Appendix B:

Summary of Winslow Levee and Ruby Wash Diversion Levee, Winslow, AZ (Navajo County): History, Composition, Foundation (USACE 2010)

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US Army Corps of Engineers

Los Angeles District
Geotechnical Branch

Summary of Winslow Levee and Ruby Wash Diversion Levee, Winslow, AZ (Navajo County): history, composition, foundation

What is known from literature on materials and construction, geotechnical conditions in the levee embankments and their foundations: data to support the Little Colorado River at Winslow feasibility study

left, Winslow Levee, looking upstream from the "meandering loop" conjunction with the Levee, sta. 163+80. Photograph by US Army Corps of Engineers, 15 May 2008.

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12 March 2010

Updated 4-14-10 with additional information on extent of riprap coverage on Winslow Levee. Updated 1-18-11 w/ PD & Navajo Co. Publ. Works review comments from Jun-Jul 2010, and with structural/Levee composition parts of the "legal briefs" files sent to us in Mar. 2010.

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Purpose. This report was prepared by the US Army Corps of Engineers, Geotechnical Branch, Geology & Investigations Section, Los Angeles, CA, The goal was to collect and summarize all that is known about the Winslow Levee and the Ruby Wash Diversion Levee, both of which are adjacent and / or in the City of Winslow, AZ, in Navajo County, The objective was to have in one readily accessible document all existing subsurface information on the levees' foundations, including boring and trench logs, and all that is known about the levees' compositions, history, repairs, and performance. The locations of the levees and important geographic reference points are shown on **fig. 1**.

This document supports the feasibility phase of a joint effort between the US Army Corps of Engineers and Navajo County Public Works Dept. to study and possibly improve the levees. Navajo County built, owns, and operates Winslow Levee. The US Army Corps of Engineers built Ruby Wash Diversion Levee, and the City of Winslow, AZ, owns and operates it. This data collection and assessment is one step in the decision-making process regarding what to do about the levees, and, initially, to decide if additional exploration and testing of the levees needs to be done as the US Army Corps of Engineers, Los Angeles District, Los Angeles, CA, and Phoenix AZ, offices[1] (*hereafter*, "the Corps"), undertakes an evaluation of the levees and considers the feasibility of trying to improve them. This study is focused on studying possible improvements to both levees, even though the City of Winslow is not at this point a local sponsor of the study. Navajo County at this point in time is the only local sponsor.

Much of the Ruby Wash Diversion Levee was petitioned by the City of Winslow in 2009 for re-accreditation under a FEMA program. The segment proposed for re-accreditation was explored and tested by consultants to Winslow, AZ, in preparation for petitioning FEMA. Through modeling of flood routing that preceded that exploration and testing, it was determined that the downstream, or eastern, end of that Levee, which adjoins the upstream end of the Winslow Levee, would be overtopped under current flood scenarios. Therefore the eastern part of Ruby Wash Diversion Levee was not included in the proposal for re- accreditation, and was not included in the geotechnical exploration and assessment effort done to support the re-accreditation package. The 15 March 2010 ruling from FEMA on the matter raised numerous issues (detailed later in this report) with the documentation submitted to support the re-accreditation request and refused to re-accredit the Levee (Curtis, 2010), while inviting submittal of additional documentation, exploration, and analysis for reconsideration. The status of a re-submittal, if any, is unknown as of the time of this writing. In the future, the Corps' work in this feasibility study may include all of Ruby Wash Diversion Levee, and most likely will be truncated to eliminate any part of Ruby Wash Diversion Levee that receives re-accreditation. At this initial phase of Corps' involvement, the effort was made to obtain and assess all the available information on the Levee, including the segment of Ruby Wash Diversion Levee petitioned for re-accreditation. The owners of Winslow Levee did not petition for re-accreditation of any part of Winslow Levee. It has been decertified and will not withstand the 100-year flood event.

The extensive library and documentation files of Navajo County Public Works, Holbrook, AZ, concerning these two levees, was the essential information source for the research that went into

[1] US Army Corps of Engineers, Los Angeles District, Planning Division (Phoenix, AZ) and Engineering Division, Geotechnical Branch (Los Angeles, CA).

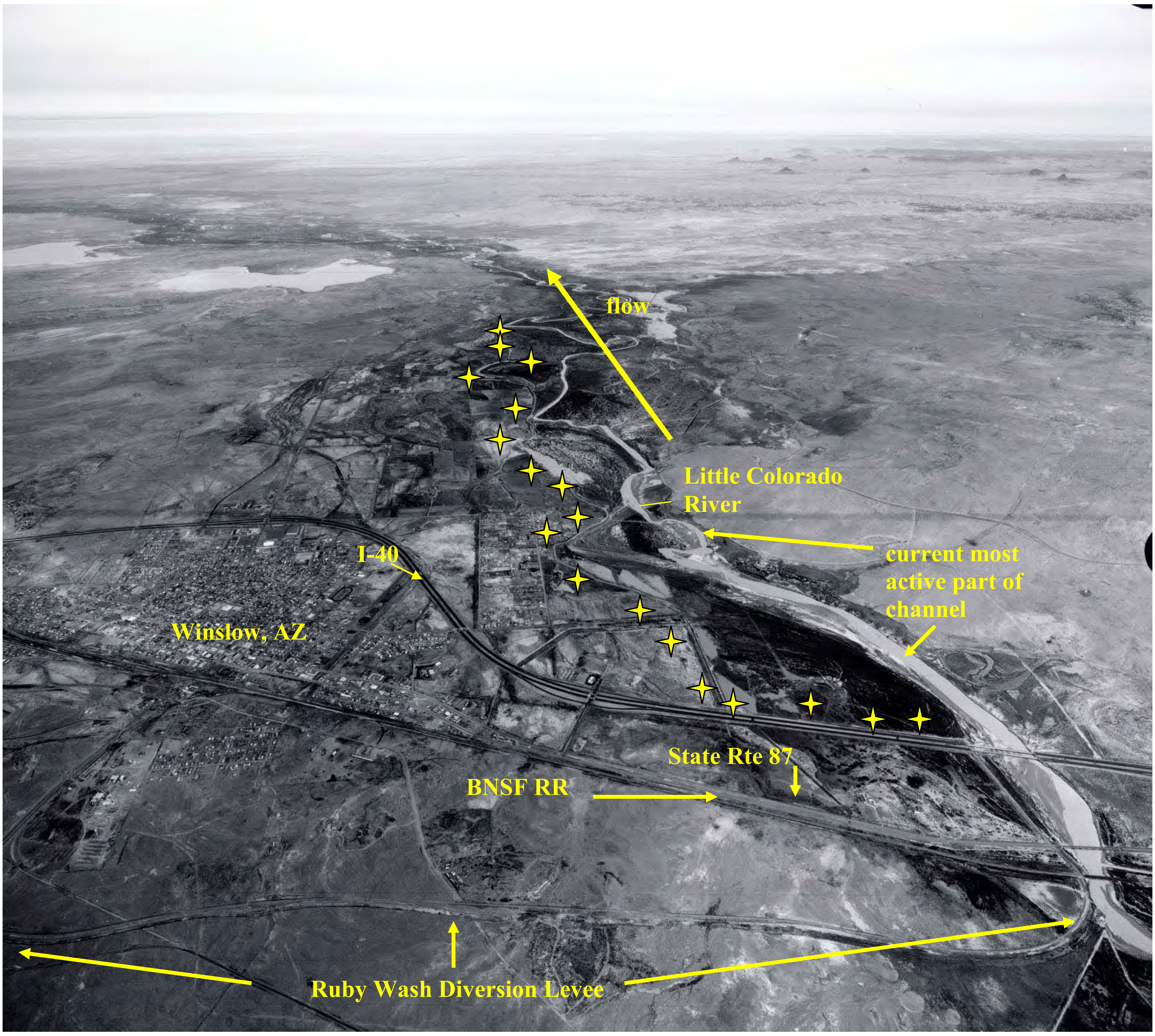


Fig. 1.—Oblique aerial photograph showing the locations of Winslow, AZ, the Ruby Wash Diversion Levee, Winslow Levee, Interstate 40, the BNSF Railroad tracks, and Arizona Route 87. The Winslow Levee alignment is marked by a series of yellow stars, all on the land side. A segment of Interstate 40 embankment does comprise a part of the levee, as it exists as of the time of this writing. It was intentionally constructed that way. Note the locations of the bridges over the Little Colorado River of the BNSF RR, I-40, and Arizona Rte 87. The east (right) bank of the Little Colorado River cannot be seen in this view, which serves to emphasize the overall great width of the channel at this location. North is to the top, left of this frame. The Little Colorado River flows northward here. Source of the photograph: undocumented, obtained from the Corps Planning Division, Phoenix, AZ, and originally, probably is from Navajo County files.

the completion of this report. The reader should note that the Little Colorado River flows north-northwestward in the vicinity of Winslow, AZ.

1. **Winslow Levee.** Winslow Levee was built, rebuilt[2], and is maintained and owned by Navajo County, AZ. The two Winslow Levees, original and current, use the same stationing system, with low numbers, at or near zero, at the upstream end, and numbers increasing to the north and downstream.

1.1 ***Background***. Winslow, AZ, is on the west (left) bank of the Little Colorado River, and overbank flooding from the Little Colorado is a concern, even though, overall, Winslow is a dry place, with annual precipitation of 7.33 inches, most of which comes as winter snow (ADWR, 1980, p. 2). When flows do occur in this, and other western, arid-environment watercourses, they can be quite large and cause extensive flooding. Flow contributions from just some of the Little Colorado tributaries upstream of Winslow can cause a flood within Winslow. Anticipated areas of flooding are shown on **fig. 2**. **Fig. 2** is the current condition, i.e., the Winslow Levee, now decertified under FEMA regulations, would not contain the 100 year event and the blue area shown on the figure is the resulting projected area of inundation of Winslow and environs at the 100-year flood. **Fig. 3** is an older map, from when the Levee was certified to contain the 100-year event. Notice the substantial increase in inundation within Winslow under the current condition. A goal of the current study is to reduce the flood risk area of Winslow to something much more like **fig. 3** than **fig. 2.**

The Little Colorado River originates 160 miles upstream of Winslow, AZ, in the White Mountains, south of Springerville, AZ, and continues for another 155 miles downstream of Winslow. Floods were noted to have occurred on the Little Colorado River in the years 1923, 1957, 1968, and 1969 and Winslow specifically was noted as sustaining flood damage[3] in December 1978, under a flow of 57,600 cfs (cubic feet per second). Two later studies estimated the 100-year flood discharge at Winslow at 65,000 cfs[4] (ADWR, 1980, pp. 1, 2), and at 69,200 cfs[5] (Tetra Tech, 2009).

The Little Colorado River at Winslow, AZ, has a large and quite wide floodplain (refer to **fig. 1**), in contrast to some of the upper reaches of this river. At and near Winslow, within a few miles upstream of the City, several important tributaries join the Little Colorado River, swelling its potential flows. These are, Clear Creek, Chevelon Creek, which were specifically noted as having a substantial contributory effect on the December 1978 flood (ADWR, 1980, p. 3), Jacks Canyon, and Cottonwood Creek (Bureau of Reclamation, 2003, p. 1).

1.1.1 *River system dynamics*. When considering upgrades on a levee system, one of the most important background conditions to recognize is the overall dynamics at work in the river system that the levee is being designed to control. The Little Colorado River has been evaluated in this

[2] Corps records report on a 1979 post-flood-damage-of-1978 rebuild by the Corps of two specific segments of the Levee, and allude to a 1973 "rebuild" under PL84-99, following a 1972 breach. PL84-99 work very likely included Corps of Engineers involvement in the construction. More definitive records have not been encountered.
[3] The Levee also was damaged in that 1978 flood, with two segments of it subsequently receiving repairs (Rodgers, 1978; Gregory, 1990, p. 1).
[4] With 47,580 cfs at the 25-year event discharge, and 55,900 cfs at the 50-year event discharge (ADWR, 1980, p. 3).
[5] Based on interpolation of existing stream gage data.

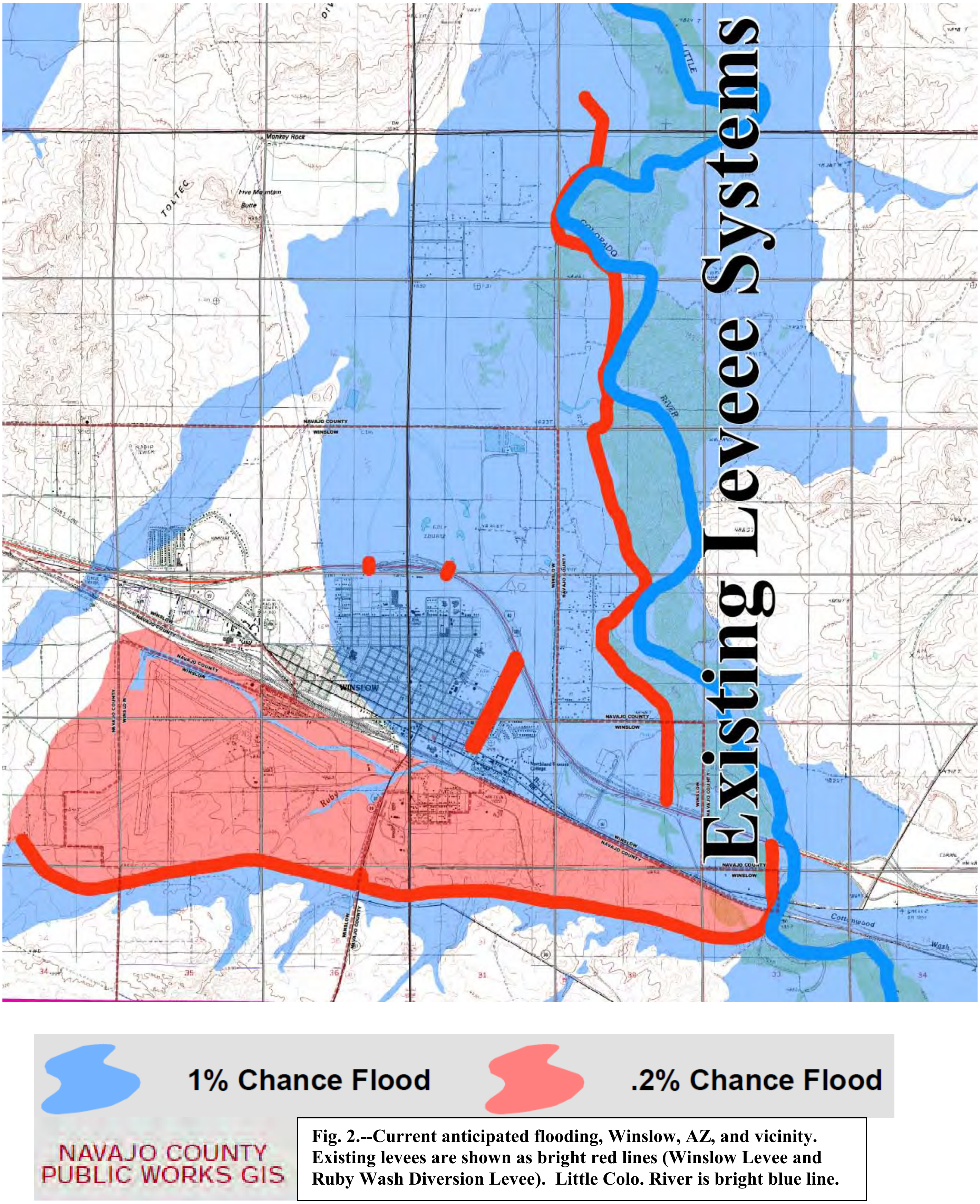


Fig. 2.--Current anticipated flooding, Winslow, AZ, and vicinity. Existing levees are shown as bright red lines (Winslow Levee and Ruby Wash Diversion Levee). Little Colo. River is bright blue line.

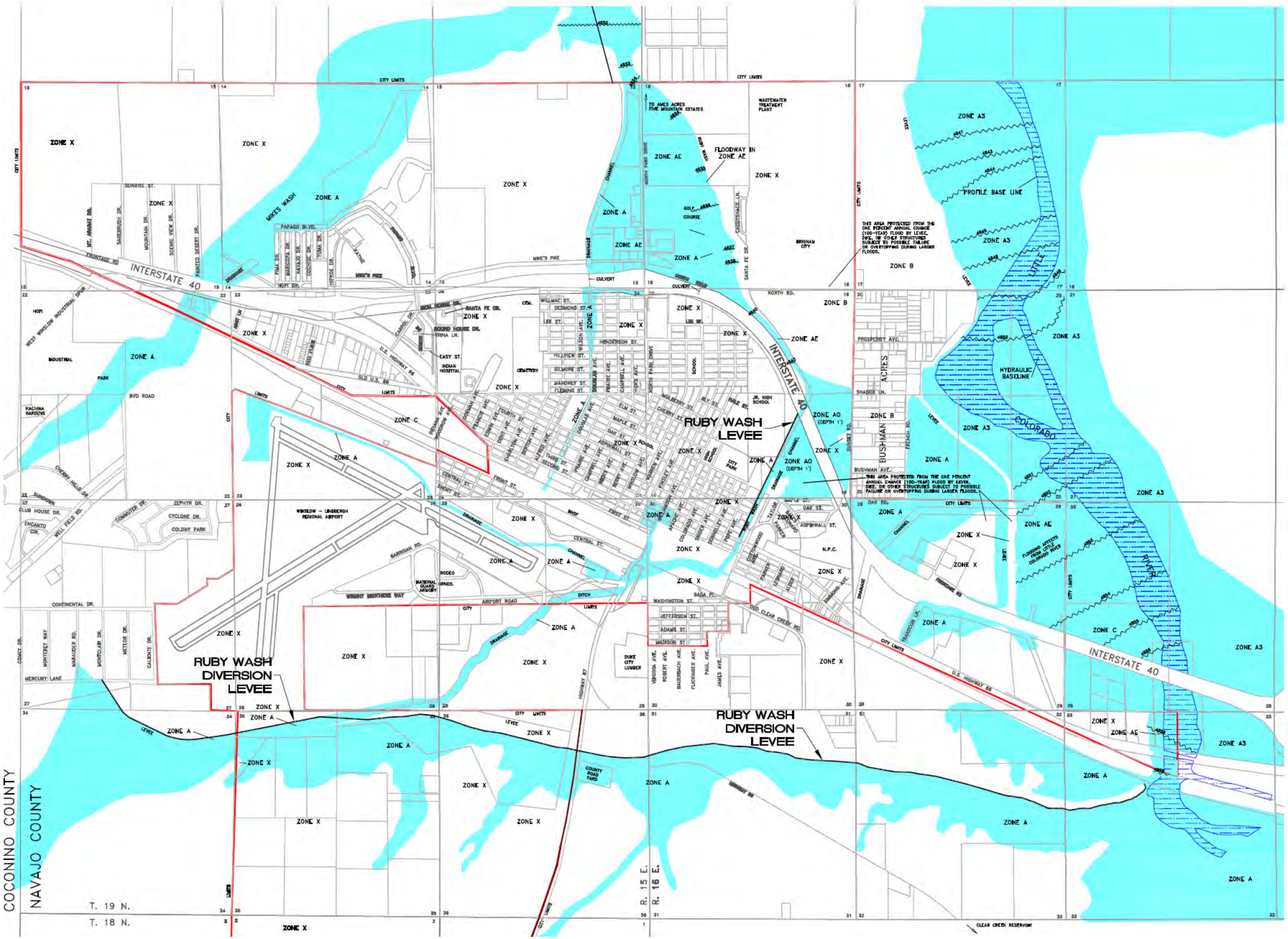


Fig. 3.—The 100 year floodplain in and around Winslow, AZ (shown in pale blue/ aqua color) in the early 1990's, prior to the decertification of the Winslow Levee. Compare to fig. 2. Dark blue with hachure marks is the current most active part of the Little Colorado River channel in this vicinity. Source of map: City of Winslow, AZ.

regard by several past researchers and the conclusions of those evaluators are that there has been interaction among the processes of climate change (increased temperature, decreased precipitation), erosion and channel incising, land use, grazing, tree planting along the river, tamarisk cultivation along the river, building of dams along the watersheds watercourses, changes in amount and severity of flooding, and streambed aggrading, best seen in the timeline illustrated in SFC Engineering (1997, chronology chart).

The assessment of river system dynamics changes over time, as documented below, assigns a major contributing role in changing river dynamics to *climate change*, particularly in terms of types and frequency of storms.

There is written documentation of pre-settlement conditions along the Little Colorado River, including some right at the Winslow area. Extensive swamps above the current Winslow, AZ, location, were reported a short distance downstream of the Chevelon Creek / Little Colorado River confluence (this confluence is about 6 miles upstream of Winslow). This "intricate labyrinth of sloughs" slowed the 1851 Sitgreaves Expedition. The 1853 Whipple Expedition described, at the Homolovi Ruins directly on the other side of the Little Colorado River from current Winslow, AZ, a Little Colorado River that was "a network of channels, all bordered with alamos[6], " and also noted "… quite a forest, extending about four miles down the valley." (SFC Engineering, 1997, p. 14). This information establishes that, pre-settlement, and pre-large-scale-herd-grazing and agriculture, vegetation and water were dominant characteristics in the study area vicinity.

A marked change occurred in the recorded history period of the area, and is ascribed to the 1880's when arroyo formation and channel entrenchment brought about deep incising of channels, accelerated lateral and vertical erosion and co-destruction of channel vegetation and the terraces on which Cottonwood tree stands lived. Wide, sandy, braided channels were left behind and attempts at agriculture were impacted (SFC Engineering, 1997, p. 14). By 1896, the same area at Homolovi that had been described in 1853 as a network of channels bordered by trees, was being described as dry, with steep banks several feet high, and a riverbed that could crossed anywhere "without obstruction" (SFC Engineering, 1997, p. 16), which suggests the swamps and heavy vegetation of the mid 1800's were by then a thing of the past. The Little Colorado River at Winslow in the 1930s was a "wide treeless valley …", with a "broad sandy bed", "almost free of vegetation", and with "steep cut banks" (Sabol, 1993, p. 62).

But instead of settlement and herd grazing, it is large scale climate change that has been cited as the major contributor to the cited-above erosional changes which starting in the 1880's (and also to the subsequent reversals of those trends). The 1880's through 1940 was a period of large flood peaks and erosion, and of dominant cold-season floods (which have less suspended sediment load and thus more capacity to pick up sediment as they move downstream (and to erode sediment) (SFC Engineering, 1997, pp. 9-12). Tamarisk, while cultivated in the river near Winslow since 1909, apparently, *was not able to establish itself in this face of the flooding*, just as existing, established vegetation was unable to resist the flood forces, and all was removed by the floods, leaving a largely vegetation-free channel into the 1930s, as was described in the paragraph above. This trend was stopped in 1940 when regional climate changed again to a

[6] Poplar trees.

drought and cooling trend, to smaller flood events, and the most apparent change seen was floodplain development on the river. Aggradation resulted. Tamarisk spread considerably in this period (SFC Engineering, 1997, p. 11-12, chart of chronology) and has been shown to enhance aggradation, by diminishing flow velocities, forming backwaters upstream of vegetated areas, and causing resulting suspended sediment deposition, and also has been noted as reducing overbank flow (Sabol, 1993, p. 61).

While the 1980s saw evidence of the return of channel incising forces and the destruction of floodplains in various places along the Little Colorado River watershed, and while there are many other factors involved at significant locations upstream of Winslow (such as the impact of Penzance dam on enhancing aggregation in and upstream of the Holbrook, AZ, area), ultimately, bedrock control of the river gradient is a very powerful control and it appears that this is particularly so in the Winslow area. The river gradient from Winslow downstream to Leupp, AZ, is very flat (Sabol, 1993, p. 64). The Winslow area may be more stable in the immediate future than some of these other locations in the watershed due to the presence of bedrock at or very near the river bottom.

Conversely, a river system that finds great resistance to downcutting, such as resistance afforded by bedrock control of downcutting, will be more prone to migrate laterally, and lateral migration is a serious concern for the long-term stability of an existing levee. The Winslow Levee is most frequently attacked by lateral migration of the Little Colorado River, as can be gleaned by reading the descriptive sections in subsequent paragraphs of this report. Tamarisk, while helping to resist erosion, also notably reduces the flood conveyance capacity of rivers, and there could be instances wherein this increases the chances for overbank flooding in the vicinity of the Winslow Levee.

Ultimately, a levee system has to be designed to counter anticipated river downcutting, or river lateral migration, and with risk of overbank flooding in mind. The collective body of knowledge at this point points strongly to the factors of lateral migration of the channel and overbank flooding as the greater long-term risks for this levee system.

1.1.2 *Summary of previous exploration work done on the Winslow Levee.* No exploration was encountered for the original Winslow Levee. None is suggested to have been done by the literature.

In preparation of replacing the original Winslow Levee with the current Winslow Levee, exploration drilling through the original Levee and into the foundation below was done by three firms. None of their reports could be located for this research, but stick-log summations of the subsurface findings in all those borings are precisely located on the as-built drawings for the current Winslow Levee (**attachment 1**) and have been summarized in this report at strategic locations to help describe the Levee and its foundation. The three sets of borings are by Dames and Moore (1980), for a geotechnical investigation (it is presumed the stick logs shown on the as-builts that are pre-fixed with "DM" are these logs); another investigations in 1980, as evidenced by stick logs on the as-builts prefixed by "DWR" (possibly Arizona Dept. of Water Resources?); a third set of seven borings were done in July 1982, as part of a geotechnical investigation by Western Technologies, Inc. See the cited references for the exact citations of the Dames and Moore and WTI work. Arizona Dept. of Water Resources was engaged in evaluation of bettering the Winslow Levee in 1980, but their report of that date, which as obtained, has no drill logs listed among the contents. It is thought possible that ADWR did the exploration and did not release the results as a part of any formal report.

The 1993 breach of the Levee resulted in exploration, drill logs, and reports by Western Technologies, Inc. (WTI, 1993), SBHAgra (1994), and Cella Barr Associates (1994, 1995). All those logs and reports have been utilized in preparation of this report and available as attachments to this report. The SBHAgra (1994) work included a series of test pits dug, logged and sampled on both the landside and riverside of the Levee in the emergency patched scour zones, and concluded that compaction was not particularly complete (SBHAgra, 1994, p. 6), and, specifically, "effective compaction … was minimal"; no location map, description, or stationing for those test pits was included in the SBHAgra report for the locations.

It should be noted by the reader that as-built drawing northing and easting coordinates used by PRC Toup are NOT the same as the northing and easting coordinates used by Cella Barr Associates (1994, fig. 2, note on figure). Apparently, different coordinate systems were used by the two studies, so this must be kept in mind when utilizing late 1980's reports and records vs. mid-1990s reports and records

1.2 ***Composition, construction, and fate of the original Winslow Levee***. Based on an examination of available maps and reports, supplemented by anecdotal information, a Winslow Levee was originally built by Navajo County in the late 1960s[7] (WTI, 1982, p. 1), at least some of it under flood-fight conditions, from approximately station -7+00 to sta. 343+83 (see **fig. 4**) (ADWR, 1980, pls. 1, 2), a linear distance along the crest of 35,000 ft, or, 6.7 miles. Gregory (1990, p. 1) states that the Levee construction began in 1968, "by county resolution".

The Levee is entirely outside of Winslow city limits (though very close to those limits, in places), and is exclusively on the west or left bank of the Little Colorado River. Its purpose is to protect Winslow from overbank flooding by the Little Colorado. A critique of this levee was encountered in one US Army Corps of Engineers document:

> "*About half a mile north of Winslow, Navajo County is constructing an earth levee of varying cross sectional dimensions. Its aim is to control flood waters from the Little Colorado River. The levee is not yet complete, and it follows neither a set schedule or a standard design. For these reasons the levee is not entirely effective.*" (U.S. Army Corps of Engineers, 1976[8])

There is no levee on the east bank of the Little Colorado River in this vicinity.

A breach of the Levee in 1972 resulted in a 1973 rebuilding of at least some of the Levee, "under Public Law 84-99", which suggests that the Corps of Engineers likely was involved in the

[7] Corps Planning Division review of Navajo County files determined that levee construction was initiated in the early 1960s, with several phases of activity, many spurred by flood fights.
[8] This report could not be located or identified. It was cited in ADWR (1980) but that report has no listing of it in cited references.

construction work. After a damaging 1978 flood, two specific segments of the Levee were rebuilt and replaced by the Corps of Engineers, work that was done in 1979 (Gregory, 1990, p. 1). The very sparse documentation available on these two events is presented later in this report, under the "Levee performance" sections. These appear to be the only exceptions, with all other work, through the history of the Levee, done exclusively by Navajo County.

Apparently, much of the original 1960s levee remains as foundation beneath the 1980s (and current) levee that was built overtop of it, this, based on examination of the as-built drawings of the 1980s levee. The composition and foundation of the original levee are best understood by examining a series of 24 exploration boring logs that were done by three different firms in 1980 through 1982, as plans were being made to improve the original levee, by building the current, existing Winslow Levee overtop of the original levee. See **fig. 5** for a map of the current levee; compare to **fig. 4** to see the differences between the currently existing and original levees. Many of these 24 borings were drilled through the top of the late 1960s levee; their locations are shown on **fig. 6. Attachment 1**, which is the set of as-built drawings of the current levee, has both the precise location of each of the 24 borings, including stationing, and also stick-log representations of the subsurface findings in those borings. The original boring logs and any notes or additional information they may have contained could not be found by the Corps during this search for existing information.

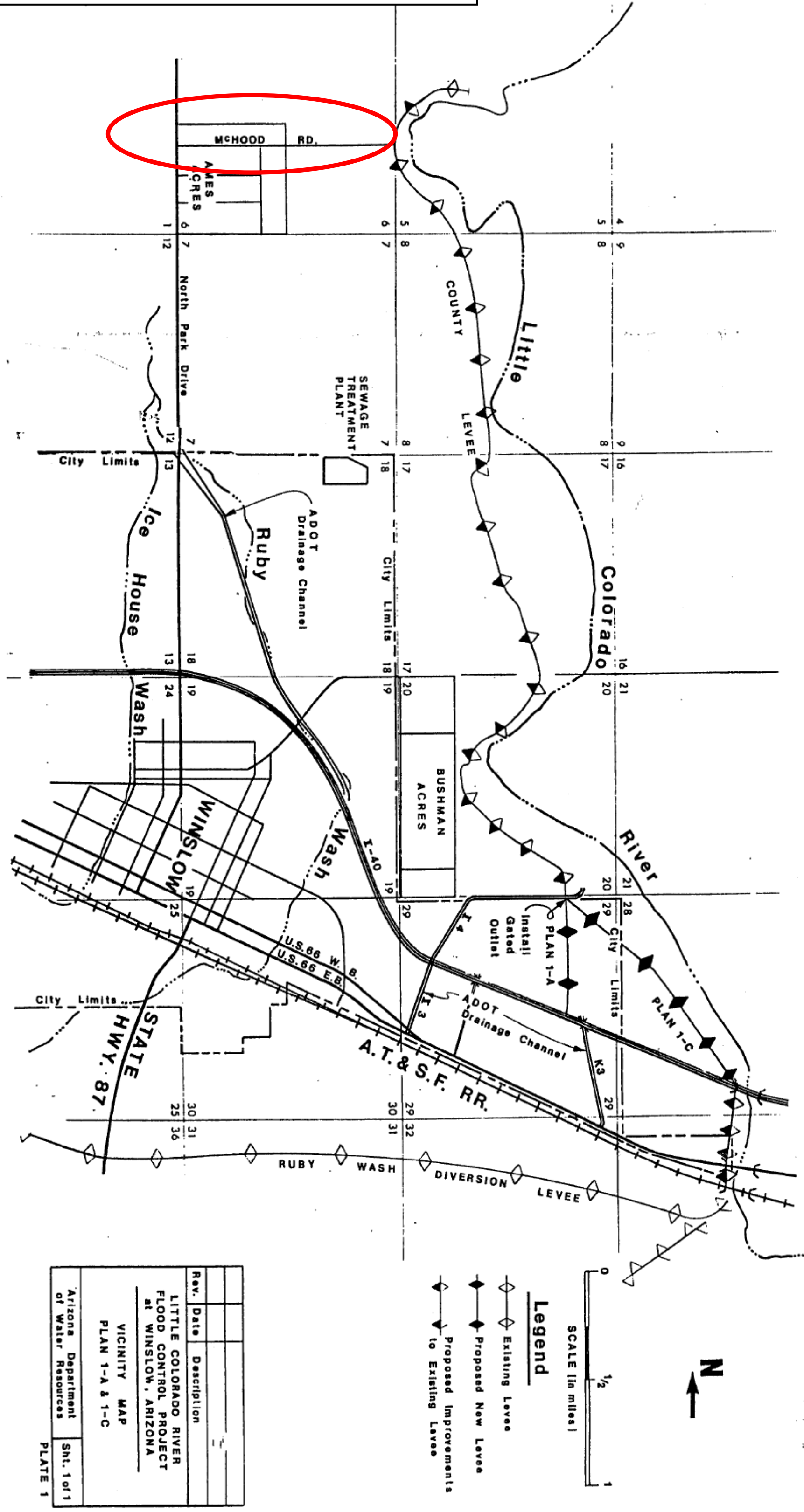
Other information on composition of the original levee from the 1960s can be gleaned from brief mentions in existing literature and anecdotal evidence, as follows.

The original levee of the 1960s, a random fill, was thought to have been built at least in part under flood fight conditions, with materials placed under uncontrolled conditions (WTI, 1982, p. 1). An ADWR study reiterates that "extensive sections of the [original] levee were constructed under emergency conditions with whatever type of material was immediately available." (ADWR, 1980, pp. 9-10) and an anecdotal report from Navajo County Dept. of Public Works is that some parts of the original levee, built under the duress of an impending flood flight, were constructed of old car bodies, among the other materials[9].

The issue of car bodies and other debris, such as tires, in (or perhaps *on*) the Levee is worth noting with regard to impacts on possible future exploration. In our 2010 effort at assembling the history of the Levee construction and rebuilds and materials involved, the Corps, up until January 2011, had been operating under the assumption that all car bodies had been removed from the structure in the course of the rebuild by Navajo County, which, records indicate (especially the stamped 1989 as-builts) was completed in 1989. But a recently encountered Corps – Los Angeles District inspection report of 25 April 1990 mentions "many old car bodies, tires, and miscellaneous brush was observed in levee banks and in the channel", and also states, "Winslow levee is a compacted earth levee … Slope faces have broken concrete, auto bodies,

[9] Navajo County Dept. Public Works reported to the US Army Corps of Engineers in May 2008 that during the late 1980s rebuild of the Levee, all such car bodies and other less-than-ideal materials were removed from the Levee fill materials and no such materials were used in the rebuild or remain within the Levee. The Corps report (Gregory, 1990) of encountering numerous car bodies on the Levee, nearly 8 months after the 1980's rebuild was completed and its drawings were stamped "as-built", reopens this issue of whether car bodies still are a component of the Levee, and is discussed in text, below.

Fig. 4.—Alignment of original Winslow Levee (see legend). Source: ADWR (1980, pl. 1). Use your document viewer's "zoom" feature to see more detail.



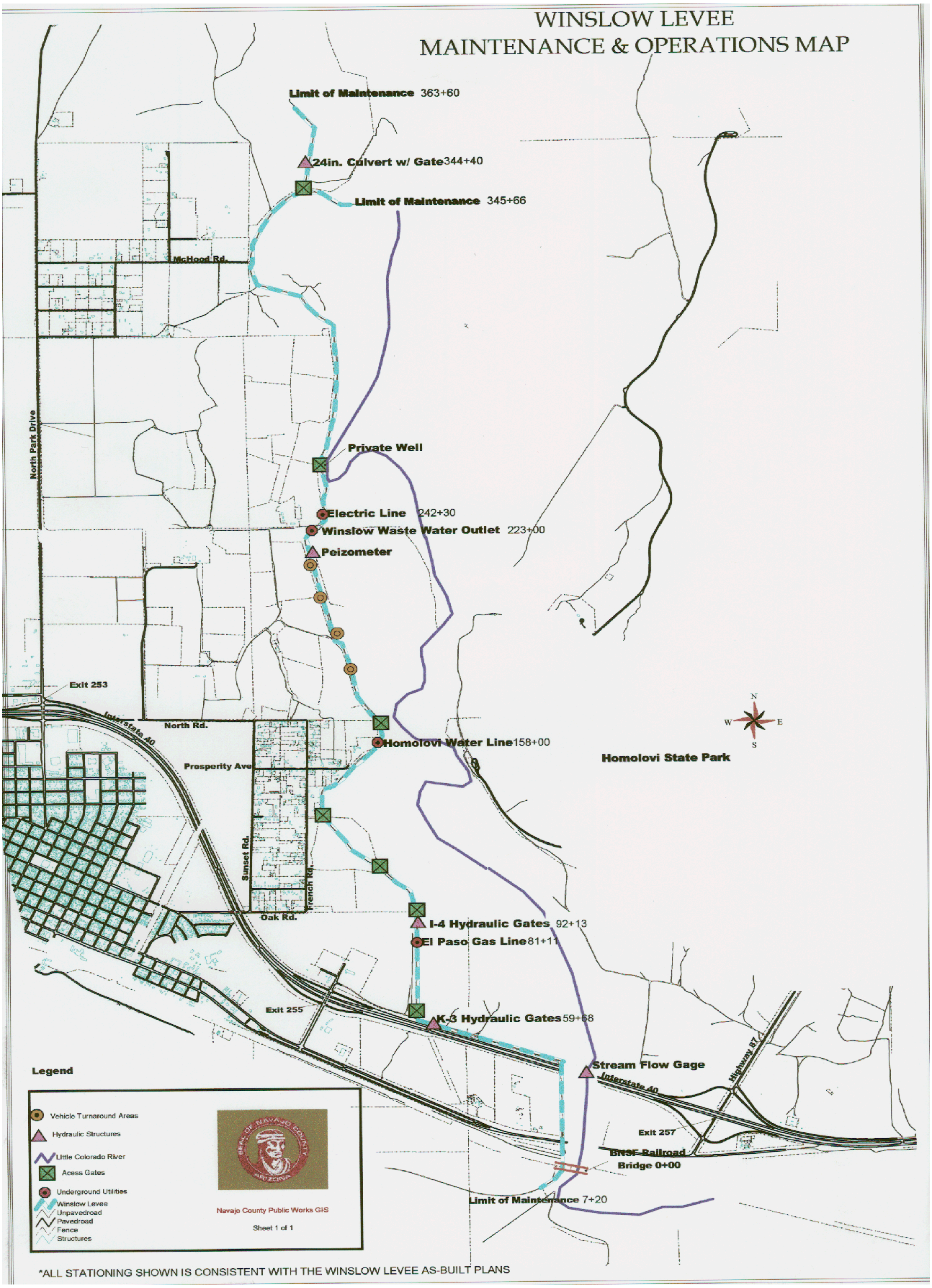


Fig. 5.—Alignment of existing Winslow Levee (see pale blue / aqua colored line). Source: Navajo County. Use your document browser's zoom feature to see more detail. Where sta. 242+30 is shown on this map, probably is approx. sta. 229 or 230, based on a study of the as-builts (sheet 8).

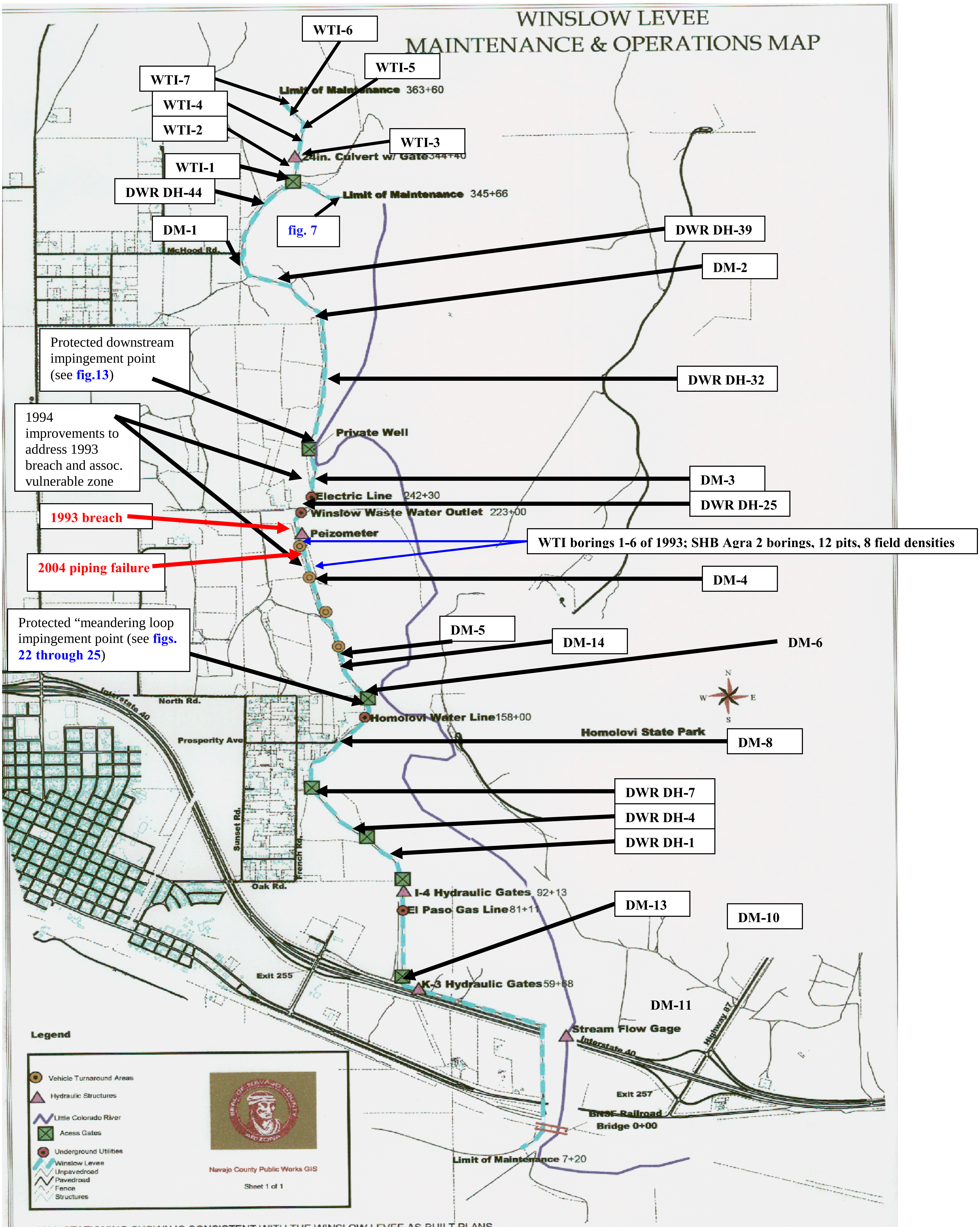


Fig. 6.—Existing Winslow Levee (see pale blue / aqua colored line), showing locations of 1993 and 2004 failures, and all known geotechnical explorations (borings, trenches). Original map source: Navajo County. Map modified by the Corps by adding the annotations showing exploration and failure points. Use your document browser's zoom feature to expand the size of this drawing and see more detail. DM = Dames and Moore boring location (shown are Dames and Moore borings from 1980, numbered DM-13, -11, -10, -8, -6, -5, -4, -3, -2, -1. DWR DH= Arizona Dept. Water resources boring from 1980 (shown are DWR borings from 1980 numbered DWR DH-44, -39, -32, -25, -7, -4, -1). WTI = Western Technologies, Inc. boring location (shown are WTI borings from 1982, numbered WTI-7, -6, -5, -4, -3, -2, -1). Also shown are a set of borings 1-6 by WTI from 1993 at the 1993 breach area. SHB Agra work of 1994 was spread along 3,500 ft of the levee; approximated work area shown. Where sta. 242+30 is shown on this map, probably is approx. sta. 229 or 230, based on a study of the as-builts (sheet 8).

and stone placed more or less randomly." (Gregory, 1990, p. 3). Gregory (1990, enclosure 8), then includes a photograph of the riverside slope at the upstream end of the Levee, and partly buried car bodies are visible in the picture (**fig. 7**). The description could indicate car bodies and rubbish used just as a slope face protective material, or it could mean that such materials compose at least some of the Levee. The importance of this is, from the perspective of the Corps of Engineers, that car bodies apparently still could be encountered if geotechnical exploration trenching or drilling of the Levee were to be undertaken in the future. Exploration should be planned to expect, watch for, and avoid such materials, which will present problems when drilling and digging. If they are on the surface only, the potential problems will be lessened, although burial (and concealment) by siltation conceivably could hide them from view.

This original Levee also was noted to have suffered seepage on the landside and was considered to have a high potential for piping under conditions of large flows in the Little Colorado River. River impingement, as it is today, was a problem with the original Levee. The original Levee was overtopped and breached in multiple locations[10] in a December 1978 flood, which was less than the 100-year design flood (WTI, 1982, p. 1). ADWR (1980, pp. 9-10), in a study of the original Levee, noted that organic material has been dumped in some segments of the Levee and buried by subsequent fills, leading to seepage concerns.

A past assessment of available-for-construction river materials by ADWR (1980, p. 9), reached the conclusion that these materials, comprised of silty and clayey river materials are "*extremely dispersive*", and thus subject to piping if used to construct a low-permeability facing or other structure within or on the riverside of the Levee. The proposed ADWR fix was to include a layer of gravel and sand, landside of the dispersive materials, to prevent propagation of piping through the Levee, or enlargement of any dessication cracks that may develop.

1.3 ***Planning and building the current Winslow Levee, built in the late 1980s***.

Assessments of how to improve the original Levee continued into the late 1980s, when the current Winslow Levee was built overtop the original Levee and extended farther north about 2,000 feet in length (compare the maps in **figs. 4 and 5**, and see where the Levee was extended to the north). The as-builts of the current Levee (**attachment 1**) indicate only that the original Levee comprises the foundation for the current Levee. No locations where original, unsuitable materials have been removed can be identified. The construction period for this Levee began in 1986, and it was completed in 1989, according to Corps of Engineers Planning Division review of Navajo County files. As-built drawings were sealed as "as-built" on 3 October 1989.

The main objectives of this Levee improvement exercise were:

- Raise the Levee;
- Flatten Levee slopes;
- Build an impermeable core in the Levee to control seepage;
- Armor the Levee with stone at river impingement points (WTI, 1982, p. 1).

[10] Neither precise nor general locations of that overtopping and breaching could be found in available documentation.

Fig. 7.—(*2 frames, one above, one below*) Two views that include at least one car body in the Levee on 25 April 1990, which is after the 1989 rebuild was completed. The top frame is Gregory (1990, enclosure no. 8), and is reported to be at station 345+66, The bottom frame, also with Gregory (1990) files, was un-annotated, but appears to be a view of the same location, with better resolution.

All available evidence and field observations support that the above listed objectives were attained by the late 1980s rebuild of the Levee.

The as-built drawings (**attachment 1**) show a Levee with:

- 2H:1V side slopes on the land side, upstream and middle reaches,
- 2.5H:1V side slopes on the river side, upstream and middle reaches,
- 3H:1V on land- and riverside, downstream reaches,
- a 12-ft-wide crest,
- a height generally of 10 to 12 ft above pre-Levee topography,
- a 2-ft-thick, vertical, slurry wall cutoff trench constructed throughout;
- slurry trench depth varies and is at elevation 4,846 ft. at the upstream end of the Levee,
- a top of this slurry cutoff wall that is 2 vertical feet (minimum) below the crest of the finished Levee,
- prescribed re-use of original Levee materials, where the original was to be removed, and provided those materials were suitable,
- built overtop the original Levee in places,
- keyed in, in places, but not throughout,
- has riprap slope protection in places, extending to within 1 ft of the Levee crest and extending in toe-down to a depth below the Levee toe to a depth about equal to the Levee height, and on a 1.5H:1V slope, with the toe-down trench then backfilled up to the Levee toe elevation (see chart, **fig. 8**, clipped from the original as-built drawings, and inserted at the end of this bullet list, for elevation information, regarding the bottom of the slope protection),
- as first re-built, riprap and filter fabric bank protection on the riverside of three zones of the Levee, as listed in **fig. 8**, below (this slope protection has been added to other areas, and to the landside, in places, as discussed below);
- has filter fabric (Mirafi 140N or approved equivalent) beneath the riprap,

Fig. 8.—Locations of riprap in rebuilt Winslow Levee (from as-built drawings)

Location	Toe of Slope Elev.	Bot. of Bank Protect. Elev.	Levee Type side slope
Sta.-(3+50)± to Sta.-(0+62)*	4853.0	4829.0	New 3.5:1
Sta.0+60* to Sta.4+31*	4853.0	4833.0	New 3.5:1
Sta.137+00 to Sta.164+00	4840.0	4812.0	New 3.5:1
Sta.233+02.5 to Sta.251+27.8	4833.0	4805.0	Exist. 2.5:1
Sta.251+27.8 to Sta.272+00	4834.0	4810.0	Exist. 2.5:1
Sta.272+00 to Sta.286+00	4828.0	4800.0	Exist. 2.5:1

*Transition into existing embankment

anchored at the top of the Levee by 10-ft-long Helix anchors on 10 ft centers,

- an existing ADOT[11] "pile retard fence" existed and was left in place, from approximately sta. 11.5 to sta. 18.25.

The current Levee feature known as "spur dike #1", is a groin or jetty contiguous with the Levee riverside slope between Levee stas. 163+50 and 164+75, and extending eastward into the Little Colorado River, approximately perpendicular to river flow, where it diverts river flows from the Levee toe. This dike is found on 1997 design drawings made by Kimley-Horn & Associates[12] for Navajo County, drawings that detail a planned addition of riprap to the Levee (an addition of protection stone that was actually made in 2009). The older as-built drawings of the current Levee show no such spur dike, so it apparently was built after 1989 (completion of the current Levee and its as-builts) and prior to May 1997 (the date of the aforementioned Kimley-Horn drawings). Composition and history of its construction are not known by the Corps. The Kimley-Horn drawings, sheet 3 of 15, note that this spur dike no. 1 is to be demolished, but Navajo County Public Work's Trent Larson reported to the Corps via a 8 June 2010 memo that this dike has not been removed and continues to function.

As of April 1990, at least 12 other groins or jetties had been built into the Levee according to a sketch by a Corps inspector of the Levee (**fig. 9**), all north of (downstream of) approximately sta. 275+00. The report (Gregory, 1990, enclosure no. 2) indicates that 10 of the 12 jetties were in need of restoration in April 1990, but no details on their composition, construction, or history were included in the report, or found in files elsewhere.

The current Levee is built of random fill, from available native materials and some recycled original Levee materials. The boring logs of WTI (1993), holes #1 and #7 only, and SBHAgra (1994) exploration, hole #2 only, provide a look at the rebuilt Levee composition as of the early-to-mid 1990s (**attachments 2 and 3**), but only the upstream and downstream ends of a 600-ft-long zone in and adjacent the breach. SBHAgra (1994) exploration via test pits was limited to areas where deep scour had been filled on an emergency basis around the same 600-ft-long zone, on the landside and riverside adjoining the Levee. But the SBHAgra report and logs lack stationing and location map. The Corps is not convinced that the materials sampled were left in place and the presumption is that during the permanent repairs of the breach zone, minimally compacted emergency fills zones were removed and reworked. Thus, the data have not been included in the body of this Corps report, although they can be examined in **attachment 3**.
The most notable assessment of the condition of the undamaged Levee embankment materials in the vicinity of the breach was made by SBHAgra (1994, p. 6): they do not need to be treated, which means they were sufficiently compact to perform their purpose (which is to act a as a suitable Levee).

1.3.1 *Levee foundation*. The foundation conditions are variable, laterally and at depth. Levee foundation materials, in different areas, are composed of the following:

- Previous Levee embankment;
- Bedrock;

[11] ADOT is Arizona Dept. of Transportation.
[12] These drawings are "**attachment 4**" to this Corps report.

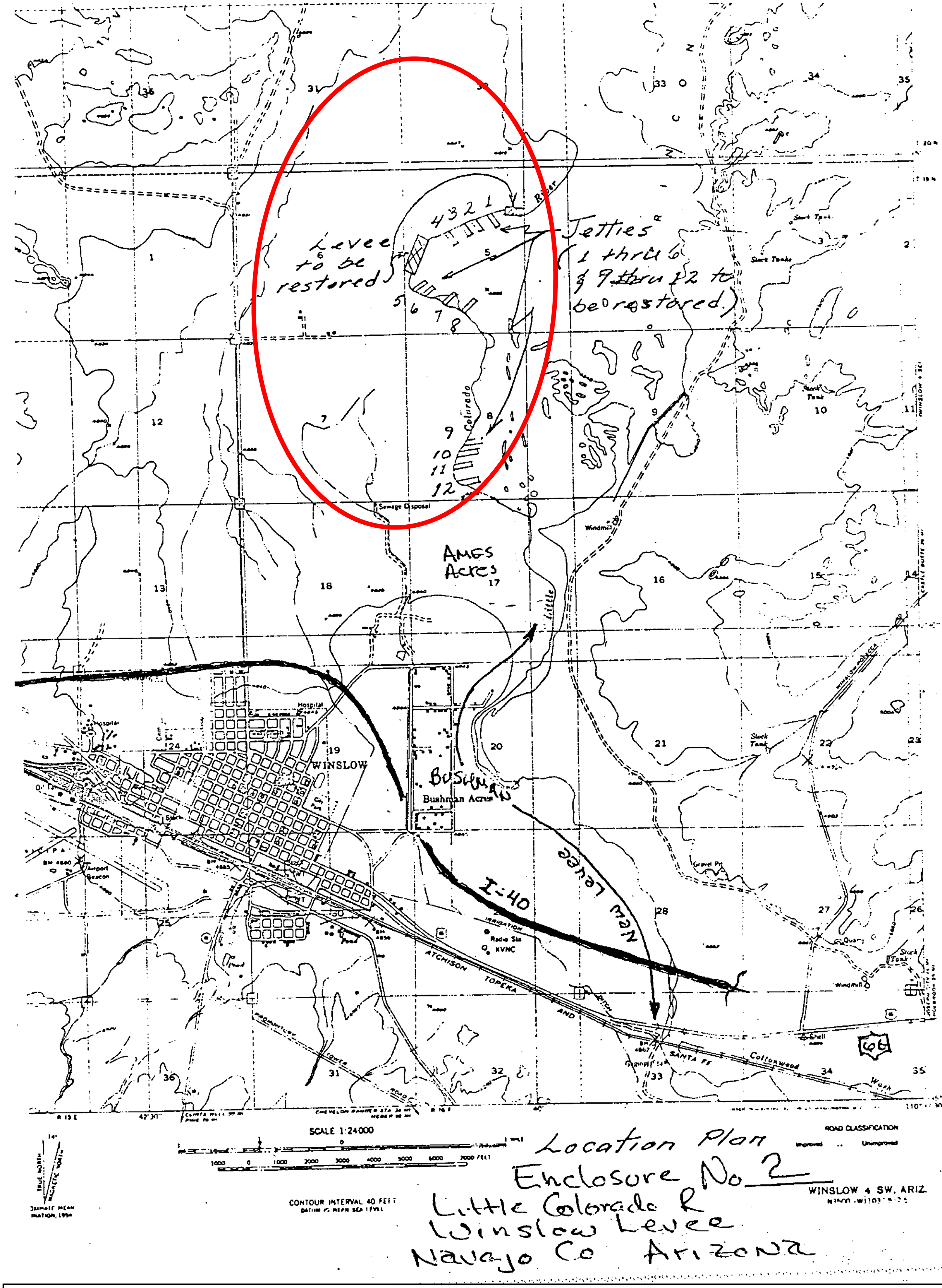


Fig. 9.—Winslow levee, from Gregory (1990, encl. 2). The only known information on locations of 12 jetties (inside red oval) north of sta. 275+00. See also two zones of Levee noted as needing restoration.

- Little Colorado River alluvium from overbank flooding;
- Little Colorado River alluvium from meanders and paleomeanders.

Table 1 is a synopsis of existing logs of borings through the current Levee, by stationing, from the upstream end of the Levee to the downstream end, and as such provides a quick overview of where to coarser and finer materials tend to be found along the Levee, and some of the uncertainties that exist with regard to interpreting existing data. Following **table 1**, each of the various foundation types is discussed. Most of the information used was drawn from stick-log summaries of the exploration borings that is shown on the as-builts; collectively, this is a fair amount of coverage, end-to-end on the Levee. Other information was drawn from the full exploration logs done after the Levee's 1993 breach was plugged (an event detailed later in this report) in preparation of impending permanent repairs; those logs are limited to a 600 ft Levee segment in and adjacent the breach.

Table 1: Winslow Levee, summary of foundation conditions, as per available boring log data in the as-built drawings for existing Levee and the 1993 breach repair explorations.

Location	Description of foundation and subsurface, based on data provided from the logs
foundation upstream of Interstate 40:	
sta 7+75:	original levee is poorly graded sand; base of that levee not defined in the log; deeper materials include silty sand, poorly graded sand, fat clay (CH) below approximately elevation 4832 ft. groundwater at approx. el. 4844 ft. new levee thickness over top of old levee is about 8 ft
sta 20+34:	original levee is poorly graded sand; base of that levee not defined in the log; deeper materials include mixed lean clay & silty sand. groundwater at approx. el. 4843 ft new levee thickness over top of old levee is about 7 ft
foundation downstream of Interstate 40:	
sta 66+80.30:	original levee is silt or sandy silty (ML); base of that levee not defined in the log; deeper materials include lean clay overlying fat clay (CH), then ML and SM-ML. groundwater at approx. el. 4843 ft new levee thickness over top of old levee is about 3 ft; new levee overbuilt by about +1/2 to +1 ft here
sta 66+80.30:	original levee is silt or sandy silty (ML); base of that levee not defined in the log; deeper materials include lean clay overlying fat clay (CH), then ML and SM-ML. groundwater at approx. el. 4839 ft new levee thickness over top of old levee is about 5 to 7 ft; new levee overbuilt by about +1 ft here
sta 95+00:	original levee is 5 ½ ft of "shale", which likely is the weakly cemented top of the Moenkopi Formation; base of that levee not defined in the log; deeper materials include mixtures of poorly graded sand and clayey sand overlying mixtures of poorly graded sand and silty sand. groundwater at approx. el. 4839 ft new levee thickness over top of old levee is about 5 to 7 ft; new levee overbuilt by about +1 ft here

Table 1: Winslow Levee, summary of foundation conditions, as per available boring log data in the as-built drawings for existing Levee and the 1993 breach repair explorations.

Location	**Description of foundation and subsurface, based on data provided from the logs**
sta 114+93.20:	original levee is 6 ½ ft of "shale", which likely is the weakly cemented top of the Moenkopi Formation; base of that levee not defined in the log; deeper materials include 5 ft of lean clay, underlain by poorly graded sand and poorly graded sand - silty sand; a few feet of fat clay is present below el. 4821-½ ft. groundwater at approx. el. 4835 ft new levee thickness over top of old levee is about 8 ft; new levee overbuilt by about +1 ft here
foundation at LCR impingement point adjacent Bushman Acres, i.e., at the "meandering loop":	
sta 130+07.14:	original levee is 6 ft of "shale", which likely is the weakly cemented top of the Moenkopi Formation; base of that levee not defined in the log; deeper materials include 9 ft of lean clay, underlain by poorly graded sand - silty sand. groundwater at approx. el. 4833 ½ ft new levee thickness over top of old levee is about 8 ft; new levee overbuilt by about +1 ft here
sta 147+50.14:	one of the deepest holes bored in this project area; original levee is 9 ½ ft of lean clay; base of that levee not defined in the log; deeper materials include 19 ft of silty sand underlain by lean clay and silt mixtures, and, at el. 4811 ft, sandy clay. groundwater at approx. el. 4839 ½ ft new levee thickness over top of old levee is about 5 ft
foundation downstream of Bushman Acres:	
sta 176+95.20:	original levee is silt and lean clay; base of that levee not defined in the log; deeper materials include silt, lean clay, and silty sand. groundwater apparently not detected new levee thickness over top of old levee is about 8 ft; new levee overbuilt by about 1/2 ft here
sta 181+76.20:	original levee is silt, silty sand and lean clay; base of that levee not defined in the log; deeper materials include poorly graded sand and lean clay. groundwater at el. 4826 ½ ft. new levee thickness over top of old levee is about 8 ft
sta 202+49.06:	original levee is ML; base of that levee not defined in the log; deeper materials include ML, lean clay and silty sand. groundwater apparently not detected. new levee thickness over top of old levee is about 5 ft
sta 221+15.02:	original levee is lean clay (CL); base of that levee not defined in the log; deeper materials include lean clay and mixtures of poorly graded sand and silty sand. groundwater apparently not detected. new levee thickness over top of old levee is about 3 ft; new levee overbuilt by about 1/2 ft here
	the 1993 breach and overtopping failure zone:

Table 1: Winslow Levee, summary of foundation conditions, as per available boring log data in the as-built drawings for existing Levee and the 1993 breach repair explorations.	
Location	**Description of foundation and subsurface, based on data provided from the logs**
sta. 202+00 to 232+00. part 1	[13]WTI (1993) exploration of the breach, immediately upstream of the breach zone: WTI boring #1 (**attachment 2**), sta. not reported, assumed sta. 207+50; Levee is 13 ft thick, and foundation immediately below is silty sand with some clay, moist, medium dense, dark gray brown color; trace gravel at -4 to -5 ft; orange brown at -5 to -6 ft; groundwater at -28 ½ ft below the boring collar (presumed to be on the Levee crest, which would make the groundwater 15 ½ ft below the Levee toe.
sta. 202+00 to 232+00. part 2	See footnote 13. WTI (1993) exploration of the breach, in the breach zone: WTI boring #2 (**attachment 2)**, sta. not reported, assumed sta. 208+71; Levee is 17 ft thick, and foundation immediately below is silty sand with some clay, dry, light brown color; moist at -23 ft; medium brown color at -25 to -26 ft; groundwater at -28 ½ ft below the boring collar (presumed to be on the Levee crest, which would make the groundwater 11 ½ ft below the Levee toe. Assumed is some scour that deepened the top of the native materials here.
sta. 202+00 to 232+00. part 3	See footnote 13. WTI (1993) exploration of the breach, in the breach zone: WTI boring #3 (**attachment 2)**, sta. not reported, assumed sta. 209+92; Levee is 21 ft thick, so surely a significant part of that is emergency fill over scour from the breach; foundation immediately below is lean clay with sand, some gravel, moisture "at the plastic limit", medium plasticity, firm, medium brown color; change to red brown with less sand below -26 ft; groundwater at -28 ½ ft below the boring collar (presumed to be on the Levee crest).
sta. 202+00 to 232+00. part 4	See footnote 13. WTI (1993) exploration of the breach, in the breach zone: WTI boring #4 (**attachment 2)**, sta. not reported, assumed sta. 211+13; Levee fill here is 25 ft thick, so surely this drilled zone is in a deep scour fill zone; auger refusal at -25 ft on a boulder, probably is one of the rocks dumped into the breach, so this drill hole provides no data on the foundation except that emergency fill is more than 25 ft thick here; no groundwater encountered.
sta. 202+00 to 232+00. part 5	See footnote 13. WTI (1993) exploration of the breach, in the breach zone: WTI boring #5 (**attachment 2)**, sta. not reported, assumed sta. 212+34; Levee fill here is 28 ft thick, so surely this drilled zone is in a deep scour fill zone; foundation immediately below is sandy lean clay with trace gravel, moisture "at the plastic limit", medium plasticity, soft, dark red brown color; drilled only 2 ft into this as the exploration plan was

[13] WTI (1993), which is Western Technologies, Inc., did a series of six geotechnical borings over an approximate equal spacing (which would be one boring every 121 ft) in an unspecified zone of stationing on the Levee, with the objective of exploring the 1993 breach zone, after it has been plugged, and in preparation of making permanent repairs. Since other cited work suggests, but doe not clearly specify that the breach was from sta. 208+50 to 212+50, an approximation of the stationing of the WTI borings has been made as follows. Since the breach was 400 ft long, and the six borings were defined as spaced over a 600 ft segment of the Levee, the assumption is the WTI work started 100 ft upstream of the breach and ended 100 ft downstream of the breach. That would make the boring stationing as follows: the upstreammost boring, #1, is presumed to have been made 100 ft upstream of the breach and therefore is assigned a sta. of 207+50. Assuming equal spacing of the subsequent 5 borings, at 121 ft apart, then WTI boring #2 is at sta. 208+71, which is in the breach zone; WTI boring #3 is then assigned a sta. of 209+92 (in the breach zone); WTI boring #4, sta. 211+13 (in the breach zone); WTI boring #5, sta. 212+34 (near the downstream edge of the breach zone); and WTI boring #6, sta. 213+50, outside of the breach zone. All related mechanical analysis, etc., of samples from these borings were exclusively of the emergency breach fill. Since all that material has been removed and reworked, the test results are considered not relevant to the current study and are not reported here.

Table 1: Winslow Levee, summary of foundation conditions, as per available boring log data in the as-built drawings for existing Levee and the 1993 breach repair explorations.	
Location	**Description of foundation and subsurface, based on data provided from the logs**
	to drill 30-ft holes; no groundwater encountered.
sta. 202+00 to 232+00. part 6	See footnote 13. WTI (1993) exploration of the breach, apparently just downstream of the breach zone: WTI boring #6 (**attachment 2)**, sta. not reported, assumed sta. 213+50; Levee fill here is 16 ft thick; foundation immediately below is silty sand, moist, medium dense, orange brown color; loose at -21 ft, increased moisture and some clay at -26 ft; change to clayey sand at -28 ft, that is moist, medium dense, medium orange brown; drilled only 2 ft into this as the exploration plan was to drill 30-ft holes; no groundwater encountered.
sta. 202+00 to 232+00. part 7	SBHAgra (1994) exploration of the breach, and this boring was made outside of the breach in undamaged Levee: SBHAgra boring #2 (**attachment 3)**, sta. not reported and is unknown but it is near the breach (SBHAGRA, 1994, p. 2); Levee fill here is 13 ½ ft thick; foundation immediately below is sand, predominantly fine-grained, light brown colored; it is described as slightly moist at -16 ft, medium dense to very loose at -19 ft, moist below -25 ft and wet below -27 ft; lenses of high plasticity clay are occasionally encountered in the sand; no groundwater reported.
sta. 202+00 to 232+00. part 8	SBHAgra (1994) exploration of the breach, and this boring was made inside the emergency plug of the breach: SBHAgra boring #1 (**attachment 3)**, sta. not reported and is unknown but it is in the breach (SBHAGRA, 1994, p. 2); Levee emergency fill here is 29 ½ ft thick; foundation immediately below is sand with considerable silt, predominantly fine-grained, brown colored; it is described as wet below -43 ft, loose to dense below -45 ft; no groundwater reported.
	downstream of 1993 breach repair zone:
sta 239+30.02:	**this is the log at the downstream, protected river impingement point on the levee, as shown on fig. 13**; one of the deepest holes bored in this project area; original levee is silty sand and silt; base of that levee not defined in the log; deeper materials include 6 ft of lean clay, 12 ft of silty sand, and 12 ft of poorly graded sand. groundwater at el. 4830 ft. new levee thickness over top of old levee is *0 ft* here; a high point on the original levee apparently was incorporated into the new levee at this location.
sta 260+30.40:	original levee is 1 ½ ft of "shale", which likely is the weakly cemented top of the Moenkopi Formation; base of that levee not defined in the log; some amount of the silty sand that underlies this "shale" likely is part of the original levee as well but this cannot be determined from the log; deeper materials include mixtures of silty sand and poorly graded sand. groundwater at el. 4826 ½ ft. new levee thickness over top of old levee is 1 ft here
sta 278+60.10:	original levee is silty sand and a mixture of silty gravel and silty sand; base of that levee not defined in the log; deeper materials include the mixture of silty gravel and silty sand and below that, about 17 ft of silty sand; at el. 4806 ½ ft is a 5 ft thickness of lean clay, underlain by silty sand. groundwater at el. 4824 ft. new levee thickness over top of old levee is less than ½ ft here

Table 1: Winslow Levee, summary of foundation conditions, as per available boring log data in the as-built drawings for existing Levee and the 1993 breach repair explorations.	
Location	**Description of foundation and subsurface, based on data provided from the logs**
foundation, downstream reaches of original Levee:	
sta 295+93.12:	original levee is 2 ft of ML over silty sand; base of that levee not defined in the log; deeper materials include silty sand with a 1-½ ft thick layer of silt (ML) at el. 4824 ft, then another 7 ft of silty sand; and finally, a mixture of poorly graded sand and silty sand below el. 4818 ½ ft. groundwater at el. 4824 ¾ ft. new levee thickness over top of old levee is 1 ft here
approx. sta 309+530: (listed as 326+35.30 on the as-built profile but this is not correct)	original levee is 2 ½ ft of silt (ML) over lean clay; base of that levee not defined in the log; deeper materials include more of the lean clay, a 2 ½ ft thick layer of silt (ML) at el. 4825+ ft, and, below that, 3-½ ft of lean clay, to the bottom of the boring. groundwater at el. 4826 ft. new levee thickness over top of old levee is less than 1 ft here.
sta 326+50.15:	original levee is layers of lean clay alternating with silt (ML); base of that levee not defined in the log; deeper materials include more of the lean clay, a 2 ½ ft thick layer of silt (ML) at el. 4825+ ft, and, below that, 3-½ ft of lean clay, to the bottom of the boring. groundwater at el. 4819 ½ ft. new levee thickness over top of old levee about 2 ½ ft here; new levee overbuilt by less than 1/2 ft here.
foundation, downstreammost point of original Levee:	
sta 336+00:	**at this point the Levee branches, retaining a curved "hook" in the east direction, while being extended northward about 2,000 ft (northward extension was built under the project that built the current Levee)**; original levee is mixtures of poorly graded sand and silty sand, underlain by thick layers of silty sand; base of that levee not defined in the log; deeper materials include more silty sand, to the bottom of the boring. groundwater at el. 4819-¾ ft. new levee thickness over top of old levee about 7 ft here; new levee overbuilt by less than 1/2 ft here.
foundation, Levee extension downstream (northward) of original Levee:	
sta 340+90 through sta 361+80:	Note: There is no original Levee in the foundation from this point to the downstream end of the current Levee. There are seven borings in this levee segment, which is a much closer spacing of exploration points than is found anywhere else on this Levee. Because of the close spacing, a summary of the foundation, gleaned from all the logs is presented below. Consult the as-built drawings, sheet 11, for more detail. Foundation is dominantly mixtures of poorly graded sand and silty sand, but the downstream end of this reach has thin layers of silt (ML) and clays intermixed, incl some fat clay. Groundwater varies from a high of el. 4818 ft to a low of 4813 ft, and DOES NOT drop continuously in the downstream direction.

Table 1: Winslow Levee, summary of foundation conditions, as per available boring log data in the as-built drawings for existing Levee and the 1993 breach repair explorations.	
Location	**Description of foundation and subsurface, based on data provided from the logs**
	The levee thickness over top of existing ground varies from about 10 ft at the upstream end of this reach to about 5 ft at the downstream end of this reach; new levee overbuilt by as much as 2 ft here, but typically, it is overbuilt by 0 ft.

1.3.1.1 Where the Levee foundation is composed of the previous Levee embankment. Much of the foundation immediately beneath the current Levee is comprised of the original Winslow Levee, as shown on the as-builts (see specific notations in **table 1**). The as-builts do indicate some limited Levee segments where demolition or partial demolition of the original Levee occurred as the current Levee was being built. What can be gleaned from the logs as to the composition of the original Levee is highlighted in **table 1**.

No information on foundation preparation for the original Levee was encountered in available documentation. It has to be presumed that the foundation of the original Levee also equates to the foundation of the current levee, in most locations.

1.3.1.2 Where the Levee foundation is composed of bedrock. Moenkopi Formation sandstone bedrock is known to be present on both banks of the Little Colorado River, and some is known to be in the foundation of Winslow Levee. The Bureau of Reclamation study (2003, pp. 32, 35) reports that the east bank of the Little Colorado River beneath the Homolovi Ruins is composed of an outcropping Moenkopi Formation sandstone bedrock ledge and this controls the River meandering there, preventing it from meandering farther east. This location is due east from the Winslow Levee / river impingement point of the "meandering loop" by Bushman Acres, or, approximately due east of Levee station 163+80.

The most reliable information concerning Moenkopi Formation sandstone bedrock in the foundation beneath the Levee comes from observations made in a limited segment of Levee length during repairs of a 1993 breach (detailed later in this report). The sandstone in the foundation was noted in the vicinity of sta. 210 to 212, but it is very important to realize that, *both laterally and at depth the degree of cementation of this sandstone varie*s. Deeper zones *can* be softer. For example, the engineer observing the breach repairs noted Moenkopi Formation sandstone bedrock at -10 ft below the Levee crest at sta. 210+50, and this was continuous at depth and also became harder at -15 ft at that location. At sta. 211+00, the bedrock still was present and hard at -18.5 ft, with the implication that an excavator could not remove it to any greater depth. But the subsurface hardness does not appear to be uniform, laterally, along the Levee foundation alignment. The sandstone bedrock was implied to still be present between stations 211+50 and 212+50 but the same excavator encountered "easy digging" at -20 ft.

Bedrock may occur elsewhere in the Levee. **Table 1** data show that several zones have been mapped as "shale" foundation material, immediately below the original Levee embankment. Such locations are both upstream and downstream of the BNSF Railway Co. bridge, and downstream of the Interstate 40 embankment. It is very important that *in **all** cases where this "shale" has been noted in the logs, softer material, "soil", has been logged beneath it*. Interpretation of what this means is uncertain due to the abridged nature of the field data that are available. The “shale” could be bedrock, a harder, but fine grained interlayer in the Moenkopi Formation that happens to occur at the surface of the west bank of the Little Colorado River, and that also happens to be underlain by softer materials that drill and log as “soils”, as seen in the logs. Another possibility is that the shale could be a placed, broken top-of-bank armoring stone layer that was put in place before the original Levee or as a foundation for the original Levee and never removed as the current Levee was built overtop everything. The answer cannot be determined from the logs available. Also hampering an interpretation of high certainty is that there was no comprehensive mapping done for the wide intervals between drill holes. What is known and what is very important to understanding the foundation is that in all cases, “shale” foundation at the top of the foundation elevation was found to be underlain by soil material at greater depths at the same location, and in most cases, the sandstone foundation material level of cementation decreases markedly, and to that of a soil, within short distances laterally from where it was described. The author’s experience with drilling the Moenkopi Formation in northern Arizona suggests this latter concept is the most likely, based on data available, because it is common for the Moenkopi Formation to be of sufficiently soft bedrock that it “drills” as soils, i.e., as sands, silts, clays, etc., and in those instances it is logged, sampled, and tested as a geotechnical “soil”, not as a rock layer.

A final possibility is that the answer was found by those doing the exploration but the information has been lost as the data were summarized as stick logs.

The Moenkopi Formation can be permeable, and thus water could move through it. Such movement conceivably could be sufficient to erode soft, soil-type interlayers in the Formation and open passageways, which could be a piping danger. The sand boil noted to have formed during the flood / Levee breaching event on 1993, on the landside of the Levee and north of the breach (SBHAgra, 1994, p. 7) is a demonstration of both the risk and lack of continuity of the subsurface data that are available. The sand boil was not precisely located in the data source but is a concern as it indicates instability in foundation materials beneath the Levee, near a known sandstone bedrock foundation, although the sub-water flow that is evidenced by the sand boil did not necessarily travel though that sandstone. Overall, the project should be expected to have a stronger and less piping prone foundation where / if the Levee is founded on the Moenkopi Formation, rather than on non-compacted sand and other alluvium. But a compacted fill, soil foundation, with fines, or the cutoff wall may serve as a better foundation.

Overall, it does not appear that a reliable, low permeability bedrock foundation is available to tie into for any appreciable length down the Levee, and that hard material at any given elevation cannot be relied upon to remain hard and relatively impermeable at depth at the same location.

1.3.1.3 Where the Levee foundation is composed of Little Colorado River alluvium from overbank flooding. A number of fine grained soil zones can be picked out of the logs on **table 1**, and these are interpreted as having formed from settlement out of slower waters at stages of overbank flooding. The materials can include sandy silt, lean clay, fat clay, and possibly true silt without sand; mixtures of all of the above can be found. No trends could be discerned from available data (no extensive clay or fine material zones identified). Deep zones of clay do exist, including fat clay, and, where present, they probably are beneficial to the Levee in that they would diminish the likelihood of piping beneath the Levee. This positive is neutralized by no evidence of extensive lateral continuity of any soil type along the Levee.

1.3.1.4 Where the Levee foundation is composed of Little Colorado River granular alluvium from meanders and paleomeanders, or larger flood events. The logs that are available reveal that deep layers gravel are uncommon, and, gravels are sparse overall, all indications that the main channel alignments of paleochannels (past alignments) may not been intersected by the drill logs. But the sparseness of the drilling should be a source of caution in such an interpretation of the subsurface from just the drill logs. The high permeability of a gravel zone is not necessary to allow piping conditions beneath the Levee. A permeable, clean sand, such as could be deposited by a River meander could be sufficient for the piping to occur.

The probable existence of sandy paleomeanders beneath the foundation of the Levee is considered to be a certainty and possibly the greatest risk for overall Levee stability, and this is because of sub-foundation piping risks. That piping event and subsequent Levee failure (this was a failure of the current Levee and is discussed in detail later in this report) strongly suggests that an evaluation of foundation materials, below the existing Levee, should be done as part of any future Levee assessment, so as to try to find any piping-prone areas that may remain in the foundation. This may, in cases, involve examination, sampling, and possibly testing of the foundation materials beneath the original Levee. The Corps' expectation is that such risk zones are going to be provided by granular soils, sandy meanders of the Little Colorado River that are now buried beneath the Levee. With that thought, the extensive and detailed mapping of the Little Colorado River meanders and deposit types by Bureau of Reclamation (2003) is presented. That work was done at and adjacent Levee sta. 168 (the "meandering loop") and at and adjacent the downstream Levee impingement point wit the Little Colorado River, which is approximately Levee sta. 240.

To understand the river meander information shown on **figs. 10 and 11**, below, use the following alluvial units descriptions, from Bureau of Reclamation (2003, pp. 11, 12, 13, 15, 16):

Youngest material:

> "Unit Qac – active channel – primarily silty sand alluvium with clay–rich alluvium in meander bends and backwater channels. This unit includes the active channel deposits on both the main stem and major tributaries to the Little Colorado River. This unit may also incorporate small outcrops of bedrock exposed at low flow in the channel bed."

Materials increasing in relative age, downward on this list ↓

> "Unit Qa1 – Desert Broom terrace – sandy alluvium that forms low point bars and flood plains immediately adjacent to the active channel with either no vegetation or sparse young Tamarisk and Desert Broom. This unit is inundated regularly except in the driest years and is roughly 1–2 feet above the active channel. Low dunes may be present in places on unit Qa1 but are localized features. Where unit Qa1 can be differentiated, two members are mapped. Qa1a, the younger member, has smaller and fewer Tamarisk and

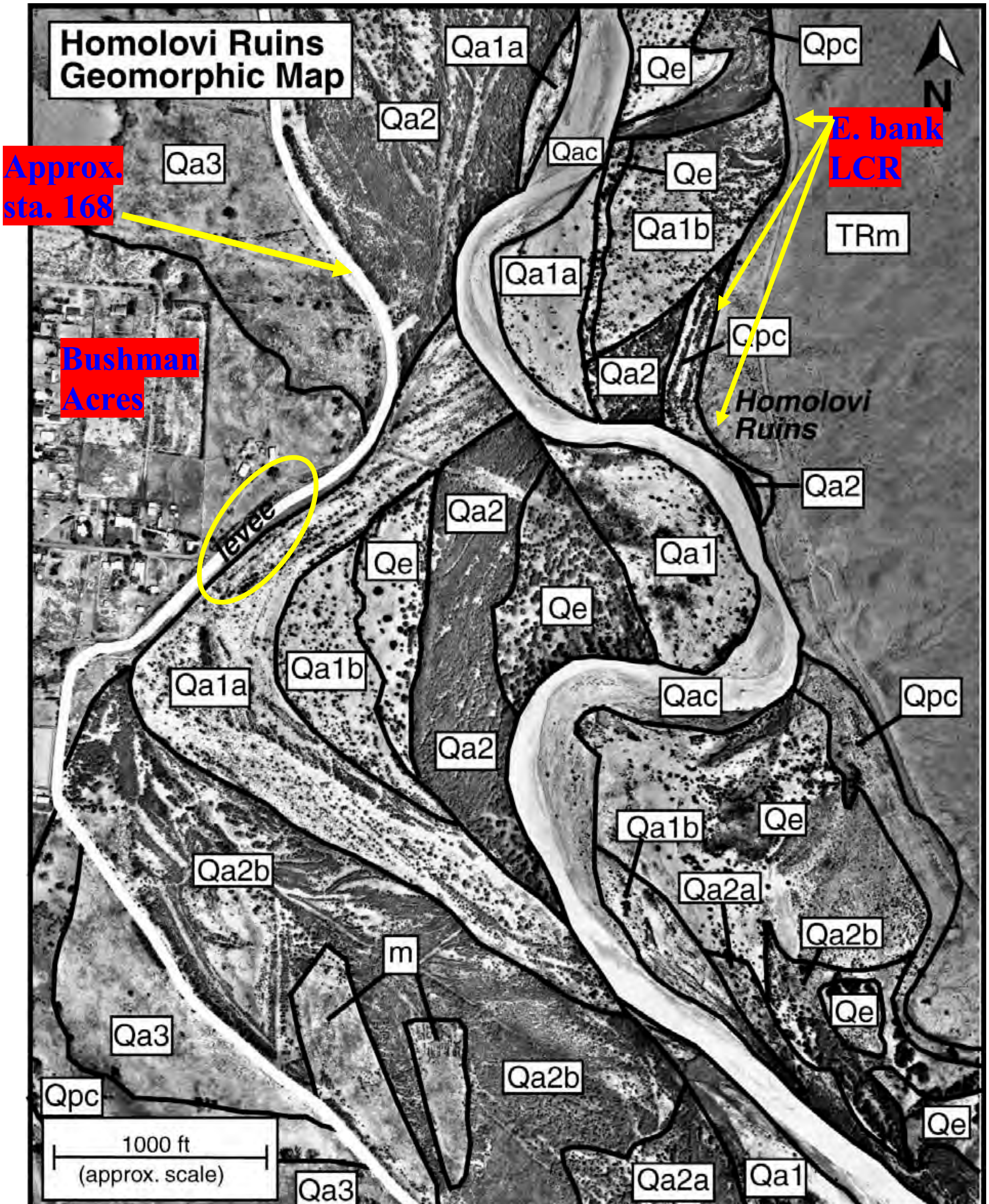


Fig. 10.--Mapped Little Colorado River meanders at the Bushman Acres – Winslow Levee – meandering loop junction, from Bureau of Reclamation (2003, p. 34), as annotated in red and yellow for this report. Note the Winslow Levee (marked "levee" on the map). "LCR" = "Little Colorado River".

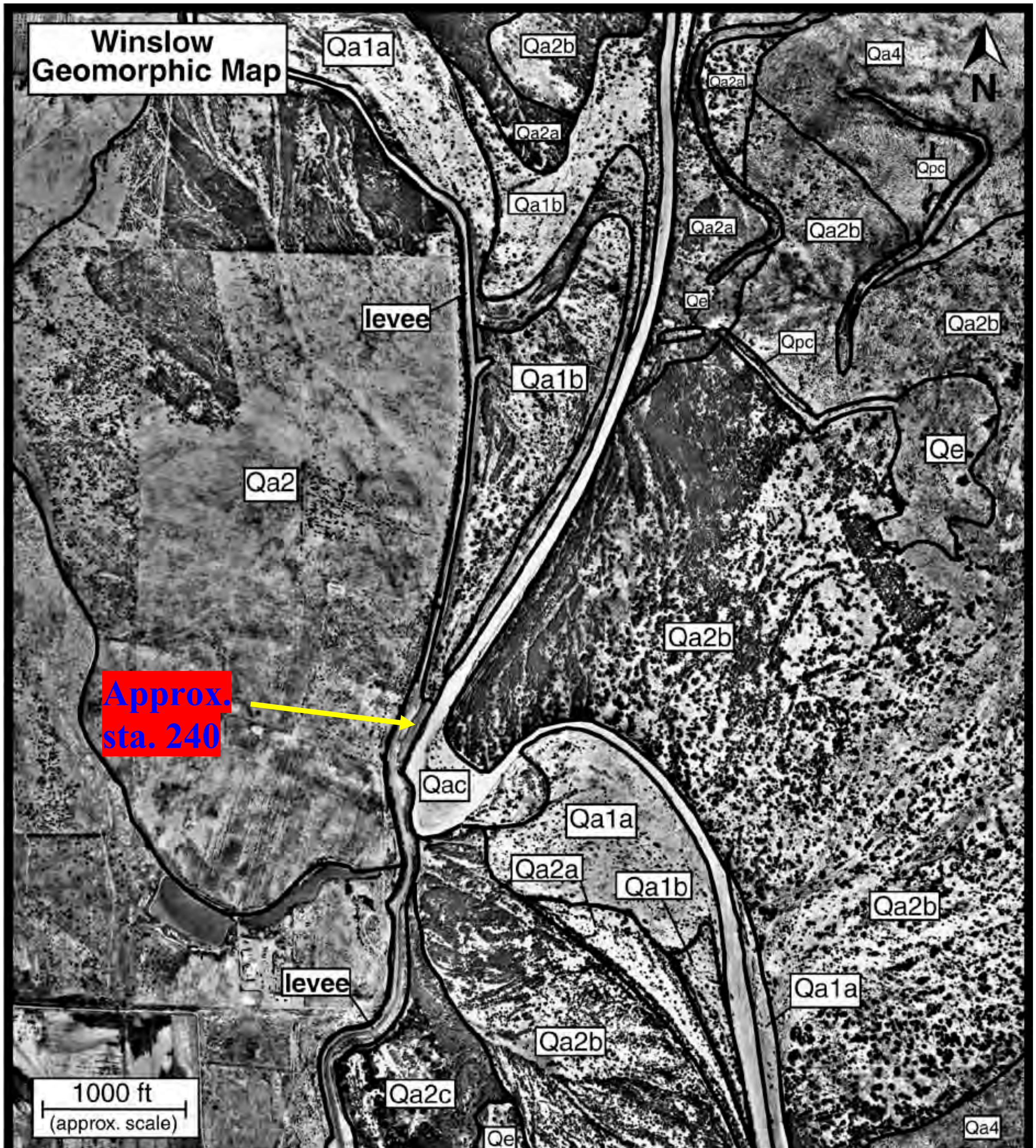


Fig. 11.--Mapped Little Colorado River meanders at the downstream impingement point, from Bureau of Reclamation (2003, p. 35), as annotated in red and yellow for this report. Note the Winslow Levee (marked "levee" on the map).

Desert Broom saplings while Qa1b is slightly higher and crosscut by Qa1a. Its vegetation is denser and larger with an increase in the presence of Desert Broom."

"Unit Qa2 – Tamarisk terrace – silty sand alluvium covered by thick vegetation, primarily Tamarisk. The surface is composed of fine–to medium–grained eolian sand that variably forms thin sheets, low coppice dunes, and high sand dunes. Where continuity and extent is adequate, sand dunes are mapped separately from Unit Qa2 as Unit Qe. Despite the fact that the eolian component of Qa2 overlies the fluvial component in most places, both deposits are considered to be equivalent in age because in exposure they are commonly found inter–bedded. Large portions of the Tamarisk terrace exhibit vegetation lineations on aerial photography that mark historical flow patterns on the Qa2 surface. Many of these deposits have been inundated historically. Unit Qa2 is roughly 2–5 feet above the modern channel. Unit Qa2 is comprised of three nearly equivalent aged members that are differentiated based on crosscutting relationships in plan view and height above the active channel. These units are labeled Qa2a, Qa2b, and Qa2c in order of increasing age. Units are mapped based on the local geomorphology and are not necessarily correlative with the same unit at other points along the river."

"Unit Qa3 – Cottonwood terrace – sandy alluvium that forms terraces marked by mature, widely spaced Cottonwood and Tamarisk trees. Thin sand beds and low coppice dunes may overlie the surface of the Cottonwood terrace. Unit Qe forms in association with Unit Qa3 in many places along the length of the mapped reach. Unit Qa3 is roughly 5–10 feet above the active channel. Where Unit Qa3 can be differentiated, it is composed of three members, Qa3a, Qa3b, and Qa3c, in order of increasing age. These members are defined based on differences in height and position relative to the main channel. These members seem to be present in areas with sufficient space to allow for multiple generations of closely aged surfaces to form, while in more narrow areas along the channel only Unit Qa3 is present. Members may not correlate in age along the length of the reach but should all fall within the age range of Unit Qa3.

"Unit Qe – Dunes – fine to medium–grained eolian sand. Although dunes overlie many of the units described previously, this unit is mapped separately where the dunes are continuous and extensive enough to map as a distinct unit. This unit includes deposits spanning a broad age range; the age of the deposit in any particular area is best estimated based on its relationship to adjacent or surrounding deposits. It is likely that the dunes are formed during several distinct periods based on differences in vegetation maturity and soil formation. The thickest eolian deposits are commonly found downwind of the active channel (Qac) along the northern side of the river."

"Unit Qpc – undifferentiated paleochannels – numerous meander scars and recently abandoned channels. Paleochannels are mapped in areas where they are either continuous or extensive enough to identify and map as a distinct unit. In many cases, the age of abandonment can be estimated by comparison to older topographic maps or by the position of the paleochannel relative to the adjacent mapped units. Paleochannels are more sinuous on the Unit Qa4 surface than the active channel, while younger paleochannels appear to have sinuosity similar to the active channel. The height above the active channel varies based on the associated geomorphic surface."

Rock units:

"TRm. Early Triassic Moenkopi Formation (roughly 225 million years old) – The Moenkopi Formation is described as a pale, reddish–brown siltstone and sandstone with inter–bedded and crosscutting gypsiferous beds. The Moenkopi Formation unconformably overlies the Coconino sandstone in the map area. Near the base of the formation, a distinctive, thin sandstone bed forms a prominent ledge in the map area and outcrops in the Little Colorado River channel in places. Near the top of the formation, a 10–20 foot thick conglomerate bed of siltstone and limestone cobbles occurs locally. On aerial photography, the Moenkopi Formation has a dark gray surface tone."

"Miscellaneous Map Unit(s)

Unit m – Modified terrain – terrain that has been modified by artificial means, such as scraping or piling of sediment in a particular area, so that the present landscape is not representative of a naturally formed surface; includes levees and embankments built along the river to prevent the river from flooding a particular area."

River meanders mapped in **figs. 10 and 11**, including the "meandering loop" in **fig. 10**, mapped as units Qpc, Qa2, or Qa3, all underlie the Levee foundation and all, according to Bureau of Reclamation (2003, p. 34-35) are less than 100 years old, meaning the river has flowed there in very recent times and reasonably could be expected to return. That the opposite bank of the River is in places entrenched against a wall of bedrock enhances the possibilities of meander return to the west (Levee-side) bank by future meanders, as currents would be expected to bounce off the bedrock and move elsewhere, probably to the west. The land immediately under Bushman Acres and adjacent Levee is the only land under or near the Levee in this vicinity that is *not* mapped as a past river meander. Granular, sandy zones are anticipated to be present within these meanders below the foundation of the Levee, and, as such, hold the potential to support piping (the known piping failure zone was not mapped by Bureau of Reclamation (2003)). Alluvial unit Qa1a was the main channel up against the Levee, prior to "dredging and channelization" from 1984 to 1993 that "shifted the channel to the east" (Bureau of Reclamation, 2003, p. 34).

1.3.2 *Freeboard issues*. A past study to assess suitability of the original Levee noted that Levee overtopping was a concern upstream of sta. 235+74, which is in the northern one-third of the Levee, but that levee overtopping was not anticipated to be a concern downstream of sta. 235+74 (ADWR, 1980, p. 9). A study done with the thought of overtopping risks of the current Winslow Levee resulted in calculation of the different amounts of freeboard available in different segments of the Levee in response to the 100-year flood event. All this information may be out-of-date, compared to Corps hydraulic studies underway at the time of this writing. Any freeboard and overtopping information that might result from that on-going work should be used preferentially, instead of the above listed stationing and **fig. 12** which is presented here primarily as background information on past work done. As of the time of this writing, the Levee is thought to be capable of containing the 50-year flood event, but not the 100-year flood event.

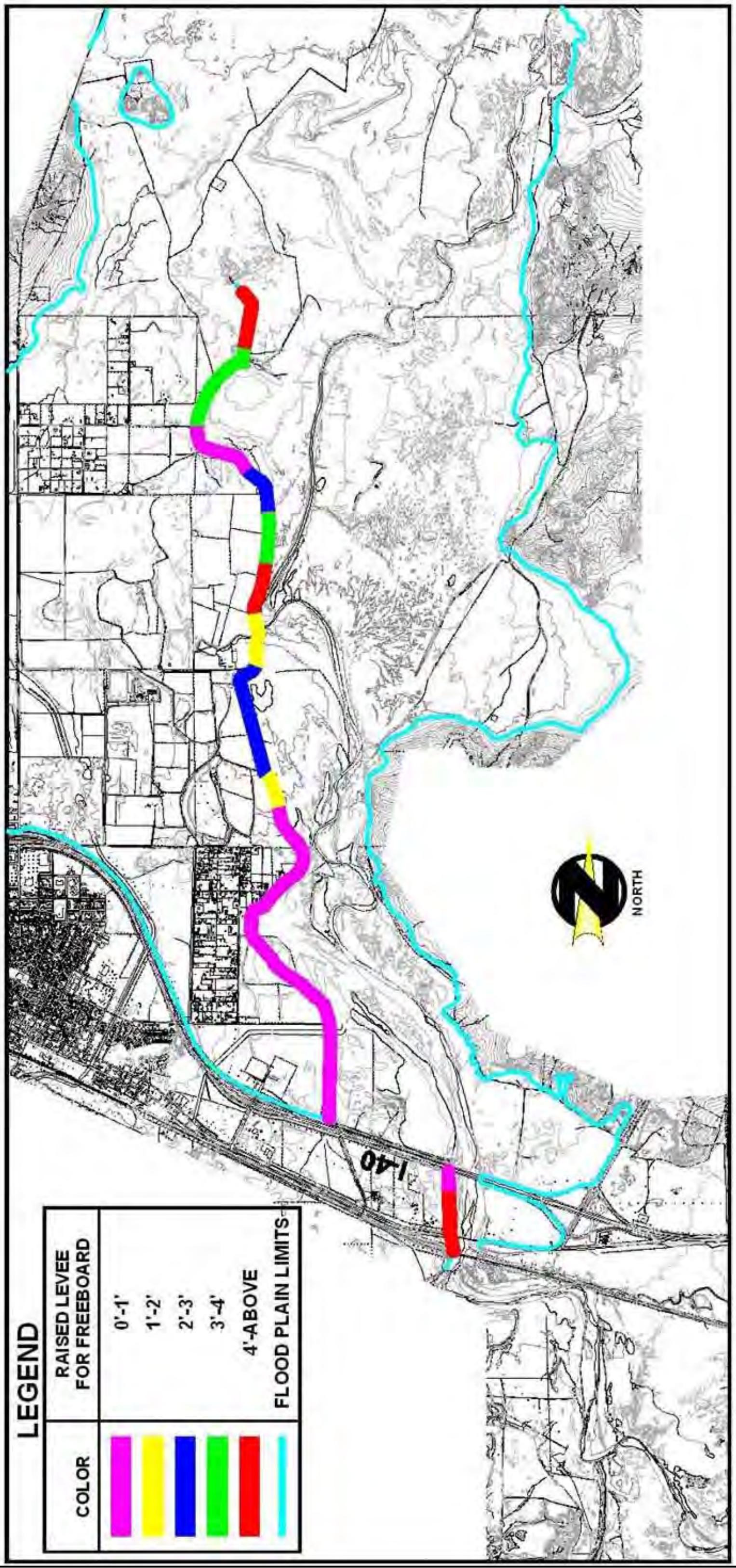


Fig. 12.—Older freeboard estimates for the current Winslow Levee. Floodplain boundary is out-of-date (more area would be inundated), and freeboard likely is less than shown on this drawing.

1.3.3 *The Levee cutoff wall*. A most important improvement of the current Levee, over the design of the original Levee, was building a core-like slurry cutoff wall in the current Levee, throughout. Its intent was to make the Levee impermeable to piping and through seepage. The wall is vertical, 2-ft in vertical side-to-vertical side width, and ends 2 feet below the crest of the Levee. It extends to varying elevations at depth, a topic explained in more detail below. Written documentation that describes the cutoff wall has been elusive. The Corps has not obtained a specification detailing the cutoff wall composition and details of its emplacement, and the trench preparation. Examination of the drawings and the description of the cutoff wall suggest it had to have been emplaced by cutting a trench down through the newly built Winslow Levee (the current, existing Levee) and that this trench was then backfilled with the bentonite slurry. Additionally, it appears that the trench had to have been cut down through not only the newly constructed (current/existing) Levee, but also through the original Levee and probably through previously undisturbed foundation materials below that (assuming that the original Levee was of a limited height and depth, but those dimensions are not found in the documentation). The as-built drawings, sheet 5 (**attachment 1**) show a 55 ft wide gap in the cutoff wall beneath the BNSF Railway Co. bridge that crosses over the Levee near the upstream end. This gap is from sta. -0+25 to sta. 0+30 ft.

Another gap in the cutoff wall is in the area of the Interstate 40 embankment, currently incorporated by the Levee embankment. No cutoff wall was built beneath the I-40 embankment, which is from sta. 24+78, downstream through sta. 64+40.34. The gap continues for another 80 ft down the Levee past the downstream end of the I-40 embankment to sta. 64+80.21. The total gap in the cutoff wall in the vicinity of the Interstate embankment is, therefore, 2,002 ft.

The as-built drawings, sheet 6 (**attachment 1**) note another gap in the cutoff wall from sta. 91+24.410 to approximately sta. 93+10, where the box culvert of the ADOT “I-4 channel” cuts through the Levee. The as-built drawings note the cutoff wall was not necessary there.

A verbal summation of that cutoff wall was obtained from the Navajo County Flood Control District in 2008, and is as follows. The cutoff wall is composed of bentonite and the design is to have it consistently at around 15 ft in total depth (top-to-bottom, vertical “length”) and extending not above a point two feet below the Levee crest.

1.3.3.1 Raising the Levee crest. The Levee crest was raised two feet at some unspecified time close to and prior to 2008 (apparently 2005-2006). It needs to be verified if this was an end-to-end crest increase or something else. Most likely, it was done locally and in conjunction with the repairs to the 2004 piping failure segment. Presumably, this means that the cutoff wall is now 4 ft below the crest of the Levee, where the crest was raised. It was not determined if the raising of the crest changes the freeboard amounts shown on any parts of **fig. 12**, above. These points need to be clarified by obtaining additional information. Levee cross-sections for selected locations from sta. 163+50 to sta. 180+00, which were made to support design of a 2009 application of more riprap (discussed below) all show the top of the cutoff wall just 2 ft below Levee crest. It is not certain whether this 2 ft distance is the current condition throughout the Levee that is downstream of I-40, or if it has been increased to 4 ft in some or all of that segment due to raising the Levee crest. Documentation about the raising of the Levee in the vicinity of the 2004 piping failure (detailed later in this report), should be considered in conjunction with this more general statement of a two-ft high Levee height increase over an unspecified zone. It could be that the only Levee raising was done in the immediate vicinity if the piping repairs. This needs to be checked and verified.

1.3.3.2 Base of the cutoff wall. Because the top of the cutoff wall is so near the Levee crest, determining the elevation of the base of the cutoff wall is considered much more critical. Examination of the as-built drawings show the *base of the cutoff wall* to be at:

- elevation 4846 ft, approximately, upstream of Interstate 40; **average depth**[14] of the base of the wall is between 14.4 and 16.3 ft;
- NOT PRESENT in the segment where Interstate 40 comprises "the Levee" (a situation discussed in more detail, above);
- starting again at sta. 64+40.34 (which is where the Levee embankment abuts the north slope of the Interstate 40 embankment and begins its extension to the north, again at an elevation of 4846 ft and extends to deeper elevations in the northward direction, on a slope of 0.2143% (see as-builts, sheet 6) to sta 92+86, where the cutoff wall base is at elevation 4840 ft; average depth varies from 10.0 ft to 19.5 ft;
- the cutoff wall base flattens to a 0% slope from sta. 92+86 to sta. 96+00 and the wall base remains at el. 4840 ft; average depth is 14.6 ft;
- cutoff wall base is at 4836 ½ ft to 4837 ft from sta. 96+00 to sta. 101+50 and is on a slight gradient to the downstream direction; average depth of the base is 17.9 ft;
- slope returns to 0% from sta. 101+50 through sta. 108+00 and the depth to the base of the wall varies, on a range to 12 ft to 17.6 ft; elevation of the base varies from 4835 ft to 4837 ½ ft;
- from sta 108 to sta. 153+67, the base of the cutoff wall is on a 0% slope at its average depth ranges from 17.6 ft to 16.2 ft; the elevation is between 4835 ½ at the upstream end of this segment to 4836 at the downstream end of the segment;
- from sta. 153+67 to sta. 168, the base of the cutoff wall again takes on a slope (0.0508%), averages about 20.6 ft in depth, and is at elevations ranging from 4831 ft to 4830 ft at the downstream end of this segment;
- from sta. 168 to sta. 192+06, the base of the cutoff wall continues on the slope of 0.0508%, is between 17.6 ft and 19.3 ft average depth, and the base of the wall is between el. 4830 and 4831 ft;
- from sta. 192+06 to sta. 195+50, the base of the cutoff wall is an average of 18.4 ft deep and ranges from el. 4827 ¾ ft to el. 4827 ft;
- from sta. 195+50 to sta. 228+00, the base of the cutoff wall continues to be built on a slope of 0.0508%, and varies from an el. of 4929 ¾ ft at the upstream end of this segment to el. 4826 ½ ft at the downstream end of the segment; average depth ranges from 13.9 ft to 16.5 ft;
- from sta. 228+00 to sta. 232+55, the base of the cutoff wall follows a 0% slope, has an average depth of 14.0 ft, and an el. of 4826 ¾ ft;
- from sta. 232+55 to sta. 237+29, the base of the cutoff wall follows a 0% slope, has an average depth of 14.5 to 19.5 ft, and el. ranging from 428 ft to 425 1.2 ft;

[14] "Depth to the base of the cutoff wall" is measured and reported from the top of the cutoff wall to the base. This is in all cases where citing "depth to base of the cutoff wall", unless otherwise noted. As initially reconstructed in the late 1980's, the top of the cutoff wall is 2 ft below the Levee crest.

- from sta. 237+29 to sta. 246+45, the base of the cutoff wall follows a 0% slope, has an average depth of 19.5 to 20.0 ft, and el. ranging from 4823 ft to 4822 ft;
- from sta. 246+45 to sta. 261+45 , the base of the cutoff wall follows a 0.1600% slope, has an average depth of 19.5 ft, and a el. ranging from 4824 ½ to 4821 ft;
- from sta. 261+45 to sta. 288+00, the base of the cutoff wall follows a 0% slope, has an average depth of 19.5 ft and an el. of 4822 ft;
- from sta. 288+00 to sta. 310+45 the base of the cutoff wall follows a 0% slope, has an average depth of 18.0 to 19.5 ft, and el. ranging from 4818 ½ ft to 4820 ft;
- from sta. 310+45 to sta.336+10.81, the base of the cutoff wall follows a 0% slope, has an average depth of 18.3 ft to 19.0 ft, and el. ranging from 4820 ½ to 4819 ¼ ft
- the "branched" segment of the original Levee that hooks eastward from sta. 336+10.81 to sta. 345+66.02 does not appear to have a cutoff wall, according to the as-builts; it may have been bypassed in the rebuild, but this is speculation;
- the northward extension of the current Levee, from sta. 336+10.81 to sta. 364+34.68, which is the downstream end of the Levee, has a gradient on the base of the cutoff wall of 0.1771%, and an average depth of 9 ft; elevations range from 4821 ft at the downstream end of this segment to 4816 ft at the downstream end.

These characteristics can be seen in more detail by studying the various as-built drawing sheets (**attachment 1**).

1.3.4 *Use of riprap for slope protection*. Riprap stone protection was another design enhancement that was added to the current Levee and that was not a part of the original Levee. When the existing Levee was rebuilt in the 1980s, riprap *on the riverside only* was added as a design feature to protect against Little Colorado River impingement points (ADWR 1980, p. 10-11), at zones with high risk of such impingement in the future as known Little Colorado meanders move and threaten to impinge upon the Levee. Stone riprap protection also was placed at locations where this new riprap had to tie in to existing stone protection at the upstream end of the Levee. These locations can be determined by examining the as-built drawings. The locations are listed by stationing in **fig. 8** (see above).

When first rebuilt, the riverside-only riprap protection stone at these locations, as per the as-built drawings (see also **fig. 8**, this report):

- sta. -3+50 to 4+31 (at the upstream end of the Levee to tie into existing stone);
- sta. 137+00 to 164+00 (this armors the Levee adjacent Bushman Acres);
- sta. 233+02.5 to sta. 286+00 (a zone with major meandering loop impingement issues).

These ranges of Levee stationing can be discerned by the reader from the maps of **figs. 5 and 6**. A part of that original location for riprap protection can be seen in **fig. 13**.

It was noted that filter fabric (Mirafi 140N or approved equivalent) was placed beneath the riprap, anchored at the top of the Levee by 10-ft-long Helix anchors on 10 ft centers, as indicated in notes on the as-built drawings.

Fig. 13.—(Top) Riprap-protected downstream impingement point, looking downstream from the Winslow Levee crest, and (bottom) inset showing more detail if the same riprap protection site. Note light tan sand and strand line in the left and left-center of frame. Photograph by US Army Corps of Engineers, 15 May 2008.

The amount of toe-down of this riprap varied, according to the amount and the way in which slopes were flattened in the Levee re-build process (recall that flattening of slops was one of the objectives in the rebuild). Generally, the toe down below the invert was equal in depth to the height that the riprap blanket extended upward on the Levee face at that particular location.

Specifically, as indicated in **fig. 8** toe down of the riprap in the upstream reaches of the levee, where the riprap ties in to other riprap blankets on the river and the existing Ruby Wash Diversion levee, the toe of the riprap on the Winslow Levee is at least 20 ft below the Levee crest and as much as 24 ft below. From sta. 137 to sta. 164 and from sta. 233 to sta. 251+27.8 the toe of the riprap is 28 ft below the Levee crest. From sta. 251+27.8 to sta. 272 the toe of the riprap is 24 ft below the Levee crest; from sta. 272 to sta. 286, the toe of the riprap is 28 ft below the Levee crest. These numbers are as-built distances. In instances where the Levee crest subsequently was raised 2 ft, add 2 ft to these totals.

Three different typical sections are shown on **fig. 14**, below, with the one shown in the middle being the most rigorous.

It also is important to realize that the riprap protection layer *was not* built all the way to the crest of the Levee. The as-built drawings indicate:

- from the upstream end of the Levee, the top of the bank protection stone layer stops about 8 ft below the Levee crest and about 2 ft above the Levee slope toe;
- no riprap downstream of sta. 4+31 to sta. 137+00;
- from sta. 137+00 to sta. 164, the stone riprap extends to a point about 2 ½ ft above the Levee slope toe, or about 8 ft below the Levee crest;
- sta. 164 to sta. 233+02.48, no riprap stone protection;
- sta. 233+02.48 to sta. 286+00, riprap extends to about 3 to 5 ft below the Levee crest, or 7 to 7 ½ ft above the Levee slope toe
- downstream of sta. 286+00: no riprap.

There isn't any documentation on the characteristics and testing of this riprap protection stone. Observations by the Corps in 2008 suggest that several different riprap sources were used. The fact that the riprap-protected area shown in **fig. 11** is composed of dense and apparently very durable basalt, and comparison of that stone to other, more recently added basalt, suggests that all the basalt on the Levee may have come from the Bidahochi quarry on the Navajo Indian Reservation, which supplied a riprap protection that is used on this Levee in other locations and which is discussed in more detail later in this report.

Corps observations in May 2008 document that not all the riprap on the Levee is basalt. There was insufficient time when in the field in May 2008 to catalog the stone types used at all points armored by riprap, or do an end-to-end survey of the riprap, but for now the presumption is that all or most of the riprapped locations downstream of Interstate 40 have the above-described basalt applied for riprap. But the riprap in the upper reaches of the Levee, where it ties into older stone protection layers on the Little Colorado River bank and Ruby Wash Diversion Levee

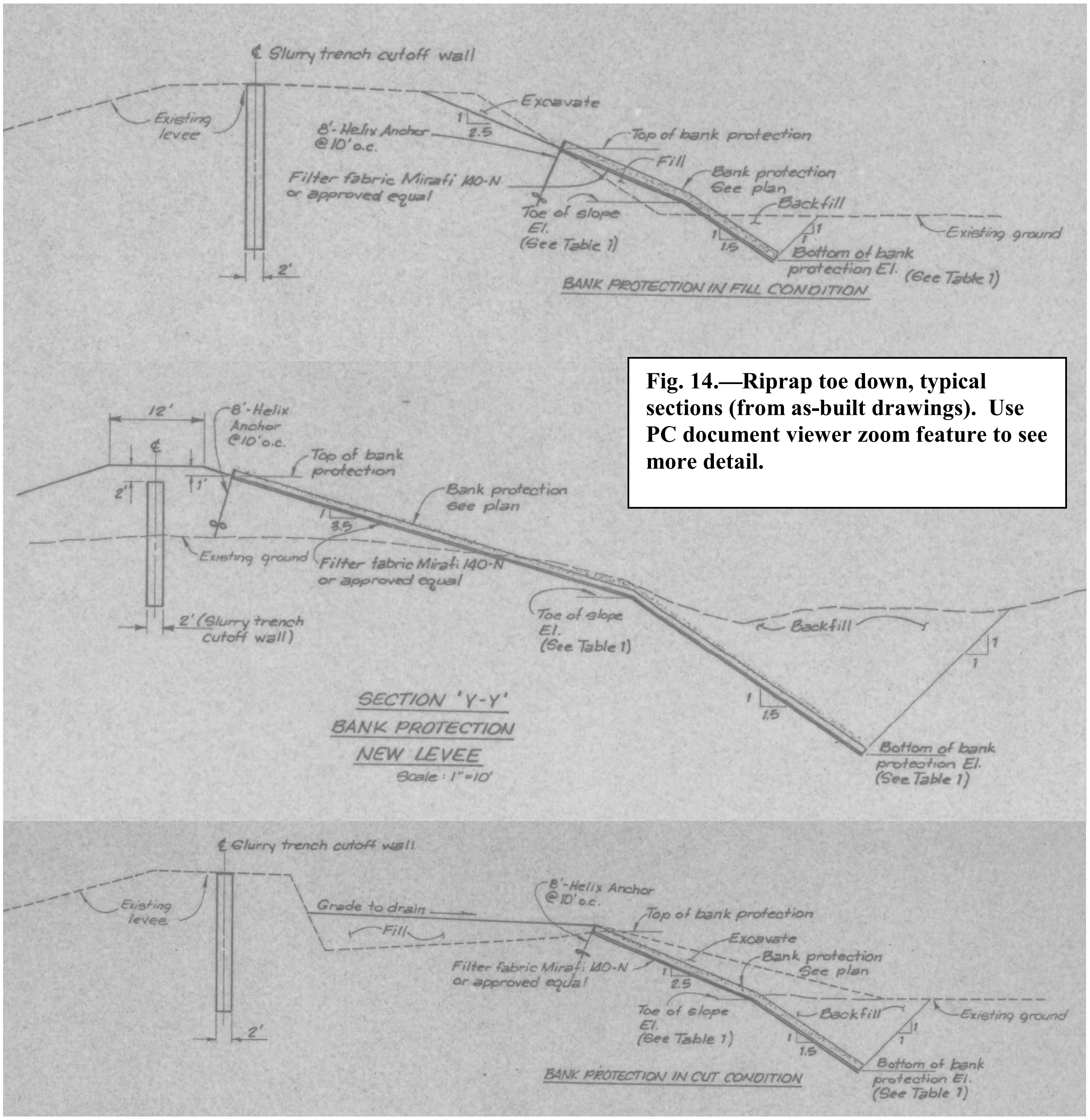


Fig. 14.—Riprap toe down, typical sections (from as-built drawings). Use PC document viewer zoom feature to see more detail.

features, generally is not composed of basalt and generally is in poor condition due to breakdown of the stone. A detailed survey would be useful to better document this. What was observed upstream of Interstate 40 in terms of riprap was that much of the riprap on the Levee is orange Moenkopi Formation sandstone, while a small amount of the riprap appears to be Kaibab Formation limestone, which is white. The Moenkopi Formation riprap is badly deteriorated due to loss of sand grain cementation and the probable Kaibab Formation riprap is badly spalling, a typical characteristic of that Formation in northern Arizona when attempts have been made to use it as exposed-to-the-elements stone for building purposes. Examples of these riprap quality problems are seen in **figs. 15, 16, and 17**. Around the BNSF Railway Co. bridge abutments over the Little Colorado River, which is sta. 0+00 on the Winslow Levee, the Levee riprap is a hard and durable basalt (**fig. 18**) that, based on appearances, is probably the Bidahochi quarry basalt that is described below and above. It is suspected that this Levee section with basalt riprap probably is a post-construction patch or overlay of the riprap blanket, to strengthen the stone protection around the bridge. This is a surmise. No documentation of the placement of such a riprap upgrade was found.

There is documentation of three additional riprap stone protection applications onto the Levee after the initial the Levee rebuild. Details follow.

1.3.4.1 <u>Repair riprap layer placed on both sides of Levee</u>. Basalt rock riprap is on both sides of the levee from sta. 202+00 to sta. 232+00 (**fig. 19**), placed as a part of permanent repairs of a 1993 levee overtopping and breach, an event that is detailed later in this report. This is a zone that was not protected by riprap under the initial rebuild, as per **fig. 8**. This placement was done in 1997 (Navajo County Flood Control written communication, 6 April 2010, from Trent Larson, to Rich Legere, US Army Corps of Engineers). Some stockpiles of the same basalt riprap were placed at strategic locations along the Levee in anticipation of future flood fights (**fig. 20**), so that it is ready to haul quickly into a flood-threatened spot, after just a short haul down the Levee.

This 1997 riprap placement extended beyond the repair zone and included parts of both sides of the Levee:

- riprap was placed from sta. 176+00 to sta. 231+60 on the landside of the Levee;
- riprap was placed from sta. 140+00 to sta. 400+00 on the riverside of the Levee.

[data from: Navajo County Flood Control written communication, 6 April 2010, from Trent Larson, to Rich Legere, US Army Corps of Engineers.]

Some of this stone placement would include overlap of areas previously protected by riprap.

The basalt riprap that was added to both sides of the Levee to repair the 1993 overtopping and breach is documented as Bidahochi basalt, taken from a stone quarry on the Navajo Indian Reservation, specifically from a pueblo named Bidahochi, AZ (quarry location shown on **fig. 21**), and truck-hauled to the site, then placed by a trackhoe. In the repair zone, 2H:1V slopes were built on both sides or the Levee in preparation for the application of this riprap. Filter fabric placed beneath the stone layer. Specified stone layer thickness on the riverside of 2.5 ft, and a thickness son the landside of near 2 ft (a 1.5 ft thickness had been specified but the stone size was large and dictated that the minimum thickness was more than 1.5 ft). The toe-down of

Fig. 15.— Moenkopi Formation riprap (orange) on the inner slope of Winslow levee, near the upstreammost extent of the levee. View is upstream, and the Little Colorado River is to the left. View to the south, 15 May 2008.

Fig. 16.— Detail of badly deteriorated, crumbling Moenkopi Formation riprap on the inner slope of Winslow levee, near the upstreammost extent of the levee. See also fig. 15. 15 May 2008.

Fig. 17.— Detail of badly deteriorated, crumbling Moenkopi Formation riprap (orange rock) and badly spalling, deteriorating Kaibab Formation riprap (white rock) on the inner slope of Winslow levee, near the upstreammost extent of the levee. See also figs. 15, 16. BNSF railroad bridge (of fig. 18) is in the background, just left of the person's head. View is downstream (north-northeast), 15 May 2008.

Fig. 18.— Basalt riprap on the inner slope of Winslow levee, near the upstreammost extent of the levee. Note the BNSF Railway Co. bridge in the background. Note stockpiled basalt riprap near the bridge. View to the northeast (downstream), 15 May 2008.

Fig. 19.— Bidahochi basalt in place on the Winslow Levee, a part of the permanent repair of the 1993 breach. Landside, looking downstream (north). Refer to fig. 6 for the breach location.

Fig. 20.—Stockpiled Bidahochi basalt, ready for the next flood fight, on the Winslow Levee, 18 May 2008.

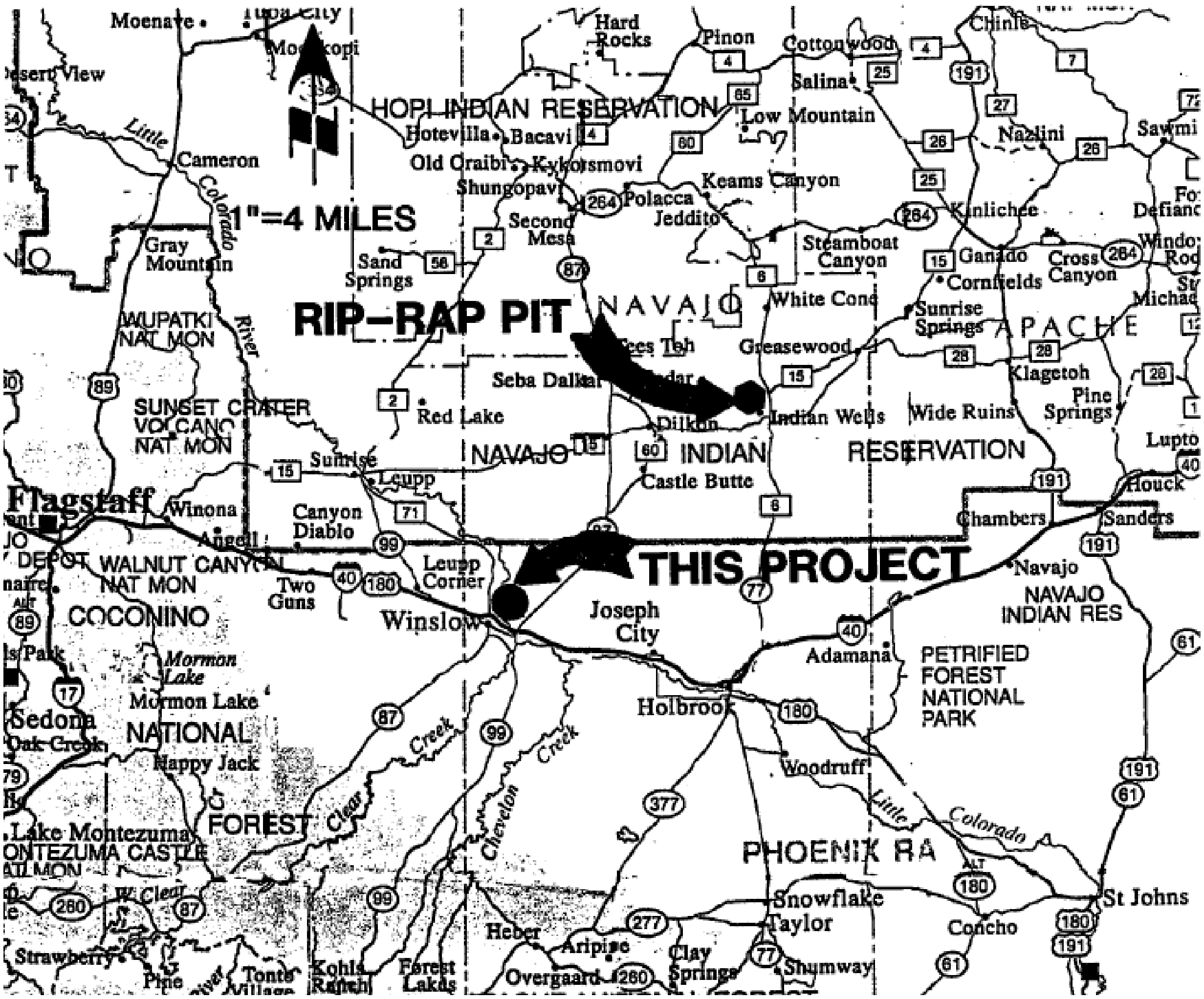


Fig. 21.—Location of the Bidahochi protection stone source quarry ("rip-rap pit"), and the relative location of the Winslow Levee ("this project"). This map clipped from Cella Barr Associates (1995, appendix A).

the stone protection layer was 6 ft on the riverside and 2.5 ft on the land side (Cella Barr Associates, 1995, appendix D). It should be noted that the adjoining riprap from the Levee rebuild has a deeper toe down of riprap. The toe of the slope downstream of sta. 232 (i.e., immediately downstream of this repair / riprap placement zone),

Laboratory testing of this Bidahochi basalt stone for the repair project in 1994 was done by Speedie and Associates, during which these stone characteristics were determined on a 4,822.2 lb sample of -24 inch stone (sample number 942-001) taken at the quarry stockpile:

- S.S.D specific gravity on four specimens was
  - Specimen A, 2.907
  - Specimen B, 2.902
  - Specimen C, 2.898
  - Specimen D, 2.902
- Los Angeles Abrasion Test loss at 500 revolutions: 3.5%;
- Los Angeles Abrasion Test loss at 100 revolutions: 15.6%;
- Absorption, %, on four specimens was
  - Specimen A, 1.5
  - Specimen B, 1.3
  - Specimen C, 1.6
  - Specimen D, 1.5
- Sulfate Soundness Test, 5.6%;
- Gradations, following, for 21 different samples:
- Gradation sample 942-001 (4,822.2 lb) taken at the quarry stockpile:
  % passing 24 inch 100%
  % passing 18 inch 100%
  % passing 12 inch 73%
  % passing 6 inch 28%
  % passing 3 ½ inch **10.7**%;

- Gradation sample 942-003 (7,002.1 lb) taken at the Levee from delivered stone:
  % passing 24 inch 100%
  % passing 18 inch 77%
  % passing 12 inch 34%
  % passing 6 inch 4%
  % passing 3 ½ inch 0.08%;

- Gradation sample 942-004 (5,068.5 lb) taken at the Levee from delivered stone:
  % passing 24 inch 100%
  % passing 18 inch 57%
  % passing 12 inch 35%
  % passing 6 inch 11%
  % passing 3 ½ inch 2.6%;

- Gradation sample 942-005 (8,144.7 lb) taken at the Levee from delivered stone:
  % passing 24 inch 100%
  % passing 18 inch 73%

% passing 12 inch 34%
% passing 6 inch 1%
% passing 3 ½ inch 0.02%;

- Gradation sample 942-006 (7,468.2 lb) taken at the Levee from delivered stone:
  % passing 24 inch 100%
  % passing 18 inch 81%
  % passing 12 inch 57%
  % passing 6 inch 10%
  % passing 3 ½ inch 1.8%;

- Gradation sample 942-007 (7,344.8 lb) taken at the Levee from delivered stone:
  % passing 24 inch 100%
  % passing 18 inch 82%
  % passing 12 inch 31%
  % passing 6 inch 3.9%
  % passing 3 ½ inch 0.4%;

- Gradation sample 942-008 (7,155.6 lb) taken at the Levee from delivered stone:
  % passing 24 inch 100%
  % passing 18 inch 74%
  % passing 12 inch 45%
  % passing 6 inch 15.9%
  % passing 3 ½ inch 1.4%;

- Gradation sample 942-009 (7,978.4 lb) taken at the Levee from delivered stone:
  % passing 24 inch 100%
  % passing 18 inch 79%
  % passing 12 inch 58%
  % passing 6 inch 28%
  % passing 3 ½ inch **7.7**%;

- Gradation sample 942-010 (7,945.7 lb) taken at the Levee from delivered stone:
  % passing 24 inch 100%
  % passing 18 inch 89%
  % passing 12 inch 38%
  % passing 6 inch 3.2%
  % passing 3 ½ inch 0.5%;

- Gradation sample 942-011 (6,154.5 lb) taken at the Levee from delivered stone:
  % passing 24 inch 100%
  % passing 18 inch 60%
  % passing 12 inch 30%
  % passing 6 inch 1.5%
  % passing 3 ½ inch 0.2%;

- Gradation sample 942-012 (7,062.8 lb) taken at the Levee from delivered stone:
  % passing 24 inch 100%
  % passing 18 inch 81%
  % passing 12 inch 45%
  % passing 6 inch 7%
  % passing 3 ½ inch 0.5%;

- Gradation sample 942-013 (9,409.9 lb) taken at the Levee from delivered stone:
  % passing 24 inch 100%
  % passing 18 inch 80%
  % passing 12 inch 33%
  % passing 6 inch 1.7%
  % passing 3 ½ inch 0.3%;

- Gradation sample 942-014 (8,363.2 lb) taken at the Levee from delivered stone:
  % passing 24 inch 100%
  % passing 18 inch 86%
  % passing 12 inch 47%
  % passing 6 inch 11%
  % passing 3 ½ inch 1.9%;

- Gradation sample 942-015 (7,888.5 lb) taken at the Levee from delivered stone:
  % passing 24 inch 100%
  % passing 18 inch 73%
  % passing 12 inch 48%
  % passing 6 inch 10%
  % passing 3 ½ inch 1.3%;

- Gradation sample 942-016 (6,112.5 lb) taken at the Levee from delivered stone:
  % passing 24 inch 100%
  % passing 18 inch 78%
  % passing 12 inch 52%
  % passing 6 inch 8%
  % passing 3 ½ inch 1.1%;

- Gradation sample 942-017 (6,898.8 lb) taken at the Levee from delivered stone:
  % passing 24 inch 100%
  % passing 18 inch 92%
  % passing 12 inch 58%
  % passing 6 inch 11%
  % passing 3 ½ inch 2.3%;

- Gradation sample 942-018 (7,743.4 lb) taken at the Levee from delivered stone:
  % passing 24 inch 100%
  % passing 18 inch 78%
  % passing 12 inch 43%

% passing 6 inch 6%
% passing 3 ½ inch 0.9%;

- Gradation sample 942-019 (5,411.2 lb) taken at the Levee from delivered stone:
  % passing 24 inch 100%
  % passing 18 inch 92%
  % passing 12 inch 49%
  % passing 6 inch 12%
  % passing 3 ½ inch 1.9%;

- Gradation sample 942-020 (5,645.5 lb) taken at the Levee from delivered stone:
  % passing 24 inch 100%
  % passing 18 inch 68%
  % passing 12 inch 29%
  % passing 6 inch 2%
  % passing 3 ½ inch 0.6%;

- Gradation sample 942-021 (6,597.0 lb) taken at the Levee from delivered stone:
  % passing 24 inch 100%
  % passing 18 inch 75%
  % passing 12 inch 44%
  % passing 6 inch 11%
  % passing 3 ½ inch 0.6%;

- Gradation sample 942-022 (6,468.0 lb) taken at the Levee from delivered stone:
  % passing 24 inch 100%
  % passing 18 inch 81%
  % passing 12 inch 61%
  % passing 6 inch 5%
  % passing 3 ½ inch 0.3%;

- **Specified gradation**:
  % passing 24 inch 100%
  % passing 3 ½ inch 0 to 5 %.

(Data on the stone testing and specifications from Cella Barr Associates (1995, appendix D)).

1.3.4.2 Hydraulic modeling with regard to suitable riprap size. Flow velocities as much as an estimated 17 ft/sec could impact the Levee at points where the Little Colorado River migrates and impinges on the Levee riverside face, and riprap with a D_{50} of 12 to 16 in. was estimated to be needed to protect the slopes in the face of such flow velocities (Cella Barr Associates, 1994, p. 5).

1.3.4.3 Analysis of stone size. The above testing shows the stone is out of gradation at the lower end of sizes (too much is smaller than the specified 3 ½ inch allowance) on two out of 21 tests, and one of those was the initial quarry stockpile test, which is done so as to check and adjust the gradation prior to initial delivery to the job site. Of the 20 subsequent tests made on deliveries of stone to the job site, which totaled 292,705 tons of riprap delivered, one test showed 7.7% of the smallest range in the gradation, whereas the maximum allowable by the specification was 5%.

While a D_{50} was not reported, it can bee seen by examining the hypothesized ideal D_{50} needed to resist anticipated flow velocities at the 100-year flood level (reported above), and examining the gradations listed above, that the actual D_{50} of this stone is very close to the hypothesized ideal. This is favorable.

1.3.4.4 Analysis of stone quality. The sulfate soundness test percentage loss on the stone is higher than is usually specified for Corps of Engineers projects, although that is a criterion on which the Corps geologist often applies some leeway and relaxation of the standard, especially if other test results are fortuitous.

Characteristics of this basalt riprap were observed in the field by a US Army Corps of Engineers geologist in 2008; the lithology was verified and the very high density of the stone was noted. The stone is hard and appears very durable. No weathering or other deterioration were observed, nor were any macroscopic deleterious mineral components. Since this stone has been on site for 12-½ years, that time span now represents an important and favorable service record for the stone under project conditions. It is anticipated that this stone will continue to perform successfully, in terms of durability. The stone density should be considered as ideal.

It would be beneficial to do some detailed mineralogic evaluation of a few specimens of the stone to verify that no deleterious clay minerals are present, but it would be expected that if present, they would have made themselves apparent by the means of stone deterioration by this time. The need for that examination is much reduced by the favorable service record of the stone.

1.3.4.5 Amount of stone on the Levee. Surely, much of total amount of riprap that was placed on the Levee as part of the 1994 repair work (292,705 tons) is in place as the riprap stone protection blanket. Some unspecified quantity of that total remains on the Levee in emergency stockpiles (as in **fig. 20**).

1.3.4.6 Waste concrete demolition debris addition as emergency riprap. Waste concrete riprap placement took place at a date unknown to fortify the riverside Levee face and slope toe at the impingement point of the Little Colorado River's "meandering loop", adjacent the Bushman Acres residential / ranching area, from approximately sta. 162+00 to sta. 163+30 on the current Levee, (**fig. 6** shows the location on the overall map of the Levee). The placed stone protects the Levee toe (**fig. 22**), and additional waste concrete was stockpiled immediately downstream at the Levee riverside edge, ready to push down the Levee face and into the river impingement point to save the Levee during some future flood fight (**fig. 23**). The materials consist of broken concrete curbing, sidewalk slabs, and highway pavement slabs.

1.3.4.7 Riprap additions of 2009. In November 2009, Navajo County placed additional stone riprap on a 1,300-ft-long segment of the Levee that previously was unprotected and that was considered vulnerable to encroachment of Little Colorado River meandering. The design

Fig. 22.— Placed waste concrete riprap to arrest toe undercutting by the meandering loop of the Little Colorado River, approximately sta. 163+30, and looking upstream. This emergency placement saved the Levee during an early 2008 flood flight. See also fig. 23. Photo of 15 May 2008.

Fig. 23.— Waste concrete riprap stockpiled at the riverside edge of the Levee and ready to use under flood fight conditions to arrest Levee toe undercutting by the meandering loop of the Little Colorado River. Location is approximately sta. 163+80 and looking upstream. See also figs. 22, 24, and 25. Photo of 15 May 2008.

drawings showing stone protection on Levee cross sections indicate this stone riprap addition originally was intended to begin at sta. 163+28.45 and extend downstream to sta. 176+96.34, which is 1,338 ft of coverage. Navajo County Public Works' Trent Larson reported to the Corps via an 8 June 2010 memo that the 2009 riprap addition began farther downstream than indicated on the design drawings, at approximately sta. 163+80, and essentially abuts the downstream end of the waste concrete emergency riprap. That suggests this 2009 riprap armoring segment is about 1,313 ft long. Views of the downstream end of the waste concrete and the upstream area that was covered with riprap in 2009 can bee seen in **figs. 23, 24, and 25**.

The work done on this segment of the Levee was extensive (refer to design drawings for this armoring in **attachment 4**) and included:

- clear vegetation;
- construct a 60-ft-wide turn-around on the landside at sta. 170, using engineered fill;
- fill with an engineered fill the riverside slopes as needed that had been over steepened (probably due to river erosion), to restore them to 1V:2H;
- over-excavate the toe of the riverside Levee slope to -6 ft below grade;
- apply filter fabric to slopes on the riverside[15] of the Levee, from the top of the slope to the bottom of the over excavated slope toes;
- apply riprap to slopes on the riverside[16] of the Levee from the top of the slope to the bottom of the over excavated slope toes (toe down is 6 ft below final riverbed grade);
- recompact the over excavated area at the toe of the riverside slopes, restoring original grade to the river bed;
- excavating landside slopes as needed to restore 1V:2H slopes (steepen those slopes).

Refer to the design drawings in **attachment 4** for details of this work.

The riprap that was placed during the initial Levee rebuild stopped at sta. 164, and was on the riverside only. It is notable that the toe down of that initial rebuild riprap was considerably deeper than what was placed in 2009. The 1980's rebuild as-built drawings (**attachment 1**) indicate the bottom of the initial rebuild riprap was at elevation 4,812 ft at sta. 164 (as can be seen in **fig. 8**). The drawings for the 2009 riprap addition (**attachment 4**) show the bottom of the riprap on the riverside at el. 4,837 ½ ft, which is much more shallow. The point of this is to remember that the sta. 163+80 (approximately) to 176+96.34 riprap does not extend as deep on the riverside as the adjoining riprap-protected segments that adjoins at or near sta. 164 [17].

[15] The design drawings indicate this filter fabric originally was intended to be applied to both the landside and the riverside of the Levee, but Navajo County Public Works' Trent Larson reported to the Corps via a 8 June 2010 memo that construction actually carried out involved filter fabric placement only on the riverside of the Levee.

[16] The design drawings indicate this riprap originally was intended to be applied to both the landside and the riverside of the Levee, but Navajo County Public Works' Trent Larson reported to the Corps via a 8 June 2010 memo that construction actually carried out involved riprap placement only on the riverside of the Levee. Toe down on the landside was to be 2 ½ ft below final riverbed grade.

[17] Obviously, there is an overlap in stationing here. Sta. 164 falls within the range of the sta. 163+80 to sta. 176+96.34 segment of the Levee (within the range being riprap protected in 2009). It is presumed by the author that 1980's rebuild riprap at sta. 164 and the immediate surrounding vicinity must have been lost to river impingement and that the segment was thus not protected by riprap at the time the 2009 riprap application was made.

Fig. 24.—Un-armored segment of Winslow Levee at approximately sta. 163+80, looking downstream (north); riverside is to the right. This is part of the Levee segment that was armored with stone riprap in Nov. 2009. Photo taken 15 May 2008.

Fig. 25.—Winslow Levee prepared for the filter fabric and riprap addition of 2009, at approximately sta. 163+80, looking downstream. The riprap application during this exercise took place from sta. 163+80 to sta. 176+96.34. Photograph supplied by Navajo County Public Works.

A photograph of the Levee surface prepared for the placement of stone in 2009 is shown as **fig. 25**.

1.3.4.8 Extent of riprap protection in 2010. Navajo County Public Works' Trent Larson reported to the Corps via a 8 June 2010 memo that then current riprap protection on the Levee was as follows:

- Riverside from approximately sta. 140+00 to sta. 400+00;
- Landside from approximately sta. 176+00 to sta. 231+60.

Note that this is an identical area of coverage as was reported after the 1997 addition of riprap (see sec. 1.3.4.1 of this report).

1.3.5 *Levee through-cutting and undercutting structures*. Knowing the location and understanding the geotechnical ramifications of all structures that cut through a levee or under it, such as, gates, conduits, buried cables, is essential to evaluate the levee condition and likely performance. It is the goal here to merely catalog these features. Most data were derived from a study of the as-built drawings (**attachment 1**). *It should be recognized that this data source may be out of date*. Additional research into the Levee database should be done to assure having the most up-to-date information on Levee ancillary structures.

1.3.5.1 K-3 channel conduit crossing through Interstate 40 embankment. The largest feature cut through the Levee is the set of ADOT K-3 channel conduits, which is found between sta. 24+78 through sta. 46+75 (**fig. 26**). All of this is the Interstate 40 embankment, incorporated as a part of the Levee. The most significant feature cutting the Levee is the I-40 embankment and gates through that embankment. Gates block the conduits unless stormwater ponds on the upstream (south) side of the embankment, at which time the gates are opened and the water can be drained through the embankment, northward, and into the Little Colorado River.

Drawings of the details of these gates have not been obtained by the Corps.

Current criteria in place for levees disallows the incorporation of a highway embankment as a part of a Levee. Structural changes will have to be made so that the two embankments, Levee and highway, are separate. Such work is beyond the scope of the current report. What is known of the gates has been cataloged here for future reference.

Fig. 26.—ADOT K-3 channel conduit set through the Interstate 40 embankment, looking south-southeast (upstream) from the downstream side of I-40. Photograph of 15 May 2008.

1.3.5.2 Other Winslow Levee through-cutting and undercutting structures. As shown on the as-builts (**attachment 1**), they are the following:

- **Railroad bridge** crossing over the Levee, sta. 0+00 is the C/L of the bridge (see **fig. 27**); crosses with track elevation at the elevation of the Levee crest; significant issues are that the cutoff wall DOES NOT extend beneath this bridge, but the cutoff wall ends on upstream side of the bridge at sta. -0+25 and begins again on the downstream side of the bridge at sta. 0+30 ft; this is a gap of 55 ft in the cutoff wall;
- **Telephone cable, buried**, abandoned, sta. 6+10; was cut through and removed where it conflicted with the cutoff wall alignment;
- **High pressure gas line**, 4 ½ in. O.D., buried; sta. 6+45; cutoff wall constructed around this line in such a manner as to form an impermeable seal;
- **Pile retard wall** in the foundation, ADOT structure, paralleling the Levee embankment from sta. 11 to 20, approximately; pre-dates the Levee; left in place;
- **High pressure gas line,** 4 ½ in. O.D., buried beneath the Interstate 40 embankment and crosses at an oblique angle; crosses under the upstream slope toe at sta. 50+00 and the downstream Interstate 40 embankment toe at approximately sta. 53+25;
- **High pressure gas line,** 4 ½ in. O.D., buried beneath the Levee embankment and crosses at an oblique angle; crosses under the riverside slope toe at sta. 79+00 and the under the landside toe at sta. 81+00 **(all three gas line crossings listed to this point are the same line)**;
- **ADOT "I-4 channel"** [18]**, a frontage drainage outlet channel (box culvert)**; sta. 91+24.410 on the upstream side of the box culvert (which cuts the Levee at about 90°) and approximately sta. 93+10 on the downstream side; the cutoff wall was NOT built below this culvert, noted as "not necessary" there in the as-builts, sheet 6;
- **Electrical conduit, buried**, sta. 232+40, buried 3 ft deep, 12 KV line; the cutoff wall was constructed around this line so as to form an impermeable seal according to notes on the as-built drawings, sheet 9.

1.3.6 *Levee Performance*.

1.3.6.1 1972 Levee breaching. "The levee was breached in 1972", according to Gregory (1990, p. 1). This breach may have been made intentionally to prevent overtopping during a flood event, or it may have been a flood-caused breach. No other information is available. The reliability of the report seems defensible, as it was made by the Corps of Engineers in the "background " section of their 1990 Levee inspection report and was immediately followed by the statement that the Levee "was rebuilt in 1973 under Public Law 84-99 (PL 84-99)". No records have been located to document how and how much of the Levee was rebuilt. Work done under PL 84-99 is near-certain verification of Corps of Engineers involvement in the construction, but this cannot be documented as having occurred.

[18] This is not a reference to the Interstate highway, known as "I-40". The designation "I-40" for the highway and "I-4" for this drainage channel were and are in use simultaneously (Gregory, 1990, p. 2), and both are correct.

Fig. 27.—BNSF Railway Co. bridge over the Levee and the Little Colorado River, looking east and perpendicularly at the Little Colorado River (vegetation on the right half of frame). The Levee is in the foreground around the bridge abutments. Photograph of 15 May 2008.

1.3.6.2 1978 Levee failure. A flood of 18 through 23 December 1978 caused "severe flood damage" in Navajo County (Rodgers, 1978) and as a result of the flood, the Levee "failed" (Gregory, 1990, p. 1). Based on the Corps' report of where the Levee subsequently was rebuilt, the failure zones (or possibly damaged zones + failure zones) extended from a point "0.25 mi south" of the BNSF Railway Co. bridge, and downstream from there to Interstate I-40, and for 3.5 mi north (downstream) of I-40. This zone, a total of 3.75 mi of Levee, was noted specifically as undergoing "levee replacement" in a re-construction effort undertaken by the US Army Corps of Engineers in 1979 under PL 84-99 (Public Law 84-99). At the same time, farther downstream, another 1.6 miles of the Levee was "rebuilt", with the rebuild stopping point at McHood Road (Gregory, 1990, p. 1). McHood Rd. can be seen on fig. 4; it is about 0.3 mi upstream of the downstream limits of the original Levee (prior to the 1980 rebuild). The Corps report that alludes to this 1979 repair work specifically distinguished between some of the Levee being "replaced", and some of it being "rebuilt".

It is noted that the same reference document (Gregory, 1990, p. 2) includes a statement from a Navajo County representative (Mr. Jim Bruce), indicating that as of 1990, *no* PL84-99 work had ever been done along the I-40 segment of the Levee, or between the BNSF RR bridge and I-40. The Corps report was the opposite, that Levee replacement was done under PL84-99, between the RR bridge and I-40 (among other places). No records have been located that would resolve this discrepancy. No details were encountered that reveal how the Levee replacement and rebuilds were done, with what materials, etc.

1.3.6.3 Damage noted in April 1990. Damage noted on 25 April 1990, and not found elsewhere in the documentation record for this Levee, included a need for some manner of restoration to 10 of 12 jetties built onto the Levee, all downstream of approximately sta. 275+00 (**see fig. 9**), damage (a need for "restoration") to the eastern extent of the Levee at sta. 345+66 and immediately adjoining areas, and damage (a need for "restoration") to the Levee in the segment between the two main groupings of 12 jetties, from approximately sta. 310+00 to sta. 313+00. The cause and nature of the damage, and the type, method, and timing of the restoration, if any, were not encountered in the record.

1.3.6.4 Winslow Levee overtopping failure of 1993. The overtopping failure of 1993 took place on 8 January 1993, and a 400-ft-long segment was breached (see **fig. 5**), while a 3,000-ft-long segment was overtopped and damaged, primarily by erosion of the levee on the landside in that segment. Damage included scour to *17 ft below the Levee base on the landside*. The flood fight began on 9 January 1993, included participation by the US Army Corps of Engineers, and lasted 5 days, during which a variety of materials were used during the flood to plug the breach, including adding large rock to reduce the thru-flow rates, then capping the area with clayey material. A temporary restoration, post-flood, included bringing the Levee back to its former height by adding clay, rock, gravel, and other fill, and the breached section was raised in height with the addition of asphaltic concrete mill tailings. In all, 70,000 cu yds of material were used for these emergency repairs (Cella Barr Associates, 1994, pp. 1, 2; Cella Barr Associates, 1995, p. 1).

The damage zone and subsequent repair zone was from sta. 202+00 to 232+00, which can be seen by the reader on **fig. 5**). The 400-ft-long breach apparently was from sta. 208+50 to sta. 212+50, based on the fact that the job include new cutoff wall from sta. 208+00 to 213+00, and that new cutoff was tied into the existing cutoff wall at both ends, as per data in Cella Barr Associates (1995, p. 3)

Permanent repairs were undertaken and completed in 1994, and included the following features:

- Rebuilding of the Levee embankment and cutoff wall within the zone specified above;
- Addition of a seepage barrier on the Levee slopes;
- Later application of Bidahochi basalt riprap to the embankment repair zone, on both sides of the Levee (stone described in detail above, under the section on riprap on this Levee); this was the first use of stone on the landside of the Levee.

The cutoff wall was made 4 ft wide in the permanent repair section of embankment and was designed to be a seepage barrier, 20 ft deep. The sketch available for this feature suggests that the 20 ft vertical measurement is begun at the *elevation of the toe of the Levee* (Cella Barr Associates, 1995, appendix E). In the area of sta. 210+50, where sandstone bedrock was encountered as the foundation beneath the Levee at -10 ft to -20 ft, this seepage barrier was shortened in length by as much as 1.6 ft, but most of it still was installed as intended to -20 ft (Cella Barr Associates, 1995, appendix D). Installation of this seepage barrier was as follows. A trench was cut and backfilled with a bentonite slurry that has a specification density of “at least 15 pcf lighter than backfill”. Some of the more dense slurry field test samples (taken after placement in the backfill trench) had density values of 82 pcf and 108 pcf, with the high numbers attributed to intermixing of sand particles that spalled from the slurry trench sides and into the slurry mix (Cella Barr Associates, 1995, Appendix D).

Preparation of the slurry mix was as follows (apparently done on site): an imported green clayey sand is spread in an area 30 ft wide and 800 ft long, to a depth of 2 ft. Bentonite, 3,000 lbs of it, was spread onto this soil layer by a loader bucket, applied over 8-ft-wide, 200-ft-long areas of the soil layer. Discing by a tractor-mounted agricultural disc was done to – 1 ft, and the first foot of this treated soil was excavated and placed. The lower 1 ft layer was then treated, and used in the same manner. Bentonite content was estimated to be, by weight, 2.04% by this process but a higher percentage of bentonite was intended. A larger amount of bentonite was added to subsequent mixing panels. This repair cutoff wall was tied into the existing cutoff wall at sta. 208+00 and 213+00 and the contact zone was bridged by “placing geogrid over slurry backfill in trench, overlapping the trench sides by 4 to 5 feet, then … placing clayey sand mixed with some bentonite slurry on top of geogrid attempting to ‘bridge’ the set slurry in the trench.” Tie-in trenches were made and backfilled with slurry in lifts, 8 to 10 ft thick, compacted “thoroughly” with a trackhoe bucket, to best effect a bond between the old cutoff wall and the new repair cutoff wall. The tie ins were done first, at each end of the repair cutoff wall trench (sta. 208+00 and 213+00) Cella Barr Associates, 1995, Appendix D).

A slope cutoff wall also was built from sta. 208+00 to sta. 213+00, apparently of the same or similar soil-bentonite mix as was used in the slurry trench for the replacement cutoff wall, and was applied dry to the riverside slope face, in one 10-ft-thick lift applied by a paddle wheel scraper. No toe down is indicated on the only drawing encountered for this feature, a sketch in Cella Barr Associates 1995, appendix E, “cutoff wall”). The material for the slope cutoff wall was pushed up the slope, applied, and then compacted on an incline. A sheepsfoot roller was used for compaction. With moisture content 9.6% below optimum, relative compaction values of 94.&% and 93.1% were obtained in two nuclear density tests of this material (Cella Barr Associates, 1995, Appendices D and E). Much additional test data were collected from the slurry and the embankment in this breach repair zone, and it is available in **attachment 5** to this report, but it should be noted that these test values are for a very limited extent of the Levee and it cannot be said and should not be considered that the materials described and test results obtained are representative of other parts of the Levee.

1.3.6.5 Winslow Levee foundation piping failure of 2004. A sand lens *in the foundation beneath* Winslow Levee allowed a piping failure of the levee to occur on 31 December 2004 at 10 AM during a storm. The failure did not occur at the peak gage reading of 20 ft[19], but was noticed when the flows had started to recede to about 16-½ ft. The failure point was small, and alert observation and quick action were credited with limiting the flooding on the landside to about 2 acres of land (**fig. 28**). The piping failure point was at approximately sta. 197+00 (some reports are that it was sta. 190+00). Other views of the piping failure are in (**figs. 29, 30, and 31**).

Emergency repairs were initiated and included adding soil to both the river side, at the piping inlet (**figs. 32, 33, 34**), and to the land side. A forensic examination in October 2005 included trenching into the levee and cutting through the bentonite core (cutoff wall). Through this it was determined that the cutoff wall remained intact and all piping was in a sand layer in the foundation, entirely below the base of the cutoff wall.

This Levee segment was rebuilt. The area was over-excavated to -12 ft below the Levee toe and the sand layer was completely removed, then replaced by high clay content soil, compacted to 100%. The Levee was then rebuilt using the original design, plus some enhancements. The enhancements included the following. The vertical cutoff wall was rebuilt using a cement slurry and a 60 mil HDPE[20] plastic liner core facing on the river side. This HDPE also covered parts of the Levee crest (**fig. 33**). Geofabric was added to the Levee slopes on both sides, then covered with riprap on both sides of the Levee (**fig. 34**), which was raised 3 ft in the vicinity to increase freeboard along the reach to provide 3 ft of freeboard over the 100 year flood event. The total length along the Levee for which the repairs were made and the freeboard increased were not encountered during research for this paper, but the intention is to verify those numbers and add them here. Design drawings of this repair zone exist but none that are legible were available to the Corps geologist at the time of this writing. If obtained later, they will be added here. The work was done from October through December 2005. All photographs of the damage to this location on the Levee and the ensuing repair work used in this report were provided by Navajo County Dept. of Public Works.

1.4 ***Conclusions regarding Winslow Levee***. Verifying that the Levee has sufficient resistance to seepage, along with sufficient height and slope protection to withstand estimated future flood events will be done as a part of this study. Some parts of the study and analysis will be led by disciplines other than the Geotechnical Branch. The first step in the decision making process

[19] US Geological Survey stream gage 09400350 on the Little Colorado River near Winslow.
[20] HDPE is high density polyethylene.

Fig. 28.--Flooding on land side from Dec. 2004 piping failure

Fig. 29.--Dec. 2004 piping failure, land side, view 1.

Fig. 30.--Dec. 2004 piping failure, land side, view 2.

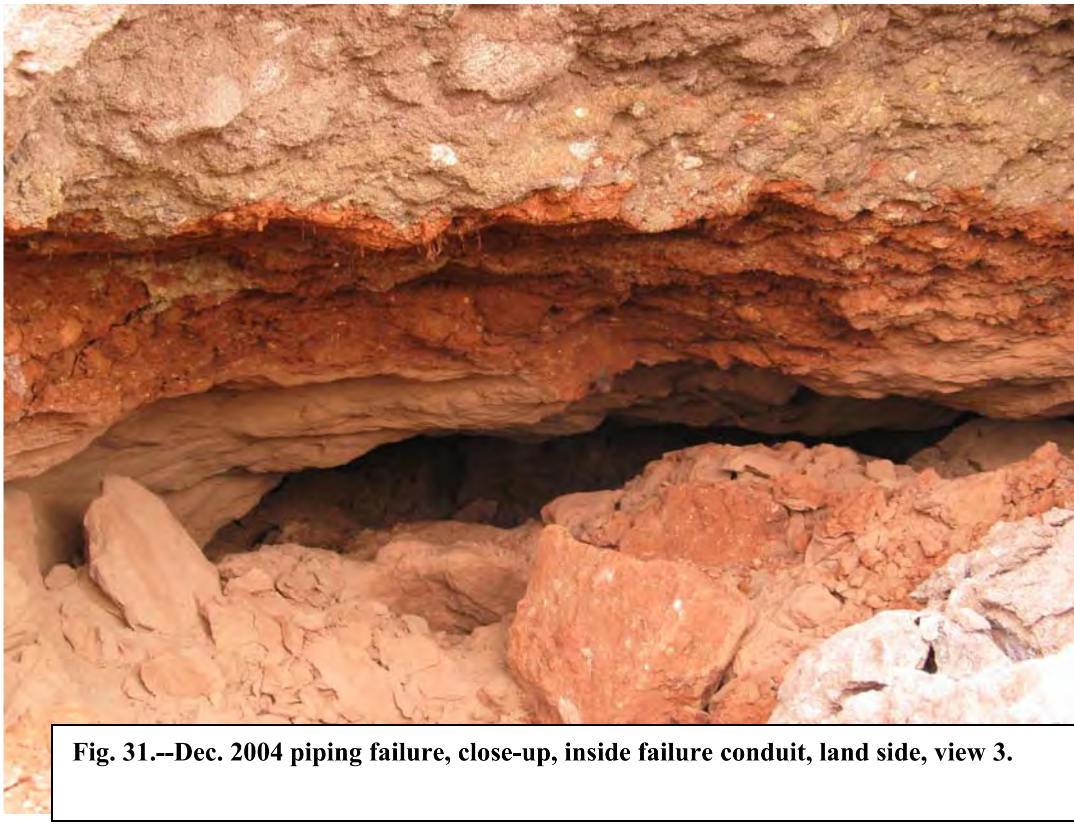


Fig. 31.--Dec. 2004 piping failure, close-up, inside failure conduit, land side, view 3.

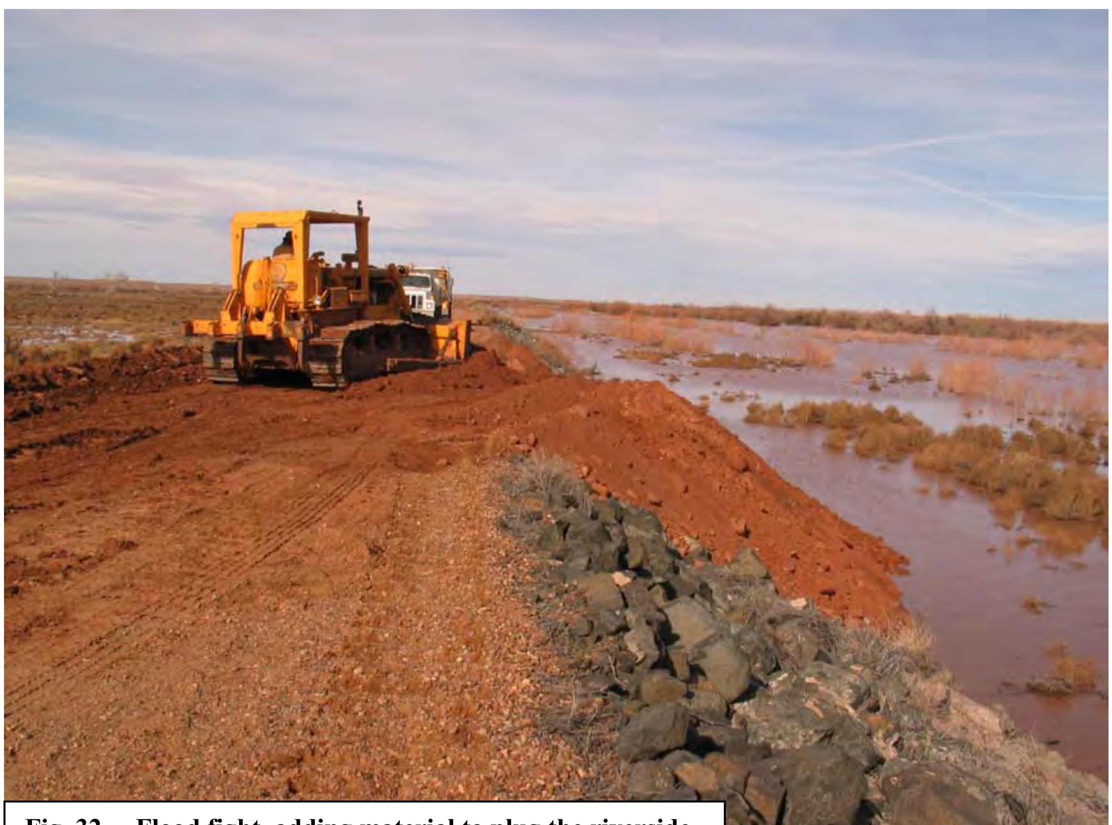


Fig. 32.—Flood fight, adding material to plug the riverside inlet point to the piping failure of Dec. 2004, view 1.

Fig. 33.—Flood fight, adding material to plug the riverside inlet point to the piping failure of Dec. 2004, view 2.

Fig. 34.—Geofabric being added to the Levee at the piping failure zone during the permanent repair phase, 2005.

will come from the Hydraulic Engineer and Hydrologist on the team: should this analysis determine that the Levee has sufficient freeboard to pass the anticipated flood event, the attention will then be focused on the seepage resistance of the embankment, which could be considerable, considering the end-to-end bentonite-based cutoff wall.

Attention next would focus on the depth of the cutoff wall and the depth of the toe down of the riprap, where riprap has been placed. It will be important to remember at that stage that the cutoff wall is not extended to the same depth throughout, as per the original design, and that repairs have been made at one location which resulted in another difference in depth of the cutoff wall (the 1993 breach), while composition of the cutoff wall was changed to cement slurry in the zone repaired following the 2004 piping failure. The toe down of riprap is not the same, as constructed, and repairs and 2009 additions of riprap are to different depths than the original design. Additions of riprap following the 1993 breach also are toed down to different depths.

Addition of more riprap, to cover more areas (some that remain unprotected) will have to be considered, and materials costs will be a factor. The cost of hauling the stone and placing it is high. Even as far back as the repair of the 1993 breach, geotechnical consultants were considering soil cement preferentially over riprap placement due to cost.

If the resulting decision is that the Levee will be overtopped or will otherwise be a non-feature in the modeled, anticipated flood event, then any subsequent geotechnical investigation will largely ignore the existing Levee embankment in terms of strength and resistance abilities of the embankment and cutoff wall, and will instead focus on finding a suitable Levee foundation. The foundation alignment would be studied in terms of identifying any geologic flaws that may exist in it, such as potential routes for piping, and to test borrow materials. If the current alignment is to be followed, geotechnical investigation will be focused there. If a new alignment is needed, different potential footprints will be the focus of any future investigations. Surely the segment of the Levee that is comprised of the current Interstate 40 embankment is a segment for which a new alignment will have to be chosen, due to regulatory requirements. To be accredited, a levee cannot incorporate part of a highway embankment as levee embankment. New alignments would have to be explored by drilling, testing, and other methods.

Some of the impingement points on the Levee that are, or most likely will be threatened by future Little Colorado River meanders that form during major floods, may have to be strengthened by setting certain Levee segments back farther from the River's edge. That too would necessitate finding and exploring new alignments.

The potential for future piping under the foundation remains a major concern, regardless of whether a decision is made to improve the Levee, or rebuild it. Considering the extensive area of Levee underlain by past river meanders, all formed in the last 100 years (**figs. 10 and 11**), it may be that over-excavation and backfill with more suitable materials, or barrier construction, such as sheet pile, may be the best route for constructing more durable segments of the Levee. The Corps is not convinced that presence of Moenkopi Formation bedrock in the foundation is a guarantee against the occurrence of piping under the Levee foundation. If exploration is undertaken, both buried paleomeanders and buried Moenkopi bedrock will receive attention, looking for zones that could support piping. All buried and through-going structures listed in this report (e.g., pipelines, conduits, and channels) will be sites of individual assessment to determine their condition with regard to stability of the Levee, because through-going and undercutting structures can be sites of embankment or foundation seepage, piping, and even failures, if any flaws exist.

The ML classification of subsurface layers, if they represent silts and have no granular component, may have to be assessed in terms of slope stability, as well as the clay layers in the foundation. CPT (cone-penetrometer testing) will be combined with standard drilling and sampling methods to achieve exploration goals. Some GPR (ground penetrating radar), or other geophysical investigation means, may be employed at the utility through- and undercrossings to get a better picture of the subsurface around them.

2 **Ruby Wash Diversion Levee**. The ephemeral Ruby Wash, Ice House Wash, and four other unnamed, parallel-flowing washes, collectively comprise a wide, braided, desert wash system that flows northeastward, primarily by the means of "overland flow" (JE Fuller, 2009, p. 1), and the alignment of this flow is essentially directly through the City of Winslow, AZ, as shown on **fig. 35**. Ruby Wash Diversion Levee was built to collect those flows south and upstream of Winslow, AZ, and divert them to the Little Colorado River via the means described below.

Ruby Wash Diversion Levee is about 5.3 miles long, and falls on the Winslow, AZ, 1:24,000 US Geological Survey topographic map, and in T. 19 N., R. 16 E., sections 31, 32, and 33. Authorized in 1965 under Public Law 89-298, this earthen fill Levee, shown on **fig. 36**, was built by the US Army Corps of Engineers beginning in the late 1960's, with completion in Sept. 1971. Its position upstream of Winslow, AZ, and alignment perpendicular to the direction of the Ruby Wash and the aforementioned affiliated smaller wash flows, was chosen so that it would collect all those flows and divert them about 90° to the east, and into the Little Colorado River channel. The Little Colorado River then conveys these flows around Winslow, to the east and north, aided by the protection of Winslow Levee, a structure covered previously in this report. The downstream end of the Ruby Wash Diversion Levee ties into the upstream end of the Winslow Levee, to form a contiguous line of protection (JE Fuller, 2009, p. 1; US Army Corps of Engineers, Los Angeles District, 1969, p. vi).

An examination of the Ruby Wash Diversion Levee design documentation reveals that the design and construction objectives were to:

- utilize on-site materials for Levee construction, including bedrock and soil;
- excavate for the project footprint only where the flow-collecting diversion channel on the upstream side of the Levee needed to be built;
- find locations where soil could be excavated for fill, preferentially, instead of bedrock;
- utilize local topography to minimize fill quantities.

There are several natural ridgelines crossing the project footprint, roughly perpendicular to the alignment of the Ruby Wash Diversion Levee. Some of these ridgelines delineate the banks of Ruby Wash and the smaller, paralleling washes. Ruby Wash Diversion Levee crosses these ridgelines at or near a perpendicular to ridgeline orientation and the Levee designers utilized the elevation of these ridgelines such that the constructed Levee fill quantities are much less in these ridgeline crossing areas; the ridgeline supplies the mass for the Levee at those locations instead

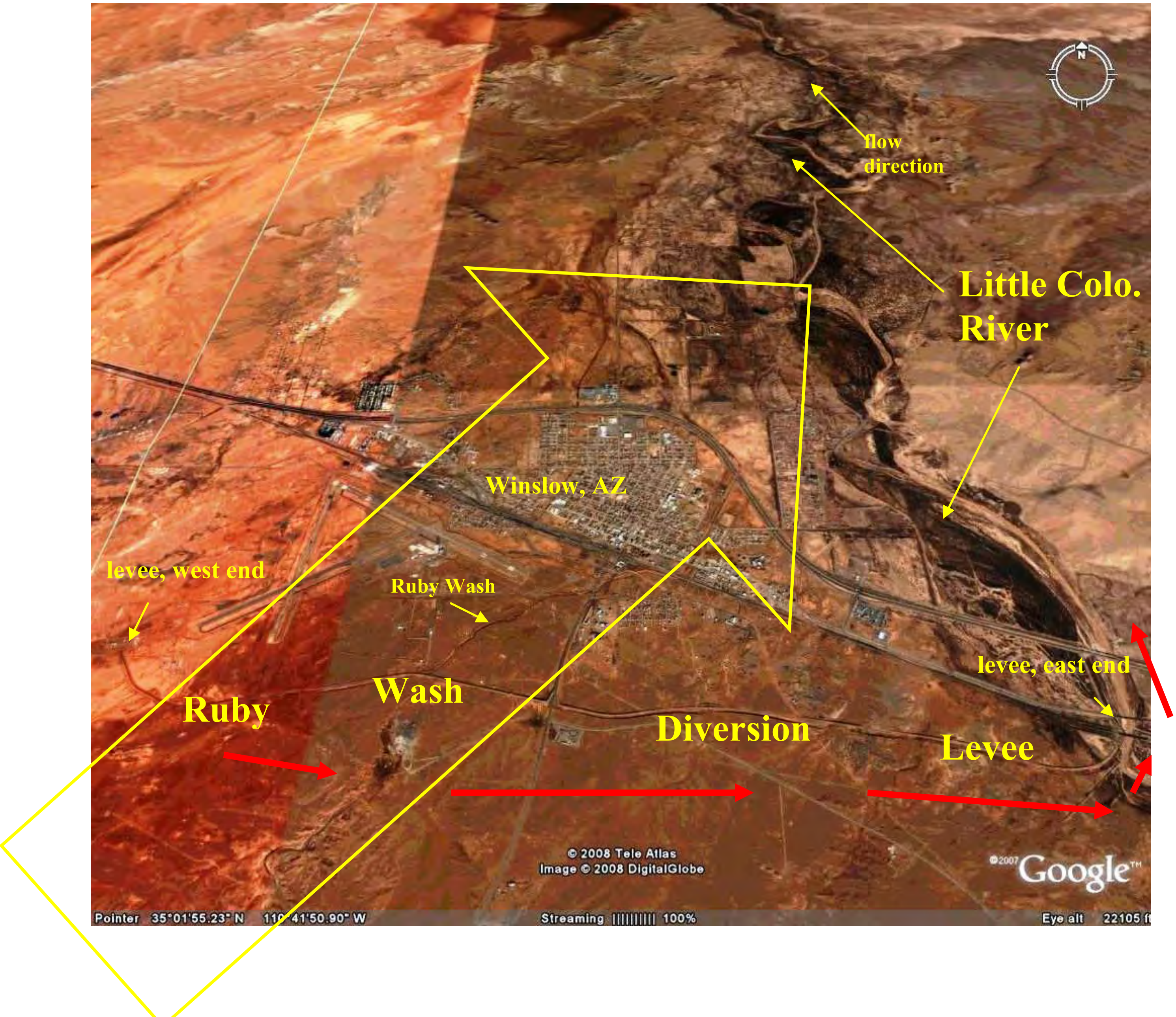


Fig. 35.—The alignment of Ruby Wash and Ruby Wash Diversion Levee, relative to Winslow, AZ. The Ruby Wash Diversion Levee is labeled. The large yellow arrow covers the approximate length and width of Ruby Wash braided channel flows, and those of several unnamed, affiliated, paralleling, washes, and shows the direction of this composite flow, pre-levee. The specific channel delineated as "Ruby Wash" was found in the cited reference Kleinfelder West (2009, pl. 1). Note the impact, pre-levee, of the combined northeasterly flows of these ephemeral washes on the location of Winslow, AZ. The City is essentially "in the channel". The direction of re-directed Ruby Wash flows is shown by the series of red arrows.

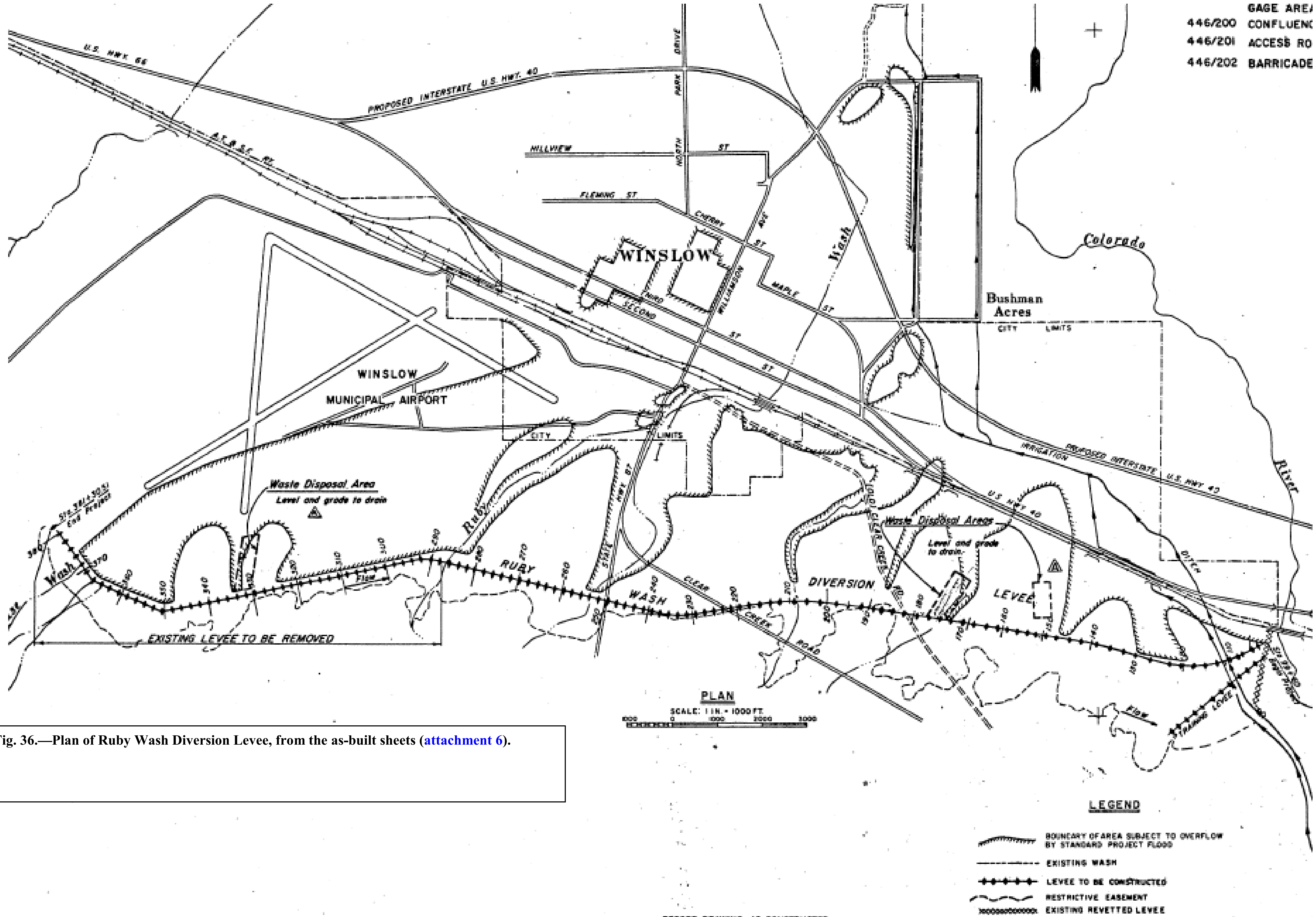


Fig. 36.—Plan of Ruby Wash Diversion Levee, from the as-built sheets (attachment 6).

of placed fill. In some of the locations, no constructed Levee exists at these crossings, and the ridgelines alone serve as a bridge to the next constructed Levee segment (JE Fuller, 2009, pp. 1, 2). The most significant of these ridgelines is the one that crosses the Levee alignment at sta. 163+80; there, the ridgeline is high enough and extensive enough to be a line of protection against floodwater breakout to the west-northwest, as per current, re-assessed flood size and routing estimates, as discussed below. Prior to considering the details of the Levee construction, composition, foundation, etc., it is important to digress into the topic of Levee re-accreditation, discussed below.

2.1 ***Levee re-accreditation.*** The City of Winslow, beginning in 2007, sought accreditation of the Ruby Wash Diversion Levee via a FEMA-based levee assessment under 44 CFR 65.10 guidelines and requirements, and hired Woodson Engineering, Flagstaff, AZ, to carry this out. Woodson Engineering subsequently engaged JE Fuller[21], Phoenix, AZ, to perform hydrologic and hydraulic modeling, and Kleinfelder West, Tempe, AZ, to do field exploration and testing, which was quite rigorous and comprehensive. The most important finding in the hydrologic and hydraulic assessment (JE Fuller, 2009) is that <u>not all of the Ruby Wash Diversion Levee has sufficient freeboard to receive re-accreditation</u>, according to freeboard requirements listed in 44 CFR 65.10.

JE Fuller (2009, p. 9) clearly notes that the most important impacting element in this determination of inadequate freeboard was their decision to model the combination of Ruby Wash flows and those of the overbank Little Colorado River 100-year flood flows, noting that this combination of flows was not done in the original Corps design of the levee. When modeled in combination, the JE Fuller study shows that flows will raise water elevations high enough to overcome freeboard requirements from the downstream (eastern) extent of the Ruby Wash Diversion Levee, continuing all the way upstream to sta. 143+00.

Considering the Ruby-Wash-flow-paralleling ridgelines discussed above, JE Fuller (2009) identified a large and extensive one at sta. 163+80 that is substantial enough to serve as a hydrologic and hydraulic boundary, such that if the levee were to fail at or downstream of sta. 143+00, the remainder of the levee upstream of sta. 163+80, utilizing the breakout protection of this ridgeline, still could function as a levee system (JE Fuller, 2009, p. 9), and the ridgeline height would prevent any breakout of flooding that might occur at sta. 143+00 or further downstream along the levee. According to the as-built drawings (**attachment 6**), sheet 7, elevation of the levee crest, as designed, at this topographic high at sta. 163+80 is approximately 4,889 ft and elevation at the highest overtopping point, sta. 143+00, as designed, is 4,872.5 ft. It is unknown if any settlement of the crest occurred since construction, but those two elevations, 4,889 ft and 4,872.5 ft are approximate guides to two critical elevations, the elevation of overtopping and the elevation of sustainable protection from overtopping.

So the Levee was, administratively, and solely for the purpose of re-accreditation, “divided” into an East Levee and a West Levee at sta. 163+80 in this 2008-2009 study, and only the West Levee segment was officially submitted by the City of Winslow for accreditation in 2009. This instance is the first use of those “East” and “West” terms to describe subdivisions of the Levee,

[21] There is very little difference between the 2008 draft report on this effort from JE Fuller, and their 2009 final report; only the 2009 report is cited here.

and the point is made so that the reader will understand the very recent origin of that naming scheme and its purpose. The terms will not be found in older literature on this Levee.

The East Levee was considered to be "non-existent" for the purposes of floodplain delineation done by JE Fuller (JE Fuller, 2009, p. 9). It is, therefore, the East Levee segment, by this JE Fuller definition of West and East segments, that likely will receive the most attention from the US Army Corps of Engineers; i.e., the Ruby Wash Diversion Levee downstream of sta. 163+80.

2.1.1 *Re-accreditation not granted*. FEMA, in its 10 March 2010 decision (Curtis, 2010) <u>*did not*</u> issue re-accreditation for the West Levee, withholding this re-accreditation on issues related solely to the documentation package that was submitted. This does appear to leave the door open for possible re-submittal of the package, after additional work and/or data assembly are completed by the City of Winslow or its contractor (for the initial submittal, that contractor was Woodson Engineering and Surveying, Inc., Flagstaff, AZ). As of the date of this writing, it is not known whether the City of Winslow has or intends to re-submit a more detailed package to FEMA, and thus seek again re-accreditation. When updated information on the matter is obtained, it will be added to this report. If the West Levee is not re-accredited, the Corps area of interest, in terms of this feasibility study, very likely will be expanded to encompass the West Levee.

Specifically, FEMA (Curtis, 2010) questioned the submittal package in these aspects:

- Inadequate documentation of adequate freeboard for the Levee between sta. 144+00 and 344+00, a segment that may be subjected to high velocity flow, direct impingement, and wave run-up;
- Suitability of the four Levee segments selected for seepage and stability analysis in the submitted package; FEMA notes the submittal package refers to the sections used for analysis as "typical", but not critical, and FEMA identifies other Levee segments that appear to be more critical and therefore better suited than those actually used for analysis;
- Seepage analysis scenarios require more detailed documentation;
- The steady-state seepage analysis scenario appears to have a phreatic surface that exits the landside Levee slope;
- Exploration done is spaced too far apart, i.e., is spaced wider than the prescribed minimum of, at least three borings, one on the crest, landside, and riverside, every 1,000 ft, according to US Army Corps of Engineers ETL guidance (ETL 1110-2-569 , May 2005);
- Documentation of closure of closed cross-cutting or undercutting features is not sufficiently detailed, and what is presented appears to have discrepancies;
- Characterization of a cross-cutting culvert at sta. 286+40 is not sufficiently detailed;
- Scour is not considered in the stability analysis;
- There is a discrepancy as to whether scour could undermine existing riprap toe-down (which is 4 ft); submitted documentation indicates segments where scour could reach 6.9 ft;
- Failure by several specific internal mechanisms (such as animal burrows) needs additional discussion of the analysis done;
- Settlement from seismic shaking is not adequately addressed.

2.2 ***Description of the Ruby Wash Diversion Levee and its diversion channel***. The general dimensions of the Levee are as follows. The Levee was designed to be 12 to 14 ft high, and as much as 18 ft in width across the crest, with 1V:2H side slopes, and a minimum 3 ft freeboard. The maximum crest elevation is 4,966.80 ft, at the western (upstream) extent. The crest elevation of the Levee decreases in the downstream (eastward) direction. Some typical sections, taken from the as-built drawings, are shown in this report as **fig. 37**.

2.2.1 *Levee stationing*. The original stationing of the levee, which still is in use, is sta. 381+30.51 at the upstream (western) end, to sta. 99+60, where the structure ends on the west (left) bank of the Little Colorado River. Stationing is in feet.

2.2.2 *Freeboard*. While 3 ft of freeboard is the design for most of the Levee, an additional 2 ft of freeboard was allotted between stas. 300+00 and 144+00 (except at State Hwy. 87, where the freeboard would remain at 3 ft) to accommodate potential wave action and run up. A co-functional structure called the Training Levee, described in more detail below, was designed to be 12 ft high with 3 ft of freeboard. (US Army Corps of Engineers, Los Angeles District, 1969, pp. vi, vii, 12, 13, 16). Refer to the as-builts, which are **attachment 6** to this report.

2.2.3 *Diversion channel*. The Ruby Wash Diversion Levee system includes a low-flow water diversion channel along the washside (south) side of the Levee to control the diverted flows, and this channel was designed to divert flows as large as 23,000 cfs, derived from a 24 sq mi drainage area. The diversion channel is separated from the Levee by a berm comprised of un-excavated, pre-Levee materials. The channel has various configurations and design, depending primarily on whether it was to be excavated into soil or into shallow bedrock. Examples can be seen in **fig. 37**. Where in soil, the channel it is trapezoidal, 1 to 20 ft deep, with 1V:2H side slopes in soil and with a grade of 0.0010000 to 0.023500. Where trapezoidal, the designed freeboard is 2.5 ft. The design of the diversion channel where it was all in bedrock was to be rectangular, with designed for 2 ft of freeboard. JE Fuller (2009) reported observing trapezoidal diversion channel configuration in sandstone bedrock with 1V:0.5H slopes.

The diversion channel cuts through a pre-existing, revetted levee (assumed to be revetted with stone), about which no information was encountered in research for this report. This intersection is at the downstream end of the diversion channel, at approximately sta. 101+40 on the north side of the channel, and approximately sta. 102+80 on the south side. The pre-existing Levee and revetment were excavated and removed to make the outlet for the diversion channel into the Little Colorado River at this location.

A grouted stone invert stabilizer was built all the way across the invert of the diversion channel at sta. 103+27 (diversion channel is 100-ft-wide here), extending between the riverside toe of the berm separating Levee embankment and diversion channel, across to a berm extending out from the toe of the Training Levee (described below). In cross section, the stabilizer has a 5-ft-wide horizontal crest, is 13-ft wide across the base, 2 ft high, has 2H:1V facing slopes, upstream and downstream, is composed entirely of a 2-ft thickness of grouted type II stone (stone types defined below), toed down 4 ft on the downstream side (so that the grouted stone is a total of 6 ft

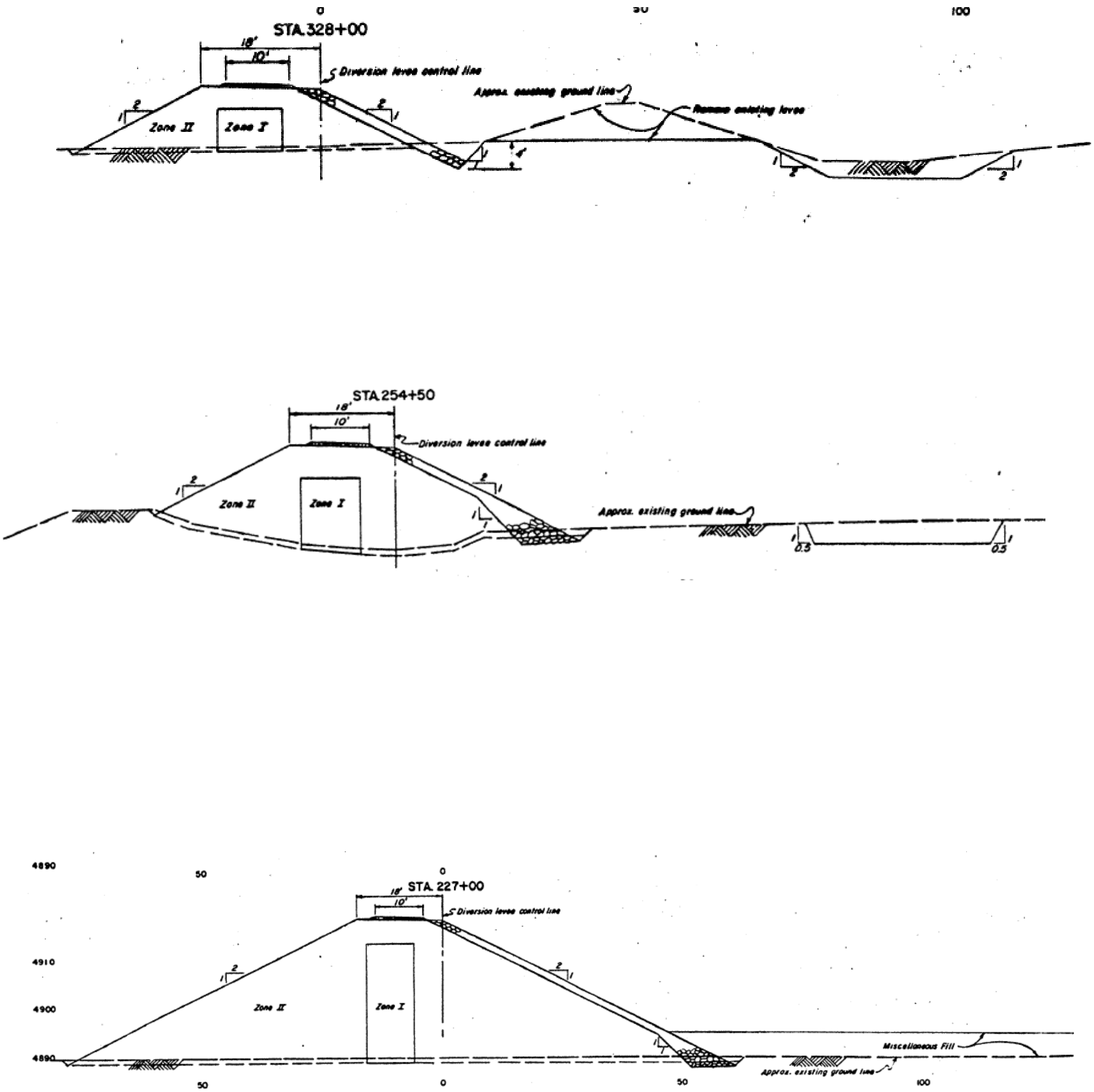


Fig. 37. Typical Ruby Wash Diversion Levee cross sections, at stas. 227+00, where the levee is tall and the diversion channel is a fill zone; at sta. 254+50, where the levee is less tall, and the diversion channel is an excavation, and sta. 328+00, where the old levee has to be demolished. Note the 2:1 riverside and landside side slopes, the 1:1 side slopes leading into the toe down, the tow-down depth, the riverside facing of riprap, and the zones of the earthen fill levee (zones I and II). From project as-builts, sheet 9, available as attachment 6 to this report).

below the diversion channel invert), and toed down and additional approximately ½ ft on the upstream side, so that grouted stone is a total of 2 ½ ft below the diversion channel invert.

2.2.4 *Training Levee*. A northeast trending training dike structure also was built to help concentrate and funnel diverted Ruby Wash flows into the Little Colorado River. This structure, called the "Training Levee" also serves to diminish the length of two siphons that had to be built to convey irrigation canal flows beneath the levee system (US Army Engineer District, Los Angeles, 1969, p. 2). The Training Levee is south of and sub-parallel to the Ruby Wash Diversion Levee and has a separate stationing system from the Ruby Wash Diversion Levee., extending from sta. 127+60 at its upstream (southwestern) end, to sta. 103+27.04 at its downstream (northeastern) end. It is, therefore, slightly more than 2,400 ft long. The as-builts, sheet 1 (**attachment 6**), clearly show the location and length of the Levee and the Training Levee. Sheet 12 of the as-builts suggests a berm separates the riverside toe of the Training Levee from the diversion channel, in the same way that a berm separates the Ruby Wash Diversion Levee toe from the diversion channel. The downstream nose of this Training Levee is revetted with stone that is tied into the pre-existing Levee that was cut through by the diversion channel (discussed above). That downstream nose is protected by revetment stone all the way around, including riverside face facing the diversion channel, the end of the nose (about 30-ft across), and for about a 30-ft length to join its stone revetment into the pre-existing Levee (see sheet 12 of the as-builts).

2.3 ***Levee foundation***. An existing levee was in place along the alignment of the westernmost (upstreammost) 1,200 ft of Ruby Wash Diversion Levee at the time the Ruby Wash Diversion Levee was built. This is shown on **fig. 36**. That existing levee did not "meet current Corps of Engineers design standards" [in the late 1960s], but appeared to be in "satisfactory condition" at the time. The existing levee was demolished and suitable materials that composed it were reused to make the current Ruby Wash Diversion Levee (US Army Corps of Engineers, Los Angeles District, 1969, p. 5). Elsewhere, the foundation immediately below Ruby Wash Diversion Levee is the thin residual veneer of soils composed of weathered sand and gravel derived from shallow, underlying bedrock. This veneer is described as, "gravelly, sandy silts which are slightly plastic". As built, the foundation immediately beneath the base of the Levee at sta. 120 and all points downstream (eastward) is soil; foundation immediately beneath the base of the Levee at all points west of sta. 120 is bedrock (US Army Corps of Engineers, Los Angeles District, 1969, pp. 16, 17). All of the Kleinfelder West (2009) borings logs describe this veneer of soil, from sta. 163, westward. The Kleinfelder West (2009) work is of additional value in that it includes logging of the contact elevation between native soils and Levee fill. Consult the logs and sample tests from the Kleinfelder West work for more details (**attachment 7**, this report).

Underlying the veneer of soils at shallow depths are the bedrock formations that weathered to form the overlying gravelly soils. Corps of Engineers borings done prior to construction (and shown among the as-built drawings, discussed below, and included as **attachment 6**) are indicative of the depths to bedrock along the full length of the Levee, as are the Kleinfelder West (2009) (**attachment 7**) borings along the western half of the Levee.

Geologic mapping of the area by the US Geological Survey, done on the scale of 1° X 2° topographic map sheets, identifies the uppermost bedrock of the entire area as lower to middle

Triassic-age[22] Moenkopi Formation, described as reddish-brown mudstone, siltstone, silty sandstone, and sandstone. In mapped geologic cross sections, the Permian-age Coconino Formation, a sandstone, is shown as being directly beneath the Moenkopi Formation in this region (Ulrich and others, 1984, map). At northern Arizona locations farther to the west of the Levee, there exist several rock formations between the Moenkopi and Coconino Formations. None of those intervening Formations are present in the Levee area.

The mapping of bedrock formations beneath the Levee foundation that was done for the design document describes the uppermost geology differently than does the cited US Geological Survey work. In the Corps work, both the Moenkopi and the Coconino Formations are bedrock formations beneath the Levee, albeit under slightly older and less-up-to-date stratigraphic nomenclature. Specifically, the "Moenkopi shale" and the "Coconino sandstone" comprise the bedrock formations beneath the Levee, and the division line of the two formations was described as being about mid-Levee, with the Coconino sandstone present in the eastern half of the Levee foundation, all the way to the Little Colorado River, and the Moenkopi shale underlying the western half. The bedrock under the eastern half of the Levee was described as very shallow, and even immediately at the surface in many places, and as a fine-grained, cross-bedded sandstone, moderately hard to hard, and white to buff in color. The Moenkopi shale was characterized as having thicker sand and gravel overburden, relative to the Coconino sandstone, and being composed of alternating, thin, sandstone and shale layers. The shale is sandy and soft to hard; the sandstone is fine grained and varies in hardness from hard to very hard (US Army Corps of Engineers, Los Angeles District, 1969, pp. 16, 17).

The exploration work by Kleinfelder West (2009) included drilling into the bedrock foundation of the levee in number of places, logging it in detail, and, in places, coring it. The Kleinfelder West logs, therefore, are sources of additional descriptive materials and tests results on the foundation soils and the bedrock beneath. Kleinfelder West didn't do any borings or other drilling or sampling work east of approximately sta. 163 on the levee, so their logs are descriptive of only what is now called the "Moenkopi Formation" (the "Moenkopi shale" of the design-era work). This Corps study likely will focus on only the segments of the levee that Kleinfelder West did *not* explore, for reasons discussed above, so there is a possibility that additional subsurface exploration of the bedrock might be done for the current study.

2.3.1 *Foundation preparation*. Foundation treatment during construction, as per the design document stated intentions: the areas are to be stripped and grubbed of all vegetation. In the rectangular channel segments (a feature used only where the low-flow channel cuts through sandstone bedrock), leveling was to be applied on areas of bedrock overbreak, and the overbreak backfill was to consist of 4-inch minus soil from the construction excavation placed in layers not exceeding 6 inches and hand compacted to 90% maximum density, as determined by AASHO test method T99-57. It was anticipated that bedrock would have to be blasted for most of the channel length to complete the low-flow channel (US Army Engineer District, Los Angeles, 1969, p. 18).

2.3.2 *Foundation soils*. Soils that comprise the foundation immediately beneath the embankment have been mapped by NRCS (National Resource Conservation Service) and the

[22] Formed about 240 million years ago.

results of that mapping has been transferred onto the exploration plates of the Kleinfelder West work of 2009 (pl. 1).

2.3.3 *Groundwater*. Groundwater was expected at -10 ft below the Ruby Wash Diversion Levee, from sta. 120+00 and all points downstream, and no groundwater was expected to be found upstream of sta. 120+00 (US Army Engineer District, Los Angeles, 1969, p. 18).

2.3.4 *Fill noted on the as-builts*. Another component of the foundation is the "miscellaneous fill" was placed in a topographic low during construction to the west of State Hwy. 87, approximately from sta. 258.5 downstream to the State Hwy. 87 bridge (sta. 250+39.97), and this fill is as much as 4 ft thick, but is less than 2 ft thick on the average (Levee as-builts, **attachment 6**, this report, sheet 6).

2.4 ***Levee composition and construction***. The Levee was built of soil and rock from project excavations and from borrow sources. It is composed mainly of random fill, with the exception of zone II fill, defined below. The embankment materials were placed as compacted fill and classified as "zone I" and "zone II". Zone II represents a vertical core wall to the embankment, typically about 10 ft wide and zone I represents the rest of the fill (as-builts, sheet 12, available as **attachment 6** to this report). These zones can be seen in **fig. 37**. Zone II fill is specified as: compacted soil, 10 ft minimum width, and its intent is to preclude the existence of an entire rock fill section of levee. Zone I fill is specified as: varying from soil to rock fill with the coarser fill placed towards the outer levee slopes. Compaction was by 50-ton rubber tired rollers, 4 passes, with the objective being an "infinite slope safety factor of 1.2, based on the assigned shear strengths," (US Army Engineer District, Los Angeles, 1969, p. 19).

Soil design parameters for the Levee include the following according to the US Army Corps of Engineers design document (US Army Engineer District, Los Angeles, 1969, p. 18):

	Compacted Soil	Compacted Rock Fill	Foundation Soil
Dry weight, pcf	105	120	90
Drained weight, pcf	121	125	105
Saturated weight	129		120
Degrees (drained)	30	35	28

2.4.1 *Stone revetment*. Mainly, riprap was used. Much less grouted stone was applied to the Levee. A study of the as-built sheets, especially sheets 8 and 9 (**attachment 6**) reveals the following characteristics of stone revetment used on Ruby Wash Diversion Levee:

- Stone is used on the riverside facing of the Levee embankment everywhere that a constructed embankment exists (some areas of the alignment utilize natural topographic highs, incorporating them into the Levee embankment and have no constructed Levee there; no stone was used there);
- Stone is used on the riverside only;

- Stone is used on both the Ruby Wash Diversion Levee embankment and the riverside of the Training Levee;
- Minimum stone layer thickness: 18 inches;
- That thickness was chosen to accommodate “500 lb slabal stone”;
- Toe down: 4 ft below the channel invert or to the top of bedrock, whichever is less;
- There is no filter layer between the stone and the random fill of the embankments;
- The objective in production of stone for revetment was to utilize local materials and simply rip or blast the rock with no processing and place it on the embankment; such stone is called **type I**;
- In zones where diversion channel velocities were anticipated to exceed 12 ft/s, type I stone was considered insufficient, and a **type II** stone was specified instead of type I; **type II** stone is defined as stone that would receive minor processing to “provide the desired results” (US Army Engineer District, Los Angeles, 1969, pp. 19, 20), the results defined simply as stone which would better resist dislodging by flow forces at flows greater than 12 ft /s;
- The stone was to be placed on random fill with no filter layer;
- Type II revetment was applied within these stationings:

Sta.	100+00	to	Sta.	103+50
"	139-00	"	"	140+00
"	143+00	"	"	145+00
"	157+00	"	"	164+00
"	178+00	"	"	200+00
"	212+00	"	"	221+00
"	305+00	"	"	330+50

- Type I revetment was applied at all other revetted locations on the Levee according to the as-builts, sheet 12 (available as **attachment 6** to this report) except the Levee crest; the Levee crest is type II stone;
- Stone on the Levee crest was grouted; any other grouted stone was to be type II (still searching for verification of any grouted locations besides the Levee crest);
- Stone gradations for type I and type II revetment (type II is processed stone, type I unprocessed material, and type I is called zone I in the chart below; Type II is called zone 2 in the chart below); chart below from US Army Engineer District, Los Angeles (1969, p. 20):

Weight of Pieces	Zone I V 12 ft/sec.	Zone II V 12 ft/sec.
	Percent smaller by weight	
500 pound	100	100
250	-	50-90
100	40-100	30-60
25	10-50	0-30
5	-	0-5
1	0-10	

The notation that slabal stone would be utilized apparently is a reference to the Moenkopi Formation bedrock that would be cut through for Levee construction and diversion channel excavation. It is clear the design was made such that the maximum amount of excavated rock material could be re-used to build the levee with the minimum of processing. Typically, slabal stone is avoided as riprap because it is easy for flow forces to dislodge it.

2.5 ***Exploration data on Ruby Wash Diversion Levee***. Exploration data that exist are informative both regarding the Levee foundation, and the Levee composition.

The exploration data represent two eras of investigation. One is pre-Levee exploration data from the US Army Corps of Engineers, and the other is the data collected by contractors for the City of Winslow in recent years for the purposes of re-obtaining FEMA-base levee accreditation in 2009.

Corps of Engineers exploration of the foundation of the Ruby Wash Diversion Levee primarily was limited to 52 "auger probe" borings, numbered "P1" through "P52" and arrayed along and on the washside of the Ruby Wash Diversion Levee and the Training Levee alignments. The only information available for these borings is "depth to refusal", and these depths range from 0.2 ft below pre-levee existing ground surface to "> 6.0 ft". Depths to refusal generally increase from west to east, and most of the deepest depths to refusal were encountered where the structure crosses ephemeral washes. The information is in the as-built drawings, sheet 3, and the locations of each boring are plotted on sheets 4 through 8 (**attachment 6**). There is flat-lying Moenkopi Formation sandstone at shallow depths below the Levee foundation soils. In addition to this auger probe exploration, a total of 6 (six) test pits were excavated along or upstream of the Ruby Wash Diversion Levee and the Training Levee alignments, numbered "TT4" through "TT9". They encountered silty sand and sandy silt above the points of excavator refusal. The log for pit TT 4 and a generalized log for pits TT5 through TT9 are shown on the as-built drawings, sheet 3 (**attachment 6**).

The main reason for the sparseness of materials assessment and the overall sparseness of data from these borings and trenches is revealed in the design document: the primary exploration was the test trenches, which were excavated by a Caterpillar D-8 dozer with a hydraulic ripper. That work was performed specifically to determine resistance to rock excavation, while the rock classified by a geologist on site. A primary goal was to ascertain the ease of excavation of the bedrock. Soil samples, taken at three foot intervals, or at soil type change boundaries, were tested to determine Atterberg limits, moisture content, and mechanical analysis (gradation). Soils were classified under the USC system. This work was done in July and August 1967. An important objective in the study of the soils was to find borrow that was suitable for the embankment, and reduce the amount of rock excavation that had to be done in order to attain the necessary quantities to build the Levee. Auger probing to verify the depth to rock was a follow-up phase of the exploration plan, done a year later, in July and October 1968 (US Army Engineer District, Los Angeles, 1969, p. 17). While that augering is often cited in more recent reports on the geotechnical aspects of the Levee, and sparseness of the data attained by that augering is always emphasized, the point that is often missed is that the preceding work on the soils was the main exploration and derived the most important data and all the test data. The author was not able to find those soils test results in the Corps archives in Los Angeles.

Exploration resulting from efforts to attain re-accreditation of the Ruby Wash Diversion Levee are much more substantial, complex, detailed, and widespread over the Levee alignment. The source for this information is Kleinfelder West (2009), which is **attachment 7** to this report.

The Kleinfelder West (2009) report is a comprehensive compendium of past exploration work, and also contains their own exploration work for Levee re-accreditation, with all exploration locations, historical and "current" shown, set on a color aerial photo base, with the Levee identified, with topography shown, and with existing NRCS (National Resources Conservation Service) soil survey mapping superimposed. This work should be considered essential reading for anyone assessing this Levee.

One can find on the plates in the back of Kleinfelder West (2009), the Corps of Engineers auger probe locations and depths to refusal found by them, the Corps of Engineers test pit locations and logs, and the following "current" work by Kleinfelder West:

- Kleinfelder West hollow-stem auger borings from 2008 (25 borings), logs and locations;
- Kleinfelder West sonic borings from 2009 (7 borings), logs and locations;
- Kleinfelder West seismic lines from 2009(?) (5 survey lines);
- Kleinfelder West levee cross sections (7 sections).

Appendix A to this Kleinfelder West (2009) report contains all the borings logs for the set of 25 hollow-tem auger and 7 sonic borings done by Kleinfelder West, including depth to groundwater, sampled and otherwise tested intervals, sample types, soil classifications and descriptions, Atterberg Limits and sieve analyses for laboratory-tested samples, classification of soils as Levee fill or native (Levee foundation), estimated soil strength and degree of cementation, results of any field tests performed on the soils, classification of bedrock, where encountered and drilled into, depths and elevations of soils and other horizons encountered in the boreholes, and the reasoning as to why the borings were stopped where they were stopped (for example, "refusal on bedrock"). These data and logs are included as part of **attachment 7** to this report (look for Appendix "A" within and at the back of **attachment 7**). Hollow-stem auger borings range from B-1 through B-26 (number "B-19" was not used). Sonic borings range from SB-1 through SB-7.

Appendix B to the Kleinfelder West (2009) report contains the soil test lab test results (mostly grain-size distribution and Atterberg Limits test results, but one consolidation test result is in the group). These data are included as part of **attachment 7** to this report.

Appendix C to the Kleinfelder West (2009) report contains the results of seismic surveys. Both seismic refraction surveys and GPR (ground-penetration radar) surveys were done and their results explained and shown in profiles and cross-sections. These data are included as part of **attachment 7** to this report. The GPR was done to look for voids. None were found (Kleinfelder West, appendix C, p. 9).

Because the Kleinfelder West (2009) work stopped at the West Levee - East Levee administrative dividing line (described above), and covered only the West Levee, and because the anticipated Corps work in the future will focus on only the East Levee, the details of the Kleinfelder West (2009) findings from exploration and testing are not reported here to any greater extent. If, in the future, the Corps emphasis is increased to cover the West Levee, this section of this report will be expanded and more data and particulars drawn out from the Kleinfelder West (2009) work. But for now, the East Levee is not explored beyond what the Corps did for pre-construction design work, over 40 years ago.

2.6 ***Utilities and features under, cut through, or placed over the Levee***. Crossings of infrastructure on, beneath, or through levees usually are critical locations, and a composite listing of them is important in understanding any levee system. There are numerous water conduits and utility lines beneath the Levee, one road embankment that the Levee adjoins, and one road over the Levee, as indicated on the as-built drawings (**attachment 6**). Those drawings should be referred to for more detail, but a summary chart of the intersections and undercrossings of the Levee are listed below:

- There is a 36-inch diameter R.C.P. (reinforced concrete pipe) through the levee at sta. 286+40. This is where Ruby Wash channel flows through the levee (Levee as-builts, **attachment 6** to this report, sheet 6).
- Existing State Hwy. 87 bridge was left in place and this project abuts it from both sides, east and west, at sta. 250+39.97.
- On the west side of State Hwy. 87 bridge, telephone lines were encased in steel pipe and run underground, perpendicular to and through the levee, at the time of construction (Levee as-builts, **attachment 6** to this report, sheet 6).
- Clear Creek Rd. crosses over the Levee at sta. 225+38.82 (Levee as-builts, **attachment 6** to this report, sheet 6).
- An existing, un-named, north-flowing wash channel crosses the Levee alignment and was filled to a maximum depth of about 25 ft and buried by the Levee between sta. 211 and sta. 204 (Levee as-builts, **attachment 6** to this report, sheet 7).
- A buried cable crosses beneath the Levee alignment on a north-south alignment at sta. 192+95.51 (Levee as-builts, **attachment 6** to this report, sheet 7).

- An existing, un-named, north-flowing wash channel crosses the Levee alignment and was filled to a maximum depth of about 24 ft and buried by the levee between sta. 186 and sta. 165+50 (levee as-builts, **attachment 6** to this report, sheet 7).
- Electrical conduit(?) ("E.C." on the as-builts) at sta. 144+31.89, orientation unclear from the drawings; dispensation unclear from the drawings (Levee as-builts, **attachment 6** to this report, sheet 8).
- Buried cable at sta. 138+02.24, orientation unclear from the drawings; dispensation unclear from the drawings (Levee as-builts, **attachment 6** to this report, sheet 8).
- Electrical conduit(?) ("E.C." on the as-builts) at sta. 125+49.25, orientation unclear from the drawings; dispensation unclear from the drawings (Levee as-builts, **attachment 6** to this report, sheet 8).
- Buried cable at sta. 116+21.33, orientation unclear from the drawings; dispensation unclear from the drawings (Levee as-builts, **attachment 6** to this report, sheet 8).
- Electrical conduit(?) ("E.C." on the as-builts) at sta. 115+06.68, orientation unclear from the drawings; dispensation unclear from the drawings (Levee as-builts, **attachment 6** to this report, sheet 8).
- Two inverted siphons, part of a pre-levee irrigation system, cross beneath both the Training Levee (approximately at Training Levee sta. 109) and the Ruby Wash Diversion Levee (at approximately sta. 108+40) on a northwesterly trend (Levee as-builts, **attachment 6** to this report, sheet 8). These siphons are pipes, approximately 3 ft in diameter, and were buried below the pre-Levee ground surface to a depth a 12 inches; burial was with protection stone, size undefined. The Ruby Wash Diversion Levee project protected these siphons in place by covering them with an additional 1.5 ft thickness of protection stone. This protection stone layer is shown as **fig. 36** (from Levee as-builts, **attachment 6** to this report, sheet 11).
- Two irrigation canals, part a of pre-levee existing system, cross beneath the Ruby Wash Diversion Levee at approximately 107+90 and 107+20, and beneath the Training Levee (approximately at Training Levee stas. 107 and 107+70) (Levee as-builts, **attachment 6** to this report, sheet 8). They were converted to the two inverted siphons, described above, according to the chart from the design documentation (**fig. 38**).
- Buried cable at sta. 100+81.18, orientation unclear from the drawings; dispensation unclear from the drawings (Levee as-builts, **attachment 6** to this report, sheet 8).
- The chart below (**fig. 39**) indicates a water line at sta. 208, not observed on the as-builts.

According to the design documentation for this levee, the following was the action taken with each of these utilities and undercrossings (data from US Army Engineer District, Los Angeles, 1969, p. 6): (see **fig. 39**, below).

2.7 ***Conclusions regarding Ruby Wash Diversion Levee***. There is a considerable difference between the Ruby Wash Diversion Levee and the Winslow Levee, in terms of the forces they have to withstand, and the foundations on which they are built. Those foundations are important pieces in determining how the Levees with counter the flood forces they are subjected to. Ruby Wash Diversion Levee is built largely over shallow to extremely shallow, flat-lying bedrock of low to moderate strengths (low to moderate degrees of cementation of the sandstone bedrock). The deep fill zones under Ruby Wash Diversion Levee, filled to close off the gullies of perpendicular washes where they are crossed by the Levee alignment, may be the weakest points

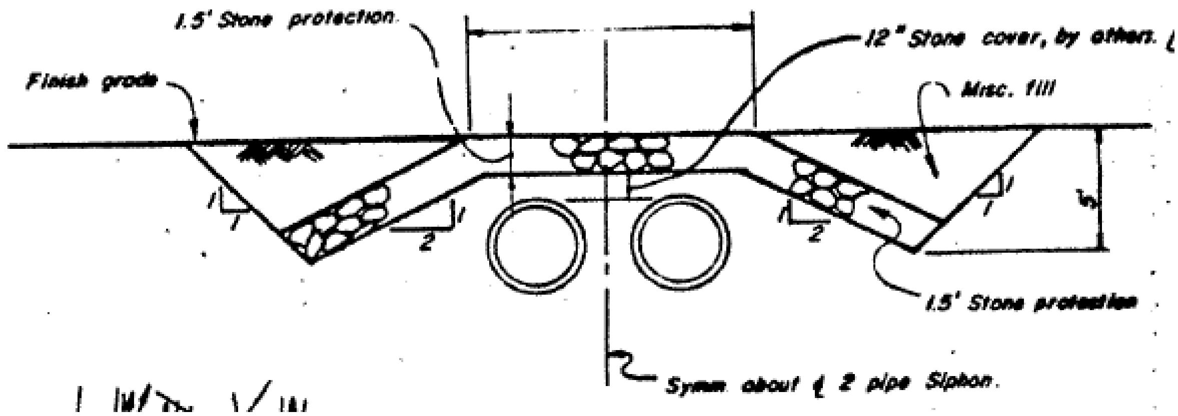


Fig. 38.—Detail of the protection in place of the siphons beneath Ruby Wash Diversion Levee, from levee as-builts, attachment 6 to this report, sheet 11.

Location Station	Description	Owner	Proposed Treatment
288+00	12" R.C.P.	City of Winslow	To be constructed
208+00	Water line 8" C.I. Pipe		To be abandoned
208+20	Power line	Arizona Public Service	Relocate poles as necessary
103+00	Irrigation ditch	Winslow Irrigation Co.	Inverted Siphon
102+00	Irrigation	City of Winslow	Inverted Siphon

Fig. 39.—Design document information, Ruby Wash Diversion Levee, showing that the irrigation ditches are to be converted to inverted siphons. It can be seen that the stationing in the design document is somewhat different than stationing on the as-builts.

in the Ruby Wash Diversion Levee foundation. They certainly will receive attention and analysis as to their integrity in any Levee structural assessment that may be done in the future.

In contrast, most of the Winslow Levee is built on old Little Colorado River meanders, some of which surely have granular (and thus potentially pipeable) materials as a major component of the meander, and all of which have been dated as less than 100 years old, according to age determination by Bureau of Reclamation (2003). In other words, nearly all the foundation of the Winslow Levee has in the past 100 years been a part of one or more large Little Colorado River meanders and has taken river flow in that time frame. Winslow Levee is the only feature to keep the river from re-establishing large meanders on approximately those same paths in future flood events. The only place that the Ruby Wash Diversion Levee will have to counter such large forces from the Little Colorado River is at its terminus, where Little Colorado River flows are perpendicular to the Levee.

Ruby Wash Diversion Levee does have a paralleling channel flow force to manage: the diversion channel that flows along it, end-to-end, is designed to carry 23,000 cfs. A berm exists between the riverside toe of Ruby Wash Diversion Levee and the diversion channel so as to keep channelized flow away from the Levee toe, and presumably make it possible to build a simpler Levee, with less riprap toe down, more permeable materials overall, no impermeable core. The berm largely is a remnant of soil and rock left behind from the original topography: the channel was excavated on one side of the berm, the Levee constructed on the other side of the berm, and the berm itself is just the un-excavated, un-moved material in between. Ruby Wash diversion Levee is not keyed in, nor is the lesser permeable core zone of that Levee.

In many ways, Ruby Wash Diversion Levee is a less robust structure than is the Winslow Levee, but the forces that it likely will have to resist in its lifetime are probably less and are directed at a more favorable angle, with less chance of impingement. If the diversion channel flows start to meander at high flow rates, this could allow channel shift toward the toe of the Levee, and impinge upon it. Ruby Wash Diversion Levee, due to the presence of more bedrock at shallower depths probably has a better foundation, end-to-end, in terms of piping resistance, than does Winslow Levee.

If it comes to assessing the eastern part of the Ruby Wash Diversion in terms of upgrading it, a similar decision-making process as described above under the Winslow Levee "conclusions" will have to be applied to the Ruby Wash Diversion Levee:

- Does the Corps agree that the Levee will be overtopped at any location[23]?;
- If so, should the potentially overtopped segments be upgraded or rebuilt?;
- Can the Levee embankment withstand the projected flood event without overtopping?
    - That raises the issue of, "is the diversion channel substantial enough to take the flows?"
    - Is the berm between toe of Levee and slope of diversion channel sufficient to hold flow forces away from the Levee riverside toe?
    - Is the riprap toe down sufficient?

[23] In this case, a consultant applied a different modeling of flows and came up with a different answer to the overtopping question than did the Corps during Levee design. A reconciling of the two concepts will have to be undertaken and one or the other chosen.

- Is the thru-seepage time sufficient to pass the flood event?

The Winslow Levee is projected by the stakeholders to not be able to withstand the 100 year flood event, and the Ruby Wash Diversion Levee was projected in a recent analysis by JE Fuller (2009) to be overtopped in its eastern half, east of sta. 143+00, but able to withstand modeled flooding and remain viable west of its sta. 163+80. The segment of Ruby Wash Diversion Levee not submitted for re-accreditation is all of it that is east of sta. 163+80, all the way to the eastern end of the project, which is the Little Colorado River junction. That is the segment most likely to receive additional exploration if this study proceeds forward.

The re-accreditation process results will either double the amount of Levee to be studied, or leave it as it is now (downstream half of the Levee only will be studied).

After that, flow modeling will be the determining step. How much water will move through the area in the anticipated flood event? The answer to that question will lead the team to the crossroads of considering rebuilding or enhancing the Levee. Exploration may be similar for either direction of study.

All buried and through going structures (listed in this report; pipelines, conduits, and channels are examples) will be sites of individual assessment to determine their condition with regard to stability of the Levee because through going and undercutting structures can be a site of embankment or foundation failures, if any flaws in them exist.

Cohesive soils in the foundation are not anticipated, but may exist. If they do, they may have to be assessed in terms of slope stability, as well as the clay layers in the foundation.

CPT (cone-penetrometer testing) will be combined with standard drilling and sampling methods to achieve this goal. Some GPR (ground penetrating radar), or other geophysical investigation means may be employed at the utility through- and undercrossings to get a better picture of the subsurface around them.

The potential for future piping under the foundation will be a concern and an element of any future Levee analysis. The presence of Moenkopi Formation bedrock in the foundation is not a guarantee against the occurrence of piping under the Levee foundation. Soft, friable, and weak zones can exist in this formation; well cemented zones frequently are not continuous, laterally and at depth.

The downstream of sta. 163 part of Ruby Wash Diversion Levee is largely unexplored other than probing to top of bedrock done at the pre-design stage.

Protection stone quality probably will have to be assessed, both in terms of the reported use of slabal stone as riprap, and a determination of the deterioration, if any, that may have occurred to the stone in the time it has been exposed to the elements. The Corps anticipates all that has been used is Moenkopi Formation sandstone. A review of **figs. 15, 16, and 17** demonstrates what has happened to Moenkopi sandstone riprap of the Winslow Levee, upon exposure to the elements for a few decades.

Riprap sources may need to be assessed. WTI (1987) is a look at a number of close by stone sources, much nearer the project than the Bidahochi quarry basalt. All that the Corps has seen of the Bidahochi basalt appears exemplary, and it now has a considerable service record, having been placed on the Winslow Levee as long ago as 1993, with no evidence of deterioration. It has test results that mostly are higher than needed for a Corps job, and it is very dense, which would allow smaller size material to be used. That could reduce cost. But overall, on the cost element, it has been expensive to place that stone, probably to a great extent due to the long haul distance. Some $400,000 was spent on that stone in the early 2000s for repair work. Possibilities for reducing that cost should be weighed, and likely would require using a closer stone source.

3.0 **References cited**:

"ADWR" is Arizona Dept. of Water Resources.

ADWR (Arizona Dept, of Water Resources), 1980, Feasibility report, Little Colorado River flood control project, Winslow, Arizona: report prepared for Navajo County Flood Control District, November 1980, 35 pp, 7 plates, plus appendix.

Bureau of Reclamation, 2003, Analysis of Little Colorado River stability between Holbrook and Winslow, report of findings, Little Colorado River sediment study: US Dept. Interior, Bureau of Reclamation, Technical Service Center, Denver, CO, 23 May 2003.

Cella Barr Associates, 1994, Revised Winslow levee repair project alternative repair schemes report for Navajo County Public Works Department: consultation report , CBA file no. 106889-01-0300 WRB 00372.03R, dated 25 April 1994, by Cella Barr Associates, 4911 E. Broadway Blvd., Tucson, AZ 85711.

Cella Barr Associates, 1995, Engineer's report, Winslow levee final report: consultation report for Navajo County, AZ, and FEMA, CBA file no. 106889-02-0280 KAD 00128.02R, dated 20 April 1995, by Cella Barr Associates, 4911 E. Broadway Blvd., Tucson, AZ 85711.

Curtis, Edward, 2010, 107506 Ruby Wash Diversion Levee; Ruby Wash Diversion Levee West recertification: letter from Senior Engineer, FEMA Mitigation Division, Oakland CA, to Mr. Jeff Swan, Woodson Engineering & Surveying, Inc., Flagstaff, AZ, dated 16 March 2010.

Dames and Moore, 1980, Conceptual design, proposed levees near Winslow, Arizona, for Arizona Department of Water Resources: consultation report; could not be located for the current paper but this citation was found in an older geotechnical report on the proposed Levee rebuilt that eventually resulted in the current Winslow Levee.

Gregory, C., 1990, Report on inspection of non-federal levees, California; Little Colorado River, Winslow Levee, Winslow, AZ: unpubl. Corps of Engineers internal report, US Army Corps of Engineers, Los Angeles District, Los Angeles, CA, dated 25 April 1990.

JE Fuller, 2009, Segmentation technical memorandum for Ruby Wash Diversion Levee, Winslow, AZ: a consultation report prepared for Woodson Engineering & Surveying, Inc., 124 N. Elden St., Flagstaff, AZ, 86001, by JE Fuller Hydrology and Geomorphology, Inc., 1 W. Deer Valley Rd., Ste. 101, Phoenix, AZ, 85027.

Kleinfelder West, Inc., 2009, Final geotechnical evaluation report, FEMA Certification, of Ruby Wash Diversion Levee West, station 163+80 to 381+30, Winslow, AZ: a consultation report prepared for Woodson Engineering & Surveying, Inc., 124 N. Elden St., Flagstaff, AZ, 86001, by Kleinfelder West, Inc., 1335 W. Auto Dr., Tempe, AZ, 85284.

Rodgers, S. J., 1978, untitled, unpublished letter: letter to Warren Hagstrom, US Army Corps of Engineers, Los Angeles District, Los Angeles, CA, on the subject of Navajo County flood damages of 18-23 Dec. 1978, and including a request for rehabilitation of the Winslow levee under Pl84-99 provisions, from S. J. Rodgers, County Administrator, Navajo County Board of Supervisors, Holbrook, AZ, dated 27 Dec. 1978.

Sabol, George V., Consulting Engineers, Inc., 1993, Little Colorado River geomorphology and river stability study; reconnaissance level engineering report: consultation report for Navajo County Dept. of Public Works, Holbrook, AZ, by George V. Sabol Consulting Engineers, Inc, Scottsdale, AZ, September 1993.

SFC Engineering Co., 1997, Geomorphology of the Little Colorado and Puerco Rivers, Arizona: consultation report for Arizona State Land Dept.-Drainage and Engineering Section, 1616 W. Adams St., Phoenix, AZ 85007, by SFC Engineering Co., 7776 Pointe Parkway West, Ste. 290, Phoenix, AZ 85044-5403, June 1997, *issued as section 4 of* Arizona stream navigability study for the Little Colorado River, Sunrise to the headwaters, and Puerco River, Little Colorado River confluence to the State boundary, final report: Arizona State Land Dept., June 1997.

SHB Agra, Inc., 1994, Geotechnical investigation report, Winslow Levee repair, Navajo County, Arizona: consultation report for Cella Barr Associates, Tucson, AZ, by SHB Agra, Inc., Engineering and Environmental Services, 3232 W. Virginia Ave., Phoenix, AZ, 85009, 12 April 1994.

Tetra Tech, Inc., 2009, Little Colorado River at Winslow Feasibility Study Baseline and Future Without-Project-Conditions Hydrology Report.

Ulrich, G. E., Billingsley, G. H., Hereford, R., Wolfe, E. W., Nealey, L. D., and Sutton, R. L., 1984, Map showing geology, structure, and uranium deposits of the Flagstaff 1° x 2° quadrangle, Arizona: U S Geological Survey Miscellaneous Investigations Series Map I-1446, 1:250,000-scale map, 2 sheets.

US Army Corps of Engineers, Los Angeles District, 1969, Winslow Food Control Project, Winslow, Arizona and vicinity, Design Memorandum No. 1 (general design): GDM by US Army Corps of Engineers.

Western Technologies, Inc. (WTI), 1982, Final evaluation of Little Colorado River Flood Control Project, Winslow, Arizona: consultation report for Navajo County Dept, of Public Works by Western Technologies, Inc., Phoenix, AZ, 9 Sept. 1982, WT no. 2212J282.

Western Technologies, Inc. (WTI), 1982, Levee extension, Little Colorado River Flood Control Project, Winslow, Arizona: consultation report; could not be located for the current paper but this citation was found in an older geotechnical report on the proposed Levee rebuilt that eventually resulted in the current Winslow Levee; it is presumed the WTI 1982 borings found on the as-builts are a part of this report, since they all are in the Levee extension zone.

Western Technologies, Inc. (WTI), 1987, Materials sources report for Winslow Levee Improvement Project: consultation report for Navajo County Dept, of Public Works project no. 429-45, by Western Technologies, Inc., job no. 2526JW108.

Western Technologies, Inc. (WTI), 1993, Subsurface exploration and testing, Winslow Levee, Navajo County, Arizona: consultation report for Navajo County Dept, of Public Works by Western Technologies, Inc., 2400 E. Huntington Dr., Flagstaff, AZ, 86004, 2 Sept. 1993, WT no. 2523JW228.

Attachment 1:
As-built drawings of existing Winslow Levee of the late 1980's by PRC Toup

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PLANS FOR THE CONSTRUCTION OF

WINSLOW FLOOD CONTROL PROJECT
WINSLOW, ARIZONA

ON

LITTLE COLORADO RIVER

PREPARED FOR

NAVAJO COUNTY
FLOOD CONTROL DISTRICT

PREPARED BY

PRC ENGINEERING
4131 NORTH 24TH STREET
PHOENIX, ARIZONA 85016
(602) 954-9191

APPROVAL

NAVAJO COUNTY FLOOD CONTROL DISTRICT
AND
BOARD OF DIRECTORS

JIM BRUCE — County Engineer, N.C.F.C.D. — Date

PETE SHUMWAY — Chairman - Board of Directors — Date
PERCY DEAL
JOHN DALTON

APPROVALS

PLANS SUBMITTED FOR APPROVAL THIS
15th DAY OF February, 19[illegible].

BY:
ED ADAIR — Registered Civil Engineer — Date

BY:
ASHOK PATEL — Registered Civil Engineer — Date

"AS BUILT"

LEGEND

- BANK PROTECTION
- TOP OF SLOPE
- TOE OF SLOPE
- PIPE; TYPE AND SIZE AS INDICATED
- GROUND WATER LEVEL AT DATE OF EXPLORATION
- BORING IDENTIFICATION AS INDICATED

REFERENCES

DWR - ARIZONA DEPARTMENT OF WATER RESOURCES

DM - DAMES & MOORE OCT. 15, 1980 CONCEPTUAL DESIGN PROPOSED LEVEES, NEAR WINSLOW ARIZONA, FOR ARIZONA DEPARTMENT OF WATER RESOURCES

WTI - WESTERN TECHNOLOGIES INC. SEPT. 3, 1982 LEVEE EXTENSION, LITTLE COLORADO RIVER, FLOOD CONTROL PROJECT, WINSLOW, ARIZONA.

SOIL TYPE DESCRIPTION

COARSE-GRAINED SOIL MORE THAN 50% LARGER THAN 200 SIEVE SIZE			FINE-GRAINED SOIL MORE THAN 50% SMALLER THAN 200 SIEVE SIZE		
LETTER	DESCRIPTION	MAJOR DIVISIONS	LETTER	DESCRIPTION	MAJOR DIVISIONS
GW	WELL-GRADED GRAVELS OR GRAVEL-SAND MIXTURES, LESS THAN 5% 200 FINES	GRAVELS MORE THAN HALF OF COARSE FRACTION IS LARGER THAN NO. 4 SIEVE SIZE	ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY	SILTS AND CLAYS LIQUID LIMIT LESS THAN 50
GP	POORLY-GRADED GRAVELS OR GRAVEL-SAND MIXTURES, LESS THAN 5% 200 FINES		CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS	
GM	SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES, MORE THAN 12%-200 FINES		OL	ORGANIC SILTS AND ORGANIC SILT-CLAYS OF LOW PLASTICITY	
GC	CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES, MORE THAN 12%-200 FINES		MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS	SILTS AND CLAYS LIQUID LIMIT GREATER THAN 50
SW	WELL-GRADED SANDS OR GRAVELLY SANDS, LESS THAN 5%-200 FINES	SANDS MORE THAN HALF OF COARSE FRACTION IS SMALLER THAN NO. 4 SIEVE SIZE	CH	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS	
SP	POORLY-GRADED SANDS OR GRAVELLY SANDS, LESS THAN 5%-200 FINES		OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS	
SM	SILTY SANDS, SAND-SILT MIXTURES MORE THAN 12%-200 FINES		PT	PEAT AND OTHER HIGHLY ORGANIC SOILS	
SC	CLAYEY SANDS, SAND-CLAY MIXTURES MORE THAN 12%-200 FINES				

GENERAL NOTES

1. CONSTRUCTION LINE IS THE CENTER LINE OF LEVEE UNLESS OTHERWISE NOTED.
2. ALL STATIONING IS CONSTRUCTION CENTERLINE STATIONING UNLESS OTHERWISE NOTED.
3. EXISTING FENCE WITHIN THE CONSTRUCTION LIMITS SHALL BE REMOVED AND RECONSTRUCTED TO THE LEVEE EASEMENT LINE OR AS DIRECTED BY THE ENGINEER.
4. DISPOSAL OF ALL WASTE MATERIAL SHALL BE AT APPROVED WASTE DISPOSAL SITE AS SHOWN ON PLANS.
5. ELEVATIONS ARE BASED ON U.S.G.S. DATUM 1929 ELEVATIONS. SHELL 2 = 4858.845 FEET.
6. ALL EXISTING CONDITIONS ARE TO BE VERIFIED IN THE FIELD, PRIOR TO CONSTRUCTION AND ANY ADJUSTMENT FROM DRAWINGS TO BE MADE AS DIRECTED BY THE ENGINEER.
7. ALL UTILITIES AS SHOWN ON PLAN ARE APPROXIMATE. IT SHALL BE THE RESPONSIBILITY OF THE CONTRACTOR TO FIELD VERIFY LOCATIONS OF ALL UTILITIES AND TO COORDINATE CONSTRUCTION WITH THE RESPECTIVE UTILITY COMPANY.
8. CORRELATION OF MATERIAL BETWEEN TEST HOLES IS INFERRED. THICKNESS OF LOOSE SURFACE MATERIAL MAY VARY, AND THE OCCURANCE OF OTHER SOIL UNITS IS POSSIBLE.
9. THE PRESENCE OF GROUND WATER INDICATION ON SOIL LOGS DOES NOT CONSTITUTE A REPRESENTATION THAT GROUND WATER WILL BE ENCOUNTERED AT THAT ELEVATION AT THE TIME OF CONSTRUCTION, NOR DOES THE ABSENCE OF GROUND WATER INDICATION CONSTITUTE A REPRESENTATION THAT NO GROAUND WATER WILL BE ENCOUNTERED DURING CONSTRUCTION.
10. ALL SOIL CLASSIFICATION SYMBOLS ARE BASED ON THE UNIFIED SOIL CLASSIFICATION SYSTEM. COMPLETE DRILLING LOGS, LABORATORY REPORTS AND GEOTECHNICAL REPORT ARE AVAILABLE FOR INSPECTION AT THE NAVAJO COUNTY FLOOD CONTROL DISTRICT.

ADOT ROADWAY CONSTRUCTION STANDARDS

STD. NO.	SUBJECT
CW2-1	INLET WINGS - RIGHT ANGLE CULVERT 2:1 SLOPE - HEIGHT 3' TO 7'
CWL-1	OUTLET LEVEL WINGS - HEIGHT 3' TO 7', TYPE B
CB-4	4 BARREL BOX CULVERT - TABLE 1
CB-3	3 BARREL BOX CULVERT - TABLE 1
CM-1	MISCELLANEOUS DETAILS FOR STANDARD BOX CULVERTS

ADOT ROADWAY CONSTRUCTION STANDARD DETAILS

DRAWING NO.	SUBJECT
C 15.09	CATCH BASIN, MEDIAN, FLUSH
C 12.01	FENCE & GATES, LINE, STEEL POSTS, 5 WIRE LINE PANELS, NO. 1 GATE
C 12.03	FENCE & GATE, CHAIN LINK
C 12.04	FENCE & GATE, INDUSTRIAL TYPE, FAB. WIRE

INDEX OF DRAWINGS

"AS BUILTS" BY WITCHER & ASSOCIATES (sheets 1–11)

SHEET NO.	TITLE
1	TITLE SHEET
2	INDEX OF DRAWINGS
3	TYPICAL CROSS SECTIONS
3-A	"AS BUILT" TYPICAL SECTIONS
4	LEVEE BANK PROTECTION
5	PLAN AND PROFILE Sta (7+19.84) to Sta 48+00.00
6	PLAN AND PROFILE Sta 48+00.00 to Sta 108+00.00
7	PLAN AND PROFILE Sta 108+00.00 to Sta 168+00.00
8	PLAN AND PROFILE Sta 168+00.00 to Sta 228+00.00
9	PLAN AND PROFILE Sta 228+00.00 to Sta 288+00.00
10	PLAN AND PROFILE Sta 288+00.00 to Sta 336+10.81
11	PLAN AND PROFILE Sta 336+10.81 to Sta 364+34.68
12	LEVEE CROSSING DETAILS AT&ST RAILROAD & U.S. 66
13	LEVEE CROSSING DETAILS I-40 & K-3 CHANNEL
14	LEVEE CROSSING DETAILS I-4 CHANNEL & FRONTAGE ROAD
15	K-3 BOX CULVERT EXTENSION - LAYOUT
16	K-3 CULVERT EXTENSION RETAINING WALL DETAILS
17	I-4 BOX CULVERT - LAYOUT
18	I-4 BOX CULVERT - RETAINING WALL DETAILS
19	SLIDE GATE DETAILS
20	TRAFFIC CONTROL PLAN

RIGHT OF WAY

1	TEMPORARY CONSTRUCTION EASEMENTS
2	TEMPORARY CONSTRUCTION EASEMENTS
3	TEMPORARY CONSTRUCTION EASEMENTS
1	PERMANENT EASEMENT
2	PERMANENT EASEMENT
3	PERMANENT EASEMENT

"AS BUILT" 10-3-89

4/15/83

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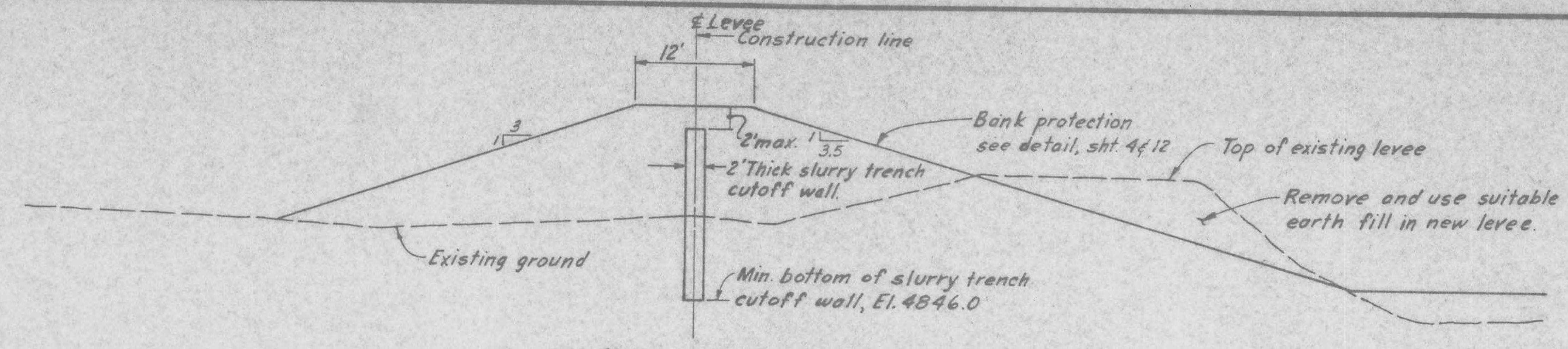
Telephone (602) 954-9191

FLOOD CONTROL PROJECT
WINSLOW, ARIZONA

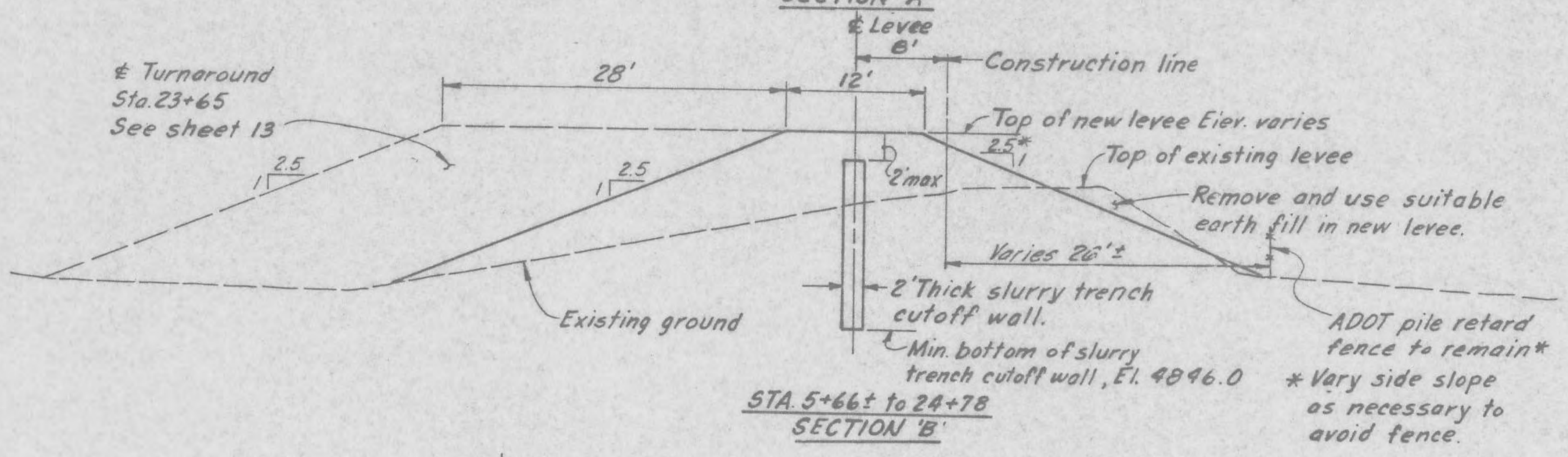
INDEX OF DRAWINGS

DATE 9-82	DRN. BY: LC, DH	DES. BY: AP, GS	CHK. BY: ACP
JOB NO. 600-600-3	FILE H414		SHEET 2 OF 20

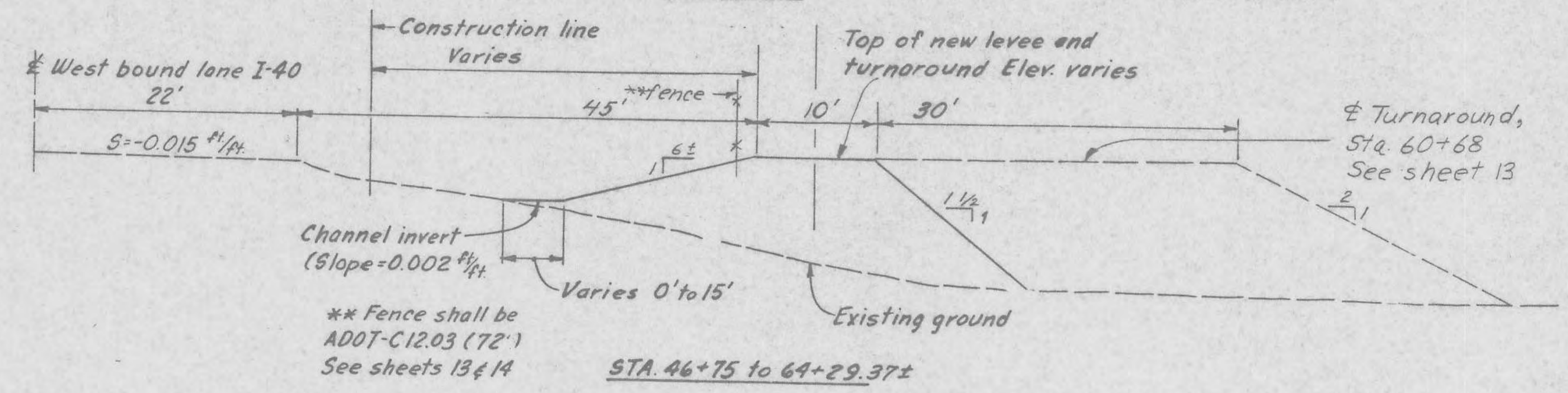
NO.	DATE	REVISION - DESCRIPTION	APPR.



STA. -(7+19.84) to -(0+62)
STA. 0+63 to 4+79
SECTION 'A'



STA. 5+66± to 24+78
SECTION 'B'



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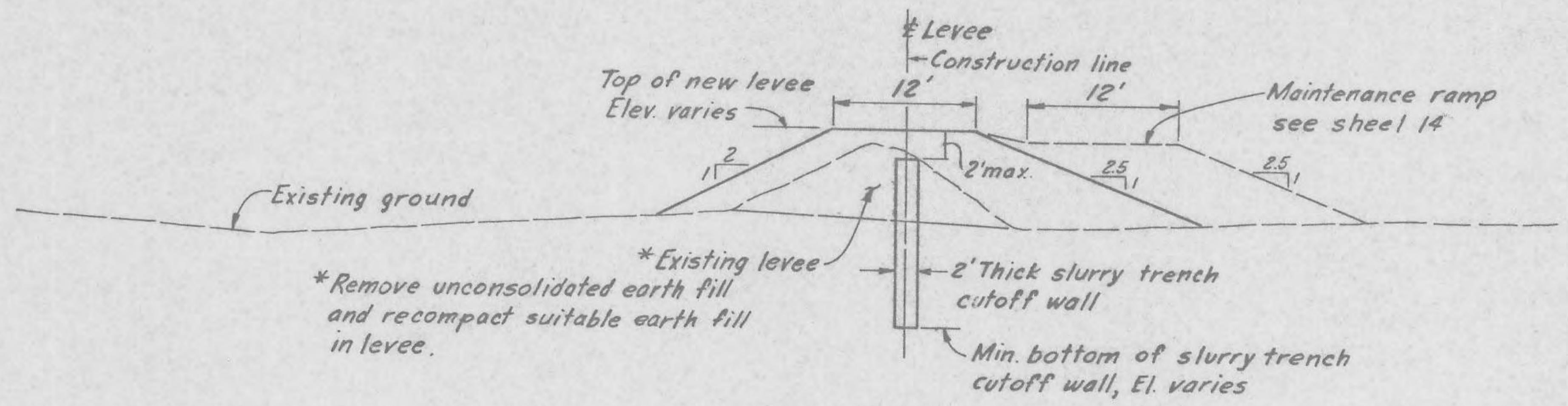
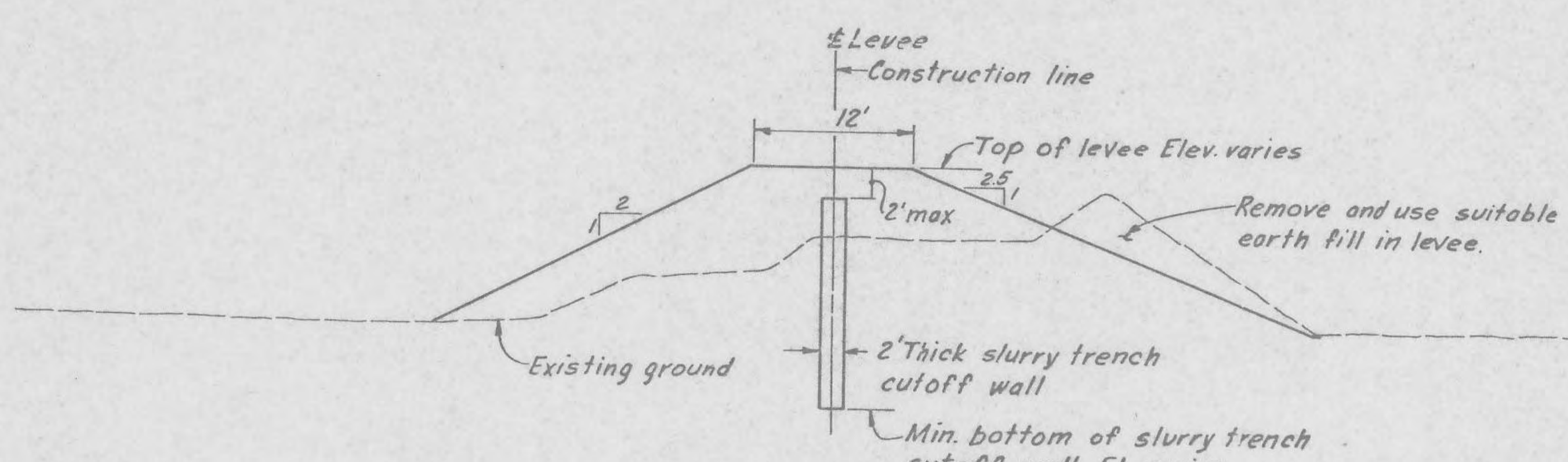
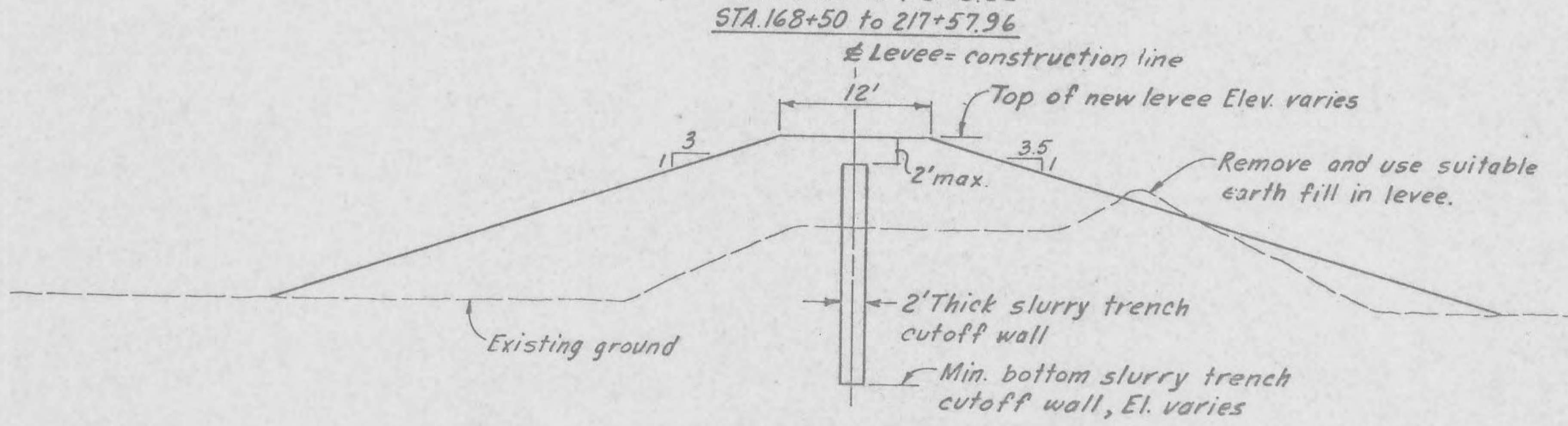


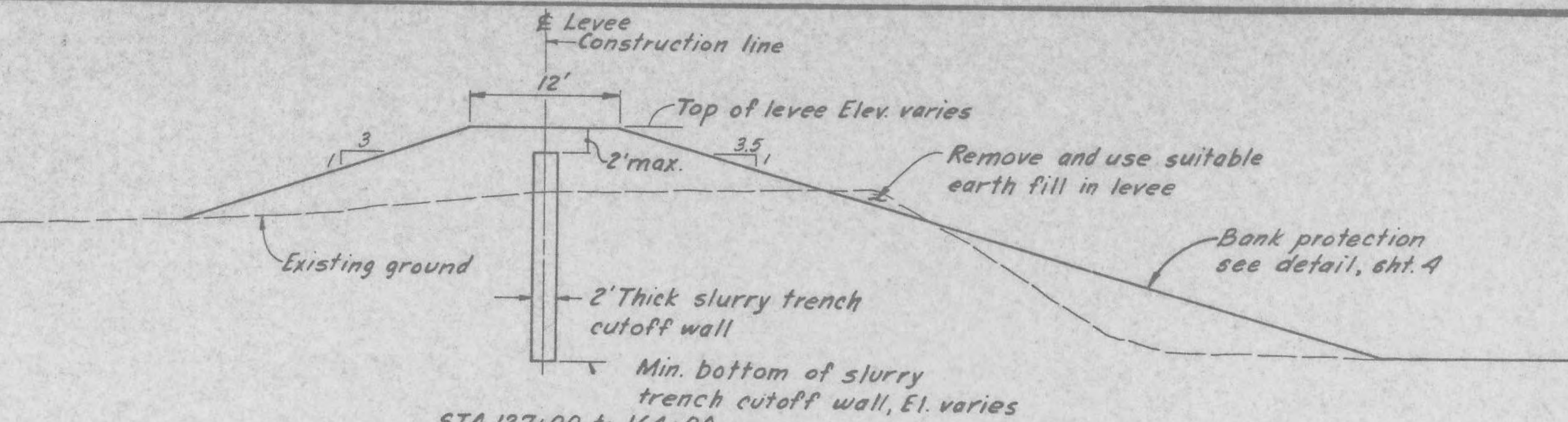
STA. 64+80.21 to 93+00



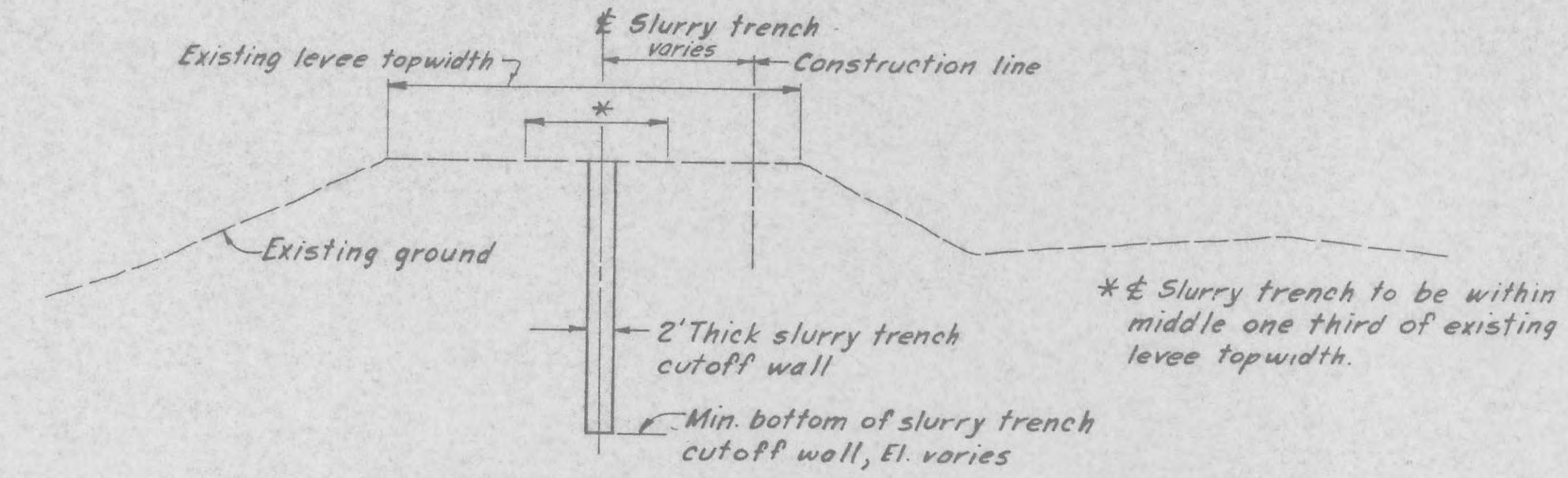
STA. 93+00 to 118+13.22
STA. 168+50 to 217+57.96



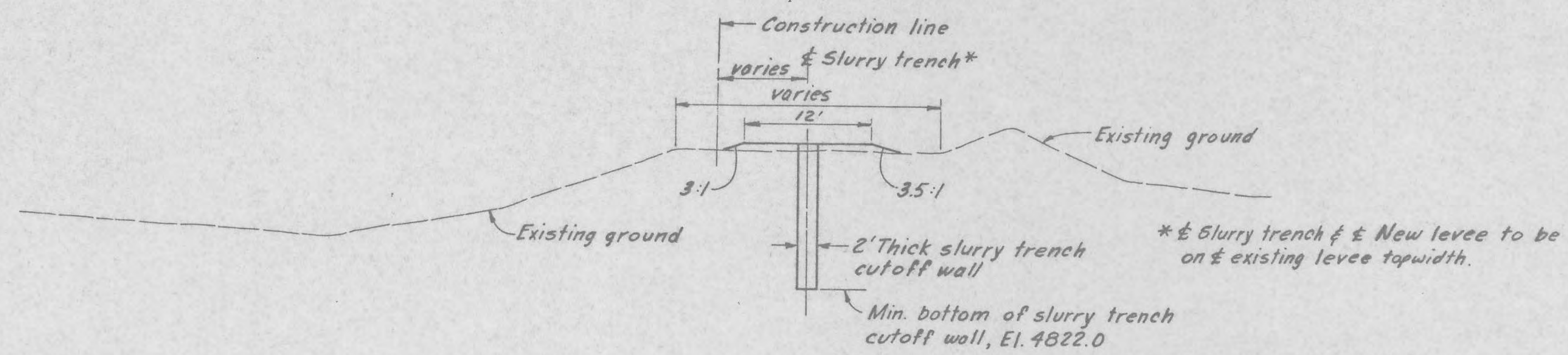
STA. 118+63.22 to 137+00
STA. 164+00 to 168+00
STA. 218+07.96 to 231+45±



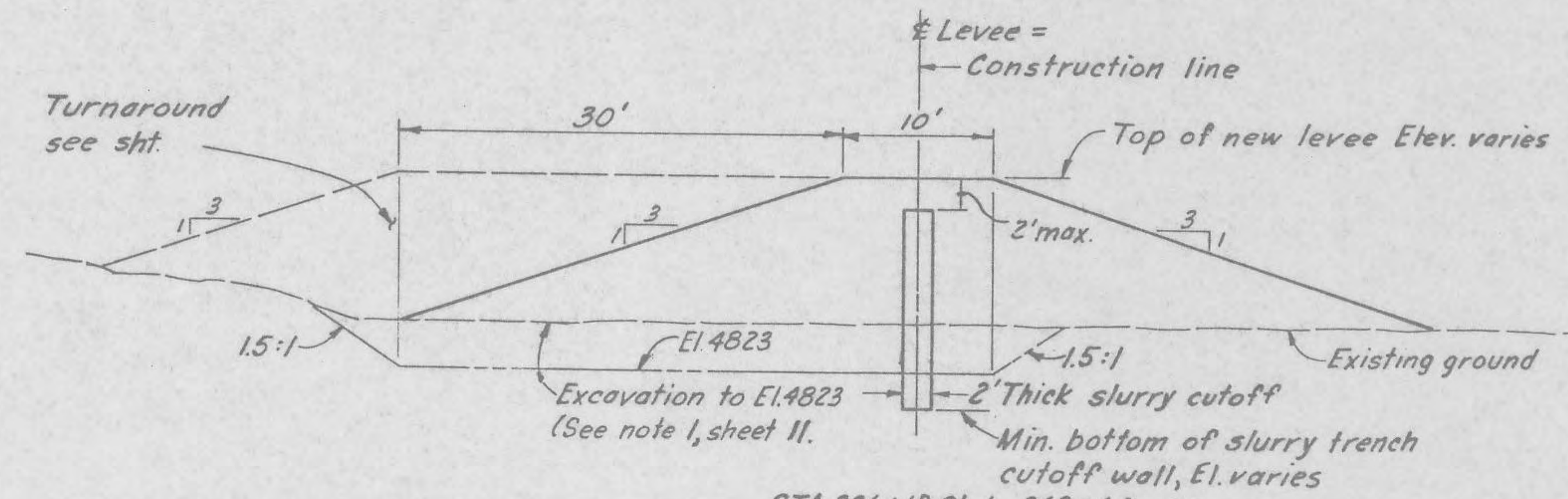
STA. 137+00 to 164+00



STA. 231+45± to 319+80±



STA. 319+80± to 336+10.81



STA. 336+10.81 to 363+60
SECTION 'J'

"AS BUILT" NOTE:
TOP OF SLURRY WALL IS 2.0 FT
BELOW FINISH GRADE. DEPTH OF
SLURRY WALL TRENCH WAS TAKEN
PRIOR TO CONSTRUCTION OF 2.0' CAP.
SEE PROFILE SHEETS 5 THRU 11 FOR
DEPTH OF SLURRY TRENCH CUT-OFF WALL

"AS BUILT"

Scale: 1" = 10'

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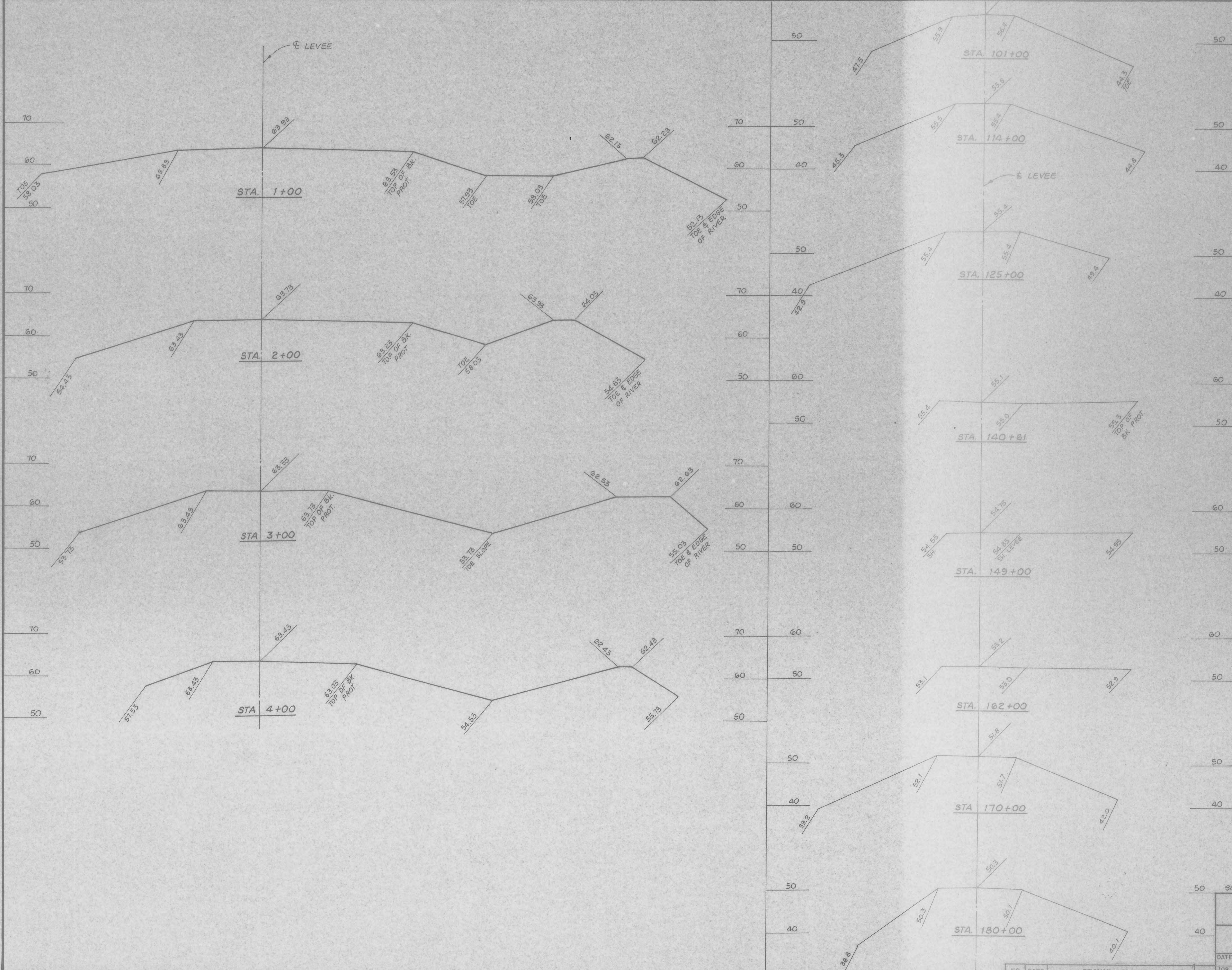
TYPICAL CROSS SECTIONS

NO.	DATE	REVISION - DESCRIPTION	APPR.
1	6/18/87	STA 46+75 to 64+95.21 MOVED CONSTRUCTION CENTERLINE 15'	

DATE 9-82 | DRN. BY LC, DH | DES. BY G.J.S. | CHK. BY A.C.P.
JOB NO. 600 600-3 | FILE H414 | SHEET 3 OF 20



NOTES:
1. STA. 233+00 THRU STA. 286+00. MOST OF THIS AREA, THE BANK PROTECTION IS AS HIGH OR HIGHER THAN THE LEVEE. THE AREA BETWEEN THE JETTIES FILLED WITH ROCK TO THE TOP OF THE LEVEE IT SELF
2. STA. 278+00, BANK PROTECTION SAME AS LEVEE.
3. STA. 281+00, LEVEE = 42.41 BANK PROTECTION = 40.81
4. STA. 283+00, LEVEE SAME HEIGHT AS BANK PROTECTION.
5 STA. 286+00, LEVEE SAME HEIGHT AS BANK PROTECTION.

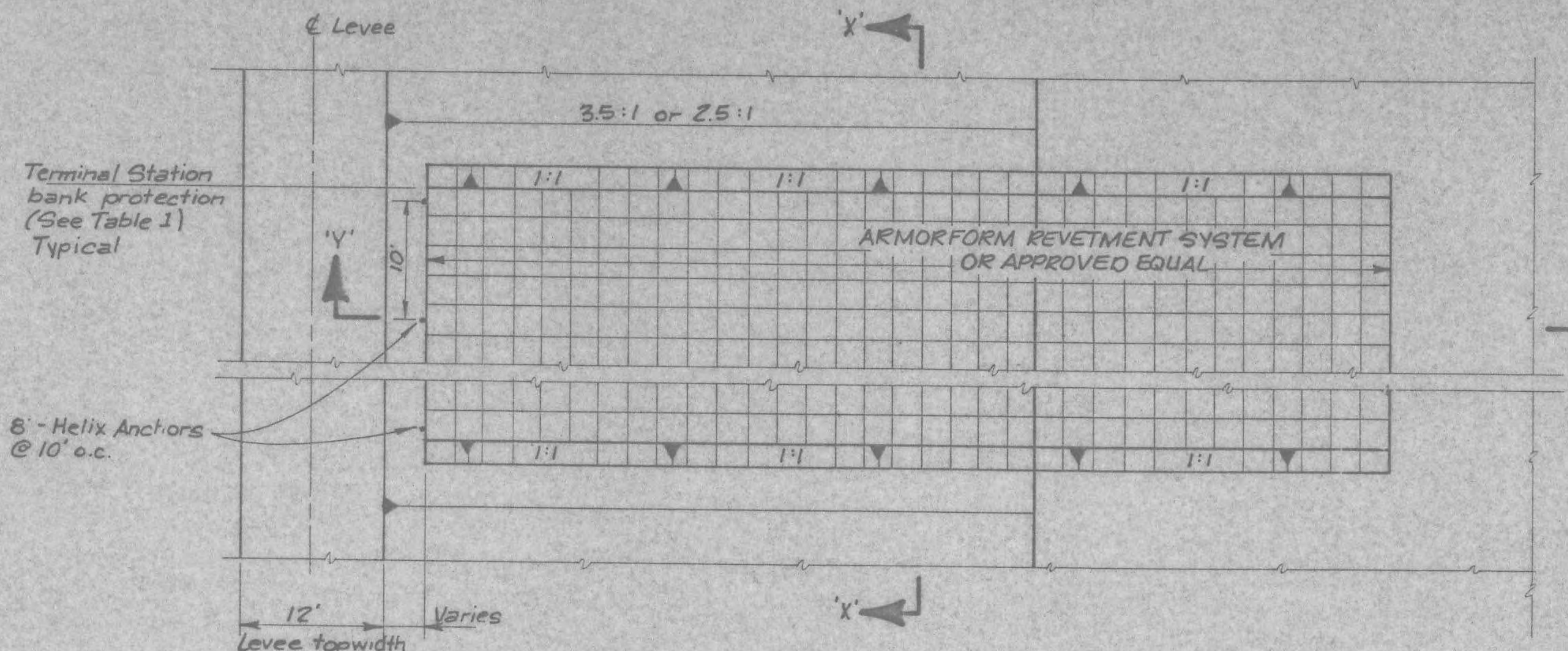
"AS BUILT"

SCALE: 1" = 10'

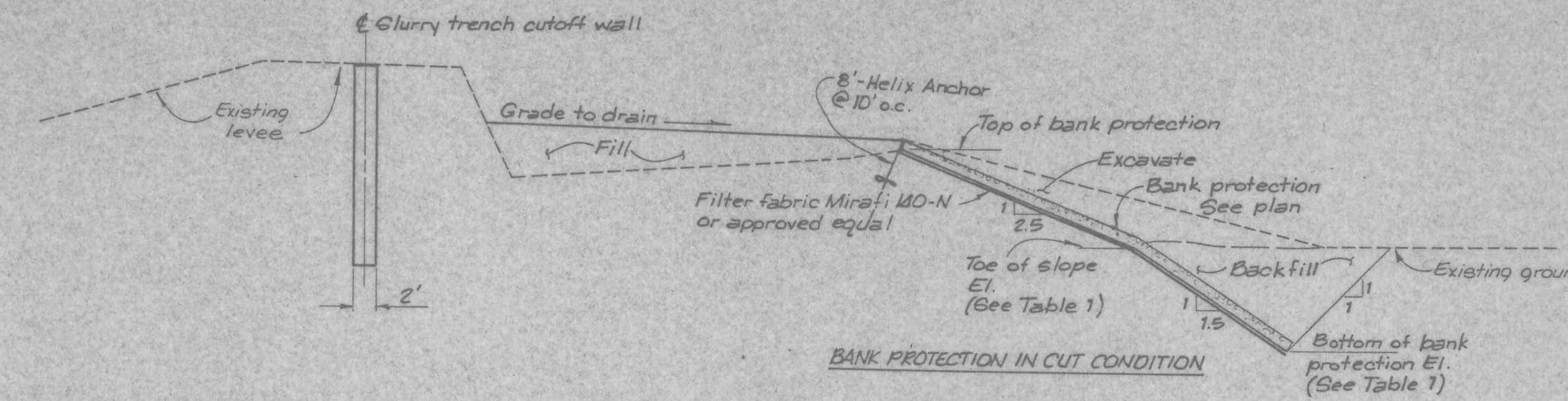
FLOOD CONTROL PROJECT
WINSLOW, ARIZONA
"AS BUILT" TYPICAL CROSS SECTIONS

NO.	DATE	REVISION - DESCRIPTION	APPR.

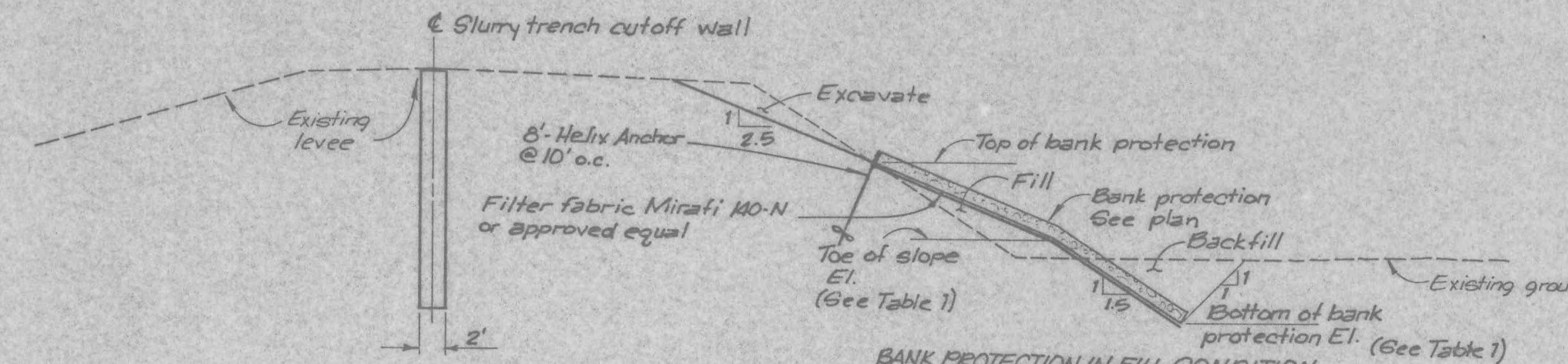
DATE 9-89 | DRN. BY: G.E.R. | DES. BY: | CHK. BY:
JOB NO | FILE: H414 | SHEET 3A OF 20



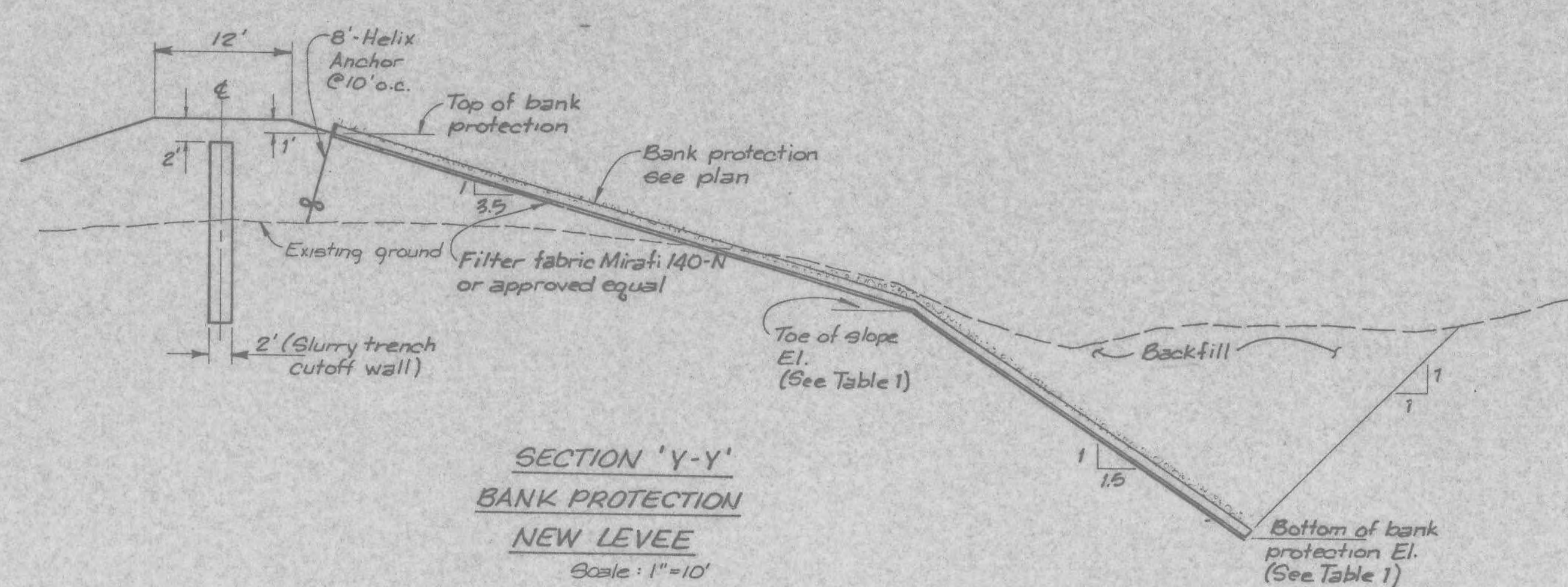
PLAN VIEW
BANK PROTECTION
Scale: 1"=10'



BANK PROTECTION IN CUT CONDITION



BANK PROTECTION IN FILL CONDITION

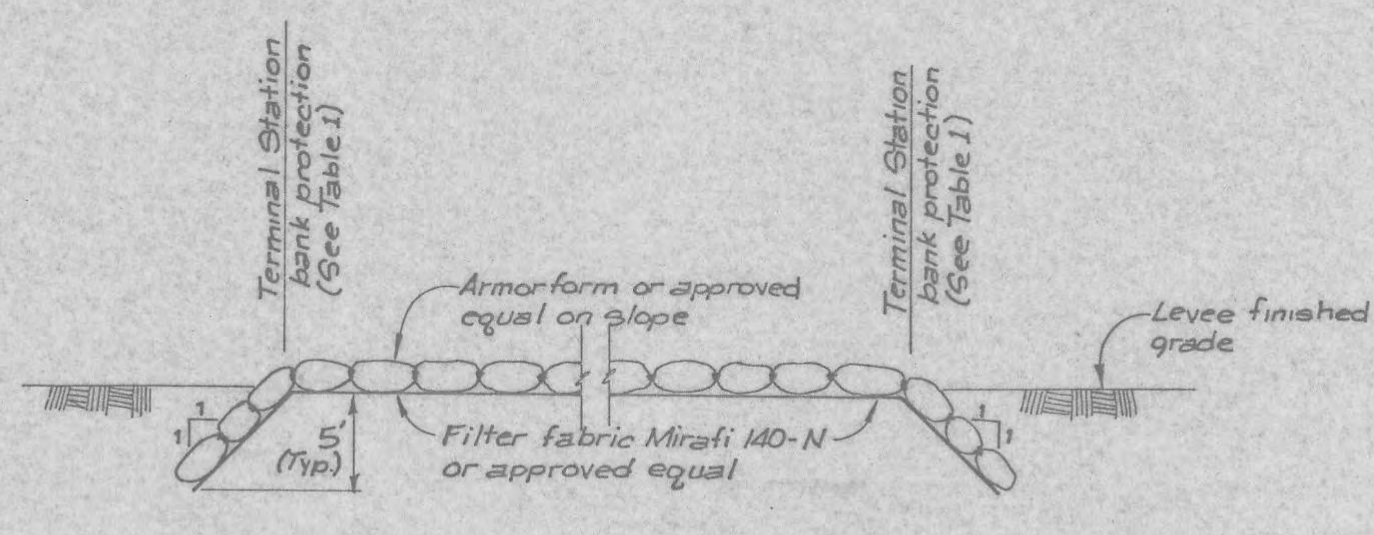


SECTION 'Y-Y'
BANK PROTECTION
NEW LEVEE
Scale: 1"=10'

BANK PROTECTION
EXISTING LEVEE
Scale: 1"=10'

TABLE 1			
Location	Toe of Slope Elev.	Bot. of Bank Protect. Elev.	Levee Type side slope
Sta.-(3+50)± to Sta.-(0+62)*	4853.0	4829.0	New 3.5:1
Sta. 0+60* to Sta. 4+31*	4853.0	4833.0	New 3.5:1
Sta. 137+00 to Sta. 164+00	4840.0	4812.0	New 3.5:1
Sta. 233+02.5 to Sta. 251+27.8	4833.0	4805.0	Exist. 2.5:1
Sta. 251+27.8 to Sta. 272+00	4834.0	4810.0	Exist. 2.5:1
Sta. 272+00 to Sta. 286+00	4828.0	4800.0	Exist. 2.5:1

* Transition into existing embankment



SECTION 'X-X'
N.T.S.

"AS BUILT"

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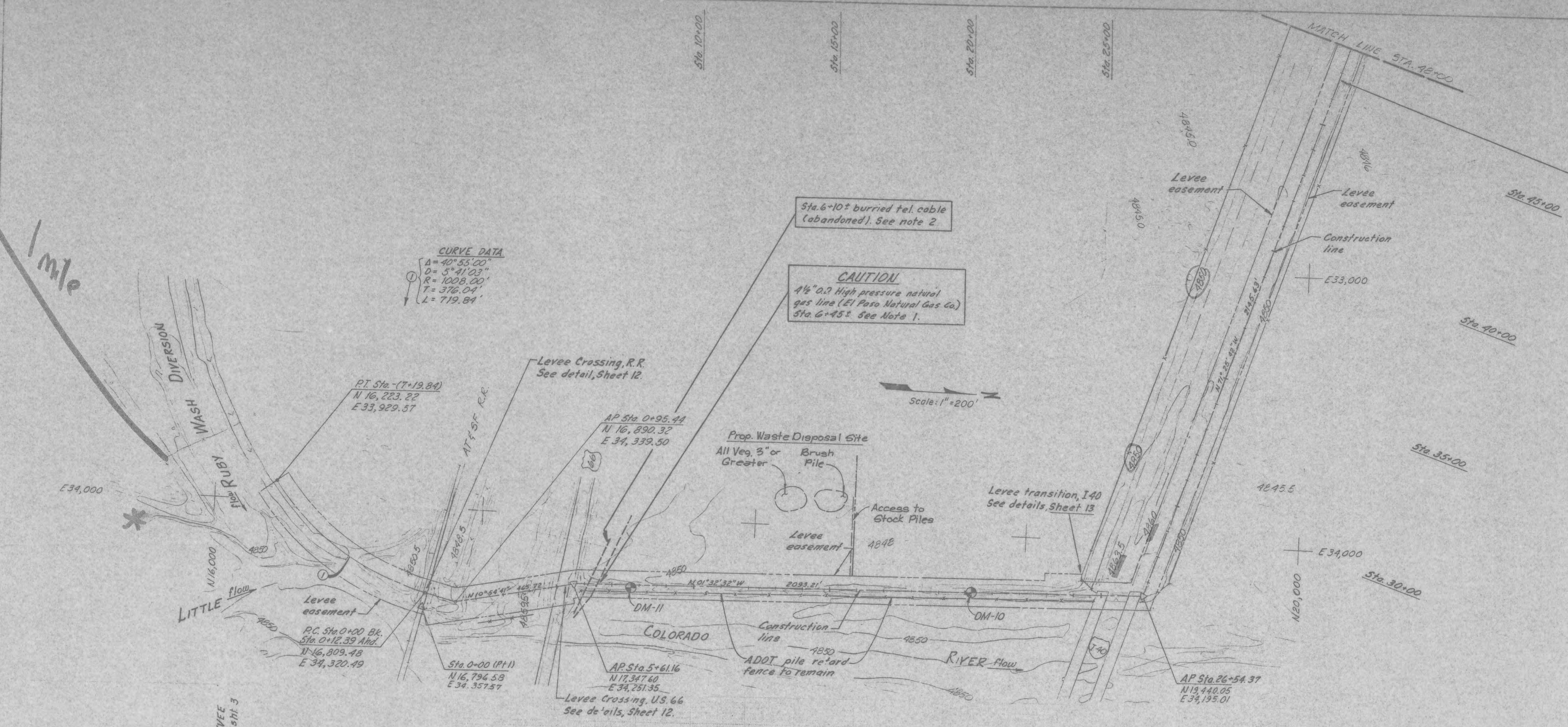
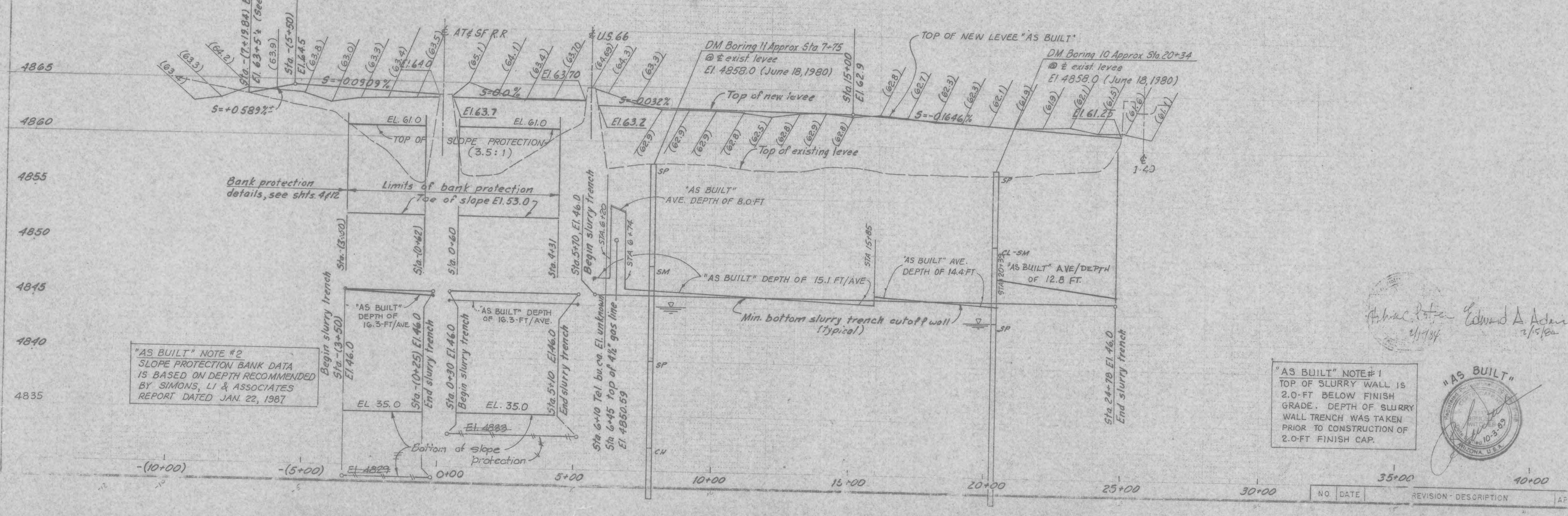
FLOOD CONTROL PROJECT
WINSLOW, ARIZONA

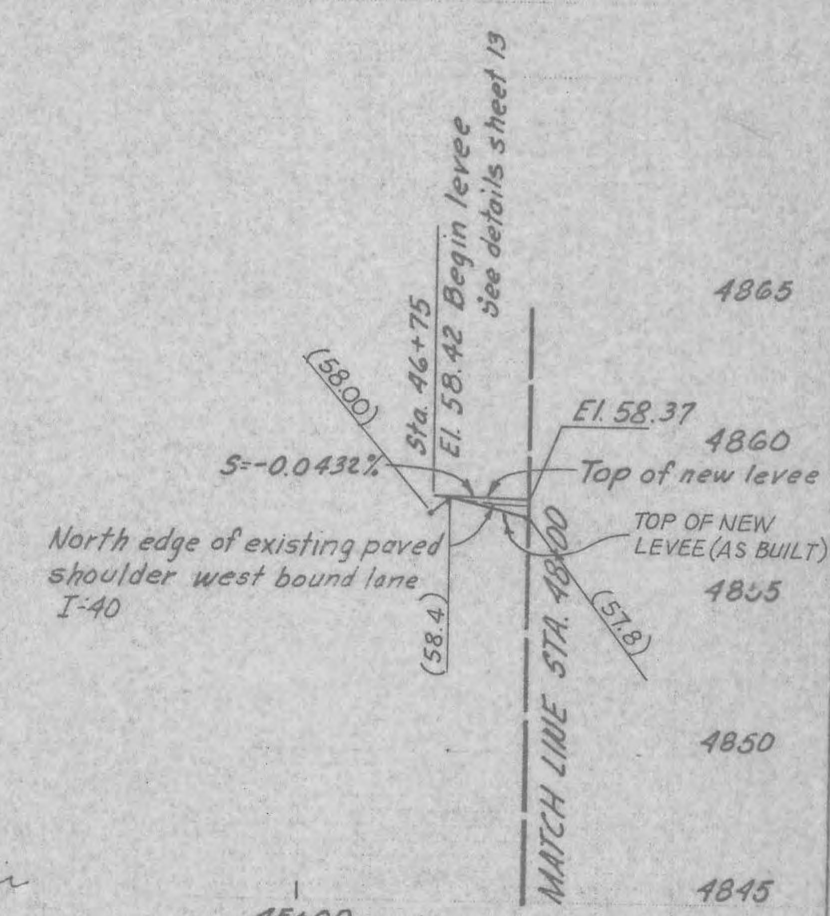
LEVEE BANK PROTECTION

DATE	DRN BY	DES BY	CK BY
9-17-82	D.H., L.C.	G.A.S.	A.C.P.

JOB NO. 600-600-3 FILE 11414 SHEET 4 OF 20







NOTES:

1. It shall be the responsibility of the contractor to determine the exact location of the high pressure gas line. The contractor shall contact El Paso Natural Gas Co. (602) 526-0890 at least 48 hours in advance of any construction activities in the vicinity of the gas lines to coordinate supervision of construction by El Paso Natural Gas Company personnel. The cutoff wall shall be installed so as to form an impervious seal around gas line.
2. The contractor shall cut and remove, as necessary, a segment of abandoned telephone cable prior to installation of cutoff wall.
3. The contractor shall seed all areas disturbed by construction of the levee within ADOT R/W for highways U.S. 66, I 40 and I 4 channel.

"AS BUILT" NOTE #2
SLOPE PROTECTION BANK DATA IS BASED ON DEPTH RECOMMENDED BY SIMONS, LI & ASSOCIATES REPORT DATED JAN. 22, 1987

"AS BUILT" NOTE #1
TOP OF SLURRY WALL IS 2.0-FT BELOW FINISH GRADE. DEPTH OF SLURRY WALL TRENCH WAS TAKEN PRIOR TO CONSTRUCTION OF 2.0-FT FINISH CAP.

"AS BUILT"

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FLOOD CONTROL PROJECT
WINSLOW, ARIZONA

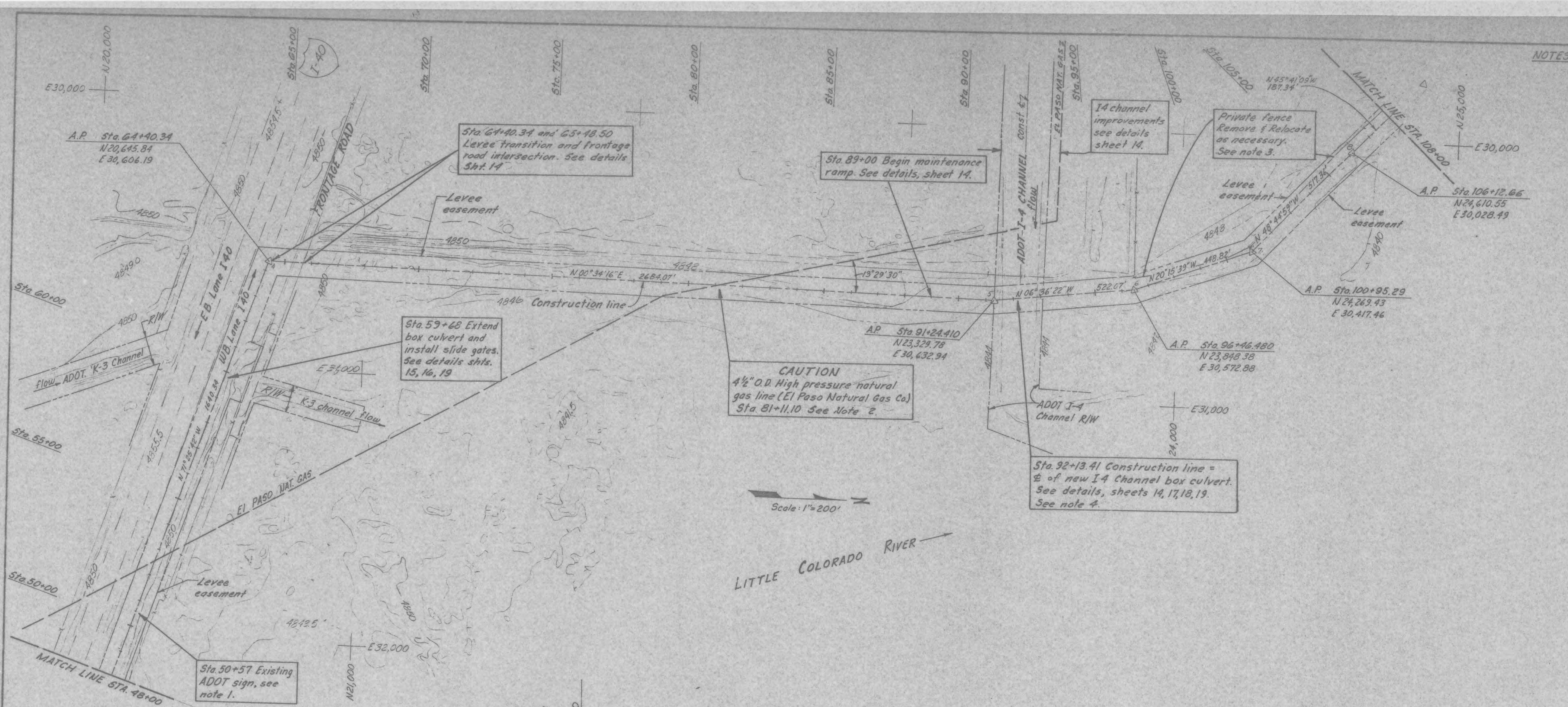
PLAN AND PROFILE
STA. -(7+19.84) TO STA. 48+00.00

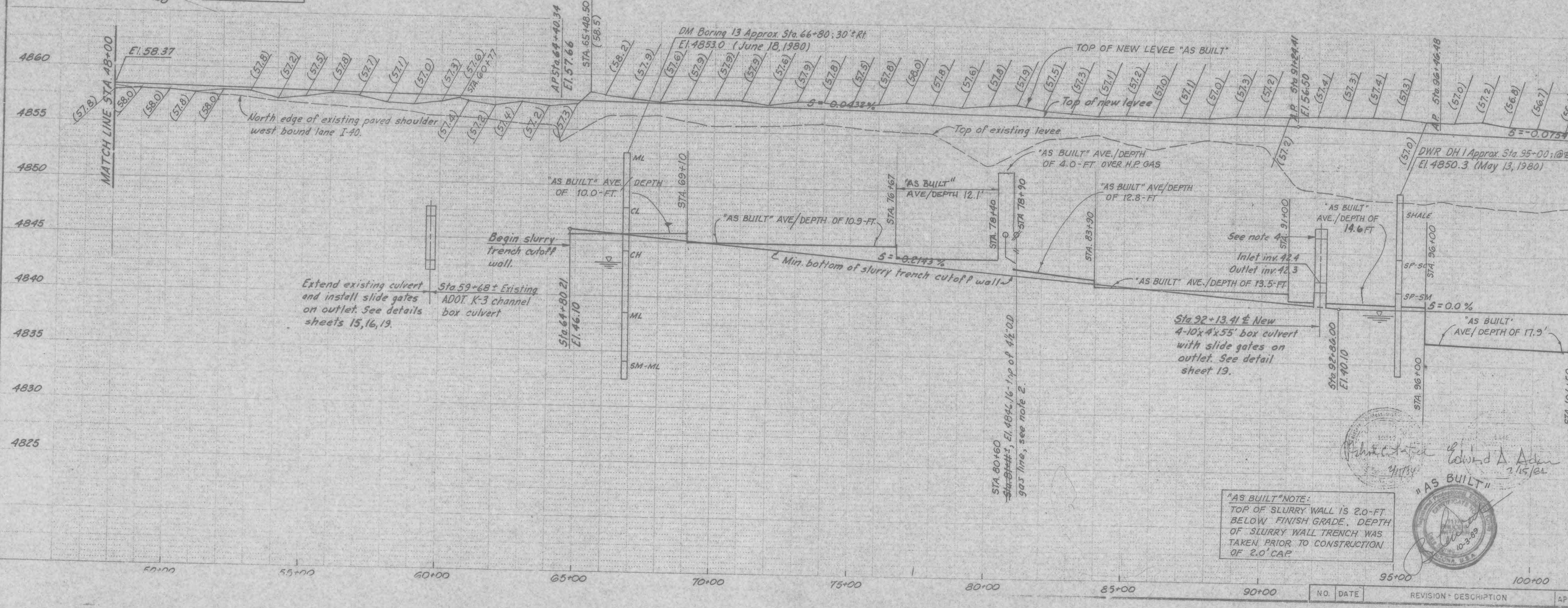
NO	DATE	REVISION · DESCRIPTION	APPR

DATE | DRN. BY L.C.C.N. | DES. BY G.A.S. | CHK. BY A.C.P.
JOB NO. 600-000-3 | FILE H414 | SHEET 5 OF 20

NOTES:

1. The contractor shall remove existing ADOT sign, including posts, store and reinstall at the completion of construction as directed by ADOT.
2. The contractor shall determine the exact location of the high pressure gas line. The contractor shall contact El Paso Natural Gas Company (EPNGC) (602) 526-0890 at least 48 hours in advance of any construction activities in the vicinity of the gas lines to coordinate supervision of construction by EPNGC personnel. The cutoff wall shall be installed so as to form an impervious seal around gas line.
3. The contractor shall remove private fence and gates as necessary within construction easement. The exact location and extent of permanent fence and gates to be installed, shall be determined by the Engineer in the field. Private fence shall be five wire barbed wire fence ADOT C-12.01, Type 2.
4. The contractor shall install slurry trench cutoff wall to the sides and along the top of the I-4 channel box culvert. Cutoff wall is not necessary below the box culvert.
5. The contractor shall seed all areas disturbed by the construction of levee within ADOT R/W for highway U.S. 66, I40 and I4 channel.





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FLOOD CONTROL PROJECT
WINSLOW, ARIZONA

PLAN AND PROFILE
STA. 48+00.00 TO STA. 108+00.00

DATE	DRN. BY L.C., D.H.	DES BY G.A.S.	CHK. BY A.C.P.
JOB NO. 600-600-3	FILE H414	SHEET 6 OF 22	

Notes

1) Vary levee sideslopes to avoid conflict with existing barn.

2. The contractor shall remove private fence and gates as necessary within construction easement. The exact location and the extent of permanent fence and gates to be installed, shall be determined by the Engineer in the field. Private fence shall be five wire barbed wire fence ADOT C-12.01, Type 2.

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FLOOD CONTROL PROJECT
WINSLOW, ARIZONA

PLAN AND PROFILE
STA. 108+00.00 TO STA. 168+00.00

DATE	DRN. BY L.C., D.I.	DES. BY G.A.S.	CHK. BY A.C.P.
JOB NO. 600-600-3	FILE H414		SHEET 7 OF 20

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Planning Research Company
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FLOOD CONTROL PROJECT
WINSLOW, ARIZONA

PLAN AND PROFILE
STA. 168+00.00 TO STA. 228+00.00

DATE	DRN BY L.C., DH	DES BY G.A.S.	CHK BY A.C.P.
J.O. NO. 600-600-3	FILE H414	SHEET 8 OF 20	

NO.	DATE	REVISION · DESCRIPTION	APPR

NOTES: 1. It shall be the resposibility of the Contractor to determine the exact location of privite underground electric conduit (12 KV).

2. The Contractor shall install cutoff wall at conduit such that soil bentonite wall forms an impervious seal around conduit.

3. The contractor shall remove private fence and gates as necessary within construction easement. The exact location and extent of permanent fence and gates to be installed, shall be determined by the Engineer in the field. Private fence shall be five wire barbed fence ADOT C-12.01, Type 2.

"AS BUILT" NOTE # 2
SLOPE PROTECTION BANK DATA IS BASED ON DEPTH RECOMMENDED BY SIMONS, LI & ASSOCIATES DATED JAN. 22, 1987

"AS BUILT" NOTE # 1
TOP OF SLURRY WALL IS 2.0 FT. BELOW FINISH GRADE. DEPTH OF SLURRY WALL TRENCH WAS TAKEN PRIOR TO CONSTRUCTION OF 2.0' CAP.

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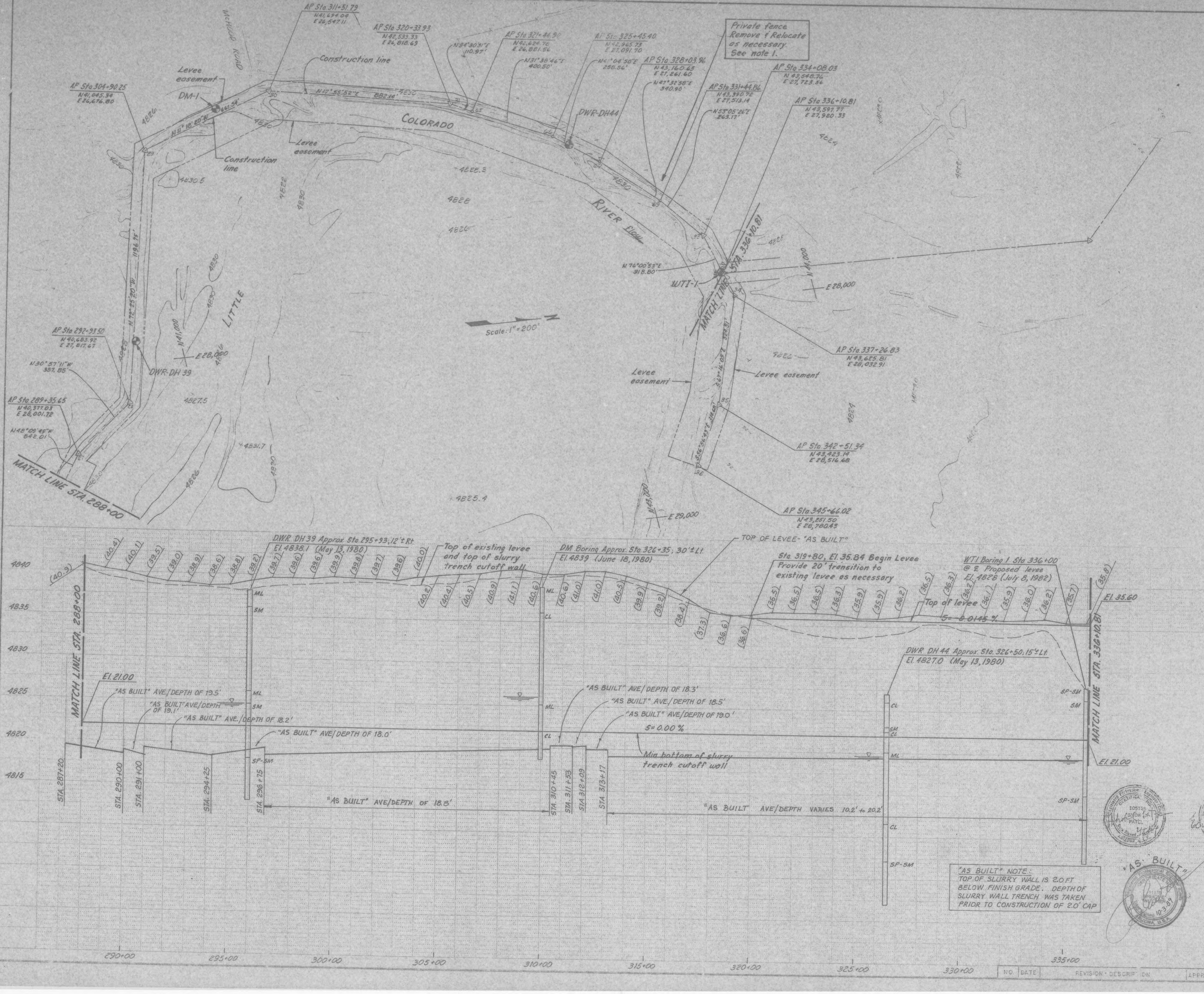
FLOOD CONTROL PROJECT
WINSLOW, ARIZONA

PLAN AND PROFILE
STA. 228+00.00 TO STA. 288+00.00

DATE	DSN BY L.C., D.H.	DES BY G.A.S.	CHK BY A.C.P.
JOB NO 600-600-3	FILE H414	SHEET 9 OF 20	

NO.	DATE	REVISION - DESCRIPTION	A. PR.



NOTES: 1. The contractor shall remove private fence and gates as necessary within construction easement. The exact location and extent of permanent fence and gates to be installed, shall be determined by the Engineer in the field. Private fence shall be five wire barbed fence ADOT C-12.01, Type 2.

"AS BUILT" NOTE:
TOP OF SLURRY WALL IS 2.0 FT BELOW FINISH GRADE. DEPTH OF SLURRY WALL TRENCH WAS TAKEN PRIOR TO CONSTRUCTION OF 2.0' CAP

"AS BUILT"

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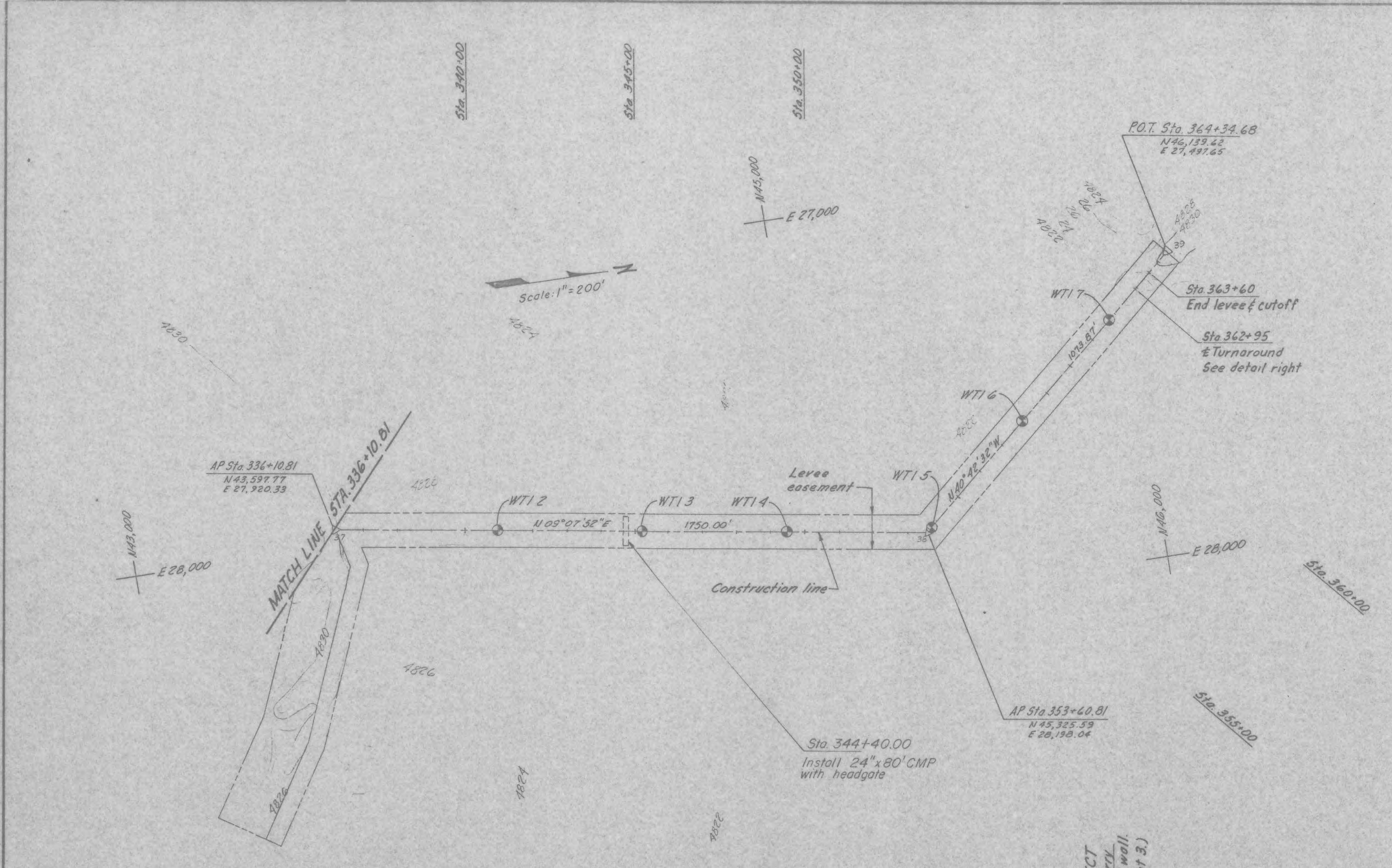
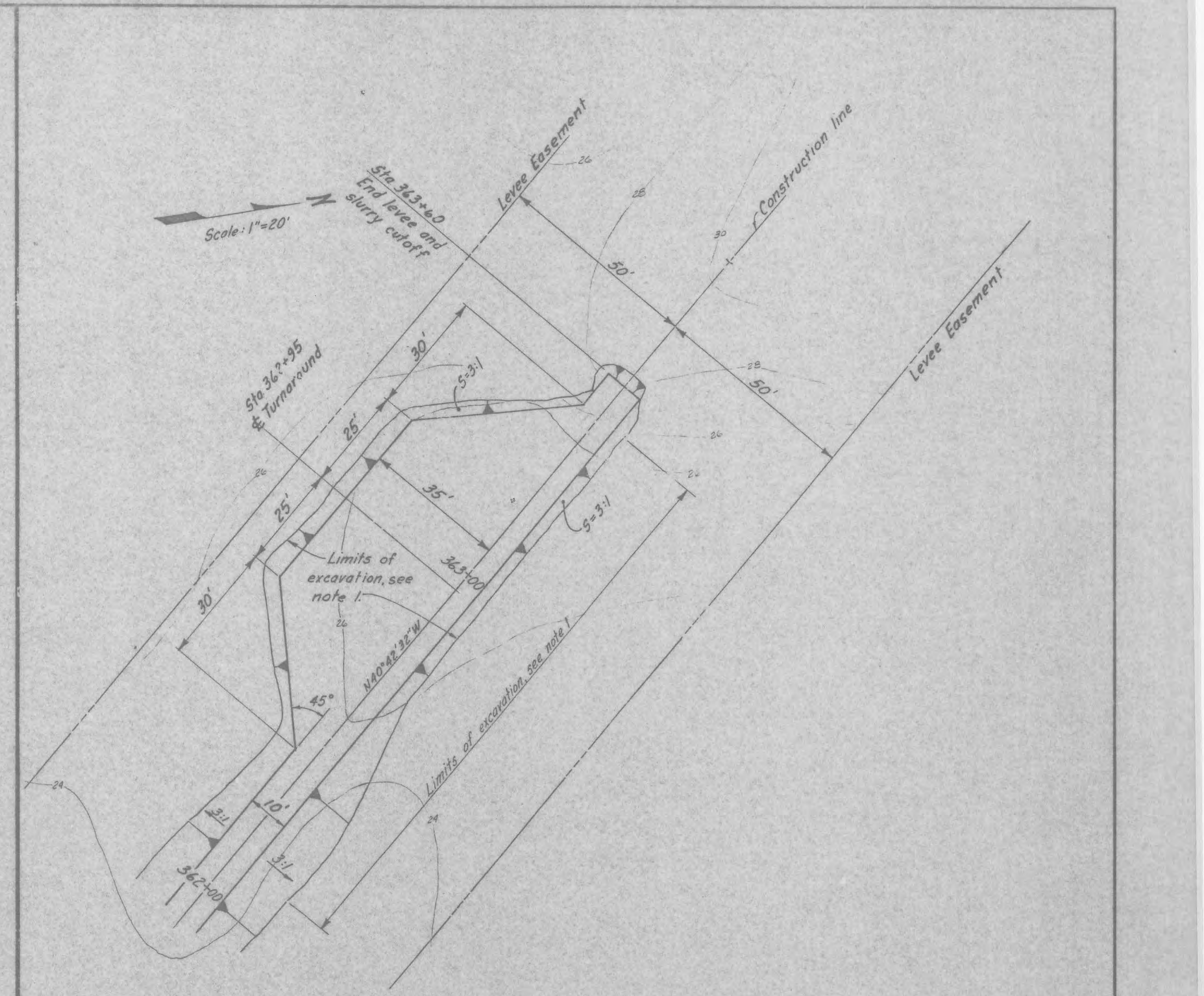
FLOOD CONTROL PROJECT
WINSLOW, ARIZONA

PLAN AND PROFILE
STA. 288+00.00 TO STA. 336+10.81

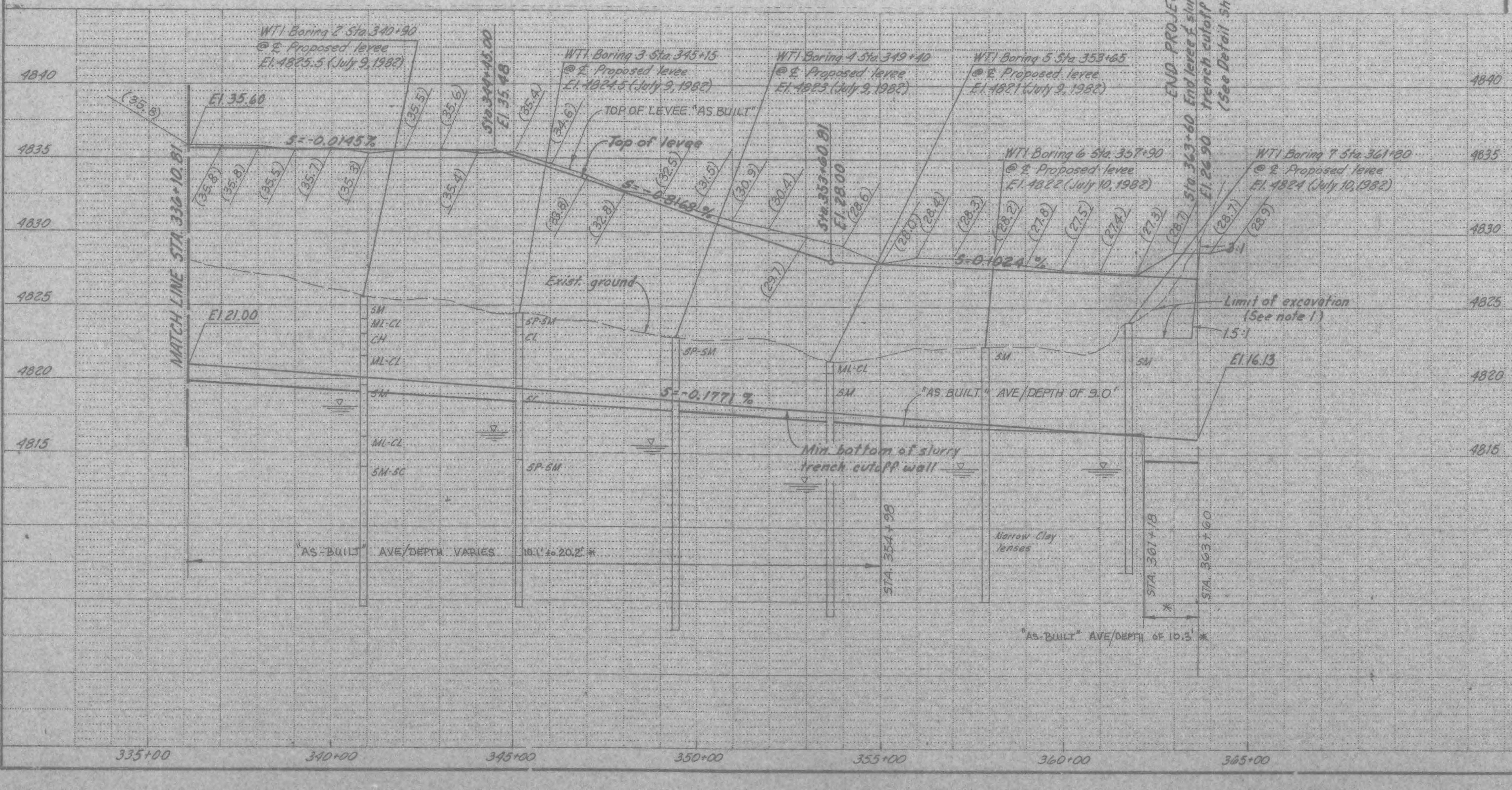
DATE	DRN BY L.C., D.H.	DES BY G.A.S.	CHK BY A.C.F.
JOB NO. 600-600-3	FILE H41K	SHEET 10 OF 20	

NO.	DATE	REVISION - DESCRIPTION	APPR





TURNAROUND DETAIL



NOTE: 1. The area bounded by Sta. 361+40 to Sta. 363+50 and the approximate slope limits, as shown, shall be leveled to elevation 4823. Material removed shall be replaced by suitable fill, compacted to the elevations and limits as shown. See Section 'J' sheet 3

"AS BUILT" NOTE:
TOP OF SLURRY WALL IS 2.0 FT. BELOW FINISH GRADE. DEPTH OF SLURRY WALL TRENCH WAS TAKEN PRIOR TO CONSTRUCTION OF 2.0' CAP.

"AS BUILT"

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FLOOD CONTROL PROJECT
WINSLOW, ARIZONA

PLAN AND PROFILE
STA. 336+10.81 TO STA. 364+34.68

NO	DATE	REVISION DESCRIPTION	APPR

DATE | DRN BY LJC/DBH | DES BY G.A.S. | CHK BY A.C.P.
JOB NO. 600-600-3 | FILE H414 | SHEET 11 OF 20

NOTES:

1. The contractor shall remove existing ADOT sign, including posts, store and reinstall at the completion of construction as directed by ADOT.
2. Sta. -(0+29), 0+32, 4+98 and 5+65, (18' Lt.) Install ADOT Type I gate, Std. Det. C-12.01, length = 12'. Gates shall be centered on levee.
3. The contractor shall contact Arizona Public Service (APS) to advise of the contractor's construction schedule and coordinate relocation of power pole. Relocation of pole to be performed by APS forces. The contractor shall contact APS within 30 working days of recieving notice to proceed.
4. The contractor shall cut and remove, as necessary, a segment of the abandoned telephone cable prior to installation of slurry trench cutoff wall.

As Built

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FLOOD CONTROL PROJECT
WINSLOW, ARIZONA

LEVEE CROSSING DETAILS
RAILROAD & U.S. 66

NO	DATE	REVISION - DESCRIPTION	APPR

DATE 9-82	DRN BY L.C., D.H.	DES BY A.C.P.	CHK BY A.C.P.
JOB NO. 600-600-3	FILE H-414	SHEET 12 OF 20	

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FLOOD CONTROL PROJECT
WINSLOW, ARIZONA

LEVEE CROSSING DETAILS
I 40 & K-3 CHANNEL

NO	DATE	REVISION DESCRIPTION	APPR

DATE 9-82 | DRN BY L.C., D.H. | DES BY A.C.P. | CHK BY A.C.P.
JOB NO 600-600-3 | FILE H-414 | SHEET 13 OF 20


NOTE
1. The contractor shall raise the north dike on the existing ADOT I-4 channel where necessary to provide a 5' height above the channel invert from the new levee crossing to the existing I-40 box culverts (3700'±)
R/W
180' R/W
135'
Existing I-4 Channel
See note 1.
10'
5'
4'
Existing invert
Existing ground
1.5:1 typ.
Existing levee
SECTION B
Scale: Hor. 1"=20' Vert. 1"=5'
Levee Easement
℄ Levee = Construction line
ADOT I-4 Channel R/W (180')
A.P. Sta. 91+24.41, El 56.5
N23,329.78
E30,632.94
N 00° 34' 14" E
N 06° 36' 22" W
Slope varies
S=10%
Sta. 89+00 Begin access ramp
Sta. 89+86
Sta. 90+06 Begin 10:1 slope
Sta. 90+46
R=10'
10' Transition to existing ground.
Sta. 91+35 (extended) 64.25' Rt.
℄ and End maintenance access ramp.
Inv. 42.4
Inv. 42.3
℄ Sta. 92+13.41
ADOT I-4 Culvert 4-10'x4' = 44'±
Note: See Shts. 17, 18, 19 for culvert details
Scale: 1"=20'
℄ Levee = Construction Line
Sta. 65+48.50 levee const. line = Sta. 2+16.50 Frontage road
Sta. 4+11 end new pavement sawcut & match existing pavement
FRONTAGE ROAD
Sta. 1+00 Begin new pavement sawcut & match existing pavement.
Sta. 65+28 Install 12 foot gate ADOT Std. C-12.04, centered on top of levee
Sta. 64+80.21 Begin slurry trench. Bottom El 4846.0
Sta. 64+95.21 to Sta. 64+14.37 Transition topwidth 10' to 12'
Remove & salvage existing ADOT fence from frontage road Sta. 1+00 to 4+00. Reinstall fence upon completion of levee and grader road.
Scale: 1"=30'
℄ Levee
N 71° 25' 42" W
Construction line
40 (West bound lane)
W.B. Const. ℄
Edge of pavement
Edge of existing pavement
Curve 3:
Δ=71°08'29"
D=229°10'59"
R=25'
T=17.88'
L=31.04
Sta. 60+40.34
N20,645.84
E30,606.19
AP - ½ rebar El 4852.72
Install 1879'± Lin. Ft. ADOT fence Std C-12.03 (72") Sta. 47+03 (52'± Rt.) to Sta. 65+30± (8'± Lt.)
Sta. 64+29.37 Channel invert = 4854.05
℄ Frontage road
S=0.02 ft/ft
6" ABC with bituminous prime coat and chip seal coat.
Existing fence to be removed, salvaged and reinstalled.
Existing road surface
Existing ground
SECTION A-A
Scale: 1"=5'
PVC Sta. 1+00, El 57 Begin new pavement match existing pvmt.
200' Vertical curve
PVI Sta. 2+00 El 59.9
℄ Levee Sta. 2+16.50 frontage road Sta. 65+48.50 levee construction line
PVT Sta. 3+00 El 56.3
+2.9%
-3.6%
Finished grade @ ℄
Existing road surface
Sta. 4+11 El 52.3 End new pavement match existing pvmt.
4860
4855
4850
0+00
1+00
2+00
3+00
4+00
FRONTAGE ROAD PROFILE
Scale: Horz. 1"=30' Vert. 1"=5'
As Built
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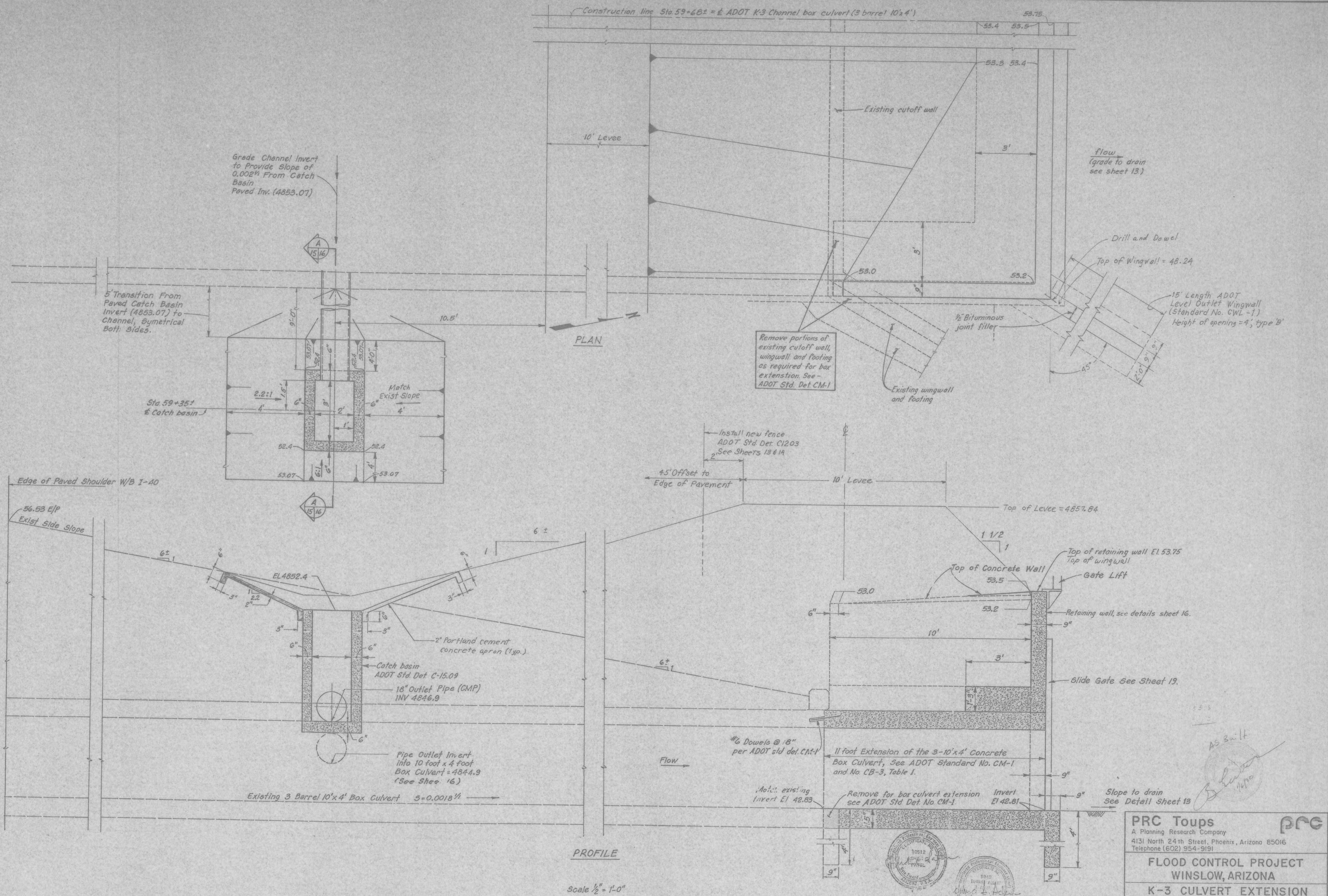
FLOOD CONTROL PROJECT
WINSLOW, ARIZONA
LEVEE CROSSING DETAILS
I-4 CHANNEL & GRADER ROAD
1 | 6/12/87 | STA. 46+75 to PT 64+95.21 MOVED CONSTRUCTION CENTERLINE 15'
NO. | DATE | REVISION · DESCRIPTION | APPR
DATE 9-82 | DRN BY L.C., D.H. | DES. BY A.C.P. | CHK. BY A.C.P.
JOB NO. 600-600-3 | FILE H-414 | SHEET 14 OF 20



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FLOOD CONTROL PROJECT
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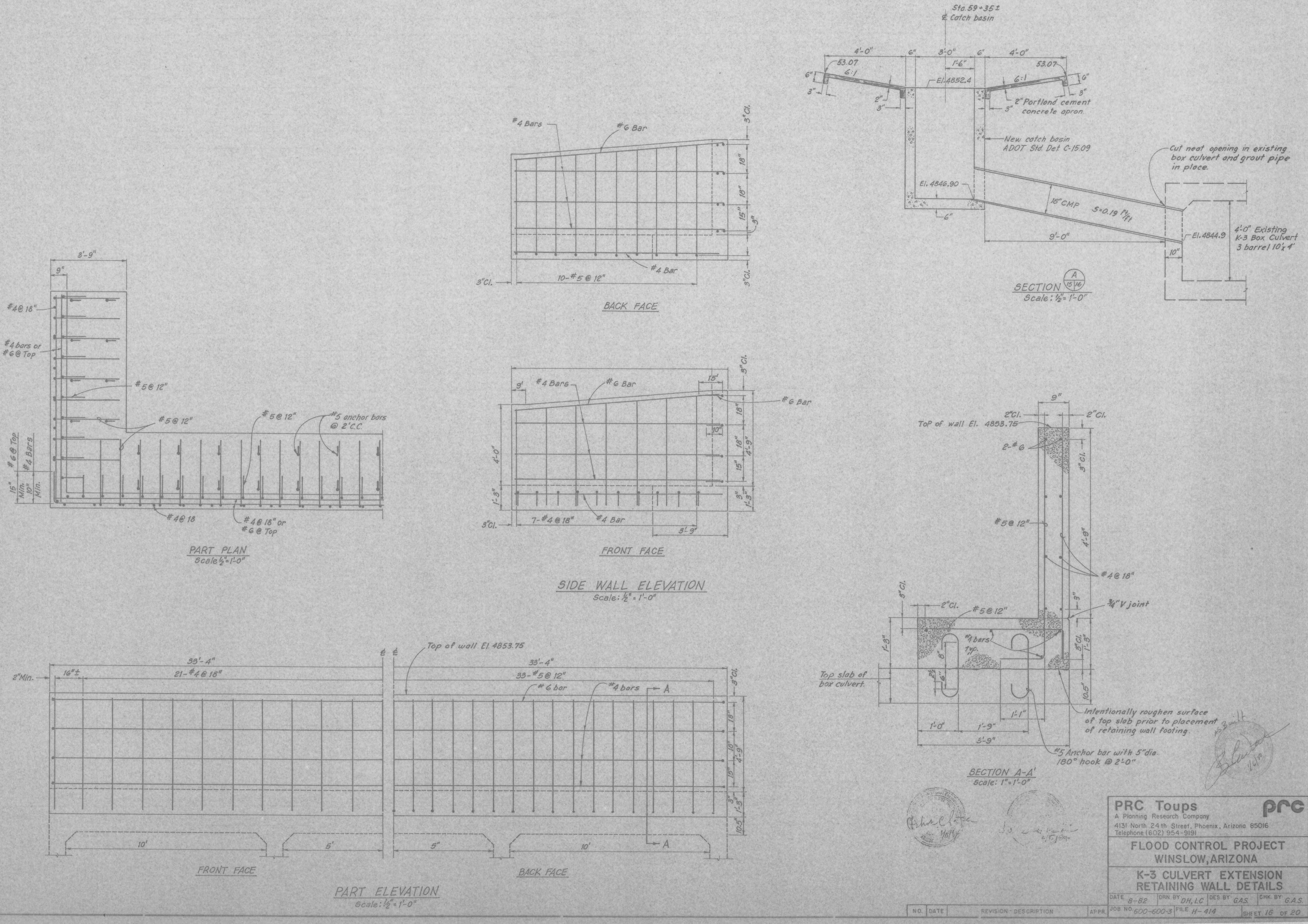
K-3 CULVERT EXTENSION LAYOUT

DATE	DRN BY	DES BY	CHK BY
9-82	LC, DH	GAS	GAS

JOB NO 600-600-3 FILE H-414 SHEET 15 OF 20

NO.	DATE	REVISION - DESCRIPTION	APPR.
1	6/12/87	CHANGED WINGWALL MOVED CONSTRUCTION CENTERLINE 15'	



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FLOOD CONTROL PROJECT
WINSLOW, ARIZONA

K-3 CULVERT EXTENSION
RETAINING WALL DETAILS

NO.	DATE	REVISION DESCRIPTION	APPR.

DATE 8-82	DRN. BY DH, LC	DES. BY G.A.S.	CHK. BY G.A.S.
JOB NO. 600-600-3	FILE H-414		SHEET 16 of 20

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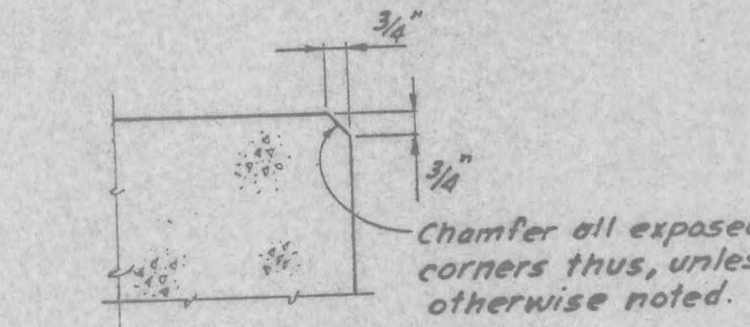
FLOOD CONTROL PROJECT
WINSLOW, ARIZONA

I-4 BOX CULVERT LAYOUT

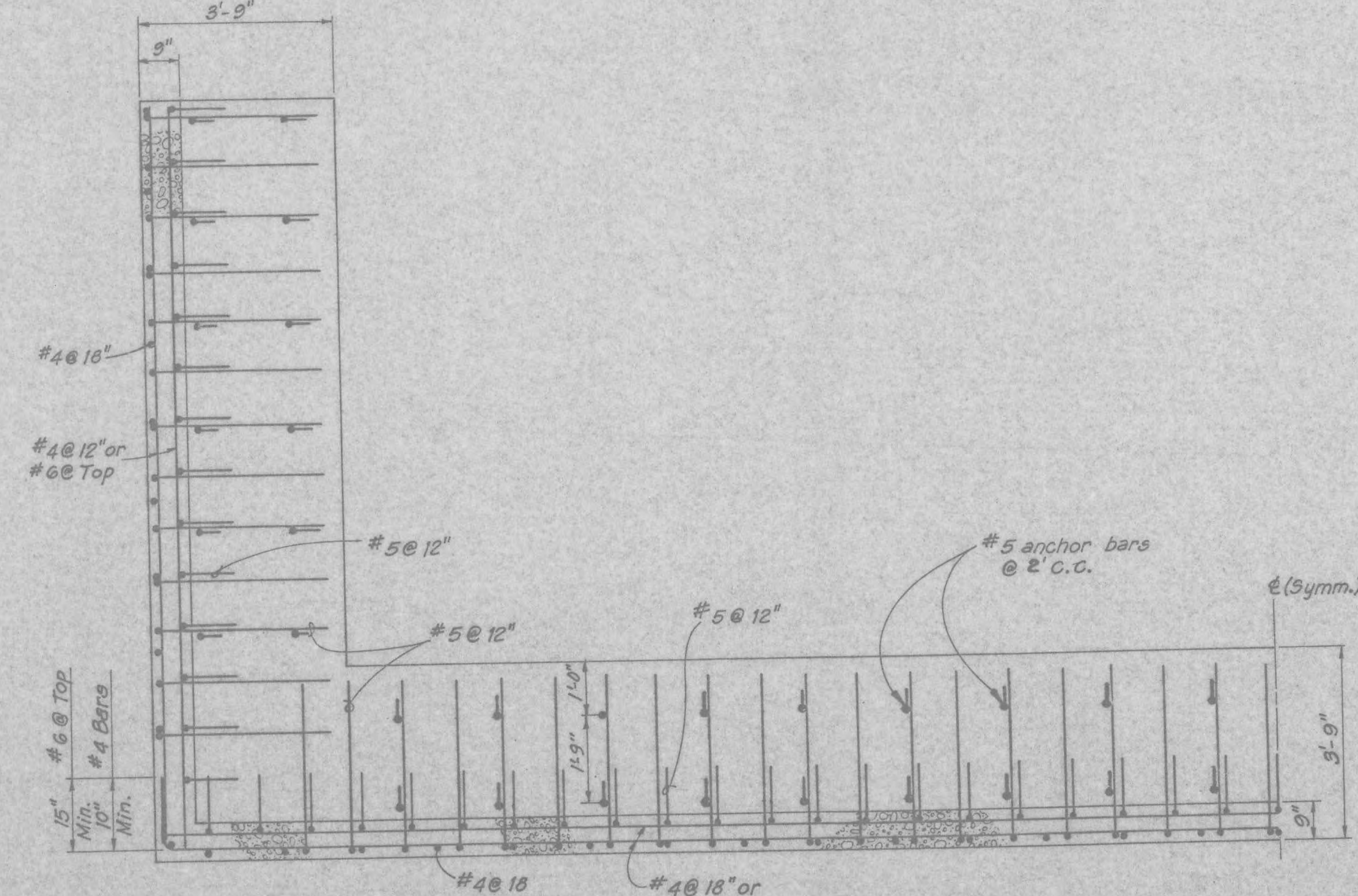
DATE	DRN. BY	DES. BY	CHK. BY
9-82	L.C. D.H.	G.A.S.	G.A.S.

JOB NO.	FILE	SHEET
600-600-3	H-414	17 of 20

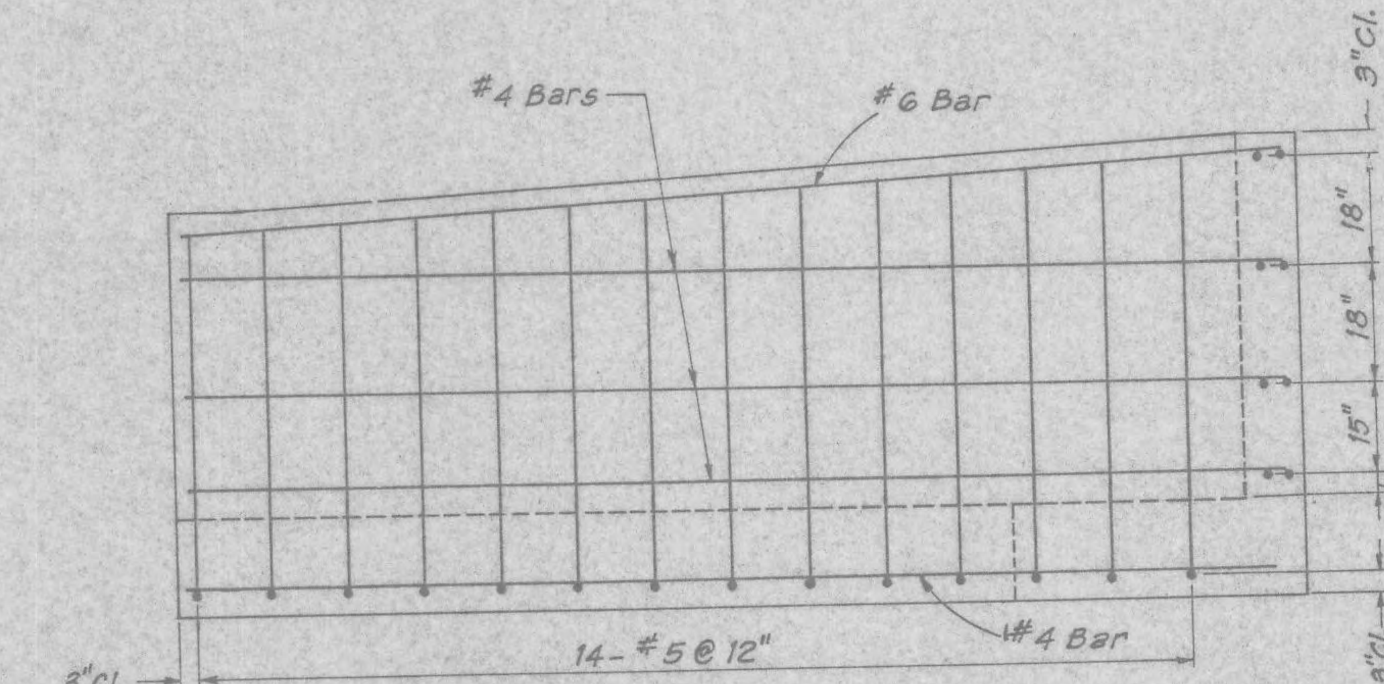
NO.	DATE	REVISION - DESCRIPTION	APPR.



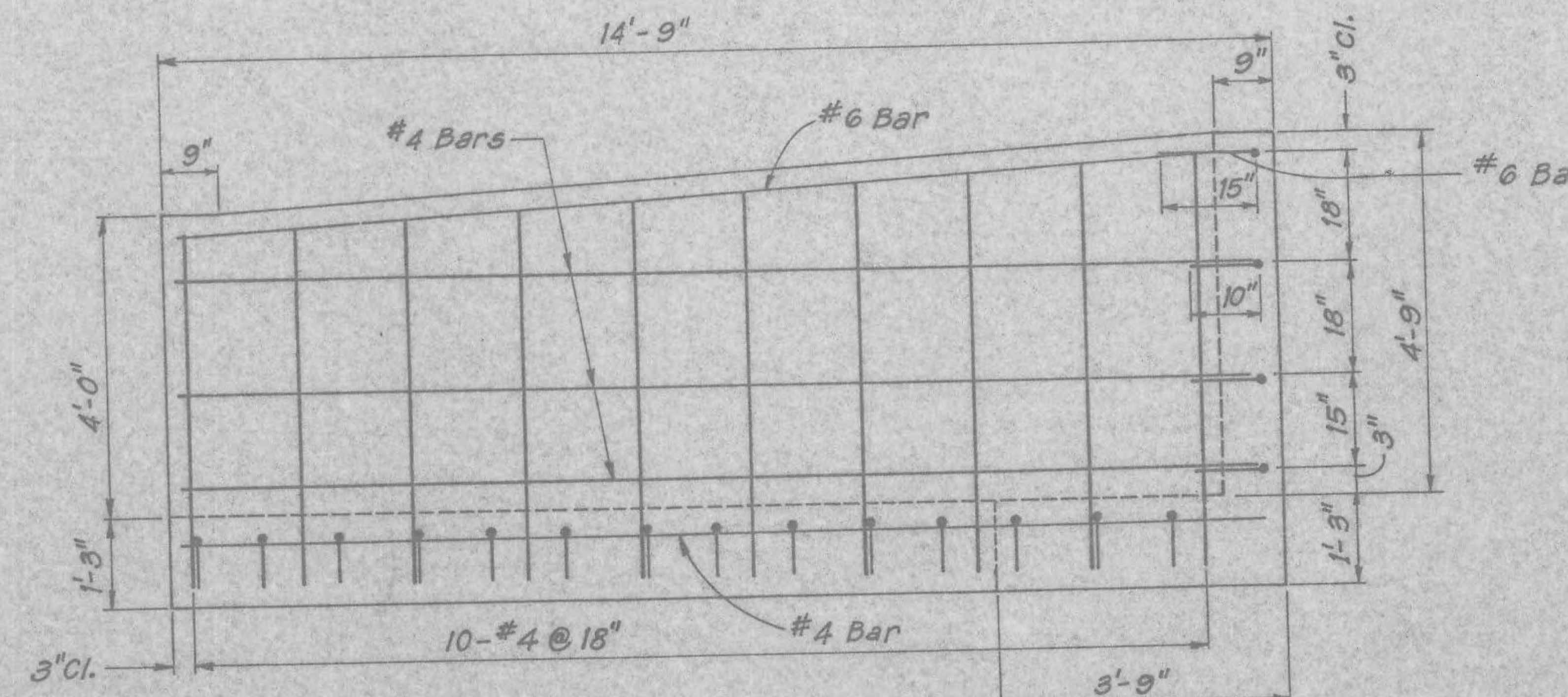
CHAMFER DETAIL
NTS



PART PLAN
Scale ½" = 1'-0"

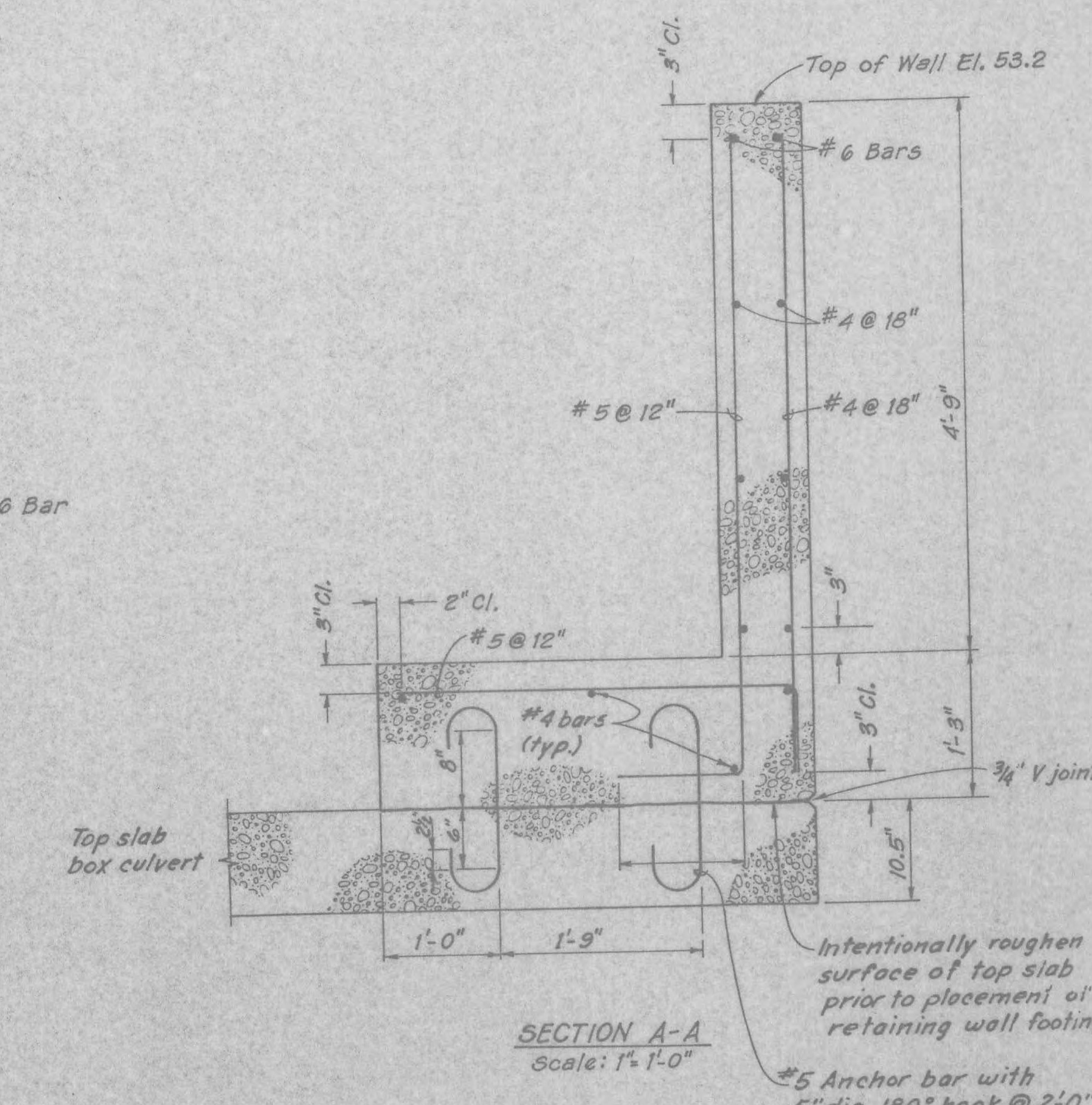


BACK FACE

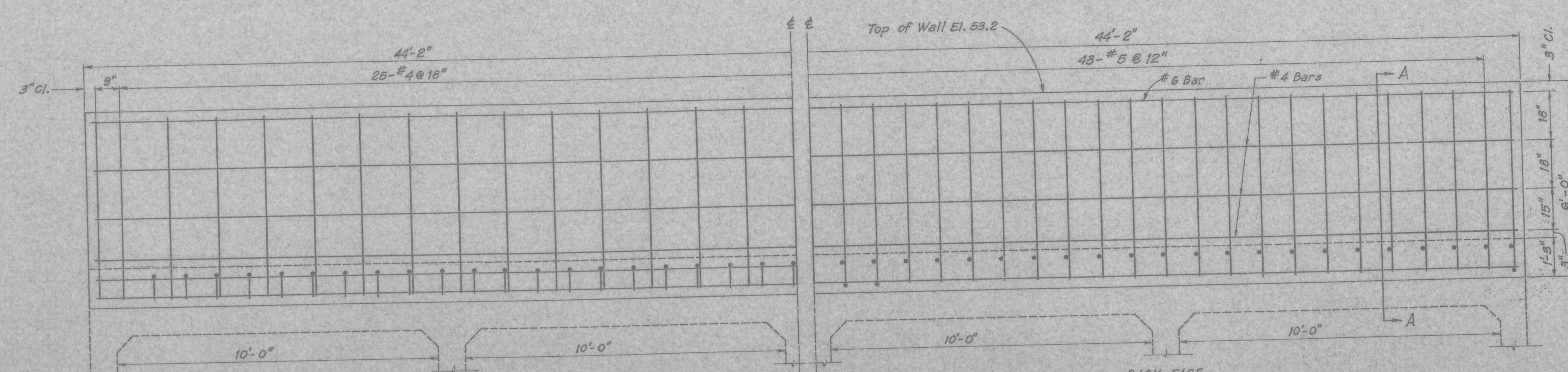


FRONT FACE

SIDE WALL ELEVATION
Scale: ½" = 1'-0"



SECTION A-A
Scale: 1" = 1'-0"



PART ELEVATION
Scale: ½" = 1'-0"

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FLOOD CONTROL PROJECT
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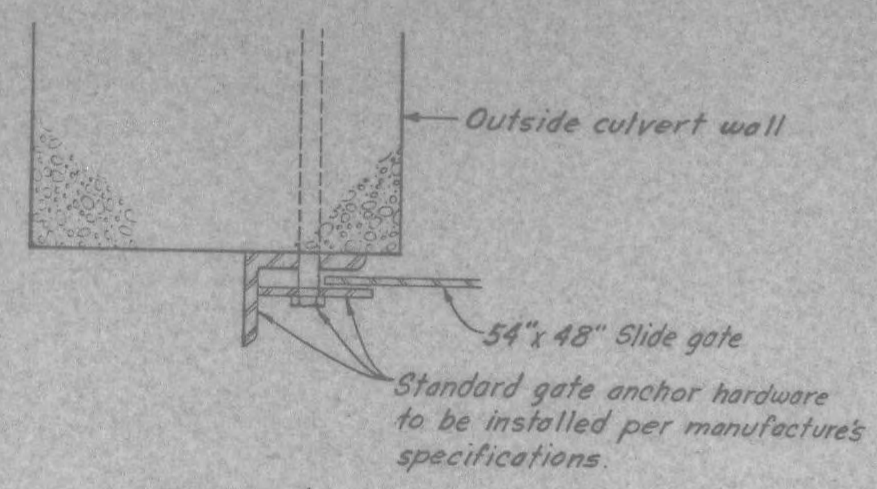
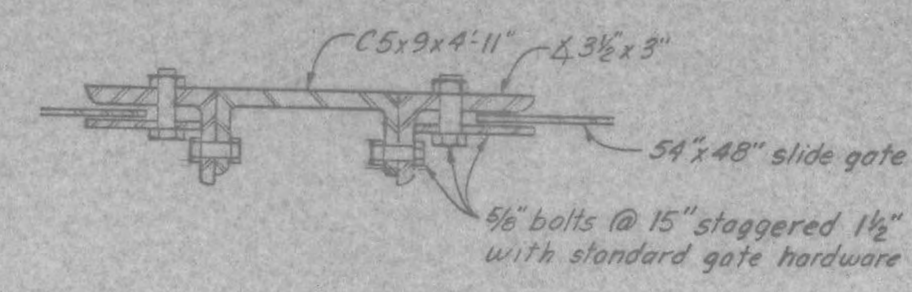
I-4 BOX CULVERT
RETAINING WALL DETAILS

DATE 8-82	DRN. BY DH, LC	DES. BY GAS	CHK. BY GAS
JOB NO. 600-600-3	FILE H-414	SHEET 18 OF 20	

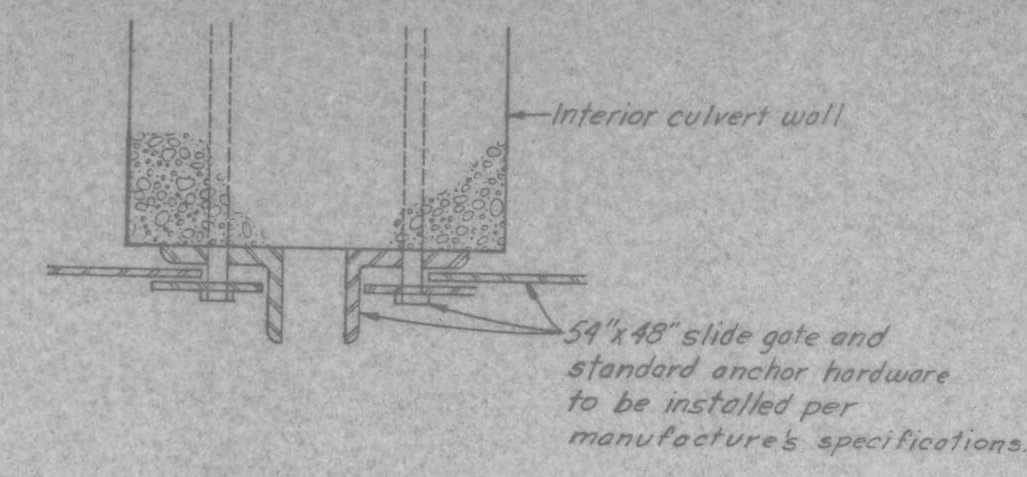
NO.	DATE	REVISION · DESCRIPTION	APPR.



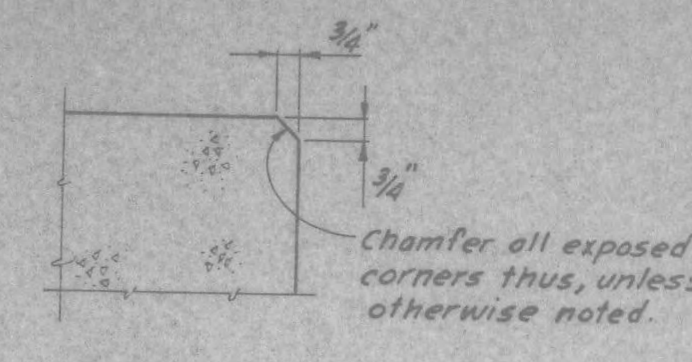
SECTION 'B-B'
Scale 2"=1'-0"



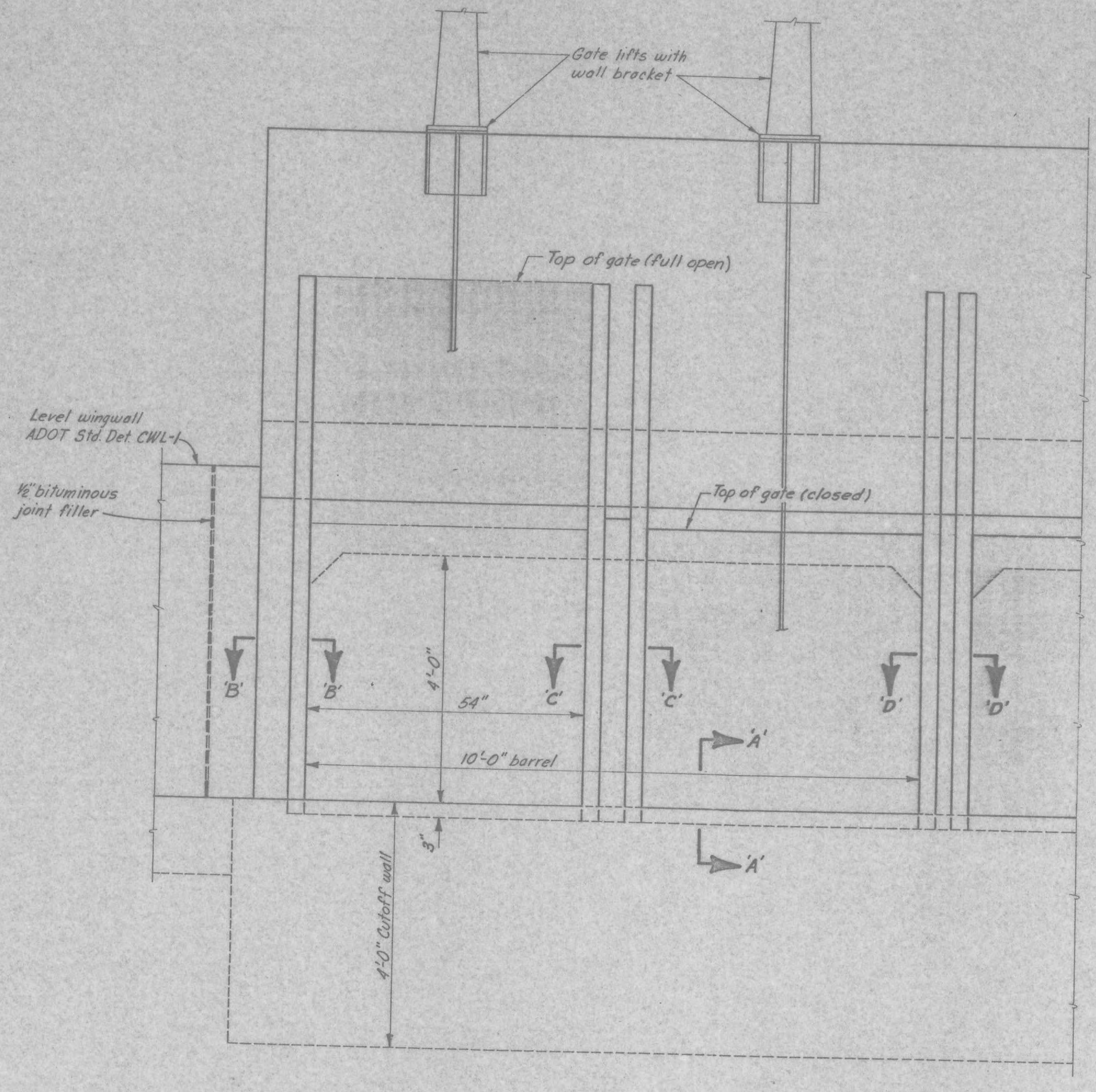
SECTION 'C-C'
Scale 2"=1'-0"



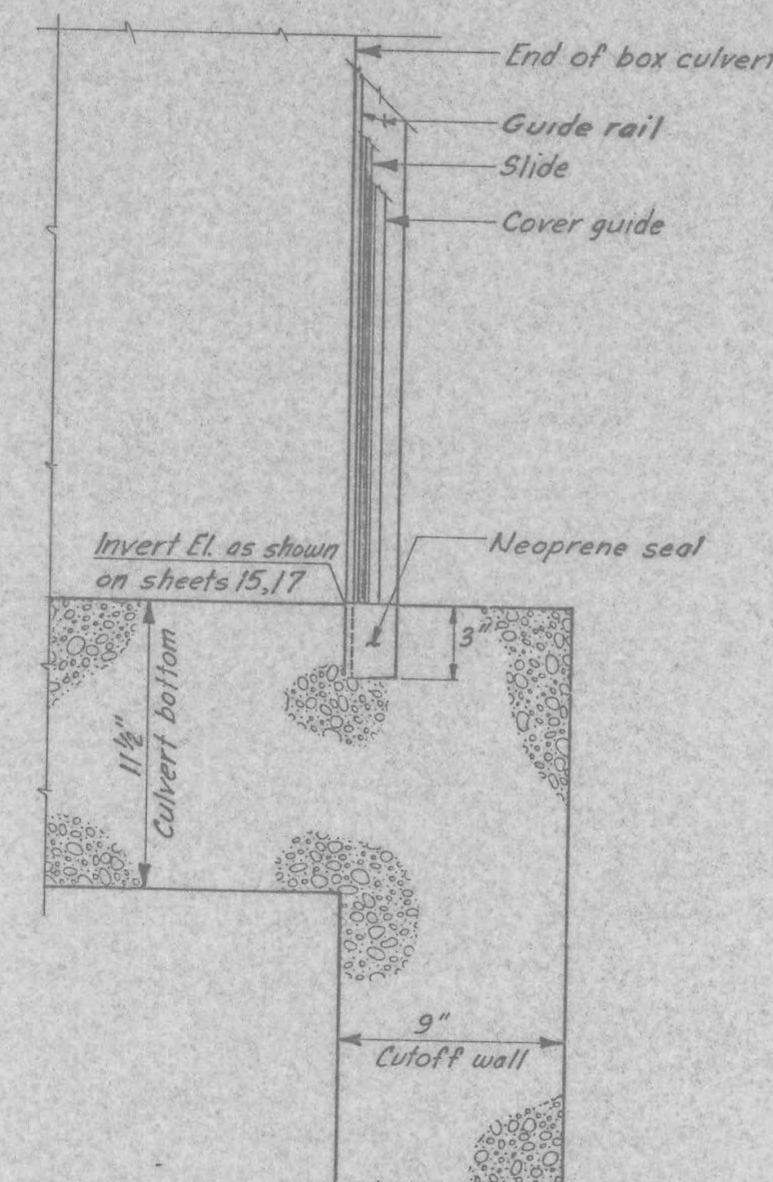
SECTION 'D-D'
Scale 2"=1'-0"



CHAMFER DETAIL
NTS



ELEVATATION
Scale ¾"=1'-0"



SECTION 'A-A'
Scale 2"=1'-0"

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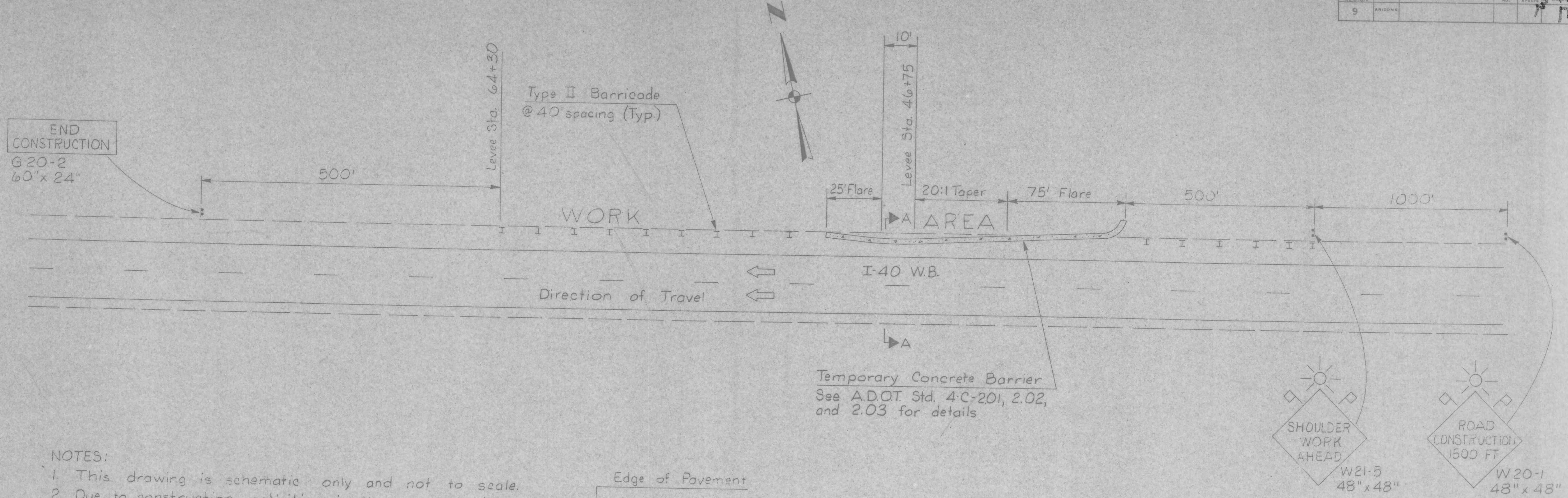
FLOOD CONTROL PROJECT
WINSLOW, ARIZONA

SLIDE GATE DETAILS

NO.	DATE	REVISION - DESCRIPTION	APPR.

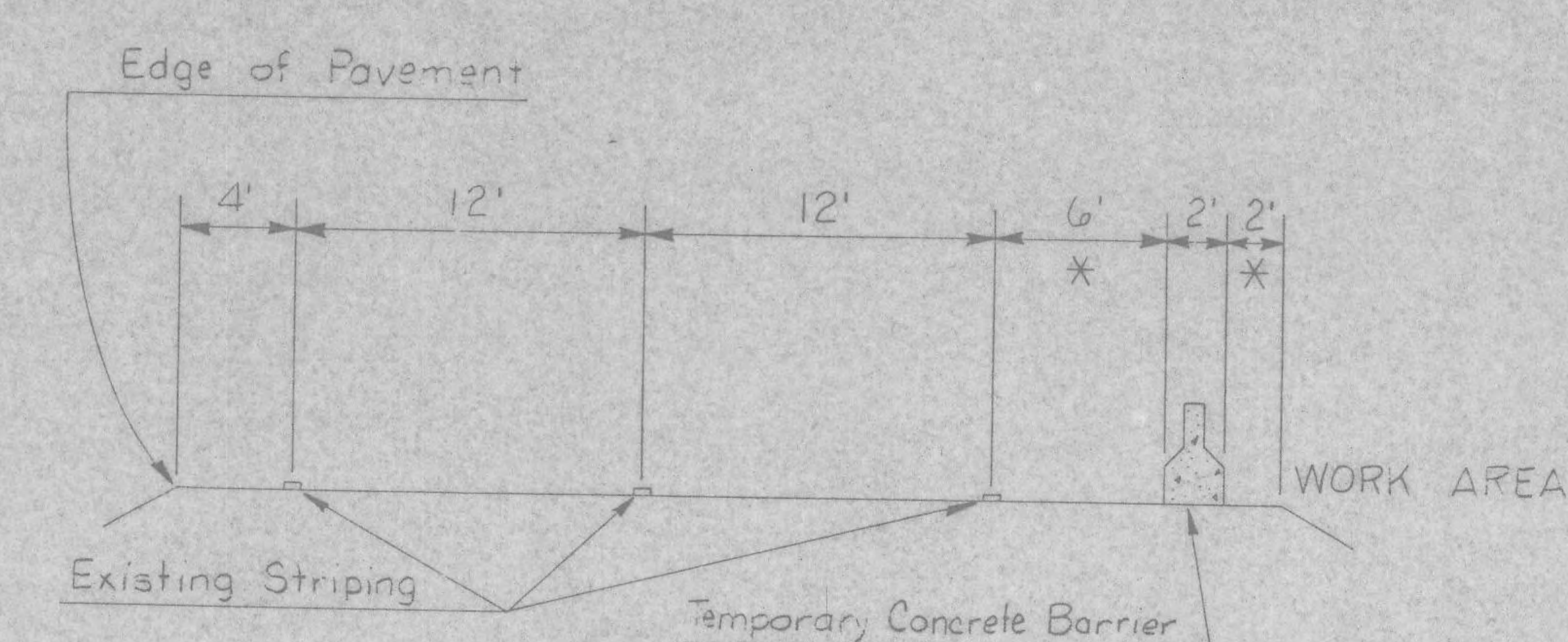
DATE 9-82	DRN. BY L.C. DH	DES. BY G.A.S.	CHK. BY A.C.P.
JOB NO. 600-6003	FILE H414		SHEET 19 OF 20

FHWA REGION	STATE	PROJECT NO.	SHEET NO.	TOTAL SHEETS
9	ARIZONA			



NOTES:

1. This drawing is schematic only and not to scale.
2. Due to construction activities in the area, adjustments in signs and their locations may be necessary as directed by the Engineer.
3. All existing signs in conflict with the construction signs shall be removed, covered with plywood or relocated.
4. Sign mounting height is minimum 5 ft. as measured from the bottom of the sign to the near edge of the pavement.
5. Flashing warning lights (Type A) and flags shall be used to call attention to the warning signs.
6. A steady burning yellow light (Type C) shall be mounted on every other type II channelizing barricade.



SECTION A-A

QUANTITIES	
Temporary Concrete Barrier	150 L.F.

* Distance may be adjusted at the direction of the Engineer

DESIGN		
DRAWN	JG	3-83
CHECKED		
APPROVED		
APPROVED ASST. TRAFFIC ENGR.		
REVISIONS		

ARIZONA DEPARTMENT OF TRANSPORTATION
HIGHWAYS DIVISION
TRAFFIC DESIGN SERVICES

DESCRIPTION
FLOOD CONTROL PROJECT
WINSLOW, ARIZONA
TRAFFIC CONTROL PLAN

TRAFFIC ENGINEER

SHEET 20 OF 20

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