OVERVIEW OF PINATUBO LAHARS & RELATED FLOODING IN CENTRAL LUZON

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OUTLINE

1. The 1991 eruption & watershed impacts
2. Lahars: definition, source, mechanism, deposition
3. Lahars, siltation and flooding in the Pampanga River Basin
4. Current mitigation measures
5. Current status and future outlook

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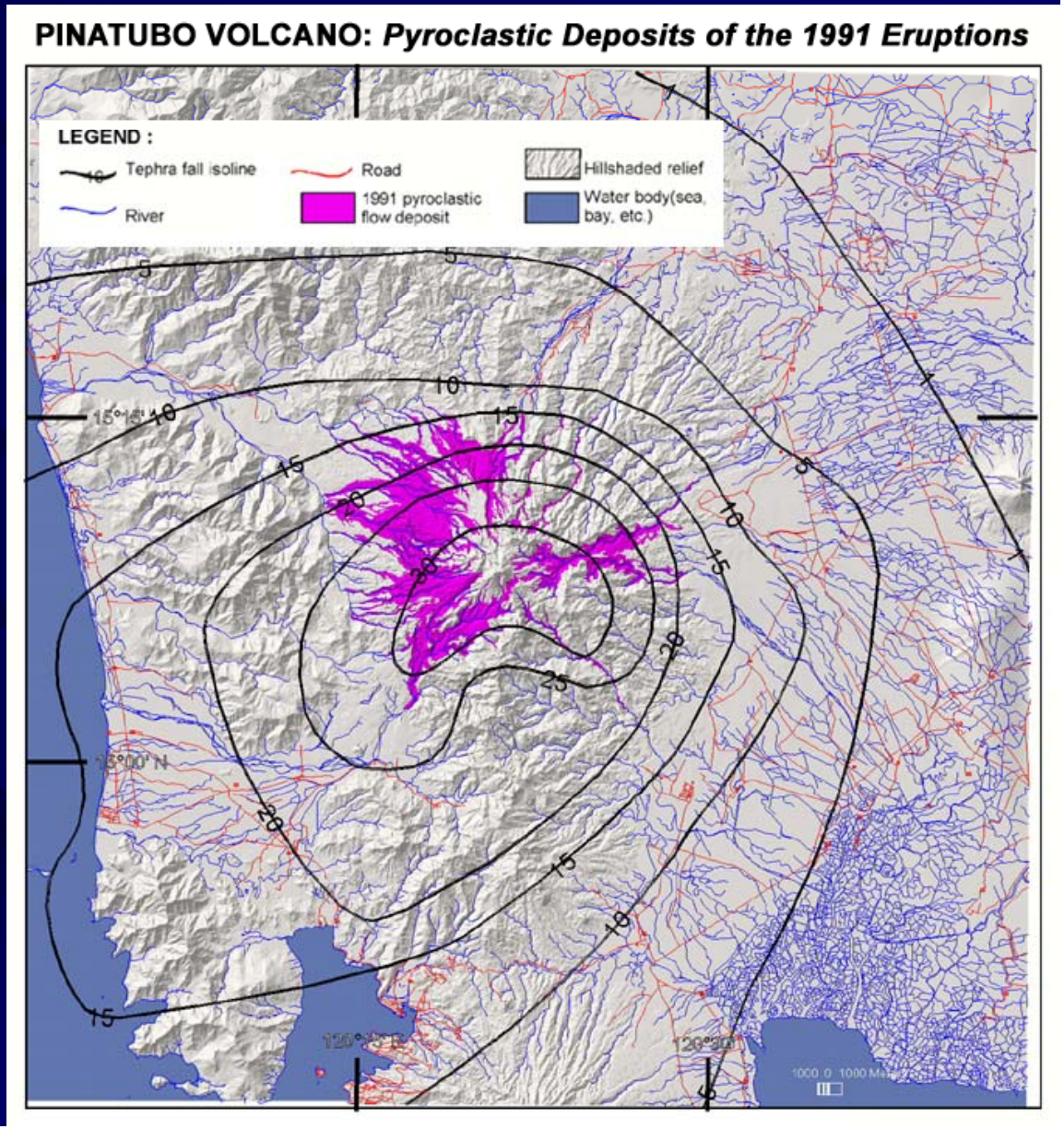
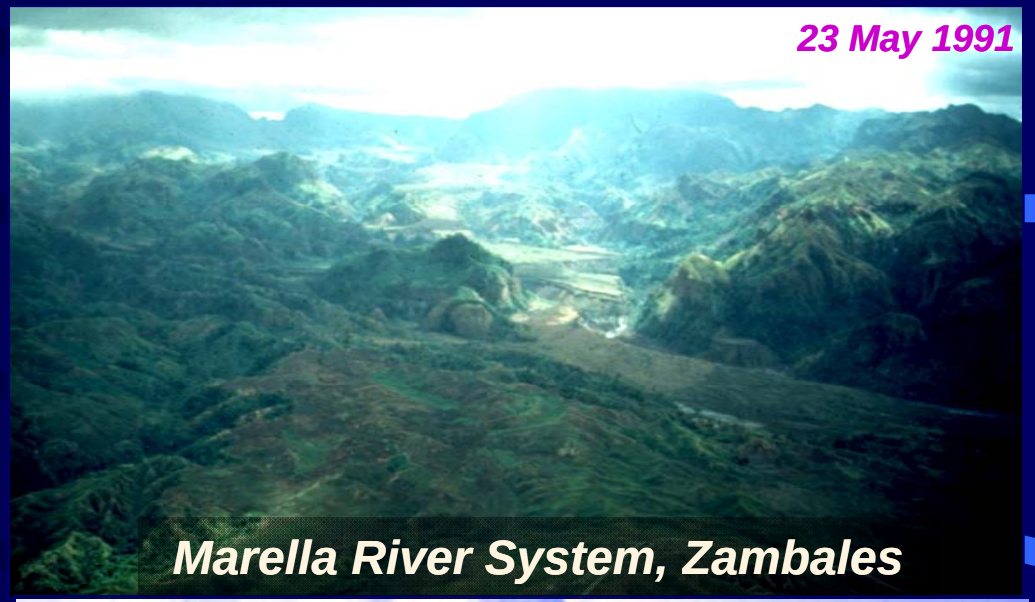
THE 1991 PINATUBO ERUPTION

- 5.5 km^3 Pyroclastic flow deposits, 50% reworked as lahars:
  - Pasig-Sacobia-Abacan
  - O'Donnell
  - Sto. Tomas-Marella
  - Maraunot-Balin-Baquero-Bucao
  - Porac-Gumain
- 3.7-5.3 km^3 Ashfall deposits, lahar source:
  - Porac-Gumain
  - Maloma
  - Tanguay



Other Pyroclastic Flow Impacts:

- Burial of river valleys in thick erodible ash-
- Loss & disturbance of natural drainage
- Incineration & stripping of vegetation



LAHARS (Volcanic Mudflows)

Sediment-laden streamflows:

- Fluid phase: frictionless mixture of water & fine sediment
- Granular phase: coarse particles (pebbles-boulders)

Flow behavior:

- Coloumb (viscous) flow
- Physically complicated

Kinds of lahars:

- Debris flow: solid fraction >80% by weight or >60% by volume
- Hyperconcentrated streamflow: solid fraction 20-60% by weight, 40-60% by volume

LAHARS (Volcanic Mudflows)

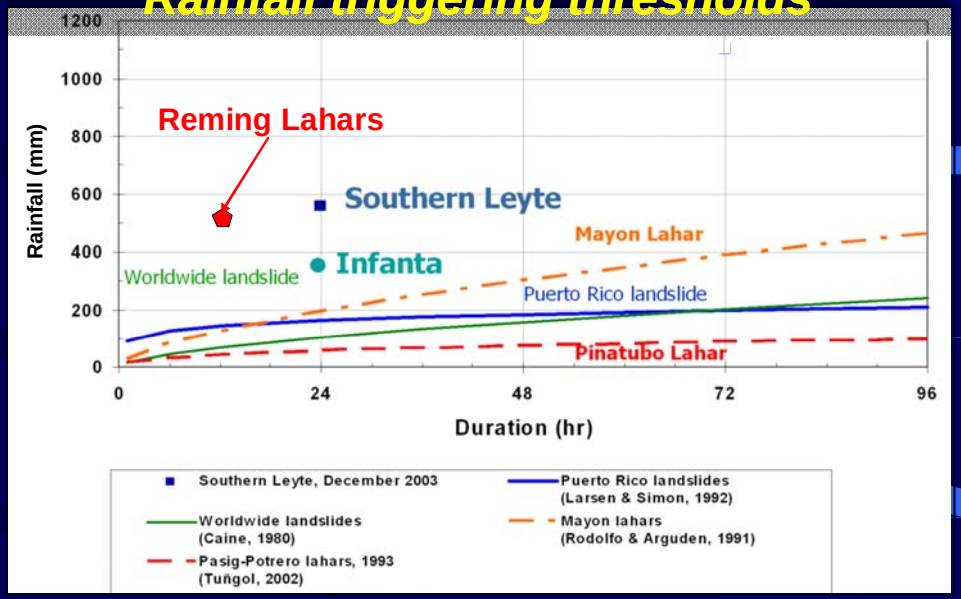
Source material:

- Pyroclastic & pre-existing lahar deposits

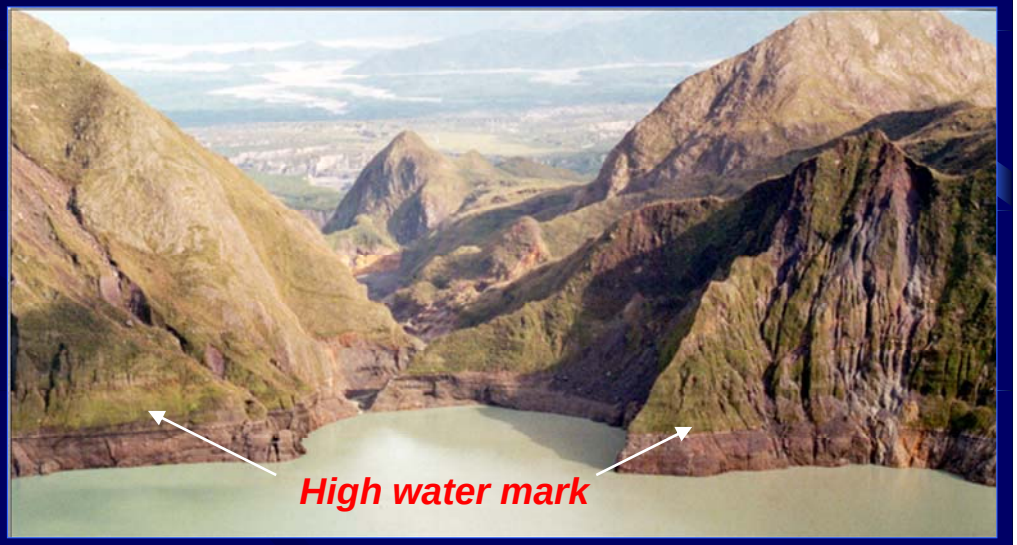
Triggering:

- Rainfall, often aided by landslides in the upper slopes
- Lake breakout (e.g. 1994 Sept Lake Cutuno; 2002 Crater Lake)

Rainfall triggering thresholds



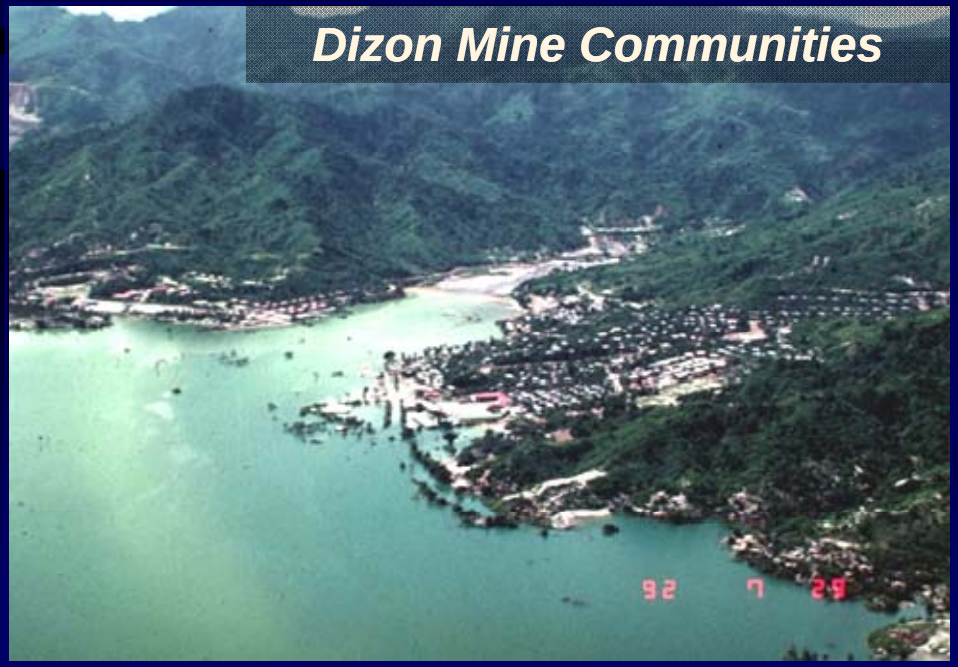
NORTHWEST CRATER RIM

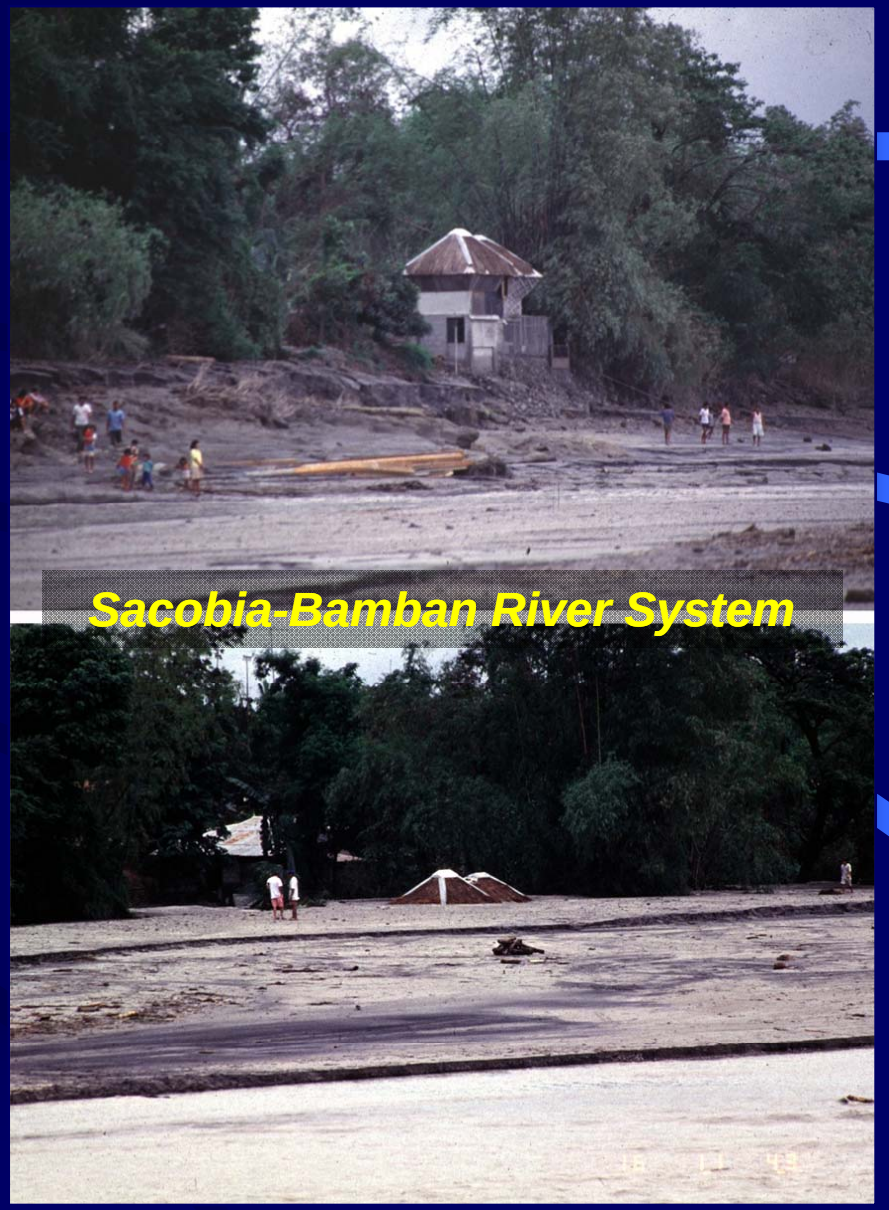


LAHARS (Volcanic Mudflows)

Impacts:

- Burial, washout, riverbank erosion cutoff, isolation
- Long-term siltation & flooding due to clogging of drainages





LAHARS (Volcanic Mudflows)

Estimated Annual Sediment Volumes:

- 2.5 billion m^3 eroded from all slopes in 10 years
  - Pierson and others, 1992

Year	Estimated Sediment Yield (in Mcm)
1991	500-1,000
1992	300-500
1993	180-350
1994	110-210
1995	65-110
1996	39-81
1997	23-48
1998	14-29
1999	8-17
2000	5-11
Total	**1,240-2,450**

LAHARS IN THE PAMPANGA RIVER BASIN:
Sacobia-Abacan-Pasig River System

700 million m^3 lahar volume (eroding 500 million m^3 pyroclastic flow deposit)

Abacan:

- Lahars ceased after secondary explosions in the catchment beheaded its watershed in 1992

Sacobia-Bamban:

- Lahars ceased after secondary explosions in the catchment during Typhoon *Kadiang* in 1993 led to watershed piracy by the Pasig-Potrero

Pasig-Potrero:

- 1 M m^3 pyroclastic flow deposits still in its watershed, making future lahars possible

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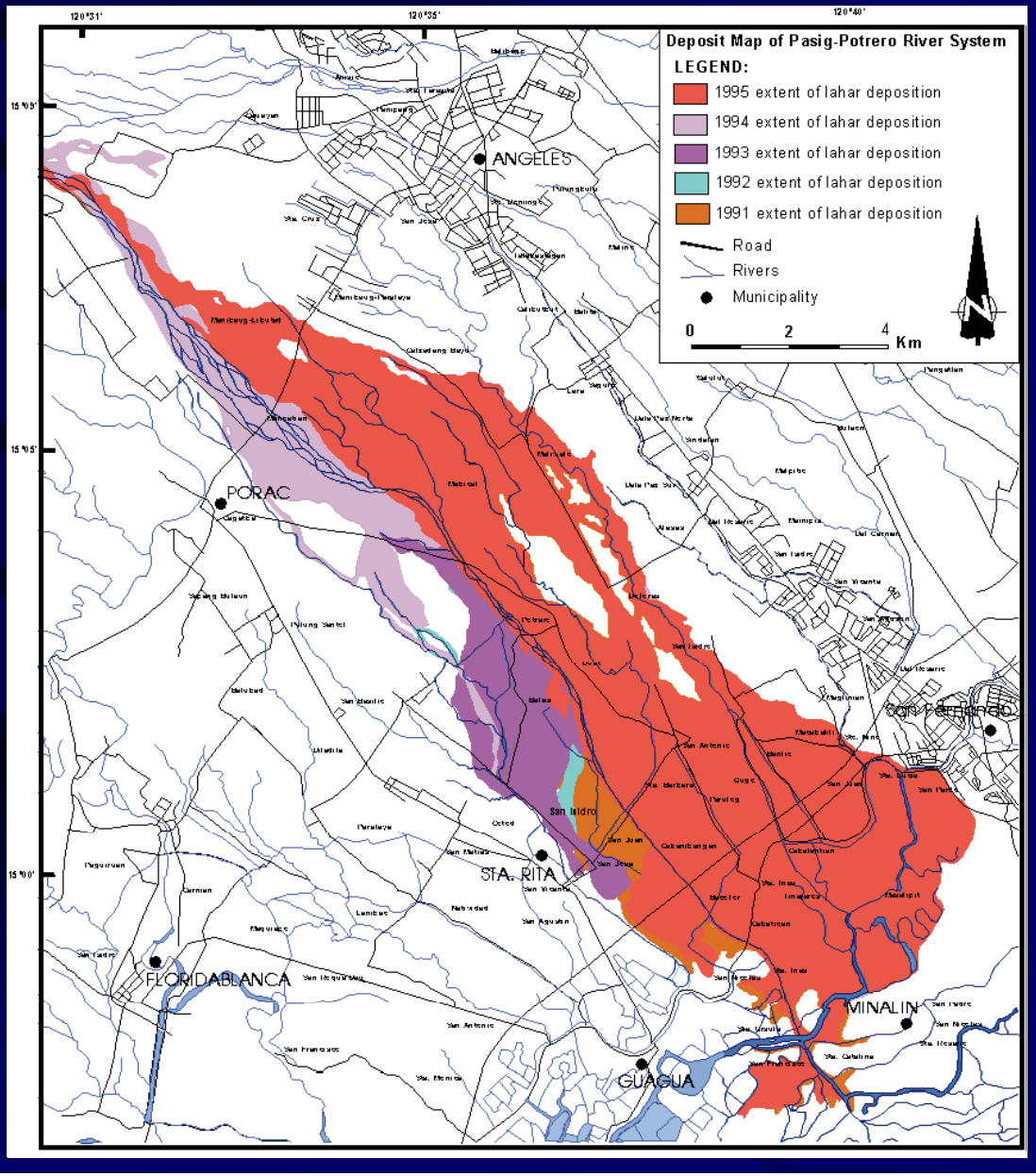
Pasig-Potrero River Lahars: 1991-95



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Pasig-Potrero River: Sedimentation & Flooding Impacts

- Approximately 400 million m^3 pyroclastics/ sediments remobilized by lahars to date
- Lahars in the upper-distal river reaches (Porac, Bacolor, San Fernando, Sta. Rita); numerous casualties, loss of habitation & livelihood
- Siltation and backflooding in communities in lowermost reaches (San Fernando, Mexico, Minalin, Sto. Tomas, Masantol, Macabebe); long-term and persistent drainage problems

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Sacobia-Abacan-Pasig River System:

- Ca 700 million m³ potential lahar volume (all sources)
  - Pierson and others, 1992

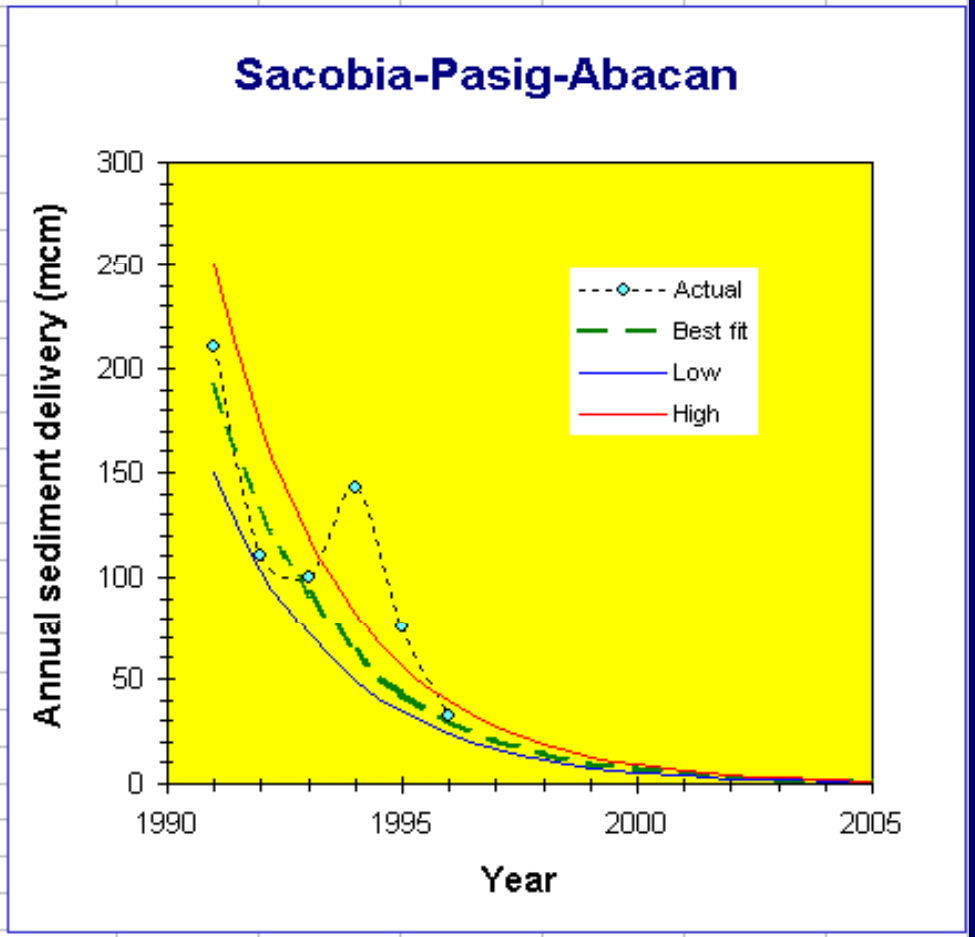
Sacobia-Pasig-Abacan
Annual Sediment Delivery

Year	Actual	Best fit	Low	High
1991	210	192	150	250
1992	110	132	104	173
1993	100	91	71	119
1994	143	63	49	82
1995	75	43	34	57
1996	32	30	23	39
1997		21	16	27
1998		14	11	19
1999		10	8	13
2000		7	5	9
2001		5	4	6
2002		3	3	4
2003		2	2	3
2004		2	1	2
2005		1	1	1
Total	670	616	482	804

Decay Rate	0.690

Regression Statistics

Multiple R	0.919
R Square	0.845
Adjusted R Square	0.689
Standard Error	0.098



Porac-Gumain River: Sedimentation & Flooding Impacts

- 50 million m^3 of pyroclastic flow (PF) deposits, ~20 million m^3 ashfall deposits
- All PF deposits, ashfall and some old pre-eruption sediments along channels remobilized by rainfall as lahars in 1991
- Sediments delivered to lowermost reaches (Floridablanca, Lubao)
- Lower Porac-Gumain distributaries choked with cohesive sediments, causing flash floods, backflooding (Lubao, Guagua, Sasmuan, Floridablanca, Dinalupihan, Orani, Hermosa)

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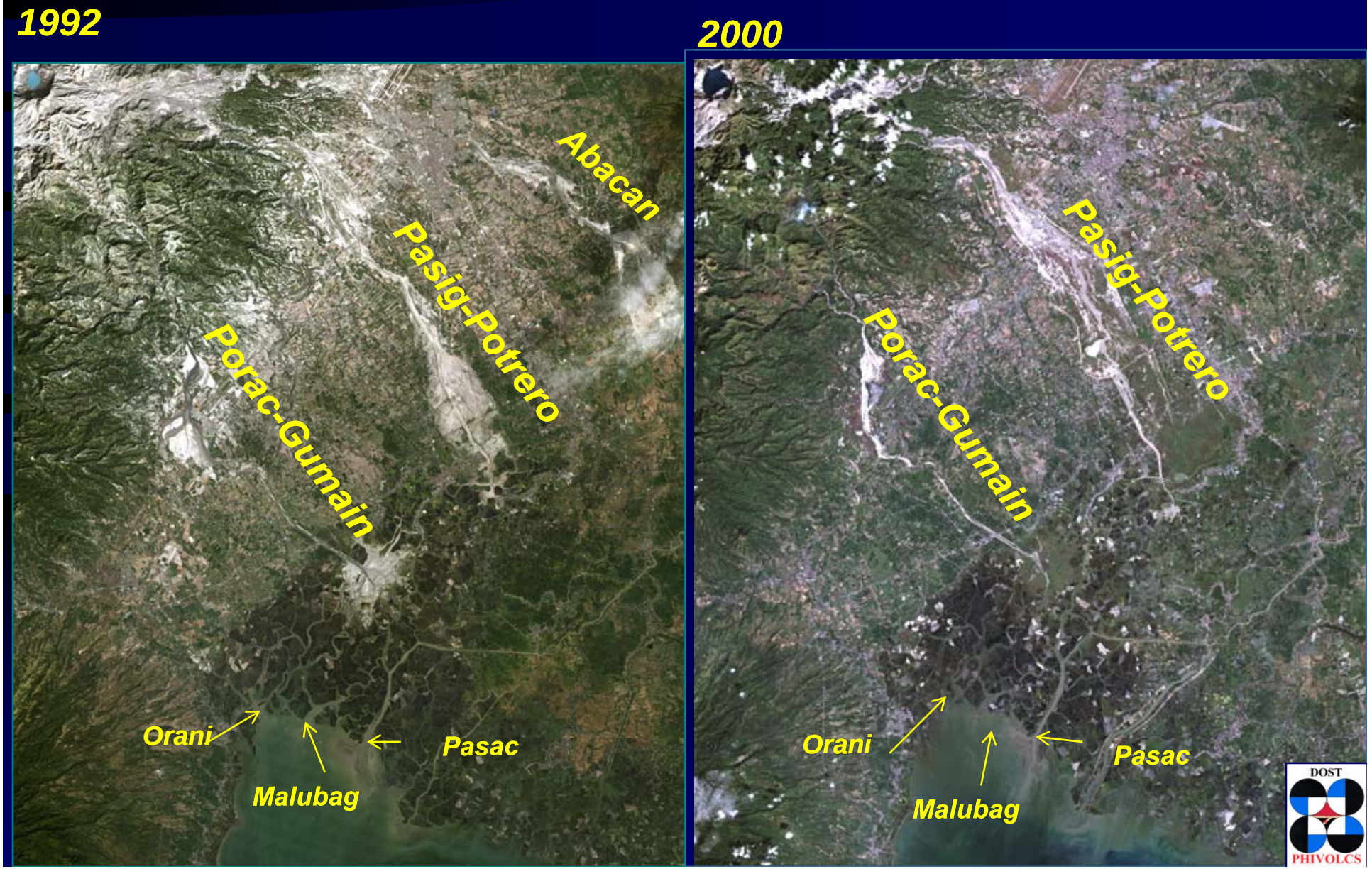
Lahars & Siltation in the Pampanga River Basin



CURRENT MITIGATION MEASURES

Mapping of lahar hazards zones:

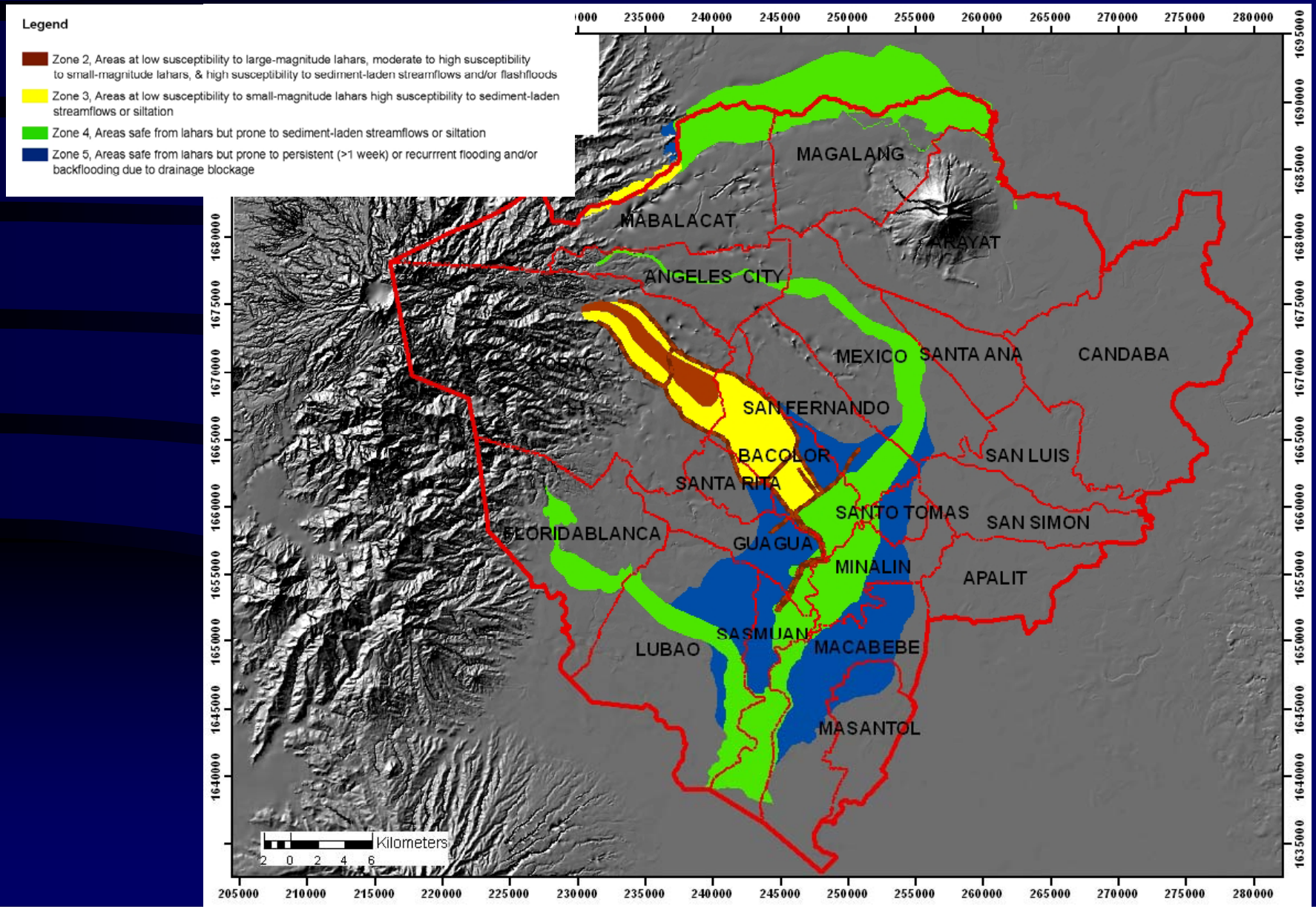
- 1991-2004: PHIVOLCS Lahar Program
- 2008: UNDP-READY Project (NDCC)
- Application to land use and development by site-specific hazards certification

Field assessments as needed

Public education:

- Emphasis on the application of hazards maps as deterrent to habitation in risk areas
- Refresher of past and reminder of still existing hazards

2004 Pinatubo Volcano Lahar Hazards Map



Lahar Hazards Classification

Following Tuñgol (2002)

Lahar Hazard Classification Scheme

Classification is based on *highest probable* hazard (lahar hazard is greater than flood hazard). Forecast of probability/frequency of occurrence is based on geological-historical precedence, sediment yield trends, erosion rates, triggering rainfall, physical modelling, *etc.*

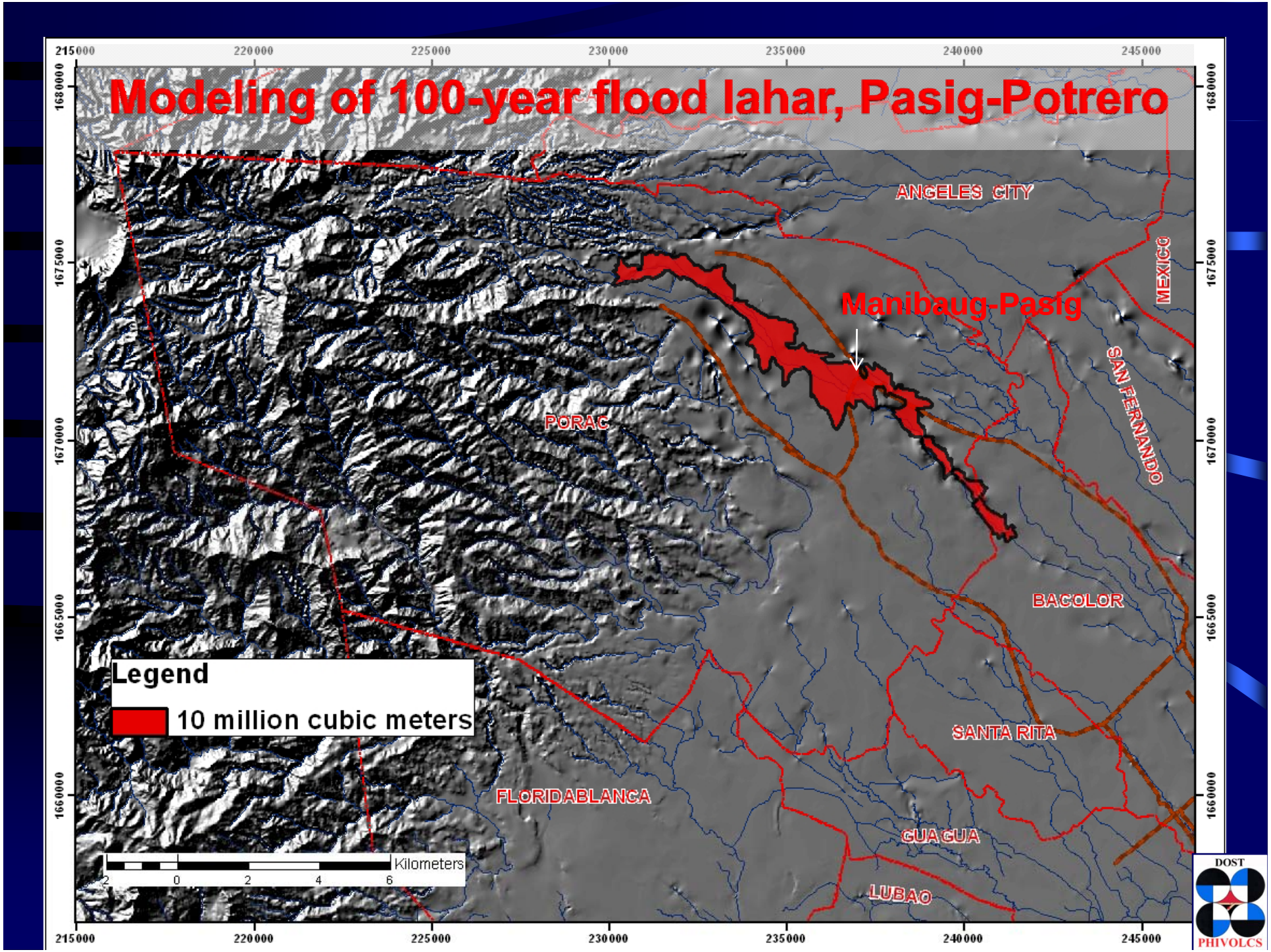
Zone	Hazard classification	Description of hazard	Areas included	Land use restrictions for urban development
1	High lahar hazard	High probability/frequency of occurrence of large-magnitude lahars (>10 M m^3 per event; *Please see Note 2*) and sediment-laden (muddy) streamflows.	Main lahar channels/valleys; upstream portions of lahar fans	Not fit for human settlement.
2	Moderate lahar hazard	Low probability of occurrence of large-magnitude lahars; moderate to high probability of small-magnitude lahars; high probability of sediment-laden flows.	Proximal and medial portions of main lahar fan	Human settlement not recommended, but may be allowed subject to prior engineering geological investigation and engineering protection.
3	Low lahar hazard	Low probability of occurrence of small-magnitude lahars; high probability of sediment-laden flows.	Distal portions of lahar fans.	Settlement may be allowed with adequate flood protection; lahar-warning systems must be vigilantly observed.
4	Muddy streamflow	High probability of sediment-laden streamflows.	Alluvial plains and deltas downstream of lahar fans along the direct path of flows	Settlement may be allowed with adequate flood protection and flood warning system.
5	Backflooding or water impoundment	High probability of flooding due to drainage blockage.	Areas whose drainage systems are blocked by lahar-affected waterways.	Settlement may be allowed with adequate flood protection and flood warning system except in deep water impoundments.

CURRENT STATUS & FUTURE OUTLOOK:

- Habitation returning to areas prone to lahars (e.g. w/in the Megadike System)
- Lack of through-going drainage in the Pasig-Potrero
- Quarrying activities: should promote active channel flow away from flood control stuctures

Maliwalo

Cabalantian


Modeling of 100-year flood lahar, Pasig-Potrero
215000
220000
225000
230000
235000
240000
245000
1680000
1675000
1670000
1665000
1660000
ANGELES CITY
MEXICO
Manibaug-Pasig
SAN FERNANDO
PORAC
BACOLOR
SANTA RITA
FLORIDABLANCA
GUAGUA
LUBAO
Legend
10 million cubic meters
Kilometers
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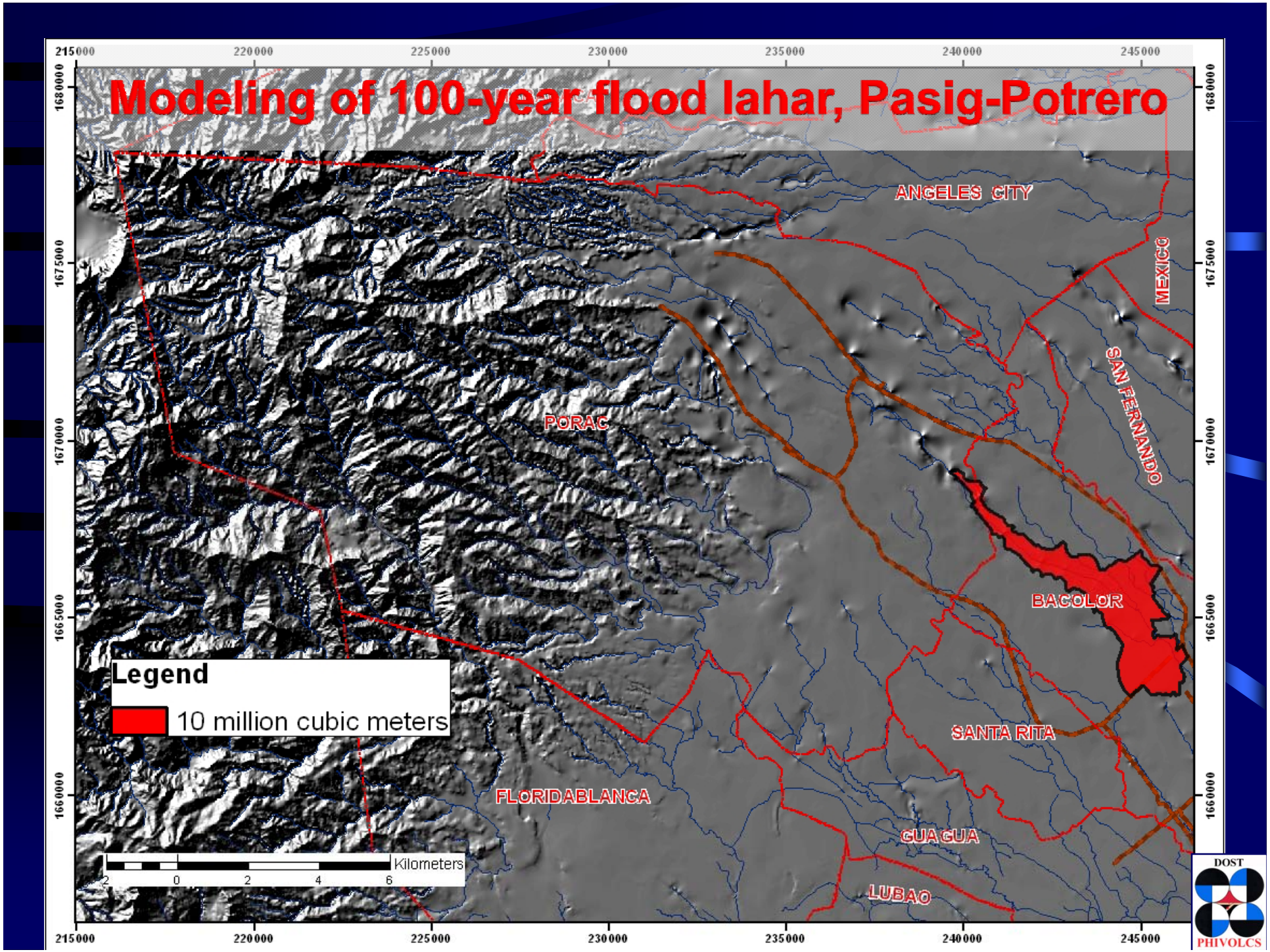
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MEXICO
SAN FERNANDO
PORAC
BACOLOR
SANTA RITA
FLORIDABLANCA
GUAGUA
LUBAO
Legend
10 million cubic meters
Kilometers
2
0
2
4
6
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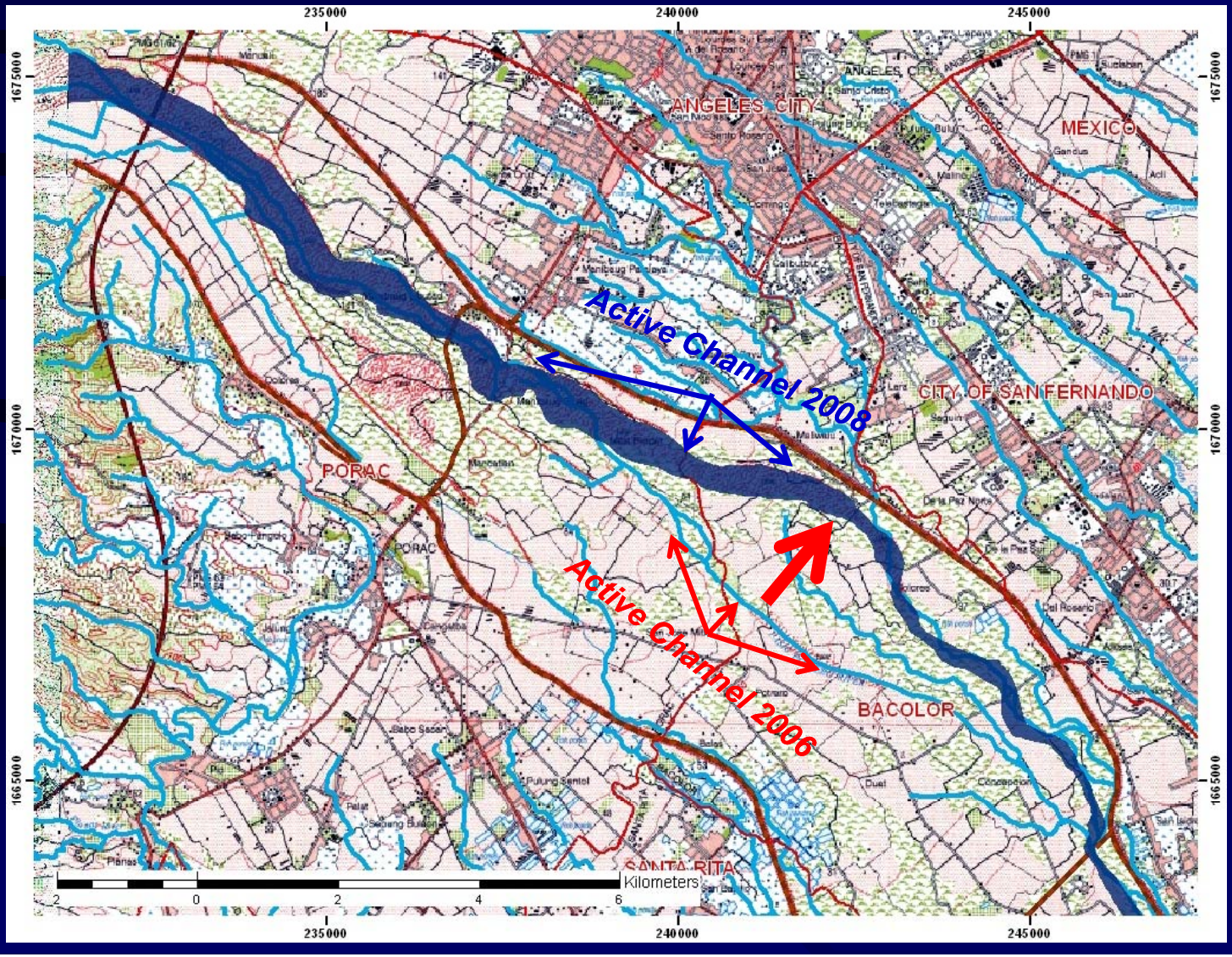
Pasig-Potrero River System

- Channel shifting reflects hydraulic instability, changing risk areas



CURRENT STATUS & FUTURE OUTLOOK:

- Small-volume (<10 million m^3) lahars can still be triggered by rainfall of 100-year flood in the Pasig-Potrero; lahar hazards persist
- Siltation in the Pasig-Potrero, Porac-Gumain, Sacobia-Bamban and Abacan will persist, decreasing channel and sediment-delivery capacities
- Long-term backflooding in the Pampanga River Basin w/ continuous sediment delivery to the downstream areas

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