2005 Infrastructure Conference

A Review of Corps of Engineers Levee Seepage Practices and Proposed Future Changes

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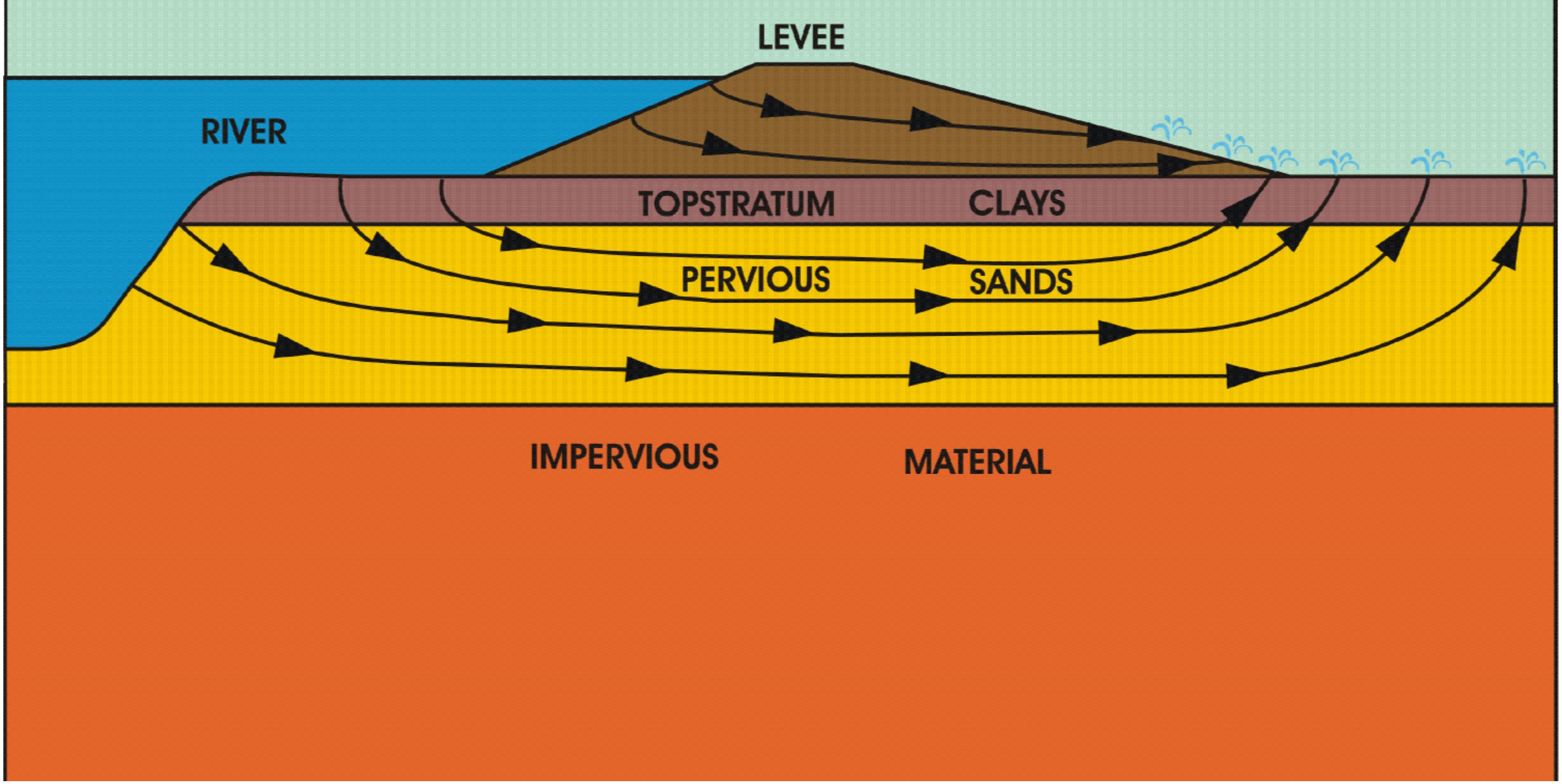
SEEPAGE THROUGH LEVEE AND FOUNDATION



Darcy's Law

$$Q = kiA$$

Piping

"Piping *cannot* be analyzed by any rational method."

TM 5-818-5

Governing Equations

- Flow can be described by the following equation

$$\frac{\partial}{\partial x}\left(T_{xx}\frac{\partial h}{\partial x}+T_{xy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial y}\left(T_{yx}\frac{\partial h}{\partial x}+T_{yy}\frac{\partial h}{\partial y}\right)=S\frac{\partial h}{\partial t}$$

  – where
    - h = head
    - T = transmissivity coefficient
    - S = storage coefficient

Governing Equations

- Transformation of governing equations and simplification by assuming isotropic condition (Txx=Tyy=T) yields

$$S\frac{\partial h}{\partial t} = \frac{T}{J^2}.\left(\alpha h_{\xi\xi} - 2\beta h_{\xi\eta} + \gamma h_{\eta\eta}\right) + \frac{\left[y_\eta T_\xi - y_\xi T_\eta\right].\left[y_\eta h_\xi - y_\xi h_\eta\right] + \left[-x_\eta T_\xi + x_\xi T_\eta\right].\left[-x_\eta h_\xi + x_\xi h_\eta\right]}{J^2}$$


Sand Boil


Sand Boil Prior to Levee Failure


Levee Crevasse

Consequences of Flooding

Sacramento Resources at Risk in a Major Flood

- 400,000 people
- 170,000 structures
- 5,000 businesses
- 1,200 public facilities
- 117 schools
- 40 major roads and highways
- $7-$15 billion in damage in a single flood event

Historic 1861 Sacramento

Flood of 1986

- Largest flood recorded for Sacramento and American Rivers
- Close to 100 year event
- 14 deaths
- $379,000,000 in damages
- American River
  - Design capacity = 115,000 cfs
  - 24 hours at 130,000 cfs
  - Potentially within 3 hours of failing the levees

Flood of 1997

- Close to 100 year event
- 37 levee breaches in levee system
- 8 deaths
- 2,300 homes destroyed
- $524,000,000 in damages
- Seepage and piping predominant mode of failure

Situational Awareness

- Many levee feasibility studies were done before 1997 flood lessons learned
- Hydrology changing
- 1997 flood lessons
- New seepage criteria
- Cost of levee projects

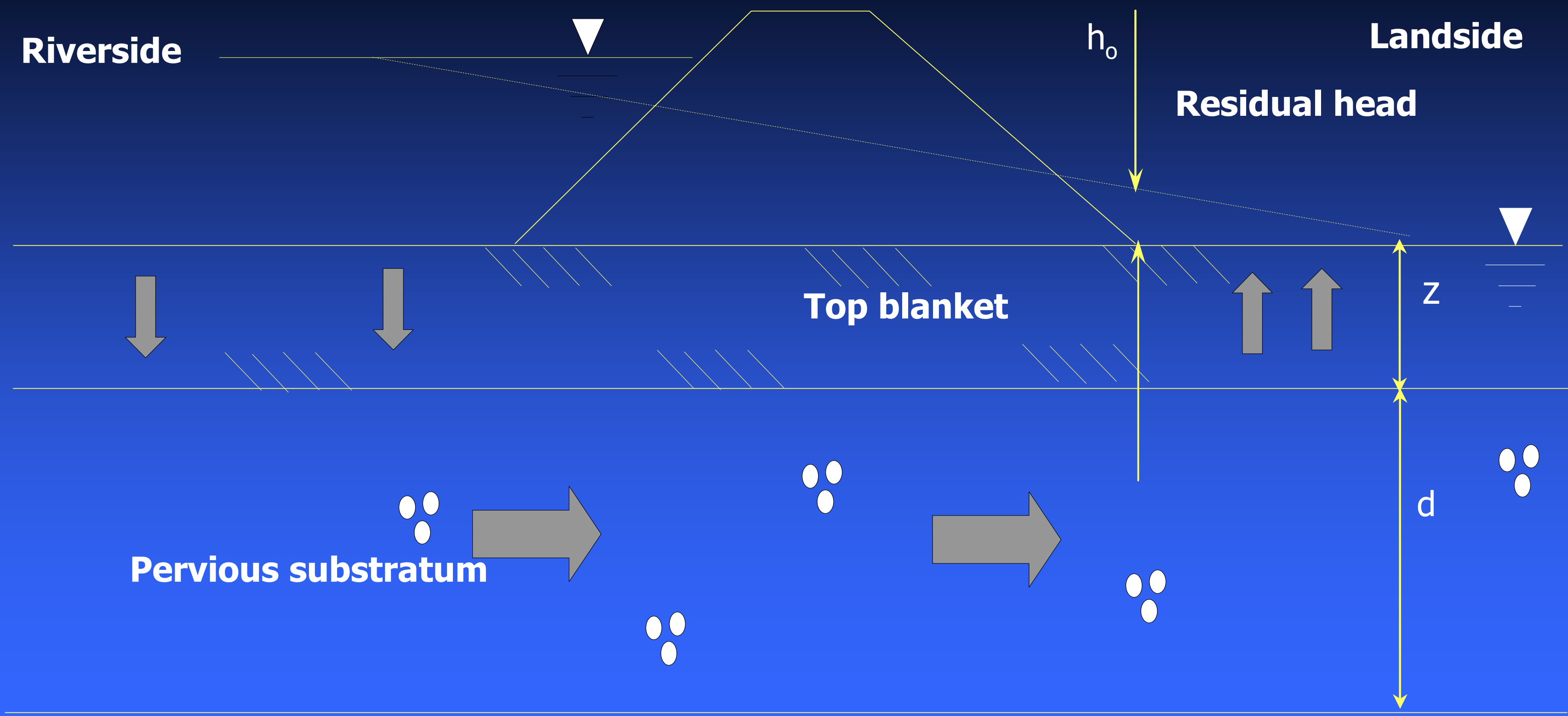
Situational Awareness

- Many levee feasibility studies were done before 1997 flood lessons learned
- Hydrology changing
- 1997 flood lessons
- New seepage criteria
- Cost of levee projects
- **Need to evaluate CESPK criteria**

Task Force Composition

	George Sills	CEMVK	Lead
SHANNON & WILSON, INC.	Chris Groves	Consultant	Member
	Dr. M. Al-Hussaini	CELRD	Member
	Dr. Les Harder	State of California	Member
	Dr. Tom Wolff	Michigan State	Seamless ITR
	Dr. Mike Duncan	Virginia Tech	ITR

Hydraulic Gradient



$$i_o = \frac{h_o}{z}$$

Major USACE Seepage Documents

- TM 3- 424, dated 1956
- CEMVD “Staff Study,” dated 1962
- EM 1110-2-1913, dated 2000
- ETL 1110-2-555, dated 1997

1962 "Staff Study"

- No berm required if
  - i < 0.5 and no past problems
- If i > 0.8 design berm
  - Designed for i = 0.3 at levee toe
  - i at berm toe = 0.8
  - Berm width 300 to 400 ft.
- Minimum berm if i > 0.5 and < 0.8, 150 ft.

EM 1110-2-1913

- No berm required if
  - $i < 0.5$ and no past problems
- If $i > 0.8$ design berm
  - Designed for $i = 0.3$ at levee toe
  - i at berm toe = 0.8
  - Berm width 300 to 400 ft.
- Minimum berm if $i > 0.5$ and < 0.8, 150
- Relief wells
  - Designed for $i = 0.5$ between wells

ETL 1110-2-555

- New levees — NOT existing projects
  - Design berm if i > 0.3 at levee toe
    - Design so that i = 0.3 at levee toe
  - Relief wells
    - Designed for i = 0.5 between wells

Recommendations

- Design to a gradient of 0.5
  – Obtain adequate subsurface information
  – Insure $\gamma sat \geq 110$ lb/ft^3
  – Study past flood histories
  – Plan to maintain
  – Develop a flood fight plan

Can ya teach this dog to hunt something new?

ETL 1110-2-569 (May 2005)

- If i > 0.8 design so i = 0.5 at levee toe for
  - Berms, between relief wells, and landside drainage ditches
- If i > 0.5 and < 0.8 minimum berm is 4 X the levee height
- Thickness of berm increased the calculated/estimated amount for shrinkage and consolidation
- Contains **WARNING** about arbitrary limiting berm width to 300 to 400 ft may not be safe.

Item 450-R Seepage Berm Analysis

			io = 0.3					io = 0.5				
Station	Zt (ft)	ha (0.8*Zt) (ft)	Berm Width Computed (ft)	ho´ (ft)	ha@x = 300 ´ (ft)	il@x = 300 ´ (ft)	Safety Factor	Berm Width Computed (ft)	ho ´ (ft)	ha@x = 300'(ft)	il@x = 300 ´ (ft)	Safety Factor
2715+00 B	7	5.6	893	18.8	11.41	1.63	**0.49**	837	18.15	11.02	1.57	**0.51**
2720+00	4	3.2	817	15.1 3	7.11	1.78	**0.45**	752	14.25	6.70	1.67	**0.48**
2725+00	8	6.4	582	14.4	8.97	1.12	**0.71**	539	13.85	8.63	1.08	**0.74**
2730+00	5	4	654	13.1 3	6.75	1.35	**0.59**	600	12.43	6.39	1.28	**0.63**
2745+00	12	9.6	480	15.8	11.32	0.94	**0.85**	448	15.42	11.04	0.92	**0.87**
2750+00	10	8	604	16.2 2	10.98	1.10	**0.73**	561	15.69	10.62	1.06	**0.75**

Item 450-R Seepage Berm Analysis for 100-yr Flood

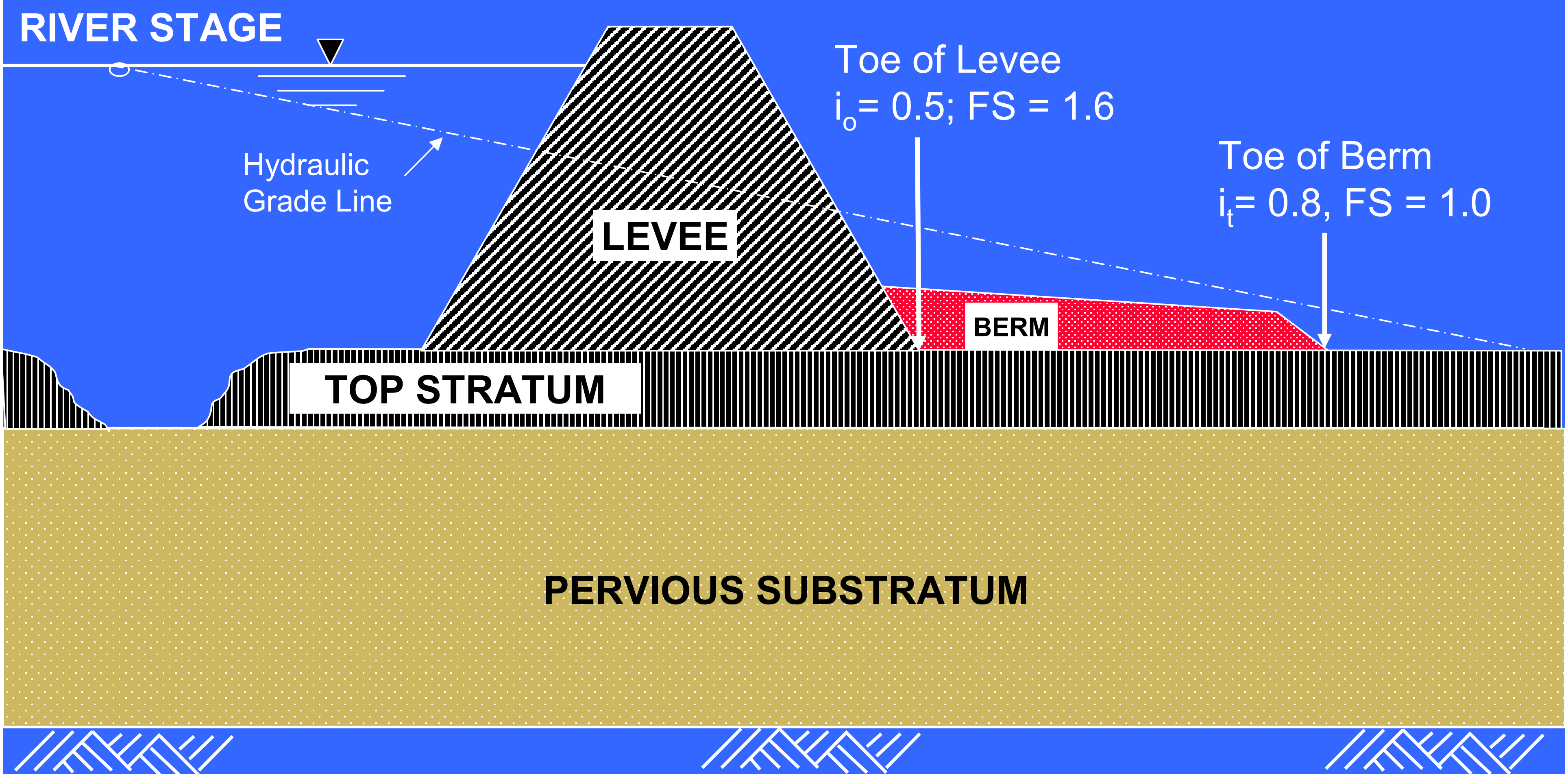
Station	Zt (ft)	t @ Design Flowline	ho ´	io	Safety Factor @ Toe of levee	ha(ft)= ho ´*e^-cx	il	Safety Factor @ Toe of Berm
2715+00 B	7	9.77	13.85	0.24	**3.29**	8.41	1.20	**0.67**
2720+00	4	8.17	10.79	0.22	**3.72**	5.07	1.27	**0.63**
2725+00	8	6.57	8.42	0.13	**6.30**	5.25	0.66	**1.22**
2730+00	5	6.62	9.16	0.22	**3.66**	4.71	0.94	**0.85**
2745+00	12	6.28	11.78	0.30	**2.66**	8.44	0.70	**1.14**
2750+00	10	7.13	12.06	0.29	**2.78**	8.16	0.82	**0.98**

Note: io = 0.5 at levee toe for design flowline

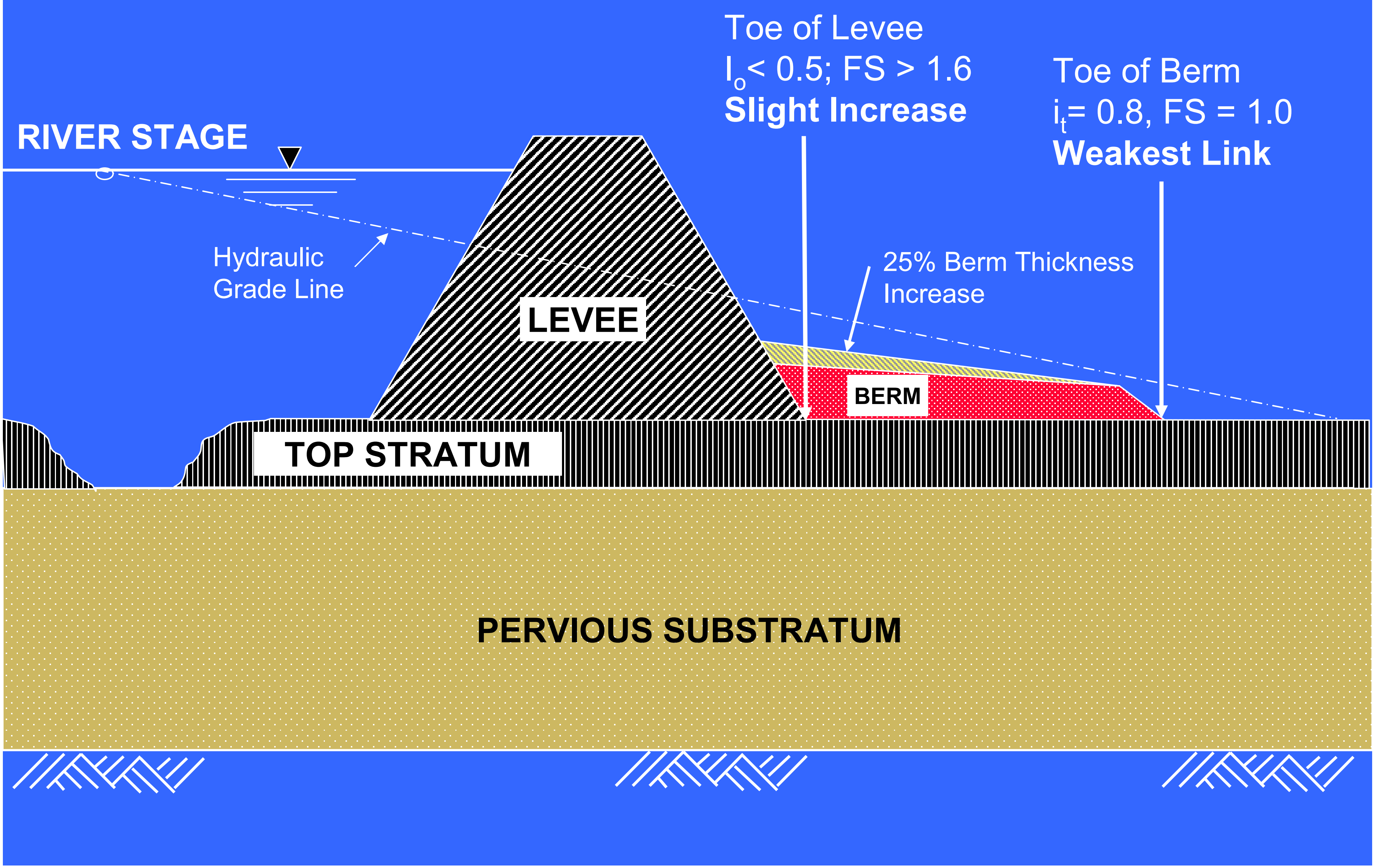
MRL Item 450-R

Berm Embankment Savings	315,000 cu yds	Cost Savings	$ 693,000
Right-of-Way Savings (from borrow area)	30 acres	Cost Savings	$ 30,000
		Total Savings	$ 723,000

Typical Levee Berm

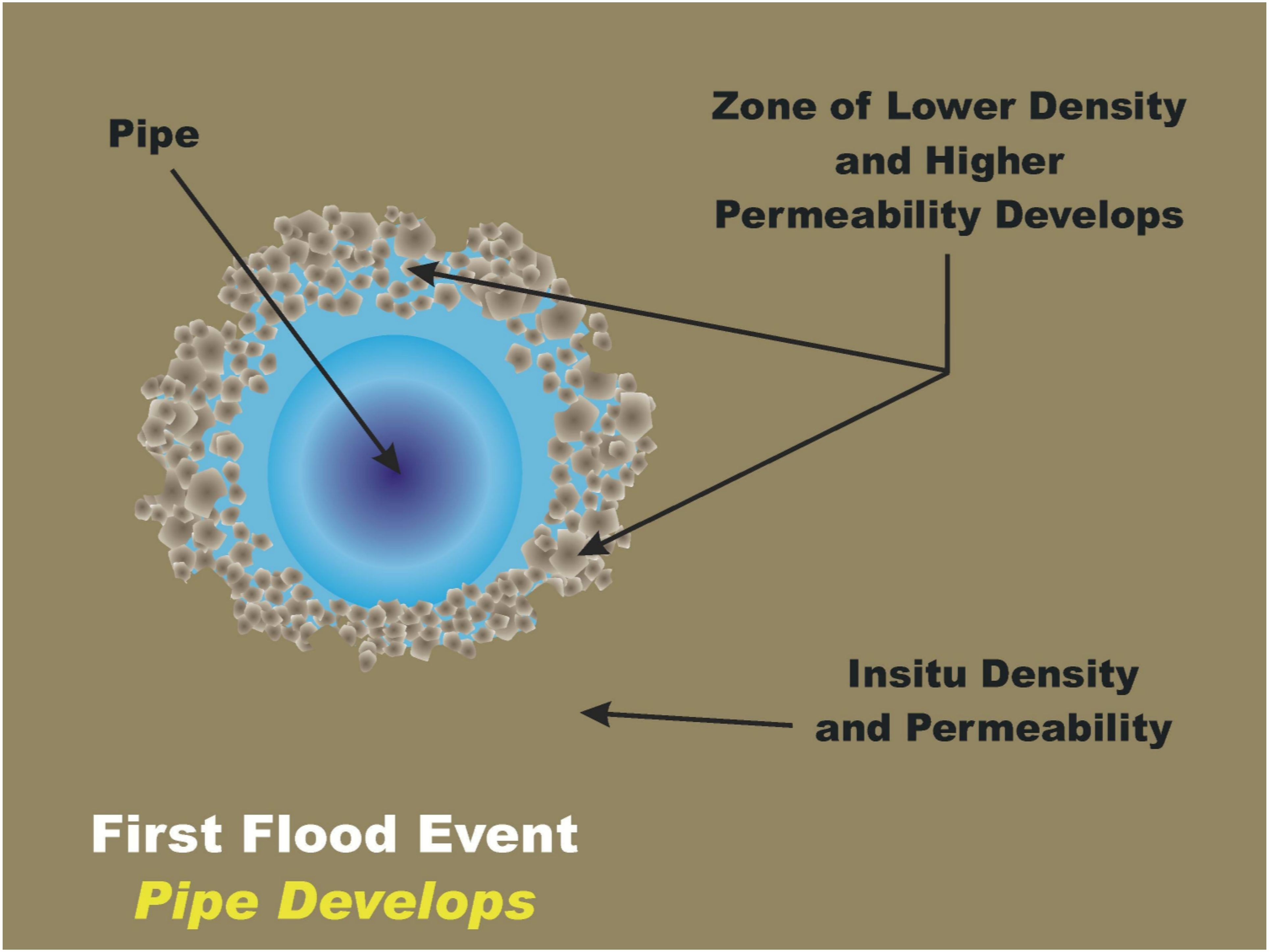


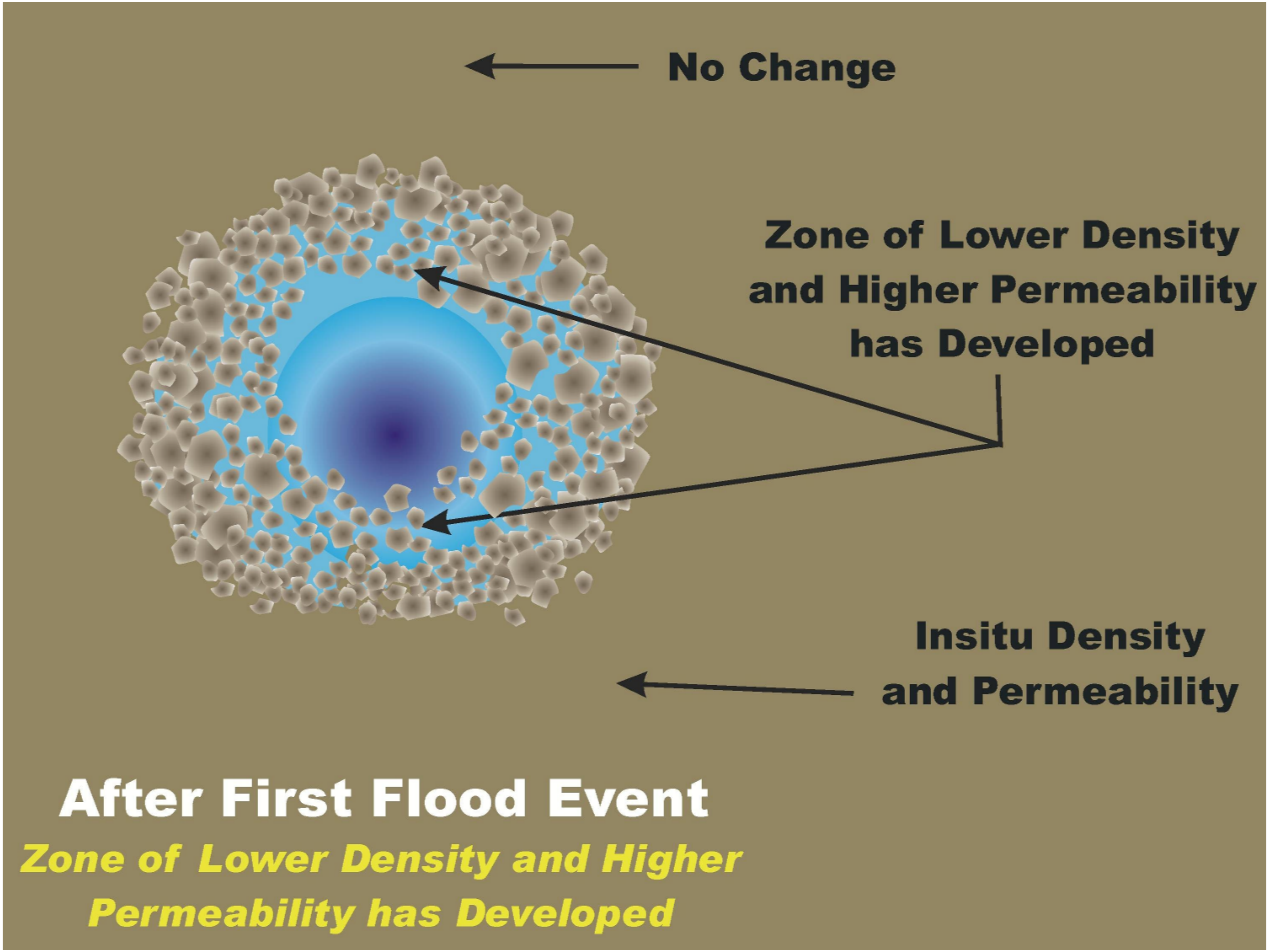
Typical Levee Berm

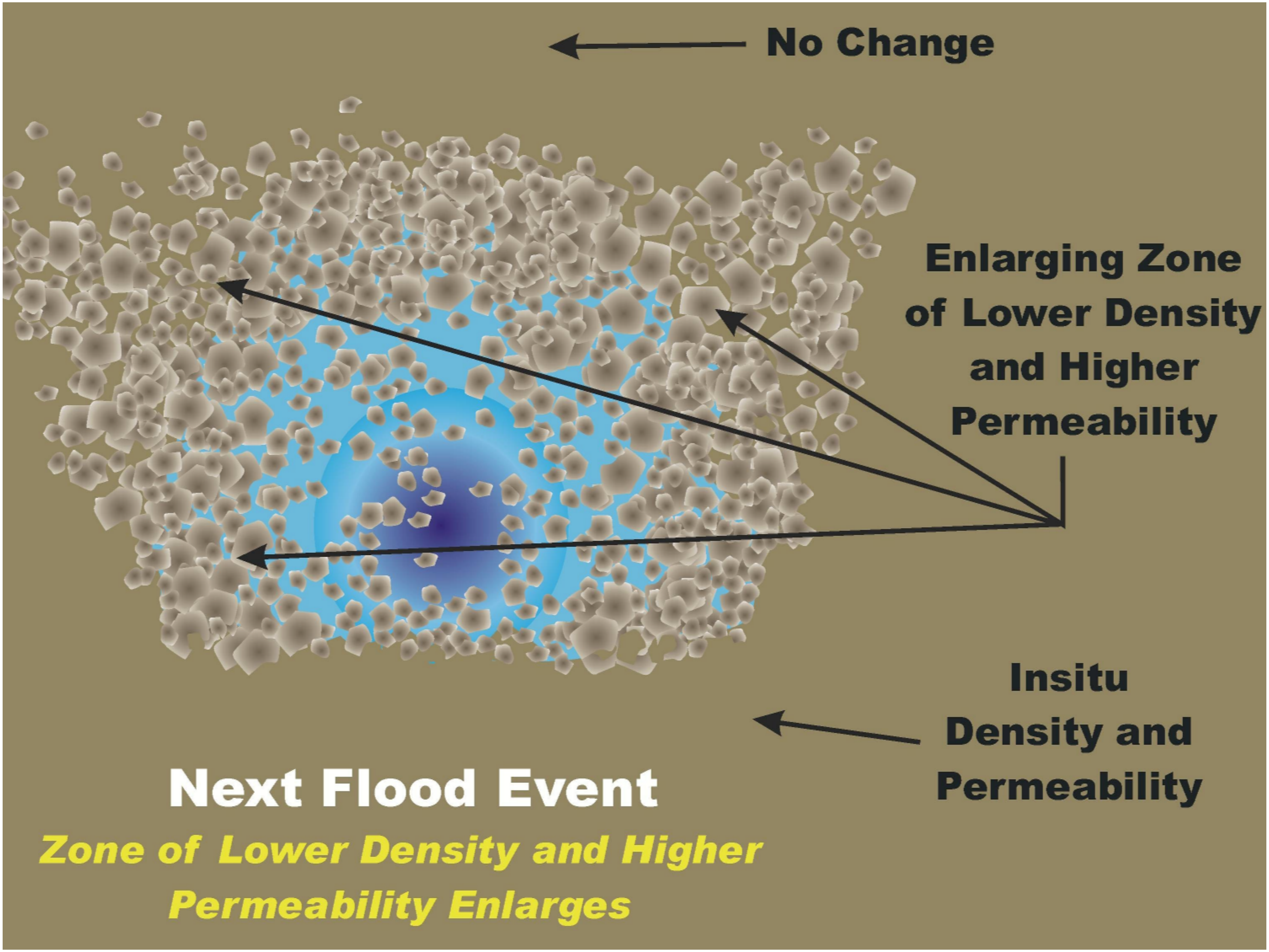


Factors Influencing Permeability

- Particle size and shape
- Properties of the fluid
- Hydraulic gradient
- Degree of saturation
- DENSITY


Pipe
Zone of Lower Density and Higher Permeability Develops
Insitu Density and Permeability
First Flood Event
Pipe Develops


No Change
Zone of Lower Density
and Higher Permeability
has Developed
Insitu Density
and Permeability
After First Flood Event
Zone of Lower Density and Higher
Permeability has Developed

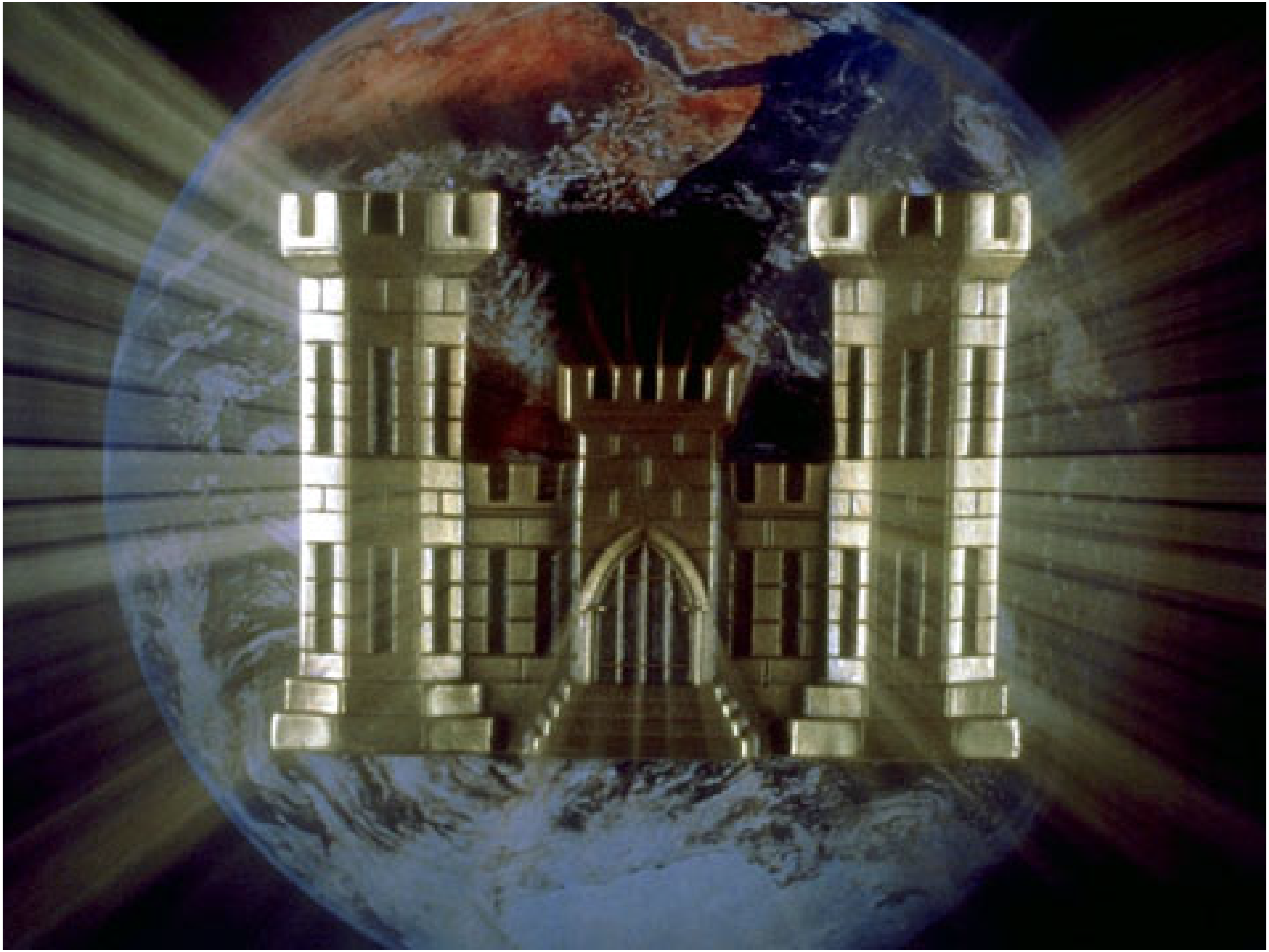

No Change
Enlarging Zone of Lower Density and Higher Permeability
Insitu Density and Permeability
Next Flood Event
Zone of Lower Density and Higher Permeability Enlarges

Research Goals

- Develop empirical basis for piping occurrence
- Develop theoretical basis for piping occurrence
- Develop predictive tool
- Develop monitoring tool

Conclusions (Needs)

- Mathematical model to predict behavior
- Identify reaches that have been affected
- Develop economical methods of repair
- EM 1110-2-1913 (Rewritten)



Probabilistic Analysis in Task Group Report

- Critical Gradient **N(0.9, 0.12)**