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Executive Summary

The South Washington Watershed District (SWWD) initiated the Infiltration Management Study (IMS) in 1997 to characterize infiltration and explore the use of infiltration as a component of overall stormwater management in the watershed. Phase I of the IMS was completed in October of 1998. Phase I emphasized literature review, obtaining background information on soils and geology, data collection through establishing a monitoring network and program, organizing Technical and Local Advisory Committees, and implementation of pilot projects in the watershed to enhance infiltration. The Phase I progress report is available at the District office.

Phase II includes continued data collection, monitoring of infiltration in the field, analysis of infiltration rates, and modeling to evaluate the importance of infiltration as a stormwater management tool. Phase II examines the behavior of the watershed through modeling of the surface and groundwaters and discussion of the effects of stormwater infiltration on groundwater quality and environmental resources. Phase II has included continued input from the Local and Technical Advisory Committees and the development of recommendations on the use of infiltration as an important component of stormwater management in the SWWD.

The Report includes the following chapters that discuss how the data was collected, how it was analyzed and interpreted, how it was utilized with predictive computer modeling to evaluate benefits and impacts, and finally, what options the District has available and how to proceed:

- Introduction
- Monitoring Methodology and Results
- Water Level Data and Infiltration Analysis
- Surface Water Modeling
- Groundwater Modeling
- Surface Water - Groundwater Interactions and Modeling
- Water Quality and Environmental Issues
- Management Options

- Summary Conclusions
- Recommendations

Monitoring Methodology and Results

The monitoring data included in the Phase II report includes data that has been collected since the fall of 1998. Data analysis prior to the fall of 1998 can be found in the IMS Phase I Report. The results are presented for the five basins monitored during this project. These five basins are illustrated on Figure II-1. The following information for each basin was collected and is presented in the report:

- topographic and landform data
- surface water level and quality monitoring results
- groundwater levels and quality monitoring results

Analysis of water level data and infiltration rates measured during spring and summer is presented separately in Section III, Water Level Data and Infiltration Analysis.

Water Level Data and Infiltration Analysis

Infiltration data was collected for four of the five basins during the spring snowmelt runoff event. The four basins include CD-P50 - Eagle Valley Golf Course Basin, CD-P69 - Pioneer Drive Wetland, CD-P76 - Mile Drive Basin, and CD-P82 - County Road 19 Basin. No pumping of runoff during snowmelt conditions into CD-P85 occurred and therefore no data was available. Data on CD-P85 includes summer infiltration data (including data summarized in the IMS Phase I Report) and data on infiltration improvements. Infiltration data was collected by measuring the depth of water in each basin over time to determine the change in storage and measuring any inflows or outflows to the basins during the event.

Both the results of the 1999 spring snowmelt runoff event and Dr. John Baker's studies (UM-Rosemount Research Station) indicate that infiltration does occur during the spring snowmelt event in a glacial outwash setting such as that found in the SWWD. The magnitude and timing of the infiltration under different conditions is still being evaluated and will be better defined in the future with more data.

The recommended values for snowmelt infiltration contained in this report are good preliminary values used to evaluate the long-term infiltration capacity of natural regional detention and infiltration basins during critical events. During spring snowmelt for the one year of this study infiltration was measured in the lowest portions of the basin, which are typically the least effective infiltration areas due to accumulation of fine sediments. Under these conditions the observed infiltration rates ranged from 0.0001 to 0.0008 ft/min. Based on observed trends at CD-P85, as the basins fill, the infiltration rates increase linearly. By extrapolating the observed infiltration rates at basins where there was limited data, to a depth of one-half to one-third the maximum basin depth, infiltration rates range from 0.0003 to 0.0018 ft/min for spring snowmelt. The rates used in the modeling were within or below this range. It is estimated that, at a minimum, current measured and predicted infiltration rates in the identified basins can be maintained in the future through management and understanding how the basins have sustained their infiltration capacities naturally over time.

Management of water levels and analysis of the data should continue to focus on the timing and rates of water delivery to the basins. Management of how water is delivered will ensure that the basin is subject to proper wet-dry cycling. Ultimately optimal wet-dry cycle requirements for various basins or basin types should be developed and quantified.

Surface Water Modeling

An existing HydroCAD hydrologic model developed jointly by the City of Woodbury and the SWWD was utilized for the surface water modeling. Several timing scenarios to evaluate the impacts of development through time were modeled in 5-year increments through 2020 and then to ultimate development of the study area.

Different hydrologic events were also evaluated to determine a critical event for the area. The events that were evaluated included a 6.0” 1-Day rainfall event and 6.0” and 7.2” 10-Day runoff events. The 7.2” 10-Day runoff event created the most critical scenario. The 7.2” runoff event could be fairly conservative considering the landforms, soils, and geology of the SWWD but is being used now as an initial assumption. For infiltration and detention purposes, 24 primary basins and 6 secondary basins were evaluated for management as part of the ultimate development scenario. This computer model has some limitations in how the infiltration data is input, the accelerated timing of the delivery of flows downstream by the model, and how different ponds interact and provide storage through the time of the event.

Modeling results indicate that based on the estimated infiltration rates for the basins operating at 1/3 to 1/2 full and implementing several detention measures, the estimated volumes of runoff in the system could be retained. Phasing in necessary natural infiltration basins with future development indicates that the system can be managed fairly effectively with minimal overflow for the events evaluated through time, at least through 2010. The next steps needed are to identify and evaluate Critical Detention options.

Since the modeling thus far is based on limited data, as additional data is collected, the new information should be incorporated into the model to evaluate the management plan. Other computer models should be evaluated to determine if another model would be better suited to this application and provide more accurate and reliable results.

Groundwater Modeling

This study developed a state-of-the-art groundwater model using MLAEM. The groundwater modeling effort was assisted by other regional modeling, specifically the MPCA Metro Model. The SWWD model is part of a larger groundwater flow model that covers most of Washington and Ramsey Counties. Model calibration within the study area was conducted with local well data. Groundwater potentiometric maps are included in the report as a visual representation of the groundwater contours.

The model results provide some useful insights into groundwater movement throughout southern Washington County. Some conclusions from the groundwater modeling include:

- The material that fills the buried bedrock valley has a very high hydraulic conductivity and transmissivity.
- The bedrock valley has a significant impact on groundwater flow patterns, channeling large volumes of water southward toward the Mississippi River.
- There is a large vertical gradient downward throughout most of the model area. Regional groundwater flow is downward from the water table to deeper aquifers before being discharged to the Mississippi and St. Croix Rivers.

As conditions change throughout the watershed, such as further development with more imperviousness or alterations to the Historic Woodbury Landfill pump out system, the model can be used to predict the impact on groundwater resources.

Surface Water - Groundwater Interactions and Modeling

Very few mathematical models exist that incorporate both surface water and groundwater flow. Even fewer have commercially available software. Therefore, an approach was developed where critical parameters from the surface water model are incorporated into the groundwater model "by hand" rather than automatically. The critical parameter in the surface water/groundwater interaction is the infiltration rate at the infiltration basins. The groundwater model was then used to evaluate how the groundwater system would behave under very intensive, concentrated infiltration at regional basins. The groundwater model would then indicate whether the groundwater flow patterns are altered and whether groundwater would mound under the infiltration basins to an extent that it would affect the infiltration rates of the basin under short-term scenarios or long-term infiltration.

Groundwater levels in Washington County appear to be at historic highs in recent years. Much of the groundwater levels assumed in the groundwater modeling are from observed groundwater levels in recent years. The analysis of a critical surface water event is being analyzed with groundwater data from what appears to be a historic high in groundwater levels for a combination of extremes in both surface waters and groundwater conditions.

The MLAEM model indicates that long-term infiltration will not significantly affect the regional groundwater flow patterns. The preliminary model of the short-term effects of mounding indicates that groundwater mounding does not appear to limit the infiltration of water at CD-P50, CD-P76, and CD-P82. Groundwater mounds could intersect the bottom of the basin during the later stages of an extreme infiltration event at CD-P69, CD-P85, and CD-P86. If this were to occur, infiltration would continue from the bottom and sides of the basin but at lower rates.

The analytical method used to evaluate the short-term mounding was relatively simple. Dr. John Nieber of the University of Minnesota is working on a much more sophisticated, time dependent model of CD-P85 that should provide more precise results. Using well data at CD-P85 and other infiltration basins during infiltration events will enable calibration of the groundwater and unsaturated flow models and greatly increase the accuracy and reduce uncertainties of the predicted results presented here. The modeling tools developed here and by the University of Minnesota's Dr. Nieber can be used to evaluate other un-monitored basins.

Water Quality and Environmental Issues

Water quality concerns in groundwater aquifers can be an issue especially since residents in the watershed draw their drinking water from aquifers. Infiltration can also play a major role in protecting surface water quality, the hydrologic system, and natural communities associated with watershed waterbodies such as lakes, streams, and wetlands. Given that there are both potential benefits and detriments of managing infiltration, most of the focus of this study has been on addressing potential impacts to groundwater quality and environmentally sensitive areas.

In general, surface water quality throughout the watershed is relatively good in terms of groundwater contaminants based on two monitoring stations and grab samples. Under current conditions, it appears highly unlikely that water from the basins would degrade groundwater quality. Analysis of groundwater flow patterns near an old hazardous waste contamination site on the Woodbury – Cottage Grove border indicate that the on-going remediation efforts for the site will not be significantly affected by infiltrating water at any of the infiltration basins.

Infiltration provides many environmental benefits by protecting water quality and protecting the natural hydrologic balance of the system. However, large water level fluctuations in regional basins could potentially have environmental impacts to wetlands, fish and wildlife populations, or rare plants and animals if those features are present. To minimize impacts to natural communities, detailed site assessments should be conducted for each potential infiltration site. Infiltration areas and basins also offer some significant opportunities for restoration of natural communities and preservation of open space in this rapidly urbanizing landscape. The benefits of using infiltration for stormwater management should not be forgotten when evaluating impacts. When evaluating and addressing impacts, a balance between positive and negative impacts needs to be found.

Management Options

The management options available can be implemented at the regional or local scale. Regional and local approaches are both important in the long-term management of infiltration. The primarily focus of the Watershed is currently on regional practices and improvements that the Watershed can actively implement, manage, and rely on. Regional strategies include:

- Maintaining natural infiltration systems
- Subwatershed-based standards
- Infiltration design guidelines
- Uses of specific infiltration practices such as trenches, tubes, swales, etc.

Issues of operation and maintenance (O & M) and land acquisition are important financial and social issues to be further evaluated in the future. A main advantage of performing infiltration management on regional basins in which infiltration occurs naturally is that, if properly and proactively managed, the operation and management costs could be significantly lower than those of man-made infiltration systems. Land acquisition costs and future uses of the land depends on several factors:

- How the proposed managed areas fit into current city stormwater plans
- How the proposed areas can be incorporated into local and regional open space and greenway efforts

- How best to phase the acquisition of areas to delay costs while also being ahead of development pressures that can drive up land costs and landowner expectations

Summary Conclusions

The IMS study has identified natural infiltration as one of the single most significant factors in determining the current hydrologic behavior of the Watershed. The IMS has also identified natural infiltration as an important resource in future stormwater management in the watershed, especially when effectively combined with a Critical Detention Program.

The Watershed's foresight in conducting the Infiltration Management Study has demonstrated that better alternatives to the "just move the problem downstream" approach exist and are viable. The findings in the IMS indicate that an integrated and coordinated effort between infiltration, critical detention, and appropriate overflows can minimize risk while at the same time accomplish several community and watershed goals such as:

- Providing open space amenities
- Protecting water quality in lakes, wetlands, and rivers
- Replenishing groundwater
- Providing an innovative, cost-effective solution

Recommendations

The recommendations of the study include:

- Continue data collection and monitoring to aid in effective decision-making and management
- Consider development of a new surface water model that will allow for time-dependent parameter input and output and then calibrate the new model, or the existing model in the interim, with new data that is collected
- Improve water quality and enhance environmental resources through a balanced approach using infiltration and continue monitoring to verify modeled results

- Continue to evaluate available management options for infiltration and Critical Detention
- The District should immediately pursue cost-effective options for minimizing the risk of flooding by utilizing critical detention and storage and infiltration management
- Ensure public support and understanding through a coordinated public education and outreach program in the community

The SWWD should utilize a proactive approach that emphasizes infiltration and critical detention to address stormwater issues that is based on the sound scientific data specific to this watershed setting and presented in this report. Utilizing the natural features of this watershed, such as extensive natural detention areas and high infiltration capacities, is a sound and innovative approach to stormwater management that is foresighted and directed toward the future of more natural, less costly solutions. Combining upstream solutions such as infiltration and detention along with "safety valve" overflows is the most environmentally sound and most cost-effective solution available to the District.

I. Introduction

The South Washington Watershed District (SWWD) initiated the Infiltration Management Study (IMS) in 1997 to characterize infiltration and explore the use of infiltration as a component of overall stormwater management in the watershed. The IMS is part of the overall Central Draw Outlet Study identified in the SWWD Watershed Management Plan.

The IMS was subsequently broken into two phases. Phase I was completed in October of 1998. Phase I emphasized literature review, obtaining background information on soils and geology, data collection through establishing a monitoring network and program, organizing Technical and Local Advisory Committees, and implementing pilot projects in the watershed to enhance infiltration. The Phase I progress report is available at the District office. The Progress Report contains all of the background information on the District including soils, hydrology, and geology, as well as a description of the current monitoring program, monitoring results from 1997 and 1998, and a description of the committees that have been involved with this project. It also gives the background on the various techniques available to enhance infiltration, and an in-depth description of the methodology used in selecting monitoring sites.

Phase II has emphasized continued data collection including monitoring of infiltration and the analysis of infiltration rates for the watershed, modeling of the surface and groundwaters, discussion of the effects of stormwater infiltration on groundwater quality and environmental resources, continued input from the Local and Technical Advisory Committees, and the development of recommendations on the use of infiltration as an important component of stormwater management in the SWWD.

This report is divided into sections, topics, and appendices that outline the processes and methodology used in developing the final recommendations found at the end of the report. This report is can be considered work in progress and will be reviewed and revised in the future as new information is collected and becomes available.

II. Monitoring Methodology and Results

The monitoring results presented here include data that has been collected since the fall of 1998, excluding the infiltration rate analysis. Data analysis prior to the fall of 1998 can be found in the IMS Phase I Report. The methodology for collecting the various types of data is presented below.

The results section is divided into five subsections based on the five infiltration monitoring basins studied during this project. These five basins are illustrated on Figure II-1. Each subsection contains the following information for the basin: topographic and landform data; water quality sampling results; and groundwater monitoring results. Infiltration analysis including water level data and infiltration rates measured during spring and summer 1999 follows in Section III.

II-A METHODOLOGY

Landform Information

Topographic data was obtained through existing grading plans, aerial photo 2-foot contour surveys, and on-site surveying to validate the existing information. Two-foot contour maps were generated for each site. The datum for all elevations is mean sea level. The topography allows the determination of the overflow elevations as well as the potential volume of water that each basin is capable of storing. Geologic cross-sections at each basin were generated by using soil boring information from the installation of monitoring wells at the basins as well as County geologic maps and surrounding well information. These cross sections allow for the identification of the local water table gradient as well as the subsurface materials. Soils taken from the Washington and Ramsey County Soil Survey (1977) are also identified on the site map for each basin. Specific soil descriptions for each soil type are found in Appendix A.

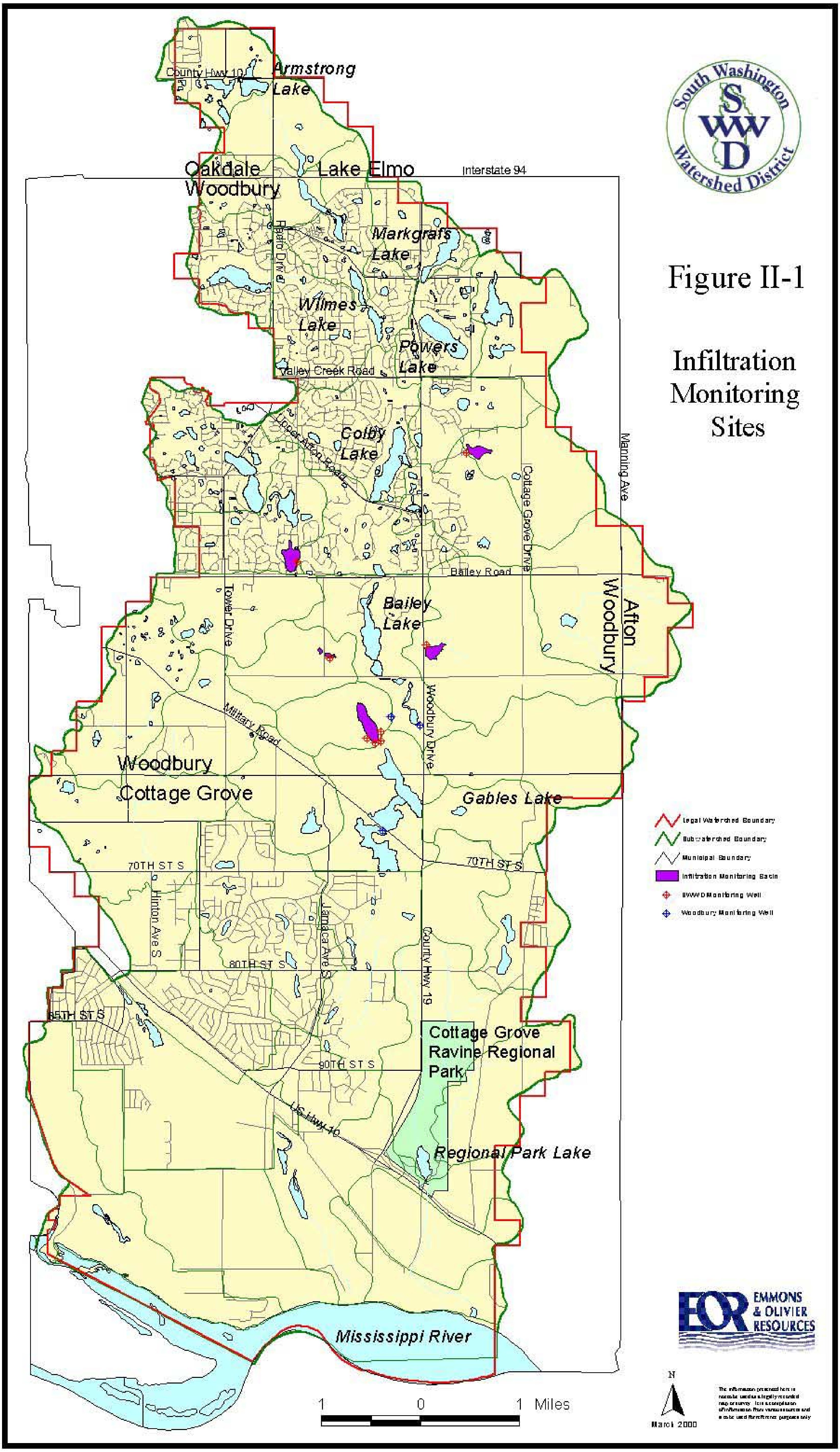


Figure II-1

Infiltration Monitoring Sites

Water Quality

Surface water and groundwater quality are both considerations for monitoring the performance of infiltration areas. The quality of water entering an infiltration facility will have an effect on the clogging of soils due to sediment load and chemical precipitation. As a result, pretreatment is necessary for all infiltration practices to ensure that high quality surface water is being infiltrated. See Section VIII for a discussion of potential water quality impacts. Monitoring of water quality, both surface and groundwater is crucial in establishing baseline data on ensuring functioning infiltration and protection of groundwater resources.

Water quality modeling was considered during this project. After discussions with the Infiltration Technical Advisory Committee (ITAC), it was agreed that water quality monitoring would provide more useful data than modeling.

<u>Groundwater Quality</u>

The SWWD installed eight monitoring wells at five basins in September of 1998. The location of these wells is indicated on Figure II-2. Wells were installed downstream of the basins based on county geologic mapping in order to determine the effect of infiltration on the water table. The specific well logs are located in Appendix A. Due to budget constraints, the maximum depth of the majority of the SWWD wells is 50 feet. Therefore, some of the wells are dry except during extreme infiltration events.

Groundwater at each of the basins was sampled and analyzed during the SWWD semi-annual sampling program associated with the Groundwater Monitoring and Protection Program. More complete and detailed analysis is presented in the 1999 Groundwater Monitoring and Protection Report. The City of Woodbury also samples three wells that are in the vicinity of CD-P85 for water quality parameters. These wells are indicated on Figure II-2 and well logs can be found in Appendix A. Appendix B contains copies of the City of Woodbury's analytical results from 1998.

Groundwater was sampled for:

- Heavy Metals including cadmium, lead, manganese, and nickel
- Chlorides
- Kjeldahl and Ammonia Nitrogen
- Nitrate + Nitrite Nitrogen
- Hardness ($CaCO_3$)
- Volatile Organic Compounds (vocs)
- Semi-volatile Organic Compounds (EPA Method 8270)

Appendix B contains lab reports for each of the infiltration basins. Groundwater samples were collected in March and November 1999. During the March 1999 sampling event, samples were not filtered prior to analysis. During the November 1999 sampling event, samples were filtered using a 0.45 micron filter prior to analysis.

Unfiltered groundwater samples show the total (dissolves plus suspended) concentrations of an analyte. This may not be representative of groundwater quality in the area around the well because suspended compounds (e.g. metals or organics) attached to soils cannot be transported through the small pore spaces in the aquifer. There are exceptions to this rule, such as when solution cavities develop in limestone karst terrains. Analytical results from unfiltered samples should be considered “conservative” because they generally reflect concentrations higher that what is actually being transported through the aquifer.

Filtering removes sediment from the groundwater samples along with any analytes that may be associated with the sediment. Filtered samples reflect the concentrations of a compound that is likely to be transported through the aquifer and away from the well. Therefore, analysis of filtered samples is usually used for comparison to regulatory standards. The March 1999 samples were not filtered, so that any compounds that might potentially be of concern would be detected. Some metals and other compounds were detected above the applicable regulatory standards. The second round of samples collected in November 1999 were filtered to screen out those compounds that were not likely to be transported throughout the aquifer.

Analytical results were compared with the Minnesota Department of Health Standards for drinking water and the EPA Federal drinking water standards. The Department of Health identifies Health Risk Limits (HRLs) as the exposure value that can be safely consumed daily for a lifetime. One analyte, chloride, does not have a Minnesota standard. The EPA has a secondary standard for this analyte. Secondary standards are not enforceable at any level, but provide a baseline for aesthetic quality. Several volatile organic compounds also did not have a concentration standard at the State or Federal level. These compounds are listed without HRLs. Volatiles and semi-volatile organic compounds that were never detected are not listed on the summary tables but can be found in lab reports in Appendix B.

Surface Water Quality

Surface water in CD-P85 was sampled by taking grab samples during 1997, 1998 and 1999 during pumping and infiltration events. The SWWD also has an ongoing surface water quality and quantity monitoring program. These results show the overall surface water quality at two points in the watershed and are useful in comparing surface water grab samples from infiltration monitoring basins. An annual report for this program is available through the watershed. Due to the lack of water in the basins, surface water samples have only been taken in CD-P85 in 1999.

Groundwater Level Monitoring

Groundwater mounding, the process by which infiltrating water creates a mound on the water table, can be a limiting factor for infiltration. Depth to groundwater, bedrock, and other impermeable layers all contribute to mounding. If groundwater mounding becomes severe, it can intersect the bottom of the basin and contribute to ponding conditions in the basin thus controlling the rate of infiltration. The literature on using infiltration for stormwater cites a minimum depth to the water table, bedrock, or impeding layers of 2 to 4 feet (MD 1984, Schueler 1987) and Wisconsin cites a minimum of 5 feet (WDNR, Draft 1997).

Water table elevations were recorded during the fall of 1998 and monthly during 1999 in all of the SWWD owned monitoring wells. Water level readings were taken with the use of an electronic water level tape at each well. SWWD values were compared with the City of

Woodbury monitoring wells near CD-P85. The City of Woodbury has been recording water levels in their three wells for several years on a quarterly basis.

II-B RESULTS

CD-P85

Landform Information

The topography of CD-P85 is illustrated in Figure II-2a. This basin is currently owned by the City of Woodbury and receives water from the Bailey Lake lift station. The overflow for the basin is approximately at 915.4, located in the southeastern portion of the basin. This basin has undergone two infiltration enhancements, discussed in Appendix C and the Phase I Report. The stage-storage for the basin is presented in Table II-1. This Table is an update to the previous table found in the Phase I Report and is based on additional field surveying of the basin. CD-P85 has a maximum storage capacity of 535 acre-feet at its overflow elevation.

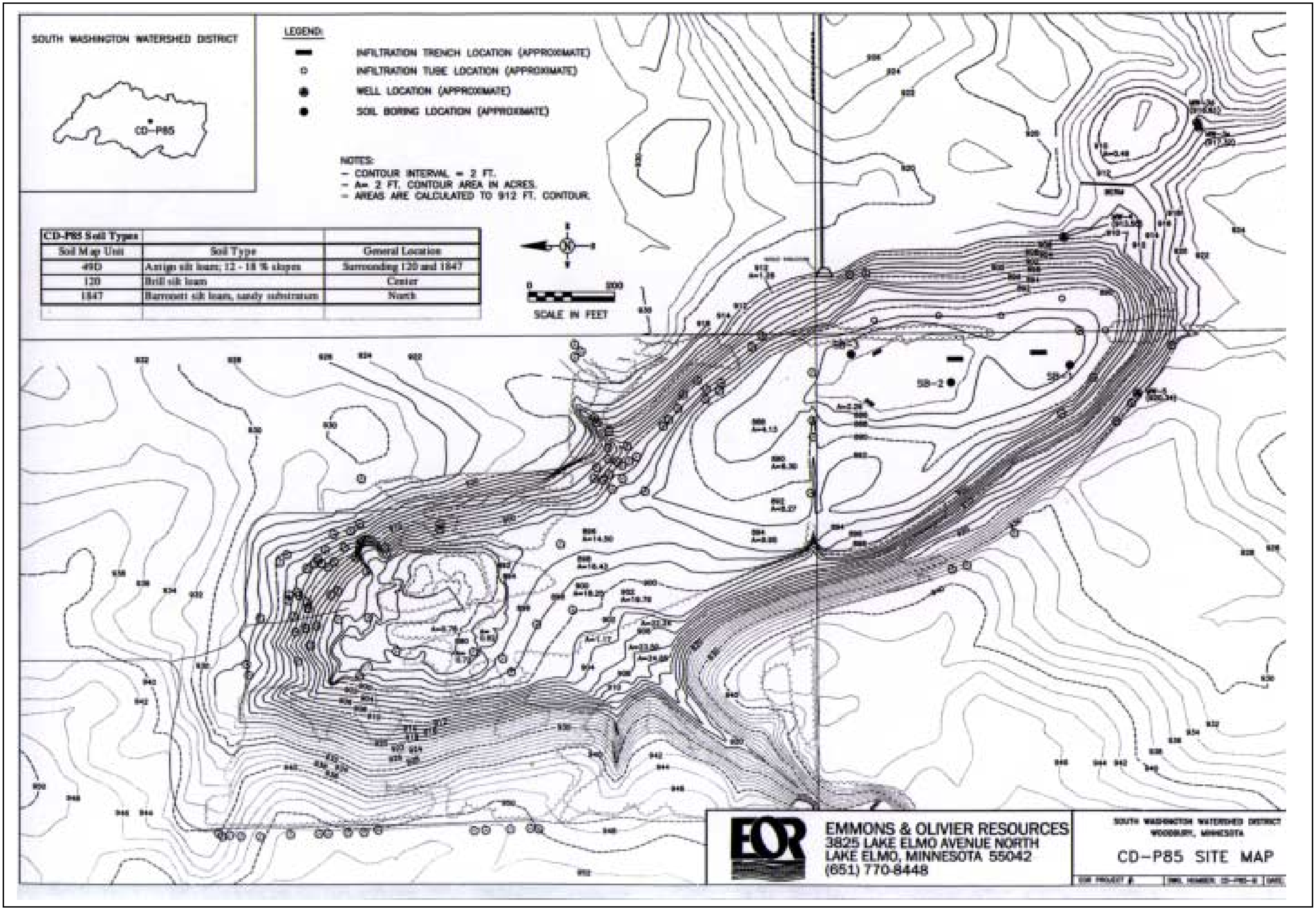
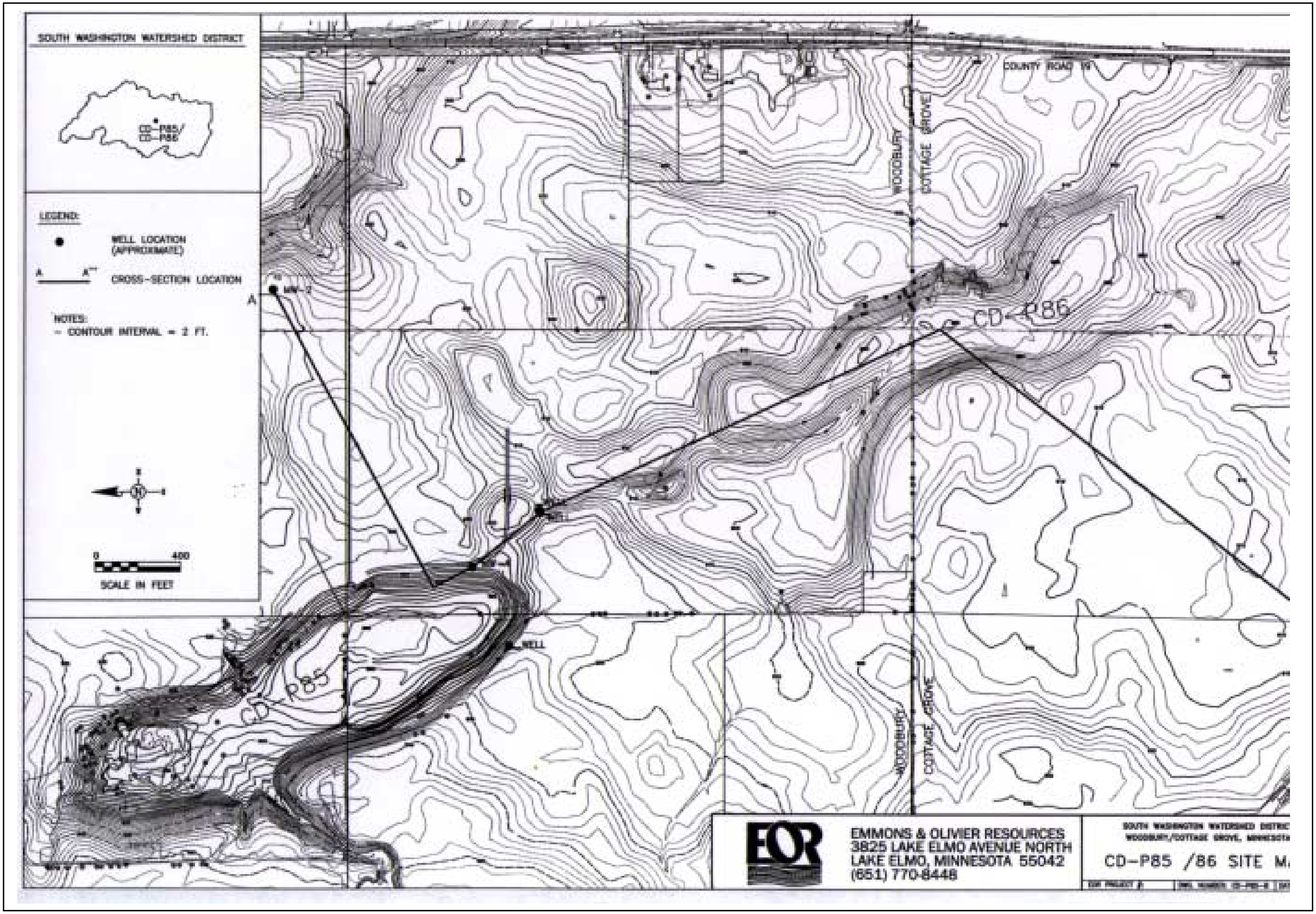
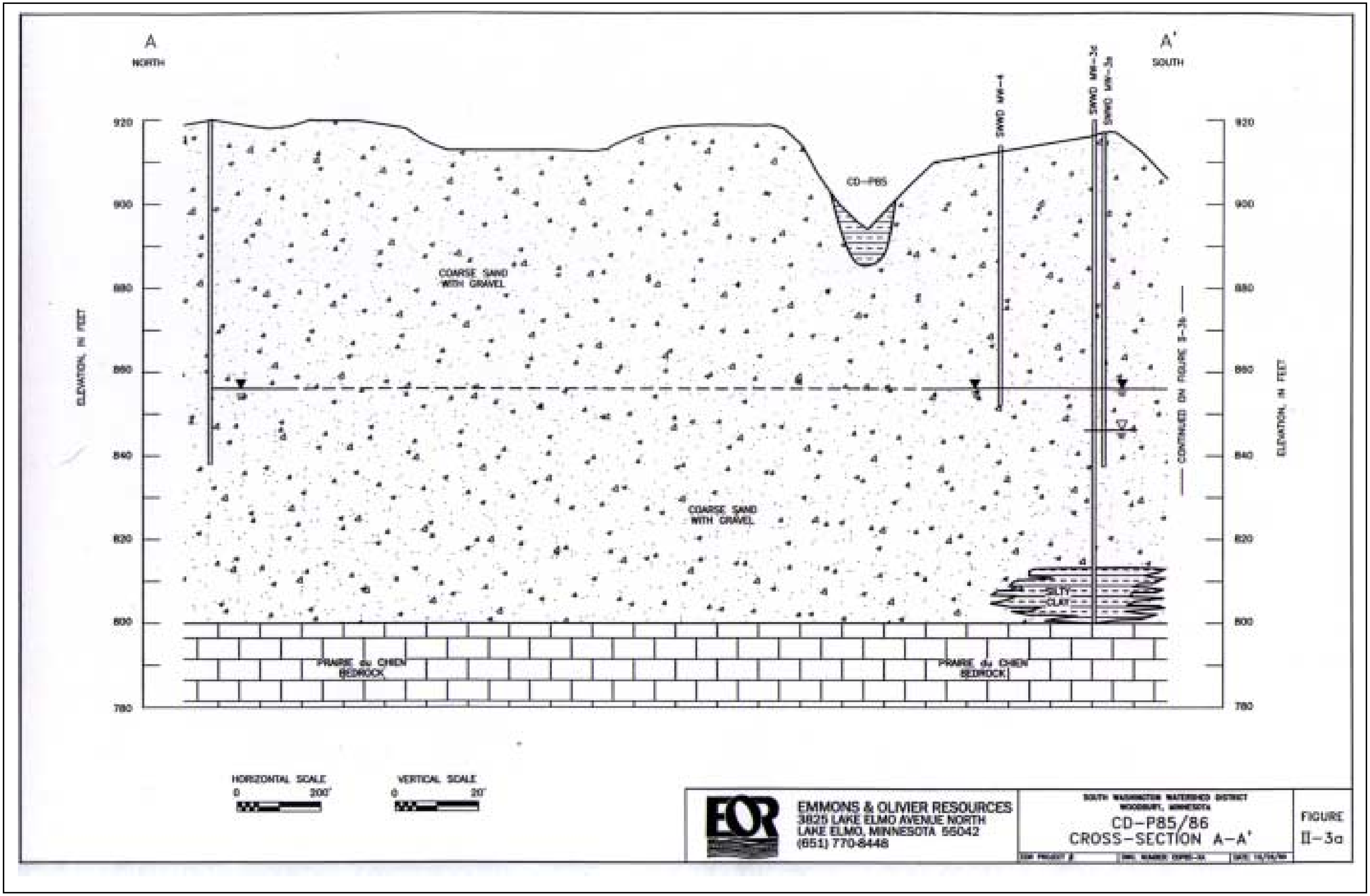

SOUTH WASHINGTON WATERSHED DISTRICT
CD-P85
LEGEND:
INFILTRATION TRENCH LOCATION (APPROXIMATE)
INFILTRATION TUBE LOCATION (APPROXIMATE)
WELL LOCATION (APPROXIMATE)
SOIL BORING LOCATION (APPROXIMATE)
NOTES:
- CONTOUR INTERVAL = 2 FT.
- A= 2 FT. CONTOUR AREA IN ACRES.
- AREAS ARE CALCULATED TO 912 FT. CONTOUR.
CD-P85 Soil Types
Soil Map Unit | Soil Type | General Location
49D | Antigo silt loam; 12 - 18 % slopes | Surrounding 120 and 1847
120 | Brill silt loam | Center
1847 | Barronett silt loam, sandy substratum | North
SCALE IN FEET
SB-1
SB-2
SB-3
EMMONS & OLIVIER RESOURCES
3825 LAKE ELMO AVENUE NORTH
LAKE ELMO, MINNESOTA 55042
(651) 770-8448
SOUTH WASHINGTON WATERSHED DISTRICT
WOODBURY, MINNESOTA
CD-P85 SITE MAP

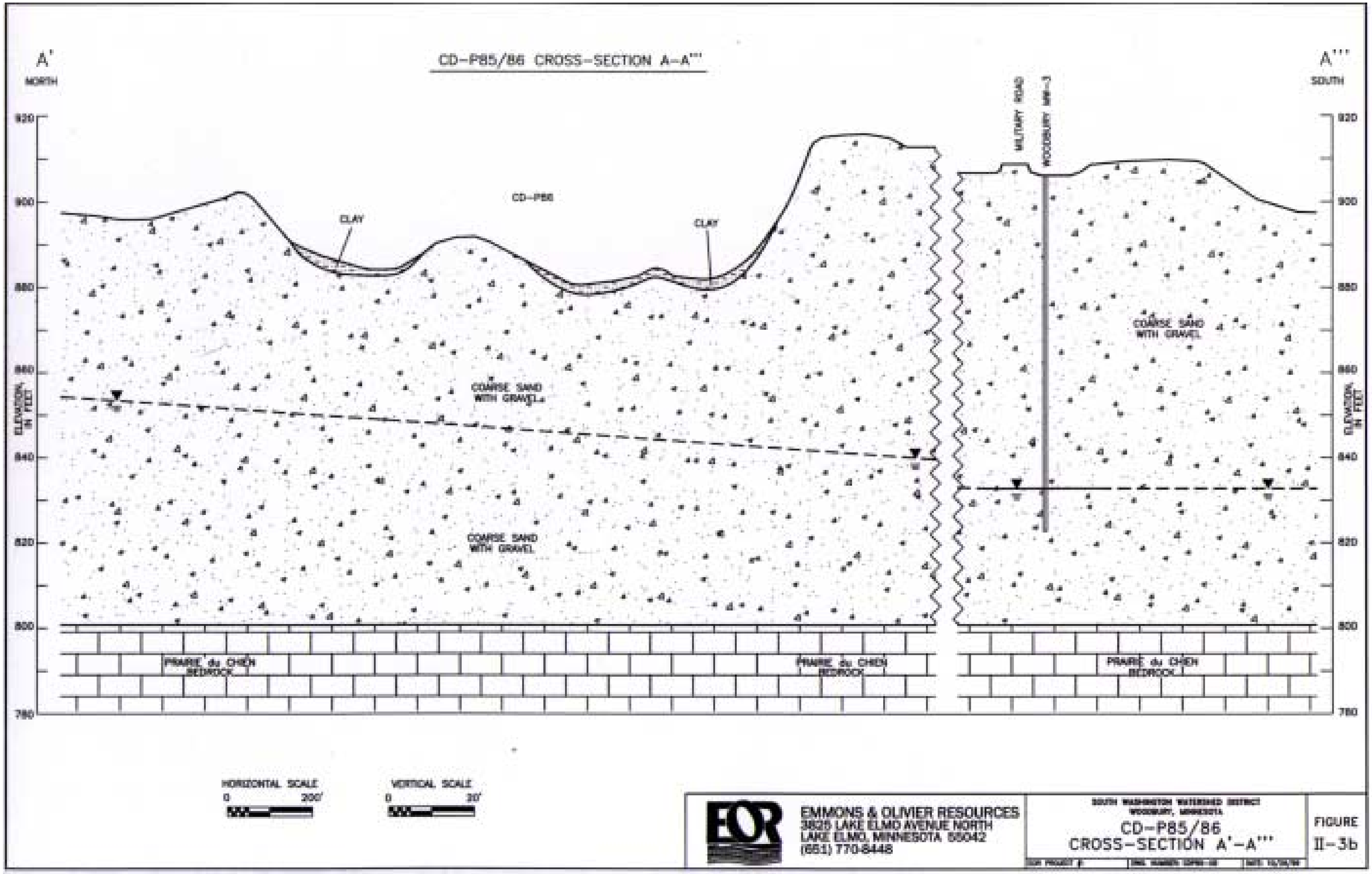
Table II-1. Stage-Storage at CD-P85

Elevation (ft)	Area (ft^2)	Area (Acres)	Storage (ft^3)	Storage (acre-feet)
886	98,446	2.26	98,446	2.26
888	179,903	4.13	376,794	8.65
890	308,405	7.08	865,102	19.86
892	456,944	10.49	1,630,451	37.43
894	552,776	12.69	2,640,172	60.61
896	631,620	14.5	3,824,568	87.80
898	715,691	16.43	5,171,879	118.73
900	794,970	18.25	6,682,540	153.41
902	862,052	19.79	8,339,562	191.45
904	913,018	20.96	10,114,632	232.20
906	968,774	22.24	11,996,424	275.40
908	1,023,660	23.5	13,988,858	321.14
910	1,095,098	25.14	16,107,617	369.78
912	1,163,923	26.72	18,366,638	421.64
914	1,398,711	32.11	20,929,273	480.47
916	1,633,500	37.5	24,299,946	557.85

Figure II-2b illustrates CD-P86, the downstream basin to CD-P85. Figure II-3a and II-3b illustrate the topography and subsurface geology at CD-P85 and CD-P86, respectively. These cross sections were developed from soil borings that were done on site and soil logs for wells installed by the City of Woodbury. The soils of this basin consist of Antigo and Brill silt loams. Well logs are located in Appendix A. Well logs indicate a groundwater gradient to the southeast. The substrate consists of predominantly sand with interspersed gravel lenses. There is a clay layer varying from 3-10 feet thick of glacial origin underlying the lowermost portion of CD-P85, but not extending out under the side slope areas of the basin. The clay layer lies between the topsoil and the underlying glacial outwash. One possible origination of this clay layer is from the meltwater of a large glacial ice block that formed the depression we now call CD-P85. There are also thin, discontinuous layers of clay that occur within this region.


SOUTH WASHINGTON WATERSHED DISTRICT
CD-P85/
CD-P86
LEGEND:
WELL LOCATION
(APPROXIMATE)
CROSS-SECTION LOCATION
NOTES:
- CONTOUR INTERVAL = 2 FT.
SCALE IN FEET
0
400
COUNTY ROAD 19
WOODBURY
COTTAGE GROVE
CD-P86
CD-P85
WELL
A
EMMONS & OLIVIER RESOURCES
3825 LAKE ELMO AVENUE NORTH
LAKE ELMO, MINNESOTA 55042
(651) 770-8448
CD-P85 /86 SITE M


A
NORTH
A'
SOUTH
SWWD MW-4
SWWD MW-3d
SWWD MW-3s
CD-P85
COARSE SAND WITH GRAVEL
COARSE SAND WITH GRAVEL
SILTY CLAY
PRAIRE du CHIEN BEDROCK
PRAIRE du CHIEN BEDROCK
ELEVATION, IN FEET
CONTINUED ON FIGURE II-3b
920
900
880
860
840
820
800
780
HORIZONTAL SCALE 0 200'
VERTICAL SCALE 0 20'
EMMONS & OLIVIER RESOURCES
3825 LAKE ELMO AVENUE NORTH
LAKE ELMO, MINNESOTA 55042
(651) 770-8448
SOUTH WASHINGTON WATERSHED DISTRICT
WOODBURY, MINNESOTA
CD-P85/86
CROSS-SECTION A-A'
FIGURE
II-3a



CD-P85/86 CROSS-SECTION A-A'''
A'
NORTH
A'''
SOUTH
MILITARY ROAD
WOODBURY MW-3
CD-P86
CLAY
CLAY
COARSE SAND WITH GRAVEL
COARSE SAND WITH GRAVEL
COARSE SAND WITH GRAVEL
PRAIRIE du CHIEN BEDROCK
PRAIRIE du CHIEN BEDROCK
PRAIRIE du CHIEN BEDROCK
ELEVATION, IN FEET
920
900
880
860
840
820
800
780
HORIZONTAL SCALE 0 200'
VERTICAL SCALE 0 20'
EMMONS & OLIVIER RESOURCES
3825 LAKE ELMO AVENUE NORTH
LAKE ELMO, MINNESOTA 55042
(651) 770-8448
SOUTH WASHINGTON WATERSHED DISTRICT
WOODBURY, MINNESOTA
CD-P85/86
CROSS-SECTION A'-A'''
FIGURE
II-3b

Water Quality

CD-P85 surface and groundwater has been sampled for water quality consistently by both the SWWD and the City of Woodbury for the past several years. The watershed began taking grab samples from the surface waters of South Bailey Lake and CD-P85 in 1997 to characterize the quality of water entering the ground through infiltration. The watershed has since begun sampling for groundwater quality at CD-P85. Surface water results for 1997 are presented and discussed in the Phase I Report. The City of Woodbury has also been sampling South Bailey Lake and groundwater surrounding CD-P85 since 1993.

Groundwater Quality

Groundwater has been sampled by the SWWD four times during 1998 and 1999. The first sampling round took place in December of 1998 after four new wells were installed downstream of CD-P85. Sampling on December 14, 1998 involved analysis for volatile organic compounds (vocs) and semi-volatile organic compounds (Semi-vocs) only. Results indicated the presence of several phthalates, vocs, in the groundwater. Washington County as well as the Minnesota Department of Health recommended that these wells be sampled a minimum of semi-annually.

The second round of sampling occurred in March of 1999 as part of the Watershed Groundwater Monitoring and Protection Program. This round sampled for all of the parameters listed in the methodology. Lead, manganese, and nickel were found at levels exceeding the MDH recommended limits. The metal contents are for total metals in the sample. During the second sampling event in April 1999, the voc and semi-voc compounds found during the first sampling event were not present, although there were detectable amounts of n-butyl benzene in both wells.

The third sampling event took place during the pumping and infiltration event in August 1999. Again, metals were detected above the MDH recommended limits. These samples were also analyzed for total metal content. Toluene was detected in the surface water; there were no other detectable vocs or semi-vocs in either the surface or groundwaters.

The fourth sampling round took place on November 2, 1999 as part of the Groundwater Monitoring and Protection Program. These sampled were filtered in the field and therefore analyzed for dissolved metal content. All of the parameters were found to be below MDH recommended concentrations.

Results of future sampling events will be examined to determine whether detected compounds initially sampled persist over time in the groundwater system. The results from the CD-P85 groundwater sampling are presented in Table II-2.

Table II-2. Groundwater Quality Results at CD-P85

Analyte	MDH HRL	3s 12/14/98**	3s 4/6/99	3s 11/2/99	3d 12/14/98**	3d 4/6/99	3d 11/2/99	4- 8/14/99
Cadmium (mg/L)	0.004	n/a	BDL	BDL	n/a	BDL	BDL	BDL
Lead (mg/L)	0.015	n/a	0.073	BDL	n/a	0.041	BDL	0.015
Manganese (mg/L)	0.1	n/a	6.3	BDL	n/a	0.9	0.039	0.172
Nickel (mg/L)	0.1	n/a	0.252	BDL	n/a	0.038	BDL	BDL
TKN (mg/L)	-	n/a	0.52	0.17	n/a	0.29	0.19	1.1
Ammonia:N (mg/L)	-	n/a	BDL	BDL	n/a	BDL	BDL	0.42
Chloride (mg/L)	250*	n/a	26.7	25.2	n/a	27.3	25.9	18.4
Hardness (mg/L)		n/a	n/a	229	n/a	n/a	206	n/a
Nitrate-Nitrite:N (mg/L)	10	n/a	BDL	BDL	n/a	0.79	1.38	2.9
Vocs Detects (u/L)								
n-Butyl Benzene	-	BDL	1.33	n/a	BDL	1.32	n/a	BDL
Semi-vocs Detects (u/L)								
Di-n-octylphthalate	-	0.9	BDL	n/a	1.1	BDL	n/a	BDL
Phenol	4000	BDL	BDL	n/a	3.9	BDL	n/a	BDL
Diethylphthalate	6000	BDL	BDL	n/a	1.9	BDL	n/a	BDL
Di-n-butylphthalate	700	BDL	BDL	n/a	7.8	BDL	n/a	BDL
Butylbenzylphthalate	100	BDL	BDL	n/a	0.6	BDL	n/a	BDL
bis(2-Ethylhexyl) phthalate	-	BDL	BDL	n/a	9.3	BDL	n/a	BDL
Naphthalene	300	BDL	1.19	n/a		BDL	n/a	
pH	6.5-8.5*	7.7	8.2	7.6	8.3	8.2	7.6	n/a
Salinity (ppt)		n/a	0	n/a	n/a	0.2	n/a	n/a
Redox (mv)		n/a	n/a	-62.2	n/a	n/a	-58.3	n/a
Conductivity (us)		n/a	0	356	n/a	378.8	358.0	n/a
Temp I		n/a	18.5	14.1	n/a	15.5	12.2	n/a
DO (%)		n/a	8.4	6.7	n/a	8.7	3.8	n/a

* EPA Secondary Standards – not enforceable MDH – Minnesota Department of Health
**The sample dated December 14, 1998 was analyzed by Spectrum Labs, New Brighton
n/a – Not applicable, was not analyzed for this parameter BDL – Below detection level

Surface Water Quality

Surface water quality has been frequently sampled at this basin. Results prior to September 1998 can be found in the Phase I Report. Results indicated concentrations below the standards for Class 2B waters for most analytes. Ammonia nitrogen was found at concentrations exceeding the MPCA standards for class 2B waters, but this concentrations does not exceed the drinking water standard for groundwater. Table II-3 summarizes the surface-water sampling results for CD-P85 and South Bailey Lake.

Table II-3. Surface Water Quality Results at CD-P85

Analyte	MPCA Class 2B Waters*	CD-P85 7/17/98	Surface 7/20/98	Waters 7/28/98	CD-P85 South Basin 9/22/98	CD-P85 North Basin 9/22/98	South Bailey Lake 7/28/98	CD-P85 South Trench 8/14/99
Cadmium (mg/L)	0.66	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Lead (mg/L)	1.3	BDL	BDL	BDL	BDL	BDL	BDL	0.006
Copper (mg/L)	6.4	BDL	BDL	BDL	BDL	BDL	BDL	n/a
Manganese (mg/L)	-	n/a	n/a	n/a	n/a	n/a	n/a	1.44
Nickel (mg/L)	88.0	n/a	n/a	n/a	n/a	n/a	n/a	BDL
Zinc (mg/L)	59.0	BDL	BDL	BDL	BDL	BDL	BDL	n/a
TKN (mg/L)	-	3.1	4.9	6.7	3.4	4.2	3.2	4.1
Ammonia:N (mg/L)	0.016	BDL	BDL	BDL	BDL	0.09	BDL	1.21
Chloride (mg/L)	230	25	28	25	25	27	26	26.9
Hardness (CaCO3)	-	62	93	67	69	92	68	n/a
Total Phosphorus (mg/L)	-	0.14	0.26	0.17	0.46	0.28	0.22	n/a
Nitrate+Nitrite (mg/L)	-	n/a	n/a	n/a	n/a	n/a	n/a	0.5
Nitrate Nitrogen (mg/L)	-	BDL	BDL	BDL	BDL	BDL	BDL	n/a
Vocs Detects		BDL	n/a	BDL	n/a	n/a	BDL	
Toluene (ug/L)	253							1.55
Semi-vocs Detects		BDL	n/a	BDL	n/a	n/a	BDL	BDL
Total Suspended Solids (ug/L)	-	32	70	90	50	n/a	50	n/a

* The limits for heavy metals assume a hardness value of 50 mg/L
n/a – Not Applicable, was not analyzed for this parameter
BDL – Below Detection Level
TKN – Total Kjeldahl Nitrogen
VOC – Volatile Organic Compound
SVOC – Semi-volatile Organic Compound
North Basin – Small north depression in CD-P85
South Basin – Small south depression in CD-P85

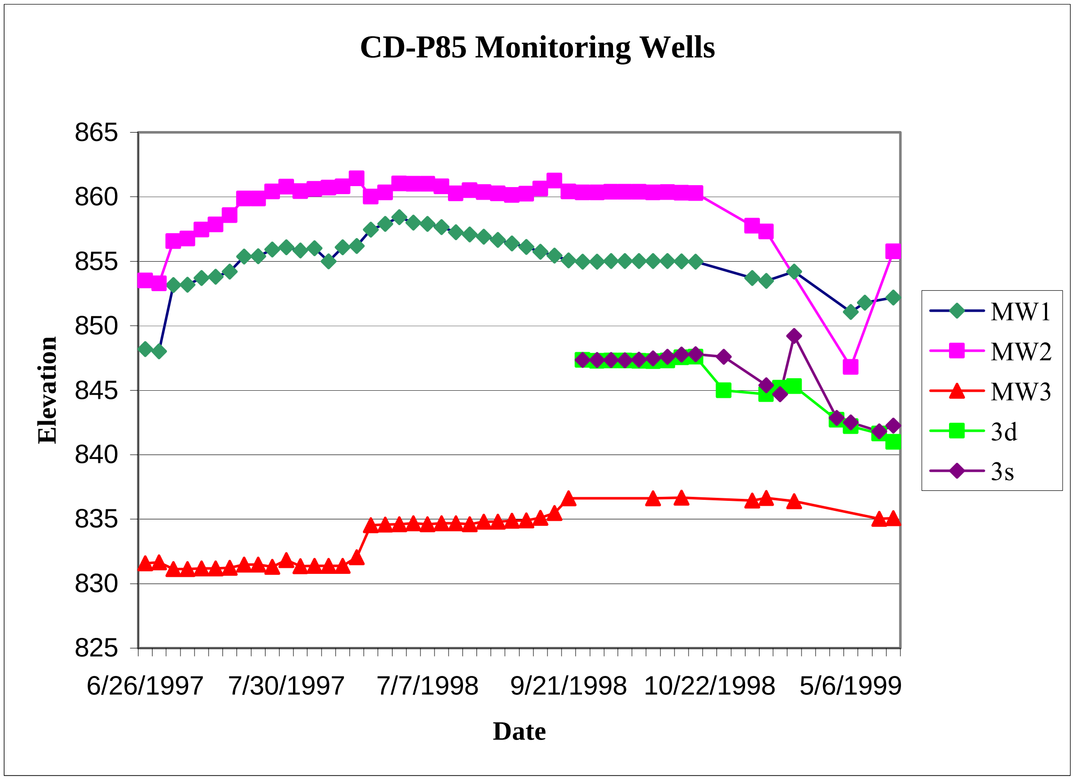
The groundwater samples indicate that three wells at CD-P85 have exceeded the MDH recommended concentrations for several heavy metals. By contrast, the surface water samples had no detectable amounts of the metals. The limited data that includes low surface water concentrations indicates that the addition of the infiltrated surface waters would not negatively impact the groundwater quality for heavy metals, or mobile nutrients, such as nitrates that were analyzed. Chlorides were at about the same concentration for both surface and groundwaters.

The City of Woodbury has a database of water quality information from both the groundwater near CD-P85 and the surface waters of South Bailey Lake. These results are available through the City. Woodbury's 1998 surface and groundwater quality results can be found in Appendix B.

Groundwater Level Monitoring

The SWWD and the City of Woodbury have monitored groundwater levels for the past several years at CD-P85. Four wells were installed by the SWWD at CD-P85 and have been monitored for water levels beginning in the fall of 1998. These wells are identified on Figure II-1 and well logs are located in Appendix A. Figure II-4 illustrates the water table fluctuations at CD-P85. Two of the wells (4 and 5) have remained dry; no data has been generated at these locations.

Figure II-4. Water Table Fluctuations at CD-P85



MW1 – Woodbury Monitoring Well #1
MW2 – Woodbury Monitoring Well #2
MW3 – Woodbury Monitoring Well #3
3d – SWWD deep nested well
3s – SWWD shallow nested well

Water levels have generally decreased since July 1998. Because the subsurface material is granular, consisting of sand and gravel, the transmissivity (rate at which water moves through the substrate) is very high. This allows the water table to recover relatively quickly after significant infiltration events. A discussion of groundwater mounding at CD-P85 is discussed in Section VI – Surface Water – Groundwater Interactions and Modeling.

CD-P82

Landform Information

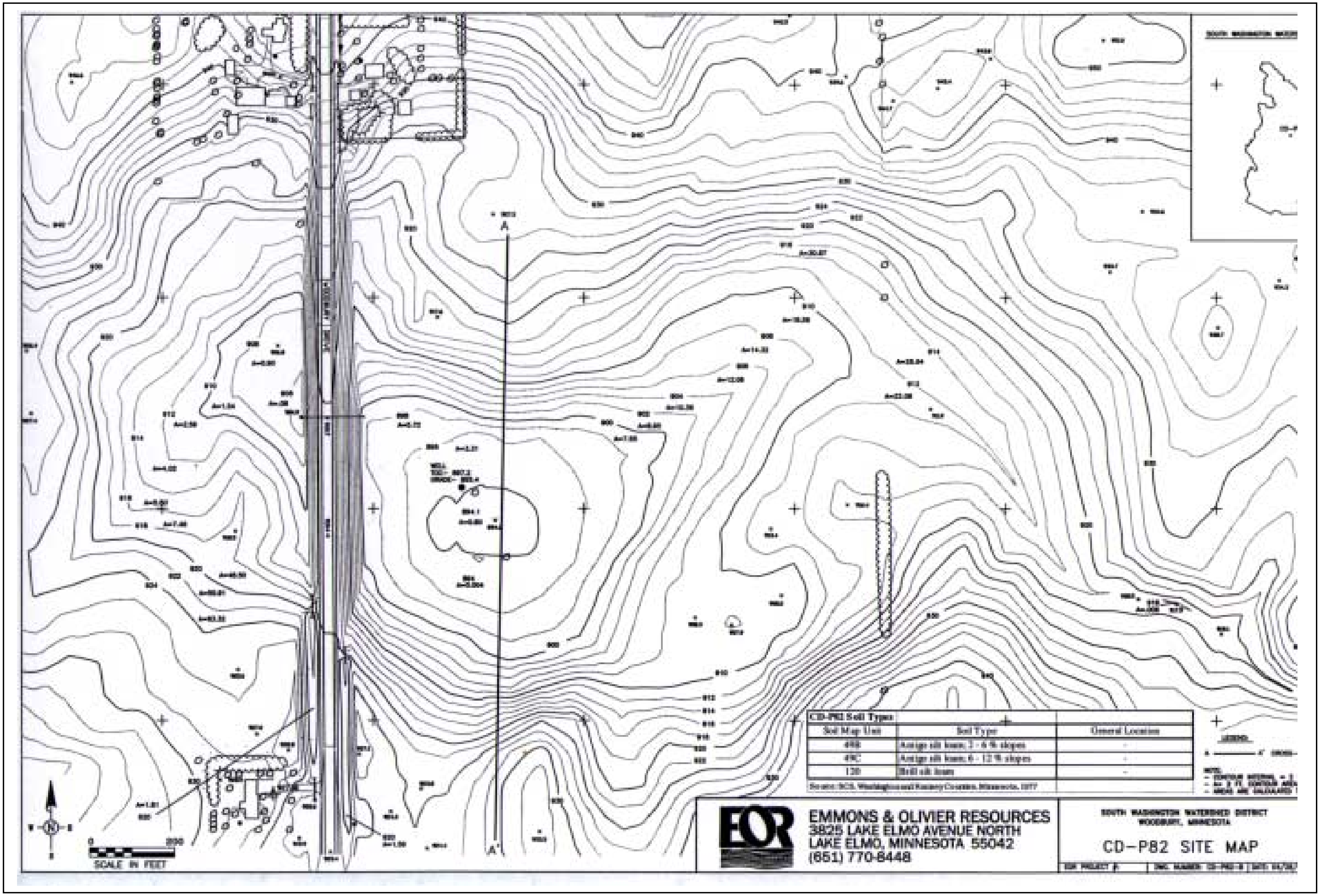
CD-P82 and contour data is illustrated in Figure II-5. CD-P82 is a landlocked, natural depression that has been predominantly farmed in row crops. This basin's natural overflow point is to the west into Bailey Lake at an elevation of approximately 925 feet. There is a total storage capacity of over 715 acre-feet at the overflow elevation. The bottom of the depression includes a small pond that retains perched water.

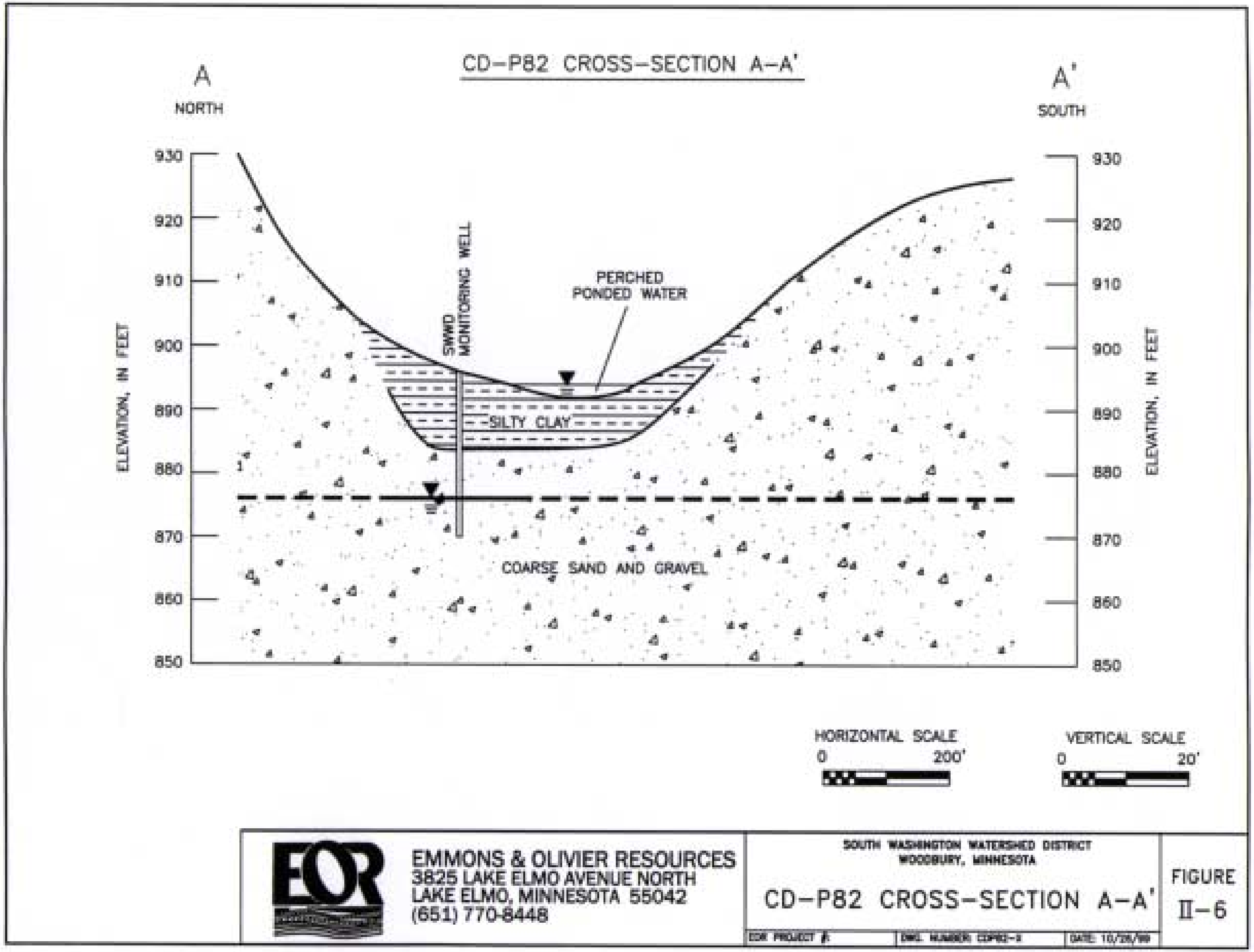
The following Table identifies the stage-storage available in CD-P82.

Table II-4. Stage-storage at CD-P82

Elevation (ft)	Area (ft^2)	Area (Acres)	Storage (ft^3)	Storage (acre-feet)
894	34,848	0.80	34,848	0.80
896	144,184	3.31	213,880	4.91
898	249,163	5.72	607,226	13.94
900	328,878	7.55	1,185,268	27.21
902	389,862	8.95	1,904,008	43.71
904	451,282	10.36	2,745,151	63.02
906	528,818	12.14	3,725,251	85.52
908	662,983	15.22	4,917,053	112.88
910	876,863	20.13	6,456,899	148.23
912	1,074,625	24.67	8,408,387	193.03
914	1,335,550	30.66	10,818,562	248.36
916	1,584,277	36.37	13,738,388	315.39
918	1,835,183	42.13	17,157,848	393.89
920	2,260,764	51.90	21,253,795	487.92
922	2,435,440	55.91	25,949,999	595.73
924	2,758,219	63.32	31,143,657	714.96

The cross-section illustrated in Figure II- 6 depicts sand and gravels with clayey-silty sediments at the surface. The soils consist of Antigo and Brill silt loams.


CD-P82 Soil Types
Soil Map Unit | Soil Type | General Location
49B | Antigo silt loam; 2 - 6 % slopes | -
49C | Antigo silt loam; 6 - 12 % slopes | -
120 | Brill silt loam | -
Source: SCS, Washington and Ramsey Counties, Minnesota, 1977
EMMONS & OLIVIER RESOURCES
3825 LAKE ELMO AVENUE NORTH
LAKE ELMO, MINNESOTA 55042
(651) 770-8448
SOUTH WASHINGTON WATERSHED DISTRICT
WOODBURY, MINNESOTA
CD-P82 SITE MAP
SCALE IN FEET
LEGEND



CD-P82 CROSS-SECTION A-A'
A
NORTH
A'
SOUTH
930
920
910
900
890
880
870
860
850
ELEVATION, IN FEET
SWWD MONITORING WELL
PERCHED
PONDED WATER
SILTY CLAY
COARSE SAND AND GRAVEL
HORIZONTAL SCALE
0
200'
VERTICAL SCALE
0
20'
EMMONS & OLIVIER RESOURCES
3825 LAKE ELMO AVENUE NORTH
LAKE ELMO, MINNESOTA 55042
(651) 770-8448
SOUTH WASHINGTON WATERSHED DISTRICT
WOODBURY, MINNESOTA
CD-P82 CROSS-SECTION A-A'
EOR PROJECT #:
DWG. NUMBER:
DATE:
FIGURE
II-6

Water Quality – Groundwater

The groundwater was sampled once on November 2, 1999 for water quality. Sampling was not possible in the spring due to high water levels. Results indicated levels of nitrate-nitrite above the HRL. Nitrate usually originates from human or animal waste and chemical fertilizers. Nitrate concentrations above the HRL are common in wells throughout Southern Washington County. Washington County Department of Health, Environment, and Land Management (with financial assistance from the SWWD) is currently undertaking a study of nitrates to determine origins and discharge points in Southern Washington County.

Table II-5. Groundwater Quality Results at CD-P82

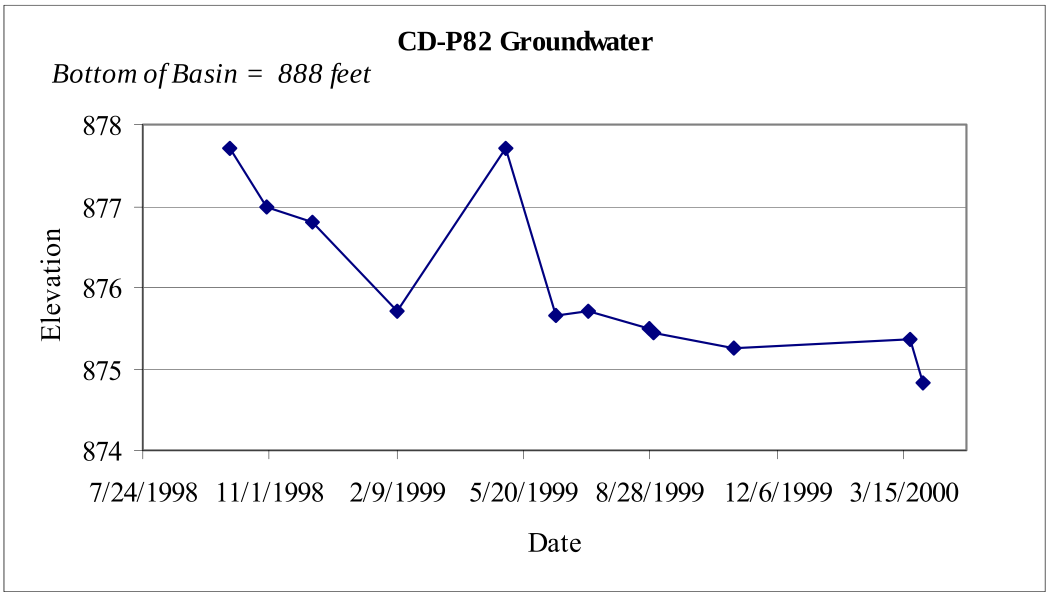
Analyte	MDH HRL	CD-P82 11/2/99
Cadmium (mg/L)	0.004	BDL
Lead (mg/L)	0.015	BDL
Manganese (mg/L)	0.1	BDL
Nickel (mg/L)	0.1	BDL
TKN (mg/L)		14
Ammonia:N (mg/L)		0.23
Chloride (mg/L)	250*	14.9
Hardness (mg/L)		126
Nitrate-Nitrite:N (mg/L)	10	15.4
vocs Detects (ug/L)		n/a
Semi-vocs Detects (ug/L)		n/a
Ph	6.5-8.5*	6.3
Salinity (ppt)		n/a
Redox (mv)		33.8
Conductivity (us)		269
Temp (C)		9.9
DO (%)		6.5

* Secondary Standards (EPA – not enforceable)
BDL – Below Detection Level
n/a – Not Applicable, was not analyzed for this parameter
TKN – Total Kjeldahl Nitrogen
VOC – Volatile Organic Compound
SVOC – Semi-volatile Organic Compound

Groundwater Level Monitoring

Groundwater levels have varied over the past year. Figure II-7 illustrates the approximate hydrograph for groundwater at CD-P82. The groundwater high occurred during the spring of 1999 and was attributable to the water in the basin and general infiltration in the area. The water table has consistently remained between 18 and 21 feet below the basin.

Figure II-7. Water Table Fluctuations at CD-P82



CD-P76

Landform Information

CD-P76 is a natural depression and is illustrated with contour data in Figure II-8. This basin is farmed. Visual field observations over the last three years indicate that there is standing water in the basin during the spring snowmelt and that this water typically infiltrates within a week. During the remainder of the year, standing water in the basin was not observed for more than two days occurring after large rainfall events. There is a natural ravine to the west that delivers most of the drainage to the basin. The overflow is to the northeast toward Bailey Lake. The overflow elevation occurs at approximately 935 feet. The natural configuration allows for approximately

72 acre-feet of storage at the overflow elevation. Table II-6 identifies the stage-storage relationship for CD-P76.

Table II-6. Stage-storage at CD-P76

Elevation (ft)	Area (ft^2)	Area (Acres)	Storage (ft^3)	Storage (acre-feet)
928	133,294	3.06	133,294	3.06
930	305,791	7.02	572,378	13.14
932	466,528	10.71	1,344,697	30.87
934	612,454	14.06	2,423,678	55.64
936	821,977	18.87	3,858,109	88.57

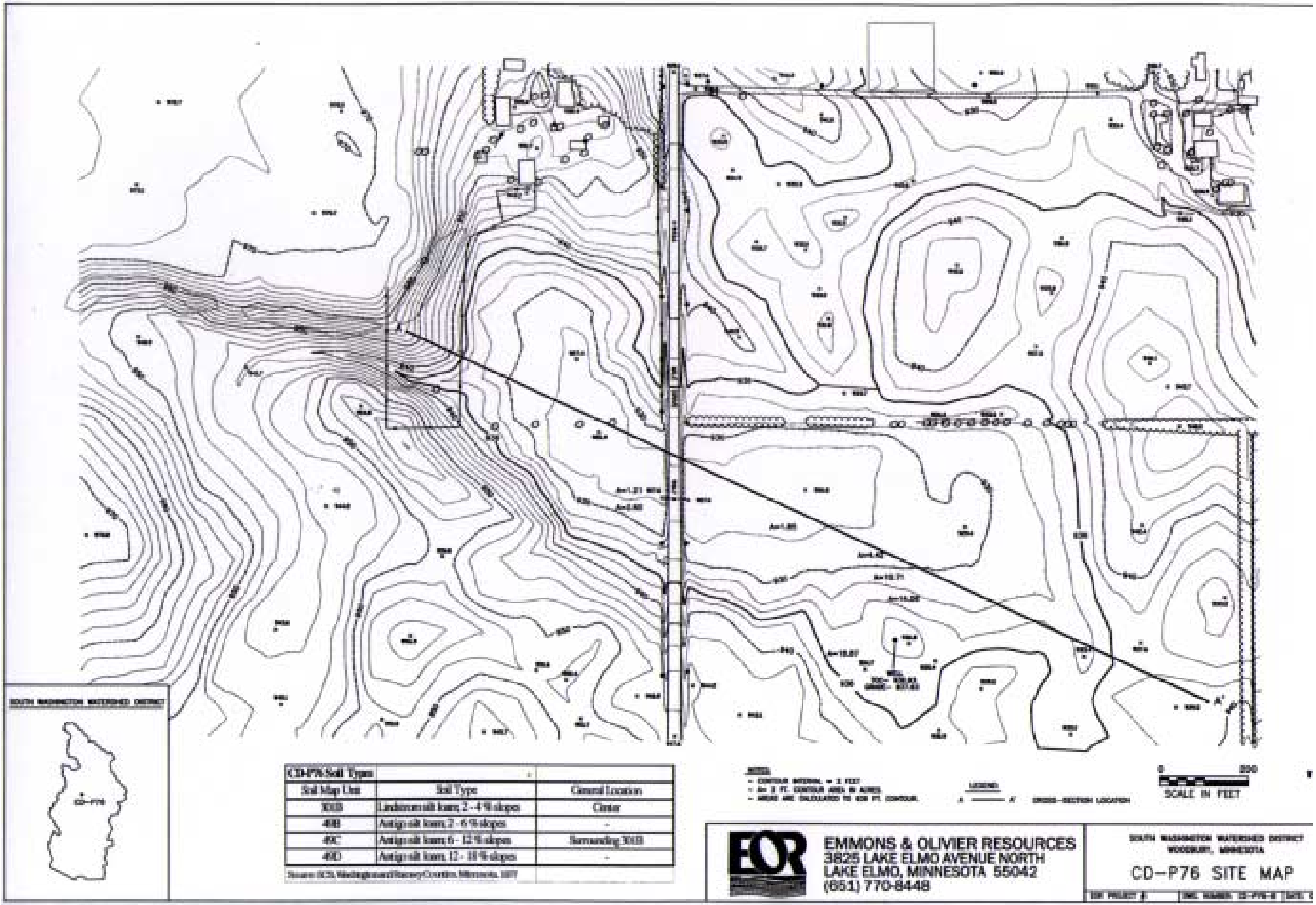
The cross section in Figure II-9 identifies sand and gravel deposits with small interspersed clay lenses down to the bedrock. The water table gradient is to the southeast. Soils consist of Lindstrom and Antigo silt loams.

Water Quality – Groundwater

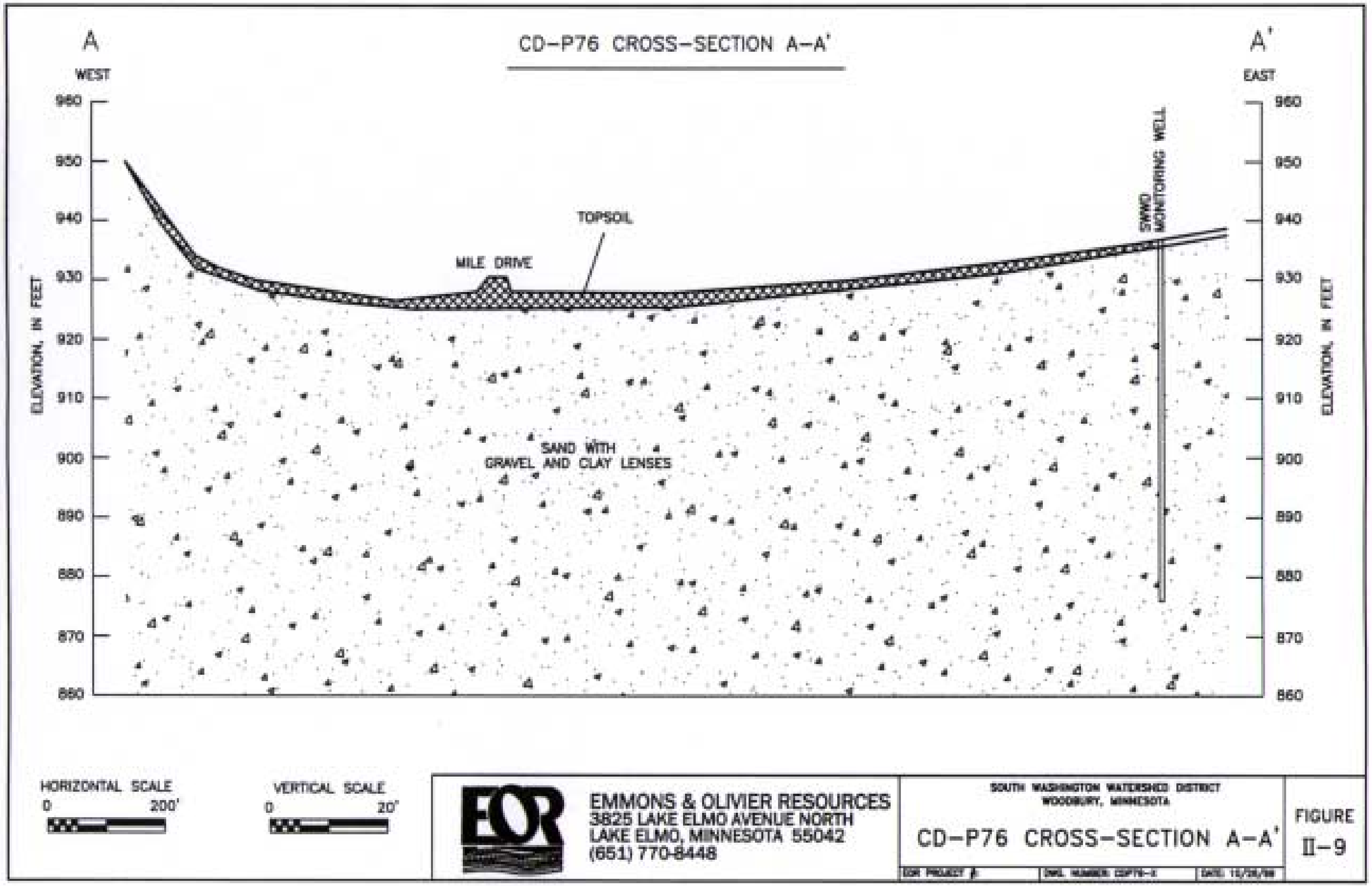
The well at this basin has not contained any measurable amount of water throughout the year. The spring event did not provide sufficient rise in the water table to collect a sample.

Groundwater Level Monitoring

The monitoring well at CD-P76 has remained dry since installation. There was no measurable change in groundwater elevations at the monitoring well throughout the year. Based on the monitoring well, the water table is consistently greater than 40 feet below the surface in the lowest portion of the basin.



CD-P76 Soil Types		
Soil Map Unit	Soil Type	General Location
301B	Lindstrom silt loam, 2 - 4 % slopes	Center
40B	Antigo silt loam, 2 - 6 % slopes	-
40C	Antigo silt loam, 6 - 12 % slopes	Surrounding 301B
40D	Antigo silt loam, 12 - 18 % slopes	-
Source: SCS, Washington and Ramsey Counties, Minnesota. 1977		



CD-P76 CROSS-SECTION A-A'
A
WEST
A'
EAST
ELEVATION, IN FEET
960
950
940
930
920
910
900
890
880
870
860
TOPSOIL
MILE DRIVE
SWWD MONITORING WELL
SAND WITH GRAVEL AND CLAY LENSES
HORIZONTAL SCALE
0
200'
VERTICAL SCALE
0
20'
EMMONS & OLIVIER RESOURCES
3825 LAKE ELMO AVENUE NORTH
LAKE ELMO, MINNESOTA 55042
(651) 770-8448
SOUTH WASHINGTON WATERSHED DISTRICT
WOODBURY, MINNESOTA
CD-P76 CROSS-SECTION A-A'
FIGURE
II-9

CD-P50

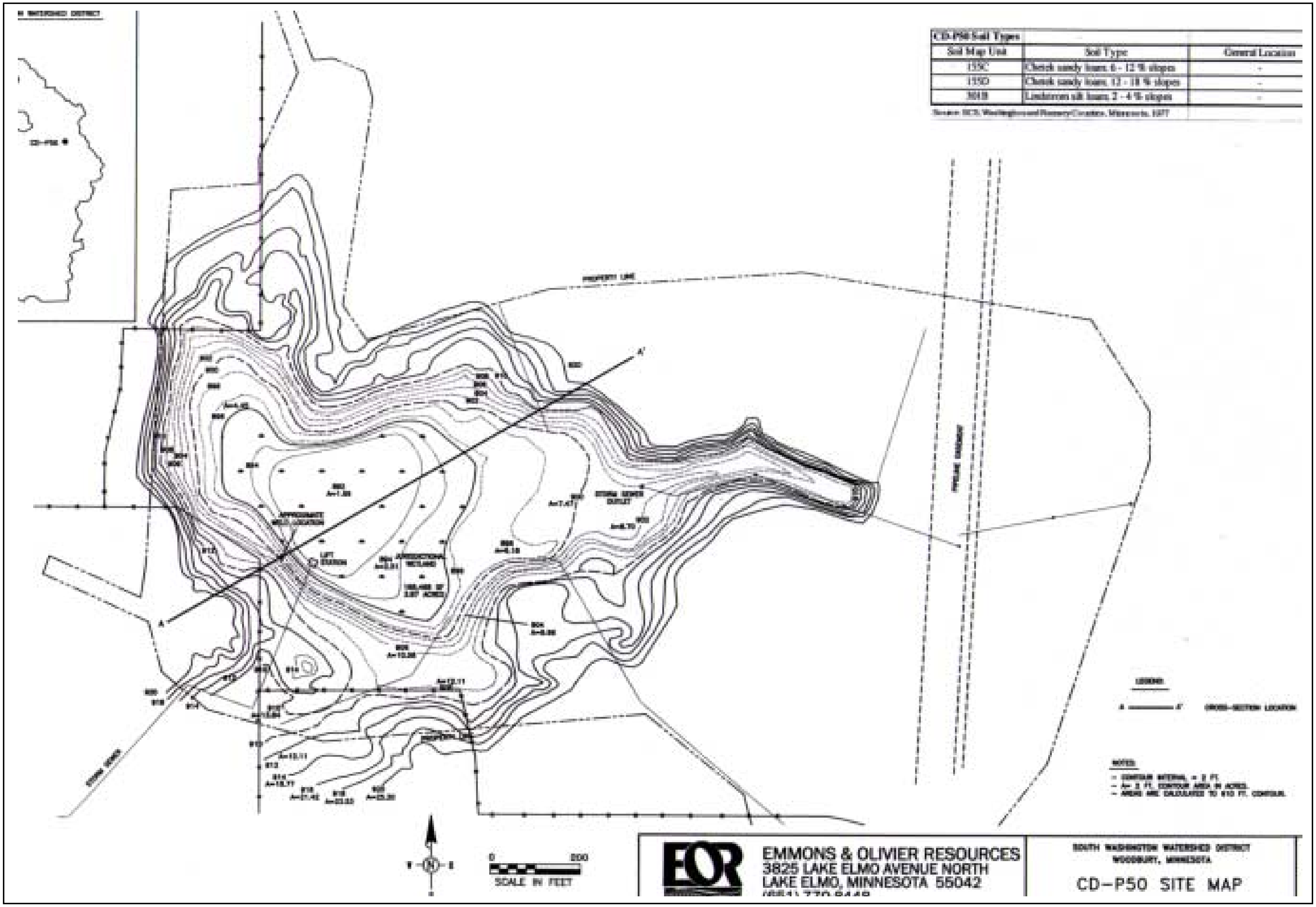
Landform Information

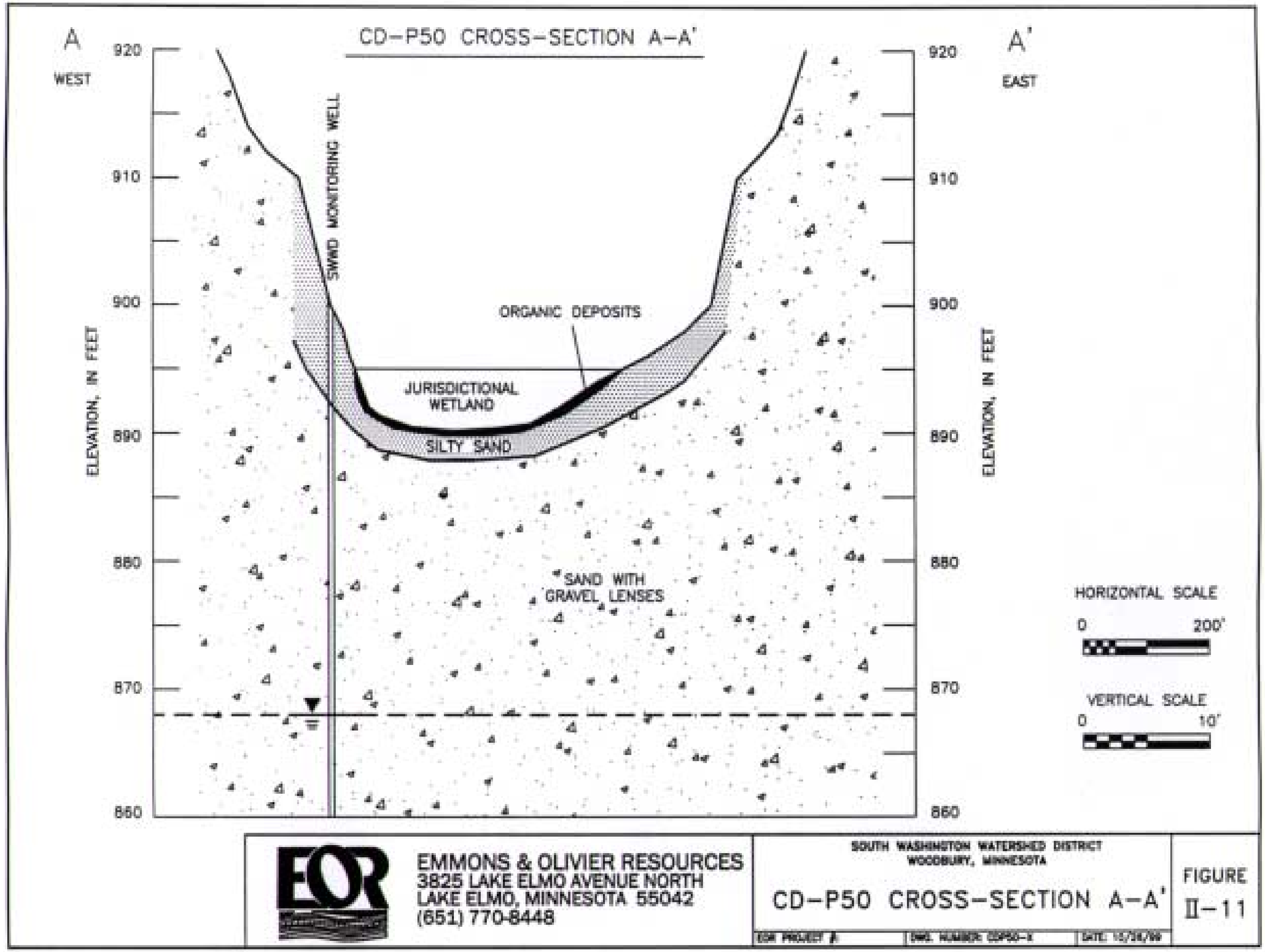
CD-P50 is located within the Eagle Valley Golf Course and is owned by the City of Woodbury. Figure II-10 illustrates the current topography of this basin. The topography was obtained from the grading plans for the golf course through the City of Woodbury and was checked through field surveying. This basin receives the direct drainage from a municipal golf course and local residential developments and will in the future serve much of the areas developed east of Cottage Grove Drive. The basin is planned to be outleted by a lift station. The lowest portion of this basin, generally within the 896 contour, is a jurisdictional wetland as well as a DNR protected wetland. This means that this portion of the basin has hydric soils and contains saturated soils or standing water for longer duration, typically more than two weeks each year during the growing season. The natural overflow is to the south at approximately 912 feet with a corresponding storage of 170.5 acre-feet. The total storage volume available at this basin is illustrated in Table II-7.

Table II-7. Stage-storage at CD-P50

Elevation (ft)	Area (ft^2)	Area (Acres)	Storage (ft^3)	Storage (acre-feet)
892	73,616	1.69	73,616	1.69
894	109,336	2.51	256,568	5.89
896	193,842	4.45	559,746	12.85
898	269,201	6.18	1,022,789	23.48
900	325,393	7.47	1,617,383	37.13
902	378,972	8.70	2,321,748	53.30
904	420,790	9.66	3,121,510	71.66
906	460,865	10.58	4,003,164	91.90
908	527,512	12.11	4,991,540	114.59
910	602,870	13.84	6,121,922	140.54
912	701,752	16.11	7,426,544	170.49

Figure II-11 illustrates the subsurface stratigraphy. The stratigraphy consists of silty deposits at the surface, underlain by sand and gravel. Soils consist of Chetek sandy loam and Lindstrom silt loam.


CD-P50 Soil Types
Soil Map Unit
Soil Type
General Location
155C
Chetek sandy loam 6 - 12 % slopes
155D
Chetek sandy loam 12 - 18 % slopes
301B
Lindstrom silt loam 2 - 4 % slopes
PROPERTY LINE
STORM SEWER
SCALE IN FEET
0
200
EMMONS & OLIVIER RESOURCES
3825 LAKE ELMO AVENUE NORTH
LAKE ELMO, MINNESOTA 55042
SOUTH WASHINGTON WATERSHED DISTRICT
WOODBURY, MINNESOTA
CD-P50 SITE MAP



CD-P50 CROSS-SECTION A-A'
A
WEST
A'
EAST
920
910
900
890
880
870
860
ELEVATION, IN FEET
SWWD MONITORING WELL
ORGANIC DEPOSITS
JURISDICTIONAL WETLAND
SILTY SAND
SAND WITH GRAVEL LENSES
HORIZONTAL SCALE
0
200'
VERTICAL SCALE
0
10'
EMMONS & OLIVIER RESOURCES
3825 LAKE ELMO AVENUE NORTH
LAKE ELMO, MINNESOTA 55042
(651) 770-8448
SOUTH WASHINGTON WATERSHED DISTRICT
WOODBURY, MINNESOTA
CD-P50 CROSS-SECTION A-A'
FIGURE
II-11

Water Quality – Groundwater

The groundwater at CD-P50 was sampled twice in 1999. Table II-8 illustrates these results. Results from the first sampling round indicated levels of manganese, nickel, and lead above HRLs. The second sampling round was analyzed for dissolved metals only. There were no concentrations above the HRL for any analyte. The decrease in metal concentrations between the March and November sampling events suggest that the metals are not dissolved in groundwater and will not be transported away from the basin.

Table II-8. Groundwater Quality Results at CD-P50

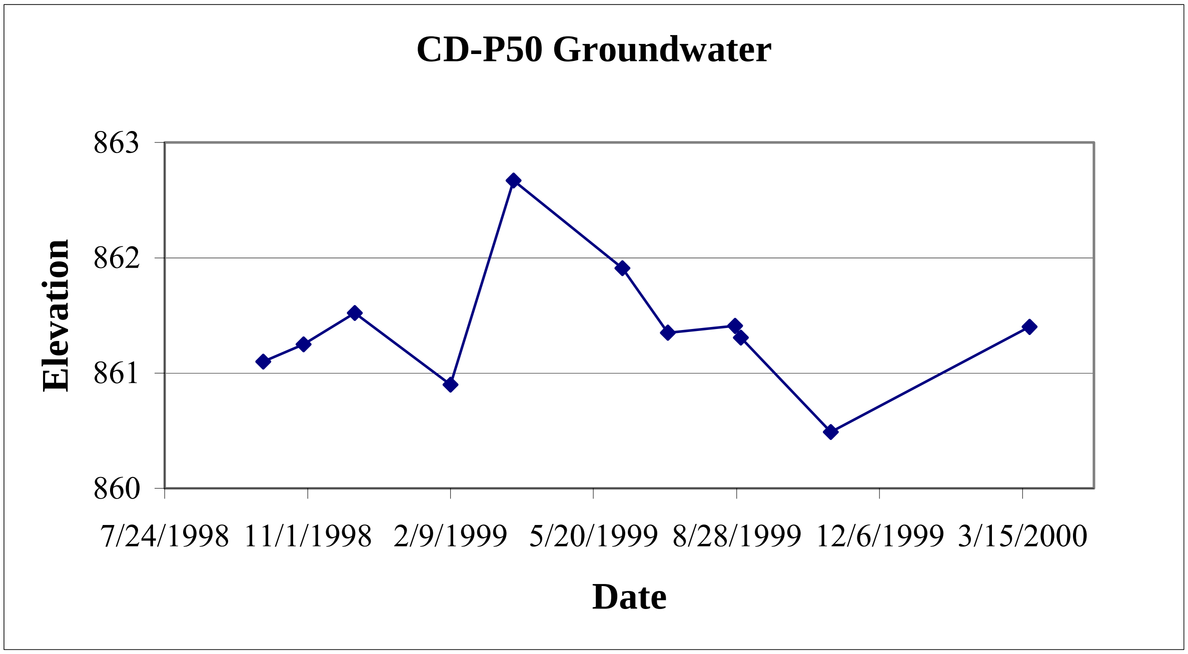
Analyte	MDH HRL	3/25/99	11/2/99
Cadmium (mg/L)	0.004	BDL	BDL
Lead (mg/L)	0.015	0.07	BDL
Manganese (mg/L)	0.1	6.25	0.08
Nickel (mg/L)	0.1	0.115	BDL
TKN (mg/L)		BDL	1.5
Ammonia:N (mg/L)		0.3	BDL
Chloride (mg/L)	250*	3.34	5.51
Hardness (mg/L)			75.6
Nitrate-Nitrite:N (mg/L)	10	3.94	3.77
Vocs Detects (ug/L)		BDL	n/a
Semi-vocs Detects (ug/L)		BDL	n/a
Ph	6.5-8.5*	6.8	6.4
Salinity (ppt)		0.1	n/a
Redox (mv)		n/a	31.0
Conductivity (us)		120	183.0
Temp (C)		9.4	9.8
DO (%)		0.31	4.4

* Secondary Standards (EPA – not enforceable)
BDL – Below Detection Level
n/a – Not Applicable, was not analyzed for this parameter
TKN – Total Kjeldahl Nitrogen
VOC – Volatile Organic Compound
SVOC – Semi-volatile Organic Compound

Groundwater Level Monitoring

The water table fluctuates with the presence and absence of water in the basin. Figure II-12 illustrates the fluctuations in water table elevations at CD-P50. Water levels varied from 27 to 31 feet below the surface of the basin.

Figure II-12. Water Table Fluctuations at CD-P50



CD-P69

Landform Information

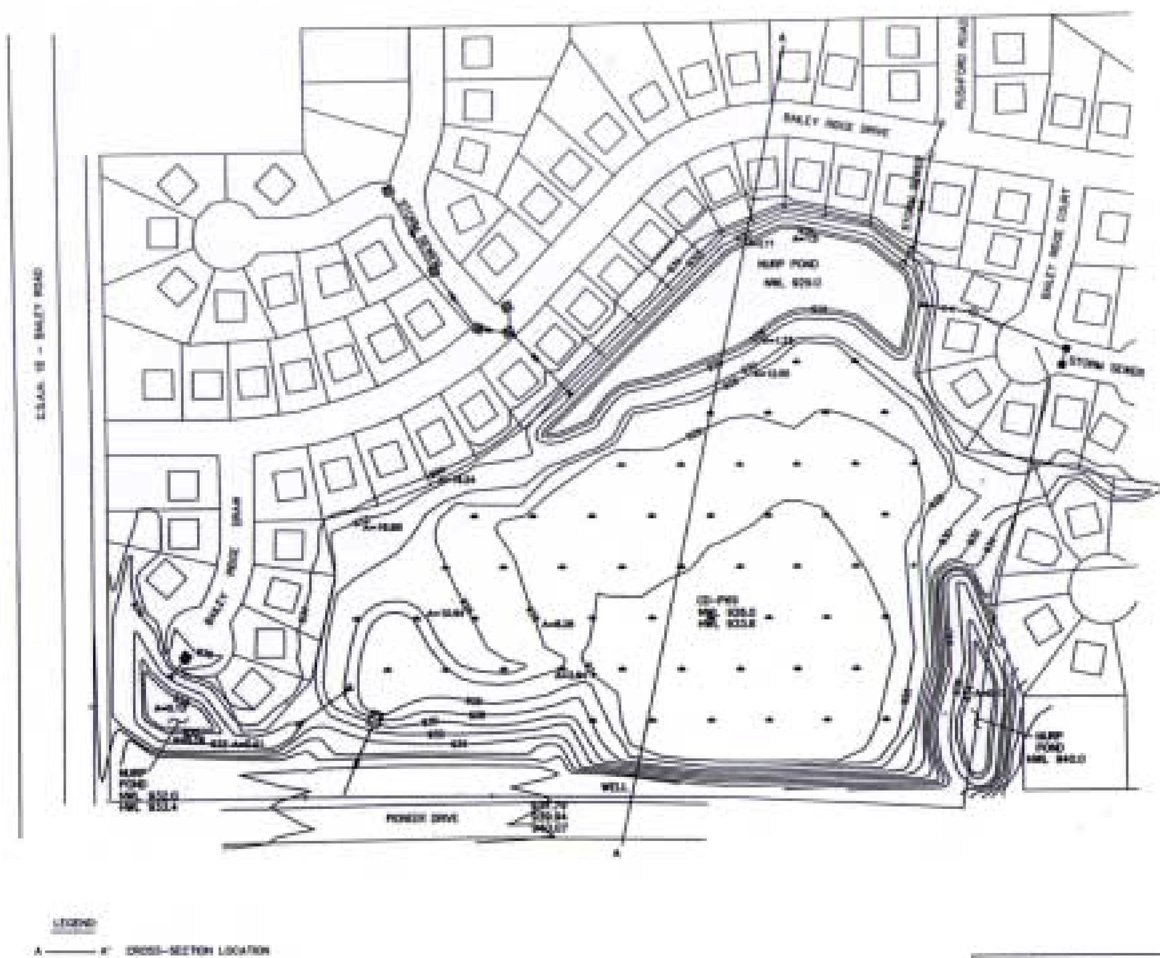
CD-P69 is located within a residential development at Pioneer Drive and Bailey Road in the City of Woodbury. The topography for the basin was obtained from grading plans for the adjacent developments through the City of Woodbury and is shown in Figure II-13. CD-P69 has the following surface water contributions: inflow from an approximately 1,100 acre developed drainage through an upstream wetland at the Savanna Oaks outlet structure; storm sewer connections from the Featherstone Ridge Development and other upstream developments generally to the west with an approximate 350 acre drainage area; and direct drainage area of approximately 100 acres from the properties surrounding the pond. The total drainage is estimated at 1,550 acres and is mostly developed with residential land-uses.

A V-notch outlet structure is located on the southeast end of CD-P69 with an invert elevation of 926. The weir collects water and carries it to Bailey Lake through the City's storm sewer system. The following Table identifies the stage-storage relationship of the pond. CD-P69 has a storage volume of approximately 136 acre-feet at 935 feet just below the lowest home.

Table II-9. Stage-storage at CD-P69

Elevation (ft)	Area (ft^2)	Area (Acres)	Storage (ft^3)	Storage (acre-feet)
924	170,320	3.91	170,320	3.91
926	287,932	6.61	628,571	14.43
928	469,577	8.59	1,290,682	29.63
930	546,242	12.00	2,187,583	50.22
932	731,808	16.85	3,444,289	79.07
934	842,015	19.33	5,020,290	115.25
936	963,547	22.12	6,825,852	156.7

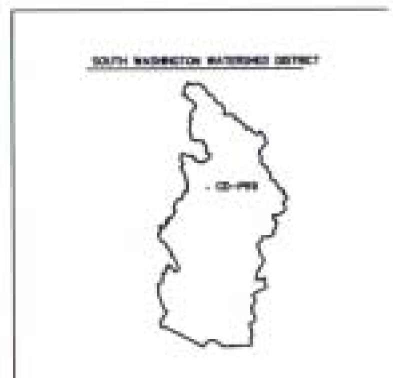
The cross-section in Figure II-14 illustrates sandy clays overlying sand and gravel. The water table remains at approximately 6 feet below the basin floor. The groundwater gradient is to the southwest. This cross section was derived from several soil borings located in the adjacent development and one drilled by the SWWD. These soil boring logs are located in Appendix A. The soils are lacuestrine in the bottom with side slopes of Brill, Antigo, Comstock, Barronett, Chetek, Lindstrom, and Crystal Lake silt loams.



CD-P69 Soil Types

Soil Map Unit	Soil Type	General Location
456	Barronett silt loam	Center
452	Comstock silt loam	South
49	Antigo silt loam; 0 – 2 % slopes	North
49B	Antigo silt loam; 2 – 6 % slopes	–
49C	Antigo silt loam; 6 – 12 % slopes	–
449	Crystal Lake silt loam; 1 – 3 % slopes	–
120	Brill Silt Loam	–
155C	Chetek sandy loam; 6 – 12 % slopes	North
301B	Lindstrom silt loam; 2 – 4 % slopes	North

Source: SCS, Washington and Ramsey Counties, Minnesota, 1977



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LAKE ELMO, MINNESOTA, 55042
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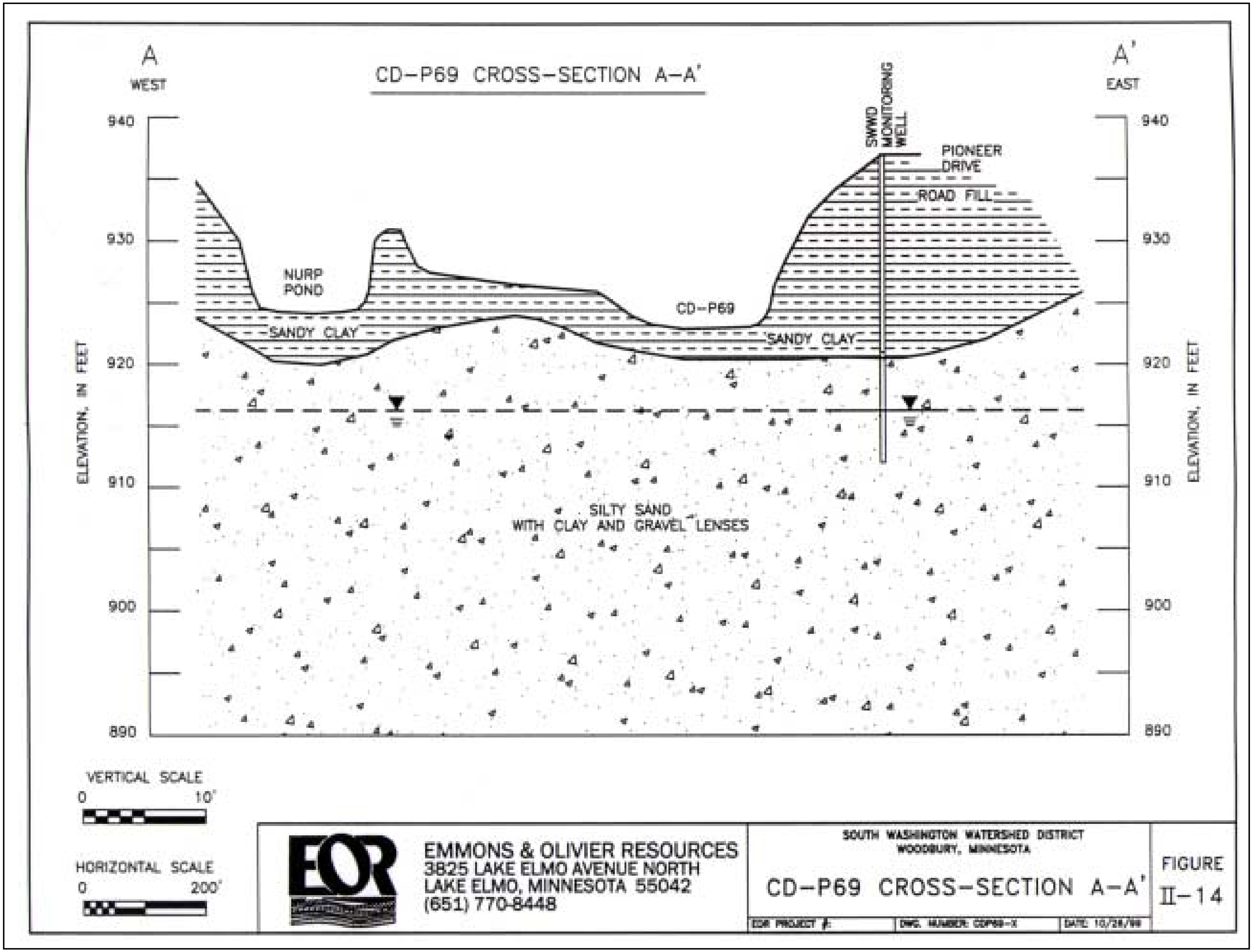
SOUTH WASHINGTON WATERSHED DISTRICT
WOODBURY, MINNESOTA

CD-P69 SITE MAP

FIGU
II-1


A
WEST
CD-P69 CROSS-SECTION A-A'
A'
EAST
940
930
920
910
900
890
ELEVATION, IN FEET
SWWD MONITORING WELL
PIONEER DRIVE
ROAD FILL
NURP POND
CD-P69
SANDY CLAY
SANDY CLAY
SILTY SAND
WITH CLAY AND GRAVEL LENSES
VERTICAL SCALE
0
10'
HORIZONTAL SCALE
0
200'
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LAKE ELMO, MINNESOTA 55042
(651) 770-8448
SOUTH WASHINGTON WATERSHED DISTRICT
WOODBURY, MINNESOTA
CD-P69 CROSS-SECTION A-A'
FIGURE
II-14

Water Quality – Groundwater

The monitoring well at CD-P69 was sampled once in March 1999 and again in November 1999. During the first sampling round, manganese was detected above the HRL. During the second sampling round, manganese was again detected above the HRL. The cause of the observed manganese concentrations above the HRL in both sampling events has not been determined. The following Table summarizes groundwater quality results at CD-P69.

Table II-10. Groundwater Quality Results at CD-P69

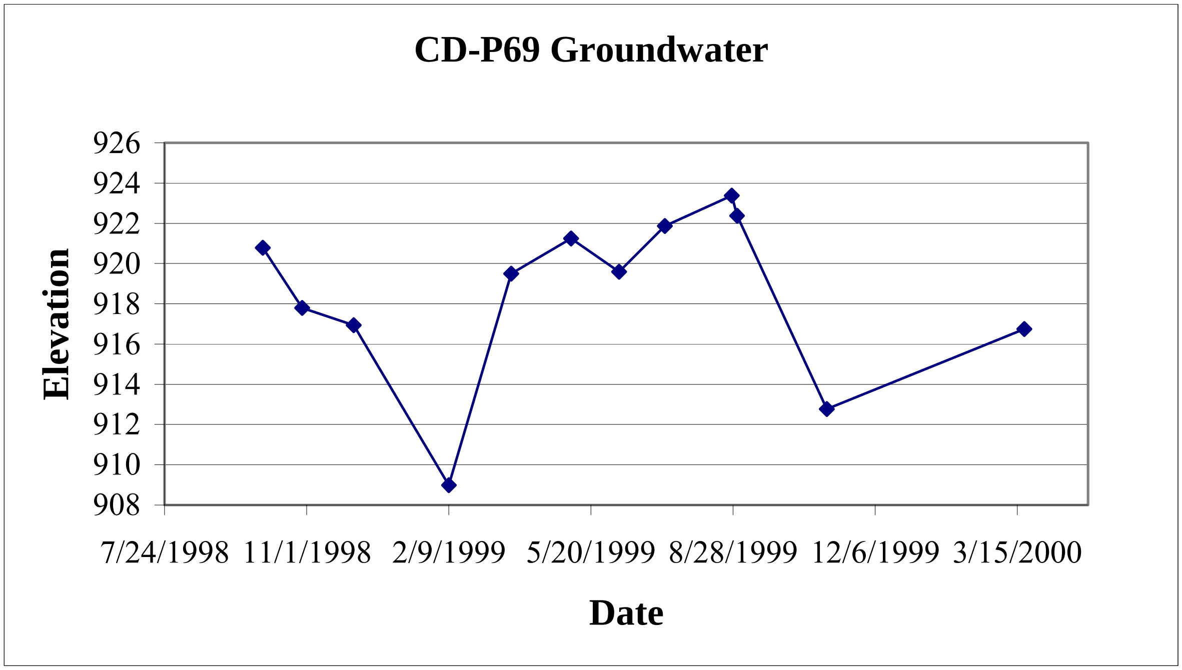
Analyte	MDH HRL	3/25/99	11/2/99
Cadmium (mg/L)	0.004	BDL	BDL
Lead (mg/L)	0.015	0.013	BDL
Manganese (mg/L)	0.1	1.14	0.473
Nickel (mg/L)	0.1	0.037	BDL
TKN (mg/L)		BDL	1.1
Ammonia:N (mg/L)		0.2	BDL
Hardness (mg/L)		n/a	192
Chloride (mg/L)	250**	29.7	30.5
Nitrate-Nitrite:N (mg/L)	10	3.37	BDL
vocs Detects (ug/L)			
m- and p-Xylene	10,000	0.684	n/a
1,2,4-Trimethylbenzene		0.957	n/a
n-Butyl Benzene		1.90	n/a
Semi-vocs Detects (ug/L)			n/a
Naphthalene	300	1.27	n/a
pH	6.5-8.5*	7.4	6.8
Salinity (ppt)		0.2	n/a
Redox (mv)		n/a	3.4
Conductivity (us)		311.2	380
Temp (C)		10.9	16.9
DO (%)		12.5	2.50

* Secondary Standards (EPA – not enforceable)
BDL – Below Detection Level
n/a – Not Applicable, was not analyzed for this parameter
TKN – Total Kjeldahl Nitrogen
VOC – Volatile Organic Compound

Groundwater Level Monitoring

The water table is at a minimum two feet below the pond. There are significant fluctuations of the local groundwater table. The water table ranges in depth from two to seventeen feet below the surface over time. Figure II-15 illustrates the changing groundwater levels with time at CD-P69.

Figure II-15. Water Table Fluctuations at CD-P69



III. Water Level Data and Infiltration Analysis

III-A. BACKGROUND

Soil infiltration data was collected for four of the five basins during the spring snowmelt runoff and late spring/early summer rainfall. These basins include CD-P50 - Eagle Valley Golf Course Basin, CD-P69 - Pioneer Drive Wetland, CD-P76 - Mile Drive Basin, and CD-P82 - County Road 19 Basin. Data on CD-P85 includes summer infiltration data (as summarized in the IMS Phase I Report) and data on infiltration improvements that connect to the subsurface materials. The subsurface results from within an infiltration trench at CD-P85 are presented in Appendix C.

In order to monitor infiltration rates in the study sites, water level and flow-monitoring equipment was purchased and installed at the five sites. The equipment includes American Sigma area/velocity flow meters to monitor the inflows to CD-P69 and CD-P50. In addition, five Telog water level pressure transducers were installed to monitor water levels at all of the basins.

Infiltration data was collected by measuring the depth of water in each basin over time as well as any inflows or outflows to those basins. Depth measurements were recorded with a pressure transducer located at the lowest portion of the basin and placed inside a PVC perforated tube. The transducers were connected to a data logger. Calibration and field inspection of the different units was performed routinely.

The pressure transducers were installed at two of the monitoring sites in February of 1999 and at all of the sites in March 1999 to record the final snowmelt. Some basins quickly receded down to the bottom ground level and the pressure transducers had to be removed to prevent damaging the equipment from overnight freezing temperatures.

The results of these monitoring events are presented for each basin in a graphical and a tabular format. A discussion of the data is provided at the end of the section. March 28th was used as a point to divide spring snowmelt infiltration from thawed soil conditions. This is based on approximately 2 weeks of consistently above-freezing average temperatures preceding that date. This date also falls just before several rainfall events that occurred in the watershed.

III-B. INFILTRATION BASIN RESULTS

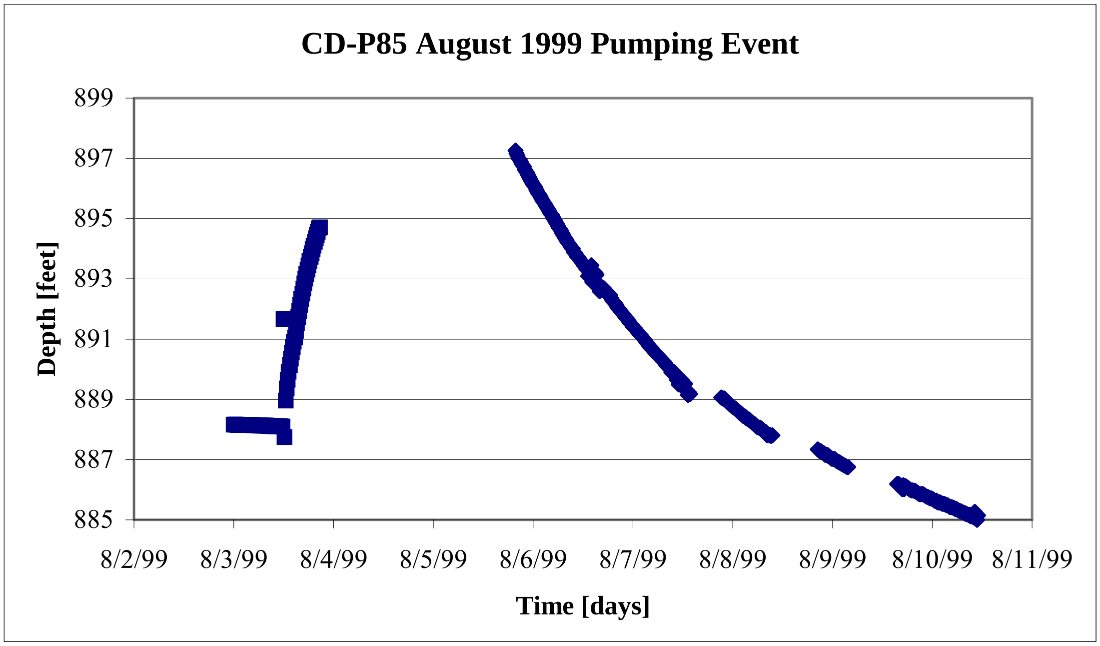
CD-P85 – Regional Infiltration Basin

The monitoring data gathered during 1999 includes data from the newly constructed infiltration trenches and basin-wide infiltration data from the August and November 1999 pumping events. Data from the infiltration trenches was recorded immediately after construction and represents the initial infiltration capacity of one of the trenches with its connection to the underlying sandy material. The discussion of the trench construction and results are presented in Appendix C of this report. Results of the August and November 1999 pumping events are presented in this section.

Data collected during the August 1999 pumping event represents the infiltration capacity of the basin with improvements. On August 3, 1999 the City of Woodbury began pumping water from South Bailey Lake into CD-P85. The beginning of the pumping event, as the basin filled, was recorded with the pressure transducer already located in one of the infiltration trenches. A second pressure transducer was installed to record water levels in the basin after the pumps had been turned off. These two curves, filling of the basin and the receding curve are illustrated in Figure III-1.

The August data which is presented in Figure III-1 required several adjustments prior to the infiltration rate analysis: the recorded water levels had to be adjusted for the actual elevation of the pressure transducer since it was relocated during the course of the event. This adjustment was performed as follows: (1) the receding portions of the curve were adjusted to datum elevations using water levels measured on a staff gage in the field and (2) data points recorded during rainfall events (fluctuating readings) were removed from the overall data set. The blanks between data points correspond to temporary equipment failure and relocation of the pressure transducer.

Figure III-1. Depth vs. Time for August Pumping Event at CD-P85.



Data collected during the November 1999 pumping event also represents the infiltration capacity of the basin with improvements. On November 15, 1999 the City of Woodbury began pumping water from South Bailey Lake into CD-P85. Water levels in the basin were recorded with a pressure transducer installed after pumping began. Figure III-2 illustrates the water levels in CD-P85 over the course of the pumping event.

As Figure III-2 illustrates the pumps were turned on and off each weekday for a period of approximately three weeks. The portion of the receding curve that corresponds to infiltration in the infiltration trenches only (the portion of the curve corresponding to elevations of 885.0 or less) is not included in this graph. This analysis of the infiltration rates for the November pumping event focuses on the infiltration capacity of the basin with improvements and not the improvements themselves.

Figure III-2. Depth vs. Time for November Pumping Event at CD-P85.

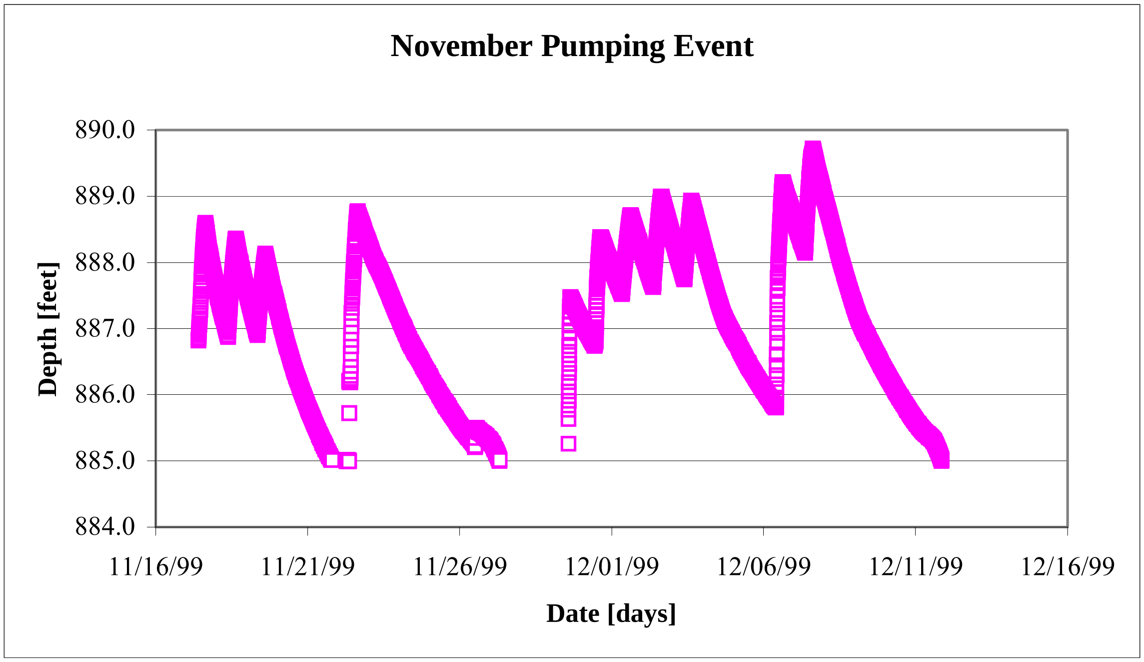


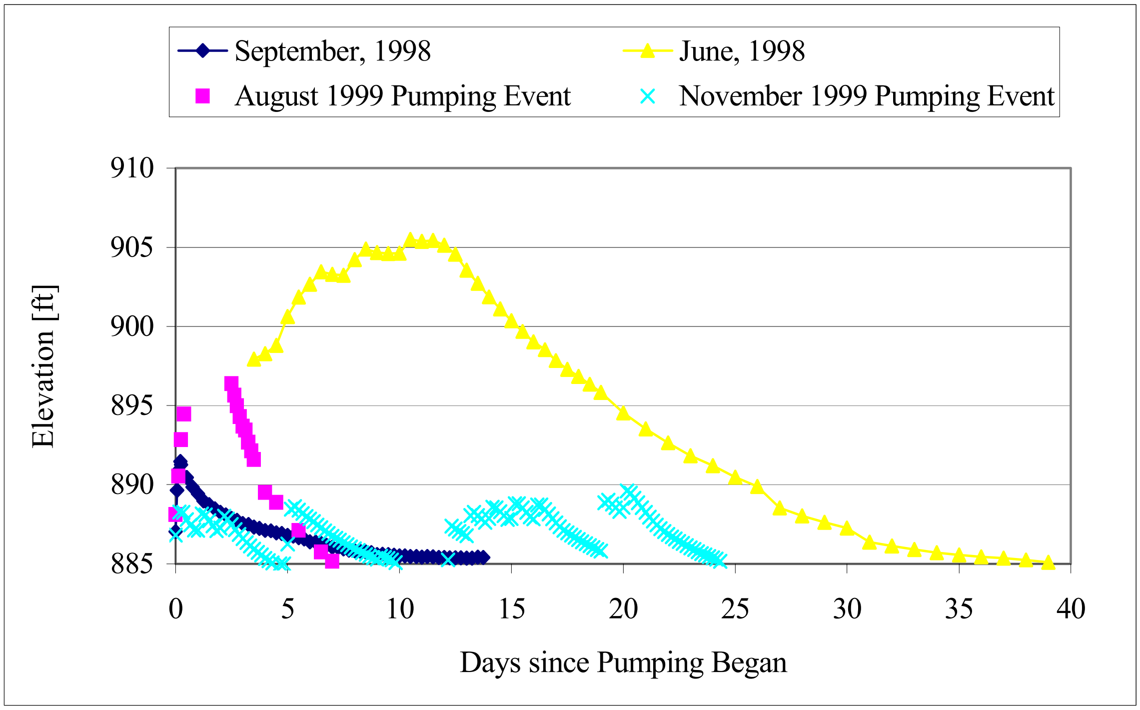
Figure III-3 presents depth vs. time data for the following four pumping events: June 1998, September 1998, August 1999, and November 1999. Although the IMS Phase I report contains the results of the June and September 1998 pumping events, it did not present the data in this format.

Figure III-3 illustrates similar behavior for the 1998-pumping events. In both cases it takes approximately 10 days for the water to infiltrate from an elevation of 891 to 886. The elevation of water ponded in the lower portion of the basin is 886. For the 1999 pumping events, this time is reduced from 10 to 3 days, as evidenced by the steeper curve. Although infiltration is dependent upon a number of parameters, this behavior could be significantly attributable to the infiltration trenches. Figure III-3 also shows that the 20 days it took in June of 1998 for the water to infiltrate from 897 to 886 has been reduced to 4-5 days in August 1999. Again, much of this increase in infiltration could be attributable to the infiltration trenches in the bottom of the basins.

As Dr. John Nieber concluded in his study of the unsaturated flow in the basin, infiltration of a highly permeable material is very sensitive to fluctuations in head. A comparison of the August 1999 and November 1999 curves illustrates this trend. The infiltration rates exhibited by the

August 1999 pumping event are significantly higher with increased depth and hydraulic head on the trenches than those exhibited by the November 1999 event.

Figure III-3. Comparison of Infiltration Events at CD-P85.



Infiltration rates (feet/hour) for the August and November 1999 events were determined by calculating the slope of the depth vs. time curve (Figure III-1 and Figure III-2) for elevation intervals with similar slopes. The slope (Δ Depth/Δ Time) is equivalent to the overall basin infiltration rate measured in feet/hour. Infiltration volumetric flow rates (cubic feet/second, cfs) were computed by multiplying the infiltration rates by the average area of the basin at the corresponding elevations. Tables III-1 and III-2 show the tabular results. The data points plotted in Figure III-4 and Figure III-5 represent the volumetric flow rate for a one-hour time interval.

Table III-1. Infiltration Rates and Volumetric Flow Rates for August Pumping Event at CD-P85.

Depth in Basin	Basin Elevation	Average Area	Infiltration Rate			Average Infiltration Volumetric Flow Rate
[feet]	[feet]	[feet]	[ft/hr]	[ft/min]	[inches/hr]	[cfs]
12 - 11	897 - 896	15.2	0.26	0.0043	3.12	49.07
11-10	896 - 895	14.1	0.23	0.0038	2.76	39.12
10-9	895 - 894	12.9	0.23	0.0038	2.76	35.73
9-8	894 - 893	11.5	0.20	0.0033	2.40	27.90
8-7	893 - 892	9.9	0.17	0.0028	2.04	20.12
7-6	892 - 891	8.3	0.17	0.0028	2.04	17.47
6-5	891 - 890	6.8	0.16	0.0027	1.92	13.26
5-4	890 - 889	5.3	0.08	0.0013	0.96	5.23
4-3	889 - 888	3.8	0.08	0.0013	0.96	5.20
3-2	888 - 887	2.6	0.07	0.0012	0.84	2.25
2-1	887 - 886	1.7	0.07	0.0012	0.84	1.37
1-0	886 - 885	0.8	0.06	0.0010	0.72	0.53

Table III-2. Infiltration Rates and Volumetric Flow Rates for November Pumping Event at CD-P85.

Depth in Basin	Basin Elevation	Average Area	Infiltration Rate			Average Infiltration Volumetric Flow Rate
[feet]	[feet]	[feet]	[ft/hr]	[ft/min]	[inches/hr]	[cfs]
4.7-4	889.7 - 889	5.2	0.10	0.0017	1.20	6.10
4-3	889 - 888	3.8	0.08	0.0013	0.96	3.75
3-2	888 - 887	2.6	0.07	0.0012	0.84	2.34
2-1	887 - 886	1.7	0.04	0.0007	0.48	0.90
1-0	886 - 885	0.8	0.04	0.0007	0.48	0.31

The shape of the infiltration volumetric flow rates vs. elevation curve (Figure III-3 and III-4) is generally consistent with the other data collected in CD-P85 for 1997 and 1998 (Figure III-5). A second-degree polynomial regression was used to represent the data trend with an R2 value of 0.984. Figure III-5 indicates that all of the infiltration volumetric flow rate data collected to date for different events follow an exponential trend (second degree polynomial).

Again, a comparison of the September 1998 and August and November 1999 infiltration data indicates that approximately 3 to 4 cfs of additional infiltration occurs between the elevation of

891 and 885. This increase in infiltration could significantly be attributable to the infiltration trenches. This conclusion is preliminary and is based upon a limited data set. Additional data collection is required to verify this finding.

Figure III-4. Infiltration Volumetric Flow Rates for August Pumping Event in CD-P85.

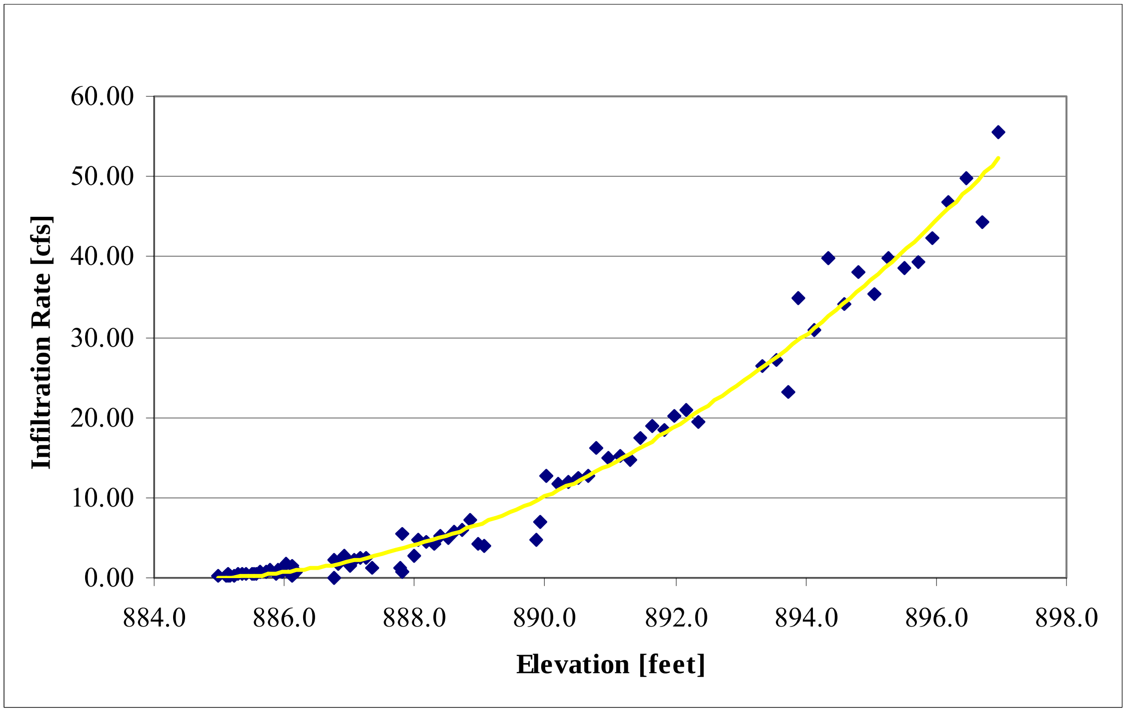


Figure III-5. Infiltration Volumetric Flow Rates for November Pumping Event in CD-P85.

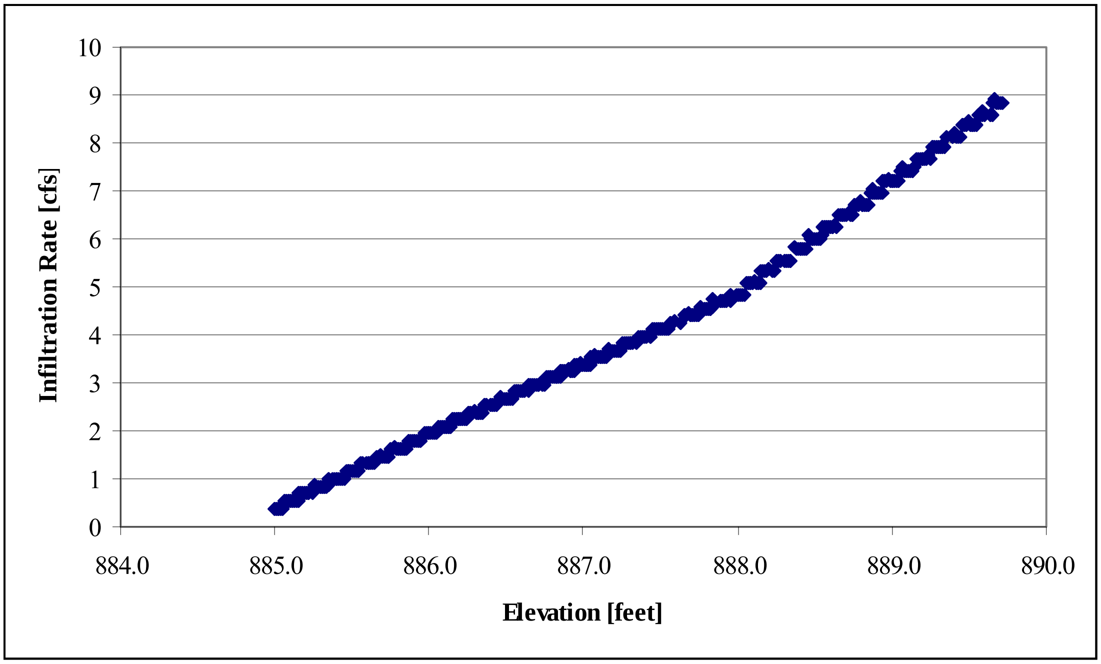
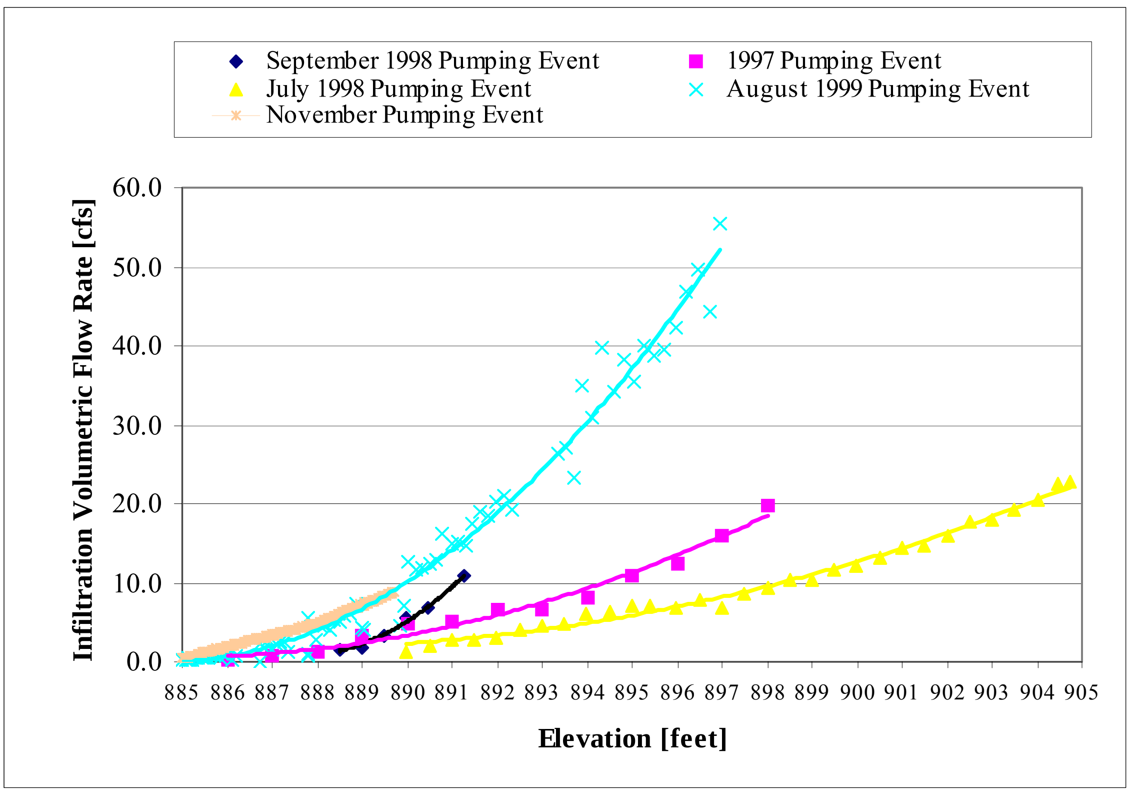


Figure III-6. Infiltration Volumetric Flow Rate Comparison for CD-P85 Pumping Events.



Monitoring Results

A complete description of background information on CD-P85 is provided in the IMS Phase I report. The results of the August and November 1999 pumping events represent increased capacity of the entire basin to infiltrate stormwater due to the construction of two infiltration trenches in the bottom of the basin.

To evaluate the performance of the basin with infiltration trenches during the 1999 pumping events, the data was compared to the 1997 and 1998 pumping events. Although these data sets represent the infiltration capacity of the basin under varying conditions (volume of water pumped in to the basin, length of inundation, time period between pumping events) it is possible to draw the following conclusions regarding the infiltration trenches:

- The time it takes to infiltrate the same volume of water is significantly faster for the August and November 1999 pumping events than it is for any of the other events
- Infiltration rates exhibited for the August and November 1999 pumping events are significantly greater at higher elevations, indicating the positive effect of increased hydraulic head on the infiltration trenches.
- Repeated inputs of water into the basin over a period of 25 days during the November 1999 pumping event did not show a decline in the infiltration rates at the end of the period.

The implications of these results and the use of infiltration trenches are discussed in the section titled Management Options.

CD-P82 – County Road 19 Basin

A pressure transducer was installed in this basin on March 20th to record the snowmelt runoff event of 1999. Previous to mid-March 1999, field inspection indicated no significant water ponding in the basin. No data was recorded from April 12th to May 18th due to equipment failure.

Infiltration rates for CD-P82 were determined by calculating the slope of the depth vs. time curve (Figure III-7) for elevation intervals with similar slopes. The slope (Δ Depth/Δ Time) is equivalent to the overall basin infiltration rate measured in feet/hour. See Table III-3 for the tabular results. Infiltration volumetric flow rates are computed by multiplying the rates shown in Table III-3 by the area of the basin at the corresponding elevations.

Figure III- 7. Depth vs. Time and Precipitation at CD-P82.

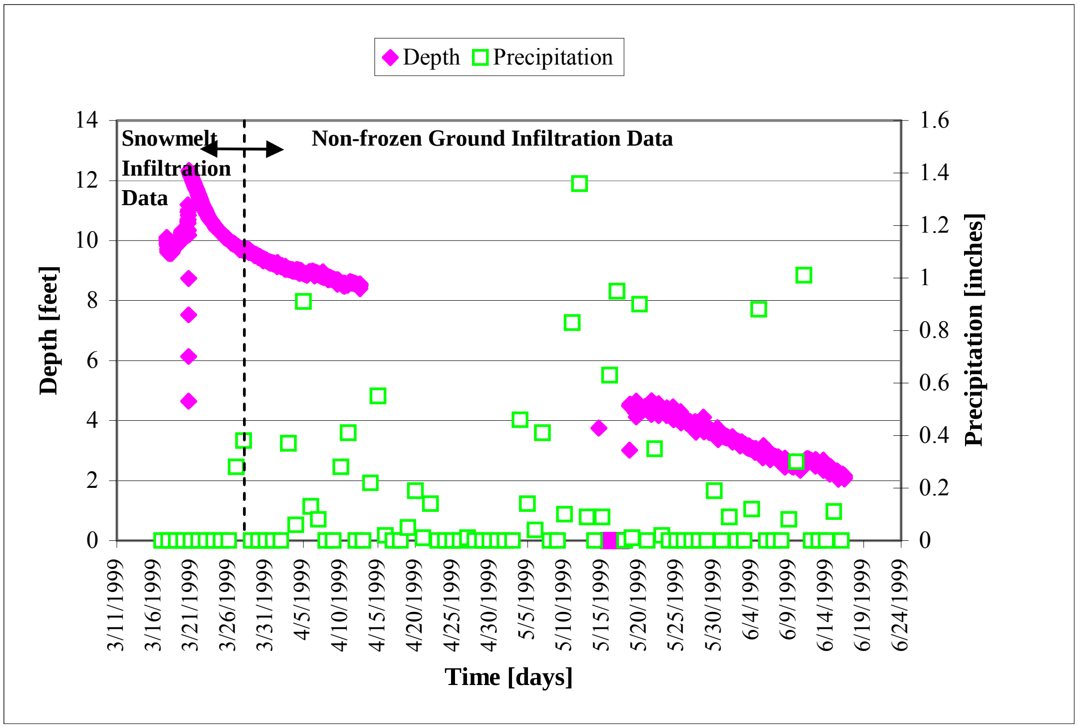


Table III-3. Infiltration Rates for CD-P82.

Basin Elevation [feet]	**Infiltration Rate** [ft/hr]	[ft/min]	[inches/hr]
12-11	0.025	0.00042	0.300
11-10	0.013	0.00022	0.156
10-9.5	0.006	0.00010	0.072
9.5-9	0.004	0.00007	0.048
4 - 3(*) (within pond)	0.004	0.00007	0.048
3 - 2(*) (within pond)	0.003	0.00005	0.036

(*) Precipitation occurred during the time period that these infiltration rates were measured (see Figure III-6). As a result, the actual infiltration rates were higher than the values presented in this table.

Monitoring Results

The lower portions of the basin, up to an approximate elevation of 910, and the major drainage swale are composed of Brill silt loam soils. The steeper, side slopes are composed of Antigo silt loam soils. Both soils have similarities in their soil profiles: silt loam textures for the first 13 to 14 inches followed by silt loam and silty clay loam underlain by sands and gravels. However, the Brill silt loam has a thicker layer of fine textured soil (silt loam and silty clay loam) before transitioning to granular materials than does the Antigo silt loam. This difference in the soils is consistent with erosional processes where more fine-grained materials are accumulated in the lower portions of the basin, which corresponds to the Brill soils.

The bottom 7.4 feet of the basin consists of a small depression that often contains standing water. Above this depth, gradual slopes extend out and the area is used for agricultural purposes.

a. Snowmelt Infiltration Data

- Snowmelt infiltration rates of 0.320 inches/hour were calculated in the basin at a depth of 11 feet (899 ft) to 12 feet (900 ft). Snowmelt infiltration rates of 0.156 inches/hour were also recorded in the basin at a depth of 10 to 11 feet.
- Based on the natural overflow elevation of 925, and an estimated bottom elevation of 888, the maximum potential depth of water in the basin is 37 feet.
- Based on similar soils, geologic characteristics, and data trends exhibited in CD-P85, higher infiltration rates are possible at elevations above those observed during the monitoring season.
- No rainfall precipitation was observed during the spring snowmelt event.

b. Non-snowmelt Infiltration Data

- Average infiltration rates of 0.072 to 0.036 inches/hour were calculated for depths of 2 feet to 10 feet.

- Higher infiltration rates are expected at elevations above the 898-foot elevation based on similar soils, geologic characteristics, and data trends exhibited in CD-P85.

CD-P76 – Mile Drive Basin

Field visits to the site on February 16th to 18th documented a water level drop of 1 to 1.5 feet in the first two days of snowmelt. A pressure transducer was also installed at the site on February 16th, but the data was lost due to a computer malfunction. A pressure transducer was installed again in CD-P76 on March 19th to record snowmelt runoff data. Since this basin has a history of not ponding water during the summer, the pressure transducer was removed at the end of March and moved to another site. Regular field visits to the site during spring and summer of 1999 verified that there was no ponding of water in the basin.

Infiltration rates for CD-P76 were determined by calculating the slope of the depth vs. time curve (Figure III-8) for elevation intervals with similar slopes. The slope (Δ Depth/Δ Time) is equivalent to the infiltration rate measured in feet/hour (see Table III-4). Infiltration volumetric flow rates were computed by multiplying the rates shown in Table III-4 by the area of the basin at the corresponding elevations.

Figure III-8. Depth vs. Time and Precipitation at CD-P76 for Spring Snowmelt.

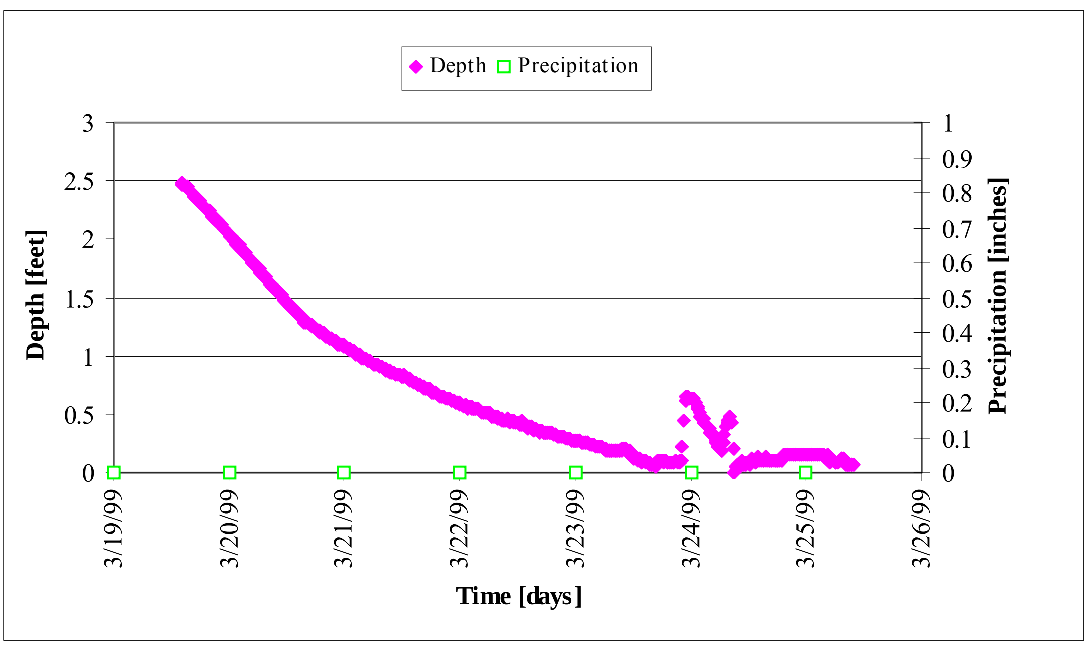


Table III-4. Infiltration Rates for CD-P76 for Spring Snowmelt

Basin Elevation [feet]	**Infiltration Rate** [ft/hr]	[ft/min]	[inches/hr]
2.5 – 1.5	0.05	0.0008	0.60
1.5-1.0	0.03	0.0004	0.32
1.0 - 0.5	0.02	0.0003	0.25
0.5 - 0.1	0.02	0.0003	0.23

Monitoring Results

a. Snowmelt Infiltration Data

- Snowmelt infiltration rates of 0.6 inches/hour were calculated for depths of 2.5 feet to 1.5 feet (See Table III-4).
- Based on the elevation of the natural overflow, the maximum depth of the basin is 10.5 feet.
- The lowest portion of the basin, elevations 927-930 or approximate depth of 0-3 feet consists of Lindstrom silt loam soils. The side slopes of the basin, elevations above 930 or depths greater than 3 feet, consist of Antigo silt loam soils. Below these depths the soil profile transitions to sands and gravels.
- Based on the soils and data trends exhibited in CD-P85, higher snowmelt infiltration rates are possible at higher elevations than those that were observed during the monitoring event.
- This basin and its drainage area have been subject to agricultural land use for approximately 150 years. The lowest portion of this basin has accumulated sediments from the long history of agricultural use as indicated by the soil types. However, the basin still maintains dry conditions in the soils compatible with agricultural use for most of the year.

b. Non-snowmelt Infiltration Data

- No infiltration data was collected after March 26th as rainfall events occurring after this date did not produce measurable ponded water conditions.

CD-P50 – Eagle Valley Golf Course Basin

A single pressure transducer was installed at CD-P50 on March 19th of 1999 to record the snowmelt runoff data. This pressure transducer was left in the field to continue recording the spring precipitation events. The transducer was removed in May 1999 for use at another site when the remaining water receded within the observed wetland boundary.

The CD-P50 basin consists of wetland soils (not described in the soil survey) surrounded by sandy loam and silt loams. The wetland soils are expected to be less permeable than the surrounding Chetek sandy loam and Lindstrom silt loam soils. The measurements only minimally included ponded water in contact with the more porous non-wetland soils. This was the case since water levels only reached 0.2 to 0.4 feet above the elevation of the delineated wetland (corresponding to an elevation between 895.6 to 895.8) onto the more porous non-wetland soils.

Infiltration rates for CD-P50 were determined by calculating the slope of the depth vs. time curve (Figure III-9) for elevation intervals with similar slopes. The slope (Δ Depth/Δ Time) is equivalent to the infiltration rate measured in feet/hour (see Table III-5). Infiltration flow rates were computed by multiplying the rates shown in Table III-5 by the average area of the basin at the corresponding elevations.

Figure III-9. Depth vs. Time and Precipitation at CD-P50

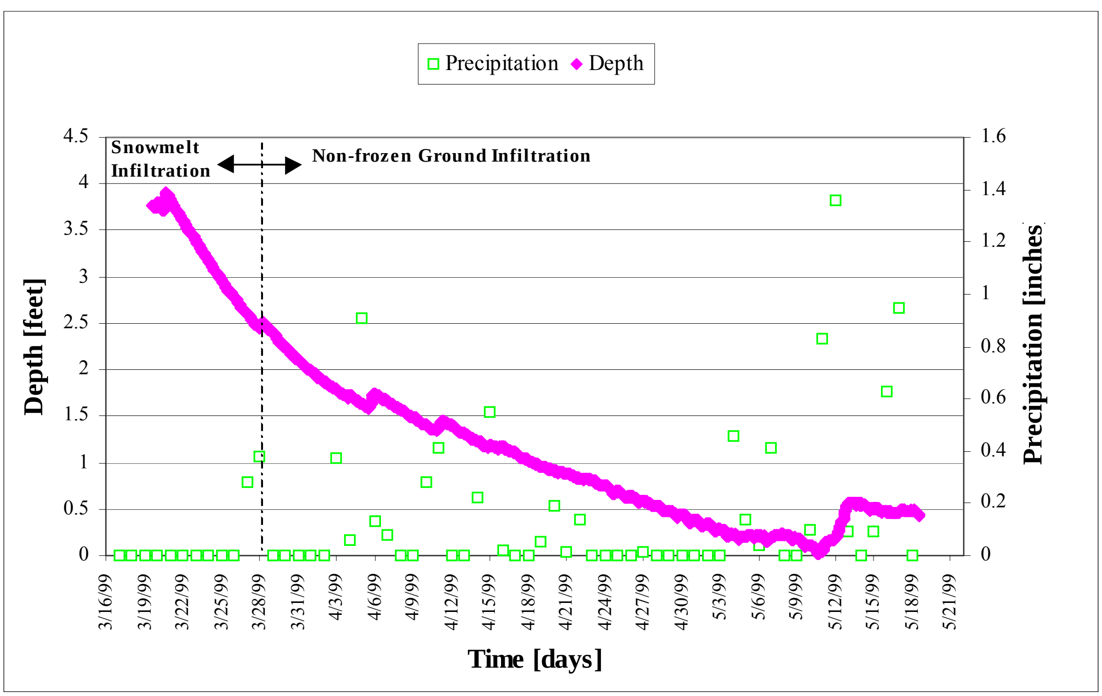


Table III-5. Infiltration Rates for CD-P50

Basin Water Depth [feet]	Infiltration Rate [ft/hr]	[ft/min]	[inches/hr]
4.0 – 3.5	0.012	0.00020	0.14
3.5 – 3.0	0.010	0.00020	0.12
3.0 – 2.5	0.009	0.00010	0.11
2.5 - 1.5(*)	0.005	0.00008	0.06
1.5-1.0(*)	0.002	0.00003	0.02
1.0 - 0.5(*)	0.002	0.00003	0.02

(*)Precipitation occurred during the time period that these infiltration rates were measured (see Figure III-9). As a result, the actual infiltration rates are higher than the values presented in this table.

<u>Monitoring Results</u>

a. Snowmelt Infiltration Data

- Water levels fell from a depth of 4.0 feet on March 20th to a depth of 2.5 feet on March 28th
- Snowmelt infiltration rates of 0.14 inches/hour were calculated for depths of 4.0 feet to 2.5 feet
- The jurisdictional wetland boundary corresponds to an elevation of 895.6 to 895.8, which is a depth in the basin of 3.6 to 3.8 feet. Therefore, infiltration data was only measured for a 0.2 to 0.4 foot depth of water on non-wetland soils.

b. Non-snowmelt infiltration data

Water levels in the basin continued to recede after March 28th although additional rainfall added water to the system. See Figure III-9 for the water level graph and precipitation data. The water levels in the basin had completely infiltrated by May 11th.

Estimated infiltration rates were calculated for the basin using the measured water levels. The estimated infiltration rates presented here are less than the actual infiltration rates since additional rainfall events added water to the system. Since the amount of water added to the basin from various rainfalls (see Figure III-9) could not be directly measured, the estimated infiltration rates, as presented here, are low-end values.

- The data collected after March 28th was from within the jurisdictional wetland boundary, not on the more permeable sandy loam and silt loam soils in the basin surrounding the wetland

- Summer rainfall events for the remainder of the year did not produce ponded water in the basin over 0.6 feet deep due to high infiltration rates in the area

- Based on the soils and data trends exhibited in CD-P85, higher infiltration rates are possible at higher elevations but are not yet quantified

CD-P69 – Pioneer Drive Wetland

A pressure transducer was installed in CD-P69 on February 16th of 1999 to collect infiltration data. Results obtained in CD-P69 represent the earliest infiltration data collected for spring 1999. Visual observations were made of water levels at the Savanna Oaks outlet structure to estimate inflows into CD-P69 at this time. Manning's equation was used to calculate flows in the culverts since the culvert was less than full.

Due to dropping water levels and cold temperatures, the pressure transducer was removed from CD-P69 for a few of weeks in March 1999 to prevent damage to the sensors. One pressure transducer was installed at the end of March 1999. A second pressure transducer was installed in the upstream wetland at the Savanna Oaks outlet structure to more accurately measure inflows into the basin. By recording depths and developing stage/discharge curves for the inflows from the Savanna Oaks outlet structure and the outflows at the South end of CD-P69, a water balance of the basin was calculated to obtain the infiltration capacity of CD-P69 for the spring and summer rainfall events. No monitoring equipment was available to be installed in the west inlet to the basin. As a result, additional inflows could have been present that were not measured.

Infiltration rates for the February snowmelt event in CD-P69 were determined by calculating the slope of the depth vs. time curve (Figure III-10) for each elevation interval. The slope (ΔDepth/Δ Time) is equivalent to the infiltration rate measured in feet/hour (see Table III-6). Infiltration flow rates can be easily computed by multiplying the rates shown in Table III-6 by the area of the basin at the corresponding elevations. For the remaining events a water balance was performed on the entire basin. The water balance was calculated in the following manner:

1. Determine discharge and volume inputs (at 6-hour time intervals Δt) for Savanna Oaks outlet structure (Q_{in}:V_{in})
2. Determine discharge and volume outputs (at 6-hour time intervals Δt) for Pioneer Drive Wetland V-notch outlet structure (Q_{out}:V_{out})
3. Calculate the difference in volume for each time step ($V_{in} - V_{out}$)
4. Calculate the additional volume being infiltrated as water elevation in the basin decreases (V_{basin})
5. Calculate total volume being infiltrated at each time step ($(V_{in} - V_{out}) + V_{basin}$)
6. Average results over the defined elevation range to obtain a composite average infiltration rate for the basin for the elevation range

The water balance was performed for two separate time periods consisting of 10 days and 4 days. Each time period began two days after the last rainfall event and ended immediately preceding the next rainfall event. This approach minimizes any unmeasured inputs to the basin from precipitation or runoff from the surrounding development. By using this approach, it is estimated that no additional inputs were occurring during the time period used for calculating infiltration rates. If there were additional inputs not measured, the infiltration rates calculated here would be underestimated.

Figure III-10. Depth vs. Time and Precipitation at CD-P69.

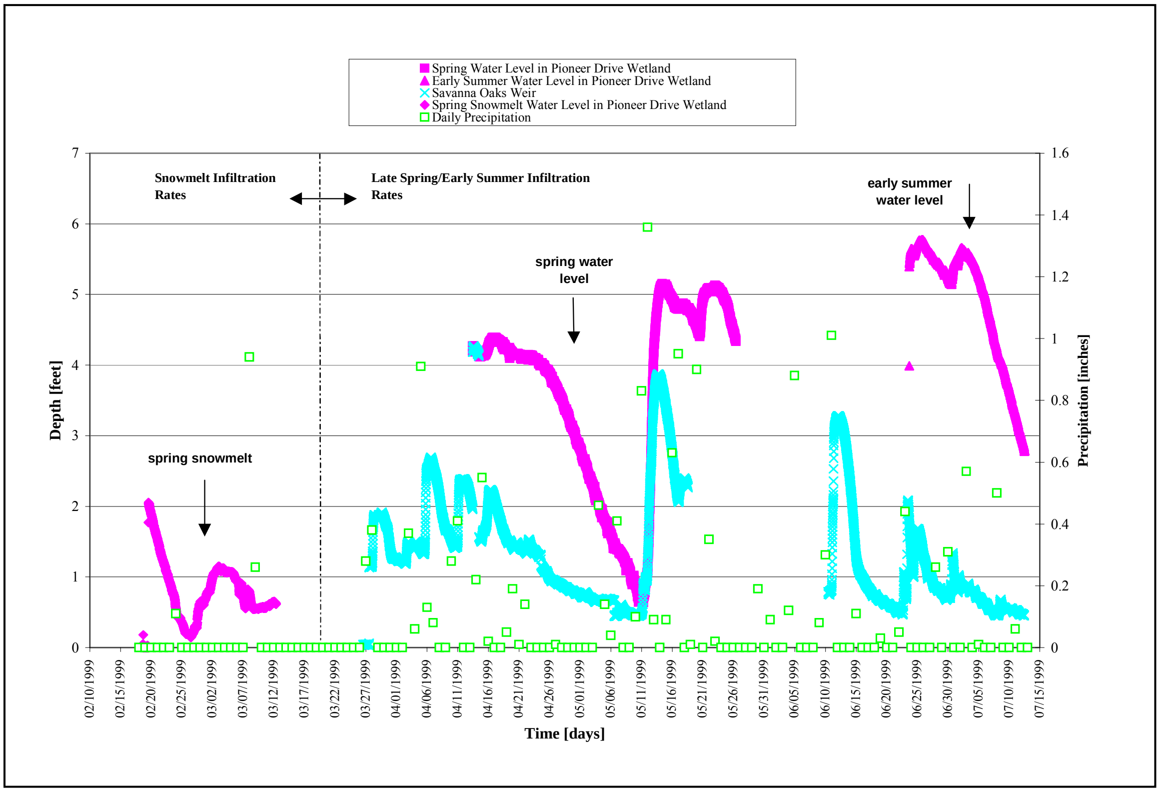


Table III-6. Calculated Infiltration Rates for CD-P69.

Basin Elevation [feet]	**Infiltration Rate** [ft/hr]	[ft/min]	[inches/hr]
2.0 - 1.5	0.012	0.0002	0.14
1.5-1.0	0.012	0.0002	0.14
1.0 - 0.5	0.016	0.0003	0.19

<u>Monitoring Results</u>

a. Snowmelt Infiltration Data

- Snowmelt infiltration rates of 0.14 to 0.19 inches/hour were calculated for depths of 2.0 feet to 0.5 feet.
- The surface overflow for the basin is approximately 3 feet from the bottom of the basin.
- Higher snowmelt infiltration rates are possible at higher elevations than those observed at or below 2.0 feet.

- This basin has operated as a stormwater detention area and natural infiltration site for approximately the last six to ten years in an urbanizing setting with a large drainage area (approximately 1,550 acres).
- The higher infiltration rates calculated at lower elevations are attributed to the lack of accurate inflow monitoring into CD-P69, both at the Savanna Oak outlet structure and the two major inlets to the wetland during the February 1999 snowmelt. Unmeasured inflow from upstream snowmelt and local precipitation would mean that the infiltration rates calculated for this report are below the actual infiltration rates.

b. Non-snowmelt Data

- Average non-frozen ground infiltration rates of 0.5 inches/hour (or approximately 2.5-3.0 cfs) were calculated in the basin at a depth of 3 to 3.5 feet (926.0 to 926.5 feet).
- The rates shown in Table III-6 could be lower than the actual rates due to unmeasured inputs into the basin.

III-C DISCUSSION OF SNOWMELT INFILTRATION CONDITIONS

Spring Snowmelt in the Watershed

In Minnesota, the seasonal melting of the winter snow is one of the most significant hydrologic events of the year. The volume of water generated by snowmelt runoff can be significant and the impact of this single event has raised concerns regarding stormwater infiltration systems.

The infiltration of runoff through the soil and percolation to the groundwater during winter (frozen conditions) is a topic of research which includes work being performed locally at the University of Minnesota's Rosemount research site. Traditional surface water hydrologic modeling of spring snowmelt assumes very little to no infiltration based on the assumption of totally frozen ground during snowmelt. The assumption that no infiltration occurs in frozen soil conditions is not accurate. In reality, the infiltration process is slower under frozen conditions than under thawed conditions but infiltration does exist albeit at reduced rates. The study of snowmelt runoff and infiltration by the District thus far has focused on the natural basins where excess snowmelt waters collect. The amount of water that reaches the basins is dependent on how efficiently the water over the landscape is delivered to the basin. The assumption in traditional modeling is full delivery of 7.2 inches per unit area. The process of retention and infiltration over the entire landscape has not been examined thus far by the watershed, so the assumptions on volume of runoff delivered have not been refined yet.

The topography and landforms of the South Washington Watershed consist of many deep natural basins. Most of the basins have a history of being used for agricultural purposes. This portion of the county went through a major land use conversion approximately 150 years ago for intensive agricultural use. A few of the basins still have remnants of natural vegetation, but they are limited. The soils are typically well drained since they are underlain by sands and gravels from glacial outwash materials. The numerous basins within the watershed are natural collection points for the excess spring snowmelt runoff. These depressions retain and store the runoff until it infiltrates into the ground. The infiltration process in these basins has been observed for several years and directly measured with monitoring equipment in the watershed in 1999 during the IMS study. The snowmelt computer modeling performed as part of the study included approximately 35 days of time to allow for drainage through the entire system. The snowmelt modeling includes a constant spring snowmelt infiltration rate for the entire duration of the simulation since a dynamic time-dependent change in infiltration rates cannot be accurately modeled with the current hydrologic model HydroCAD. Thus a transition from a spring infiltration rate to a summer infiltration rate is not explicitly accounted for in the model. Table III-7 in the following section presents the spring infiltration rates used and some discussion of how they were determined.

Winter and Spring Climatic Data

An analysis of the monthly average temperature records for the Minneapolis/St. Paul Airport shown in Figure III-11 shows that the monthly average temperatures for 1999 are above the long-term average for that weather station. Figure III-11 compares the average monthly temperature for 1999 to the average monthly temperatures for the last 50 years. The temperature for the December-March time period was 25 percent above average for the last 50 years with the month of February having the highest deviation from the average.

Figure III-11. Average Monthly Temperature at Minneapolis/St. Paul Airport for 1999.

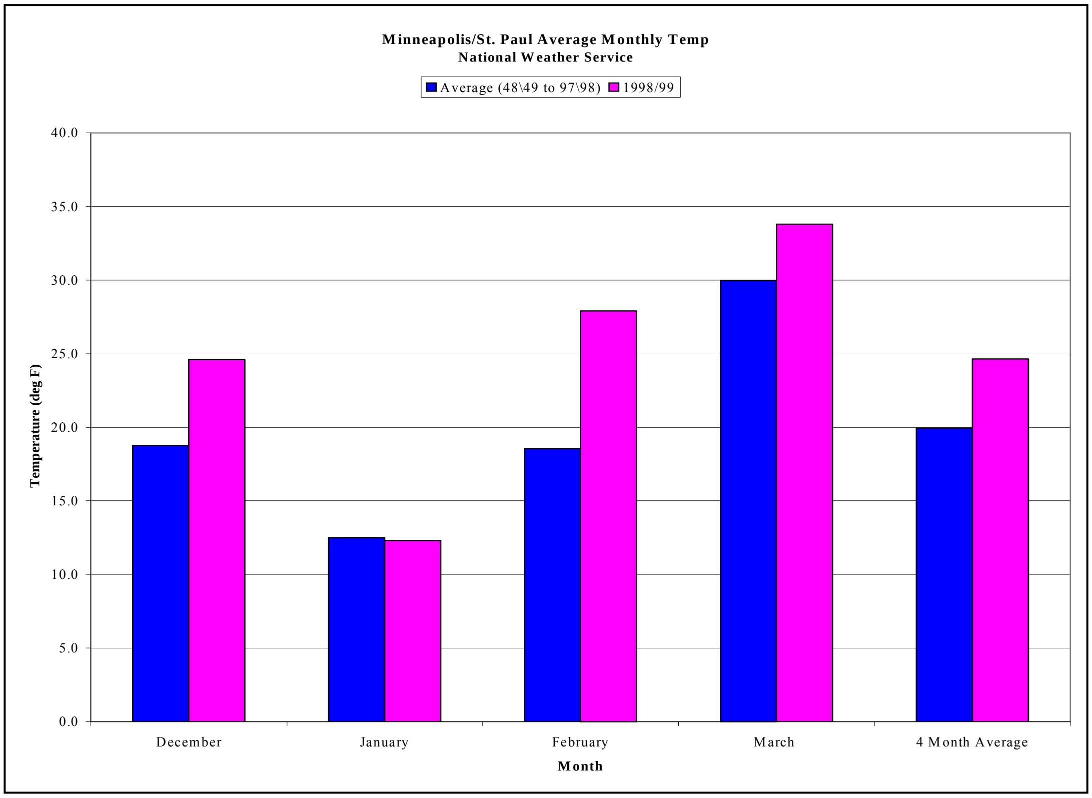


Figure III-12 shows average total snowfall at the Minneapolis/St. Paul Airport. The graph compares the monthly snowfall for 1999 to the average monthly snowfall over the last 50 years. The average total snowfall for 1999 was eight percent above average for the last 50 years with January receiving a large amount of snow. Average daily temperatures and average daily precipitation are shown in Figure III-13 for December 1998 through March 1999.

An analysis of graphs indicates that the volume of snowmelt for 1999 was distributed into two separate snowmelt events. Snowfall for December through February melted in late February due to above average temperatures and was monitored in CD-P69 (Pioneer Drive Basin) and CD-P76 (Mile Drive Basin). Heavy snowfall in March melted by mid-March and that snowmelt event was monitored in all of the basins.

Figure III-12. Snowfall at Minneapolis/St. Paul Airport for 1998/1999.

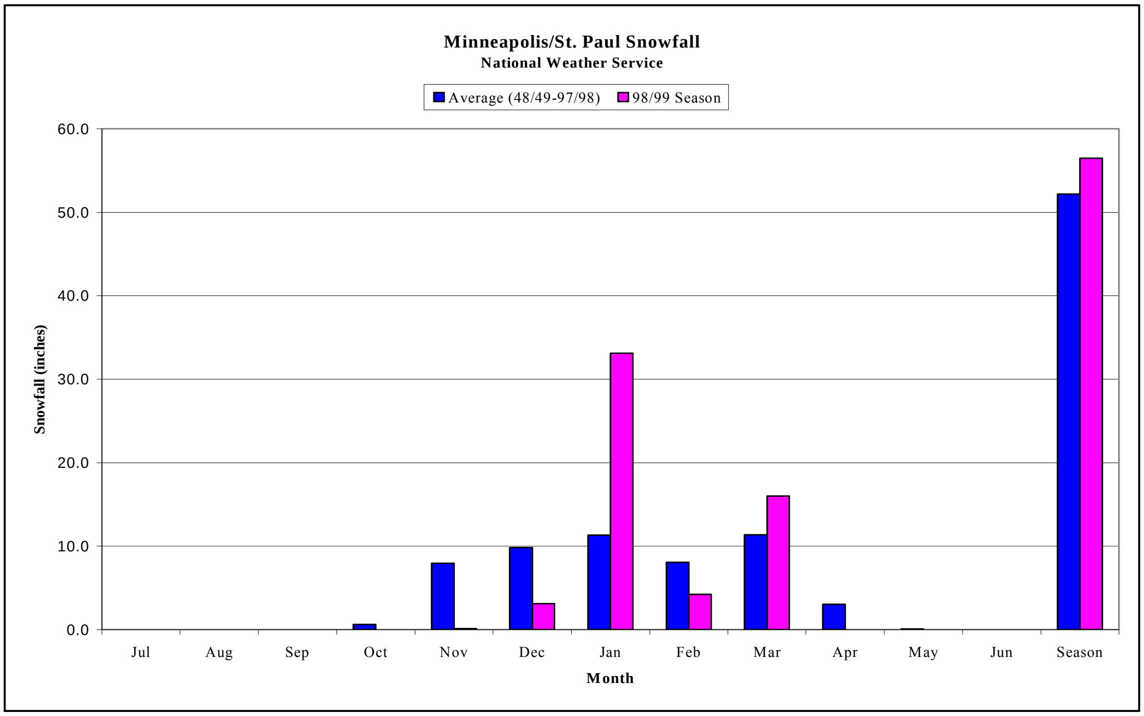
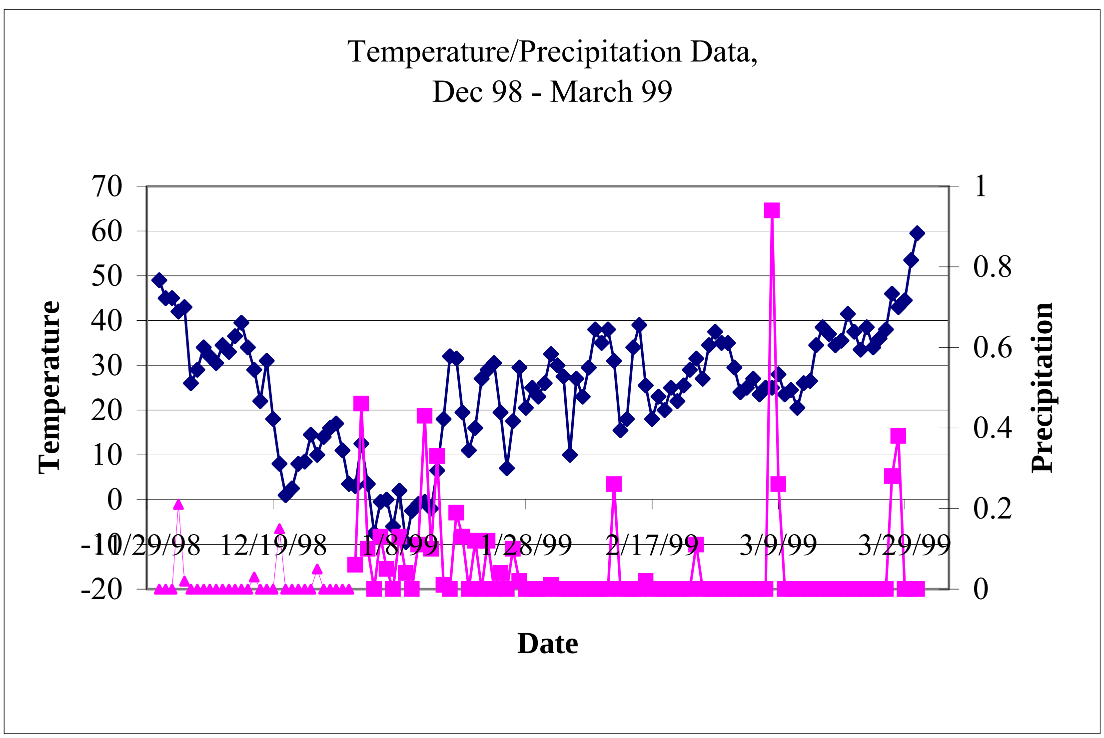


Figure III-13. Daily Temperature and Precipitation at Minneapolis/St. Paul Airport for 1998/1999.



Comparison of Spring Infiltration Data

Snowmelt Infiltration Events

An ongoing study by Dr. John Baker at the University of Minnesota, Soil Science Department (1999) has investigated the infiltration of spring snowmelt. This study has taken place over eight years in a similar geologic setting to the SWWD's. Dr. Baker's study has led to the postulation that soils covered with vegetative debris during the freezing process may contribute to the development of preferential flow paths through the soil column. These flow paths would allow for increased infiltration of snowmelt. Dr. Baker has recently documented the formation of the preferential flow paths and monitored the infiltration capacity of the soils under spring snowmelt frozen ground conditions.

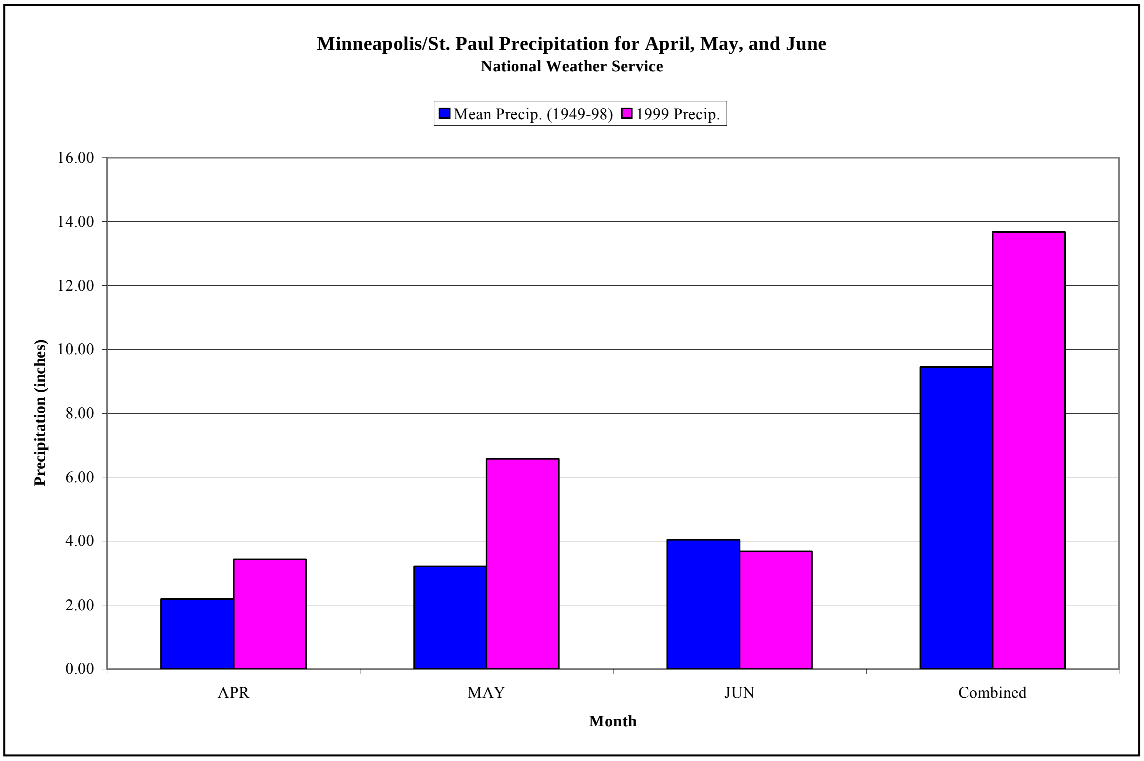
Both the results of the 1999 spring snowmelt runoff event, and Dr. John Baker's studies, clearly indicate that infiltration does occur during the spring snowmelt event in a glacial outwash setting such as that found in the SWWD. To evaluate the infiltration capacity of the basins under various snowmelt conditions additional monitoring is required for the future. Continued contact with Dr. Baker and his work in Rosemount will provide additional data and information on the physical phenomenon and processes of snowmelt infiltration for the SWWD. The infiltration rates measured for the 1999 spring snowmelt event and review of Dr. Baker's work in Rosemount is an excellent starting point for understanding and managing spring infiltration.

The data collected to date represents spring snowmelt with above average temperatures. This spring infiltration data was collected for a single year in the bottom of the basins where the lowest capacity, least permeable soils are found.

Non-Snowmelt Infiltration Events

The analysis of the rainfall record from the Minneapolis/St. Paul Airport (Figure III-14) indicates that the total rainfall generated in April through June of 1999 was above average.

Figure III-14. Precipitation for Minneapolis/St. Paul Airport for April-June 1999.



This graph compares the total monthly precipitation for 1999 to the average monthly precipitation for the last 50 years. Total precipitation for the months of April, May and June of 1999 was 47 percent above the average for the last 50 years. During these above average conditions, no sustained ponded water was found in any of the monitored basins, except for CD-P69, after May 15 1999. Accordingly there was not an opportunity to directly measure summer infiltration rates for the majority of the sites. Several pumping events into CD-P85 during 1997, 1998, and 1999 provides the most complete infiltration rates measured under summer conditions in regional basins. Basin CD-P69 data is also valuable but the record is not as long or complete as that for CD-P85. The continual inputs to the basin from each rain event, the numerous inflow locations along with an overflow structure, and monitoring equipment problems have made collection of data for CD-P69 more difficult.

III-D. Conclusions & Recommendations

Recommended Rates

Based upon the data obtained during the monitoring phase of the Infiltration Management Study, an average snowmelt infiltration range was calculated for each of the basins. Average snowmelt infiltration rates are presented in Table III-7 and compared to the rates used in the initial modeling effort.

Average snowmelt infiltration rates for the monitored basins were determined by extrapolating the measured data to higher contours in the basins. This method of extrapolating is based on the monitoring results obtained for CD-P85 during 1997, 1998 (see IMS Phase I report) and 1999. This data clearly illustrates the following trend: infiltration rates increase with higher elevations (water depths) in the basin (see Monitoring Results section). The higher infiltration rates exhibited at higher elevations are due to more permeable soils than those found at the bottom of the basin and to the presence of thicker, more established vegetation. The soils situated in the bottom of the basin are more frequently inundated, are subject to longer inundation periods, have little to no vegetation and have filtered out the fine material associated with the waters being infiltrated.

As a result of these measurements and observations, the infiltration data collected during the spring of 1999 at the lower portion of the basins were extrapolated to calculate average infiltration rates consistent with the observed behavior at CD-P85.

For each basin, the measured infiltration rates at different elevations were plotted and fit with the best-fit linear regression with R^2>95. By extending this trend-line, the infiltration rates at higher elevations could be estimated (see Figure III-15 and III-16). Figure III-16 shows that the change in infiltration rates with depth of water in CD-P85 follows a linear trend; therefore a linear extrapolation was also used for the other natural basins similar to CD-P85. Figure III-16 also shows that extrapolated spring infiltration rates fall below the lowest recorded saturated summer rates for CD-P85 except for CD-P76. The slope of the CD-P76 regression for spring infiltration lies between the recorded CD-P85 summer infiltration curves. These results could be attributed to permeable soils and better overall infiltration conditions at CD-P76 compared to the rest of the infiltration basins monitored including CD-P85.

Figure III-15. Example of Linear Regression at CD-P50 for Determination of Infiltration Values.

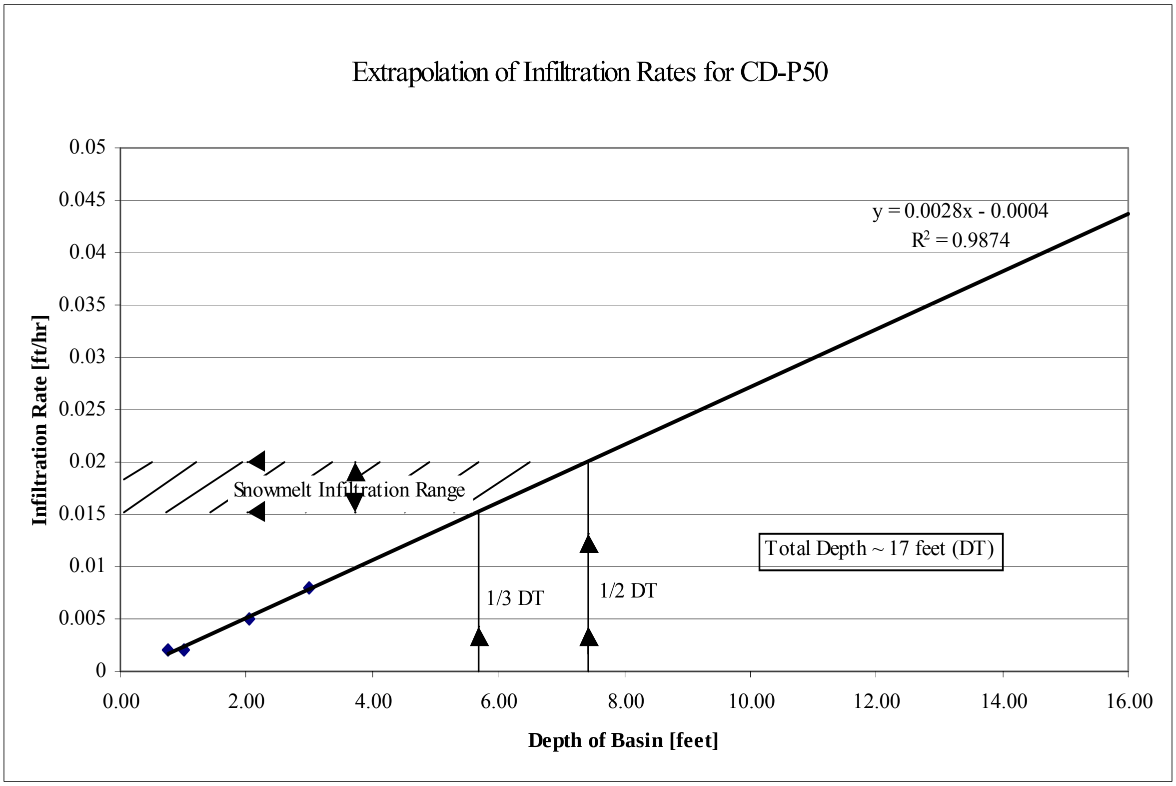
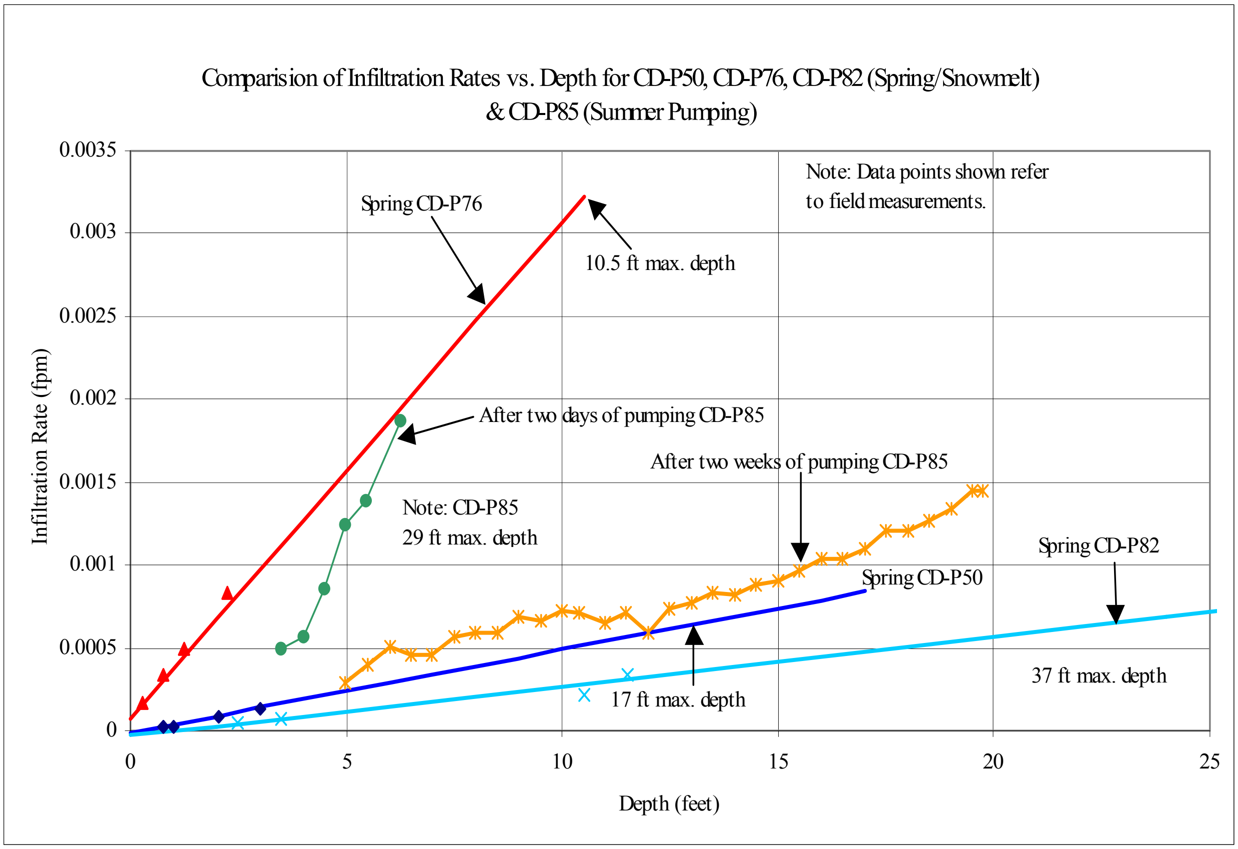


Figure III-16. Linear Regression for Basins used to Calculate Infiltration Rates.



In order to be able to use one infiltration rate over the entire basin that would account for the change in infiltration with depth and time with in the basin, 1998 data for CD-P85 was used. The analysis of this data indicated that the infiltration rate associated with 1/2 of CD-P85's maximum water depth for any given pumping event represents a depth/time composite average that accurately characterizes the infiltration behavior of the entire basin for that event. This rationale has been applied to the snowmelt infiltration data and associated linear regression developed for the other basins.

The range of average snowmelt infiltration rates shown in Table III-7 represent the expected average infiltration rates measured in the regression line at one-third to one-half of the total depth of the basin (see Figure III-15). These infiltration rates are applied uniformly over the entire basin. A comparison with typical SCS permeability values is also included in Table III-7.

Table III-7. Average Snowmelt Infiltration Rates for Monitoring Sites.

Infiltration Basin	Max. Depth	Average Snowmelt Infiltration Rates for Basins Determined by a Linear Extrapolation of Field Measured Values (Based upon 1999 Field Data)			Infiltration Rate used in Initial Model (*)		Non-frozen Permeability from SCS Soil Survey
	[ft]	[ft/hr]	[ft/min]	[in/hr]	[ft/min]	[in/hr]	[in/hr]
CD-P50 Eagle Valley Golf Course	17	0.015–0.020	0.00025-0.00033	0.18-0.24	0.0002	0.144	0.6-6.0
CD-P69 Pioneer Drive Wetland	12	0.038-0.060	0.00063-0.001	0.46-0.72	0.0010	0.72	0.2-2.0
CD-P76 Mile Drive	10.5	0.082-0.123	0.0014-0.0018	0.98-1.48	0.0012	0.864	0.6-2.0
CD-P82 County Road 19	30	0.050-0.010	0.0008-0.0016	0.60-1.20	0.0005	0.36	0.6-2.0

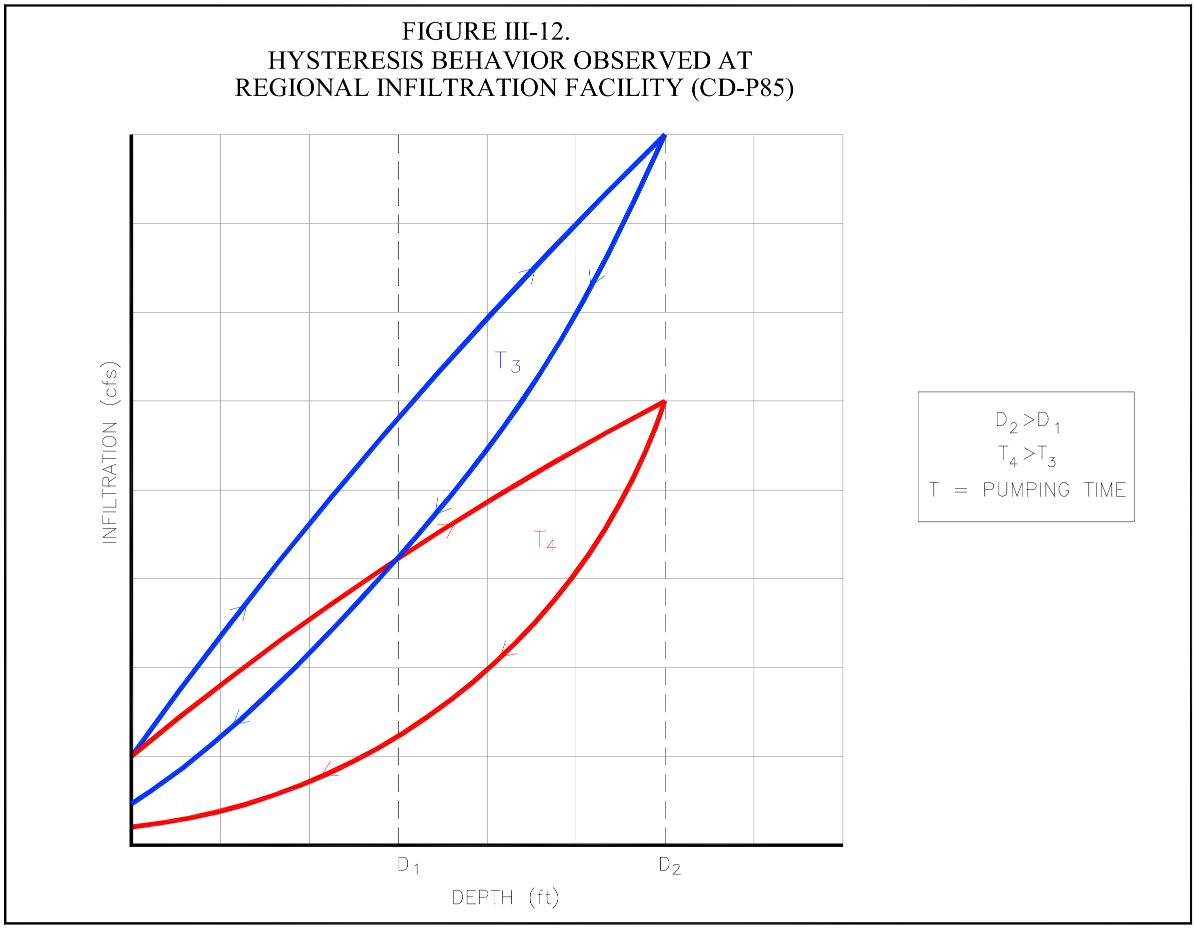
(*) Infiltration rates were assumed for modeling purposes prior to 1999 data being available. The rates used in the initial model are below the low end of the ranges except for CD-P69. For the basins that were not directly measured in the field, similar ranges from monitored basins were used based on similar geology, soils, vegetation and general configuration (see modeling assumptions under the modeling section).

The data presented in this section confirms that natural infiltration is the single largest determining factor in the current naturally landlocked configuration of the watershed. The amount of detention volume and infiltration capacity available at existing natural depressions makes this watershed uniquely capable of preserving a sustainable hydrologic balance. Complete detention and infiltration has been naturally occurring for centuries and still occurs today under significant development conditions in the watershed.

No projections for future infiltration capacity losses have been included in this analysis in the same way that no future enhancement techniques (such as excavation, vegetation management, infiltration trenches, infiltration tubes, etc.) were considered as a means of improving existing infiltration capacity.

Figure III-17 shows a conceptual model, based on the data collected in CD-P85, of how infiltration occurs in a regional basin located in glacial outwash. The model illustrates how infiltration may vary with the timing of pumping. The model resembles a hysteresis cycle and emphasizes the importance of optimizing pumping timing and pumping rates to achieve maximum infiltration in the basin. The arrows on Figure III-17 indicate time progression: the longer it takes to reach a particular elevation in the basin (slow pumping), the lower the infiltration rates. This will be true for both branches of the hysteresis cycle. On the other hand, the quicker the pumping, the higher the infiltration at a given elevation. Also, the quicker the pumping the closer the receding curve will be to the basin-filling curve. Theoretically, maximum infiltration values would be achieved under an "instantaneous" filling of the basin. In this case, the receding infiltration curve will follow the maximum basin-filling curve.

Figure III-17. Conceptual Infiltration Model.



Recommendations

General

- The infiltration and field data collected throughout this study (Phase I and II) is technically sound and in line with similar studies done or being done in other parts of the U.S and the world.

- The data analysis and data interpretation methodology shown in this section have been developed in close coordination with recognized experts in the field of infiltration and watershed management (see Acknowledgements). The input from the ITAC has been directly incorporated throughout this section.

- The regional natural detention and infiltration areas identified in the study are potentially reliable and important elements of the Central Draw stormwater management system.

- Future preservation of open space and natural areas for infiltration management is a viable, cost-effective and environmentally sound alternative for the watershed that fits into the watershed's overall goals.

Technical

- The recommended values for snowmelt infiltration contained in this section are good preliminary values used to evaluate the long-term infiltration capacity of natural regional detention/infiltration basins during critical events.

- If management of the critical detention and infiltration areas is well planned, it is estimated that, at a minimum, current measured and predicted infiltration rates in those basins can be maintained. This will require coordination with the Cities and/or watershed-wide participation regarding future development of subwatersheds draining to those regional areas.

- It is recommended that the SWWD maintain the on-going monitoring program to continue developing baseline infiltration data and to evaluate the need for and effectiveness of operation and maintenance methods. It will be valuable to obtain infiltration rates for the basins under varying conditions: colder winter conditions and/or larger rainfall events as well as applying management techniques. This data may be used to adjust or confirm the values incorporated into the present analysis.

- Management of water levels and analysis of the data should continue to focus on the timing and rates of water delivery to the basins. This will ensure that the basin is subject to wet-dry cycling and will verify if the hysteresis optimal cycle characterizes basin operation. Ultimately optimal wet-dry cycle requirements for various basins or basin types should be developed and quantified.

IV. Surface Water Modeling

Computer models are commonly used in surface water management to analyze and design facilities or systems. The use of hydrologic computer models to analyze infiltration is not as common. Models that analyze for infiltration are not commonly available or commonly used. The selection of a surface water computer model was done with the assistance of the Infiltration Technical Advisory Committee (ITAC). Several surface water models were discussed, including HydroCAD and XP-SWMM, as well as models that are linked to groundwater models, since groundwater analysis is one of the components of the study.

The SWWD has access to an existing surface water model for the watershed. The surface water model is in a HydroCAD program format developed jointly by the City of Woodbury and the SWWD. One potential model package discussed by the ITAC entitled the Florida Institute of Phosphate Research (FIPR) Hydrologic Model developed at the University of Florida. This model was identified as one that was designed to integrate surface water and groundwater modeling. The (FIPR) model integrates two existing models, HSPF (Hydrologic Simulation Program – Fortran) supported by the U.S. Environmental Protection Agency (EPA) for surface water modeling and MODFLOW supported by the U.S. Geological Survey (U.S.G.S.) for groundwater modeling. The FIPR model was developed to serve as an interface between the two existing models, HSPF and MODFLOW, as well as providing a means to manage input and output data using Geographic Information System (GIS) databases.

Given the time and budget constraints and aware of the effort needed to put together a new model, it was concluded by the committee that the project should use the existing modeling resources of HydroCAD for the surface water modeling. For the groundwater portion, the Multi-Layer Analytical Element Model (MLAEM) was selected. Both HydroCAD and MLAEM were recognized to have their limitations for this type of application. However, it was felt that these two models would be a good first-cut screening tools to analyze and evaluate the system and benefits of infiltration. It was concluded that in the future, more in-depth analysis would be needed and other models could be more seriously investigated and selected at a later time.

IV-A SURFACE WATER MODEL BACKGROUND - HYDROCAD

HydroCAD is a computer aided design program used for modeling hydrology and hydraulics of stormwater runoff. Hydrology is the study of runoff and the factors that influence it. Hydraulics is the study of water flow in channels, pipes, streams, ponds and rivers. HydroCAD's rainfall-runoff-routing methodology used in this study is based primarily on the hydrology techniques of TR-20, which was developed by the Soil Conservation Service. The hydrology portion is then combined with standard hydraulic methodologies and equations. HydroCAD is designed primarily as a hydrograph generation and routing program.

HydroCAD maintains a complete database for a watershed and drainage system. With this database, it becomes a working model where changes to the entire system such as different size storm events can be easily made and the effects viewed. This allows for quick evaluation of different possible designs.

HydroCAD has the following capabilities:

- The Soil Conservation Service and Santa Barbara Urban Hydrograph procedures
- The following techniques: TR-55, TR-20, Channel Flow (based on Manning's velocity), upland method
- The SCS Dimensionless Unit Hydrograph
- The SCS Storm Distributions
- The SCS Runoff Equation
- The Rational Method for predicting runoff
- The Intensity-Duration-Frequency Relationship

The modeling effort included the use of the SCS Unit Hydrograph, TR-20, and SCS Type II storm distribution procedures. One limitation of HydroCAD in this application is its event-based approach rather than continuous simulation. Another limitation is the limited time-dependent features of the model, which include lack of dynamic, time-dependent backwater effect between basins. Channel hydraulics are also limited in HydroCAD. The model does work well in routing from basin to basin where there is little backwater interaction between ponds.

The existing model used for this project was derived from various modeling efforts. The City of Woodbury first developed a HydroCAD model for its “Tri-lakes” and “Meadowview” areas of the city as part of a local surface water management plan. The two areas that were modeled terminated at Wilmes Lake for “Tri-lakes” and Pioneer Drive Wetland for “Meadowview” as the most downstream waterbodies in the drainage areas.

The City of Woodbury soon thereafter added to this model the other areas in the city that are part of the Central Draw and would drain to Bailey Lake, CD-P85, and CD-P86 based on their 1979 Stormwater Plan. The areas added in this second modeling work were not to the level of detail as the “Tri-lakes” and “Meadowview” models. These additions also included very basic modeling for areas in Oakdale, Lake Elmo, and Afton that would be tributary to the central drainage corridor based on the 1979 city drainage plan.

The Watershed then incorporated the modeling included to that point and refined some areas in the model. There were several additional refinements in the Oakdale area based on the City of Oakdale's draft local water management plan. There were also areas of Cottage Grove that lie adjacent to and south of CD-P85 and CD-P86 added to the model. The HydroCAD model has continued to be added to and refined by the City of Woodbury as new development has occurred.

The HydroCAD model was provided for this project as 12 separate projects. The projects are linked through the model’s linking structures within the project according to hydrologic system configuration. Four different scenarios were provided of the HydroCAD model for the Central Draw of which addressed two primary factors: time frame and different events. The timing scenarios included current MUSA build-out (approximately year 2000-2002), which is basically equivalent to the existing conditions. The second scenario was ultimate development and connection of all areas within the watershed in the Central Draw. The two different hydrologic events were the 100-year rainfall event which is a 6.0” rainfall event in 24-hours and the 7.2” snowmelt runoff event over 10-days. A summary of the four different models is presented below.

- Current MUSA build-out (existing) for the 24-hour, 6.0” rainfall event
- Ultimate development for 24-hour, 6.0” rainfall event
- Current MUSA build-out (existing) for the 10-day, 7.2” snowmelt runoff event
- Ultimate development for the 10-day, 7.2” snowmelt runoff event

IV-B MODELING ASSUMPTIONS

For this study, it is assumed that the existing model, as transferred, was accurate and current with the development and storm sewer system, as it existed at that time. The basic assumption of land uses and associated curve numbers (CN) values are based on existing conditions and the city comprehensive plans for undeveloped areas. CNs are a description of the permeability and condition of the soil that determines the amount of runoff.

Assumptions for Modeling the System

Ultimate development of the watershed was anticipated in the modeling and CN values. In the case of the spring snowmelt modeling, the conservative assumption is made that the soils are impermeable and all CN values are set to 99.

For all basins, the beginning water level in the basin at the beginning of the modeled event is set at the overflow elevation or planned management level for pumped outlets except for basins considered to be regional infiltration and detention basins. Infiltration basins start the model simulation at the bottom of the basin or any pre-existing water level that has been historically maintained in the basin. A summary of the basic data on the regional basins that included infiltration and/or detention that were incorporated into the model is presented below in Table IV-1.

Table IV-1. Basic Data on Infiltration and/or Detention Areas Used for Modeling

Basin Number or Name	Year Likely Needed	NWL Starting Water Elevation	Infiltration Rate Summer (ft/min)	Infiltration Rate Spring Snowmelt (ft/min)
CD-P69 (Pioneer Dr. Wetland)	Existing	922.0	0.0015	0.0008
South Bailey Lake	Existing	868.5	3 cfs	2 cfs
CD-P85	Existing	885.0	*0.0014**	*0.0009**
North CD-P86	2000	875.6	0.0014	0.0009
Armstrong Lake	2000	1018.2	0	0
Powers Lake	2000	888.0	0	0
CD-P28	2005	914.0	NA	0.0003
CD-P42	2005	924.7	NA	0.0008
CD-P43	2005	922.0	NA	0.0008
CD-P74b (Existing Mining Area)	2000	880.0	NA	0.0014
CD-P48	2010	934.0	NA	0.0008
CD-P49	2010	926.5	NA	0.0010
CD-P50 (EV Golf Course)	2010	891.0	0.0006	0.0002
CD-P74a	2015	892.0	NA	0.0008
CD-P74c	2015	926.0	NA	0.0008
CD-P76 (Mile Dr.)	2015	927.0	NA	0.0012
CD-P80	2020	918.0	NA	0.0010
CD-P82 (Co. Rd. 19)	2020	894.0	NA	0.0005
CD-P83	2025	914.0	NA	0.0010
CD-P87	2025	934.0	NA	0.0008
CD-P88	2025	919.0	NA	0.0009
CD-P78	2030	934.0	NA	0.0003
CD-P89/CGR-P92	2025	878.0	NA	0.0010
CGR-P90	ND	914.0	NA	0.0004

* Input in the model as a stage-discharge relationship based on collected data as presented in Table IV-2 below. The value shown in the table reflects the average overall value derived from the stage-discharge relationship and is included here for comparison purposes only.

NA = None Assumed since modeling of the 24-hr rainfall event of the overall system showed that no outflow from North CD-P86 occurred utilizing only infiltration in the few regional basins identified in the table.

Basin CD-P85 has a larger data set including infiltration data at a range of elevations within the basin. Based on the CD-P85 data, a stage versus discharge (cfs) relation was possible and was input into the computer model. CD-P85 is the only basin that was input in this format. The table below summarizes the stage versus discharge (cfs) relationship used in the modeling for CD-P85.

Table IV-2. CD-P85 Elevation Versus Average Infiltration Rate

Summer Rates		
Elevation	Infiltration Flow Rate (cfs)	Infiltration Rate (fpm)
885	0.2	0.0008
887	1.5	0.0010
889	2.5	0.0009
894	7.5	0.0009
896	10.0	0.0010
898	14.0	0.0012
902	21.5	0.0015
906	28.0	0.0018
912*	35.0	0.0019
914*	35.0	0.0017
Spring Snowmelt Rates		
Elevation	Infiltration Flow Rate (cfs)	Infiltration Rate (fpm)
885	0.0	0.0000
887	0.3	0.0002
889	0.9	0.0003
894	3.8	0.0005
896	5.0	0.0005
898	8.4	0.0007
902	15.1	0.0011
906	21.0	0.0014
912*	26.2	0.0014
914*	26.2	0.0012

*Due to lack of data at these elevations, the infiltration flow rate was assumed to level off (declining infiltration rate).

A limited number of existing facilities were included primarily as detention or storage management areas where the outlets or pumping would be managed to detain additional runoff for the large snowmelt runoff event. Table IV-3 summarizes the basic data on the basins managed for detention under existing conditions. Pumping operation for the Bailey Lake lift station was modified to provide more capacity for a few critical timing scenarios when there was minimal infiltration or storage management in the system. The future pumping rates at Bailey Lake are presented in the modeling results section.

Table IV-3. Basic Data on Regional Basins with Detention

Basin Name	NWL Starting Water Level Elevation	Pumping Operation (if applicable) Control Elevation	Pumping Rate (cfs) Unmanaged	 Managed
Armstrong Lake	1018.2	1022.7	NA	NA
Powers Lake	888.0	888 – 890.5	0	0
		890.5 & above	5	0
Bailey Lake	868.5	868.5 – 872.0	0	75
		872.0 – 875.0	60	75
		875.0 & above	90-135	75

Several different scenarios were modeled including different combinations of management options as well as phases of development through time. The scenarios and results are presented in the Modeling Results section.

General Assumptions Inherent in the Modeling Approach

There are several factors that are inherent to the modeling approach here that should be kept in mind.

Computer Model Factors

- HydroCAD (TR-20-based model) typically simulates a quicker than actual observed delivery times for the hydrograph. This was verified during a calibration of the HydroCAD model compared to actual SWWD monitored data from monitoring station #2 (MS2). The DNR has had similar experience in other river basins (Dave Ford – DNR Hydrologist/ITAC member; personal communication at ITAC meeting, 1999)
- The model represents higher peak flow rates and higher runoff volumes than observed at MS2 at Bailey Road during a calibration comparison of the model.
- The model represents a "perfectly functioning and connected" system which does not account for the likely obstruction or plugging of culverts with ice such as during a spring snowmelt event.

Background on Snowmelt Runoff Event

- The 7.2” runoff event was based on monitored data from an agricultural watershed with a well-defined stream and outlet; in contrast, the SWWD is very different and characterized by numerous isolated basins (due to its glacial past) and lacking any defined outflow stream.
- The snowmelt runoff event was derived in an agricultural setting; the SWWD is in an urbanizing setting with snow plowing and uneven piling of snow that affects the timing and distribution of the melt.
- The 7.2” runoff event was derived over 30 years ago in the 1960’s based on a limited historic database following large flooding events.
- The largest recorded runoff event gauged in a metropolitan stream was 6.0”, which is 20%, lower than the 7.2” used here.

Amount of Infiltration Included in Modeling

- Infiltration is only accounted for in identified Regional Basins during the model simulation.
- No infiltration is accounted for over the winter in nearly 300 existing stormwater ponds in the system.
- The spring infiltration rates being used are based on data collected from infiltration occurring at the lowest elevations of the basins where thick layers of fine-grained soils have accumulated.
- The spring infiltration rates are based on limited data including one year’s measured data when winter temperatures were above average and visual observations for another two years.
- The spring infiltration rates measured and used in the modeling do not explicitly account for two factors that could effect how quickly the basins transition from spring frozen conditions to summer-type, unfrozen conditions: 1) presence of permanently vegetated soils that reduces frozen ground conditions as was found in CD-P85’s vegetated areas (field investigation on March 24th, 1997) and 2) the delay of runoff delivery to regional basins allows more time for the soils in the regional basins to thaw before the water arrives.

- Additional storage management techniques to provide more storage and delayed delivery of the snowmelt runoff to regional basins has not been fully explored except in Armstrong Lake, Powers Lake, and Bailey Lake. The additional storage management techniques could include:
  - Bottom release for standard water quality ponds (i.e. fall draw down)
  - Modifying and optimizing outlet designs for snowmelt hydrology
  - Managing overflow structures where significant additional storage could be gained

IV-C MODELING RESULTS

Modeling results from the various timing and management scenarios are presented in this section and in the appendices. The modeling thus far should be considered **preliminary** and can be refined as additional data is collected and additional management practices are considered. The preliminary modeling indicates a large and very significant potential for infiltration to be a key component of the Watershed's surface water management system.

There were many different scenarios modeled to determine the impact from different hydrologic events and combinations of management options, at different points over time as development occurs. The analysis of such a large number of scenarios provides a better understanding of the timing, need for additional facilities, and the determination of the optimal management system. Management options were added to the system in an incremental manner to determine the least number needed for the system as shown in #3 below. The three basic variables and the various parameters are listed below:

1. Hydrologic Event
   - 7.2" 10-day Snowmelt Runoff
   - 6.0" 10-day Snowmelt Runoff
   - 6.0" 24-hour Rainfall

2. Development Timing/Phasing
   - Existing
   - 2005
   - 2010
   - 2015
   - 2020
   - Ultimate

3. Management Scenarios
   - The connected system with ponding assumptions consistent with the 1979 City of Woodbury Stormwater Plan except for infiltration in seven locations* and natural detention and infiltration for unconnected areas.
   - Addition of a 6-foot high berm at North CD-P86 natural overflow point
   - Addition of regional basins with infiltration as-needed through time

*The infiltration rates assumed for the seven basins including CD-P50, CD-P69, CD-P82, CD-P76, Bailey Lake, CD-P85, and CD-P86, are based on the five monitoring sites.

Table IV-4 summarizes the preliminary modeling results for the 7.2" runoff event within the key regional basins that were included in the modeling for the scenario of active infiltration and storage management of the basins.

Table IV-4. Summary of 7.2" Runoff Event Results for Regional Basins, Ultimate Conditions

Basin Number or Name	Year Likely Needed	NWL	HWL	Area at HWL (Ac)	Infiltration Rate (ft/min)	Volume In (ac-ft)	Volume Out (ac-ft)
CD-P69 (Pioneer Dr. Wetland)	Existing	922.0	931.8	22.0	0.0008	880	407 *
South Bailey Lake	Existing	868.5	879.6	129.0	2 cfs	3469	3440
CD-P85	Existing	885.0	915.2	32.2	*0.0009***	3676	1970
North CD-P86	2000	875.6	906.2	60.6	0.0009	2158	20
Armstrong Lake	2000	1018.2	1022.7	66.0	0	284	87
Powers Lake	2000	888.0	894.9	70.0	0	425	1
CD-P28	2005	914.0	922.0	26.0	0.0003	260	18
CD-P42	2005	924.7	930.9	7.0	0.0008	60	10
CD-P43	2005	922.0	928.0	2.8	0.0008	36	0
CD-P74b (Existing Mining Area)	2000	880.0	899.7	19.0	0.0014	671	0
CD-P48	2010	934.0	940.0	9.6	0.0008	164	44
CD-P49	2010	926.5	931.3	4.6	0.0010	77	27
CD-P50 (EV Golf Course)	2010	891.0	912.1	14.5	0.0002	214	7
CD-P74a	2015	892.0	902.5	9.9	0.0008	292	182 *
CD-P74c	2015	926.0	934.7	9.4	0.0008	342	217
CD-P76 (Mile Dr.)	2015	927.0	935.6	25.0	0.0012	247	0
CD-P80	2020	918.0	924.2	20.0	0.0010	513	177
CD-P82 (Co. Rd. 19)	2020	894.0	915.9	34.1	0.0005	488	0
CD-P83	2025	914.0	923.0	9.0	0.0010	133	4
CD-P87	2025	934.0	940.1	33.4	0.0008	379	51
CD-P88	2025	919.0	930.4	12.8	0.0009	201	32
CD-P78	2030	934.0	940.9	54.3	0.0003	782	312
CD-P89/CGR-P92	2025	878.0	884.6	9.5	0.0010	160	0
CGR-P90	ND	914.0	922.4	30.9	0.0004	336	0

*Outflow is routed to CD-P74b, existing mining area/depression.

** Input in the model as a stage-discharge relationship based on collected data as presented in Table IV-2 below. The value shown in the table reflects the average overall value derived from the stage-discharge relationship and is included here for comparison purposes only.

Tables IV-5 and IV-6 summarize the rainfall (6.0") and snowmelt (7.2") preliminary modeling results for the various timing scenarios and levels of management at key locations in the system to provide an overview of how the system behaves under different scenarios.

Table IV-5. Summary of Results at Key Locations – 6.0" Rainfall Event

Waterbody	Init. Water Level [ft]	Woodbury's Plan HWL [ft] *	Lowest Elev. [ft] (house/structure)	Runoff Volume Downstream [Ac.-Ft.] (1)	(2)	(3)	(4)	(5)	HWL [ft] (1)	(2)	(3)	(4)	(5)
Powers Lake	888.0	893.9	898.6	138	244	244	244	244	892.0	893.7	893.7	893.7	893.7
Markgrafs Lake	925.0	928.7	932.2	106	136	136	136	136	927.3	928	928	928	928
Wilmes Lake	901.1	906.5	911 - 912	1066	1239	1220	1220	1220	909.4	909.9	909.8	909.8	909.8
CD-P56 (Preswick Golf Course)	870.0	887.0	900.5	1700	1892	1880	1880	1880	885.7	886.0	886.1	886.1	886.1
Bailey Lake (North & South)	868.5	877.0	883.0	1590	1766	2269	2542	2567	875.2	875.4	877.2	878.7	878.6
CD-P85	885.0	N/A		345	421	766	980	1013	915.1	915.1	915.1	915.1	915.1
CD-P86 (North Lobe)	875.6	N/A	908.6-County Rd.19	0	0	0	0	0	892.9	893.6	897.5	899.0	899.2
CD-P86 (No./So. of Military Road)	895.7	N/A	904.2 - Military Rd. 906.7 - 70th St.	0	0	0	0	0	898.6	898.6	898.6	898.6	898.6

* For a 100-Year, 24-Hour, 6" Rainfall Event

(1) Current conditions. No infiltration and no retrofitting detention assumed except for CD-P85, CD-P86, CD-P50, Pioneer Dr. wetland and Bailey Lake (3 cfs)

(2) 2005 conditions same as (1)

(3) 2010 conditions same as (1)

(4) 2015 conditions same as (1)

(5) 2020 conditions same as (1)

Table IV-6. Summary of Results at Key Locations – 7.2" Snowmelt Runoff Event

Waterbody	Init. Water Level [ft]	Woodbury's HWL [ft] *	Lowest Elev. [ft] (house/structure)	Runoff Volume Downstream [Ac.-Ft.]						HWL [ft]					
				(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
Powers Lake	888.0	893.9	898.6	281	281	376	376	376	376	893.4	893.4	897.2	897.2	897.2	897.2
Markgrafs Lake	925.0	928.7	932.2	248	248	248	248	248	248	929.0	929.0	929.0	929.0	929.0	929.0
Wilmes Lake	901.1	906.5	911 - 912	2410	2410	2490	2490	2490	2490	913.8	913.8	913.9	913.9	913.9	913.9
CD-P56 (Preswick Golf Course)	870.0	887.0	900.5	4130	4130	4335	4551	4551	4551	891.2	891.2	892.2	893.3	893.3	893.3
Bailey Lake (North & South)	868.5	877.0	883.0	4105	4105	4260	4476	5139	5987	881.2	881.2	881.5	882.2	880.9 **	881.4 ***
CD-P85	885.0	N/A		2470	2470	2533	2697	3476	4272	915.3	915.3	915.3	915.3	915.5	915.6
CD-P86 (North Lobe)	875.6	N/A	908.6-County Rd.19	868	297	917	998	1885	2377	901.0	906.4	901.2	901.2	904.2	905.8
CD-P86 (North and South of Military Road)	895.7	N/A	904.2-Military Rd 906.7 - 70th St.	0	0	0	0	0	0	901.0	899.9	900.9	900.9	904.2	905.8

* For a 100-Year, 24-Hour, 6" Rainfall Event

** Upgrade of Bailey Lake L.S. assumed in the modeling (4 pumps, peak pumping rate = 120 cfs) to compensate HWL at Bailey Lake due to no improvements

*** Upgrade of Bailey Lake L.S. assumed in the modeling (5 pumps, peak pumping rate = 135 cfs) to compensate HWL at Bailey Lake due to no improvements

(1) Current conditions. No infiltration and no retrofitting detention assumed except for CD-P85, CD-P86, CD-P50, Pioneer Dr. wetland and Bailey Lake (2 cfs)

(2) Current conditions as defined in (1) plus adding 5' x 350' overflow earth berm at the south end of CD-P86

(3) 2005 conditions. No infiltration and no retrofitting detention assumed except for CD-P85, CD-P86, CD-P50, Pioneer Dr. wetland and Bailey Lake (2 cfs)

(4) 2010 conditions. No infiltration and no retrofitting detention assumed except for CD-P85, CD-P86, CD-P50, Pioneer Dr. wetland and Bailey Lake (2 cfs)

(5) 2015 conditions. No infiltration and no retrofitting detention assumed except for CD-P85, CD-P86, CD-P50, Pioneer Dr. wetland and Bailey Lake (2 cfs)

(6) 2020 conditions. No infiltration and no retrofitting detention assumed except for CD-P85, CD-P86, CD-P50, Pioneer Dr. wetland and Bailey Lake (2 cfs)

IV-D CONCLUSIONS AND RECOMMENDATIONS

The basic analysis presented in the results accounts for snowmelt infiltration rates lower than summer infiltration rates. The modeling includes simulation of the 7.2" snowmelt runoff event which corresponds to roughly two and a half times the runoff volume of the 6.0" rainfall event. The 6.0" rainfall event in 24 hours is the typical 100-year design event that has traditionally been used in the past as the design criteria for the cities' stormwater facilities. Recently the City of Woodbury has begun considering the 7.2" snowmelt runoff event during design. As demonstrated in Table IV-5, for the 6.0" rainfall event the stormwater system with only five managed infiltration areas, including North CD-P86, is capable of handling the 100-year rainfall event from now at least through 2020 with no outflow from of North CD-P86.

The 7.2" snowmelt 100-year event is spread over a longer period of time (10-days), but accounts for a much higher volume of runoff than the 100-year rainfall event (approximately $2^1/_2$ times). In a naturally landlocked watershed such as the SWWD, the large volume events become critical to the system. Table IV-6 shows that with minimal management (only the five infiltration basins), the system could produce outflow out of North CD-P86, likely into South CD-P86 and/or Gables Lake. The outflow could range from 900 acre-feet to less than 300 acre-feet with the addition of one improvement, a berm at CD-P86. Through the year 2020, the volume increases to about 2,400 acre-feet if no additional management is done.

By managing the new development and utilizing natural depressions that exhibit good infiltration capabilities, there is a high potential to significantly reduce the volume downstream at CD-P86. The inclusion of new regional facilities that continue to infiltrate runoff as they naturally do currently can be phased into the system as new development occurs in those areas. The phasing approach will allow new development to be designed around the infiltration areas and could lead to significant cost savings. The tables in Appendix D present the detailed modeling results with active management. The positive impact of infiltration management is shown in Appendix D to the extent that only minimal, if any, outflow would leave CD-P86.

The current stormwater runoff generated in the watershed is being infiltrated naturally within the system with little management or costs being incurred. With designed, managed systems, infiltration can be an important, viable part of the Watershed's system as it addressed flood control protection. The flood control aspects of infiltration are just one of the benefits, since infiltration is very effective at addressing water quality issues, groundwater recharge, and preservation of open space in urbanizing watersheds.

The following recommendations apply to the use of surface water modeling in the future:

- Continue to incorporate new data on infiltration into the model to refine the model and results.
- Review other computer models to determine if another, more versatile, time-dependent model is needed for future analysis and evaluation of the system and management options.
- Calibrate the computer model with actual snowmelt runoff event(s), once data is available, to better define the timing and actual amount of runoff (i.e. is 7.2 inches of runoff realistic) that occurs under this watershed's landform and geologic setting. These parameters will be key to determining if the current analysis is under or over estimating the impacts of snowmelt.
- Identify and model critical detention scenarios to optimize the system for delay and infiltration of runoff.
- Based on the preliminary results, the District should immediately pursue cost-effective options for minimizing the risk of flooding by utilizing critical detention, storage, and infiltration management while overflow options are being considered.
- Determine if the 7.2" spring runoff event is appropriate as the critical event for the system.

V. Groundwater Modeling

V-A HYDROGEOLOGIC SETTING AND CONCEPTUAL MODEL

When discussing groundwater resources in the SWWD it is important to remember that the surface watershed does not correspond to the "groundwatershed". Groundwater flow patterns can be related to surface topography, but groundwater flow patterns may be entirely different than surface water flow patterns, especially in deeper aquifers. Therefore, areas outside the SWWD must be considered in the groundwater analysis. In this case, groundwater features in the entire southern half of Washington County can have an influence on groundwater within the SWWD. Fortunately, there are other regional groundwater studies being conducted in southern Washington County by the Minnesota Science Museum (through a grant from the Legislative Commission on Minnesota Resources), the Minnesota Pollution Control Agency, and the Minnesota Department of Health. Emmons & Olivier Resources has been very involved with these studies. This report draws from the collective body of information that is developing as work progresses throughout the county.

In this report, regional groundwater flow refers to watershed-scale flow patterns, from the area of recharge to the points of discharge, specifically creeks or rivers. The hydrogeologic setting is a description of the various unconsolidated and bedrock units the groundwater passes through as it moves from the recharge area to a creek or river. A conceptual model of this system is a qualitative assessment of regional groundwater flow based on available information about the regional geology and hydrology. This qualitative model is useful for guiding the construction and evaluation of the more rigorous computer model to be presented later. The geologic framework, basic groundwater flow concepts, and the likely hydrogeologic boundaries of the flow system are introduced into the model. The discussion must range beyond the SWWD to include the entire southern half of Washington County, because the groundwater flow system can only be defined within the context of the surrounding regional groundwater flow system.

Major Geologic Units That Affect Groundwater

Aquifers in the Twin Cities metropolitan area include unconsolidated surficial materials overlying lower bedrock units, separated by variably leaky confining units (Kanivetsky and

Cleland, 1990; Mossler and Bloomgren, 1990). These aquifers are, from youngest to oldest, the surficial Quaternary aquifer, the St. Peter aquifer (Ordovician sandstone), the Prairie du Chien aquifer (fractured Ordovician dolostone), the Jordan aquifer (Cambrian sandstone), the Franconia aquifer (Cambrian dolostone), the Ironton-Galesville aquifer (Cambrian sandstone), and the Mount Simon aquifer (Cambrian sandstone). The bedrock units dip to the west and so rise progressively in elevation from west to east across the county. The rise steepens near the mouth of Valley Creek, where the bedrock forms the Hudson-Afton anticline (an upward fold), which brings the deeper bedrock units to some of their highest elevations in the county. In southern Washington County, the uppermost bedrock aquifer, the St. Peter, has patchy distribution across the county, as portions were evidently eroded away in earlier times. The lower bedrock aquifers are generally extensive across southern Washington County, except in bedrock valleys cut in pre-glacial times that are now commonly filled with glacial drift of sometimes high permeability. Quaternary drift covers most of the county, except in the most southeastern part of the county which was beyond the extent of the last glacial advance. This area has only a thin layer of unconsolidated materials overlying bedrock (Meyer and others, 1990).

Mapping of Groundwater Levels in Aquifers

In this study, potentiometric surfaces were mapped from several data sources. These maps are found in Appendix E. For the Quaternary aquifer, the potentiometric map was developed from the elevations of surface-water bodies (perennial lakes, wetlands, and streams) as depicted on 1:24,000 topographic maps of the area. The implicit assumption is that these water bodies are contiguous with the water table, and that the heads indicated by this inferred water-table surface are representative of those deeper in the Quaternary deposits. That is, we assumed that most perennial water bodies are not perched and that vertical head gradients are small compared to horizontal gradients. For each of the underlying bedrock aquifers, static water levels of wells were used to determine the potentiometric surface. A file of well locations in Universal Transverse Mercator coordinates was merged with a file of static water level readings for each well by matching unique well identification codes (Minnesota Geological Survey, personal communication). The resultant file was sorted according to the aquifer in which the well was screened. Base maps for Washington County were produced with ArcView geographic information system (GIS) software. For each aquifer, data points were plotted on this base map and labeled with their water levels. Water elevations in each aquifer were contoured by hand, as opposed to using electronic contouring programs. On the resulting contour maps of potentiometric surfaces, groundwatersheds were delineated for each aquifer by hand-tracing groundwater divides as indicated by the contour lines.

The reader is cautioned that the maps of potentiometric surfaces are interpretations of point data, the quality and spatial distribution of which are variable. Static water levels of wells were taken from drillers' logs collected over many years and subject to prevailing conditions in the aquifer at that time, artifacts due to drilling, and the judgment of the driller. Determination of the overlying stratigraphy and screened aquifer is subject to interpretation of well logs by Minnesota Geological Survey personnel.

Infiltration and Groundwater Recharge

Groundwater recharge derives from precipitation (including snowmelt) that is in excess of losses to evapotranspiration and overland runoff. Recharge can occur over the entire landscape but is especially prone to occur on relatively level areas with coarse soils and closed drainages, such as the glacial outwash plains that are extensive in Washington County. The infiltrated water percolates vertically through the Quaternary (or other surficial) deposits to the water table, where it begins to flow via hydraulic head gradients mostly horizontally through the aquifers (and perhaps vertically through some of the confining units) to the points of discharge. The major points of discharge are rivers and streams; wells are also points of discharge but generally have negligible influence on groundwater flow patterns unless the pumping rate is extremely high. In Washington County, the St. Croix River to the east and the Mississippi River to the south and west are the major points of discharge for regional groundwater flow, although tributary streams such as Valley Creek can also be significant. Discharge to these streams and rivers essentially drains water from the aquifers, thereby lowering the water table and potentiometric surfaces of deeper aquifers in the vicinity of streams and rivers. Consequently, the water table and potentiometric surfaces of deeper aquifers are mounded in the central part of the county and slope toward the streams and rivers. As a result, groundwater in central and southern Washington County generally flows from the central part of the county outward toward the major rivers to the east, south, and west. The depth of groundwater flow is not well known, but water from the central part of the county may penetrate to the deeper bedrock aquifers before moving toward the St. Croix or Mississippi Rivers, where it must migrate vertically back upward to discharge. Water that recharges closer to the rivers may only penetrate to the uppermost aquifers before reaching the discharge point.

V-B BACKGROUND ON ANALYTIC ELEMENT GROUNDWATER MODELING

Analytic element groundwater modeling (Strack, 1989) is a method to mathematically simulate groundwater heads (elevations) and flow in a computer. Input to the model consists of geologic and hydrologic data. The basic geologic data consists of the elevations and permeabilities the various aquifers and confining units. The hydrologic data includes the recharge rate (e.g., the centimeters of water that percolates down to the water table each year over the watershed) and the elevations of known points of discharge, namely the major rivers and creeks. Other features such as wells with known pumping rates and lakes with estimated water balances can be added. The model then calculates the potentiometric surface for each aquifer, the amount of discharge reaching the creeks and rivers, and the groundwater flow paths and travel times.

The analytic element method works by creating mathematical functions that simulate the geometry and hydrology of various hydrological features that occur in aquifers or at their boundaries. Each of these features becomes an "analytic element" in the model. Each element has a geometry appropriate to the type of feature being simulated: wells are represented by points; small streams are represented by linked line segments; and larger water bodies, areas of recharge, areas of different aquifer permeability, and areas of leakage between aquifers are represented by polygons.

One advantage of analytic element models over other types of groundwater models is that very detailed information for an area of interest can be easily added to a regional model that serves as a starting template. Groundwater flow systems interact over very large areas, and a model of a local area must mesh with the regional flow pattern to be realistic. One disadvantage (at present) is that the analytic element method is limited to steady-state conditions, i.e., conditions that do not change over time. For example, if the recharge rate suddenly decreased because of a change in climate, an analytic element model could not simulate the rate of change as the water table dropped; it could, however, estimate the final position of the new water table in response to the drier climate.

Mathematical groundwater models differ from actual field conditions in several ways. First, the subsurface geometry and hydraulic variables of subsurface geologic strata are difficult to determine and must be estimated from well logs. Even if the geometry and hydraulics of various aquifers and confining beds were known perfectly, the model could never replicate the complexity that exists in the real world. Thus, the model must necessarily simplify the geologic framework, which is probably the largest source of error in groundwater models. Second, the equations cannot perfectly simulate all types features in the aquifer. Simplifying assumptions must be made in order for the groundwater-flow equations to be solvable. These errors can become apparent near the edges of some analytic elements but are generally not significant in affecting the regional pattern of groundwater flow. Third, the actual amounts of groundwater flowing through the system can be difficult to estimate, namely, how much water recharges the aquifer system each year? Recharge is an episodic event that is difficult to measure at any one point on the landscape and is extremely variable over an area. One of the best ways to obtain a spatially averaged estimate of recharge is by calibrating a groundwater model to known baseflows of creeks. In the SWWD this is not possible because there is only one stream that has any consistent base flow, running through the Cottage Grove Ravine. The flow of the Mississippi River and especially the St. Croix River is difficult to gauge. The flow data is of limited use for this model because both rivers receive ground water discharge from the opposite banks, which are outside the domain of this ground water model.

V-C ANALYTIC ELEMENT GROUNDWATER MODEL

The regional groundwater studies being conducted by state agencies and other watershed districts in Washington County also include analytic element groundwater models. One great advantage of this modeling method is that data may be relatively easily transferred from one regional model to another regardless of scale. Therefore, the SWWD model benefits from having a wealth of calibration data and other data that might not normally be available. The only disadvantage is the extra computational time required to run the model, but this was not significant.

Modeling groundwater flow for the SWWD area consisted of three steps: model construction, model calibration, and model application. The model was based upon known geologic and hydrologic data for the area. The geologic data were used to construct the basic model geometry of stacked aquifers and confining beds. The hydrologic data were used for calibration of the model. That is, the known potentiometric surfaces and baseflows of creeks in the vicinity of SWWD were the “targets” that the model tried to simulate. The hydraulic properties of these geologic units were then adjusted to obtain a good fit to the hydrologic calibration data.

Model Construction

Background

The MPCA has constructed a regional groundwater flow model for the Twin Cities Metropolitan Area (the “Metro Model”; MPCA, 1997), including the SWWD. Their model uses coarse analytic elements to simulate regional groundwater flow patterns. The SWWD Groundwater Model used the Metro Model as a template. Additional analytic elements were added to the template to refine the model to fit local hydrogeologic features and observed data. The computer code used for the Metro Model and the SWWD Groundwater Model was MLAEM v.5.02 (Strack Consulting, 1997).

Domain

The MLAEM model has an infinite areal domain. That is, boundary conditions do not need to be imposed at the edges of the model. For practical purposes, inputs to the model have been limited to a domain bounded by the Phalen Channel and Mississippi River to the west, the Mississippi River to the south, the St. Croix River to the east, and the approximate extent of the St. Peter Sandstone to the north. The boundaries are shown, along with the bedrock geology, on Figure

V-1. The Mississippi and St. Croix Rivers represent no-flow boundaries, but the other boundaries are more arbitrary.

Layers

The Metro Model consists of five horizontal layers representing major aquifers in the area. The layers are numbered 1 to 5 from the top down. The layers are separated by four "leaky layers" that represent confining layers or leaky confining layers between the aquifers. The Metro Model is more completely described in the Metro Model Interim Progress Report (MPCA, 1997).

The SWWD Groundwater Model uses only layers 1, 2, and 3 of the Metro Model. The layers and leaky layers are as follows (descriptions include excerpts from MPCA, 1997):

- Layer 1 represents an aquifer of unconsolidated glacial materials throughout the model domain. Groundwater recharge occurs at the top of this layer through infiltration. Water losses from this aquifer are to surface water streams and to the underlying aquifer via leakage.
- Leaky Layer 1 represents the basal unit(s) with vertical hydraulic resistance underlying the lower-most glacial drift aquifer. This leaky layer represents the effects of one or more of the following: glacial till, Decorah Shale, Platteville Limestone, and the Glenwood Shale. Therefore, its location is dependent on the areal distribution of these units.
- Layer 2 represents groundwater flow through the St. Peter Sandstone. Most recharge to the St. Peter Sandstone aquifer is expected to come from overlying drift materials in areas where the overlying bedrock layers are absent. Discharge of groundwater from this layer occurs through leakage to underlying units and discharge to surface waters. Where the land-surface elevation drops near the rivers and the St. Peter Sandstone is not present, Layer 2 represents the unconsolidated glacial materials at the surface.
- Leaky Layer 2 represents the base of the St. Peter Sandstone, which provides significant vertical hydraulic resistance. Where the St. Peter Sandstone is not present, Leaky Layer 2 represents the basal unit(s) with vertical hydraulic resistance underlying the lower-most glacial drift aquifer.

- Layer 3 represents groundwater flow in the Prairie du Chien-Jordan Aquifer, and includes both formations as one hydrostratigraphic unit. Recharge to this aquifer occurs as leakage from overlying bedrock units and also from the glacial drift where the formation subcrops beneath it. The Mississippi and St. Croix Rivers serve as major discharge zones for this aquifer.
- Leaky Layer 3 represents the St. Lawrence Formation. This formation serves as an impermeable aquiclude everywhere in the SWWD Groundwater Model domain, except in the area of the St. Croix anticline described below.

The glacial and bedrock units are represented by simplified polygons in the model, especially where the units are not present everywhere in the model domain. Figure V-2

shows the polygons that represent the bedrock units. Figure V-2 can be compared to Figure V-1 to see the relationship between the model elements and the mapped bedrock units. Figure V-3 shows an idealized cross section through the southern part of Washington County. Figure V-3 illustrates the relationship of the model layers to the topography and the bedrock valley (discussed below).

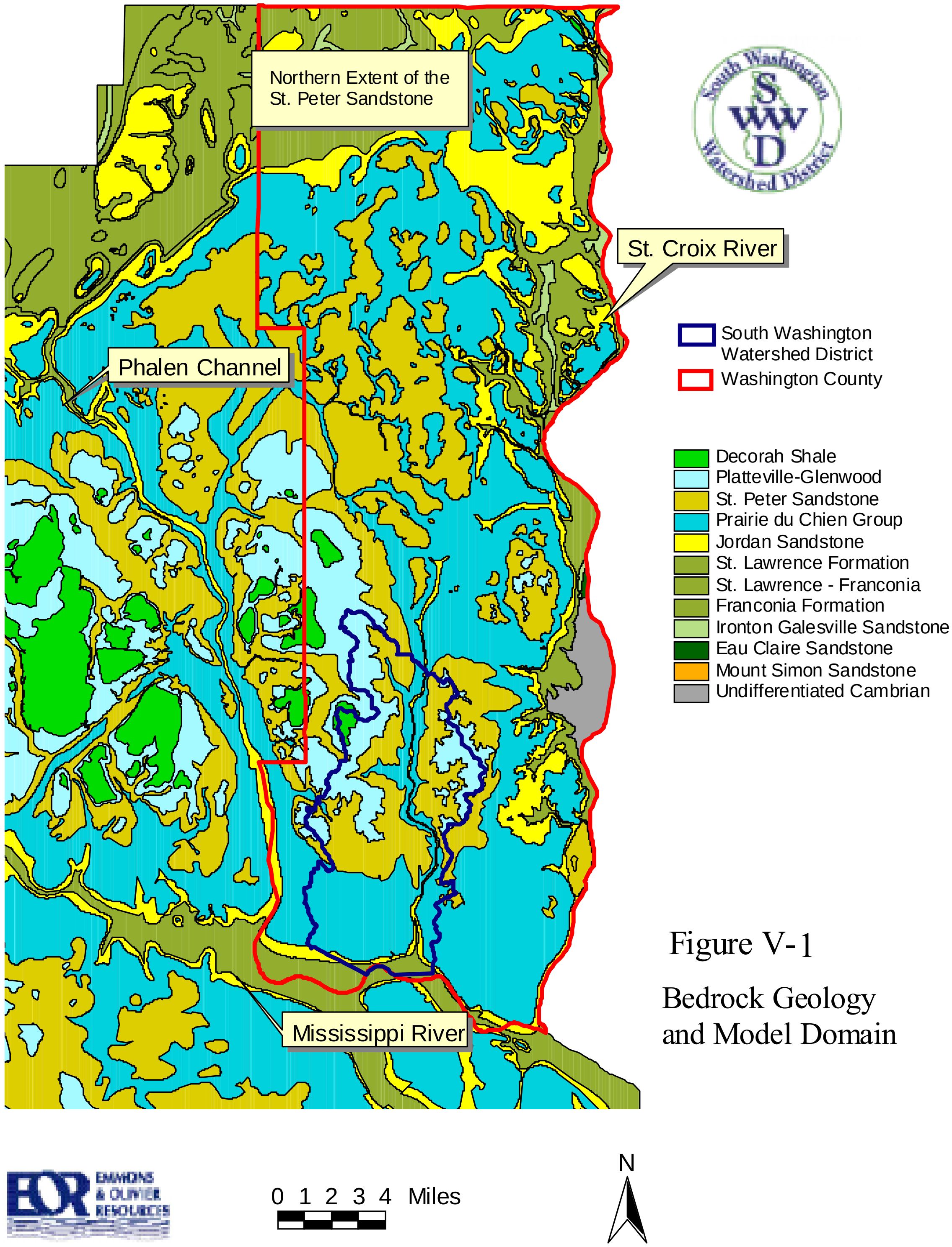


Figure V-1

Bedrock Geology
and Model Domain

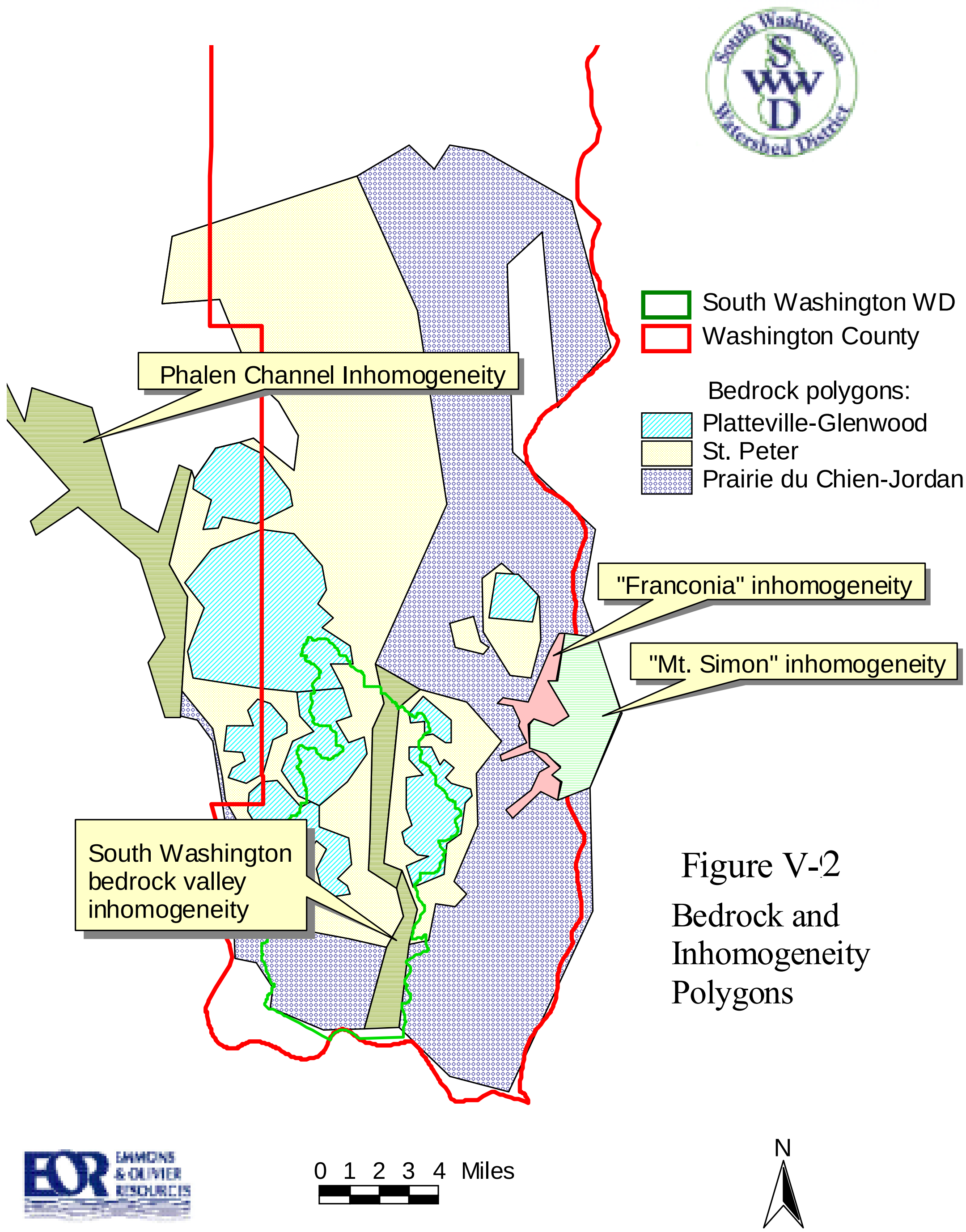
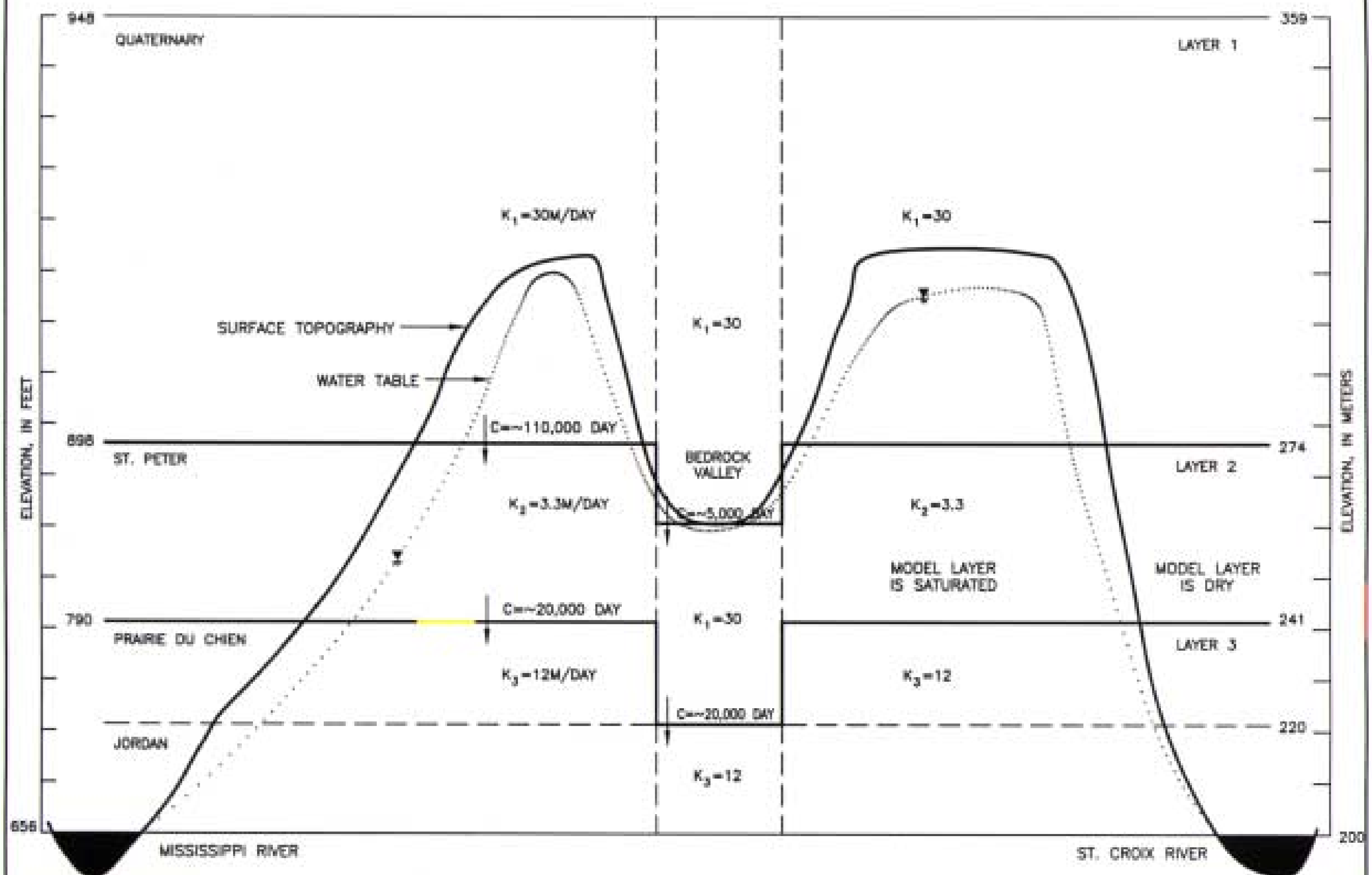


Figure V-2

Bedrock and Inhomogeneity Polygons



EMMONS & OLIVIER RESOURCES
3825 LAKE ELMO AVENUE NORTH
LAKE ELMO, MINNESOTA 55042
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SOUTH WASHINGTON WATERSHED DISTRICT

GENERALIZED CROSS–SECTION AND MODEL CONFIGURATION

EOR PROJECT #: SWWD	FILENAME: X-SECTION.DWG	DATE: 04/26/98

FIGURE V-3

Aquifer Properties

The aquifer properties that can be varied throughout the model domain are the permeability (or hydraulic conductivity), thickness, base elevation, porosity, and vertical leakage. Figure V-3 shows some of the values that were used and how they relate to the model elements. The permeability values were taken from the Washington County Geologic Atlas and the Metro Model. Values did not vary significantly within individual formations except in a few areas where data such as well discharges or stream baseflow were known. The thickness and base elevation of each geologic formation (and model layer) were taken from the Washington County Geologic Atlas. Adjustments were made in key areas near the South Washington Bedrock Valley (discussed below) where recent drilling had provided new data on the elevation of the Prairie du Chien bedrock. Very little data regarding the porosity of aquifer materials is available. A default value of 0.3 was used everywhere. The model simulated vertical leakage into and out of each layer by assigning resistance values to the bordering leaky layers. Polygons were created to represent different geologic formations within the leaky layers, as shown on Figure V-2. "Resistance varels" were assigned to each polygon. The amount of water moving into or out of the model is dependent on the resistance value and the difference in head between the layers. Very little data are available on resistance values because they are virtually immeasurable in the field. A broad range of values has been compiled as a result of developing the Metro Model. Consequently, the resistance values vary significantly in different parts of the model.

Inhomogeneities

Inhomogeneities (also called heterogeneities) are areas within a model layer where the permeability, base elevation, thickness, and/or porosity vary from the rest of the layer. Four inhomogeneities have been added to the model:

1. The Phalen Channel is a bedrock valley filled with relatively high-permeability glacial deposits. It trends north-south through St. Paul on the west edge of the model domain.
2. The South Washington Bedrock Valley is another bedrock valley filled with relatively high-permeability glacial deposits. It trends north-south through Woodbury and Cottage Grove.

The St. Croix Anticline (sometimes called the Hudson-Afton Anticline) is a structural feature that underlies Valley Creek on the east edge of the model domain. In this area the older sedimentary formations are at a relatively high elevation and subcrop below the glacial deposits. Two inhomogeneities have been defined:

3. The "Franconia" inhomogeneity extends from the edge of the Jordan Sandstone to the edge of the Franconia formation. This area is characterized by groundwater flow through the Franconia formation and the relatively thick overlying glacial deposits.
4. The "Mt. Simon" inhomogeneity extends from the edge of the Franconia formation to the St. Croix River. This area is characterized by groundwater flow through very thick glacial deposits. Several bedrock units including the Mt. Simon Sandstone subcrop below these glacial deposits and are locally important sources of groundwater. The bedrock units lie mostly below the bottom elevation of Model Layer 3. Because the model in this area is primarily concerned with shallow groundwater flow, the deeper bedrock units were not incorporated into the model.

Reference Elevation

The reference elevation is necessary to complete the mathematical equations in the Analytic Element Model. The SWWD Ground model uses the reference elevation established for the MPCA Metro Model. The reference point is located in Iowa, far away from other elements in the model, and has negligible influence on the model solutions.

Rainfall Infiltration and "Superblocks"

Rainfall infiltration is the precipitation that eventually reaches the saturated aquifers. A rainfall infiltration value of 6 in/yr (0.00042 m/d) was used throughout the model area.

The model layers are at the same elevation throughout the model domain except in the South Washington Bedrock Valley inhomogeneity. Changes in surface elevation result in areas where one or more of the upper model layers is above the ground surface. Figure V-4 shows where the top and bottom of the model layers intersects the ground surface. In areas where Layer 1 is above the ground surface, the model's rainfall infiltration is added to Layer 2. In areas where Layer 1 and Layer 2 are above the ground surface, the model's rainfall infiltration is added to Layer 3. The rainfall infiltration is added to the model via polygons and constant strength elements defined on the tops of the appropriate model layers. Figure V-5 shows the location of the rainfall polygons.

For purposes of calibration, it is useful to have the model simulate groundwater flowing to the St. Croix and Mississippi Rivers from all directions. Similarly, the model should simulate regional groundwater flow beyond the model domain to the north and northwest. To accomplish this, infiltration was added to model layers 2 and 3 via large scale "superblocks" shown on Figure V-5. The superblocks very crudely simulate precipitation and groundwater flow in these outer regions, and they help to create an accurate simulation of conditions near the domain boundaries.

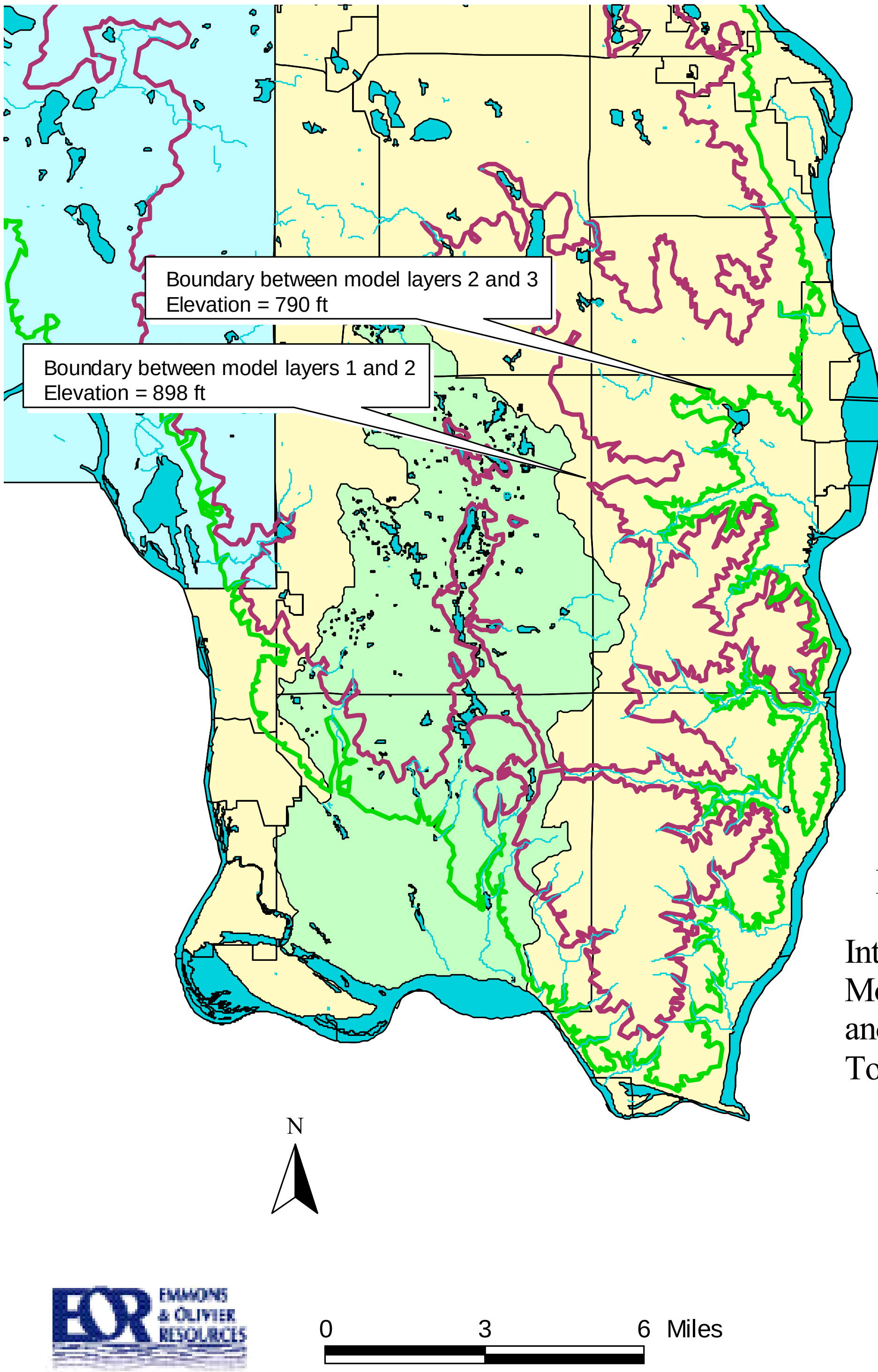


Figure V-4

Intersection of Model Layers and Surface Topography

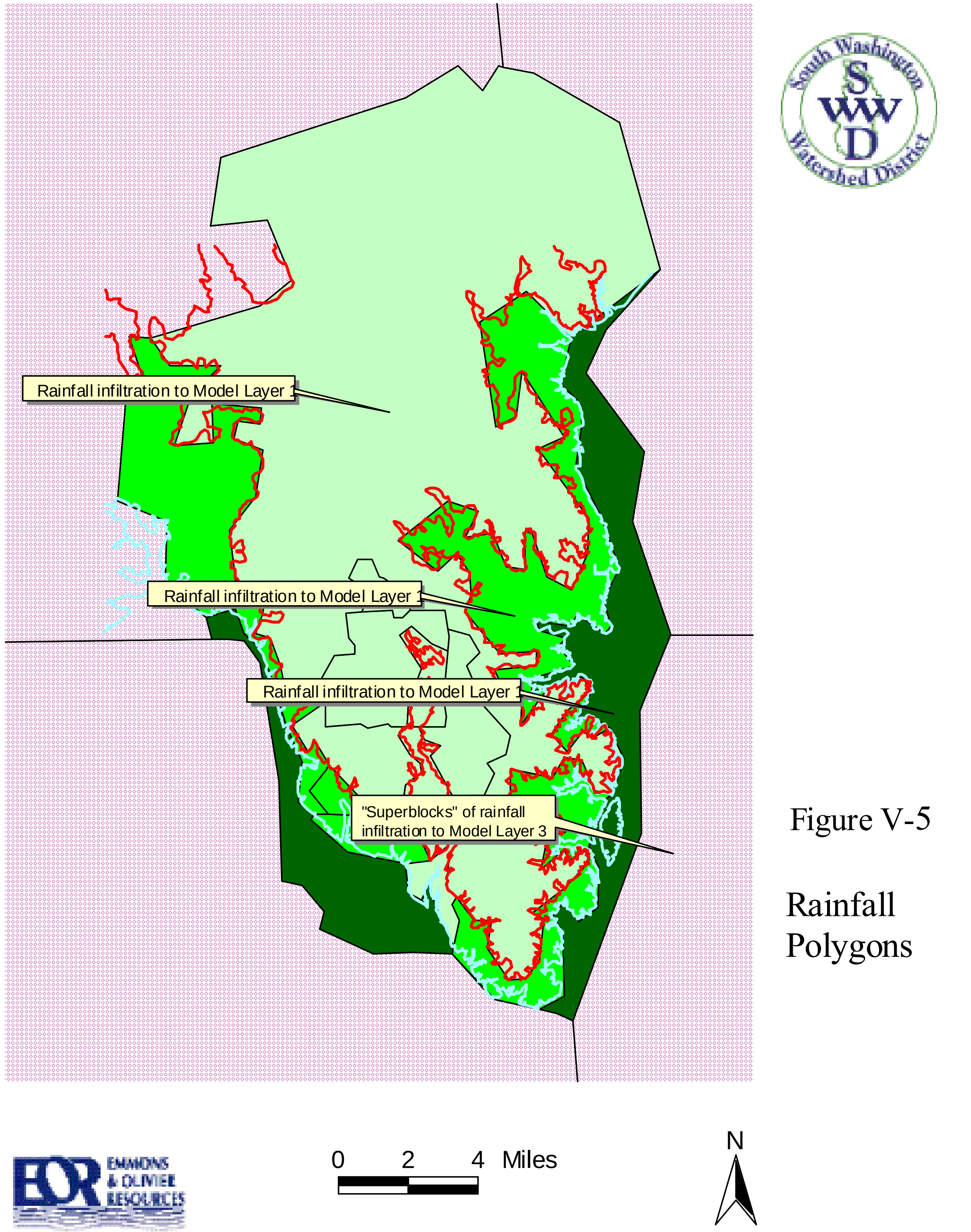


Figure V-5

Rainfall Polygons

Ponds, Lakes, and Wetlands

The need for computational efficiency dictates that only the largest ponds, lakes, and wetlands are added to the model. These surface water bodies were added as polygons to the top of the appropriate model layer, depending on their elevation. The polygons are shown on Figure V-6. "Resistance varels" were added to the surface water polygons. The varels specified a head and bed resistance within each polygon. A relatively low resistance of 5000 days was used as the default value. Elevation data were obtained from USGS topographic maps or more recent measurements by the Minnesota DNR and others, if available. The effect of the varels is to allow water in the model to flow freely into or out of the polygons depending on the head in the underlying aquifer, similar to a "fixed head" model element. Perched conditions could be created in the surface water bodies by increasing the resistance value.

Rivers and Streams

Rivers and streams in the model, including the Mississippi and St. Croix Rivers, were simulated using curvilinear elements. The elements were assigned head values at known locations. Locations of the curvilinear elements are shown on Figure V-6.

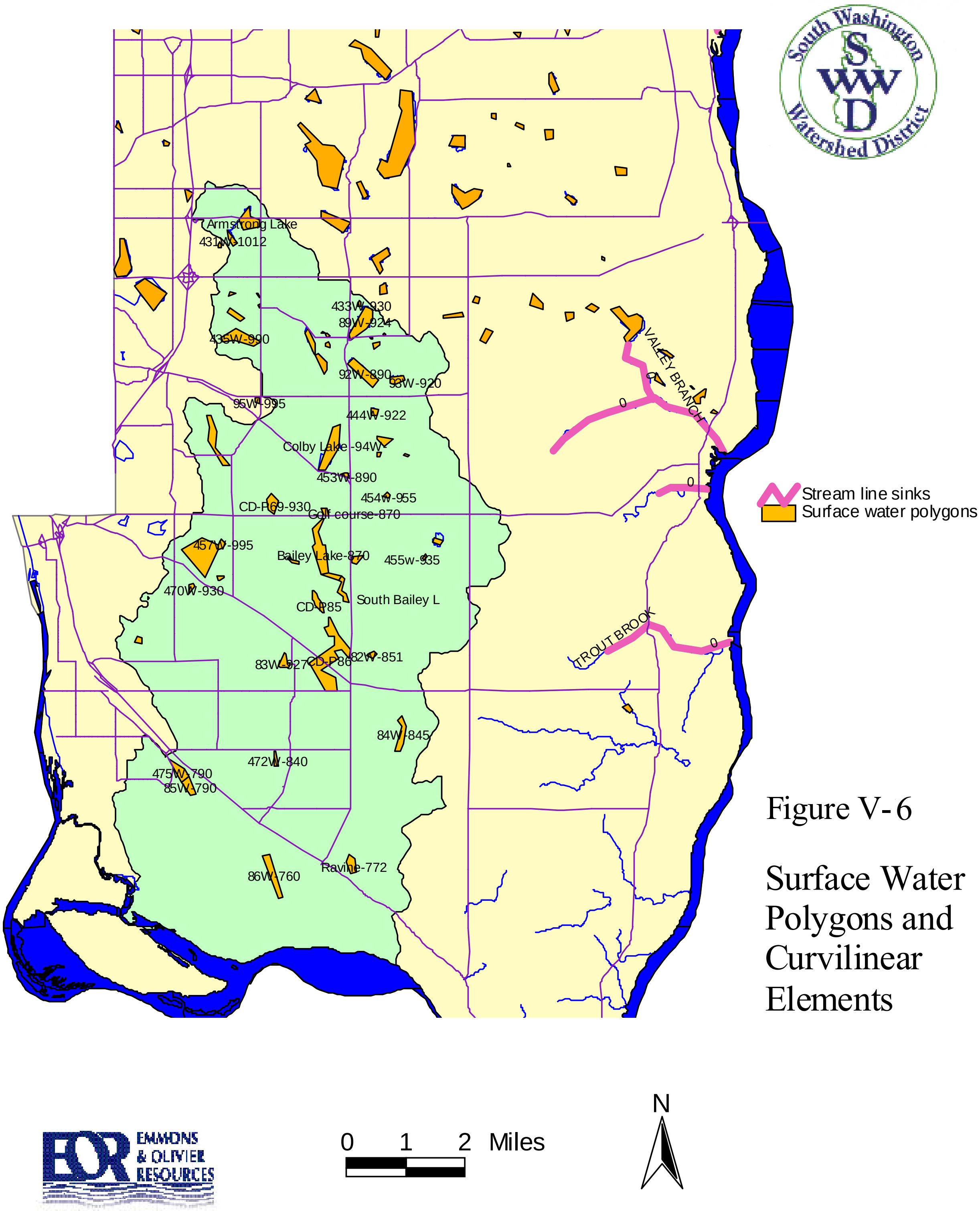


Figure V-6

Surface Water Polygons and Curvilinear Elements

Model Calibration

Calibration of the model was conducted in two ways: (1) comparing measured baseflows and calculated groundwater discharges to streams, and (2) comparing measured and calculated hydraulic heads.

Baseflow Calibration

The SWWD model is part of a larger groundwater flow model that covers most of Washington and Ramsey Counties. The model was calibrated to baseflow data from several small streams including Valley Creek, Trout Brook, and Brown's Creek. Within the SWWD there are no streams with a consistent baseflow. No data are available for baseflow rates of the stream that runs through the Cottage Grove Ravine. Baseflow data for the Mississippi and St. Croix Rivers are difficult to determine due to their large watersheds and many large tributaries. Therefore, data from those rivers are not commonly used for model calibration. Calibration data for other streams outside of the SWWD are included in Appendix F.

Head Calibration

The potentiometric maps found in Appendix E provided a quick visual check on how well the computer model was simulating the hydraulic heads in each aquifer. For actual model calibration, however, a subset of hydraulic heads at selected points was chosen for each aquifer from the maps, and model results were checked numerically against these control points. Several statistical methods are applicable to define how well the predicted heads correlate to the observed heads. A detailed analysis of the calibration is included in Appendix F.

V-D RESULTS

The predicted heads produced by the model for each layer are shown on Figures V-7 through V-9. These results are an important intermediate step and will be used as a "platform" for further analysis. Predictions of future groundwater conditions will be based on these results, and the predicted conditions will be compared against these baseline conditions. The effects on groundwater and surface water infiltration at specific locations is examined in the following section – Model Interactions.

The model input parameters give important information about the water balance and aquifer properties throughout the model domain, such as hydraulic conductivity, resistance between aquifers, and infiltration rates throughout the area. Input files for the SWWD Model are included in Appendix G, and some aquifer parameters are shown on the cross section in Figure V-3.

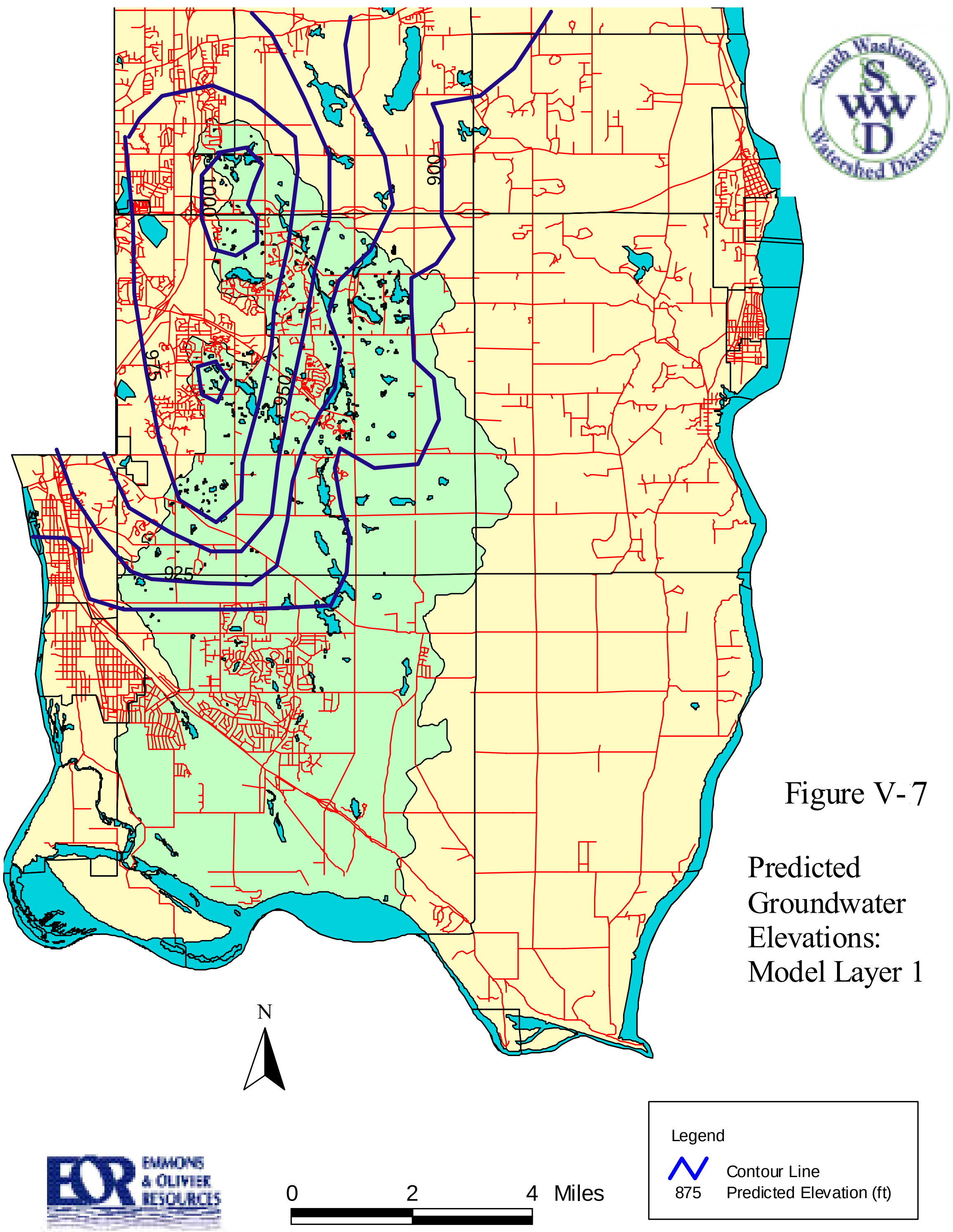


Figure V- 7

Predicted Groundwater Elevations: Model Layer 1

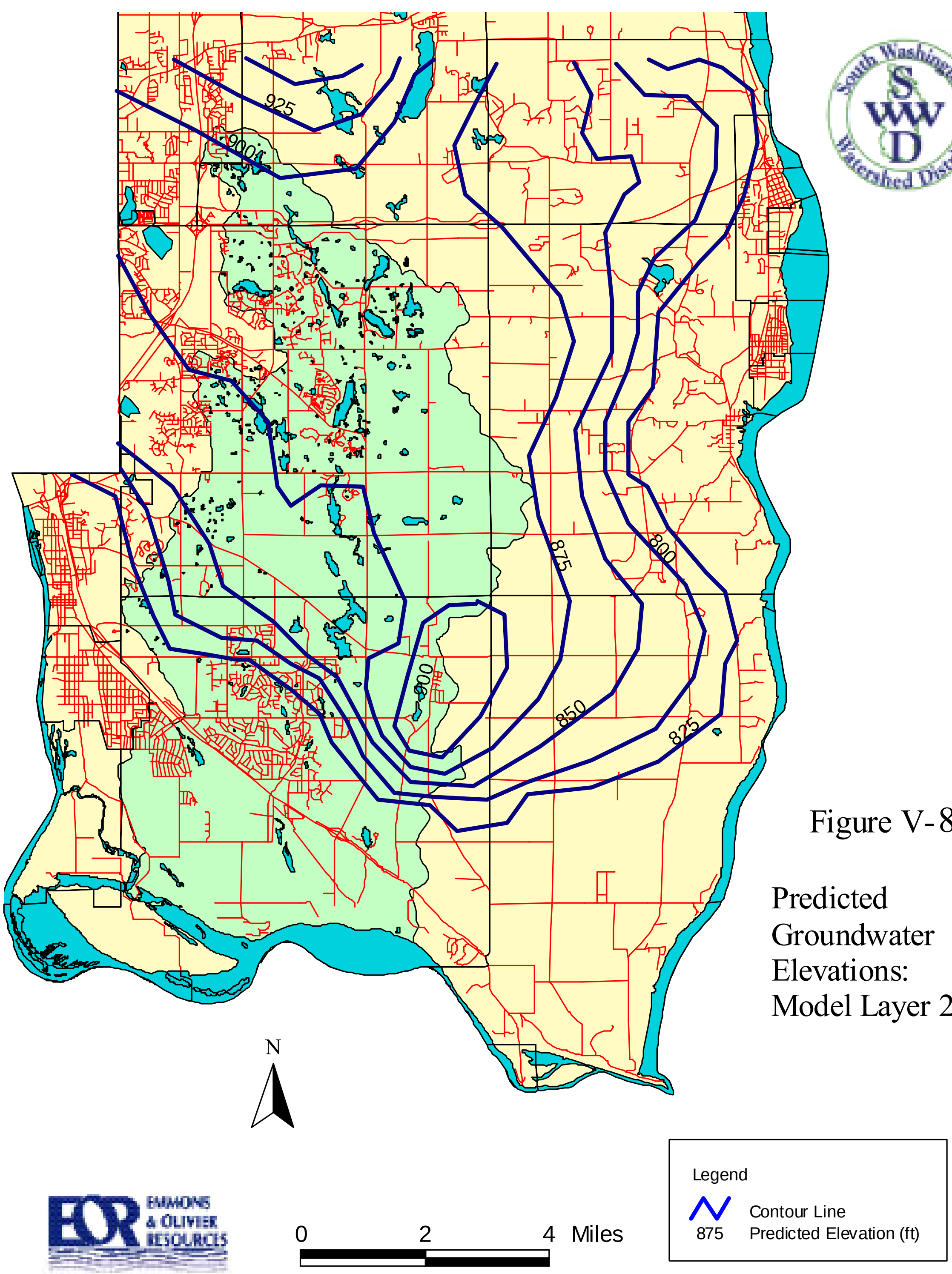


Figure V-8

Predicted Groundwater Elevations: Model Layer 2

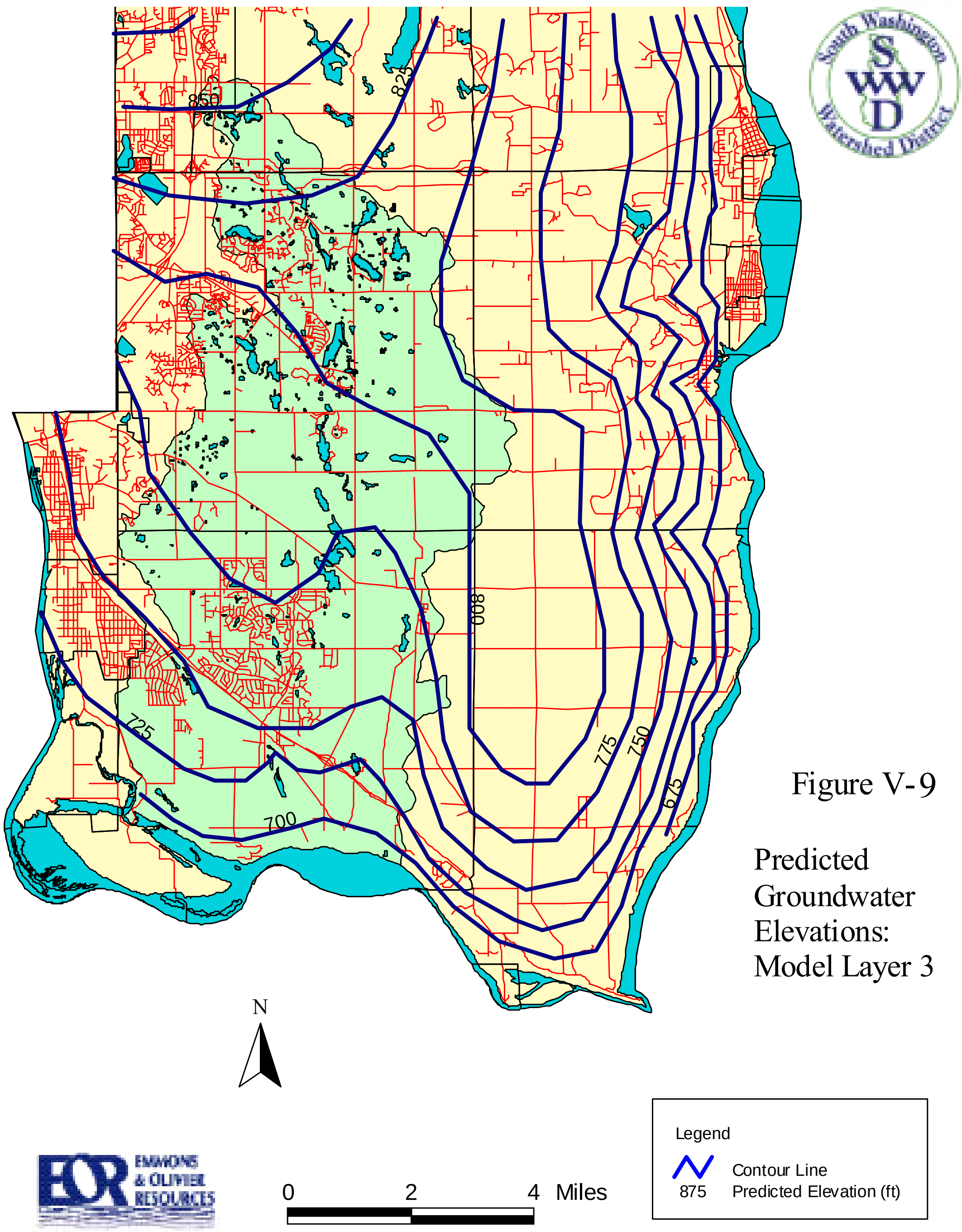


Figure V-9

Predicted Groundwater Elevations: Model Layer 3

V-E Conclusions and Recommendations

The model results provide some useful insights into groundwater movement throughout southern Washington County. Some conclusions that can be drawn from this model include:

- The material that fills the buried bedrock valley has a very high hydraulic conductivity and transmissivity.
- The bedrock valley has a significant impact on groundwater flow patterns, channeling large volumes of water southward toward the Mississippi River.
- There is a large vertical gradient downward throughout most of the model area. Regional groundwater flow is downward from the water table to deeper aquifers before being discharged to the Mississippi and St. Croix Rivers.

Additional conclusions related to the groundwater model are discussed in the following section on interaction of models. The model results obtained here are generally good, but they can be improved as additional data become available. The model should be updated as other groundwater issues are examined. For example, the city of Cottage Grove and the Minnesota Department of Health will be conducting wellhead protection analyses for the Cottage Grove municipal water supply. This model will be used to define the capture areas of the municipal wells. The model will be updated based on additional data that will become available (i.e. age dating of groundwater samples).

As conditions change throughout the watershed the model should be used to predict the impact on groundwater resources. For example, further development in Woodbury and Cottage Grove will impact regional infiltration rates and groundwater flow patterns. Also, if pumping of the barrier wells at the Historic Woodbury Landfill is reduced or stopped, groundwater flow patterns throughout the area around CD-P85 will be significantly altered, as discussed in the following section.

VI. Surface Water-Groundwater Interactions and Modeling

VI-A. INTERACTION PROCESS

The surface water model was constructed to analyze how stormwater would move through the watershed's system of culverts, lakes, and infiltration basins. The groundwater model was constructed to analyze how stormwater would move after it infiltrated to the subsurface system of aquifers. Coupling the two models creates a comprehensive analysis tool for water movement throughout the watershed.

Very few mathematical models exist that incorporate both surface water and groundwater flow. Even fewer have commercially available software. Therefore, an approach was developed where critical parameters from the surface water model are incorporated into the groundwater model "by hand" rather than automatically. The critical parameter in the surface water/groundwater interaction is infiltration rates at the infiltration basins.

Three groundwater model results relating to infiltration were of particular interest:

1. Groundwater levels away from the basin.
2. Groundwater flow patterns. Wells draw their water from "capture zones" around the wells. Infiltration influences groundwater flow patterns and can change the capture zone of a well.
3. The development of a groundwater mound below infiltration basins. The elevation of the water table will rise to accommodate a local increase in infiltration. If the resulting mound rises close enough to the surface, it can become a limiting factor for the infiltration rate. The groundwater mound dissipates when infiltration is stopped.

Groundwater levels and flow patterns away from the basins were analyzed using the MLAEM steady-state (not time-dependent) model discussed in the previous chapter. The development of the groundwater mound below the basin was analyzed using a transient (time dependent) analytical model

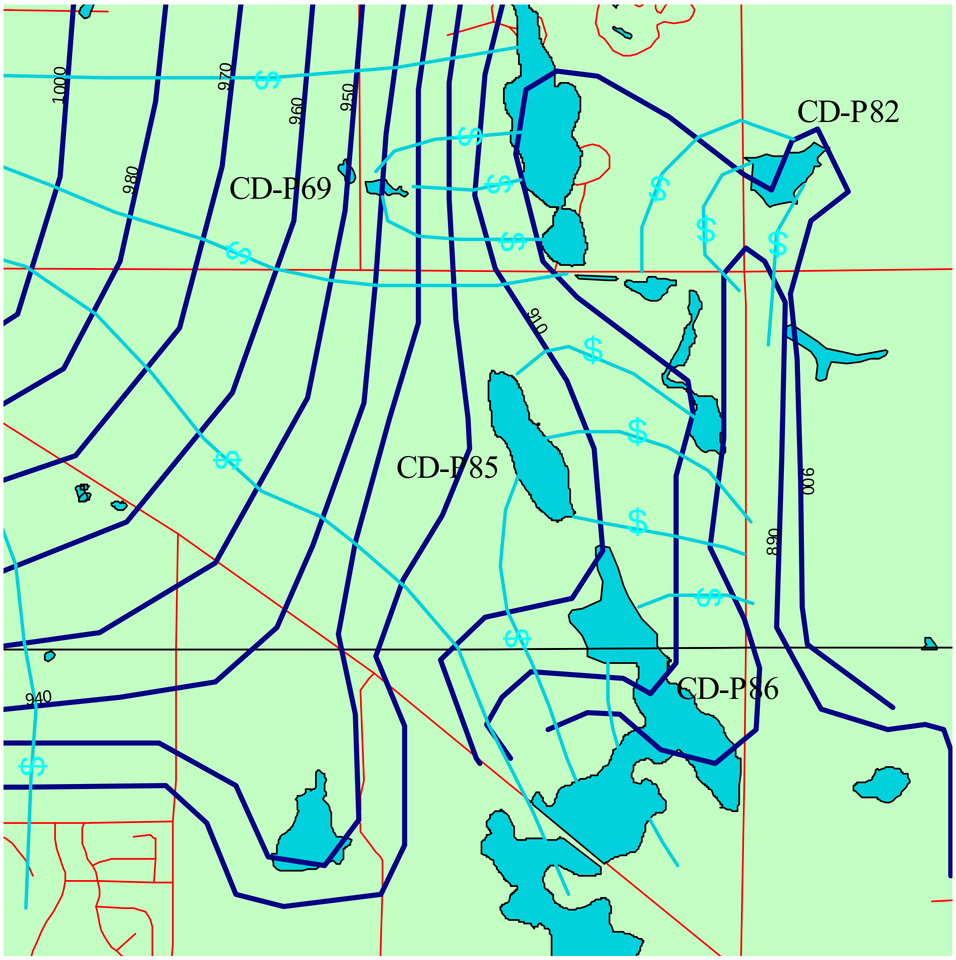
VI-B. GROUNDWATER LEVELS AND FLOW PATTERNS

Groundwater levels and flow patterns were analyzed using the MLAEM model described previously in this report. High water levels used in the surface water model were imposed on the groundwater model. Table IV-1 identifies these water levels and infiltration rates. The predicted groundwater elevations were used to evaluate groundwater flow patterns when the maximum infiltration is occurring. Much of the groundwater levels assumed in the groundwater modeling are from observed groundwater levels in recent years. The analysis of a critical surface water event and interactions with the groundwater system are being analyzed with groundwater data from what appears to be a historic high in groundwater levels for a combination of historic highs in both surface waters and groundwater conditions.

Model results for the areas around the basins are shown on Figures VI-1 through VI-3. No problem areas of elevated groundwater levels were identified. Groundwater elevations and flow patterns around CD-P50 (Eagle Valley Golf Course) and CD-P76 (Pioneer Drive) were not significantly altered, so they were not included on the figures. The area of South Bailey Lake (Figure VI-1) shows groundwater levels higher than the normal pool elevation. This is not considered a problem since during such a dramatic infiltration event the water level in Bailey Lake would also have risen dramatically.

The groundwater modeling results on Figure VI-1 through VI-3 show the infiltrated water being discharged to nearby surface water bodies and wells. It is important to note that much of the infiltrated water will migrate vertically downward to lower aquifers (and lower model layers), as discussed in earlier sections of this report. As the water migrates through the layers, its flow path may change directions several times until it is ultimately discharged to a well, lake, or the Mississippi or St. Croix River.

While the results show that groundwater flow patterns in the area of the basins will be altered, no problem areas were identified. The conditions simulated in this analysis will probably never occur because the high water levels are transient and would recede before the simulated steady-state flow patterns could be established. Nevertheless, the analysis is useful for examining the range of conditions that might arise due to increased infiltration in the basins.



N

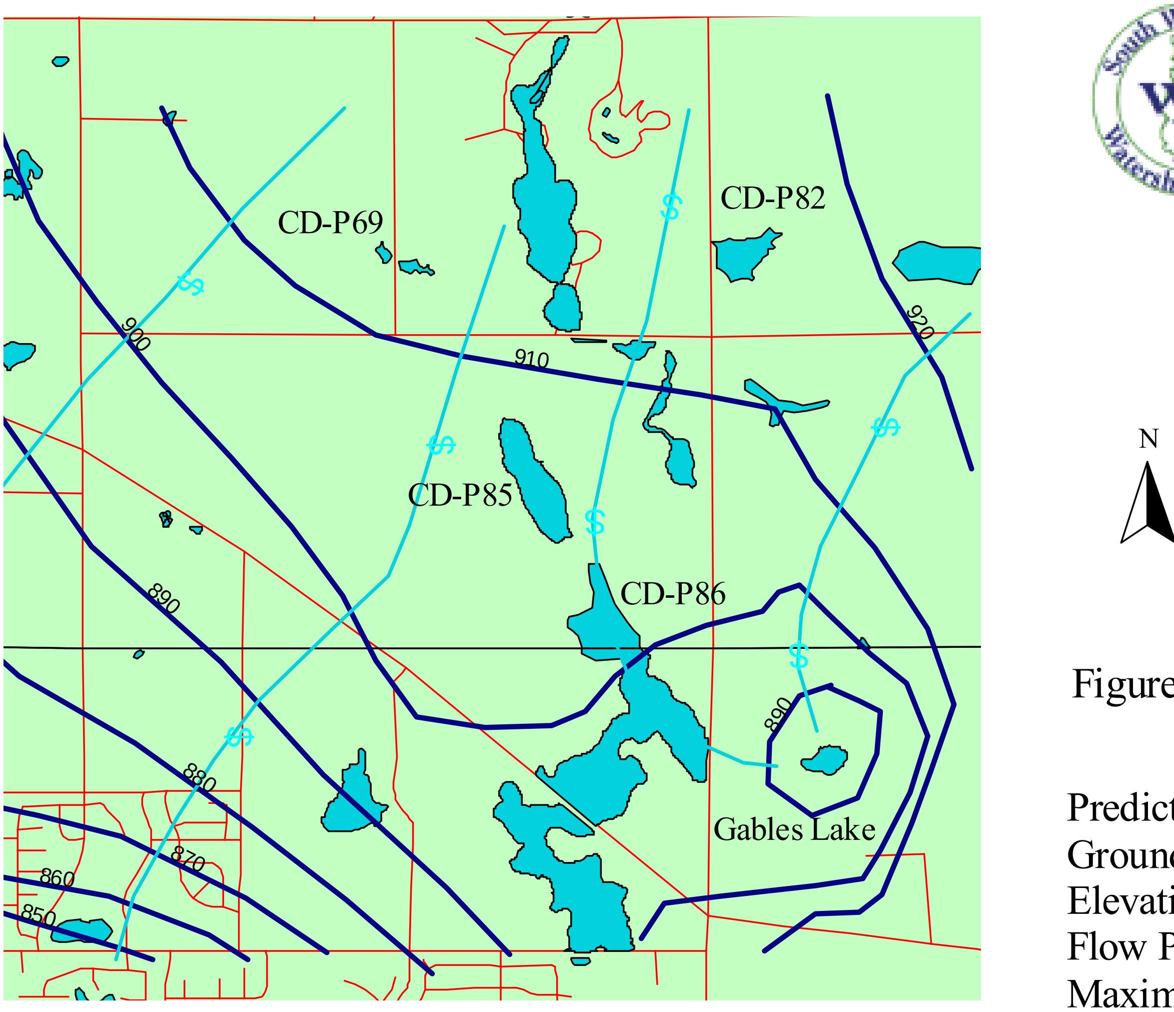
Figure VI-1

Predicted Groundwater Elevations and Flow Paths at Maximum Infiltration: Model Layer 1

Note: Much of the infiltrated water in Model Layer 1 discharges downward to deeper aquifers

0 0.3 0.6 Miles

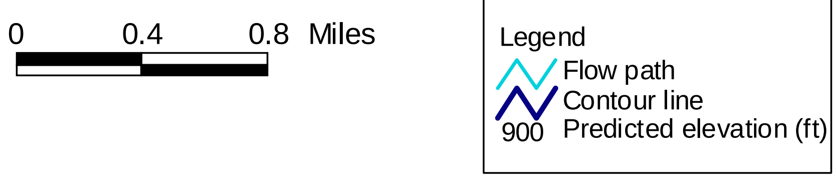
Legend
Flow path
Contour line
900 Predicted elevation (ft)

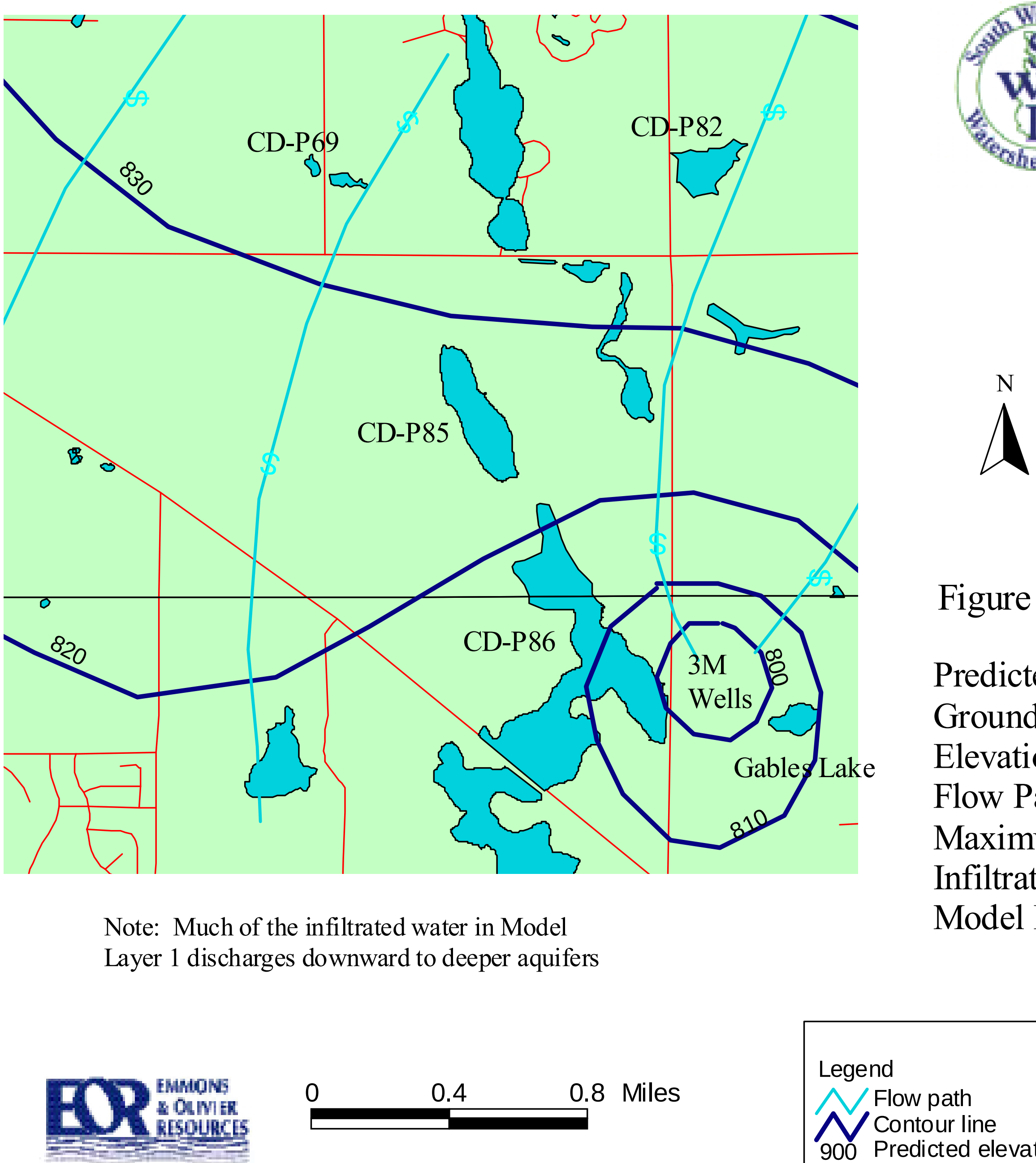


Note: Much of the infiltrated water in Model Layer 1 discharges downward to deeper aquifers

Figure VI-2

Predicted Groundwater Elevations and Flow Paths at Maximum Infiltration: Model Layer 2





Note: Much of the infiltrated water in Model Layer 1 discharges downward to deeper aquifers

Figure VI-3

Predicted Groundwater Elevations and Flow Paths at Maximum Infiltration: Model Layer 3

Water quality changes at nearby wells were not investigated because the quality of the infiltrated water has been shown to be of similar or better quality than the groundwater currently below the basins, as discussed in Section VII – Water Quality. The significance and influence of infiltration on the Historic Woodbury Landfill site is also discussed in Section VII.

VI-C. GROUNDWATER MOUNDING

The major basins where infiltration would be greatest were analyzed using the method developed by Hantush (1967). The model simulates the rise and fall of a groundwater mound below a rectangular basin based on the size of the basin, the infiltration rate and duration, and hydrogeologic parameters such as permeability, aquifer thickness, and depth to the water table.

Input parameters and results are summarized on Table VI-I. The infiltration rates and durations used are the summer values reported previously in Table IV-4. Hydrographs were examined to determine an appropriate duration of infiltration during extreme summer infiltration events.

The results indicate that groundwater mounding does not appear to limit the infiltration of water at CD-P50, CD-P76, and CD-P82. This is due to the relatively high permeability and depth to water table found at the basins. Groundwater mounds could intersect the bottom of the basin during the later stages of an extreme infiltration event at CD-P69, CD-P85, and CD-P86. If this were to occur, infiltration would continue from the bottom and sides of the basin. The infiltration rate could be somewhat lower because the water would be flowing through saturated rather than unsaturated soils.

Table VI-1. Groundwater Modeling Results, Mounding Analysis

Basin	Initial Water Table Elevation (ft)	Bottom of Basin Elevation (ft)	Unsaturated Depth (ft)	Area at HWL (ac)	Model Pool Length (ft)	Model Pool Width (ft)	Model Pool Area (ac)
CD-P50	864	891.0	27.0	14.5	850	650	13
CD-P69	905	922.0	17.0	22.0	1000	850	20
CD-P76	880	927.0	47.0	25.0	1400	700	22
CD-P82	828	894.0	66.0	34.1	1500	900	31
CD-P85	845	885.0	40.0	32.2	2200	600	30
CD-P86	840	875.6	35.6	60.6	4000	650	60
Basin	**Modeled Infiltration Rate (ft/min)**	**Modeled Infiltration Rate (ft/d)**	**Modeled Infiltration Duration (h)**	**Modeled Infiltration Duration (d)**	**Hydraulic Conductivity (ft/d)**	**Aquifer Thickness (ft)**	**Maximum Calculated Mounding (ft)**
CD-P50	0.0006	0.9	250.0	10.4	100	45	16
CD-P69	0.0015	2.2	150.0	6.3	100	45	34
CD-P76	0.0020	2.9	40.0	1.7	100	45	16
CD-P82	0.0010	1.4	350.0	14.6	100	45	45
CD-P85	0.0014	2.0	450.0	18.8	100	45	61
CD-P86	0.0014	2.0	200.0	8.3	100	45	38

The analytical method used to evaluate the mounding was relatively simple. Dr. John Nieber of the University of Minnesota and his students are completing a much more sophisticated, time dependent model of CD-P85. Their results will likely provide new insights into determining infiltration rates at all the basins.

VI-D CONCLUSIONS AND RECOMMENDATIONS

The surface water and groundwater models were coupled to determine whether there would be a significant impact on groundwater levels and whether groundwater mounding would limit the infiltration rate at the basins. Groundwater levels and flow patterns will be changed by increased infiltration at the basins, but no problem areas were identified. The results indicate that groundwater mounding will not be a limiting factor on infiltration rates, except near the end of extreme infiltration events at some basins such as CD-P69, CD-P85, and CD-P86. Calibration of the groundwater models with actual field data in the future will greatly increase the accuracy of the predicted results presented here.

The following recommendations discuss how to address the interaction between surface water and groundwater modeling.

- Use well data at CD-P85 during infiltration events to calibrate the unsaturated flow model to better understand the mounding dynamics and verify that proper aquifer properties were defined.
- Coordinate with review of other surface water models to determine if an integrated model such as FIPR Hydrologic Model would be justified.
- Use these tools and Dr. Nieber's unsaturated flow model to do detailed evaluation of un-monitored infiltration/detention areas as other areas that are considered for management and/or purchase.

VII. Water Quality and Environmental Issues

Water quality issues, both groundwater and surface water, and environmental issues are important parts of infiltration's role in the natural hydrologic system and infiltration management. Water quality concerns in groundwater aquifers can be an issue especially since residents in the watershed draw their drinking water from aquifers. Infiltration can also play a major role in protecting surface water quality, the hydrologic system, and natural communities associated with watershed waterbodies such as lakes, streams, and wetlands.

The infiltration process serves as a filtering system for stormwater through the soils and geologic formations and as a stabilizing factor in maintaining a natural hydrologic cycle and budget that feeds and sustains waterbodies both through surface waters and groundwaters. Environmental issues can arise as the hydrologic system is altered for natural communities in and around waterbodies and depressions in the landscape. Protection of natural infiltration areas can also provide some environmental benefits by preserving and restoring open spaces and enhancing the connectivity of other protected natural areas. Infiltration tends to mitigate the alteration of natural hydrologic systems, particularly in the SWWD, and reduce environmental impacts, but some issues may still exist in and around extensively managed regional basins.

Based on the potential benefits and detriments of managing infiltration, most of the focus has been on addressing potential impacts to groundwater and environmentally sensitive areas near infiltration areas. The positive aspects of hydrologic restoration or maintaining natural hydrologic systems via infiltration should not be forgotten while addressing the negative aspects.

Municipalities and rural residences within the SWWD draw all of their water supply from the groundwater aquifers located within the District, hence, groundwater quality is of major importance in the watershed to the residents and the District. The Infiltration Management Study has addressed this issue by:

- Researching the literature for reported changes in groundwater chemistry due to infiltration practices
- Monitoring surface water chemistry to identify constituents that may be of concern

- Installing monitoring wells and monitoring ground water quality in the vicinity of several basins
- Monitoring water quality at residential wells to establish background groundwater quality and identify changes over time
- Using the groundwater model to predict groundwater flow paths away from the infiltration basins to know where to monitor in the future to track potential impacts

VII-A LITERATURE REVIEW

Much research has been done to identify changes in groundwater chemistry as a result of infiltration practices. Schueler (1987), for example, reports that infiltration practices have a moderate to high treatment capacity, depending on the volume of runoff that is effectively infiltrated through the soil. Infiltration is one of the most effective means of protecting surface water quality. Typically water quality concerns are more associated with ground water quality.

The water quality constituents of major concern include:

- Sediment
- Nutrients (phosphates and nitrates)
- Organics (hydrocarbons and pesticides)
- Heavy metals and other inorganics
- Salts
- Pathogenic microorganisms.

Sediment

Suspended sediment is one of the most common urban pollutants (Ferguson, 1994). Most of the sediment originates from construction sites and areas of high erosion along steep slopes. Infiltration is one of the most effective means of controlling sediment in surface waters due to filtration. It is also beneficial by reducing the amount of runoff moving downstream, thus reducing the erosive forces of flow downstream in channels, and streams, or other water bodies. Excess sediments in surface waters do pose a potential risk of clogging and thus reducing the infiltration capacity.

Sediment does not pose a direct risk to groundwater quality because of filtration at the surface. This process traps virtually all of the sediment before it reaches the water table. The filtration is particularly effective in areas with a deep water table (greater than 5 ft below ground surface, as is the case almost everywhere in the SWWD) and where thick deposits of sand, silt, and clay cover the aquifer. Because of the filtration process, the groundwater is unaffected by sediment.

Nutrients

Nutrients are typically treated by infiltration from a surface water standpoint. The solubility of nitrates does present some concern that nitrates can re-enter the surface water system at groundwater discharge points. Nutrients of concern from a groundwater standpoint include phosphates and nitrates. The sources of these compounds vary but include fertilizers used in rural agriculture and suburban lawn care, automobiles, and leachate from dumpsters and services areas where trash is handled (Ferguson, 1994). Nitrate-Nitrogen is a mobile compound and is a human health hazard at high concentrations. It is usually found in low concentrations in urban runoff and thus has low to moderate potential to impact groundwater (Pitt, 1994).

There is a significant impact from irrigated agriculture that promotes the movement of nitrates into the soils and groundwater. The most prone areas are agricultural fields that are on sandy soils with little moisture holding capacity (Mossbarger, 1989). Nitrogen can be lost to the atmosphere as a gas if anaerobic conditions exist and a wet/dry cycle is used to manage infiltration practices (O'Hare et al., 1986, p. 42).

Phosphorus is mostly transported bound to the surfaces of suspended particles. Soils have the ability to trap sediment and also to precipitate dissolved phosphates, thus removing them from infiltrating water. The degree of removal is dependent upon the depth to the water table. Minimal impacts are reported when the water table is more than 3 ft below ground surface. This minimum depth provides the surface area needed to precipitate phosphates and provide for sediment deposition.

Organic Compounds

Most of the organic compounds that pose a threat to human health are derived from petroleum products and pesticides. Sources of petroleum products include highway, parking lot runoff and gas stations that contain oil and gasoline. Pretreatments, such as sand filters and grass channels were found to be very effective in the removal of hydrocarbons, oil, and grease (Claytor, 1996). These can be used as a pretreatment to infiltration or can be incorporated into an infiltration practice. Pesticides also pose a risk to human health when concentrated in drinking waters. These are found on turf management areas and agricultural production areas. Infiltration through soils has the potential to remove pesticides and other organics. A study in Long Island by Ku and Simmons (1986) found that pesticides found in water within infiltration areas were also found in the soils after infiltrating. This indicated that the soils removed at least a portion of the pesticides during infiltration. Biodegradation by microorganisms offers the potential conversion of organics into harmless compounds (O'Hare et al., 1986).

Heavy Metals

Infiltration provides very effective control of heavy metals in surface waters. Heavy metals such as zinc, lead, and nickel are substantially removed by percolation through the soil layers. The sources of zinc include rooftop runoff that passes over galvanized roofing materials (Bannerman, 1993) and automobile tires. Lead is found in urban runoff through leaded gasoline and wearing automobile parts. Lead is often found in high concentrations along heavily traveled streets (Ferguson, 1994). Many heavy metals are attached to particles in surface water. A series of detention and sediment ponds will reduce the amount of solids arriving at an infiltration basin and thus reducing the concentration of heavy metals that would infiltrate. As with the other constituents discussed above, there is also significant removal of the remaining metals in the first few centimeters of soil (Wigington et al, 1983).

Salts

Chlorides are a common part of salts, such as those that are applied to roads as a de-icer. Chlorides have a high mobility in surface and groundwater. There is no known means of pretreatment for chlorides in storm water runoff (Pitt, 1994). Salts that are applied to roads throughout the winter end up in surface runoff and some eventually reaches the groundwater.

Salts do not pose any human health risks, but they can degrade the water for drinking water purposes by altering the taste, or if concentrated enough, affect biological communities.

Pathogens

Pathogenic microorganisms can include bacteria, viruses, protozoa, and parasitic worms (O'Hare et al., 1986, p. 42). These are normally present in surface waters and soils. Sources of pathogens include animal waste, restaurants, garbage handling facilities, and septic systems and sanitary sewers (Ferguson, 1994). Ferguson (1994) states that removal of pathogens is almost complete by passage of water through most soils.

VII-B SURFACE WATER MONITORING

Surface water quality has been monitored for several years throughout the watershed. Monitoring methods and results have been reported in several previous reports, including

- SWWD IMS Progress Report (1998)
- SWWD Surface Water Monitoring Program (1996-1998)

Results of recent monitoring conducted by SWWD are summarized in Section II of this report. In general, surface water quality throughout the watershed is very good. There have not been any monitored parameters above drinking water standards for surface water. Therefore, under current conditions, it is highly unlikely that water from the basins could degrade groundwater quality in the future.

When considering the design and use of infiltration practices or facilities, pretreatment of that water is imperative. Several pretreatment devices have been developed that include vegetated filter strips, water quality inlets, and sand filters. The use of upstream settling ponds and water quality ponds can also be used as a means of water quality pretreatment.

VII-C GROUND WATER MONITORING

The SWWD has installed monitoring wells and collected groundwater samples near the basins. The SWWD has also monitored groundwater throughout the watershed in order to define background conditions.

Monitoring wells were installed in unconsolidated materials, at or near the water table, in the area of each infiltration basin. One well, MW-3D was installed downgradient of CD-P85 at the top of bedrock (Prairie du Chien limestone). Monitoring well locations are found in Section II of this report.

The monitoring wells have been sampled as part of an ongoing groundwater monitoring program. In addition, previously installed monitoring wells near Bailey Lake have also been regularly sampled by the City of Woodbury. Analytical results have been reported in the IMS Phase I report and City of Woodbury Monitoring Reports and are summarized in Section II.

The number of groundwater analytical results is limited and therefore no trends can be determined. Future sampling of both the groundwater and surface waters will allow for a better analysis of trends in groundwater quality and the origin of detected substances. Heavy metals including manganese and lead have been observed at concentrations above the HRL in the monitoring wells south of CD-P85, CD-P86, and CD-P69. The results were reported to regulatory agencies including the Department of Health, and Washington County Department of Health, Environment and Land Management. Subsequent monitoring results at CD-P85 have shown no concentrations of these compounds. Manganese was observed at concentrations above the HRL in both rounds of sampling at CD-P69. Monitoring will be continued, but no other action appears warranted at this time. Future sampling will include filtering of metals samples to ensure accurate analysis of dissolved metals, which are the main concern in the SWWD.

VII-D WATER QUALITY IMPLICATION FROM GROUNDWATER MODELING

The groundwater model developed for this study can aid in assessing water quality issues since it can predict changes in groundwater flow paths due to changes in infiltration patterns. The results of the modeling are discussed in Section V of this report. The model can be used to identify areas that are downgradient of infiltration basins, and therefore are susceptible to changes in groundwater chemistry due to infiltration practices.

Potential areas of concern are fairly limited at this time due to the results of the surface water sampling thus far, which indicates minimal risk to contamination of the groundwater. Areas of concern have been limited to the Historic Woodbury Landfill since it is a known site of previous disposal of contaminants and is in the vicinity of some of the infiltration areas. Concerns raised previously about impacts to municipal water supplies appear not to be significant issues due to the favorable groundwater and surface water chemistry monitoring results. The groundwater model will be especially useful when the Department of Health, municipalities, and other major groundwater users develop, implement and refine their wellhead protection plans as required by law.

Ground Water Flow Near the Historic Woodbury Landfill

Pumping wells in the area of the Historic Woodbury Landfill Site, also called barrier wells, have a large influence on groundwater flow patterns near Gables Lake, South Bailey Lake, CD-P85, and CD-P86. The wells were originally installed to control groundwater flow directions near the landfill. 3M pumps the water to its Chemolite facility in Cottage Grove for use as non-contact cooling water. The water is then discharged to the Mississippi River. Currently, 3M has reported the contaminant concentrations in the wells as below regulatory limits.

Some of the groundwater infiltrating from CD-P85, CD-P86, and South Bailey Lake will flow toward the 3M pumping/barrier wells and be removed from the aquifer. An expanded view of this area and the predicted groundwater flow patterns is shown on Figure VI-1.

The EAW completed for the Bailey Lake Stormwater Management Facilities (City of Woodbury, 1994) also recognized that water infiltrating from CD-P85 and South Bailey Lake would reach the pumping/barrier wells at the Historic Woodbury Landfill. The part of the EAW dealing with groundwater (Question 20) and the response to comments are included in Appendix H.

The EAW was prepared using similar groundwater modeling methods to those used in this Infiltration Management Study. Barr Engineering prepared a groundwater model based on the best available data. Analytic Element Method software was used to construct the model. Key differences between the two models are listed in the table below.

Table VII-1. Comparison Table for Existing Models at the Historic Woodbury Landfill Site, Woodbury

EAW Model	Infiltration Management Study Model
Two-dimensional (SLAEM software)	Three-dimensional (MLAEM software)
Regional flow data from the Washington County Geologic Atlas and a few local wells	Regional flow data from over 1000 well locations recently added to the County Well Index
Regional flow only coming from the north	Regional flow from several directions depending upon the aquifer and elevation
Aquifer interaction only with CD-P85, CD-P86 and South Bailey Lake.	Aquifer interaction with all lakes and most basins throughout the watershed
All wells included in same aquifer and same model layer	Monitoring wells screened in the Quaternary aquifer are in Model Layer 1. Wells screened in the St. Peter aquifer are in Model Layer 2; Wells screened in the Prairie du Chien/Jordan aquifer are in Model Layer 3

The results of the two models can be compared visually by observing the predicted flow patterns shown on Figure VI-1 and the predicted flow patterns shown on Figure 2 of Appendix H. Despite the differences in model construction and input data, the two models have agreement on a few important results:

- Some of the water infiltrating from South Bailey Lake, CD-P85, and CD-P86 will flow toward the Historic Woodbury Landfill and be removed by the barrier wells.
- The current pumping rates of the barrier wells are more than adequate to capture ground water flowing beneath the landfill disposal areas.

- The ongoing remediation efforts will not be significantly impacted by infiltrating water at either CD-P85 or CD-P86.

3M has not expressed any intent to stop pumping at their barrier well system in the foreseeable future. 3M is currently working with the MPCA regarding agency management of the site.

VII-E ENVIRONMENTAL IMPACT ANALYSIS

Infiltration practices are generally appropriate in low-lying natural depressions and may include wetlands and other natural communities. Infiltration provides many benefits by protecting water quality and supporting the natural hydrologic balance and system. However, large water level fluctuations could potentially impact wetlands, fish and wildlife populations, or rare plants and animals if uncontrolled or magnified over the natural cycle.

To minimize impact to natural communities, detailed site assessments can be conducted for each potential infiltration site. Existing data including any natural resource inventories, wetland assessments, soil maps, and other data are reviewed on a site-by-site basis. By mapping the boundaries of the proposed basin and noting water levels, adjacent natural communities, soil types, and topography, the suitability of the site for infiltration can be determined. If significant potential impacts to a site are high, alternate sites will be identified and evaluated or mitigation plans can be developed. In most cases, the changes in the existing natural hydrology of the sites will avoid and minimize impacts.

Wetland Communities

The magnitude of impacts to wetlands from infiltration facilities is directly correlated to the wetland community type and quality. Wetlands in proposed infiltration areas were compared for floral diversity, wildlife habitat, and aesthetics using the Minnesota Routine Assessment Method, Version 2.0 (MNRAM) in the SWWD draft Wetland Management Plan.

Many wetland plants are tolerant of seasonal inundation but cannot survive repeated or extended periods of submersion through the growing season. Plant mortality resulting from increased frequency of inundation may shift the plant community towards species more tolerant of hydrologic fluctuations, such as cattails and reed canary grass.

The functional values and in-field observation indicate that most of the wetlands proposed for infiltration are low-quality, reed-canary grass/cattail monotypes. 70% of the sites have low floral diversity and the remaining 30% possess moderate/low diversity. The majority (70%) of the wetlands also have moderate to low wildlife value, and nearly all (90%) possess moderate to low aesthetics and cultural values based on the draft wetland plan.

Two sites, Wetland BL-6-4 and PL-1-9 possess moderate to high floristic values. Their floristic value, size, and proximity to good-quality oak forest resulted in being ranked as priority sites in the Woodbury Natural Resources Inventory (1997). Although no records exist for rare features in these wetlands, there is potential for the presence of state-listed species. Acquisition of natural areas is being pursued by the City of Woodbury and the two wetlands listed here are included.

Upland Communities

The upland communities adjacent to the proposed infiltration sites are predominantly oak woods or oak forest of varying quality, with sections of lowland hardwood forest, oak savanna, old field, or pasture. (Woodbury Natural Resources Inventory, 1997.)

Flooding upland communities can be an issue if water level fluctuations are significant and greater than the natural fluctuations. Most plants typical of oak woods and oak forests have a low tolerance to flooding, which has the potential to decrease species diversity and favor disturbance-adapted species such as buckthorn and reed canary grass. The potential loss of individual trees is likely to concern landowners as well as alter the composition of existing natural communities. Most of the sites under consideration do not have significant woodlands adjacent to them. The sites with woods or trees should be evaluated closely and based on the tree species, impacts and mitigation strategies quantified. In upland communities, standard guidelines for determining safe water levels, based on tree elevation and trunk diameter, can be applied.

Fish, Wildlife, and Ecologically Sensitive Resources

Fisheries resources in the proposed infiltration sites are limited to only a few sites and consist largely of small minnow species, sunfish, and rough fish such as bullheads. These species are present only where there are connections between wetlands and larger basins or lakes. As no significant fisheries exist for the proposed sites, no significant fisheries impacts are anticipated.

Wildlife species are determined largely by the composition and quality of natural communities. Species likely to be found at the sites include generalists, such as deer, raccoon, and blue jays in the wooded areas and redwing blackbirds, geese, and mallards in the emergent marsh wetlands. A variety of amphibians and reptiles are present, most of which spend portions of their life cycle in both upland and wetland habitats. No occurrences of rare species or natural communities are known to exist within or near any of the wetlands proposed for infiltration, although there is potential for listed species in wetlands BL-6-4 and PL-1-9.

The potential impacts to wildlife will result from changes to plant communities. Where wetland plant community diversity increases as a result of planting and restoration efforts, wildlife is likely to benefit. Impacts are also possible along wetland fringes, where changes in inundation timing and frequency may affect bird and turtle nests and young. Sensitive communities are often susceptible to water level bounce, and flooding as discussed in the previous section, but the occurrence of sensitive resources are limited near the infiltration basins since the areas are naturally occurring basins with a history of water level fluctuations. In addition, much of the area has well drained soils that have been heavily subjected to agricultural uses historically, leaving few natural communities on the landscape. The management of these areas offers the opportunity for restoration of natural communities on disturbed areas.

Overall, habitat value of the remaining sites can be improved, by the following methods:

- All sites to include a generous buffer area around the basin, which will likely expand the potential nesting area for ground-nesting wildlife.
- Prior to use of a site for infiltration, trees, shrubs, grasses and forbs adapted to the anticipated hydrologic regime will be planted. This will increase plant diversity in most cases.

- Most of the basins are expected to be linked to a watershed-wide greenway corridor. This will increase opportunities for plant and animal migration through the site and increase the overall habitat value and ecological integrity of the watershed.

VII-F CONCLUSIONS AND RECOMMENDATIONS

Based on the potential benefits and detriments of managing infiltration, most of the focus has been on addressing potential impacts to groundwater and environmentally-sensitive areas near infiltration areas. The positive impacts and aspects of hydrologic restoration and maintaining natural hydrologic systems via infiltration should not be forgotten while addressing the negative aspects. The objective is to develop an acceptable balance between the positive and negative aspects of infiltration in an urbanizing watershed.

Woodbury's existing stormwater management system in the Central Draw appears to be efficient at removing sediments and many of the nutrients in surface waters through a series of settling basins and water quality treatment ponds followed by existing wetlands and lakes before reaching CD-P85. Based on the monitoring data thus far, the quality of the surface water entering this infiltration facility has been very good.

Groundwater contamination concerns appear to be minimal based on the available information. This is primarily due to the fairly good quality of the surface water samples relative to potential groundwater contaminants. By preserving infiltration in the system, groundwater recharge and natural groundwater flow systems are preserved.

The management of infiltration areas and basins offers the opportunity for restoration of natural communities and preservation of open space in an urbanizing landscape. This is especially true in many of the basins since they have a history of being intensively used for agricultural purposes and the natural plant communities there have already been heavily disturbed and impacted.

The following recommendations are proposed to address on-going concerns with water quality, both above and below ground, and with environmental issues and opportunities for restoration.

- Continue monitoring surface waters and groundwater wells to establish good baseline data and periodically evaluate the data to determine if any trends are evident in groundwater chemistry that could be attributable to the managed infiltration system.

- Environmental impacts to management sites should be evaluated and minimized as part of the overall basin evaluation, and where possible, improve habitat value of the management areas by the following methods:
    - All sites to include a generous buffer area around the basin, which will likely expand the potential nesting area for ground-nesting wildlife.
    - Prior to use of a site for infiltration, select trees, shrubs, grasses and forbs adapted to the anticipated hydrologic regime and use these plant materials in the basins. This will increase plant diversity in most cases.
    - Plan for linking the management sites to a watershed-wide greenway corridor. This will increase opportunities for plant and animal migration through the site and increase the overall habitat value and ecological integrity of the watershed.

VIII. Management Options

The South Washington Watershed District has been confronted with a challenge to wisely and effectively manage its water resources in an urbanizing area of the Twin Cities Metropolitan area. The state law governing Watershed Districts, chapters 103B and 103D sections 201, sets forth important guiding principles for managing water resources based on sound scientific principles. The most relevant to the principles to the SWWD's management challenge are:

- Protect, preserve, and use natural surface and groundwater storage and retention systems;
- Minimize public capital expenditures needed to correct flooding and water quality problems;
- Identify and plan for means to effectively protect and improve surface and groundwater quality;
- Promote groundwater recharge;
- Secure the other benefits associated with the proper management of surface and groundwater.

The SWWD has further defined four criteria any solution for managing stormwater in its watershed must meet:

- Environmentally sensitive
- Technically feasible
- Financially responsible
- Socially acceptable

Infiltration was identified in the Watershed's planning and public review process as a key factor that should be better understood and utilized in the watershed's stormwater management system. Infiltration was identified as offering the potential to responsibly handle stormwater in a manner that is good for the environment. Utilizing a valuable emerging technology in urban stormwater management could save significant public funds and provide additional open space and park amenities to the community.

With a clear understanding of the goals and criteria, the Watershed now looks to the future of how it can utilize infiltration as an important part of the system. The investigations and data compiled thus far indicate many valuable uses and methods to use infiltration to address flooding issues, water quality protection, and recharge of groundwater.

The management options available can be implemented at the regional or local scale. Regional and local approaches are both important in the long-term management of infiltration. The primarily focus of the Watershed is currently on regional practices and improvements that the Watershed can actively implement, manage, and rely on.

VIII-A REGIONAL STRATEGIES

The use of infiltration is part of a larger effort to identify and utilize Critical Detention areas. By using basins for infiltration as well as detention, recreation, open space, and water quality improvements, the District can maximize its use of regional facilities for the community's benefit.

Maintaining Natural Infiltration Systems

The data collected and the fact that the watershed currently can contain and absorb all the precipitation that falls within the watershed demonstrates the existence and great potential of numerous naturally occurring basins that detain and infiltrate significant amounts of water. The understanding of the geology, soils, groundwater systems, management, and maintenance of these natural areas is key to their successful preservation and utilization in the future. Numerous basins with high infiltration potential have been identified and the next steps are to begin to prioritize, select, analyze, and acquire those basins that have the greatest potential for future management.

Regional basin CD-P85 continues to be a significantly important resource in the system that will also provide valuable experience and data in management techniques. The use of infiltration tubes and infiltration trenches has already proven a valuable management technique to improve infiltration capacity in low capacity areas and reduce wet conditions in the soils. Future plans to manage vegetation in the basin will serve to enhance natural infiltration capacities in the soil as well as help reduce frozen ground conditions in the spring when spring snowmelt waters may need to be routed to the basin.

The data collection and analysis thus far has indicated numerous basins or natural depressions that have a high potential for management for infiltration as well as detention both within the 20 year timeframe, based on preliminary land use plans and projections, and beyond. Table VIII-1 is a list of the basins with the highest potential for regional infiltration, but other depressions exist with potential for infiltration.

During the preliminary analysis, additional basins were identified as potential regional infiltration areas. The basins are listed in Table VIII-2. During further modeling and analysis, these basins were excluded since the primary basins were sufficient to address the volumes of stormwater within the system. The additional basins can still be considered as alternative or secondary sites if any of the primary basins are limited in function or eliminated from the planned system due to environmental, technical, financial, or social concerns.

Table VIII-1. Primary Basins for Infiltration

	Basin Number/Name **(by City Stormwater Plan #)**	**Year Likely Needed**	**Approximate Area (Acres)**
1	CD-P69 (Pioneer Drive)	Existing	23.0*
2	CD-P50 (Eagle Valley Golf Course)	Existing	16.0*
3	South Bailey Lake	Existing	32*
4	CD-P85 (Regional Infiltration Basin)	Existing	32.2*
5	North CD-P86	2005	60.6
6	CD-P74b (Existing Mining Area)	2005	21.7
7	CD-P28	2005	28.3
8	CD-P42	2005	7.0
9	CD-P43	2005	2.8
10	CD-P48	2010	9.6
11	CD-P49	2010	5.5
12	CD-P74a	2015	9.4
13	CD-P74c	2015	9.9
14	CD-P76 (Mile Drive)	2015	25.0

15	CD-P80	2020	21.6
16	CD-P82 (County Road 19)	2020	41.5
Post-Year 2020 Basins			
1	CD-P78	2030	54.3
2	CD-P83	2025	9.0
3	CD-P87	2025	33.4
4	CD-P88	2025	12.8
5	CD-P89/CGR-P92	2025	20.0
6	CGR-P90	ND	48.8

*Currently established as a stormwater management facility and mostly or all controlled by a public entity, typically a city, through ownership or easement.

ND = Not Determined. The comprehensive land use plan for this area is under study and no urban development time frame has yet been determined. The basin is not necessarily beyond the year 2020.

Table VIII-2. Alternative Basins for Infiltration

	Basin Number/Name (City Stormwater Plans)	Year Likely Needed	Approximate Area (Acres)
1	CD-P25/26	2005	20
2	CD-P27	2005	12
3	CD-P45	2005	3
4	CD-P51	2010	3*
5	CD-P57	2010	11
6	South CD-P86 /CGR-P91 (South of Military Rd. only or all north of 70th St.)	Post 2020	62 - 96

Subwatershed-based Standards

Within the SWWD, several subwatersheds have potential for the use of specialized standards in critical areas that have high infiltration potential and capacity. This can provide a long-term method to preserve areas that do not now naturally contribute much runoff to the central drainage system. The use of customized standards can serve to enhance the infiltration efficiencies in those subwatersheds as well as maintain operation and maintenance costs low over the long-term.

Subwatershed standards would need to address sediment and erosion control, especially during any construction period in a land use conversion. Pretreatment of runoff is key to protecting infiltration areas from sediments and contaminants. Certain construction practices such as minimizing compaction, reducing disturbance of natural infiltration areas, and phasing construction to reduce sediment loads to infiltration areas will reduce costs of implementing and maintaining infiltration practices. The use of buffer areas in and around infiltration areas will serve to filter out sediments that might clog the infiltration areas.

Subwatershed standards could be implemented in a tiered manner. The basin-shed is the area that is closest and directly tributary to a key regional infiltration facility. These areas would have fairly restrictive standards to prevent damage to existing or new infiltration facilities. The next tier out would be the subwatershed, which would have more than normal restrictions, but potentially not as restrictive as the inner zone. The outer tier would be the overall watershed to the facility and this area would probably be subject to normal controls since the runoff from these areas would pass through the other zones before reaching the key facility.

Infiltration Design Guidelines

In order to effectively implement the necessary controls to protect and manage infiltration facilities or areas, design guidelines or standards tailored to the setting of the watershed would be needed. Design standards can be conveyed to the appropriate target audiences such as contractors, site designers, and design engineers through the use of design manuals, information sheets, training courses, or demonstration sites. Operation and maintenance manuals or guidelines are also an important piece to ensure infiltration practices are working at proper efficiencies and continue to be assets to the communities.

Uses of Specific Infiltration Practices

There are several infiltration practices that work well within the Watershed based on the geology, soils, topography, and land uses. The following is a list of the recommended infiltration practices for regional facilities. It is not a complete list of all potential practices since other practices may apply better to specific situations or site configurations.

- Infiltration basins (natural depressions preferred over constructed basins)
- Infiltration trenches
- Infiltration tubes
- Sunken infiltration parking lot islands
- Infiltration swales

Based on the data collected on various basins for the past three years, the use of natural infiltration areas have a large potential to handle stormwater runoff, even in spring snowmelt conditions.

Infiltration trenches and infiltration tubes also show significant potential for enhancing infiltration in glacial outwash areas. The data collected in August and November of 1999 at CD-P85 indicate that the infiltration trenches and tubes increased the infiltration capacity of the basin significantly as well as ensuring that the bottom areas are completely dry after a significant pumping event.

VIII-B ENCOURAGING LOCAL INFILTRATION

Local practices and how they can potentially be applied on individual development sites has been examined and outlined in the Phase I report. Local practices can be implemented through standards, financial incentives, and educational efforts in the watershed in the future.

The involvement of a Local Advisory Committee (LAC) identified several non-structural and alternative methods of managing and reducing stormwater such as:

1. Collect and Reuse Water

2. Apply Land Use Strategies such as Clustering and Preserving Open Spaces and Establishing Greenways
3. Retrofitting Existing Ponding Facilities
4. Encourage Alternative Development Practices
5. Continue Volume Control through Watershed Standards

VIII-C OPERATION AND MAINTENANCE ISSUES

The ITAC has identified a number of operation and maintenance techniques applicable to the management of infiltration in natural settings. The following is a list of the main issues identified:

Soft Maintenance (Routine Maintenance)

- Wet/Dry Cycling of soils
- Inspection and Efficiency Assessment
- Monitoring (Water Quality, Groundwater Elevations, Long-term Infiltration Capacity, etc.)
- Mowing and General Vegetation Management. Replanting
- Debris and Litter Removal
- Erosion Control
- Education

Hard Maintenance (Non-Routine Maintenance)

- Tillage and/or Scraping of Soils and Hauling
- Re-vegetation (Seeding and/or Planting)
- Structural Repairs/Replacement. Engineering

Sources:

- Schueler (1987)
- Ferguson (1994)
- Nassau Department of Public Works, Nassau NY (1998)

The main advantage of performing infiltration management on regional basins in which infiltration occurs naturally is that, if properly and proactively managed, the operation and management costs could be significantly lower than those of man-made infiltration systems. In reality, the Watershed may be looking at preserving and potentially improving, through proper management techniques, the infiltration that is already taking place in selected regional areas. No major infrastructure and, therefore, no major operation and maintenance costs are envisioned at this point.

The cost of performing the hard and soft maintenance listed above for the regional basins shown in this section was preliminarily estimated at about $2.1 million for the next 50 years. This cost represents the present worth (at 5% interest) of all the estimated maintenance to be performed in regional basins for the next 50 years (15 year hard maintenance intervals and 3-year soft maintenance intervals). This cost represents about $42,000/year on a present worth cost basis.

VIII-D LAND ACQUISITION

The single highest potential cost in managing natural basins for infiltration, detention or other purposes is the cost of land and/or easements. There are several issues related to land acquisition for regional infiltration/detention management that are relevant to the SWWD:

1. The regional basins shown in this section coincide with the regional ponding areas shown in the most recent overall City of Woodbury Storm Sewer Management Plan (1979). Even though the basins shown in the 1979 Plan were identified for the purpose of peak rate control, it is possible to use some of them for storage, infiltration, and water quality management. The 1979 Plan basins were sized for the 100-yr. rainfall event (6.0” in 24 hours). The additional land (above the HWL shown in the 1979 Plan) needed to address the 100-yr. snowmelt and optimize infiltration is estimated to be 100 acres.

2. By proactively coordinating with the Cities, County and other entities regarding land use, open/park space and environmental/greenway corridors, the cost of additional required land for regional basins could be significantly reduced through park land dedication and greenway grants. Potentially, more than half of the regional basins shown in this section have been initially identified as corridors, open space or park land and therefore additional land costs for infiltration could be coordinated with the purchase of open space.

3. The timing of when the different basins are needed could also represent a cost savings to the SWWD by sequentially purchasing or managing facilities in the years to come and take advantage of a progressively bigger tax base.

IX. Summary Conclusions

The IMS study has identified natural infiltration as one of the single most significant factors in determining the current hydrologic behavior of the Watershed. The IMS has also identified natural infiltration as an important resource in future stormwater management in the watershed, especially when effectively combined with a Critical Detention Program. Infiltration as observed and measured in this study accomplishes several key SWWD **objectives** including:

- Reducing capital expenditures by minimizing magnitude and frequency of overflows. Infrequent overflows may open the door to using natural overflow features in the watershed.
- Protecting water quality within the watershed as well as other regional water resources downstream such the Mississippi River, Lake Pepin, and ultimately the Gulf of Mexico.
- Maintaining groundwater recharge to replenish aquifers.
- Providing additional open space resources for use by the residents and communities of the watershed, such as active recreation, trails, aesthetic enhancements, and ecological preservation and restoration.

The Watershed's foresight in conducting the Infiltration Management Study has demonstrated that better alternatives to the "just move the problem downstream" approach exist and are viable. The findings in the IMS indicate that an integrated and coordinated effort between infiltration, critical detention, and an appropriate overflow(s) can minimize risk while at the same time accomplishing several community and watershed goals including:

- Providing open space amenities
- Protecting water quality in lakes, wetlands, and rivers
- Replenishing groundwater
- Providing an innovative, cost-effective solution

X. Recommendations

The IMS study has identified several opportunities to pursue for utilizing infiltration for managing stormwater in the watershed.

X-A. GENERAL RECOMMENDATIONS

The activities needed to responsibly incorporate and manage infiltration as an important part of the stormwater management system include;

- **Data Collection and Monitoring** of pertinent surface water and groundwater features to aid in:
  - Effective decision-making regarding water quality issues and critical detention management
  - Developing and assessing sustainable management, operation, and maintenance techniques
- **Modeling Evaluation and Calibration** and further analysis of computer modeling tools beyond that utilized in the IMS by:
  - Evaluating and selecting another computer modeling program that would better suit the hydrologic setting and management goals of the District
  - Calibrating the model with new data collected in the monitoring program
- Address and where possible enhance **Water Quality and Environmental Resources** by:
  - Continued monitoring and coordination with state agencies to ensure infiltration is accepted as a long term solution for management
  - Develop habitat restoration plans for infiltration and detention basins customized to the periodic and infrequent inundation of the areas
  - Proactive planning for inclusion of infiltration and detention areas in greenway corridors and open space acquisition efforts

- Actively pursue all **Infiltration and Detention Management Options and Techniques**, focusing primarily on key **critical detention areas** by:

  - Fully exploring infiltration and detention as significant parts of the overall Central Draw solution by collecting key data on potential sites to determine their feasibility and impact on the system
  - Prioritizing sites, including consideration for the timing of development, to determine timing and extent of SWWD involvement in future basins
- Coordinate **Public Education and Outreach** efforts to ensure public acceptance of the solutions and maximize the benefits to the community by:
  - Coordinating with the planning and development of community open space and greenways through CAC involvement
  - Developing public education tools on the importance of infiltration, critical detention, and proactive source-control stormwater management

X-B. SPECIFIC TECHNICAL RECOMMENDATIONS

Within the overall needs for implementing infiltration within the watershed's management strategies, there are several activities that need to be performed to support each aspect of the infiltration management effort. The specific recommended activities are summarized below for each major area of activity.

Data Collection and Monitoring

Land Forms

- Collection of better contour data (at a minimum, 2-foot contours) in priority subwatersheds would be used to map regional infiltration and detention basins as well as in the hydrologic analysis of the basins and subwatershed. The hydrologic analysis for the basin would be used to develop management criteria for wet-dry cycling for the basins and to establish High Water Levels (HWLs), area, and location for each basin.
- Field soil surveys of the remainder of CD-P85 (northern portion) and other regional basins to map the configuration of each basin. The mapping will identify accumulated fine sediments in the bottom areas (due to natural erosion, farming practices, or glacial deposits) to understand the efficiency of the basins and types of management practices that are most appropriate for each basin.

- Conduct a geophysical survey (ground penetrating radar and/or electroresistivity) and mapping of subsurface features of CD-P86, CD-P85, and possibly other priority basins to explore geophysics as a cost-effective, non-intrusive method of data collection and potentially use the results in Dr. Neiber's unsaturated flow model.

Surface Water

- Continue to monitor at the five regional basins contained in this study to build a long-term database for sites within the District. Add Bailey Lake (North and South) and CD-P86 to the monitoring program to better quantify infiltration in those key sites.
- Monitor infiltration pilot projects, such as the Math and Science Charter School and potentially St. Ambrose Church, to increase the database on the effects of infiltration enhancements.
- Periodically re-evaluate the monitoring programs to ensure data is complete and appropriate for calibration of the surface water model. Include spring frozen soil conditions and snowmelt yield to regional basins.
- Continue to update the literature review on infiltration practices and impacts of infiltration.

Groundwater

- Continue to monitor groundwater levels at infiltration basins when the basins are operating and the period immediately afterwards. Explore the feasibility of acquiring automatic water level recording devices for all or a portion of the wells.
- Continue monitoring to determine the effects of infiltrating stormwater on groundwater. Continue to coordinate current and future groundwater activities with other agencies.
- Install additional monitoring wells to the existing monitored basins to accurately define groundwater flow direction, horizontal and vertical gradients, and mounding effects.

Modeling Evaluation and Calibration

- Evaluate other surface and groundwater modeling methods and programs for a more appropriate model for the setting and management goals of the SWWD.

- Use collected field data and link it to climatic data to calibrate the model emphasizing the spring snowmelt runoff event.

Management Options and Techniques

- Watershed-wide Strategies:
  - Analyze and evaluate Critical Detention areas
  - Develop vegetation management and restoration guidelines
  - Identify criteria for sustaining natural infiltration systems
  - Develop subwatershed management standards
  - Establish operation and maintenance needs for infiltration practices
  - Prioritize the subwatersheds to assist in decision-making and timing issues
  - Cost-share program for pilot projects
  - Maximize the multiple use of infiltration and detention facilities for amenities that could include parks, greenways, trail corridors, habitat preservation and restoration, and athletic facilities.
  - Explore opportunities to cost-share with other governmental entities or through grants for land acquisition and development of areas for multiple uses and benefits.

- Site-Based, Feasibility-Level Strategies:
  - Obtain detailed contour, soils, and hydrogeologic mapping data
  - Perform detailed hydrologic and hydraulic analysis based on more detailed data to provide preliminary design and high water levels for the basins
  - Determine buffer sizes and locations around basins to address water quality and social issues, such as:
    - Filter runoff to protect water quality of groundwater recharge
    - Filter runoff to prevent erosion and sedimentation in the basins and therefore reduce the needed maintenance
    - Provide a setback for adjacent homeowners' to prevent expectations and concerns that the basins may not have permanent water
    - Provide additional open space for trails and park amenities for residents

- Determine if or what infiltration enhancements (trenches, tubes, etc.) are needed based on soils, geology, and performance of the basin
- Develop a vegetation management and restoration plan for the site
- Develop a monitoring, operation, and maintenance plan
- Explore the feasibility of multiple use options for the facilities
- Explore opportunities for cost-sharing approaches for multiple use benefits with cities, granting agencies, and potential developers
- Evaluate acquisition and management options for the following basins for their critical detention and infiltration potential. The following basins will potentially be needed over the next 10 years:

#	Basin Name or Number	Year Potentially Needed
Acquisition and Management		
1	North CD-P86	2000
2	CD-P74b (Existing Mining Area)	2000
3	CD-P28	2005
4	CD-P42	2005
5	CD-P43	2005
6	CD-P48	2010
7	CD-P49	2010
#	**Basin Name or Number**	**Year Potentially Needed**
Management		
1	CD-P69 (Pioneer Drive)	2000
2	CD-P50 (Eagle Valley Golf Course)	2000
3	South Bailey Lk Mgm't Area	2000
4	CD-P85 (Regional Infiltration Basin)	2000
5	Armstrong Lake	2000
6	Powers Lake	2000

- Reducing Risk:
  - Better understand natural infiltration in spring snowmelt conditions within the watershed.
  - Fully pursue Critical Detention in coordination with infiltration as key elements of stormwater management.
  - Pursue overflows for the system that have adequate capacity for the types of overflow that is expected.
  - Consider Spill Response Plans for hazardous substances for accidental discharges in order to provide a contingency plan to protect surface and groundwaters.

Public Education and Outreach

- Target education efforts and signage at residents traveling on trails in city open space and residents living around regional facilities (ex. Pioneer Drive wetland) on the benefits of infiltration and stormwater management
- Explain the benefits of infiltration in protecting water quality of valued waterbodies such as lakes, wetlands, and the Mississippi River; recharging groundwater aquifers; providing open space and greenway amenities; and restoring natural habitats
- Actively involve the SWWD's CAC in identifying uses and developing multiple use plans for infiltration and detention areas
- Share new information with other entities such as other Watershed Districts, City and County staff, and elected officials
- Participate with Cottage Grove, Woodbury, Lake Elmo, and Oakdale on wellhead protection efforts and water supply planning.

The SWWD should utilize a proactive approach that emphasizes infiltration and critical detention to address stormwater issues that is based on the sound scientific data specific to this area presented in this report. Utilizing the natural features of this watershed, such as extensive natural detention areas with high infiltration capacities, is a sound, innovative approach to stormwater management that is very foresighted directed toward the future of more natural, less costly solutions. Combining upstream solutions such as infiltration and detention along overflow contingencies is the most effective and sound watershed approach for stormwater management in the District.

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Glossary

Aquifer a porous water-bearing formation of permeable rock, sand, or gravel capable of yielding significant quantities of water.

Baseflow is streamflow during dry periods, which is contributed to the stream channel by groundwater.

Berm is a mound made from earthen or man-made materials to direct the flow of runoff around or through a best management practice.

Best Management Practice's (BMP's) are structural devices that temporarily store or treat urban stormwater runoff to reduce flooding, remove pollutants, and provide other amenities.

Bottom scraping is the process of physically removing soil from the lowest point of a landform.

Checkdam an earthen or log structure used in grass swales to reduce water velocities, promote sediment deposition, and enhance infiltration.

Detention/Retention facilities a best management practice used to temporarily store, control peak discharge rates and provides gravity settling of stormwater runoff.

Drift any glacially transported sediment

Evapotranspiration amount of water transferred from the soil to the atmosphere by evaporation and plant transpiration

Gravel lens is a naturally occurring, localized area of gravel that acts as an impermeable layer to runoff infiltration.

Groundwater Table is the surface separating the upper unsaturated soil from the lower saturated soil.

Hydrograph is a graph that shows some property of ground water or surface water as a function of time.

Hydrology is the science that deals with the properties, distribution and circulation of water on the surface of the land, in the soil and underlying rocks, and in the atmosphere.

Hydrologic Cycle is the succession of stages through which water passes from the atmosphere to the earth and returns back to the atmosphere.

Impervious is the quality of not allowing entrance or passage. With respect to development imperviousness refers to the construction of surfaces which do not allow for the absorption and infiltration of runoff.

Infiltration is the movement of water into the soil profile from the boundary (ground surface).

Infiltration capacity is the maximum rate at which water can be absorbed for a given soil per unit surface under given conditions.

Infiltration facilities are natural or artificial (un-constructed or constructed) depressions used to trap, store and infiltrate the amount of runoff associated with the design event.

Infiltration sump is also referred to as an infiltration tube or a dry well.

Lacuestrine deposit is material that is deposited in lake water and exposed when the water level is lowered or the elevation of the land is raised.

Landlocked area corresponds to a depression where there is no readily available surface overflow for stormwater drainage during a 100-year or larger event.

Loess is a glacial deposit consisting predominantly of silt with subordinate amounts of very fine sand and/or clay.

Outwash is a glacial deposit composed of stratified sand or sand and gravel that has been deposited by streams flowing from the front of the glacier.

Percolation is the downward movement of water through the soil.

Permeability is the property of a porous medium allowing for the movement of liquids and gases through the medium under the combined action of gravity and pressure.

Pervious is the ability of one medium (soil) to accept or be permeable to another medium (water).

Potentiometric Surface a theoretical surface indicating the elevation corresponding to hydrostatic pressure in a confined aquifer; analogous to the water table in an unconfined aquifer.

Runoff is the amount of excess precipitation or snowmelt that is not permanently stored in depressional areas or infiltrated into the soil.

Semi-landlocked area corresponds to a depression where there is no available surface overflow or outlet for stormwater drainage up to a 25-year storm.

Till is glacial sediment that is primarily made up of impermeable materials such as clay.

Transpiration is the loss of water vapor by any part of the plant body, although leaves are by far the principal organs of transpiration.

Volatile Organic Compounds generally have a boiling point less than or equal to 100 ^{o}C and/or a vapor pressure greater than 1mm Hg at 20 ^{o}C

Water Table Gradient indicates the direction of flow in an aquifer.

Watershed means an area bounded peripherally by a drainage divide, which collects precipitation and provides runoff to a particular drainage system.

Watershed Management Plan is the SWWD's watershed management plan, as defined by Minnesota Statutes 103B.231.