Geologic and Geotechnical Hazards Assessment Bay City, Oregon

Prepared for:
City of Bay City

February 7, 2007
1200-00

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Environmental and Geotechnical Consultants

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CERTIFIED
OREGON
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1.0 Introduction

This report presents Ash Creek Associates' report for the geologic and geotechnical hazards assessment for the City of Bay City (the City) in accordance with our signed contract dated March 14, 2006, and amended on April 13, 2006. The Geographic Information System (GIS) and map products were provided by Real Urban Geographics of Portland, Oregon.

2.0 Purpose and Scope of Work

The purpose of our work was to provide a preliminary geologic hazard assessment of the City and the Urban Growth Boundary (UGB), and provide a GIS-based set of Hazard Maps to be used in future planning and development. This task identifies the document review process, a geologic overview of the City, identification and descriptions of the hazards affecting the City, and provides recommendations for investigation and/or mitigation of the hazards.

Our scope of work for this project included:

- A review of general geologic literature in the project vicinity;
- A review of the existing Hazard Overlay Map of the City;
- A detailed surficial reconnaissance;
- Review of past subsurface explorations and available geotechnical reports;
- Review of aerial photographs;
- Review of available wetlands and storm water studies for the City;
- Other maps and documents available from the City and Tillamook County; and
- Preparation of this report and accompanying Hazard Maps.

During the early stages of scope development the issue of a "block-specific" hazard evaluation arose. In an e-mail to the Oregon Department of Land Conservation and Development (DLCD) on March 13, 2006, we pointed out that the terms should be "area-specific" in order to be more realistic. With the low level of precision on the best available maps and the budget limitations, area-specific is a reasonable expectation.

3.0 GIS

GIS data presented as part of this assessment consist of three main categories: public and semi-public GIS datasets; local data in printed map form; and information created during the project. A brief description of the GIS methodology for each of these categories is provided below.

Public and Semi-Public GIS Data. Existing GIS data serve as the base information upon which the remainder of the GIS information is registered, and also provide the majority of analysis and mapping features. Primary base data consist of parcels and aerial photography provided by Tillamook County GIS. Generally, all data in this category are included with their original projection and positional accuracy and without modification. These data consist of:

- Tax lots (Tillamook County);
- Street centerlines (Tillamook County);
- Bay City Urban Growth Boundary (Tillamook County);
- Bay City limits (Tillamook County);
- Flood Zone (Tillamook County);
- Streams (Pacific NW Hydrography Framework);
- Debris Flow areas (Tillamook County);
- Topography (U.S. Geological Survey [USGS] 7.5' 10m DEM, Garibaldi and Kilchis River quadrangles);
- National Wetlands Inventory (U.S. Fish and Wildlife Service [USFWS]);
- Orthophotography (2004, Tillamook County); and
- Geology (USGS, see map for source).

Printed Map Sources. Mapped results from previous geologic hazard assessments were made available from the City in digital scanned format, without geographic referencing, from a source of six Mylar maps, each roughly 24 by 36 inches. These maps consist of a base map with parcel lines, City boundary and UGB, and a series of overlays designed to correspond to this base using four registration marks that allow for proper alignment. In order to convert these images to geographically accurate information, parcel, City limit, and UGB GIS data provided by Tillamook County served as a source for geographic transformation. The base map was first georeferenced using a first order transformation. First order transformations involve rotating, translating, and scaling; they do not include "rubber-sheeting" or other higher order deformative or orthorectified transformations. This method preserves the spatial integrity of the original documents, but limits the ability to more closely rectify the originals to current GIS information. Other maps in the series were then georeferenced to the base map tics to ensure that all data appear in the GIS in the same position as is illustrated in the overlay series. Items from this previous effort include wetland delineations, sinkhole and landslide observations, and filled areas. It was then possible to digitize selected features from any of the map graphics in their proper geographic position. Accuracy in this effort was necessarily limited to the geographic accuracy of the tax lots, City boundary, and UGB illustrated on the Mylar base map, which range from 0 to 50 feet across any given sheet.

The final report was created using resources from the following maps:

- Base Map
- Hazard Overlay: sinkholes, fills
- Wetland Overlay: wetlands
- Aerial Overlay
- Contour Overlay
- Land Use Plan and Zoning Overlay

GIS Data Creation. Other than the conversion of features in the Mylar map series to GIS format, a number of GIS themes were created as part of this assessment. Field observations such as sinkholes, landslides, and slope failures were marked on a base map in the field and digitized to within 2 feet of observed features. Topographic contours, percent slope, and Tsunami Run-Up elevation were extracted from the USGS Digital Elevation Models (DEMs) applicable to the study area. Created or derived data consist of:

- 10-meter contours;
- Slope;
- Landslides;
- Sinkholes;
- Fills; and
- Tsunami Run-Up Elevation.

GIS tasks were processed in ArcGIS 9.1 with native geoprocessing tools and those available with the Spatial Analyst extension. More detailed metadata on individual datasets are available accompanying the GIS files provided with this assessment.

4.0 Limitations

General. Ash Creek Associates completed this work in general accordance with our proposal. This work was performed for the exclusive use of the City of Bay City, their agents, and their consultants for specific application to this project and site. The work was performed in accordance with generally accepted professional practices in the same or similar localities and related to the nature of the work accomplished at the time the services were performed. No other warranty, express or implied, is made.

This study is not intended to be all-inclusive of existing and potential hazards. Rather, it is intended to provide current site conditions as best defined in the study and to allow for addition to, and modification of, the Hazard Maps provided herein. For example, if a steep cut or fill is made as part of an ongoing or future development, it would not show up on the slope hazard section of the maps. With the GIS capability, the hazard areas could be electronically added to the map on Figure 3 of the report for future reference. In the case of landslides, a previously stable or marginally stable property may become unstable or slide due to off-site drainage alteration, non-engineered cuts or fills, extreme storm events, etc. The new slide areas can be added to the map on Figure 3 of the report for future reference.

The Geologic Hazard Study was designed to report conditions as they presently exist because no one can predict hazards that may become known or occur in the future. By updating the maps with information as hazards occur, the report becomes a "living document" that will remain valid for years to come.

The important distinction between *accuracy* and *precision* must be made to understand the slope analysis, its correlation to actual conditions on the ground, and the inherent limitations of the data from which slope classifications were created. The slope analysis was derived from USGS 10-meter contours, the best topographic information available at the time of the report. While this USGS information and the slope classifications based on them are *accurate*, they are, like any topographic information, a generalization of actual conditions and, in this case, lack the *precision* or fineness of detail to capture slope characteristics that may fall within the 10-meter contour interval. In other words, if there are depressions, plateaus, escarpments, swales, etc. that fall within the 10-vertical-meter resolution of the base data, the data is essentially "blind" to them. Users of this report should be aware that this limitation of the base data precision likely produces results in localized instances where mapped slope classifications do not reflect actual ground conditions. A brief description of methods used to collect more precise topographic base information, and therefore derive a more precise slope analysis, is included in the Recommendations section of this report.

As stated previously, the best maps available used for the study had 10-meter (32.81-feet) contours. In order to increase the accuracy of the maps, a City-wide topographic survey provided by a licensed Land Surveyor, and mapped at a minimum contour interval of 2 feet, would be needed. The surveys can be completed by actual land mapping, orthotopographic mapping, or Light Detection and Ranging (LIDAR) mapping.

5.0 Site Description

The study area is located on both sides of Highway 101, approximately 5 miles north of the city of Tillamook, and 4 miles south of Garibaldi in Tillamook County, Oregon. At the beginning of the project we performed a brief geologic reconnaissance with the City Planner on April 13, 2006. Upon completion of the reconnaissance, we reviewed the existing Hazard Overlay Map, the City of Bay City Storm Water Master Plan, and several geologic and geotechnical reports prepared for development and construction within the City limits. After submittal of an initial reconnaissance report on May 1, 2006, we performed more detailed surface mapping and visited with a variety of City personnel. On May 18, 2006, we again accompanied City personnel on a brief reconnaissance of the City, focusing on drainage, high groundwater, and filled areas.

East of Highway 101 the terrain slopes moderately downward toward the west and southwest and is incised by a number of drainages. A great deal of the land has been logged and/or developed over the 100+ year history of the City, and the original contours and drainages have been altered and in some cases completely obliterated.

West of Highway 101 the City is relatively flat and appears to be old tidal flats and marshland. A number of areas have been developed for decades and may have been elevated by man-made fills to provide drainage and stay above groundwater and flood levels.

The Bay City area is hydrologically divided into thirds by two distinct northeast-to-southwest trending drainage basins. Jacoby and Patterson Creeks originate in the lower reaches of the Coast Range and join together to form a single drainage generally between Main and A Streets. The other drainage dividing the town is an unnamed stream originating in the Tillamook-Seattle-Morton Avenue area and trending through the McCoy Street-Warren Avenue area.

In addition to the above-noted drainage areas, a number of lesser drainages were identified in the May 2003 City of Bay City Storm Water Master Plan conducted by HLB & Associates, Inc. Many of these drainages contain fine-grained sands and gravels derived from weathering of rocks directly upslope. These soils are highly susceptible to erosion because of their granular nature and the steeper gradients. Many of these drainages have been filled, or the streets crossing them contain fills without adequate surface drainage. As a result, the smaller, shorter drainages are more prone to fill erosion and sinkhole formation.

These factors make planning and construction difficult within Bay City and a comprehensive geologic hazard study and Hazard Overlay Maps are being prepared to help ease the burden for the Planning, Building, and Public Works departments.

6.0 Hazard Maps

As noted previously, City personnel have previously identified a number of geologic hazards and potential geologic hazards within the city limits of Bay City. Over the years, City personnel, to aid in development and planning, have created a series of local Hazard Overlay Maps. We incorporated as much existing information from the Hazard Overlay Maps as possible to augment our study.

Overall, we have created five figures to accompany the Geologic Hazard Study. In addition to the Geologic Hazards, this document contains a variety of overlays that do not necessarily fall into the hazard category, but are useful nonetheless. In general, all the figures use an aerial photograph dated 2004 as a base with the overlays as listed below.

6.1 Figure 1 - Study Area

This figure contains the tax lot layout, City limits, UGB, and select street names. This figure can be used as a base for adding additional GIS information not necessarily related to hazards, such as zoning and infrastructure (storm, sewer, water, etc.).

6.2 Figure 2 - Geology

This figure contains the geologic formations and fault locations within Bay City and surrounding areas. The information was derived from existing geologic mapping and publications and was not field-verified as part of this study. As part of our library research we reviewed the extensive geologic reports performed in the area over the past 35 years, geotechnical reports prepared on nearby sites in Bay City and nearby coastal areas, historical USGS topographic maps, and aerial photos. The review indicates that historical slopes in the immediate area of this site have generally maintained their present configuration.

Bay City is located upon weathered bedrock and soils that have been classified by past geologic mapping (Schlicker, 1972; Wells, et al., 1983; Wells, et al., 1994; and others) as Oligocene- to Miocene-aged (approximately 24 million years ago [mya]) marine sedimentary rocks generally accepted as being part of the Alsea Formation. The accompanying geologic mapping and other available geologic maps refer to this unit as Tal or Tals (Tertiary-aged Alsea Formation).

The Alsea Formation consists of marine sedimentary sandstone and mudstone materials scraped off the ocean floor at the continental margin by seafloor spreading. The Alsea Formation has been mapped as dipping southwest at 30 to 38 degrees in the northern part of Bay City, but no other exposures are located nearby to verify the actual inclination. East and northeast of Bay City, near the fault zones and basaltic intrusive rocks, the bedding appears to have been deformed, and dips are measured in the 45 to 90 degree range in northeast and southwest directions.

The Alsea Formation nearby is mapped by Schlicker as having landslide topography at or near the ground surface, making the slopes in the area susceptible to further movement if improperly graded or if drainage patterns are altered. The Slope Hazard Maps (Figure 3) have taken the landslide-prone nature of the Alsea Formation into account.

The mountain-forming volcanics located east of Bay City are part of the Tillamook Volcanics Formation and have been dated as Eocene-aged (34 to 55 mya). The volcanic rocks in the area are primarily breccias and flows with interspersed submarine pillow lavas.

The low-lying central parts of Bay City east of Highway 101, within the lower parts of the Patterson Creek and Jacoby Creek drainages, and the area south of Tillamook Avenue in the McCoy Street area, have been mapped as being underlain by Quaternary-aged silty clay soils of fluvial (stream-deposited) and estuarine origin. Typically the silts and clays are thought to be thin (generally less than 15 feet thick) surficial deposits derived from the marine sedimentary rocks beneath and surrounding the site, and from intrusive volcanic rocks at the upper reaches of the drainage basin. We anticipate that many of the areas mapped as Quaternary alluvium have been filled, so these soils may not be exposed at the ground surface.

The Quaternary fluvial soils are also mapped west of Highway 101 in the tide flat area. These soils are potentially in a highly unconsolidated state and can be subject to extensive settlements under only light loading. In some areas these soils are known to have settled several inches to several feet under loading from fills or by added weight from moderately-heavy buildings.

The geologic mapping within the area has consistently shown a northwest-southeast fault zone (Tillamook Bay Fault Zone) in the area. In addition, it is widely accepted that a major active fault is located along the Cascadia Subduction Zone (CSZ) about 75 miles off the Oregon Coast. Although the recurrence interval of fault movement and tsunami inundation generated along the CSZ appears to be every 400 to 600 years (the most recent earthquake was in 1700), no displacement of Recent or Holocene sediments has been recorded in the Bay City area, possibly indicating that movement on the CSZ and Tillamook Bay Fault Zone are not connected.

As future geologic information is derived, Figure 2 can be altered to reflect current information.

6.3 Figure 3 – Slope Hazards

This figure contains the slope hazards and known landslides within and close to the Bay City limits and UGB. The following sections provide a brief description of the hazards associated with steep slopes.

Steep Slopes. The slope hazard areas used on this figure are consistent with those used by Bay City on the existing Hazard Overlay Maps (i.e., 0 to 12 percent slopes, no designation; 12 to 25 percent and 25+ percent slopes are differentiated). The slope zones as depicted on Figure 3 are not necessarily consistent with those on the existing overlays, but we feel that they more accurately depict the actual slopes. We concur with the existing overlay maps that the percentages of slope are appropriate for the geologic conditions. Had the existing slopes been underlain by intact basalt or sandstone formations then the percentages would have allowed for steeper slopes without necessarily constituting a hazard. Since the existing slopes have been mapped as landslide topography and no site-specific subsurface information is available to contradict the assumptions, we have assumed that the slopes in the 12 to 25 percent range are marginally stable, and slopes steeper than 25 percent are unstable.

Soil Creep. During our reconnaissances, we observed soil creep on the natural steep portions of the site, along slopes over-steepened by cutting or filling, adjacent to drainages, and near areas of active erosion. Slopes steeper than approximately 25 percent are prone to soil creep, but the occurrence is typically confined to the upper 2 to 3 feet and can be controlled by maintaining a heavy vegetative cover, flattening slopes, constructing retaining walls, or embedding foundations. The Hazard Maps will not specifically identify soil creep, but they will assume that it occurs on slopes steeper than 25 percent.

Landslides General. The landslides depicted on this figure include those taken from the existing Bay City Hazard Overlay Maps and those observed in the field. As noted above, all slopes steeper than 25 percent should be considered as unstable and landslide-prone. As discussed in previously, the underlying bedrock in this area is many millions of years old and has undergone deep chemical and mechanical weathering. The face of the Coast Range and the present day slope configurations have been formed by eons of soil and rock movement generated by earthquakes, floods, stream erosion, and landsliding. This being the case, the soil and rock on the existing slopes are assumed to be in a state of near-equilibrium. Depending upon the type of the rock and soil, they may be subject to renewed movement if disturbed by earthquakes, undercutting, re-routing of stream or drainage courses, raising groundwater levels, removing vegetation, etc. In addition, non-engineered fills placed on slopes can create a soil or rock overload triggering landslides, and fills placed over shallow, sloping bedrock can move down slope.

Rapidly Moving Landslides. Mudflows or debris flows are another type of landslide, commonly termed Rapidly Moving Landslides (RML) which can occur naturally or due to human activity. Based upon the soil types on available geologic maps (those listed in the Natural Resource Conservation Service [NRCS] Soil Surveys) and our observations, natural mudflow events are not likely to occur on most areas of this site.

The DLCD, Oregon Forestry Department (OFD), Earth Systems Institute, and the Oregon Department of Geology and Mineral Resources (DOGAMI) collaborated on a paper (DOGAMI IMS-22) to map RML throughout the state of Oregon. Although the information has not necessarily been field-verified, Figure 3 includes zones within the Bay City Limits that were mapped as having the potential for RML.

As future slope hazard information is derived, Figure 3 can be altered to reflect current information.

6.4 Figure 4 – Sinkholes & Fill

This figure depicts sinkhole areas and fills, including those taken from the existing Bay City Hazard Overlay Map, and filled drainages field-mapped during the course of this study that have the potential for sinkhole formation.

Sinkholes. All the areas mapped as sinkholes or potential sinkholes depicted on this figure have fills associated with them. For years the City has been concerned about sinkholes developing on both public and private property, and the possible consequences to public safety. True sinkholes typically form in areas where the geologic setting is conducive to subsurface ground loss such as collapse of limestone caverns or lava tubes, fault movements, landslide scarp openings, crevasse separation, etc. The geologic conditions underlying Bay City do not fall into these categories, but numerous sinkholes have formed nonetheless. Based upon our surface reconnaissance and mapping, it appears that most, if not all, of the sinkholes formed as a result of improperly filled drainages. The existing Bay City Hazard Overlay Map has some of the sinkholes plotted, but we have identified additional areas prone to sinkhole formation on Figure 4. It should be understood that more sinkholes may exist on private property, and that the potential for others to form cannot be discounted.

The accompanying maps should be updated as new sinkhole areas are discovered or mitigated.

Fills. The significant fills depicted on Figure 4 include those observed in the field as man-made fill or disturbed ground that requires close scrutiny. In our opinion, the filled areas include the low-lying drainages east of Highway 101 and the tide flat areas west of Highway 101. The fills indicated in the low-lying areas east of Highway 101 were probably placed during the early years of development of Bay City. This would include ground highly disturbed by construction activity, logging, and ground clearing.

The areas labeled as fill west of Highway 101 appear to have received dredge disposal materials placed over marsh lands and tide flats at some time during the past. We understand from conversations with Bay City personnel that in the past, the U.S. Army Corps of Engineers (USACE) has also used sites east of Highway 101 for dredge soil disposal.

The fills on Figure 4 should be updated as new fill areas are discovered or the limits of existing fills are more closely identified through subsurface explorations or utility trench inspections.

6.5 Figure 5

This figure contains the 100-year flood limits established by the Federal Emergency Management Agency (FEMA; as obtained from Tillamook County's GIS system), wetland areas mapped in both the 1996 Draft *Bay City Local Wetlands Inventory,* by Wilson, Scoles, and Brophy (furnished by the City of Bay City) and as derived from the National Wetlands Inventory (NWI), where available. We did not confirm or modify any of these documents and are providing them as an additional GIS tool for the City.

Drainages. All of the figures accompanying this report have stream courses and drainages plotted on them and labeled as perennial, intermittent, or unknown. The stream data were obtained from the Bureau of Land Management (BLM) database of stream hydrology. Many of the drainages have been identified on Figure 4 as having been filled and containing potential for sinkhole formation; others are shallow enough that roads traverse them without fills and they only carry water during extensive wet periods.

Groundwater. High groundwater can result in softening of near-surface soils, flooding, landsliding, and spring activity. High groundwater is anticipated in the low-lying tide flat and floodplain areas, and on steep slopes with shallow bedrock or aquicludes. According to Bay City personnel, an area north of Doughty Road and east of Bewley Road has an artesian spring during the winter months. This spring area also appears to be associated with a disturbed or filled drainage area at the base of a relatively-steep slope. Our general recommendation is to assume that high groundwater will be present throughout Bay City during the wet season, and provisions should be made for controlling surface and subsurface water in all new construction. Because of the widespread nature of the subsurface water, we have not included it in on our Hazard Maps.

7.0 Seismicity

General. The Bay City area is widely acknowledged to be in an area of impending seismic hazards. The most likely hazards are tsunami inundation, liquefaction, ground subsidence, ground shaking, and earthquake-induced landslides. DOGAMI has produced Earthquake Hazard Maps for some communities on the Oregon coast (IMS-10 Relative Earthquake Hazard Maps for Selected Urban Areas in Western Oregon), but Bay City was not included. A comprehensive seismic hazard study is beyond the scope of the current contract and will not be included on the Bay City Hazard Maps. However, some elements of earthquake hazards are related to the current study, so we will briefly relate the known conditions to potential seismic hazards.

Bay City Seismic Hazards. The December 2004 earthquake and tsunami inundation in Southeast Asia is evidence of the destructive nature and dangers associated with subduction zone earthquakes. Figure 5 has a tsunami run-up elevation (El.) of 52.5 as derived from a 2005 USGS Study of tsunami potential for Washington, Oregon, and Northern California. The run-up elevation is dependent upon the magnitude of the earthquake and the length of the fault rupture zone, but El. 52.5 is considered the worst case for a magnitude
8.5 earthquake.

In addition to tsunami damage, large earthquakes can set up seiches from the shaking action, terrestrial landslides, or submarine landslides. Seiche is the back and forth sloshing of waves in bays or closed basins, and on occasion can be as destructive as tsunamis.

Liquefaction is the settlement or lateral spreading of unconsolidated, cohesionless sediments by ground shaking in an area of saturation. This model generally fits the low-lying areas of Bay City shown on the geologic map (Figure 2) as Qf or Qt sediments. Liquefaction also can occur in granular fills under saturated conditions.

Ground subsidence is another hazard related to CSZ earthquakes. As the strain is relieved due to movement along the rupture zone, the ground surface along the Oregon coastline is anticipated to drop suddenly by as much as 6 feet. The result is permanent inundation of near-shore lands, altered beach slopes, and high potential for future shoreline erosion.

Ground shaking can cause building collapse and liquefaction of granular soils as described above. The primary danger is usually from falling debris.

Landslides can be generated by earthquake-induced ground shaking, especially on steep slopes combined with saturated soils. Non-engineered fills on steep slopes are highly vulnerable to earthquake-induced landslides.

Regional Seismicity. The seismicity in the area, and hence the potential for ground shaking, is controlled by three separate fault mechanisms. These include the CSZ, the mid-depth intraplate zone, and the relatively shallow crustal zone. Descriptions of these potential earthquake sources are presented below.

The CSZ is located offshore and extends from Northern California to British Columbia. Within this zone, the oceanic Juan De Fuca Plate is being subducted beneath the continental North American Plate to the east. The interface between these two plates is located at a depth of approximately 15 to 20 kilometers (km). The seismicity of the CSZ is subject to several uncertainties, including the maximum earthquake moment magnitude (Mw) and the recurrence intervals associated with various Mw earthquakes. (Mw is used by seismologists to measure larger earthquakes and is based on fault displacement and area of fault rupture, while for smaller earthquakes, the Mw is approximately equal to the familiar Richter Scale Magnitude.) Anecdotal evidence of previous CSZ earthquakes has been observed within coastal marshes along the Oregon coast. Sequences of interlayered peat and sands have been interpreted to be the result of large subduction zone earthquakes occurring at intervals on the order of 300 to 500 years, with the most recent event taking place approximately 300 years ago. A definitive study of Oregon seismic hazards completed by Geomatrix (1995) suggests that the maximum earthquake associated with the CSZ is Mw 8 to 9. This is based on an empirical expression relating Mw to the area of fault rupture derived from earthquakes that have occurred within subduction zones in other parts of the world. An Mw 9 earthquake would involve a rupture of the entire CSZ. As discussed by Geomatrix (1995), this has not occurred in other subduction zones that have exhibited much higher levels of historical seismicity than the CSZ and is considered unlikely. For the purpose of this study, an earthquake of Mw 8.5 was assumed to occur within the CSZ.

The intraplate zone encompasses the portion of the subducting Juan De Fuca Plate located at a depth of approximately 30 to 50 km below western Oregon. Very low levels of seismicity have been observed within the intraplate zone in Oregon. However, much higher levels of seismicity within this zone have been recorded in Washington and California. Several reasons for this seismic quiescence were suggested in the Geomatrix (1995) study and include changes in the direction of subduction between Oregon and British Columbia as well as the effects of volcanic activity along the Cascade Range. Historical activity associated with the intraplate zone includes the 1949 Olympia (Mw 7.1) and the 1965 Puget Sound (Mw 6.5) earthquakes. Based on the data presented within the Geomatrix (1995) report, an earthquake of Mw 7.25 has been chosen to represent the seismic potential of the intraplate zone.

The third source of seismicity that can result in ground shaking on the Oregon Coast is near-surface crustal earthquakes occurring within the North American Plate. The historical seismicity of crustal earthquakes in western Oregon is higher than the seismicity associated with the CSZ and the intraplate zone. The 1993 Scotts Mills (Mw 5.6) and Klamath Falls (Mw 6.0) earthquakes were crustal earthquakes.

8.0 Tsunami and V-Zone

The Bay City area has been mapped as a site at risk to storm surges, ocean flooding, and tsunami inundation following a seismic event. The Hazard Mapping in DOGAMI Bulletin 74 (1972) shows the ocean flood elevation as reaching as high as El. 40, probably near the levels reached during the January 3, 1939 "killer wave" storm surge and the December 2 to 3, 1967 storm waves on top of 10-foot-high tides.

Regarding tsunami inundation, DOGAMI OFR O-95-18, *Tsunami Hazard Map of the Garibaldi Quadrangle (1985), Tillamook County, Oregon*, has mapped the inundation area for Bay City, as a result of an Mw 8.8 earthquake, as being approximately El. 20 (NGVD 29) on the west side of the railroad tracks and Highway 101. Conversations with Dr. George Priest, C.E.G., and author of OFR O-95-18, indicate that over the past 10 years of study it has been revealed that the actual tsunami inundation levels may be as much as 50 percent or more higher than those currently mapped, or closer to El. 35 to 40. More recently, a 2005 USGS study (Professional Paper 1661b) by Eric Geist has rated the Tillamook Bay maximum tsunami inundation at El. 46 to 52.5, depending upon the fault rupture characteristics of the CSZ. For the purposes of this study we are using the more conservative tsunami run-up elevation of 52.5.

As more current tsunami run-up information is developed, the elevation can be modified on the GIS system.

9.0 Recommendations

General. As noted previously, this study has been conducted to provide the City of Bay City with tools to aid in future planning and development. The hazards as used in this report are related to the types of soils mapped or observed during the course of the study. These materials range from recently deposited alluvium to deeply-weathered bedrock derived from weathered marine sedimentary rocks of the Alsea Formation. As the new development occurs, the materials contained in this report are intended to trigger different levels of site evaluation from visual geologic assessment to in-depth subsurface geotechnical explorations. Geologic assessments should be conducted by a State of Oregon Certified Engineering Geologist (C.E.G.) utilizing the GUIDELINES FOR PREPARING ENGINEERING GEOLOGIC REPORTS IN OREGON, adopted by The Oregon State Board of Geologist Examiners (OSBGE); geotechnical assessments should be conducted by a State of Oregon registered Professional Engineer (P.E.), with a specialty registration as a qualified Geotechnical Engineer (G.E.); and in cases where both engineering geology and geotechnical engineering are required, reports should contain the signatures and stamps of both. The extent and detail of the reports should be commensurate with the degree of the suspected or mapped hazard, ranging from brief written evaluations of moderate slope hazards to in-depth evaluation of landslide areas.

Use of Maps by Bay City Personnel. The existing geologic Hazard Overlay Maps provide a visual tool to trigger hazard reports on given properties. Typically, a particular owner or developer may not be aware of a hazard prior to applying for building permits, zone changes, etc. As stated previously, the maps contained in this report serve a similar purpose but ultimately will be available online for use by both applicants and City personnel.

Bay City personnel should examine official Hazards Maps or other in-house information to determine whether any of these conditions exist at the planning stage of new developments. Although the slope maps are based upon the best information publicly available, small areas of cuts, fills, stream bank erosion, and other irregularities in contours may not show up as hazards. During the early stages of implementation, the City field personnel may be aware of these irregularities and can have them electronically added to the maps. Ultimately, we anticipate that more accurate topographic mapping will add a higher level of precision to the existing maps and the small irregularities will be incorporated; from that point, zones can be added as needed. In the interim, we recommend that applicants be requested to provide a topographic map of the areas proposed for development to establish that slope hazards do, or do not, exist.

The discussion of adding slope hazards to the maps can be extended to drainage alteration, sinkholes, wetlands, and flood zones. For example, the map on Figure 4 labeled “Sinkholes and Fill” reflects hazards as they are presently known to exist, but we do not imply that all sinkholes or potential sinkhole areas have been discovered. As new sinkhole areas are discovered in the public right-of-way or are reported on private property by the citizenry, these areas can be electronically added to the maps.

Slopes. In general, development on slopes flatter than 12 percent does not require a geologic or geotechnical engineering assessment. However, for proposed development on areas mapped as 12 percent slopes or less, the presence of non-engineered fills, sinkholes, proposed cuts and fills exceeding 4 feet in height, or landslides will trigger a geologic or geotechnical engineering assessment.

Slopes in the 12 to 25 percent range are considered to be marginally stable and should be visually evaluated on a site-specific basis by a C.E.G. for the presence of soil creep, fills, or signs of past instability. Geologic mapping and investigation of the parcel shall be completed in sufficient detail to describe the geology of the parcel, and to evaluate and describe existing or potential geologic hazards associated with the parcel. The scope of the investigation and level of detail will depend in part on the size of parcel, slope, existing geologic conditions and hazards, and the proposed improvements. The description shall address:

- Soil and rock types;
- Stratigraphy;
- Soil and rock properties;
- Geologic structure;
- Surficial expressions of potential geologic hazards;
- Groundwater conditions;
- Relevant surface and topographic features;
- Any geologic or topographic changes to the site between available published geologic maps (if used) from field observations;
- Seismic setting and seismic hazards; and
- The three-dimensional distribution of earth material exposed and inferred within the area. A clear distinction shall be made between observed and inferred features and relationships.

One or more appropriately positioned and scaled cross-section maps showing subsurface relationships may be used for descriptive purposes. If hazards are found to be present, a recommendation should be made for further evaluation by a C.E.G., G.E., or both. If through the visual evaluation the C.E.G. or G.E. determines that no hazards are present, this shall be documented in writing by the C.E.G. or G.E. and submitted to the City when a permit for development is submitted.

Slopes steeper than 25 percent are assumed to be unstable, or potentially unstable, and prior to development should be evaluated in detail by a C.E.G. through a geologic assessment using visual or subsurface explorations. The preliminary evaluation can be visual, using the parameters described above for slopes in the 12 to 25 percent range, depending upon access, the proposed construction, and potential effects on adjacent properties, in order to confirm the stability or instability of the slopes. Before a building permit or other land use approval is issued, the slope conditions should be verified by subsurface exploration. If the slopes are found to be unstable, analysis and mitigation measures should be made in conjunction with a G.E. using OSBGE guidelines and the Oregon State Board of Examiners for Engineering and Land Surveying (OSBEELS) standards of care for engineering practice.

Landslides. If development or construction is planned within 100 feet of known or suspected landslides, including Debris Flow Hazard Zones, the potential effects of the slide areas on the development should be made by a C.E.G. through a geologic assessment. This includes areas above, below, and alongside known or suspected slides. Prior to development, the slide area should be evaluated by subsurface exploration. It should be kept in mind that potential effects on property adjacent to landslides can span the life of the structure or development, usually on the order of 50 years.

During the investigation of a landslide, the limits of the slide mass should be accurately measured, and the stability of the slide mass and the mechanics of slide movement should be determined. The methodology of determining stability should be explained in the report and should be used for recommending a suitable setback, keeping in mind the anticipated life of the structure or development.

If the known or suspected landslide area is to be built upon, or if the proposed development or structure is within the setback or buffer zone, an in-depth stabilization and construction plan should be developed by the C.E.G. in conjunction with a G.E. The reports should be prepared utilizing the OSBGE Engineering Geologic Report guidelines and (OSBEELS) standards of care for engineering practice.

Sinkholes. Considering the amount of time and expense necessary for Bay City to eliminate the problems, it is not feasible to repair all areas of known and suspected sinkholes. In addition, the sinkhole areas may not necessarily share common origins or sizes, so developing a singular plan for mitigation and repair would be difficult at best. Future explorations for development and new street and storm water upgrades should address the sinkhole problems as part of the design phase. If new sinkholes develop, the property owner should have the area investigated and provide stabilization and mitigation plans.

New development within 50 feet of the centerline of areas mapped as having sinkholes or potential sinkholes should be evaluated by a C.E.G. or G.E. using subsurface exploration measures to insure the stability of new construction. If construction is to include streets or roads across these areas a plan should be prepared for stabilizing the soil and allowing drainage to occur without further erosion in the construction zone.

It is beyond the scope of this study to cover all possible mitigation methods when encountering sinkhole areas, but a few general issues to keep in mind are presented below.

- Prior to mitigation, define the limits of the sinkhole area under consideration. Exploration methods can range from hand-dug or backhoe-excavated test holes to Ground Penetrating Radar (GPR).
- Prior to mitigation, determine whether the drainage is perennial or intermittent, and estimate how much water it carries so that a new culvert can be correctly sized.
- Define the native soil or rock beneath the stream channel. Fine-grained granular soils can erode or "pipe" as easily as the fill materials used for the original fill. The original fills may have been derived from the same erodible native materials, so avoid trading one problem for another.
- When using backfill, specify an Oregon Department of Transportation (ODOT) or Federal Highway Administration (FHWA) material that meets the requirements for a graded filter. Graded filters are those materials, usually angular, that have a uniform size gradation that prevents fine-grained materials from eroding, or piping, through the void spaces of the larger size materials.

Drainage. As noted previously, we have assumed that high groundwater will be present throughout Bay City during the wet season, and provisions should be made for controlling surface and subsurface water in all new construction.

Surface water flowing from an existing property or new development should be controlled such that it does not negatively impact adjacent public or private property by increasing flow, concentrating flow, or stimulating erosion that was not present beforehand. New developments should submit a storm drainage plan at the time of application. The City of Bay City personnel will judge the extent of the plan necessary, up to and including a detailed engineered Storm Drainage Plan.

Anticipating that seasonal or permanent groundwater will be present in most of the Bay City area, we recommend that all new construction incorporate basement and foundation drainage to control water and keep it from crawl space, under-slab, and below-grade areas. Groundwater control can range from perforated PVC pipe for foundation drains to engineered retaining wall drainage systems.

Fills. The significant fills include those observed in the field as man-made fill or disturbed ground that requires close scrutiny, including the low-lying drainages east of Highway 101. We recommend that new development in filled areas require subsurface exploration to confirm whether any deleterious materials exist that may affect building foundations, utilities, or pavements in future developments. The initial evaluation of the suspected filled area can be conducted by a C.E.G. or G.E., but if conditions require recommendations for foundation construction outside those in the International Building Code (IBC), such recommendations should be provided by a G.E.

Tide Flats. The areas labeled as fill west of Highway 101 appear to have received dredge disposal materials placed over tide flats some time during the past. Although the fills appear to be relatively thin, we are more concerned about the potential presence of peat and the settlement-sensitive nature of the native sandy and silty soils. To our knowledge no subsurface information is currently available on the thickness or content of the tide flat soils, but similar tide flat deposits in the north Tillamook area are highly unconsolidated and settlement-sensitive. Until a database of detailed soil conditions and engineering properties of the soils is established, we recommend that requirements for new development and construction include a subsurface exploration conducted by a G.E., accompanied by soils laboratory testing and settlement analysis.

Liquefaction. In considering that many of the soils underlying Bay City would be classified as subject to liquefaction, we do not recommend a liquefaction study on all new construction. However, we do recommend that during the course of subsurface analysis, the liquefaction potential of the soils should be noted. By doing so, the owners can judge whether their developments would be impacted by settlement-induced liquefaction. Critical facilities are required to be evaluated for liquefaction, tsunami run-up, seiche, etc., so they are already covered by prevailing law.

Increasing Topographic Base Data Precision. In order to address precision limitations in deriving slope classifications from 10-meter USGS elevation data, the City may want to consider capturing more precise topography information. There are generally three methods used to do so:

1. *Aerial photogrammetry*. This involves a skilled technician interpreting stereoscopic images and estimating topographic characteristics. This is likely the least expensive and least precise of the three methods, but may be a good choice if existing photogrammetric surveying programs overlap or are adjacent to the City, and sufficiently high precision can be achieved (2- to 5-foot contour interval).
2. *Land-based survey.* Delivers high-precision data from ground measurements. Methods and costs vary widely.
3. *LIDAR.* While LIDAR is typically collected by aircraft, ground-based LIDAR is becoming more widely available. LIDAR data consists not only of extremely precise ground measurements in the centimeter range, but can be processed in a number of different ways to extract features like buildings and trees, assess geomorphologic change over time, or provide a base for dozens of other applications. Judging from articles in recent trade journals and elsewhere, it may be that Bay City will benefit from current plans to capture much of western Oregon in an upcoming phase of planned statewide LIDAR data collection.

Recent studies indicate that LIDAR can increase the number of identified landslides by 2,000 percent over conventional USGS 10-meter elevation models, while decreasing the minimum size of detected slides from almost 35,000 m^2 to less than 30 m^2. In the fall of 2006, DOGAMI published its bulletin *Cascadia* (Vol. 4, No. 2), which serves as an excellent guide to how LIDAR is used, the limitations of low-resolution contour information, and the status of ongoing LIDAR projects in Oregon.

10.0 References

In addition to topographic maps, aerial photos, and existing geotechnical reports, we relied upon information contained in:

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FIGURE 1

Study Area

Geologic Hazards Report

DLCD Technical Assistance Grant 2005-2006

City of
Bay City, Oregon

CITY OF BAY CITY
PEARL OF TILLAMOOK BAY

Ash Creek Associates, Inc.
Environmental and Geotechnical Consultants

Oregon Department of Land Conservation and Development

Legend

- Bay City Limits
- Bay City Urban Growth Boundary
- Tax Lots
- Contour (10m)

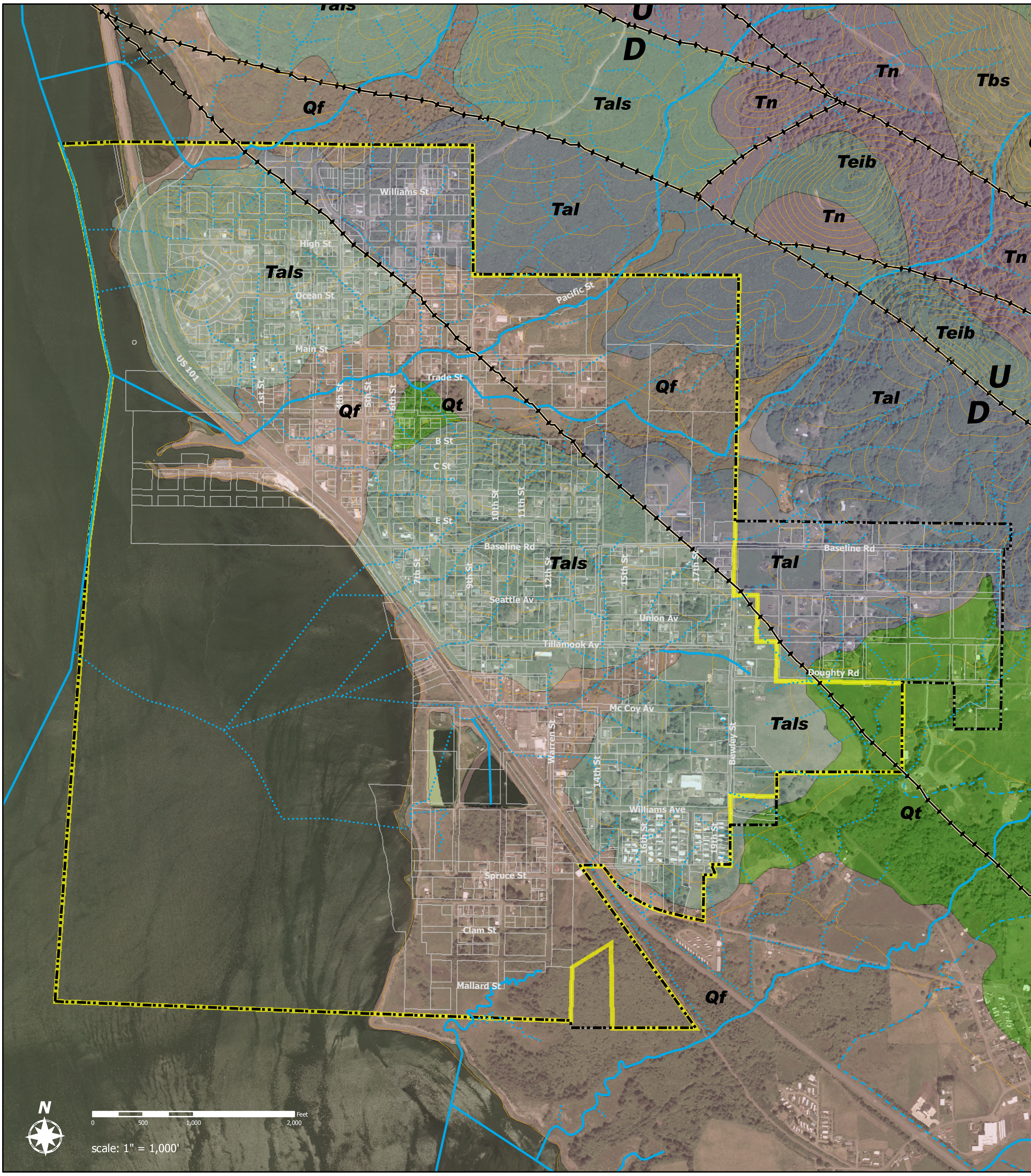

FIGURE 2

Geology

Geologic Hazards Report

DLCD Technical Assistance Grant 2005-2006

City of
Bay City, Oregon

Ash Creek Associates, Inc.
Environmental and Geotechnical Consultants

Oregon Department of Land Conservation and Development

Legend

*Geology (USGS)**

- Fault, All Types
- Qf - fluvial and estuarine deposits
- Qt - older fluvial and estuarine deposits
- Tal - Alesa Form.
- Tals - feldspathic sandstone
- Tbs - basaltic sandstone, variable
- Teib - basalt sills
- Tn - Nestucca Form.

Streams - Flow Type

- Perennial
- Intermittant
- Unknown
- Bay City Limits
- Bay City UGB
- Tax Lots
- Contour (10m)

*Geology derived from USGS Open File Report 95-670, *Geologic Map of the Tillamook Highlands, Northwest Oregon Coast Range*, by Wells, Snavely, et al. 1995

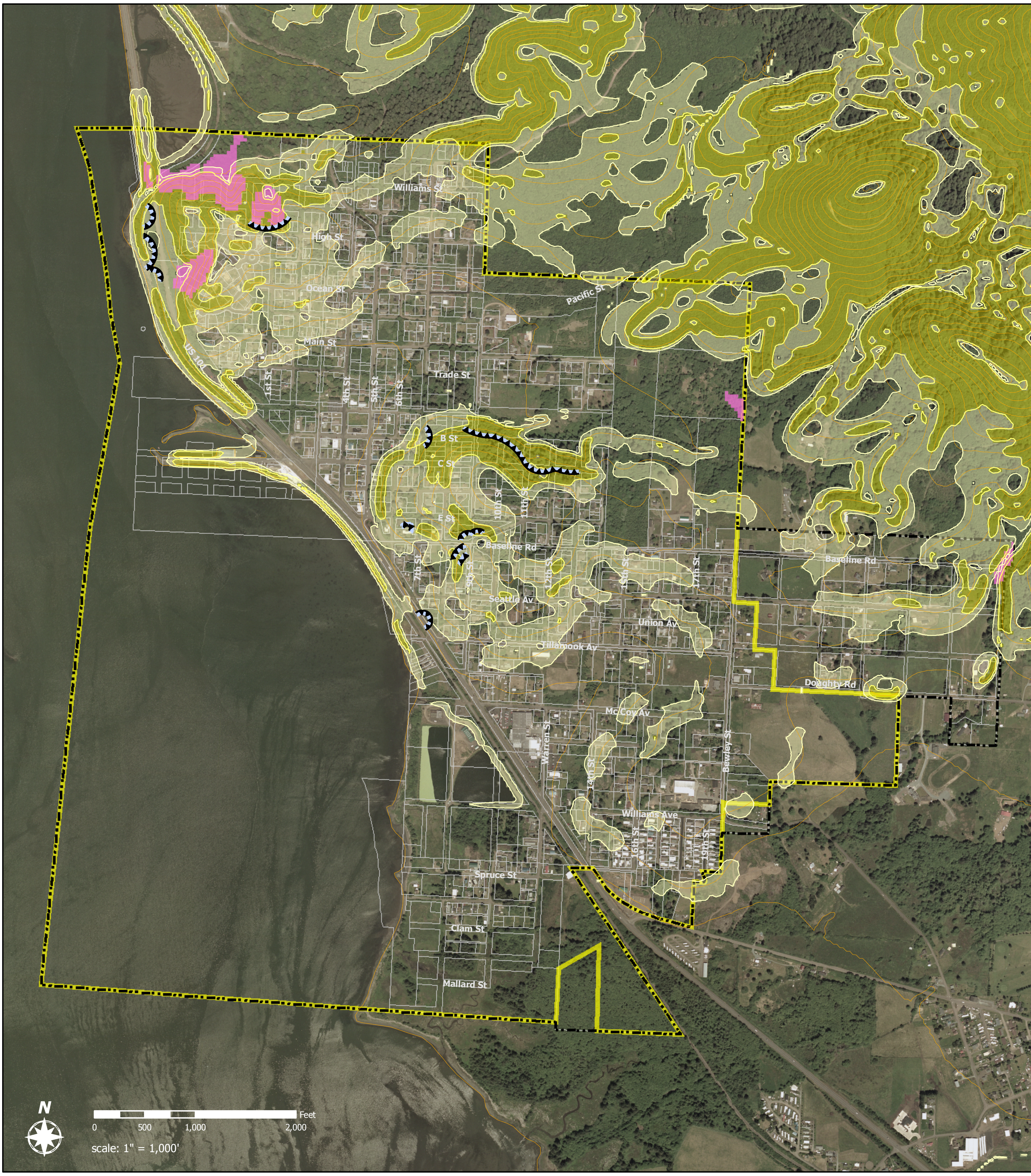

FIGURE
3

Slope Hazards

Geologic Hazards Report

DLCD Technical Assistance Grant 2005-2006

City of
Bay City, Oregon

CITY OF BAY CITY
PEARL OF TILLAMOOK BAY

Ash Creek Associates, Inc.
Environmental and Geotechnical Consultants

Oregon Department of Land Conservation and Development

Legend

Slope, Percent Rise

- 12% - 25%
- > 25%
- Landslides
- Debris Flow (RML)
- Contour (10m)
- Bay City Limits
- Bay City Urban Growth Boundary
- Tax Lots

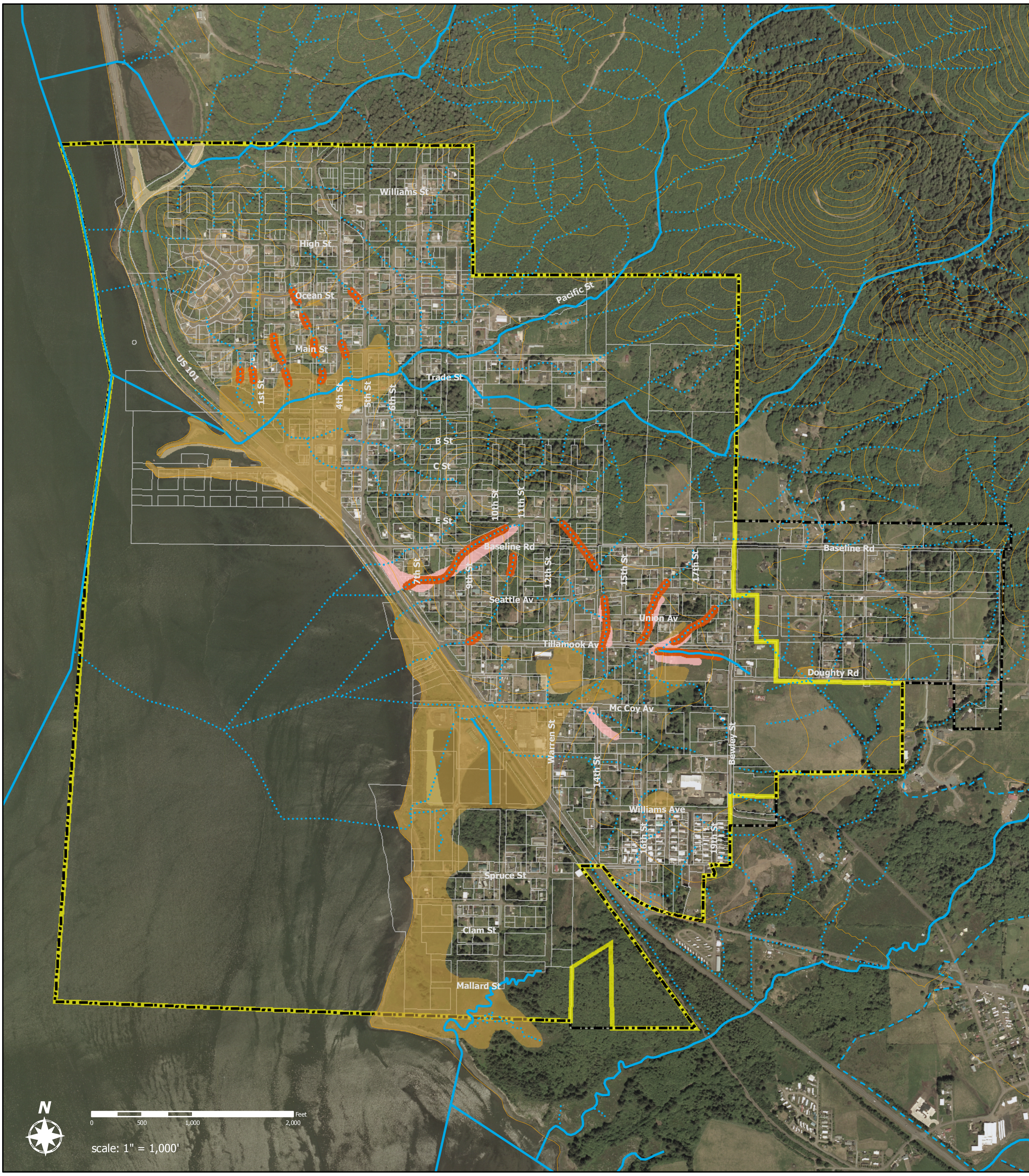

FIGURE 4

Sinkholes & Fill

Geologic Hazards Report

DLCD Technical Assistance Grant 2005-2006

City of
Bay City, Oregon

CITY OF BAY CITY
PEARL OF TILLAMOOK BAY

Ash Creek Associates, Inc.
Environmental and Geotechnical Consultants

Oregon Department of Land Conservation and Development

Legend

Sinkholes
- Current
- Historic

Fill/Disturbed Area
- Current
- Historic

*Streams - Flow Type**
- Perennial
- Intermittent
- Unknown

*Pacific Northwest Hydrography Framework, 2004

- Bay City Limits
- Bay City Urban Growth Boundary
- Tax Lots
- Contour (10m)

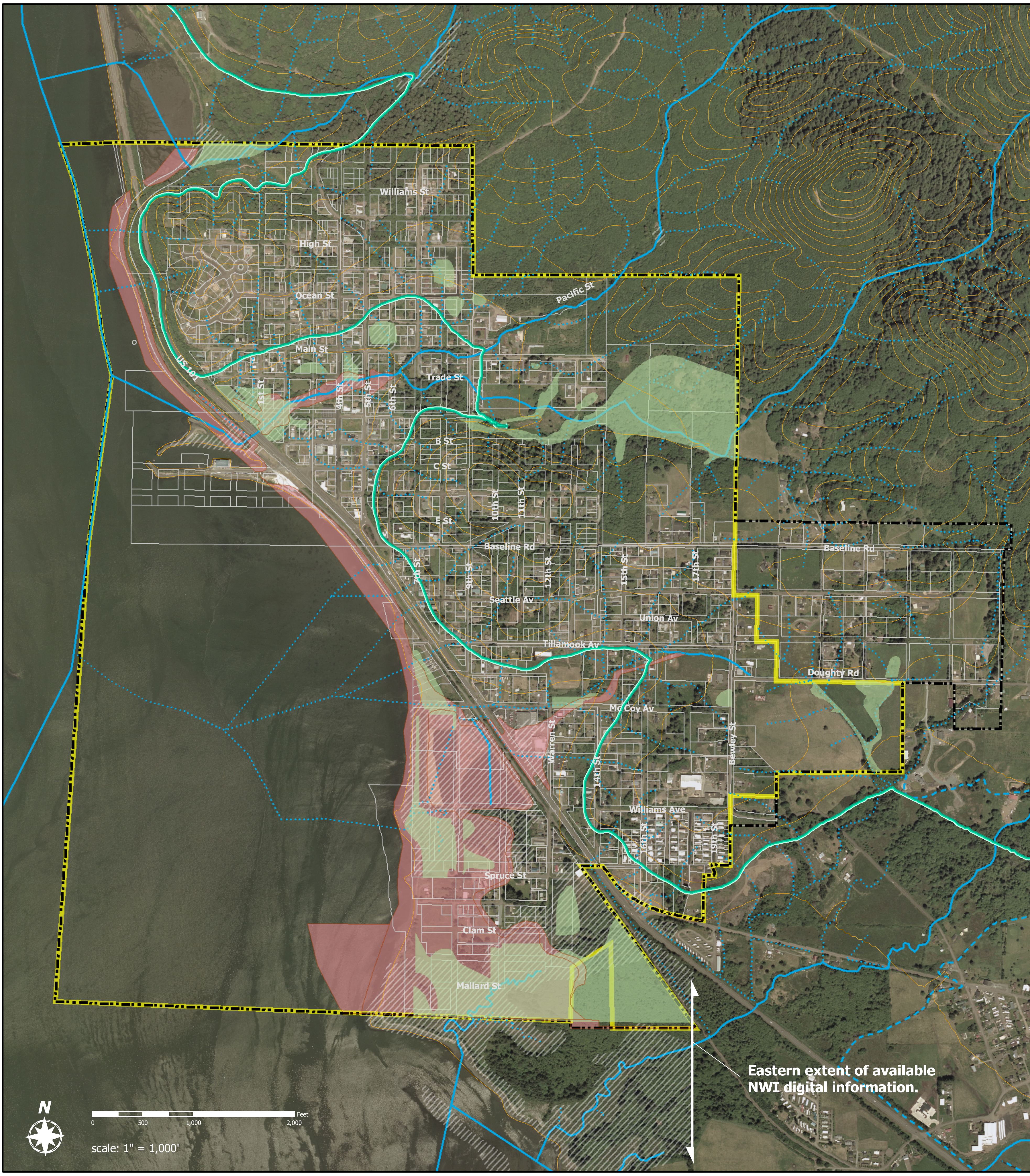

FIGURE
5

Hydrology/Wetlands

Geologic Hazards Report

DLCD Technical Assistance Grant 2005-2006

City of
Bay City, Oregon

CITY OF BAY CITY
PEARL OF TILLAMOOK BAY

Ash Creek Associates, Inc.
Environmental and Geotechnical Consultants

Oregon Department of Land Conservation and Development

Legend

Flood Zone
- Flood Zone - City of Bay City
- Wetlands - City of Bay City
- Wetlands - NWI (where available)

Streams - Flow Type
- Perennial
- Intermittant
- Unknown
- USGS Tsunami Run-Up Elevation - 52.5'
- Bay City Limits
- Bay City Urban Growth Boundary
- Tax Lots
- Contour (10m)