REPORT
STORMWATER INFILTRATION EVALUATION
CITY OF BEND, OREGON

OCTOBER 4, 2007

FOR
URS CORPORATION

GEOENGINEERS

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Report
Stormwater Infiltration Evaluation
City of Bend, Oregon
File No. 12098-004-00

October 4, 2007

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INTRODUCTION

This report presents results of the first phase of our geologic and hydrogeologic investigation in support of a Stormwater Master Plan for the City of Bend, Oregon, herein termed the City. The City is located in central Oregon, approximately as shown on the Vicinity Map, Figure 1, and is underlain by soil and rock units that, in many places, limit the subsurface infiltration of stormwater. The infiltration characteristics of these soil and rock units in combination with aging of some infiltration facilities, and increased development have resulted in numerous areas within the City that have a history of flooding after storm events. The City and surrounding area has urbanized rapidly, increasing both the potential for drainage problems and the need for comprehensive stormwater planning.

This phase of investigation included a compilation and review of existing geologic, hydrogeologic, and geotechnical information as a basis for formulating conclusions and opinions regarding stormwater infiltration issues. GeoEngineers' personnel conducted a site visit to 10 known problem areas on January 10, 2007, to observe infiltration issues and develop recommendations. A preliminary evaluation of the infiltration capacity of rock units underlying five of these areas is provided in this report. A subsequent phase of investigation could include the identification of areas within the City that have potential for the siting of regional stormwater facilities.

There are limitations to the use of this planning level study. In the draft version of this report, dated April 11, 2007, limitations were discussed within the sections of the report that they pertained to. At the request of the City and URS Corporation, these considerations have been consolidated within the Limitations section of this report.

SCOPE OF SERVICES

The purpose of this study was to review readily-available technical information as a basis for evaluating the relationship between soil and rock conditions within the City and stormwater infiltration capacity. Our scope of services included:

1. Acquire, compile and review readily-available geologic, hydrogeologic, and geotechnical data and information specific to the City and surrounding area. The information included geologic maps, water well reports, aquifer test results, existing geologic and hydrogeologic reports, previous geotechnical reports on file with the City, and water well information on file with the state of Oregon Water Resources Department.
2. Review existing information regarding the occurrence and extent of previous stormwater drainage problems or complaints.
3. Attend a project workshop with URS Corporation (URS) and City personnel during which historic drainage problems within the City were described.
4. Review the draft Central Oregon Stormwater Manual for information pertinent to the subsurface infiltration of stormwater.

5. Conduct a hydrogeologic/geologic reconnaissance of the City and surrounding area.
6. Describe the general geologic and hydrogeologic conditions within the City.
7. Evaluate the relationship between geologic and hydrogeologic conditions and the long-term viability of infiltration of stormwater runoff.
8. Identify areas within the City that, based on existing information, are characterized by favorable conditions for stormwater infiltration via underground injection control (UIC) structures such as drywells. Provide a rationale for area selection.
9. Identify areas within the City that, based on existing information, are generally unsuitable for infiltration of large stormwater volumes using UIC structures. We provide our opinion regarding stormwater disposal alternatives appropriate for these areas.
10. Describe any concerns regarding adverse impacts in areas that appear to be suitable for infiltration of stormwater. Recommend the data or studies necessary to make a reasonably sound judgment as to the long-term viability of infiltration without adverse impacts.
11. Provide a cost estimate associated with the construction of additional dry wells and drill holes.
12. Present spatial results of our evaluation in a GIS-compatible format.

GEOLOGIC AND HYDROGEOLOGIC SETTING

GENERAL

The following summary of geologic and hydrogeologic conditions within the City of Bend and surrounding area was compiled from existing geologic and hydrogeologic reports, including Gonthier (1985), Gannett et al. (2001), Lite and others (2002), and Sherrod et al. (2002 and 2004).

GEOLOGIC SETTING

The City of Bend, Oregon is located in upper Deschutes Basin, an approximately 4,500-square-mile portion of the Deschutes River watershed located in central Oregon. Regional geologic features within the upper Deschutes Basin largely are the result of volcanic activity along the Cascade Range, which has resulted in the deposition of a thick sequence of Quaternary-age (0 to about 1.5 million years ago [MA]) and Tertiary-age (about 1.5 to 65 MA) volcanic and volcanically-derived sedimentary rocks.

The oldest described geologic unit in the upper Deschutes River Basin is the Tertiary-age John Day Formation, which underlies the entire study area at depth but does not outcrop surficially. The John Day Formation comprises a stratigraphic section up to about 4,000 feet thick that primarily consists of sandstone, shale, ash, ash-flow tuff, and lava flows that range in age from about 22 to 39 MA

The Prineville Basalt stratigraphically overlies the John Day Formation in the northeast portion of upper Deschutes Basin. The Prineville Basalt is up to 700 feet thick and was emplaced about 16 MA. The occurrence of this geologic unit in the subsurface in and around the City of Bend is poorly defined.

Stratigraphically overlying the Prineville Basalt is the Tertiary-age Deschutes Formation. The Deschutes Formation was deposited in a fluvial basin on the east flank of the Cascade Mountains and consists of sedimentary and pyroclastic rocks with occasional lava flows. Rocks from the Deschutes Formation range in age from about 4 to 7½ MA. Based on geophysical data presented by Lite and Gannett (2002), the depth to the top of Deschutes Formation near the Bend Airport is about 300 feet and total thickness is uncertain but likely exceeds 300 feet. The Deschutes Formation includes several volcanic vents, one of which is basaltic in composition and forms the Awbrey Butte area in the City of Bend.

Stratigraphically overlying the Deschutes Formation is a series of Pliocene (1.8 to 4 MA), Pleistocene (0.011 to 1.8 MA) and Holocene (11,000 years to the present) lava flows, pyroclastic deposits, and sediments. These rocks are described as Cascade Range and Newberry Volcanic deposits by Lite and Gannett (2002) and include most of the surficial geologic units within and surrounding the City.

Quaternary sedimentary deposits within the upper Deschutes Basin include alluvial sediment deposited along area drainages, mass wasting deposits, and glacial deposits. These sediments locally reach thicknesses in excess of 100 feet.

Strands of the Sisters Fault zone trend northwest-southeast through Bend, the longest strand of which is the Tumalo Fault, shown approximately in Surficial Geology, Figure 2. Paleoseismic studies have placed a tentative youngest possible age of 25,000 years for the most recent movement on the Tumalo Fault. The sense of slip of any of the faults in the Sisters Fault zone is unknown, though both vertical and right-lateral separations have been observed indicating oblique motion. Evidence for vertical separation up to 70 meters has been found on the Tumalo fault. The fault zone is considered to still be active.

The surficial distribution of major geologic units within and near the City is presented in Figure 2. The ages and stratigraphic relationships of geologic units in the upper Deschutes Basin are summarized in Figure 2 from Sherrod et al. (2002), which is provided in Appendix A.

HYDROGEOLOGIC SETTING

The location, movement, and availability of groundwater are controlled by the distribution and properties of surface and subsurface geologic units, local variations in precipitation, and human activities such as irrigation. The upper Deschutes Basin aquifer system primarily is recharged by infiltration of precipitation within the Cascade Range. However, leakage from irrigation canals and streams and infiltration of irrigation water also have been identified as major sources of recharge to the aquifer system. A smaller, though locally significant, source of groundwater recharge is infiltration of stormwater through drilled drainage wells and drywells. For example, engineering maps provided by the City, dated 1994, documented a total of 1,175 drainage structures within City limits (Gannett et al., 2001). Groundwater within the basin primarily discharges to streams such as the Deschutes River, though minor amounts also discharge to water supply wells and through evapotranspiration.

Rock units associated with the John Day Formation have been subjected to extensive weathering and chemical alteration. As a result, these rocks tend to be very low in permeability and are frequently described as clay or claystone in driller's logs. Because of its low permeability, the John Day Formation generally acts as the regional hydrologic basement (the base of the regional aquifer system).

The relatively unweathered, highly fractured and porous rocks of the Deschutes Formation are quite permeable and form the principal aquifer system within the upper Deschutes Basin. Primary aquifers occur within heavily-fractured volcanic rocks and sedimentary interbeds. The yield of individual wells open to the Deschutes Formation range up to 5,000 gallons per minute.

Lava flows associated with the Cascade Range and Newberry Volcanic deposits also are relatively fractured and unweathered, resulting in relatively high permeability. These rocks outcrop surficially in the Bend area and, where unsaturated rocks are highly fractured, have relatively high infiltration capacity.

Quaternary alluvial deposits tend to be more permeable than glacial till and mass wasting deposits, but their shallow depth and limited thickness limit their utilization as regional aquifers.

The regional groundwater flow direction generally is to the northeast. Static groundwater levels in the Bend area generally are greater than 200 feet below ground surface. However, static water levels between 100 to 200 feet below ground surface have been measured in local areas influenced by infiltration of irrigation water, and leakage from streams and unlined canals.

CITY OF BEND SURFICIAL GEOLOGY

The oldest rocks outcropping within the City are volcanic, vent-derived basalt flows (designated unit QTmv on Figure 2) associated with the Deschutes Formation. These deposits form the Awbrey Butte upland area in the northwest portion of the City. These basalt flows are relatively unweathered and, in places, heavily fractured, resulting in a wide range in rock permeability.

Stratigraphically overlying the vent deposits are Pliocene- and Pleistocene-age tuffaceous sedimentary rocks and tuff deposits (QTst). The tuffs were deposited by volcanic eruptions from sources west of Bend and primarily outcrop west of the Deschutes River. The tuffaceous sediments were formed by reworking these tuff deposits and from material transported directly from the Cascade Range. These rocks generally have low primary porosity and are relatively unfractured, resulting in low permeability and associated infiltration capacity. This geologic unit is the most areally extensive unit outcropping within the City west of the Deschutes River. Fingers of Pliocene- and Pleistocene-age basalt (QTba) overlie tuffaceous rocks in the southwest and northwest portions of the City. These basaltic rocks, where present, generally are of higher permeability than the surrounding tuffaceous rocks.

The most areally extensive geologic unit within the City consists of Pleistocene- and Holocene-age basalt (Qb) that originated from the Newberry volcanic center southeast of Bend. These relatively young volcanic rocks are unweathered and fractured, resulting in zones of relatively high permeability. This geologic unit primarily outcrops east of the Deschutes River.

Isolated pyroclastic deposits (QTp) outcrop south and east of downtown Bend. These rocks were aerially deposited by eruptions from cinder cone volcanoes and are of limited areal extent. These rocks generally have low primary porosity and are relatively unfractured, resulting in low permeability and associated infiltration capacity.

Small deposits of alluvial (river-deposited) sediment (Qal) outcrop along the Deschutes River near the center of the City. These sedimentary deposits primarily consist of stratified gravel, sand, and silt and are characterized by a wide range in permeability.

CITY OF BEND SURFICIAL SOIL DISTRIBUTION

A complex sequence of relatively thin soil units have been mapped within the City. Soil generally is derived from decomposition and weathering of volcanic and sedimentary rocks. Depth to bedrock typically ranges from 10 to 60 inches below grade. With the exception of the Suilotem member of the Suilotem-Circle soil complex whose drainage class is “somewhat poorly drained”, most of the soil units within the City limits are “well to excessively drained.” The capacities of the most limiting layer to transmit water range from “moderately-high to high” (0.75 to 1.98 inches per hour) to “high to very high” (5.95 to 19.98 inches per hour).

The distribution of soil units within the City of Bend and surrounding area are presented in Surficial Soil Distribution, Figure 3. For each surficial soil unit, the unit symbol, soil description, depth to underlying aquitard layer, drainage class, and the capacity of the most limiting layer to transmit water are presented in Table 1.

GEOTECHNICAL DATA REVIEW

GeoEngineers reviewed the following geotechnical reports during this investigation. Reports were provided by the City.

- Geotechnical Exploration Report, Proposed Southern River Crossing, Bend, Oregon. Kleinfelder, Inc., dated April 18, 2001.
- Geotechnical Exploration Report, Oregon Street Parking Structure, SW of Oregon Street and Lava Road, Bend, Oregon. Kleinfelder, Inc., dated June 4, 2004.
- Geotechnical Exploration Report, Newport Avenue Bridge Replacement, Bend, Oregon. Kleinfelder, Inc., dated February 3, 2005.
- Geotechnical Exploration Report, Mt. Washington Drive Bridge Replacement, Bend, Oregon. Kleinfelder, Inc., dated February 7, 2005.
- Rock Bluff Reservoir Expansion, Bend Oregon. Siemens and Associates, dated December 8, 2005.
- Report of Geotechnical Engineering Services, Shevlin Ridge/Westside Meadows Subdivision, Bend, Oregon. GeoEngineers, Inc., dated June 5, 2006.
- Technical Memorandum, Bend River Mall, Storm Water Drill Hole Evaluation, 3188 N. Highway 97, Bend, Oregon. Kleinfelder, Inc., dated June 30, 2006.
- Geologic Site Characterization Report, Westside Village Marketplace, NE of Century Drive and Simpson Avenue, Bend, Oregon. Kleinfelder, Inc., dated October 17, 2006.
- Technical Memorandum, Infiltration Rate Data, Reed Market Corridor, Bend, Oregon. Kleinfelder, Inc., dated December 1, 2006.

The above referenced information was used, in part, to interpret geologic and hydrogeologic conditions at known locations throughout the City and correlate such conditions with geologic units. Where available in the referenced documents, we also correlated infiltration rates with soil and rock conditions, although this data was limited to a few locations and values. Information we derived from our review, correlations and interpretations are incorporated into the discussion in following sections of this report.

INFILTRATION PERFORMANCE OF GEOLOGIC UNITS

GENERAL

Based on our understanding of area geology and hydrogeology, site reconnaissance, investigation of water well reports and geotechnical borings, and the infiltration characteristics of City soils, GeoEngineers developed boundaries for identifying areas that may be well- or poorly-suited for conventional UICs such as drywells. Spatial analysis of compiled subsurface data was used to identify areas in which drill holes are more suitable for use than dry wells.

RECOMMENDED BOUNDARIES

Using subsurface data compiled during our review, we performed spatial analysis to estimate the locations and areal extent of zones within the City that have varying suitability for drywell performance, herein designated drainage areas. We identified four primary drainage areas within the City. The approximate limits of these drainage areas are displayed in Drainage Areas, Figure 4. These areas are shaped by geologic conditions, rather than geographic boundaries such as roads. The geologic conditions that characterize each drainage area and preliminary estimates of their hydraulic conductivities are presented in Table 2, Infiltration Performance of Drainage Areas. This table also includes preliminary estimates of the exfiltration capacities of drywells and drill holes completed within these geologic units.

The most areally extensive drainage area, denoted as **Drainage Area 1** in Figure 4, is located within the eastern portion of the City, primarily east of the Deschutes River, and generally is underlain by Pleistocene- and Holocene-age basalt (Qb). These rocks have an estimated hydraulic conductivity of 2.5×10^{-3} centimeters per second (cm/s) and a corresponding exfiltration rate of about 0.1 cubic feet per second (cfs) for a standard double-depth drywell (with an active barrel section of about 10 feet), generally allowing for efficient use of drywells in these areas. The exfiltration rate for a drill hole 100 feet in depth and 6 inches in diameter is about 0.01 cfs. While drill holes have a lower exfiltration rate than drywells, they may still be efficient for use in these areas.

A smaller geologic unit is characterized by **Drainage Area 2** and located in the northwest portion of the City. The unit is composed of older Pliocene- and Pleistocene-age basalt units (QTmv and QTba). Portions of the unit extend past NW Mt. Washington Drive to the west, north, and east, and NW Summit Drive to the south. We anticipate that, because of weathering conditions, these older basalt deposits have a slightly lower hydraulic conductivity of about 1×10^{-3} cm/s, drywell exfiltration rate of about 0.04 cfs, and drill hole exfiltration rate of approximately 0.004 cfs.

We estimate that pyroclastic rocks of basaltic and andesitic cinder cones (QTp) underlying **Drainage Area 3** have hydraulic properties similar to the older basalt group, with an approximate hydraulic conductivity of 5×10^{-3} cm/s, an estimated drywell exfiltration of about 0.2 cfs, and a drill hole exfiltration of about 0.02 cfs. This unit is located in three isolated sections throughout the City, including downtown, to the northeast and to the southwest of downtown Bend, as shown in Figure 2.

The fourth geologic unit and corresponding drainage condition, **Drainage Area 4**, is composed of tuffaceous sedimentary rocks and tuffs (QTst). Tuff deposits have a relatively low hydraulic conductivity (approximately 1×10^{-4} cm/s), an estimated drywell exfiltration rate of only about 0.004 cfs, and a drill hole exfiltration rate of 4×10^{-4} cfs, assuming the entire depth is encased in tuff. Based on these estimates, tuff generally is not suitable for installation of drywells. Drill holes can be viable if the depth of the tuff layer is penetrated and a more porous material is encountered below, such as pumice, basalt, or sediments.

TUFF DISTRIBUTION ANALYSIS

Analysis of the aerial distribution and thickness of tuff within Drainage Area 4 was performed using data provided in geotechnical reports and water supply well reports. Water supply wells and geotechnical borings located within Drainage Area 4 are presented in Geotechnical Report and Water Supply Well Locations, Figure 5, and listed in Tables 3 and 4. Depth below ground surface to the tuff layer in each of these geotechnical reports and water supply well reports is presented in Approximate Depths to Top and Bottom of Tuff, Figure 6. Within the Bend city limits, tuff is predominantly found west of the Deschutes River and south of Awbrey Butte, and can also be encountered in isolated areas at depths below the mafic vent complexes of Awbrey Butte. As shown in Figure 2, tuff may also be found up to about 3,000 feet east of and parallel to the Deschutes River, south of downtown Bend. However, only two of the six subsurface explorations in this area have encountered tuff.

Our interpretation of the approximate depth to the top and bottom of the tuff deposit is presented in Figure 6. Several water well reports encountered tuff-like material listed as claystone, solid lava, or red soft rock, suggesting that tuff was in fact encountered, but not consistently described by the various drillers. Within Drainage Area 4, tuff deposits occur near the ground surface, with the top of the tuff layer ranging from 0 to about 50 feet below ground surface. Depth to the bottom of the tuff layer ranges from about 19 to 85 feet below ground surface. In general, the tuff layer is deepest toward the northern section of Drainage Area 4. Depth to the bottom of the tuff layer is up to 85 feet below ground surface to the northwest, and many of the subsurface explorations did not encounter the bottom of the tuff layer. Within the southwest portion of Drainage Area 4, tuff was not encountered in water well reports to the depths explored, suggesting that tuff distribution is discontinuous in this area.

CONCLUSIONS AND RECOMMENDATIONS

GENERAL

The City of Bend and surrounding area are underlain by soil and rock units that, in many cases, limit the infiltration of stormwater, resulting in flooding during storm events. Most surficial soils have a high infiltration capacity, and are “well to excessively drained.” However, they are limited for stormwater infiltration because of their limited thickness. Surficial soils are underlain by a variety of rock units with estimated hydraulic conductivities that range from 1×10^{-4} cm/s to 5×10^{-3} cm/s. Based on estimated hydraulic conductivities, we approximately delineated four drainage areas that group geologic conditions of similar hydraulic properties. Preliminary exfiltration rates were developed for drywells and drill holes completed within the drainage areas. Preliminary exfiltration rates range from 0.004 cfs to 0.2 cfs for double-depth drywells and 4×10^{-4} cfs to 0.02 cfs for drill holes 100 feet in depth and 6 inches in diameter. We recommend that a safety factor of 2 to 4 be considered for these rates before being used for planning. As noted previously, higher safety factors might be warranted.

DRAINAGE AREA RECOMMENDATIONS

In general, the most favorable conditions for stormwater infiltration occur within Drainage Area 1, which generally is underlain by relatively young, unweathered, and fractured basalt units east of the Deschutes River. In these areas, we recommend the use of drywells for stormwater disposal in this area. Our preliminary evaluation suggests that a drywell exfiltration rate on the order of about 0.1 cfs can be anticipated.

Moderate exfiltration rates can be expected within Drainage Areas 2 and 3. In these areas, we also recommend the use of drywells for stormwater disposal. However, we estimate that drywell exfiltration rates in the range of about 0.04 to 0.2 cfs should be expected in these areas.

The least favorable conditions for stormwater infiltration occur within Drainage Area 4, which is underlain by tuff. Our preliminary evaluation suggests that drywell exfiltration rates under these geologic conditions are only about 4×10^{-3} cfs. We recommend the use of drill holes in these areas, provided that the bottom of the tuff is less than 60 feet below ground surface, the tuff is underlain by basalt or relatively coarse-grained sediments, and regulatory approval for installation of drill holes can be obtained. Drill holes should be drilled to 100 feet in depth, the maximum currently allowed by the Oregon Department of Environmental Quality. If tuff extends below 60 feet in depth, we recommend that alternative stormwater disposal options be considered, such as development of regional stormwater systems, routing treated stormwater to the Deschutes River, or installation of evaporation ponds.

DEVELOPMENT OF REGIONAL STORMWATER INFILTRATION FACILITIES

Regional stormwater infiltration facilities provide an alternative to site-specific stormwater disposal design and should be located on sites with exceptional infiltration capacities. In our opinion, such conditions are most likely to be found within basalt deposits associated with Drainage Area 1. Specific locations should be sited based on the presence of significant fracture zones and/or lava tubes. We recommend a subsequent phase of study be performed to closely examine structural features within Drainage Area 1 and identify specific locations for exploration and testing.

HIGHEST PRIORITY PROBLEM SITES

General

The City of Bend has currently listed 35 existing problem areas with respect to stormwater infiltration. The five highest priority problem areas within the City, as shown in Highest Priority Existing Problem Sites, Figure 7, were reviewed. Westside Village Shopping Center and Bend Fire Station, Franklin Underpass, 3rd Street Underpass, Archie Briggs, and Fairview Heights on Awbrey Butte, are considered Priority 1-5, respectively. Each problem area frequently incurs stormwater drainage problems, and requires a permanent solution to prevent flooding of residential areas and streets. The following preliminary recommendations are based on existing water well reports and geotechnical reports within the general area of each problem site. Therefore, site-specific subsurface investigations are essential.

Problem Area 1

Problem Area 1 includes the Westside Village Shopping Center and Bend Fire Station, located at the northeast corner of Simpson Road and 14th Street. Currently, drainage problems include standing water in the roadways and parking lots, and stormwater flow into the City of Bend Fire Department Administration offices and parking lots. This site is situated within Drainage Area 4, and is underlain by tuff at a depth that ranges from about 3.5 to 11 feet below ground surface. The bottom of the tuff layer is about 51 to 64 feet below ground surface and underlain by a rock unit described as pumice. We recommend the following:

- Installation of drywells should not be considered because of the shallow depth to the top of the tuff unit.
- The infiltration capacity of the underlying pumice (and the viability of stormwater disposal through drill holes) should be evaluated by site-specific borehole infiltration testing. Based on the assumed permeability of area pyroclastic rocks (5×10^{-3} cm/s) and a drill hole that encounters tuff from 0 to 60 feet in depth and pumice from 60 to 100 feet in depth, we preliminarily estimate that the exfiltration rate of an individual drill hole would be about 0.009 cfs.
- If drill holes are determined to not be feasible, routing stormwater to a regional infiltration facility, the Deschutes River after treatment, or evaporation ponds should be considered.

Problem Area 2

Problem Area 2 is the Franklin Underpass, located at Franklin Avenue and Highway 97. Current drill holes and infiltration basins are effective when properly maintained, but have been recently overwhelmed with additional stormwater runoff from adjacent properties. Based on our hydrogeologic reconnaissance and review, the Franklin Underpass area is underlain by basalt. We recommend the following:

- A maintenance program should be initiated to remove sediment and debris from the existing structures.
- Additional drywells and infiltration structures within the surrounding properties would reduce stormwater runoff impact to the Franklin Underpass by reducing the drainage area.
- If additional infiltration structures are required below the underpass, we recommend the installation of drywells. Preliminary drywell exfiltration rates are estimated to be about 0.1 cfs.

Problem Area 3

The 3rd Street Railway Underpass is the third highest priority problem site. Based on our hydrogeologic reconnaissance and review, the 3rd Street Railway Underpass also is underlain by basalt. However, stormwater runoff from adjacent sites to this low-lying area overwhelm the current system of drywells and drill holes. We recommend the following:

- A maintenance program should be initiated to remove sediment and debris from the existing structures.
- Additional drywells and infiltration structures within the surrounding properties would reduce stormwater runoff impact to the Franklin Underpass by reducing the drainage area.
- If additional infiltration structures are required below the underpass, we recommend the installation of drywells. Preliminary drywell exfiltration rates are estimated to be about 0.1 cfs.

Problem Area 4

The fourth highest priority area is located on Archie Briggs Road west of the Deschutes River. Steep terrain and the lack of drainage structures allow for stormwater discharge into the Deschutes River without pretreatment. This site is underlain by the mafic vent complexes that compose Awbrey Butte. We recommend the following:

- Drainage design should incorporate drywells for stormwater infiltration. Preliminary drywell exfiltration rates are estimated to be about 0.04 cfs.
- If site-specific testing indicates that drywell exfiltration rates are not sufficient for site stormwater disposal, routing stormwater to the Deschutes River after treatment should be considered.

Problem Area 5

Fairway Heights on Awbrey Butte is the fifth highest priority problem site. Many homes exist in this area with steep terrain and a problematic easement that includes abrupt narrowing and a 90-degree angle within a surface drainage structure. As in Problem Area 4, the Fairway Heights area is underlain by mafic vent complexes of Awbrey Butte. We recommend the following:

- Additional drywells would be useful in this area to reduce stormwater runoff through the easement to the River's Edge Golf Course, in addition to larger culverts along the easement and frequent maintenance of existing infiltration structures.

- If drainage design incorporates drywells for stormwater infiltration, preliminary drywell exfiltration rates are estimated to be about 0.04 cfs.
- If site-specific testing indicates that drywell exfiltration rates are not sufficient for site stormwater disposal, routing stormwater to a regional stormwater infiltration facility, the Deschutes River after treatment, or evaporation ponds should be considered.

INFILTRATION STRUCTURE INSTALLATION COSTS

Based on rate schedules available at the time of our report, we estimate the following construction costs:

- Installation of a double-depth drywell per Spokane County, Washington standards is estimated to cost about $3,500.
- Installation of a drill hole 100 feet in depth and 6 inches in diameter with a 20-foot surface seal and no liner is estimated to cost about $3,700.

These estimates are limited to installation of the infiltration structure only, and do not include costs associated with surface completions or connections to piping. Note that construction costs are increasing rapidly because of the rising costs of fuel, metals, concrete, and other construction materials.

RECOMMENDED ADDITIONAL STUDY

Additional study is recommended to provide a partial basis for regulatory controls design guidelines. Such additional study should include but may not be limited to the following general elements:

1. Exploration of soil, rock and groundwater conditions in each of the geologic units that coincide with the drainage areas defined in this report. Multiple full-scale tests should be conducted in each geologic unit. Samples of soil and rock should be acquired as part of the exploration program.

2. Full-scale testing of drywells and drill holes. Such testing should be completed on relatively new installations as well as older installations. Infiltration rates may be back calculated from the field data. The results also may be used to assess the range of safety factors that might be warranted for use in design.

3. Laboratory testing to assess pertinent physical and engineering properties of soil and rock.

4. Analyses of the data and formulation of design procedures for evaluating feasibility of, and siting and sizing drywells and drill holes for disposal of stormwater.

A more detailed scope of services can be provided upon request.

LIMITATIONS

GENERAL

We prepared this report for use by the URS and the City of Bend to assist in the development of a stormwater master plan for Bend, Oregon. Within the limitations of scope, schedule and budget, our services have been executed in accordance with generally accepted practices in the field of geotechnical engineering in this area at the time this report was prepared. No warranty or other conditions, expressed or implied, should be understood.

Please refer to Appendix B, Report Limitations and Guidelines for Use for additional information pertaining to use of this report.

The following specific limitations are organized by pertinent report section.

SCOPE OF SERVICES

Execution of the scope of services described in this report was intended as an initial step in understanding the relationships between soil and rock conditions, and infiltration potential of the various soil and rock units common to the City of Bend. As noted, we used existing information as the basis for delineating approximate boundaries of the various geologic units, presumptive infiltration rates of those units, and estimated capacity of drywells and drill holes to discharge stormwater into soil and rock that make up the geologic units. There were limitations to the available data we reviewed and those limitations are reflected in the conclusions and recommendations presented in this report.

The limited scope of this initial study was not intended to develop information that could be used for establishing land development regulations or design procedures for siting and sizing of stormwater disposal facilities. Additional study, including field exploration and testing, laboratory testing and engineering analyses, is warranted to revise, refine and expand upon the conclusions and recommendations in this report. A preliminary scope of services for an appropriate subsequent study phase is provided above. Results of such additional study then could be used for refining estimated infiltration potential, and establishing regulations and design procedures.

INFILTRATION PERFORMANCE OF GEOLOGIC UNITS

It must be stressed that the preliminary infiltration rates, and drywell and drill hole discharge rate estimates presented in the Infiltration Performance of Geologic Units section of this report are intended for planning purposes only and not for design. The infiltration rates we used to estimate drywell and drill hole performance are presumptive properties derived from the literature. Consequently, site-specific exploration and testing should be performed before drainage regulatory and design guidelines are finalized at specific sites. Field-measured infiltration rates might be higher or lower than those used in our evaluations. Also note that these estimates are unfactored. We recommend a safety factor of 2 to 4 be applied to these estimates, although higher safety factors might be warranted. Safety factors up to 20 have been used for some design applications. The value of safety factors that are eventually applied depend on a variety of variables, including but not limited to, quantity and quality of field and laboratory data, and perceived consequences of the failure of stormwater management facilities.

CONCLUSIONS AND RECOMMENDATIONS

The stormwater disposal recommendations presented in the Conclusions and Recommendations section of this report are intended for planning purposes only. Considerable variability in infiltration capacity is likely to be observed within each of the drainage areas. Site-specific exploration and testing should be performed before a specific stormwater disposal design is finalized. In areas underlain by seasonal high groundwater elevation less than 20 feet below ground surface, mounding analyses should be performed to evaluate the potential impact of project development on adjacent structures and surfaces.

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Table 1
Surficial Soil Descriptions
Stormwater Infiltration Evaluation
Bend, Oregon

Soil Symbol	Soil Description	Soil Complex Member Name	Depth to Restrictive Feature	Drainage class	Capacity of the most limiting layer to transmit water (Ksat):
18D	Bluesters gravelly sandy loam, 15 to 50 percent slopes	Bluesters	14 to 30 inches to Strongly contrasting textural stratification	Excessively drained	High (1.98 to 5.95 in/hr)
27A	Clovkamp loamy sand, 0 to 3 percent slopes	Clovkamp	35 to 50 inches to Strongly contrasting textural stratification	Somewhat excessively drained	Moderately high or high (0.57 to 1.98 in/hr)
28A	Clovkamp loamy sand, bedrock substratum, 0 to 3 percent slopes	Clovkamp	35 to 50 inches to Strongly contrasting textural stratification; 40 to 60 inches to Lithic bedrock	Somewhat excessively drained	Moderately high or high (0.57 to 1.98 in/hr)
31A	Deschutes sandy loam, 0 to 3 percent slopes	Deschutes	20 to 40 inches to Lithic bedrock	Well drained	High (1.98 to 5.95 in/hr)
34C	Deschutes-Stukel complex, 0 to 15 percent slopes	Deschutes	20 to 40 inches to Lithic bedrock	Well drained	High (1.98 to 5.95 in/hr)
		Stukel	10 to 20 inches to Lithic bedrock	Well drained	High (1.98 to 5.95 in/hr)
36A	Deskamp loamy sand, 0 to 3 percent slopes	Deskamp	20 to 40 inches to Lithic bedrock	Somewhat excessively drained	High or very high (5.95 to 19.98 in/hr)
36B	Deskamp loamy sand, 3 to 8 percent slopes	Deskamp	20 to 40 inches to Lithic bedrock	Somewhat excessively drained	High or very high (5.95 to 19.98 in/hr)
38B	Deskamp-Gosney complex, 0 to 8 percent slopes	Deskamp	20 to 40 inches to Lithic bedrock	Somewhat excessively drained	High or very high (5.95 to 19.98 in/hr)
		Gosney	10 to 20 inches to Lithic bedrock	Somewhat excessively drained	High or very high (5.95 to 19.98 in/hr)
57B	Gosney stony loamy sand, 3 to 8 percent slopes	Gosney	10 to 20 inches to Lithic bedrock	Somewhat excessively drained	High or very high (5.95 to 19.98 in/hr)
58C	Gosney-Rock outcrop-Deskamp complex, 0 to 15 percent slopes	Gosney	10 to 20 inches to Lithic bedrock	Somewhat excessively drained	High or very high (5.95 to 19.98 in/hr)
		Deskamp	20 to 40 inches to Lithic bedrock	Somewhat excessively drained	High or very high (5.95 to 19.98 in/hr)
59C	Gosney-Rock outcrop-Deskamp complex, dry, 0 to 15 percent slopes	Gosney	10 to 20 inches to Lithic bedrock	Somewhat excessively drained	High or very high (5.95 to 19.98 in/hr)
		Deskamp	20 to 40 inches to Lithic bedrock	Somewhat excessively drained	High or very high (5.95 to 19.98 in/hr)
61C	Henkle-Fryrear-Lava flows complex, 0 to 15 percent slopes	Henkle	10 to 20 inches to Lithic bedrock	Somewhat excessively drained	High (1.98 to 5.95 in/hr)
		Fryrear	20 to 40 inches to Lithic bedrock	Well drained	High (1.98 to 5.95 in/hr)
62D	Henkle-Lava flows-Fryrear complex, 15 to 50 percent slopes	Henkle	10 to 20 inches to Lithic bedrock	Somewhat excessively drained	High (1.98 to 5.95 in/hr)
		Fryrear	20 to 40 inches to Lithic bedrock	Well drained	High (1.98 to 5.95 in/hr)
65A	Houstake sandy loam, 0 to 3 percent slopes	Houstake	NA	Well drained	Moderately high or high (0.57 to 1.98 in/hr)
72C	Laidlaw sandy loam, 0 to 15 percent slopes	Laidlaw	NA	Well drained	High (1.98 to 5.95 in/hr)
81F	Lickskillet-Rock outcrop complex, 45 to 80 percent slopes	Lickskillet	12 to 20 inches to Lithic bedrock	Well drained	Moderately high or high (0.57 to 1.98 in/hr)
85A	Lundgren sandy loam, 0 to 3 percent slopes	Lundgren	20 to 40 inches to Strongly contrasting textural stratification	Well drained	High (1.98 to 5.95 in/hr)
98A	Plainview sandy loam, 0 to 3 percent slopes	Plainview	50 to 65 inches to Duripan	Well drained	Very low or moderately low (0.00 to 0.06 in/hr)
98B	Plainview sandy loam, 3 to 8 percent slopes	Plainview	50 to 65 inches to Duripan	Well drained	Very low or moderately low (0.00 to 0.06 in/hr)
101E	Redcliff-Lickskillet-Rock outcrop complex, 30 to 50 percent south slopes	Redcliff	20 to 40 inches to Lithic bedrock	Well drained	Moderately high or high (0.57 to 1.98 in/hr)
		Lickskillet	12 to 20 inches to Lithic bedrock	Well drained	Moderately high or high (0.57 to 1.98 in/hr)
106D	Redslide-Lickskillet complex, 15 to 30 percent north slopes	Redcliff	20 to 40 inches to Lithic bedrock	Well drained	High (1.98 to 5.95 in/hr)
		Lickskillet	12 to 20 inches to Lithic bedrock	Well drained	Moderately high or high (0.57 to 1.98 in/hr)
		Redcliff	20 to 40 inches to Lithic bedrock	Well drained	High (1.98 to 5.95 in/hr)

Soil Symbol	Soil Description	Soil Complex Member Name	Depth to Restrictive Feature	Drainage class	Capacity of the most limiting layer to transmit water (Ksat):
106E	Redslide-Lickskillet complex, 30 to 50 percent north slopes	Lickskillet	12 to 20 inches to Lithic bedrock	Well drained	Moderately high or high (0.57 to 1.98 in/hr)
116E	Shroyton loamy sand, 30 to 50 percent slopes	Shroyton	40 to 60 inches to Lithic bedrock	Well drained	High or very high (5.95 to 19.98 in/hr)
123C	Sisters-Yapoah complex, 0 to 15 percent slopes	Sisters	NA	Well drained	Moderately high (0.20 to 0.57 in/hr)
		Yapoah	NA	Somewhat excessively drained	High or very high (5.95 to 19.98 in/hr)
123D	Sisters-Yapoah complex, 15 to 30 percent slopes	Sisters	NA	Well drained	Moderately high (0.20 to 0.57 in/hr)
		Yapoah	NA	Somewhat excessively drained	High or very high (5.95 to 19.98 in/hr)
123E	Sisters-Yapoah complex, 30 to 50 percent slopes	Sisters	NA	Well drained	Moderately high (0.20 to 0.57 in/hr)
		Yapoah	NA	Somewhat excessively drained	High or very high (5.95 to 19.98 in/hr)
128C	Statz-Deschutes complex, 0 to 15 percent slopes	Statz	10 to 20 inches to Duripan; 20 to 40 inches to Lithic bedrock	Well drained	Very low or moderately low (0.00 to 0.06 in/hr)
		Deschutes	20 to 40 inches to Lithic bedrock	Well drained	High (1.98 to 5.95 in/hr)
128D	Statz-Deschutes complex, 15 to 30 percent slopes	Statz	10 to 20 inches to Duripan; 20 to 40 inches to Lithic bedrock	Well drained	Very low or moderately low (0.00 to 0.06 in/hr)
		Deschutes	20 to 40 inches to Lithic bedrock	Well drained	High (1.98 to 5.95 in/hr)
141C	Stukel-Deschutes-Rock outcrop complex, 0 to 15 percent slopes	Stukel	10 to 20 inches to Lithic bedrock	Well drained	High (1.98 to 5.95 in/hr)
		Deschutes	20 to 40 inches to Lithic bedrock	Well drained	High (1.98 to 5.95 in/hr)
143B	Suilotem-Circle complex, 0 to 8 percent slopes	Suilotem	NA	Somewhat poorly drained	High (1.98 to 5.95 in/hr)
		Circle	40 to 50 inches to Strongly contrasting textural stratification	Well drained	Moderately high or high (0.57 to 1.98 in/hr)
151D	Tetherow-Clovkamp complex, 8 to 50 percent slopes	Tetherow	14 to 28 inches to Strongly contrasting textural stratification	Excessively drained	High (1.98 to 5.95 in/hr)
		Clovkamp	35 to 50 inches to Strongly contrasting textural stratification	Somewhat excessively drained	Moderately high or high (0.57 to 1.98 in/hr)
152A	Tumalo sandy loam, 0 to 3 percent slopes	Tumalo	20 to 40 inches to Duripan	Well drained	Very low or moderately low (0.00 to 0.06 in/hr)
152B	Tumalo sandy loam, 3 to 8 percent slopes	Tumalo	20 to 40 inches to Duripan	Well drained	Very low or moderately low (0.00 to 0.06 in/hr)
155C	Wanoga sandy loam, 0 to 15 percent slopes	Wanoga	20 to 40 inches to Paralithic bedrock; 30 to 50 inches to Lithic bedrock	Well drained	High (1.98 to 5.95 in/hr)
155D	Wanoga sandy loam, 15 to 30 percent slopes	Wanoga	20 to 40 inches to Paralithic bedrock; 30 to 50 inches to Lithic bedrock	Well drained	High (1.98 to 5.95 in/hr)
156C	Wanoga-Fremkle-Henkle complex, 0 to 15 percent slopes	Wanoga	20 to 40 inches to Paralithic bedrock; 30 to 50 inches to Lithic bedrock	Well drained	High (1.98 to 5.95 in/hr)
		Fremkle	10 to 20 inches to Lithic bedrock	Well drained	High (1.98 to 5.95 in/hr)
		Henkle	10 to 20 inches to Lithic bedrock	Somewhat excessively drained	High (1.98 to 5.95 in/hr)
157C	Wanoga-Fremkle-Rock outcrop complex, 0 to 15 percent slopes	Wanoga	20 to 40 inches to Paralithic bedrock; 30 to 50 inches to Lithic bedrock	Well drained	High (1.98 to 5.95 in/hr)
		Fremkle	10 to 20 inches to Lithic bedrock	Well drained	High (1.98 to 5.95 in/hr)
159C	Wilt sandy loam, 0 to 15 percent slopes	Wilt	20 to 40 inches to Lithic bedrock	Well drained	Moderately high (0.20 to 0.57 in/hr)
W	Water	NA	NA	NA	NA

Notes:
[1]Data obtainted from the following source: Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic (SSURGO) Database for Survey Area, State [Online WWW]. Available URL: "http://soildatamart.nrcs.usda.gov" . Acessed January 13, 2007.

Table 2
Infiltration Performance of Drainage Areas
Stormwater Infiltration Evaluation
Bend, Oregon

Drainage Area	Geologic Unit	Description	Hydraulic Conductivity[1] (centimeter/second)	Drywell Exfiltration Rate[2] (cubic feet/second)	Drywell Exfiltration Rate[2] (gallons/minute)	Drill Hole Exfiltration Rate[3] (cubic feet/second)	Drill Hole Exfiltration Rate[3] (gallons/minute)
1	Qb	Basalt and basaltic andesite	2.5E-03	0.1	50	0.01	5
2	QTmv, QTba	Older basalt, including mafic vent complexes	1.0E-03	0.04	20	0.004	2
3	QTp	Pyroclastic rocks of basaltic and andesitic cinder cones	5.0E-03	0.2	95	0.02	10
4	QTst	Tuffaceous sedimentary rocks and tuffs	1.0E-04	0.004	2	0.0004	0.2

Notes:
[1]Hydraulic conductivity estimated from typical values for various rock types presented in Freeze and Cherry (1979)
[2]Exfiltration (q) calculated from Appendix I of the Spokane County Public Works Guidelines for Stormwater Management (1998).
$k = (q/(2\pi H^2))*(\ln[H/r + ((H/r)^2 + 1)^{1/2}] - (((H/r)^2 + 1)^{1/2})/(H/r) + 1/(H/r))$
where k = hydraulic conductivity, H = side depth = 10 feet, and r = effective radius = 9.5 feet for a standard Type B drywell.
[3]Exfiltration rate calculated from "Soil Mechanics" by Lambe and Whitman (1969), using an equation appropriate for deeper bore holes with smaller diameter:
q = 2.75*k*D*H, where k = hydraulic conductivity, D = diameter, and H = head in the drill hole
Rate assumes that drill hole is 100 feet deep, 6 inches in diameter, and is excavated in a uniform subsurface material.

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Table 3

Summary of Water Supply Well Reports[1]

Stormwater Infiltration Evaluation
Bend, Oregon

Well Log Number		Well Name	Location[2]				Tuff Depth[3]		Depth of Boring	Notes
			Q-Q	Section	Township	Range	Start	End		
DESC	57575-57586	T17SR11ES36N1-N11	SE-SW	36	17S	11E	0	0	25-35	
DESC	57854	T17SR11ES36B1	NW-NE	36	17S	11E	0	0	60	
DESC	57855	T17SR11ES36B2	NW-NE	36	17S	11E	50	55	55	
DESC	57856	T17SR11ES36B3	NW-NE	36	17S	11E	40	45	45	
DESC	57857	T17SR11ES36B4	NW-NE	36	17S	11E	45	45	45	
DESC	57858	T17SR11ES36B5	NW-NE	36	17S	11E	45	45	45	
DESC	57859	T17SR11ES36B6	NW-NE	36	17S	11E	45	45	45	
DESC	57860	T17SR11ES36B7	NW-NE	36	17S	11E	25	25	25	
DESC	57861	T17SR11ES36B8	NW-NE	36	17S	11E	25	25	25	
DESC	57862	T17SR11ES36B9	NW-NE	36	17S	11E	25	35	35	
DESC	57863	T17SR11ES36B10	NW-NE	36	17S	11E	25	35	35	
DESC	52702	T18SR11ES13M1	SW-SW	13	18S	11E	0	0	450	
DESC	53556	T18SR11ES13F1	SE-NW	13	18S	11E	0	0	460	
DESC	55200	T18SR11ES13E1	SW-NW	13	18S	11E	0	0	512	
DESC	55201	T18SR11ES13E2	SW-NW	13	18S	11E	0	0	512	
DESC	55203	T18SR11ES13F2	SE-NW	13	18S	11E	0	0	372	
DESC	55204	T18SR11ES13H1	SE-NE	13	18S	11E	0	0	465	
DESC	56041	T18SR11ES13E3	SW-NW	13	18S	11E	0	0	492	
DESC	56727	T18SR11ES13F3	SE-NW	13	18S	11E	0	0	475	
DESC	56966	T18SR11ES13E4	SW-NW	13	18S	11E	0	0	490	
DESC	57142	T18SR11ES13L1	NW-SW	13	18S	11E	0	0	210	
DESC	57158	T18SR11ES13L2	NW-SW	13	18S	11E	0	0	430	
DESC	57178	T18SR11ES13L3	NW-SW	13	18S	11E	0	0	500	
DESC	57660	T18SR11ES13E5	SW-NW	13	18S	11E	0	0	510	
DESC	1738	T18SR12ES7J1	NW-SE	7	18S	12E	0	0	800	
DESC	5580	T18SR12ES6M1	SW-SW	6	18S	12E	1	42	367	Tan claystone underlain by pumice layers
DESC	5581	T18SR12ES6M2	SW-SW	6	18S	12E	15	40	40	Black claystone
DESC	5582	T18SR12ES6B1	SE-NW-NE	6	18S	12E	5	65	160	Red soft rock underlain by pumice
DESC	5589	T18SR12ES7		7	18S	12E	0	0	360	
DESC	5591	T18SR12ES7LM1	W 1/2 - SW 1/4	7	18S	12E	225	277	408	Tuffa
DESC	9108	T18SR12ES7J2	NW-SE	7	18S	12E	32	39	812	Black lava, solid
DESC	50900	T18SR12ES5E1	SW-NW	5	18S	12E	0	40	40	
DESC	50901	T18SR12ES5E2	SW-NW	5	18S	12E	0	40	40	
DESC	50902	T18SR12ES5E3	SW-NW	5	18S	12E	0	40	40	
DESC	50903	T18SR12ES5E4	SW-NW	5	18S	12E	0	40	40	
DESC	51804	T18SR12ES6E1	SW-NW	6	18S	12E	15	45	45	Red fractured tufstone (brown tufstone above)
DESC	51805	T18SR12ES6E2	SW-NW	6	18S	12E	48	58	58	Red tufstone (brown tufstone above)
DESC	51806	T18SR12ES6E3	SW-NW	6	18S	12E	28	39	39	Fractured red tufstone (brown turfstone above)
DESC	51807	T18SR12ES6E4	SW-NW	6	18S	12E	32	80	80	Fractured red tufstone (brown turfstone above)

Well Log Number		Well Name	Location[2]				Tuff Depth[3]		Depth of Boring	Notes
			Q-Q	Section	Township	Range	Start	End		
DESC	51808	T18SR12ES6E5	SW-NW	6	18S	12E	28	48	48	Fractured red tufstone (brown turfstone above)
DESC	51809	T18SR12ES6E6	SW-NW	6	18S	12E	37	80	80	Fractured red tufstone (brown turfstone above)
DESC	51810	T18SR12ES6E7	SW-NW	6	18S	12E	53	55	55	Fractured red tufstone (brown turfstone above)
DESC	51811	T18SR12ES6E8	SW-NW	6	18S	12E	25	50	50	Fractured red tufstone (brown turfstone above)
DESC	51812	T18SR12ES6E9	SW-NW	6	18S	12E	25	50	50	Fractured red tufstone (brown turfstone above)
DESC	53855	T18SR12ES6J1	NW-SE	6	18S	12E	0	0	25	
DESC	53856	T18SR12ES6J2	NW-SE	6	18S	12E	0	0	25	
DESC	53857	T18SR12ES6J3	NW-SE	6	18S	12E	0	19	29	
DESC	56394	T18SR12ES7G13	SW-NW	7	18S	12E	0	0	465	
DESC	57655	T18SR12ES6H1	NE-NE	6	18S	12E	10	27		Pumice between tuft layers
DESC	57655	T18SR12ES6H1	NE-NE	6	18S	12E	47	55	67	
DESC	57656	T18SR12ES6H2	NE-NE	6	18S	12E	5	40		Pumice between tuft layers
DESC	57656	T18SR12ES6H2	NE-NE	6	18S	12E	95	>95	95	
DESC	57782	T18SR12ES6H3	NE-NE	6	18S	12E	0	0	20	
DESC	57783	T18SR12ES6H4	NE-NE	6	18S	12E	0	0	20	
DESC	57784	T18SR12ES6H5	NE-NE	6	18S	12E	0	0	20	
DESC	57785	T18SR12ES6H6	NE-NE	6	18S	12E	0	0	20	
DESC	57815	T18SR12ES6O1	SW-SE	6	18S	12E	0	0	20	
DESC	57816	T18SR12ES6O2	SW-SE	6	18S	12E	0	0	20	
DESC	57817	T18SR12ES6O3	SW-SE	6	18S	12E	0	0	20	
DESC	57818	T18SR12ES6O4	SW-SE	6	18S	12E	0	0	20	
DESC	57819	T18SR12ES6O5	SW-SE	6	18S	12E	0	0	20	
DESC	57820	T18SR12ES6O6	SW-SE	6	18S	12E	0	0	20	
DESC	57821	T18SR12ES6O7	SW-SE	6	18S	12E	50	>50	50	
DESC	57822	T18SR12ES6O8	SW-SE	6	18S	12E	40	>40	40	
DESC	57823	T18SR12ES6O9	SW-SE	6	18S	12E	35	>35	35	

Notes:
[1]Well logs obtained from the Oregon Department of Environmental Quality.
[2]Location based on Township and Range Coordinate System. Q-Q refers to quarter to quarter section.
[3]Tuff depth refers to ground surface and was estimated from water well report information. The various terms used by drillers to describe the interpreted tuff unit are presented in the "Notes" column.

P:\12\12098004\00\Finals\[Well Logs.xls]Infiltration Performance

Table 4
Summary of Geotechnical Reports[1]
Stormwater Infiltration Evaluation
Bend, Oregon

Project	Boring Number	Boring Name	Tuff Depth[2]		Notes
			Top	Bottom	
Westside Village Marketplace	B-1	T18SR12ES6I1	11	51	Interbedded with pumice and
	B-2	T18SR12ES6I2	3.5	64	fractured basalt
Shevlin Meadows Subdivision	B-1	T18SR12ES31M1	25	30.4	Bottom of tuff not encountered
	B-2	T18SR12ES31M2	10	30.5	Bottom of tuff not encountered
	B-3	T18SR12ES31M3	8	41.5	Bottom of tuff not encountered
	B-4	T18SR12ES31M4	0	0	No tuff encountered
	B-5	T18SR12ES31M5	20	30.8	Bottom of tuff not encountered
	B-6	T18SR12ES31M6	25	30.3	Bottom of tuff not encountered
	B-7	T18SR12ES31M7	30	35.3	Bottom of tuff not encountered
	B-8	T18SR12ES31M8	26	30.3	Bottom of tuff not encountered
	B-9	T18SR12ES31M9	25	31.3	Bottom of tuff not encountered
	B-10	T18SR12ES31M10	13	25.3	Bottom of tuff not encountered
	B-11	T18SR12ES31M11	7.5	27	Bottom of tuff not encountered
	B-12	T18SR12ES31M12	13	40.3	Bottom of tuff not encountered
	B-13	T18SR12ES31M13	20	30.3	Bottom of tuff not encountered
	B-14	T18SR12ES31M14	33	35.8	Bottom of tuff not encountered
	B-15	T18SR12ES31M15	0	0	No tuff encountered
Bordeaux Ln and Skyline Ranch Rd	Drill Hole	T18SR12ES31M16	18	85	Pink Ash
Rock Bluff Reservoir	B-1	T18SR12ES7G1	25	36	Bottom of tuff not encountered
	B-2	T18SR12ES7G2	0	0	No tuff encountered
	B-3	T18SR12ES7G3	21	36	Bottom of tuff not encountered
	B-4	T18SR12ES7G4	20	36	Bottom of tuff not encountered
	B-5	T18SR12ES7G5	27	36	Bottom of tuff not encountered
	B-6	T18SR12ES7G6	25	65	Bottom of tuff not encountered
	B-7	T18SR12ES7G7	19	55	Bottom of tuff not encountered
	B-8	T18SR12ES7G8	21	66	Bottom of tuff not encountered
	B-9	T18SR12ES7G9	24	28	Bottom of tuff not encountered
	B-10	T18SR12ES7G10	31	36	Bottom of tuff not encountered
	B-11	T18SR12ES7G11	24	36	Bottom of tuff not encountered
	B-12	T18SR12ES7G12	18	28	Bottom of tuff not encountered

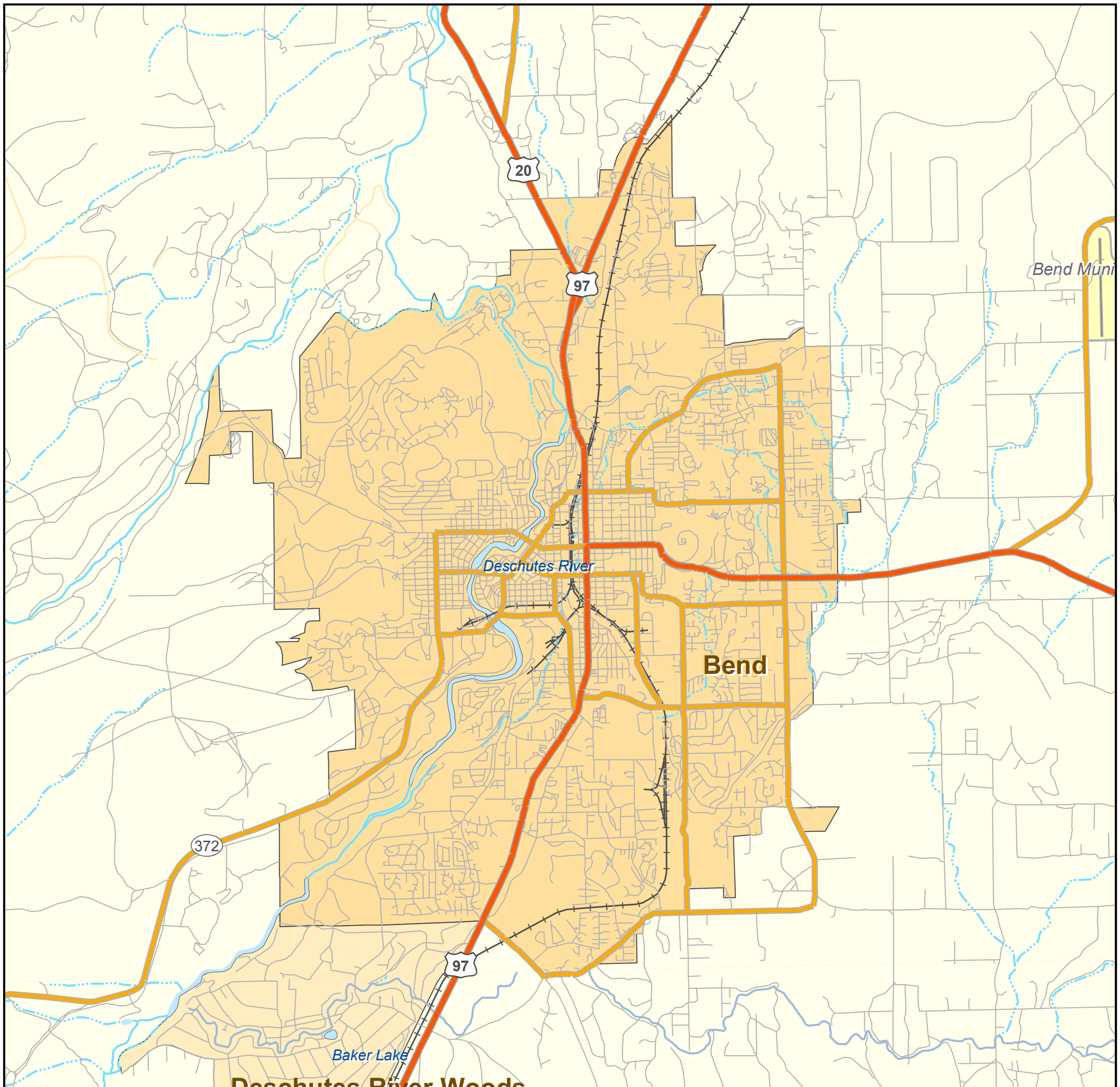
Notes:
[1]Geotechnical reports were provided by the city of Bend, Oregon.
[2]Tuff depth was interpreted from information presented in the exploration logs.

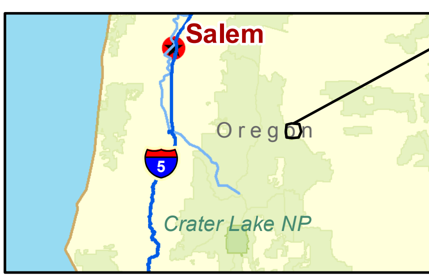
P:\12\12098004\00\Finals\[Well Logs.xls]Well Logs

Map Revised: March 6, 2007

Path: P:\12\1209800400\GIS\1209800400Figure1.mxd

Office: SPOK





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Feet

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. can not guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record of this communication.
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Data Sources: ESRI Data & Maps, Street Maps 2005

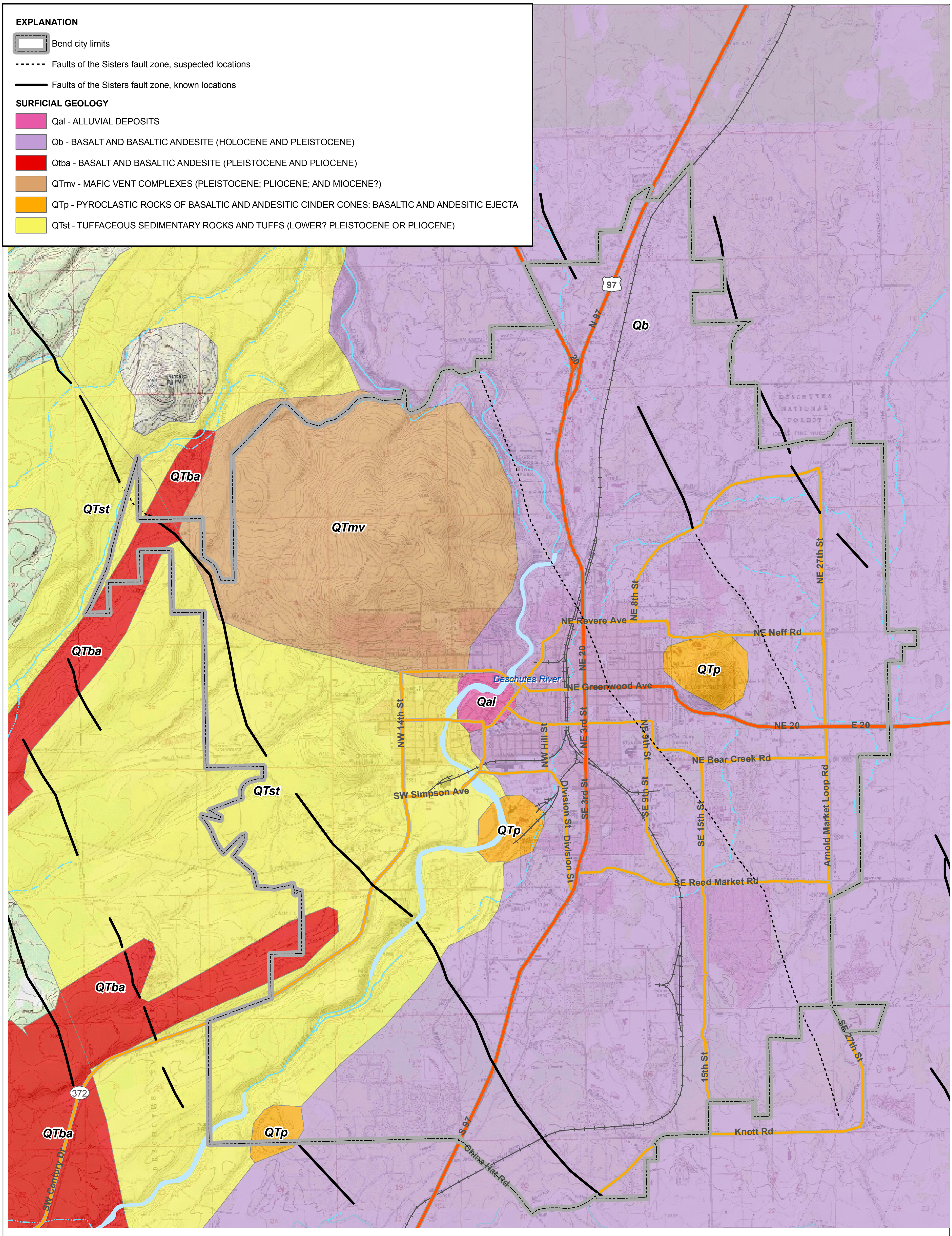
Transverse Mercator, Zone 10 N North, North American Datum 1983
North arrow oriented to grid north

Vicinity Map

Bend Stormwater Master Plan
Bend, Oregon

GeoEngineers

Figure 1



Reference: Geology from U.S. Geological Survey Open-File Report 03-67 (revised 1/5/2005).
U.S. topographic map from TerraServer (obtained Janaury 2007).

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for infomation purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. can not guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record oth this communication.

Surficial Geology

Bend Stormwater Master Plan
Bend, Oregon

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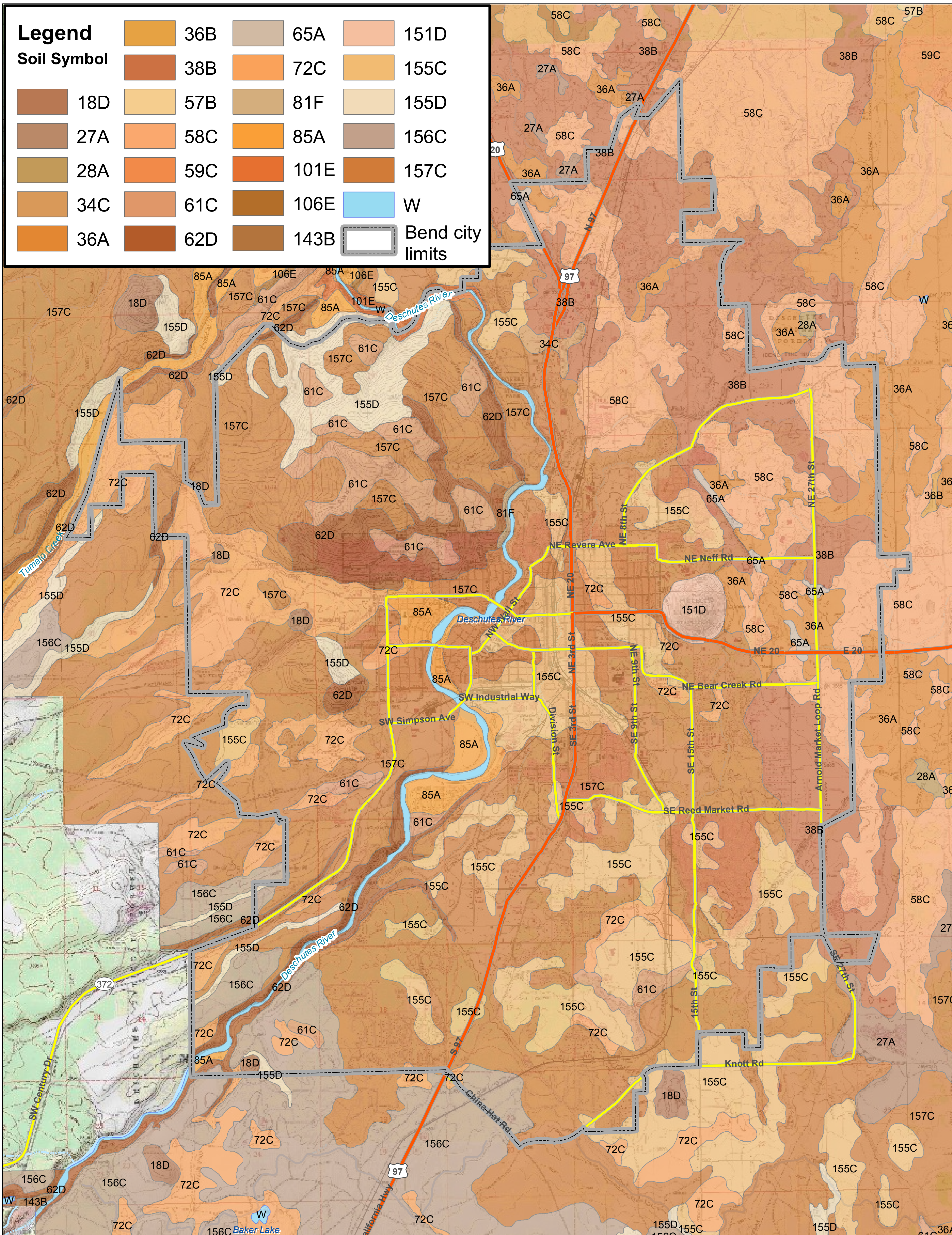
Figure 2



4,000 0 4,000
Feet

N W E S

Reference: Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic (SSURGO) Database for Survey Area, State [Online WWW]. Available URL: "http://soildatamart.nrcs.usda.gov" . Accessed February 13, 2007.

U.S. topographic map from TerraServer (obtained Janaury 2007).

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Surficial Soil Distribution

Bend Stormwater Master Plan
Bend, Oregon

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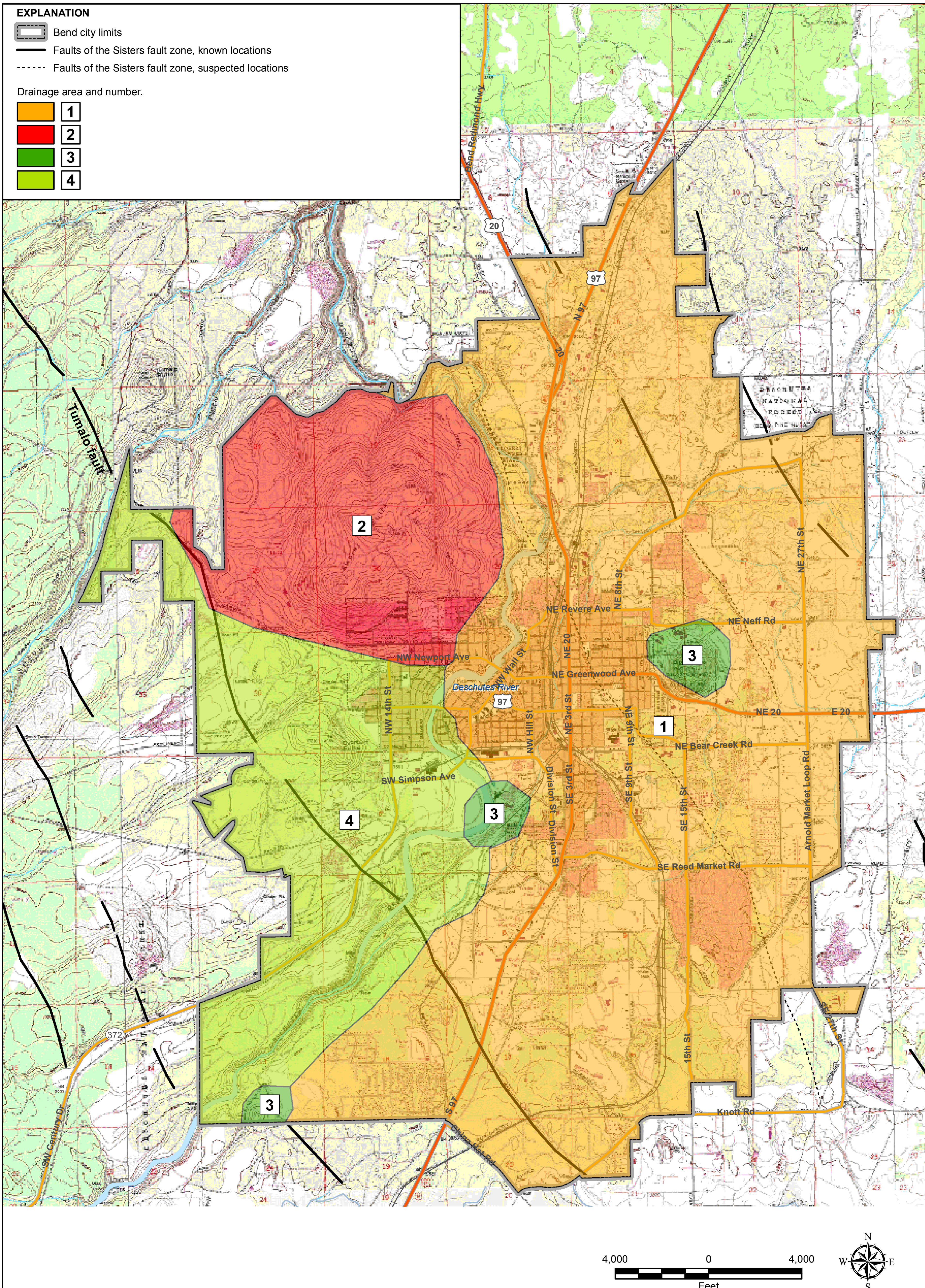
Figure 3

OfficeLocation : SPO Path: P:\12098004\00\GIS\1209800400Figure4.mxd Map Revised: April 3,2007



Reference: Geology from U.S. Geological Survey Open-File Report 03-67 (revised 1/5/2005).
U.S. topographic map from TerraServer (obtained Janaury 2007).

Notes:
1. The locations of all features shown are approximate.
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Drainage Areas

Bend Stormwater Master Plan
Bend, Oregon

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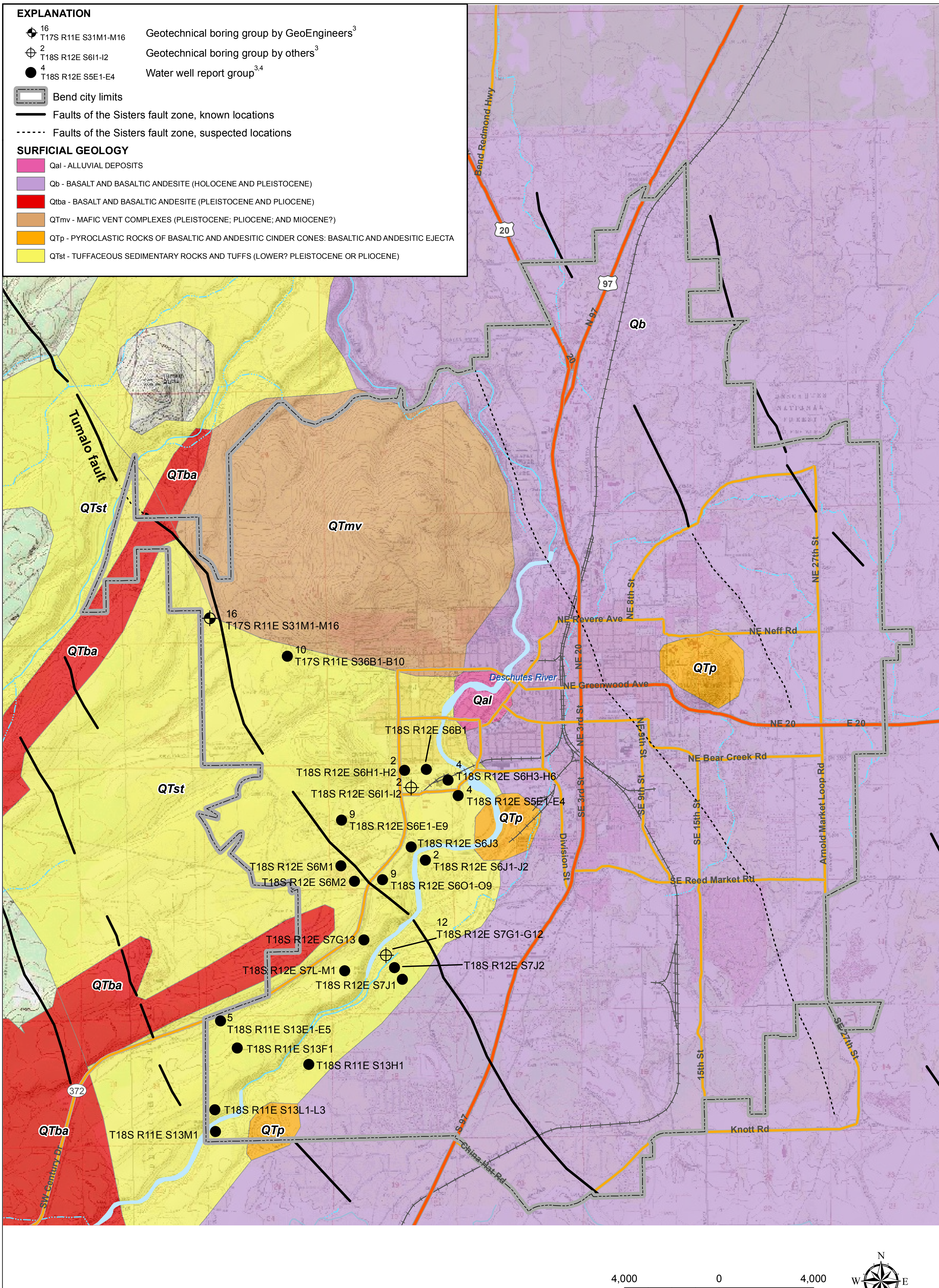
Figure 4



Reference: Geology from U.S. Geological Survey Open-File Report 03-67 (revised 1/5/2005).
U.S. topographic map from TerraServer (obtained Janaury 2007).

Notes:
1. The locations of all features shown are approximate.
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3. Superscript denotes number of borings or water well reports per group location. Subscript denotes boring or water well report group identification composed of group Township, Range, Section, and Subsection.
4. Well logs obtained from Oregon Water Resources Department, www.wrd.state.or.us.

Geotechnical Report and Water Supply Well Locations

Bend Stormwater Master Plan
Bend, Oregon

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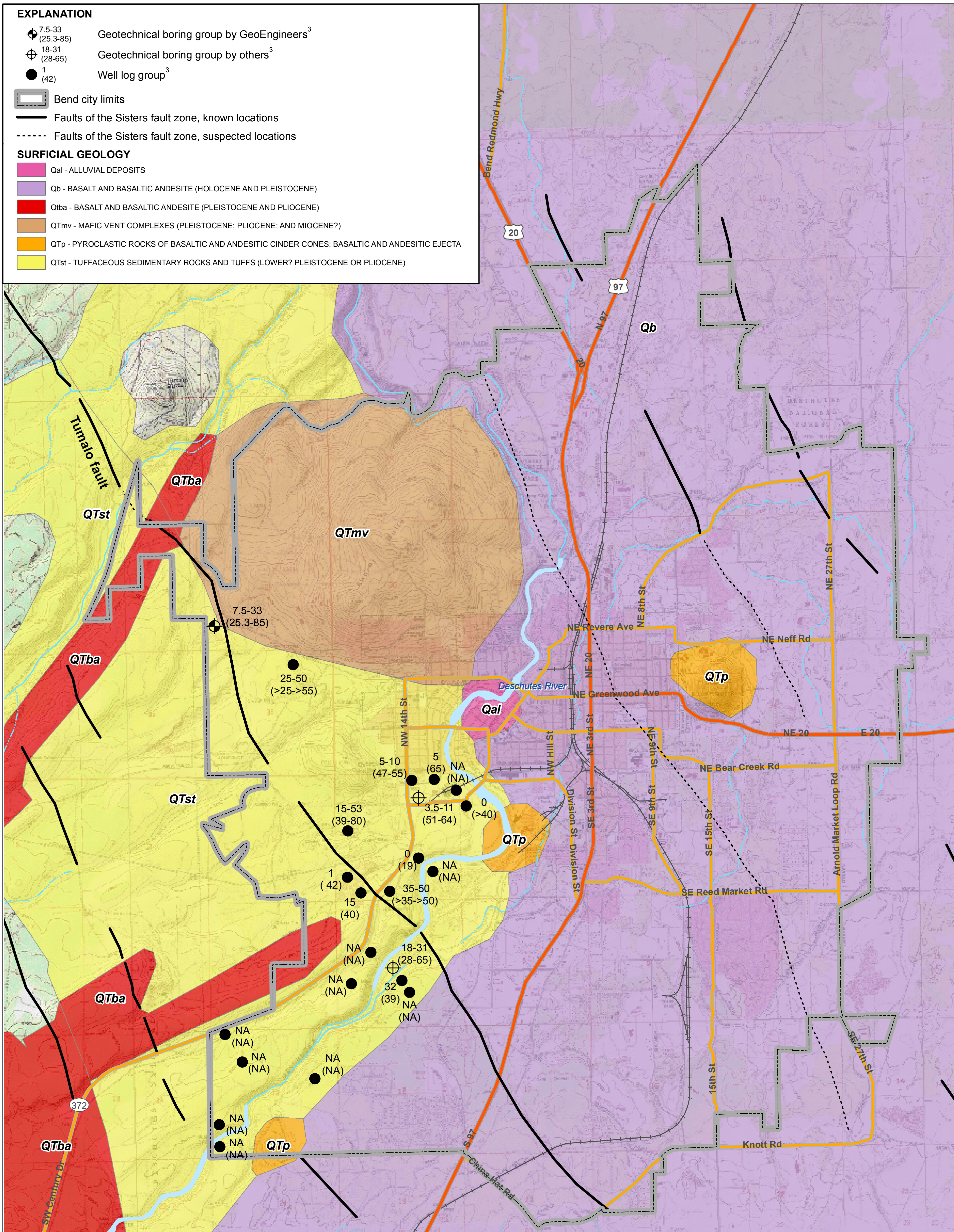
Figure 5

OfficeLocation : SPO   Path: P:\12098004\00\GIS\1209800400Figure6.mxd   Map Revised: April 3,2007



Reference: Geology from U.S. Geological Survey Open-File Report 03-67 (revised 1/5/2005).
U.S. topographic map from TerraServer (obtained Janaury 2007).

Notes:
1. The locations of all features shown are approximate.
2. This drawing is for infomation purposes. It is intended to assist in showing features discussed in an attached document. GeoEngineers, Inc. can not guarantee the accuracy and content of electronic files. The master file is stored by GeoEngineers, Inc. and will serve as the official record oth this communication.
3. Depths to top and bottom (in parentheses) of tuff layer given in feet.
4. Our interpretation of tuff layer, stated as another name in well logs.
5. Excavations only reached 20 feet in depth.

"NA" = Tuff not encountered. ">" = Bottom of the tuff layer was not penetrated.

Approximate Depths to Top and Bottom of Tuff

Bend Stormwater Master Plan
Bend, Oregon

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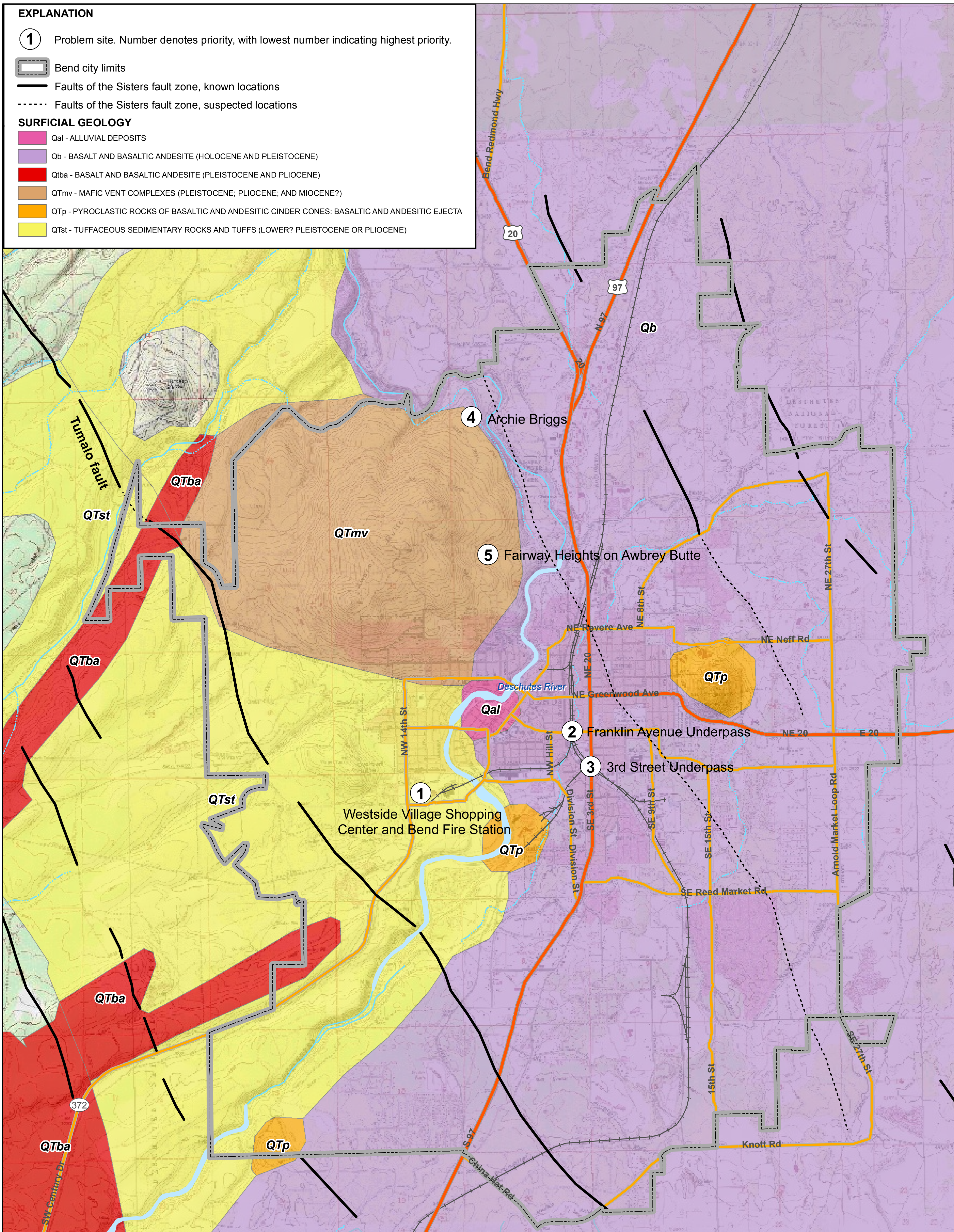
Figure 6



Reference: Geology from U.S. Geological Survey Open-File Report 03-67 (revised 1/5/2005).
U.S. topographic map from TerraServer (obtained Janaury 2007).

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Highest Priority Existing Problem Sites

Bend Stormwater Master Plan
Bend, Oregon

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Figure 7

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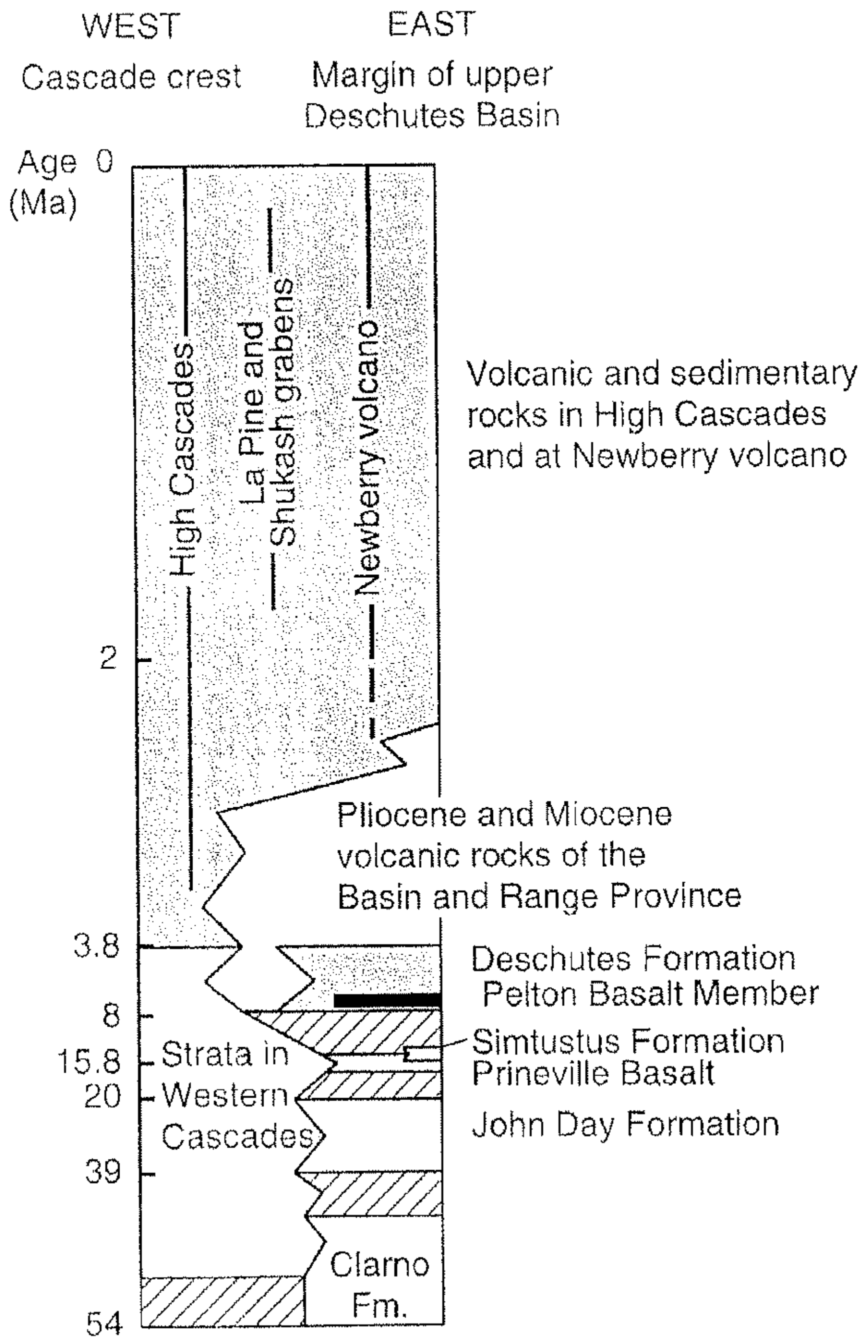
Appendix A
Stratigraphic Section



Generalized stratigraphic column for the upper Deschutes Basin. Diagonal pattern indicates nondeposition. Several names have descriptive geographic value but do not designate formally defined stratigraphic units.

Figure and abbreviated caption from Sherrod et al. (2002).

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APPENDIX B

REPORT LIMITATIONS AND GUIDELINES FOR USE

APPENDIX B
REPORT LIMITATIONS AND GUIDELINES FOR USE[1]

This appendix provides information to help you manage your risks with respect to the use of this report.

GEOTECHNICAL SERVICES ARE PERFORMED FOR SPECIFIC PURPOSES, PERSONS AND PROJECTS

This report has been prepared for use by URS and the City of Bend. This report may be made available in its entirety to contractors for information only. This report is not intended for use by others, and the information contained herein is not applicable to other sites.

GeoEngineers structures our services to meet the specific needs of our clients. For example, a geotechnical or geologic study conducted for a civil engineer or architect may not fulfill the needs of a construction contractor or even another civil engineer or architect that are involved in the same project. Because each geotechnical or geologic study is unique, each geotechnical engineering or geologic report is unique, prepared solely for the specific client and project site. No one except URS and the City of Bend should rely on this report without first conferring with GeoEngineers. This report should not be applied for any purpose or project except the one originally contemplated.

A GEOTECHNICAL ENGINEERING OR GEOLOGIC REPORT IS BASED ON A UNIQUE SET OF PROJECT-SPECIFIC FACTORS

This report has been prepared for URS and the City of Bend. GeoEngineers considered a number of unique, project-specific factors when establishing the scope of services for this project and report. Unless GeoEngineers specifically indicates otherwise, do not rely on this report if it was:

- not prepared for you,
- not prepared for your project,
- not prepared for the specific site explored, or
- completed before important project changes were made.

For example, changes that can affect the applicability of this report include those that affect:

- the function of the proposed structure;
- elevation, configuration, location, orientation or weight of the proposed structure;
- composition of the design team; or
- project ownership.

If important changes are made after the date of this report, GeoEngineers should be given the opportunity to review our interpretations and recommendations and provide written modifications or confirmation, as appropriate.

[1] Developed based on material provided by ASFE, Professional Firms Practicing in the Geosciences; www.asfe.org .

SUBSURFACE CONDITIONS CAN CHANGE

This geotechnical or geologic report is based on conditions that existed at the time the study was performed. The findings and conclusions of this report may be affected by the passage of time, by manmade events such as construction on or adjacent to the site, or by natural events such as floods, earthquakes, slope instability or groundwater fluctuations. Always contact GeoEngineers before applying a report to determine if it remains applicable.

MOST GEOTECHNICAL AND GEOLOGIC FINDINGS ARE PROFESSIONAL OPINIONS

Our interpretations of subsurface conditions are based on field observations from widely spaced sampling locations at the site. Site exploration identifies subsurface conditions only at those points where subsurface tests are conducted or samples are taken. GeoEngineers reviewed field and laboratory data and then applied our professional judgment to render an opinion about subsurface conditions throughout the site. Actual subsurface conditions may differ, sometimes significantly, from those indicated in this report. Our report, conclusions and interpretations should not be construed as a warranty of the subsurface conditions.

GEOTECHNICAL ENGINEERING REPORT RECOMMENDATIONS ARE NOT FINAL

Do not over-rely on the preliminary construction recommendations included in this report. These recommendations are not final, because they were developed principally from GeoEngineers' professional judgment and opinion. GeoEngineers' recommendations can be finalized only by observing actual subsurface conditions revealed during construction. GeoEngineers cannot assume responsibility or liability for this report's recommendations if we do not perform construction observation.

Sufficient monitoring, testing and consultation by GeoEngineers should be provided during construction to confirm that the conditions encountered are consistent with those indicated by the explorations, to provide recommendations for design changes should the conditions revealed during the work differ from those anticipated, and to evaluate whether or not earthwork activities are completed in accordance with our recommendations. Retaining GeoEngineers for construction observation for this project is the most effective method of managing the risks associated with unanticipated conditions.

A GEOTECHNICAL ENGINEERING OR GEOLOGIC REPORT COULD BE SUBJECT TO MISINTERPRETATION

Misinterpretation of this report by other design team members can result in costly problems. You could lower that risk by having GeoEngineers confer with appropriate members of the design team after submitting the report. Also retain GeoEngineers to review pertinent elements of the design team's plans and specifications. Contractors can also misinterpret a geotechnical engineering or geologic report. Reduce that risk by having GeoEngineers participate in pre-bid and preconstruction conferences, and by providing construction observation.

DO NOT REDRAW THE EXPLORATION LOGS

Geotechnical engineers and geologists prepare final boring and testing logs based upon their interpretation of field logs and laboratory data. To prevent errors or omissions, the logs included in a geotechnical engineering or geologic report should never be redrawn for inclusion in architectural or other design drawings. Only photographic or electronic reproduction is acceptable, but recognize that separating logs from the report can elevate risk.

GIVE CONTRACTORS A COMPLETE REPORT AND GUIDANCE

Some owners and design professionals believe they can make contractors liable for unanticipated subsurface conditions by limiting what they provide for bid preparation. To help prevent costly problems, give contractors the complete geotechnical engineering or geologic report, but preface it with a clearly written letter of transmittal. In that letter, advise contractors that the report was not prepared for purposes of bid development and that the report's accuracy is limited; encourage them to confer with GeoEngineers and/or to conduct additional study to obtain the specific types of information they need or prefer. A pre-bid conference can also be valuable. Be sure contractors have sufficient time to perform additional study. Only then might an owner be in a position to give contractors the best information available, while requiring them to at least share the financial responsibilities stemming from unanticipated conditions. Further, a contingency for unanticipated conditions should be included in your project budget and schedule.

CONTRACTORS ARE RESPONSIBLE FOR SITE SAFETY ON THEIR OWN CONSTRUCTION PROJECTS

Our geotechnical recommendations are not intended to direct the contractor’s procedures, methods, schedule or management of the work site. The contractor is solely responsible for job site safety and for managing construction operations to minimize risks to on-site personnel and to adjacent properties.

READ THESE PROVISIONS CLOSELY

Some clients, design professionals and contractors may not recognize that the geoscience practices (geotechnical engineering or geology) are far less exact than other engineering and natural science disciplines. This lack of understanding can create unrealistic expectations that could lead to disappointments, claims and disputes. GeoEngineers includes these explanatory “limitations” provisions in our reports to help reduce such risks. Please confer with GeoEngineers if you are unclear how these “Report Limitations and Guidelines for Use” apply to your project or site.

GEOTECHNICAL, GEOLOGIC AND ENVIRONMENTAL REPORTS SHOULD NOT BE INTERCHANGED

The equipment, techniques and personnel used to perform an environmental study differ significantly from those used to perform a geotechnical or geologic study and vice versa. For that reason, a geotechnical engineering or geologic report does not usually relate any environmental findings, conclusions or recommendations; e.g., about the likelihood of encountering underground storage tanks or regulated contaminants. Similarly, environmental reports are not used to address geotechnical or geologic concerns regarding a specific project.