CACTUS ROAD
•STORM DRAIN•

ALTERNATE CONDUIT SECTION & MATERIALS COMPARISON REPORT

for

FLOOD CONTROL DISTRICT
of
MARICOPA COUNTY

•DRAFT•

June 1991

Registered Professional Engineer (Civil)
CERTIFICATE NO. 14615
MARK EVERETT COURTNEY
Date Signed 6/14/91
ARIZONA, U.S.A.

STANLEY
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CACTUS ROAD STORM DRAIN
ALTERNATIVE CONDUIT AND SECTION
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1.0 INTRODUCTION

The Cactus Road Storm Drain project consists of constructing a storm drain main along Cactus Road from 67th Avenue to the Agua Fria Outer Loop Freeway (figure 1) capable of handling the 10-year storm event. As a portion of the design services to be performed, various conduit materials and sections have been evaluated to determine those that would be most suitable for this particular installation.

Preliminary design flows, established from the 1987 Glendale/Peoria Area Drainage Masterplan, vary from 340 cfs at the upstream end (67th Avenue) to 970 cfs at the downstream end (Agua Fria Outer Loop). Corresponding pipe diameters, for a pipe flowing full but with nominal hydraulic pressure, will vary from 84 to 120 inch (figure 2). Comparable box conduit sizes would vary from 7 ft X 6 ft to 10 ft X 9 ft. Additional review of these flows is being conducted to update the previous studies because of changes in the flood plain drainage patterns created from the installation of the Agua Fria Outer Loop Freeway. As the updated flow data becomes available, hydraulic designs will be adjusted.

Final alignment of the storm drain both horizontally and vertically is affected by the existing utilities in Cactus Road. However, a minimum of 4 ft cover will be maintained with total trench depth for the 84- to 120-inch diameter pipe varying from about 11 to 20 ft. The variety of utilities located in and crossing Cactus Road include natural gas lines, sanitary sewer service lines, 18 and 30 inch sanitary sewer collection lines, water distribution and service lines, cable television lines, Salt River Project irrigation pipelines, telephone service lines, a large fiber-optic telephone line, electric service lines, and a 7.2 kV plus electric line. All effort to avoid these utilities will be made. However, the mere existence of significant numbers of utilities will have an impact on the selection of precast versus cast-in-place conduit materials.

Soil samples are being analyzed and a soils report will be written defining the types and nature of the soils along the storm drain alignment. The soil studies and report were not started until the preliminary alignment was defined to locate and identify the numbers and types of borings required. A preliminary evaluation of the soils shows that a number of cobbles and gravel will be encountered in the lower elevations with an 11- to 20-foot trench depth. Unstable or cobbly soils also greatly impact the selection of precast versus cast-in-place conduit materials.

2.0 STORM DRAIN PIPE ALTERNATIVES

The basic design criteria for the storm drain include:

- 10-year return period storm.
- Ability to carry flow rates varying from 340 to 970 cfs.
- Full flowing pipe at full capacity.
- Hydraulic grade line should be maintained below road elevation and elevation required to drain local catch basins.
- Minimal traffic interference.
- Reasonable construction time frame.

Based on this criteria, five conduit materials have been deemed suitable for evaluation as possible construction alternatives:

- Reinforced Concrete Pipe (RCP)

- Concrete Lined Corrugated Metal Pipe (CMPCL)
- Precast Box
- Cast-In-Place Pipe (CIP)
- Cast-In-Place Box (CIP Box)

3.0 EVALUATION OF STORM DRAIN CONDUIT ALTERNATIVES

3.1 Reinforced Concrete Pipe (RCP)

Of the five conduit materials RCP is by far the most common material for installations that require the shortest construction time with the greatest flexibility to be routed around utilities. This material has an excellent track record for durability and minimal long-term maintenance, particularly in these diameters. RCP manufacturers like to say that for all practical purposes their material will last forever; not technically true, but with proper construction and installation, the life of the pipe far exceeds a 50- or 75-year life. Good quality control during construction of the pipeline material itself can be maintained without strict field inspection because the pipe is constructed in a factory and not on-site. In addition, the pipe is a rigid structure and the backfill requirements can be much less stringent than for other conduit materials; further easing field inspection requirements. Other advantages include: (1) a wide variety of local manufacturers providing good availability with a fair amount of competition between manufacturer's prices; (2) relatively fast installation and therefore reduced traffic control problems; and (3) invert erosion in high-sediment conditions is seldom a problem.

The greatest disadvantage to RCP is associated with the rigid nature of the pipe and the resulting installation considerations. To achieve the rigid structure of RCP, a large amount of rebar and concrete are used. To provide reasonable manageability, pipe segments must be kept short. In these diameters (86 to 120 inches) the pipe lengths are kept between 6 and 12 ft depending on the equipment and weight capacity of the particular job and contractor. Even with the reduced pipe segment lengths, each piece of pipe is relatively heavy requiring the use of one or two large cranes for installation. The delivery costs are also increased due to the reduced number of pipe segments that can be delivered to the job site. Table 1 further evaluates the weight considerations of RCP in relationship to other conduit materials and section 4.0 fully evaluates the cost comparison of RCP to other conduit materials in terms of material cost (including delivery to the job site), installation cost and long term Operation and Maintenance (O&M) cost.

3.2 Concrete Lined Corrugated Metal Pipe (CLCMP)

Corrugated Metal Pipe (CMP) is a conduit material that has been used extensively in short culvert road crossing situations that have not required an extremely long design life nor stringent hydraulic requirements. Relatively recent improvements have led to the potential use of CMP for longer storm drains and locations that require a longer life.

The first improvement was the use of aluminized coatings. G. E. Morris and L. Bednar prepared an evaluation of aluminized versus galvanized coatings for Armco, the predecessor to Contech Construction Products, Inc. (Contech) and the largest distributor of CLCMP in the area. The evaluation was based on 30-year field tests of drainage pipelines coated in the two materials, located and exposed together, in 54 sites and originally installed in 1952. The aluminized coating far out-performed the galvanized coating both on the interior and the exterior in all moisture conditions (extremely wet, moderate and dry climates) and in all soil conditions (moderately corrosive to severely corrosive). Aluminized coatings showed no attack or only minor localized coating loss with associated slight substrate penetration on the soil side. These studies helped provide guidelines for the suitability of aluminized coatings in various soil conditions.

Aluminized CMP is still not recommended for highly corrosive soils; resistivities below 1,500 ohm/cm and a pH range of 5 to 9. (Aluminized coatings are also more durable than asphalt coatings and perform better with the second improvement to CMP discussed below.)

The second improvement to CMP was the use of a concrete lining to improve hydraulic characteristics. The most modern method of applying the concrete lining is to apply the concrete from a revolving head moving inside the stationary metal pipe. Mechanical trowels immediately following the spray head to provide a smooth finish. This equipment can also be used for applying linings in situ.

The concrete lining is added to a corrugated metal pipe (usually with aluminized coatings, but asphalt or galvanized can be used) with an inside diameter equivalent to the required diameter. The concrete lining is usually 3/8- to 3/4-inch thick at the crest of the interior corrugation and fills the corrugations.

In addition, CLCMP is designed as plain corrugated metal pipe with no allowance for structural contribution from the lining. The function of the lining is only to improve the hydraulic characteristics of the CMP and the lining is not intended to adhere to the metal pipe interior. Therefore, cracks or spalls in the lining do not create any structural integrity problems. The only concern is the hydraulic integrity if a large number of cracks or spalls are exhibited in the pipe (and a large number of these would be required to affect the hydraulic efficiency).

Hairline stress cracks are a common characteristic of CLCMP because the metal portion of the pipe is flexible and the concrete portion is rigid. As the concrete lining dries and as the pipe flexes during handling and installation these cracks are formed. However, most are "healed" when the pipe is filled with water.

Studies were performed by the United States Department of the Army, Corps of Engineers (COE) from January 1985 to March 1986 on approximately 12,000 ft of recent (2-year old) CLCMP installations. The condition of all installed pipelines was relatively consistent:

> "a. Some chipping or spalling of the lining was noted, but the metal pipe directly behind the damaged lining showed evidence of blows to the end or to the outside of the pipe. Hence, this damage was probably caused by rough handling during transportation or installation and not by in-service loads or conditions. Satisfactory repairs of these types of damage have been made by most of the contractors by applying a rich grout in accordance with the manufacturer's recommendations.
>
> 'b. Deflections of the installed pipe ranged from -1 to +6 percent of the nominal diameter, but were generally less than 3 percent. No popping or spalling resulted from these deflections. The characteristic, randomly spaced, circumferential and longitudinal cracks were observed in uninstalled pipe joints at both the plant and job sites, indicating that they result from plastic shrinkage of the concrete during curing and/or handling. These cracks remain tightly closed in the installed pipe except when the deflection exceeds approximately 5 percent of the nominal diameter."[1]

In addition, COE evaluated five concrete-lined, corrugated metal culverts in San Mateo County, California that were originally installed in 1952 as asphalt- or galvanized-coated CMP. These pipelines showed extensive damage to their original inverts within a few years. The culverts were repaired in June 1960 by in situ concrete lining as described above. In general, the concrete lining showed little sign of deterioration.

Based on these studies and similar findings in the recent Phoenix-area installations, CLCMP can be evaluated; not as extensively as other pipeline materials, but CLCMP is not a totally brand new product and should be considered for this project.

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[1]Potter, John, C. Evaluation of Buried, Concrete-Lined Corrugated Metal Pipe. November 1966. Department of the Army, Corps of Engineers, Geotechnical Laboratory. Vicksburg, Mississippi.

CLCMP has many advantages based on its flexible structure. Table 1 compares CLCMP with RCP in terms of weight and delivery lengths. CLCMP is significantly lighter than RCP and therefore can come in much longer lengths (20 ft). Even in the longer lengths the pipe segments are still much lighter than the comparable RCP segments; therefore much smaller lighter equipment is required for placing the pipe in the trench. In addition, more pipe can be delivered at a time, not only because more segments can be delivered at a time but also because each length is longer. The longer lengths also lead to fewer joints and reduced leakage potential.

CLCMP has several other advantages. High material quality control can be maintained because the pipeline is manufactured in the factory not in the field. Second, the installation is relatively fast because the pipe is delivered at the site ready for installation and backfill and the trench can be closed as soon as the pipe has been installed and tested. Third, the concrete lining provides similar hydraulic characteristics to RCP, therefore diameters of the pipe are similar to those of RCP. Finally, CLCMP is relatively thin and the outside diameter (OD) is only 2 inches larger than the inside diameter of 120-inch CLCMP (OD = 122 inches). RCP on the other hand can be up to 8 or 11 inches thick; for 120-inch class III RCP, the OD is 142 inches. In areas with a lot of utilities, 20 inches can be a significant addition to the pipeline OD and required trench width.

CLCMP achieves advantages from the lighter weight because the pipe behaves as a flexible rather than a rigid conduit. Rigid conduits, such as RCP, cannot deflect more than about 0.1 percent of their diameter without damage. Therefore, the pipeline must be designed to carry the soil loads above and the arching soil loads beside the pipe. Flexible conduits, however, may deflect as much as 5 percent under load without damage. In deflecting, these pipes transfer part of the vertical load into a horizontal thrust which is carried by the passive resistance of the soil beside the pipe.

Several disadvantages also result from this flexibility. First, backfill and compaction requirements must be much more stringent to prevent pipeline deflections from exceeding the allowable 5 percent. RCP is generally backfilled and compacted in thin layers to the springline. CLCMP must be backfilled and compacted in thin layers to 1 ft above the top of the pipe. In large diameter pipelines this additional placement and compaction can be a significant cost. In addition, if the backfill and compaction is not handled properly and additional pipeline deflection is created beyond the allowable 5 percent, then the concrete lining can be cracked, reducing the hydraulic ability of the pipeline, and perhaps worse, the aluminized coating can be cracked longitudinally, allowing corrosion attack from the soil side of the pipe. The life of the pipeline can be greatly reduced if the aluminized coating is cracked.

CLCMP has several other disadvantages. First, CLCMP is a metal pipe and although the aluminized coating greatly extends the life of the steel, CLCMP is still not suitable for highly corrosive soil environments. Detailed soils information for Cactus Road is not available yet however, it is anticipated that these soils will not be highly corrosive. Second, concrete lining can not be used in an arched CMP except for very short segments where the coating is applied in situ by hand. Arched CMP is sometimes desirable for extreme loads or more efficient hydraulic characteristics. Third, there is still some concern in the industry about the lack of bond between the steel and concrete. This does not appear to be a problem either from a corrosion or hydraulic concern based on the studies performed to date. But this is still a relatively new product. In fact, the Arizona Department of Transportation (ADOT) has restricted the use of CLCMP based on concerns about the life of the product. ADOT requires a material life of 75 years on storm drains in freeways and primary roads. The material life for secondary and minor roads are 50 and 25 years, respectively. ADOT does not feel there is sufficient data to show that CLCMP will provide a 75-year life. Therefore, CLCMP is not allowed for freeway or primary road storm drains in lengths over 1,000 ft. CLCMP is allowed for installations that only require a 50-year life.

3.3 Precast Box

Precast box conduits offer similar advantages as RCP and CLCMP in terms of high quality control and relatively rapid installation because the conduit material is prefabricated. Precast box conduits are also similar in nature to RCP, in that the box is a rigid conduit and requires thin-layer compaction only to the top of the box in trench conditions. The design of the conduit itself withstands the soil loads above and adjacent to the box and does not require optimum trench backfill to resist deflection.

Precast box conduits have two major disadvantages. First, a good gasket has not been designed for the box joints; therefore, leakage can be a problem in some installations. In fact, it is not certain whether a precast box conduit can meet the Maricopa Association of Government (MAG) specifications on leakage. A few precast box conduits have been installed in the Phoenix area and leakage is one of the drawbacks that remains to be evaluated. Second, precast box sections are larger in total area to meet the same hydraulic criteria of an arched or round pipeline and therefore require additional concrete and rebar over RCP. The increased material requirements leads to short lengths (due to weight), increased material cost, increased delivery cost and increased leakage potential due to frequent joints. However, a precast box conduit recently won the bid on a job over other materials because a special piece of equipment was used to backfill and compact the square trench reducing installation costs to the point that the box conduit could compete. Compaction of the haunches of a circular pipe is more difficult than the haunches of a square box.

3.4 Cast-In-Place Pipe (CIPP)

CIPP has been used extensively in the Valley for smaller diameter applications and where utility interference has been negligible. CIPP is cast in the trench using the trench walls and floor as part of the form and a special piece of equipment which places the inside diameter split-ring forms and pours the concrete. After sufficient drying the forms are removed from the inside and the interior troweled smooth where necessary. This type of conduit is highly cost effective and many contractors in the area have experience installing the smaller diameters. The nature of the pipe construction virtually eliminates pipe joints reducing leakage potential. With quick-setting concrete mixes, open trench times have been reduced and the trench can be backfilled within 24 to 48 hours.

The most significant disadvantage to CIPP is that the conduit is constructed in the trench in the field. Optimum field conditions and a reliable contractor along with rigid, careful specification and inspection are required to maintain quality control of the conduit construction. Soil conditions must be adequate to provide a good form for the bottom and sides of the conduit. If a soil is cobbly or unstable, wall thicknesses will vary and may not meet specification requirements or greatly increase material requirements and increase costs. The City of Phoenix will no longer allow installation of CIPP if the bedding is unsuitable without overexcavation and backfill to form the floor and walls of the trench. Preliminary soil conditions for Cactus Road indicate that significant cobbles may be encountered in the lower depths (over 15 ft) and therefore CIPP would not be a suitable conduit. Final soils recommendations will help determine the viability of CIPP.

A second disadvantage, despite the use of quick-setting concrete, is the open trench installation time. CIPP can be installed at a similar rate to precast pipe when installing in areas with few utility interferences and few external connections. However, Cactus Road contains many utility crossings that will reduce the lengths of run and cause delays in construction and may require the use of precast conduits in these areas. There is also some concern about the structural integrity of large diameter CIPP. ADOT and the City of Phoenix among others will not allow CIPP in diameters over 96 inches. Over half of the Cactus Road Storm Drain is larger than 114 inches.

3.5 Cast-In-Place Box (CIP Box)

CIP box conduits provide good structural characteristics and are used extensively as road crossings where strength is required or cover is minimal (e.g. freeways commonly use box culverts). CIP box construction follows several steps: the trench is excavated, the floor rebar cage is constructed, the floor poured, the wall and roof rebar cage is constructed, the forms are constructed for the walls and roof and the walls and roof poured. Even with quick-setting concrete it is still a tedious job to construct a CIP box culvert.

A 4,500-ft CIP box storm drain was recently constructed parallel to Interstate 10 in the City of Tempe. The upstream portion was 12 ft X 8 ft and the downstream portion was 16 ft X 8 ft (somewhat larger than the largest portion of the Cactus Road Storm Drain). The trench path was parallel to the freeway and unobstructed by all but a few utilities. Construction of this box culvert was very successful because of the large size (paddle wheel scrapers were used very economically to excavate the trench), 1/2 mile reaches could be opened at one time, there was no interference with either traffic patterns or existing utilities, the soils were suitable to support a box and shoring was not required for trench walls. A quick-setting concrete mix was used for the walls and roof, which sped up construction to a 24-hour period and made construction almost like a slip-form operation. Wall and roof forms were set up in the morning with concrete poured at 2:00 p.m. and allowed to cure to the next morning when the forms were moved to the next reach. The use of paddle wheel scrapers, long open reaches and quick-setting concrete all reduced construction time. However, construction still took 6 months for 4,500 ft. If the same techniques and subsequent construction time frame could be used on the Cactus Road storm drain, construction would take up to 2 years to complete; far longer than any of the other methods.

As stated above, CIP box conduits have good structural characteristics and as in the case of CIPP, CIP box conduits are continuous with relatively little leakage problem. Quick-setting concrete mixes have reduced installation times over previously used concrete mixes but the installation time is still a drawback for high traffic areas. CIP box conduits are also constructed in the trench. Soil conditions affect quality control and a good contractor along with rigid specifications with strict field supervision is required to insure a quality conduit.

4.0 COST COMPARISON OF STORM DRAIN CONDUIT ALTERNATIVES

4.1 Conduit Construction Cost

Local suppliers and contractors were contacted to determine an estimated cost for RCP, CLCMP, Precast Box and CIPP. It was not possible to determine the quantity of concrete, rebar and labor required to construct a CIP Box, therefore prorated costs for these items were used from the City of Tempe box culvert discussed in section 3.5 above. The current edition of The Richardson Rapid System General Construction Estimating Standards was used to determine cost of earthwork and installation of precast conduits. Table 2 lists the estimated total cost and the estimated cost per linear foot for each type of pipe. These costs do not include the cost of the numerous fittings/structures that will be required to connect the Cactus Road storm drain to collector basins and stubouts to future storm drain laterals. These costs also do not include the cost of rerouting or accommodating the existing utilities or the traffic control problems.

At this point, the CIPP alternative is the least expensive followed in order by CLCMP, RCP, CIP Box, and Precast Box. As stated in section 3.4 and 3.5, utilities and numerous specially constructed inlets will greatly affect the cost of the cast-in-place conduits and raise their unit prices. In addition, these conduits are constructed in the field and special features will increase the construction time. Special structures affect the cost RCP, CLCMP, and Precast Box conduits, but not as much. Secondly, construction time to install prefabricated special fittings is much faster than construction and installation of cast-in-place special fittings because the construction takes place in the factory and only installation is required in the field.

4.2 Conduit Operation and Maintenance Cost

Small conduits are subject to occasional plugging that would require occasional maintenance. The Cactus Road storm drain is a very large diameter conduit and plugging is not likely to be a problem. However, sediment load can accumulate in large conduits affecting the hydraulic characteristics and the ability of the pipeline to carry the water it was designed for. This can be accommodated in the design analysis and, if necessary, slightly oversize the conduit. The greater impact to the conduit would be the material life, if the sediment load were to erode the invert of the pipeline. In the Phoenix area, the sediment load of storm drains is not a significant problem, either in terms of quantity of sediment deposition or invert erosion. Secondly, the Cactus Road storm drain is not a steeply-sloped conduit which also causes invert erosion problems.

Periodic inspection would be suggested for large diameter pipelines to insure that the interior of the pipeline is in good condition. These inspections should be more frequent (e.g. annual inspection) during the early years for the flexible CLCMP conduit and for CIPP to insure that these pipelines were properly installed and backfilled. CLCMP deflections should be monitored both when the pipe is first installed and during the periodic inspections. The inside diameter measurements of CIPP should be taken after construction prior to acceptance of the conduit by the Cities of Peoria and Glendale and the Flood Control District of Maricopa County to insure proper sizing of the conduit.

Costs for O&M have not been calculated because the cost of annual inspections is relatively nominal and no other maintenance is anticipated to be required for the main storm drain. Some maintenance of the catch basins may be required but the cost of this maintenance will be equal for all alternatives and therefore catch basin maintenance has not been estimated or included.

5.0 PRELIMINARY DESIGN RECOMMENDATIONS

Reinforced concrete pipe is obviously suitable for the Cactus Road storm drain and it is not the most expensive conduit. There are sufficient companies in the area to ensure a reasonably good price on RCP. Competitive bidding is improved however, if other alternatives are allowed. CLCMP offers many of the same advantages of RCP with a potential, substantial cost savings. Soils data will be evaluated in the final draft of this report to determine if CLCMP, CIPP and CIP Box are acceptable alternatives. In addition, CIPP may not be suitable in the larger 114- to 120-inch diameters at all. Neither the City of Phoenix nor ADOT would allow CIPP in these diameters. In addition, if the life of the storm drain is to be 75 years or longer, then CLCMP may not be suitable; extrapolating 30-year studies to a 75-year life is quite a reach. The precast box conduit was the most expensive alternative, however the main reason was the cost of the material itself. The earthwork costs for the Precast Box were the lowest of all of the alternatives. Competitive bidding may get the cost of the Precast Box down into the competitive range.

None of the alternatives have been eliminated at this time. However, it is likely that CIPP should be eliminated in the larger diameters and will probably be eliminated in the smaller diameters to avoid changing pipe materials midway and possibly due to soil and utility conditions. CLCMP and CIP Box may be eliminated due to soil conditions or to the conduit material life requirements.

TABLE 1
Conduit Material Physical Characteristic Comparison

	84-in				120-in			
	RCP Class III a/	RCP Ameron b/	CLCMP 5 X 1 14 ga c/	Precast Box 7' X 6' d/	RCP Class III a/	RCP Ameron b/	CLCMP 5 X 1 14 ga c/	Precast Box 10' X 9' d/
Pipe Length, ft	6	12	20	7.5	6	12	20	7.5
Approx. Weight, lb/ft	2,409	2,090	318	3,066	4,716	4,830	542	5,520
Approx. Weight per Piece, lb	14,454	25,080	6,360	22,995	28,296	57,960	10,840	41,400
Outside Dia., in	100	100	86	8.33'X7.33'	142	142	122	11.67'X10.67'
Max. Allowable Fill, ft	17	N.A.	45	N.A.	18	N.A.	54	N.A.
Truck Loads per 1000 ft of Pipe	50	N.A.	25	N.A.	99	N.A.	25	N.A.
Joints per 1000 ft of Pipe	166	N.A.	49	N.A.	166	N.A.	49	N.A.

a/ Information provdided by Contech Construction Products, Inc.
b/ Information provided by Ameron
c/ Information provdided by Contech Construction Products, Inc.
d/ Information provided by Gifford-Hill

N.A. = Information Not Available or Not Provided

Source: SFC Engineering Co., June 1991

TABLE 2
Alternative Conduit and Section Material Cost Estimate

	Reinforced Concrete Pipe Metal	Concrete Lined Corrugated Pipe	Precast Box	Cast-in Place Pipe	Cast-in Place Box
Total Cost ($)	6,222,000	5,032,000	7,599,000	4,743,000	6,273,000
Unit Cost ($/lin ft)	366	296	447	279	369

Source: SFC Engineering Company, June 1991

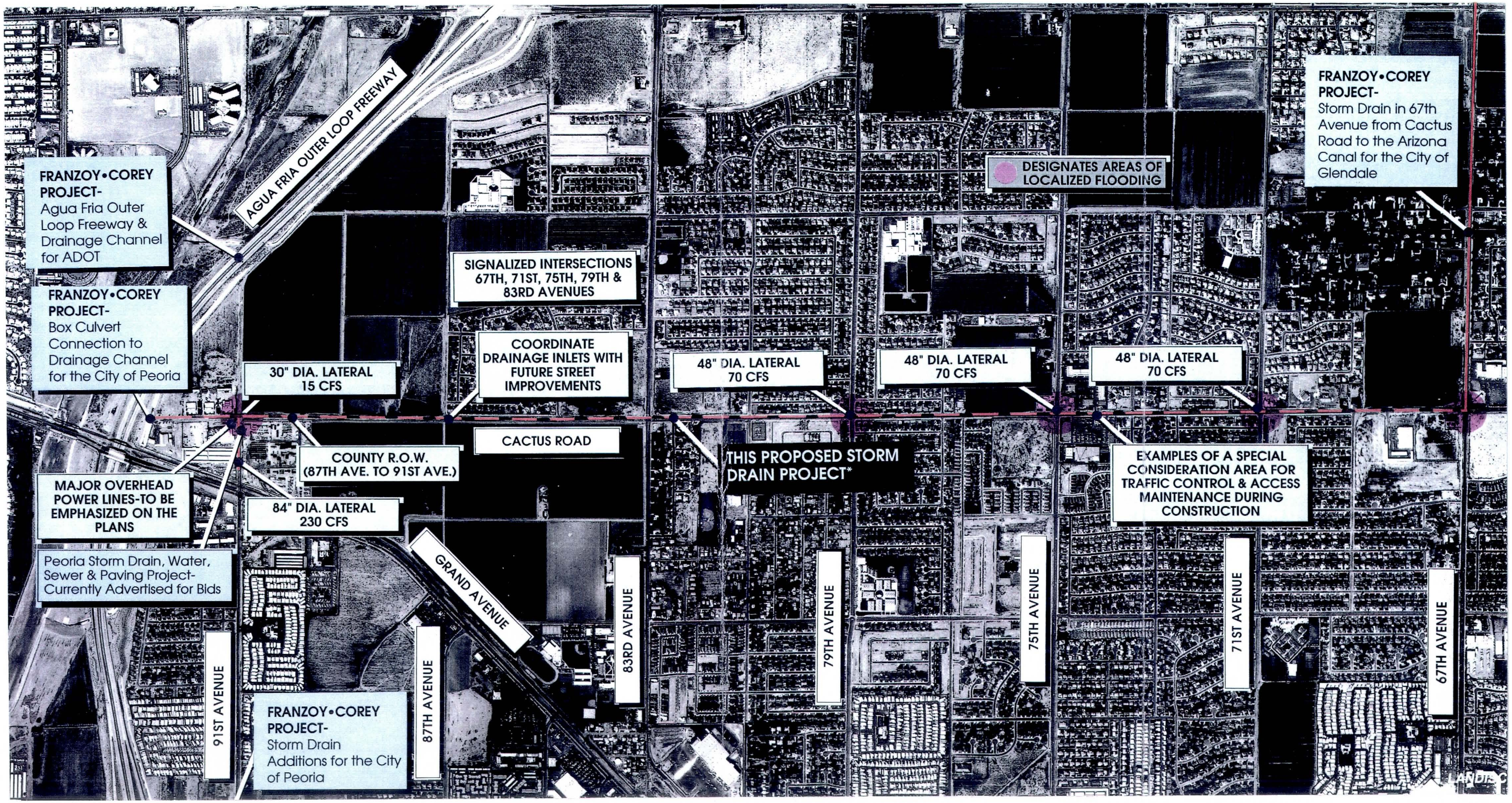
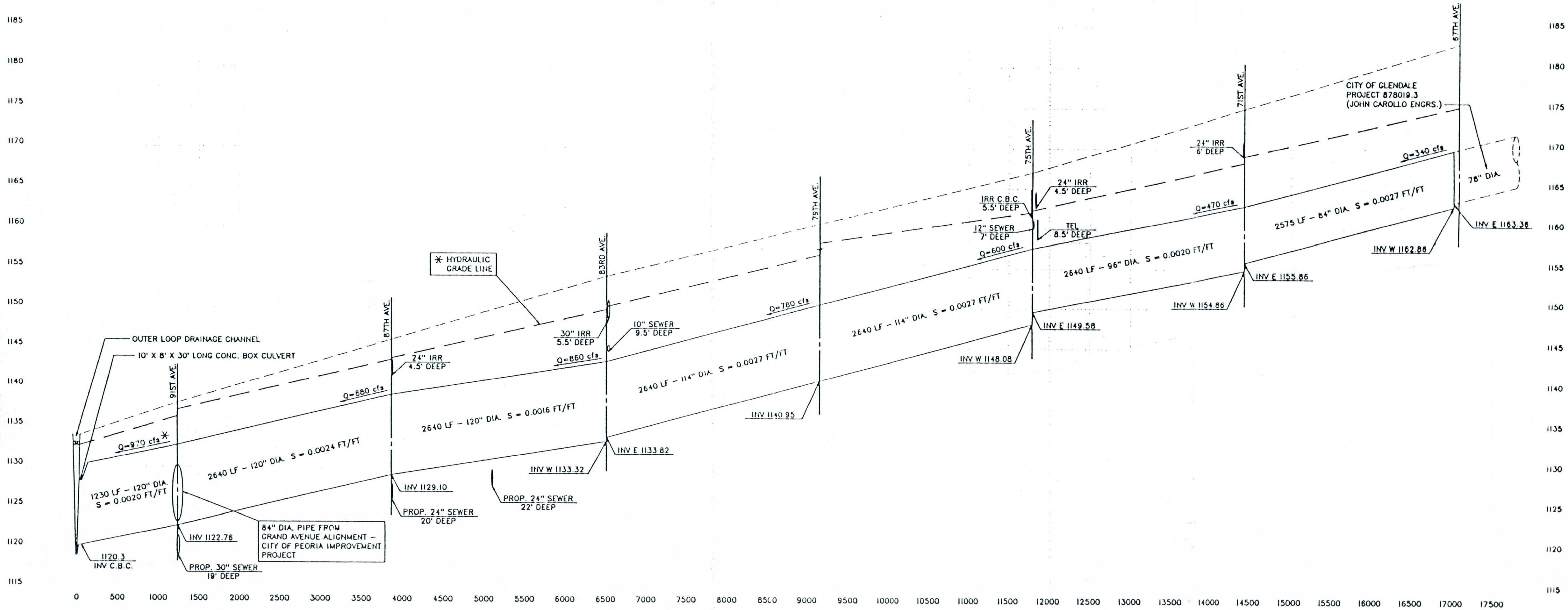


FIGURE 1
CACTUS ROAD STORM DRAIN ALIGNMENT

ENGINEERING COMPANY

CACTUS ROAD DRAIN

67TH AVENUE TO THE AGUA FRIA OUTER LOOP FREEWAY



* DOES NOT INCLUDE EFFECTS OF 84" DIA. STORM DRAIN FROM GRAND AVENUE ALIGNMENT CONTRIBUTION

CONCEPTUAL PROFILE

SCALE: 1" = 500' HORIZONTAL
1" = 5' VERTICAL

FIGURE 2
CACTUS ROAD STORM DRAIN HYDRAULIC PROFILE

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