SITE CHARACTERIZATION AND FAILURE MODELS FOR THE PATERNO et al vs STATE OF CALIFORNIA FLOOD CASE

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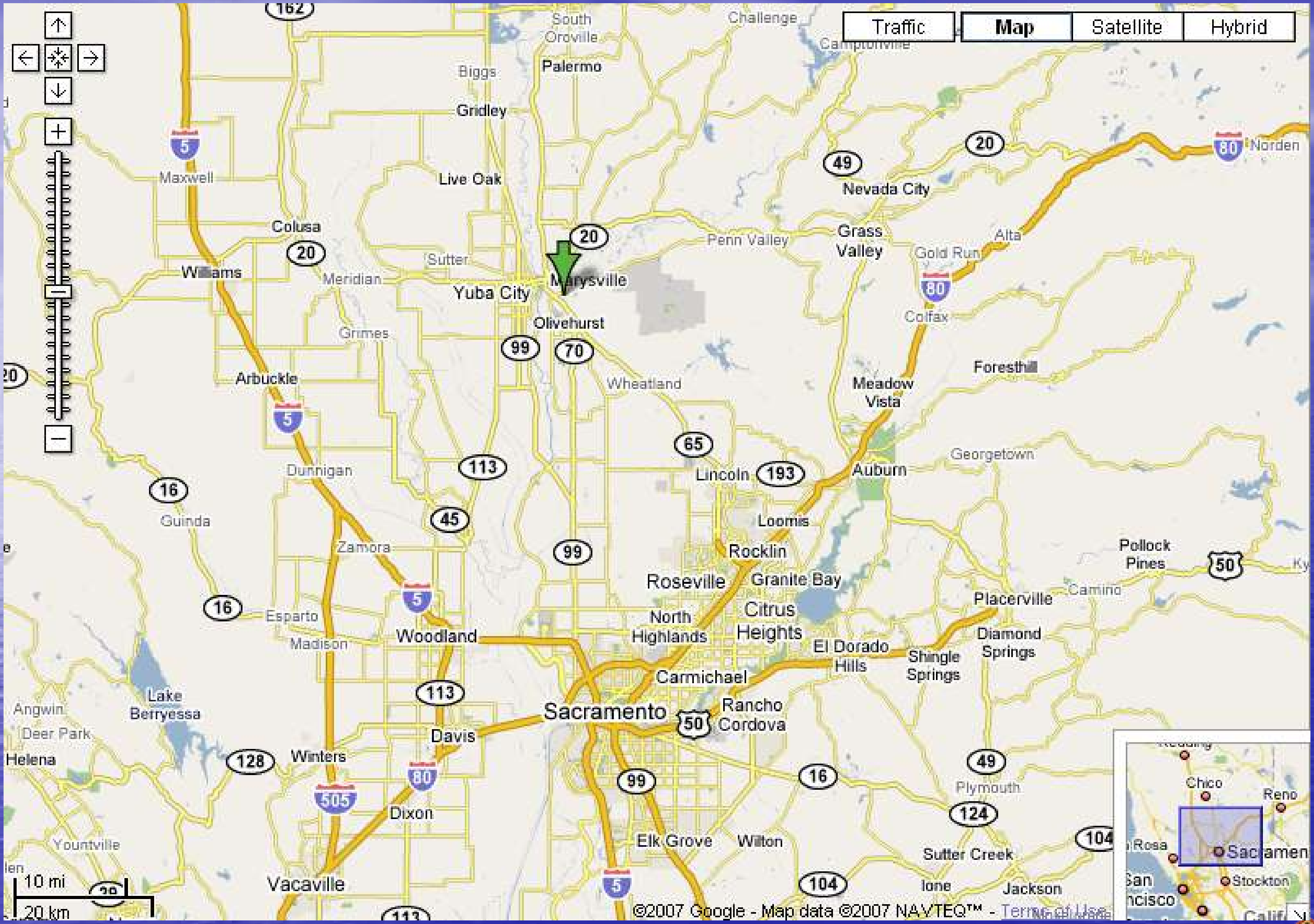
for the

2007 Annual Meeting

Association of Environmental and Engineering Geologists

Los Angeles, California

September 28, 2007



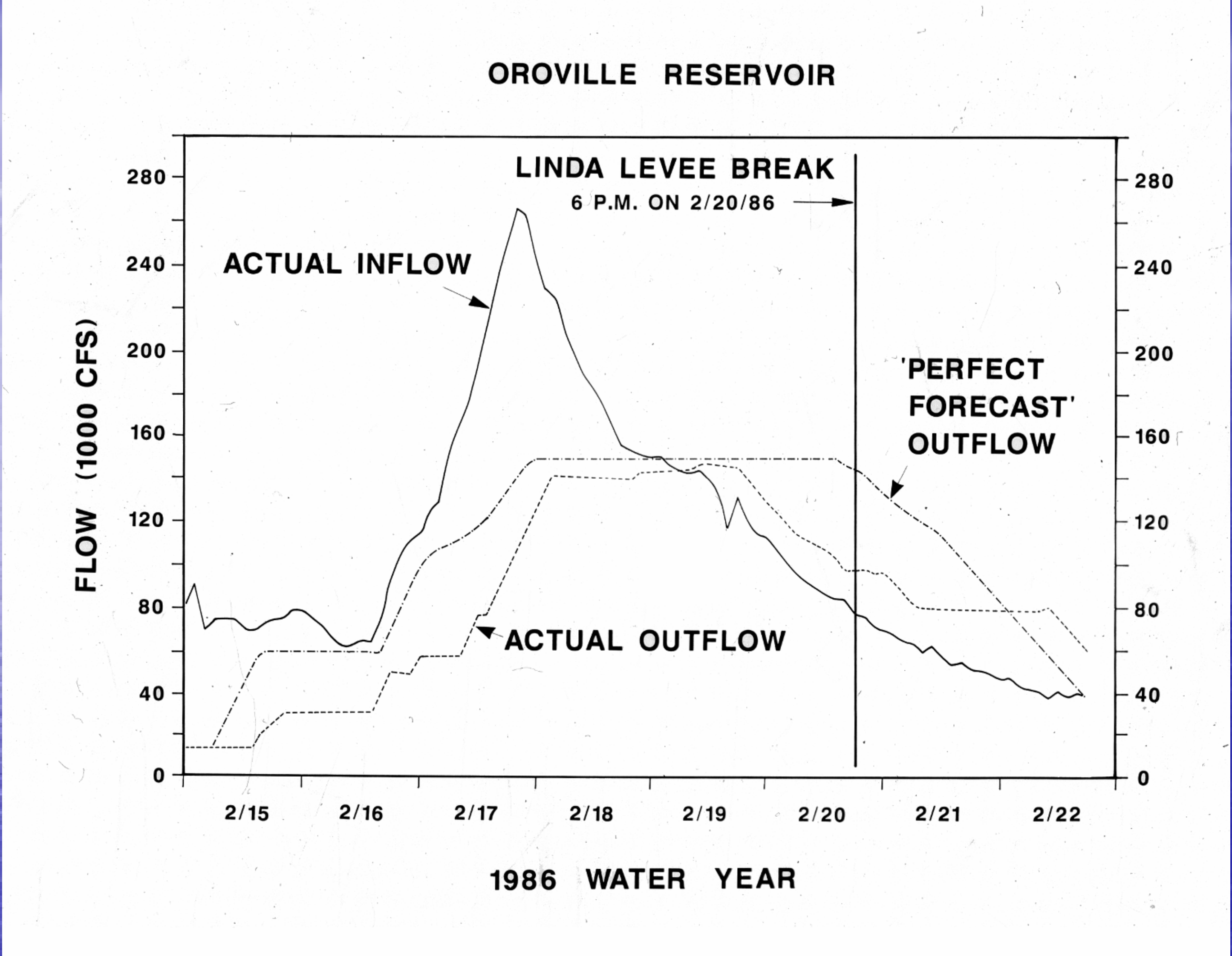
- The communities of Marysville, Yuba City, Linda, and Olivehurst are located about an hour's drive north of Sacramento, in the Sacramento Valley.

- **Junction of the Yuba River with the Feather River. Marysville is at upper left, while Linda occupies the area at lower right.**

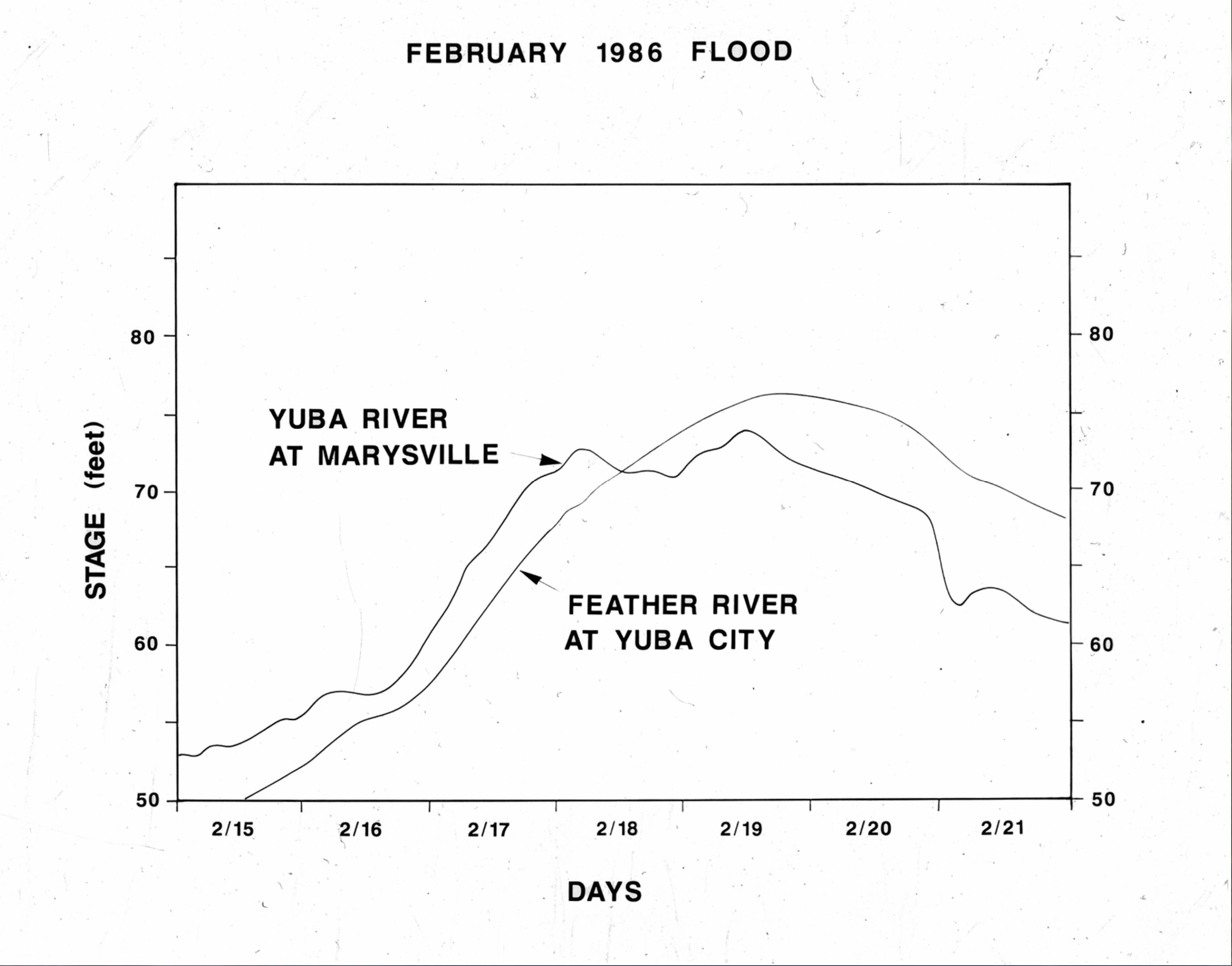
- Around 6 PM on February 20, 1986 the Linda Levee on the south side of the Yuba River, about half a mile above its mouth, suddenly disintegrated.

- The flooding spread through the area, inundating the communities of Linda and Olivehurst, causing >$1.5 billion damage.

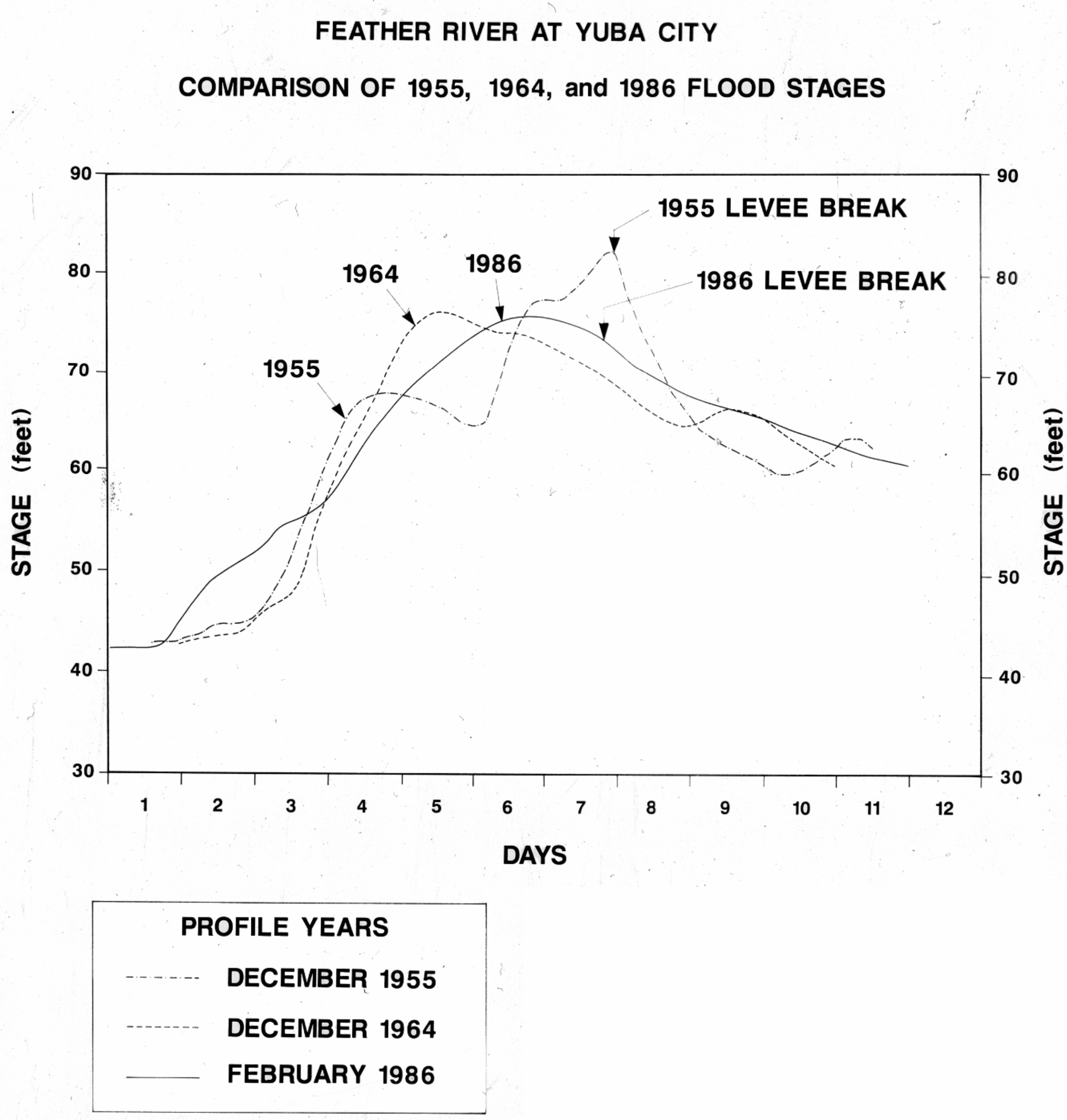
- **Entire neighborhoods were flooded, and relief efforts were complicated by the loss of High way 70, shown here, which is the main access corridor serving the area.**



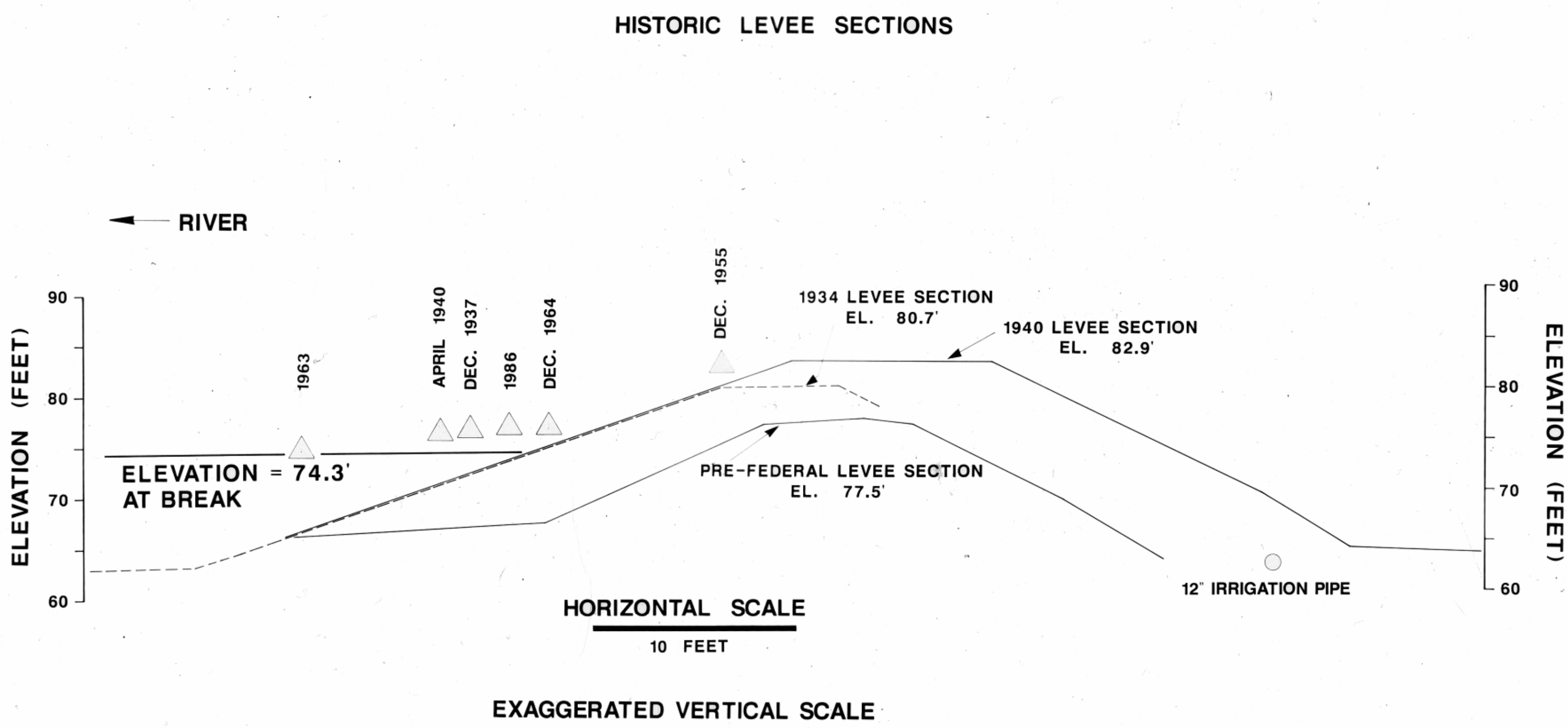
- Oroville Reservoir was intended to store runoff for several days, so peak flows of the Feather River would not coincide with those of major downstream tributaries, like the Yuba River.



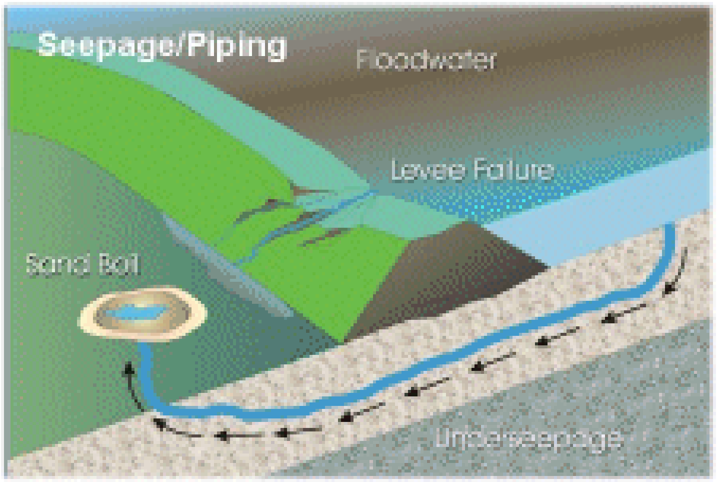
- Unfortunately, the peak flows of the two rivers nearly coincided with one another, as shown here.

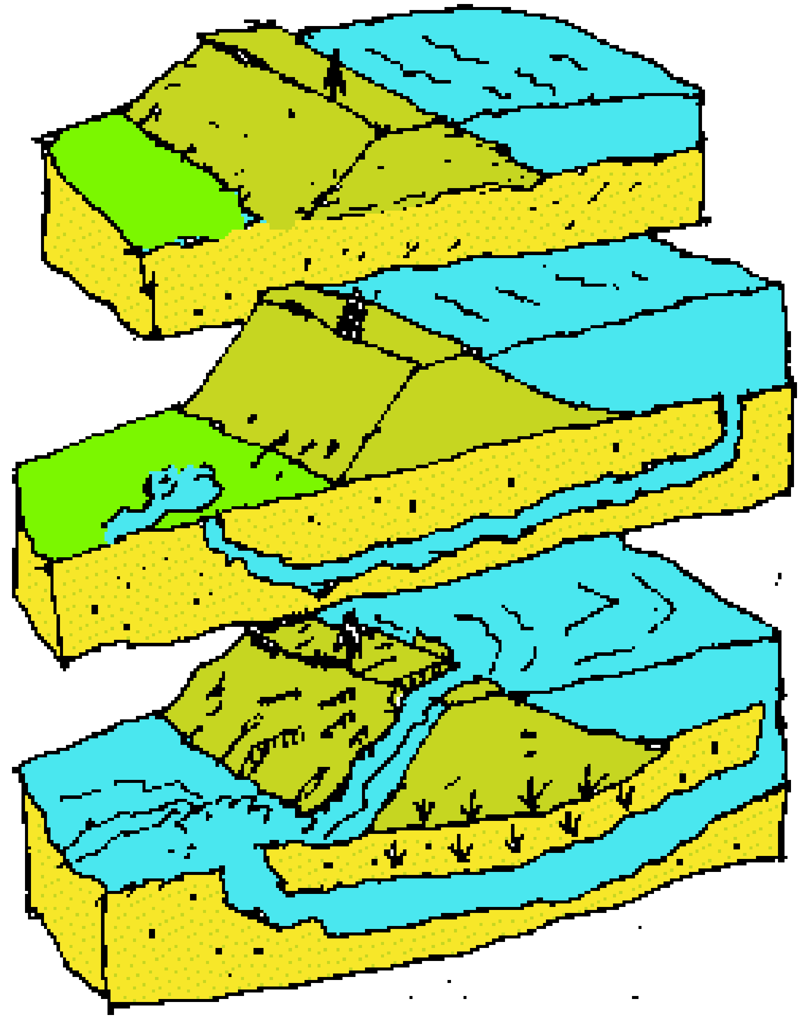


- Historic hydrographs of the Feather River at Yuba City, illustrating the stages where major levee failures have occurred.



- **The February 20th failure occurred *after* the flood had crested, 9 feet *below* the levee crown.**

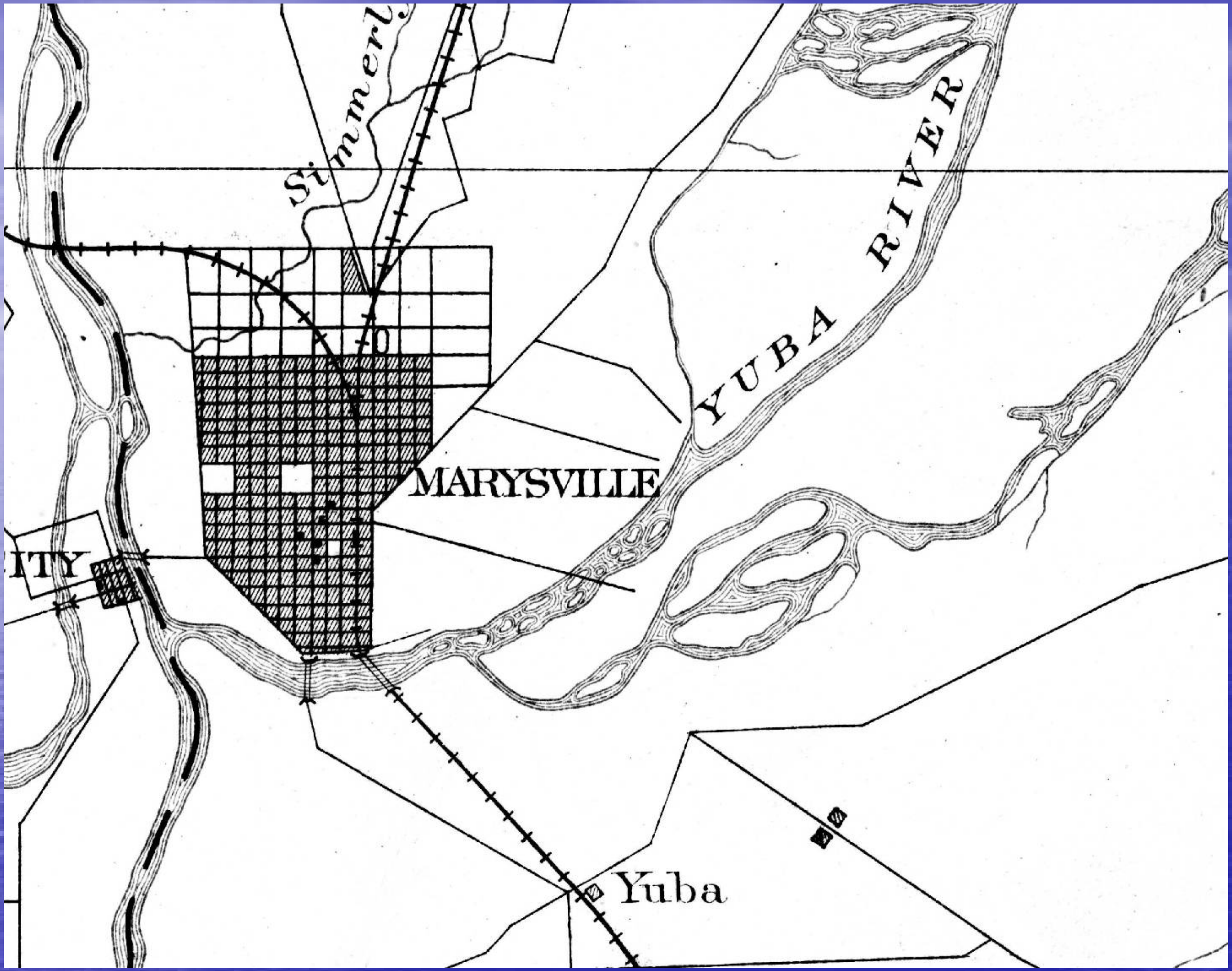




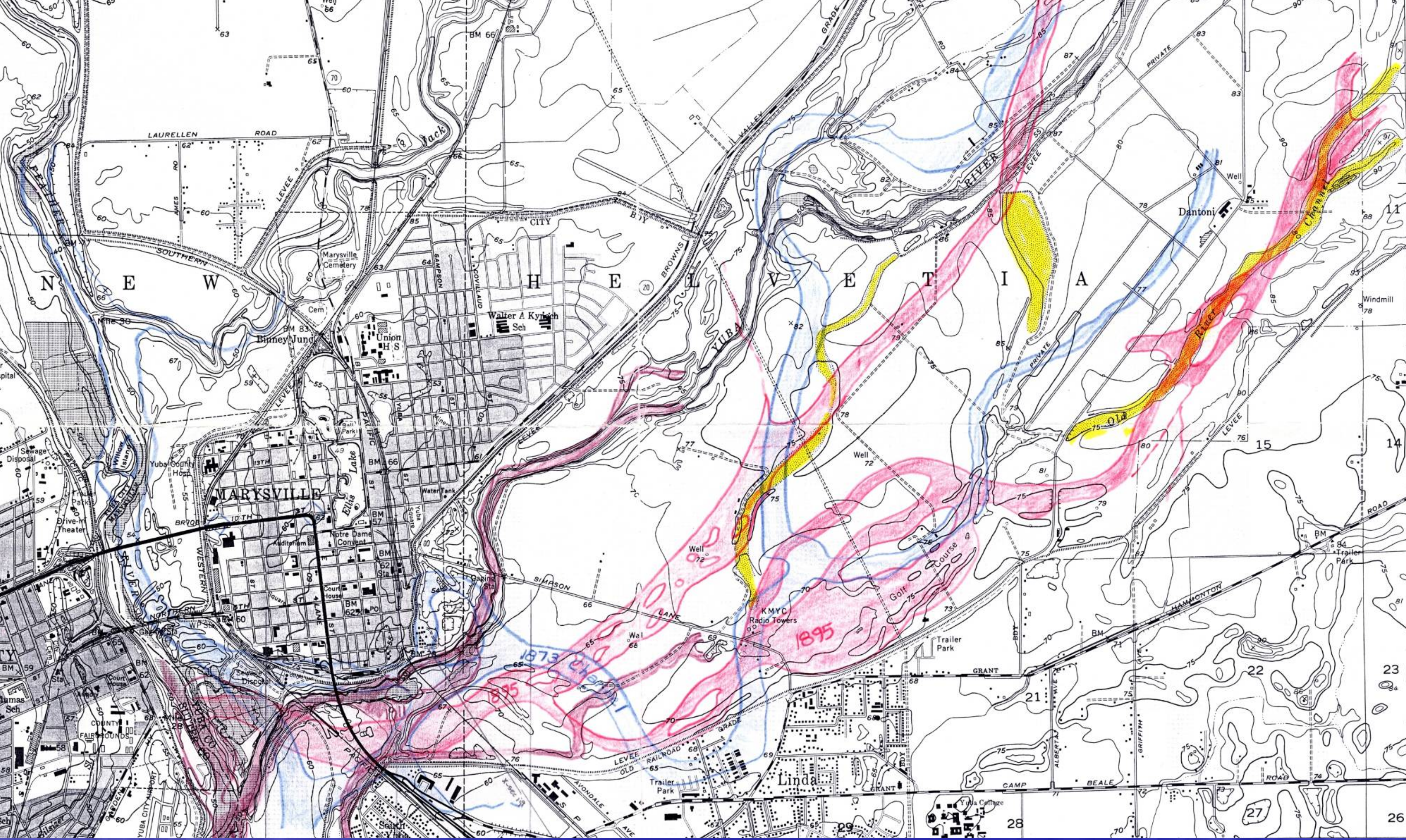
- **The precise mode of failure remained a major mystery. Eyewitness accounts described “bubbling” near the levee toe, followed by the land-side of the levee “disintegrating” and “falling into a hole”. The failure was catastrophic.**

SITE CHARACTERIZATION MUST ALWAYS BEGIN WITH A REVIEW OF THE SITE'S KNOWN HIST0RY

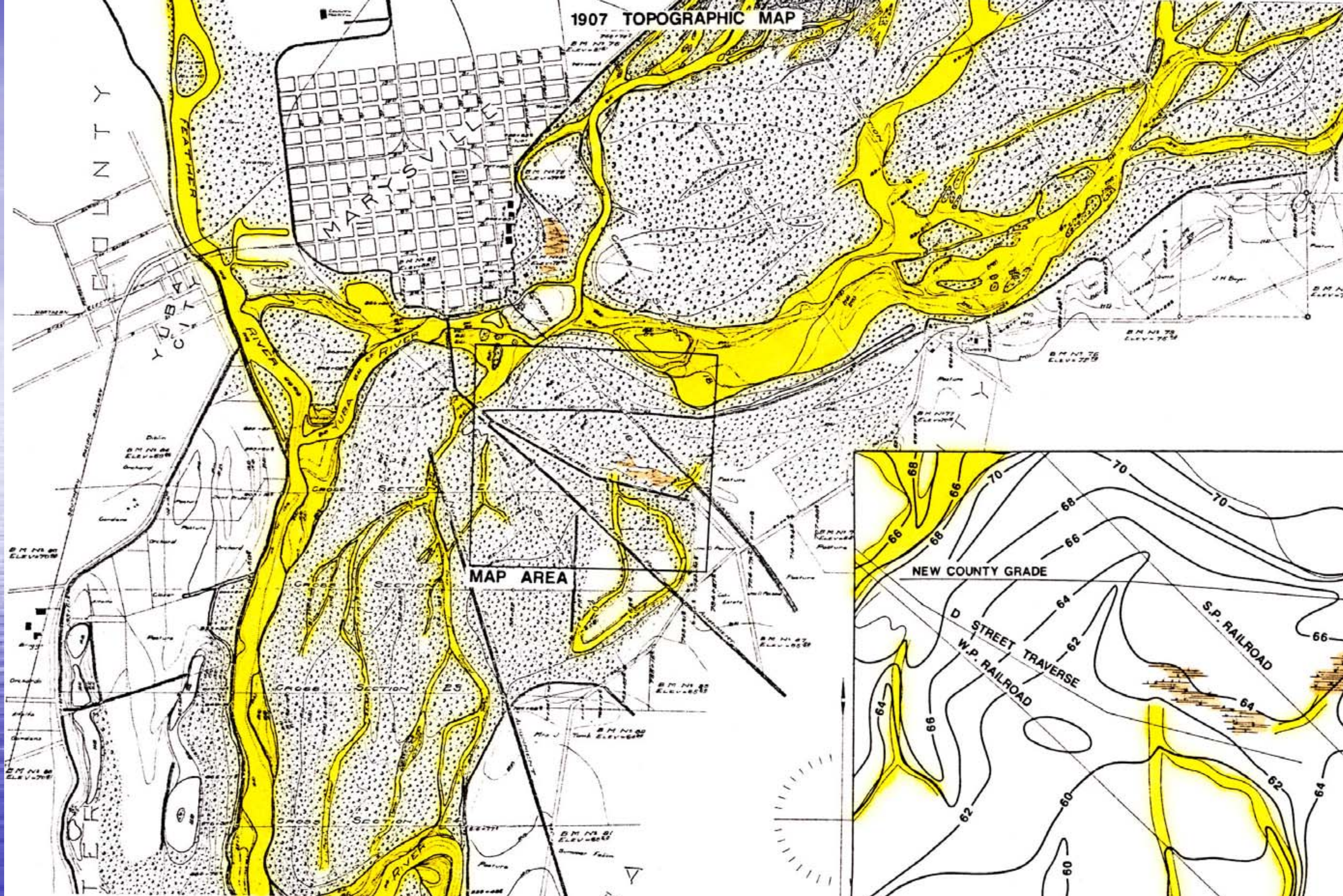
- Prior to the record floods of 1862, river boats like these plied the Sacramento and Feather Rivers all the way to Marysville
- Diurnal tidal fluctuations were recorded upstream as far as Marysville prior to 1862.



- **The earliest USGS map of the levee breach area was prepared in 1895 at a scale of 1" = 2 miles (30 minute).**



- **The shows an overlay of the 1873 and 1895 river channels on a modern-day USGS 1:24K topo map.**

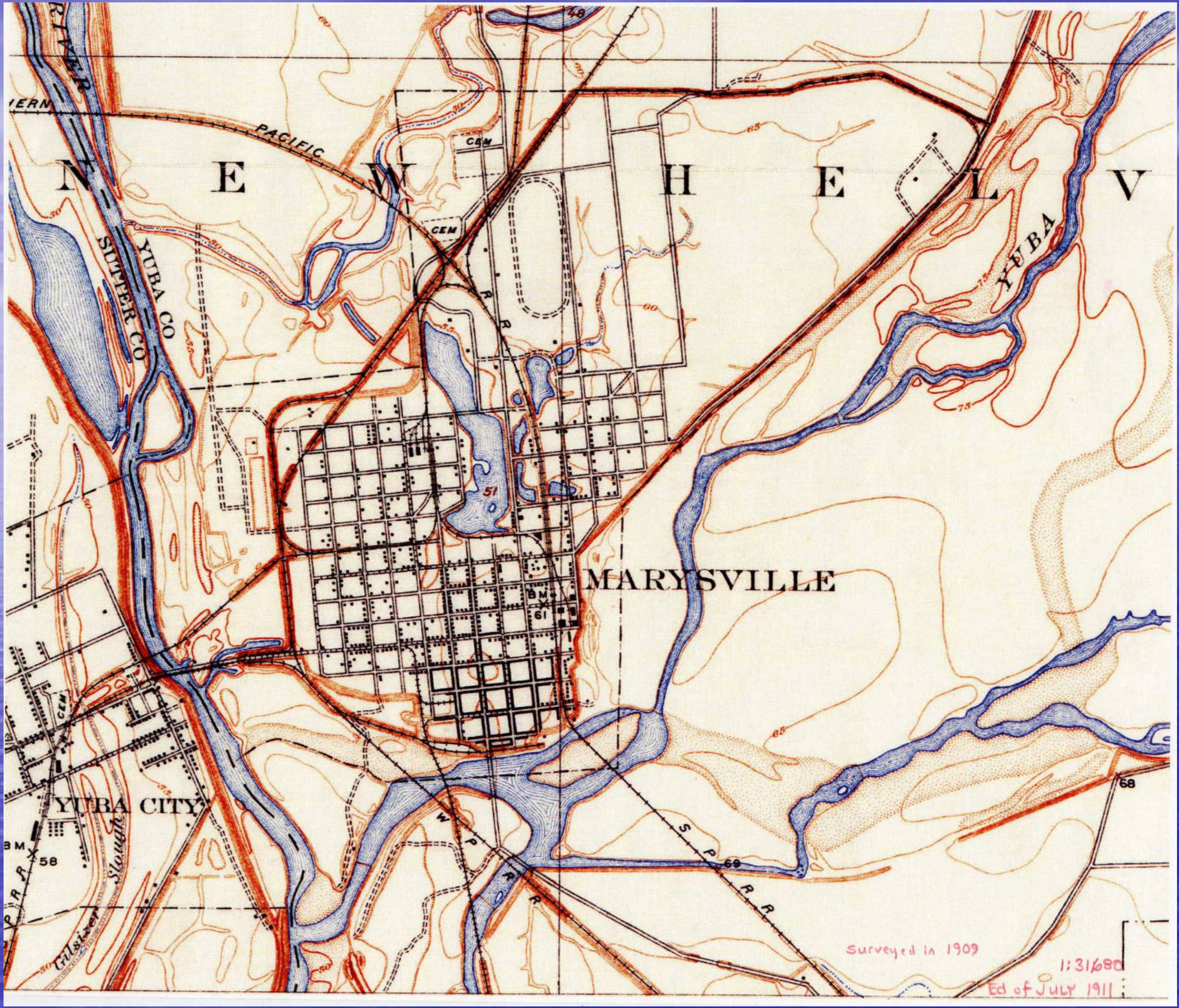


- **This is a map of the lower Yuba River prepared by the California Debris Commission in 1907.**

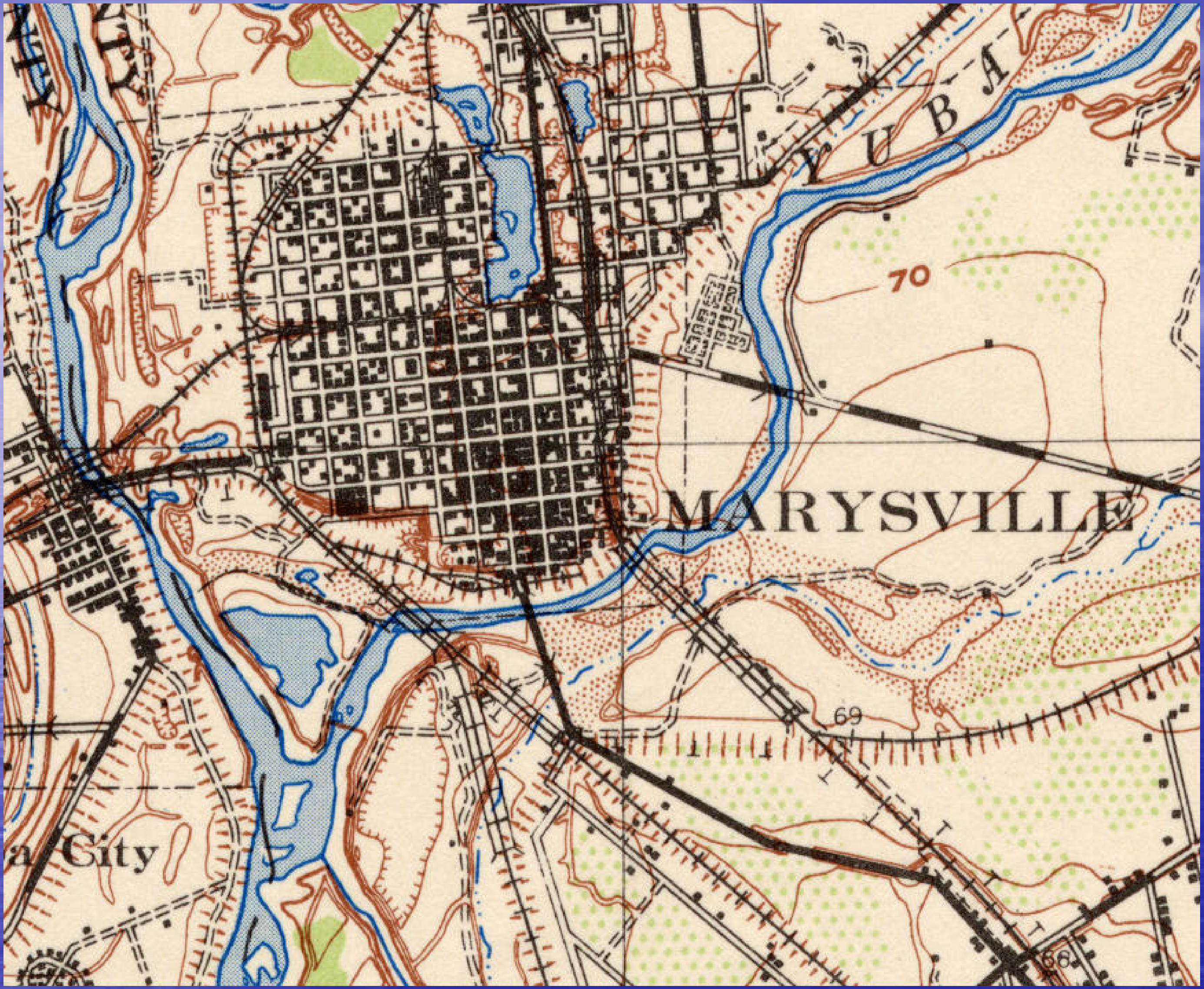
Break in east levee of the Feather River just south of Marysville during flood of January, 1914.

- **The Yuba and Feather Rivers experienced severe flooding in 1907, 1909, and again in 1914 (shown here). This was last flood to inundate the Linda-Olivehurst area prior to 1986.**

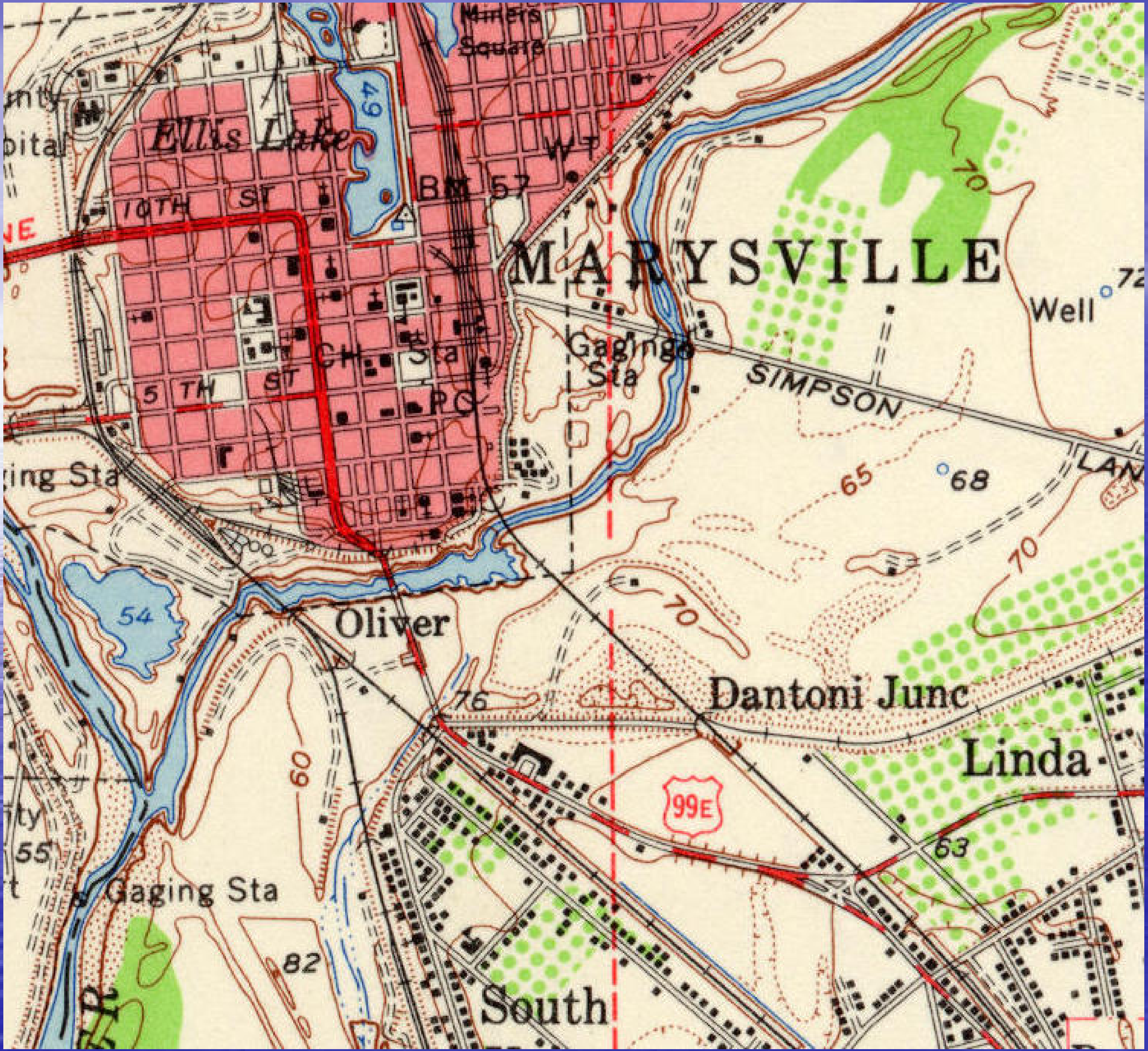
- Most of the areas around adjoining Marysville were diked off between 1900 and 1915



- **15 minute USGS topo map, edition of 1911**



- **USGS 15 minute topo map in 1942, during the Second World War.**



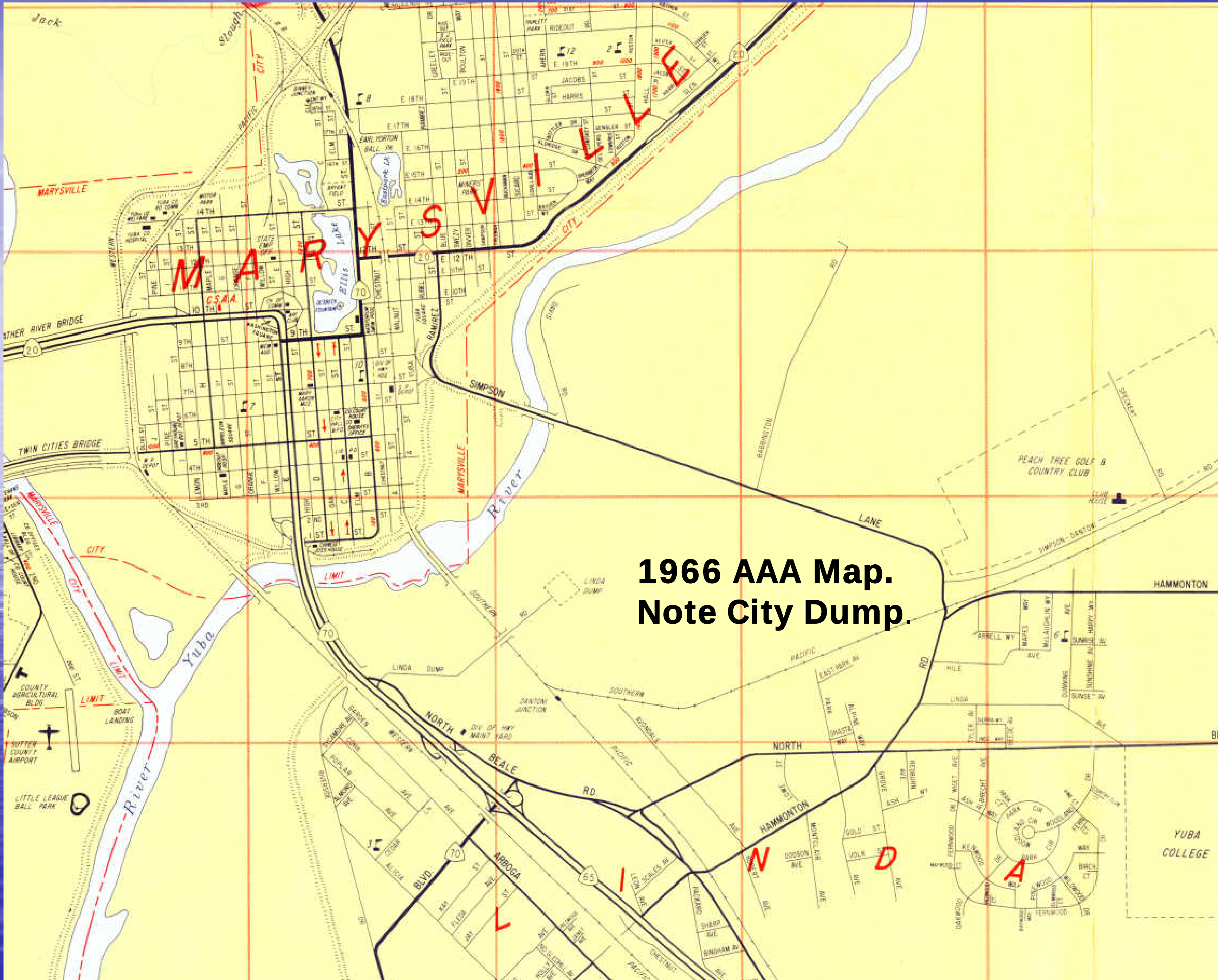
Valuable details

1952 7.5 minute USGS topo map

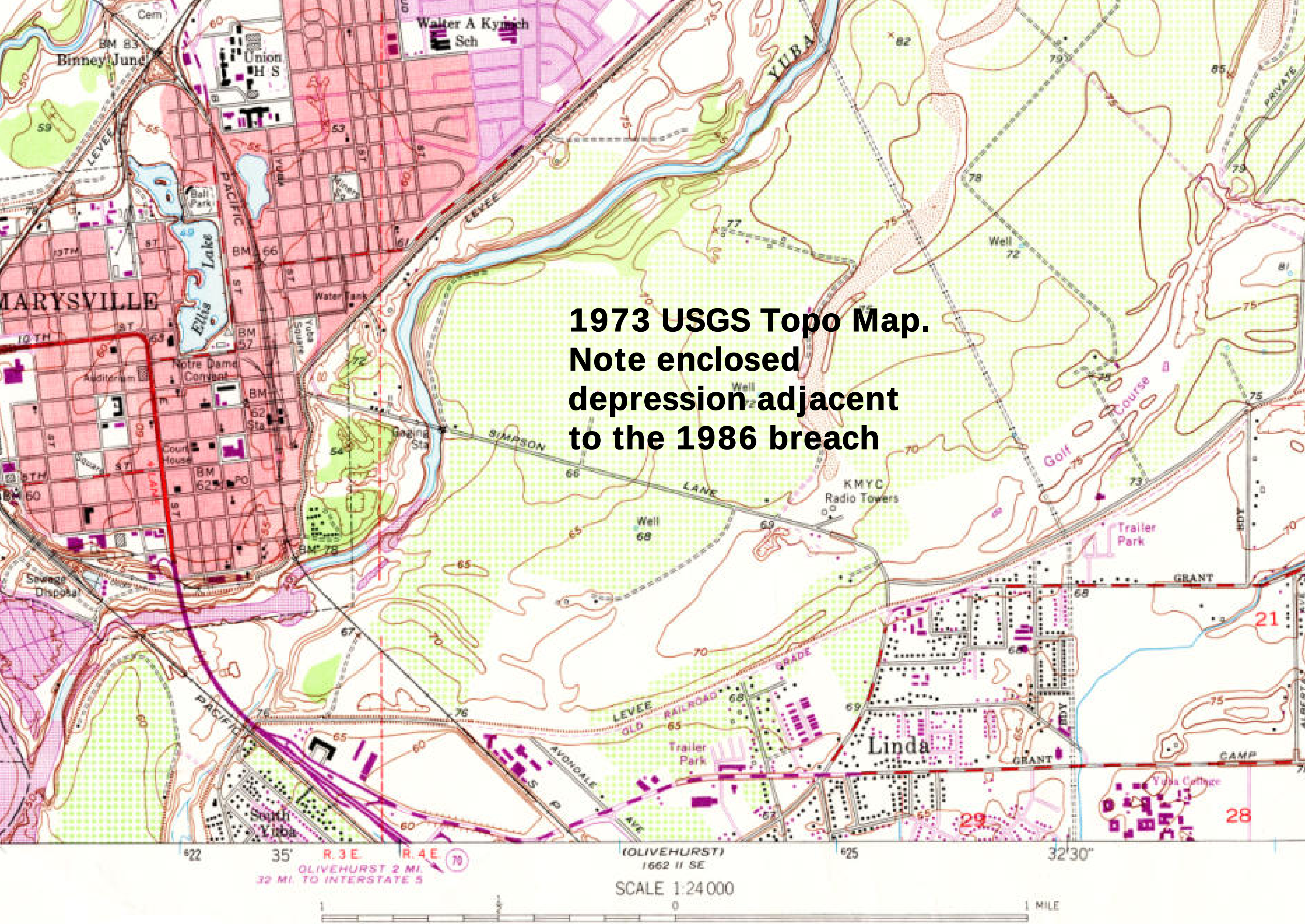
Note borrow pits for 1940 levee additions adjacent to 1986 breach

RR grade infilled on south side of Yuba Channel

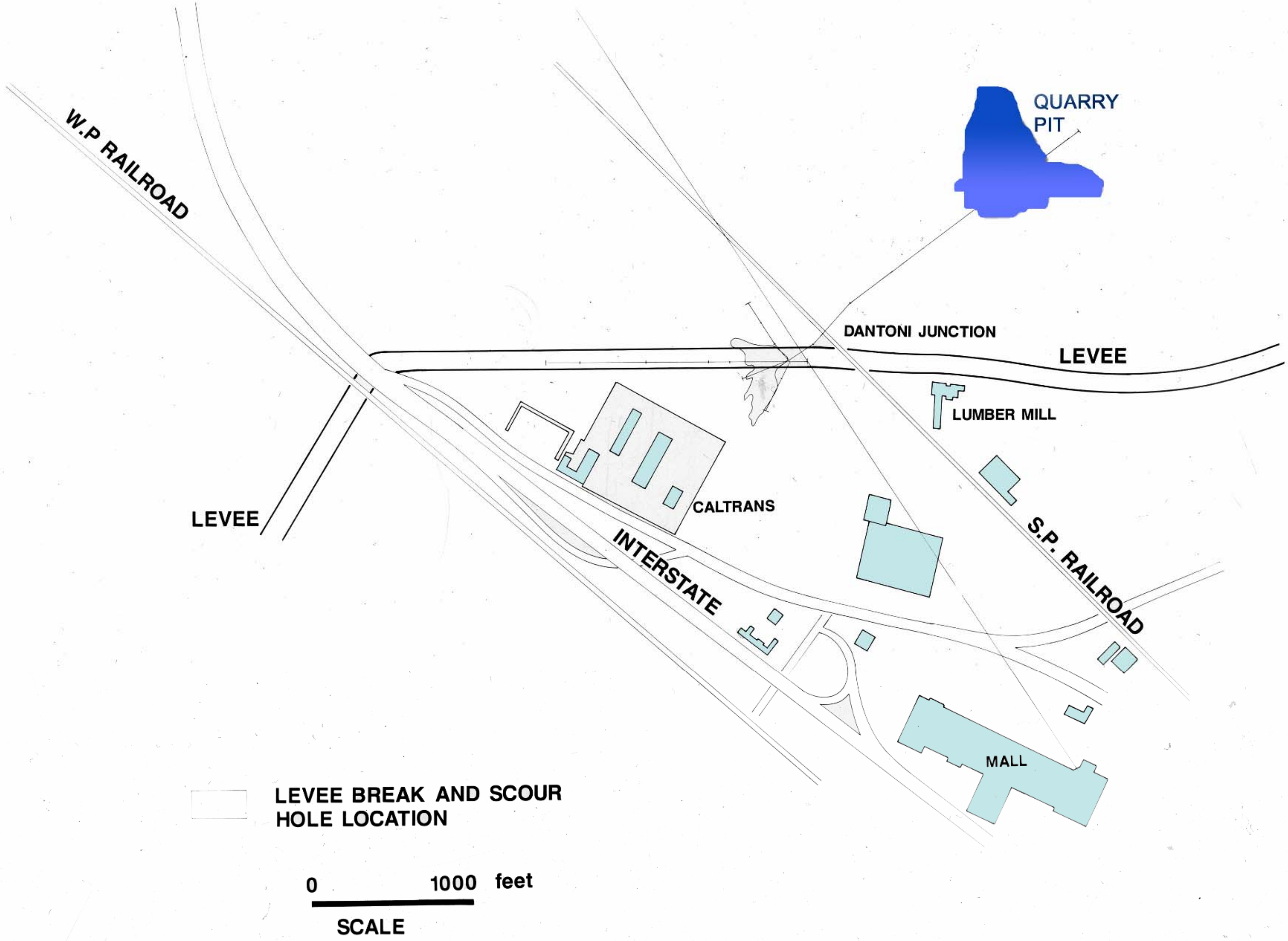
- **1953 Marysville City map shows bifurcation of Yuba channel near its mouth, and infilled rail crossing**



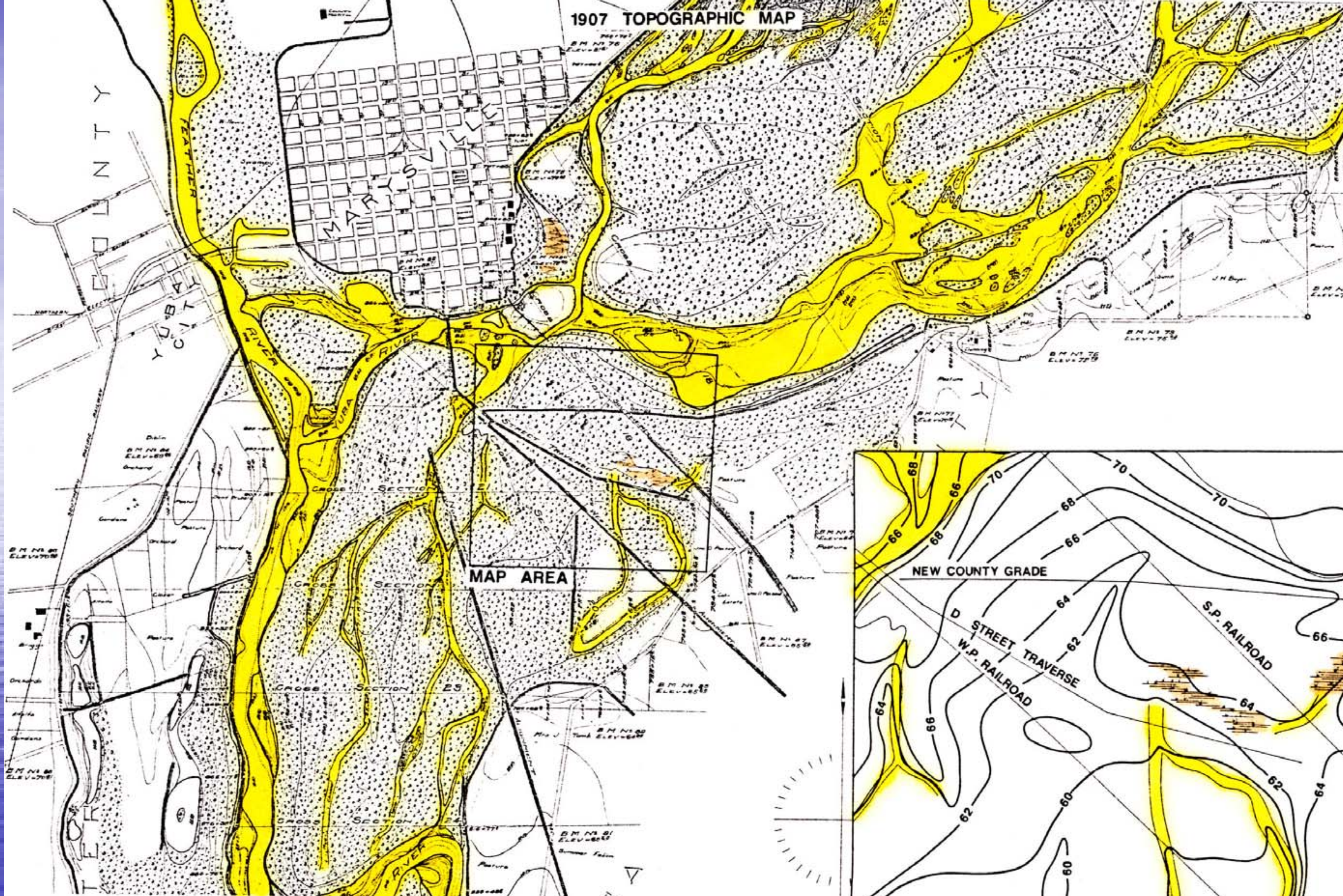
1966 AAA Map.
Note City Dump.



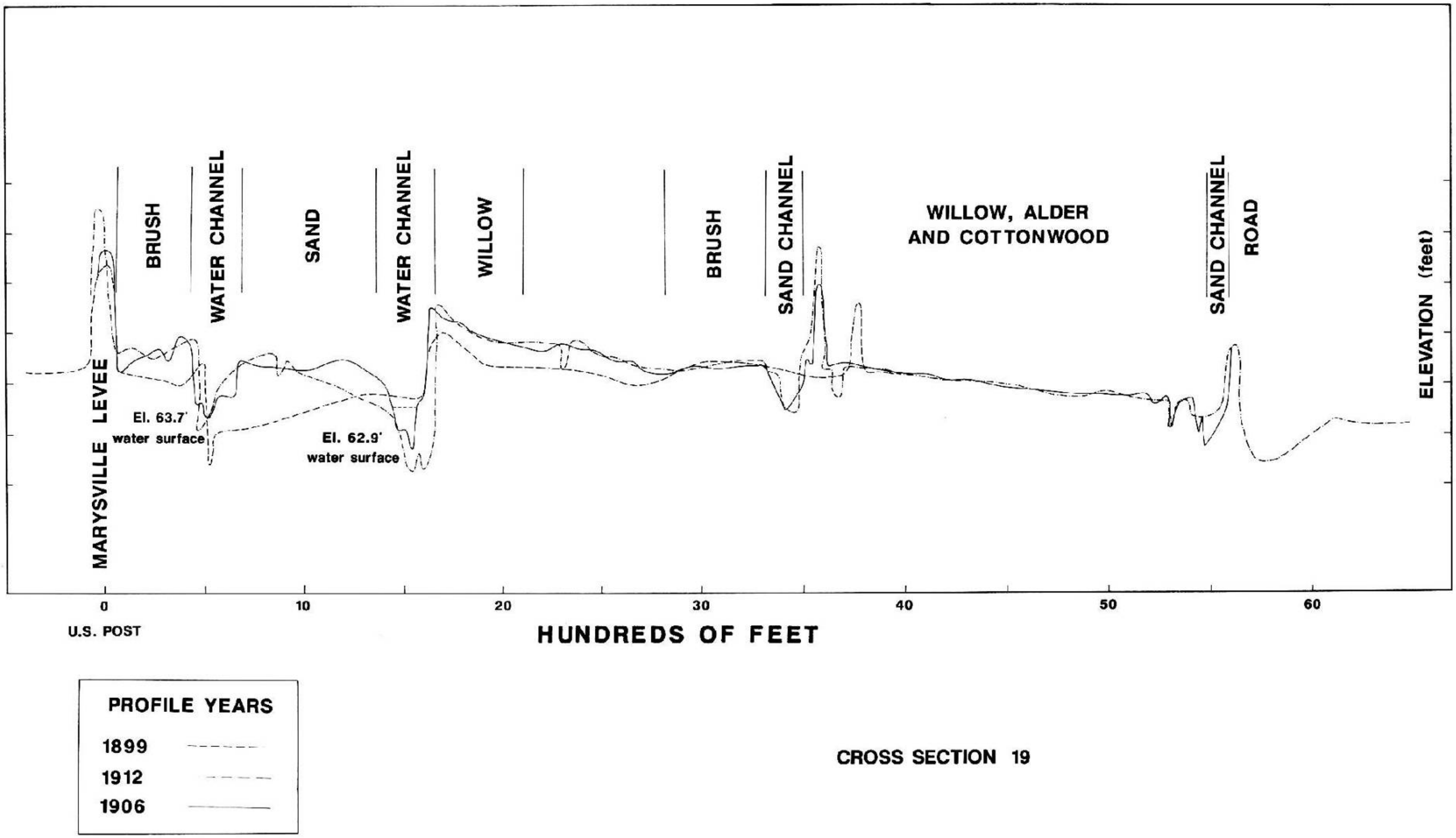
1973 USGS Topo Map.
Note enclosed depression adjacent to the 1986 breach


QUARRY
PIT
W.P RAILROAD
DANTONI JUNCTION
LEVEE
LUMBER MILL
LEVEE
CALTRANS
S.P. RAILROAD
INTERSTATE
MALL
LEVEE BREAK AND SCOUR
HOLE LOCATION
0
1000
feet
SCALE

Site Characterization must also consider *position* on the prehistoric flood plain

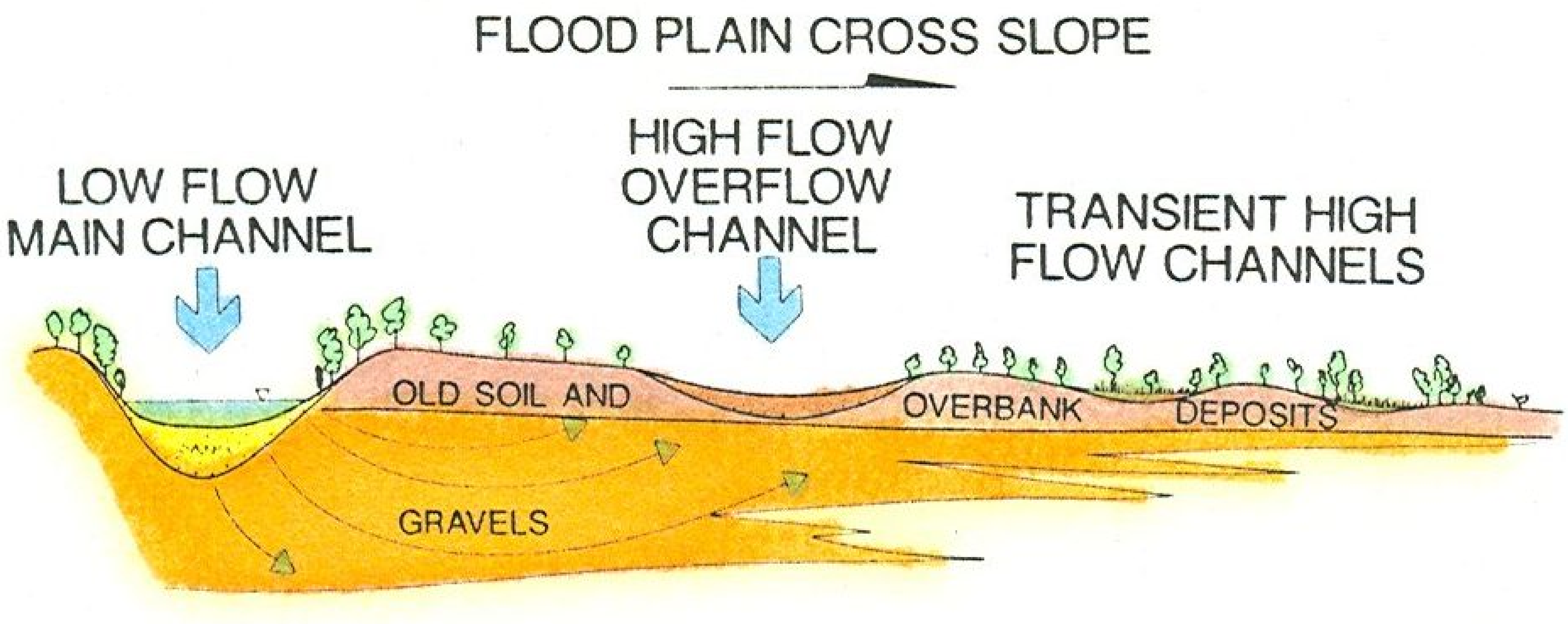


- This is a map of the lower Yuba River prepared by the California Debris Commission in 1907. Inset shows 1986 breach area. Note contours of small swale, coinciding with location of breach.

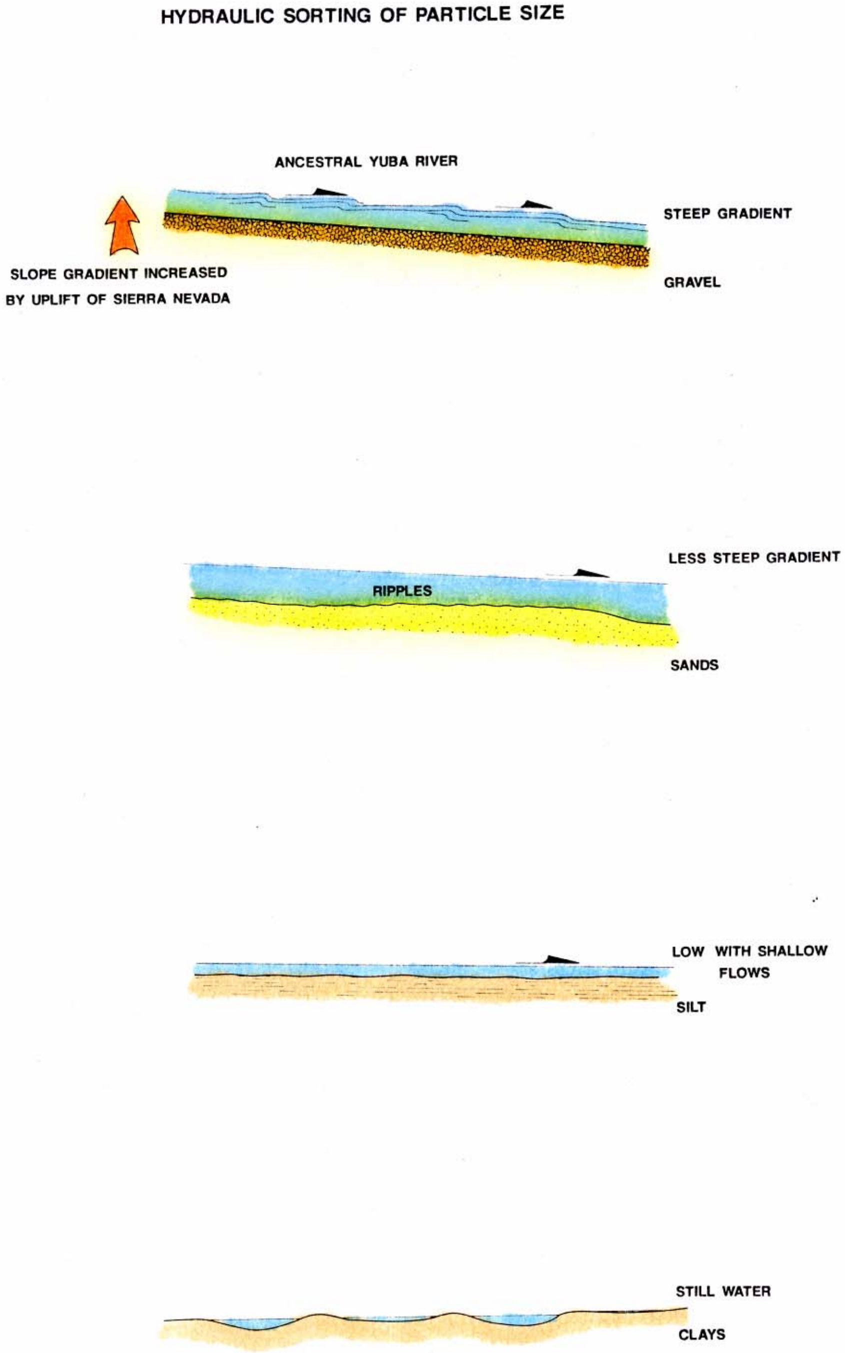


- This cross section through the lower Yuba River was also prepared by the Debris Commission in 1907. Note gradient of the clogged flood plain, diminishing with increasing distance from the main channel.

FLOODPLAIN VEGETATION

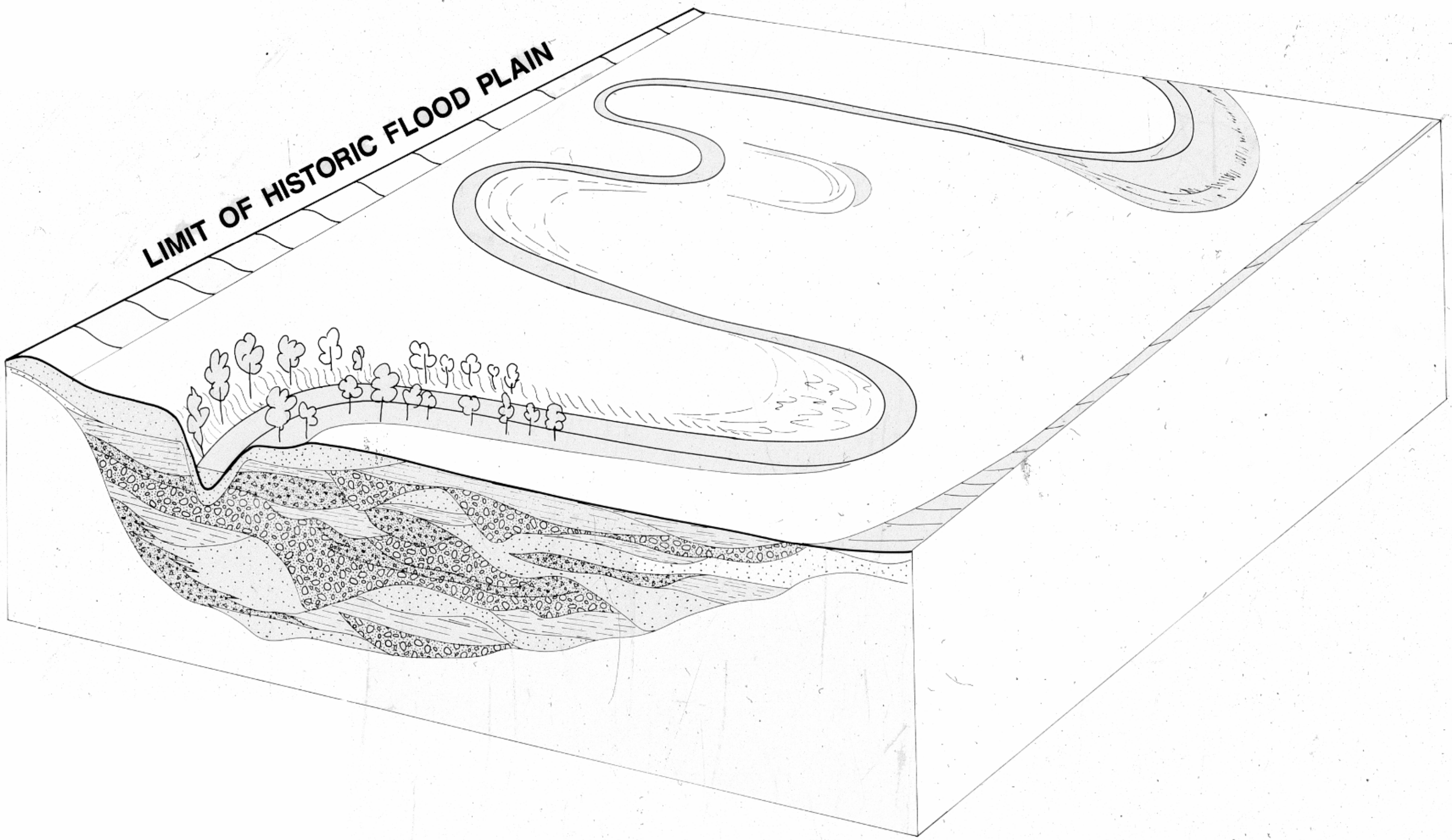


- Like any deposit of overbank silt, the hydraulic mine slickens deposited after 1862 tended to be thickest near the main channel, the diminishing outboard. High overflow channels would periodically carve material off, causing the cover to be thinner in those locations.



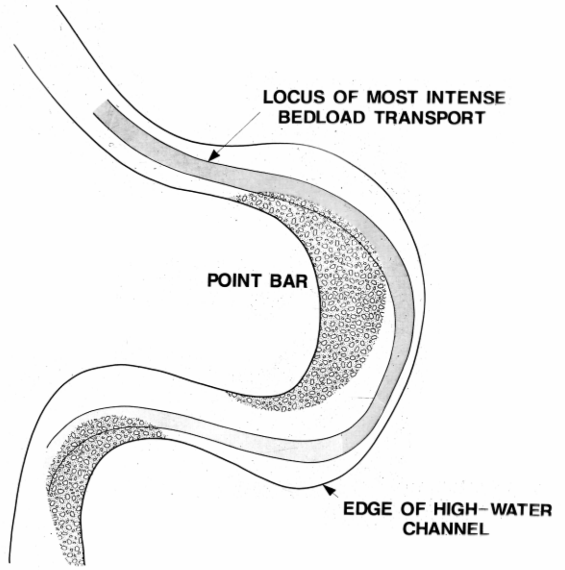
Hydraulic sorting

- Particles are hydraulically sorted; according to: flow quantity, hydraulic grade, channel depth, roughness, and sinuosity.
- Coarse materials most rare; while silts (flood stage) are most common.

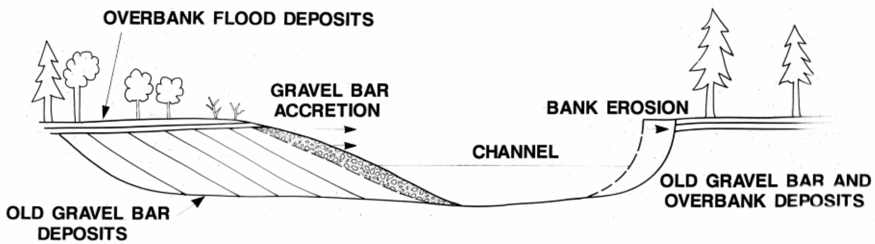


- Coarse lag gravels tend to accumulate in braided bars and point bars, as sketched here. Proximity to the stem channel controls the relative percentage of high permeability materials filling the channel.

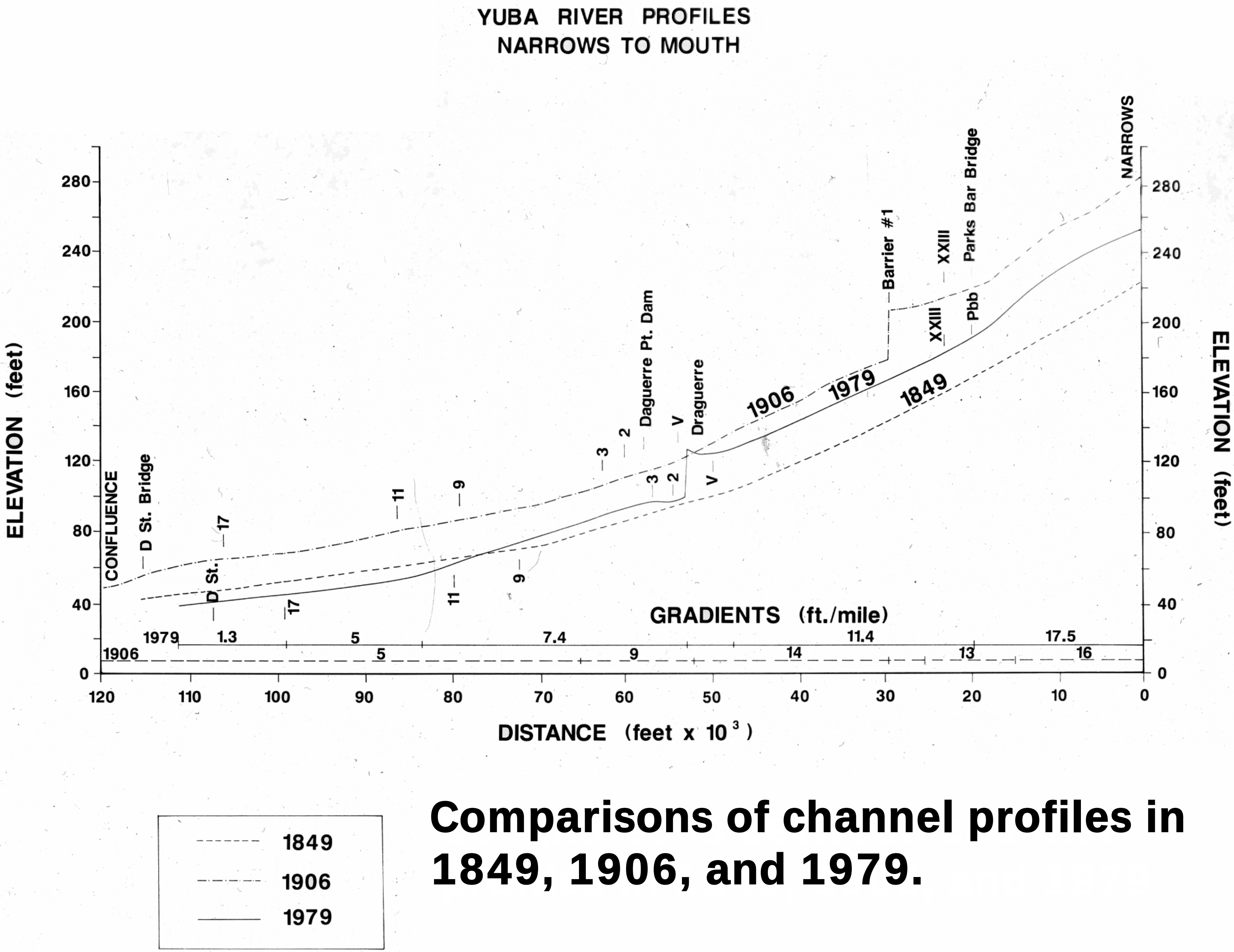
PATH OF MOST INTENSE BEDLOAD TRANSPORT THROUGH A RIVER BEND



LATERAL CHANNEL SHIFTING AT A RIVER BEND

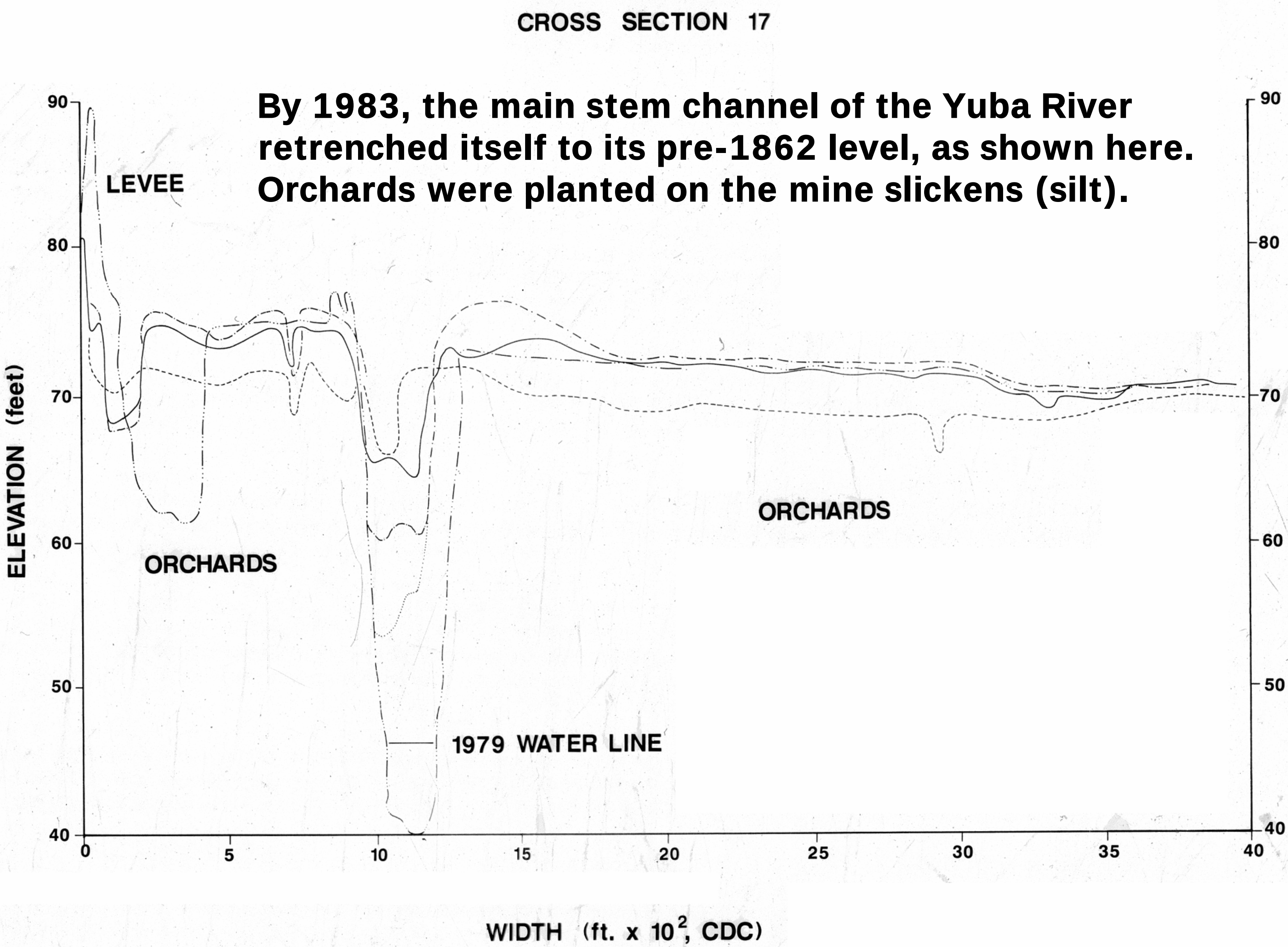


- The lower Yuba River deposits coarse gravels in point bars.
- Note how these can be discontinuous features, accreting on the inside bends of the channel
- These create a 3D site characterization problem



Comparisons of channel profiles in 1849, 1906, and 1979.

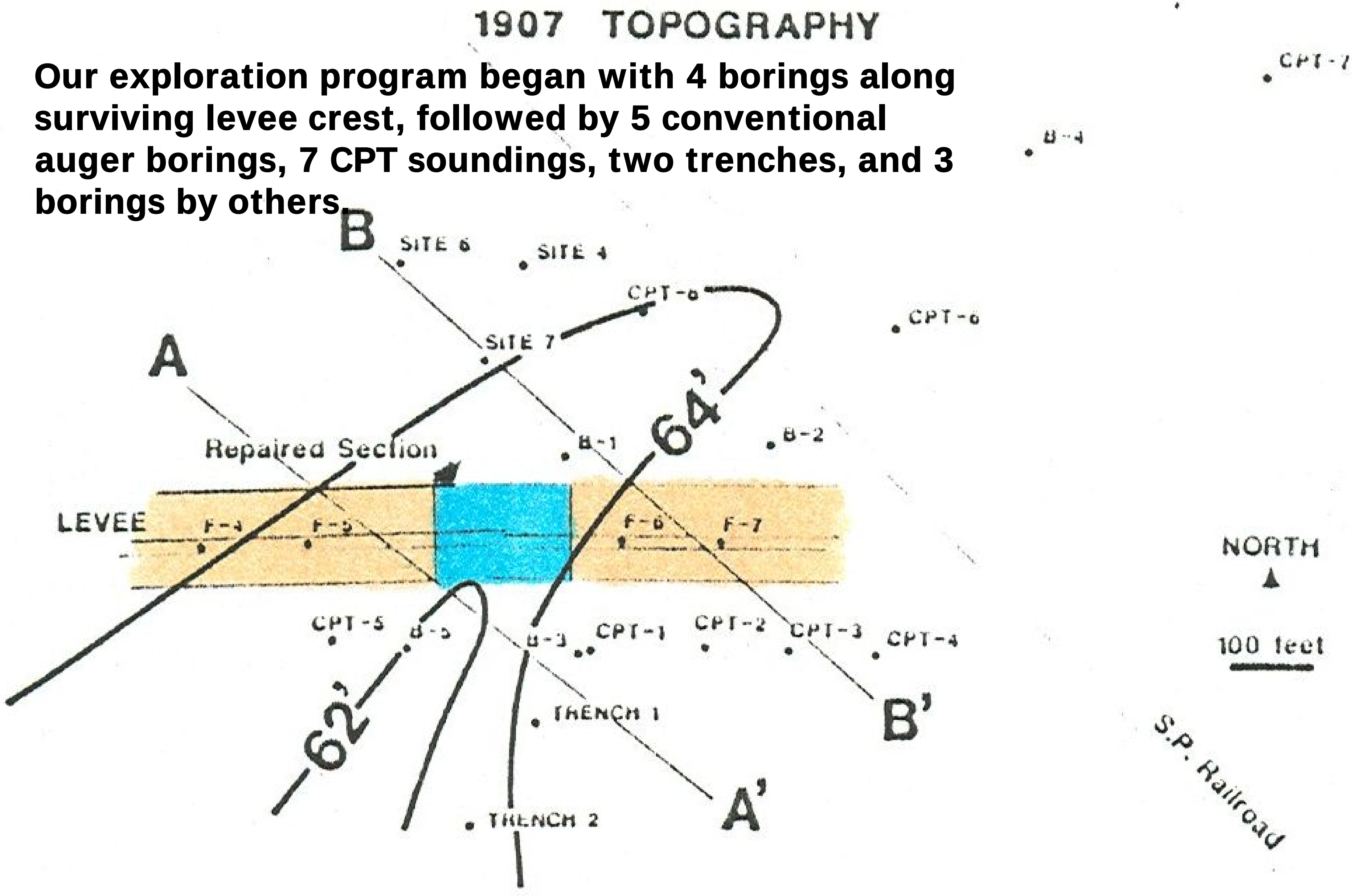
By 1983, the main stem channel of the Yuba River retrenched itself to its pre-1862 level, as shown here. Orchards were planted on the mine slickens (silt).

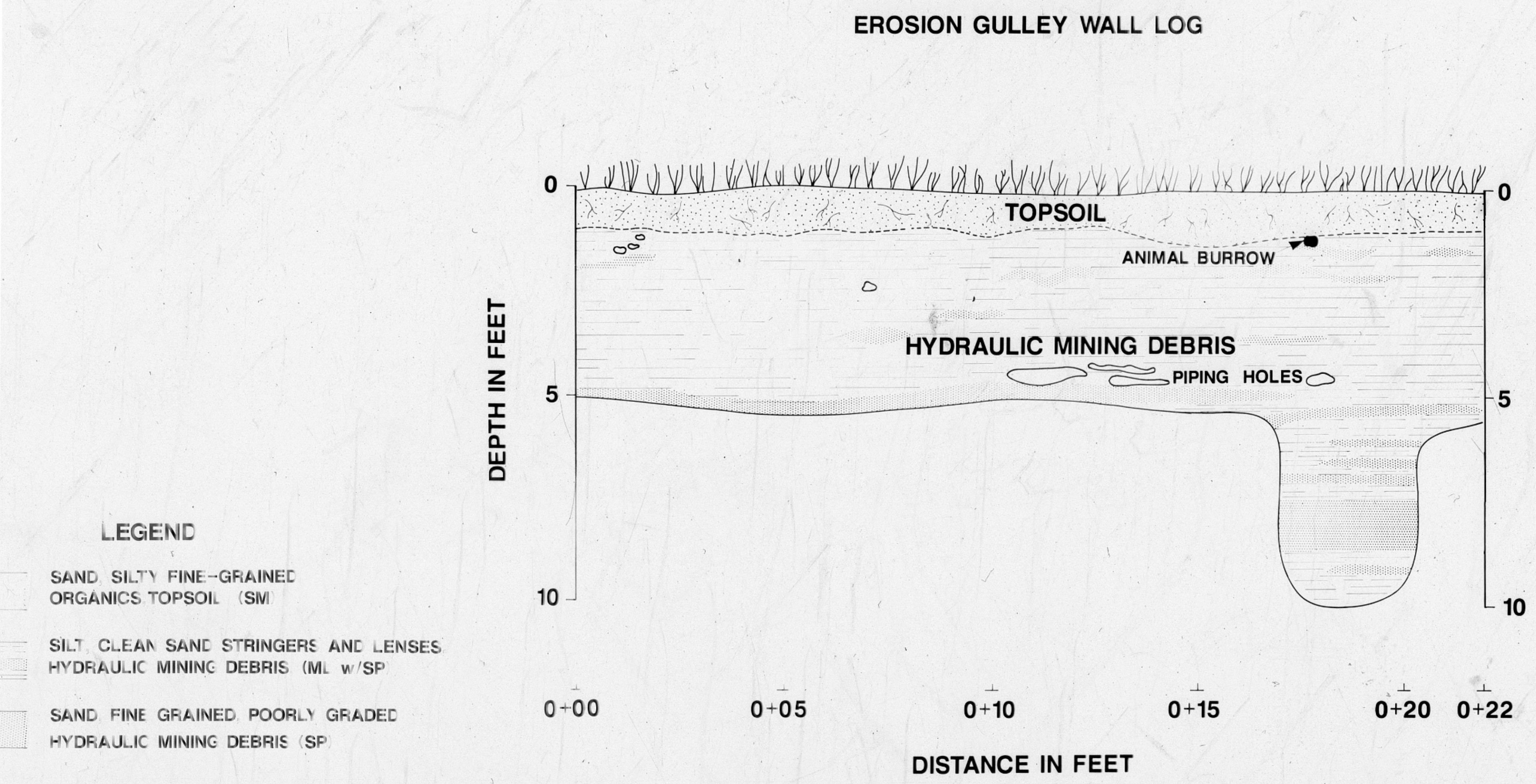


SUBSURFACE EXPLORATION:

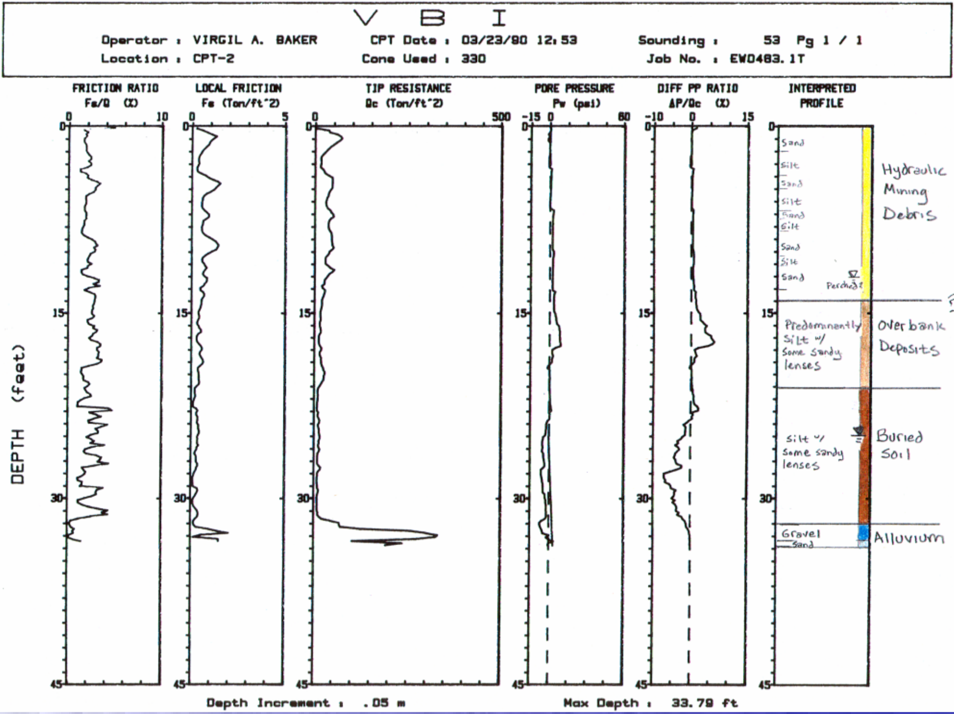
Beware of the Corps of Engineers standard that limits subsurface exploration to a depth equal to the levee height, below native grade

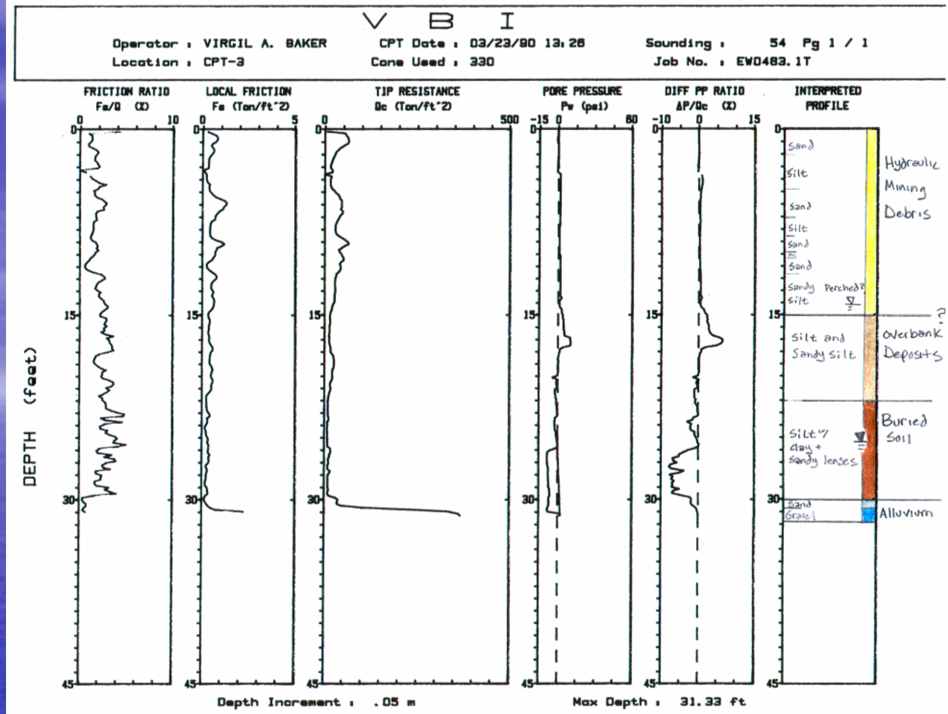
Our exploration program began with 4 borings along surviving levee crest, followed by 5 conventional auger borings, 7 CPT soundings, two trenches, and 3 borings by others.

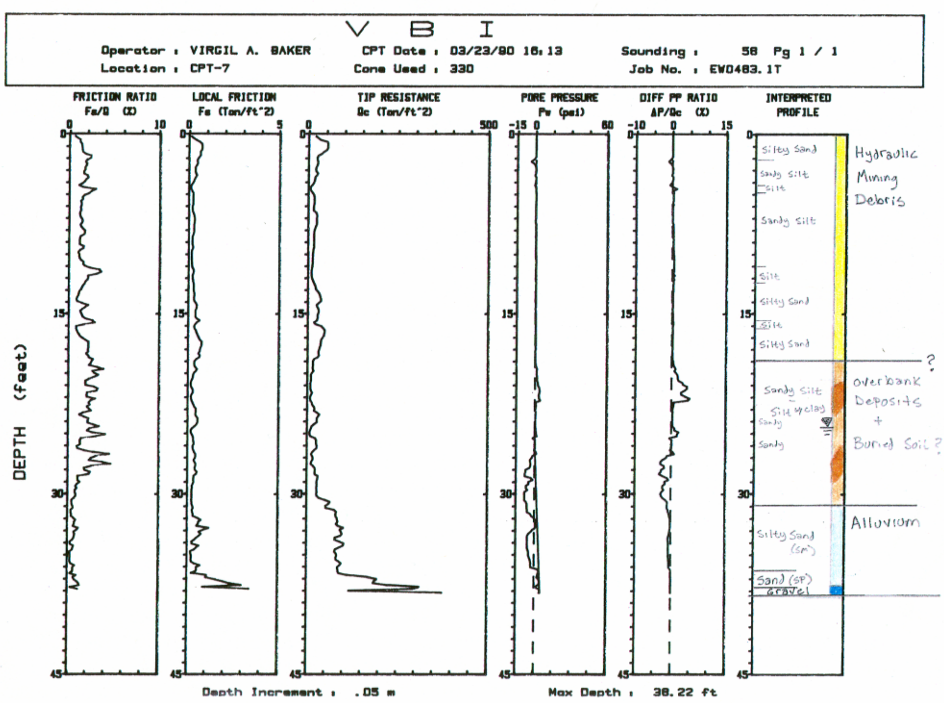




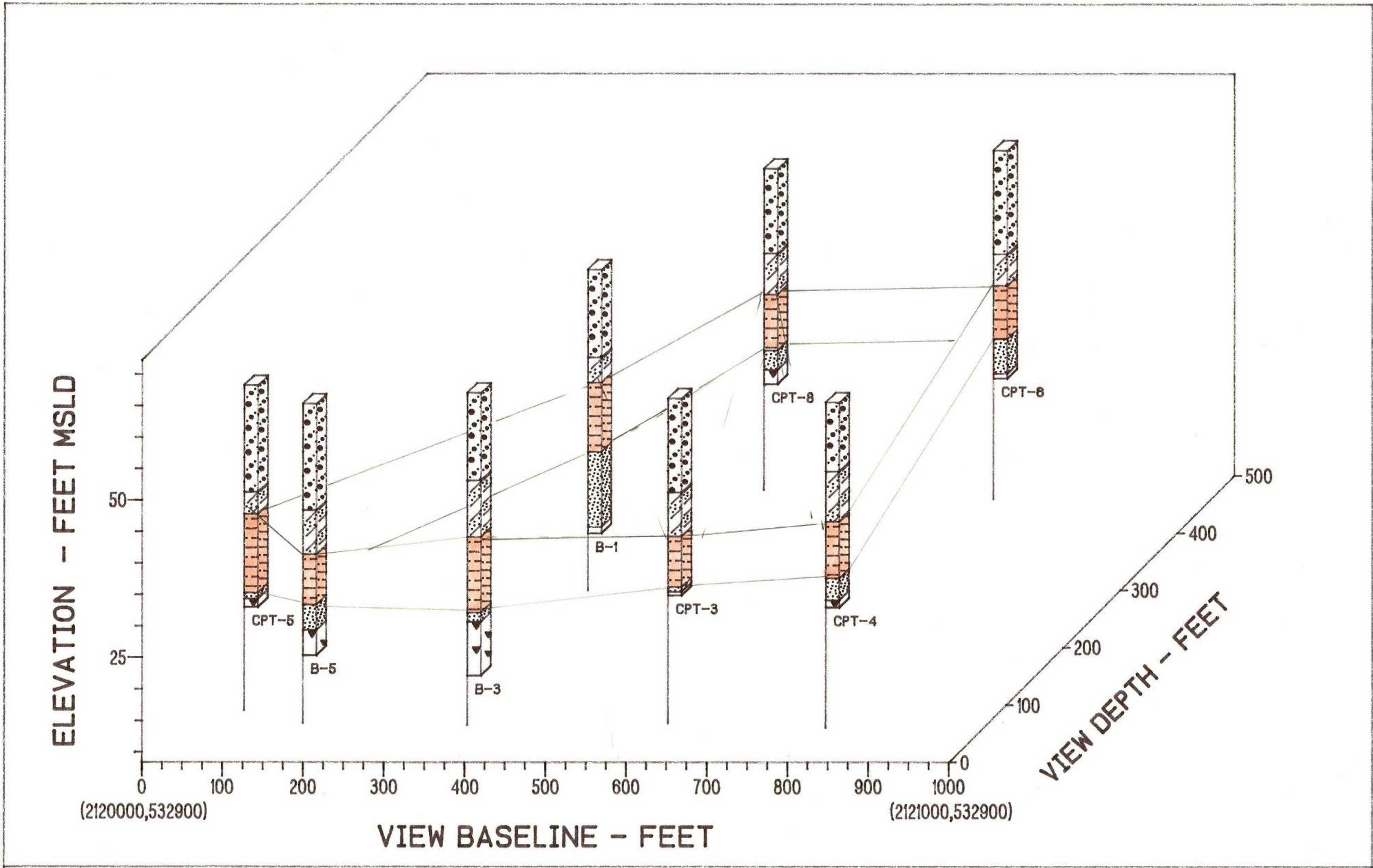
- Our subsurface exploration commenced with a series of trenches along the bounding walls of the channel scoured by the breach outflow. There was some evidence of piping holes at a depth of ~5 feet.







CPT logs are most useful for analyzing discrete horizons, zones of saturation, and unraveling subsurface stratigraphy; to ascertain the continuity of various units.

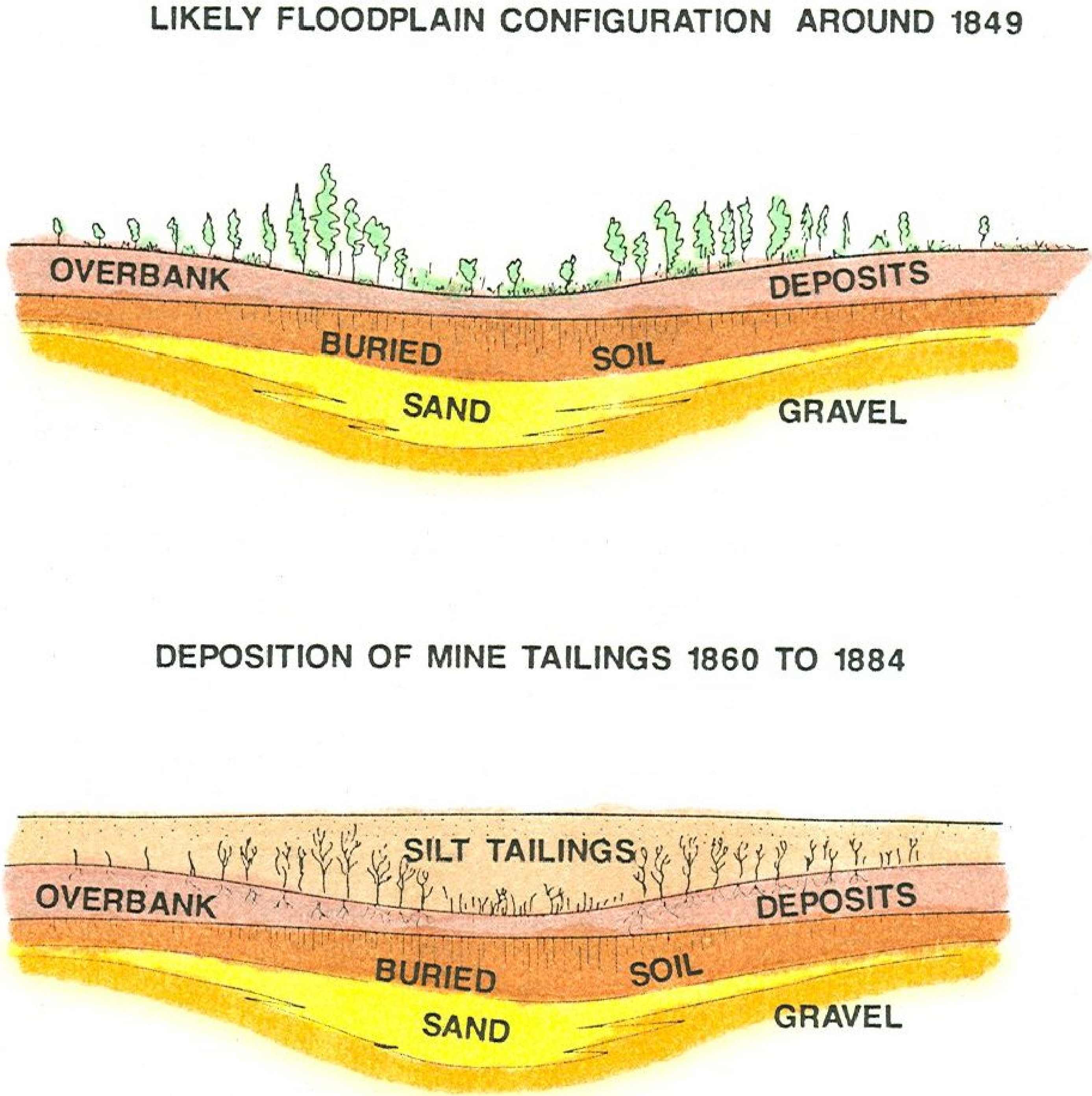


- **Fence diagrams are useful for assessing stratigraphy in three dimensions.**

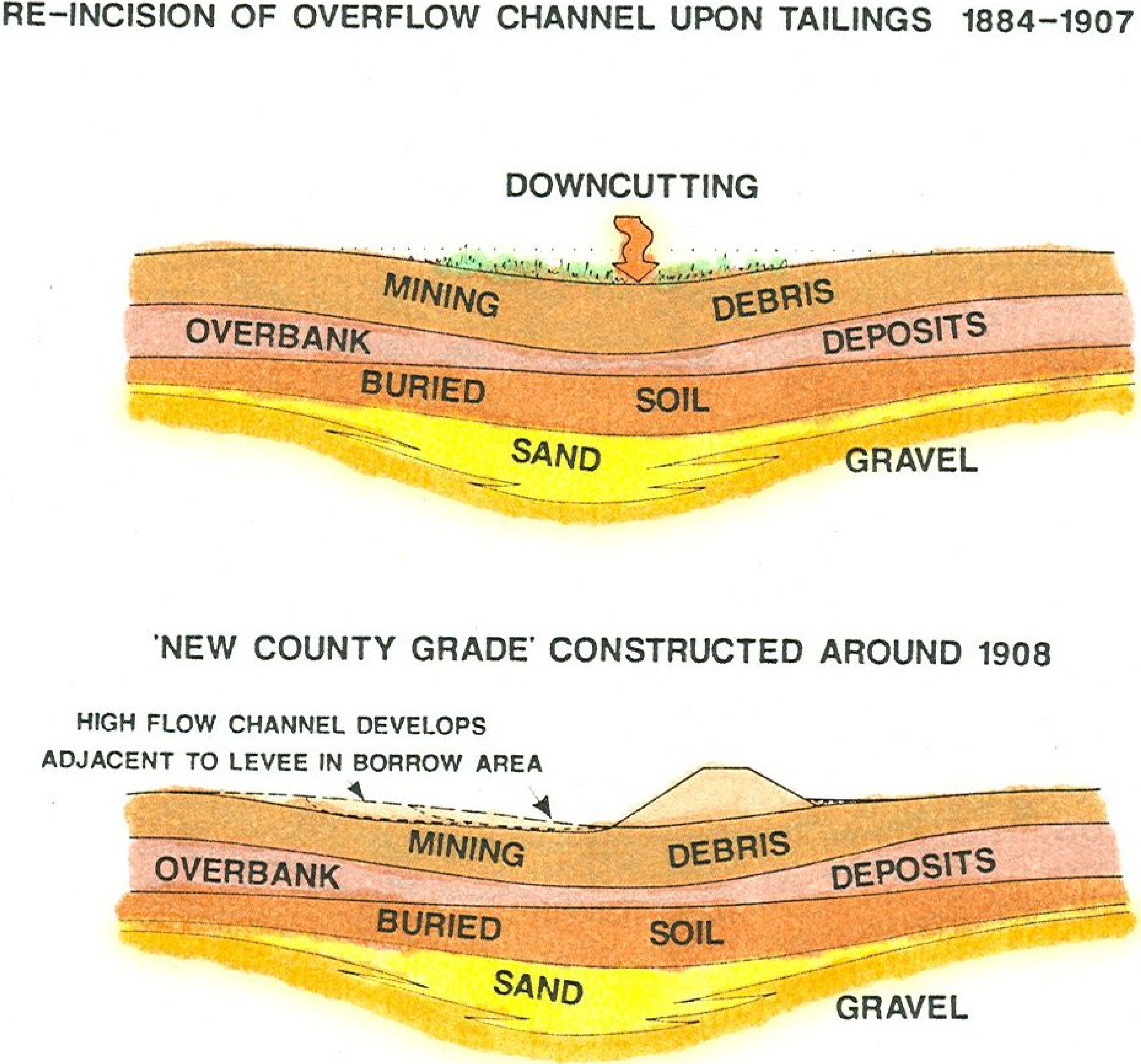
- The stratigraphy always leaves us a distinctive fingerprint; testifying to the depositional history at any given site.

- The following slides summarize what we learned about the 1986 levee breach site at Linda

1849 to 1884

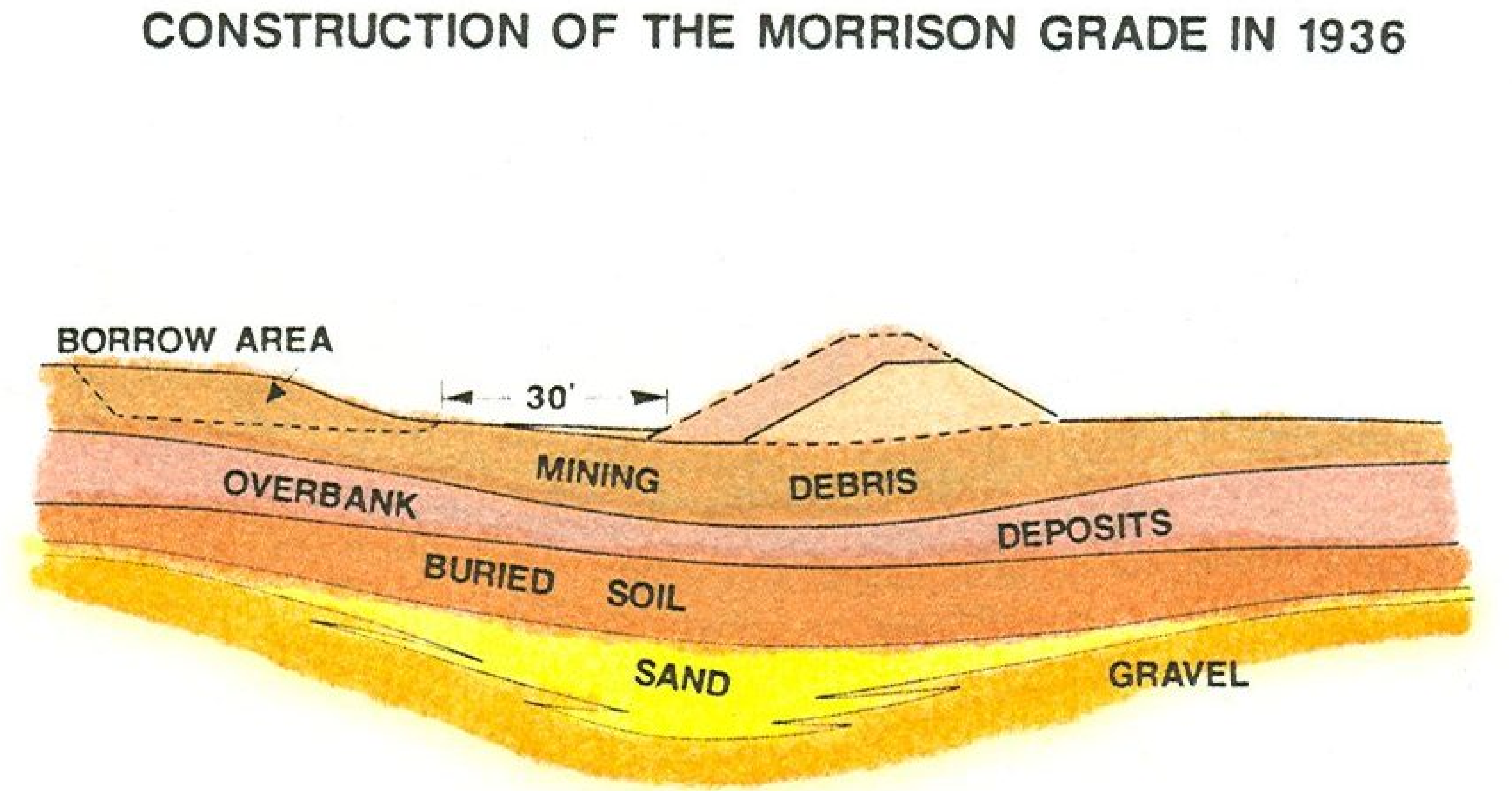


- The pre-1849 flood plain was inundated by silt from 1862 till at least 1884
- Note axis of swale, beneath breach area



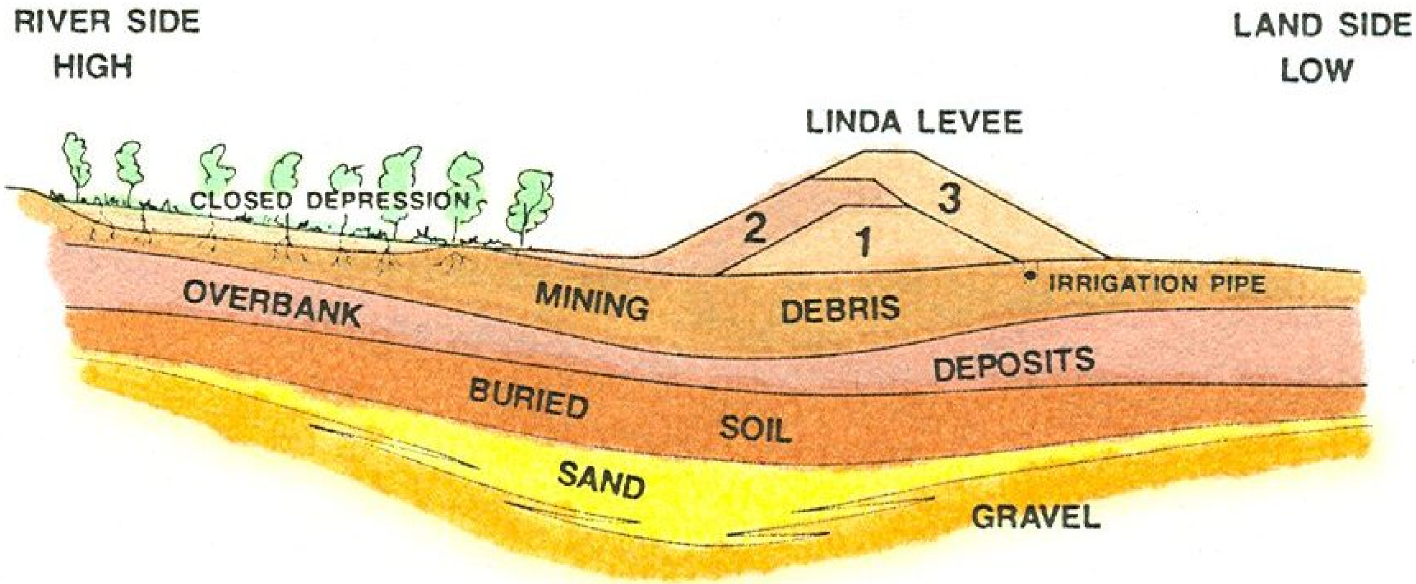
1884 to 1908

- The mine slickens were reworked several times by major floods, then used as fill for the original levee in 1908



- The Morrison Grade was heightened in 1936, using borrow material from the river side of the embankment.

CORPS OF ENGINEERS LEVEE HEIGHTENING IN 1940



OTHER MAN ACTICITIES

- IRRIGATION PIPELINE CONNECTED TO WELL BURIED BENEATH EMBANKMENT
- S.P.RR BRIDGE PARTIALLY INFILLED ACROSS FLOODPLAIN
- CLOSED DEPRESSION AREA LEFT FALLOW

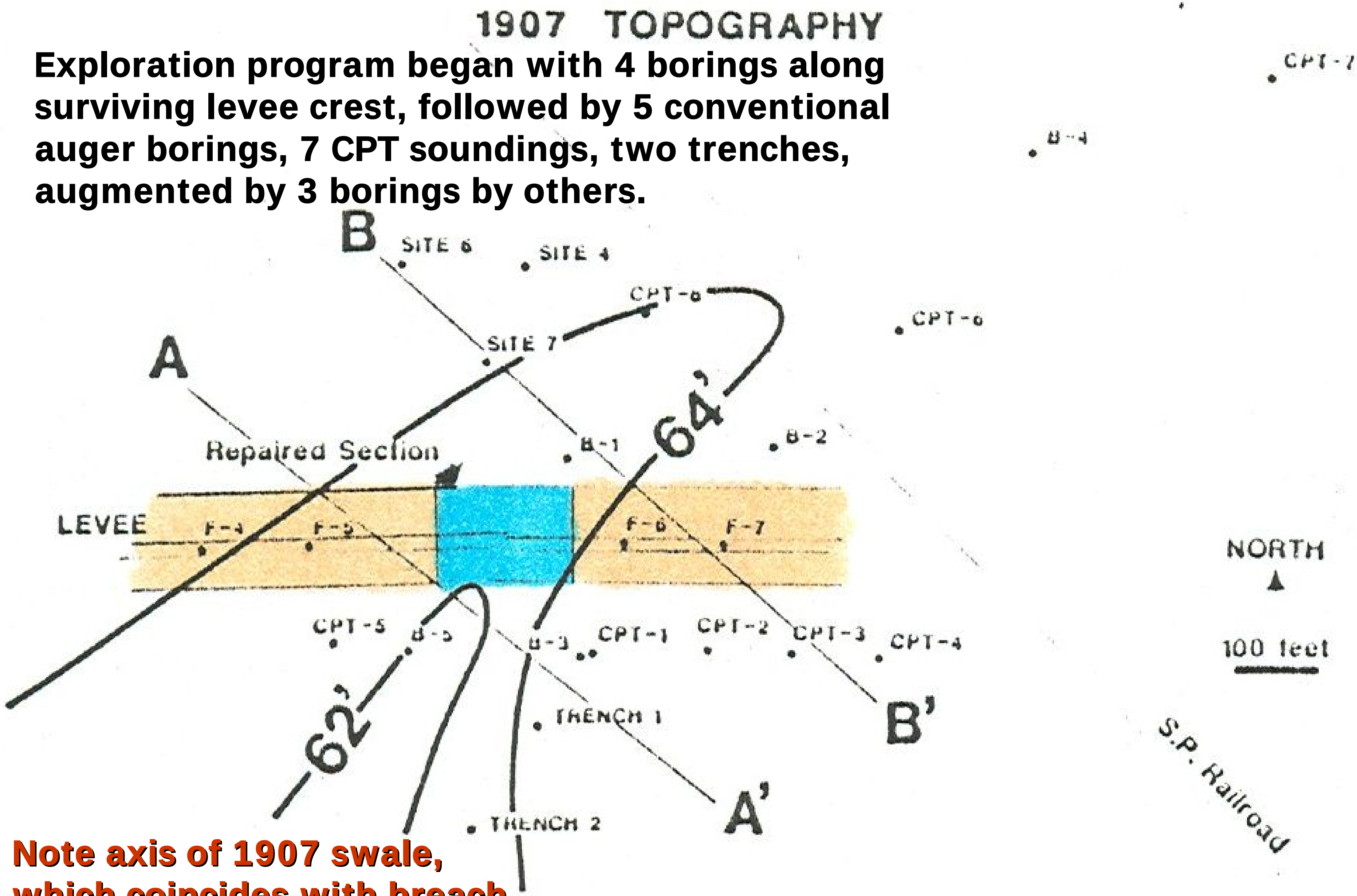
LATER

- SPECKERT PIT OPENED
- ORCHARD WITH WELL PLACED IN CLOSED DEPRESSION

1940

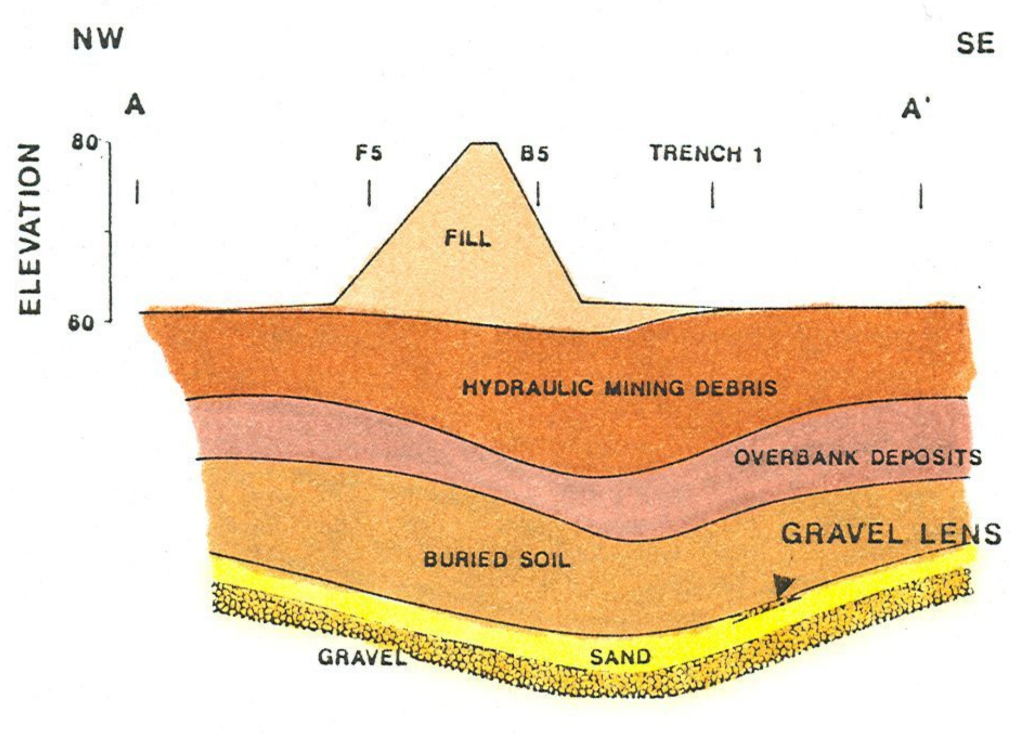
- The Corps of Engineers raised the Morrison grade a third and final time in 1940

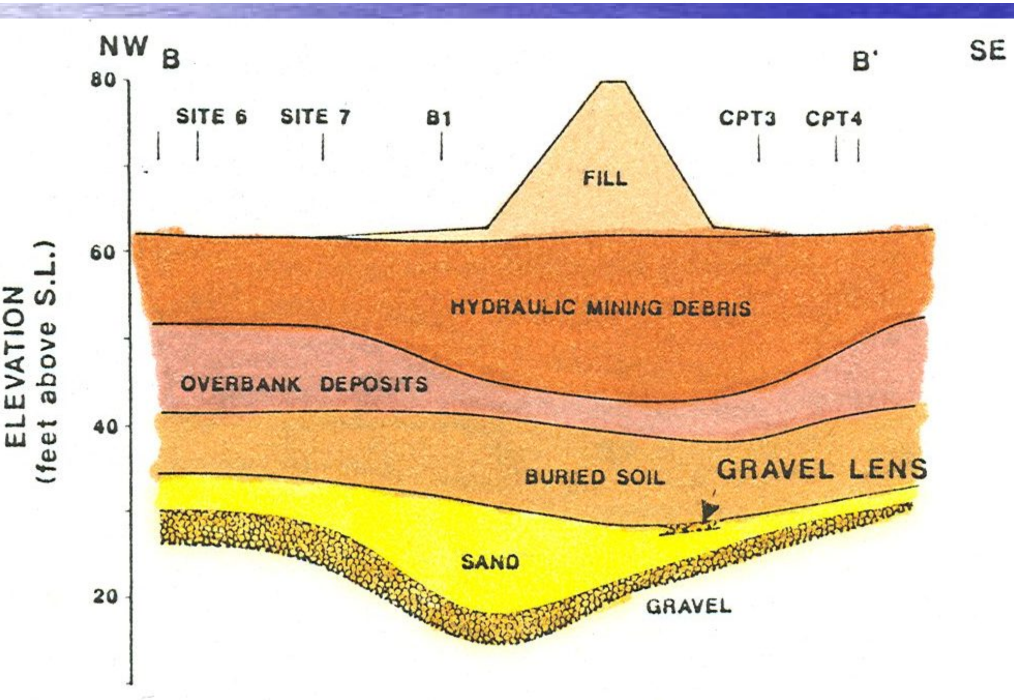
Exploration program began with 4 borings along surviving levee crest, followed by 5 conventional auger borings, 7 CPT soundings, two trenches, augmented by 3 borings by others.



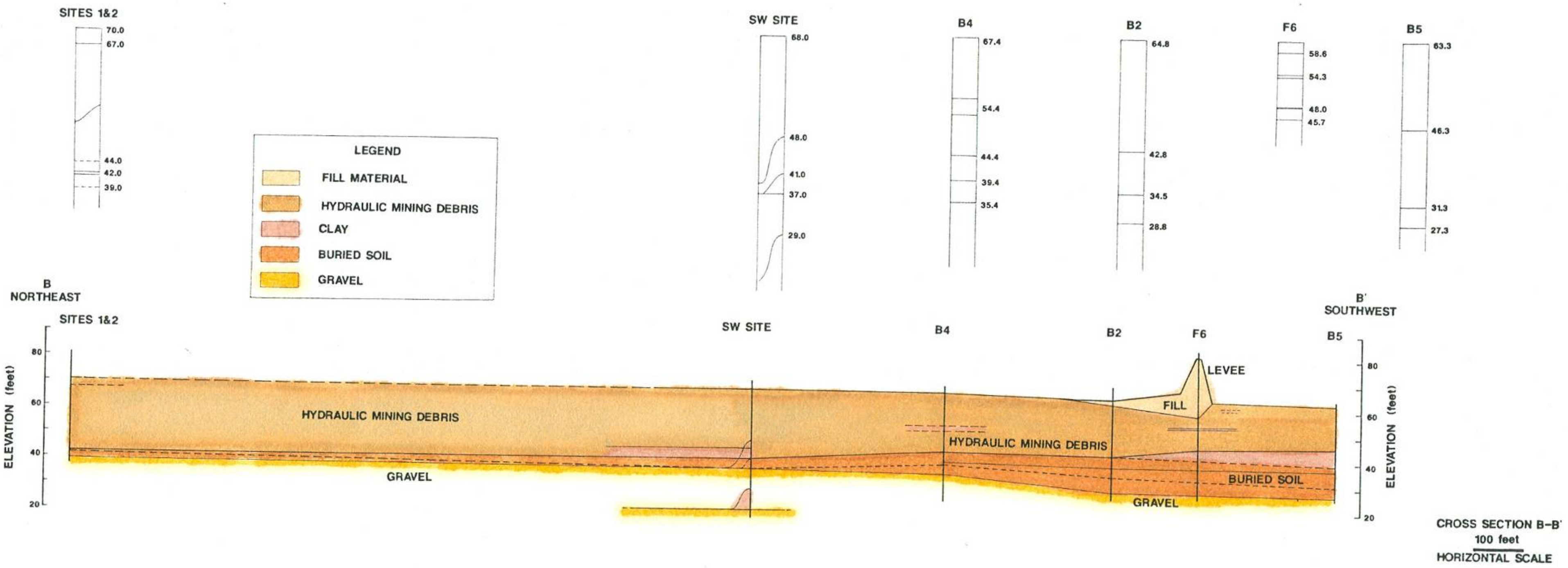
Note axis of 1907 swale, which coincides with breach

Sections through breach area

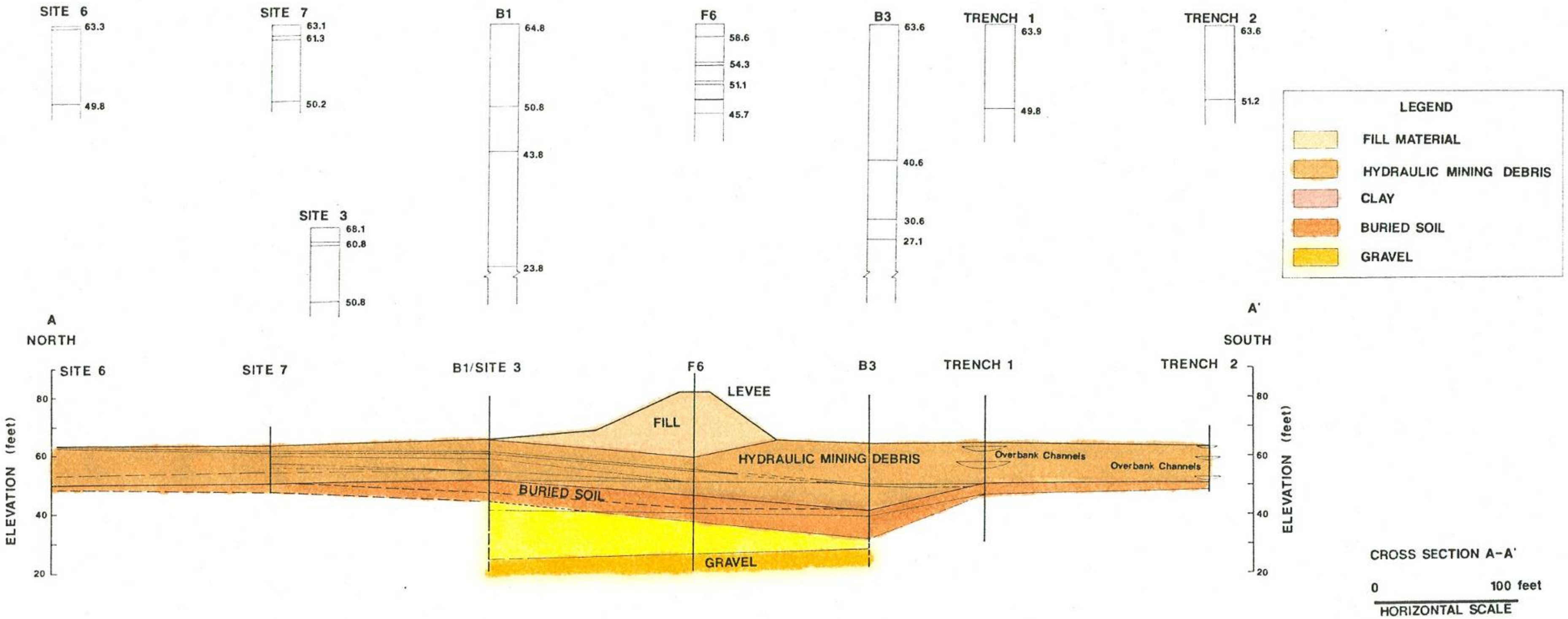




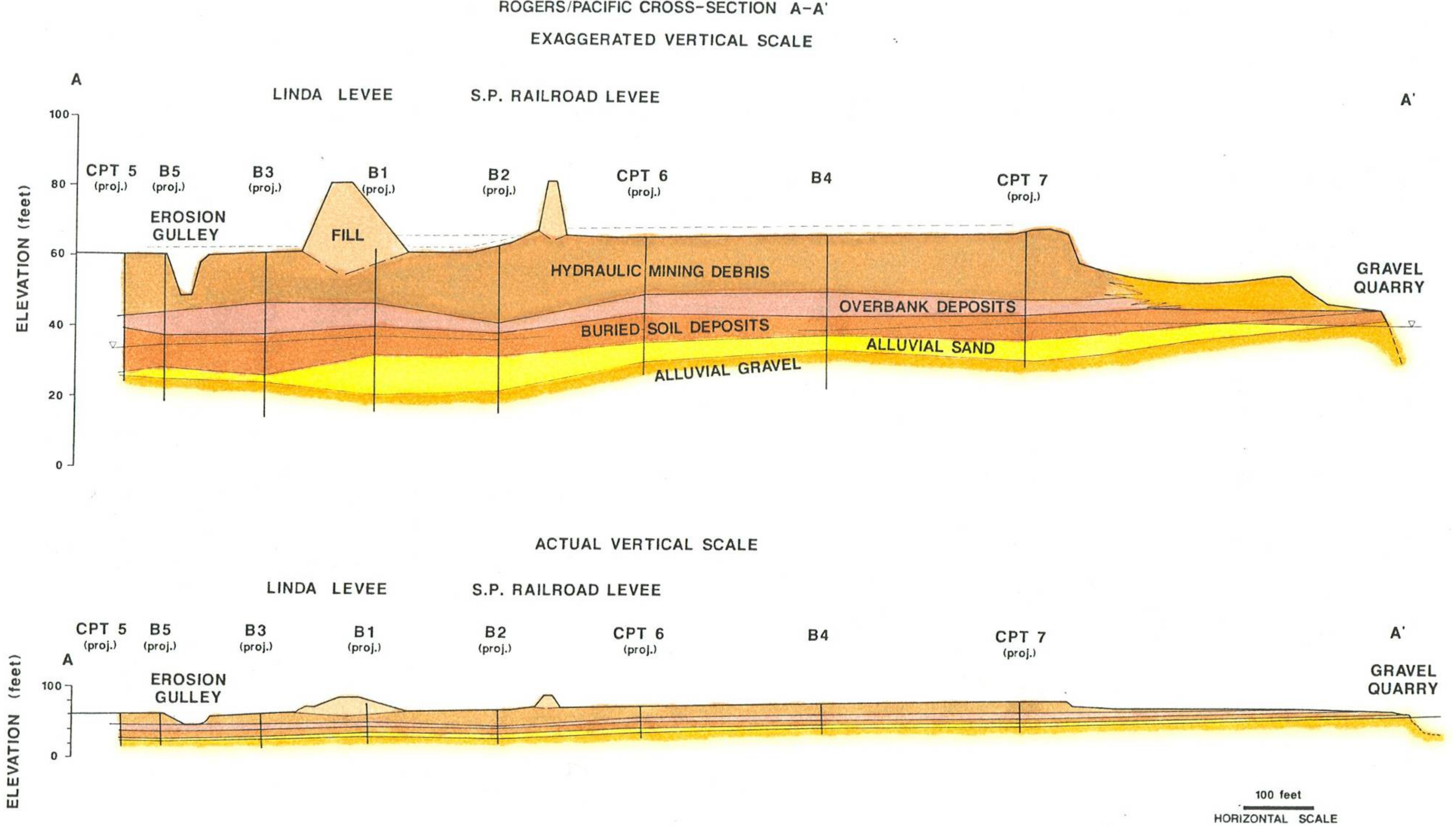
- Sections A-A' and B-B' were cut perpendicular to the 1907 swale, more or less aligned with the historic direction of flow of the Yuba River. Note axes of previous swales in succeeding deeper units.



- **Section B-B' extends from the breach area northwest, towards the main stem channel of the Yuba River.**
- **This is the section most engineers would choose for their obligatory seepage assessments.**
- **But the section is cut perpendicular to the overall "grain of flow"; the flow is normal to the viewing plane. This is not always useful in any anisotropy exists in underlying alluvial deposits.**



- **Preliminary Section A-A' highlighted what might be a serious problem: highly conductive channels feeding *upward*, into a lower permeability cap, deposited in previous overflow channels.**
- **This is a classic "leaky aquifer" condition.**



- **Section A parallels the line of expected seepage and surface flow, from NE to SW. This was extended 1800 ft, to the Speckert Gravel Pit. Note slope of the alluvial materials between the pit and the levee.**

Range of Values of Hydraulic Conductivity and Permeability

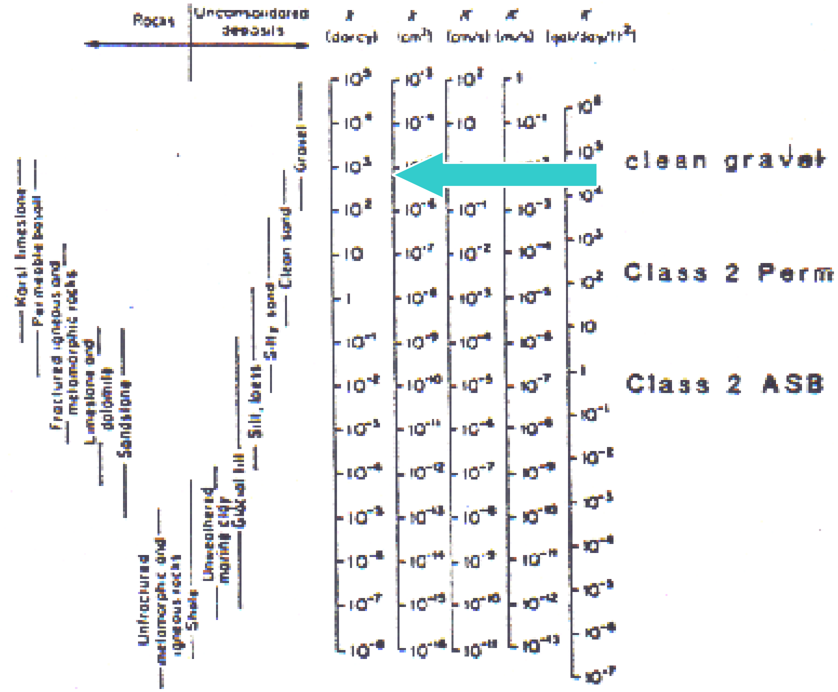


Table 2.3 Conversion Factors for Permeability and Hydraulic Conductivity Units

	Permeability, k*			Hydraulic conductivity, K		
	cm²	ft²	darcy	m/s	ft/s	gal/day/ft²
cm²	1	1.08×10^{-3}	1.01×10^{8}	9.80×10^{2}	3.22×10^{3}	1.85×10^{9}
ft²	9.29×10^{2}	1	9.42×10^{10}	9.11×10^{5}	2.99×10^{6}	1.71×10^{12}
darcy	9.87×10^{-9}	1.06×10^{-11}	1	9.66×10^{-6}	3.17×10^{-5}	1.82×10^{1}
m/s	1.02×10^{-3}	1.10×10^{-6}	1.04×10^{5}	1	3.28	2.12×10^{6}
ft/s	3.11×10^{-4}	3.35×10^{-7}	3.15×10^{4}	3.05×10^{-1}	1	5.74×10^{5}
gal/day/ft²	5.42×10^{-10}	5.83×10^{-13}	5.49×10^{-2}	4.72×10^{-7}	1.74×10^{-6}	1

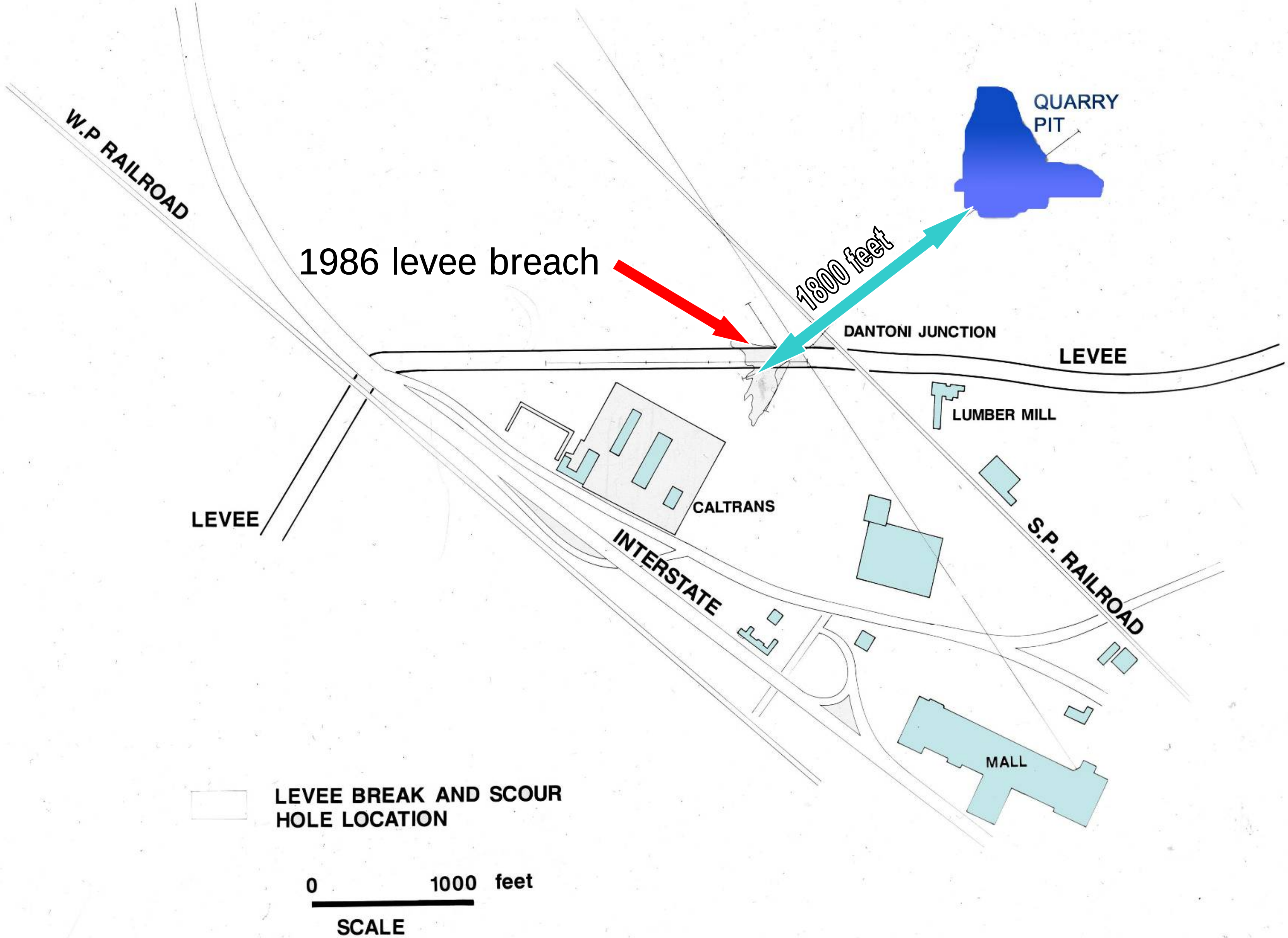
*To obtain k in ft², multiply k in cm² by 1.08×10^{-3}.

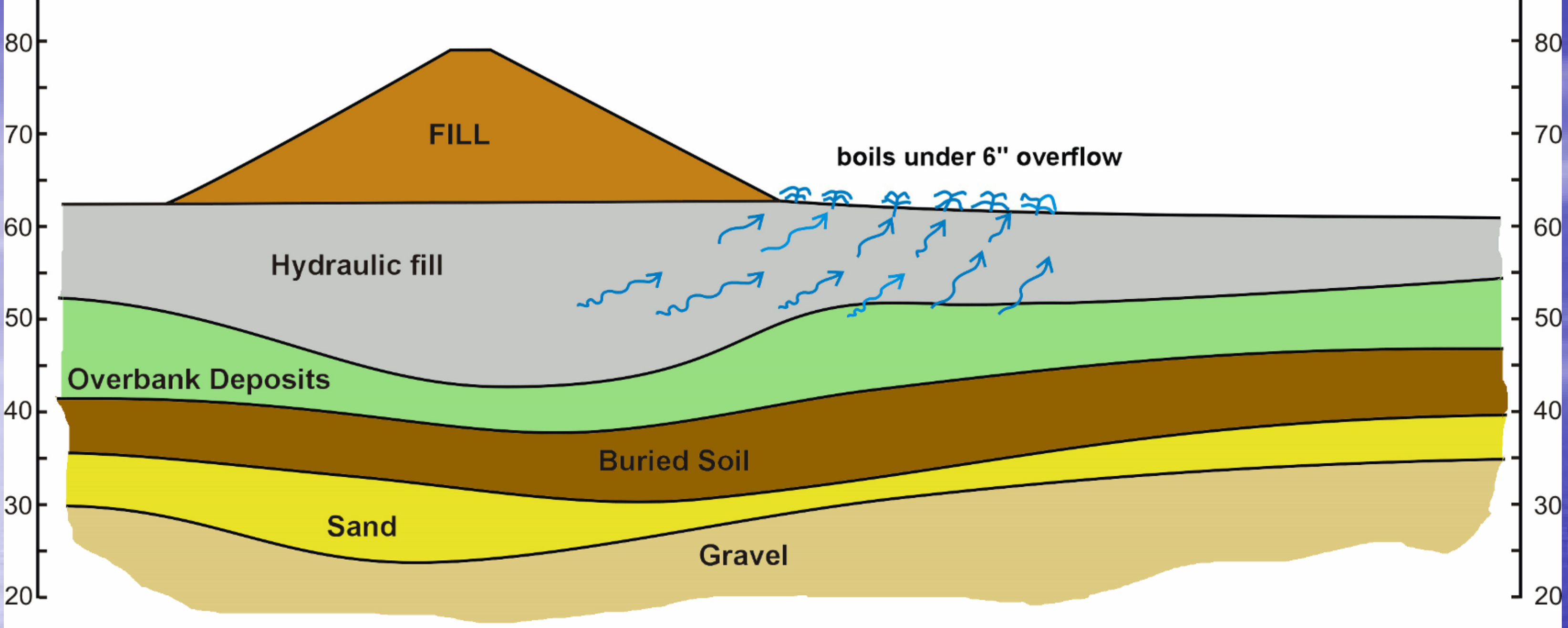
Average permeability values performed by Rogers/Pacific on random field samples, taken from truck loads upon delivery.

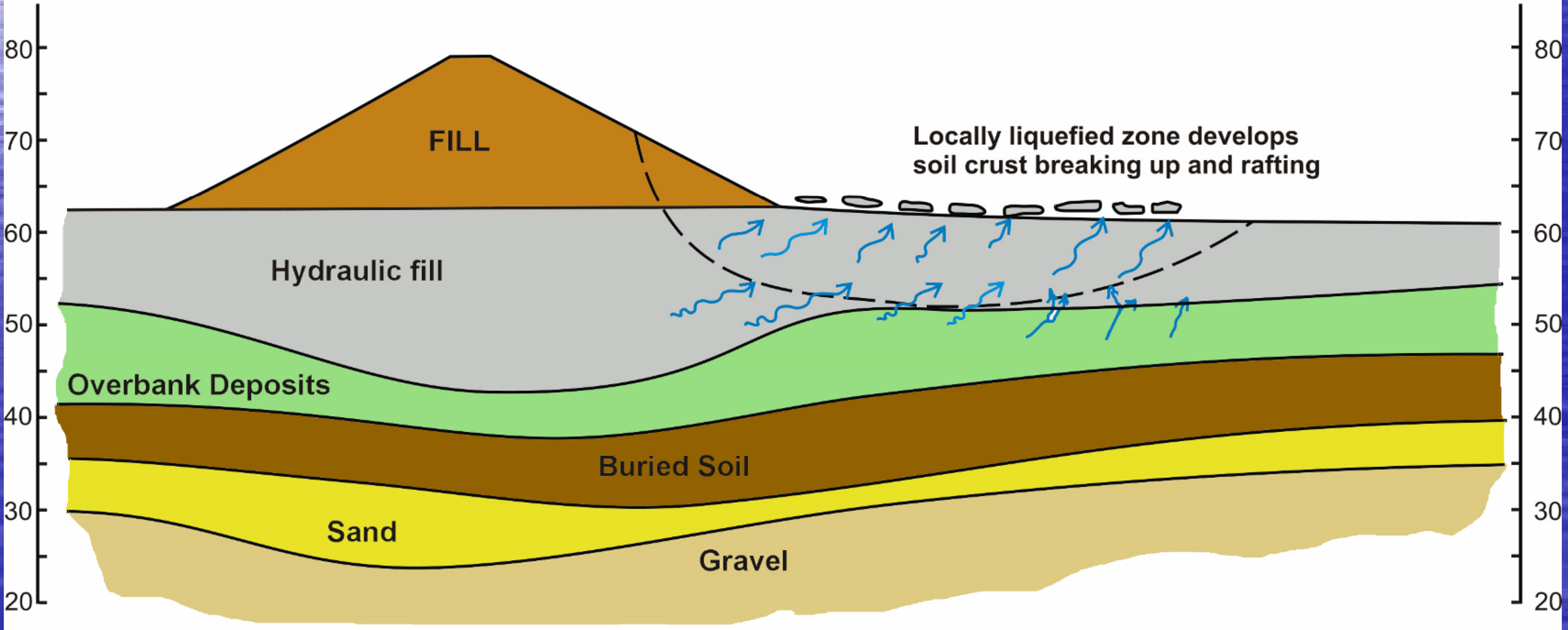
Tests performed with constant head permeameter, in accordance with ASTM D2434-74.

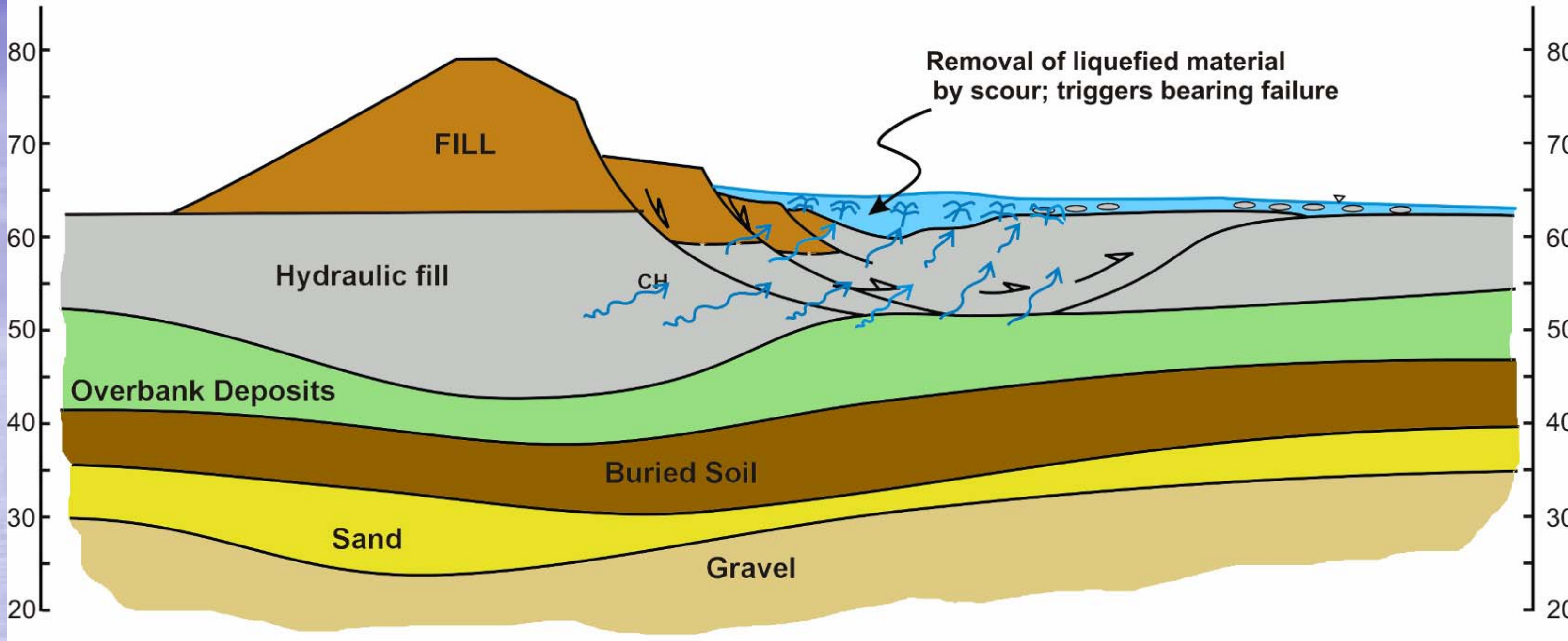
Channel Gravel Permeability

- A pump test of the well on the Dhillon Orchard close to the 1986 breach revealed a hydraulic conductivity, k = 0.2 cm/sec
- This would correspond to 23. 6 ft/hr, and 567 ft/day
- Under 15 ft of driving head, the wetting front could have reached the land side of the levee breach area in 3.2 days.
- The breach suddenly occurred 7.5 days after flood stage brought water up against the levee

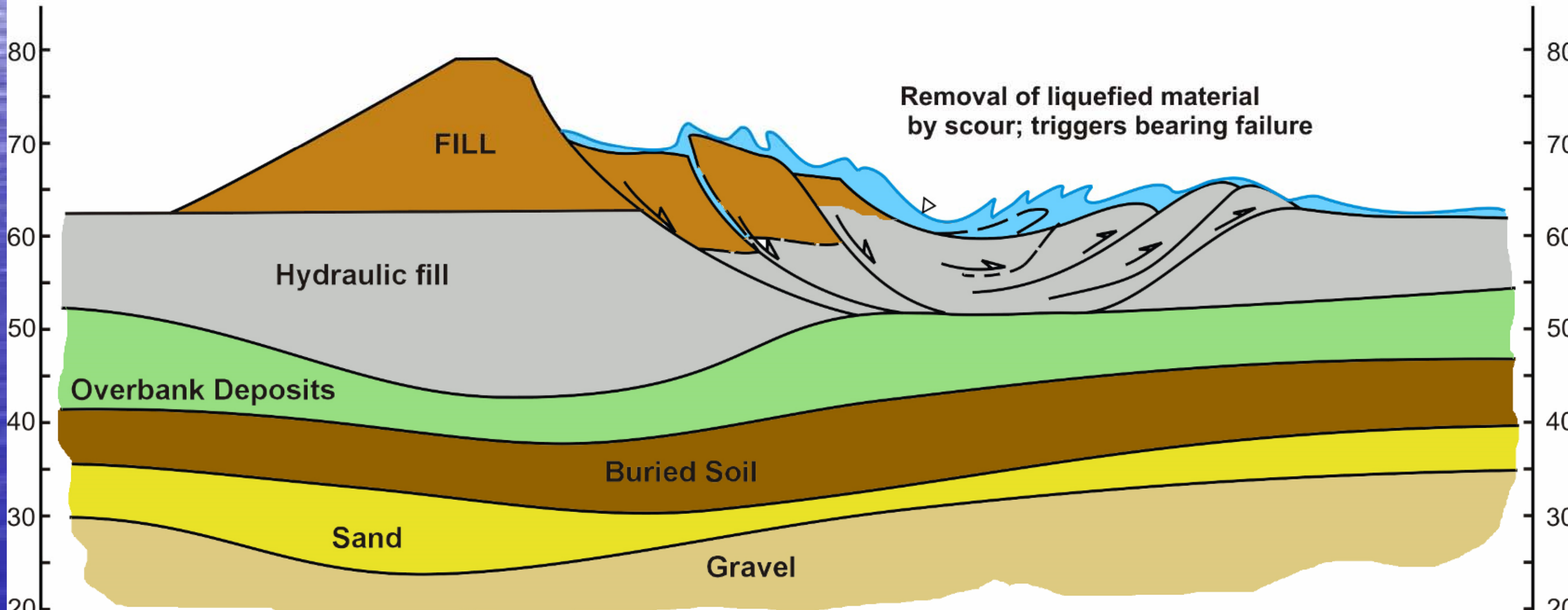

QUARRY PIT
1800 feet
1986 levee breach
DANTONI JUNCTION
LEVEE
W.P RAILROAD
LUMBER MILL
LEVEE
CALTRANS
S.P. RAILROAD
INTERSTATE
MALL
LEVEE BREAK AND SCOUR HOLE LOCATION
0
1000
feet
SCALE


80
70
60
50
40
30
20
FILL
boils under 6" overflow
Hydraulic fill
Overbank Deposits
Buried Soil
Sand
Gravel


80
70
60
50
40
30
20
FILL
Locally liquefied zone develops
soil crust breaking up and rafting
Hydraulic fill
Overbank Deposits
Buried Soil
Sand
Gravel

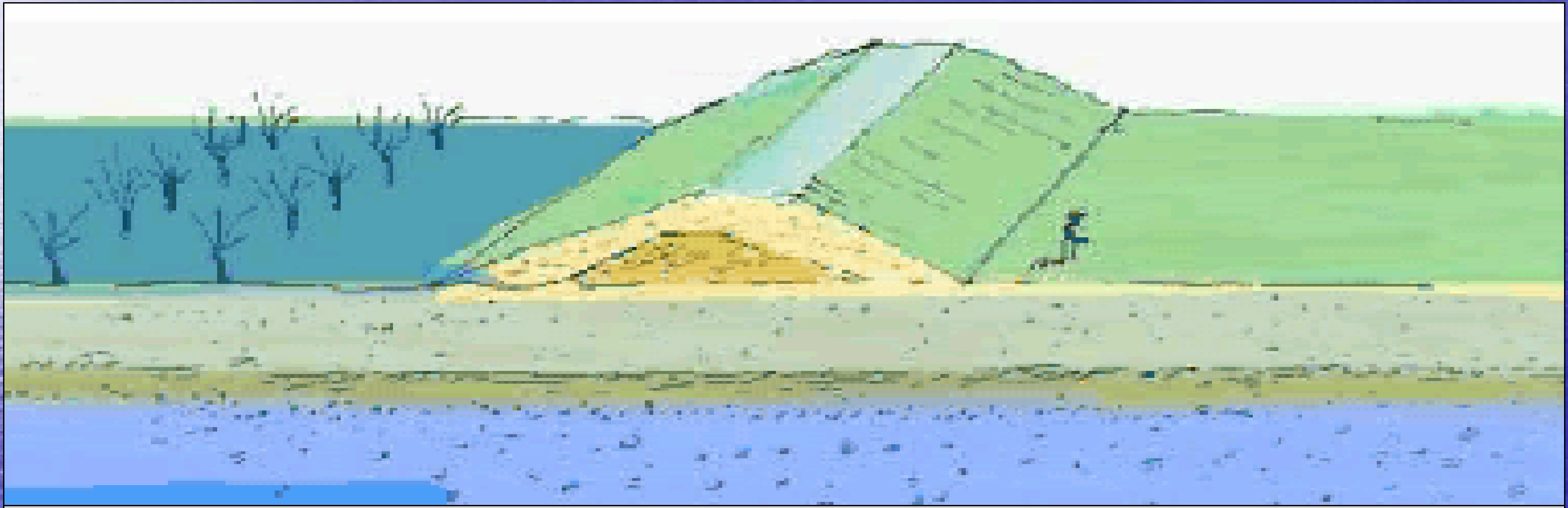


Removal of liquefied material
by scour; triggers bearing failure
FILL
Hydraulic fill
CH
Overbank Deposits
Buried Soil
Sand
Gravel
80
70
60
50
40
30
20



Removal of liquefied material
by scour; triggers bearing failure
FILL
Hydraulic fill
Overbank Deposits
Buried Soil
Sand
Gravel
80
70
60
50
40
30
20

Three wetting fronts assail the levee simultaneously



Movie11