Pipe Rehabilitation with Polyethylene Pipe Liners

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Iowa Highway Research Board
Project HR-370

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8. ABSTRACT

Corroded, deteriorated, misaligned, and distorted drainage pipes can cause a serious threat to a roadway. Normal practice is to remove and replace the damaged drainage structure. An alternative method of rehabilitating these structures is to slip line them with a polyethylene liner.

Twelve drainage structures were slip lined with polyethylene liners during 1994 in Iowa. Two types of liners installed were "Culvert Renew" and "Snap-Tite". It was found that the liners could be easily installed by most highway, county, and city maintenance departments. The liners restore the flow and increase the service life of the original drainage structure. The liners were found to be cost competitive compared with the removal and replacement of the existing drainage structure. Slip lining has the largest economic benefit when the roadway is paved, the culvert is under a deep fill, or traffic volumes are high. The annular space between the original pipe and the liner was filled with flowable mortar. Care should be taken to properly brace and grout the annular space between the liner and the culvert to avoid deformation of the liner.

9. KEY WORDS

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INTRODUCTION

Many problems can affect the performance of a drainage culvert; including physical deterioration, misalignment and distortion. These problems can lead to reduced water flow and possibly loss of road bed material into the culvert.

The conventional approach to fixing these problems is to excavate a trench and remove and replace the damaged culvert. This practice causes considerable disruption of traffic and has a significant risk of settlement problems.

An alternative method for rehabilitation of these culverts is the insertion of a polyethylene pipe into the existing culvert. This process is called slip-lining. Slip-lining offers to improve flow volume and extend the service life of the culvert. An added benefit claimed by the procedure is that installation can be performed under traffic and uses the in-place soil structures. As a result, there is little traffic disruption and no settlement problems. Slip-lining may have an economic benefit compared to removal and replacement.

OBJECTIVES

The primary objective of this research was to evaluate the applicability of the slip-lining technique for actual projects in Iowa. Specific topics were to

1. discuss construction techniques and challenges with the process,
2. determine the cost savings (if any) of culvert rehabilitation using slip-lining with polyethylene pipe, and
3. evaluate the field performance of the liners over time.

PROJECT LOCATIONS AND DESCRIPTIONS

This research covered 14 locations around the state. An overview of the projects is provided in Table 1. Maps of the project locations are provided in Appendix A. Five of the projects were funded through the Iowa Highway Research Board. The remaining projects were funded by the local government agencies involved.

Two brands of pipe liners were evaluated. These were Culvert Renew™ and Snap-Tite™. Culvert Renew™ is a profile-walled, high density polyethylene (HDPE) pipe with a threaded joint coupling system and very shallow corrugation on the interior and exterior surfaces. Snap-Tite™ is a solid-walled, HDPE pipe with interlocking mechanical joints and smooth interior and exterior surfaces.

Table 1
Project Overview

County	Funded	Existing Culvert	Slip-Liner Brand and Dimensions				
			Dimensions	Length	Brand	ID	OD
Dallas	Y	CMP	900 mm Diameter	32 m	Culvert Re-new™	760 mm	860 mm
Jefferson	Y	Wooden Box	1100 mm Square	11 m	Snap-Tite™	760 mm	810 mm
Jones	Y	Concrete Pipe	1400 mm Diameter	18 m	Culvert Re-new™	1070 mm	1210 mm
Jones	Y	Concrete Pipe	1400 mm Diameter	18 m	Snap-Tite™	1130 mm	1220 mm
Mahaska	Y	CMP	600 mm Diameter	30 m	Culvert Re-new™	460 mm	510 mm
Taylor	Y	CMP	800 mm Diameter	31 m	Culvert Re-new™	610 mm	690 mm
Audubon	N	Concrete Pipe	600 mm Diameter	18 m	Snap-Tite™	480 mm	510 mm
Audubon	N	Concrete Pipe	600 mm Diameter	18 m	Snap-Tite™	480 mm	510 mm
Crawford	N	CMP (Spiral)	1050 mm Diameter	37 m	Snap-Tite™	810 mm	860 mm
Henry	N	CMP	450 mm Diameter	18 m	Snap-Tite™	384 mm	410 mm
Jones	N	CMP	900 mm Diameter	18 m	Snap-Tite™	763 mm	813 mm
Mahaska	N	CMP	600 mm Diameter	27 m	Culvert Re-new™	460 mm	510 mm
Pottawat-tamie	N	CMP	1800 mm Diameter	18 m	Snap-Tite™	1290 mm	1370 mm
Hamilton	N	CMP	1067 mm Diameter	107 m	Snap-Tite™	860 mm	914 mm

GENERAL SLIP-LINING PROCEDURE

This is intended as an explanation of the installation procedure based on manufacturers' recommendations and the experiences encountered in the field on these projects. There are lots of photographs throughout the report that will help to illustrate some of the many installation methods tried. However, this is not intended to be a comprehensive manual for slip-liner placement and does not represent a standard, specification, or special provision.

Clean the Existing Culvert

The liner is easier to insert and the grout is easier to place if the culvert is cleaned out first. Cleaning is usually accomplished by simply flushing with water. It is generally done several days before construction to allow the work site to dry.

Prepare the Work Area

The work area should be dry and cleared of brush and other obstacles. This may require a temporary water diversion or dam. Also, the pipe liner is easier to insert if it is at the same angle as the culvert. This may require some excavation in the ditch area prior to construction.

Prepare Access Points for Grouting

Access points will need to be cut into the existing culvert for placing grout into the annular space around the insert. When deciding on the location of the access points, consideration should be given to how the grout will be transported to these access points. Also, it is usually easier to cut the access points prior to inserting a liner.

Inserting a Cable Through the Culvert

Placing a cable through the culvert to pull the liner through represents potential safety hazards (principally confined space hazards). Care should be taken to make sure that the safety of workers is not compromised. If there is no clearly safe way to place the cable, the pushing method for slip-liner insertion should be used.

Pulling Head or Nose Cone

If the existing culvert is misaligned or badly deteriorated, a nose cone or pulling head may be necessary. These devices will help keep the liner from catching on obstructions as it is inserted.

A pulling head can be constructed easily from the liner itself. Simply cut wedges out from the front part of the first segment of liner. Drill holes through the remaining wedges and tie them together with wire or cable to form a cone. After lining the culvert, cut off the nose cone. If several culverts are to be lined with the same diameter of liner, a short segment of liner may sometimes be purchased to make a detachable nosecone which can be reused.

Slip-liner Assembly

Check to see if any of the segments have plain ends. If some do have plain ends, these sections will be the first and last segments used. If a reusable nose cone is to be used, make sure that the first segment has the required joint assembly at both ends. The slip-liner may be fully assembled prior to use. However, lack of space will often make this procedure impractical. The alternative is to assemble and insert the liner, segment by segment. If this is required, the following tips may be helpful:

1. Don't insert each segment completely into the existing culvert. Leave enough of the liner exposed to attach the next liner segment.
2. Placing a board under the two segments to be joined may help guide the alignment of segments.
3. Insertion of the liner can be done by either pulling or pushing. Pulling simply requires attaching cable or chain to the end of the liner, stringing the cable through the culvert, and pulling with the appropriate equipment. Pushing can be accomplished by pushing on the end of the pipe with a backhoe or by attaching a choker chain around the end of the pipe and using the backhoe to pull the chain. If the former method is chosen, be sure to place a plate or board between the end of the pipe and the bucket of the backhoe to avoid damage to the pipe.

GROUTING

Grouting should be performed according to manufacturer's specifications. Note that the liner may be pushed upward during grouting. To avoid this the liner may need to be braced and/or the grout placed in multiple lifts. This is especially important when there is a large annular space (i.e. the liner is significantly smaller than the original culvert) or when grouting is performed under pressure. Braces for the projects in this research were placed transverse to the pipe length. This resulted in deformation of the liner in several cases. A better method might be to place the brace longitudinally. However, some allowance will be needed to make sure grout can get to both sides of the liner around the brace.

The method of grouting is very important to culvert liner installations. If the culvert is being lined permanently, the liner must be able to withstand the results of the original culvert losing its capacity to support soil and traffic loads. A slip-lined culvert that is fully grouted in the annular space will tend to distribute those loads along the length of the liner. If the grouting is only at the ends, the liner may be subject to heavy point loads under failure of the original culvert. Additionally, this type of installation result in materials falling into the annular space as the original culvert deteriorated. This could lead to settlement of the roadway above.

The grouting method chosen may depend on the purpose of the slip-lining and the condition of the original culvert. If the lining is intended to restore flow only until reconstruction can occur in the relatively near future, the grouting method will not be critical as long as the original culvert is in reasonably good structural condition.

Grouting for the installations in this research was performed with flowable mortar. The mortar was usually placed by gravity through holes in the top of the original culvert near the ends. However, this method does not always fill the annular space completely. The following tips may be helpful in completing the fill.

1. A stand pipe can be used when pouring the grout. This vertical pipe assists flow by providing additional head on the mixture being placed.

2. Adding more holes for grout entry can help. These may be placed in the shoulders or even drilled through the center line.
3. Grout can be placed under pressure. Note that bracing will be more important in this case, and specialized attachments may be required.
4. The grout may be placed with a long delivery pipe stretched through the length of annular space to be filled. The delivery pipe is slowly removed as the grout fills in the space.
5. The liner itself can be used as a grout tube. Holes are drilled into the top of the liner and used to fill the annular space.
6. Use small pipes or holes in the surrounding culvert for air to escape as the grout enters the annular space.

BRACING

Bracing procedures were very important to the projects in this research. Neither liner supplier provided a bracing guideline, so the responsibility for proper bracing was left to the engineer. Problems developed when the existing culvert and the liner had a large difference in diameter. In this case the liner needed to be braced to keep the liner at the bottom and maintain the water flow level. Practical bracing techniques for slip-lining is an area that needs to be addressed in the future.

The pressures exerted on a liner are especially large when the entire annular space is being grouted. These pressures can cause the liner to experience deflection or failure if the bracing is not adequate. The following suggestions may be of help in minimizing the effects.

1. Try placing the grout in several lifts.
2. Build headwalls at the ends of the culvert to weigh down and secure the culvert liner before grouting.
3. Try using low density grouts.
4. Monitor the pressure applied if pressure grouting is used.
5. Try using longitudinal bracing.

Headwalls

Headwalls at the inlet and outlet are beneficial to the lined culvert. They anchor the liner, reduce erosion, provide fire protection and may improve water flow.

FLOW CAPACITY

An advantage of smooth interior wall polyethylene liners is their low Manning roughness coefficient. The range in values for these liners is anywhere from 0.009 to 0.015 (depending on the information source). The coefficient for corrugated metal pipe (CMP) ranges from 0.022 to 0.026 and that for concrete pipe ranges from 0.011 to 0.016. A lower coefficient for plastic pipe compared to CMP means that a smaller diameter liner will provide a flow equal to or greater than the culvert being lined. Note that even though both brands of liners are polyethylene, Culvert Renew™ has shallow corrugations. This probably means the roughness coefficient is slightly higher within the range shown than Snap-Tite™.

If pipe flow is simplified to consider only the Manning equation (i.e. ignoring entrance effects), a simple calculation will provide an estimate of the liner diameter which will have the same flow as the original culvert. Sample calculations at the extremes of the ranges indicate that a liner being placed in a CMP culvert could have a diameter between 72 and 87 percent of the original culvert diameter and still maintain (theoretically) the same flow rates as the original culvert. Note that a reduced diameter will increase the velocity of water in the pipe, and this increase may create a need for special end treatments to prevent erosion.

The Manning roughness coefficient for concrete pipe has a range of values that is considerably closer to those for plastic pipe. This means that from a design standpoint there is less justification for decreasing the diameter of the existing culvert. It would be possible in some cases to have a (designed) liner that is very close to the diameter of the original culvert. In any event, the engineer will need to use judgment about the design requirements of the culvert in question to determine the size of slip-liner that is appropriate.

DETAILED PROJECT DESCRIPTIONS

The projects in this research have been evaluated annually since construction. All of the lined culverts are performing well after more than five years in use. Descriptions of each of the liner placements with photographs, and field evaluations over the subsequent seven years are provided in the following pages for each of the projects (note that not all of the information is available for all of the projects).

Dallas County (Funded)

This project site was 3.5 km west of county road P58 on county road F51 (see map, Appendix A). Slip-lining took place on June 22, 1994. The Culvert Renew™ liner was delivered to the project site in five - 6.1 m sections and one - 1.5 m section.

The process began with excavation of an assembly area beyond the north end of the existing culvert. An area approximately 8 m long by 1.5 m wide was cleared so that the pipe sections could be assembled and inserted in alignment with the existing culvert inlet. Earth around the inlet was removed to expose the CMP approximately 1.2 m from the north end and 3.7 m from the south end.

Figure 1

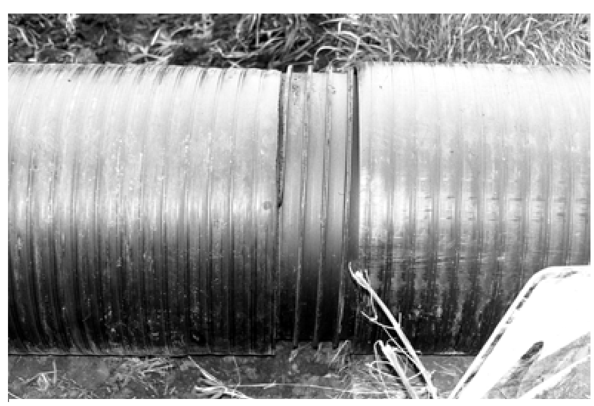


Figure 2

Examples of the Culvert Renew™ liners used in this project. Note the threaded joints and corrugation.

Installation of the liner began with the 1.5 m section placed first into the CMP. Approximately 0.6 m of liner was left extending out to provide space for connecting the next section. That next section was lowered into place and left suspended at the level of the first section using a chain attached to a backhoe. At this point, the second liner was

Figure 3
Threading two liner segments together.

threaded onto the first using a chain and steel bar as a strap wrench. Then, using an aluminum plate to protect the end of the liner, the backhoe was used to push the combined sections into the CMP until about 0.6 m remained. This process was repeated with the remaining liner sections.

Figure 4
Inserting liner section into culvert with a backhoe.

Figure 5
Cutting grout access holes in original culvert.

Once the insertion was complete, the contractor cut 100 mm diameter holes at the top of the exposed CMP to provide entry points for grouting. Grout was injected into the annular space under pressure from both ends. Unfortunately, the pressure from the grouting caused the center of the liner to float to the top of the CMP. The process required approximately 2.5 m^3 of flowable mortar.

Figure 6
Pouring grout into concrete pump hopper.

Installation took four hours. One backhoe operator and two laborers (at 4 hours each)

Figure 7
Pumping grout into annulus through access.

Figure 8
Close-up of north end showing liner movement.

and one welder (1 hour) were required. The equipment used for placement was a Case 580K backhoe. Expenses for slip-lining the culvert as well as estimated expenses for replacing the culvert conventionally are provided as part of the cost comparison table discussed later.

After seven years of service the culvert is performing well. The liner has shifted about 60 mm to the south as shown in Figure 8, but neither that nor the higher elevation of the center seems to be causing any problems with performance. The joints appear tight and there is no sign of leakage.

Jefferson County (Funded)

This project site was in Jefferson county 11 km east of Fairfield, 0.3 km east of Umber Avenue on 195th Street (see map in Appendix A). The existing drainage structure was a 1.1 m square wood box culvert with a length of approximately 11 m. The wood had deteriorated, and granular material from the roadway was falling through the top of the culvert.

Figure 9
North end of original culvert.

Installation of the liner took place on August 24, 1994. For this project, the liner chosen was Snap-Tite™ with an ID of 760 mm, an OD of 810 mm and length of 18 m. The liner was delivered to the site in two equal length segments.

Preparation of the culvert for lining included clearing brush from the foreslopes, removing the wing walls from the north end of the existing structure and placing braces. Five braces were placed along the top of the wooden box culvert, one at each end and at each quarter point. The purpose of these braces was to prevent the liner from floating to the top of the existing culvert when the annular space was filled with grout.

Liner assembly took place at the north end of the existing structure. The two segments were connected prior to insertion. This connection process consisted of wrapping the ends of each pipe segment tightly with chain and pulling them together with a winch until they locked together.

The completed liner was then pulled through the existing culvert. Soil was placed at the end of the liner to act as an earth dam to contain the flowable mortar.

While the mortar was being placed, the liner began to deform near the middle due to hydraulic pressure. This deformation occurred about 0.3 m from the liner connection joint and produced a high stress on the connection. The connection held but did open enough to allow some water leakage. At this point the grouting was halted with the liner

Figure 10
South end of original culvert with a short segment of PCC pipe inserted.

Figure 11
Section of roadway that was subsiding into the old culvert.

Figure 12
Unloading and aligning the two segments.

Figure 13
North end after clearing.

Figure 14
Joint between two segments showing sealing strap.

Figure 15
Coupling of liner segments.

Figure 17
Mortar being poured into annulus in front of earthen dam.

approximately half submerged in grout. Total liner deformation was approximately 75 mm. Grouting was completed the next day with no further deformation occurring.

This installation required six hours. The crew required was one equipment operator and two laborers at six hours each. Equipment required for moving and inserting the liner in this case was a John Deere 595D backhoe.

Figure 16
Pulling the liner through the culvert.

Figure 18
Mortar was delivered and placed with an ordinary ready-mix truck.

Figure 19
Mortar is half-placed. Note brace above the liner.

Figure 20
South side of culvert after slip-lining was complete.

As of this writing it has been eight years since the liner was placed in this culvert.

During that time, the liner has performed well. It has not been possible to measure movement of the liner in this case because headers were not constructed on the project. However, the lined culvert has been free flowing and has no visible breaks or leaks (although the top of the liner remains deformed from the grouting). Additionally, there has been no indication of further settling of the road above.

Figure 21
View of the inside of the lined culvert several years after construction. Note the indentations in the top of the liner from the grouting pressure.

Figure 22
View of the south end of the culvert as it appeared in 2001.

Jones County (Funded)

This project site was 2.2 km east of US 151 on county road E23 (see map in Appendix A). There were two existing culverts - twin 1400 mm diameter Portland Cement Concrete (PCC) pipes. The joints between the pipes had separated and the PCC was showing signs of deterioration.

Figure 23
Original culverts with back hoe in place to assist with liner insertion. Note the aggregate placed to try to stabilize the soggy ground.

The roadway above the existing structure, had been replaced once due to settlement around the culvert. Subsequently, the area had settled again, causing cracking and faulting.

Both products, Culvert-Renew™ and Snap-Tite™ were used in this project, providing a side-by-side comparison of installation and performance. The Culvert-Renew™ liner had an ID of 1070 mm an OD of 1210 mm and a length of 21.3 m, while the Snap-Tite™ liner had dimensions of 1130 mm ID, 1220 mm OD and 20.1 m length.

Project preparation included cleaning sediment from both culverts and excavating an area beyond the south end of the culverts to allow enough workroom for assembly of the culvert liners. The area had received rain the previous night, so the ground was saturated. The contractor placed gravel to improve the condition of the assembly area. This helped but the area was still soft and difficult to work in.

After the sediment had been cleaned out, holes were cut into the tops of the culverts to provide for grout entry and braces were attached inside.

The liners were installed on September 13, 1994. Culvert-Renew™ was installed first in the west culvert. This liner was fabricated in three pieces which were connected

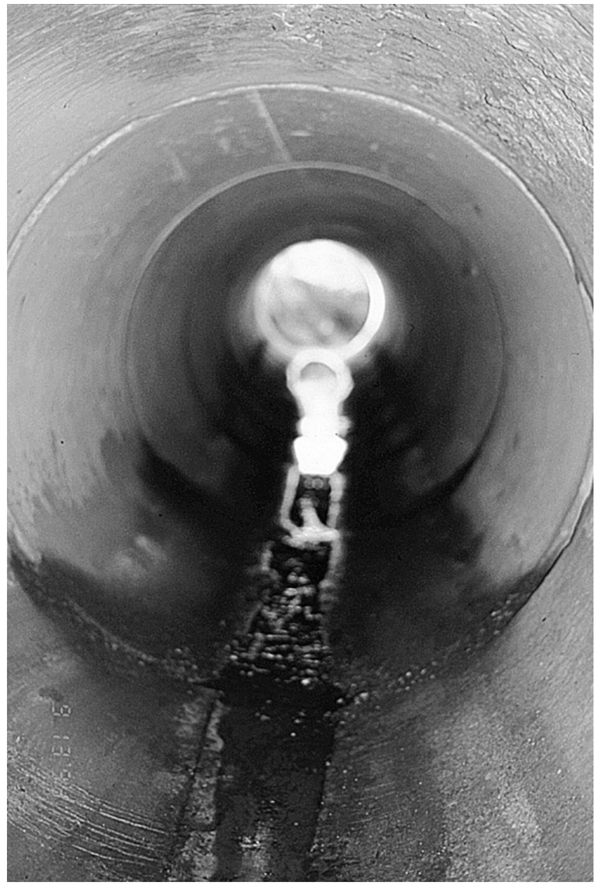


Figure 24
Photograph of original culvert showing deterioration and joint separation.

and inserted as described earlier. The entire operation was made quite difficult because of the wet, soft conditions of the ground at the site.

On the same day, the Snap-Tite™ liner was placed in the east culvert. The process was

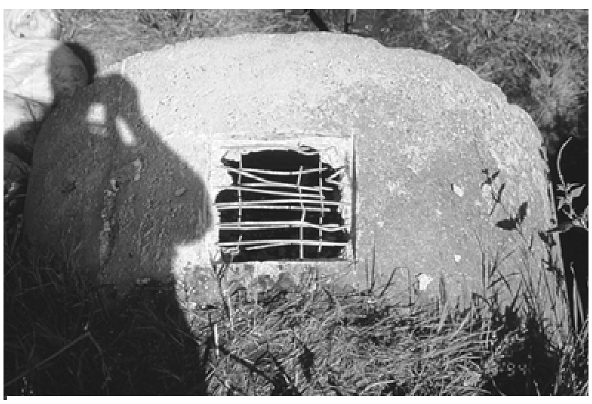


Figure 25
Grout entry hole in top of one culvert.

also similar to that described previously. However, the liner segments had a slightly oval deformation in cross section. This made connection of the first joint difficult. The oval cross sections were lined up prior to connecting the second joint which made the process smoother.

Grouting took place the following day. The Culvert Renew™ liner experienced deformation during the grouting procedure. This deformation was a maximum of 100 mm at the bracing points tapering off for 3 m to

Figure 26
Transverse brace above liner in the west culvert.

Figure 27
Connecting two Culvert-Renew™ liner segments together using a strap wrench.

Figure 28
Inserting the Culvert-Renew™ liner into the west culvert with a piece of plywood to protect the end of the liner from the back hoe bucket.

either side. One brace was directly over a liner joint. This joint was deformed but remained connected and showed no indications of leaking.

Note that the annular space in the culvert with the Culvert-Renew™ liner was slightly larger than that with a Snap-Tite™ liner. This would have led to use of a slightly larger amount of grout in the installation of the Culvert-Renew™.

Figure 29
Connecting two Snap-Tite™ liner segments together using chains and winch.

Installation took about 10 hours including site preparation, lining the culverts, grouting and cleanup. The crew required was one equipment operator (10 hours) an four laborers (three for 6 hours and one for 10 hours). The equipment used was a Case 1085 back hoe.

Both liners are performing well. There has been no significant movement to-date, and the joints have maintained their integrity.

Figure 30
Inserting the Snap-Tite™ liner into the east culvert.

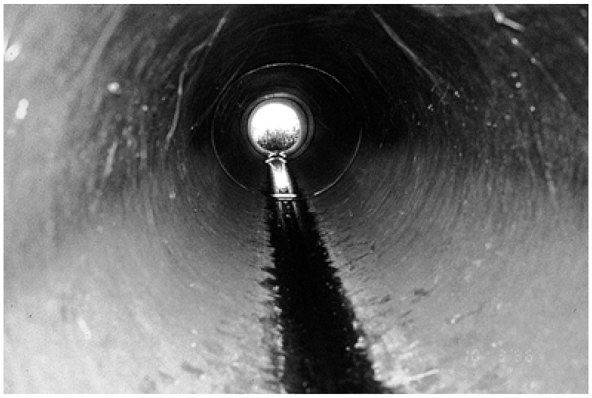


Figure 31
Installed Snap-Tite™ liner as it looked in 1996.

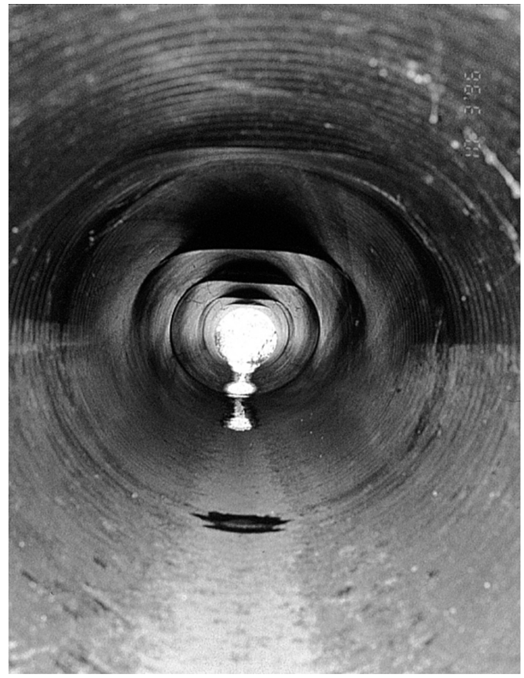


Figure 32
Installed Culvert-Renew™ liner as it looked in 1996. Not deformations in the roof.

Mahaska County G-77 (Funded)
This project was located 1.4 km west of county road T-67 on county road G-77, about 100 m east of the junction of 340th St. and Rowland Ave. (see map in Appendix A). The existing drainage structure was a 600 mm diameter CMP with a length of 29.6 m. The bottom quarter of the CMP had rusted away completely and this culvert had a 30° bend located approximately 6 m from the south end. The cause of the bend was a landslide on the foreslope.

Figure 33
Bottom of original culvert.

Figure 34
Clearing around the existing culvert to enable adjustment of the alignment.

Installation of the liner took place on July 27, 1994. The product used for this project was a Culvert Renew™ liner with an ID of 460 mm, OD of 510 mm and a length of 29 m. The work crew began at the south end of the culvert by attempting to straighten the bent portion to be in line with the rest. Earth was placed beneath the exposed CMP and compacted. After straightening, there remained about 5° of bend.

A small area on the south end of the pipe was cleared to allow for assembly of the liner; the area was deep enough for the liner to be aligned with the south end of the existing culvert. The first segment of liner was lowered into position and inserted into the pipe using a chain attached to the bucket of the backhoe. It was placed into the culvert until approximately 1.5 m of liner was left exposed. The second segment was aligned with the first and threaded into it using a strap wrench. These two combined sections were then pushed into the culvert with the backhoe. An old road sign was used to protect the end of the liner while it was being pushed.

Figure 35
Placement of the first liner segment.

Figure 36
Threading two liner segments together.

Filling of the annular space with grout was performed on the north (upstream) side. A welder cut a hole approximately 150 mm in diameter through the top of the CMP. The work crew then fabricated a funnel using an empty steel barrel, which was placed above the hole. It was surrounded with dirt to hold it in place. The annular space around the liner was packed at each end with a fiberglass blanket to hold in the grout.

Figure 37
An old road sign was used to protect the end of the liner during insertion. Note that there is still some deformation.

Grout was placed by gravity flow through the funnel on the north side. The standing head in the funnel was inadequate to push the mortar fully to the south side of the culvert leaving several meters of the south end of the culvert without grout in the annulus. However, the pipe liner supplier representative was of the opinion that enough of the annular space had been filled for satisfactory performance. The same road sign was used as a cap for the culvert and liner during pouring and left above the culvert after. Also, the annulus on the north end was occluded with fiberglass cloth.

Figure 38
Funnel used to provide added head to the grout being poured into the annulus.

Figure 39
The funnel was placed over the entry hole and surrounded with soil.

The crew required for this project included one equipment operator (6 hours), two laborers (5 hours each) and one welder (1 hour). The equipment used to move and insert the liner was a Link-Belt LS-2800 C-Series II track backhoe.

As of this writing (2002) the liner has been in place for eight years. The liner appears to be functioning well. There are no breaks or leaks visible in the interior, and the liner does not appear to have shifted with respect to the culvert. However there is a visible downward bend in the liner, implying that the slide which caused the original bend may have reoccurred.

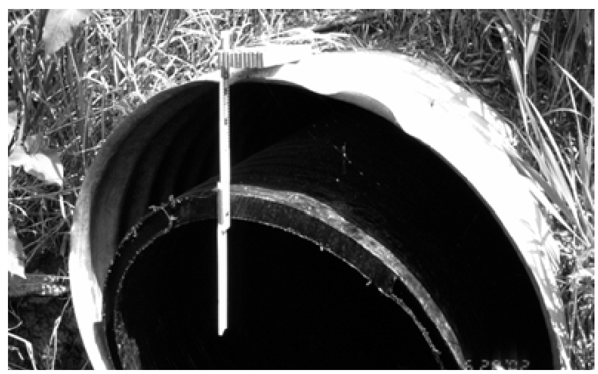


Figure 40
The grout did not reach the downstream end of the culvert leaving a large annular gap.

Figure 41
Water flow under the liner at the south end.

An important note with this project is that, at least since 1996, there has been a steady flow of water out of the annulus on the south end. There is no corresponding flow into the culvert on the north side. It is reasonable to conclude that active water flow in the fill underneath the road caused the original and subsequent soil movements.

Taylor County (Funded)

This project was located 3.2 km west of IA-148 on county road J-20. The existing drainage structure was an 800 mm diameter CMP with a length of 31.4 m. The bottom quarter of the CMP had rusted out.

Installation of the liner began November 2, 1994 with clearing of the work area and cutting holes in the CMP for flowable mortar placement.

Figure 42
Clearing of work area at south end of culvert.

Figure 43
Cable attached to the cone at the front of the liner.

Actual liner installation took place on November 3. A Culvert Renew™ liner with ID of 610 mm, OD of 690 mm and length of 33.5 m was used. To aid in the insertion process, the end of the liner was cut and folded to form a cone with holes for a steel pulling cable. Instead of being pushed in, the liner was pulled through the culvert using this cable attached to a truck. The liner segments were held in alignment with a crane. Once the full liner was in place, the cone end was cut off.

Figure 44
Pulling the liner through the culvert.

In this project truck tire inner tubes were placed around the ends of the liner and inflated to provide an annular seal. Approximately 0.8 m^3 of grout was pumped into the annular space at each end of the culvert. The grout did not fill the entire annular space but was sufficient to keep the liner in place according to the supplier representative. After grouting was completed, the contractor constructed a head wall at each end.

The crew required for lining this culvert included one equipment operator and two laborers at ten hours each. Equipment required was one winch-equipped truck and a Link-Belt HC-48A crane.

Note that the fill above this culvert extended approximately five meters. Excavation and fill in this case would have been significant had conventional culvert replacement techniques been used.

Figure 45
Inlet end of lined culvert showing headwall.

Figure 46
Outlet of lined culvert with headwall and rip-rap.

Figure 47
Movement of liner or headwall at inlet end.

At the time of this writing, the liner has been performing well. There has been a small amount of movement of the liner or headwall, visible mostly at the inlet. It amounts to approximately 10 mm.

Audubon County (Not Funded)

This project was located 2.4 km west of US-71 on county road F-16 near the town of Gray (see map in Appendix A). The existing drainage structures were two 600 mm diameter concrete pipes with lengths of 18.3 m.

Installation of the liners began May 23, 1994. Both culverts were lined using Snap-Tite™ liners with ID of 480 mm and OD of 510 mm. Liner lengths were 18.3 m and 18.9 m. One existing culvert (the easternmost) was in poorer condition than the other. To aid in the insertion process into this culvert, the end of the longer liner was cut and folded to form a cone or "bullet nose". The liners were pushed into place using an excavator.

Figure 48
Maneuvering the first liner segment into position.

Figure 49
Preparing joint for adding the second segment.

After insertion, the bullet nose was cut off of the longer liner, the ends were blocked, and the annular space was filled with flowable mortar. No noticeable lifting occurred with the flowable mortar placement. Small headwalls were formed and poured on the inlet ends only.

Figure 50
Joining the first and second segments.

Figure 51
Appearance of “bullet nose” at the other end of the culvert.

Figure 52
Headwall for the east culvert.

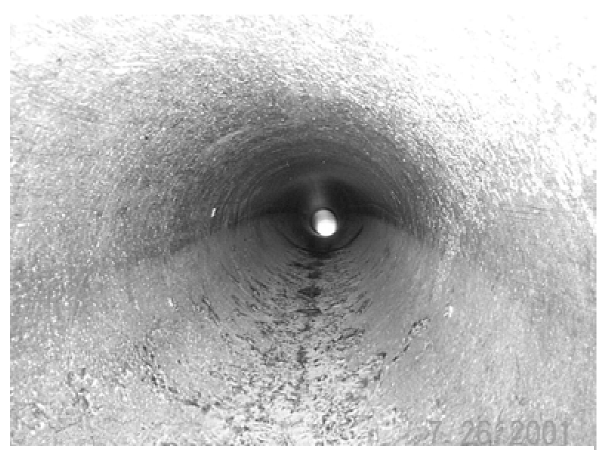


Figure 53
View through the liner in the east culvert.

Figure 54
Measurement of slippage at the upstream side of the west culvert.

As of this writing, both culverts are performing well. The west liner has slipped in the downstream direction approximately 125 mm. If the slippage continues, appropriate remedial actions will probably need to be taken to prevent further slipping and possible water bypass.

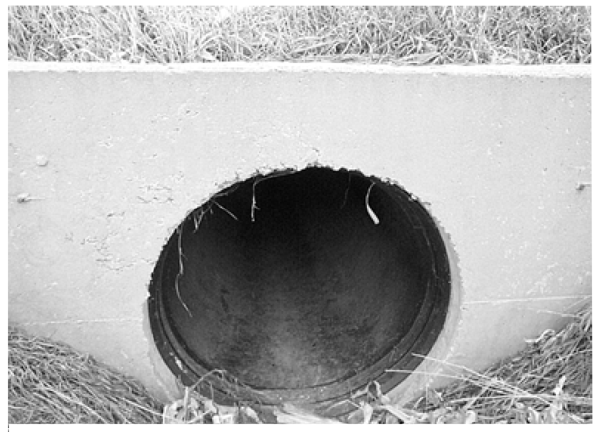


Figure 55
Headwall at the upstream end of the culvert.

Crawford County (Not Funded)

This project was located 5 km west of county road M64 on county road E16 (see map in Appendix A). The existing drainage structure was a 1050 mm diameter spiral CMP with a length of approximately 37 m. In this somewhat unusual case, the culvert extended horizontally approximately 18 m under the road, then turned down slope at an angle of about 20 degrees for an additional 18 m. Only the horizontal portion of the culvert under the road was slip-lined in this project.

Installation of the liner began May 25, 1994. The culvert was lined using a Snap-Tite™ liner with ID of 810 mm, OD of 860 mm and a length of 20 m. The extra liner length was used to allow the culvert inlet to be moved further away from the shoulder. A headwall was built at the culvert entrance.

Figure 56
The downstream end remains the original CMP.

Figure 57
The opposite opening was slightly visible from the upstream end) in 2000 but was not visible in 2003.

Figure 58
Movement of the liner with respect to the headwall on the north side.

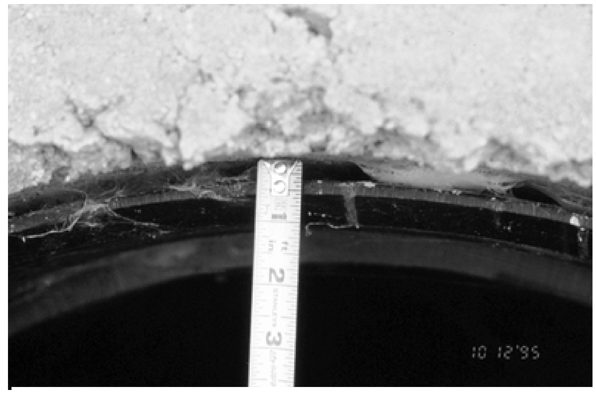


Figure 59
Gap between the liner and the edge of the headwall.

Figure 60
Cracking that appeared above the culvert. These cracks were not observed in the previous inspection (2001).

At the time of this writing the culvert seems to be performing well. The liner has moved into the culvert approximately 70 mm - most of the movement occurred during the first year after placement. Also a gap of some 12 mm has formed between the top of the liner and the edge of the head wall.

Of greater concern is that the fill above the culvert appears to have settled in the intervening years causing cracks in the overlying road. This could indicate additional loss of material in the unlined portion of the culvert.

Henry County (Not Funded)

This project was located in Geode State Park on the east side of the lake, just south east of the entrance to the boat ramp (see map in Appendix A). The existing drainage structure was a 600 mm diameter CMP with a length of approximately 18 m. The bottom quarter of the pipe was rusted out.

Figure 61
Equipment in place to insert the liner.

Installation of the liner began September 8, 1994. The culvert was lined using a Culver Renew™ liner with ID of 384 mm, OD of 410 mm and a length of 19.8 m. Grout was placed through a hole cut into the CMP.

Installation required two laborers and an equipment operator for five hours each. The liner was inserted using a John Deere backhoe.

Figure 62
Pouring the grout.

As of this writing, the slip liner has been performing well. There was no sign deformation from the grouting other than a slight curve downward at the downstream end of the liner. The liner does not appear to have moved since installation, but with no headwalls this is difficult to determine.

Figure 63
West end of lined culvert after about six years.

Figure 64
View through liner at six years.

Jones County (Not Funded)

This second project in Jones county was located approximately 2.5 km north of Anamosa on county road X31 (see map in Appendix A). The existing drainage structure was a 900 mm diameter CMP with a length of approximately 18 m. The overlying PCC pavement had settled and cracked. This settlement had become severe enough at some point that mud jacking was used to raise and fix the pavement surface.

Figure 65
Pavement over culvert showing settlement cracking and mud-jacking holes.

Installation of the liner began September 12, 1994. The culvert was lined using a Snap-Tite™ liner with ID of 763 mm, OD of 813 mm and a length of 18 m.

The ends of the culvert were sealed with soil during grouting. Excess grout formed a large mass above the culvert at each end, which was initially flush with the surface of the foreslope.

For a while this mass of grout acted as a de facto headwall and provided a relatively stable basis for measuring liner movement. However, over the course of the next few years, the soil surrounding the entrance and exit of the culvert eroded away, leaving just two masses of solidified grout extending over the top of the liner. The mass on the west end of the liner eventually broke off. Nonetheless, measurement was still possible and the liner did not exhibit significant movement.

Figure 66
Grouted "headwall" at the downstream side of the lined culvert.

Figure 67
Grout at upstream side of lined culvert.

Figure 68
Grout covering on the downstream side after several years of erosion of the slope around it. This piece subsequently broke off and rests in the ditch below.

Deformation visible at the time of this writing was limited to a slight downturn in the liner at the west (downstream) end.

Figure 69
Inlet end of lined culvert. The annulus was blocked for grouting with fiberglass fabric. Note the funnel above the liner. It was the same design as the first Mahaska project.

Mahaska County G-71 (Not Funded)
This second project in Mahaska county was located approximately 1 km west of county road T-37 on county road G-71 (see map in Appendix A). The existing drainage structure was a 600 mm diameter CMP, approximately 27 m long with the bottom quarter of the CMP corroded.

Installation of the liner began September 12, 1994. The culvert was lined using a Snap-Tite™ liner with ID of 763 mm, OD of 813 mm and a length of 18 m.

Figure 70
Inlet end of lined culvert after several years. The fabric has come loose and tends to interfere with water flow (it was moved out of the way for this photograph).

Figure 71
Outlet end of the lined culvert.

Pottawattamie County M-47
(Not Funded)

This project was located on Pottawattamie county road M-47 just north of the junction with U.S. 6 (see map in Appendix A). The existing drainage structure was an 1800 mm diameter CMP, approximately 18.3 m long. That makes it the largest diameter culvert slip-lined during this research. The bottom quarter of the CMP was corroded.

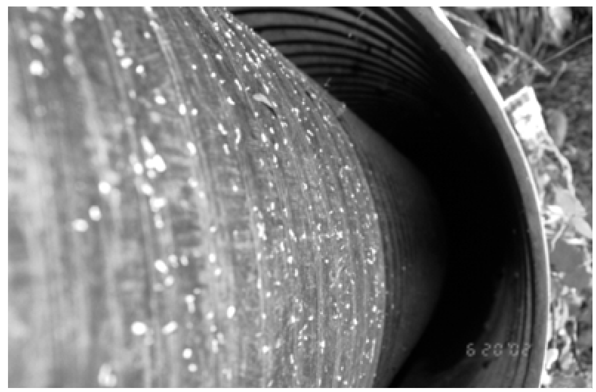


Figure 72
Annular space around liner at outlet end.

Installation of the liner occurred May 24, 1994. The culvert was lined using a Snap-Tite™ liner with ID of 1290 mm, OD of 1370 mm and a length of 18.3 m. The difference in size between the liner and surrounding culvert was also larger than the other projects. This difference averaged approximately 125 mm for the other projects and was 430 mm for this project.

Figure 73
Outlet of lined culvert.

Figure 74
View through the lined culvert showing no deformations.

Despite the large annular area in this project, the liner did not visibly deform during grouting.

Hamilton County R-27 (Not Funded)

The project in Hamilton county was not an original part of this research. However, the fill above the culvert (more than 50 feet) was significantly more than any of the other projects. In this case, sliplining was the only feasible method available for repairing the culvert as excavation was out of the question. Additionally, this project had extensive photographic records of the installation process.

This project was located on Hamilton county road R-27 approximately 1.6 km south of the junction with county road D-46 (see map in Appendix A). The existing culvert was 1067 mm diameter and 107 m long. The liner used was a Snap-Tite™ brand, 860 mm diameter. Lining took place on July 7, 1995.

Figure 75
Road that was built to provide access to the culvert, showing the large elevation difference (the culvert is below the tree line visible in the photograph).

Figure 76
Fastening the sleeve, which is to hold the annular plug, onto the end of the existing culvert.

Figure 77
Positioning the liners.

Figure 78
Lubricating the joint prior to connecting two liner sections.

Figure 79
Connecting two sections.

Figure 80
Pumping grout into the annulus at the outlet end.

Figure 81
Close-up of the hose attachment.

Figure 82
This is what happens if the pumping is stopped to wait for a second ready-mix truck.

Figure 83
After the problem shown in the last photograph, it was impossible to pump more grout into the outlet end. The remaining mortar was pumped into the inlet end of the lined culvert.

Figure 84
This is the outlet of the lined culvert after about six years. The headwall for this end was constructed from metal instead of concrete.

Figure 85
The inlet to the lined culvert, also at about six years. It was mostly covered and clogged with debris (some of which was removed for this photograph.

CONCLUSIONS/RECOMMENDATIONS

The culvert liners placed during this research have been performing well. Costs, generally, were lower than the estimated costs of conventional methods. Therefore, sliplining appears to be a practical, cost effective method for rehabilitating damaged or poorly performing culverts.

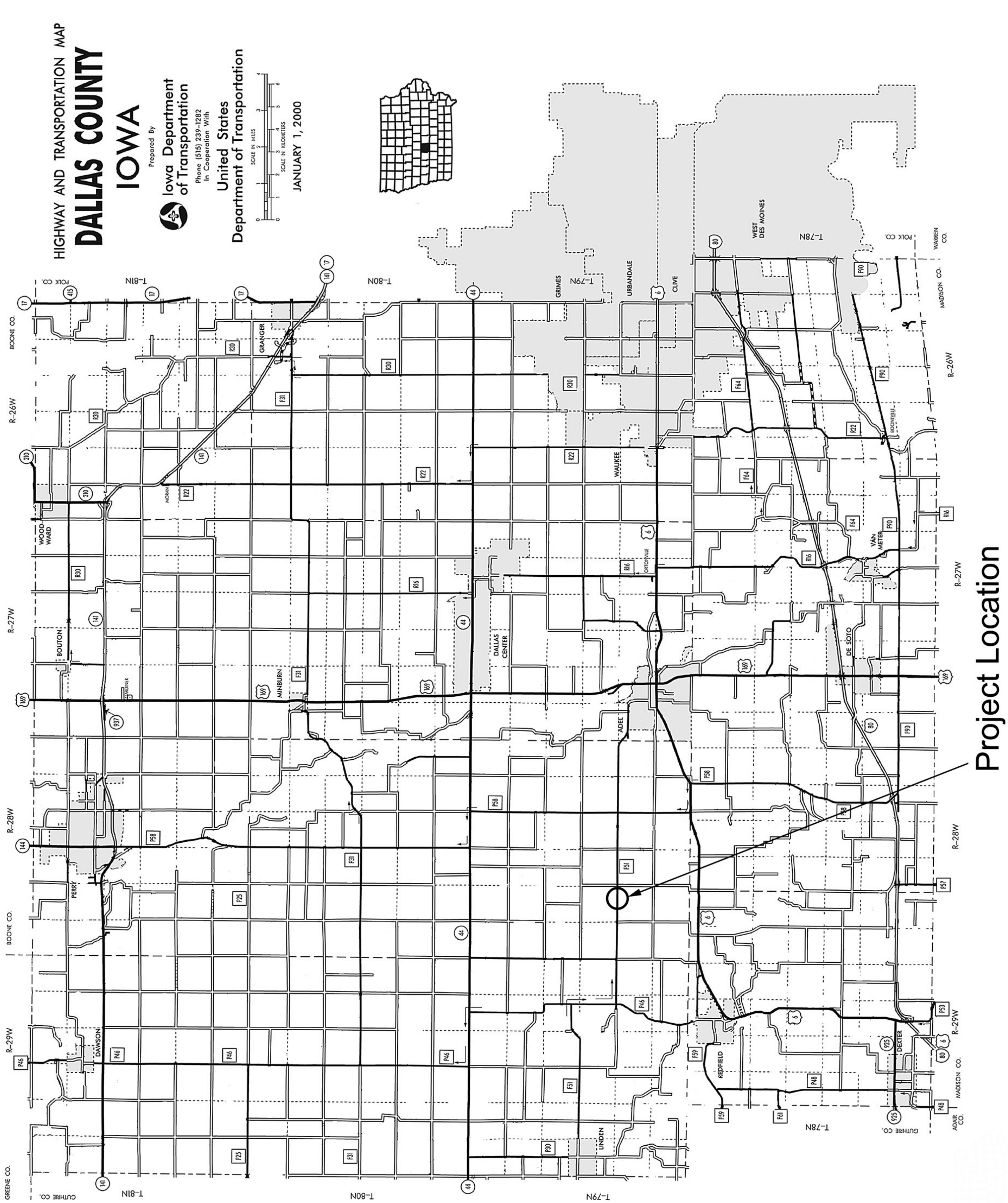
However, there are several areas that need further investigation:

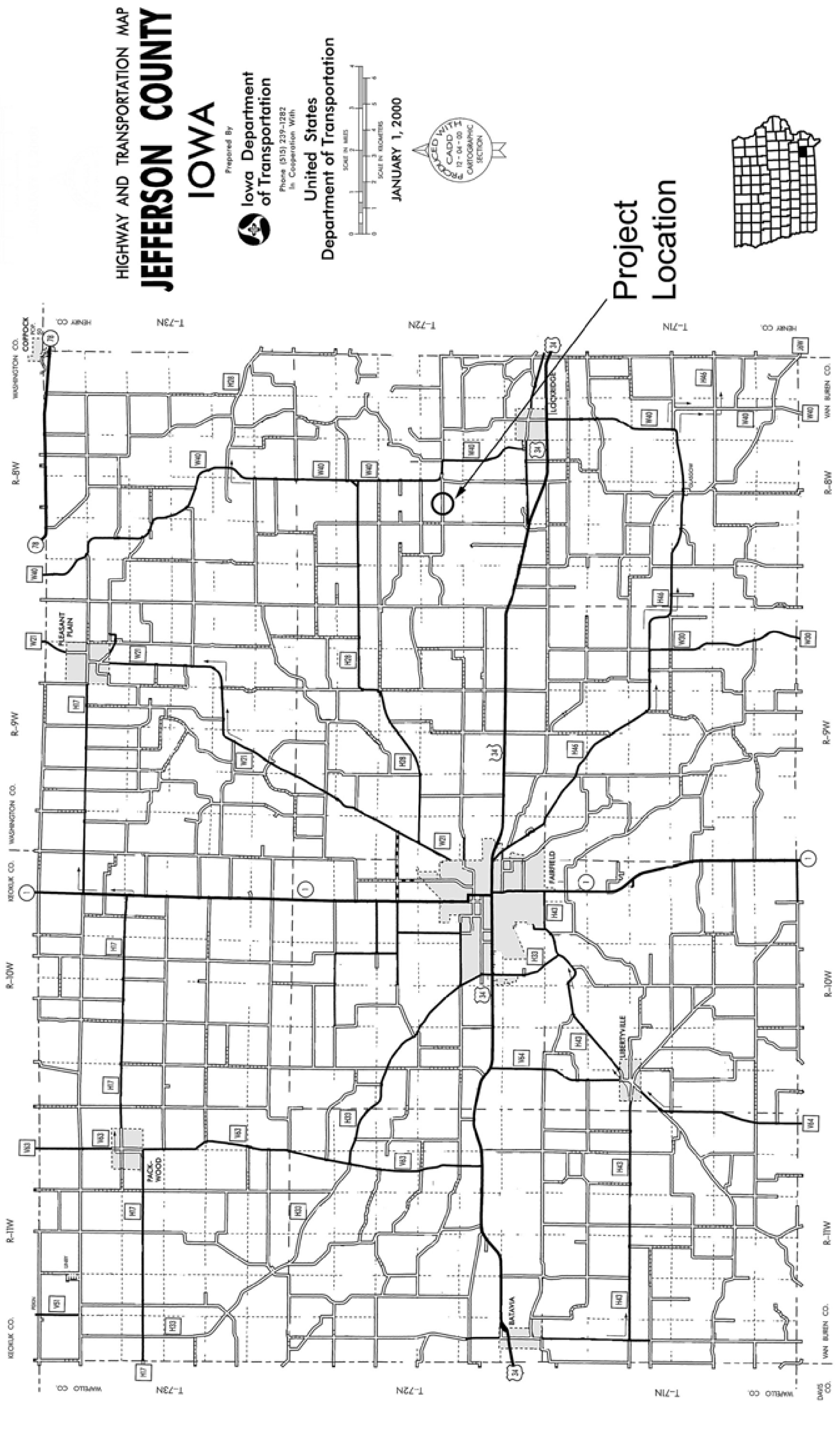
1. The ends of the slipliners did not generally remain anchored to the headwalls. Further investigation would determine if this is a problem and ,if so, how best ot provide adequate anchorage.
2. The sizing of the slipliner is based on several assumptions, including the Manning's roughness coefficient value, neglect of entrance effects, and the importance of water velocity. These factors should be further evaluated so that the engineer can make good judgements about the necessary size of the final culvert. An example of this involves the value of the Manning's roughness coefficient. Standard references list this value for plastics as falling in a range between 0.009 and 0.015. Which number applies to a particular liner is not often apparent (manufacturers' literature generally cites very low numbers). The number chosen can make a significant difference in the design size of the liner.
3. Finally, it is very important that a practical method be developed for assuring that the liner does not lift or become deformed as mortar is being placed in the surrounding annular space. The methods attempted in this research were only partially successful. It did appear that the solid walled Snap-Tite™ liners showed little or no deforming in several cases where the Culvert Renew™ liners showed significant deformation.

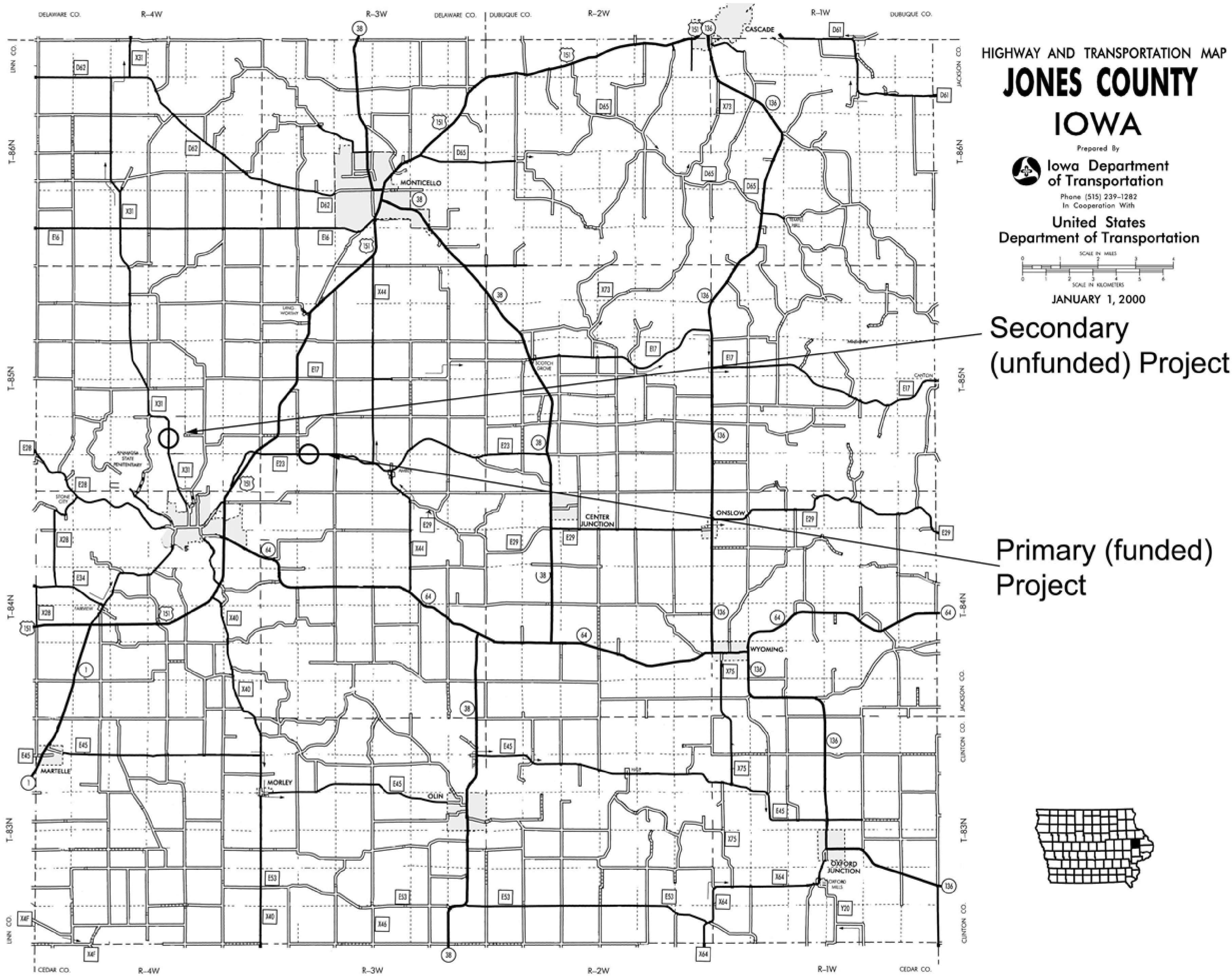
A balance will have to be found between time and effectiveness of various methods. For example, placing the grout in several shallow lifts (with some bracing) would minimize uplift, but require a significant amount of time. Simply bracing the liner is quick and easy, but often resulted in deformation and stress in the liner. Would a different type of bracing (such as longitudinal) work better? Could the liner be filled with water during grouting?

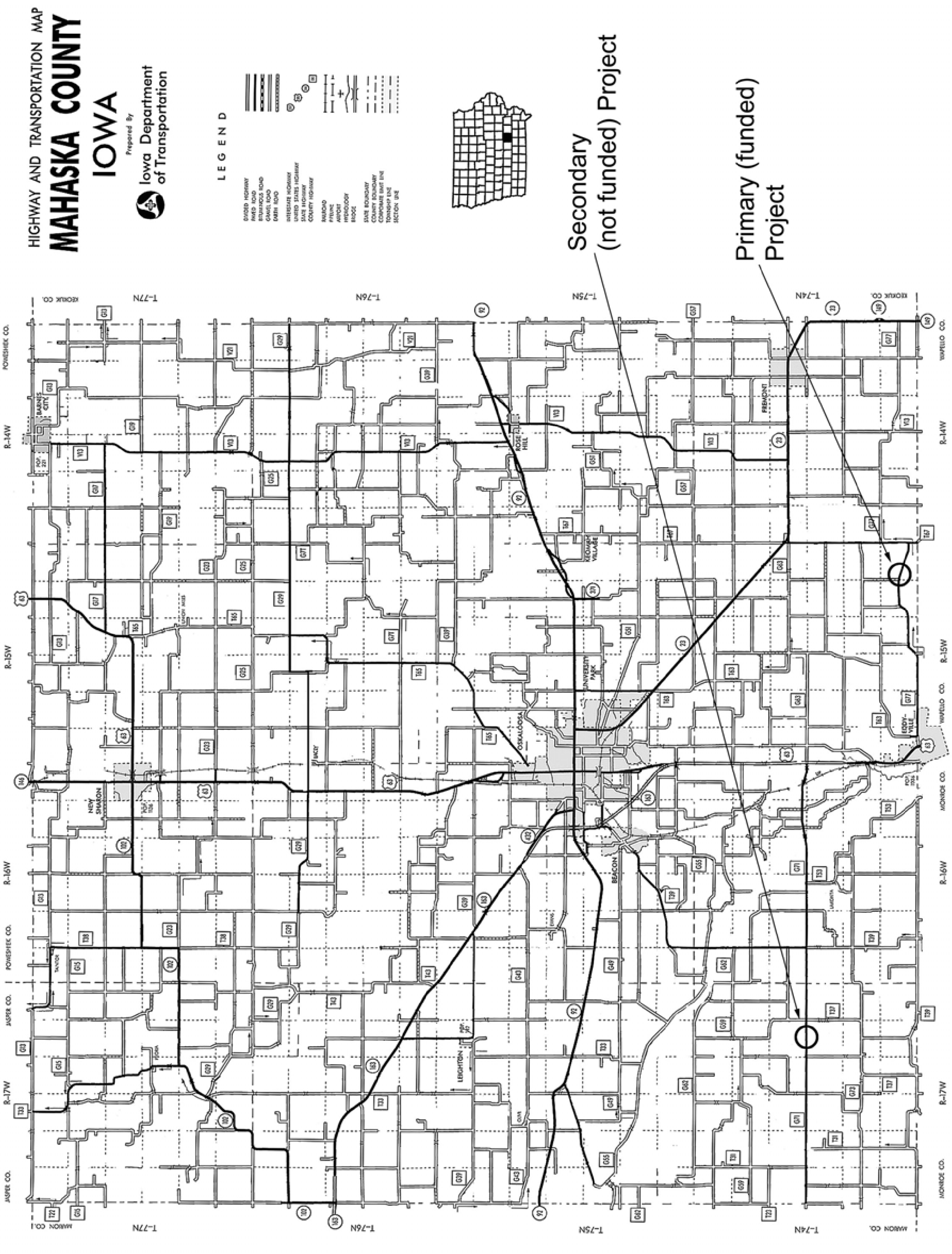
Many more culverts have been lined in the intervening years between the projects described and the writing of this report. As a result, these questions may have been resolved by the county engineers using trial and error. It would be beneficial to survey the counties and discover what best practices they have determined.

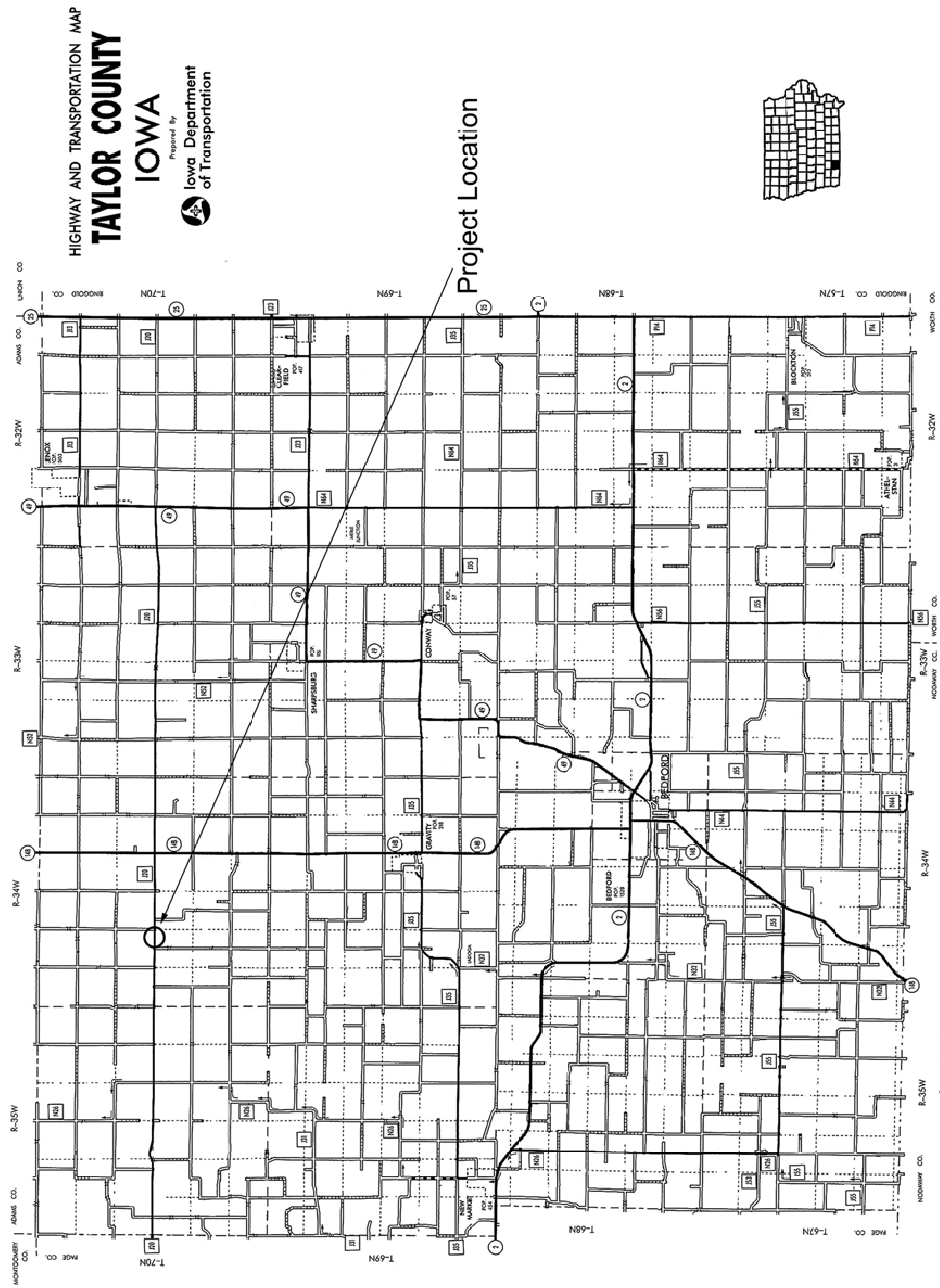
Appendix A
Project Location Maps

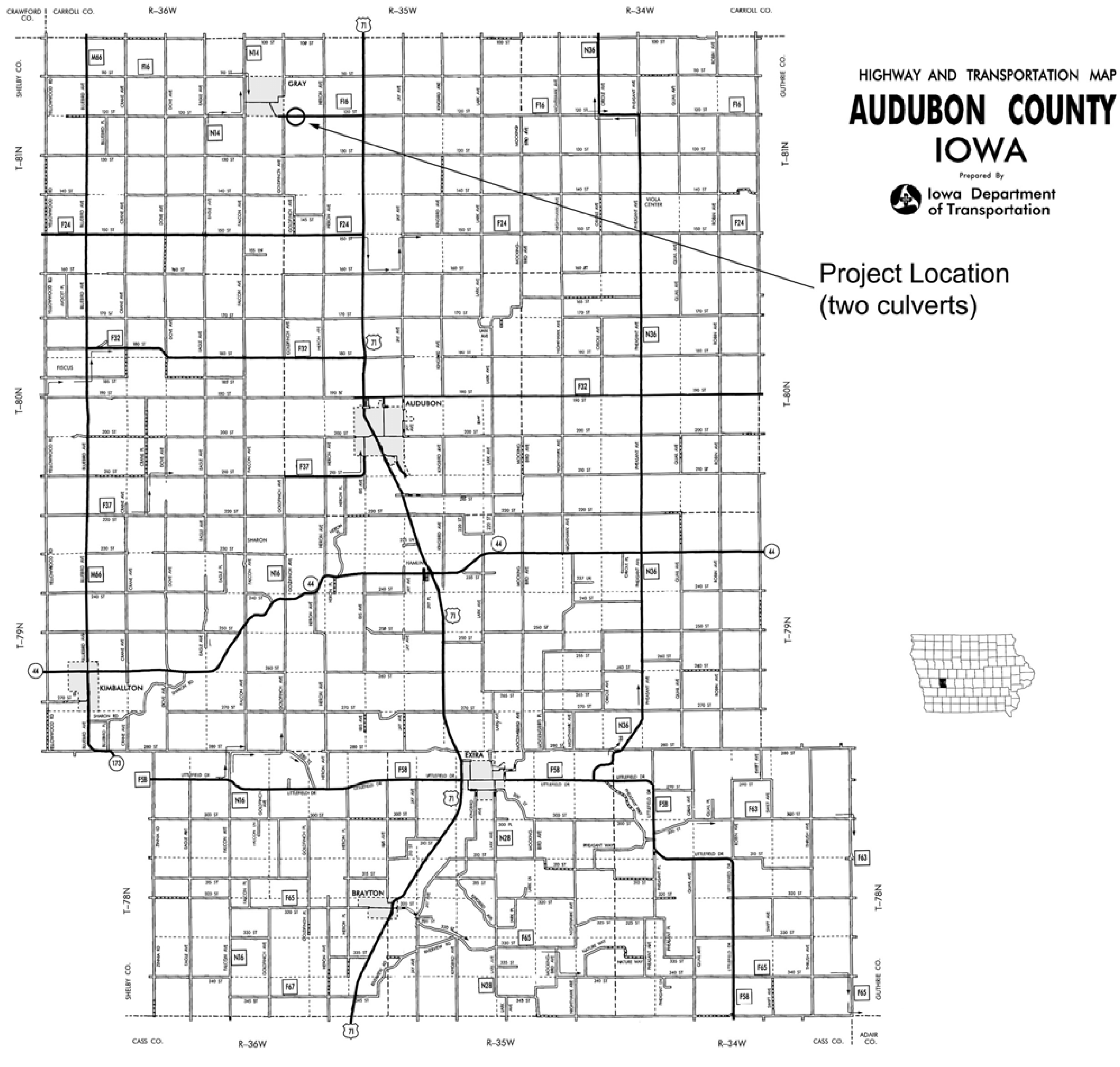

HIGHWAY AND TRANSPORTATION MAP
DALLAS COUNTY
IOWA
Prepared By
Iowa Department of Transportation
Phone (515) 239-1282
In Cooperation With
United States Department of Transportation
JANUARY 1, 2000
Project Location
GRANGER
WOODWARD
BOUTON
MINBURN
DALLAS CENTER
WAUKEE
GRIMES
URBANDALE
CLIVE
WEST DES MOINES
VAN METER
DE SOTO
ADEL
PERRY
DAWSON
LINDEN
REDFIELD
DEXTER
BOONE CO.
POLK CO.
GREENE CO.
GUTHRIE CO.
MADISON CO.
WARREN CO.
ADAIR CO.
R-26W
R-27W
R-28W
R-29W
T-81N
T-80N
T-79N
T-78N

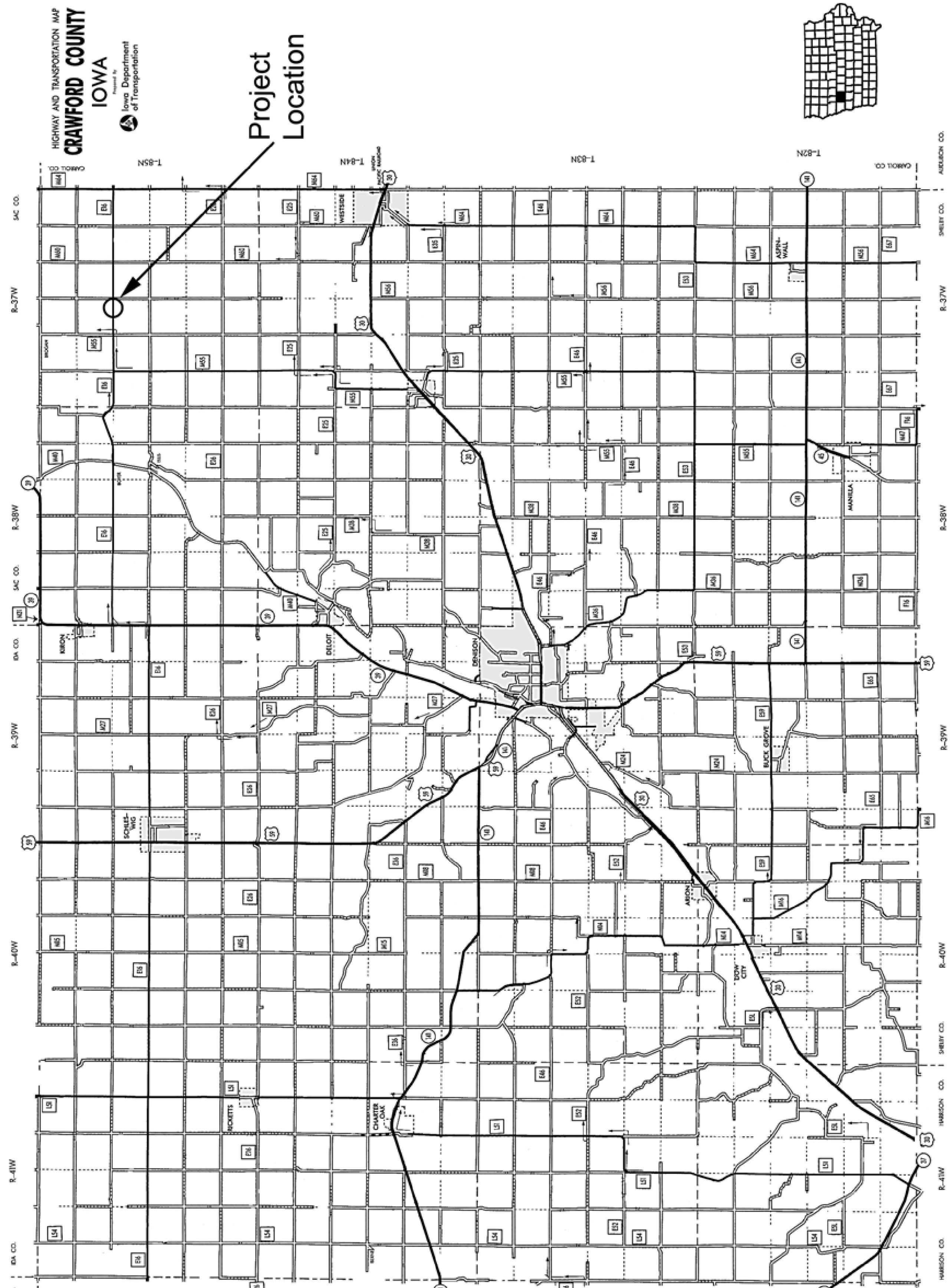

HIGHWAY AND TRANSPORTATION MAP
JEFFERSON COUNTY
IOWA
Prepared By
Iowa Department of Transportation
Phone (515) 239-1282
In Cooperation With
United States Department of Transportation
JANUARY 1, 2000
Project Location
FAIRFIELD
LIBERTYVILLE
BATAVIA
PACKWOOD
PLEASANT PLAIN
LOCKRIDGE
COPPOCK
R-8W
R-9W
R-10W
R-11W
T-73N
T-72N
T-71N
WASHINGTON CO.
KEOKUK CO.
HENRY CO.
VAN BUREN CO.
WAPELLO CO.

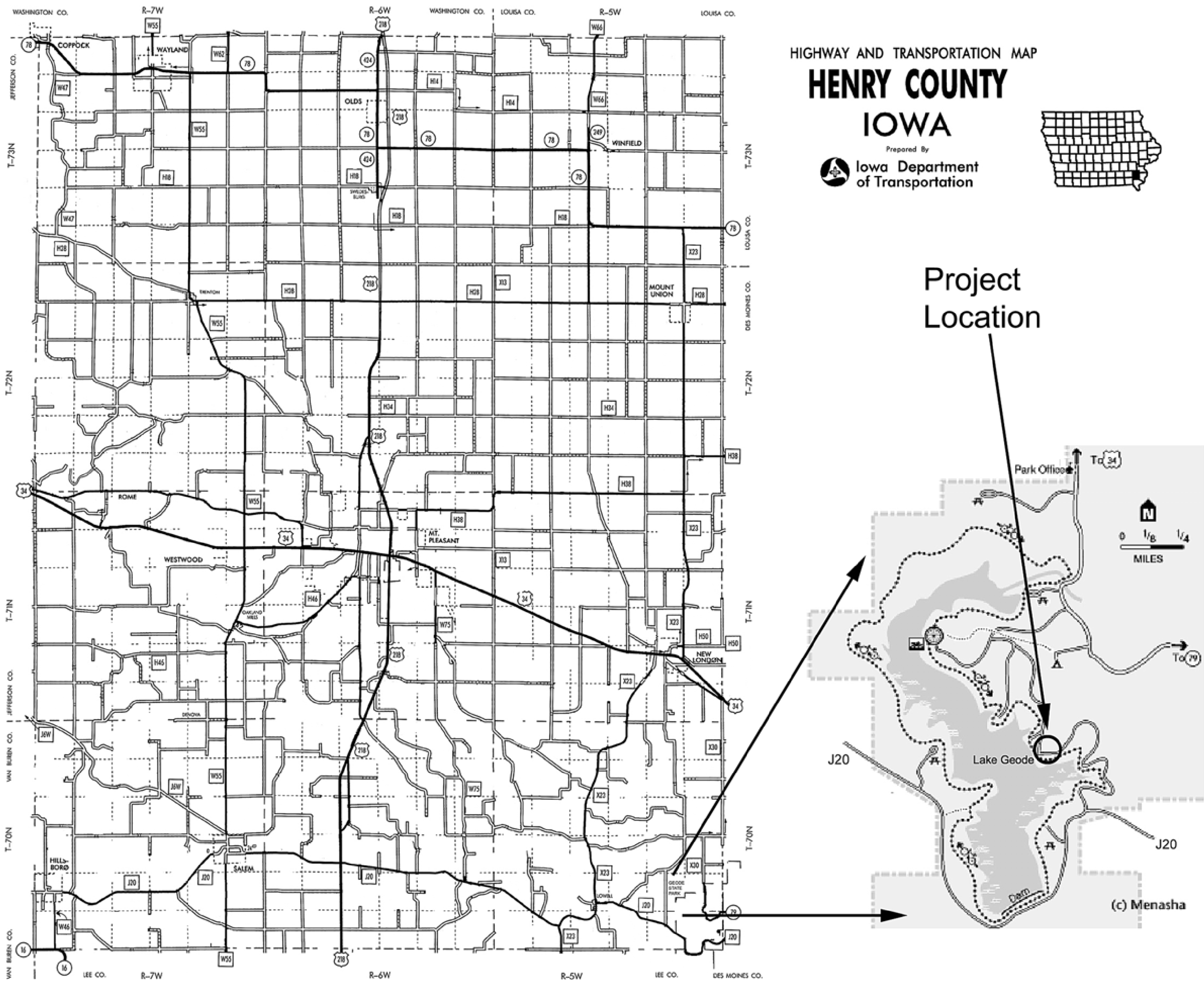

HIGHWAY AND TRANSPORTATION MAP
JONES COUNTY
IOWA
Prepared By
Iowa Department of Transportation
Phone (515) 239-1282
In Cooperation With
United States
Department of Transportation
SCALE IN MILES
SCALE IN KILOMETERS
JANUARY 1, 2000
Secondary (unfunded) Project
Primary (funded) Project
DELAWARE CO.
DUBUQUE CO.
JACKSON CO.
CLINTON CO.
CEDAR CO.
LINN CO.
R-4W
R-3W
R-2W
R-1W
T-86N
T-85N
T-84N
T-83N
CASCADE
MONTICELLO
CENTER JUNCTION
ONSLOW
WYOMING
MARTELLE
MORLEY
OLIN
OXFORD JUNCTION
STONE CITY
ANAMOSA STATE PENITENTIARY

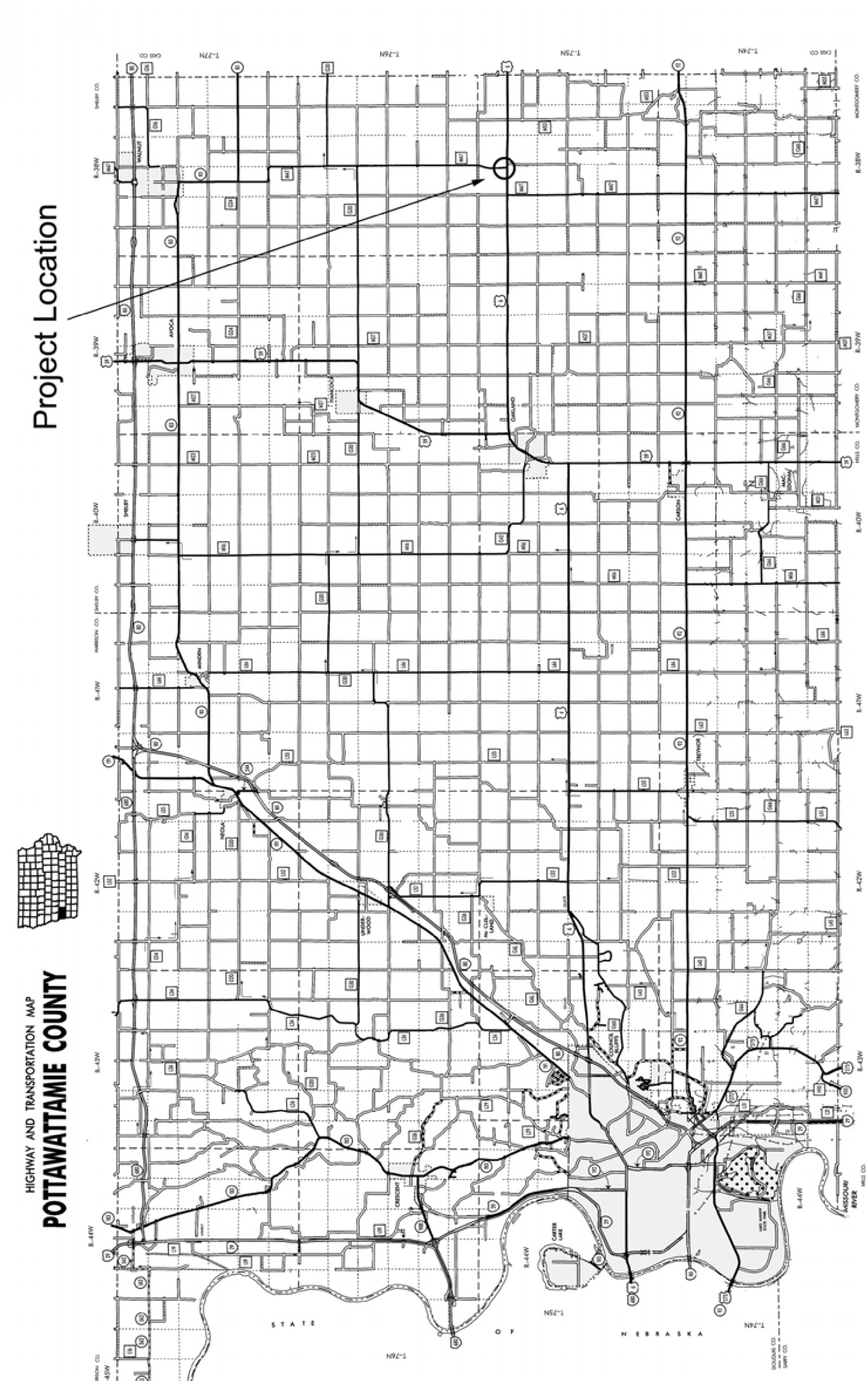

HIGHWAY AND TRANSPORTATION MAP
MAHASKA COUNTY
IOWA
Prepared By
Iowa Department of Transportation
LEGEND
Secondary
(not funded) Project
Primary (funded)
Project
OSKALOOSA
NEW SHARON
UNIVERSITY PARK
BEACON
LEIGHTON
FREMONT
EDDYVILLE
BARNES CITY
ROSE HILL
KEOMAH VILLAGE

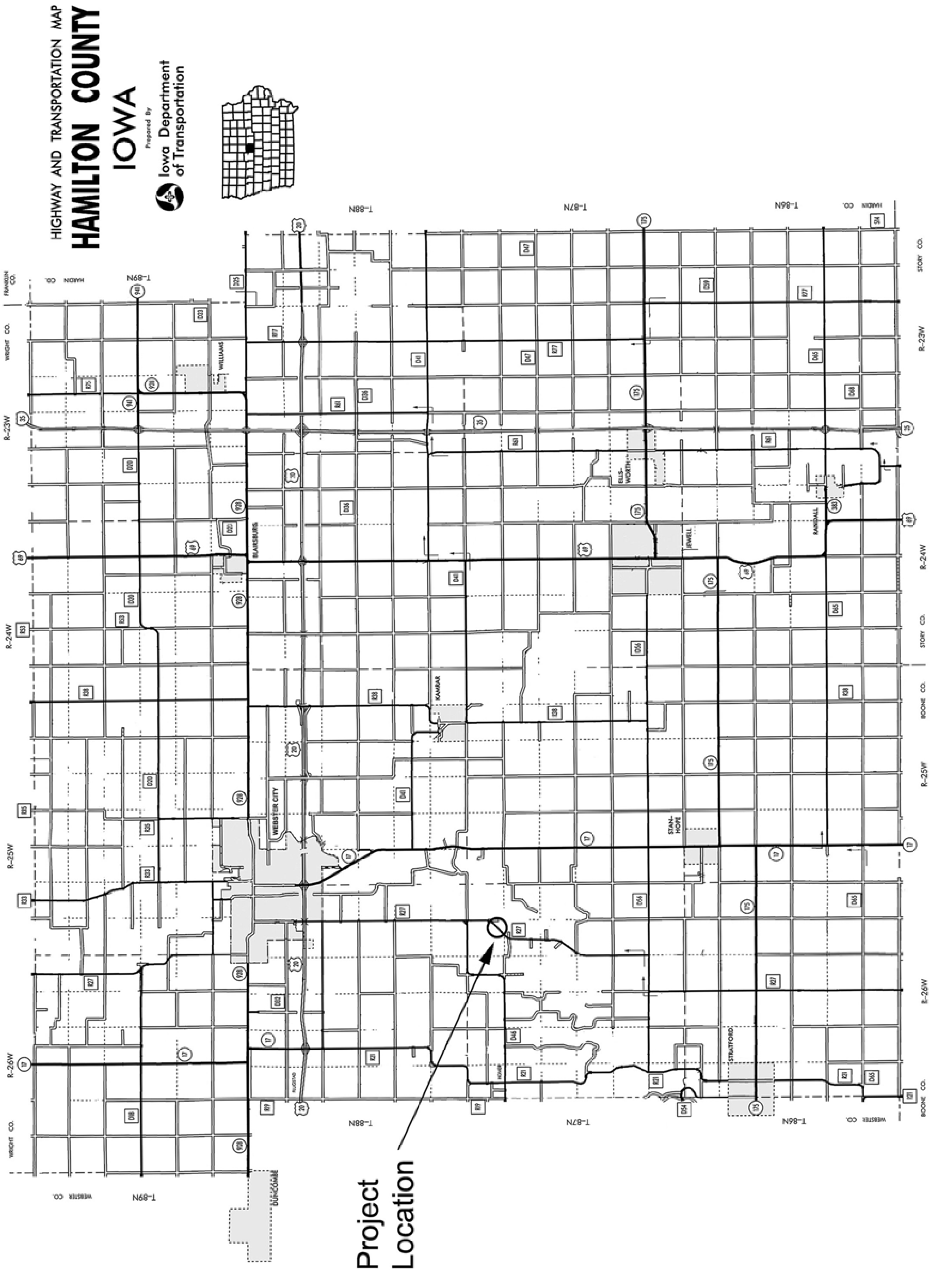

HIGHWAY AND TRANSPORTATION MAP
TAYLOR COUNTY
IOWA
Prepared By
Iowa Department of Transportation
Project Location
BEDFORD
CONWAY
SHARPSBURG
GRAVITY
NEW MARKET
LENOX
CLEARFIELD
BLOCKTON
S T A T E   O F   M I S S O U R I


HIGHWAY AND TRANSPORTATION MAP
AUDUBON COUNTY
IOWA
Prepared By
Iowa Department of Transportation
Project Location
(two culverts)
CRAWFORD CO.
CARROLL CO.
R-36W
R-35W
R-34W
SHELBY CO.
GUTHRIE CO.
CASS CO.
ADAIR CO.
T-81N
T-80N
T-79N
T-78N
GRAY
AUDUBON
KIMBALLTON
EXIRA
BRAYTON
VIOLA CENTER
SHARON
HAMLIN
FISCUS


HIGHWAY AND TRANSPORTATION MAP
CRAWFORD COUNTY
IOWA
Iowa Department of Transportation
Project Location
WESTSIDE
ASPINWALL
MANILLA
KIRON
DELOIT
DENISON
BUCK GROVE
SCHLESWIG
ARION
DOW CITY
RICKETTS
CHARTER OAK


HIGHWAY AND TRANSPORTATION MAP
HENRY COUNTY
IOWA
Prepared By
Iowa Department of Transportation
Project Location
Park Office
To 34
To 79
MILES
0 1/8 1/4
Lake Geode
Dam
J20
J20
(c) Menasha
WASHINGTON CO.
LOUISA CO.
DES MOINES CO.
LEE CO.
VAN BUREN CO.
JEFFERSON CO.
R-7W
R-6W
R-5W
T-73N
T-72N
T-71N
T-70N
COPPOCK
WAYLAND
OLDS
WINFIELD
TRENTON
MOUNT UNION
ROME
WESTWOOD
MT. PLEASANT
NEW LONDON
SALEM
HILLSBORO
LOWELL
GEODE STATE PARK


HIGHWAY AND TRANSPORTATION MAP
POTTAWATTAMIE COUNTY
Project Location
STATE OF NEBRASKA


HIGHWAY AND TRANSPORTATION MAP
HAMILTON COUNTY
IOWA
Iowa Department of Transportation
WILLIAMS
BLAIRSBURG
WEBSTER CITY
KAMRAR
ELLSWORTH
JEWELL
RANDALL
STANHOPE
STRATFORD
DUNCOMBE
Project Location

Appendix B
Cost Comparisons

Dallas County
Cost Comparisons

Slip Lining Actual Expenses

760 mm ID Polyethylene Liner	$4,058.28
Pressure Grouting and Mortar	$1,214.72
Labor	$ 532.19
Equipment	$ 225.00
Total	**$6,030.19**

Estimated Conventional Replacement Costs

760 mm Concrete Roadway Pipe ($39.22/LF*, 105 LF)	$4,118.10
Excavation, Class 20 ($5.30/CY*, 200 CY)	$1,060.00
Backfill/Compaction ($6.39/CY*, 200 CY)	$1,278.00
Standard, Class C, PCC Pavement ($44.70/SY*, 73 SY)	$3,263.10
Road Closure and Detour**	$1,000.00
Total	**$10,719.20**

*Costs for the replacement of the culvert were estimated from the average unit costs listed in the Summary of Awarded Contract Prices, 1994 for the Iowa DOT.
**Engineer 's estimate.

Jefferson County
Cost Comparisons

Slip Lining Actual Expenses

760 mm ID Polyethylene Liner	$3,500.00
Flowable Mortar (11.5 CY)	$ 413.25
Labor	$ 253.70
Equipment	$ 110.80
Total	**$4,295.75**

Estimated Conventional Replacement Costs

914 mm Concrete Roadway Pipe ($45.58/LF*, 60 LF)	$2,734.80
Excavation, Class 20 ($5.30/CY*, 75 CY)	$ 318.00
Backfill/Compaction ($6.39/CY*, 200 CY)	$ 479.25
Class B Gravel on roadway ($7.63/ton*, 16 tons)	$ 122.08
Road Closure and Detour**	$ 500.00
Total	**$4,154.13**

*Costs for the replacement of the culvert were estimated from the average unit costs listed in the Summary of Awarded Contract Prices, 1994 for the Iowa DOT.
**Engineer's estimate.

Taylor County
Cost Comparisons

Slip Lining Actual Expenses

610 mm ID Polyethylene Liner	$3,768.10
Pressure Grouting	$1,444.17
Mortar (3 CY)	$ 210.00
Labor	$ 622.53
Equipment	$ 319.20
Total	**$6,364.00**

Estimated Conventional Replacement Costs

760 mm Concrete Roadway Pipe ($39.22/LF*, 105 LF)	$4,118.10
Excavation, Class 20 ($5.30/CY*, 1050 CY)	$5,565.00
Backfill/Compaction ($6.39/CY*, 1050 CY)	$6,709.50
Standard, Class C, PCC Pavement ($44.70/SY*, 147 SY)	$6,570.90
Road Closure and Detour**	$1,000.00
Total	**$23,963.50**

*Costs for the replacement of the culvert were estimated from the average unit costs listed in the Summary of Awarded Contract Prices, 1994 for the Iowa DOT.
**Engineer's estimate.