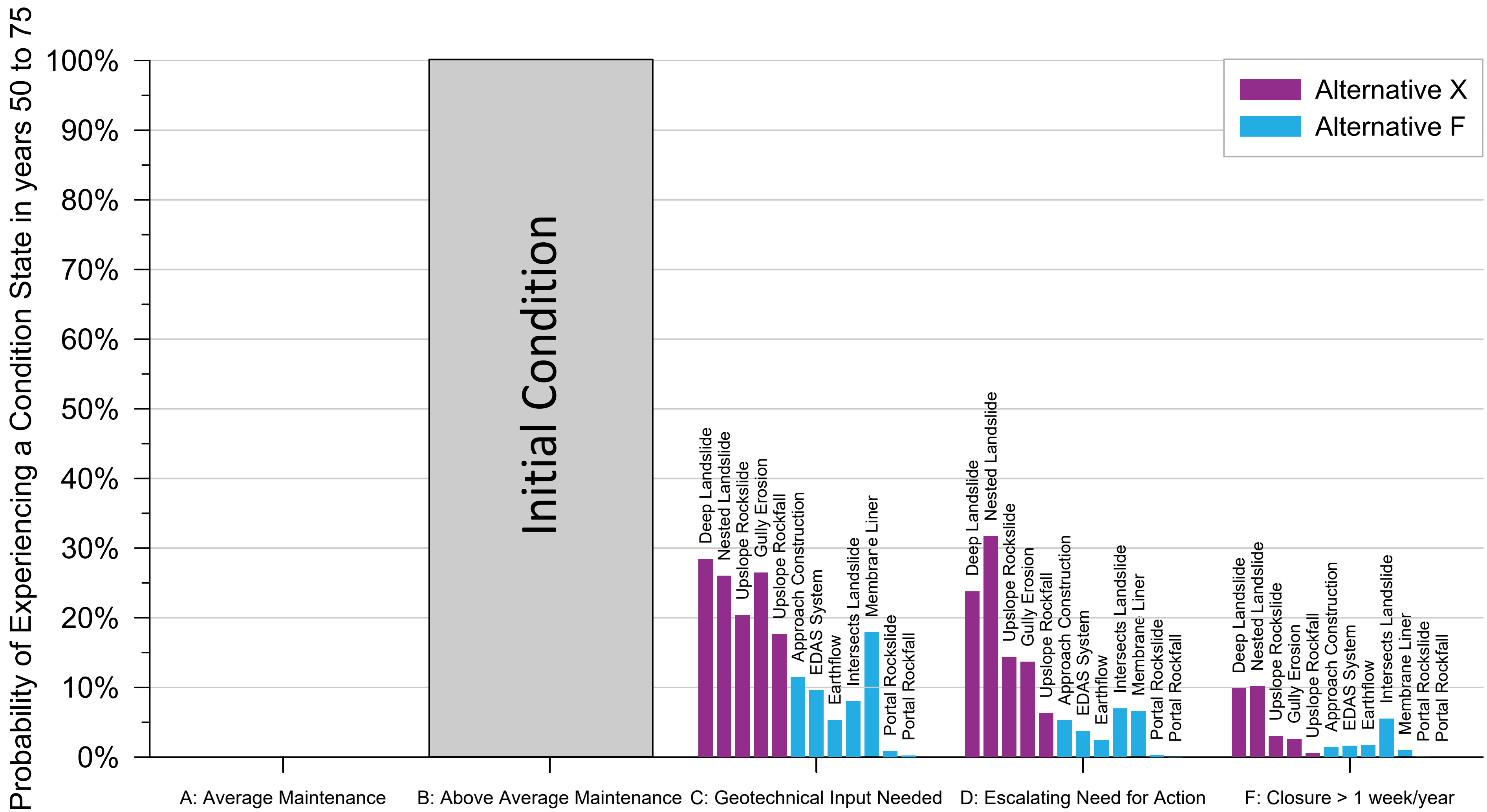

NOTES:

1. This figure should be read in conjunction with BGC/WSP's report titled "Geotechnical Risk Assessment", and dated July 2024.
2. Condition States A through F are defined more completely in Table 3.2 of the report.
3. Threats are listed on the figure by Thread ID and are defined in Tables 3.3 and 3.4 of the report.

PREPARED BY:	FIGURE TITLE:		
STM	PROBABILTIES OF EXPERIENCING A CHANGED CONDITION STATE BY THREAT – 50 TO 75 YEARS		
CHECKED BY:	CLIENT:		
MAW	CALIFORNIA DEPARTMENT OF TRANSPORTATION		
APPROVED BY:	SCALE:	PROJECT NO:	FIGURE NO:
SAA	NTS	1716009/ 30901047	4

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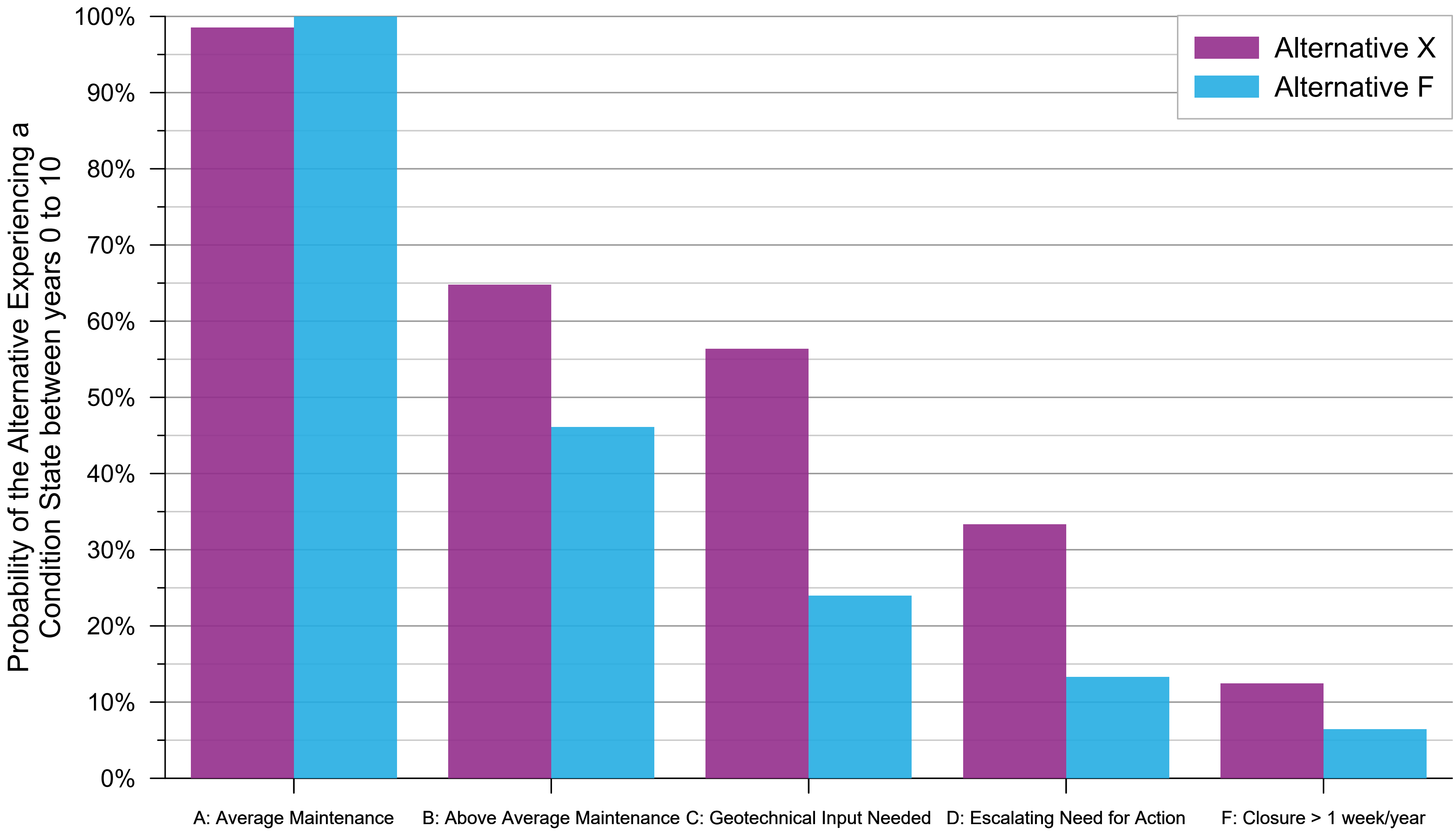
BGC ENGINEERING INC. AND WSP USA INC.



NOTES:

1. This figure should be read in conjunction with BGC/WSP's report titled "Geotechnical Risk Assessment", and dated July 2024.
2. Condition States A through F are defined more completely in Table 3.2 of the report.
3. Threats are listed on the figure by Thread ID and are defined in Tables 3.3 and 3.4 of the report.

PREPARED BY: STM	FIGURE TITLE: CONDITION STATE PROBABILITIES BY ALTERNATIVE - 0 TO 10 YEARS		
CHECKED BY: MAW	CLIENT: CALIFORNIA DEPARTMENT OF TRANSPORTATION		
APPROVED BY: SAA	SCALE: NTS	PROJECT NO: 1716009/ 30901047	FIGURE NO: 5

0 5 10 mm in ANSI A sized paper

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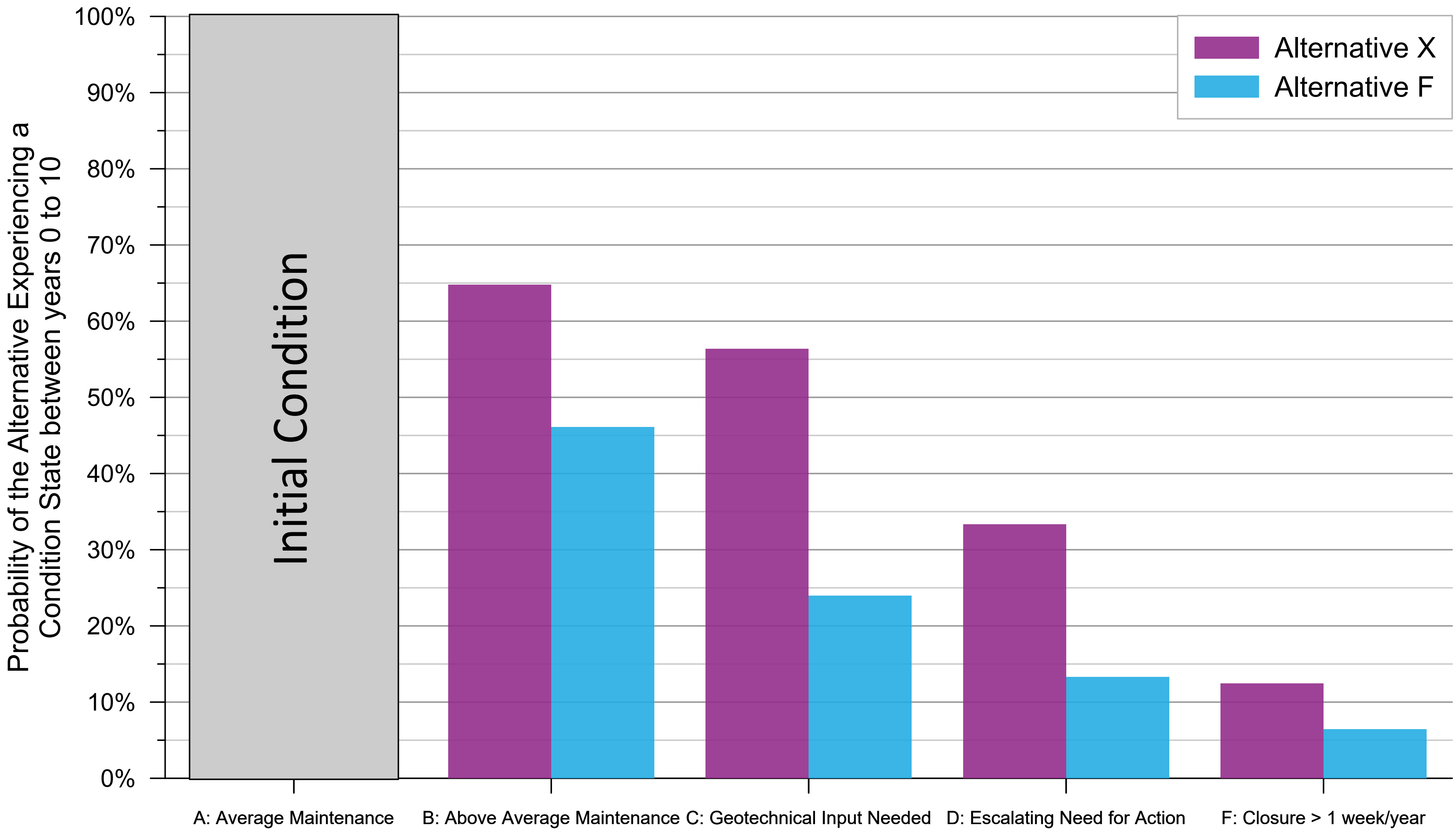

NOTES:

1. This figure should be read in conjunction with BGC/WSP's report titled "Geotechnical Risk Assessment", and dated July 2024.
2. Condition States A through F are defined more completely in Table 3.2 of the report.
3. Threats are listed on the figure by Thread ID and are defined in Tables 3.3 and 3.4 of the report.

PREPARED BY: STM	FIGURE TITLE: PROBABILTIES OF EXPERIENCING A CHANGED CONDITION STATE BY ALTERNATIVE – 0 TO 10 YEARS		
CHECKED BY: MAW	CLIENT: CALIFORNIA DEPARTMENT OF TRANSPORTATION		
APPROVED BY: SAA	SCALE: NTS	PROJECT NO: 1716009/ 30901047	FIGURE NO: 6

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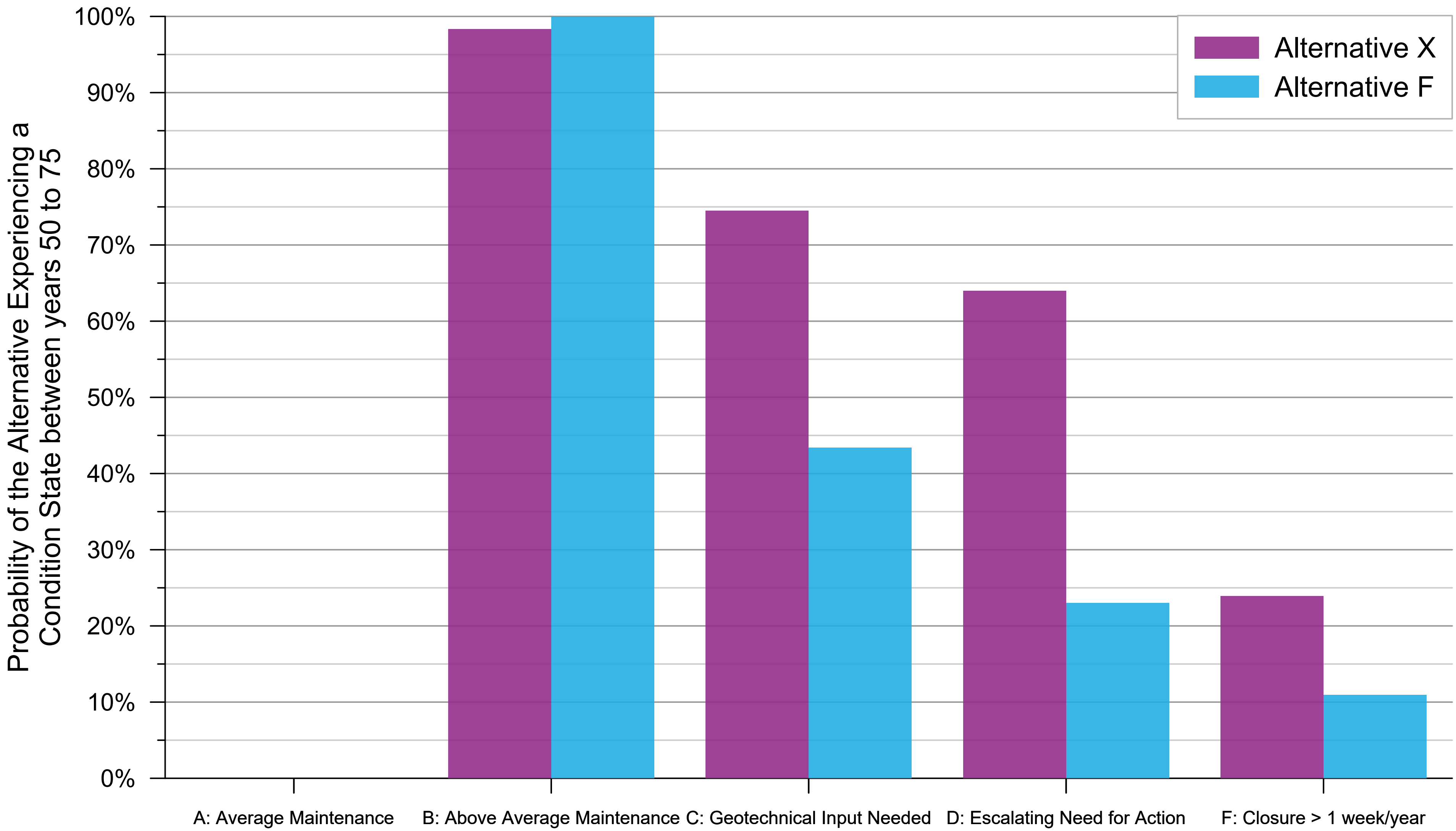

NOTES:

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2. Condition States A through F are defined more completely in Table 3.2 of the report.
3. Threats are listed on the figure by Thread ID and are defined in Tables 3.3 and 3.4 of the report.

PREPARED BY:	FIGURE TITLE:		
STM	CONDITION STATE PROBABILITIES BY ALTERNATIVE - 50 TO 75 YEARS		
CHECKED BY:	CLIENT:		
MAW	CALIFORNIA DEPARTMENT OF TRANSPORTATION		
APPROVED BY:	SCALE:	PROJECT NO:	FIGURE NO:
SAA	NTS	1716009/ 30901047	7

0 5 10 mm in ANSI A sized paper

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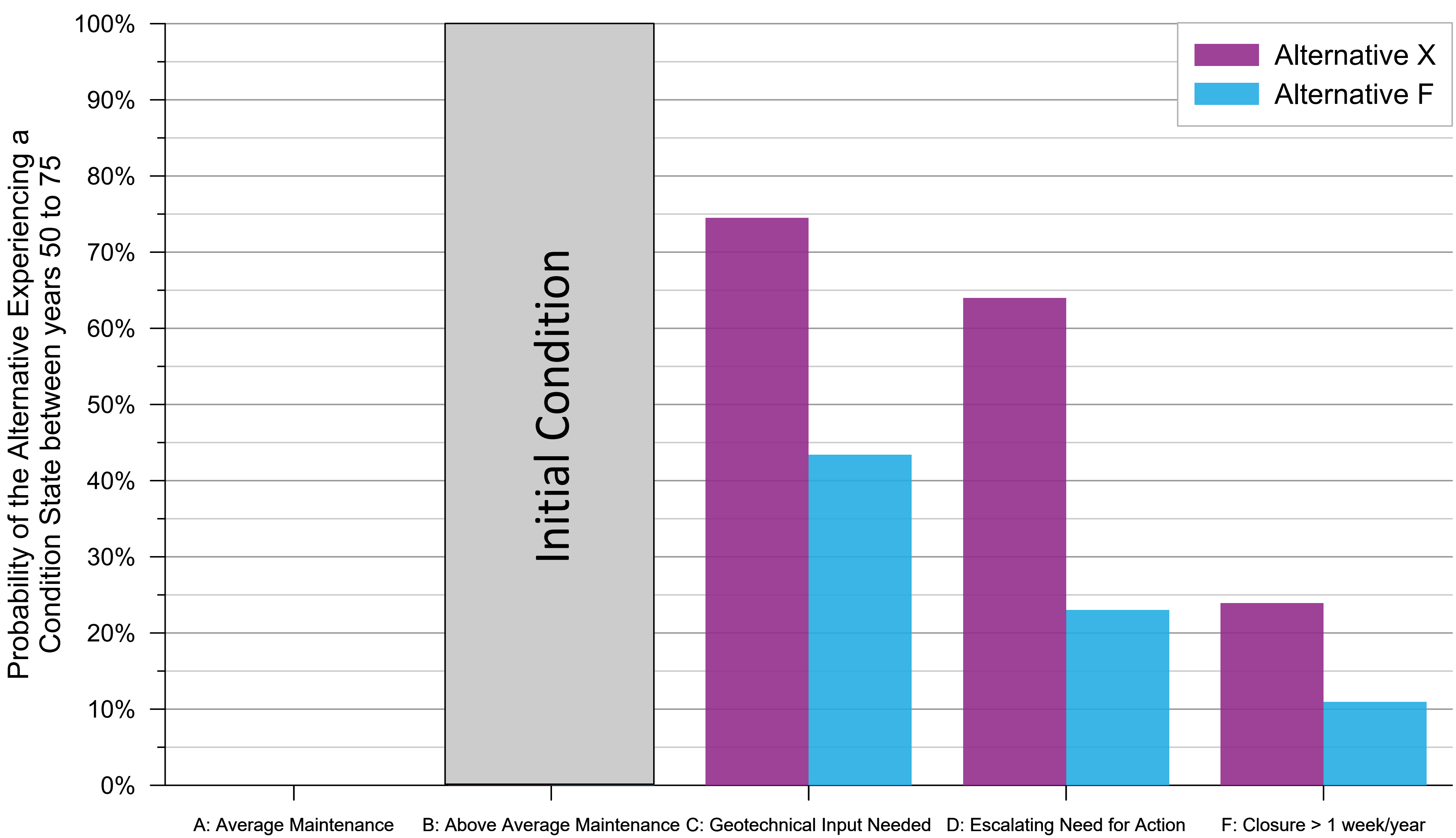

NOTES:

1. This figure should be read in conjunction with BGC/WSP's report titled "Geotechnical Risk Assessment", and dated July 2024.
2. Condition States A through F are defined more completely in Table 3.2 of the report.
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PREPARED BY: STM	FIGURE TITLE: PROBABILTIES OF EXPERIENCING A CHANGED CONDITION STATE BY ALTERNATIVE – 50 TO 75 YEARS		
CHECKED BY: MAW	CLIENT: CALIFORNIA DEPARTMENT OF TRANSPORTATION		
APPROVED BY: SAA	SCALE: NTS	PROJECT NO: 1716009/ 30901047	FIGURE NO: 8

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APPENDIX A
ADDITIONAL CONSIDERATIONS

A-1 ADDITIONAL CONSIDERATIONS

As a part of the expert-based Geotechnical Risk Assessment workshop on February 2024 to assess the performance and delivery risks associated with Alternatives F and X for the Last Chance Grade Permanent Restoration Project, moderators asked the expert panel to generate some considerations for Caltrans on the project. The exact prompt posed by the moderators was, "Considerations for Caltrans on Last Chance Grade (separate from the risk assessment tasks)". Note that contributions to this list also include comments and thoughts from the panelists generated during follow-up discussions with the panelists. The following bullet points are the considerations which have been grouped by the WSP/BGC team:

Current Highway Management:

- Consider initiating a test program of horizonal drain installations at the road grade to improve cut slope and retaining wall stability. Include nested piezometers, inclinometers, and on-site rain gages, so the efficacy of the drains could be assessed and used for future design efforts.
- Consider improving ability to complete rapid airborne lidar surveys in response to storm damage to benefit stabilization design and to improve understanding of how gully erosion progresses in response to large storm events.
- Try some subsurface drainage that include piezometers to evaluate efficacy of technology at Last Chance Grade. Specifically consider this for soldier pile tieback walls.
- Address downhill movement below existing walls by augmenting/reinforcing existing walls with additional rows of anchors and/or additional soldier piles in front of existing structures to replace the lateral restraint from soil which has moved downhill. Incorporate horizontal drains and piezometers into new/remediated walls.
- Consider installing downslope drainage pipes (tight-lined) to convey stormwater and subdrain water down to the toe of the landslides, to avoid infiltration and therefore reduce groundwater pressures within the landslides.
- Consider horizontal drains that could be installed from accessible locations downslope of the highway, to reduce groundwater pressures within nested slides.

Alternative X Considerations:

- Consider roadway edge drainage subdrain flowing to South end past Alternative X improvements.
- For Alternative X, the relatively small diameter of the TBM drives from relatively deep shafts create a worker egress issue in the event of an emergency within the tunnel while it is being bored. Further, required spoil removal and segment delivery through the deep shafts create a falling object risk. Also, the TBM launch and retrieval through the same shafts also create a falling object risk.
- For Alternative X consider the applicability of viaduct sections over deep erosion gullies to avoid erosion impacts. Based on the site visit, erosion gullies below existing walls (see stops 1-3) are the greatest threat to the existing highway. Gullies will continue to progress and will eventually undermine the walls and existing highway. This does not

appear to be addressed by current design. Consider stabilization and drainage elements to Alternative X to address this.
- For Alternative X note that maintenance of deep drainage tunnels will be essential to their effectiveness and longevity.
- For Alternative X consider a “leaky tunnel” design concept with permeable backfill around the segmental concrete liner. This can facilitate drainage in areas of high inflow while allowing radial drain installation in tunnel portions that don’t flow as freely.
- For design development on Alternative X, consider including targeted design elements to focus on making specific slide zones more stable and resilient.
- Valentine’s Day Slide east of highway in head scarp is indication of possible instability of other slopes east of the highway, which causes concern for “big cut” where tiered wall is planned in Alternative X. Consider that the “big cut” might be in rock less stable than currently anticipated.
- Consider directional drilling from highway down to beach as an alternative to deep drainage galleries.
- For Alternative X, the planned areas for new borings/ the entire permit process are good areas, however, there are additional areas where borings should be planned in order to develop reliable/accurate geo-models for stability analysis of each.
- Consider horizontal drains that could be installed from accessible locations downslope of the highway, to reduce groundwater pressures within nested slides and improve performance of fill walls.
- Structural designs for retaining walls should consider means to accommodate future slide movements/deformations and provisions for future wall repairs and installation of supplemental anchors and underpinning. Consider structural members that are ductile rather than brittle, with designs to accommodate deformations in structural elements impacted by differential landslide movements.
- Consider the efficacy/necessity of the drainage tunnels and their ability to affect necessary hydrogeologic improvements to mitigate the shallower processes of slope distress (i.e. nested slides, gully erosion). The drainage tunnels may only appreciably mitigate for deep movement, which appears to have had less and more localized consequence to the highway than shallower processes.
- There is a need for more hydrogeologic investigations for both alternatives, but understanding the hydraulic conductivity and the efficacy of the drainage tunnels for Alternative X is very important.

Alternative F Considerations:
- For Alternative F, note that there may be significant permitting delays due to the location of the North Portal in the old growth Redwoods.
- For Alternative F, consider twin SEM or twin TBM tunnels instead of single tunnel. Consider safety issues with bi-directional road tunnel of this length. There is a potential for head on collisions and egress issues in the event of tunnel fires.

Both Alternatives Considerations:

- Consider increasing future borings to 300-ft when possible and installing SIs or piezometers.
- If feasible, take any new borings down to 0-ft MSL or even -50-ft MSL to better define geologic profile at depth.
- If additional embankment is needed, consider utilizing light weight fills to reduce driving forces.
- Consider retaining a drilling consultant to advise on difficult drilling conditions, deep borings, production rate, and instrumentation installations.