METHODS OF LANDSLIDE INVESTIGATION

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Methods of landslide investigation

1) Preliminary work
   - Study of archival materials
   - Terrain reconnaissance
   - Talk to local people
   - Conceptual engineering geological model

2) Landslide investigation
   - Engineering geological mapping
   - Longitudinal and cross sections
   - Boreholes, trial pits, rock and soil sampling, field tests, geophysics
   - Laboratory tests

3) Depth of rupture surface

4) Monitoring
   - Monitoring of deformation
   - Monitoring of hydrogeological features, GWL and pore pressure fluctuation, spring yield
   - Measurement of stress
   - Indirect methods - geophysics

5) Methods of prognosis
   - Spatial prognosis
   - Prognosis of mechanisms and dimension of failure
   - Time prognosis
Methods of landslide investigation

- Board fences tilted, pulled apart
- Monuments tilted
- Curved tree trunks
- Tension cracks, tilted pavements
- Tilted guard rails, utility poles
- Hummocky terrain
- Tilted retaining walls
- Rock strata curved near surface; blocks in soil downslope
Methods of landslide investigation

Hummocky terrain of landslide with recent movements (locality Germany, Gradenbach, photo J. Rybář)
Methods of landslide investigation

Hummocky terrain

Photo J. Novotný

Austria, Salzburg
Methods of landslide investigation

Hummocky terrain

Carpathian Flysch

Photo J. Rybář, Hervenice, NE from Zázriva
Methods of landslide investigation

Hummocky terrain

Photo J. Novotny

Sakhalin, Russia
Methods of landslide investigation

Hummocky terrain

Czech Republic, Vsetín, Kateřinice

Photo: J. Novotny
Methods of landslide investigation

Hummocky terrain

Head of Hoštálková earth flow after 90 years

Photo: J. Novotný
Methods of landslide investigation

Active landslide morphology
Photo: J. Rybář

Minor scarp
Methods of landslide investigation

Phase of slope deformation evolution
- Initial
- Developed
- Final
Methods of landslide investigation

Tree bending (Záruba, Mencl)
Methods of landslide investigation

Bending of trees

Photo J. Rybář

Dneboh, Czech Republic
Methods of landslide investigation

Bending of trees

Photo J. Novotný

Dneboh, Czech Republic
Methods of landslide investigation

Moved gravestones by creep movements
Photo: J. Rybář
Methods of landslide investigation

Moved gravestones by creep movements
Photo: J. Rybář
Methods of landslide investigation

Moved grave monuments by creep movements, Photo: J. Rybář
Methods of landslide investigation

In winter periods frozen water from springs can be observed in landslide areas,
Photo: J. Zvelebil
Methods of landslide investigation

Road deformed by long-term movements
Photo: J. Rybář
Methods of landslide investigation

Main scarp of a flow
Methods of landslide investigation

Main scarp
Methods of landslide investigation

Slickensided surface on surface of rupture

Ústí nad Labem, Motorway D8, Czech Republic

Photo: J. Novotný
Methods of landslide investigation

Slickensided surface on surface of rupture

Photo: J. Rybář
Methods of landslide investigation

Rotation in head area

Ústí nad Labem, Motorway D8, Czech Republic

Photo: J. Novotný
Methods of landslide investigation

Rotation in head area

Ústí nad Labem, Motorway D8, Czech Republic

Estimated curvature of rupture surface

Photo: J. Novotný
Methods of landslide investigation

Open tension crack, without rotation in head area

Azerbaijan, Devechi

Photo: J. Novotny
Methods of landslide investigation

Surface of rupture

Azerbaijan, Devechi

Photo: J. Novotný
Methods of landslide investigation

Frank Slide (Canada)

Unstable tower

Graben

Open crack

Photo: P. Olišar

Photo: J. Novotný
Methods of landslide investigation

Frank Slide (Canada)

Open cracks

Photo: J. Novotný
Methods of landslide investigation

Open cracks, ditches, grabens

Photo J. Rybář
Methods of landslide investigation

Open cracks, ditches, grabens

Beskydy, Lukšinec, Czech Republic

Photo: J. Novotný
Methods of landslide investigation

Potvorov, Czech Republic

Open cracks, ditches, grabens

Photo: J. Novotný
Methods of landslide investigation

Stretched tree roots in fissures indicate active movement

Photo: J. Rybář
Methods of landslide investigation

„Drunken forest“

Photo: J. Novotný

Czech Republic, Hoštálková
Cracks in buildings can be caused by:

- **a, c, e** – slope movements
- **b** – shrinkage of clayey soils
- **d** - undermining
Methods of landslide investigation

before

Aerial photography
Methods of landslide investigation

after

Aerial photography
Methods of landslide investigation

Aerial photography

before

after
Methods of landslide investigation

Aerial photography

new landslide cutting through an old landslide

old landslide
Longitudinal profile
Methods of landslide investigation

Cross sections
of earth flow near
Handlová, Slovak Republic

b – squeezed lateral ridges

d – lake in the depression of the surface
Methods of landslide investigation

Rupture surface

Photo: J. Rybář
Methods of landslide investigation

Rupture surface

Photo: J. Novotný
Methods of landslide investigation

Rupture surface

Photo: J. Novotný
Methods of landslide investigation

Measurements of movements in a well
Methods of landslide investigation

Landslides mapping

Part of Map of landslides in Czechoslovakia in the scale 1 : 1 000 000
Methods of landslide investigation

Landslides mapping

Use of colors

Fossil landslide and potential landslide – black line (difference in sign)

Active landslide – red line

Hydrogeological features – blue line, areas

Man-made construction – green line
Methods of landslide investigation

Landslides in maps 1 : 25 000

Fossil landslides

Wet ground

Undrained depression

Potential landslide

Active landslides

Constructions damaged, endangered

After Rybář 1973
Methods of landslide investigation

Landslides – mapping in to scale 1 : 5 - 10 000

Example of landslide representation on the scale 1:5-10,000 with schematic profile 1-2 of the sliding area.
1—scarp and outercrops of buried slide block (fossil landslide); 2—outlines of emerging blocks; 3—scarps and accumulation ramparts of two generations of potential landslides; 4—recent active landslides representing two developmental stages, with main joints; 5—springs; 6—watercourses and lakes; 7—wet ground; 8—undrained depressions; 9—plastic clayey rocks; 10—solid rocks.

After Rybář 1973
Methods of landslide investigation

After Rybář 1973
Methods of landslide investigation

Landslides – mapping in to scale 1 : 5-10 000

Photo J.Rybář
Photo J.Rybář
Methods of landslide investigation

Landslides – mapping in to scale 1 : 5 - 10 000

DOMOUSNICE, November 1981, after J.RYBÁŘ
Methods of landslide investigation

Landslides – mapping in to scale 1 : 5 - 10 000

POTVOROV 1872

Photo J.Rybář
Methods of landslide investigation

Landslides – detailed mapping

Upper part of the slide

After Rybář 1973

1—tension joints; 2a—width of gaping joint in cm; 2b—subsidence of lower block along joint in cm; 2c—depth of gaping joint; 2d—inclination of joint in degrees; 3—tension joint with expressive subsidence (uncovered sliding plane); 4—shear joint with indicated direction of movement; 5, 6, 7—different types of failures in the toe of the slide, with exaggeration in cm; 8—undrained depressions; 9—wet ground; 10—contours and gradient hatchings underlining the bulges.
Methods of landslide investigation

Landslides – detailed mapping

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Methods of landslide investigation

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Methods of landslide investigation

Landslides – detailed mapping

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After Rybář 1973
Methods of landslide investigation

Landslides – detailed mapping

Toe of the slide

After Rybář 1973

1—tension joints; 2a—width of gaping joint in cm; 2b—subsidence of lower block along joint in cm; 2c—depth of gaping joint; 2d—inclination of joint in degrees; 3—tension joint with expressive subsidence (uncovered sliding plane); 4—shear joint with indicated direction of movement; 5, 6, 7—different types of failures in the toe of the slide, with exaggeration in cm; 8—undrained depressions; 9—wet ground; 10—contours and gradient hatchings underlining the bulges.
Methods of landslide investigation

Landslides – detailed mapping

Toe of the slide

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Methods of landslide investigation

Landslides – detailed mapping

Toe of the slide

After Rybář 1973

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Methods of landslide investigation

Landslides – detailed mapping

After J. Novotný
Methods of landslide investigation

Landslides – detailed mapping

After J. Novotný, T, Šmejkalová, J. Rybář

Žatec earth flow
After J. Novotný, T, Šmejkalová, J. Rybář
Methods of landslide investigation

Landslides – detailed mapping

Žatec earth flow
After J. Novotný, T, Šmejkalová, J. Rybář
Methods of landslide investigation

Landslides – detailed mapping

Žatec earth flow
After J. Novotný, T, Šmejkalová, J. Rybář
Methods of landslide investigation

Landslides – detailed mapping

Profil II-II'

landfill - silty sand to sandy silt
fluvial sediments - sandy gravel to gravely sand
probable surface of original terrain
springs
probable surface of original terrain
earth flow accumulation

Žatec earth flow
After J. Novotný, T. Šmejkalová, J. Rybář
Methods of landslide investigation

Landslides – detailed mapping

Head

Žatec earth flow
After J. Novotný, T. Šmejkalová, J. Rybář
Methods of landslide investigation

Landslides – detailed mapping

rotated block
main scarp
minor scarp

Head

Žatec earth flow
After J. Novotný, T. Šmejkalová, J. Rybář
Methods of landslide investigation

Landslides – detailed mapping

main scarp

Rupture surface covered by sandy gravel to gravely sand during the movement

Žatec earth flow
After J. Novotný, T, Šmejkalová, J. Rybář
Methods of landslide investigation

Landslides – detailed mapping

After J. Novotný, T. Šmejkalová, J. Rybář

Žatec earth flow
After J. Novotný, T. Šmejkalová, J. Rybář

main scarp

Rupture surface covered by sandy gravel to gravely sand during the movement
Methods of landslide investigation

Landslides – detailed mapping

Profil I-I'

- landfill - silty sand to sandy silt
- fluvial sediments - sandy gravel to gravely sand
- probable surface of original terrain
- horizontal bedding here
- probable course of rupture surface
- surface of rupture
- Žatec layers
- earth flow accumulation

Žatec earth flow
After J. Novotný, T, Šmejkalová, J. Rybář
Methods of landslide investigation

Landslides – detailed mapping

Žatec earth flow
After J. Novotný, T, Šmejkalová, J. Rybář

horizontal bedding
Methods of landslide investigation

Landslides – detailed mapping

Profil I-I'

- landfill - silty sand to sandy silt
- fluvial sediments - sandy gravel to gravely sand
- horizontal bedding here
- probable course of rupture surface
- probable surface of original terrain

Žatec earth flow

After J. Novotný, T. Šmejkalová, J. Rybář
## Methods of landslide investigation

### Slope Deformation Field Checklist

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Number of slope deformation</td>
</tr>
<tr>
<td></td>
<td><em>Unique number for each slope deformation</em></td>
</tr>
<tr>
<td>2</td>
<td>Map number</td>
</tr>
<tr>
<td></td>
<td><em>Map number where is marked slope deformation</em></td>
</tr>
<tr>
<td>3</td>
<td>Near town, village</td>
</tr>
<tr>
<td></td>
<td><em>Near town or village</em></td>
</tr>
<tr>
<td>4</td>
<td>Coordinates (GPS)</td>
</tr>
<tr>
<td></td>
<td><em>Is related to the highest point of slope deformation in main scarp</em></td>
</tr>
<tr>
<td>5</td>
<td>Author of documentation and institution</td>
</tr>
<tr>
<td></td>
<td><em>Name of geologist who is documenting slope deformation and his affiliation</em></td>
</tr>
<tr>
<td>6</td>
<td>Date of documentation</td>
</tr>
<tr>
<td></td>
<td><em>Day / month / year:</em></td>
</tr>
<tr>
<td>7</td>
<td>Slope deformation</td>
</tr>
<tr>
<td></td>
<td>□ Single</td>
</tr>
<tr>
<td></td>
<td>□ Complex</td>
</tr>
<tr>
<td></td>
<td>□ Part of complex</td>
</tr>
<tr>
<td>8</td>
<td>Type of slope deformation</td>
</tr>
<tr>
<td></td>
<td><strong>Classification (Varnes 1978)</strong></td>
</tr>
<tr>
<td></td>
<td>□ Falls</td>
</tr>
<tr>
<td></td>
<td>□ Topples</td>
</tr>
<tr>
<td></td>
<td>□ Slides</td>
</tr>
<tr>
<td></td>
<td>□ Lateral spreads</td>
</tr>
<tr>
<td></td>
<td>□ Flows</td>
</tr>
<tr>
<td></td>
<td>□ Complex</td>
</tr>
</tbody>
</table>
Methods of landslide investigation

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Total length (m)</td>
<td>the minimum from the tip of the landslide to the crown</td>
</tr>
<tr>
<td>10</td>
<td>Width of displaced mass (m)</td>
<td>the maximum breadth of the displaced mass perpendicular to the length of the displaced mass</td>
</tr>
<tr>
<td>11</td>
<td>Width of rupture surface (m)</td>
<td>the maximum width between the flanks of the landslide</td>
</tr>
</tbody>
</table>
| 12 | Slope deformation according affected depth | Based on estimated vertical distance between surface and base of slope deformation:  
- Shallow (1-5 m)  
- Medium deep (5.1-50 m)  
- Very deep (more than 50 m)  
- Unknown |
| 13 | Slope inclination | Average slope inclination of not affected original slope – estimation |
| 14 | Rock / soil type | |
# Methods of landslide investigation

<table>
<thead>
<tr>
<th></th>
<th>Hydrogeology</th>
<th>Surface state:</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td></td>
<td>□ Dry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Locally wet</td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Springs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Lakes, undrained depressions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Brook / river</td>
</tr>
<tr>
<td>16</td>
<td>Phase of slope deformation evolution</td>
<td>□ Initial (main movement is being expected)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Developed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Final (there is not space for next movement)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Unknown</td>
</tr>
<tr>
<td>17</td>
<td>Degree of activity</td>
<td>□ Active</td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Dormant</td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ Stabilized</td>
</tr>
<tr>
<td>18</td>
<td>Main scarp</td>
<td>Height:</td>
</tr>
<tr>
<td>19</td>
<td>Accumulation</td>
<td>Height:</td>
</tr>
<tr>
<td>20</td>
<td>Cracks</td>
<td>□ Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▶ width:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▶ estimated depth:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>□ No</td>
</tr>
</tbody>
</table>
## Methods of landslide investigation

<table>
<thead>
<tr>
<th></th>
<th>Triggering factors</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>_precipitation / water saturation</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Seismic activity / tectonic activity</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Change of slope geometry</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>natural</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>anthropogenic</em></td>
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<tr>
<td></td>
<td><em>Human activity</em></td>
<td></td>
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<tr>
<td></td>
<td><em>Unknown</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Remedy measures</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Performed:</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Proposed:</em></td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td>23</td>
<td>Land use</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Forest</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Bush</em></td>
<td></td>
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<tr>
<td></td>
<td><em>Meadow, pasture</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Field</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Urbanized area (settlements)</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Other</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Endangered objects:</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---------------------</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Remarks, recommendations, (sketch of slope deformation):</td>
<td></td>
</tr>
</tbody>
</table>
Methods of landslide investigation

Monitoring of landslides

A) Measurement of deformations
   - geodesy
   - extensometry
   - inclinometry
   - dilatometry

B) Monitoring of water state within landslide body
   - ground water level and pore pressure observation
   - measurement of spring yield

C) Measurement of stress
   - stress in anchors

D) Indirect methods
   - geophysics
Methods of landslide investigation

Inclinometry

cable of the probe

probe

casing

Wheel probe groove casing grout

\[ \Delta = L \times \sin \theta \]
Methods of landslide investigation

**Saddle of Jezerka**
- Precise leveling
- Optical long distance measurement

**Fault slope**
- Tape extensometry
- Spatial dilatometry in fissures
- Tilt measurements

**Toe of the slope**
- Geodesy
- Visual observation

**Monitoring boreholes**
- Precise inclinometry
- Pore pressure measurement
- Brittle wires

**Investigation gallery**
- Tape extensometry
- Rod extensometry
- Geodesy
- Hydraulic leveling
- Tilt measurements
Methods of landslide investigation

Scheme of reconstruction of rupture surface course based on vector measurement by optical long distance measurements
Methods of landslide investigation

Selected types of gauges for monitoring of displacements on rock slopes:

1 – wire extensometer
2 – rod extensometer
3 – deflectometer
4 – rod extensometer with mechanical warning apparatus
5 – portable rod dilatometer
6 – points for portable rod dilatometry
7 – dilatometric gauge TM-71
Methods of landslide investigation

"TM 71" interference system used for crack monitoring in all spatial components (Košťák 1991)
Methods of landslide investigation

Long-term monitoring of groundwater level changes and long-term precipitation balance

Třebeňice landslide (Cretaceous claystones)

After J. Novotný 2005
Comparison of frequency of regime monitoring with quasicontinual monitoring

Třebenice landslide (Cretaceous claystones)

After J. Novotný 2005
Methods of landslide investigation

Fluctuation of piezometric level in the P4.1 borehole (tip 9.5 m under the terrain) and the piezometric level in the P4.2 borehole (tip 4.5 m under the terrain). Grey areas represent time period with upward groundwater flow.

Třebeňice landslide (Cretaceous claystones)

After J. Novotný and M. Kobr 2009
Methods of landslide investigation

Schematic flow net for the period of seasonal culmination (above) and seasonal minimum (below) in the ground water storage

Třešenice landslide (Cretaceous claystones)

After J.Novotný and M.Kobr 2009
Methods of landslide investigation

Methods of prognosis

- Spatial prognosis

- Prognosis of mechanism and dimensions of failure

- Time prognosis
Methods of landslide investigation

Spatial prognosis

Landslide distribution map at 1: 10 000 scale
Vsetínská Bečva River site, northern of the town Vsetín (E Moravia)

Landslide susceptibility map at 1: 10 000 scale
Vsetínská Bečva River site

After J. Rybář
## Methods of landslide investigation

<table>
<thead>
<tr>
<th>Zone</th>
<th>Characteristic of the Area Regarding Stability Conditions</th>
<th>Conditions for the Area to Be Used as Construction Site of</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td><strong>stable areas</strong></td>
<td><strong>usable areas</strong></td>
</tr>
<tr>
<td>I.1</td>
<td>flat flood plains</td>
<td>foundation conditions suitable for not sophisticated structures (exceptionally even for more sophisticated ones) under specific conditions.</td>
</tr>
<tr>
<td>I.2</td>
<td>permanently stable slopes with very moderate gradient and flat areas above valleys</td>
<td>simple foundation conditions usually suitable even for more sophisticated structures.</td>
</tr>
<tr>
<td>II.</td>
<td><strong>area where slope instability cannot be excluded</strong></td>
<td><strong>conditionally usable areas</strong></td>
</tr>
<tr>
<td>II.3</td>
<td>moderate slopes without verified signs of more serious failure</td>
<td>suitable for not sophisticated structures, stability failures due to improperly designed earthworks are not excluded (e.g. cut-offs, embankments, water drainage etc.)</td>
</tr>
<tr>
<td>II.4</td>
<td>steep slopes without signs of deeper failure</td>
<td>unsuitable for ordinary building, otherwise enormous expenditures must be accepted.</td>
</tr>
<tr>
<td>II.5</td>
<td>slopes deformed by superficial creep movements</td>
<td>suitable only for local roads (e.g. forest roads)</td>
</tr>
<tr>
<td>II.6</td>
<td>slope deformed by landslides and block-type movements in the past time</td>
<td>construction possible only with enormous increased expenditures</td>
</tr>
<tr>
<td>III.</td>
<td><strong>unstable areas</strong></td>
<td><strong>unsuitable areas</strong></td>
</tr>
<tr>
<td>III.7</td>
<td>slope deformed by present active or dormant deformations, as well as by earthflows</td>
<td>construction has to be avoided unless establishment measures can be carried out technically with successful results proved by monitoring.</td>
</tr>
<tr>
<td>III.8</td>
<td>erosion gullies of occasional as well as of permanent small flows</td>
<td>unsuitable area.</td>
</tr>
<tr>
<td>III.9</td>
<td>steep rock slopes and their toes where rockfalls may occur</td>
<td>unsuitable area.</td>
</tr>
<tr>
<td>N.</td>
<td><strong>areas unusable regarding other than stability reasons</strong></td>
<td>unsuitable area.</td>
</tr>
<tr>
<td>N.1</td>
<td>large water plains</td>
<td>unsuitable area.</td>
</tr>
<tr>
<td>N.2</td>
<td>quarries, dump sites, protected areas, etc.</td>
<td>unsuitable area.</td>
</tr>
</tbody>
</table>

Explanations to landslide susceptibility maps

After J. Rybář 2003
Methods of landslide investigation

Time prognosis

Rock fall in Hřensko, Czech Republic, March 1978

Photo J. Rybář

After J. Zvelebil 1984
Methods of landslide investigation

Real and three year gradually dispersed annual precipitation total from Louny hydrometeorological station, periods of sliding activity are marked by asterisks

After Novotný 2000
Methods of landslide investigation

The effect of precipitation and evapotranspiration on fluctuation of groundwater level for Třebenice landslide

Correlation between climate, piezometric levels and movement for Třebenice landslide

After Novotný 2000