SECTION 3.0
METHODS

3.1 SURVEY DATA COLLECTION

The two primary sources of survey data used for hydrologic and hydraulic modeling, preliminary design and the estimation of plan quantities, are a traditional ground survey completed by Houston Engineering, Inc. during September, 2007 and an aerial survey completed by AERO-METRIC, Inc. during late October, 2007. The primary uses of the traditional ground control survey included developing the channel, culvert and bridge geometry for the hydraulic model, establishing existing waterway and channel slopes within the hydraulics model, modeling roadway overtopping, developing rating curves for hydrologic modeling and for roadway design. The results of the topographic data from the aerial survey were used to construct the channel geometry within the hydraulic model for the overbank areas, mapping the flood inundation results, establishing floodway alignments, and estimating earthwork quantities. The aerial and traditional survey data were merged into a common file for purposes of design.

The aerial survey collect area is shown within Figure 3-1. Products resulting from the aerial survey included:

- color photography at scale of approximately 1' = 425' suitable for preparing 1 ft. topographic contours and 0.25 ft orthophoto mapping;
- digital terrain model (DTM) consisting of a series of mass points (x,y,z) and breaklines;
- mass points and breaklines processed to generate continuous contours with a one (1.0) foot contour interval;
- planimetric base maps at a scale of 1" = 50' digitally compiled from the aerial photography. Planimetric features collected included roads, bridges, railroads, culverts, roadway shoulders, and water features in 2-dimensions; and
- 0.25-foot color digital orthophotography.
Figure 3-1
Approximate Aerial Survey Boundary

Legend
- Yellow: Aerial Survey Limits
- Black: MN State Hwy
- Dark Gray: Roberts Co. Roads
- Red: City Boundary

Prepared by:
Houston Engineering, Inc.
6901 East Fish Lake Road, Suite 140
Maple Grove, MN 55369
Bus: (763) 493-4522
Fax: (763) 493-5571
Web: www.houstonengineeringinc.com
The specifications for the final map aerial survey products were consistent with United States National Map Accuracy Standards. Topographic information generated by the aerial survey was independently verified using traditional ground control survey. The analysis showed an average elevation difference across bare earth, high grass, urban, plowed fields and hard surfaces (e.g., roads) of 0.18 feet. The maximum absolute difference occurred within high grass, which is a limited portion of the project area.

3.2 HYDROLOGY

This section presents the hydrologic analyses performed for the BVFMP. The purpose of the hydrologic analysis is to establish input data for the hydraulic model, which is the tool used to simulate the behavior of the Little Minnesota River through Browns Valley and assist in the design of the flood mitigation alternatives (see Section 4.0, Range of Flood Mitigation Alternatives Considered). This section includes descriptions of the methods used in the following hydrology tasks:

- hydrologic frequency analysis, used in the selection of historical flood events to be analyzed, as well as to generate peak discharges and stages for various runoff events in the Little Minnesota River and downstream lakes (Section 3.2.1);
- the estimation of discharge/stage versus time data (hydrographs) for historical flood events in Browns Valley, which is used in the calibration and validation of the hydraulic model (Section 3.2.2); and
- the estimation of design discharges for sizing the flood mitigation project (Section 3.2.3).

3.2.1 Frequency Analysis of Discharge and Stage

Flood frequency analysis is the determination of flood flows at different recurrence intervals (i.e. the 1% chance of occurrence in any given year, also known as the “100-year recurrence interval”). Frequency analysis is used to determine how often on average a certain discharge or stage is expected to occur. Discharge and stage frequency analyses were performed in this study for three primary purposes:
• to aid in the selection of historic storm events for hydraulic model calibration. Calibration is the process by which the model’s input parameters are estimated and adjusted so that computed results agree as well as possible with observed data and in accordance with expected physical performance. Calibration will concentrate on those events most pertinent to the study purpose of developing a flood mitigation plan for the City of Browns Valley;

• to aid in the selection of historic storm events for model validation. Validation is the process of testing the calibrated model. The model is tested with data not used in the calibration process, i.e. historical flood events, other than the calibration events; and

• to estimate steady state peak discharges and stages in the Little Minnesota River which are used in the hydraulic model to design the flood mitigation project.

A hydrologic frequency analysis determines probabilities of discharges by fitting the observed stream discharge record to specific probability distributions and estimating the parameters of the distribution. In this study, the data of interest are the annual maximum discharges, stages, and volumes in the Little Minnesota River and downstream receiving waters. The analytical frequency procedure recommended for annual maximum data is the logarithmic Pearson type III distribution.

The US Army Corps of Engineers HEC-FFA Flood Frequency Analysis (FFA) model was used to complete the frequency analyses. The analyses targeted the boundary conditions of the hydraulic model, which are the hydrologic data (discharge or stage) representing the upstream and downstream ends of the model network used for calibration and design (see Section 3.3). The FFA was performed with historic data collected at the USGS Gage at Peever, South Dakota, which is the upstream boundary condition of the hydraulic model. The model network has two downstream boundaries, Lake Traverse and Big Stone Lake, for which historic stage data were collected and FFA analyses also performed.
3.2.1.1 USGS Gage at Peever, SD

An FFA analysis was performed for the Peever Gage (438 square miles) for 55 years of record (1940 – 1981; 1990 – 2002) to analyze annual peak discharges, annual maximum stages, and annual maximum 24-hour and 10-day run-off volumes. (The Peever Gage is an upstream boundary for the hydraulic model). The period of record includes data affected by ice and debris and therefore, potentially the statistical relationship between stage and discharge.\(^1\)

Annual peak discharge and stage data were retrieved from the USGS National Water Information System website [http://mn.water.USGS.gov](http://mn.water.USGS.gov) for the entire period of record for the USGS Gauging Station, USGS 05290000 Little Minnesota River near Peever, South Dakota (see Figures 3-2 and 3-3). For the discharge frequency analysis, the computed station skew was weighted with a generalized skew coefficient of -0.30 and a mean square error of 0.182, based on the location of Browns Valley.\(^2\) For the stage and volume frequency analyses, the skew of the computed curve was based solely on the station skew computed from the data points, and no weighting was performed.

The annual maximum 24-hour volumes and 10-day volumes were computed from the mean daily discharges at the Peever Gage. The annual maximum series was used as input to the FFA program. Table 3-1 lists the estimated peak discharges, stages, and volumes resulting from the frequency analysis. Figures 3-4, 3-5, 3-6, and 3-7 present the FFA model results graphically for discharge, stage, and volume (median plotting positions). Full FAA input data and output files are presented in Appendix C.

---

\(^1\) For design purposes, the effects of ice and debris were assessed using an unsteady hydraulic HEC-RAS model for historic floods caused by ice and debris conditions and period of non-ice and debris conditions, rather than reflected in the FFA analysis.

USGS 05290000 Little Minnesota River Near Peever, SD

Annual Instantaneous Peak Flow
USGS 05290000 Little Minnesota River Near Peever, SD
Annual Maximum Elevation (1988 NAVD)
Flow Frequency Curve - USGS Gage at Peegers 05290000
(Annual Maximum Series, 1940-2002)
Elevation Frequency Curve - USGS Gage at Peevers 05290000 - 1988 NAVD
(Annual Maximum Series, 1940-2002)

Exceedence Frequency in Percent

Elevation at Gage (1988 NAVD)

Figure 3-5
USGS Gage near Peegers, 24-hr Volume Frequency Curve
(Annual Maximum Series, 1940-2002)

Exceedence Frequency in Percent

Maximum Annual 24-hr Runoff Volume (AF)
USGS Gage near Peevers, 10-Day Volume Frequency Curve
(Annual Maximum Series, 1940-2002)

Exceedence Frequency in Percent

Maximum Annual 24-hr Runoff Volume (AF)
Table 3-1
Results of FFA Analysis* for USGS Gage near Peever, South Dakota

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
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<td>16,100</td>
<td>1021.05</td>
<td>29,381</td>
<td>138,410</td>
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<tr>
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<td>21,170</td>
<td>103,540</td>
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<td>9,300</td>
<td>1018.55</td>
<td>16,153</td>
<td>81,303</td>
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<td>7,070</td>
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<td>12,020</td>
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</tr>
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<td>5</td>
<td>20</td>
<td>4,660</td>
<td>1015.65</td>
<td>7,716</td>
<td>41,545</td>
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<td>10</td>
<td>3,200</td>
<td>1014.25</td>
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<td>28,857</td>
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<td>326</td>
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<td>90</td>
<td>1.11</td>
<td>199</td>
<td>1006.75</td>
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<td>1.05</td>
<td>131</td>
<td>1006.05</td>
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<td>60</td>
<td>1004.75</td>
<td>104</td>
<td>602</td>
</tr>
</tbody>
</table>

* For design purposes, the effects of ice and debris were assessed using an unsteady hydraulic HEC-RAS model for historic floods caused by ice and debris conditions and periods of non-ice and debris conditions.

3.2.1.2 Lake Traverse

Lake Traverse is one of two downstream locations in the hydraulic model network (see Section 3.3) that is a boundary condition. An FFA analysis was performed for the period 1942 – 2007 to analyze annual maximum lake stage for the period of record.

Daily stage records from Lake Traverse were retrieved from the U.S. Army Corps of Engineers Water Control Center website (the stage data may be downloaded from [http://www2.mvr.usace.army.mil/WaterControl/new/layout.cfm](http://www2.mvr.usace.army.mil/WaterControl/new/layout.cfm)). The maximum stage for each year was determined and used to create an annual maximum series to use in the FFA program (see Figure 3-8). Note that the lake stage data is not a continuous daily record. The data includes an average of 256 values per year recorded primarily during the open water period. This period generally includes the maximum recorded stage in any given year.
Lake Traverse Maximum Annual Lake Level Data

(COE Water Control Center - Reservation Dam - 1988 NAVD)
The results of the stage frequency analysis\textsuperscript{3} are summarized in Table 3-2. Figure 3-9 presents the results graphically. Full model input data and output files are presented in Appendix D.

### Table 3-2
Results of FFA Analysis for Lake Traverse Elevation

<table>
<thead>
<tr>
<th>% Chance Exceedance</th>
<th>Recurrence Interval (year)</th>
<th>Elevation (NAVD 1988)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>500</td>
<td>984.15</td>
</tr>
<tr>
<td>0.5</td>
<td>200</td>
<td>983.22</td>
</tr>
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<td>1</td>
<td>100</td>
<td>982.50*</td>
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<td>50</td>
<td>981.77</td>
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<td>5</td>
<td>20</td>
<td>980.75</td>
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<td>10</td>
<td>979.94</td>
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<td>976.75</td>
</tr>
<tr>
<td>90</td>
<td>1.11</td>
<td>976.37</td>
</tr>
<tr>
<td>95</td>
<td>1.05</td>
<td>976.11</td>
</tr>
<tr>
<td>99</td>
<td>1.01</td>
<td>975.77</td>
</tr>
</tbody>
</table>

* Comments provided by the U.S. Army Corps of Engineers through the Interagency Hydrology and Hydraulics Review Committee recommend an alternative curve fit approach which results in a 1% chance elevation of 981.56 (1988 NAVD)

### 3.2.1.3 Big Stone Lake

Big Stone Lake is one of two downstream locations in the hydraulic model network (see Section 3.3). Results of an Army Corps of Engineer’s Analysis from October, 2001, were adopted for this study.\textsuperscript{4} Figure 3-10 displays the FFA model results for Big Stone Lake stage as

\textsuperscript{3} The Army Corps of Engineers generally recommends a linear fit to the annual maximum series, rather than use of a Log Pearson Type II analysis. The use of a linear fit results in a lower value for the 100-year flood. From a practical perspective this would result in more water entering Lake Traverse (rather than Browns Valley) when completing hydraulic analyses.

\textsuperscript{4} Based on Army Corps of Engineers Flood Frequency Analysis of Big Stone Lake, “Section 22 Study – Minnesota River Main Stem Hydrologic Analysis.” October, 2001.
Lake Traverse Elevation Frequency Curve - 1988 NAVD
(Annual Maximum Series, 1942-2007)

Exceedence Frequency in Percent

Lake Elevation 1988 NAVD
Figure 3-10

Excerpt from Flood Frequency Analysis of Big Stone Lake
“Section 22 Study – Minnesota River Main Stem Hydrologic Analysis.”
Army Corps of Engineers. October, 2001
presented in the Corps study, in NGVD 1929 datum. Figure 3-11 graphically displays a partial data set in NAVD 1988 datum. The results of the Corps study are listed in Table 3-3.

### Table 3-3

<table>
<thead>
<tr>
<th>% Chance Exceedance</th>
<th>Recurrence Interval (year)</th>
<th>Elevation (NAVD 1988)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>500</td>
<td>- -</td>
</tr>
<tr>
<td>0.4</td>
<td>250</td>
<td>973.79</td>
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<tr>
<td>1</td>
<td>100</td>
<td>971.89</td>
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<tr>
<td>2</td>
<td>50</td>
<td>970.99</td>
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<td>969.89</td>
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<td>1.11</td>
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<tr>
<td>95</td>
<td>1.05</td>
<td>- -</td>
</tr>
<tr>
<td>99</td>
<td>1.01</td>
<td>- -</td>
</tr>
</tbody>
</table>

#### 3.2.1.4 Selection of Historic Modeling Events

The hydrologic event selected for calibration should be reflective of the purpose of the study, i.e. to develop a flood mitigation plan for the City of Browns Valley. Browns Valley has historically experienced flooding problems due to: (1) spring ice jams in the Little Minnesota River, which reduces the capacity of the river channel, causing it to overtop its banks, and (2) spring or summer peak flows in the Little Minnesota River. In addition to satisfying this criterion regarding the type of event, the other criterion is that there is sufficient observed data to which to calibrate.

The March 13-14, 2007 event was selected for model calibration because of the large number of high water marks and availability of aerial imagery. This event can be characterized as follows:

- a flooding event caused by an ice jam on the Little Minnesota River;
Big Stone Lake Elevation Frequency Curve - 1988 NAVD
(Annual Maximum Series)

Exceedence Frequency in Percent

Lake Elevation 1988 NAVD

Figure 3-11
• a maximum elevation (high water mark) at the Peever Gage during that event was recorded as 1013.00 (1988 NAVD), which approximately matches a 5 to 6 year peak stage events\(^5\);

• according to the discharge frequency analysis, the peak flow at the Peever Gage of 4,467 cfs (based on USGS stage-discharge rating table) approximately matches a 20-year peak flow event\(^5\);

• the maximum elevation (high water mark) at Lake Traverse of 978.94 (1988 NAVD) approximately matches a 5-year event\(^6\); and

• the maximum elevation at Big Stone Lake of 967.83 (1988 NAVD) corresponds to less than a 10-year event\(^7\).

The calibrated hydraulic model needs to be subjected to a validation process of testing it with other historical flood events to evaluate its performance. Two flooding events were selected based on their estimated high peak discharges, the availability of photographs to assess model performance, and the desire to understand the flooding mechanism of both a flood caused by an ice jam and high peak discharge without an ice jam.

The first historical flood event selected for model validation is July 25, 1993. The event is characterized as follows:

• summer event – no ice jam;

• a recorded peak flow at the Peever Gage of 8,900 cfs approximately matches a 100-yr event\(^5\); and

• a maximum elevation at the Peever Gage of 1,016.53 (1988 NAVD) approximately matches a 35-year event\(^5\).

---

\(^5\) Houston Engineering, Inc. Annual Maximum Series Flood Frequency Analysis, September, 2007

\(^6\) Assuming 1912 MSL – 0.39 = 1929 NGVD – Source: COE Water Control Center.

\(^7\) Based on COE Flood Frequency Analysis of Big Stone Lake, “Section 22 Study – Minnesota River Main Stem Hydrologic Analysis.” October, 2001.
• a maximum elevation at Lake Traverse of 980.31 (1988 NAVD) approximately matches a 15-year event;
• a maximum elevation at Big Stone Lake of 968.26 (1988 NAVD) corresponds to less than a 10-year event; and
• Drawback: no high water marks or photographs.

The second historical flood event selected for model validation is March 28, 1997. The event is characterized as follows:

• A spring flooding event with ice jam;
• a recorded peak flow at the Peever Gage of 3,590 cfs approximately matches a 12-yr event;
• a maximum elevation at the Peever Gage of 1,017.35 (1988 NAVD) approximately matches a 50-year event, reflecting a downstream ice jam;
• a maximum elevation at Lake Traverse of 982.52 (1988 NAVD) approximately matches a 100-year event; and
• a maximum elevation at Big Stone Lake was recorded as 973.78 (1988 NAVD), which is the highest stage ever recorded.

3.2.2 Hydrograph Development for Unsteady Hydraulic Model Calibration and Validation

Flow and stage hydrographs need to be generated as input into the unsteady HEC-RAS hydraulic model for the three historical events identified in Section 3.1.1 for model calibration and validation.

3.2.2.1 Boundary Conditions Hydrographs

The downstream boundary conditions consist of daily stage time series at Big Stone Lake and Lake Traverse, both having continuous daily data available through the time periods necessary to model the three historic events in 1993, 1997, and 2007.
Daily discharge data is also available for the upstream boundary condition, represented by flows from the USGS Gage Station 05290000 Little Minnesota River near Peever, South Dakota, for the selected flooding events in 1993 and 1997. However, because the gage was discontinued in 2002, a hydrograph was estimated for the March 2007 flood event. A high water mark of 10.05 (1013.00 NAVD 1988) provided by Traverse County from the March 2007 flood event at the USGS gage near Peever was translated to a discharge using the stage-discharge rating table from the discontinued gageing station (see Figure 3-12).  

To estimate the shape of the hydrograph, the hydrograph shape of other historic March events were graphed to determine whether a “typical” shape can be expected for this time of year at the Peever Gage. Figure 3-13 shows that a 10-day duration fits fairly well to the general shape of the other historic events. In addition, according to the 10-day volume-frequency analysis presented in Section 3.1.1, the volume under the hydrograph is approximately a 20-year event, the same recurrence interval as the estimated peak flow of 4467 cfs from the March 2007 event. The 10-day triangular-shaped hydrograph was therefore adopted as the estimated hydrograph to be used for the upstream boundary condition in the March, 2007 modeling event.

Two important reasons for selecting the 2007 flood event for calibration and unsteady HEC-RAS simulation included the availability of the large number of known (surveyed) high water reference elevations and the excellent aerial photography suitable for understanding the flood mechanism. The aerial photography proved valuable for not only understanding the extent of flooding but the general flood mechanism. These factors were deemed more critical than the need to estimate the hydrograph shape and volume at the Peever Gage.

---

8 “Rating curves are only as stable as the river channel they represent. This curve was established in 1999, and it is unknown whether the 2007 flood changed the shape of the channel, or if downstream ice jam affected the stage-discharge relationship at Peever.” James Fallon, USGS, Mounds View, MN.
Stage Discharge Rating Curve USGS Gage near Peever, SD 05290000
(Gage datum 1,002.2 ft NGVD29, 1929 NGVD + 0.75 = 1988 NAVD)
Figure 3-13

Historical March Flood Event Flow Hydrographs
USGS Gage and Peevers

4467 cfs, approx 20-yr event

Estimated March, 2007 Flow Hydrograph
(10-Day Duration, 1.90 in. of Runoff, approx. 20-yr recurrence interval)
Figures 3-14, 3-15, and 3-16 show the historic stage hydrographs for the downstream boundary conditions and the mean daily discharge hydrograph for the upstream boundary condition developed for the HEC-RAS hydraulic model.

3.2.2.2 Ungaged Subwatershed Inflow Hydrographs

In addition to the boundary conditions, a number of locations in the hydraulic model receive ungaged tributary inflow from local drainage areas (see Table 3-4 and Figure 3-17). These ungaged drainage areas are small and relatively unimportant in terms of sizing the flood mitigation features because of the small amount of discharge compared to the Little Minnesota River. These areas can be important for sizing local drainage features. For purposes of completeness, the discharge hydrographs for these areas were estimated by applying the unit flow (cfs/square mile) determined from the Peever Gage mean daily discharge, to the local drainage areas at each location. This method prorates the observed flow at the Peever gage over the rest of the modeled area and was only used for the historic events where similar flows per square mile throughout the watershed are expected. Given the uncertainties in hydrologic analysis, this approach is likely as accurate as other methods and is reasonable for the design of the flood mitigation purposes. Figures 3-18, 3-19, and 3-20 show all of the tributary hydrographs for input to the unsteady HEC-RAS model for the three historic modeling events.

Table 3-4
Drainage Areas for Ungaged Locations

<table>
<thead>
<tr>
<th>No.</th>
<th>Ungaged Locations</th>
<th>Local Drainage Area (sq. mi.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>South Dakota/Minnesota State Line</td>
<td>14.0⁹</td>
</tr>
<tr>
<td>2.</td>
<td>Traverse/Big Stone County Line</td>
<td>2.0</td>
</tr>
<tr>
<td>3.</td>
<td>Little Minnesota River, confluence with Toelle Coulee</td>
<td>8.6</td>
</tr>
<tr>
<td>4.</td>
<td>Toelle Coulee, from TH 28/Traverse CSAH 2 to confluence with Little Minnesota River</td>
<td>1.9</td>
</tr>
<tr>
<td>5.</td>
<td>T.H. 28 on east side of Browns Valley</td>
<td>0.45</td>
</tr>
<tr>
<td>6.</td>
<td>Toelle Coulee, upstream of Traverse CSAH 2</td>
<td>2.8</td>
</tr>
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</table>

3.2.3 **Design Discharges**

To complete initial design of the flood mitigation solution, a steady state hydraulic model was used to simulate the proposed alternative flood mitigation concepts for discharges with various return periods. (see Section 3.3) (Note: once the features were sized, the historic floods using unsteady HEC-RAS were used to evaluate performance.) The hydraulic model requires peak discharges and/or stages at the upstream and downstream ends of the model network (boundary conditions), as well as peak discharges representing the additional flow in the channel from localized ungaged drainage areas.

3.2.3.1 **Boundary Conditions**

Synthetic peak discharges for the upstream boundary condition and peak stages for the downstream boundary conditions were determined from the frequency analysis described in Section 3.2.2. The results are again presented in Table 3-5. The sizing and designing of the flood mitigation features initially focused on the 100-year recurrence interval event. A range of flows, representing other recurrence intervals, were then modeled to assess the system response to a range of other hydrologic events (as well as the historic floods).

<table>
<thead>
<tr>
<th>Recurrence Interval</th>
<th>Peever Gage (cfs)</th>
<th>Big Stone Lake (NAVD 1988)</th>
<th>Lake Traverse (NAVD 1988)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>16,100</td>
<td>- -</td>
<td>984.15</td>
</tr>
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<td>1.25</td>
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<td>976.75</td>
</tr>
</tbody>
</table>
Figure 3-14

Hydrographs for Hydraulic Model, March 13-14, 2007 Flood Event
Flow at Peever Gage, Lake Level at Big Stone Lake and Lake Traverse

Date

Flow (cfs)

Elevation (1988 NAVD)
Hydrographs for Hydraulic Model, July 25, 1993 Flood Event
Flow at Peever Gage, Lake Level at Big Stone Lake and Lake Traverse

Date

Flow (cfs)

Elevation (1988 NAVD)

7/1/1993
7/6/1993
7/11/1993
7/16/1993
7/21/1993
7/26/1993
7/31/1993
8/5/1993
8/10/1993
8/15/1993
8/20/1993
8/25/1993
8/30/1993

0
1000
2000
3000
4000
5000
6000
7000
8000
9000
970.0
972.0
974.0
976.0
978.0
980.0
982.0
984.0
982.0
984.0

970.0
972.0
974.0
976.0
978.0
980.0
982.0
984.0

Peever Gage
Big Stone Lake
Lake Traverse

Figure 3-15
Figure 3-16

Hydrographs for Hydraulic Model, March 28, 1997 Flood Event
Flow at Peever Gage, Lake Level at Big Stone Lake and Lake Traverse
July 25, 1993 Flood Event
Estimated Inflow Hydrographs for Ungaged Areas

Date
Flow (cfs)

State Line (14 sq.mi.)
County Line (2 sq.mi.)
Little Minn. R., confluence with Toelle Floodway (8.6 sq. mi.)
Toelle Floodway, from TH28/CSAH 2 to confluence with Little MN R (1.9 sq.mi.)
T.H. 28 on east side of Browns Valley (0.45 sq.mi.)
Tolle Coulee, upperam of CSAH 2 (2.8 sq.mi.)
March-28, 1997 Flood Event
Estimated Inflow Hydrographs for Ungaged Areas

Flow (cfs)

Date


State Line (14 sq.mi.)
County Line (2 sq.mi.)
Little Minn. R., confluence with Toelle Floodway (8.6 sq. mi.)
Toelle Floodway, from TH28/CSAH 2 to confluence with Little MN R (1.9 sq.mi.)
T.H. 28 on east side of Browns Valley (0.45 sq.mi.)
Tolle Coulee, upsteram of CSAH 2 (2.8 sq.mi.)
March 13-14, 2007 Flood Event
Estimated Inflow Hydrographs for Ungaged Areas
(estimated by applying Peever gage unit flow (cfs/sq. mi.) to local drainage area)
Note: Hydrograph at Peever Gage for March 13-14, 2007 flood event estimated

Date
Flow (cfs)

State Line (14 sq.mi.)
County Line (2 sq.mi.)
Little Minn. R., confluence with Toelle Floodway (6.6 sq. mi.)
Toelle Floodway, from TH28/CSAH 2 to confluence with Little MN R (1.9 sq.mi.)
T.H. 28 on east side of Browns Valley (0.45 sq.mi.)
Tolle Coulee u/s of CSAH 2
3.2.3.2 Ungaged Subwatersheds

Peak discharges for steady state flow change locations were estimated throughout the model by a drainage area ratio technique. The peak flow values defined for the gageing station at Peever were multiplied by a drainage area ratio raised to an exponent. The ratio is the drainage area for the ungaged site divided by the drainage area for the Peever gageing station. An exponent 0.796 was used, which is that listed in the regional regression equation corresponding to Minnesota Region D.\(^\text{10}\) Table 3-6 shows the resulting peak flows at selected flow change locations using the results of the discharge-frequency analysis at Peever Gage presented in Section 3.2.1.

<table>
<thead>
<tr>
<th>Recurrence Interval</th>
<th>Peever Gage DA=438 sq mi (cfs)</th>
<th>Little Minn. River State Line DA=452 sq mi (cfs)</th>
<th>Little Minn. River County Line DA=454 sq mi (cfs)</th>
<th>Little Minn. River D/S of confluence with Toelle Coulee DA=468 sq mi (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>16,100</td>
<td>16,508</td>
<td>16,566</td>
<td>16,970</td>
</tr>
<tr>
<td>200</td>
<td>11,900</td>
<td>12,202</td>
<td>12,245</td>
<td>12,543</td>
</tr>
<tr>
<td>100</td>
<td>9,300</td>
<td>9,536</td>
<td>9,569</td>
<td>9,802</td>
</tr>
<tr>
<td>50</td>
<td>7,070</td>
<td>7,249</td>
<td>7,275</td>
<td>7,452</td>
</tr>
<tr>
<td>20</td>
<td>4,660</td>
<td>4,778</td>
<td>4,795</td>
<td>4,912</td>
</tr>
<tr>
<td>10</td>
<td>3,200</td>
<td>3,281</td>
<td>3,293</td>
<td>3,373</td>
</tr>
<tr>
<td>5</td>
<td>2,020</td>
<td>2,071</td>
<td>2,079</td>
<td>2,129</td>
</tr>
<tr>
<td>2</td>
<td>822</td>
<td>843</td>
<td>846</td>
<td>866</td>
</tr>
<tr>
<td>1.25</td>
<td>326</td>
<td>334</td>
<td>335</td>
<td>344</td>
</tr>
</tbody>
</table>

3.2.3.3 Toelle Coulee

On June 1, 1965, a flash flood caused significant flooding in the northeastern portion of Browns Valley.\(^\text{11}\) Within the Toelle Coulee watershed, ½ inch of rain fell at about 5 P.M. (saturating the soil). A very intense rainstorm occurred later in the evening from 8:00 to 8:45 P.M. Total rainfall depths within the Toelle Coulee watershed were 3.75 to 5.0 inches.


The resulting runoff flowed across saturated ground into the coulee and was impounded to a depth of about 25 feet upstream from the County Highway 2 crossing, at which point it overflowed into the west ditch of the highway and discharged down into the eastern portion of the village.\footnote{Section 205, Flood Control Reconnaissance Report. Unnamed Coulee at Browns Valley, Minnesota. U.S. Army Corps of Engineers, St. Paul District, January, 1966.} To determine the flooding risk due to high flows from Toelle Coulee, as well as provide synthetic peak flows to the hydraulic model, a hydrologic model was developed for Toelle Coulee and the local drainage area on the northeast side of the City draining to culverts crossing TH 28 (see Figure 3-21). We used the Hydrologic Modeling System (HEC-HMS) developed by the US Army Corps of Engineers. The model is designed to simulate the precipitation-runoff processes of dendritic watershed systems. The HEC-HMS model allows the simulation of surface runoff from a set of interconnected hydrologic components. HEC-HMS determines the surface runoff in a basin resulting from precipitation. The selected transform and loss methods were the SCS unit hydrograph and the SCS curve number methods, respectively. Time of concentration was determined using methods recommended in the Minnesota Hydrology Guide.\footnote{U.S. Department of Agriculture, Soil Conservation Service. 1975, revised 1993. Hydrology Guide for Minnesota, St. Paul, Minnesota.} The curve number was determined by applying Minnesota DNR land use designations and hydrologic soil groups, as defined by the NRCS. Table 3-7 summarizes the hydrologic parameters used in the HEC-HMS model.

<table>
<thead>
<tr>
<th>Subwatershed</th>
<th>Drainage Area (acres)</th>
<th>Drainage Area (sq. mi.)</th>
<th>Curve Number</th>
<th>Time of Concentration (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toelle Coulee</td>
<td>1,795</td>
<td>2.8</td>
<td>76</td>
<td>93</td>
</tr>
<tr>
<td>Northeast Browns Valley</td>
<td>329</td>
<td>0.51</td>
<td>68</td>
<td>36</td>
</tr>
<tr>
<td>West of CSAH 4</td>
<td>59</td>
<td>0.09</td>
<td>68</td>
<td>9.3</td>
</tr>
</tbody>
</table>

Table 3-7
Hydrologic Parameters for HMS Hydrologic Model
Storage upstream of Traverse CSAH 2 was estimated using the aerial survey data (see Figure 3-22). HydroCAD was used to determine a discharge rating curve at the 60-in culvert crossing Traverse CSAH 2 to the south.

When the water surface elevation upstream of Traverse CSAH 2 exceeds the elevation of 1025.0 NAVD 1988, water flows in the ditch to the south along the west side of Traverse CSAH 2. A HEI survey of the ditch was used to build a HEC-RAS model to determine a relationship between water surface elevation upstream of Traverse CSAH 2 and discharge in the ditch. The rating curves for the 60-in. culvert and ditch were incorporated into the HEC-HMS model to define the distribution of flow at the outlet. These rating curves are shown in Figure 3-23. The rainfall amounts applied, as well as peak flows resulting from the HEC-HMS modeling effort, are presented in Table 3-8.

<table>
<thead>
<tr>
<th>Recurrence Interval</th>
<th>Rainfall 14 (24-hour) (inches)</th>
<th>Peak Flow (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Toelle Coulee Runoff</td>
<td>Traverse CSAH 2 culvert</td>
</tr>
<tr>
<td>2</td>
<td>2.25</td>
<td>340</td>
</tr>
<tr>
<td>5</td>
<td>3.0</td>
<td>695</td>
</tr>
<tr>
<td>10</td>
<td>3.5</td>
<td>965</td>
</tr>
<tr>
<td>50</td>
<td>5.0</td>
<td>1862</td>
</tr>
<tr>
<td>100</td>
<td>6.0</td>
<td>2504</td>
</tr>
</tbody>
</table>

* Flow in ditch and local runoff to TH28 has non-coincident peaks.

Stage-Storage Curve
Toelle Coulee, Upstream of CSAH 2

Storage (Acre-Feet)

Elevation (1988 NAVD)
Stage-Discharge Rating Curve for Storage in Toelle Coulee
Stage-Discharge Ratings for CSAH 2 60-in. Culvert and Ditch

Figure 3-23

Stage-Discharge Rating Curve for Storage in Toelle Coulee
Stage-Discharge Ratings for CSAH 2 60-in. Culvert and Ditch

Flow (cfs)

Elevation (1988 NAVD)

Culvert
Ditch
Total
3.3 METHODS - HYDRAULICS

This section describes the methods used to complete the hydraulic analyses performed for the Browns Valley Flood Mitigation Project. It describes the development of the existing conditions hydraulic model and how it is used as a tool to analyze alternative flood mitigation design concepts. This section includes descriptions of the methods used in the following tasks:

- hydraulic model development (Section 3.3.1);
- hydraulic model calibration (Section 3.3.2),
- hydraulic model validation (Section 3.3.3), and
- modeling and design of flood mitigation concepts (Section 3.3.4).

3.3.1 Model Development

The process of developing the hydraulic model involves data collection, constructing the physical representation of the system (i.e. schematic and geometry of the model), establishing hydrologic boundary conditions, and setting the model’s options and tolerances. The HEC-RAS hydraulic model (version 3.1.3), developed by the U.S. Army Corps of Engineers, is the selected model for this analysis. It is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels.

3.3.1.1 Data Collection

Data collected and used in the development and calibration of the model include the following:

- Ground survey completed by Houston Engineering, Inc.;
- Aerial survey completed by AERO-METRIC, Inc. (see Section 3.1);
- Plan drawings from State Aid Project 06-631-01 & 78-604-16 for Traverse County 4 dated March 2000;
- A survey completed by Traverse County on CSAH 4 over the Little Minnesota River in 2006; and
- High water marks from DNR reports, USACE reports and field survey.

The ground survey performed by HEI included a total of 58 cross-sections, 19 culverts, 2 bridges on the Little Minnesota River, dikes and breakout areas along the Little Minnesota River, and sections and profiles along Toelle Coulee. The data collected on the structures included upstream and downstream cross sections, bridge geometry (waterway openings, piers, low steel, railings, etc.) and road profiles. All new survey work was completed in NAVD 1988, and existing surveys were converted to NAVD 1988 as required.

### 3.3.1.2 Model Schematic and Geometry

Based on the data collected, an existing conditions HEC-RAS geometry file was built for a 9.7 mile reach of the Little Minnesota River, from the USGS gageing station 05290000 at Peever, South Dakota to Big Stone Lake. Areas of breakout flows to the south and west of the river, as well as to Lake Traverse, are also incorporated into the model schematic. Figure 3-24 is a schematic of the model extents.

An overflow to Lake Traverse was simulated in the hydraulic model by entering a split flow junction. In this manner, the model computes the amount of breakout flow to Lake Traverse versus the flow remaining in the Little Minnesota River channel. The breakout amount is influenced by the ice conditions and agricultural levees, in addition to channel geometry, friction and flow. Breakout flows to Lake Traverse, in excess of the capacity of the box culverts through the Browns Valley Dike, are modeled to overtop TH 28, enter virtual floodplain storage areas, and have the potential to overtop TH 27 and flow into the north side of Browns Valley. The overland flow path of this breakout water is simulated flowing south to where it meets again with the Little Minnesota River and continues on to Big Stone Lake.

HEC-geoRAS, a GIS software tool, was used to develop the geometric data to the hydraulic model. Together with a digital terrain model (DTM) developed from the aerial survey, the tool develops geometric data, including river centerlines, cross section profiles, reach lengths, bank stations, and storage areas. The field surveyed channel cross sections and road profiles were used to provide more definition to the cross-sections and profiles developed for the DTM.
Where necessary, the surveyed channel cross-sections were copied to nearby cross sections without channel survey and adjusted vertically along the channel slope.

Two storage areas located along the breakout flow path north of Browns Valley were incorporated into the HEC-RAS geometry. This feature was used to simulate flow along the north breakout flow path and account for floodplain storage west and east of TH 27. HEC-geoRAS was used to calculate storage-elevation relationships using the aerial survey 1-foot contours.

3.3.1.3 Boundary Conditions

HEC-RAS was used in unsteady mode for model calibration and validation. This type of model uses time-varying data, i.e. flow/stage versus time hydrographs at boundaries of the model schematic, as well as internal hydrograph input locations. Section 3.2.2 presents the flow and stage hydrographs which were generated as input into the hydraulic model for three historic events at the upstream and downstream ends of the model to represent the boundary conditions. Steady state boundary conditions used for design, and represented by synthetic event peak flows and elevations are presented in Table 3-5 in Section 3.2.2.

3.3.1.4 Model Options and Tolerance Settings

The HEC-RAS model was run with the computation options and tolerances listed in Table 3-9. The default settings were adopted except that the number of warm up time steps was set to 20, with a time step of 1 hour for model stability.

3.3.2 Hydraulic Model Calibration

Calibration is the process by which the model’s input parameters are adjusted so that computed results agree as well as possible with observed data and in accordance with the historic flood mechanism. The March 13-14, 2007 historic flood event was selected for model calibration. The selection process of the historic events is presented in Section 3.1, and the hydrologic data is presented in Section 3.2.1. This flood was caused by rapid snow melt in the watershed leading to an abrupt rise in flow and a major ice jam that formed in the channel of the Little Minnesota River one mile upstream from the city.
The ice blockage forced water over the river banks, primarily to the north towards Lake Traverse.\textsuperscript{15} When the 3 – 9’x 6’ reinforced concrete box culverts leading to Lake Traverse through the Browns Valley Dike were unable to carry the entire flow, water overtopped TH 28, then TH 27, and eventually entered the north side of Browns Valley.

\textbf{3.3.2.1 Calibration Method}

The unsteady HEC-RAS model was calibrated by adjusting Manning roughness coefficients and adjusting the thickness of ice placed on the river channel in specific locations, to achieve reasonable agreement between simulated and observed data. The observed data includes high water marks and aerial photos taken during high water. The goal was to match the simulated to the observed to within the following target ranges:

\textsuperscript{15} JOR Engineering Inc report on Browns Valley 2007 Spring Flood.
Target 1: Match 2/3, or 66%, of the high water marks within 0.5 feet.\textsuperscript{16}

Target 1: Match 2/3, or 66%, of the high water marks within 0.5 feet.\textsuperscript{17}

Target 2: Match those locations inundated as seen on historic aerial photographs (visually) by comparing a flood inundation map created from model results.

The following adjustments were made to the model as part of the calibration effort.

“$n$” values:

The final “$n$” values used in the calibrated model are listed in Table 3-10. These values are within an expected range for natural channels.

\begin{center}
\textbf{Table 3-10}
\begin{tabular}{|l|c|c|}
\hline
\textbf{Reach} & \textbf{Roughness Coefficient, $n$} & \\
 & \textbf{Channel} & \textbf{Overbank} \\
\hline
\textbf{Little Minnesota River} & & \\
Peever Gage to Browns Valley & 0.04 & 0.065-0.10 \\
Through Browns Valley to Big Stone Lake & 0.04 & 0.075 \\
\textbf{Traverse Breakout} & 0.05-0.065 & 0.065 \\
\textbf{North Breakout Path} & & \\
Through Browns Valley & 0.045 & 0.10 \\
TH 28 to confluence with Little Minnesota River & 0.045 & 0.075 \\
\hline
\end{tabular}
\end{center}

Ice thickness:

Ice thickness and placement was first estimated by studying aerial photographs taken during the March, 2007 flood. The thickness was varied until the Calibration Targets listed above were attained to the extent possible. The final ice thickness in the calibrated model is 3-feet.

\textsuperscript{16} FEMA Appendix C, “Guidelines and Specifications for Flood Hazard Mapping Partners: Guidance for Riverine Flooding Analyses and Mapping.” FEMA often recommends calibration to within 0.5 feet for flood insurance studies.

\textsuperscript{17} FEMA Appendix C, “Guidelines and Specifications for Flood Hazard Mapping Partners: Guidance for Riverine Flooding Analyses and Mapping.” FEMA often recommends calibration to within 0.5 feet for flood insurance studies.
3.3.2.2 Assessment of Model Calibration

Target 1: Match 2/3, or 66%, of the high water marks within 0.5 feet

High water marks were obtained from DNR reports, USACE reports, and field survey. Figure 3-25 displays the locations of these high water marks. Table 3-11 lists the available 2007 event high water marks, as well as the maximum water surface elevations at the corresponding locations in the HEC-RAS model. The table shows that the simulated maximum water elevations match the observed high water marks to within 0.5 feet in 9 out of the 15 cases, or 60%, of the time, nearly meeting the target of 66%.

### Table 3-11

#### 2007 Compiled High Water Marks

<table>
<thead>
<tr>
<th>ID</th>
<th>Description</th>
<th>Observed HWMs</th>
<th>HEC-RAS</th>
<th>Computed Elev. Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Spring 2007 HEI¹</td>
<td>River Station</td>
<td>Model W.S. Elev.</td>
</tr>
<tr>
<td>10</td>
<td>Fireworks building west of TH 28 near LT</td>
<td>984.51</td>
<td>2272</td>
<td>984.37</td>
</tr>
<tr>
<td>5</td>
<td>COE HWM on power pole west side on TH 28 north of LT inlet</td>
<td>985.13</td>
<td>517</td>
<td>984.27</td>
</tr>
<tr>
<td>7</td>
<td>COE HWM on power pole west side on TH 28 south of LT inlet</td>
<td>984.34</td>
<td>901</td>
<td>984.29</td>
</tr>
<tr>
<td>19</td>
<td>COE HWM west side TH 28 west of LT inlet</td>
<td>984.31</td>
<td>901</td>
<td>984.29</td>
</tr>
<tr>
<td>9</td>
<td>COE HWM west side Hwy 28 south of LT inlet</td>
<td>983.27</td>
<td>901</td>
<td>984.29</td>
</tr>
<tr>
<td>6</td>
<td>Debris mark 150' DS on LT inlet</td>
<td>978.93</td>
<td>100</td>
<td>979.3</td>
</tr>
<tr>
<td>11</td>
<td>West of CSAH 27 near Lake Traverse</td>
<td>981.64</td>
<td>SA-West</td>
<td>981.67</td>
</tr>
<tr>
<td>12</td>
<td>West of CSAH 4 north of town</td>
<td>981.06</td>
<td>SA-East</td>
<td>980.91</td>
</tr>
<tr>
<td>14</td>
<td>523 4th St. on garage</td>
<td>982.17</td>
<td>SA-East</td>
<td>980.91</td>
</tr>
<tr>
<td>13</td>
<td>524 4th St. in yard</td>
<td>982.26</td>
<td>SA-East</td>
<td>980.91</td>
</tr>
<tr>
<td>20</td>
<td>Broadway Bridge</td>
<td>981.6</td>
<td>23235</td>
<td>980.38</td>
</tr>
<tr>
<td>22</td>
<td>506 E Broadway St. (Reeds Fish Company)</td>
<td>979.73</td>
<td>14432</td>
<td>980.53</td>
</tr>
<tr>
<td>21</td>
<td>134 E. Broadway St. (Curt Powers Residence)</td>
<td>980.33</td>
<td>14802</td>
<td>980.53</td>
</tr>
<tr>
<td>16</td>
<td>Broadway Avenue and Jefferson Street</td>
<td>980.13</td>
<td>14802</td>
<td>980.53</td>
</tr>
<tr>
<td>18</td>
<td>1st Ave N and Washington Street</td>
<td>980.46</td>
<td>14802</td>
<td>980.53</td>
</tr>
</tbody>
</table>

Note: All Elevations are in NAVD (1988).
Notes:
1. Results generated from calibrated HEC-RAS model.
3. Little Minnesota is the only mapped flooding source.
4. Flood inundation areas created using aerial photogrammetry data.

Legend
- High Water Marks
  - <0.5'
  - 0.5-1'
  - 1-2'
  - >2'

- Floodplain Evaluation Areas
- State Boundary
- County Boundary
- Roads
- Railroads

Figure 3-25 - 2007 Flood Calibration Map

Scale: [Diagram scale]
Target 2: Match flood inundation maps and aerial photographs (visually)

A flood inundation map (Figure 3-25) was created from the modeled peak elevations during the March, 2007 flood for comparison to a March, 2007 aerial photograph (Figure 3-26).

By visually evaluating the floodplain, we were able to confirm the model’s accuracy. Areas of the floodplain were split into sections and evaluated separately.

- Area 1 – Breakout to Lake Traverse, bounded by the Little Minnesota River on the South and TH 28 on the East. This area matches very well. The entire area is inundated in the aerial photograph. On the modeled inundation map, the entire area is shown as flooded with the exception of a small area along the Little Minnesota River.

- Area 2 – Breakout path around north side of Browns Valley. This area generally matches well. The section immediately south of Lake Traverse is nearly entirely flooded on both the inundation map and the photograph. In the section east of CSAH 4, the inundated area resulting from the modeling covers less of an area than does the flooding seen on the photograph. In the section east of CSAH 4, the inundated area matches well between the simulated and observed on the photograph.

- Area 3 – Little Minnesota River. A comparison between the simulated and observed flooded areas along the Little Minnesota River varies along its length. Some areas match closely while other locations don’t match as well, however, the results are considered satisfactory.

- Area 4 – Toelle Coulee. The simulated and observed flooded areas match closely south of TH 28. Further south, the mapped area of inundation is somewhat larger than shown on the aerial photograph, but the overall match is considered satisfactory.

3.3.3 Hydraulic Model Validation

Validation is the process of testing the calibrated model with data not used in the calibration process, i.e. other historical flood events. The July 25, 1993 summer event and the March 28, 1997 spring event, which was influenced by an ice jam, were used to verify that the model behaved properly for these two floods. The selection process for these two events is
2007 Aerial Flood Photograph
(looking southeast from Lake Traverse)

Figure 3-26
discussed in **Section 3.2.1**, and the hydrologic data input is presented in **Section 3.2.2**. Slight modifications of calibrated model geometry were necessary to simulate the 1997 and 1993 events to account for the physical conditions during that time:

- Geometry representing CSAH 4 was changed to reflect its condition prior to modifications made in the year 2000. Construction included the replacement of an overland flood flow opening and a grade re-alignment. The road was modified to create a lower sag curve to convey flood flows at a lower elevation;

- 3-feet of ice cover was again simulated from the Broadway bridge and continued upstream for the 1997 event; and

- agricultural levees were removed from the simulation of this event based on information received from local officials and landowners. This allowed for simulation of the overland breakout south of the city.

The 1993 model geometry is identical to 1997 except for the removal of the ice cover in the river.

As the primary indicator to assess model validation, locations were selected to compare the simulated and observed results, in terms of whether particular roads were overtopped (note that no highwater marks are available). The observed roadway overtopping information was taken from previous reports and first-hand accounts recalled by local officials and residents. **Tables 3-12 and 3-13** present this comparison and indicate that for both the July, 1993 and March, 1997 flood events, the modeling results show the same roads overtopping as were observed. The hydraulic model was therefore considered to satisfactorily represent the flood mechanism and considered validated.

### 3.3.4 Modeling and Design of Flood Mitigation Concepts

To complete the concept design, a steady state hydraulic model was used to simulate the proposed alternative flood mitigation concepts for runoff events with various return periods (see **Section 3.2.3**). Once the sizing and design was completed with the steady state model, the performance of each of the designs concepts was checked by applying the geometry files to an
unsteady modeling analysis of the historic floods of 1993, 1997, and 2007. The following paragraphs describe the process followed to complete the modeling of the concept designs.

3.3.4.1 Blockage Analysis to Determine Maximum Flow through City

Since ice jams and debris blockages are known to be a recurring problem and can worsen the effects of flooding, an analysis was done to determine the amount of flow that should be typically allowed through the town during floods. Free flow bankfull channel capacity through Browns Valley ranges from 1,200-1,600 cfs, with a minimum capacity of 1,200 cfs at a cross section upstream of the Broadway Bridge (a bridge where ice and debris blockage occurs. To determine the capacity of the river at the bridge during an event with an ice jam or debris blockage, a portion of the waterway opening at the Broadway bridge was blocked in the HEC-

### Table 3-12
**Summer 1993 – Observed versus Modeled Roadway Overtopping**

<table>
<thead>
<tr>
<th>Locations</th>
<th>Roadway Overtopped (yes/no)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed</td>
</tr>
<tr>
<td>Broadway Bridge</td>
<td>yes</td>
</tr>
<tr>
<td>CSAH 4 - South</td>
<td>yes</td>
</tr>
<tr>
<td>Low Water Crossing – CR 24</td>
<td>yes</td>
</tr>
<tr>
<td>TH 27</td>
<td>no</td>
</tr>
<tr>
<td>TH 28 near Lake Traverse</td>
<td>no</td>
</tr>
<tr>
<td>TH 28 - East of town</td>
<td>no</td>
</tr>
<tr>
<td>CSAH 4 - North of town</td>
<td>no</td>
</tr>
</tbody>
</table>

### Table 3-13
**Spring 1997 – Observed versus Modeled Roadway Overtopping**

<table>
<thead>
<tr>
<th>Locations</th>
<th>Roadway Overtopped (yes/no)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed</td>
</tr>
<tr>
<td>Broadway Bridge</td>
<td>yes</td>
</tr>
<tr>
<td>CSAH 4 - South</td>
<td>yes</td>
</tr>
<tr>
<td>Low Water Crossing – CR 24</td>
<td>yes</td>
</tr>
<tr>
<td>TH 27</td>
<td>no</td>
</tr>
<tr>
<td>TH 28 near Lake Traverse</td>
<td>no</td>
</tr>
<tr>
<td>TH 28 - East of town</td>
<td>no</td>
</tr>
<tr>
<td>CSAH 4 - North of town</td>
<td>no</td>
</tr>
</tbody>
</table>
RAS model to various degrees. The flow capacity was further constrained by requiring one foot of freeboard, i.e. the river was considered at maximum capacity at one foot below the top of bank, reducing the minimum flow capacity to 980 cfs. **Table 3-14** displays the percentage of the bridge opening blocked and the corresponding capacity in the river. A maximum flow of 500 cfs was selected as a reasonable amount of flow to allow in the Little Minnesota River as it passes through the City.

<table>
<thead>
<tr>
<th>Blockage at Broadway Bridge (%)</th>
<th>Waterway Opening (sq. ft.)</th>
<th>Flow Capacity (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>417</td>
<td>980</td>
</tr>
<tr>
<td>10</td>
<td>375</td>
<td>880</td>
</tr>
<tr>
<td>20</td>
<td>334</td>
<td>860</td>
</tr>
<tr>
<td>30</td>
<td>292</td>
<td>800</td>
</tr>
<tr>
<td>40</td>
<td>250</td>
<td>640</td>
</tr>
<tr>
<td>50</td>
<td>209</td>
<td>440</td>
</tr>
</tbody>
</table>

Note: all waterway openings and flow capacities listed correspond to the same elevation, i.e. 1-foot below top of bank

**3.3.4.2 Design Discharges and Boundary Conditions**

In designing the flood mitigation alternatives, the steady flow simulation component of HEC-RAS was applied. The initial sizing and designing of the flood mitigation features focused on the 100-year recurrence interval event of approximately 9,300 cfs in the Little Minnesota River (see **Section 2.0 Design Goals**). A range of flows, representing other recurrence intervals, as well as historic events, were then also modeled to assess the system performance to a range of other hydrologic events. **Tables 3-5 and 3-6** in **Section 3.2.3** present the steady state discharges used for various recurrence intervals at the boundary conditions and other ungaged flow locations internal to the model, respectively. Coincident flooding is assumed at the upstream and downstream boundary conditions, i.e. if modeling a 100-year upstream boundary condition, than 100-year lake levels at Big Stone Lake and Lake Traverse are used as downstream boundary conditions.
Design discharges used to model Toelle Coulee flood mitigation concepts were determined with a hydrologic model. The methods and resulting synthetic peak flows are presented in Table 3-8 of Section 3.2.3.

The design criteria considered in the hydraulic modeling for the various flood mitigation alternatives included the following:

**Little Minnesota River**
- maintain approximately 500 cfs in the Little Minnesota River through the City;
- divert 1,020 cfs to Lake Traverse, as determined to be the 100-year breakout flow in the 1986 Flood Insurance Study;\(^\text{18}\) and
- divert the remaining 7,780 cfs of the 9,300 cfs (100-year flow) down the flood way to meet up again with the river south of the City.

**Toelle Coulee**
- Prevent the 100-year synthetic peak flow from flowing west to the City.

The calibrated HEC-RAS model was used as a tool to design the various flood mitigation alternatives to meet the above criteria. Section 5.0 describes the detailed analyses and results for each alternative.