The process was computed for each point along the length of the segment and a total derived, resulting in the total length of pipeline contributing to spill potential in the forward sense.

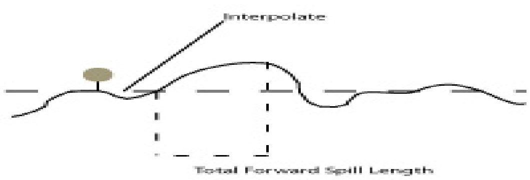

Figure 5. Interpolated forward spill.

After the forward spill length was computed, it was necessary to complete the same for any points behind the point of interest, if any. Because .NET generic lists were used, it was simply a matter of reversing the data in the list by using the built in Reverse() method and processing in the same fashion, switching the order of items in the interpolation for highest point and calculating the measure.

The total length of pipe contributing to the spill volume was then

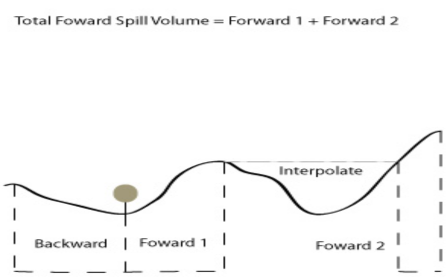

Figure 6. Total spill length.

calculated using the summation of all forward spill lengths added to the summation of all backward spill lengths as shown in Figure 6.

The summation of spill lengths used to determine the volume of potential spill using the cylinder volume equation (Figure 2) where height (h) is defined as the total length of pipeline. The pseudo-code would be represented similar to the following example:

```
for each [point] in [pointList]:
  do until stop:
    for each [point+1] in [pointList]:
     if [end]: stop
     if [point].[measure] >=
[point+1].[measure]:
      [measure]+= [point+1].[measure] –
[point].[measure]
     else:
        {function}FindNextHighestPoint
       {function}InterpolateMeasure
        [measure] +=
[interpolatedMeasure]
  if {function}InterpolateMeasure or
[end]:  stop.
```

Analysis / Case Study

The application works in a variety of situations and for the purpose of demonstration, a demo site was created to show the program output. A pipeline route was created in two segments. The first segment traversed the straight line distance from Red Wing to Rochester, Minnesota and the second segment traversed from Rochester to Winona, Minnesota. The bluffs common to this area provided a wide range in elevation values within a short distance and were ideal to show fluctuations in volume due to natural landforms (Figure 7). DEM, or digital elevation models, show the elevation or relief of the area. For this demonstration application, DEM data was obtained from the Minnesota Department of Natural Resources Data Deli (http://deli.dnr.state.mn.us/) for the counties of Winona, Wabasha, Goodhue and Olmstead. To run the program, a continuous elevation grid was required,

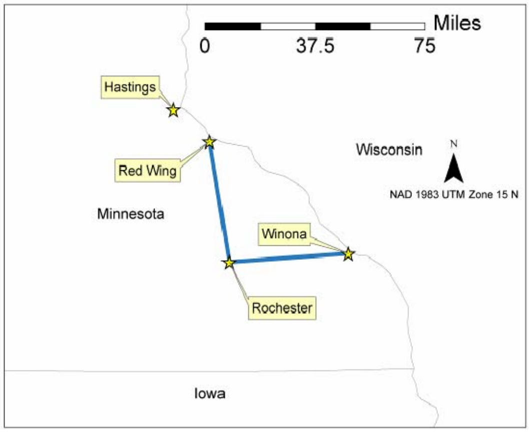

Figure 7. Potential spill volume demo project area.

thus a mosaic image was created. The first pipeline segment traversed approximately 39.7 miles, from Red Wing to Rochester, with a diameter defined as 12 inches and the second segment totaled approximately 40.8 miles, from Rochester to Winona with a diameter of 12 inches. Valves were created at random intervals along both pipeline segments. The program was then exercised with an interval of ½ mile (Figure 8).

The program generated 179 potential spill volumes calculated within 2 minutes with a range of 0 to 5316.73 cubic feet. Comparing the potential spill volume to elevation resulted in the following figures: Figure 9 for segment 1 and Figure 10 for segment 5. These figures show the relationship between potential spill and elevation within the constraints of valves.

The change in volume due to elevation can be observed by showing only the segment of pipeline that occurs between the beginning and ending valves on the 5th segment (Figure 11). The following figures depict the potential volume spilled using a dark blue line and the elevation using a light blue line. Potential spill volume at a point is related to the surrounding relief

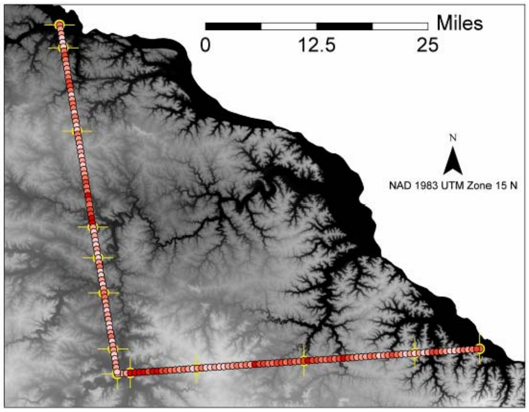

Figure 8. Program output. Points classified as light to dark red correlating to low to high potential spill volume. DEM classified from black to white correlated to low to high elevation values. Valves are shown in yellow. Correlation of higher potential spill elevation in longer valve to valve segments with elevation drop between the valves was shown.

within the constraints of stop valves. Areas of lower relief have a higher potential for spill. Conversely, areas at higher relief have a lower potential volume of spill for segments of pipeline between the stop valves or start and end points of the segment (Figures 9-12).

Stop valves are seen in Figure 12, where the potential spill volume drops to zero independent of the elevation. The analysis created does not take in to account failures directly at the stop valves resulting in null or zero values.

Conclusions / Future Usage

The output of this program can be used to identify high risk spill areas by using GIS to display the data on a map, tables to show quantitatively the degree of potential spills, and to allow users to show potential spill within pipeline volumes along with the corresponding elevations through the generated user interface.

At this point the program does not allow for direct modeling of the