Geography 586

Term Project Report – June 2008 Flood: Cedar Rapids, IA

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Topic -

In June of 2008, historic flooding occurred in Cedar Rapids, IA, with the Cedar River cresting at 31.12 feet on June 12th. The previous record was 20 feet. Much of the central part of the city was flooded beyond the 500 year flood plain. The Cedar River has natural sharp bend to the river to the south of downtown (Figure 1). Just after this bend, on the east side of the river are some small bluffs which limit open land which can be flooded adjacent to the river. In 1972, Landfill #1 (known locally as Mt. Trashmore) was opened on the west side of river.

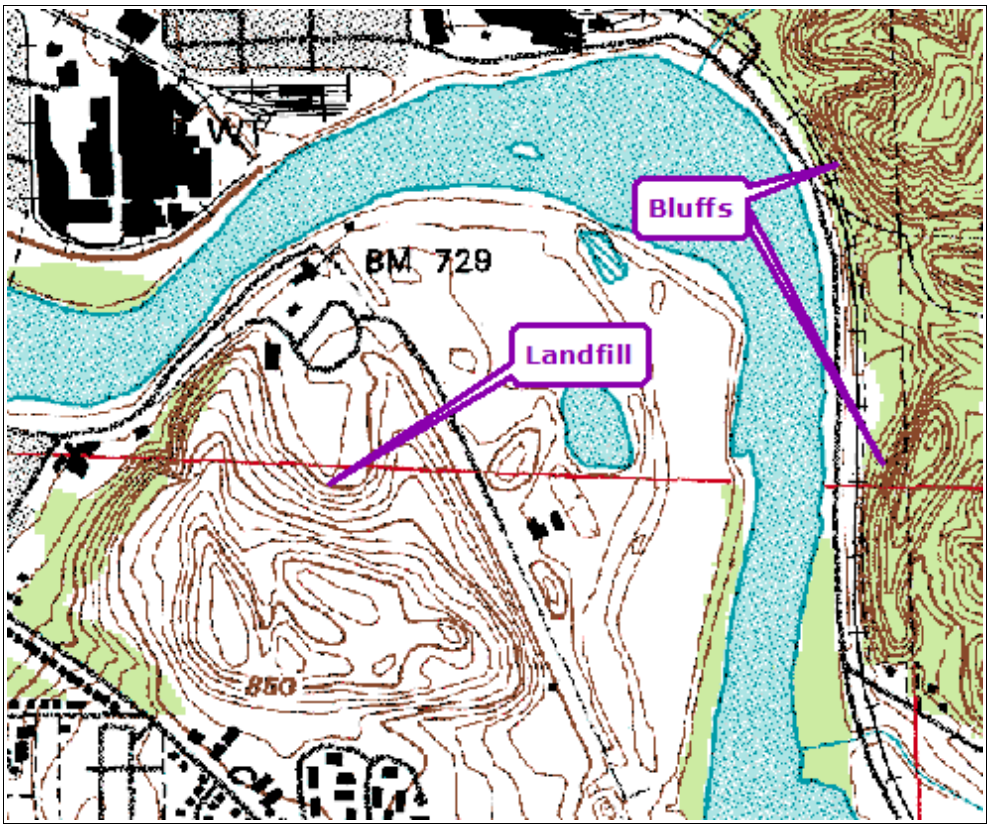

Figure 1: Problem Area. Source: Cedar Rapids North, USGS 7.5' quadrangle, 1994.

Hypothesis -

The narrow channel of the Cedar River between the bluffs and the landfill created a dam effect which caused the height (stage) of the 2008 flood to be worse than if the landfill was not there.

A map of the extent of the flood (Figure 2) shows a wide area of water that must fit into the narrower channel to traverse the bend around the landfill and between the landfill and the bluffs. Also shown is the location of the gauge station where the flow readings used in the project were recorded.

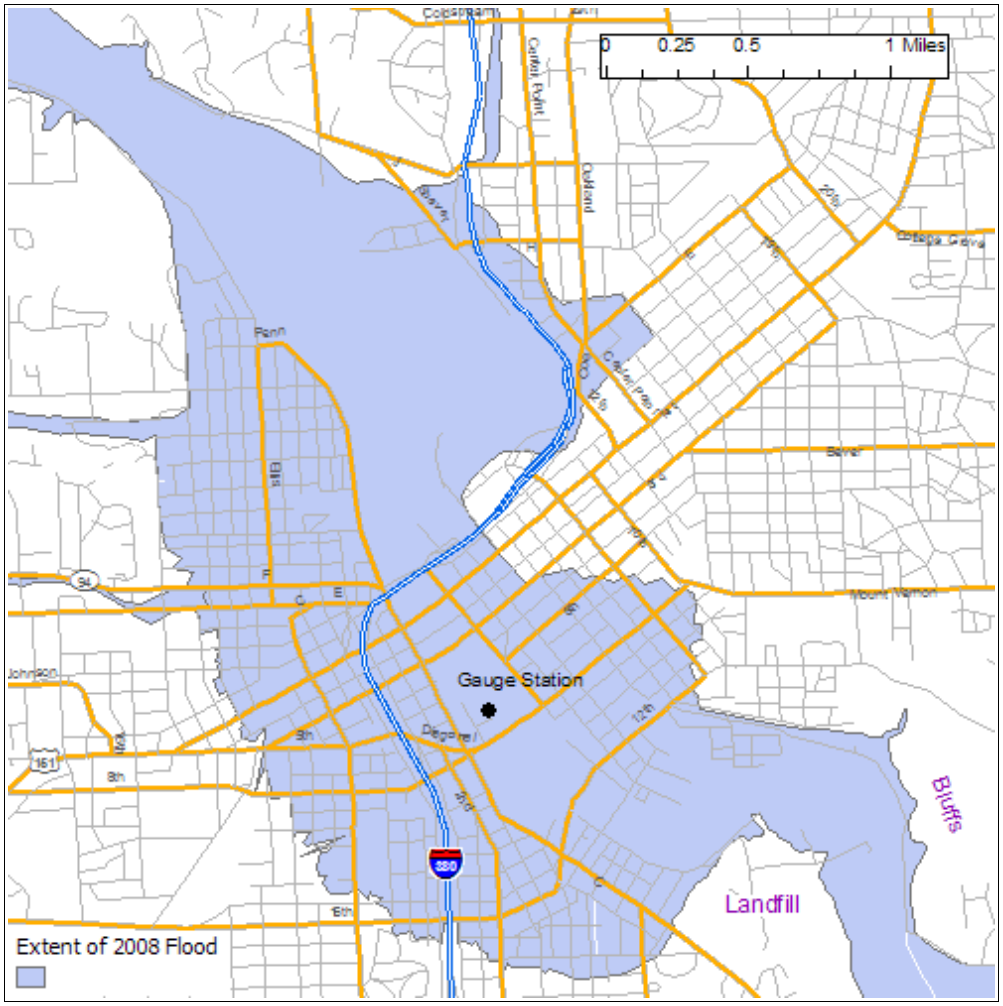

Figure 2: Project Area. Source: City of Cedar Rapids, 2008 and StreetMapUSA, 2005.

Data Sources -

In order to investigate the hypothesis, data needed to be procured. Two surfaces needed to be collected, a 'modern' surface and a 'historic' surface. For the modern surface, a digital image of the current 'Cedar Rapids – North' 7'5' USGS quadrangle map was obtained from the Iowa DNR GIS Library. The goal was to find the same map in a series from the 1960s but this map was unavailable (although its northern and eastern neighbors were!). However, a 15' USGS survey map from 1891 was discovered in the Library's file archives. After georeferencing both the maps to a StreetMapUSA background, contours were drawn in ArcMap.

The process of georeferencing and contouring the 1891 map showed there would be some challenges to its use. First the contour interval was 20' compared to the 10' contours on the modern map. Second, it was difficult to have a good georeference over the entire project area. This leads to error in the calculations of all three dimensions at any given point. Since there were no national map standards at the time (at least that I am aware of) it is difficult to quantify what this error may be. Regardless the historic map is still suitable for demonstrating the geostatistical tools needed to produce meaningful results in this context.

Finally, flow and stage data for the USGS gauge station in Cedar Rapids was obtained. This data can be used to understand how much water was involved in the flood.

Data Preparation -

The following steps were undertaken to produce the data used for analysis:

1. Create contour layers from the source maps.
    - Use centerline of the river as base elevation (700').

2. Create TINs from the contours with ArcScene.

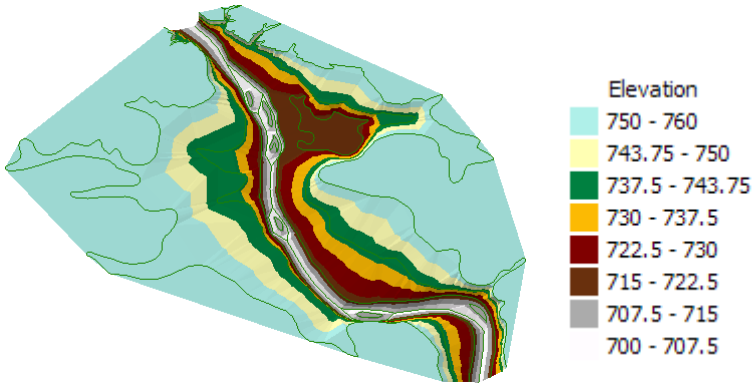

Figure 3a: TIN created from 1891 contours

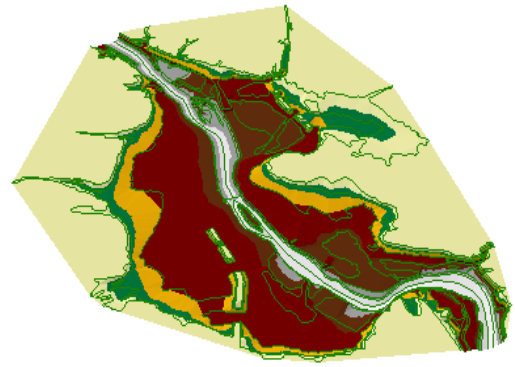

Figure 3b: TIN created from 1994 contours

3. Calculate the basin volume at one foot elevations above the base elevation (700') for each dataset using the Surface Anaylsis tool for 'Area and Volume'.
4. Calculate the volume of outflow for the two datasets based on the width of the channel at the south end of the project area. This was accomplished by creating a 'clip' polygon one foot in width and then editing copies of TINs produced in step 2 by using the the clip polygon as a 'hardclip'. This return a TIN for just the one foot cross-section. Area and volume was then calculated as in step 3.
5. Repeat step 4 with a cross-section of the 'inflow' at the gauge station.
6. Develop a basin model with actual flow data, elevation, total volume, volume at the gauge, and volume at the outflow location (Figure 4).
7. Apply the model to the historic data (Figure 4).
8. Use the Raster Calculator to compare the elevations between the two data sources to help explain differences in the models.
9. Use the results to show what effect the location of landfill had on the stage of the 2008 flood in Cedar Rapids.

Stage	1994 Volume	1891 Volume	Actual Inflow	1994 Inflow	1994 Outflow	1891 Inflow	1891 Outflow	1994 Ratio In	1994 Ratio Out	1891 Ratio In	1891 Ratio Out
701	736927	1529364		36.42	40.89	17.09	18.2	0.0000	0	0.0000	0.0000
702	2847402	4221450		146.02	163.86	68.35	72.63	0.0000	0	0.0000	0.0000
703	6327254	8061507	323	330.13	368.94	153.8	163.27	0.9784	0.88	2.1001	1.9784
704	11172312	13034780	1910	588.59	656.14	273.42	290.12	3.2450	2.91	6.9856	6.5835
705	17378404	19126521	3380	921.22	1025.47	427.18	453.17	3.6691	3.3	7.9124	7.4585
706	25302730	26321974	9070	1299.04	1479.81	614.75	652.44	6.9821	6.13	14.7539	13.9016
707	35220270	34606389	10100	1693.1	2022.62	836.19	887.92	5.9654	4.99	12.0786	11.3748
708	47156907	43965012	13500	2103.53	2653.94	1091.5	1159.61	6.4178	5.09	12.3682	11.6418
709	61138525	54383093	17300	2532	3373.77	1380.7	1467.51	6.8326	5.13	12.5299	11.7887
710	77191007	65845878	23400	2979.09	4182.15	1703.77	1811.62	7.8547	5.6	13.7343	12.9166
711	97359155	79234293	28600	3438.33	5040.86	2060.71	2191.94	8.3180	5.67	13.8787	13.0478
712	118181604	93412993	32300	3903.21	5911.74	2451.54	2608.47	8.2752	5.46	13.1754	12.3828
713	139680824	108381898	37600	4373.73	6794.83	2876.24	3061.2	8.5968	5.53	13.0726	12.2828
714	161879291	124140931	42600	4849.9	7690.07	3334.82	3550.14	8.7837	5.54	12.7743	11.9995
715	184799474	140690014	47600	5331.73	8597.49	3827.28	4075.3	8.9277	5.54	12.4370	11.6801
716	208536954	158029070	53400	5819.23	9517.07	4353.61	4636.66	9.1765	5.61	12.2657	11.5169
717	233192468	176158020	58600	6312.38	10448.82	4913.83	5234.23	9.2833	5.61	11.9255	11.1955
718	258796224	195076788	63800	6811.2	11392.74	5507.92	5868	9.3669	5.6	11.5833	10.8725
719	285378431	214785296	69600	7315.72	12348.83	6135.88	6537.98	9.5138	5.64	11.3431	10.6455
720	312969301	235283465	75300	7826.55	13317.07	6797.73	7244.17	9.6211	5.65	11.0772	10.3946
721	351963740	258663631	81200	8639.26	14306.46	7509.04	7988.81	9.3990	5.68	10.8136	10.1642
722	400996405	291489671	89550	9589.26	15325.17	8285.41	8773.83	9.3386	5.84	10.8082	10.2065
723	453127060	326203004	94710	10676.54	16373.03	9126.83	9599.14	8.8709	5.78	10.3771	9.8665
724	508646893	362889684	100300	11924.04	17450.05	10033.3	10464.75	8.4116	5.75	9.9967	9.5846
725	567849147	401235771	105000	13422.77	18556.22	11004.82	11370.65	7.8225	5.66	9.5413	9.2343
726	630801399	441527319	112000	15191.71	19691.54	12041.4	12316.85	7.3724	5.69	9.3012	9.0932
727	697571230	483650386	118000	17230.87	20856.02	13143.04	13303.34	6.8482	5.66	8.9781	8.8700
728	768226215	527591028	124000	19562.49	22049.64	14309.76	14330.13	6.3387	5.62	8.6654	8.6531
729	842833934	573335303	131000	22439.18	23272.42	15543.88	15397.21	5.8380	5.63	8.4278	8.5080
730	921461965	620869267	138000	25845.42	24524.34	16846.8	16504.58	5.3394	5.63	8.1915	8.3613
731	1029627874	670178976	144000	32369.94	25992.5	18218.52	17652.24	4.4486	5.54	7.9040	8.1576
Units	cf	cf	cfs	cf	cf	cf	cf	per s	per s	per s	per s

Figure 4: Project Data

Analysis and Results -

Volume

An initial perusal of the data shows the 1994 volume is significantly greater than the 1891 volume (Figure 5). There are two possible reasons for this: 1) the more precise contouring from the 1994 map gives a more accurate volume calculation, 2) natural or man-made changes to the flood plain have occurred in the past 100 years.

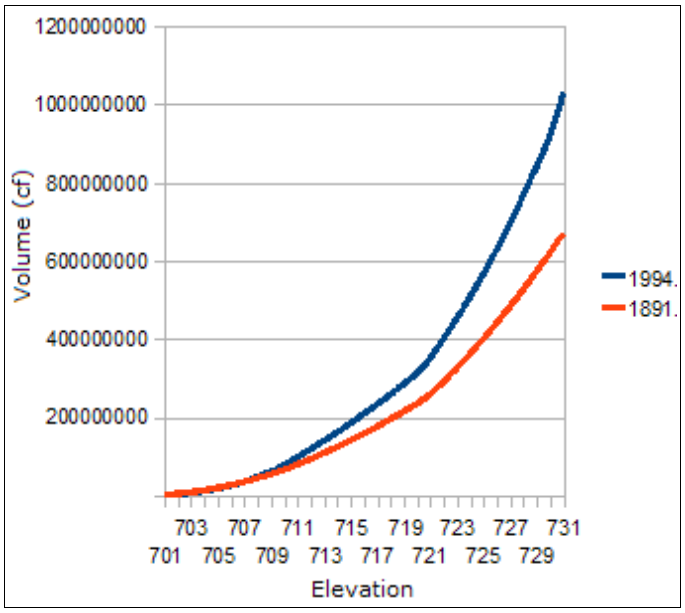

Figure 5: Volume profiles of the project data.

In order to investigate the first possibility, a cross-section of the outflow clip polygon set to the base heights of the TINs was compared. This area is good for comparison due to its landuse (the river, railroad beds on either side, and bluffs) changing very little during the time period. Figure 6 shows the 710' and 730' contours from the 1994 map are much closer to the next higher contour then the next lowest. The wider contours of the 1891 cannot capture this situation and as a result its volume calculation is smaller.

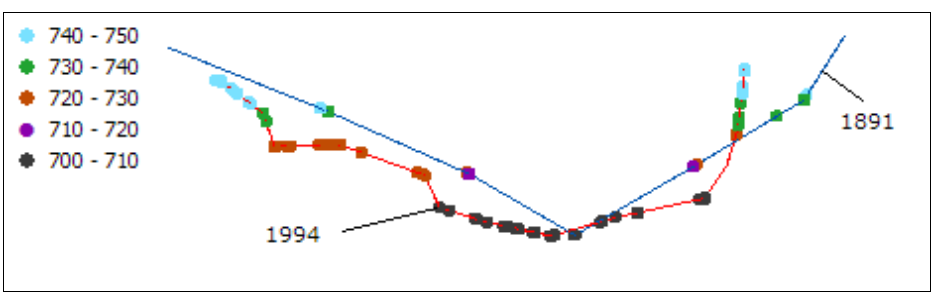

Figure 6: Cross-sections of outflow clip polygon. Vertical height is exaggerated ten times.

The same problem exists in the center of flood area. In fact the effect there is much greater as the 730' elevation is much further away from the river than estimate by the 1891 TIN (look back at Figure 3b). Figure 7 shows the results of obtained from the Raster Calculator where [1891 elevation] – [1994 elevation]. The blue area is where the elevation is greater on the 1994 map. The red has a greater 1891 elevation. As indicated by the volume data, most of the map is red. This seems to confirm the idea that the different contours account for the difference in the volumes. However, local knowledge of the area suggests a number of man-influenced features are present as well.

Raster Calculator

Figure 7 Items:

A) Interstate 380
B) Spillway (5 & 1 Dam)
C) Location of the Landfill
D) Angle of River
E) Unclear: Leveling for neighborhoods or contours
F) Quaker Oats

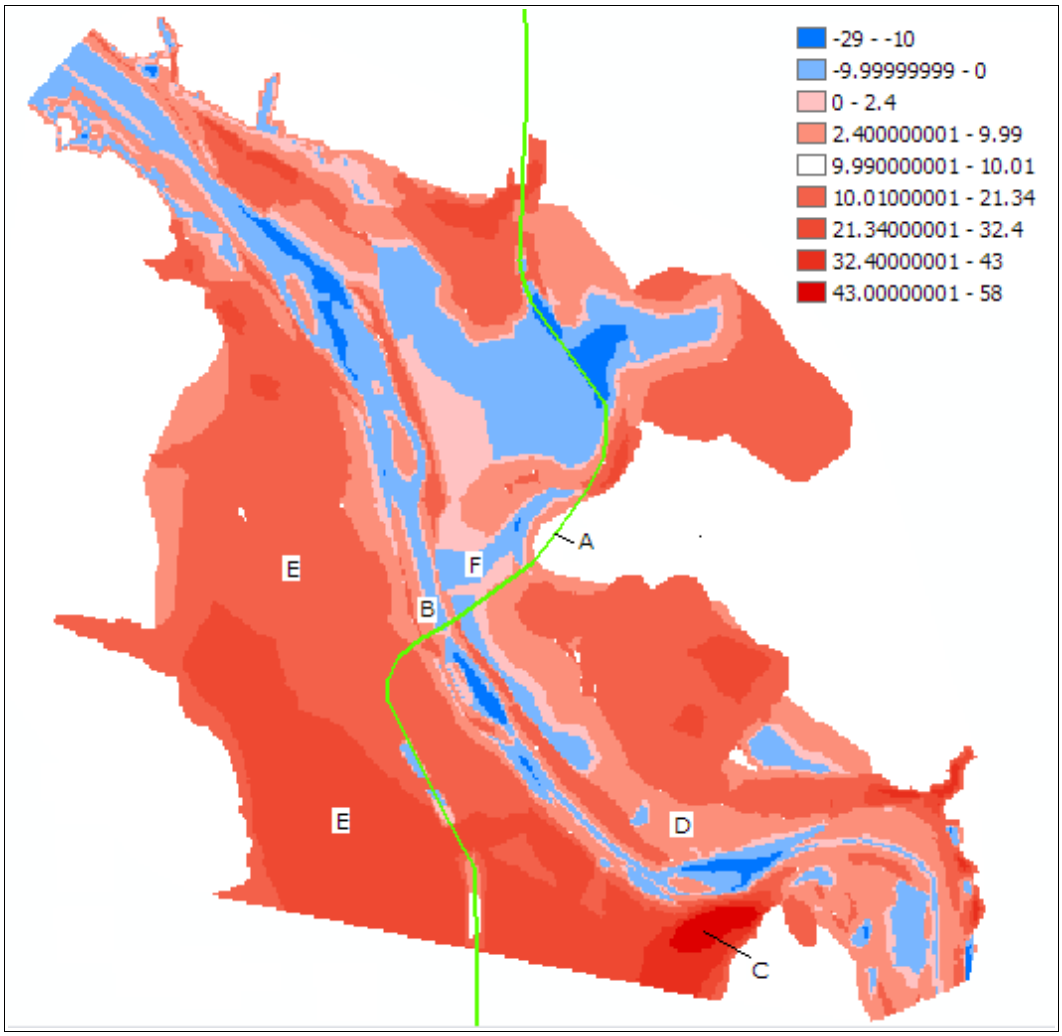

Figure 7: Results of Raster Calculator comparing 1891 and 1994 elevations.

Generally, items A and F are places were the elevation would have been raised, therefore decreasing the volume. In the case of Interstate 380 (A) with earthen berms to support the road and the leveling of a large area (F) for the Quaker Oats complex (one of largest grain processing sites in the world).

Item B is a man-made spillway built at this location on the river. It is accounted for in the 1994 contours (the lowest elevation north of the spillway is 705') but not for 1891. This explains why the 1891 volume is initially so much greater but the difference is nominal when compared to the volume totals at the upper elevations.

Items C and D are major differences in the overall topography between the maps. While both maps show the same features (the landfill - C and the river - D), their relative locations merits some discussion, especially since the effects of the landfill are central to this project. By comparing Figure 8 to Figure 1 there are three logical conclusions that can be made. First, most of the landfill work has occurred above 740' and therefore should have no effect on the volume calculation. Similarly, the base of the hill has likely been in the same location over time but it is possible the west end of the hill was leveled – there are now more city blocks extending southeast from downtown. Due to the extreme difference in elevation (over 45'), the most likely difference for the hill location on the 1891 map is the result of surveying error. However, the change in the river location is not so simple. Rivers are dynamic creatures – that it carved a deeper path into the hill and has slowly changed course over time is not surprising.

Figure 8: Landfill area, 1891. Source: USGS 15' Survey, 1891.

Finally, items E are the most inconclusive. These large regions account for the majority of the difference in the volume calculation. Even though there are greater local differences elsewhere, as described above, the scale involved here results in a large amount of volume. As shown on the TIN maps in figure 3, the 730' elevation is much further away from the river on the 1994 map. While this is indeed the case today and these areas are very flat now, much of this area was not yet developed in 1891, so there is the possibility some portion of this area was leveled for city construction. The conclusion that the lack of detailed contouring on the 1891 is to account for the volume difference is very convincing but natural and man-made factors have also changed the shape of the land as well.

<u>Landfill Volume</u>

In order to further inquire into the changes surrounding the landfill, a clip polygons were created, one for each map (Figure 9). Unlike the flow polygons, the major map differences required two separate polygons in order to adequately capture the volumes represented by the corresponding TINs.

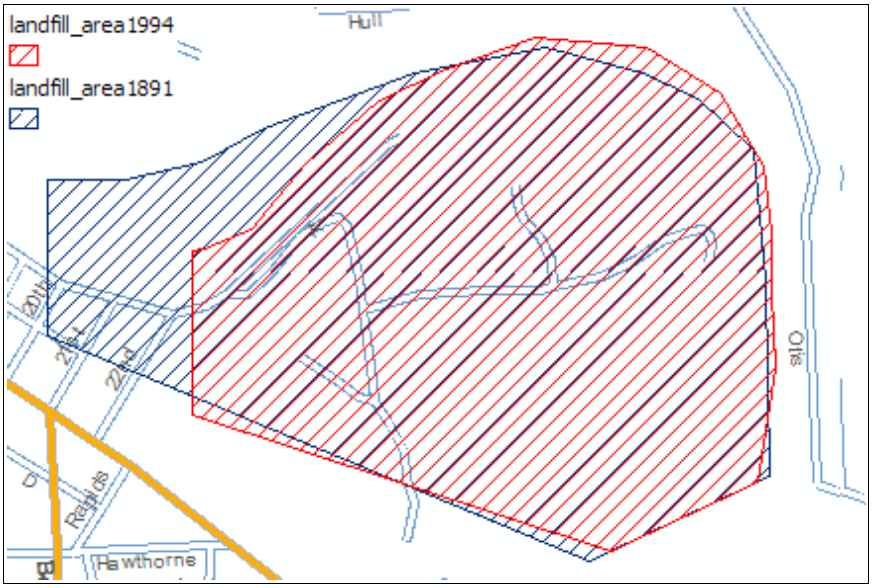

Figure 9: Landfill area, clip polygons.

From the shape of the polygons, the larger area of the 1891 polygon suggests it would have more volume. Figure 10a shows the opposite is true, although the amount is small and the differences appear to remain somewhat constant. However, the scale of the y-axis is somewhat misleading. Figure 10b display the difference between the two volumes

on a more meaningful scale. The 'humps' in the data centered at 710' and 730' show the contour interval is a very important factor in the volume differences. A normalized ratio of the volumes show how this is evident. The same situation discussed earlier about the distance between the next higher or lower contour is also significant here. Since it is the lower elevations (up to the height of a flood) that are the most important for calculating volume, accurate contours at appropriate intervals are very important.

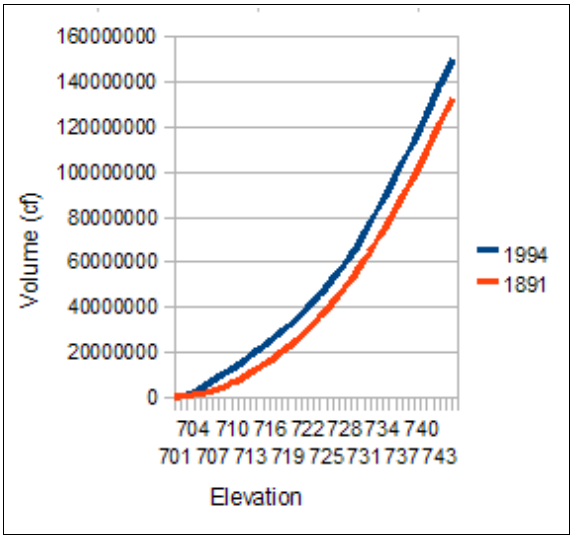

Figure 10a: Volume between river and landfill/hill

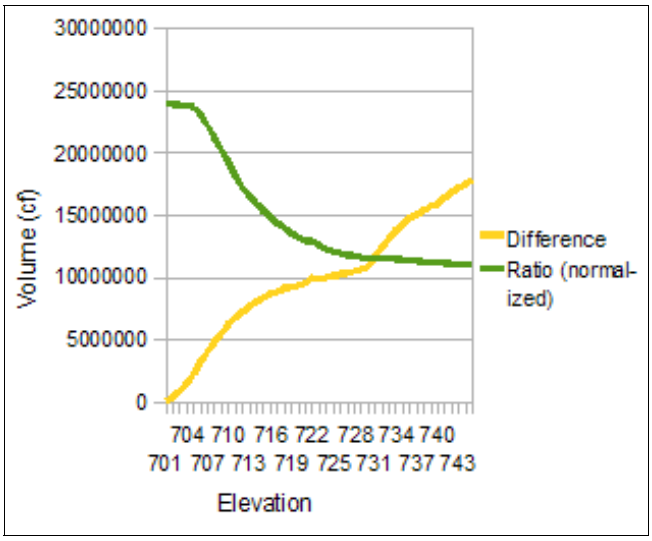

Figure 10b: Volume Difference & Ratio

Rate of Flow

Up to this point, many conclusions have been reached but the main question has still not been answered. Did the location of the landfill increase the height of flood? In order to answer this question, the volumes at the 'inflow' and 'outflow' cross-sections on the map were compared to the actual flow of the river

Figure 11a shows the amount of water the river can handle at each elevation. The 1891 profilea suggest the river was capable of carrying a constant amount of water in its course through Cedar Rapids and this amount of water was less than it is today. The analysis must be careful here not to suggest there would be 'less' flooding just that volumes are smaller due to the overall higher elevations in the 1891 profile. Two conclusions can be reached: first, the elevation of the 2008 flood may have been higher with the 1891 profile as the ability of the area to contain that much water is more limited. While the analysis has taken steps to discuss only the study area, another logical conclusion is the lesser volume capacity of the 1891 profile means water would tend to 'pass through' the area at greater speed looking for a less elevated region to flood.

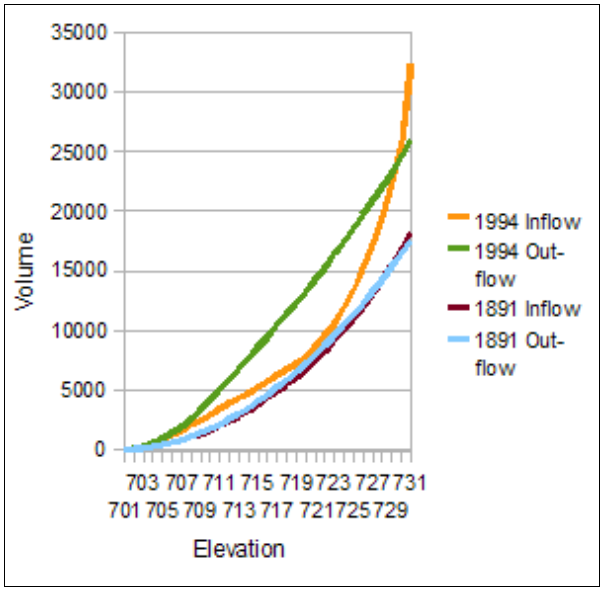

Figure 11a: Flow profiles

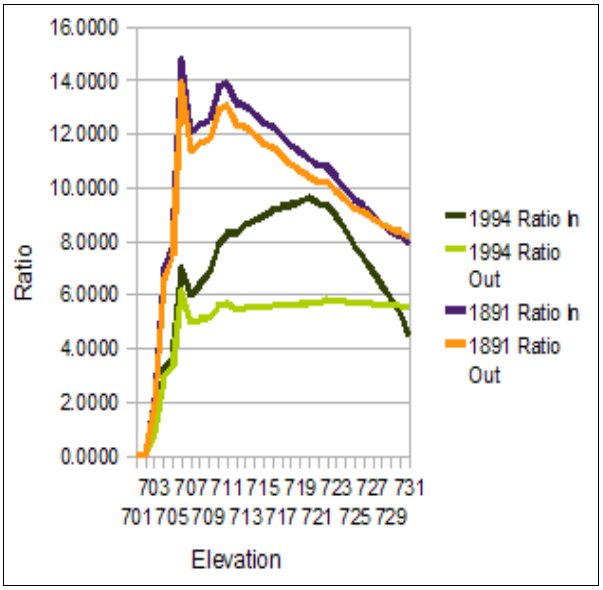

Figure 11b: Flow profiles in ratio to actual flow

The 1994 profile shown in Figure 11a is very different. The most notable feature is the ability of the outflow cross-section to handle a much greater amount of water than the inflow. From previous discussions, it has been noted the outflow section has had very little change across time and the likely difference in the volume calculations is the contour interval. Another possibility is the change in the course of the river and flooding previous to 2008 worked to create a wider river that could handle the amount of water efficiently. This is also suggested by the 1994 inflow profile. The river at the location of the gauge station flows past the downtown portion of Cedar Rapids. There is no low-lying land here. The river basin rises quickly to 720' on the west side and 723' on the east. This is why the volume rises slowly to 720' then increases more quickly to 723' at which point it rises exponentially as the river is completely out of its banks within the city. Amazingly the flow of the river around the bend and past the landfill is capable of handling all the additional volume until about 729'. It is only at this point where the lack of additional low-elevation land at the outflow could even begin to cause any additional flooding to the city center as the hypothesized dam effect begins to take place.

The speed of the river is a major factor. The analysis so far has mostly assumed a constant speed throughout the area but has rightly suggested rate of flow is an important topic. Figure 11b attempts to shed light on the issue. The ratio was achieved by dividing the actual flow by the flow profiles. This returns the number of times in a second the sections must be filled to handle the actual rate of flow. Flood stage for the river is 12' (712' elevation) so the elevations and ratios below this point should be considered easily handled by the river. In that respect, the higher ratios can be thought of as an efficiency rating with the river naturally creating a basin capable of handling its flow. This gives additional weight to the previous suggestion that the 1891 river profile could handle the flow of the river with a lesser volume at greater speed. However, if this faster rate can not be achieved it also implies the 1891 profile would create more smaller floods as water is forced to higher elevations more quickly to compensate. This could explain why the historic flood stage is 12' when now flooding doesn't really begin until 15'5' and not significantly until over 17'.[1]

The 1994 ratios are again quite different from their 1891 counterparts. The '1994 Ratio In' on Figure 11b shows the river can handle the flow of the river up to about 720'. This is interesting for two reasons – this was the previous record height of flooding and t is also the maximum limit of the natural river basin before massive flooding occurs. Again the 723' mark is also an important level and it is from this point the ratio declines precipitously, indicating the river can no longer manage the rate of flow without either flooding or a faster river (or both)..

In contrast the '1994 Ratio Out' profile is much more constant. From the nominal height of the river at about 705' on upwards, the outflow is efficient in two respects. One: the river does not require a great rate of speed to handle the flow. This is important because the flow is likely to be limited around the bend. Two: the lack of adjacent low-lying land in this section means the river must contain all the flow. The constant ratio across the elevations shows that it can.

Conclusion

The conclusions to be drawn here with respect to the original hypothesis are as follows. Landfill #1 is an important feature on the Cedar Rapids landscape but the hill it is a part of not new. However, the flow of the Cedar River is currently capable of manuvering this obstacle. It is only at the greatest extent of flooding known to man that a dam effect is created. At the most, minimal if any additional flooding can be expected for any flood below the epic stage reached in June 2008 as a result of this situation.

Reflection

First, a liberty taken with the data should be revealed. In addition to the contours from the 1994 map, a 723' contour was drawn on the east side of the river for the portion adjacent to downtown Cedar Rapids. This data and analysis shows this decision was well founded as this particular contour has been evident repeatedly in the graphs. Hopefully the importance of good data is well-heeded. Now where's that Iowa LiDAR data....

While the 1891 map was less than desirable and a lot of extra work was spent investigating the data implications, it did allow for some additional analysis that may not have been done otherwise. I knew I wanted to address the rate of flow from the outset of the project but it was the large differences in the cross-section volumes between the 1891 and 1994 that led me to the line of thinking used here. Since I was very happy with the results, it was worth the trouble. Ideally, though I would have used two entirely different data sets. The modern one would have been closer in time to 2008. The landfill had another 13 years of operation after 1994, it is possible there were topographic changes that existed at the time of the 2008 flood but are not represented on the 1994 map. Of course I found out too late in the project that the city of Cedar Rapids has a 2005 contour set derived from air photos. In fact, it is how the flood area shown in

1 http://www2.mvr.usace.army.mil/WaterControl/stationinfo2.cfm?sid=CIDI4&fid=CIDI4&dt=S then click 'NWS Flood Impact Statements'.

Figure 2 was developed!

Clearly, a 7.5' quad from the 1960s would have been ideal. It would have most likely eliminated the surveying and elevation deficiencies completely, allowing the project to focus on the narrow scope of the hypothesis. Even so, the analysis steps themselves would be the same just with better data. If the same conclusions are reached then there aren't any additional steps required. If the dam effect of the landfill became relevant at a lower elevation (unlikely) then the extra work of calculating the extent of the effect would be necessary.