Incorporating GPS and Mapping Capability into Ground Penetrating Radar (GPR) Operations for Pavement Thickness Evaluations

Minnesota Department of Transportation

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16. Abstract (Limit: 250 words)

Ground Penetrating Radar (GPR) investigations performed by Mn/DOT of pavements and other subsurface features have been limited by an inefficient and poorly documented GPR survey process and underdeveloped project mapping and reporting process.

The objectives of this project were; first to develop a more robust system for GPR surveying using dual air-coupled antennas to provide redundancy in data collection and to improve accuracy and completeness of the survey results. Secondly; the addition of Global Positioning System (GPS) location data, acquired in coordination with the GPR data, for improved project location and ArcGIS mapping capability. Thirdly; the development of a standard format for GPR data reporting in a more user-friendly, exportable format.

After completing the other objectives, a GPR Manual was developed, describing GPR vehicle and survey operations, GPS with GPR data collection, mapping using ArcGIS, and the new standardized reporting format. The result was an improved and better documented subsurface data collection and reporting process that incorporates GPS and improves the effectiveness of Mn/DOT's GPR program.

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Ground Penetrating Radar, GPR, GPS for GPR, dual air-coupled antennas, Global Positioning System, GPS, ArcGIS mapping, GPR data reporting, GPR Manual		No restrictions. Document available from: National Technical Information Services, Alexandria, Virginia 22312	
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Incorporating GPS and mapping capability into Ground Penetrating Radar (GPR) operations for pavement thickness evaluations.

Final Report

Submitted by:

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CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

Mn/DOT districts are increasingly requesting Ground Penetrating Radar (GPR) investigations of pavement layer thickness and other subsurface investigations. Research completed to date at Mn/DOT concerning GPR has focused on procurement of radar equipment, defining Mn/DOT GPR operational methods, performing GPR field surveys, and development of improved methods of layer analysis.

The ground penetrating radar equipment currently owned by Mn/DOT uses a vehicle distance measurement Instrument (DMI) and written notes taken by the operator to define survey limits and report on features and/or defects found. Although distance measurement instruments are commonly used at Mn/DOT to record positions along trunk highways, the level of accuracy using reference post data provides insufficient detail to precisely map the route of the radar survey vehicle and the features found. Also the GPR surveys requested by Districts often involve operations in small localized areas off the roadway, where highway reference posts are not applicable.

The antenna mounting system used by Mn/DOT previously allowed only one single air coupled antenna to be operated, and was of poor design. A more robust system for GPR surveying using dual air-coupled antennas was identified as a need. The simultaneous use of dual GPR antennas provides redundancy in data collection and a comparison tool to improve accuracy and completeness of the survey results.

The GPS positional data obtained also had be coordinated with the GPR data and made available to the districts in a user-friendly, exportable format. The development of a standard format for GPR data reporting at Mn/DOT was indicated as a potential improvement. Also, the accurate coordinate data acquired with GPS system developed with this project could be used to apply ArcGIS mapping and database capability to the GPR reporting. Incorporating GPS into this kind of pavement management survey has been requested by Mn/DOT soils engineers and industry partners, and is important for effective data sharing.

Because the addition of GPS equipment, data collection, and mapping to the GPR system increases the complexity and difficulty of standard survey operations, a “GPR user manual” was requested. The user manual would describe GPR vehicle and manual survey operations, data collection and analysis, mapping using ArcGIS, and a standardized data reporting format.

Therefore it was determined that an additional GPR project would be beneficial in order to accomplish the necessary tasks and to incorporate global positioning system (GPS) data collection and mapping capability into Ground Penetrating Radar (GPR) operations for pavement evaluations.

1.2 OBJECTIVE

The overall objective of this project is to incorporate GPS and mapping capability into Ground Penetrating Radar (GPR) operations for pavement thickness evaluations. At the conclusion of this project, enhanced GPR data collection and reporting methods will be available to all Mn/DOT users. The addition of GPS capability will allow detailed mapping of GPR survey projects and improve the positional accuracy of subsurface locates. Defining and clarifying GPR operations with the development of standardized reports and a user manual will benefit current and future employees involved with the system at all levels. The analyses described herein, presents the compilation of the projects tasks as a final report (Task 6).

1.3 SCOPE

The GPS for GPR implementation study included the following activities:

a) Upgrading the data collection vehicle to allow dual antenna GPR data collection by installing and testing a compatible antenna mounting device on the Mn/DOT GPR vehicle.
b) Incorporating GPS capability in to the GPR system by identifying and obtaining suitable GPS equipment, configuring the GPR system to incorporate the GPS data, and developing a standardized GPS data transfer and collection process.
c) Developing an improved, standardized GPR project mapping capability in ArcGIS format.
d) Developing a uniform, comprehensive data reporting format for GPR projects that includes; GPS coordinate data, Mapping of project locations and detailed mapping of specific underground investigations, and Standardized layer thickness data.
a) Developing a GPR user operating manual which will compile operating instructions for GPR & GPS equipment, mapping software, and reporting examples developed in other tasks of this project.
e) Preparation of a final report describing; field testing of the new dual antenna and GPS system and results of the subsequent analysis, documentation on the GPS and mapping development, recommended GPR standardized reports to accompany the new equipment enhancements, and final recommendations on full implementation of GPR equipment and standardized reports.

CHAPTER 2 PROJECT ACCOMPLISHMENTS

2.1 GPR VEHICLE ANTENNA FRONT-MOUNT SYSTEM

In December of 2008, a literature and internet search was performed to determine the best system for a vehicle mount that would allow dual antenna GPR data collection and be safer and more stable than the in-house system built during the GPR research phase. Mn/DOT was informed that a new vehicle mount system had recently been developed by the manufacturer of Mn/DOT's radar system; Geophysical Survey Systems, Inc. (GSSI) of Salem, NH USA. Because the system was designed to mount the GPR antennas that MnDOT already had and was fully compatible with the system, it was determined to be the best option for upgrading the GPR survey vehicle mount.

The system was purchased from GSSI and installed by Mn/DOT Central Shops in April of 2009. The vehicle was configured and proper operation of the vehicle mount took place at the Maplewood Research Lab in May, 2009. The first field trial of the rig was done in Mn/DOT District 2, near the town of Oslo, Mn. The work required testing of MN TH1 in an area that had recently experienced flooding. The new vehicle front mount performed well and no problems were experienced. (See the GPR survey report of TH1 testing in Appendix A).

The new vehicle front antenna mount system also allows simultaneous dual channel data collection, which gives additional information and flexibility. It also provides faster, safer and more stable vehicle survey operations, especially at highway speeds.

Figure 2.1 Previous GPR vehicle antenna mount

Figure 2.2 New GPR vehicle antenna mount

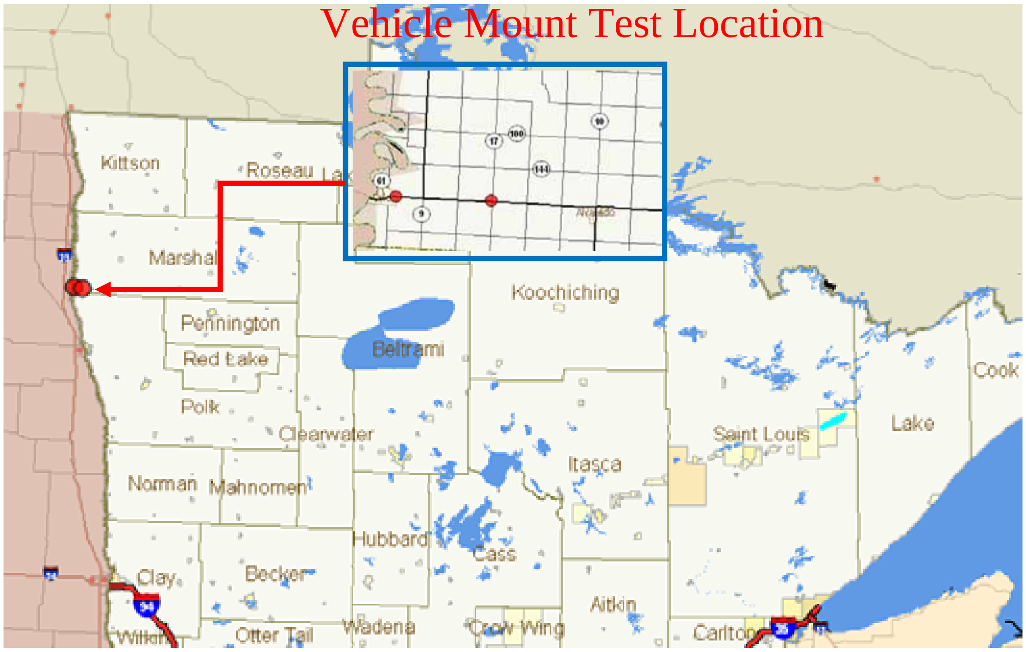


Figure 2.3 Mn Trunk Highway 1, Test Site Location

2.2 INCORPORATING GPS CAPABILITY IN TO THE GPR SYSTEM

In January of 2009, a separate literature and internet search was performed to determine suitable Global Positioning System (GPS) equipment for the Mn/DOT GPR vehicle and hand cart. The goal was to acquire a GPS system that would provide an acceptable level of GPS accuracy, while functioning during GPR data collection at highway speeds. The GPS data output format also had to be compatible with the Radar equipment owned by Mn/DOT.

It was determined that the best GPS system for the GPR needs would be a Trimble ProXRT receiver with GLONASS capability. The ProXRT is commonly used in Mobile GPS for GPR operations by other users. It allows a 1 Hz re-positioning rate with uncorrected sub-meter accuracy. Higher positional accuracy can be obtained with post processing or real-time with a correction signal. To control the mobile receiver, a JUNO handheld device was acquired, along with processing software and vehicle mounting hardware for the GPS equipment.

In July, 2009 the GPS equipment specified was purchased from Frontier Precision, INC, of Bloomington, MN. This is a company that had previously supplied Mn/DOT with Trimble equipment and had a good track record of expertise and support. In fall of 2009, training was provided by Frontier Precision at the Maplewood research lab to familiarize the employees working with the radar equipment with the GPS system.

2.3 STANDARDIZED GPR MAPPING AND REPORTING

To complete the standardized mapping and reporting tasks of this project, the consultant firm American Engineering Testing (AET) was contracted in 2009. AET was tasked with creating a standardized ARCGIS mapping and reporting format for the collected GPR/GPS data. A test section for the new GPR/GPS system was identified on TH96, between TH61, and TH95. This section was already scheduled to be GPR surveyed in 2010 as part of the regular GPR production work.

The TH96 test data was useful for this purpose as it represented a ‘real life’ GPR project, and had the type of road conditions expected to be regularly encountered. The field data collection took place in March of 2010, and GPR/GPS system performed as expected. The data, along with Mn/DOT cad mapping, was collected and transferred to AET for reporting and mapping development.

Two different types of GPR mapping were identified as needs. First, “project level” mapping, which shows the actual route the GPR vehicle (or hand cart) travels. This is needed because of the extreme variability of the subsurface materials often encountered – precise positioning and mapping is needed to properly correlate the GPR readings to points the data is taken. The second level of mapping needed is “system level” - to show where in the state or district GPR projects have been completed. This is useful for project tracking and provides information to Mn/DOT soils and materials engineers.

The process for mapping GPS/GPR data using ARCGIS was completed by in June, 2010. Microstation mapping was acquired from Metro Design and was used along with an aerial photo to map the test data. The process for properly configuring the equipment, transferring the GPS/GPR data, and developing the maps needed was well defined and submitted by AET.

ArcGIS is versatile mapping software that meets the identified needs of the project, and is the preferred (supported) mapping software for all GIS users at Mn/DOT. Both the system and project level GPR mapping that will now be normally produced will be readily available to all interested users in ArcGIS format. GPR data is attached to each GPS location and can be labeled, organized, and presented in several desired mapping schemes, depending on the project requirements. Visual examples of the mapped TH96 test section GPR data are shown in figures 2.4 and 2.5.

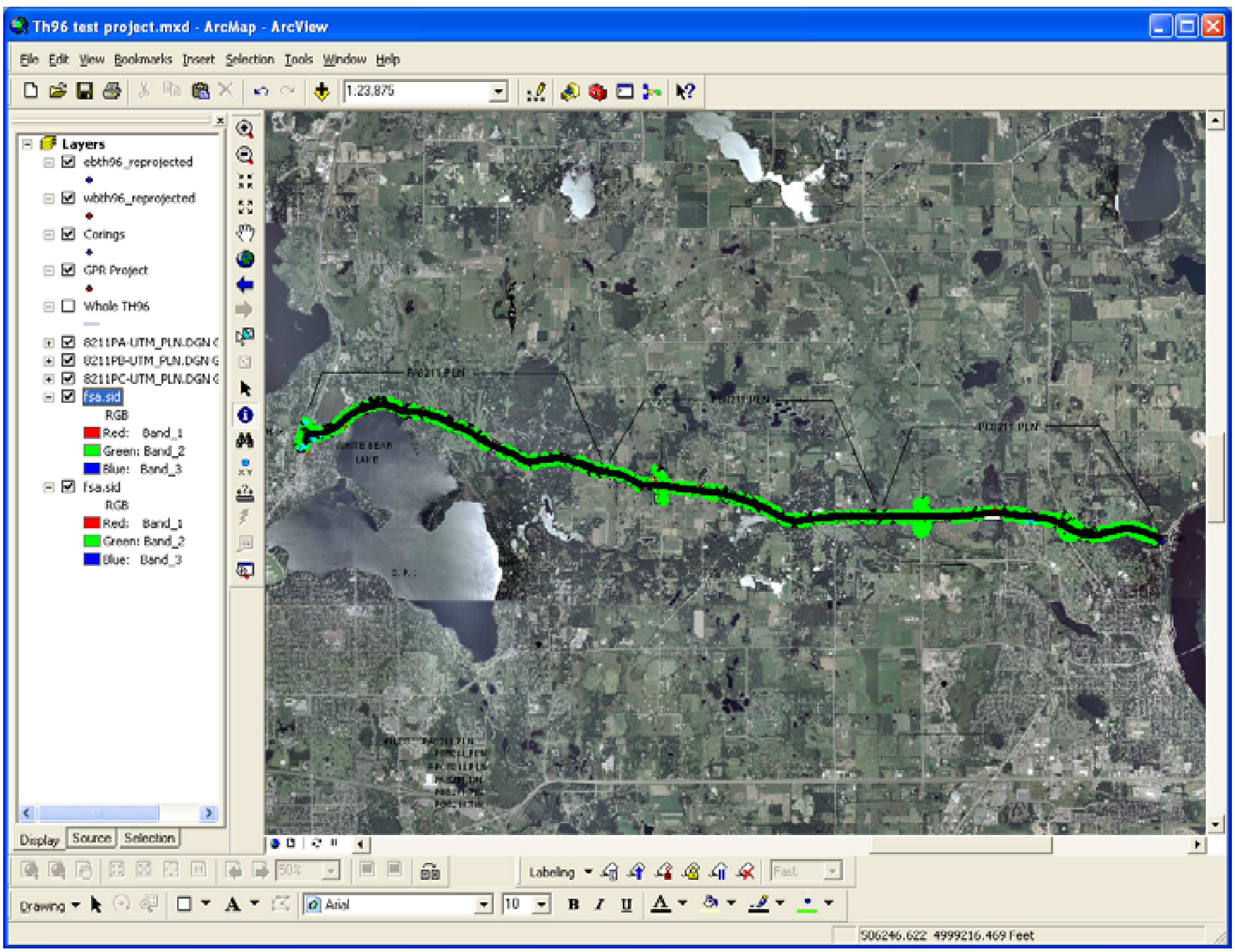


Figure 2.4 Mn Trunk Highway 96 GPS/GPR mapping test

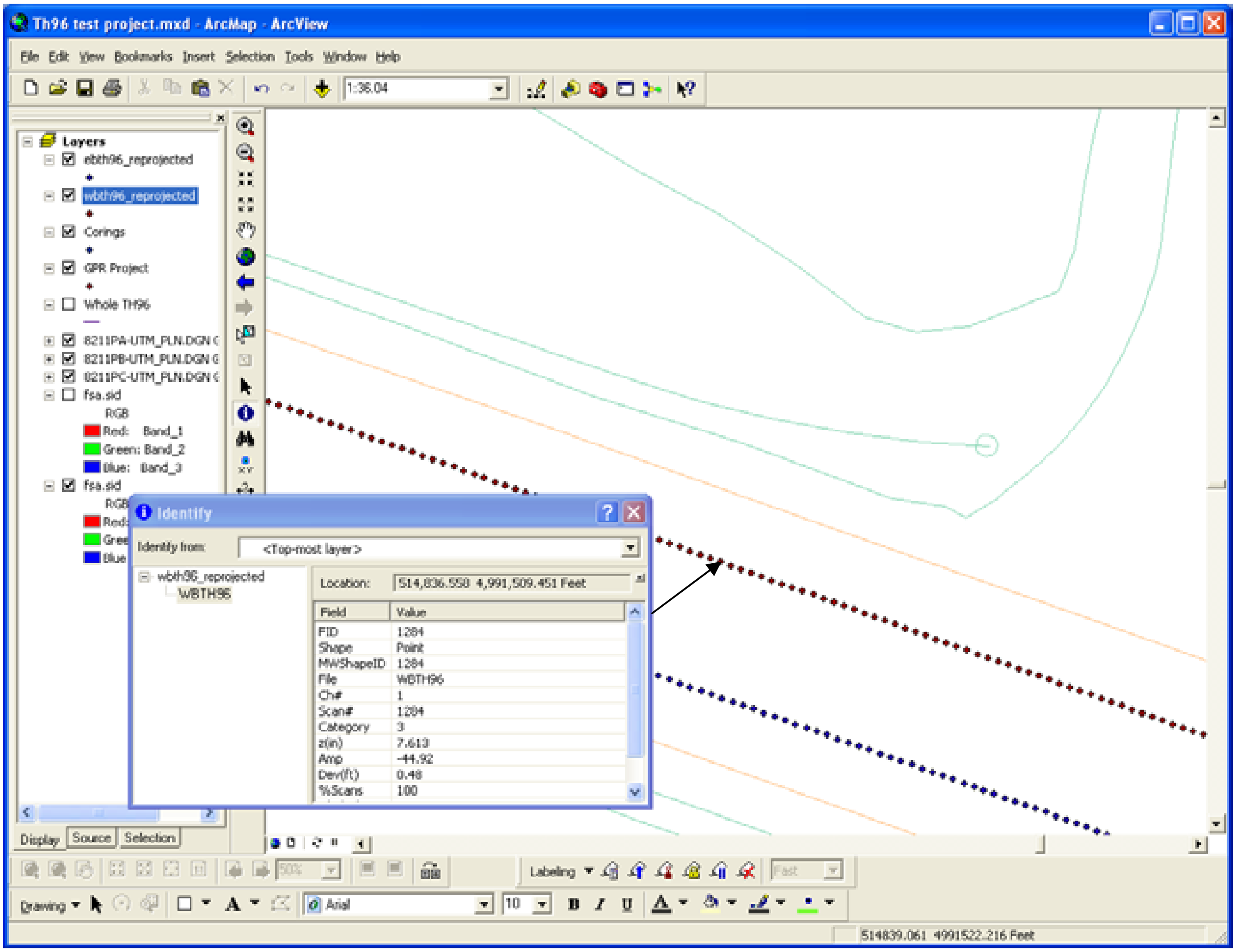


Figure 2.5 TH 96 GPS/GPR data point

For the TH96 test project, the pavement thickness was the primary focus of study. A standard method to report this type of GPR survey was developed. The standard report contains general project information, a statistical thickness and length summary, and both graphical and listing representations of pavement thickness.

The inputting and reporting spreadsheets developed with this project can be adapted to any future GPR project. They were developed in a user-friendly checkbox format. An example of the GPR reporting input form is shown in figure 2.6. A summary pavement thickness report for the TH96 test project is attached in Appendix B. The process for mapping and reporting the GPR data was documented and provided to Mn/DOT for use in creating the GPR user manual required as part of this project.

SUMMARY OF PAVEMENT SURVEY

COUNTY	**Wahington**		**Test Date**	**Date**
PROJECT NO.	**50204**		**3/8/2010**	**6/11/10**
PFN	**1234-5**			
STATE ROAD	**TH 96**			
MILEPOST LIMITS (SLMP)	**0.368**	**to 10.200**		

PAVEMENT TYPE

Milepost		Lanes			
From	To	L1	R1	L2	R2
0.368	10.200	F			

Legend:
F = Flexible, R = Rigid, B = Composite (HMA / PCC) and W = Composite (PCC/HMA)

SUMMARY STATISTICS & PLOT SETTINGS **(Please use the menu in this block to modify the settings.)**

Display: ☑ Statistics ☑ Plots

Data: Thickness for HMA or PCC

Cross Slope

Rut Depth

Lanes: ☑ All or ☑ L1R1 ☐ L2R2 ☐ L3R3 ☐ L4R4 ☐ L5R5 ☐ L6R6

Limits:

	Minimum	Maximum	Maj. Unit	Min. Unit
x	0.368	10.200	1.0	0.50
y	0.0	20.0	2.0	1.00

or Initialize

SUMMARY STATISTICS

Units: in.

Lane #	L-Direction				R-Direction			
	Average	Stdev	Max.	Min.	Average	Stdev	Max.	Min.
1	7.54	1.56	16.93	4.45	7.59	1.89	21.25	3

Figure 2.6 TH 96 Sample Report

At the completion of the project, certain key information will be captured from the data spreadsheet and stored in a project history database file. The database file will contain project name, date, and GPS positional data that will be periodically exported into an ARCGIS shapefile. The shapefile that contains the project info will be shared with MnDOT districts and other interested people. Instructions will be provided about how to load the shapefile into the MnDOT Interactive Basemap – located on IHUB at;

http://gisservices.dot.state.mn.us/mndot-basemap/

The TH96 test project info was exported into a shapefile and loaded into the interactive basemap as a test of that process. Examples of how this output appears are shown in figures 2.7 and 2.8

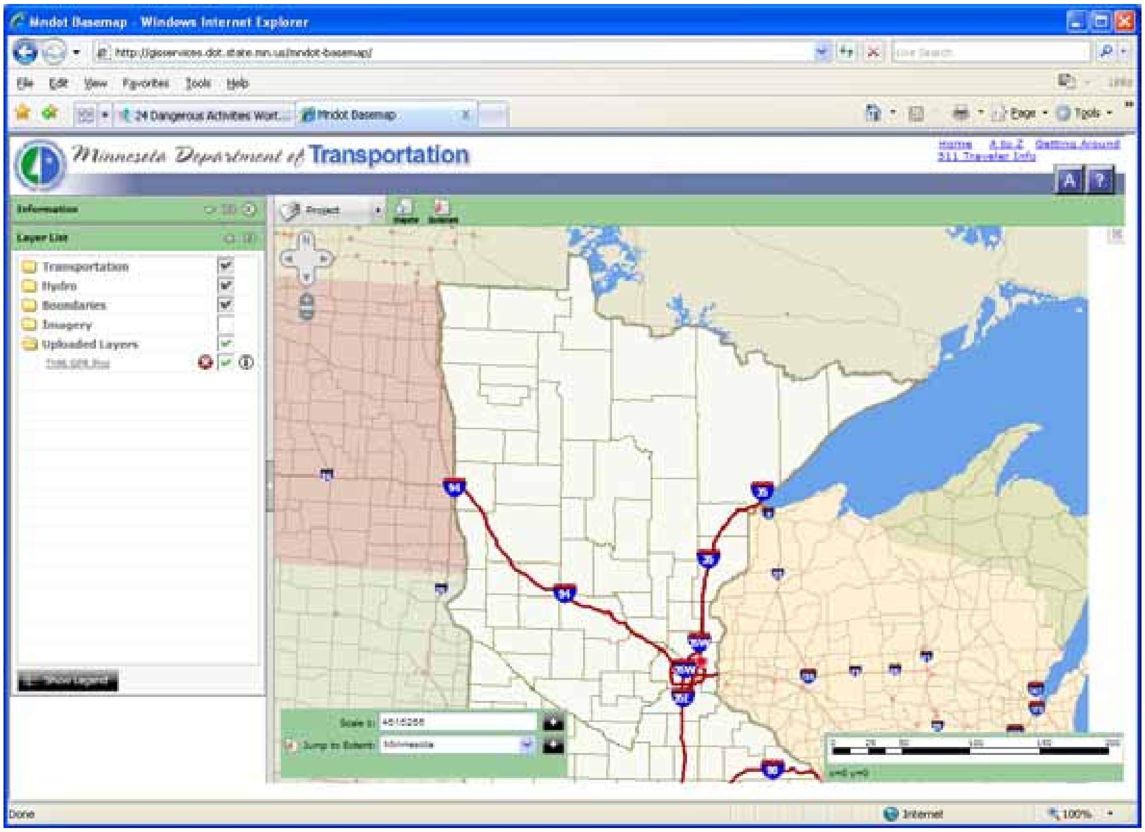


Figure 2.7 MnDOT Basemap TH 96 Project Location

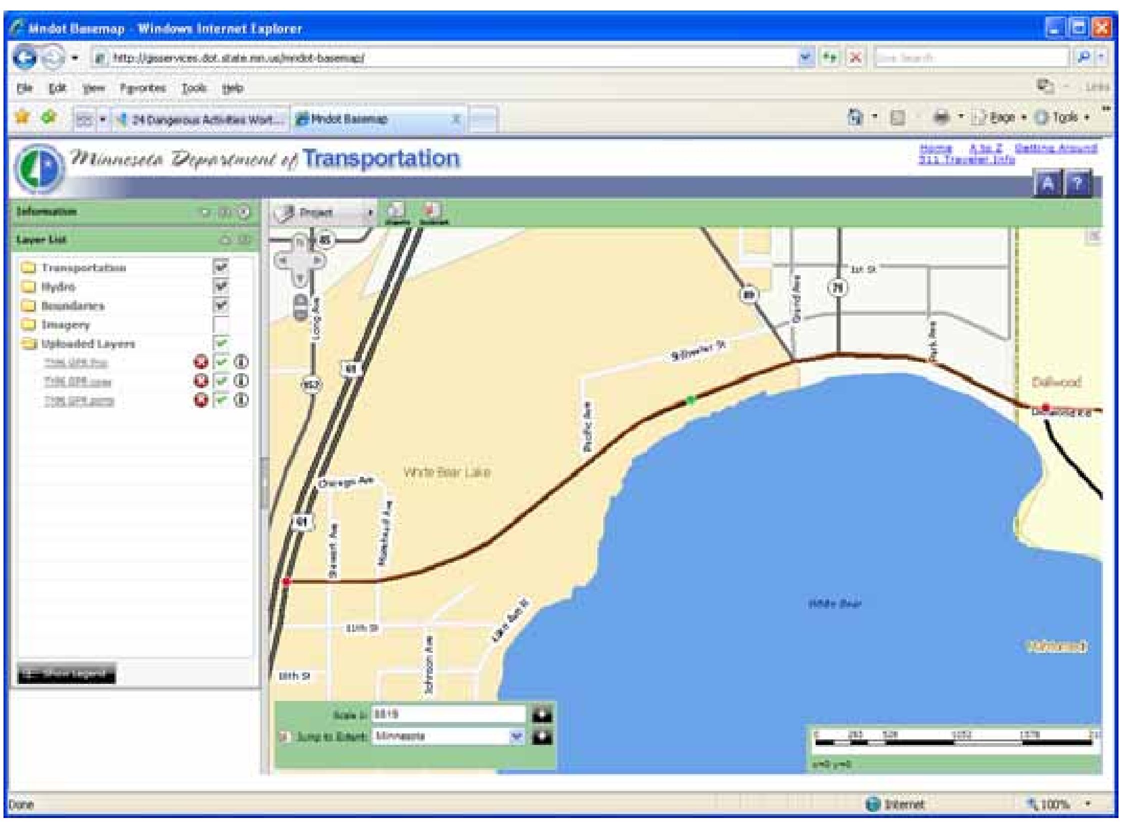


Figure 2.8 MnDOT Basemap TH 96 Project Detail

2.4 DEVELOPMENT OF GPR MANUAL

Throughout the term of this project, all aspects of the steps needed for GPR field operations data functions were being observed, recorded and compiled for development of a GPR user manual. A successful GPR manual would contain the essential operating instructions for GPR & GPS equipment, field mapping software, and reporting methods and examples.

The version 1.1 GPR user manual was completed by AET and transferred to Mn/DOT in June 2010. It is considered complete for purposes of this project, but may be updated and improved upon as future changes to the GPR operations or reporting needs develop. It is intended that at some point the manual created with this project will be incorporated into the Mn/DOT standard manual system, therefore the format of the GPR manual follows the typical Mn/DOT manual format. The June, 2010 GPR Manual (version 1.1) is attached in appendix C.

CHAPTER 3 PROJECT SUMMARY

A safer, more robust system for GPR survey operations using either single or dual air-coupled antennas was accomplished with this project. The simultaneous use of dual GPR antennas provides redundancy in data collection and a comparison tool to improve accuracy and completeness of the survey results.

Incorporating GPS into GPR pavement management surveys has been requested by Mn/DOT soils engineers and others, and is important for effective data sharing. The accurate coordinate data obtained with the GPS system acquired for this project will be used to apply ArcGIS mapping and project information and history capability to the GPR reports. The development of a user-friendly, standardized format for GPR data reporting at Mn/DOT will also be a useful improvement. The GPS positional data obtained will be precisely coordinated with the GPR data and both the layer analysis and project locations will be made available to the districts in an easy to use, viewable and/or exportable format.

Because the addition of GPS equipment, data collection, and mapping to the GPR system will increase the complexity and difficulty of standard survey operations, a “GPR user manual” was developed as part of this project. The user manual describes GPR vehicle and manual survey operations, data collection and analysis, mapping using ArcGIS, and describes a method to standardize the GPR data reporting. The manual was written in the proper format for potential inclusion in the Mn/DOT standard manual series. The tasks accomplished with this project will improve the efficiency and effectiveness of the ground penetrating radar (GPR) program at Mn/DOT.

APPENDIX A TEST PROJECT FOR VEHICLE FRONT MOUNT

TH 1, 2009 Red River Flooding GPR Study

Survey for voids and deterioration caused by floodwater overtopping by Red River of the North
Approximate Location: TH 1; From Milepost 0.86, to Milepost 3.56
Eastbound and Westbound traveling lanes, both wheel paths
In Oslo, MN
Mn/DOT District 2
May 2009

Background

The project location is along MN TH1, east of the town of Oslo, in Mn/DOT district 2. The project area is between Milepost 0.86 and 3.56. TH1 in this area is a 2-lane rural highway, with minimal shoulders. The pavement is Bituminous over granular base.

In spring of 2009, the Red River of the North experienced severe flooding and overtopped TH1 to a depth of more than 1ft in this area, causing deterioration of the shoulders and some of the pavement cracks. Temporary repairs were made when the flooding subsided to allow vehicle traffic, but the roadway was restricted to 7TON loads at the time of the survey. The goal of the Ground Penetrating Radar (GPR) survey was to examine the area of the floodwater overtopping for structural soundness and to attempt to detect unknown voids beneath the pavement.

TH1 Spring Flooding 2009

Surveys

The GPR survey was performed on May 5th, 2009. Ambient conditions were cloudy and dry, however water from flooding was still standing in ditches and subsurface soils were very moist. The GPR system used was the SIR-20, manufactured by GSSI. The antenna used was the 1-GigHz air-coupled, attached by a GSSI front vehicle mount system.

Both Eastbound and both Westbound traveling lanes (all four wheel paths) were surveyed between Reference posts 0.86 and 3.56. The instrument was attached to the front vehicle mount and driven at approximately 10 MPH. Traffic control in the form of GPR vehicle protection was provided by District 2 Maintenance forces.

Mn/DOT GPR Survey Vehicle with vehicle antenna mount

Results

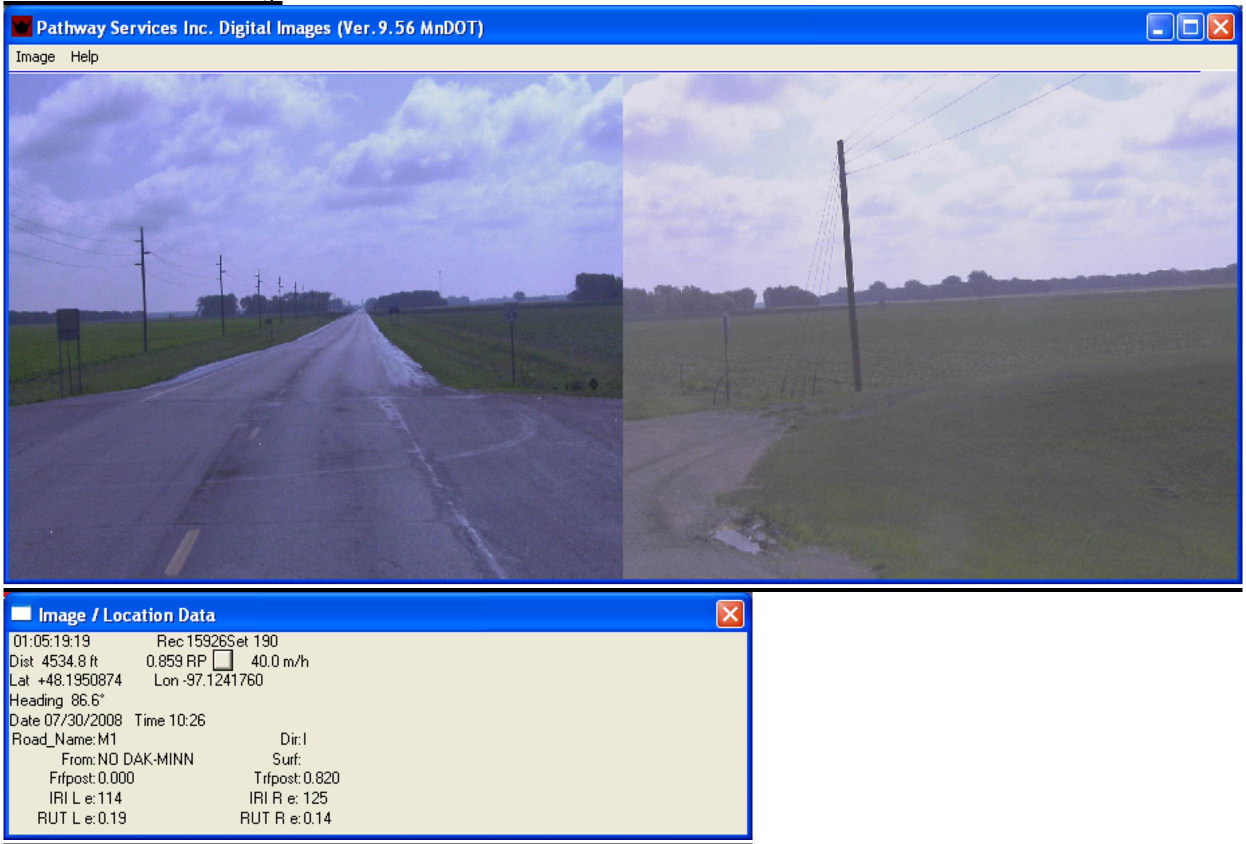
Subsurface void locations that were visible in the data at the time of surveying were immediately marked in the field for evaluation and repair. Most voids located during the GPR survey were associated with pavement cracks that had been widened or “washed out” by the flooding. Most of the voids and damage was visible on the surface. However, some subsurface voids appeared at crack locations where the pavement surface looked fairly sound.

The moist materials caused degradation of the radar signal below approximately 3 feet, but voids above that depth in the wheel paths were observed with a high degree of confidence. A utility crossing visible in the radar data during testing verified that the GPR equipment was functioning and was able to view anomalies at depths of at least 36 inches with expected resolution.

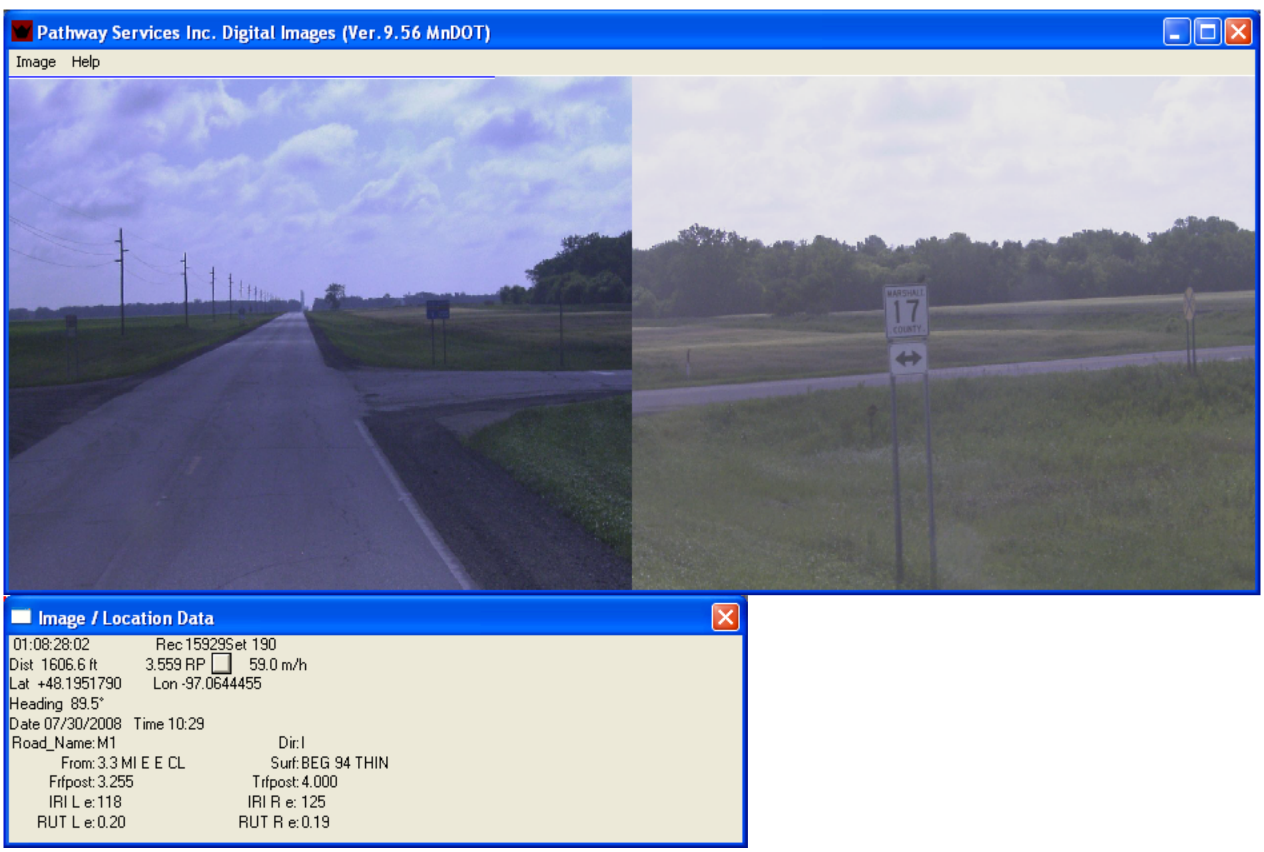
Voids visible in the radar data after post processing in the office are summarized in the spreadsheet shown in the following pages. Note that the radar data measures conditions directly under the path of the antenna, in an approximately 1-foot wide scan path. Voids outside the survey path will not be visible, nor will any anomalies be visible deeper than approximately 48 inches (the maximum depth range). Cracks that had been totally washed out and temporarily repaired at the time of GPR surveying may not appear in the following spreadsheet.

No extremely large, un-collapsed voids appeared in the GPR survey of the traveling lanes. The spreadsheet summarizes the crack void locations at distances (in feet) going eastbound, starting from the overhead power line crossing at MP 0.86.

Pavement Survey



Begin Eastbound pavement scans @ Milepost 0.86 (directly under the overhead utility line crossing)



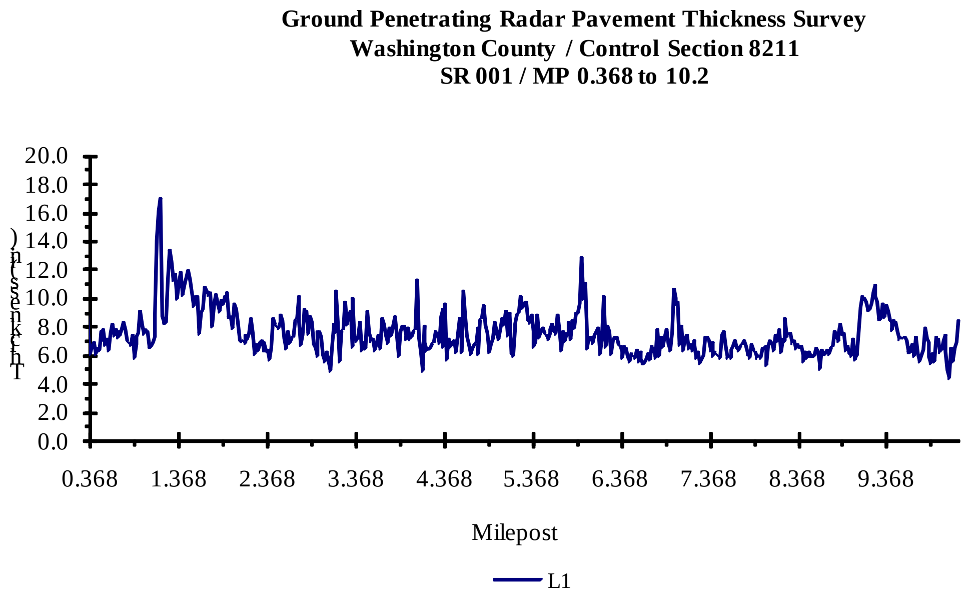
End Eastbound pavement scans @ Centerline of Co Rd 17 (approx. Milepost 3.56)

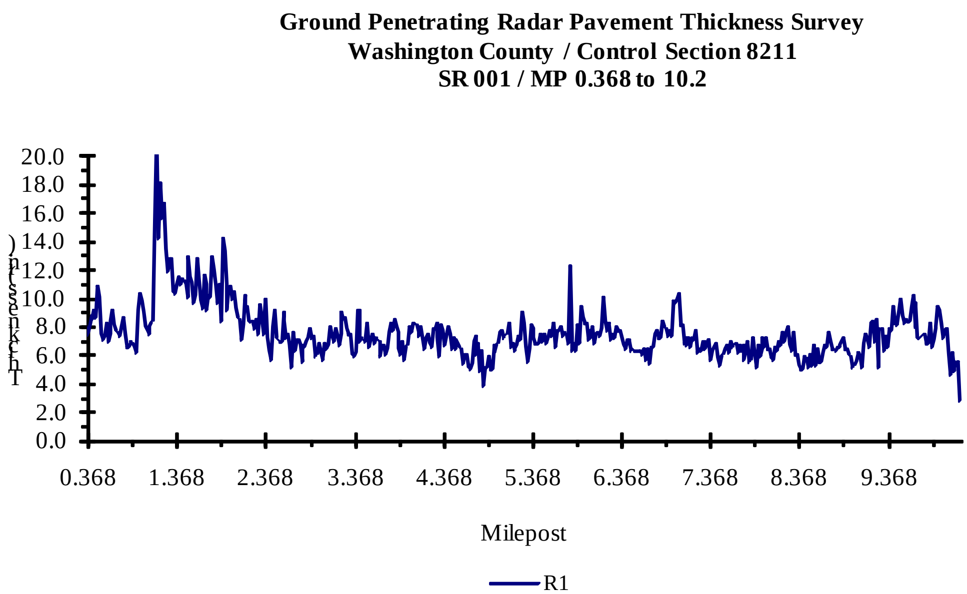
Th1 Voids visible in Radar Data			
milepost	dist	dist from power line crossing	File
0.86	4540.8	0.00	start
0.962	5081.214	540.4	WBLTVOIDPICKS
0.995	5252.963	712.2	EBLTVOIDPICKS
1.024	5405.462	864.7	EBRTVOIDPICKS
1.114	5883.959	1343.2	WBLTVOIDPICKS
1.123	5928.459	1387.7	WBRTVOIDPICKS
1.125	5941.375	1400.6	EBLTVOIDPICKS
1.144	6039.708	1498.9	WBRTVOIDPICKS
1.147	6056.291	1515.5	EBRTVOIDPICKS
1.160	6125.208	1584.4	EBRTVOIDPICKS
1.225	6466.372	1925.6	EBRTVOIDPICKS
1.248	6591.288	2050.5	WBRTVOIDPICKS
1.251	6606.872	2066.1	EBRTVOIDPICKS
1.263	6668.371	2127.6	WBRTVOIDPICKS
1.274	6726.871	2186.1	EBRTVOIDPICKS
1.305	6887.87	2347.1	EBRTVOIDPICKS
1.341	7079.369	2538.6	EBRTVOIDPICKS
1.410	7447.2	2906.4	WBRTVOIDPICKS
1.445	7630.865	3090.1	WBRTVOIDPICKS
1.500	7918.697	3377.9	WBRTVOIDPICKS
1.558	8226.196	3685.4	EBLTVOIDPICKS
1.688	8914.192	4373.4	EBLTVOIDPICKS
1.744	9209.024	4668.2	EBRTVOIDPICKS
1.766	9325.357	4784.6	WBRTVOIDPICKS
1.792	9459.772	4919.0	WBLTVOIDPICKS
1.794	9470.439	4929.6	EBRTVOIDPICKS
1.817	9594.105	5053.3	WBRTVOIDPICKS
1.820	9610.855	5070.1	EBRTVOIDPICKS
1.829	9658.188	5117.4	WBLTVOIDPICKS
1.852	9776.354	5235.6	WBRTVOIDPICKS
1.901	10034.69	5493.9	WBRTVOIDPICKS
1.935	10216.52	5675.7	WBLTVOIDPICKS
1.956	10327.6	5786.8	WBRTVOIDPICKS
1.959	10345.18	5804.4	EBRTVOIDPICKS
2.207	11651.93	7111.1	WBLTVOIDPICKS
2.209	11665.09	7124.3	EBRTVOIDPICKS
2.244	11847.68	7306.9	EBRTVOIDPICKS
2.267	11970.51	7429.7	WBRTVOIDPICKS
2.269	11981.01	7440.2	EBLTVOIDPICKS
2.314	12215.42	7674.6	WBLTVOIDPICKS
2.340	12353.84	7813.0	EBLTVOIDPICKS
2.402	12684.09	8143.3	EBLTVOIDPICKS
2.575	13596.17	9055.4	EBRTVOIDPICKS
2.657	14028.41	9487.6	WBRTVOIDPICKS
2.660	14046.91	9506.1	EBRTVOIDPICKS
2.670	14098.5	9557.7	WBRTVOIDPICKS
2.673	14114.83	9574.0	EBRTVOIDPICKS
2.690	14201.58	9660.8	WBRTVOIDPICKS
2.692	14211.5	9670.7	EBLTVOIDPICKS

2.702	14267.5	9726.7	WBRTVOIDPICKS
2.830	14940.91	10400.1	WBRTVOIDPICKS
2.856	15080.49	10539.7	WBRTVOIDPICKS
2.859	15098.16	10557.4	EBRTVOIDPICKS
2.898	15303.74	10762.9	EBRTVOIDPICKS
2.939	15515.49	10974.7	WBRTVOIDPICKS
2.942	15532.07	10991.3	EBRTVOIDPICKS
3.127	16508.98	11968.2	WBRTVOIDPICKS
3.127	16511.4	11970.6	WBLTVOIDPICKS
3.130	16526.82	11986.0	EBRTVOIDPICKS
3.166	16713.9	12173.1	WBRTVOIDPICKS
3.196	16874.73	12333.9	WBRTVOIDPICKS

APPENDIX B TH96 GPS/GPR EXAMPLE REPORT

PLOTS





L1					R1				
Milepost	HMA Thickness (in.)	PCC Thickness (in.)	Cross Slope (%)	Rut Depth (in.)	Milepost	HMA Thickness (in.)	PCC Thickness (in.)	Cross Slope (%)	Rut Depth (in.)
0.019	8.8				0.019	8.9			
0.038	8.1				0.038	7.2			
0.057	10.2				0.057	6.8			
0.076	9.6				0.076	7.0			
0.095	9.2				0.095	8.4			
0.114	8.5				0.114	10.9			
0.133	7.7				0.133	8.3			
0.152	8.5				0.152	9.6			
0.170	7.0				0.171	9.3			
0.189	7.6				0.189	8.0			
0.208	7.1				0.208	9.7			
0.227	7.6				0.227	7.7			
0.246	7.4				0.246	7.4			
0.265	8.3				0.265	7.8			
0.284	8.5				0.284	8.5			
0.303	10.6				0.303	8.3			
0.322	9.7				0.322	8.6			
0.341	7.2				0.341	7.3			
0.360	6.1				0.360	7.6			
0.379	6.5				0.379	8.2			
0.398	6.9				0.398	8.7			
0.417	6.1				0.417	8.5			
0.436	6.5				0.436	9.1			
0.455	6.3				0.455	8.7			
0.474	7.6				0.474	10.8			
0.492	7.0				0.492	10.0			
0.511	7.7				0.511	7.5			
0.530	6.8				0.530	7.1			
0.549	7.1				0.549	7.4			
0.568	6.4				0.568	8.3			
0.587	7.5				0.587	7.0			
0.606	8.2				0.606	7.5			
0.625	7.4				0.625	8.4			
0.644	7.7				0.644	9.2			
0.663	7.3				0.663	8.1			
0.682	7.6				0.682	7.7			
0.701	7.3				0.701	7.7			
0.720	7.7				0.720	7.4			
0.739	8.3				0.739	8.0			
0.758	7.8				0.758	8.7			
0.777	7.0				0.777	7.4			
0.795	6.9				0.796	6.6			
0.814	6.7				0.814	6.6			
0.833	7.4				0.833	6.8			
0.852	5.9				0.852	7.0			
0.871	6.8				0.871	6.9			
0.890	7.3				0.890	6.5			
0.909	7.5				0.909	6.2			
0.928	9.1				0.928	9.1			
0.947	8.2				0.947	10.3			
0.966	7.6				0.966	9.8			
0.985	7.8				0.985	9.0			
1.004	7.6				1.004	8.0			
1.023	6.6				1.023	7.7			
1.042	6.6				1.042	7.5			
1.061	6.9				1.061	8.0			
1.080	7.3				1.080	8.2			
1.098	8.8				1.099	8.4			
1.117	14.0				1.117	15.4			
1.136	16.1				1.136	21.2			
1.155	16.9				1.155	14.2			
1.174	8.7				1.174	18.1			
1.193	8.3				1.193	15.6			
1.212	8.3				1.212	16.7			
1.231	11.3				1.231	13.5			
1.250	13.3				1.250	11.9			
1.269	12.5				1.269	12.4			
1.288	11.2				1.288	12.7			
1.307	11.3				1.307	12.7			

APPENDIX C GPR OPERATIONS MANUAL

CHAPTER 1 - GENERAL

1-1 INTRODUCTION

1-1.01 PURPOSE

The Minnesota Department of Transportation (Mn/DOT) GPR Operation Manual provides an overview of the GPR data collecting with a GPS extension and mapping functions in the department. This manual contains material that is of both an informational and instructional nature. Guidelines and procedures are spelled out in detail in the hope that greater uniformity and quality can be obtained in GPR and GPS data collecting and mapping related activities within Mn/DOT.

The manual clarifies procedures technical and professional GPR data collecting and mapping personnel use in their day to day work. Using these procedures should result in uniform GPR and GPS data collecting and mapping practices.

The manual introduces procedures to work with GPR systems now being used throughout Mn/DOT.

1-1.02 SCOPE

The manual is written for use at the Senior Highway Technician level or above.

The manual contains definitions of common GPR and GPS data collecting and mapping terms used to communicate with colleagues and clients.

The manual also references other Mn/DOT manuals and other references as necessary for understanding a topic.

1-2 GPR SECTION - OFFICE OF MATERIALS AND ROAD RESEARCH

1-2.01 GPR SECTION FUNCTIONS

Develop and implement GPR and GPS data collecting and mapping procedures and training.

Test and research new GPR and GPS methods and systems for Mn/DOT.

Budget, purchase and integrate these new methods and systems.

Represent Mn/DOT with governmental agencies and professional and private organizations.

Work with the District Offices to provide training to GPR and GPS data users in understanding of the standardized reporting format.

Coordinate Mn/DOT GPR and GPS data collecting and mapping activities with each District.

Provide GPR and GPS data collecting and mapping products and services as necessary for planning, design, construction and maintenance of the transportation system.

1-2.02 GPR SECTION ACTIVITIES

Develop and implement GPR and GPS data collection and mapping procedures and training.

Test and research new GPS and GPS data collection and mapping methods and equipment for Mn/DOT.

Budget, purchase and integrate these new methods and equipment.

Represent Mn/DOT with governmental agencies and professional and private organizations.

Work with the District Offices to provide training to GPR and GPS data collection and mapping personnel in applications of pavement thickness surveys, pavement steel reinforcement and load transfer surveys, concrete pavement defect surveys, and project mapping.

Coordinate Mn/DOT GPR and GPS data collection and mapping activities with each District Engineer.

Provide GPR and GPS data collection and mapping products and services as necessary for planning, design, construction and maintenance of the transportation system.

1-2.03 REQUESTS FOR SERVICES FROM THE GPR SECTION

In order to avoid duplication of work and effort on a project, requests for GPR data collecting and mapping services should be channeled through the appropriate District Office. The District Pavement Engineer is responsible for their GPR and GPS records and should be knowledgeable about past and present respective district data collecting and mapping activities.

Each District submits the GPR requests along with Falling Weight Deflectometer (FWD) requests or submits GPR requests for individual projects separately. These requests should be sent to the GPR Section as soon as possible in order to efficiently schedule projects. A minimum of one month’s notice is usually requested for GPR surveys.

Requests for GPR survey should include the following information:

a. Roadway ID (e.g. US 10, TH 52)
b. County Name (e.g. Ramsey)
c. Project Limits (e.g. MP 171.700 to MP 188.900)
d. Exceptional Needs (e.g. Test on shoulder, Call for distress and roughness surveys)
e. Recommended Due Date

After a request has been received, the GPR Request Tracker (an EXCEL spreadsheet) should be updated and field work should be scheduled accordingly.

1-3 LIMITATIONS

The most significant performance limitation of GPR is in high-conductivity materials such as clay soils and soils that are salt contaminated or water saturated. GPR surveys should be performed in the dry season if at all possible, especially when base and subbase layers are of interest. Soil moisture, especially in high-clay soils, only increases the radar attenuation rates, further limiting the radar performance.

With the noise reduction the interferences from the power lines and telecommunication can be reduced significantly. However, spurious radar echoes (known as "clutter") can also be expected in many test areas because of buried debris such as old rails, wire scraps, boulders, and small metal objects. Usually a trained operator can interpret the desired radar signatures in the midst of a moderate amount of such clutter. Performance is also limited by signal scattering in heterogeneous conditions (e.g. rocky soils).

Interpretation of GPR records is an art as well as a science, even with the best available state of the art radars. Interpretation of radar grams is generally non-intuitive to the novice. Considerable expertise is necessary to effectively design, conduct, and interpret GPR surveys.

CHAPTER 2 - SURVEY

2-1 INTRODUCTION

Road Structures are defined here as the layered asphalt or concrete paving and any geo-textiles, base and sub-base materials. While it is sometimes possible to detect buried utility lines, that particular application is not a focus of the RoadScan technique.

The RoadScan technique described here involves the use of a GSSI SIR-20 control unit, Model 4105, 4105NR, 4108, or 4108(F) Horn antennas, and some type of distance measure instrument (DMI). The unit is mounted on a vehicle for high speed data acquisition. Data processing is done with GSSI's RADAN processing software with Road Structure Assessment module.

The RoadScan technique used for PCC pavements involves the use of a GSSI SIR-20 control unit, Model 5100 (1.5 GHz) or Model 5100B (1.6 GHz) antenna, and some type of distance measure instrument (DMI).

The RoadScan technique used for Utility involves the use of a GSSI SIR-20 control unit, Model 5103A (400 MHz) and Model 3207 (100 MHz) antenna, and some type of distance measure instrument (DMI).

The current state of the art has competent practitioners review each project site for adequate pavement and soil conditions and employ GPR when it is suitable. They use multiple frequencies and use GPR in conjunction with other techniques. A site appropriate survey and data referencing methods are selected.

Data can be collected in closely spaced parallel profiles and combined in a 3-D volume of data for post-processing and time or depth-slice interpretation. While GPR is still rarely used for conventional locating, it is becoming more common as equipment costs drop and ease of use improves.

2-2 EQUIPMENT

2-2.01 GPR

The GPR equipment currently used by Mn/DOT is summarized in Table 2-2. All of this equipment has been purchased from Geophysical Survey Systems Inc. in North Salem, NH. This equipment consists of two data collection systems (SIR-020 and SIR-2000), two data collection and analysis software packages (RADAN and ROADDOCTOR), 3 ground-coupled (GC) antennas (100 MHz, 400MHz, and 1.5 GHz) and 2 air-coupled (AC) antennas (1.0 GHz and 2.0 GHz).

Table 2-2 Mn/DOT GPR Antenna

	Air-Coupled		**Ground-Coupled**		
	1 GHz	**2 GHz**	**1.5 GHz**	**400 MHz**	**100 MHz**
Model:	4108	4105	5100	5103A	3207
Range:	12 ns	12 ns	12 ns	50 ns	500ns
Depth of penetration (ft.):	3	1.5	1.5	8	36
Samples per Scan:	512	512	512	512	512
Resolution:	16 bits	16 bits	16 bits	16 bits	16 bits
Number of gain pts:	5	1	5	5	5
Vertical High Pass Filter:	250 MHz	300 MHz	250 MHz	100 MHz	25 MHz
Vertical Low Pass Filter:	3000MHz	5000 MHz	3000MHz	800MHz	300MHz
Scans per second:	100	150	100	100	16
Transmit Rate:	100 kHz	100-500 KHz	100 kHz	100 kHz	50 kHz

The approximate depths of penetration for each of these antennas are given in Table 2-2. In general the depth of penetration is inversely proportional to the antenna transmission speed. In addition, Mn/DOT maintains a vehicle totally dedicated to GPR data collection that includes an independent power source, GPS data collection, electronic DMI device, GPS unit and a Video camera. Also, for “off-road” projects, a baby buggy has been modified for GPR data collection, which includes a battery power source and survey wheel.

The SIR-20 is a high-speed, powerful, multi-channel ground penetrating radar system that is ideal for a wide variety of applications. With different installations, two same or different antennas can be operated simultaneously with one SIR-20. The maximum number of antennas that can be operated by one vehicle and two SIR-20 processors is four. Two DMI units are required for four antennas, one for controlling data acquisition and one for synchronizing two SIR-20 processors.

References that should be used are:

a. SIR System-20 Manual.
b. Handbook for GPR Inspection of Road Structures.
c. RADAN Version 6.6 Manual.

2-2.02 GPS

The Trimble ProXRT GPS receiver uses H-Star technology in real time by connecting to a real-time correction source for decimeter (10 cm) to subfoot (30 cm) positions in the field. A wireless link to your local VRS™ network or local base station can be used for the flexibility. The ProXRT GPS receiver is also capable of using the OmniSTAR XP (20 cm accuracy) services.

Installing the GLONASS option on GPS Pathfinder ProXRT receiver increases the number of GNSS satellites that can be observed when working in the field. GLONASS improves the ability to maintain lock on enough satellites to keep working when sky visibility becomes limited in tough environments. Tracking GLONASS satellites as well as GPS satellites can also improve productivity by reducing the time required to achieve real-time decimeter or subfoot accuracy.

The National Marine Electronics Association (NMEA, pronounced "NEE'ma") has generated a standard set of messages for communicating GPS information. GPR uses the NMEA 0183 version 2.1 protocol that requires the NMEA output from a Pathfinder ProXRT GPS receiver.

GPS Pathfinder® ProXRT Receiver User Manual.

To configure NMEA output on a GPS Pathfinder ProXRT receiver, the NMEA output option must be enabled on the receiver. The following settings have been modified from their default values on the Trimble GPS Pathfinder ProXRT receiver:

a. Input: None
b. Output: NMEA
c. Output Baud Rate: 9600
d. Output Message: GGA (disable all others)
e. Output Rate: ASAP
f. GPS Configuration: (see Trimble manual)
g. Position Rate: 5 Hz
h. DGPS Configuration: (see Trimble manual)
i. Source: OmniStar

GPS data from the Trimble GPS Pathfinder ProXRT receiver is logged using the Acumen Data Logger for GPR. The settings on the Acumen Data Logger shipped with the SIR-20 system are factory preset to match the baud rate of the SIR-20 Tough-book computer serial communication port (115,200 bps). Acumen data logger settings are adjusted using the HyperTerminal communication utility by specifying the following parameters:

a. Bits per second: 115200
b. Data Bits: 8
c. Parity: None
d. Stop Bits: 1
e. Flow control: Hardware

The mandatory reference is Acumen Data Logger and Trimble AG132 GPS, SIR-20 System Settings and User Notes.

2-2.03 DMI

GSSI provides the Model 630B High Resolution Distance Measuring Instrument (DMI) with the RoadScan system. Model 630B Distance Measuring Instrument (DMI) represents the state-of-the-art in high-speed, high-accuracy survey control. The 630B is designed to be used on the rear wheel of a vehicle.

The mandatory reference is Model 630B Distance Measuring Instrument (DMI) Assembly Guide.

2-3 DATA COLLECTION

2-3.01 PROJECT RECORDS

The amount of research required will depend on the needs of the project. The following documents may contain useful project information:

a. Construction Plans. Both State and County plans will furnish construction centerline alignment and reference termini of the constructed highways. The plans will also furnish pavement design that includes materials types and design thickness of pavement layers and reinforcement and load transfer design for PCC pavements.

b. Geotechnical Reports. Geotechnical reports will furnish subgrade soils types and moisture conditions of the constructed highways.

2-3.02 WORK PLAN

The GPR data collection is planned after the project information has been completed. The project starting and ending locations are identified for route planning. The work plan should include the following major components:

a. Safety.
b. Quality.

2-3.03 SYSTEM PARAMETER SETUP

The project number will be used to create the project folder to keep this data organized prior to staring data collection program. If the project number is not available the roadway ID and staring milepost will be used to create the project folder. A new project should be created under that folder with a unique name. The followings are steps to define the folders previously created and set some other parameters:

a. Start from the initial RADAN/SIR-20 screen.
b. Find the View pull-down menu at the top of the screen and click on it. Look for the Customize options.
c. Click Customize.
d. Click Directories tab.
e. Click the Source button for a window pop-up with a list of folders that are on your computer. Find the folder created in the previous section and click the picture of the little folder to open it. Then click OK.
f. Click the Output button to select the same folder as Source and create a subdirectory called “Output” under the source folder. Source and Output folders should be separated because the SIR-20 will store different parts of data in different places. It does this so that parts of data that won’t get overwritten by accident (like project info files) are protected in the Source folder while the system stores other files in the Output (processed data).

g. Click the Linear Units tab. Click the down arrow for a pull-down menu list after Vertical button to select “INCH”. Click the down arrow for a pull-down menu list after Horizontal button to select “FOOT” if the project length is less than 5 miles or select “MILE” if the project length is greater than 5 miles. Click the down arrow for a pull-down menu list after GPS Units button to select “Lat Long”.
h. Click the SIRVEYOR tab to configure the GPS. Click the down arrow for a pull-down menu list after GPS button to select “SDR Logger”. Click the down arrow for a pull-down menu list after Port button to select “COM1”. Click the down arrow for a pull-down menu list after Baud rate button to select “115200”.
i. Click OK once you are satisfied that you have set up the system to your desired parameters.

The SIR-20 collects data with a project file system. The Project file defines settings for the whole data collection project and then collects a series of data files with some common settings.
A new collection project is created by going to File>New with the following file convention (the name should not be more than 8 characters because the name will be cropped after the eighth character):

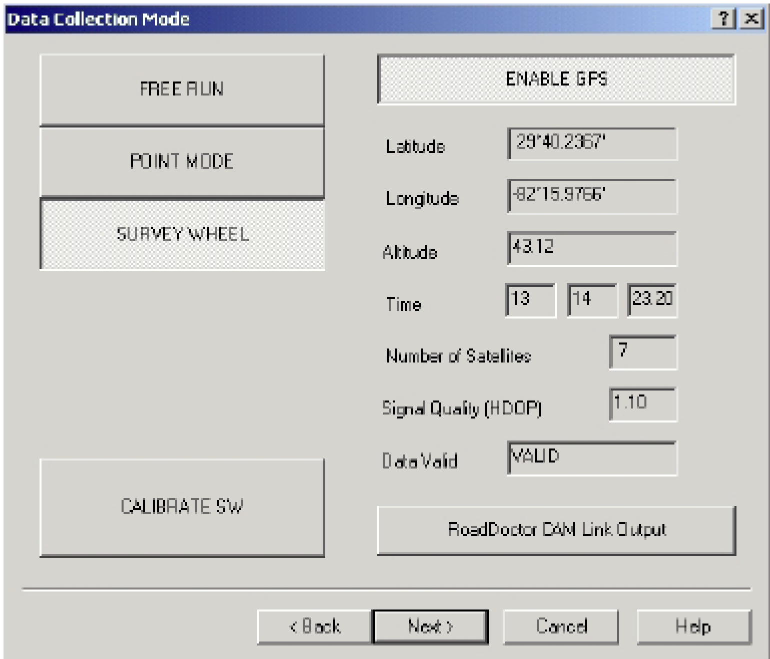
a. First numerical digit: Computer Number
b. Second letter: Data Collection Direction (W – West; E – East; N – North; S – South)
c. Third and fourth numerical digits: Section Number
d. Fifth and sixth numerical digits: Pass Number
e. Seventh and eighth numerical digits: Processing Sequence Number

Survey wheel data collection method will be used. In this method the system is equipped with a DMI so that the rate of data collection (scans per foot) can be controlled. These devices allow collecting data at a specific even scan spacing so that data is collected with a linear horizontal scale, no matter what speed of collecting data at. Survey wheel should be calibrated by laying out a 100-foot distance with tape measure and by doing the following steps in SIR-20:

a. Enter the distance in the “Calibration Distance” window and inch the vehicle forward so that the front wheel is at that start of the tape.
b. Click Calibrate and drive to the end of that distance.
c. Record the number of ticks.

Collecting synchronized GPS data consists of the following steps:

a. Press the Enable GPS button in the dada collection mode (There may be a delay of several seconds before you see the GPS information appear in the window).
b. Make sure you are receiving valid GPS information. (GPS must be receiving 4 or more satellites in order to provide a good solution).
c. Run the project and start collecting a file. (You should hear a beep within the first several seconds of collecting a file. This beep signifies that GPS information is synchronized with the GPR file.)
d. Upon closing the GPR file you will see a window pop up signifying that GPS data is being downloaded from the logger. This may take anywhere from several seconds to more than a minute depending on the length of the file.



When the following "Configuration" window appears, the value of 512 should be selected in the "Samp/Scan" drop down box. Also, the values for "Scans / ft" and "ft / Mark" should be changed to 1 and 528, respectively. All GPR surveys for pavement thickness at highway speed should be conducted in this setting unless the survey is for a special research need. The detailed settings under different conditions are shown in Table 2-3.

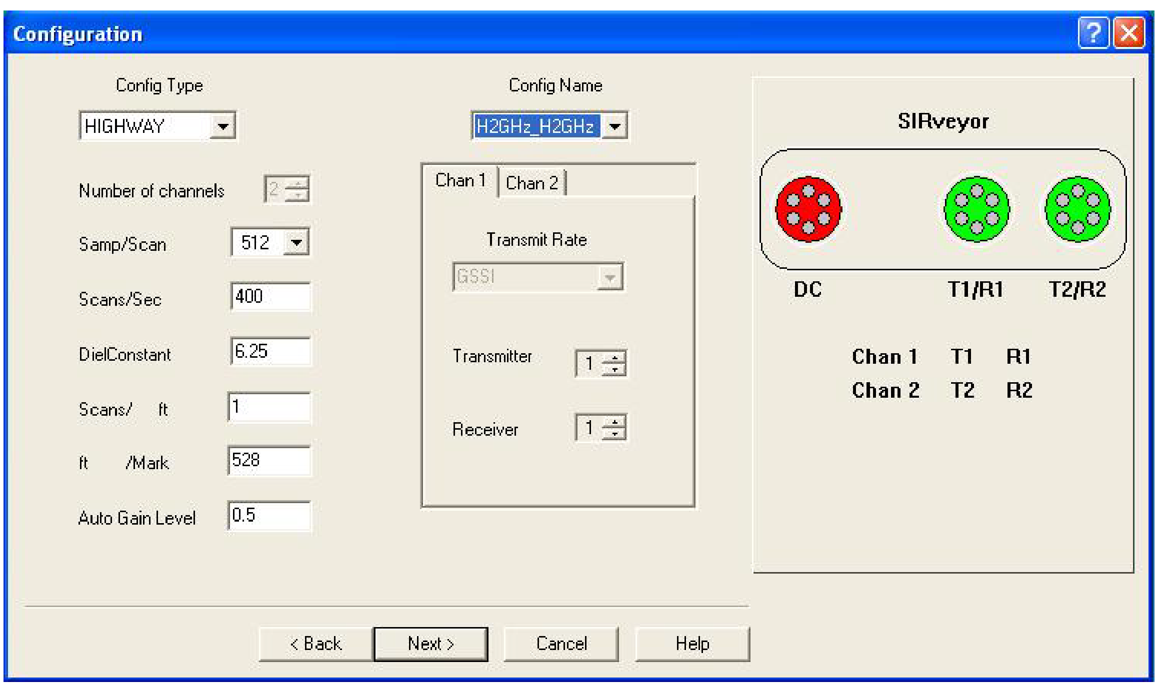


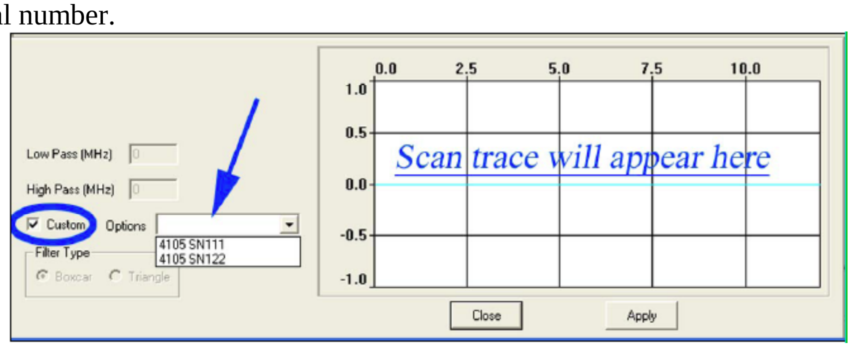
Table 2-3 Parameter Settings

Application	**Asphalt Concrete Pavement Thickness**			
Configuration Type	Highway			
Channels	1	1	2	2
Configuration Name	H2GHz	H2GHz	H2GHz_H2GHz	H2GHz_400MHz
Speed (miles/hour)	60	30	60	30
Scans per second	400	400	400	200
Dielectric Constant	6.25	6.25	6.25	6.25
Scans per foot	1	2	1	1
Foot per mark	528	100	528	100
Auto Gain Level	0.5	0.5	0.5	0.5

Next step is to open the Macro window. This window will allow for either creating a new macro, or attaching an existing macro. If there are no pre-saved macros on the system, the new macro should be created. Upon clicking the button for Create New Macro and clicking Finish the antenna will initialize, clock will count a few seconds and then data will scroll across the screen.

You will need to make a few adjustments before beginning collection. The steps below should be followed:

a. Configure Position
b. Check Gain
c. Check Filter. The correct filter settings of different antennas are listed in Table 2-2. If the noise reduction filter has been installed in the antenna (4105NR), "Custom" filter should be applied instead by selecting the filter which corresponds to your 4105NR's serial number.



d. Save Macro

After assigning the correct parameters for data collection, click the "Antenna Calibration File" button followed by the "Next" button.

2-3.04 CALIBRATION

The Bumper Jump Antenna Calibration file (.CZT) is crucial to Horn antenna processing. A 4 × 4 foot (1.2 × 1.2 m) minimum size sheet of metal is used for the antenna calibration. This metal plate should be clean and smooth. A Bumper Jump file will be collected at the beginning of each day's data collection. If the filed work lasts longer than 6 hours an additional one will be collected at the end of the day as well. The calibration file should have the same system parameter setup as data files defined in Section 2-3.03.

2-3.05 FIELD WORK

The field work is performed by a two-person crew that consists of a designated driver and a GPR operator. The GPS receiver is attached at the center of GPR antenna mounted to the vehicle front bumper or the GPR buggy.

Manually inserted markers are needed to assist in minimizing the error due to the starting offset in the data. The operator should take notes of what the markers are representing. As many markers as necessary should be inserted manually to indicate the following:

a. Starting and ending points and/or mileposts (if present) of the section under survey.
b. Any physical objects with known milepost. (e.g., bridges, intersections, railroad crossing and etc.)
c. Pavement changes.

After the data collection is completed, the data should be copied and pasted to the GPR data server or hard drive. If the coring was conducted, these results should also be saved in the same project folder. The field notes taken by the operator(s) should be scanned and saved electronically.

2-3.06 VERIFICATION CORES

The accuracy of the analyzed GPR data will be determined by correlating the computed layer thickness values to core data which have not been used in the analysis process. Where possible, the short scans will be selected to cover areas where cores have already been taken. Where core data are not available for correlation, GPR data will be used to recommend locations for coring.

CHAPTER 3 - ANALYSIS

3-1 INTRODUCTION

The Road Structure Assessment Module (RSA) in RADAN is a specialized data processing tool used to assess thickness (depth) and physical characteristics of multiple road layers. The RSA module can be used to process data obtained with GSSI SIR Systems using the 1 GHz (Model 4108) or 2 GHz (Model 4105) horn antennas.

The collected GPR data should be processed using GSSI's RADAN 6.6 software. The software allows the user to view the amplitude of the reflected waves in either stacked waveform or color coded display as shown in Figure 5. The horizontal axis at the top shows the traveling distance of the vehicle while the vertical axis on the left shows the two-way travel time of the radar wave. The color coded display mode is preferred for data processing since it is easier to understand and more convenient to use.

3-2 PAVEMENT LAYER THICKNESS

3-2.01 CALIBRATION FILE GENERATION

Each raw calibration file (*.dzt) is processed using the Calibration file generation tool in RADAN. The default extension on the output from the Calibration Tool is *.czt. The calibration generation tool reorganizes input data scans, performs some scan stacking, and overwrites the last 6 samples of each output scan with specific amplitude and height information. Choose 4105HR for the 2 GHz and 4108HR for the 1 GHz. Save the .CZT file with a name that consists of the calibration date. If more than one calibration files exist add the letter at the end of the date file name. Save CZT file to the folder called "Horn Calibration".

3-2.02 AUTO LOAD CALIBRATION FILE

RADAN will search for a CZT file in the Current folder selection. Check to make sure that the calibration file displayed is correct and if not uncheck "auto load calibration file", click "browse" to pick the appropriate calibration file, and click 'finish". The data file will scroll rapidly and it will prompt you to save the new, processed file. Give the file a unique name and click Save. Remember to add display gain. Note that in the processed data file, the pavement surface is now flat and Time-Zero is now at the pavement surface.

3-2.03 INTERACTIVE LAYER TRACKING

The processed antenna calibration file is used to process the raw data files in the process, called the horn reflection picking, which eliminates the effect of bouncing of the van during data collection. In addition, the vertical time scale is automatically adjusted such that the zero time corresponds to the point of time the radar wave reaches the pavement surface instead of the time the radar wave leaves the antenna.

There should be at least two markers indicating the beginning and ending locations of the section. After the beginning and ending locations are identified in the data, the horizontal scale should be corrected such that those locations match the mileposts of project termini. For increasing direction, horizontal offset can calculated as:

$$X_{offset} = X_{actual} - X_{RADAN}$$

For decreasing direction, horizontal offset can calculated as:

$$X_{offset} = -X_{actual} - X_{RADAN}$$

When this offset value is inputted into RADAN by selecting "edit">"edit database">"regions/position, the horizontal scale will be updated.

To obtain the depth to a layer interface using RADAN, the interface under consideration should be identified and picked from the data. The interface can be found in the data as a series of positive or negative peaks. Whether the peaks will be positive or negative depends on the dielectric properties of the layers above and below the layer interface. Positive peaks appear when the radar wave passes through an interface from a material with lower dielectric permittivity to a material with higher dielectric permittivity and vice versa for the negative peaks.

The results can be saved in a comma delimited file with an extension *.lay. This output contains the thickness information as well as other useful information such as the propagation velocity, reflection amplitude and two-way travel time.

3-2.04 EXPORT

Project information are stored in the header file and exported into tabular data that contains geographic locations in the form of x,y coordinates to your map.

The GPR results can be directly exported to KML files under the conditions that the GPS coordinate systems have be enabled prior to exporting. A KML file is a file type used to display geographic data. KML files have a tag-based structure with names and attributes used for specific display purposes. KML files can be imported in ArcGIS 9.2 as a line layer.

The GPR results can also be exported from the ASCII test file with the file extension of lay as a result of picking. The test files should be imported into either Excel or Access applications to create coma separated text files that can be imported in ArcGIS 9.2 as a point or line layer.

The output from RADAN can be imported into MS Access for further summarizing the layer thickness at 100 ft. interval and the reported thicknesses are the averages of those from one or both wheel paths.

3-3 STEEL TARGETS

When the antenna crosses a target (tie bar, rebar) at a right angle, the resulting image looks like a hyperbola. In all GSSI antennas, steel target reflection is a copy of the transmit pulse that has a certain polarity: positive peak first, then a negative peak (possibly followed by a second positive). In a grayscale line scan, this looks like a white band followed by a black band (then possibly another white).

3-3.01 TIME ZERO

Time Zero function will shift the vertical scale so time zero is aligned with the surface reflection in each scan. After opening the data file that will be processed, it is possible to run the process by selecting Process > Infrastructure, then selecting Structure Identification to open the dialog window. The processing parameters should be selected as follows:

a. Check "Set time Zero"
b. Select the antenna of 5100 (1.5 GHz)
c. Check "Background Removal"

3-3.02 MIGRATION

The radar antenna radiates energy with a wide bandwidth pattern such that objects several feet away may be detected. As a consequence of this, objects of finite dimensions may appear as hyperbolic reflectors on the radar record as the antenna detects the object from far off and is moved over and past it. Migration is a technique that collapses hyperbolic diffractions.

The Kirchhoff method should be selected for migration by adjusting the shape of the Ghost Hyperbola in the following steps:

a. Left-click and hold the mouse button when the cursor is over the center of the Ghost Hyperbola to drag the Ghost Hyperbola to center it over a real hyperbola in the data.
b. Use the Shaping Handles to match the shape of the Ghost Hyperbola to a real one by covering up the entire real hyperbola using to tails of the real hyperbola to help shaping.
c. Adjust the Width by left-clicking and holding on the Slider Bar Handle at the top or the bottom of the profile window to make the slider bars to be wide enough to encompass the real hyperbola, but not so wide as to include adjacent hyperbolas.
d. Click on Run 2-D Constant Velocity Migration.

3-3.03 INTERACTIVE TARGET TRACKING

Interactive Interpretation allows the user to semi-automatically locate and analyze features in radar data by placing "picks" on the data. A "pick" is a peak of amplitude identified in a scan that can correspond to a point target. The hyperbola becomes a point after migration that can be picked.

If this is the first time on a GPR image file after it was processed in Time Zero and Migration, there is no result (ASCII) file associated with it. It is possible to run the process by selecting View > Interactive to open the dialog window. The Generate New ASCII File option should be checked and OK clicked.

The target picking options should be specified prior to picking. All of the user options available in Interactive Interpretation are accessed first by moving the mouse cursor so that it is within the Interactive Interpretation data window (upper pane), then pressing the right mouse button.

Clicking on the Target Options menu item from the Main Menu opens up a list box containing the names and properties of all of the targets. Targets are added by clicking New Target. The new target properties are edited by placing the mouse cursor over the target name and double-clicking. The following properties should be used:

a. Name: Steel Bar
b. Color: White
c. Size: 5
d. Diameter: 0
e. Picking Criteria: Positive Peak
f. Velocity Calc.: User-specified or Core Data

The target points can be picked either using single point or EZ Tracker. The pick locations, depths, and reflection amplitudes are stored in an ASCII file (*.lay) when the user selects the "Save Changes" option. An ASCII file can be opened and edited many times.

3-3.04 EXPORT

Project information are stored in the header file and exported into tabular data that contains geographic locations in the form of x,y coordinates to your map.

The GPR results can be directly exported to KML files under the conditions that the GPS coordinate systems have be enabled prior to exporting. Only depth of steel bars can be exported in this operation. KML files can be imported in ArcGIS 9.2 as a line layer.

The GPR results can also be exported from the ASCII test file with the file extension of lay as a result of picking. The test files should be imported into either Excel or Access applications to create coma separated text files that can be imported in ArcGIS 9.2 as a point or line layer.

3-4 DEFECT TARGETS

A phase inversion occurs at a concrete-air interface because of the low dielectric of air. A phase inversion is a flip-flopping of the normal polarity sequence. So instead of a positive/negative/positive (white/black/white) peak, the phase inverted sequence is negative/positive/negative (black/white/black). A concrete-air reflection starts with a negative (black) peak followed by a positive (white) peak.

3-4.01 TIME ZERO

Time Zero function will shift the vertical scale so time zero is aligned with the surface reflection in each scan. After opening the data file that will be processed, it is possible to run the process by selecting Process > Infrastructure, then selecting Structure Identification to open the dialog window. The processing parameters should be selected as follows:

a. Check "Set time Zero"
b. Select the antenna of 5100 (1.5 GHz)

3-4.02 FIR FILTER

RADAN contains Vertical and Horizontal FIR filters. FIR filters, when encountering a feature in the data, are guaranteed to output a finite filtered version of that feature. The Triangular FIR filter should be used for filtering defect features in concrete pavement. The Triangular filter emphasizes the center of the filter more heavily than the ends of the filter. This type of filter is a weighted moving average, with the weighting function shaped like a triangle. A portion of the data, determined by the filter length, is multiplied and summed by this function. The result is output at the center of the triangle.

FIR filter settings should be the followings:

a. Background Removal (scans): 349
b. Low Pass (MHz): 500
c. Filter Type: Triangle

3-4.03 RESTORE GAIN

The Restore Gain function removes the gain applied to the data during acquisition. Restoring gain is an important option should you wish to export your data to a forward modeling program, or determine the dielectric permittivity, conductivity, and dispersion (approximate attenuation) of layers. The Restore Gain function uses gain information found in the file header to remove the gain function and normalize the gains.

3-4.04 INTERACTIVE TARGET TRACKING

Clicking on the Target Options menu item from the Main Menu opens up a list box containing the names and properties of all of the targets. Targets are added by clicking 

. The new target properties are edited by placing the mouse cursor over the target name and double-clicking. The following properties should be used:

a. Name: Defect
b. Color: Red
c. Size: 5
d. Diameter: 0
e. Picking Criteria: Negative Peak
f. Velocity Calc.: User-specified or Core Data

The target points can be picked either using single point. The pick locations, depths, and reflection amplitudes are stored in an ASCII file (*.lay) when the user selects the “Save Changes” option. An ASCII file can be opened and edited many times.

3-4.05 EXPORT

Project information are stored in the header file and exported into tabular data that contains geographic locations in the form of x,y coordinates to your map.

The GPR results can be directly exported to KML files under the conditions that the GPS coordinate systems have be enabled prior to exporting. Only depth of defects can be exported in this operation. KML files can be imported in ArcGIS 9.2 as a line layer.

The GPR results can also be exported from the ASCII test file with the file extension of lay as a result of picking. The test files should be imported into either Excel or Access applications to create coma separated text files that can be imported in ArcGIS 9.2 as a point layer.

CHAPTER 4 - MAPPING

4-1 INTRODUCTION

A standardized mapping process is developed for GPR project information and data specifically designed to report GPR results in an ArcGIS format. The developed ArcGIS mapping process will provide the following capability:

a. A standardized process to convert the GPR and GPS data exported by RADAN software into an ArcGIS format will be developed and documented.

b. Data that is transferred into ArcGIS using the procedure developed in step a) will be presented using two different mapping processes.

The standard process includes written instructions for GPR and GPS data conversion and transfer process, a statewide Minnesota mapping process, showing the locations of GPR data collection projects, and a method of prompting the user for the required information. The statewide map layer (point layer) developed will display the following attributes of the GPR projects:

a. GPR project type
b. Mn/DOT district
c. Trunk Highway number
d. Project limits
e. The date the data was collected
f. GPR data file name.

The attributes for the projects listed above are searchable and able to be sorted and outputted into a written report format, which will include a printed Minnesota ArcGIS project location map.

A more detailed level of project mapping developed shows the GPR vehicle track as data was collected. At each point a GPR/GPS data point is recorded, the pavement thickness data will be mapped by color coding the GPS locations (line layer). If there was a core taken at a certain point, the coring information of the cores is mapped by color coded GPS locations (point layer). The mapping system also allows the user to 'click on' individual project points on the map for the detailed information by 'hotlink' to the color coded pavement and base layer thickness with GPS X/Y coordinates, photos of the pavement, and GPR filename information. The mapping layers generated are presented in ArcGIS format, and utilize the Mn/DOT GIS base map and/or county highway GIS maps. The mapping capability developed is in a format allowing output into a written report, which will include a printed Minnesota ArcGIS project details map.

Mn/DOT Web-based interactive basemap is used to display the GPR project information and test results if the size of the GPR shape file is less 20 MB. Custom ArcGIS toolbars developed in the basemap provide point-and-click data automation, enabling analysts and scientists to easily navigate through GPR project layers and state highways, while hyperlinked features provide real-time access to project reports and GPR data.

4-2 CONVERSION

4-2.01 FILE ORGNIZATION

GPR Project information in tabular format are supplemented or merged with the highway project information into a project file. The GPR supporting files include the followings:

a. Report files.
b. Results files.
c. Core picture files.

4-2.02 IMPORT

Coma delimited files (.csv) are preferred for importing GPR results files into ArcGIS to create the shape files. Both project files and results files can be converted into .cvs files using MS Excel. During importing the MnDOT projection is needed to be specified as follows:

a. Group: UTM Nad 1983
b. Name: NAD 1983 UTM Zone 15N

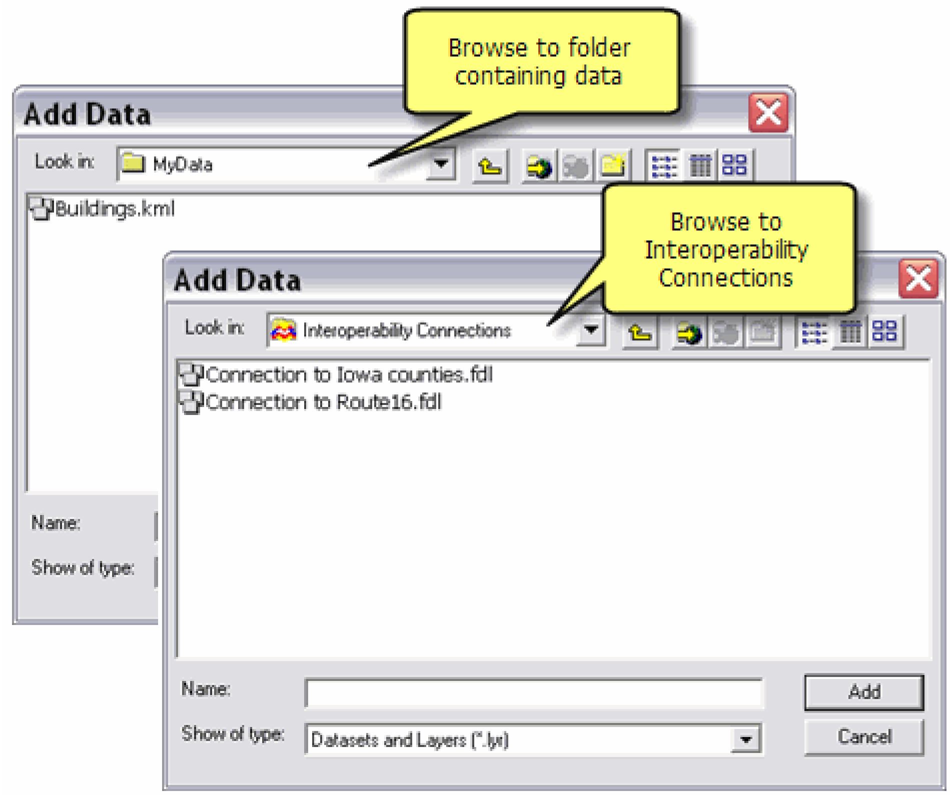
Keyhole Markup Language (KML) is an XML-based language for defining the display of three-dimensional spatial data. KML files have either a .kml file extension or a .kmz file extension (for zipped KML files). Support for KML 2.0 is included in the ArcGIS 9.2 release. The purpose of adding KML functionality to ArcGIS is to allow interoperability between ArcGIS and the Google Earth system. ArcGIS can act as a client for KML data. It can also export KML files for sharing with others, and serve KML content to the Google Earth browser.

In ArcGIS, KML data is represented using a KML Layer. KML layers are supported in ArcGlobe, ArcGIS Explorer, and the ArcGIS Engine Globe control. Like other layers (such as feature or raster layers), a KML layer is based on a data source, appears in the table of contents, has a context menu, property sheet, and associated toolbars and tools.

The ArcGIS KML layer treats the KML document as read-only information. It does not support functionality for interactively editing or creating new KML content. You cannot use KML elements as input for analysis operations.

The Data Interoperability Extension allows you to add KML data formats directly to ArcMap and ArcGlobe. The steps required for this procedure are the same as adding Geodatabase feature classes or shapefiles as follows.

1. Start ArcMap or ArcGlobe.
2. Enable the extension if need be.
3. Click the Add Data ( ) button. The Add Data dialog opens.
4. Click the Look in drop-down arrow and navigate to the folder or Interoperability Connection that contains the external data source, as shown below.



5. Click the data source and click Add.

4-2.03 SERVICES

You can also use a service as a basemap to go under your local data. For example, you might use satellite or aerial photographs or administrative boundaries from a service, and then overlay your own data, such as parcels, land uses, or demographics.

A GIS portal provides access to a variety of data and services gathered together in one clearinghouse. GIS portals organize content and services such as directories, search tools, community information, support resources, data, and applications. They provide capabilities to query metadata records for relevant data and services and link directly to the online sites that host content services.

Another place you can find data is in a metadata service provided by an organization or agency. These services are online catalogs of metadata that can be searched and browsed over the Internet to find and access data. Each metadata service has a Metadata Explorer Web page that allows you to search and browse the data that the organization or agency has made available.

A layer based on an ArcIMS feature class works the same as any other feature layer. A Feature service layer acts like a group layer, as a container layer for child layers. These child layers are ArcIMS Feature Classes, which reference individual feature classes residing on an ArcIMS server.

An ArcGIS Server map service provides mapping data associated with a single data frame of an ArcGIS map document (.mxd or .pmf) that is being served through ArcGIS Server. You can connect to an ArcGIS Server map service over the Internet or over a local area network (LAN).

4-3 CONVERSION

4-3.01 PROJECT POINT LAYER

Creating a point feature class from x,y coordinates exported from GPR header file consists of the following steps:

a. Right-click a table in the ArcCatalog tree that has columns containing coordinates, point to Create Feature Class, and click From XY Table.
b. Click the X Field drop-down arrow and click the name of the column that contains the x-coordinates.
c. Click the Y Field drop-down arrow and click the name of the column that contains the y-coordinates.
d. If appropriate, click the Z Field drop-down arrow and click the name of the column that contains the z-coordinates.
e. Click Spatial Reference of Input Coordinates and define the coordinate system for the input values as necessary.
f. Click the Browse button.
g. Click the Save as type drop-down arrow and click the format in which to create the new point features.
h. Navigate to the folder in which you want to store the new features.
i. Type a name for the new data source.
j. Click Save.
k. Set any Advanced Geometry Options and ArcSDE configuration keywords as necessary.
l. Click OK.

4-3.02 Project Callout Text Box

Adding text with a callout box and leader line consists of the following steps:

a. Click the Callout button  on the Draw toolbar.
b. Click a project point for the leader line and drag and release the mouse pointer where you want the callout and text to be placed (in the image below, the start point is the yellow dot).

c. Type the text string.

4-3.03 HYPERLINKS

Hyperlinks let you provide additional information about the features to people who will be using your maps with ArcMap. When you click a feature with the Hyperlink tool, a document or file is launched using the application with which that file type is currently associated.

Accessing a feature's hyperlink consists of the following steps:

a. Make sure the layer containing the feature for which you want to access a hyperlink is checked on (visible) in the table of contents.

b. Click the Hyperlink tool. Any visible features in the map that have hyperlinks defined are drawn in blue, the default color, or outlined in blue in the case of polygons. When you are over a feature for which a hyperlink exists, the mouse pointer turns into a pointing hand and you see a pop-up tip with the name of the target.

c. Click the feature. A hyperlink is invoked. If more than one hyperlink has been defined for the feature you clicked, a dialog box will appear from which you can select the hyperlink you want to launch.

4-3.04 INTEGRATION

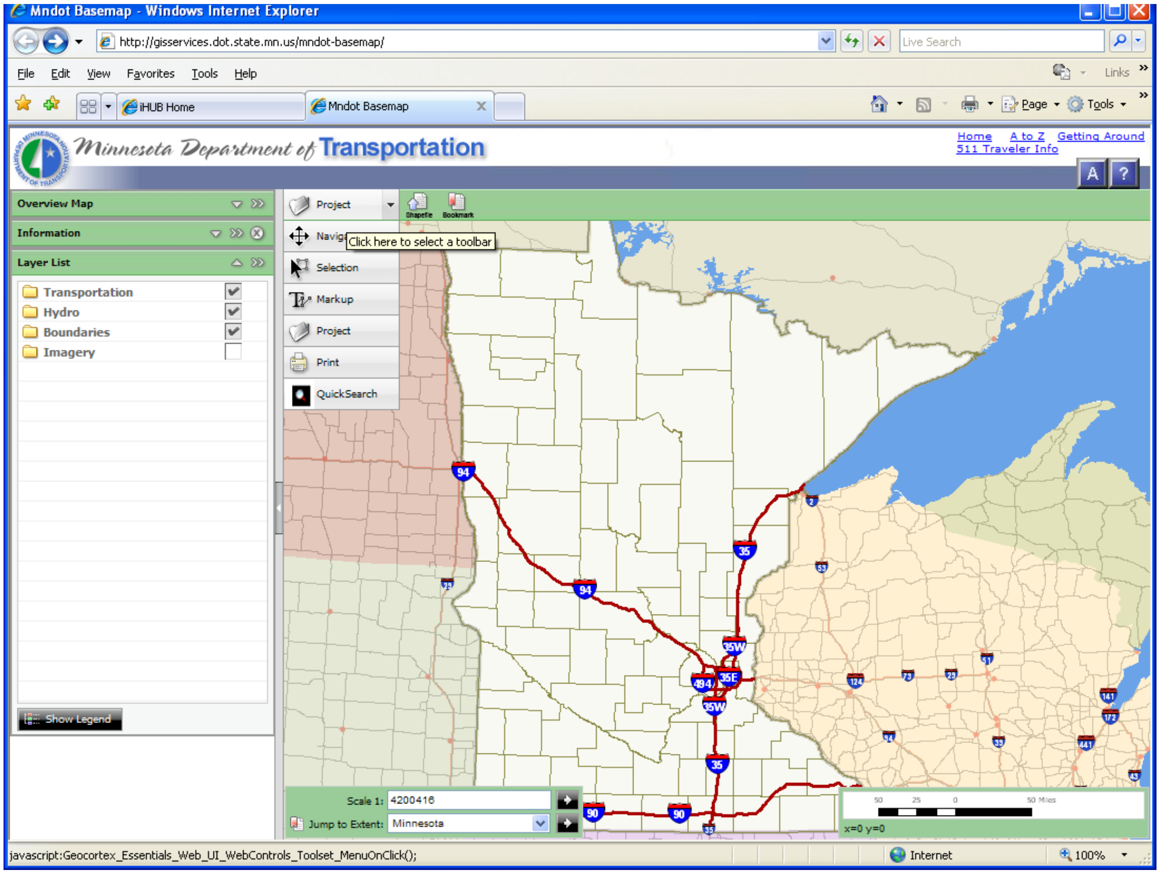
The integration of all project related files consists of two major stages: initial and expanding. The initial stage is focused on setting up a statewide Minnesota mapping process, showing the locations of GPR data collection projects. The expanding stage is involved in adding the new GPR projects to the existing map with elapsing of time.

4-4 WEB APPLICATION

4-4.01 GPR PROJECTS

The GPR projects shape files should be imported into the Mn/DOT web-based interactive basemap that can be accessed via:

http://gisservices.dot.state.mn.us/mndot-basemap/



In the web based GIS map as shown above, there is a pulldown menu in the toolbox at the upper left. The down arrow should be clicked to select project and then, just to the right is “upload shapefile”. The shape files are uploaded using the following steps:

a. Browse for the shapefile files created in ArcGIS 9.2
b. Load all four of the necessary files (.shp, .shx, dbf. and .prj)
c. Name your new map layer
d. Press ”Submit” and if the points are valid they should show up as an uploaded layer
e. Change point properties in the “symbolize layer” box

CHAPTER 5 - REPORTING

5-1 INTRODUCTION

The reporting is in a format allowing output into a written report, which will include a printed Minnesota ArcGIS project details map.

5-2 DATA REPORT

A spreadsheet reporting the layer thickness should be prepared and sent electronically to the requestor. The spreadsheet contains 2 worksheets: a summary sheet and a data sheet.

5-2.01 SUMMARY

The summary sheet consists of the following separate blocks:

a. Pavement Inventory: This block describes the inventory of the project. The survey date should also be included in this block.
b. Pavement Type: Pavement types and their limits should be provided in this block for the viewer. Comments should be made in this block to let the engineer be aware of any findings that may be useful for rehabilitation design or any issues with the radar data such as presence of noise due to interferences from other sources.
c. Summary Statistics & Plot Settings: This is the only block in the summary sheet that can be modified by the viewer. Included in this block is the menu that controls the settings for the summary statistics and the plots provided in blocks 4 and 5.
d. Summary Statistics: Summary statistics of the data between the limiting mileposts are shown as a table format. The statistics include average, standard deviation, minimum and maximum values and the limiting mileposts are the x-limits in 3rd block.
e. Plots: The data is plotted and shown in this block. Using the menu in the 3rd block, the viewer can choose to plot different data: thickness, cross slope or rut depth. The horizontal and vertical axes can be modified for zooming in and out.

5-2.02 DATA

The data sheet consists of the actual data, including mileposts, thicknesses, and drilling data placed under the corresponding columns and lanes. Mileposts and the thicknesses can be copied from the excel files exported from Access and pasted into this spreadsheet.

5-3 GIS REPORT

5-3.01 MAP TEMPLATE

If the map is part of a series, you might have a template to work from, or you might create a new template for the series. Map templates make it easy to produce maps that conform to a standard, and they save time by letting you do the layout work for all the maps in the series at once.

5-3.02 MAP PRINTING

In the web based GIS map as shown above, there is a pull-down menu in the toolbox at the upper left. The down arrow should be clicked to select navigation and then, just to the right are "in", "out", and "pan". At the left, there is layer list. The map layer created in the previous chapter should be checked. When the map is ready to print, the down arrow should be clicked to select print and then, just to the right is "print". The project details map is printed using the following steps:

a. Select a page size
b. Select an output format
c. Select "Show All Layers"
d. Type the project title
e. Enter the map description
f. Press "View"
g. Press "Download"