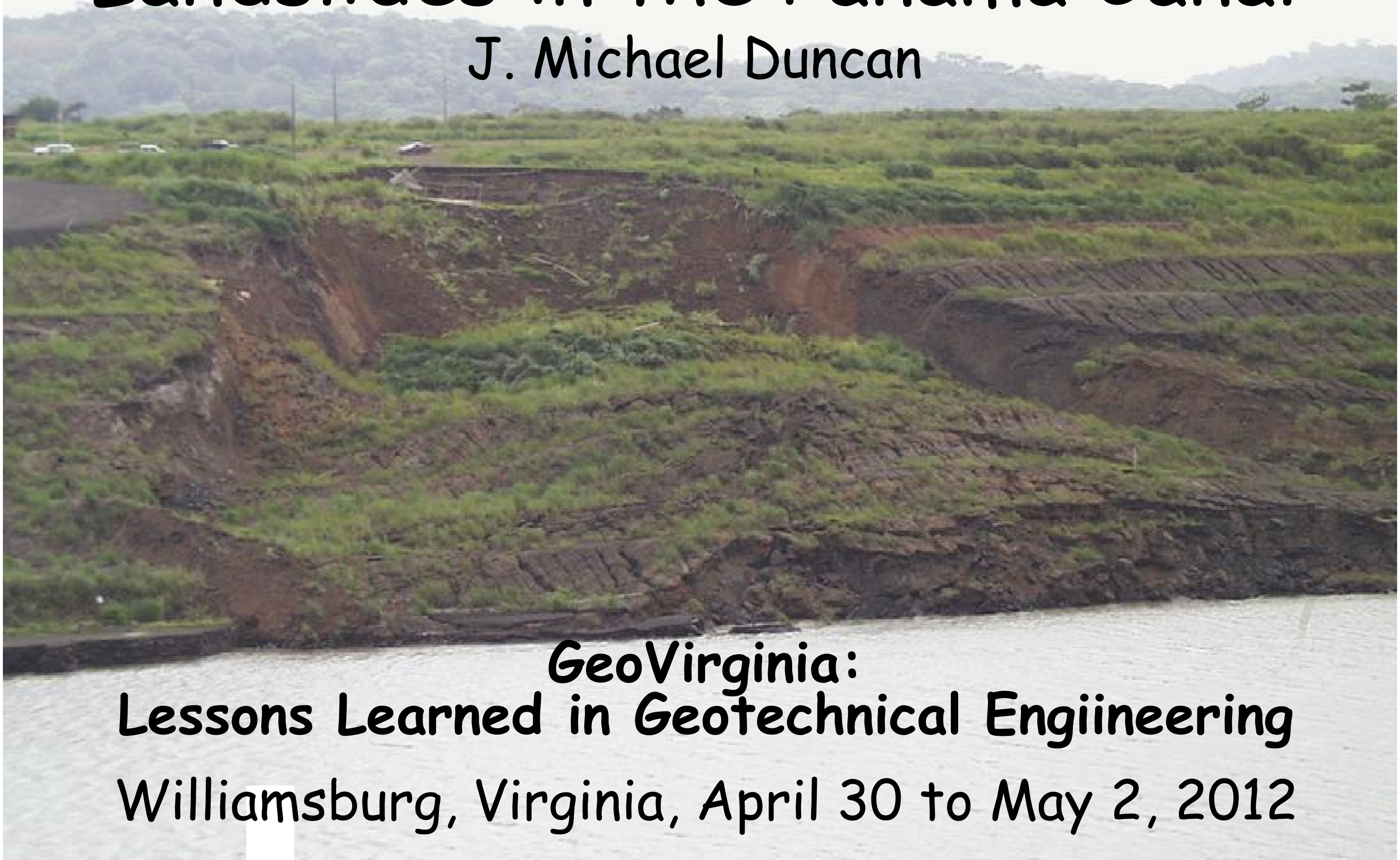
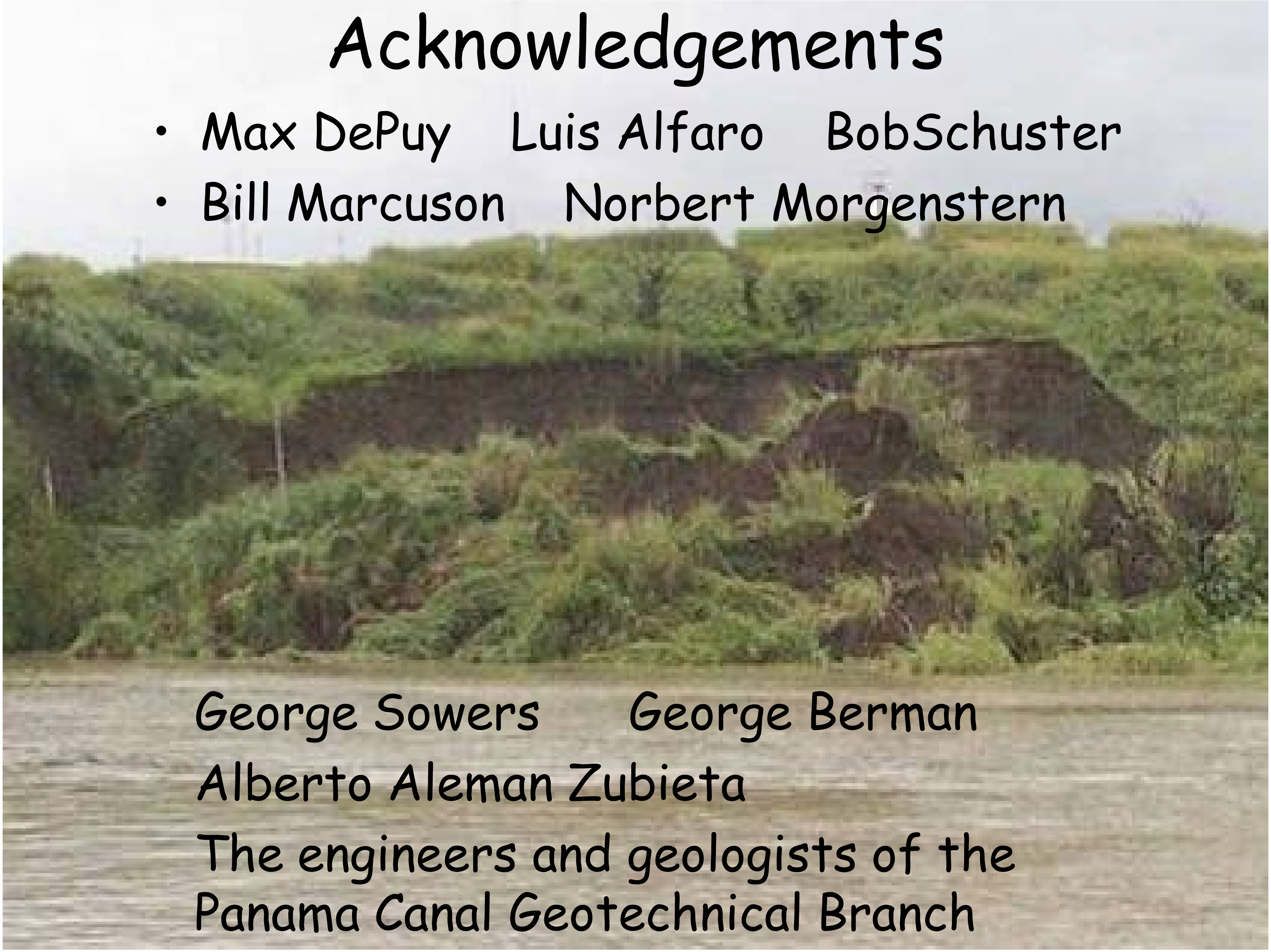
Lessons Learned from Landslides in the Panama Canal

J. Michael Duncan



GeoVirginia:
Lessons Learned in Geotechnical Engiineering

Williamsburg, Virginia, April 30 to May 2, 2012



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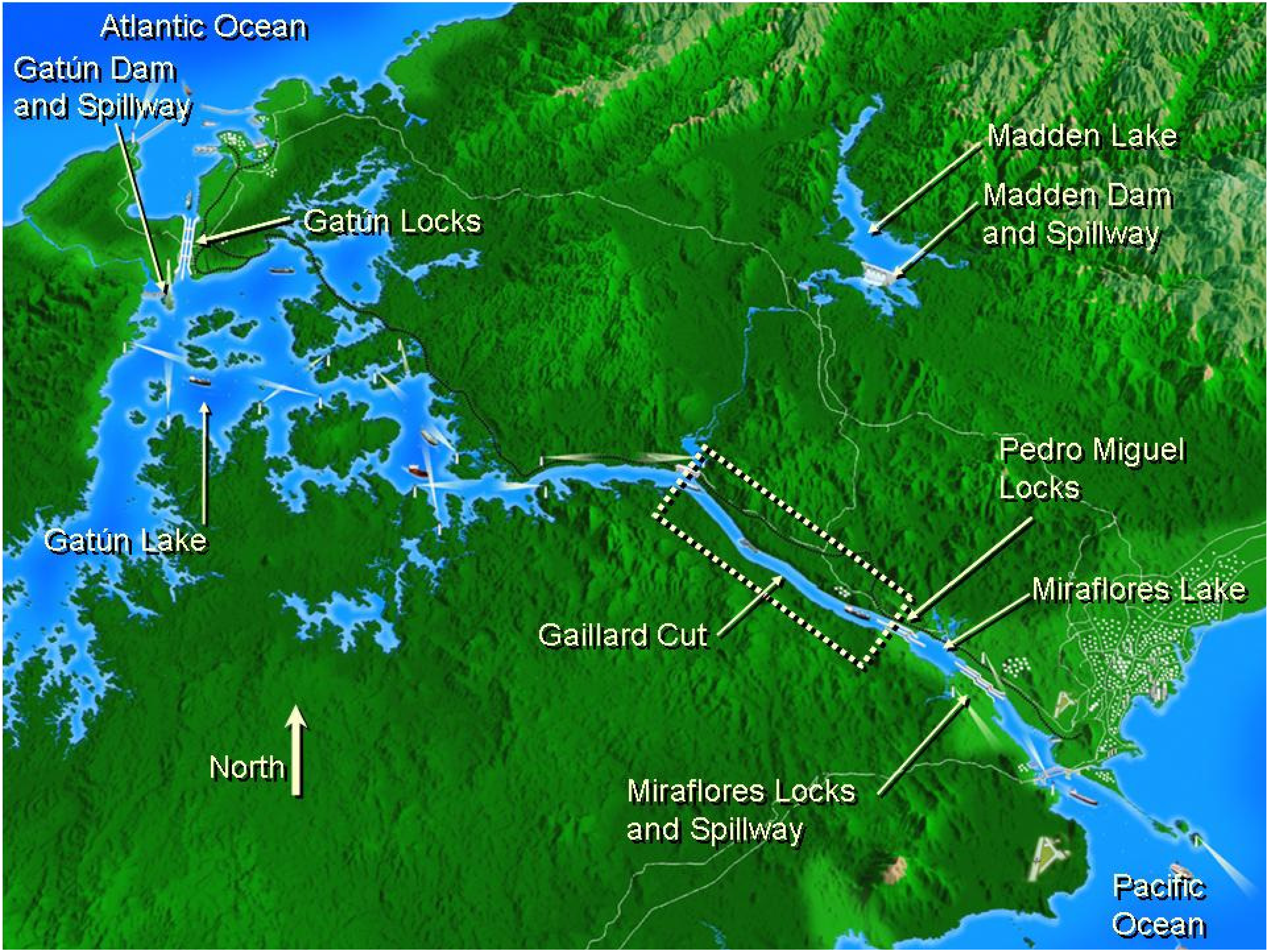
The engineers and geologists of the Panama Canal Geotechnical Branch

Evolution of Excavation Design

Excavation of soil and rock was central to the construction of the Panama Canal

– 264,000,000 cubic meters

- mostly in Gaillard Cut


Atlantic Ocean
Gatún Dam and Spillway
Gatún Locks
Gatún Lake
North
Madden Lake
Madden Dam and Spillway
Pedro Miguel Locks
Miraflores Lake
Gaillard Cut
Miraflores Locks and Spillway
Pacific Ocean

Gaillard Cut

Gaillard Cut

- Excavated across the Isthmian Divide
- Slopes rise 500 ft above canal invert
- Plagued by 70 major landslides through the history of the canal, many of them active several times

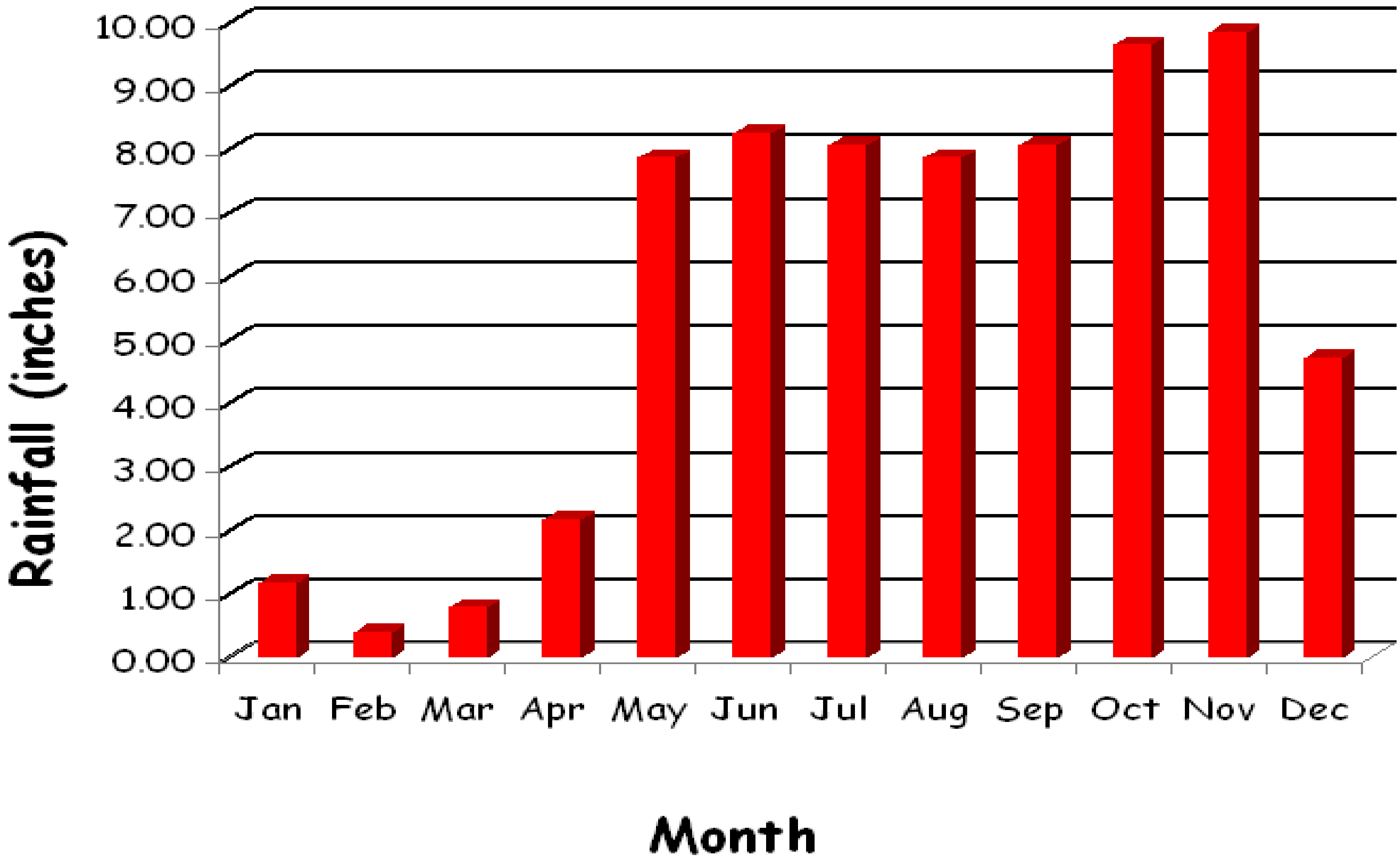
Gaillard Cut Geology

- Hard basalt and Pedro Miguel agglomerate, juxtaposed with soft Cucaracha and Culebra shales
- Rocks are dissected and offset by many faults
- The shales are prone to softening over time after unloading by excavation

Causes of landslides in Gaillard Cut

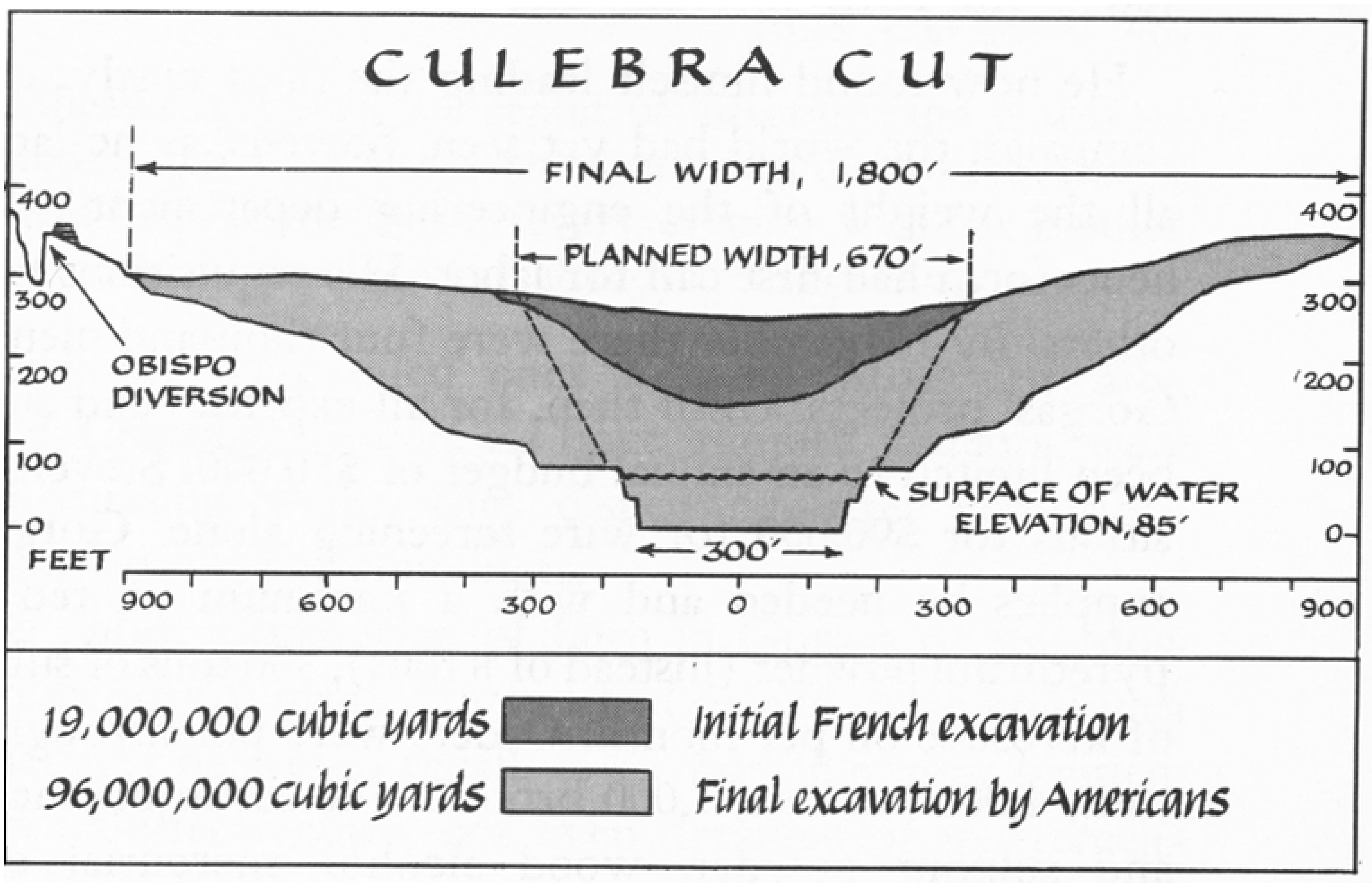
- Slope steepening – excavations required to develop, to deepen, to widen, and to straighten the Canal
- Gradual softening of weak rocks
- Rainfall

Rainfall

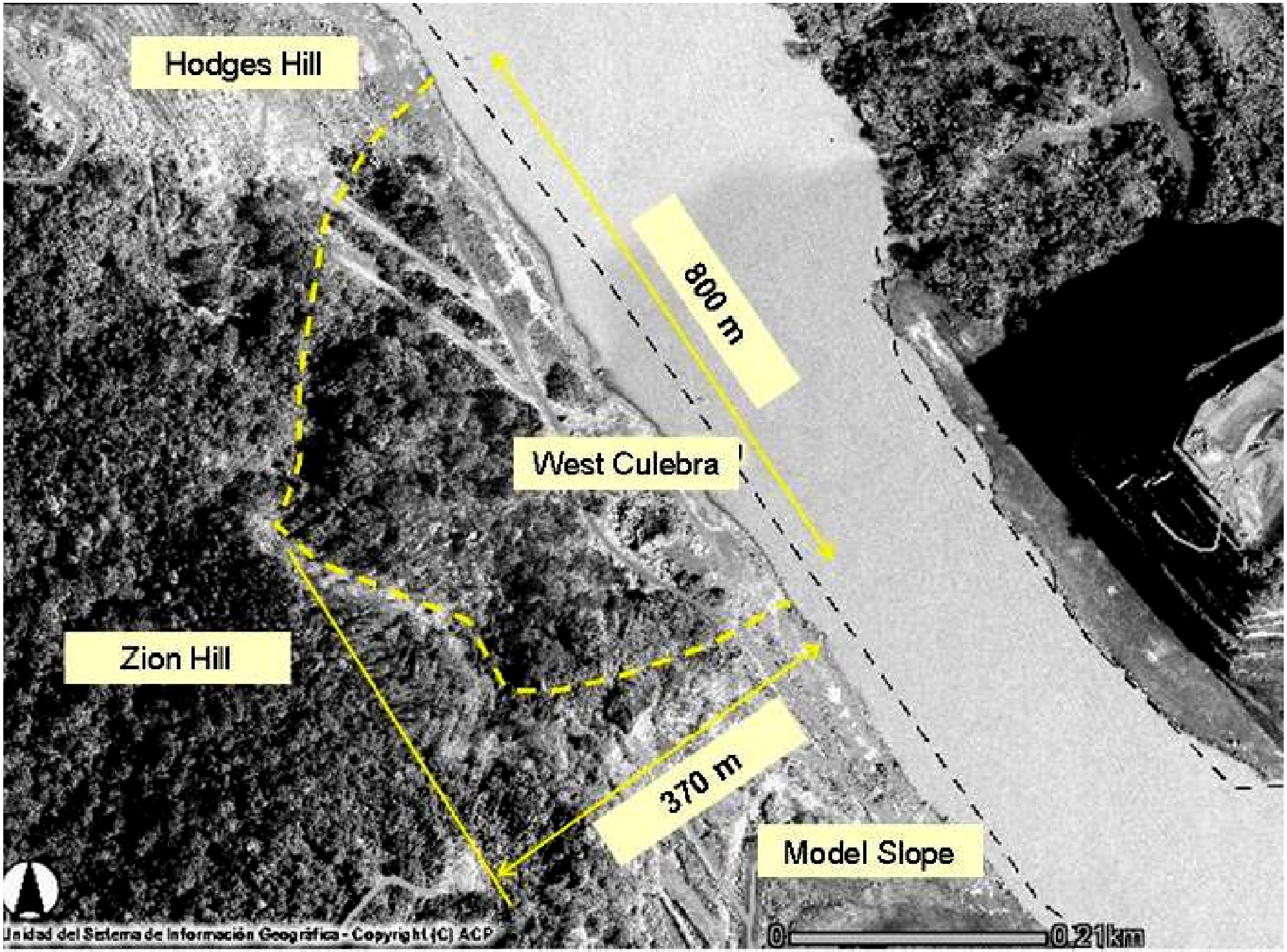


10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Rainfall (inches)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

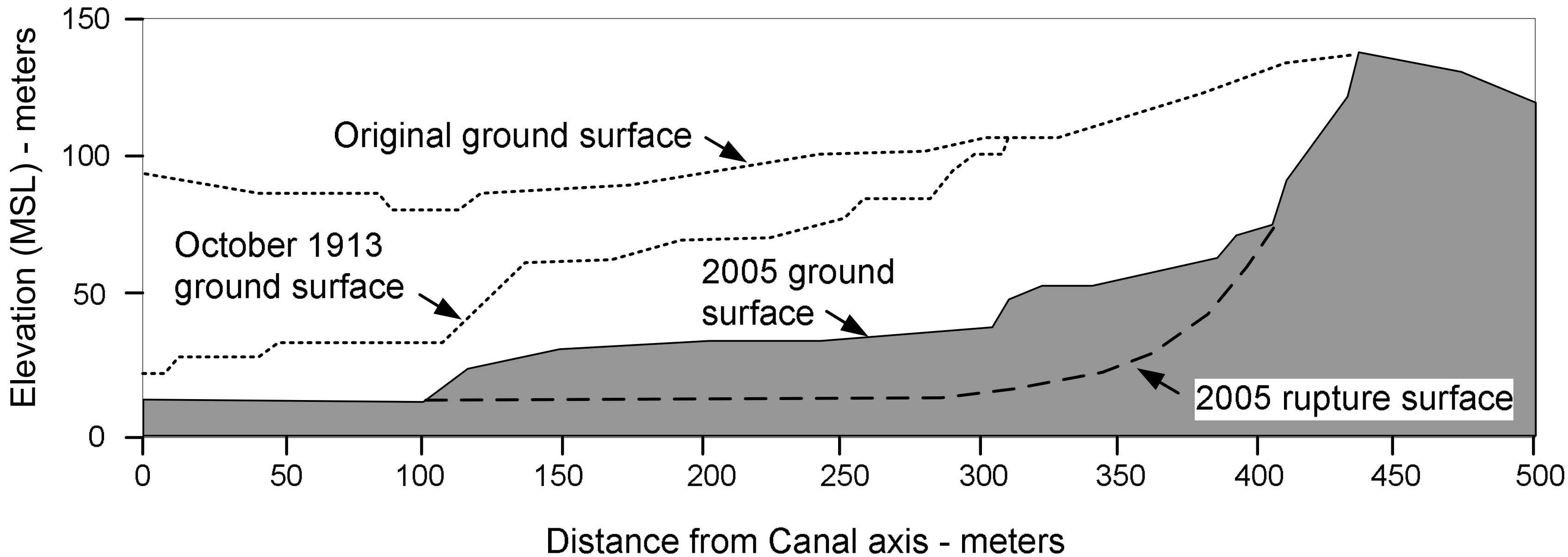
First approach to excavation design – excavate steep slopes - then excavate the resulting landslides when the steep slopes failed



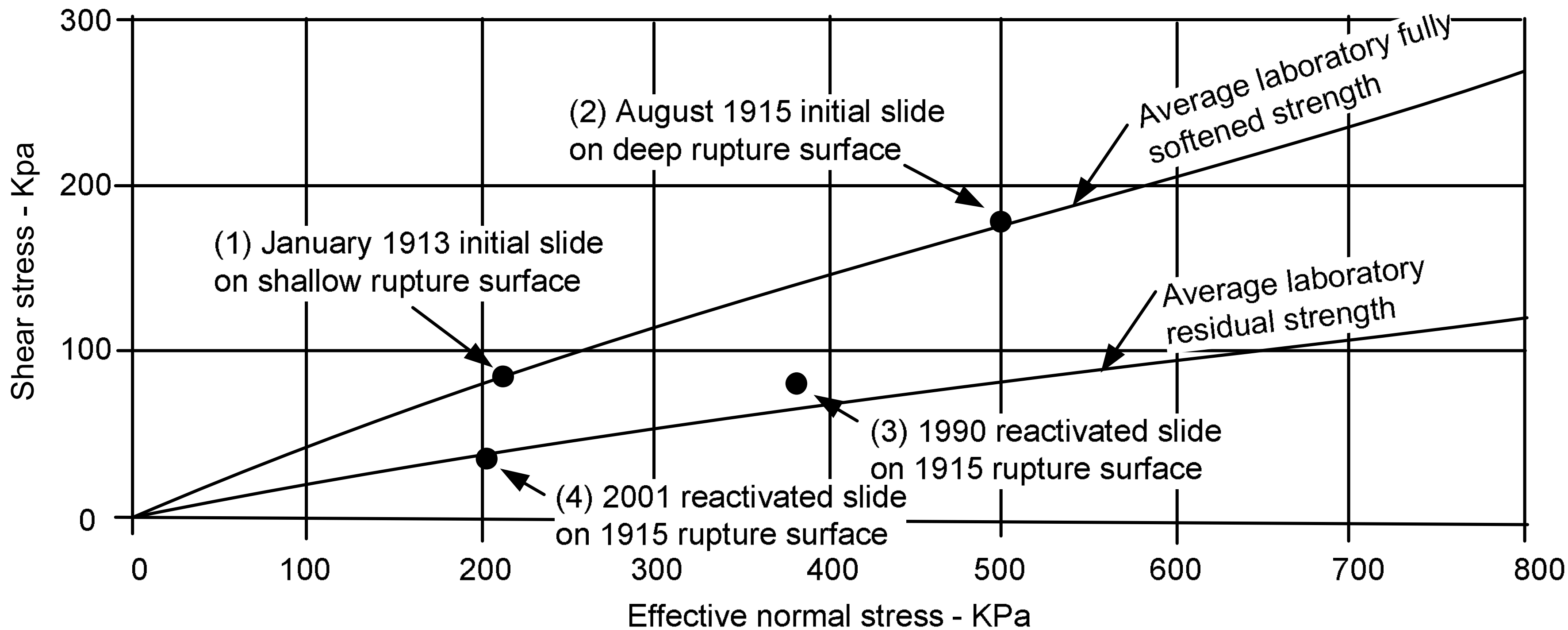
An example – West Culebra



West Culebra



West Culebra - declining soil strength



Excavation Volumes

Category	Volume (Millions of cubic meters)	Percentage (of 264 million cubic meters total volume)
Original construction	84	32%
Removal of landslides	73	28%
Widening, deepening, and straightening	107	41%

Learning from experience

- From 1914 through 1917, the Canal was closed by landslides seven times for a total of eight months
- From 1920 through 1986, the Canal was closed four times by landslides for a total of six days
- Since 1986, the Canal has not been closed

Learning from experience

In 1968, Arthur Casagrande recommended a proactive approach to managing the landslides – the "Landslide Control Program"

This has been a key factor in learning from experience

Professor Casagrande's first visit - 1968

The last closure - Cucaracha – October 1986 – 12 hours

Learning from experience

A “Geotechnical Advisory Board” was established in 1986, and the Panama Canal Geotechnical Branch has been expanded from 13 to 37 engineers and geologists, plus 16 drillers

Landslide Control Program - key elements

- Continual monitoring of slope movements
- Visual observations and instrumentation
- Limits on amount and rate of movement
- Rapid response to prevent material from sliding into the sailing prism
- Preventive excavation and construction

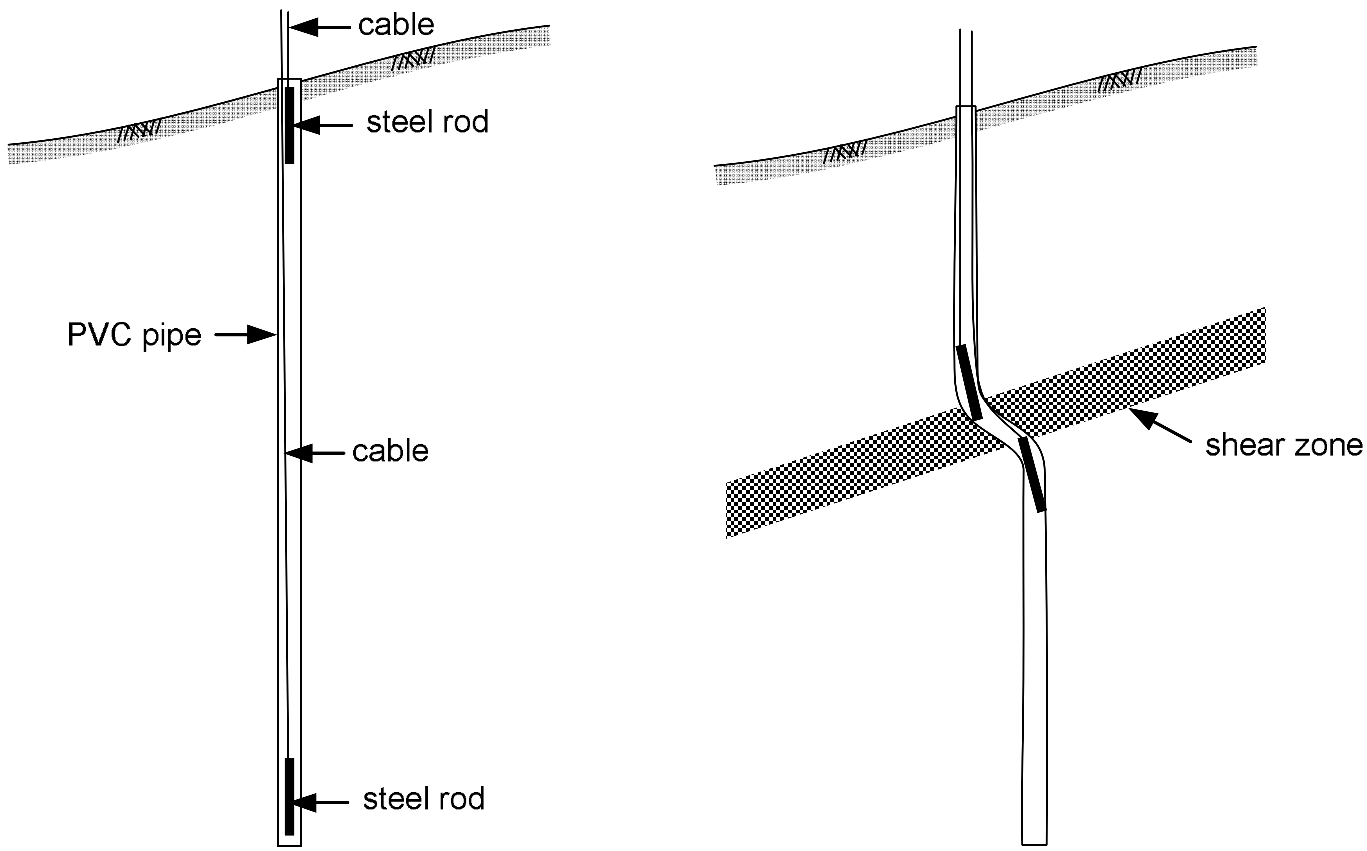
Landslide stabilization

- Excavation of slides and potential slides
- Surface drainage
- Subsurface drainage – horizontal drains
- Erosion control

Instrumentation

- 214 Electronic Distance Measuring stations to measure surface movements
- 52 Casagrande piezometers
- 34 multipoint piezometers
- 106 traveler pipes (also serve as open wells)

Traveler pipes



When first installed

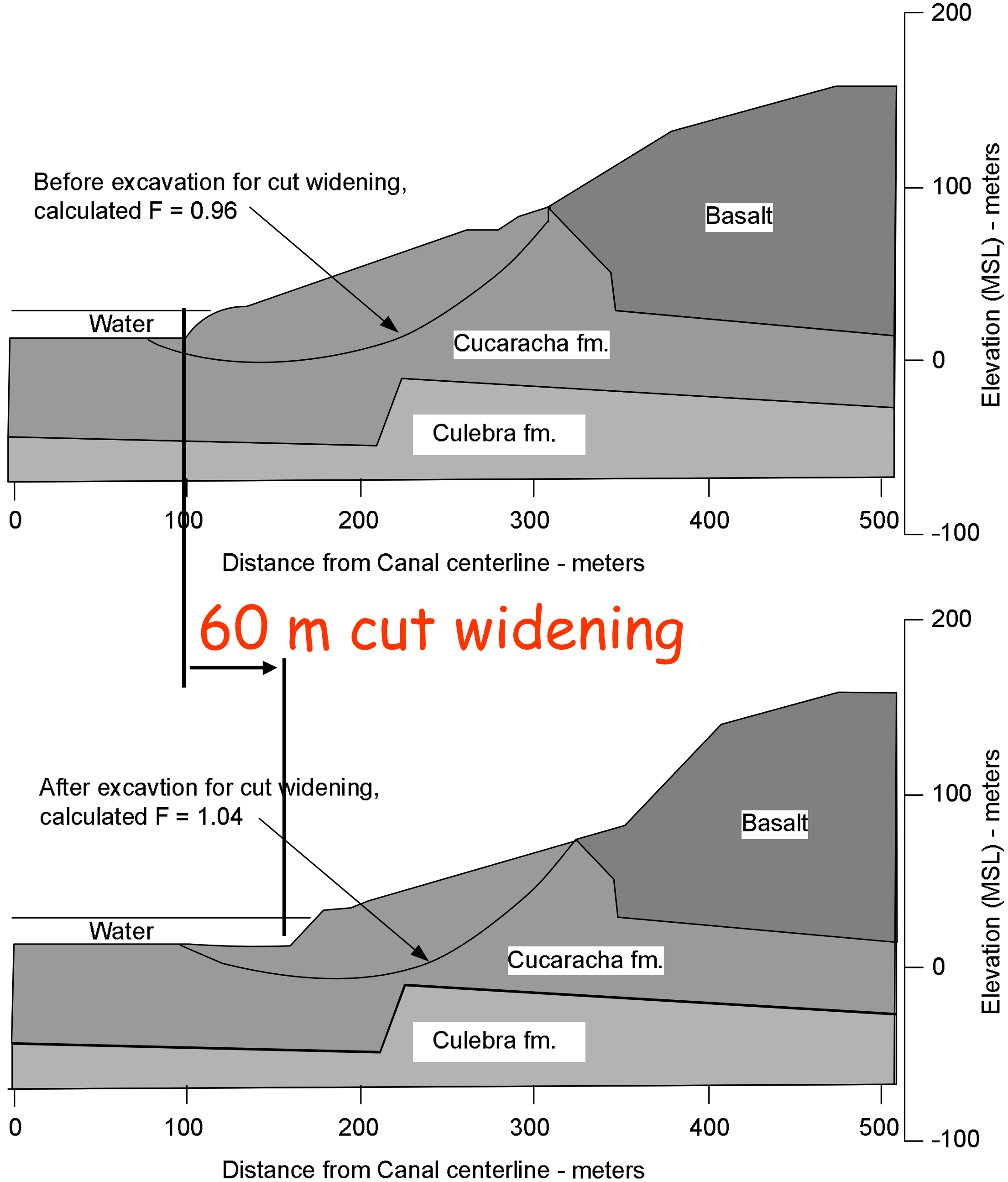
After slide movement

Excavation Design Methodology

- Perform analyses of the original slope profile and the profile after reshaping by excavation
- Guiding philosophy – excavation should never reduce the computed factor of safety
- Change in factor of safety should be positive, but need not be large

Example -

Model Slope Excavation for cut widening



Case history – East Lirio Slide Repair

Based on a presentation to the Geotechnical Advisory Board by

Carlos A. Santamaria R., January 6, 2007

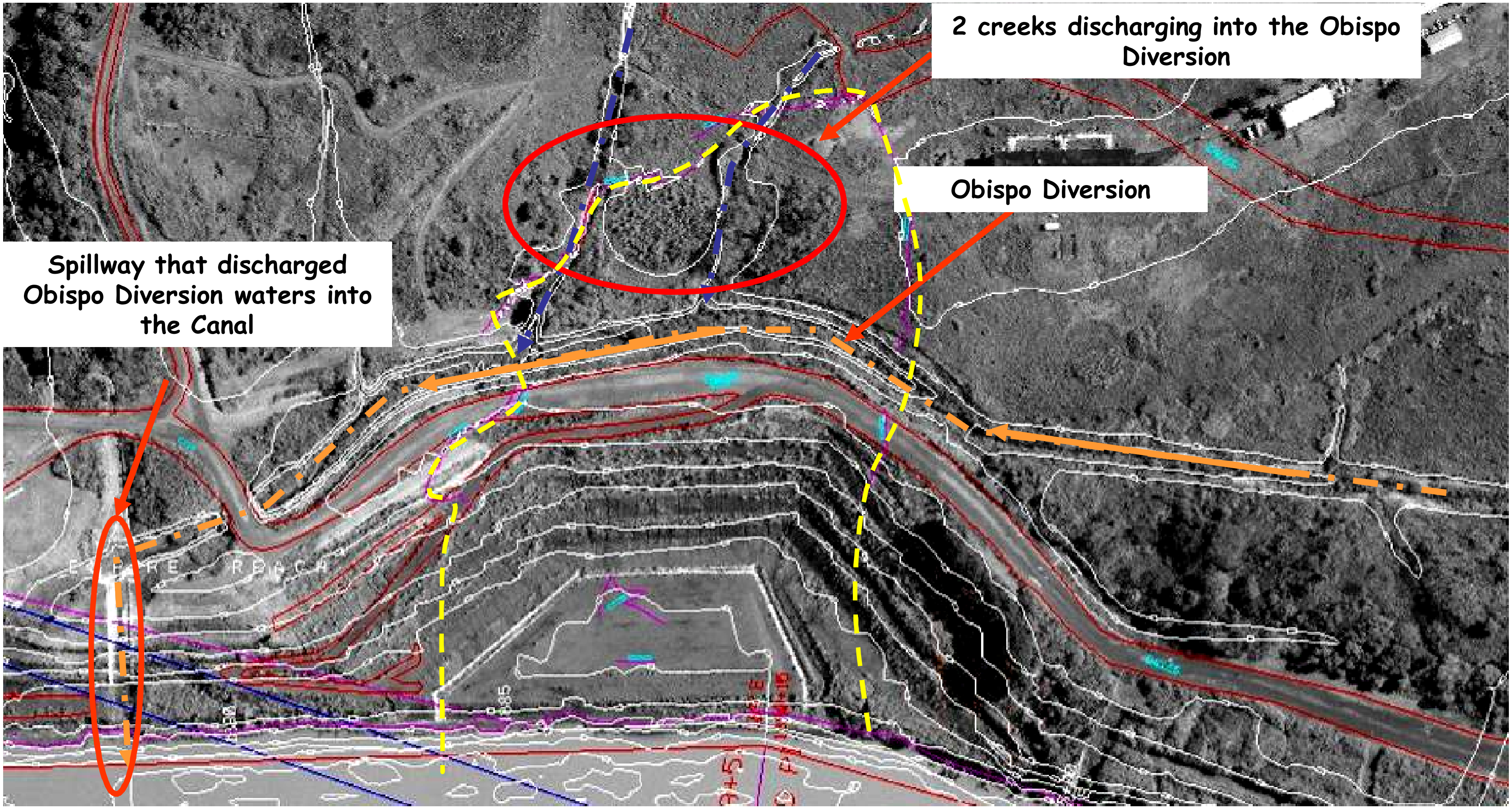
East Lirio Slide – occurred in 2005

- **Estimated volume**: 1.5 million cubic meters.
- **Failure mechanism**: predominantly translational
- **Background**: Most recent activity occurred in 1987, for which stabilization works were performed. The last excavation was in 1995 for the Cut Widening Project.
- **Geology**: The slide developed through siltstone of the Culebra and/or Gatuncillo Formation.
- **Encroachement**: About 60,000 m^3 of the sliding mass encroached 100 m into the navigation channel – and closed one shipping lane for four months.

Causes of the slide

- Excavation to widen the Channel
- Deterioration of Obispo Diversion drainage
- Heavy rainfall during 2005

Drainage conditions before the slide



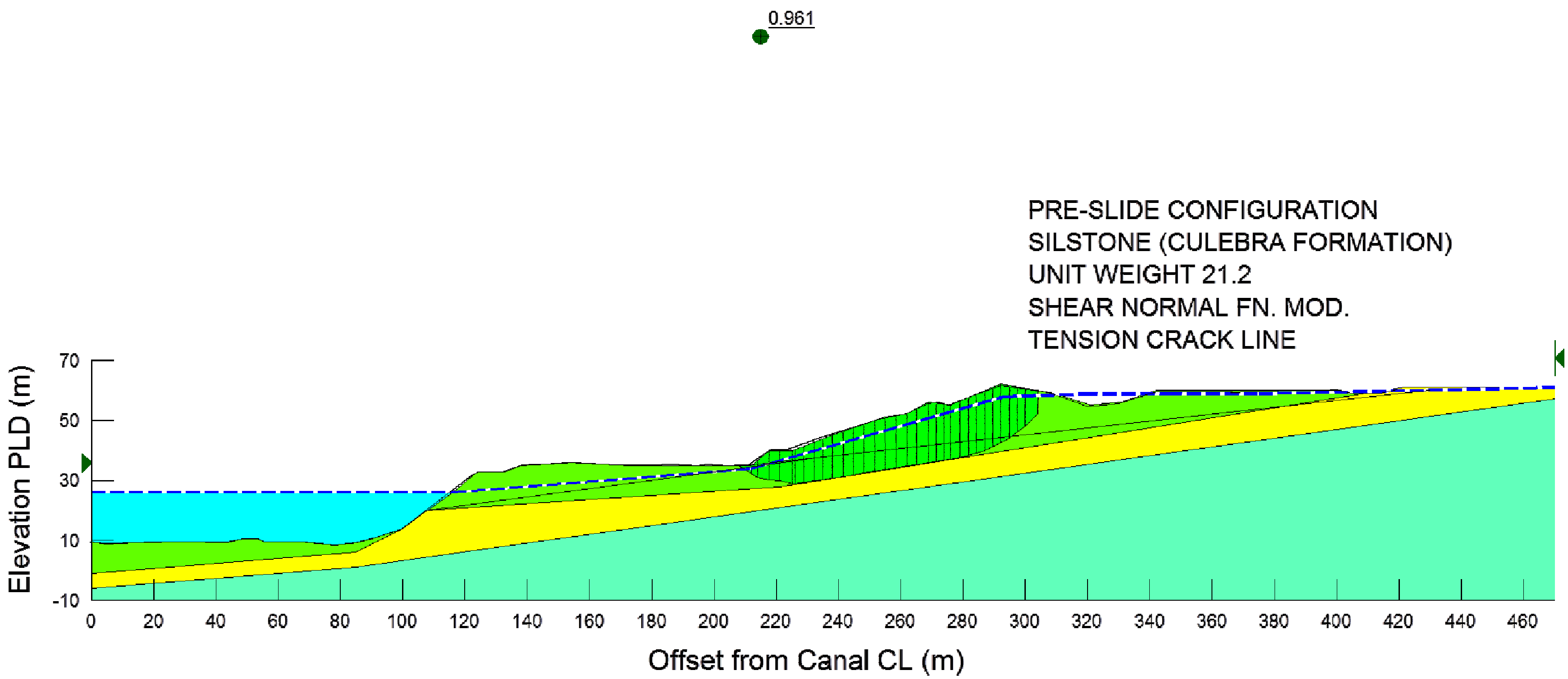
Obispo Diversion

October 17, 2005 : The backscarp of the slide was discovered. The rate of movement was about 10 cm/week

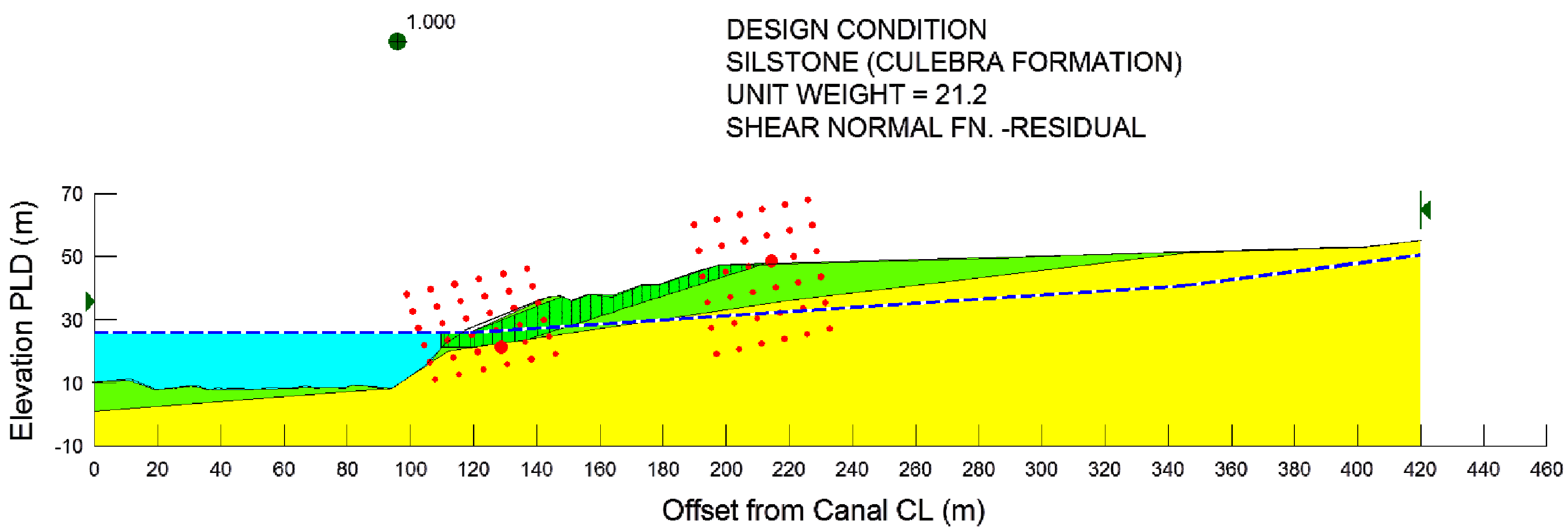
October 22, 2005 : Due to the emergency, crews worked 12-hour shifts 7 days a week

October 22, 2005 : Removal of culverts that created a bottleneck in the diversion

Pre-slide calculated FS = 0.96



Calculated FS = 1.00 after repair



Excavation under way - late November 2005

Excavation under way – mid-December 2005

Excavation complete – February 2006

Rapid response to threat

- October 17, 2005 – slide discovered, drainage improvements started.
- October 27, 2005: Plans and specifications for 411,000 m^3 excavation completed.
- October 31, 2005: Contract awarded for US$950,000 – $2.30 per m^3.
- February 4, 2006: Excavation completed.
- 110 days from discovery of slide to completion of the repair project

In 1936, Karl Terzaghi said

"……the catastrophic descent of the slopes of the deepest cut on the Panama Canal issued a warning that we were overstepping the limits of our ability to predict the consequences of our actions……"

Today, conditions are much better –

Landslides are controlled by

- By continual monitoring to achieve early warning of landslides
- By rapid response to prevent landslides from entering the Canal prism
- By ensuring that new excavations do not reduce the stability of slopes