4.3 GEOLOGY, SOILS, AND SEISMICITY

This section addresses the effects of construction of the Proposed Project at Gnoss Field Airport (DVO or Airport) as it relates to the geologic conditions, including soils and seismicity of the site. Geologic conditions of the Detailed Study Area (DSA) were surveyed as part of this environmental analysis, the full report of which is included in Appendix M, *Geology, Soils, and Seismicity Resources*.[1]

4.3.1 ENVIRONMENTAL SETTING

4.3.1.1 Regulatory Framework

STATE OF CALIFORNIA LAWS AND POLICIES

Alquist-Priolo Earthquake Fault Zoning Act

The Alquist-Priolo Earthquake Fault Zoning Act (formerly the Alquist-Priolo Special Studies Zone Act), signed into law December 1972, requires the delineation of zones along active faults in California. The purpose of the Alquist-Priolo Act is to regulate development on or near fault traces to reduce the hazard of fault rupture and to prohibit the location of most structures for human occupancy across these traces. Cities and counties must regulate certain development projects within the zones, which includes withholding permits until geologic investigations demonstrate that development sites are not threatened by future surface displacement. Surface fault rupture is not necessarily restricted to the area within an Alquist-Priolo Zone.

Seismic Hazards Mapping Act

The Seismic Hazards Mapping Act was developed to protect the public from the effects of strong ground shaking, liquefaction, landslides, or other ground failure, and from other hazards caused by earthquakes. This act requires the State Geologist to delineate various seismic hazard zones and requires cities, counties, and other local permitting agencies to regulate certain development projects within these zones. Before a development permit is granted for a site within a seismic hazard zone, a geotechnical investigation of the site must be conducted and appropriate mitigation measures incorporated into the project design. The California Geologic Survey (CGS) has not yet completed a preliminary Seismic Hazards Map for the Novato or Petaluma area, which includes the project location.

MARIN COUNTY POLICIES

The Environmental Hazards Element of the *Marin Countywide Plan* provides goals and policies to ensure acceptable protection of people and structures associated with environmental hazards, including geology. Goals and policies pertaining to geologic/seismic hazards that may be applicable to the Proposed Project are listed below.

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1 *Geology, Soils and Seismicity, Gnoss Field Airport EIS/EIR, Marin County Airport*, Prepared by Kleinfelder West, Inc., 2009.

Goal EH-2: Safety from Seismic and Geologic Hazards. Protect people and property from risks associated with seismic activity and geologic conditions.

Policy EH-2.1: Avoid Hazard Areas. Require development to avoid or minimize potential hazards from earthquakes and unstable ground conditions.

Policy EH-2.2: Comply with the Alquist-Priolo Act. Continue to implement and enforce the Alquist-Priolo Earthquake Fault Zoning Act.

Policy EH-2.3: Ensure Seismic Safety of New Structures. Design and construct all new buildings to be earthquake resistant. The minimum level of design necessary would be in accordance with seismic provisions and criteria contained in the most recent version of the State and County Codes. Construction would require effective oversight and enforcement to ensure adherence to the earthquake design criteria.

Policy EH-2.4: Protect Coastal Areas from Tsunamis. When inundation maps become available, address tsunami wave run-up and inundation when reviewing proposed development along coastal areas of Marin County.

4.3.1.1 Existing Conditions

The following sections describe the project area in relation to geology, soils, and seismicity, as well as the potential geologic hazards that may be present within the DSA.

GEOLOGY

DVO lies within the Petaluma River Valley approximately two feet above sea level. The geology of the DSA is characterized by soils deposited within the San Pablo Bay drainage basin during the late Holocene Epoch (less than 11,500 years ago).[2] The existing airfield is underlain by artificial fill placed over Bay Mud, with levee fill around the northern perimeter of the runway. Additional levees separate the airfield from an artificial section of Black John Slough, and also extend east and west of the Airport facility.

SOILS

Soils within the DSA are predominately Reyes clay, which is a somewhat poorly drained soil.[3] The Airport facilities are constructed on fill materials classified as urban land and fill Xerothents, which overlays the Reyes Clay soil layer. See **Exhibit 4.3-1, *Site Soils***, for locations of soil types within the DSA.

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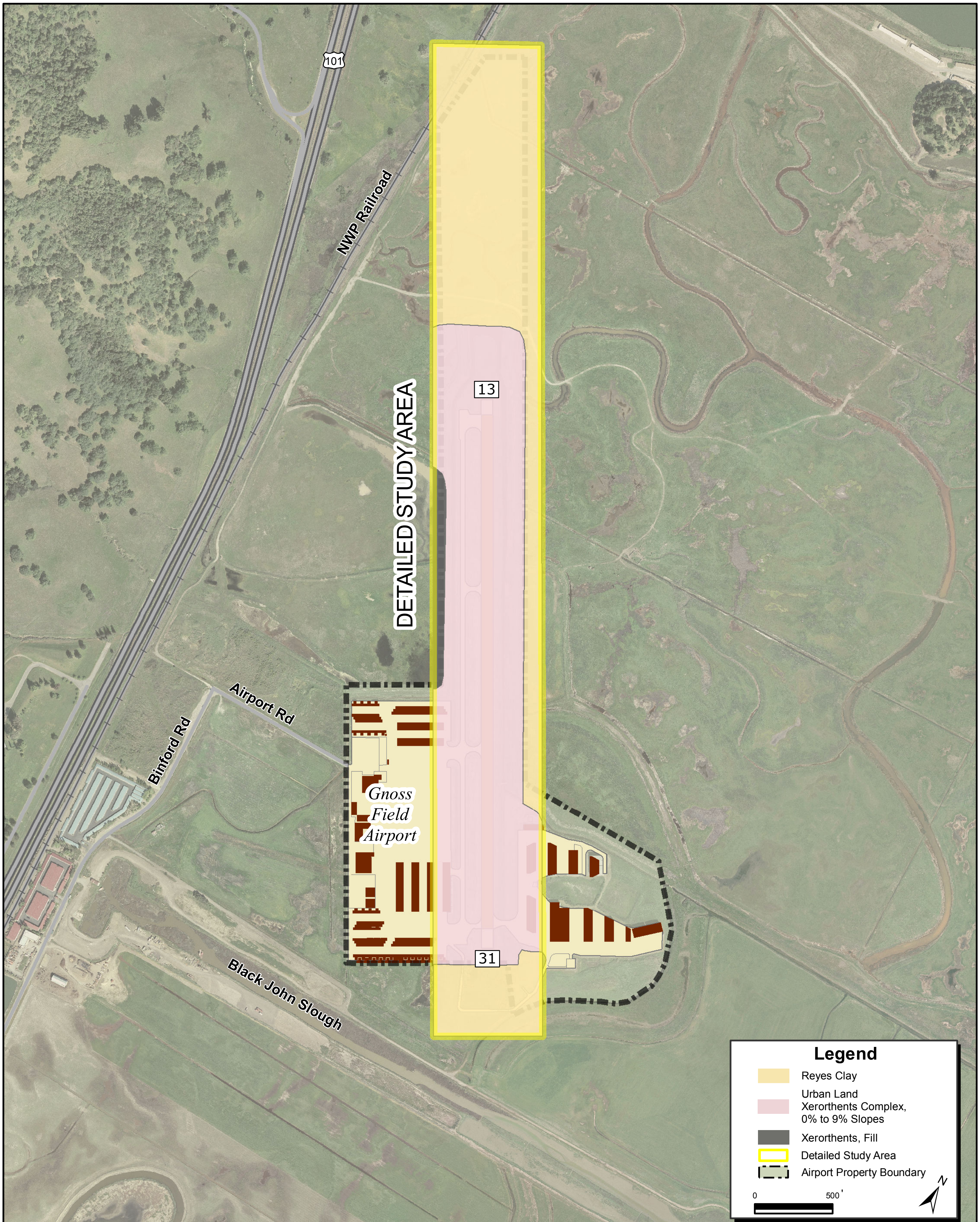
[2] U.S. Department of Interior, U.S. Geological Survey. Geologic Map of the San Francisco Bay Region, 2006.

[3] U.S. Department of Agriculture, Natural Resources Conservation Service. Soil Survey Geographic (SSURGO) database for Marin County, California, 10/12/2007.



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Site Soils

Exhibit: 4.3-1

BACK OF EXHIBIT 4.3-1

SEISMICITY

DVO is located within the seismically active North Bay/North Coast region of California and is subject to seismically-induced ground shaking from nearby and distant faults. Several faults have been mapped in the general site vicinity of the Airport. The San Andreas fault zone, located southwest of the site, is the boundary between two tectonic plates; the Pacific Plate (west of the fault), and the North American Plate (east of the fault). At this boundary, the Pacific Plate is moving north relative to the North American Plate.

The Airport is not located within an Earthquake Fault Zone, as defined by the CGS in accordance with the Alquist-Priolo Earthquake Fault Zone Act of 1972.[4] The nearest known sufficiently-active fault is the Hayward-Rodgers Creek fault, located approximately six miles northeast of the Airport. The Hayward-Rodgers Creek is capable of producing a maximum moment magnitude event of 7.2; as such, moderate to major earthquakes generated on the Hayward-Rodgers Creek fault can be expected to cause strong ground shaking at the site. Strong ground shaking can also be expected from moderate to major earthquakes generated on other faults in the region such as the Maacama fault (located 31 miles north), the West Napa fault (located 15 miles east/northeast), the Concord-Green Valley fault (located 22 miles east/northeast), and the San Andreas fault (located 14 miles southwest).

In addition to the active faults discussed above, the U.S. Geological Survey identifies a Quaternary (<1.6 million years old) fault known as the Burdell Mountain fault in the area. As shown in **Exhibit 4.3-2, *Fault Lines***, the Burdell Mountain Fault crosses the southwest corner of the Airport property and is located approximately 460 feet from the southeast end of the runway.[5] Based on the Quaternary designation, the Burdell Mountain fault may be considered "potentially active". A generally accepted definition of "potentially active" is a fault showing evidence of displacement that is older than 11,000 years (Holocene age) and younger than 1.7 million years (Pleistocene age). However, "potentially active" is no longer used as criteria for zoning by the CGS.

A number of large earthquakes have occurred within this region in the historic past. Some of the significant nearby events include the 2000 Yountville earthquake (M5.2), two 1969 Santa Rosa earthquakes (M5.6, 5.7), the 1868 Hayward earthquake (M6.8), and the 1906 San Francisco earthquake (M8+). Future seismic events in this region can be expected to produce strong seismic ground shaking at the Airport. The intensity of future shaking will depend on the distance from the site to the earthquake focus, magnitude of the earthquake, and the response of the underlying soil and bedrock.

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4 California Geological Survey, 2000, Digital Images of Official Maps of Alquist-Priolo Earthquake Fault Zones of California, Central Coast Region, DMG CD 2000-004.

5 U.S. Geological Survey (USGS) (Quaternary Fault and Fold Database. Online at: http://earthquake.usgs.gov/regional/qfaults/.

GEOLOGIC HAZARDS

Shallow Groundwater/Tidal Influence

The areas proposed for the runway, taxiway, and safety area extension are located at or slightly above sea level, within a partially-drained reclaimed tidal marsh and currently protected from inundation by levees. While the natural and artificial channels, coupled with levee protection, have generated a relatively firm ground surface, apparent static groundwater was observed as shallow as two to three feet in depth during site reconnaissance. Shallow groundwater (within five feet of the surface) should be anticipated within the areas proposed for runway and taxiway expansion.

Expansive Soils

Expansive soils have the capacity to undergo large volume changes with changes in moisture content and typically are associated with high plasticity clays. Expansive soils are located throughout the areas proposed for runway, taxiway, and safety area extension.

Compressible Soils

Compressible soils are typically fine-grained soils that possess low density and are incapable of supporting significant vertical loads without excessive settlement. Compressible soils tend to coincide with younger, Holocene age deposits that have not had sufficient time to densify. The reclaimed tidal marsh on which the existing airfield and proposed extension areas are located are underlain by Bay Mud deposits.[6,7,8] Bay Mud thickness under the existing and runway and proposed extension varies from approximately 40 feet to 25 feet.[9] As such, the existence of variable thickness compressible soils is present within the areas proposed for the runway extension. [10]

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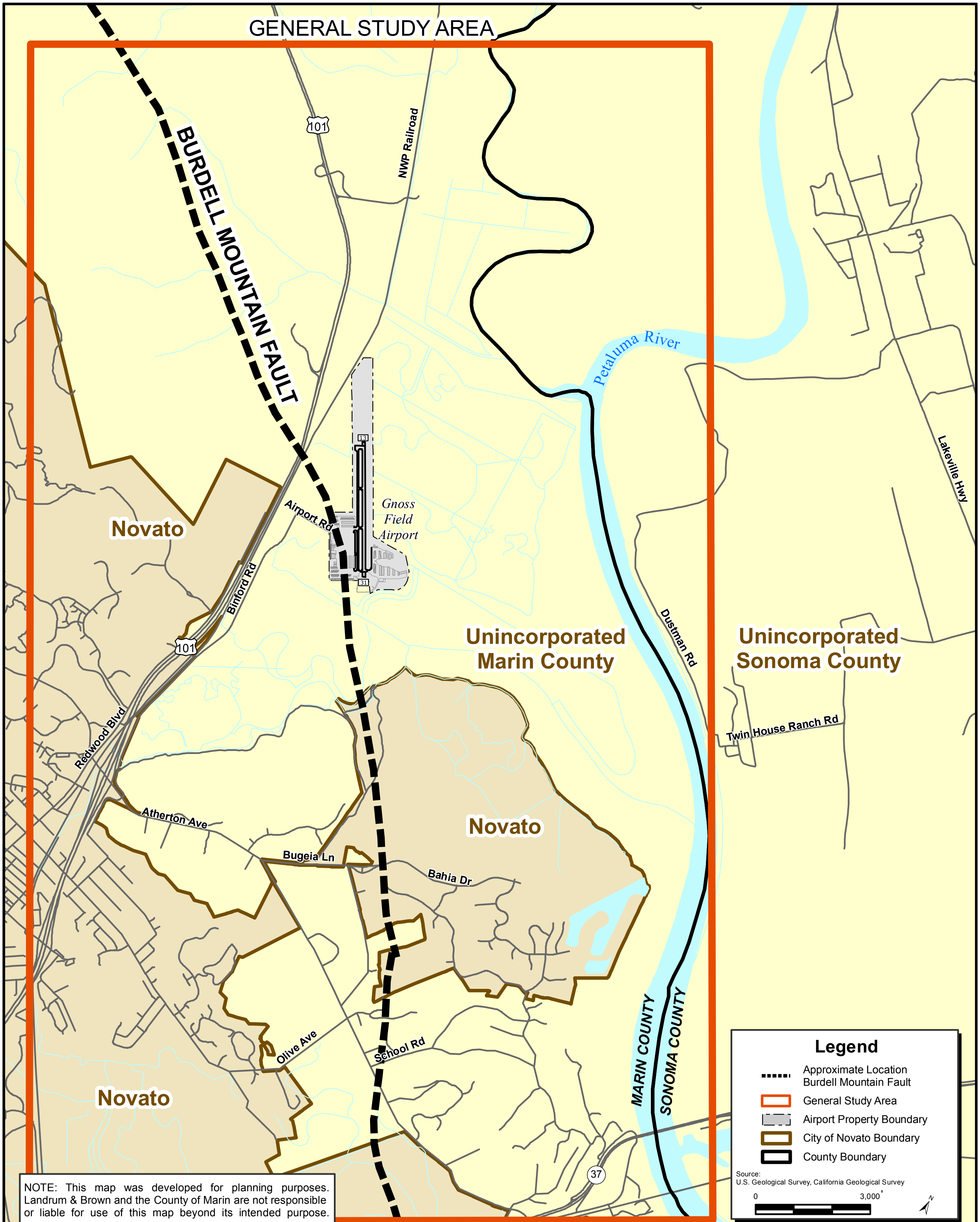
6 Wagner, David L., Rice, Salem R., Bezore, Stephen, Randolph-Loar, Carolyn E., Allen, James, and Witter, Robert C. (2002), Geologic Map of the Petaluma River 7.5' Quadrangle, Marin and Sonoma Counties, California: A Digital Database Version 1.0.

7 Blake, M.C., Graymer, R. W., and Jones, D.L., (2000). Geologic Map And Map Database of parts of Marin, San Francisco, Alameda, Contra Costa and Sonoma Counties, California, U.S. Geological Survey Miscellaneous Field Studies MF-2337, Version 1.0.

8 Rice, Salem J. (1975), Geology for Planning, Novato Area, Marin County, California, California Division of Mines and Geology Open File Report 75-1.

9 Environmental Science Associates, December 2002, Administrative Draft, Redwood Landfill Solid Waste Facilities, Permit Revision, Subsequent Environmental Impact Report.

10 Cortright & Seibold, Preliminary Design Report Runway Extension Gnoss Field Marin County, California FAA AIP Project No, 3-06-0167-08, December 20, 2002.



NOTE: This map was developed for planning purposes. Landrum & Brown and the County of Marin are not responsible or liable for use of this map beyond its intended purpose.

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Fault Lines

Exhibit: **4.3-2**

BACK OF EXHIBIT 4.3-2

EARTHQUAKE GROUND MOTIONS

Data presented by the Working Group on California Earthquake Probabilities[11] suggests the likelihood of a Magnitude 6.7 or greater seismic event to occur within the San Francisco Bay region in the next 30 years is approximately 63 percent. Within the San Francisco Bay Region, the Hayward-Rodgers Creek fault has the highest probability of an event at 31 percent, with the San Andreas fault at 21 percent. As such, the Airport is expected to experience strong seismic ground shaking resulting from future earthquakes on the Hayward-Rodgers Creek, San Andreas, and other active faults in the region during the lifetime of the improvements at this site. Time, location, and magnitude of earthquakes are not accurately predictable with existing technology. It is, however, generally agreed that the intensity of ground shaking from future earthquakes will depend on several factors including the distance from the site to the earthquake focus, the magnitude and duration of the earthquake, and the response of the underlying soil and bedrock.

Ground Surface Rupture

The nearest known active fault is the Hayward-Rodgers Creek fault, located approximately six miles northeast of the site. The Burdell Mountain fault is located approximately 460 feet from the southeast end of the runway. Relatively young geomorphic features and alignment of low level seismic event epicenters give evidence of recent activity along the Burdell Mountain fault. In general, this fault has recognized activity in the Quaternary and may be considered "potentially active", but has not been zoned as "sufficiently active" or "well defined" by the CGS. Therefore, no impact on the Proposed Project due to fault ground surface rupture is anticipated.

Liquefaction and Cyclic Softening

Soil liquefaction and cyclic softening are conditions where saturated soil undergoes substantial loss of strength due to pore pressure increase resulting from cyclic stress application induced by earthquakes. In the process, the soil acquires mobility sufficient to permit both horizontal and vertical movements if the soil mass is not confined. Soil most susceptible to liquefaction are saturated, loose, clean, uniformly graded sand deposits. Soft, saturated, unconsolidated clay and high plasticity silt, which typically comprise Bay Mud deposits, are most susceptible to cyclic softening. If either ground effect occurs, improvements resting on or within the affected layers may undergo settlements. The site is underlain by Holocene age estuarine deposits with very high susceptibility to liquefaction.[12] Based on this data, it is anticipated that the potential for liquefaction and cyclic softening to occur within the areas proposed for runway extension is high.

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[11] Working Group on California Earthquake Probabilities (2007), Uniform California Earthquake Rupture Forecast (UCERF): Notes on Southern California Earthquake Center (SCEC). Online at: http://www.scec.org/ucerf/.

[12] Sowers, Janet M., Noller, Jay S., and Lettis, William R., U.S. Geological Survey, Liquefaction Susceptibility and Quaternary Deposits Map, Napa, California 1:100,000 Quadrangle: A Digital Database, derived from Open File Report 98-460.

Lateral Spreading and Lurching

Lateral spreading and lurching are potential secondary seismic effects commonly associated with liquefaction where extensional ground cracking and settlement occur as a response to lateral migration of liquefiable material. These phenomena typically occur adjacent to free faces such as steep slopes and creek channels, both natural and manmade. Should liquefiable layers exist at or above the flow line elevation of a channel, lateral spreading and/or lurching could potentially occur during a seismic event.

Landslides and Slope Instability

The site is located on an effectively estuarine plain, traversed by artificial and natural drainage channels ranging in depth from one to five feet below the ground surface. In deeper channels with near vertical banks, shallow slumping of the banks is conceivable on a local level, particularly during periods of saturation, rapid draw down, and/or seismic events. Levees surround the existing airfield and agricultural field in the vicinity of the site. In general, the levees were constructed at approximately 2H:1V (Horizontal:Vertical), and slightly steeper in some areas. Shallow erosion and severe bioturbation of the levees was observed during site reconnaissance. The fact that evidence of mass landsliding or levee instability is not apparent does not preclude the possibility of occurrence, due to secondary ground effects during seismic events.

In addition, the geologic publications reviewed for the project all identify large landslide features west of the detailed study area, the closest of which is located approximately 200 feet west of the proposed runway extension.[13] Analysis of aerial photography identified several large landslides in the vicinity of those mapped on previous publications. The features appear to terminate west of Highway 101, or immediately at the roadway; in some cases, the existing geomorphology of the features have been altered by original construction, suggesting the landslide possibly extended beyond (east of) the roadway. The feature is located within 200 feet of the proposed northwest runway extension, which past studies[14] identified as a landslide; however, other studies[15] [16] [17] interpreted the feature to be an alluvial fan. If this interpretation is considered, the closest landslide deposit to the proposed runway extension is approximately 1,000 feet to the west, and landslides would not be categorized as a constraint to the runway extension project.

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13 Rice, Salem J. (1975), Geology for Planning, Novato Area, Marin County, California, California Division of Mines and Geology Open File Report 75-1.

14 Rice, Salem J. (1975), Geology for Planning, Novato Area, Marin County, California, California Division of Mines and Geology Open File Report 75-1.

15 Wagner, D.L., Gutierrez, C.I., and Clahan, K.B., 2006, California Geological Survey, Geologic Map of the South half of the Napa 30’x60’ Quadrangle, California

16 Wagner, David L., Rice, Salem R., Bezore, Stephen, Randolph-Loar, Carolyn E., Allen, James, and Witter, Robert C. (2002), Geologic Map of the Petaluma River 7.5’ Quadrangle, Marin and Sonoma Counties, California: A Digital Database Version 1.0.

17 Blake, M.C., Graymer, R. W., and Jones, D.L., (2000). Geologic Map And Map Database of parts of Marin, San Francisco, Alameda, Contra Costa and Sonoma Counties, California, U.S. Geological Survey Miscellaneous Field Studies MF-2337, Version 1.0.

Tsunami and Seiche

Tsunamis are oceanic waves that are generated by earthquakes, submarine volcanic eruptions, or large submarine landslides. The waves are generally formed in groups that may have very long wavelengths (several miles to more than 100 miles), but only a few feet high. As a tsunami enters shallow water near coastlines, the wave velocity diminishes and the wave height increases. If the trough of the wave reaches land first, the arrival of a tsunami is preceded by recession of coastal waters; if the crest of the wave reaches land first, there would be a rise in water level. The large waves that follow can crest at heights of more than 50 feet and strike with devastating force. However, since the study area is more than four miles from San Pablo Bay and seventeen miles from the nearest coastline, the potential for this condition is considered low.

Seiche is a standing wave condition whereby large bodies of water, when subjected to seismic accelerations, can generate significant waves that overtop the basin boundaries. The nearest large body of water to the study area is San Pablo Bay which is four miles to the southeast. Therefore, the potential for a seiche hazard within the study area is also considered low and no impact on the Proposed Project due to tsunami or seiche inundation is anticipated.

4.3.2 ENVIRONMENTAL IMPACTS AND MITIGATION

4.3.2.1 Significance Criteria

Based on the California Environmental Quality Act guidelines outlined in Appendix G[18] impacts of the Proposed Project may be considered significant if it:

- Exposes people or structures to potential substantial adverse effects, including the risk of loss, injury, or death involving:
    - Rupture of a known earthquake fault, as delineated on the most recent Alquist-Priolo Earthquake Fault Zoning Map issued by the State Geologist for the area or based on other substantial evidence of a known fault;
    - Strong seismic ground shaking;
    - Seismic-related ground failure, including liquefaction; or
    - Landslides.
- Results in substantial soil erosion or the loss of topsoil.
- Is located on a geologic unit or soil that is unstable, or that would become unstable as a result of the project, and potentially result in on- or off-site landslide, lateral spreading, subsidence, liquefaction or collapse.
- Is located on expansive soil, as defined in Table 18-1-B of the Uniform Building Code (1994), creating substantial risks to life or property.

[18] Title 14, California Code of Regulations, Chapter 3, Guidelines for Implementation of the California Environmental Quality Act.

Additionally, the Marin County Environmental Impact Review Guidelines[19] require the following analysis:

- Is the site located within an Alquist-Priolo Special Studies Zone, or contain a known active fault zone, or an area characterized by surface rupture that might be related to a fault?
- Does the substrate consist of material that is subject to liquification or other secondary seismic hazards in the event of groundshaking?
- Is there evidence of static hazards, such as landsliding or excessively steep slopes that could result in slope failure?
- Is the in the vicinity of soil that is likely to collapse, as might be the case with karst topography, old mining properties or areas of subsidence caused by groundwater drawdown?
- Are soils characterized by shrink/swell potential that might result in the deformation of foundations or damage to structures?
- Is the site located next to a water body that might be subject to tsunamis or seiche waves?

4.3.2.2 Environmental Impacts of the Proposed Project

The potential impacts due to geologic conditions were assessed based on an analysis of existing site conditions and the expected changes due to the Proposed Project. The assessment was prepared according to guidelines established under the California Code of Regulations, *Guidelines for Implementation of the California Environmental Quality Act*.[20]

All information, assumptions, and methodologies used to develop this assessment are provided in Appendix M.

Based on the scope of the proposed project, the project would not result in impacts associated with fault rupture, soil collapse, steep slopes or tsunamis. Further, all impacts of the project would be mitigated, as described in this section.

Impact 4.3-1: Shallow groundwater will potentially impact construction (potentially significant unless mitigated).

Shallow groundwater will potentially hinder access and operation of equipment during construction of the Proposed Project. Utility trench excavations extending down to or below the static groundwater table may also experience loss of trench wall stability and require dewatering for utility installation. Shallow groundwater may have other impacts on the future performance of any improvements, particularly in the presence of compressible and liquefiable soils (see Impacts 4.3-3 and 4.3-6) and heavy surface loads, if not mitigated during construction.

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[19] Marin County, Environmental Impact Review Guidelines (EIR Guidelines): Policy and Procedures for Implementation of the California Environmental Policy Act, May 17, 1994.

[20] Title 14, California Code of Regulations, Chapter 3, Guidelines for Implementation of the California Environmental Quality Act.

Mitigation Measure 4.3-1: Temporary Dewatering during excavation will reduce the potential for impacts on construction due to shallow groundwater.

Significance After Mitigation – Implementation of Mitigation Measure 4.3.1 is expected to reduce the impact to less than significant levels.

Responsibility and Monitoring – The Marin County Department of Public Works shall be responsible for incorporating the provisions of Mitigation Measure 4.3-1 into all construction contracts and individual contractors would ultimately implement the mitigation measures. Marin DPW shall verify compliance with Mitigation Measure 4.3-1.

Impact 4.3-2: Expansive soils can cause distress and failure to shallow founded structures, pavements, slabs on grade, and other surfaces (potentially significant unless mitigated).

If not properly mitigated, the cyclic volume changes capable of expansive soils (i.e. high shrink-swell potential) can cause distress and failure of shallow founded structures, pavements, slabs on grade, and other surfaces. In the case of paved surfaces and slabs on grade, the effects of heave occur particularly along (but not limited to) the margins, where surface water may infiltrate immediately adjacent to the improvement, whereas the remainder is effectively impermeable. The increased moisture content creates a differential or "edge" condition, where soils along the margin of the proposed runway improvements expand to a greater magnitude than those underlying the impermeable area beneath the improvement, and beyond the zone of influence of the edge, causing uplift cracking and other forms of distress.

Mitigation Measure 4.3-2: Allow for expansion and settlement of soils by overfilling the site and allowing several years before establishing the final fill top elevation. From previous geotechnical studies, it is anticipated that an extra 25% - 50% of fill would be required on top of the initial surcharge amounts at the end of the primary over-burden loading period.[21] In addition, an engineering geologist or geotechnical engineer shall conduct site investigation and recommend one or more of the following mitigation measure to reduce the impact:

- Chemically treat expansive soil within the zone (depth) of influence to reduce its plasticity and expansion potential to an acceptable level.
- Remove expansive soil within the zone of influence, and replacement with non-expansive import soil.
- Construct subsurface moisture barriers along the perimeter of improvements, which extend to depths below the zone of influence.

Significance After Mitigation – Implementation of Mitigation Measure 4.3-2 will reduce the impacts due to expansive soils to less than significant levels.

[21] Cortright & Seibold, Preliminary Design Report Runway Extension Gnoss Field Marin County, California FAA AIP Project No, 3-06-0167-08, December 20, 2002.

Responsibility and Monitoring – The Marin County Department of Public Works shall be responsible for incorporating the provisions of Mitigation Measure 4.3-2a-c into the final earthwork plan for the runway extension, as well as all construction contracts, and individual contractors would ultimately implement the mitigation measures. Marin DPW shall verify compliance with Mitigation Measure 4.3-2.

Impact 4.3-3: Compressible soil may settle, causing damage to paved surfaces (potentially significant unless mitigated).

When loaded by fill placement and/or building pressures, compressible soil (and Bay Mud in particular) undergoes settlement, due to consolidation of the soil, and may potentially experience both vertical and lateral displacement due to plastic deformation. Rarely is this settlement uniform, due to the variability in thickness and composition of the deposit, which, in the case of Bay Mud, may include lenses of peat. Differential settlement at the airfield facility has necessitated frequent pavement rehabilitation throughout the field's existence; settlement actually rendered the runway inoperable approximately 30 years ago.[22] As such, improvements constructed on un-remediated compressible soil can be subject to differential settlement which can approach five feet or more, occurring over 100 to 200 years, depending upon the thickness of the Bay Mud and the vertical load placed upon it.[23] In the case of the runway extension, this would result in an irregular runway surface and progressive damage to any subsurface utilities requiring substantial future maintenance and repair, comparable to that experienced at the existing facility.

Mitigation Measure 4.3-3: Allow for expansion and settlement of soils by overfilling the site and allowing several years before establishing the final fill top elevation. From previous geotechnical studies, it is anticipated that an extra 25% - 50% of fill would be required on top of the initial surcharge amounts at the end of the primary over-burden loading period.[24] In addition, an engineering geologist or geotechnical engineer shall conduct site investigation and recommend one or more of the following mitigation measure to reduce the impact:

- Install a wick drain system and place fill surcharge along and in the vicinity of the proposed runway extension, engineered for anticipated loads.
- Compressible soils shall be deep soil mixed with cement or lime for their full depth.
- Construct the proposed runway extension and related structures on deep foundation elements, such as driven piling or equivalent.

Significance After Mitigation – Implementation of Mitigation Measure 4.3-3 will reduce any impacts due to compressible soils to less than significant levels.

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22 Communication with Ken Robbins, Airport Manager, Gnoss Field, May and June, 2009.
23 Rice, Salem J. (1975), Geology for Planning, Novato Area, Marin County, California, California Division of Mines and Geology Open File Report 75-1.
24 Cortright & Seibold, Preliminary Design Report Runway Extension Gnoss Field Marin County, California FAA AIP Project No, 3-06-0167-08, December 20, 2002.

Responsibility and Monitoring – The Marin County Department of Public Works shall be responsible for incorporating the provisions of Mitigation Measure 4.3-3a-c into the final earthwork plan for the runway extension, as well as all construction contracts and individual contractors would ultimately implement the mitigation measures. Marin DPW shall verify compliance with Mitigation Measure 4.3-3.

Impact 4.3-4: Liquefaction and Cyclic Softening May Occur (potentially significant unless mitigated).

If left unmitigated at the site, the existing soils will be subject to differential settlement due to the previously discussed ground effects during a seismic event, particularly under load of the proposed runway extension. The effects of the seismically induced differential settlement will be comparable to those incurred from settlement of compressible soils (i.e. pavement distress, cracking, subsurface utility damage). However, the effects are likely to be immediate and of considerably greater magnitude, potentially posing a threat to air traffic utilizing the runway.

Mitigation Measure 4.3-4: An engineering report prepared by an engineering geologist or geotechnical engineer shall evaluate the use of the following in order to mitigate the detrimental effects of liquefaction on the proposed runway extension:

- Utilization of deep soil mixing
- Structural solutions described for compressible soils

Significance After Mitigation – Implementation of Mitigation Measure 4.3-4 is expected to ensure any impacts due to liquefaction and cyclic softening are reduced to less than significant levels.

Responsibility and Monitoring – The Marin County Department of Public Works shall be responsible for incorporating the provisions of Mitigation Measure 4.3-4 into all construction contracts and individual contractors would ultimately implement the mitigation measures. Marin DPW shall verify compliance with Mitigation Measure 4.3-4.

Impact 4.3-5: Lateral Spreading and Lurching May Occur (potentially significant unless mitigated).

While the areas proposed for runway extension are located within a flat estuarine plain, the plain is traversed by several natural and artificial channels with near vertical sides which approach approximately five feet in depth. Should liquefiable layers exist at or above the flow line elevation of a channel, lateral spreading and/or lurching could potentially occur during a seismic event, causing immediate damage to the proposed runway extension, subsurface utilities, and any structures if not remediated during construction. Likewise, a seismically induced levee breach or failure in areas where significant elevation changes exist across the levee, combined with and/or caused by liquefaction and lateral spreading of the material contained by the levee, could result in the inundation/flooding of proposed improvements, locally. A condition similar to the one described exists at the southeast end of the existing airfield in the area proposed for the safety area extension.

Mitigation Measure 4.3-5: The hazard posed by secondary seismic ground effects to the proposed runway extension will be mitigated by utilizing the deep soil mixing and/or structural solutions described for liquefiable soils, particularly given the shallow incision depth of the existing channels. It is anticipated similar methods could be utilized for mitigation of existing levees after their individual assessment.

Significance After Mitigation – Implementation of Mitigation Measure 4.3-5 will ensure that any impacts due to lateral spreading and lurching will be reduced to less than significant levels.

Responsibility and Monitoring – The Marin County Department of Public Works shall be responsible for incorporating the provisions of Mitigation Measure 4.3-5 into all construction contracts and individual contractors would ultimately implement the mitigation measures. Marin DPW shall verify compliance with Mitigation Measure 4.3-5.

Impact 4.3-6: Levees and Runway/Taxiway Extension May be Damaged by shallow slope failure (potentially significant unless mitigated).

Shallow failure of drainage channel banks, levees, and/or fill slopes could impact the proposed extension if not taken into account during design and construction. Channel blockage and levee breach due to localized failure could potentially result in flood inundation. Failure of fill slopes could conceivably damage newly constructed pavements, depending upon fill slope height and the proximity of the improvements to the slope face.

The large landslide features west of the airfield appear to underlie Highway 101 locally, and may extend as far east as the rail line. Distress or damage to the roadway pavement or rail line due to movement of the landslides, or geomorphology suggestive of landsliding in the vicinity of the proposed extension was not apparent during our reconnaissance. As such, it is assumed that the potential impact of the large (apparently dormant) landslides along Highway 101 should will be less than significant, provided any proposed construction does not alter the current topography in the vicinity of the landslide toe.

Mitigation Measure 4.3-6: It is assumed the proposed runway extension will require construction of fill slopes. Fill slopes shall be designed and constructed to maintain integrity under static conditions and/or during a seismic event.

Significance After Mitigation – Implementation of Mitigation Measure 4.3-6 will ensure that the potential for damage due to shallow slope failure will be reduced to less than significant levels.

Responsibility and Monitoring – The Marin County Department of Public Works shall be responsible for incorporating the provisions of Mitigation Measure 4.3-6 into all construction contracts and individual contractors would ultimately implement the mitigation measures. Marin DPW shall verify compliance with Mitigation Measure 4.3-6.

4.3.3 CUMULATIVE IMPACTS OF THE PROPOSED PROJECT

Potential project impacts related to geology, soils, and seismicity are site-specific and would not combine with related impacts of other projects to create cumulative impacts.

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