ABSTRACT

The Pacific Northwest Center for Geologic Mapping Studies (GeoMapNW), a research center within the Earth and Space Sciences Department at the University of Washington, develops and conducts high-resolution geologic mapping informed by a database of geotechnical boreholes. These maps, database, and derivative products, currently available for the Seattle area, constitute one of the most comprehensive set of geologic information available for an urban area in the U.S. and as such provide the basis for detailed seismic shaking maps, landslide hazard maps, groundwater studies, engineering studies, transportation planning, and geological hazard assessments. GeoMapNW also conducts geologic research fundamental to understanding our earth materials and maintains an outreach program for technical and lay audiences. All data maps, and 3-D visualizations are available through the internet and are heavily used by government and private parties alike.

1. INTRODUCTION

Geologic maps are the foundation for making geologic hazard maps. They are also the foundation for making landslide hazard maps, building surface-water and groundwater models, evaluating infiltration and contamination, finding natural resources, and determining strength of earth materials. When we combine geologic maps with subsurface databases we then have the ability to: evaluate aquifer susceptibility to contamination, find earthquake faults, and make earthquake shaking maps. Geologic maps are THE initial and fundamental source of information used by engineers and planners to find sites for new buildings, highways, tunnels, sewage treatment plants, and critical facilities. If the maps are wrong, then the basis for initial site selection may be wrong.

GeoMapNW recently developed high-resolution geological mapping techniques that allow users to view the geology of Seattle and Mercer Island in 3-D, at the scale of a city block, and even look beneath the ground. These techniques and products were developed in collaboration with the City of Seattle and Mercer Island and the U.S. Geological Survey (USGS). With detailed geologic maps, detailed hazards maps, like seismic shaking maps, and landslide probability maps, have been developed that are extremely beneficial for mitigation planning and emergency response. The cities have been able to assess the vulnerability of their utility lines to earthquake shaking by using the subsurface database and new digital geologic maps. More importantly, the cities use the maps and database daily to provide baseline information for permit evaluations, development planning, and as a basis for critical areas ordinances. Professional geologists and engineers rely on these products for their basic understanding of ground conditions.

2. STAKEHOLDER NEEDS

Communication with stakeholders is an integral part of the research Center for several reasons including: our goals of making useful maps and making a contribution to society, and obtaining funding. So who are the stakeholders and what do they need? The stakeholders are simply the users and funders of the maps and geodatabase. If the fundamental geologic information is obtained, then many products can be produced that will satisfy multiple users’ needs.

The stakeholders need: high-resolution geologic maps; derivative maps; subsurface maps and models; easy-access-to maps, data, and queries, and help using the maps and data. They need geologic products that will help them with policy and review. They need “Best Available Science”, help with critical areas ordinances, help defining aquifer recharge areas, and help with mitigation. In the Pacific Northwest, most stakeholders are asking for two types of derivative maps: infiltration/groundwater and geologic hazards. For any jurisdiction within the state of Washington, the Growth Management Act dictates that Geologic Hazards be addressed. Therefore, maps showing hazards from tsunamis runup, liquefaction, fault rupture and earthquake shaking, landsliding, seiche impacts, and volcanic effects are desired. For groundwater and surface-water evaluation purposes, aquifer mapping, locations of possible groundwater surface-water
interactions, aquifer susceptibility to contamination, and infiltration mapping are required. For land-use planning and redevelopment, maps showing infiltration potential, critical areas (geologically hazardous areas), and geology by strength of material are requested. Often, making these maps available is the key to winning partnerships. With high-resolution geologic maps, having a subsurface database by definition, means that these products are all easily obtained.

Figure 1. (A) Status of database with locations of boreholes (small dots). (B) Status of high-resolution geologic mapping

3. GEODATABASE

The geodatabase has grown well beyond the city limits of Seattle, the first area to be mapped. Figure 1 shows the extent of coverage of the subsurface database that is used to support the high-resolution geologic mapping and the extent of completed and in-progress mapping. The database contains approximately 76,900 boreholes, most of which are geotechnical boreholes (52%), many are test pits (39%), only 6% are water well logs, and less than 2% are CPTs, probes, and vactor holes. All of the layer data have been entered for the boreholes and the material descriptions are parsed for normalization since the database contains logs from 475 unique authors. Seventy percent of the boreholes are less than 8 m in depth, but over 5000 boreholes are over 35 m in depth. In highly populated areas, the average data density is 116 points/km² (300 points/mi²) like shown in Figure 2. In rural areas, the average data density is 20 points/km² (50 points/mi²). Geotechnical boreholes are obtained from publicly available sources, such as building and transportation departments. Some consulting firms have offered and even provided copies of their report files.
4. HIGH-RESOLUTION GEOLOGIC MAPPING

The geology of our region hasn’t changed but our ability to interpret the geology, find geologic information, and depict the geology on maps has improved tremendously. Many of Washington’s urban areas were mapped decades ago at small scales (large areas, but less detail) and those geologic maps don’t show any faults. Today we know of 12 active faults just in the Puget Lowland and none of these are shown on the geologic maps, until the most recent of maps, those with 2005 or younger publication dates.

Seattle and Mercer Island were recently remapped using high-resolution geologic mapping, conducted in collaboration with the City of Seattle City of Mercer Island and the USGS to provide the basis for new hazard maps for the City to mitigate and reduce costs from geologic hazards. This technique has resulted in a reclassification (new geologic unit assignment) over as much as 50 to 70% of the land area. High-resolution geologic mapping consists of: building a subsurface database of geotechnical boreholes and water wells (example map at left), new field mapping, integration with geophysical findings, and making a large-scale digital geologic map integrating all these data.

In Seattle the differences between the pre-existing geologic map (1962) and the new map (2005) are striking, Figure3. By comparison to the old map, the new map has:

- 22% more land area potentially susceptible to ground failure from earthquake shaking
- 28% more sandy ground (28% less clayey ground), more places where water (and contamination) could potentially infiltrate into underlying aquifers (map next page)
- 9% land area mapped as landslide debris, none was mapped before
- the Seattle fault zone
- 51 geologic units or layers, the old map had 18, nearly 3 times the geologic units

The types and degree of changes seen on the new Seattle map are consistent with the changes seen on all of the new high-resolution geologic maps completed thus far. The old maps are being replaced with new digital geologic maps showing much greater detail, more sandy ground, more landslides, ability to show landfill areas, mapping geologic materials beneath filled areas, delineating more peat bogs, and more ground susceptible to failure during an earthquake. These types of map changes have prompted many other jurisdictions to be interested in having a high-resolution geologic map and geodatabase for their city/county.

5. 3-D MODELING AND VISUALIZATION

3-D visualization and subsurface modeling are essential tools for stakeholders. Here an image of Mercer Island shows how 3-D visualization helps with interpretation and explanation (Figure 4a). The boreholes can

Figure 2 Example of database coverage for northern Mercer Island: circles = boreholes, circles with dots = field exposures, squares = test pits, half black circles = water wells.
be viewed in 3-D as well, (Figure 4a) Digital geologic maps can be easily converted and added to Google Earth and Microsoft Virtual Earth for internet browsing, tilting, and rotating (Figure 4c).

Figure 3. Geologic map from Troost et al., 2005. Warm colors=post glacial and recessional outwash deposits, purple=till and till-like deposits, light blue=advance outwash, greens=older glacial and interglacial deposits, red=bedrock

6. DERIVATIVE MAPPING

As important as detailed geologic maps are, the most helpful maps for many stakeholders are derivative maps. They want maps that are interpretive in nature; maps that can be used directly for land-use planning, policy making, or emergency response planning for example.

The Pacific Northwest Seismograph Network, with the USGS and Washington Geological Survey, has developed a high resolution ShakeMap using the high resolution geologic map of Seattle and there is interest in improving the validity of ShakeMap for the rest of the urban corridor beyond Seattle. ShakeMap Seattle relied on another derivative map that shows the depth of glacially- overridden deposits, or depth of the strong ground, Figure 5a. In addition to SHakeMap, the USGS was able to produce a set of acceleration maps for Seattle, part of the seismic hazard maps for Seattle, Figure 5b.

One of the most requested maps in the Pacific Northwest is one showing infiltration potential because of the amount of development, heavy rainfall, the need to address surface runoff, and the issues surrounding salmon. An example from Seattle is shown as Figure 6.
CONCLUSIONS AND GOALS

Having high-resolution geologic maps and an active outreach program has elevated the general understanding of geology in our region. Having web access to boreholes and geologic data has also been a factor in raising the bar in the quality of the geologic reports in our region. So, we (the collective we) know we are doing something right. We must continue to partner with our stakeholders to provide useful maps and products that will benefit society, our ultimate users. We must provide continuing support for those products via education, web access, and finding better ways to display our data. Future efforts must look toward developing user friendly, inexpensive 3-D visualization and interactive tools for the internet. And we must combine efforts to develop repositories for all types of borehole data.
Figure 5. (A) Map showing depth to glacially-overridden deposits, obtained from the geodatabase. (B) Urban amplification map for Seattle, an example of a derivative map product.

Figure 6. Change in preliminary infiltration based on surficial geology from the 1962 and the 2005 maps.