LANDSLIDE POTENTIAL IN
THE ATLANTIC HIGHLANDS OF NEW JERSEY

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Written under the direction of
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and approved by

[Signatures]

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ABSTRACT OF THE THESIS
Landslide Potential in
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Thesis director: Dr. Martha Hamil

A variety of landslides has damaged heavily many residences in the suburban communities between Atlantic Highlands and Waterwitch, New Jersey. Factor mapping provides inexpensive regional analysis of potential landsliding areas. Three factors, slope, geology and water, are crudely analogous to variables which a soil mechanics study considers. Slope, expressed as a percentage of a given horizontal distance, compares to engineering considerations of load and slope angle. Geologic unit roughly labels cohesion and angle of internal friction values for each formation. Relative water abundance approximates seepage force and indicates the position of a water table. Comparison of factors in landslide case histories with study area factors determines landslide potential.

Steep slopes of the Atlantic Highlands continue to have high landslide potential. Slope failure occurs mainly in the medium-grained sand of the Shrewsbury
Member of the Red Bank Sand Formation. Not only are the potential landsliding areas susceptible to the slump-type failure but also to other types of landsliding such as slow earthflows, debris slides and other complex landslide forms.
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INTRODUCTION

The Atlantic Highlands of New Jersey are sand hills on the southern side of Sandy Hook Bay and 32 kilometers south of New York City. (Fig. 1). Recently, houses on an escarpment that faces the bay have been damaged by movements in the escarpment soil and rock. Physical aspects of the landslides have been studied intensively since the last major event in 1972. The studies include engineering slope stability analysis presently in legal litigation and mapping of landslides (Minard 1969, 1974). The method used in this paper is factor mapping. It uses landform and surface measures that Blanc and Cleveland (1968) suggested for a regional study of landslide-prone areas in California. Nilsen and Brabb (1973) demonstrated a factor mapping technique in the San Francisco Bay area of California.

In discovering potential landslide areas, an objective was to provide a cogent investigative approach. This has been accomplished by using a topographic map and a geology map with field identification of landslides based on shape and with field recognition of relative surface water abundances. The data from these exercises has been interpreted by factors of
Figure 1: Topographic map of the Atlantic Highlands, New Jersey (after USGS, 1954). Contour interval is 6.1 meters (20 feet). The study area is enclosed within the box. Inset: Location of the Atlantic Highlands in New Jersey.

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landslide case histories. The result is a preliminary inexpensive regional tool that directs more detailed research into the best areas and locates areas where further development should be approached with caution.

GEOLOGIC SETTING

The Atlantic Highlands area receives its name from a group of high sandy hills that rise sharply between Sandy Hook Bay and the Navesink River near the Atlantic Ocean. The elevation of the broad summits of the hills commonly is 67 meters with a maximum elevation near Waterwitch, New Jersey of 81 meters. These elevations occur within 300 meters of Sandy Hook Bay forming a steep escarpment. Nearby elevations of coastal areas that are a similar distance from the Atlantic Ocean are 33 meters in Red Bank five kilometers to the south and 12 meters in Leonardo three kilometers to the west.

The Atlantic Highlands are the easternmost exposed portion of a gently dipping sequence of Late Cretaceous and Tertiary marine sediments (Minard, 1969). This sedimentary sequence forms marked relief along the strike of the Marshalltown Formation in the form of a cuesta (Widmer, 1964).
Most of the outcropping formations in the escarpment are composed of non-indurated quartz sand. However, two formations, the Navesink Formation and the Hornerstown Formation contain chiefly the dark green mineral, glauconite. Another formation, the Tinton Formation, is cemented by the iron oxide mineral, siderite. Minard (1969) has interpreted the grain sizes and mineralogy of the Atlantic Highlands in a geologic map and lithologic table (Fig. 2; Table 1).

PREVIOUS WORK

Much geologic and geographic work in the region focused on the nearby prominent sand bar, Sandy Hook, and gave only incidental attention to the Atlantic Highlands. Landslide occurrences were first mentioned in the early works by Barker and Howe (1844) who described a large rapid landslip that was reported by several witnesses. Cook (1885), in the Report of the State Geologist of that year, contributed a contour map and a cross-section of Sandy Hook Bay. The cross-section suggested landslide material on the Atlantic Highlands escarpment. Much geologic work on the Atlantic Highlands has been published recently (Minard, 1969; 1974). His first report, on the 7½
Figure 2: Geologic map of the Atlantic Highlands study area, New Jersey (after Minard, 1969). The box is an enlargement of the area enclosed in the box of Figure 1. The line passing through the box is the Sandy Hook Bay strand line.
<table>
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<tr>
<th>FORMATION GEOLOGIC NAME</th>
<th>AGE</th>
<th>GRANULE SIZE BY WEIGHT PERCENTAGE</th>
<th>GRANULE</th>
<th>VERY COARSE</th>
<th>MEDIUM FINE TO COARSE</th>
<th>MEDIUM FINE TO VERY FINE</th>
<th>SILT TO CLAY</th>
<th>MINERALOGY</th>
<th>THICKNESS IN METERS</th>
</tr>
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<tr>
<td>upper Colosey Fm.</td>
<td>Paleozoic</td>
<td>7</td>
<td>48</td>
<td>33</td>
<td>11</td>
<td>1</td>
<td>Quarts</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>lower</td>
<td></td>
<td>14</td>
<td>26</td>
<td>46</td>
<td>13</td>
<td>1</td>
<td>Quarts, Calcarenite cement locally. Clay-Kaolinite, Mica.</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Vincentown Fm.</td>
<td>Cretaceous</td>
<td>0</td>
<td>10</td>
<td>53</td>
<td>23</td>
<td>14</td>
<td>Glaucnite</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Hornerstown Fm.</td>
<td>Late Cretaceous</td>
<td>0</td>
<td>5</td>
<td>25</td>
<td>27</td>
<td>43</td>
<td>Clay-Glaucnite</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Tinton Fm.</td>
<td></td>
<td>0</td>
<td>12</td>
<td>18</td>
<td>38</td>
<td>32</td>
<td>Quartz, Glaucnite, Smearite cemented.</td>
<td>8</td>
<td></td>
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<tr>
<td>upper Shrewsbury Member</td>
<td>Cretaceous</td>
<td>0</td>
<td>16</td>
<td>52</td>
<td>24</td>
<td>18</td>
<td>Quartz, Feldspar, Clay-Quartz, Kaolinite</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>lower</td>
<td></td>
<td>0</td>
<td>10</td>
<td>50</td>
<td>30</td>
<td>10</td>
<td>Lessening Glaucnite</td>
<td>9</td>
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<tr>
<td>upper Sandy Hook Member</td>
<td>Cretaceous</td>
<td>0</td>
<td>2</td>
<td>18</td>
<td>53</td>
<td>27</td>
<td>Quarts, Glaucnite, Feldspar. Clay-Kaolinite, Smectite, Muscovite, Pyrite Carbonaceous material.</td>
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</tr>
<tr>
<td>lower</td>
<td></td>
<td>0</td>
<td>3</td>
<td>9</td>
<td>52</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>upper Navesink Fm.</td>
<td></td>
<td>0</td>
<td>35</td>
<td>25</td>
<td>10</td>
<td>30</td>
<td>Glaucnite, Clay-Kaolinite, Smectite, Chlorite.</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>lower</td>
<td></td>
<td>0</td>
<td>10</td>
<td>32</td>
<td>32</td>
<td>26</td>
<td>Increasing Glaucnite</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>upper Mt. Laurel</td>
<td></td>
<td>3</td>
<td>2</td>
<td>32</td>
<td>32</td>
<td>31</td>
<td>Quarts, Glaucnite, Clay-Quartz, Kaolinite, Lignite</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>lower</td>
<td></td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>54</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

After Minard, 1969, 1974
minute Sandy Hook Quadrangle, details geologic formations on dual bases of lithology and mineralogy and on fossil assemblages. Using Varnes (1958) classification, he delineated principle slump blocks. A subsequent report (Minard, 1974) analyzed these and other features to determine time relationships and motions within each block. Pschunder (1977) provided a soil mechanics method-of-slices solution for slope stability at a part of the escarpment which overlooks Waterwitch, New Jersey.

METHOD

Landslide Identification and Location

A geologic dictionary defines a landslide as "the perceptible downward sliding or falling of a relatively dry mass of earth, rock or mixture of the two" (American Geological Institute, 1962). It should be added that landsliding is distinguished from stream erosion by having a wider uphill portion relative to the lower portion of an affected slope.

Using a widely accepted landslide classification (Varnes, 1958), Minard (1969, 1974) recognized slump landslides in the Atlantic Highlands. This study also uses the classification. Varnes (1958) basis for the classification is landslide shape and type of material movement which
is related to landslide factors of slope, mechanical strength of rock and to water abundance.

Factor Mapping

In natural science, a factor is any entity that influences a physical or chemical process. A factor map shows a two-dimensional array of abundances or other evaluations of the factor. A potential landslide factor map shows an array of factor measures that may cause landsliding. Nilsen and Brabb (1973) suggested measuring of physical factors, slope and geologic formation in California. The California climate, however, does not include water as a factor because that climate is dry. Soil engineering and geological literature of more temperate climates, much like the climate of the Atlantic Highlands, includes water as a third physical factor. A discussion follows on the importance and possible roles of the three landslide factors in the Atlantic Highlands.

Slope

Generally, studies of landslide occurrences relate the event to the steepness of the slope. Steepness is a proportion of two dimensions, height and horizontal distance from the bottom to the top of the slope. Terzaghi (1959) expressed this proportion as the slope angle, $\theta$, 

which is the angle formed by the slope surface and a horizontal line at the top of the slope. Landslide potential was determined by a mathematical relationship of the slope angle to measures of soil strength. Sharpe (1938) suggested that landslides occur on steep slopes. His definition of landslide excluded slower flow forms such as slow earthflow which also occur on lesser slopes. Previous factor mapping exercises in California by Nilsen and Brabb (1973) and by Wilson et. al. (1976) examine slope as a percentage of vertical distance over horizontal distance. Nilsen and Brabb (1973) used a computerized analysis of special aerial photographs to produce slope percentage.

In the Atlantic Highlands, other workers have related slope steepness to landsliding. Minard (1974) speculated that ocean wave action had steepened portions of the escarpment enough to cause the first ancient landslides. Pschunder (1977) included a measure of slope steepness into slope stability calculations of his research in the escarpment.

In this study, standard sized square grids measuring 61 meters (200 feet) on a side facilitate slope percentage measurement. Slope factor values are obtained by overlaying a grid transparency on a 7½ minute topographic contour map (1954). By fixing a standard horizontal
distance, this type of measure of slope percentage considers height and therefore load as well as steepness. The grid method also compensates for not having the sophisticated machinery used by Nilsen and Brabb (1973) to analyze slope. Under this evaluation system, higher slope factors indicate a greater landslide potential due to greater steepness.

Water

Water is another factor that causes landslides. It may act in three places; within rock joints, soil pores or as an external erosion agent. Water has been included in many studies of landslides. Its roles depend on climate. Water action in landslides has been studied both in general terms and in specific case histories. Taylor (1948) studied seepage force of water in slopes formed in non-indurated sediments.

In the Atlantic Highlands, Minard (1974) suggested water as a cause of landsliding after reviewing lithology and permeability of the geologic formations. A soil mechanics engineering model of a site in the Atlantic Highlands by Pschunder (1977) made a similar conclusion about water.

Factor mapping in this study also considers water to be an important contributing factor to instability.
Review of a classic work (Terzaghi, 1950) on the potential roles of water in landsliding shows that Atlantic Highlands conditions allow water to destabilize the slopes. The conditions are presence of a fluctuating water table near the escarpment base, high porosities and great slope steepness. The associated destabilizing effects are additional load, seepage force, pressures which push the rock grains apart and lubrication of slip surfaces. Water has often been measured as a volume that is assumed to occupy all soil pores below a water table. This procedure cannot be used in the Atlantic Highlands because of local ordinances which ban digging in the hillsides. Abundances of water instead have been determined by the occurrence of surface sources, such as springs, pools and other surface forms.

Geology

Many landslide observers have studied geologic parameters. In areas primarily of cemented rock outcrop, structure and mechanical strength are deciding factors (Jahns and Wondr Linden, 1973). In areas of non-indurated rock, mineralogy, grain size distribution and grain arrangement are important (Sharpe, 1938). Different physical aspects are studied in geological units. Lambe and Whitman (1969) discuss friction between soil particles. Terzaghi and Peck (1967) also discuss a frictional variable.
RESULTS

Landslide Identification and Location

Four other kinds of landslides besides the slumps documented by Minard (1974) have been recognized in this research (Table 2). These landslides are found in additional locations to the landslide locations of Minard (1974) (Fig. 3). Generally, these additional landslide locations are smaller but do not appear to have begun recently.

Factor Maps

More than 500 observation grids, each measuring 61 meters on-a-side, cover three factors of slope, geology and water in the study area. Figure 4 shows how the slope factors have been evaluated in the Atlantic Highlands and shows their distribution. Figure 5 shows how the geologic formations in the study area have been identified in the observation grids and shows their distribution. Figure 6 shows how the water factors have been evaluated in the Atlantic Highlands and shows their distribution. Slope factors in the study area range from 0, indicating flat areas to 9 indicating a vertical distance that is 90 per cent of the grid side.
<table>
<thead>
<tr>
<th>TYPE OF MOVEMENT</th>
<th>LANDSLIDE CLASSIFICATION</th>
<th>FAILURE MOTION</th>
<th>ASSOCIATED LANDSLIDES</th>
<th>ACTIVITY AND SIZE IN THE ATLANTIC HIGHLANDS</th>
<th>RATE</th>
<th>CONTRAST TO VARNES (1958)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slide:</td>
<td>bench slump</td>
<td>Rotation of bottom of slide down and out along a wide area of a slope. Width exceeds length. Failure surface curved up.</td>
<td>earthflow at the bottom.</td>
<td>1972, 100 meters through shoreside residential area</td>
<td>1 minute to 1 day</td>
<td>Slow and sudden failure. ornaments at top</td>
</tr>
<tr>
<td></td>
<td>&quot;spoon-shaped&quot; slump</td>
<td>Same motion as bench slump. Length exceeds width.</td>
<td>earthflow at the bottom.</td>
<td>1972, 15 meters wide scarp, 46 meters length</td>
<td>1 minute to 1 day</td>
<td>Slow- not sudden failure. Springs at bottom</td>
</tr>
<tr>
<td></td>
<td>debris slide</td>
<td>Straight breakaway along a planar slightly curved surface. More broken-up material than in slump.</td>
<td>debris flow at bottom.</td>
<td>On going. Shown on 1943 Topographic map. 31 meters wide scarps and slope length. Shallow-affects soil and 3 meters into slope</td>
<td>Minutes to imperceptible</td>
<td>Slow- not sudden failure. Springs at bottom</td>
</tr>
<tr>
<td></td>
<td>sand run</td>
<td>Flow of particles as small stream.</td>
<td>----</td>
<td>Small areas affected.</td>
<td>Continuous</td>
<td>Grain by grain movement in other landslide scarps.</td>
</tr>
<tr>
<td>Flow:</td>
<td>broken-up mass</td>
<td>---</td>
<td>---</td>
<td>Slope walkways and retaining walls destroyed. Many damaged structures rotting and unused. Structures being pushed downhill. Damage of this kind also being done by creep.</td>
<td>Continuous</td>
<td>Some features immobile</td>
</tr>
<tr>
<td></td>
<td>between all particles in the landslide</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>Imperceptible</td>
<td>---</td>
</tr>
</tbody>
</table>

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Figure 3: List and map of landslide types in the Atlantic Highlands study area, New Jersey. Lineaments and features in parentheses are after Minard (1974).
Figure 5: Map of geology factor values in the Atlantic Highlands study area, New Jersey. Numbers identify the geologic formation that outcrops in each observation grid.
Figure 6: Map of water factor values in the Atlantic Highlands study area, New Jersey. Higher values indicate greater abundances of water coming out of the slope.

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High values of slope steepness which are greater than 3 are concentrated along the coast of Sandy Hook Bay and trend to the Southeast in the eastern portion of the study area. Moderately high slope factor values, which range in the 3 to 4 category are located in other isolated places in the study area. The most prevalent geologic unit in the study area is the Shrewsbury Member of the Red Bank Sand Formation. Outcrop diminishes at inland places where the Cohansy and Tinton formations outcrop. Water factors range from no trace to small rivulet discharges coming out of a slope. The factors are higher at the escarpment bottom near to but several meters in elevation above mean high tide of Sandy Hook Bay and follow a southeastward trend in the eastern part of the study area. Water is absent on the surface further inland except in the western portion of the study area.

DISCUSSION

This study interprets landslide potential from 3 physical factors, unlike California factor mapping studies which interpret 2 factors (Blanc and Cleveland, (1968); Nilsen and Brabb, (1973)). Nilsen and Brabb (1973) determined the effect of a geologic unit upon slope by finding the lowest slope angle at which failure
occurred in that given unit. With three factors, determining landslide potential cannot be achieved by making one adjustment, as was possible in California. The third factor in the Atlantic Highlands, water, sometimes causes landslides on more gentle slopes than on slopes where it is absent. Orderly interpretation of landslide potential from the factors is possible by adjusting expected factor ranges from landslide case histories to fit observed factor ranges of the study area landslides. Potential landslide areas have the same factor ranges as the areas in which landslides have already occurred.

Thirty-eight of the grids that were assigned to the study area contain landslides (Fig. 7). The factors of each grid fall into one of four groups of factor ranges which correspond to four groups of landslide case histories. The first case history group (Group I) states that landslides occur wherever there is a steep slope, susceptible geology and much water (Table 3). Abundance of all three factors ultimately causes the slope to fail. Lambe and Whitman (1969) document several case histories of this group that are "progressive failures" in overconsolidated clay. Terzaghi (1950) describes a similar rock landslide near Frank, Alberta. The Alberta slide occurred after a long period of mining
Figure 7: Landslide occurrences in the Atlantic Highlands study area, New Jersey (darkened observation grids).
landsides. The potential landslide areas lie topographically above the present landslide areas on the escarpment (Fig. 8). Eight grids are scattered outside and on the other side of the Atlantic Highlands from the escarpment.

One form of landsliding, slumping, especially concerns residents (Fig. 9) and landslide observers in the Atlantic Highlands. There are two types of slumps in the study area according to the classification by Varnes (1958). These types, bench-shaped slumps and spoon-shaped slumps, occur mainly under landslide case history groups I and II. The principles have steep slope as a common characteristic. Eighty-one grids locate potential slumping areas (Fig. 10). The grid distribution is similar to potential for all landslides (Fig. 8) with an exception that there are fewer potential slumping areas in the western portion of the study area. Only grids 5,19 to 5,25 are not included in groups I and II because slumps in those grids uniquely occurred in older landslide material. Continued landsliding potential of the landslide material is consistent with Blanc and Cleveland's (1968) expectation of landslides in old landslide material in California because of weakening by past movement. Twenty-four of the eighty-one potential slumping areas have had landslides. Only seven of these twenty-four grids have had slumps. This result contradicts Sharpe's (1938) contention that slump
Figure 10: Potential slumping areas in the Atlantic Highlands study area, New Jersey (darkened observation grids). Partially darkened grids indicate areas where slump landslides are expected to occur in old landslide material.

REHM, J.M., (1977)
variable. Blanc and Cleveland (1968) cite structure and location within a geological unit. Jahns and Vonder Linden (1973) mapped geological units as contributing factors to landslides in California.

In the Atlantic Highlands, Minard (1974) speculated that a chemical reaction between weathering products of the mineral, glauconite, and calcium minerals caused weakening of rock structure. This weakening in the Navesink Formation was supposed to precede slump-type landslides. No chemical data is available from the Atlantic Highlands to confirm this model of landsliding.

In the present study, geological formations are based on the map by Minard (1969) and are basic units of the geology factor. To record geological formations in the observation grids, the geology map was enlarged to twice its published size and then was overlaid with an observation grid transparency. The lowermost geological unit occupying at least one-third of any observation grid is the identified unit for each grid. Treating geological formations as distinct units is possible because Minard's (1969) geological formations are based on mineralogy, grain size and on cementation instead of on fossil assemblages, although fossil assemblages are coincident. As such, the geological formations are distinct from one
another. The Mount Laurel Formation is fine quartz sand with glauconite and clay. The Navesink Formation is medium and fine glauconite sand. The Sandy Hook Member of the Red Bank Sand Formation is a fine micaceous quartz and glauconite sand with clay. It also has abundant calcareous fossils and contains a water table that is apparent along the escarpment by numerous seeps. The Shrewsbury Member of the Red Bank Sand Formation is a loose medium quartz sand. The Tinton Formation is a fine iron oxide cemented quartz sand. The Hornerstown Formation is a weathered fine glauconite sand with clay. The Vincentown Formation is medium quartz sand. The Cohansey Formation is a cross-bedded pebbly medium and coarse quartz sand.

Soil mechanics data could probably distinguish the landslide potential of each geologic formation but, in the absence of such data, assigning stability values to each formation is difficult. Terzaghi and Peck (1967) do not compare stability calculations of sand and of clays to each other. It is probably correct to say only that the iron oxide cemented Tinton Formation is less likely to landslide than the non-indurated formations. Therefore, with all available data considered, identifying numbers label the formations.
activity and rainfall. In the study area 10 observation grids have factors that fit into this group of landsliding (Table 3).

Table 3: Observed factor ranges of landslide case history group I in the Atlantic Highlands, New Jersey.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Atlantic Highlands Factor Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steep Slope</td>
<td>$\geq 4$</td>
</tr>
<tr>
<td>Weak Geology</td>
<td>4, 5, 8</td>
</tr>
<tr>
<td>Much Water</td>
<td>$\geq 4$</td>
</tr>
</tbody>
</table>

The second case history group (Group II) states that susceptible terrain has steep slope, a high load, and little water (Sharpe, 1938). In the study area, 18 observation grids have factors that fit into this group (Table 4).

Table 4: Observed factor ranges of landslide case history group II in the Atlantic Highlands, New Jersey.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Atlantic Highlands Factor Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steep slope</td>
<td>$\geq 4$</td>
</tr>
<tr>
<td>High Load</td>
<td>$\geq 3$</td>
</tr>
<tr>
<td>Moderately Strong Geology</td>
<td>2, 4, 1, 4</td>
</tr>
<tr>
<td>Strong Geology</td>
<td>5, 8</td>
</tr>
<tr>
<td>Little Water</td>
<td>$\leq 3$</td>
</tr>
<tr>
<td></td>
<td>$\leq 3$</td>
</tr>
</tbody>
</table>
A third case history group states that landslides occur where there is a gentle slope, weak geology and much water (Varnes, 1958). In the study area, 4 observation grids have factors that fit into this group (Table 5).

Table 5: Observed factor ranges of landslide case history group III in the Atlantic Highlands, New Jersey.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Atlantic Highlands Factor Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gentle slope</td>
<td>2 - 3</td>
</tr>
<tr>
<td>Weak geology</td>
<td>3, 5</td>
</tr>
<tr>
<td>Much water</td>
<td>&gt; 3</td>
</tr>
</tbody>
</table>

A fourth case history group and several grids, which are exceptions in this method, are grouped together. The case history group states that landslides will continue in former landslide material (Jahns and Vonder Linden, 1973). Generally, the slope on the fallen landslide material is much less than its original slope. The original geologic material has been broken up and therefore has been considerably weakened and the potential for water action in future landsliding is enhanced. The grids that are exceptions to this method do not fully account for the flow type landslides in their area because their positioning does not cover the entire 25 meter
slope height and because their standard 61 meter to-a-side dimension is insensitive to the steep slopes which are locally 50 to 60 per cent of the horizontal distance. If it were not for their smaller scale, these slopes would be included in Group II landslides (Table 4). Both the exceptions and the old landslide material of the fourth case history group share the same factor ranges (Table 6).

Table 6: Observed factor ranges of landslide case history group IV and of former landslide sites in the Atlantic Highlands, New Jersey.

<table>
<thead>
<tr>
<th>Description</th>
<th>Factor</th>
<th>Atlantic Highlands Factor Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old landslide material</td>
<td>Slope</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Geology</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>0</td>
</tr>
<tr>
<td>Small Scale Type II</td>
<td>Slope</td>
<td>2</td>
</tr>
<tr>
<td>Exceptions</td>
<td>Geology</td>
<td>5, 1</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>0</td>
</tr>
</tbody>
</table>

One-hundred-and-two grids locate potential landslide areas based on the four landslide case history types. The general distribution of grids showing potential landslides is similar to distribution showing present
landsides occur on slopes whose factors are measureably greater than factors of slopes which contain types of landslides such as slow earthflows. Atlantic Highlands data suggest, however, that slow earthflows, debris slides and small complex landslides share the same ranges of factor values as slumps (Table 7).

CONCLUSIONS

Field mapping indicates 11 newly documented landslide sites in addition to the slump sites already documented. Four landslide types besides slumps are debris slide, slow earthflow, sand run and a small complex landslide.

Like previous landslide work in the Atlantic Highlands, this research concludes that future landslides are likely along the entire escarpment. Comparison of study area factors with slope, geology and water factors of landslide case histories shows that the landslides may occur in or inland and upslope of existing landslides. Landslides are likely to occur on the side of the Atlantic Highlands summits away from the Sandy Hook Bay although there are no landslides on that side presently. High factors of slope and water are always in the potential landslide areas. The Shrewsbury Member of the Red Bank Sand Formation is probably the least stable geologic formation.
Table 7: Distribution of factors within landslide types according to case history groups in the Atlantic Highlands, New Jersey +.

<table>
<thead>
<tr>
<th>Landslide Type</th>
<th>Group I</th>
<th>Group II</th>
<th>Group III</th>
<th>Group IV</th>
<th>Number of Grids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bench and Spoon-shaped Slumps</td>
<td>4</td>
<td>3</td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Slumps in Old Landslide material</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Debris Slides</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Complex Slides</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Slow Earthflows</td>
<td>7</td>
<td>8</td>
<td>1</td>
<td>3</td>
<td>19</td>
</tr>
</tbody>
</table>

---

+ For factor ranges of case history groups see Tables 3-6.
Study of landslide types and case history groups shows that other types of landslides have equal likelihood of occurring where slumps are possible. The slow earthflow in particular occurs in a large variety of terrains.

<table>
<thead>
<tr>
<th>Landslide Type</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>Number of Grids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bench and Spoon-shaped Slumps</td>
<td>4</td>
<td>3</td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Slumps in Old Landslide Material</td>
<td></td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Debris Slides</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Complex Slides</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Slow Earthflows</td>
<td>7</td>
<td>8</td>
<td>1</td>
<td>3</td>
<td>19</td>
</tr>
</tbody>
</table>

**Table 7:** Distribution of factors within landslide types according to case history groups in the Atlantic Highlands, New Jersey. *

* For factor ranges of case history groups see Tables 3-6.
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American Geological Institute, 1962, Dictionary of geological terms 7500 words: Garden City, Dolphin Books, p. 278.


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