Marie Creek Feasibility Study

Prepared for
Lower Mississippi River Watershed Management Organization

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1.0 Background

Recently, a variety of problems and changes involving Marie Creek have been brought to the attention of the City of Mendota Heights and the Lower Mississippi River Watershed Management Organization (LMRWMO) by concerned citizens. Some residents have observed changes to the flow in the creek, including a decrease in base flow. This has been a concern primarily along the upper reaches of the creek near the new Hidden Creek development, but also extending downstream to where the creek crosses Dodd Road and Marie Avenue. Other residents have noted erosion problems downstream of Dodd Road and Marie Avenue. Please see Figure 1 for approximate locations of major points of interest.

To investigate possible causes of the low base flow, the site was visited several times to observe conditions in the creek; residents were contacted to obtain several historical perspectives of the problem; and potential changes to the hydrology, groundwater levels, and land use were investigated. Findings are presented in this report and potential actions that can be taken to help restore a more sustained flow to the stream are also discussed.

The eroding streambanks along the lower portion of the stream were surveyed and photographed in 2005. An additional set of photos was taken in 2006, which helped to show which sites are experiencing the most active erosion. Various flood flows and velocities were modeled and concept designs were developed to stabilize the streambanks. These designs are also presented in this report.

A Water Quality Feasibility Study was prepared for the LMRWMO in 2004, in which the installation of a wet detention pond for water quality purposes was studied. The feasibility of this pond in relation to the base flow and erosion issues was studied and conclusions are presented in this report.

The study area for this project includes the contributing watershed for Marie Creek to the point where the creek passes through the culvert under Wachtler Avenue. The 438-acre watershed includes 153 acres in West St. Paul and 285 acres in Mendota Heights.

2.0 Hydrology and Hydraulics

2.1 Hydrologic and Hydraulic Modeling

The hydrologic and hydraulic modeling was completed using XP-SWMM software. This is a commonly used model that can accurately model rainfall, infiltration and runoff from several watersheds, and also can accurately model the flow of water through creeks, pipes, and culverts.

In order to develop a hydrologic model, several pieces of information must be gathered, including watersheds, topography, land use, soil information, stage-storage curves for ponds and wetlands, and pipe/culvert dimensions or open channel dimensions to route moving water from place to place.

Two-foot contours that covered the study area had previously been obtained from Dakota County. Watersheds for the study area were delineated using these contours. In general, drainage points for the watersheds were either storage areas, such as ponds or wetlands, or the upstream end of culverts that go under roads or driveways. In a few cases, watersheds were delineated to other land features if it was important to get an accurate look at the flow in a particular stretch of stream and a significant watershed area contributed flow to that section. The topography was also used to determine watershed slope and to determine the stage-storage curves for ponds and wetlands.

Land use was determined with aerial photos, and impervious area percentages were assigned to each land use. The area consists of low- to medium-density housing, wetlands, and parks.

Data about the soils in the study area help to estimate how much infiltration takes place during rain storms. This data was obtained from the Soil Survey of Dakota County (Soil Conservation Service, 1983).

Pipe/culvert dimensions were either surveyed or provided by the City of Mendota Heights, and open channel dimensions were surveyed.

Once the XP-SWMM model was developed, it was calibrated to match observed data. Unfortunately, there is not a record of flow data for Marie Creek, nor is there elevation data for the ponds and wetlands in the watershed. Therefore, the model was calibrated in two ways. First, it was adjusted to match the peak elevations for 10- and 100-year events as reported in the 1993 and 2005 Mendota

Heights Surface Water Management Plans. Then, it was adjusted to match some basic trends that residents reported. For example, in the Dodge Nature Center (DNC), there is a pond with an outlet that supplies water to the upper reaches of the stream, and workers from DNC report that water only flows from the pond during spring runoff, during wet periods, or after large storms. Also, residents along Marie Creek reported that, historically, the stream flowed well in the spring, but would become dry during the summer months. Recent reports indicate that the stream still runs in the spring, but to a lesser extent, and that flow is most commonly observed after rain events.

The XP-SWMM model was run for varying precipitation scenarios, including both long-term and short-term simulations. To examine the base flow question, the model was run from March 31 to November 1, 1998. The March 31 to November 1 period was chosen because it was assumed to be warm enough to neglect snowfall and snowmelt. The year 1998 was chosen because there was an average amount of rain during the spring, summer, and fall, when compared to all years from 1971 to 2005. Also, for each month during the study period, there was not a large variation in the total amount of rainfall, meaning that there was not one month with a large amount of rain with another month with a very small amount of rain. In addition, when compared to other years, 1998 featured a good mix of storm sizes with significant dry periods between storms. The maximum rainfall in one storm during 1998 was 2.95 inches.

To examine the erosion along the lower reaches of Marie Creek, single event storms were studied. Using an SCS Type-II rainfall distribution, 10-year (4.2 inch) and 100-year (5.9 inch) storm events were studied in addition to storm events of 1.5-, 2.0-, 2.25-, and 2.5-inches. The smaller events were used to determine bankfull flow, and the larger events were used to determine maximum probable flows the stream will experience.

2.2 Determination of Bankfull Flow

Bankfull flow is one of the most important considerations in any stream restoration project. It is sometimes called the “channel forming flow” because it is the flow that does the most work on the channel. It is defined as the flow in a stream such that water just begins to spill out onto the floodplain. This flood typically occurs approximately once every 1 to 2 years, depending on the stream and contributing watershed. Urbanizing watersheds tend to have a higher frequency of bankfull discharges, and the stream must adjust its dimensions accordingly.

During the April, 2005 survey of Marie Creek, several cross sections were surveyed, and these were used to help determine bankfull flow. Values for channel area and perimeter were calculated, channel slope was measured, and Manning's n constant for channel roughness was determined. Using Manning's equation, bankfull flow was calculated to be approximately 20 cubic feet per second (cfs). Cross sections and channel slope information was then put into both HEC-RAS and XP-SWMM to verify hand calculations of bankfull flow and to determine which rainstorm results in bankfull flow. Results in HEC-RAS and XP-SWMM confirmed that bankfull flow occurs at approximately 20 cfs. This flow occurs with an SCS Type II 24-hr rainfall of 1.5 inches. It is important to note that a 1.5-inch storm occurs approximately 2.7 times per year for a return frequency of 0.4 years. However, not every 1.5-in storm will result in bankfull flow because of wide variability in antecedent conditions, storm intensity, and storm duration.

3.0 Base Flow Investigation

3.1 Investigation of Causes

3.1.1 Site Visits and Discussions with Homeowners

Marie Creek was visited several times during April 2005. Staff from Barr Engineering Company (Barr) and the City of Mendota Heights walked the creek to obtain a first look at the creek and the problems that have been reported by residents. There was no flow in the upper portion of the creek during this first visit. Based on this initial site visit, it was thought that the stream originated in a wetland area to the North and West of the cul-de-sac on Ridgewood Drive, since there was an obvious point where a channel began (Point B in Figure 2); upstream of this point no channel was observed. Also in April 2005, staff from Barr and the City completed a survey of the creek to measure channel slope and cross sections, and to document erosion sites.

In November 2005, Barr staff again visited the area to investigate some features upstream of the perceived headwaters of the creek. Of particular interest were the ponds in the Dodge Nature Center and what appeared to be a small pond on private property near the corner of Marie Avenue and Delaware Avenue (see Figure 2 where this pond is labeled “Old Pond”). During this site visit it was discovered that there are two small ponds, instead of one, on private land near the aforementioned corner. The “New Pond” in Figure 2 was relatively small, and according to nearby residents, build approximately 5 years ago. The Old Pond was immediately downstream of the New Pond; was approximately 2 to 3 times the size of the New Pond; and had experienced a berm failure at some point. There were culverts in and beside the creek downstream of the failed berm and a channel had cut through the berm. None of the residents that were contacted knew exactly when this berm failed, but one estimate by a long-time resident and an immediate neighbor of the property on which the berm and pond are located was that it failed approximately 8 years ago. According to this resident, the berm was installed in the early 1970’s to form a private pond. Unfortunately, the landowner who installed the berm and created the pond passed away in 2004.

Another interesting feature was discovered during the November site visit. Even though there was a defined channel downstream of the Old Pond, this channel disappears, along with the water flowing in it, near Point A on Figure 2. Upstream of this point, water was observed to be flowing in the creek, however, near Point A, ice gradually became thicker and, eventually, too thick to break. There was not a defined channel between Point A and Point B and no flowing water was observed downstream of Point A. The "disappearing stream" phenomenon was confirmed during another site visit on March 12, 2006, when an early spring flow was observed to spread out and dissipate near Point A. Video and photos were taken. On that date, Barr staff estimated approximately 0.5 cfs (225 gallons per minute) flowing in the stream, and all of the flow was disappearing in the area around Point A. No flow was present in the channel at Nature Way. According to the same resident mentioned previously, his family has lived in the neighborhood for over 100 years, and they used to own and farm as much as 40 acres in the immediate vicinity. He said the creek has always disappeared near Point A, and that both the Old Pond and New Pond were low, marshy areas prior to being converted into ponds. It is possible that the flow that disappears at Point A stays in shallow groundwater and returns to the creek further downstream via springs near Point C. It is also possible that the water contributes to deeper groundwater recharge.

In total, 10 residents were contacted and asked about their observations of changes in the creek. The houses of residents who were contacted are highlighted in yellow in Figure 2. These residents had a wide range of perceptions of how the creek has changed in recent years. Some believe the flow has gradually decreased over time, while others believe changes have been abrupt. Some believe that significant changes have occurred as the Hidden Creek development has been built, while others do not think this is the case. A few mentioned the possibility that groundwater levels have been dropping in the area as they have noticed formerly marshy lands gradually become drier. There was, however, a general consensus that the creek was usually dry during the summer except for immediately after rain.

3.1.2 Changes to Area Hydrology

One possibility that could explain a change in base flow in the creek is if the regional hydrology had been affected by either reduced total precipitation or due to a trend of fewer but more intense storms. If rain falls in fewer but more intense storms, then more runoff would be generated during these storms and less precipitation would infiltrate, even though the average annual precipitation may remain constant. Infiltration of rainfall into shallow groundwater contributes significantly to base flow in most streams. These possibilities were investigated by obtaining 101 years (1905-2005) of daily precipitation data for Mendota Heights from the University of Minnesota Climatology website (http://www.climate.umn.edu/). Trends for periods 1905-2005 and 1971-2005 were examined. The period from 1905 to 2005 was chosen because that is the extent of the data available through the climatology website. The period from 1971 to 2005 was chosen because the currently used 30-year period for examining hydrologic trends is 1971-2000, and data from 2001-2005 was added to provide insight into the most recent changes that have been observed in the creek.

For both periods, there is a trend for an *increase* in annual total precipitation. Please see Figures A1 and A2 in Appendix A. Therefore, it is reasonable to conclude that the amount of annual precipitation is not contributing to the problem.

In order to examine the second possibility of less frequent, but more intense storms, it was necessary to quantify the frequency that larger storms occur and if a greater proportion of annual precipitation falls during these storms. Rainfall amounts of 1 inch and 1.5 inches were chosen as thresholds for a "larger storm" because they can often be intense enough to generate significant runoff; and they usually occur at least 2 to 3 times per year so an increase in the frequency would be easy to track. The storm frequency was examined by looking at the number of days with precipitation amounts of greater than 1 inch and 1.5 inches. For both periods, there is a trend for an increase in the number of days with precipitation greater than both 1 inch and 1.5 inches (Figures A3 and A4).

To determine if a greater amount of the annual precipitation has been falling during the larger storms, the total annual precipitation outside of the larger storms was quantified by subtracting the precipitation in the larger storms from the total annual precipitation. The resulting precipitation amount is then the total that fell in all storms smaller than the thresholds of 1 inch or 1.5 inches. For both periods, there was a trend for an increase in total precipitation for storms less than 1.5 inches. There was also a very slight increase in the total precipitation for storms less than 1-inch (Figures A5 through A8), however, from 2002 to 2005, there has been slightly below-normal precipitation in storms less than 1 inch. This could partially account for the observations from some residents that the creek has been drier than normal during the past 2 to 3 years.

Even though there has been an increase in the number of storm events larger than 1 inch and 1.5-inches, it does not appear that total precipitation from smaller events has significantly decreased. Therefore, based on these results, it is reasonable to conclude that changes to local rainfall patterns have not contributed in a significant way to the decrease in base flow in Marie Creek.

3.1.3 Changes to Land Use

A few of the residents believe that the recent development of the Hidden Creek subdivision has contributed significantly to the reduction in base flow in the stream. They also report that the flows in the creek tend to be flashier. This hypothesis was tested by constructing XP-SWMM models for both pre- and post-development models for the area, with the pre-development model assuming conditions prior to the development of the Hidden Creek subdivision. Results from these models show that there is a slight increase in the flashiness of the creek downstream of the Hidden Creek subdivision; however, the results do not show a significant drop in the duration of the flow directly attributable to runoff. Therefore, it does not appear that the development of the Hidden Creek subdivision is a major contributor to the decrease in base flow in Marie Creek.

The area has become fully developed during the past 50 years through a series of short periods of development. Before the Hidden Creek development, the last major period of development was during the early to mid 1970s, which is when the majority of the houses in the area were built. Between the development in the 1970s and the current period of development, houses were occasionally constructed and the area became more fully developed. There was another development period in the mid-1950s, and prior to that the area was sparsely developed without any obvious periods of rapid change in housing density. Of course, each phase of development increased the total impervious area for the watershed, and even the pervious areas within developments (lawns, golf courses, etc) tend to be more compact than pre-existing conditions, thus reducing infiltration capacity. Both factors lead to an increase in runoff and a decrease in infiltration.

Barr staff also had conversations with Dodge Nature Center's groundskeeper. He stated that the outlet structure for the pond that directly feeds Marie Creek was reconstructed in 1991, but the overflow elevation remained the same. He also said that the water level for this pond is usually below the overflow elevation, so this pond usually does not contribute flow to Marie Creek, except after rainfall events. Besides the changes to the one outlet structure, no other changes have taken place within the Dodge Nature Center that would have altered runoff patterns.

3.1.4 Groundwater

As noted previously, a few residents believe groundwater levels have been dropping because they have observed previously marshy areas gradually become drier. Another resident has reported that his yard is "sinking," which could be caused if groundwater levels have fallen. It should be noted that in this resident's yard, there are springs next to the creek, so a change in groundwater levels could have effects on the surface.

The nearest Minnesota DNR monitoring well with current data is located in Eagan. Data from this well show that groundwater levels have dropped approximately 15 feet from 1978 through 2005.

Typical causes of falling groundwater levels include decreased rainfall, increased development, and pumping from the aquifer. The last two have been occurring in this area and could be contributing to falling groundwater levels. The effect of development was addressed in Section 2.3, and there are several high capacity wells throughout Mendota Heights, West St. Paul, and Eagan that supply water for municipal use, golf courses, and industry.

3.1.5 Conclusions

The cause for a decrease in base flow in Marie Creek appears likely to be from falling groundwater levels. Given the likely causes of the falling groundwater levels, there is not a logical way to reverse that trend and directly eliminate the cause of the decrease in base flow. Therefore, other alternatives have been explored and are discussed below.

3.2 Investigation of Base Flow Restoration

As stated earlier, an XP-SWMM model was constructed for the Marie Creek watershed to model flow through the creek. An “Existing Conditions” model was used as a baseline and assumed full development of the Hidden Creek subdivision. Several alternative scenarios were also run to determine what course of action would best restore base flow to the creek. Hourly precipitation from the Minneapolis-St. Paul International Airport was used. Each model was run from March 31 to November 1, 1998. The spring, summer, and fall of 1998 had a relatively average amount of rainfall with the largest storm event approximately equal to the 2-year, 24-hour event. The largest rainfall event was 2.95 inches, and total precipitation for the study period was 31.57 inches.

The XP-SWMM models were calibrated to the 10- and 100-year flows at Dodd Road, as reported in the City’s 1993 Water Resources Management Plan. Due to changes in assumptions for stormwater routing, it was not feasible to calibrate to a point closer to the area of interest. Additional flow data that would have aided in the calibration was unavailable. Furthermore, field observations of the “sink” near Point A provided one estimate of the amount of water that disappears at this point, however, further observations and measurements should be taken to provide additional information about this feature.

Table 1 provides a list of the courses of action considered and their descriptions. Please refer to Figure 3 for their approximate locations. Table 2 provides results for flow duration in the creek under each scenario.

As can be seen in Table 2, the two individual actions that result in the greatest increase in the duration of flow in the creek are to plug the sink at Point A and to construct a pond to the west of Point A. Two different pond sizes were modeled; however, there was not a significant difference between them in the increased duration of flow. Combining actions continued to increase the duration of flow in the creek, but the net effects were not additive.

Preliminary cost estimates are provided in Table 3. These estimates should only be used to compare the relative costs of each option and should not be used for budgeting purposes. The cost estimates are based on project-related information available to Barr at this time and include conceptual-level design of the potential options. The cost estimates include foreseeable construction related activities only and do not include soil exploration, land acquisition or additional surveys. For greater assurance as to the probable cost, LMRWMO should perform the recommended pre-construction activities listed in Section 3.3.

Plugging the sink is probably the greatest unknown among the potential courses of action. At this point, more investigation would need to be done in order to accomplish this task. It is not known where the sink begins and where it ends, nor is its width known. One option would be to install drain tile from the area where the channel disappears to where the creek reappears. There is also a potential concern that plugging the sink would have additional adverse effects on the groundwater. Groundwater experts at Barr Engineering Company believe that it is not likely that this sink is a major contributor to groundwater recharge, and in all likelihood, the water stays near the ground surface and reappears in a downstream spring by the creek. Eliminating the sink with use of a drain tile would cost approximately $10,500. Costs of other potential methods to eliminate the sink are nearly impossible to estimate until additional information is gathered.

All scenarios with a new pond of any size assume that there will be minimal infiltration from the pond. Given the potential for infiltration in the area, as evidenced by Point A, it may be necessary to line a pond with clay to make it less permeable. Assuming a clay liner, preliminary cost estimates for a 1-acre pond and a 2.7-acre pond are $50,000 and $85,000, respectively.

Repairing the Old Pond would be relatively simple, although not the most effective. New culverts would need to be put in place and the berm repaired. The preliminary cost estimate is $14,000.

Because berms would be relatively short and provide less storage than a pond, they could potentially be placed further downstream where houses are closer to the creek. It is also assumed that infiltration like that near Point A will not be a problem this far downstream. The preliminary estimated cost for each berm is $12,000.

Diverting flow from the North Wetland to the south is probably one of the least appealing options because it would obviously have adverse effects on the stream that normally flows out of this wetland to the west. And given that it seemed to have smaller increases in flow duration, it is not a particularly attractive option for meeting the objective of this study. The cost estimate for diverting flow to the south is $105,600.

3.3 Recommendations for Base Flow Restoration

Dropping groundwater levels appear to be the primary cause of the loss of base flow in Marie Creek. Recent development of the Hidden Creek Estates within the watershed has had an insignificant effect on the base flow in the creek.

The best options for restoring base flow in the creek are to eliminate the sink and to create additional storage, either in the form of a pond near the South Wetland, or in the form of low berms upstream of Nature Way.

A meeting between staff from the City of Mendota Heights and Barr was held on February 14, 2006, to discuss the results of the base flow portion of this study and to determine the best course of action. The City preferred the option of constructing the large pond (shown in Figure 3), but preferred to not plug the sink at Point A (shown in Figure 2) for the time being due to the potential difficulty in permitting such a measure. Other potential options discussed with City staff included the construction of an additional pond between the Old Pond and Point A and constructing rainwater gardens to increase the amount of infiltration and therefore possibly raise groundwater levels. The option of constructing an additional pond between the Old Pond and Point A was examined, and the results were nearly identical to those of simply repairing the Old Pond. Therefore, that option did not appear to be a beneficial solution.

The possibility of using rainwater gardens to raise groundwater levels was not investigated in detail at this time. Significant amounts of data about the soil layers and groundwater characteristics of the area would need to be obtained in order to accurately determine if rainwater gardens would have the desired effect. Given the volume of water observed infiltrating at Point A, it is believed that significant amounts of runoff would need to be infiltrated to significantly raise the groundwater levels. Also, if there is interaction between the shallow and deeper groundwater in the area around

Point A, and assuming that the dropping groundwater levels at the DNR monitoring well are indicative of a regional problem, then rainwater gardens in the Marie Creek watershed would not be likely to have a significant effect on groundwater levels.

Prior to the final design and construction of any measure to restore base flow, flow gauging should be performed to determine if the disappearing flow reappears in the creek and to help calibrate the model. Also, acquisition of property where the storage would be located should be investigated.

4.0 Streambank Erosion Investigation

4.1 Inventory of Erosion Sites

Stream erosion sites were inventoried and surveyed in April 2005; staff from Barr and the City of Mendota Heights completed a survey of the creek to measure channel slope, cross sections, and to document erosion sites. Digital photographs were taken of the erosion sites. The survey data was incorporated into GIS mapping of the creek and watershed. The survey data was used in creating the SWMM model, to estimate the bankfull flow characteristics of the channel, and to prioritize the erosion sites and propose suitable solutions.

The erosion sites are shown in Figures 4, 5 and 6. Photographs of the sites are shown in Appendix B.

4.2 Prioritization of Erosion Sites

The erosion sites were prioritized based on the magnitude of the erosion, potential damage to homes and property, and likelihood of continued erosion at the site. The erosion sites are summarized in Table 4, along with the listed recommended repair technique and a cost estimate. All of the sites are located downstream of Dodd Road and upstream of Wachtler Avenue. Detailed cost estimates are presented in Table 5. Photos of each of the erosion sites are in Appendix B.

4.3 Feasibility of BMP 8

The Lower Mississippi River Watershed Management Organization (LMRWMO) Water Quality Feasibility Study was complete in 2003. One of the recommendations from that study was to install BMP 8, a water quality pond on the northeast corner of Marie Avenue and Dodd Road. If this pond was to be installed, it would be a relatively short distance upstream of the erosion sites, therefore, it is logical to investigate the potential impacts of this pond on downstream reaches.

The stage-storage curve and outlet information for the proposed pond were added to the XP-SWMM model. Model results indicate that a detention pond in this area would reduce peak flows through the lower reaches of Marie Creek by 10-25%, with the greatest reduction in peak flows occurring in the smallest event modeled. Therefore, BMP8 would provide benefits from the standpoint that peak flows would be reduced and would occur less frequently. However, locating such a pond in the middle of the stream would likely have sedimentation problems that would negate any benefit from the reduced peak flows. Every stream has a natural sediment carrying capacity, and it constantly finds a balance between the flow in the channel, the sediment already in the flow, and the substrate and sediment in the channel bed. When a stream enters a pond, the sediment that it is carrying tends to settle out due to lowered flow velocity. The water leaving the pond will then have less sediment than the water entering the pond.

A stream that is significantly below its sediment carrying capacity is referred to as "sediment starved," and it will try to pick up additional sediment where it is available. Therefore, adding a pond such as BMP 8 has the potential to exacerbate existing erosion problems downstream as the stream tries to pick up the equivalent amount of sediment that it lost through settling in BMP 8. The pond would likely require periodic dredging in order to maintain its effectiveness.

In conclusion, BMP 8 is not recommended for Marie Creek. Even though Marie Creek has features such as a gravel bed and cohesive banks that are more resistant to erosion than other materials, the potential for additional erosion downstream of BMP 8 is greater than any benefit gained by reduced peak flows.

4.4 Recommended Stabilization Methods

To address the erosion problems along Marie Creek, there are four primary activities that need to be completed in order to help stabilize the stream bed and the eroding streambanks: 1) lower bank stabilization; 2) upper bank stabilization; 3) grade control; and 4) vegetation management. Recommended methods for accomplishing these needs are discussed below.

4.4.1 Lower Bank Stabilization

Lower bank "toe" protection measures are used at the lower portion of the bank when it is being undercut by channel flow, resulting in bank sloughing and mass wasting. Such erosion is common on Marie Creek, and these measures are recommended at many of the restoration sites.

The recommended bank toe protection measures explained below should be used in conjunction with upper bank stabilization techniques.

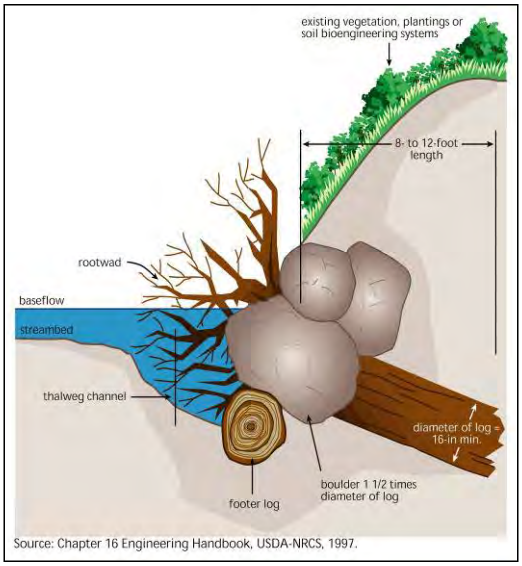
- *Rock vanes*, or "berms" of rock or boulders constructed on the creek bottom, divert channel flow toward the center and away from the bank. They are typically oriented in the upstream direction and occupy no more than one third of the channel width. Vanes are largely submerged and fairly inconspicuous. The rocks are chosen such that they will be big enough to not be moved during flood flows or by vandalism, with additional smaller rock material to add stability. Rock vanes function in much the same way as rootwads in that they push the stream centerline away from the outside bend. They also promote sedimentation behind the vane, which adds to the toe protection.

Rock vanes point upstream to deflect flow from this eroding bank.

- *Coconut fiber rolls* (or biologs) provide temporary protection to bank toes so that vegetation can become established. They are suitable for sites that receive adequate sun to support good plant growth and where channel velocities are relatively low.

Installation of coconut fiber roll can often be performed without heavy equipment.

- *Root wads* consist of logs with the root ball attached anchored into the bank, so that only the root ball is exposed. Typically placed about half below and half above the normal water line, they are well suited to deeper locations such as outside bends. The trunk portion is placed in the bank by either placing it in a trench or by pushing the trunk into the bank. The root wad absorbs energy and diverts flows away from the bank.   Rootwads are generally cost effective and provide excellent fish habitat.



Above left: cross-sectional view of a root wad. Above right: Root wads in place in a streambank, with vegetation fully established on bank above the root wad.

- *Stone toe protection* employs stones to armor the toe of the bank. It is often used on sites that are too shaded to support good ground vegetation cover, and where vanes or root wads are not necessary. Stones are selected to be large enough so that they would not be moved by flood flows, but small enough to be consistent with the size of other stones found in and near the stream and thus appear natural.

Natural stone is used to protect the toe of this bank adjacent to a pathway.

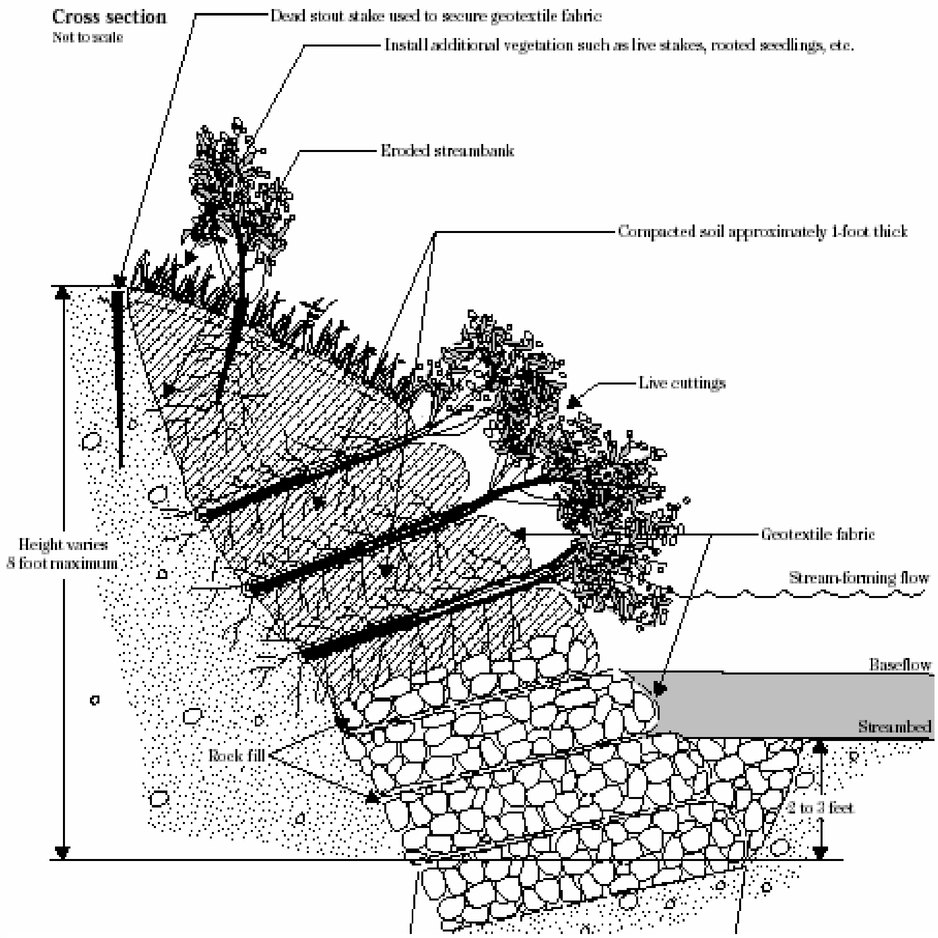
4.4.2 Upper Bank Stabilization

Upper bank stabilization methods are employed on the upper portions of the banks to prevent slumping and bank failure. Bank stabilization will reduce sediment loading to the stream and will reduce the loss of adjacent property.

Two methods of upper bank stabilization are recommended for Marie Creek – bank grading and revegetation, and vegetated reinforced soil slope technique. With either method, stabilization of the lower bank is almost always required and is a priority if resources are limited.

Grading and revegetation of the eroded bank is the most common method for stabilization. With this method, the upper bank is graded at a 2:1 (2 foot horizontal to 1 foot vertical) or flatter slope to allow for replanting. The slope is typically seeded with a cover crop and covered with erosion control fabric. Plant plugs and shrubs such as willows or dogwood can then be installed through the erosion control fabric. The stable slope and vegetation work together to prevent erosion from stream flows, wind, and raindrop impact.

Vegetated reinforced soil slope (VRSS) is the second method recommended for upper bank stabilization on Marie Creek. It is typically used on steep slopes where grading the bank to a more stable slope is not an option due to site restrictions. VRSS typically involves protecting layers of soils with a blanket or geotextile material (e.g. erosion control blanket) and vegetating the slope by either planting selected species (often willow or dogwood species) between the soil layers or by seeding the soil with desired species before it is covered by the protective material. In either case, if given enough light and moisture, the vegetation grows quickly and provides significant root structure to further strengthen the bank. This method tends to be labor intensive and, therefore, somewhat expensive. It is recommended for only one site on Marie Creek.



Typical cross-section of a vegetated reinforced soil slope design

Other methods commonly used for both upper and lower bank stabilization include riprap and other "hard armoring" methods, but these are not recommended for the sites along Marie Creek.

4.4.3 Grade Control

Grade control measures are used where channel downcutting has occurred. This is commonly seen where a channel has been artificially straightened by ditching or where construction of a culvert, bridge or road has occurred. It also may happen naturally when a stream straightens itself by cutting off a meander bend. The slope and velocity of the stream tends to increase in straightened reaches, thereby increasing its sediment-carrying capacity. This tends to result in increased bank erosion and channel widening.

Grade control measures are recommended downstream of the culvert at Erosion Site #3 on Marie Creek. In general, the remaining stream has acceptably adjusted to the existing structures and to the artificial channel straightening that has occurred.

The grade control measures should be constructed with boulders and coarse gravel. A V-shaped weir is constructed so that the flow is concentrated toward the center of the channel and away from the banks. Multiple weirs can be constructed to stabilize a longer reach.

A constructed riffle acts as grade control downstream of a pedestrian bridge

4.3.4 Vegetation Management

Vegetation management involves the selection of an optimal species mix to contribute to a healthy and stable stream. Typically an optimal species mix will provide good root structure to help stabilize streambanks and provide good habitat for riparian birds and animals. Obtaining this mix often requires planting new species, removing unwanted or exotic species, and/or thinning existing vegetation to provide enough sunlight to allow new ground vegetation to become established. Vegetation management is recommended for nearly all of the erosion sites on Marie Creek. The entire creek corridor could benefit from a vegetation management program.

4.5 Estimated Cost

The estimated costs to complete the recommended streambank stabilization projects are summarized in Table 4. A breakdown of the estimated costs is provided in Table 5. The cost estimates assume that several projects would be completed together in order to provide cost savings. If only one or two of the projects are completed at a given time the cost would likely be higher. It should also be noted that the costs are preliminary in nature and would be finalized during the detailed design process. As noted earlier, the cost estimates are based on project-related information available to Barr at this time and includes conceptual-level design of the project potential options. The cost estimates may change as further design is completed. In addition, since we have no control over the cost of labor, materials, equipment, or services furnished by others, or over the contractor's methods of determining prices, or over competitive bidding or market conditions, Barr cannot and does not guarantee that proposals, bids, or actual construction costs will not vary from the estimate of probable construction cost prepared by Barr. LMRWMO should wait until further information about land acquisition costs, and order and grouping of projects is available if they desire greater assurance as to probable cost.

5.0 Cost Allocation Strategy

There are two components to the proposed Marie Creek improvements: base flow enhancement and stream bank erosion repair. Neither component was considered a water quality improvement. For intercommunity drainage projects that are not considered water quality projects, the LMRWMO typically apportions the cost of the project based on the concepts of allowable flow and allowable volume. Several allowable flow examples are incorporated into the LMRWMO joint powers agreement. Examples A, E and G provided guidelines for our allowable flow and allowable volume calculations.

The cost allocation for the base flow enhancement (added ponding) is based on allowable volume. The 10-year allowable volume from West St. Paul is 19.3 acre feet of water. The 10-year design volume from West St. Paul is 15.7 acre feet of water, indicating that West St. Paul is not contributing any excess volume to Mendota Heights.

The cost allocation for the stream bank erosion protection is based on allowable flow. Approximately 153 acres of West St. Paul drains to Marie Creek prior to its discharge into Mendota Heights. The 10-year allowable flow of Marie Creek at the community boundary is 44 cubic feet per second (cfs); the 10-year design flow at the community boundary, as computed by XP-SWMM, is 33 cfs. This indicates that West St. Paul is not contributing any excess flow to Mendota Heights.

Since West St. Paul is not contributing any excess flow or excess volume to Mendota Heights, the City of West St. Paul is not obligated to participate in the project cost for either the stream bank stabilization project or the base flow enhancement project, according to the allowable flow provisions of the LMRWMO joint powers agreement.

6.0 Conclusions

The base flow of Marie Creek appears to be decreasing primarily due to lowering groundwater levels on a regional basis. Restoration of base flow to Marie Creek will be difficult to achieve, but several measures can help to restore the base flow. Development of a pond upstream of Nature Way will provide additional water storage and allow the creek to flow for a greater number of days than it does currently. Plugging a sink located near Ridgewood Drive would prevent the loss of streamflow to groundwater, but may be difficult to permit due groundwater concerns. Also, it is not known whether the flow is truly lost or if it reappears further downstream in the creek. At this time, the City of Mendota Heights supports construction of the pond but not plugging the sink.

Twelve streambank erosion sites located downstream of Dodd Road and upstream of Wachtler Avenue were inventoried and prioritized as high, medium, or low priority. Preliminary cost estimates for streambank stabilization were made for eight of the twelve sites. The remaining four sites should be monitored for continuing erosion.

Two additional activities should be considered in the near future: First, limited flow monitoring should be performed to provide calibration and verification of the hydrologic modeling, and to determine how much flow is lost to the sink and whether it reappears. Second, a vegetation inventory should be performed in order to determine the quality of the vegetation (including trees) in the riparian corridor. A cost estimate could also be developed for managing the vegetation in the creek corridor. Managing and improving the vegetation would greatly improve the ecology and aesthetics of the corridor, and would greatly increase the ability of Marie Creek to resist future erosion.

Tables

Table 1. Modeled Options for Restoring Base Flow

Action	Description
Plug "sink"	Eliminate the loss of water at Point A (Figure 2), possibly by sealing the area where water is infiltrating, or through a constructed, clay-lined channel.
Constructed Pond	Create a pond to the west of Point A to capture peak flows and slowly release water to the creek. Two different pond sizes were modeled.
Berms	Create berms, approximately 2-feet high in the stream and floodplain upstream from Nature Way. The berms would basically behave as small ponds and would have small outlet pipes to allow water to drain to the creek. Scenarios with one, two, and three berms were modeled.
Divert from North Wetland	Divert water from the wetlands to the north through a constructed channel to the wetlands near Point A.
Repair Old Pond	Repair the failed berm in the "Old Pond" in Figure 3

Table 2. Duration of Flow for each of the Modeled Scenarios

Model	Duration of Flow[1] (days)	Percent increase	Percent of study period
Existing Conditions	23.9	--	11
Individual Actions			
1. Plug sink	121.6	408	57
2. Pond 1 – 1 acre	131.5	450	61
3. Pond 2 – 2.7 acres	133.2	457	62
4. Repair Old Pond	25.1	5	12
5. Berm	59.1	147	27
6. 2 Berms	60.4	153	28
7. 3 Berms	66.4	178	31
8. Divert	72.4	202	34
Combined Actions			
1,4 Repair and plug sink	140.8	489	65
3,4 Repair and Pond 2	164.7	589	77
1,3,4 Repair, Pond, & plug sink	183	665	85
4,5 Repair and berm	59.7	150	28
1,4,5 Repair, berm, and plug sink	146.8	514	68
1,2 Pond 1 and plug sink	165	590	77
1,3 Pond 2 and plug sink	165.7	593	77
1,5 Berm and plug sink	130.7	447	61
1,6 2 Berms and plug sink	131.6	451	61
1,7 3 Berms and plug sink	133.3	458	62
1,8 Divert and plug sink	121.8	410	57

[1] Total days in study period (March 31 to Nov. 1) = 216 days

Table 3. Preliminary Cost Estimates for Base Flow Restoration

Item	Description	Quantity	Unit	Unit Cost	Extension	Subtotal
Plug sink						
1	Drain tile from Point A to Point B	500	L.F.	$21	$9,500	
2	Engineering and design	1	L.S.	$1,000	$1,000	$10,500
Pond – 1 acre						
2	Pipe – 12-inch diameter RCP	50	L.F	$50	$2,500	
3	Flared End Section – 12-inch diameter RCP w/ Trash Rack	1	Each	$1,500	$1,500	
4	Manhole outlet structure with Weir and Grate	1	L.S.	$7,000	$7,000	
5	Clay for berm and pond lining	1200	C.Y.	$25	$30,000	
6	Seeding and mulching	0.25	acre	$3,000	$750	
7	Engineering and Design	1	L.S.	$8,250	$8,250	$50,000
Pond – 2.7 acres – RECOMMENDED						
8	Pipe – 12-inch diameter RCP	50	L.F	$50	$2,500	
9	Flared End Section – 12-inch diameter RCP w/ Trash Rack	1	Each	$1,500	$1,500	
10	Manhole outlet structure with Weir and Grate	1	L.S.	$7,000	$7,000	
11	Clay for berm and pond lining	2600	C.Y.	$25	$65,000	
12	Seeding and mulching	0.25	acre	$3,000	$750	
13	Engineering and Design	1	L.S.	$8,250	$8,250	$85,000
Repair Old Pond						
14	Pipe – 12-inch diameter RCP	50	L.F	$50	$2,500	
15	Flared End Section – 12-inch diameter RCP w/ Trash Rack	1	Each	$1,500	$1,500	
16	Imported clay for berm repair	300	C.Y.	$25	$7,500	
17	Engineering and Design	1	L.S.	$4,250	$2,500	$14,000
Berm						
18	Pipe – 12-inch diameter RCP	25	L.F	$50	$1,250	
19	Flared End Section – 12-inch diameter RCP w/ Trash Rack	1	Each	$1,500	$1,500	
20	Imported clay for berm	250	C.Y.	$25	$6,250	
21	Engineering and Design	1	L.S.	$4,250	$2,000	$12,000
2 Berms						$24,000
3 Berms						$36,000
Divert Flow from North Wetland						
22	Excavate 900-ft long channel with off-site disposal	8000	C.Y.	$12	$96,000	
23	Engineering and Design	1	L.S.	$9,600	$9,600	$105,600

Table 4. Site Descriptions and Cost Estimate Summaries

Priority Level	Site #	Description	Recommended Repair Techniques	Estimated Cost
High	1	Approx. 50 feet of eroding bank. Vertical face on bank is 4-6 feet high, with a 1.4:1 (H:V) slope above the top of the face.	Vegetation management, vegetated reinforced soil stabilization, rock vanes	$11,700
High	2	Approx. 55 feet of vertical bank, 6 feet high.	Bank shaping, revegetation, bank toe protection with rootwads, rock vanes.	$7,600
High	3	Approx. 90 feet of steep bank, up to 6 feet high. Channel incised and culvert is perched.	Bank shaping, revegetation, grade control with cross-vanes, toe protection with biologs, vegetation management	$14,270
High	4	Approx. 25 feet of eroded bank. Manhole exposed. Also, approx. 25 feet of eroded bank upstream and on the opposite side of the stream from the manhole. Banks approx. 2-3 feet high.	Stone toe protection, bank shaping, vegetation management, rock vanes	$5,310
High	5	Approx. 80 feet of steep bank on 2 neighboring sites. Banks on meander up to 6 feet high; banks on straight up to 4 feet high	Bank shaping, rootwads, bank toe protection with biolog, clear debris from channel, rock vanes, vegetation mangement	$12,890
High	6	Approximately 50 feet of 5-foot high vertical bank.	Bank shaping, rootwads, clear debris from channel, rock vanes, vegetation mangement	$9,600
Medium	7	Approximately 35 feet of eroding banks 3-6 feet tall.	Bank shaping, rootwads, clear debris from channel, rock vanes, vegetation mangement	$8,020
Medium	8	Approximately 50 feet of eroding bank, approximately 3 feet tall.	Reshape banks, rootwads, rock vanes, vegetation mangement	$5,110
Low	9	Approximately 25 feet of eroding bank up to 7 feet tall.	Monitor to determine potential for long-term problems.	$0
Low	10	Channel widening, banks 3 feet tall, some unstable banks	Monitor to determine potential for long-term problems.	$0
Low	11	Approximately 15 feet of eroding bank up to 5-feet tall	Monitor to determine potential for long-term problems.	$0
Low	12	Approximately 25 feet of eroding bank up to 5 feet tall	Monitor to determine potential for long-term problems.	$0

Table 5. Estimated Cost for each of the Prioritized Erosion Sites[1]

Item	Description	Quantity	Unit	Unit Cost	Extension	Subtotal
Erosion Site #1 *– Approximately 50 feet of eroding bank. Vertical face on bank is 4-6 feet high, with a 1.4:1 (H:V) slope above the top of the face.*						
1	Mobilization	1	Each	10%	$900	
	Engineering and design	1	Each	20%	$1,800	
	Vegetation thinning to allow more sunlight into site	0.4	Acre	$5,000	$2,000	
	Vegetated reinforced soil stabilization	1	L.S.	$5,000	$5,000	
	Rock vanes for flow redirection	4	Each	$500	$2,000	$11,700
Erosion Site #2 *– Approximately 55 feet of vertical streambank, 6 feet high.*						
	Mobilization	1	Each	10%	$600	
	Engineering and design	1	Each	20%	$1,200	
	Regrading streambank – reshape bank and remove unnecessary fill	125	C.Y.	$10	$1,250	
	Rootwads, including footer logs	6	Each	$500	$3,000	
	Erosion control blanket	150	S.Y.	$3	$450	
	Seeding/Plantings	150	S.Y.	$4	$600	
	Rock vane to prevent erosion upstream	1	Each	$500	$500	$7,600
Erosion Site #3 *– Approximately 90 feet of steep bank, up to 6 feet high. Channel incised and culvert is perched.*						
	Mobilization	1	Each	10%	$1,100	
	Engineering and design	1	Each	20%	$2,200	
	Vegetation thinning to allow more sunlight into site	0.5	Acre	$5,000	$2,500	
	Constructed boulder riffle/cross vanes	3	Each	$2,000	$6,000	
	Biolog toe protection	100	L.F.	$15	$1,500	
	Regrading streambank and offsite disposal of excess fill	55	C.Y.	$10	$550	
	Erosion control blanket	60	S.Y.	$3	$180	
	Seeding/Plantings	60	S.Y.	$4	$240	$14,270
Erosion site #4 *– Approximately 25 feet of eroded streambank immediately adjacent to a manhole. Also, approximately 25 feet of eroded streambank immediately upstream and on the opposite side of the stream from the manhole. Banks are approximately 2-3 feet high.*						
	Mobilization	1	Each	10%	$400	
	Engineering and design	1	Each	20%	$800	
	Vegetation thinning to allow more sunlight into site	0.3	Acre	$5,000	$1,500	
	Stone toe protection	25	L.F.	$20	$500	
	Fill behind toe protection – assume excess fill from adjacent site can be used	4	C.Y.	$15	$60	
	Regrade streambank - excess soil disposed offsite	20	C.Y.	$10	$200	
	Rock vanes for flow redirection	3	Each	$500	$1,500	
	Erosion control blanket	50	S.Y.	$3	$150	
	Seeding/Plantings	50	S.Y.	$4	$200	$5,310

Item	Description	Quantity	Unit	Unit Cost	Extension	Subtotal
***Erosion site #5** – Approximately 80 feet of steep bank between 2 neighboring sites. Banks on meander are up to 6 feet high; banks on straight up to 4 feet high*						
	Mobilization	1	Each	10%	$1,000	
	Engineering and design	1	Each	20%	$2,000	
	Vegetation thinning to allow more sunlight into site	0.5	Acre	$5,000	$2,500	
	Clear debris from channel – remove and dispose	1	LS	$2,000	$2,000	
	Rootwads, including footer logs	5	Each	$400	$2,000	
	Rock vanes for flow redirection	2	Each	$500	$1,000	
	Regrading streambank – assume all fill can be used onsite	70	C.Y.	$6	$420	
	Biolog for toe protection	80	L.F.	$15	$1,200	
	Erosion control blanket	110	S.Y.	$3	$330	
	Seeding/Plantings	110	S.Y.	$4	$440	$12,890
***Erosion site #6** – Approximately 50 feet of 5-foot high vertical bank.*						
	Mobilization	1	Each	10%	$750	
	Engineering and design	1	Each	20%	$1,500	
	Vegetation thinning to allow more sunlight into site	0.4	Acre	$5,000	$2,000	
	Rootwads, including footer logs	7	Each	$500	$3,500	
	Clear debris from channel – remove and dispose	1	L.S.	$1,000	$1,000	
	Regrading streambank and offsite disposal of excess fill	50	C.Y.	$10	$500	
	Erosion control blanket	50	S.Y.	$3	$150	
	Seeding/Plantings	50	S.Y.	$4	$200	$9,600
***Erosion site #7** – Approximately 35 feet of eroding banks 3-6 feet tall.*						
	Mobilization	1	Each	10%	$600	
	Engineering and design	1	Each	20%	$1,200	
	Vegetation thinning to allow more sunlight into site	0.3	Acre	$5,000	$1,500	
	Rootwads, including footer logs	5	Each	$500	$2,500	
	Clear debris from channel – remove and dispose	1	LS	$1,500	$1,500	
	Regrading streambank and offsite disposal of excess fill	30	C.Y.	$10	$300	
	Erosion control blanket	60	S.Y.	$3	$180	
	Seeding/Plantings	60	S.Y.	$4	$240	$8,020
***Erosion site #8** – Approximately 50 feet of eroding bank, approximately 3-feet tall.*						
	Mobilization	1	Each	10%	$400	
	Engineering and design	1	Each	20%	$800	
	Vegetation thinning to allow more sunlight into site	0.4	Acre	$5,000	$2,000	

Item	Description	Quantity	Unit	Unit Cost	Extension	Subtotal
	Rock vanes for flow redirection	3	Each	$500	$1,500	
	Regrade streambank – assume all fill can be used onsite	10	C.Y.	$6	$60	
	Erosion control blanket	50	S.Y.	$3	$150	
	Seeding/Plantings	50	S.Y.	$4	$200	$5,110

[1] Photos of each site can be found in Appendix B.

Figures

Appendices

Appendix A

Rainfall Investigation

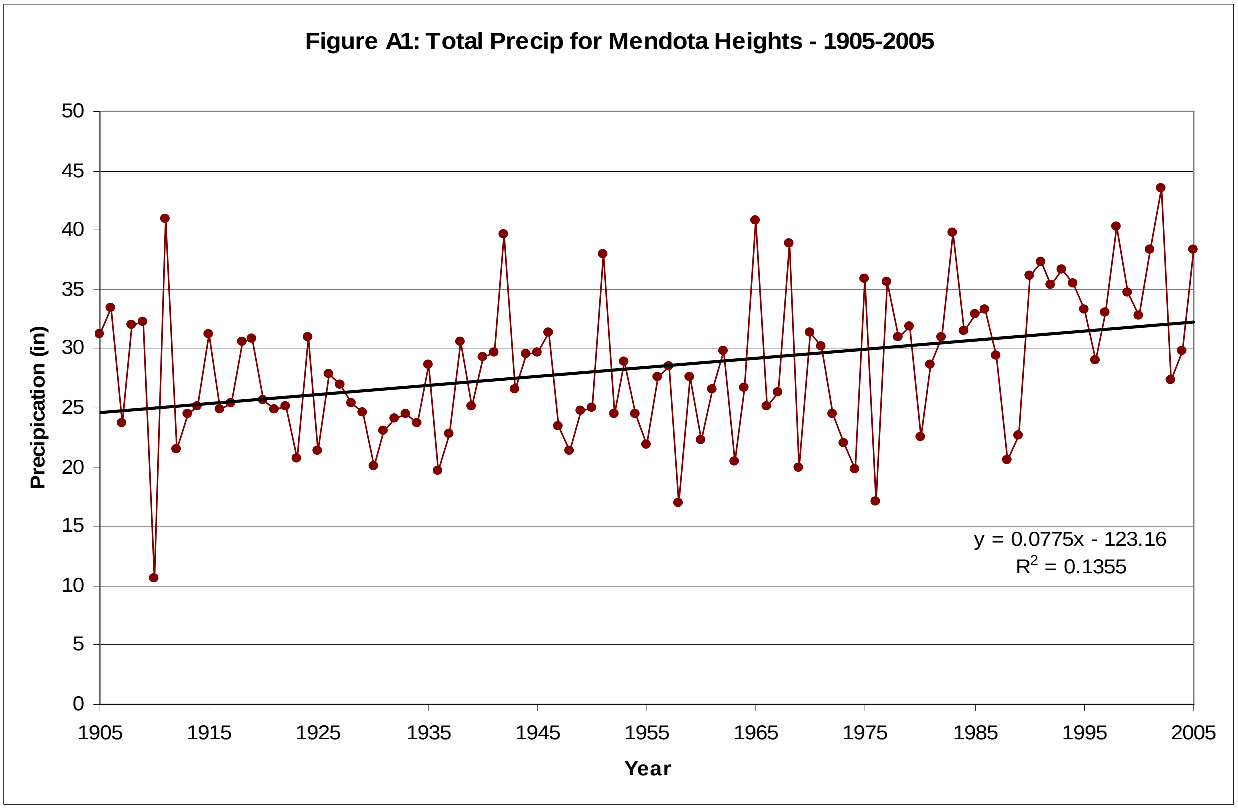


Figure A1: Total Precip for Mendota Heights - 1905-2005
Precipication (in)
50
45
40
35
30
25
20
15
10
5
0
1905
1915
1925
1935
1945
1955
1965
1975
1985
1995
2005
Year
y = 0.0775x - 123.16
R2 = 0.1355

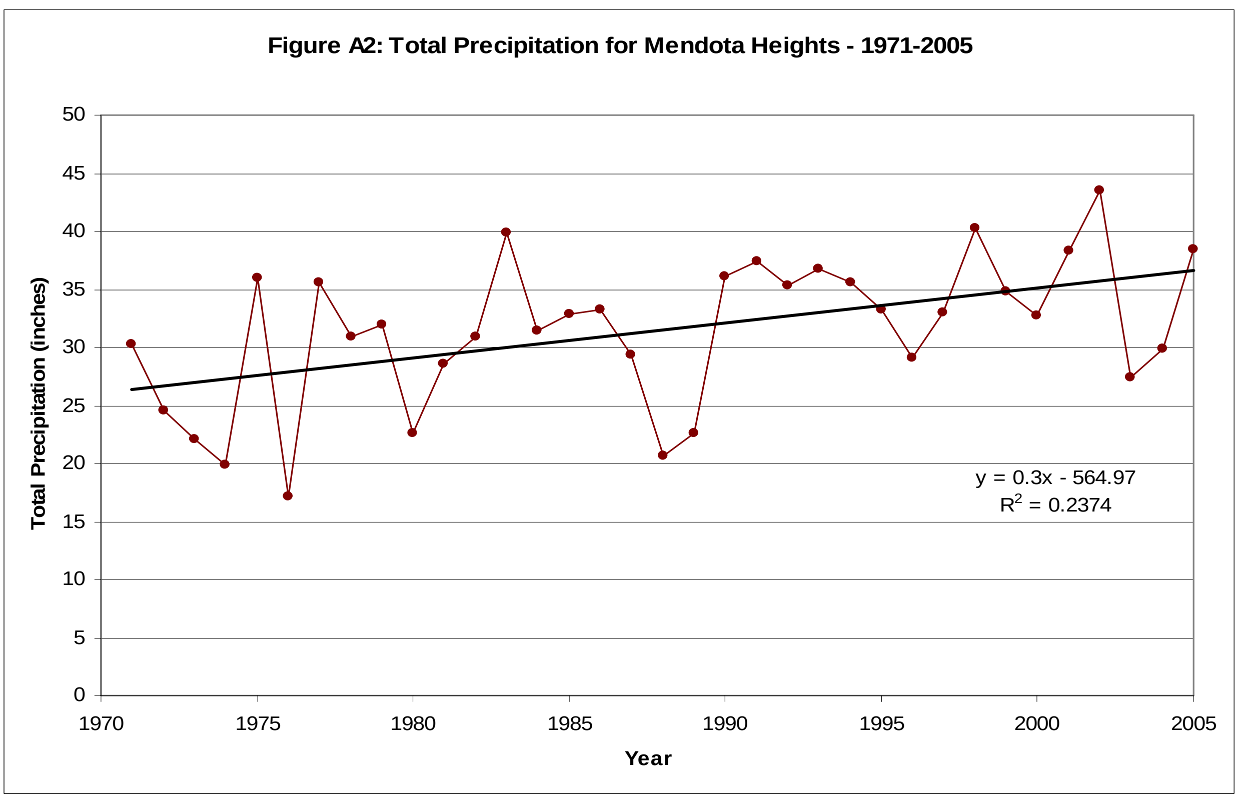


Figure A2: Total Precipitation for Mendota Heights - 1971-2005
Total Precipitation (inches)
50
45
40
35
30
25
20
15
10
5
0
1970
1975
1980
1985
1990
1995
2000
2005
Year
y = 0.3x - 564.97
R2 = 0.2374

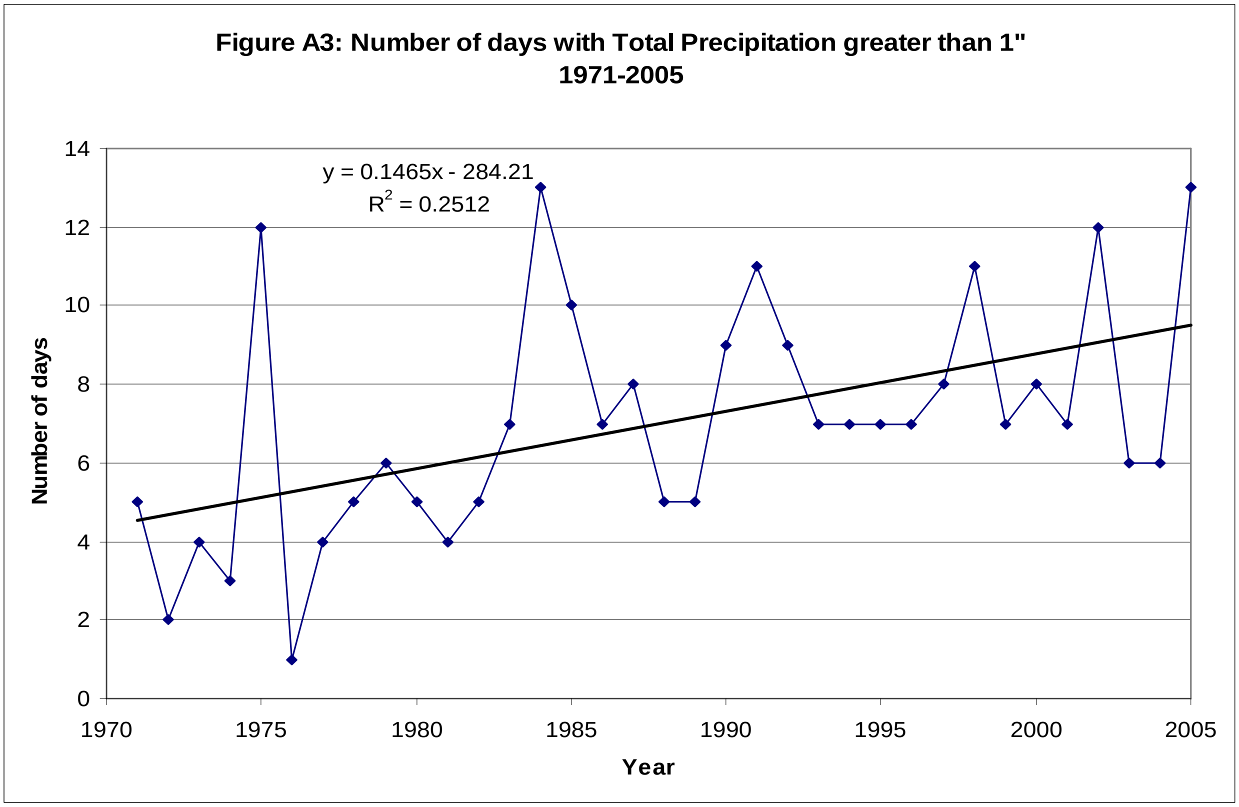


Figure A3: Number of days with Total Precipitation greater than 1"
1971-2005
y = 0.1465x - 284.21
R2 = 0.2512
Number of days
Year
0
2
4
6
8
10
12
14
1970
1975
1980
1985
1990
1995
2000
2005

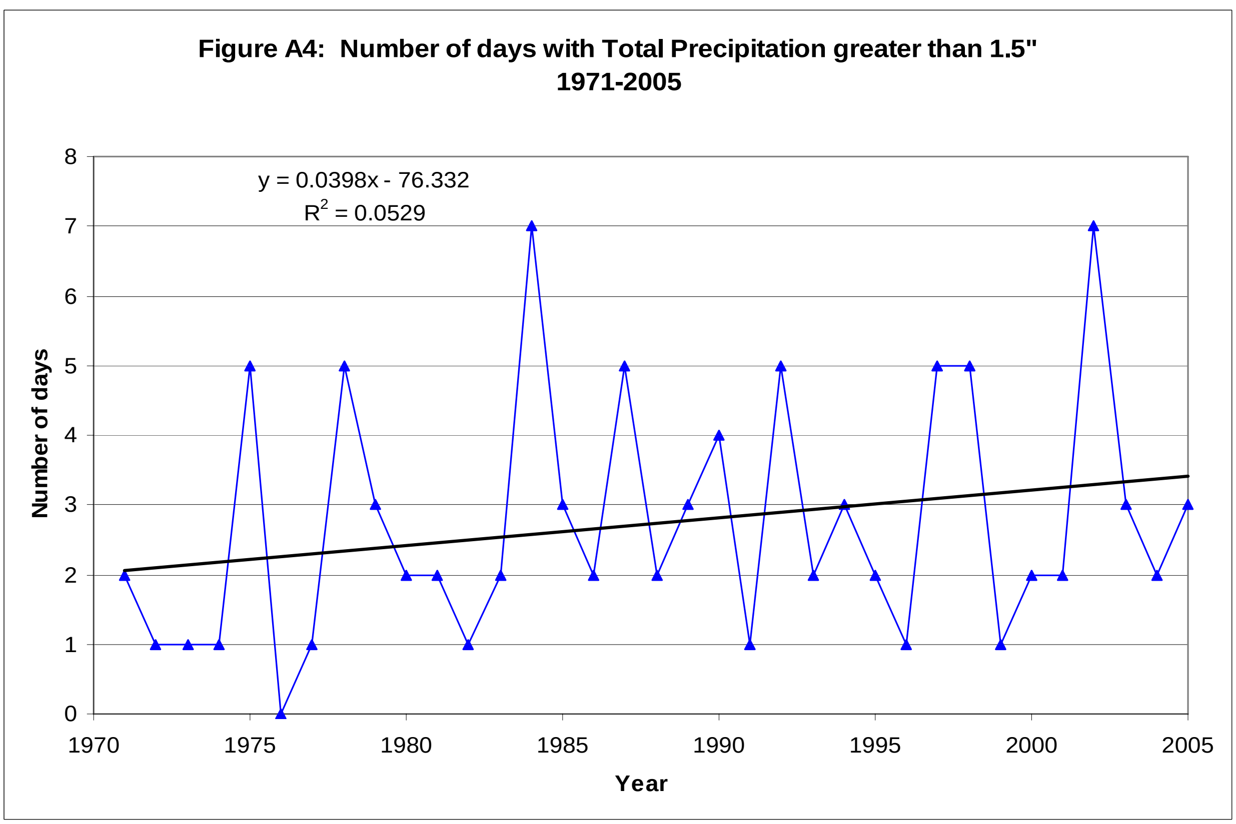


Figure A4: Number of days with Total Precipitation greater than 1.5"
1971-2005
y = 0.0398x - 76.332
R2 = 0.0529
Number of days
Year
0
1
2
3
4
5
6
7
8
1970
1975
1980
1985
1990
1995
2000
2005

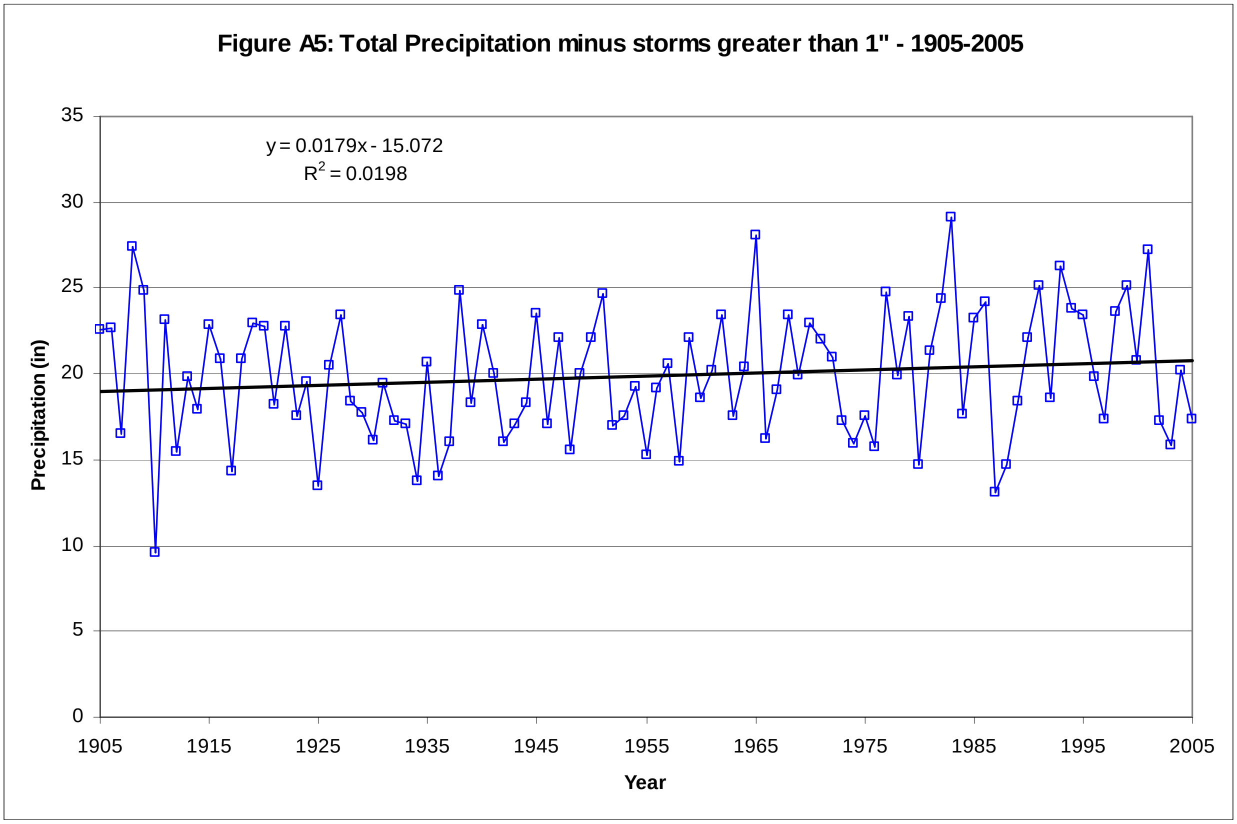


Figure A5: Total Precipitation minus storms greater than 1" - 1905-2005
y = 0.0179x - 15.072
R2 = 0.0198
Precipitation (in)
Year
0
5
10
15
20
25
30
35
1905
1915
1925
1935
1945
1955
1965
1975
1985
1995
2005

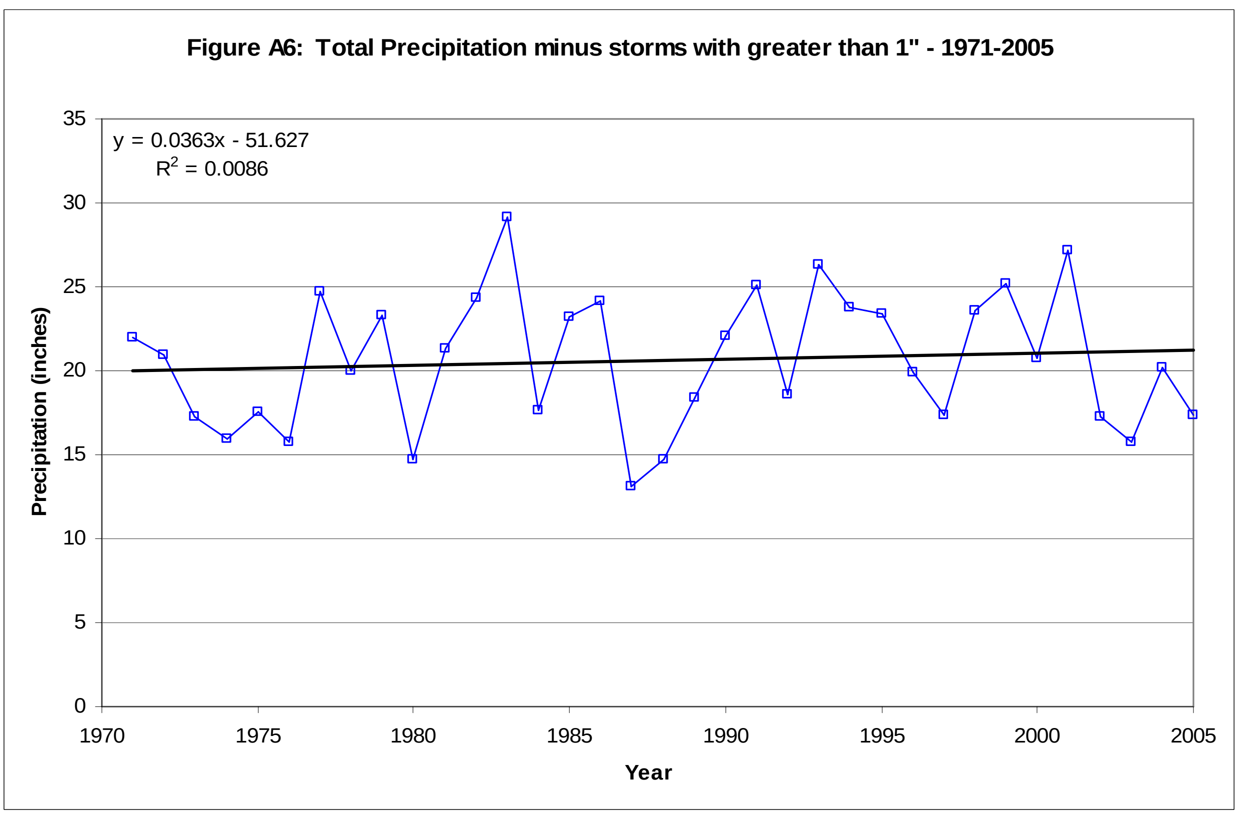


Figure A6: Total Precipitation minus storms with greater than 1" - 1971-2005
y = 0.0363x - 51.627
R2 = 0.0086
Precipitation (inches)
Year
0
5
10
15
20
25
30
35
1970
1975
1980
1985
1990
1995
2000
2005

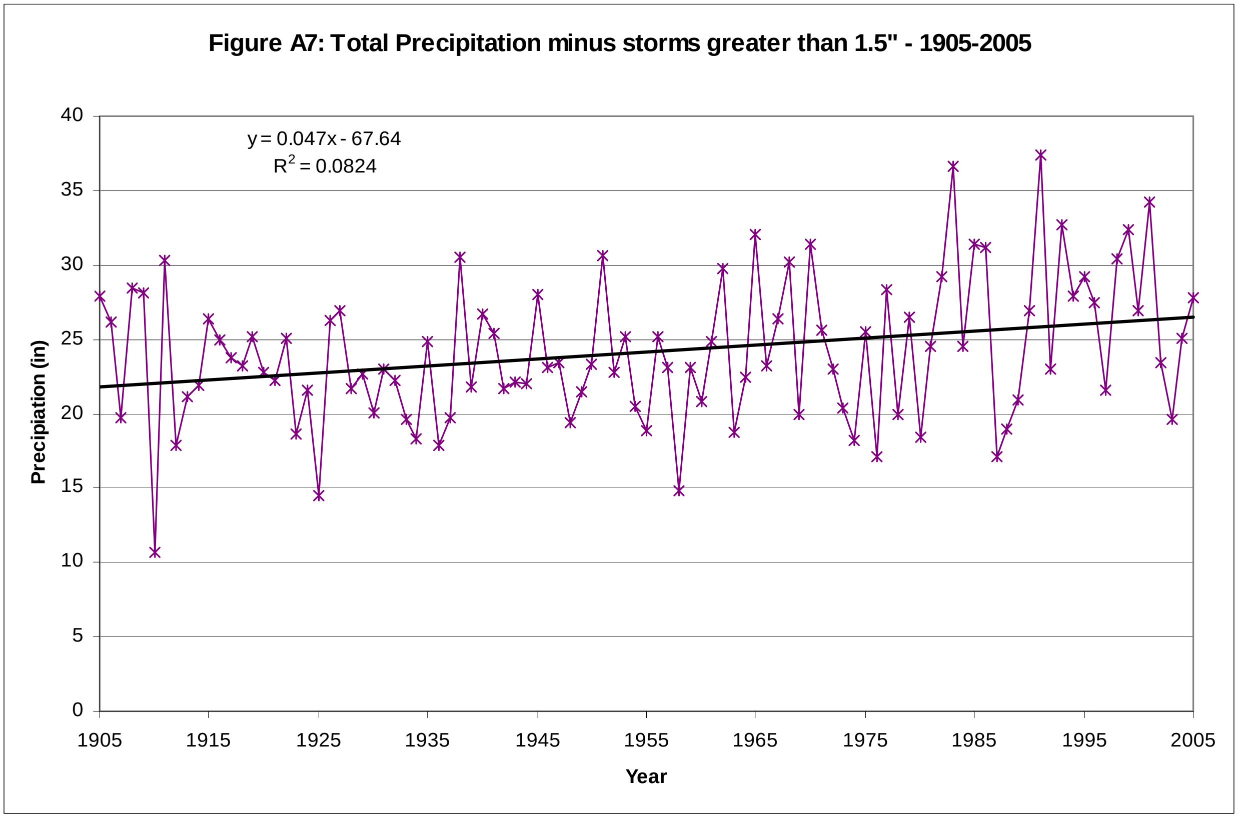


Figure A7: Total Precipitation minus storms greater than 1.5" - 1905-2005
y = 0.047x - 67.64
R^2 = 0.0824
Precipitation (in)
Year
0
5
10
15
20
25
30
35
40
1905
1915
1925
1935
1945
1955
1965
1975
1985
1995
2005

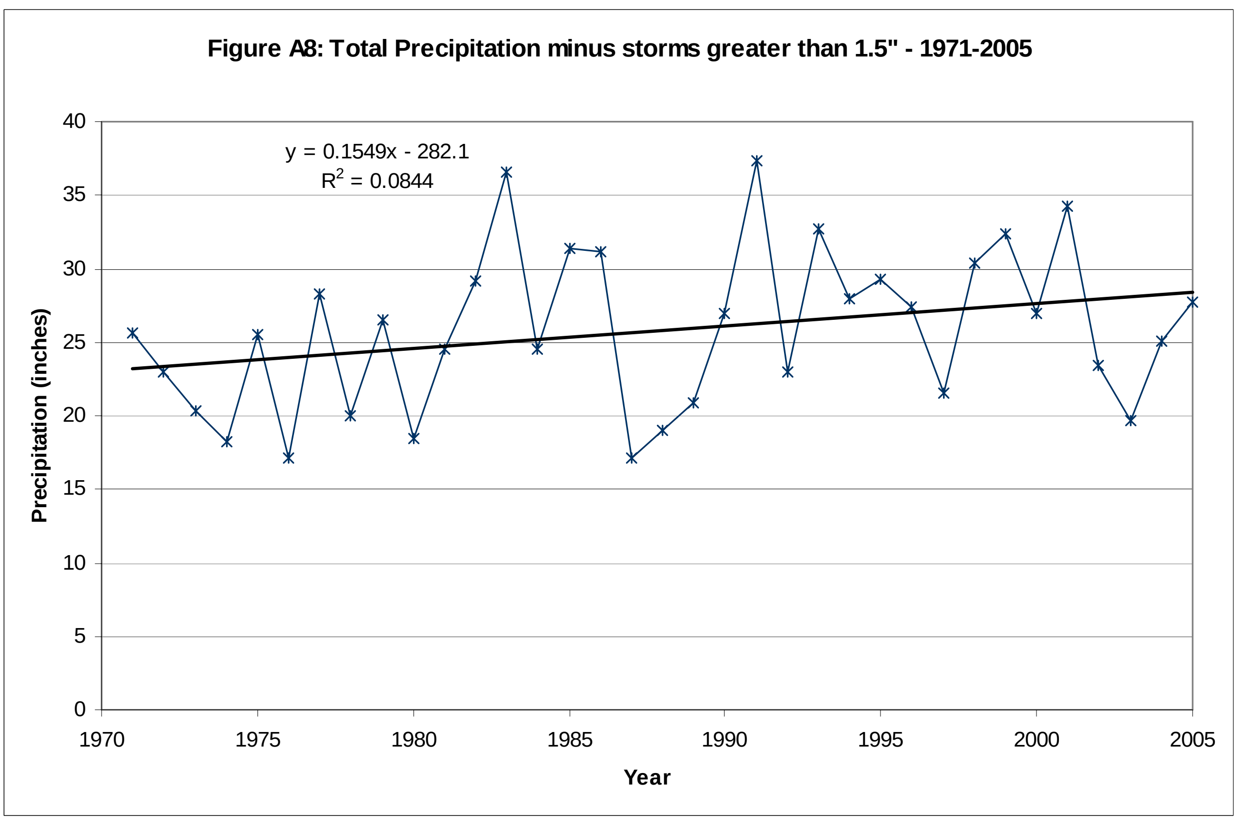


Figure A8: Total Precipitation minus storms greater than 1.5" - 1971-2005
y = 0.1549x - 282.1
R^2 = 0.0844
Precipitation (inches)
Year
0
5
10
15
20
25
30
35
40
1970
1975
1980
1985
1990
1995
2000
2005

Appendix B

Photos of Erosion Sites Taken March 12, 2006

Erosion Site #1 – a) looking downstream (photo taken in 2005); b) looking downstream (2006); c) looking upstream (2006)

a)

b)

c) 

Erosion Site #2

a) looking downstream (2005); b) looking downstream (2006); c) looking upstream (2006)

a) 

b)

c)

Erosion Site #3

a) perched culvert (2005); b) erosion by culvert (2005); c) looking upstream (2006); d) looking downstream (2006)

a)

b)

c) 

d) 

Erosion site #4

a) looking downstream at manhole (2005); b) looking downstream at manhole (2006); c) looking downstream at bank (2005); d) looking downstream at bank (2006)

a)

b)

c) 

d) 

Erosion Site #5

a) looking downstream to meander (2005); b) looking downstream to meander (2006); c) looking upstream to eroding bank (2005); d) looking upstream to eroding bank (2006)

a)

b)

c)


d)

Erosion site #6

a) looking upstream (2005); b) looking upstream (2006); c) looking downstream (2006)

a)

b)

c) 

Erosion site #7

a) looking upstream (2006); b) looking downstream (2006)

a) 

b) 

Erosion site #8

a) looking at meander (2005); b) looking upstream (2006); c) looking downstream (2006)

a) 

b)

c)

Erosion site #9 - Looking downstream (2006)

Erosion site #10 – looking downstream (2006)

Erosion Site #11 – looking upstream (2006)

Erosion Site #12 – looking at eroding bank, flow in creek from left to right (2006)

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Figure 1

STUDY AREA
Marie Creek Base Flow and Erosion Study
Lower Mississippi River
Watershed Management Organization
Mendota Heights, MN

Legend

- Marie_Creek
- Watersheds
- Contacted property owners
- Ponds
- water
- 2ft contours
- flow arrows

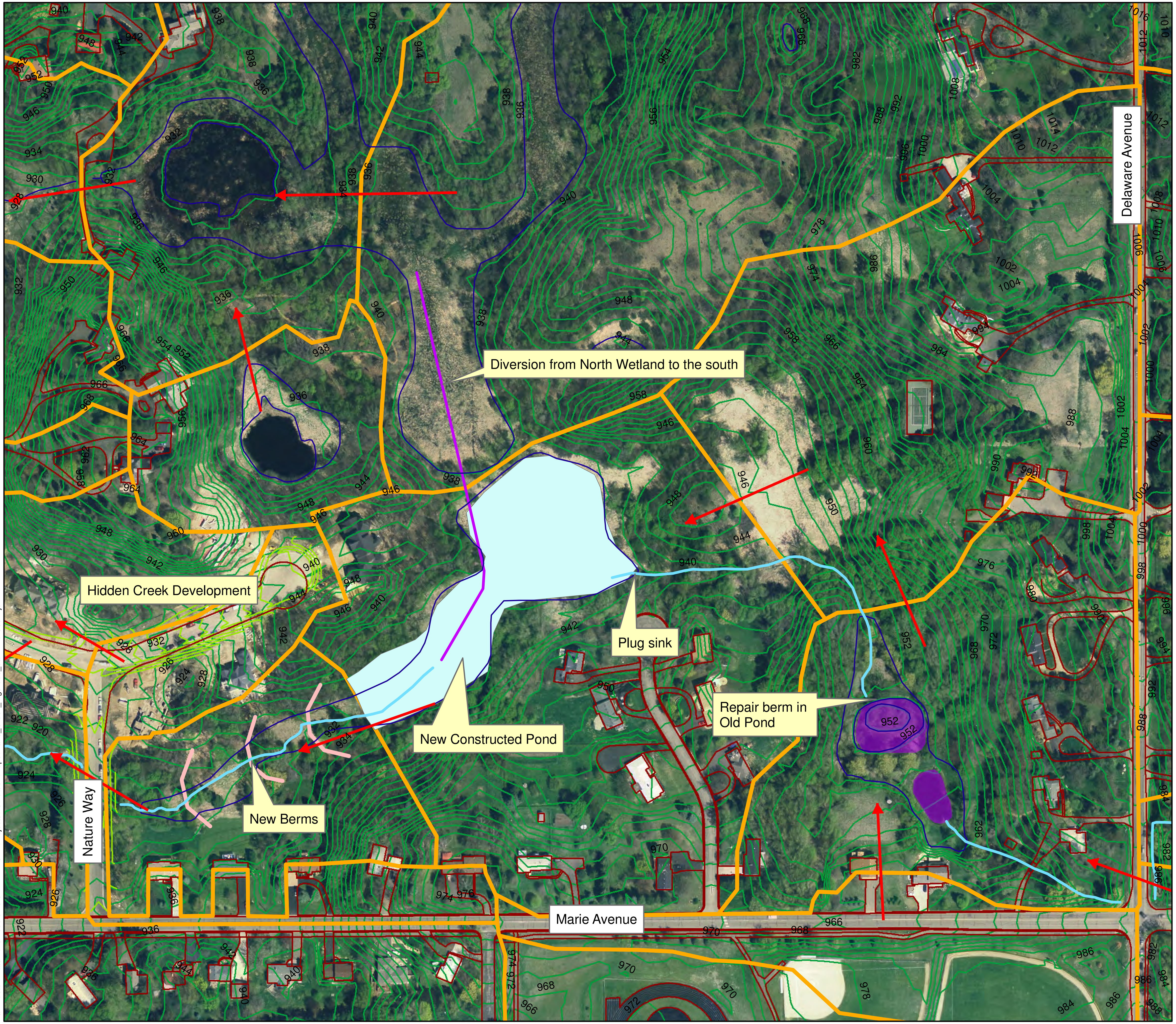
0 125 250 500 750 1,000 Feet

0 37.5 75 150 225 300 Meters

BARR

Figure 2

UPPER REACHES OF MARIE CREEK
Marie Creek Base Flow and Erosion Study
Lower Mississippi River
Watershed Management Organization
Mendota Heights, MN



Legend

- diversion
- Berms
- Pond
- Marie_Creek
- Watersheds
- Ponds
- water
- 2ft contours
- flow arrows

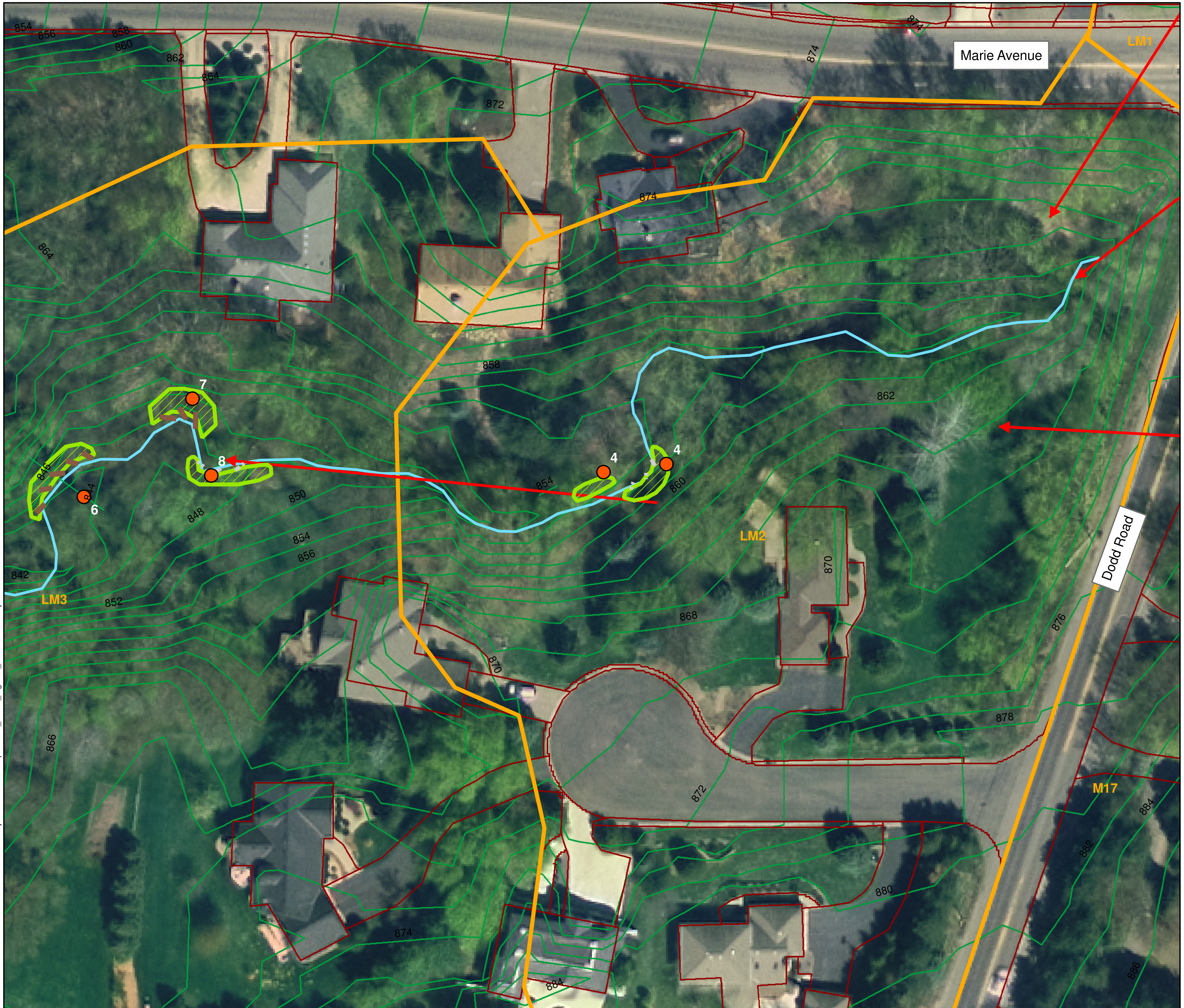
0 75 150 300 450 600 Feet

0 25 50 100 150 200 Meters

BARR

Figure 3

LOCATIONS OF POTENTIAL COURSES OF ACTION TO RESTORE BASE FLOW
Marie Creek Base Flow and Erosion Study
Lower Mississippi River
Watershed Management Organization
Mendota Heights, MN



Legend

- Priority Points
- Rock vanes
- Root Wads
- Regrading and Reseeding
- Grade Control
- Marie_Creek
- 2ft contours
- Watersheds

Feet
50 0 50 100

Meters
10 0 10 20 30

BARR

Figure 4

Erosion Sites #4, #6, #7 and #8 on Marie Creek
Marie Creek Base Flow and Erosion Study
Lower Mississippi River
Watershed Management Organization
Mendota Heights, MN

Legend

- Priority Points
- Rock vanes
- Root Wads
- Regrading and Reseeding
- Grade Control
- Marie_Creek
- 2ft contours
- Watersheds

N

Feet
50 0 50 100

Meters
10 0 10 20 30

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Figure 5

Erosion Sites
#1, #2, #3, #6, #7, #8, #9, #10, and #11
Marie Creek Base Flow and Erosion Study
Lower Mississippi River
Watershed Management Organization
Mendota Heights, MN

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Figure 6

Erosion Sites #3, #5, #10, and #12
Marie Creek Base Flow and Erosion Study
Lower Mississippi River
Watershed Management Organization
Mendota Heights, MN