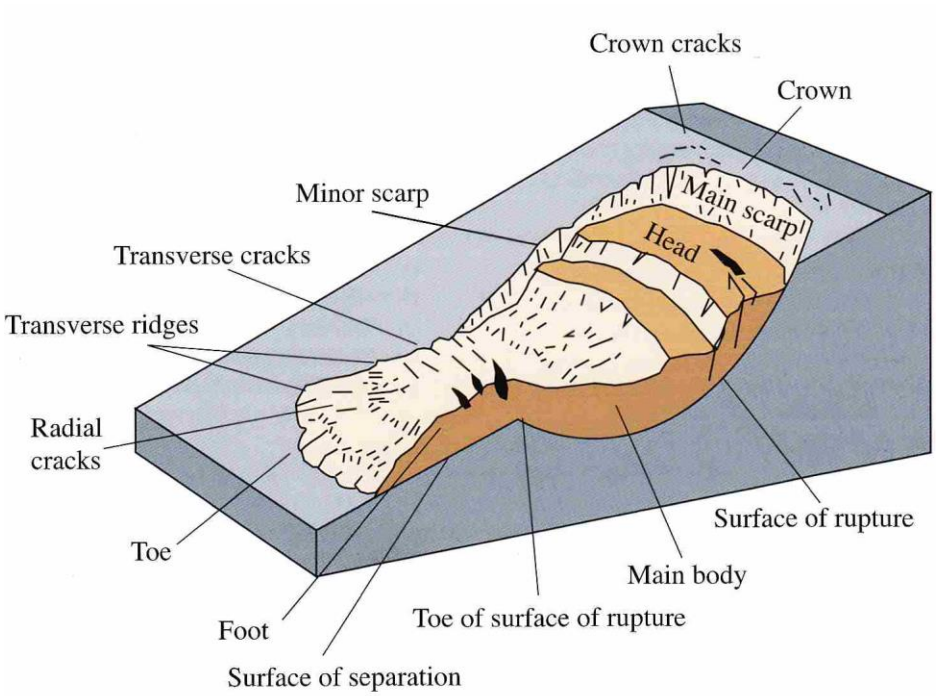
9.0 LANDSLIDES

9.1 Landslide Overview and Definitions

The term “landslide” refers to a variety of slope instabilities that result in the downward and outward movement of slope-forming materials, including rocks, soils, and vegetation. Many types of landslides are differentiated based on the types of materials involved and the mode of movement.

The descriptive nomenclature for landslides is summarized in the following figure.

Figure 11.1
Landslide Nomenclature[1]



Debris flows and mudslides (mudflows) are often differentiated from the other types of landslides, for which the sliding material is predominantly soil and/or rock. Debris flows and mudslides typically have high water content and may behave similarly to floods. However, debris flows may be much more destructive than floods because of their higher densities, high debris loads, and high velocities.

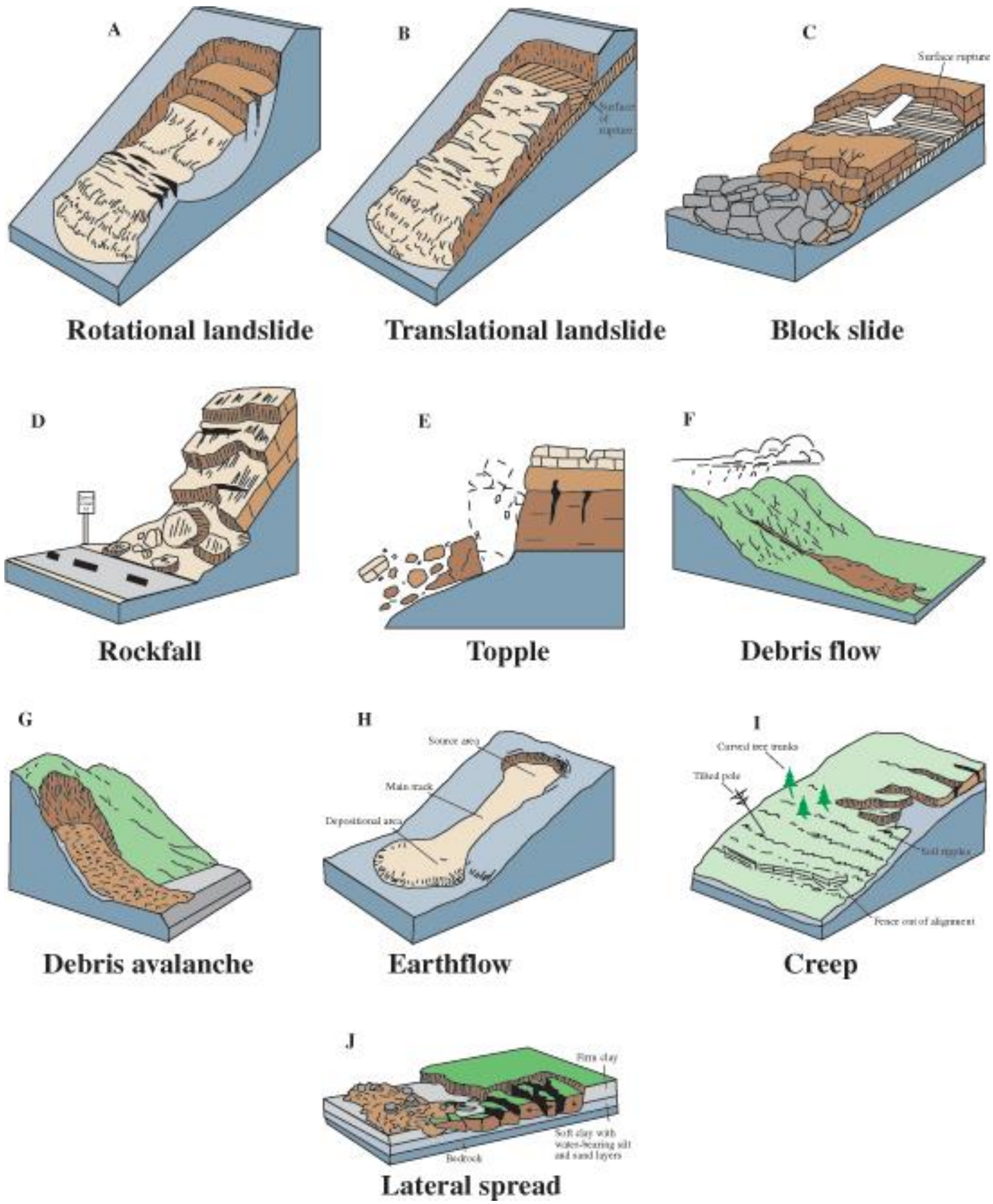
There are three main factors that determine the susceptibility (potential) for landslides at a given location:

1) Slope,

2) Soil/rock characteristics, and

3) Water content.

Figure 9.2
Major Types of Landslides[1]



Steeper slopes are more prone to all types of landslides. Loose, weak rock or soil is more prone to landslides than are competent rocks or dense, firm soils. Water saturated soils or rocks with a high water table are much more prone to landslides because the water pore pressure decreases the shear strength of the soil or rock and thus increases the probability of sliding.

Most landslides occur during rainy months when soils are saturated with water. As noted previously, the water content of soils or rock is a major factor in determining the likelihood of sliding for any given landslide-prone location. However, landslides may occur at any time of year, in dry months as well as in rainy ones.

Landslides are also commonly initiated by earthquakes. Areas prone to seismically triggered landslides are exactly the same as those prone to ordinary (non-seismic) landslides. As with ordinary landslides, seismically triggered landslides are more likely from earthquakes that occur when soils are saturated with water.

Any type of landslide may result in damages or complete destruction of buildings in their path, as well as deaths and injuries for building occupants. Landslides frequently cause road blockages by depositing debris on road surfaces or road damage if the road surface itself slides downhill. Utility lines and pipes are also prone to breakage in slide areas.

The destructive power of major landslides was demonstrated by the devastating March 2014 landslide in Oso, Washington which resulted in several dozen deaths as well as extreme damage to buildings and infrastructure. This landslide is illustrated on the following page.

The following figures show examples of landslides in Washington State.

Figure 9.3
Oso Landslide 2014[3]
Before and After the Landslide
Landslide Type: Debris Flow (Mudslide)

Figure 9.4
Road 170 Near Basin City 2006[4]
Landslide Type: Debris Flow

Figure 9.5
Highway 410 Near Town of Nile 2009[5]
Landslide Type: Translational

Figure 9.6
Rolling Bay, Bainbridge Island 1997[2]
Landslide Type: Debris Flow

9.2 Landslide Hazard Mapping and Hazard Assessment

There are two approaches to landslide hazard mapping and hazard assessment:

- Mapping historical landslides, which also provides an indication of the potential for future landslides, and
- Landslide studies by geotechnical engineers to estimate the potential for future landslides.

Maps of areas within Washington with moderate or high landslide incidence and landslide potential are shown in Figures 11.7 and 11.8.

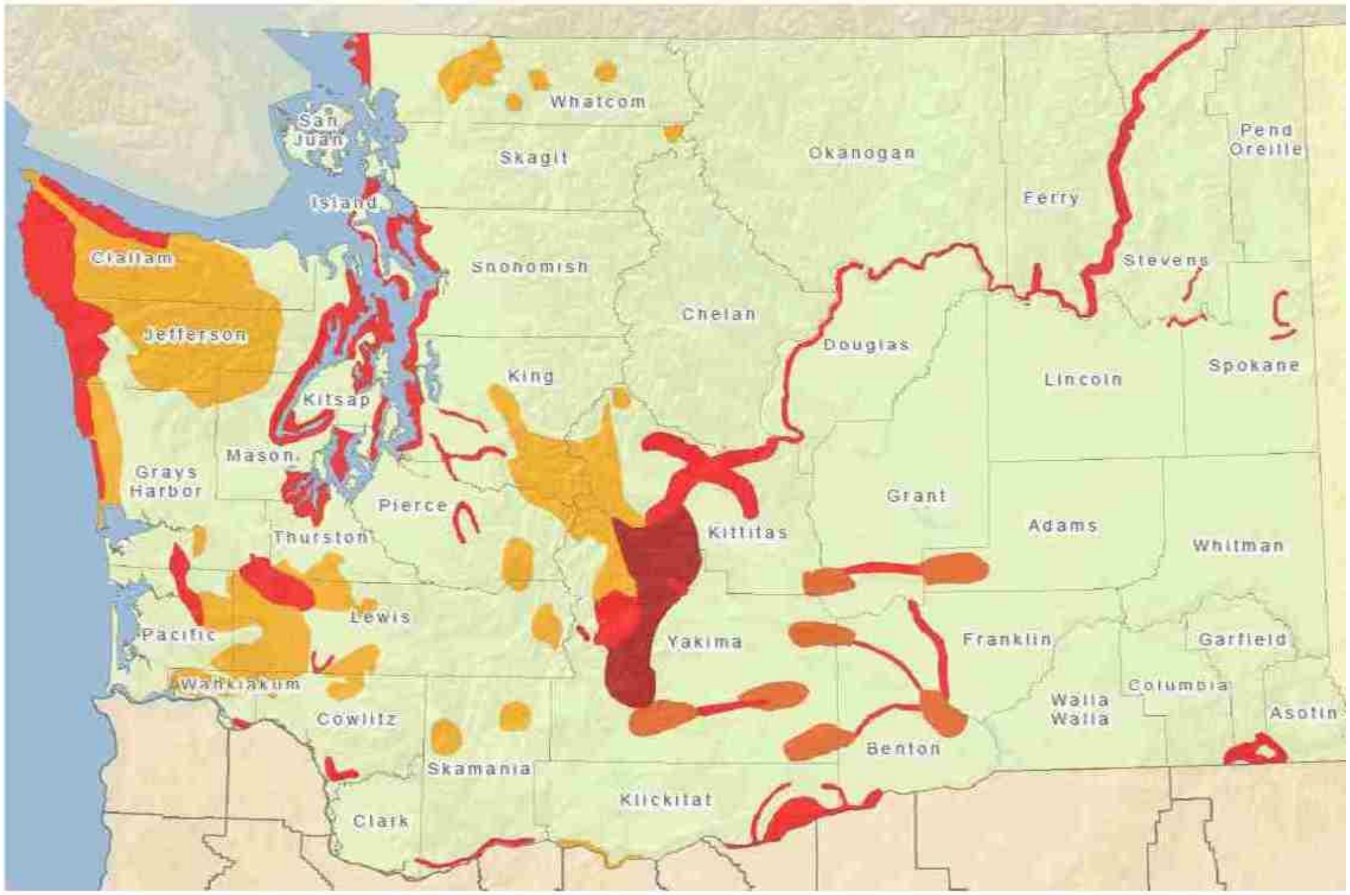
A more accurate understanding of the landslide hazard for a given campus requires a more detailed landslide hazard evaluation by a geotechnical engineer. Such site-specific studies evaluate the slope, soil/rock, and groundwater characteristics at specific sites. Such assessments often require drilling to determine subsurface soil/rock characteristics.

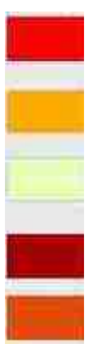
An important caveat for landslide hazard assessments is that, even with detailed site-specific evaluations by a geotechnical engineer, there is inevitably considerable uncertainty. That is, it is very difficult to make quantitative predictions of the likelihood or the size of future landslide events. In some cases, landslide hazard assessments by more than one geotechnical engineer may reach conflicting opinions.

These limitations and uncertainties notwithstanding, a detailed site-specific landslide hazard assessment does provide the best available information about the likelihood of future landslides. For example, such studies can provide enough information to determine that the landslide risk is higher at one location than another location and thus provide meaningful guidance for siting future development.

Given the above considerations, landslide hazard and risk assessments are generally qualitative or semi-quantitative in nature.

Figure 9.7
Landslide Incidence and Potential[2]





High Incidence: >15% of area involved

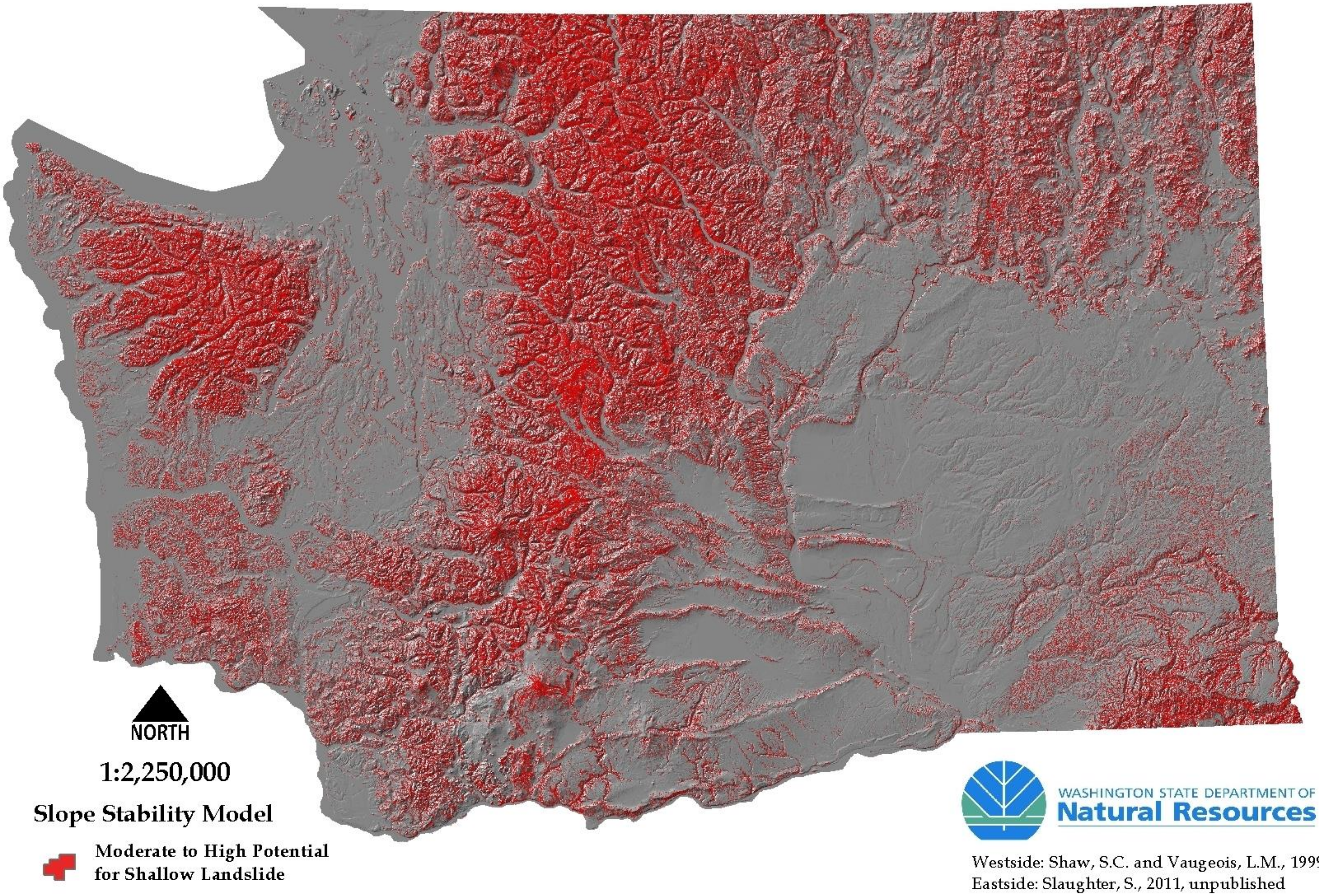
Moderate Incidence: 1.5% to 15% of area involved

Low Incidence: <1.5% of area involved

High Susceptibility

Moderate Susceptibility

Figure 9.8
Department of Natural Resources – Landslide Potential Map[5]



9.3 Toledo School District: Landslide Hazard and Risk Assessment

The potential impacts of future landslides on the Toledo District include deaths and injuries, primarily damage to buildings and contents (include possible complete destruction), disruption of educational services, and displacement costs for temporary quarters if some buildings have enough damage to require moving out while repairs are made.

The vulnerability of the Toledo District's facilities to landslides varies from campus to campus. The approximate levels of landslide hazards and vulnerability are identified at the campus level in the following sections.

Campus-level landslide hazard and risk assessments are made in the OSPI ICOS Pre-Disaster Mitigation database, using the following data:

- Slope data in the vicinity of each campus, from digital elevation data for the campus and a grid of data points in the north, south, east, and west directions from the campus.
- Whether or not the campus is within 500 feet of a DNR mapped landslide.
- Information provided by the Toledo School District.
    - Are there channels, gullies, or swales upslope from the campus?
    - Are there slumps or historical landslides upslope from the campus?
    - Are there buildings <50 feet from a deeply incised stream or other steep slopes?

The preliminary landslide hazard level is based on slope data only:

Slope	Preliminary Landslide Hazard Level
>40%	High
30% to 40%	Moderate
20% to 30%	Low
<20%	Very Low

The preliminary screening for landslide hazards for the Toledo School District, as described above, did not identify any campuses with significant landslide risk.

However, there are two locations where the landslide risk may be significant, although the steep slopes were too small to be identified on the preliminary screening described above.

- The slope between the cemetery and the campus on the north side of the Middle School campus. This steep slope, which is approximately 15 feet high, has shown evidence of slumping.
- The steep slope adjacent to the south side of the Middle School building.

11.4 Mitigation of Landslide Risk

Mitigation of landslide risks is often difficult from both the engineering and cost perspectives. In many case, there may be no practical landslide mitigation measure. In some cases, mitigation may be possible. Typical landslide mitigation measures include the following:

- Slope stability can be improved by the addition of drainage to reduce pore water pressure and/or by slope stabilization measures, including retaining walls, rock tie-backs with steel rods, and other geotechnical methods.
- For smaller landslides or debris flows, protection for existing facilities at risk may be increased by building diversion structures to deflect landslides or debris flows around an at risk facility.
- For very high risk facilities, with a high degree of life safety risk, abandoning the facility and replacing it with a new facility may be the only possible landslide mitigation measure.
- For new construction, siting facilities outside of landslide hazard areas is the most effective mitigation measure.

The Toledo School District’s mitigation Action Items for landslides are shown in the table on the following page.

Table 11.2
Toledo School District: Landslide Mitigation Action Items

Hazard	Action Item	Timeline	Responsible Party	Plan Goals Addressed			
				Life Safety	Protect Facilities	Enhance Emergency Planning	Enhance Awareness and Education
Landslide Mitigation Action Items							
Short-Term #1	Consult with a geologist or geotechnical engineer regarding possible landslide risk from the steep slope on the south side of the Middle School	1-2 Years	Supt.	X	X	X	X
Short-Term #2	Complete slope stabilization of the slope between the cemetery and the Middle School campus by planting suitable, low-maintenance vegetation.	Ongoing	Supt.	X	X	X	X

The funding source for the two action items above will be District funds.

9.5 References.

1. United States Geological Survey (2004), Landslide Types and Processes, Fact Sheet 2004-3072.

2. Washington State Military Department, Emergency Management Division (2009), Hazard Identification and Vulnerability Assessment (HIVA).

3. Google Earth photos (2013 and 2014).

4. Washington State Enhanced Hazard Mitigation Plan, Section 5.6, Hazard Profile – Landslide, October 2010.

5. Photo by Washington Department of Natural Resources:

http://www.historylink.org/index.cfm?DisplayPage=output.cfm&file_id=9224

6. Washington Department of Natural Resources (2011), unpublished map: Slope Stability Model for Shallow Landslide Potential, West and East Side.