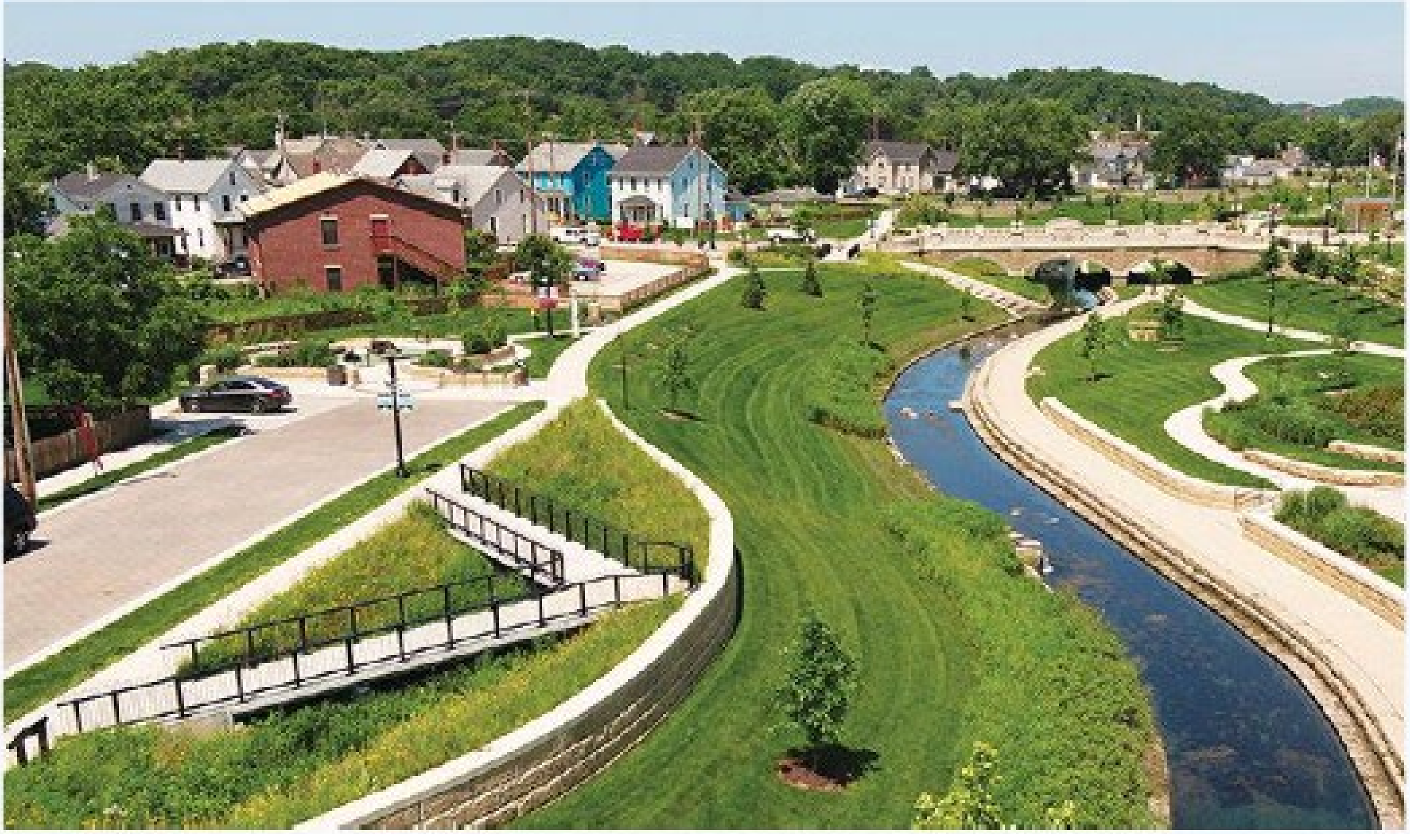
THE CITY OF DUBUQUE
Masterpiece on the Mississippi

The City of Dubuque

Stormwater Climate Action Plan



May 2, 2024

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Foreword

Introduction

Across the nation, communities are recognizing their responsibility to prepare for the changing climate. In the past year, Dubuque has experienced several record-breaking rainfall events, and the catastrophic 14” rainfall in 2011 is a strong call-to-action to prepare for the ever-changing climate and its effects on Dubuque. Without action, climate change jeopardizes Dubuque’s economy, welfare, and human lives.

Recognizing the threat climate change and has established, this climate action plan helps prepare the City of Dubuqu for future rainfall events. By analyzing four basins in the Catfish Creek Watershed, the findings can be translated to the entirety of Dubuque’s stormwater system and will give insight to the action Dubuque can take now to create a resilient city for the future. Our recommendations are summarized in Table 4 on page 12.

Process

Over the past two months, our engineering project team. has analyzed historical rainfall trends over the past 100 years in northeast Iowa. With help from John Wiley, the industrial pretreatment coordinator for the Water and Resource Recovery Center for the City of Dubuque, and advising from Rick Fosse, professor Priscilla Williams, and research engineer Humberto Vergara, we estimated a range of future rainfall intensities that the City of Dubuque can use to design their stormwater system. We have also completed analyses on four detention basins in Dubuque using the projected rainfall intensities. Comparing the performance of the basins from the current recommended design to the projected design values gives insight to the adaptation strategies Dubuque can implement in their stormwater system.

Climate Change Impacts for the City of Dubuque

In order to prepare for the impacts climate change will have on rainfall, historical rainfall data must be analyzed to project and estimate what the future holds. We identified likely changes that Dubuque will experience over the next 80 years; these trends are illustrated below.

Rainfall Frequency

The frequency of 2-inch extreme precipitation events has increased, with the highest number of days with a 2-inch rainfall occurring during the past 16 years. This trend is expected to continue. That means that extreme precipitation events are likely to occur more. On the contrary, the frequency of rainfall events that are less than 2 inches are expected to decrease.

Rainfall Volume

While the frequency of extreme events is expected to increase, the time between these events is predicted to increase as well. That means that the extreme events are going to become essentially the typical standard rainfall event. Because rainfall events that are less than 2-inches won’t happen as much, the total volume of rainfall that Dubuque will experience is expected to decrease. Although extreme events are going to happen more often, the time between these events is expected to increase, leading to less annual rainfall.

Rainfall Intensity

As seen from rainfall frequency analysis, the intensity of a rainfall event is expected to increase when it does rain. Historical patterns have shown that Dubuque and Iowa in general is seeing more intense storms with more time between each storm event. This leaves Dubuque susceptible to drought between rainfall events. In fact, Dubuque is expected to experience more periods of drought in the future.

Design Recommendations

Currently, the City of Dubuque's stormwater system is designed under SUDAS recommendations; that is, a 100-year 24-hour design storm. This amounts to 7.48 inches of rain over a 24-hour period, leading to an intensity of 0.31 inches/hour. Because the frequency of extreme precipitation events is expected to increase, the intensity of typical storms is projected to increase, while the total volume of rainfall per storm is predicted to decrease, we recommend that a design storm that incorporates a higher intensity and lower volume be used when designing for Dubuque's stormwater system. This decision leads to the utilization of the 100-year 6-hour Climate Change Action Design Storm [CCADS]. This is a 5.98-inch rainfall over a 6-hour period, resulting in an intensity of 1.00 inches/hour. While the overall volume of the new design storm is less, the intensity of the design storm is much more. Using this storm when analyzing the stormwater system in Dubuque will better prepare the city for the expected nature of future rainfall.

Basin Risks and Vulnerabilities

With the recommendation of the Climate Change Action Design Storm, weaknesses within the stormwater conveyance and detention systems can be displayed. A higher intensity rainfall means a larger flood peak traveling downstream and interacting with existing and future water resource infrastructure. Possible outcomes from this interaction include the early activation of emergency spillways, aggressive channel erosion, and other degrading actions like property damage and public disruptions. When considering a heavier rainfall, a city should understand if the water resource infrastructure can perform as expected. A significant aspect of the Stormwater Climate Action plan is to ensure effective use, which means inspecting and reporting any deficiencies in existing infrastructure. For future water resource projects, a wide breadth of performance and resiliency need to be considered and designed for. A few considerations from the team are mentioned in the ensuing categories.

Emergency Spillways

Often associated with detention basins and dams, emergency spillways have an important role in water resource infrastructure that involves keeping the integrity of an embankment that is holding the flood peak from uncontrolled downstream flow. According to Iowa SUDAS standards, the spillway should activate at a 100-year 24-hour design storm which is the 7.48 inches of rainfall on the watershed in the Dubuque area. The performance of a detention basin is based on the length of time it takes to release the flood peak into the downstream channel. The longer a basin holds water (attenuation) the more storage capacity the basin needs. Issues of large basin storage often come from space and topography restrictions, therefore the storage and discharge from the basin must be designed together. If a basin is designed for Iowa SUDAS standards, then the attenuation of the flood peak is accommodating an average intensity of 0.31 inches/hour. The team predicts an issue occurs when the relationship between storage and discharge is too restrictive to handle more intense storms. For example, if a gutter system on a house is created for light rain rather than heavy rain then the gutter will overflow the side and fall uncontrollably to the ground. The same instance exists in a detention basin where a heavier rainfall causes an early activation of the emergency spillway due to the restriction of outflow or storage. This prediction can be seen in Figure 1 and Figure 2 when we tested the NW Arterial basin with an Iowa SUDAS storm and the CCADS, respectively.

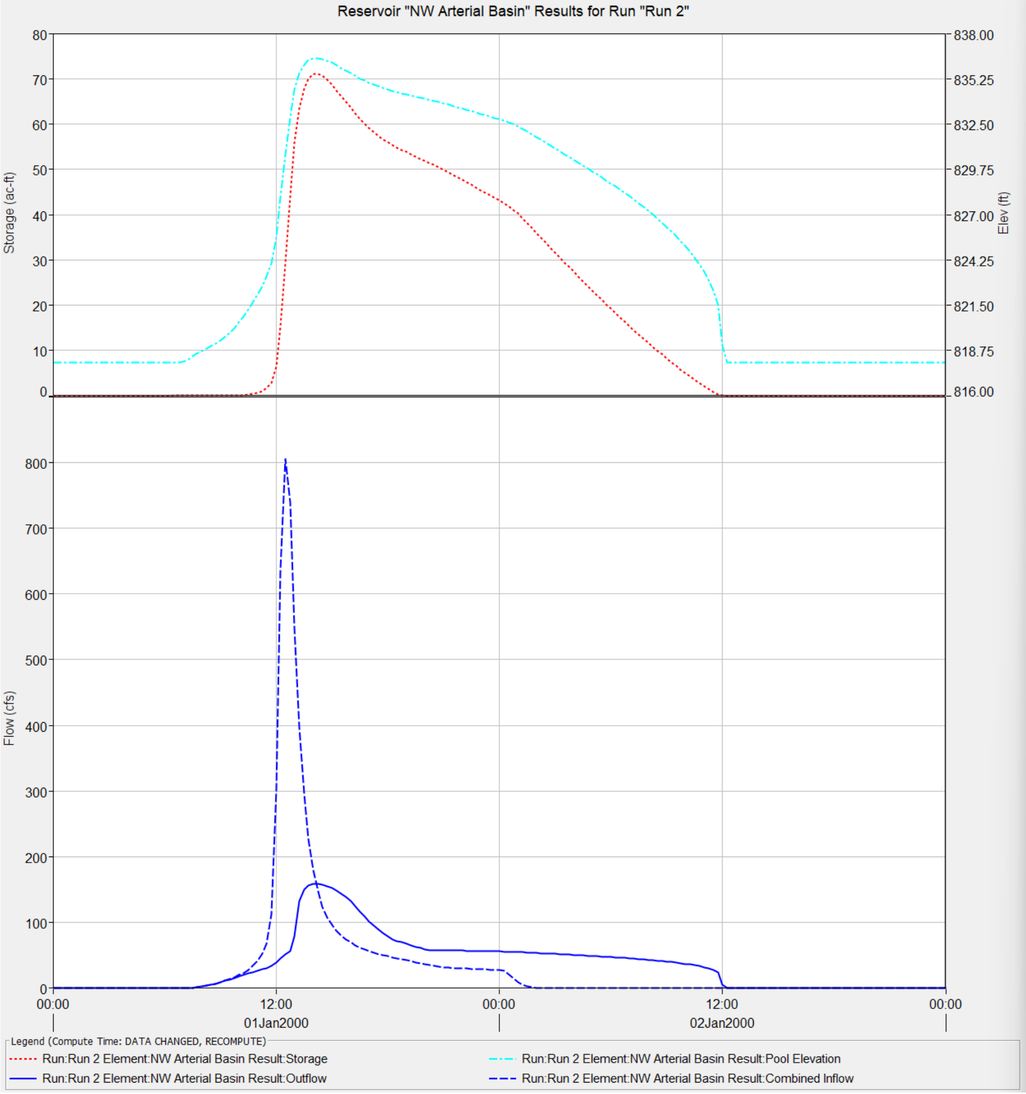


Figure 1. NW Arterial Iowa SUDAS design storm simulation results

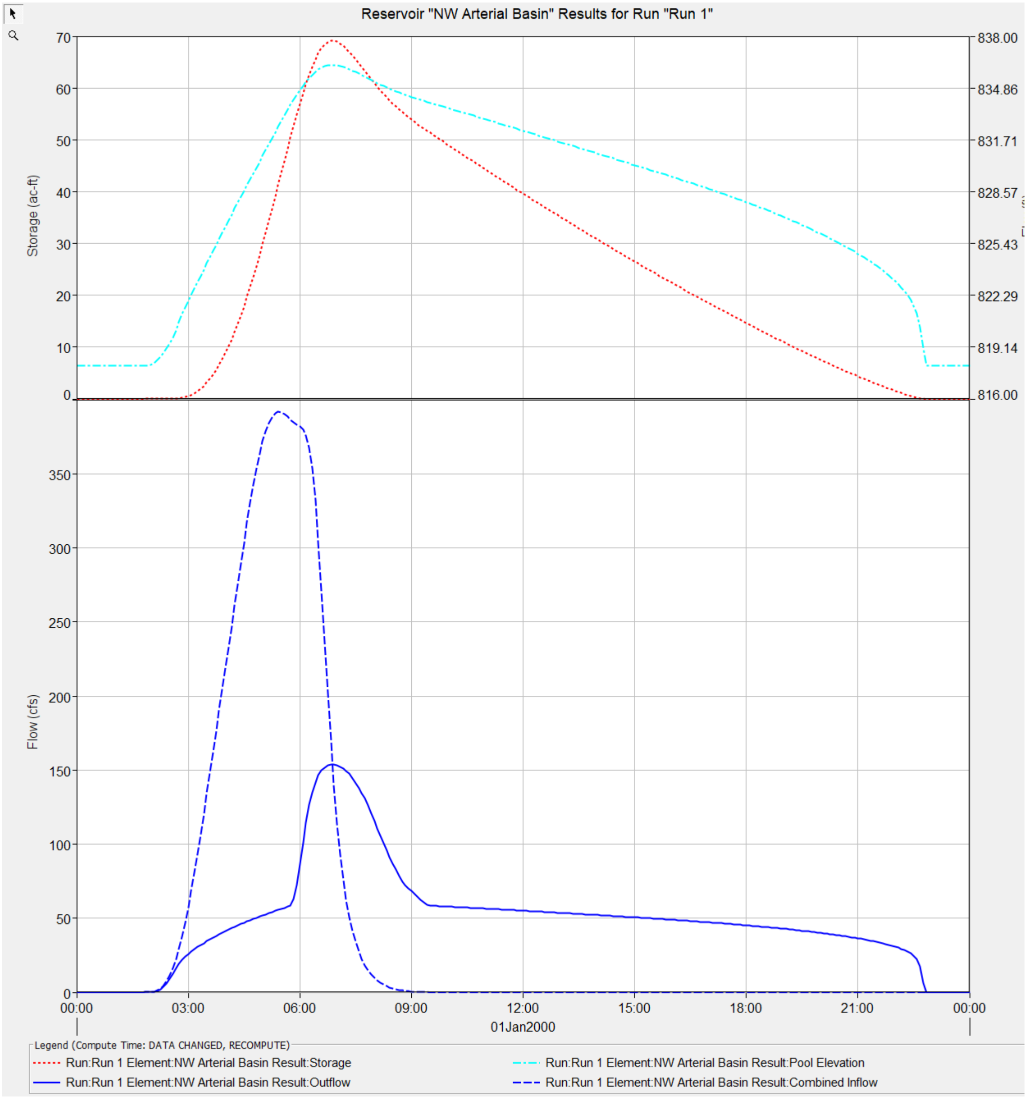


Figure 2. NW Arterial CCADS simulation results

One of the key takeaways from the NW Arterial basin simulations is the 100-year 6-hour storm consumes the almost identical amount of storage and at the same elevation of the 100-year 24-hour storm with 1.5 inches less rainfall over the total watershed. One thing to note is that the emergency spillway did not activate during the Iowa SUDAS Design Storm or the Climate Change Action Design Storm simulation. As land cover changes and the city develops, the runoff from a given rainstorm will increase unless Best Management Practices (BMPs) are implemented in the headwaters of the watershed where sheet flow is dominant.

The impacts of an emergency spillway activation can be predicted but not fully understood. Although at large scale, the Oroville Dam Crisis in February 2017 is a primary example of an uncontrolled discharge that almost caused a complete failure of the embankment and devastating impacts to humans physically, socially, and economically. Likewise, the NW Arterial basin's emergency spillway crosses over a major thoroughfare resulting in a severed transportation artery for the city of Dubuque. Additionally, the safety of the individuals that may be caught in flooded conditions is in question. A risk assessment would be practical for every emergency spillway within the Dubuque area to ensure the safety of individuals and existing infrastructure is maximized. While revisiting and recording basin performance information, the transferring of information to other departments like Public Works, Fire & EMS, and Police for a more integrated and knowledgeable response should occur.

Channel Erosion

The natural environment contains thresholds that are subtle but important for how cities and nature interact. Streams have one of the thresholds displayed in the banks of the channel. Over a long period of time, streams experience a consistent rainfall that seems to define the width and geometry of the channel. Before settlement and urbanization, land cover consisted of mostly prairie grass within the Midwest. This native grass is excellent for allowing rainfall to percolate and slowing rainfall volume down during the early runoff stages. Given these circumstances, the flood peak during this time was slower and less volume than what cities experience today. Channel geometries and widths have adapted to the modern-day discharges that are larger due to increased impervious surfaces and less native land cover. A concern for the city is the erosion of existing channels because of higher velocities in flows. A channel's reconstruction is relatively inexpensive if the city wants to address areas that experience significant erosion, but if the velocities are not mitigated then similar degradation will occur. Fortunately, a channel geometry exists that will decrease velocities during rainfall events and stabilize banks for channels (i.e. prevent erosion) which is mentioned in the Adaptation Strategies section of the report.

Adaptation Strategies

Based on the findings of our evaluation of the four sample basins, it appears that modifications may only be required on a limited number of basins. We have prepared three adaptations strategies that can be used in those cases. However, it is important to note that the maintenance activities that we identified will be important for all basins because the higher intensity storms will be less forgiving to maintenance issues. Ultimately, the listed strategies provide a simpler alteration to an already complicated stormwater conveyance system.

The first adaptation strategy is increasing the embankment height of a detention basin that fails during a given Design Storm whether that is the Iowa SUDAS event or the CCADS. Situations where the current basin layout can accommodate an additional dimension increase should consider this adaptation option due to the relatively low cost compared to the adaptation options listed next. From the current study of four basins within the city, one of the basins did not successfully attenuate the 100-year 6-hour Climate Change Action Design Storm which means a premature activation of the emergency spillway. Although no public are at risk due to the flowing emergency spillway, the activation reveals an imbalance of attenuation and storage for a particular basin. The suggestion is the basin does not have enough outflow or has too little storage. Adaptation Option 1 solves insufficient storage that other basins in the city stormwater drainage network may be experiencing. A designing challenge beyond available space around the basin is the new emergency spillway. A model should be created to understand the inflow and outflow of the basin being studied. Iowa SUDAS offers design guidelines for velocities on earthen and revetment spillways. The dimensions adjusted to velocities are heights and widths of the spillways. Additionally, the location of a spillway should avoid being designed near or on the outlet structure to prevent any large risk of complete basin failure. Spillways should be on native soils rather than fill soil and should accommodate twice the inflow during the design storm event.

The second adaptation strategy is to make no modifications to the embankment but modify the outlet structure of a basin to allow more flow, reducing the maximum surface elevation. Although a more expensive approach, an in-depth understanding of the basin characteristics and outflows is required. If the basin is designed more recently, then certain characteristics like stage-storage-elevation curves, discharges from primary and secondary inlets, and past hydrology data can be used. Issues can arise when outdated information shows an adequate performance of a basin. Hydrologic characteristics are known to change within a city due to the development of land and alteration of stormwater systems. A discharge design centered around orifice and weir flow must be completed when sizing the new pipe for the basin. Additionally, the style and location of the pipe must be considered to keep the functionality of the basin while completing construction. A benefit of completing this adaptation is the need to survey and report the upstream and downstream channel conditions to ensure the integrity of the new pipe. An additional study must include the area and geometry of the downstream channel to ensure the increase in discharge can be accommodated by the existing stream. A HEC-RAS model will aid in this study by simulating the new discharges during current conditions.

The final adaptation strategy is a two-stage channel system that creates a lower stage channel that passes a traditional rainfall runoff while the upper stage passes a larger flood peak that comes with a design storm like the CCADS. The geometry consists of a main channel with flood plain benches that expands to a larger trapezoidal channel for the upper stage. Figure 3 displays a two-stage channel designed for the downstream reach of the DIC2 detention basin.

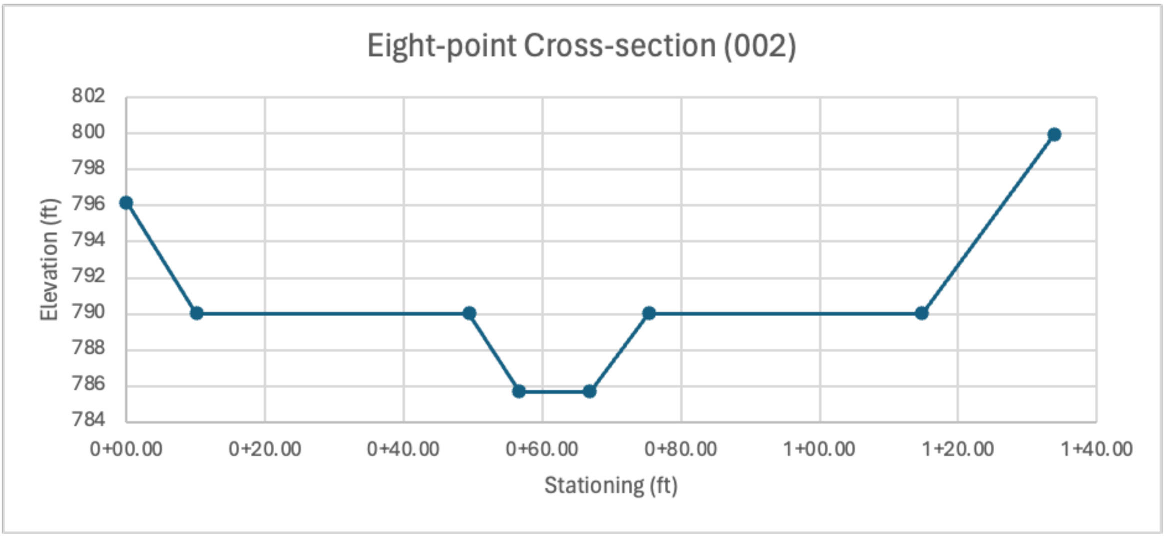


Figure 3. Designed two-stage cross-section for DIC2 basin

The major benefits from the two-stage channel are the channel reach stability and reduced maintenance which can attributed to the significant reduction in erosion potential because of the wider and shallower flood plain. The toe of the embankment experiences far less shear stress during these circumstances.

Additionally, better habitat is produced because of the deeper flow within the main channel and the flood plain vegetation providing cover over the stream. Finer sediments will deposit onto the flood plain and coarse sediments will stay within the main channel. This system has an overall impact on water quality and wildlife. The HEC-RAS simulation for the DIC2 basin two-stage channel can be seen in Figure 4 and Figure 5.

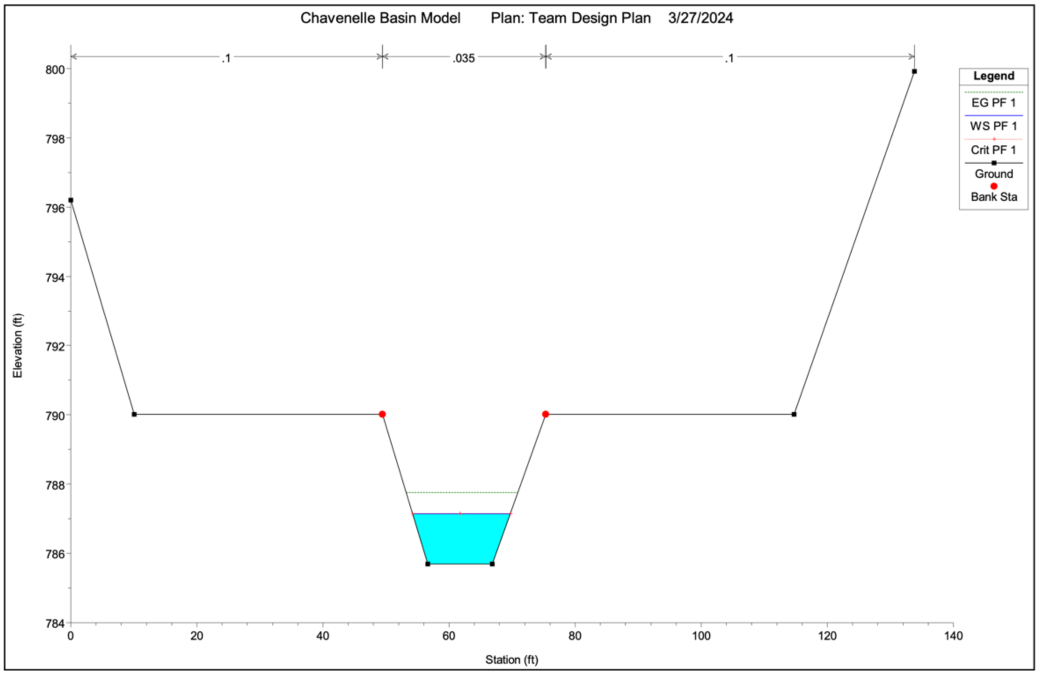


Figure 4. Downstream reach cross-section immediately following the outflow of the DIC2 basin

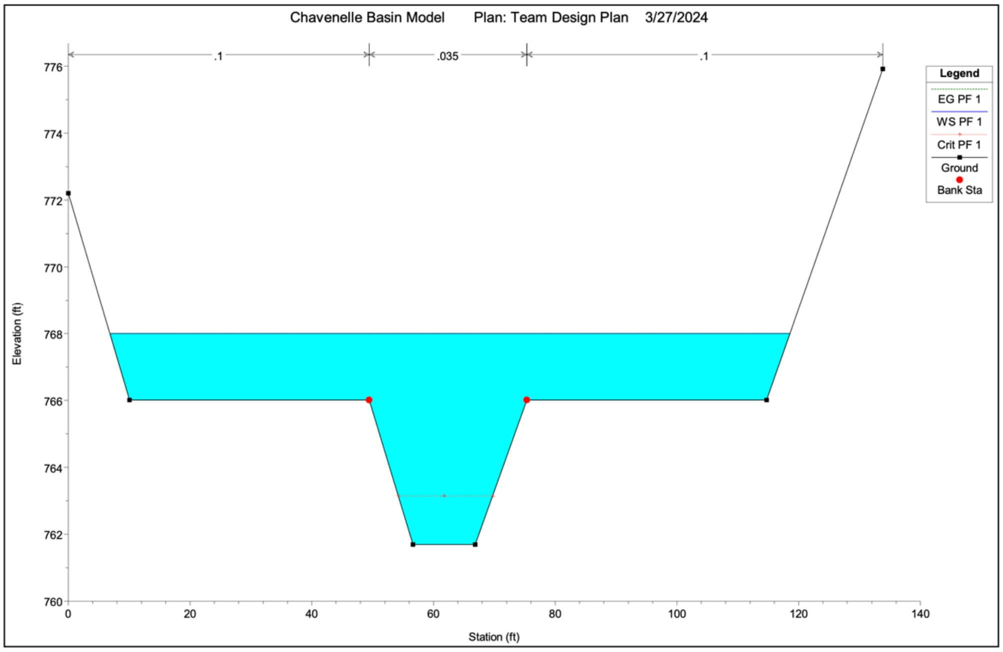


Figure 5. Downstream reach cross-section beyond the outflow section of the DIC2 basin

When comparing the existing channel geometry with the two-stage geometry, the downstream reach had a significant reduction of 55% in velocity within the latter portion in the downstream reach near the Middle Fork Catfish Creek. Additionally, an increase of 76% in channel area and an increase of 5% in the composite Manning's n were observed. Table 1, Table 2, and Table 3 show the results from the DIC2 basin study.

Table 1. Downstream channel roughness for the DIC2 basin

Adaptation Option 3	
Type	Composite Manning's n
Original Cross-section	0.084
2-stage Cross-section	0.089
Percent Change in Composite Manning's n	+5.4%

Table 2. Downstream channel area for the DIC2 basin

Adaptation Option 3	
Type	Area (ft^2)
Original Cross-section	447
2-stage Cross-section	788
Percent Change in Area	+76.4%

Table 3. Downstream channel velocity for the DIC2 basin

Adaptation Option 3	
Type	Velocity (ft/s)
Original Cross-section	0.89
2-stage Cross-section	0.40
Percent Change in Velocity	-55.1%

As mentioned and proven in the case study above, the two-stage channel creates opportunities for habit and integrity while addressing channel stability and water quality issues that the city will experience in the future. A constraint within this adaptation option is the need for more space beyond the stream's banks. The types of areas difficult for this adaptation option are dense urban areas that have housing near the stream bank where expanding the stream cross-section can compromise soil stability of buildings and create safety risks for the residents.

The adaptation strategies mentioned above are considering the rainfall intensity increase that is suggested by the current climate research. Every issue that occurs with the current climate outlook cannot be addressed by one adaptation strategy. Also, the strategies listed may not be effectively implemented across all basins. Every location needs to have a comprehensive inspection and study to fully describe the basin and downstream characteristics to ensure a sufficient adaptation option plan or combination of plans is/are chosen.

Overland Flow Routes

Alternative to basin redesign, the City of Dubuque should also consider modifying their overland flow routes, when the storm sewer system becomes overwhelmed by a storm. Assuming the overland flow routes are designed for a 100-year storm, it is recommended they are designed for a 500-year design storm in the future. This may entail expanding the capacity of the current overland flow routes by heightening the embankment or increasing the infiltration along the corridors. With a more intense storm, it can be expected that the storm sewer will be overwhelmed with a large amount of rain over a short period, hence the recommendation to increase the overland flow route capacity.

Storm Sewer System

The final recommendation is to reexamine the performance of the storm sewer system during the Climate Change Adjusted Design Storm; increased intensity may overwhelm the system and additional capacity may be necessary. In this event, it is pertinent that the storm sewer system along a major arterial street allows enough flow such that one lane width on the road is not flooded, preventing closure of the street. Additionally, capacity may need to be increased for storm sewers near neighborhoods, since the overland flow routes encompass peoples' properties in these areas.

Action Items

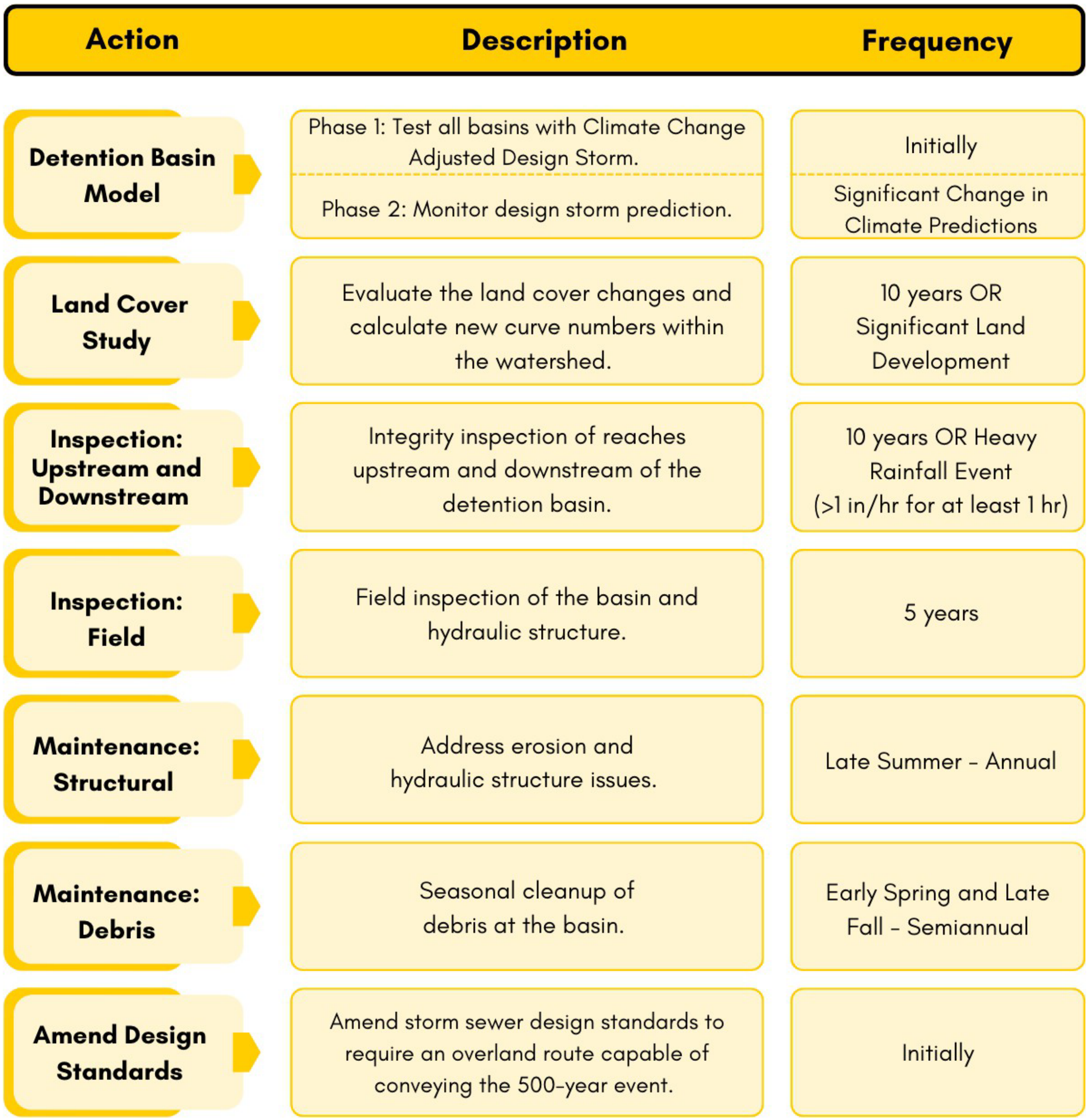
The design life of a detention basin depends on the anticipated watershed characteristics for the future which is why Phase 1 includes simulating all basins for the CCADS event and Phase 2 tests any change in climate predictions. City planning and design need to consider future land development or rehabilitation to ensure downstream water resource infrastructure can accommodate the new circumstances. Additionally, upstream infrastructure must reduce the development footprint that is apparent in the runoff volume. The increase in impervious areas from buildings, parking lots, or compacted fill significantly increases the amount of rainfall the downstream water resource infrastructure must handle. A proactive task of completing an evaluation of upstream land cover needs to be completed every decade. Generally, new developments of infrastructure (urban, commercial, industrial) attempt to reduce the runoff through created detention basins, but how the basins are maintained and altered may not be within the city's control. If drastic changes are observed, then modeling the detention basin(s) will be required. The familiarity of the watershed will help with emergency response and recovery during periods of devasting rainfall and flooding.

As said previously, a typical action taken to prevent increased runoff in new developments are relatively small detention basins to keep the runoff discharge near the same level as pre-development conditions. Other actions can be found under Best Management Practices (BMPs) within the Iowa Stormwater Management Manual. A few listed are already being implemented into the community like pervious pavements, detention basins, and wetlands. Additional BMPs include infiltration trenches, grassed swales, and vegetated filter strips. With the goal of improving water quality and decreasing runoff, BMPs are best implemented in certain locations. The headwaters of the watershed consist mostly of sheet flow overland before being concentrated into a small stream. Applications of the additional BMPs are most effective when collecting rainfall runoff at these headwaters. The concentration of rainfall acts like a snowball rolling downhill where the better location to filter and detain is earlier in the runoff path. As the runoff develops, larger infrastructure must be implemented. The small efforts completed by multiple BMPs in the headwaters can and will decrease the hydrograph entering a downstream channel or detention basin.

Three of the four basins contained maintenance issues affecting the performance of the basins. Common problems may be beaver encroachment of the inlet weirs, signs of erosion around inlet and outlet structures, urban and natural debris blocking inlets, and the ongoing degradation of existing infrastructure. Detention basins contain redundancy when primary and secondary inlets are constructed, but the complete restriction or destruction of a hydraulic structure places the basin into critical condition. Yearly monitoring of potentially critical conditioned basins is suggested.

The outline for actions needed to be completed on current detention basins within the Dubuque area is presented in Table 4. These actions are focused on current climate research.

Table 4. Action list for detention basins located within the Dubuque area

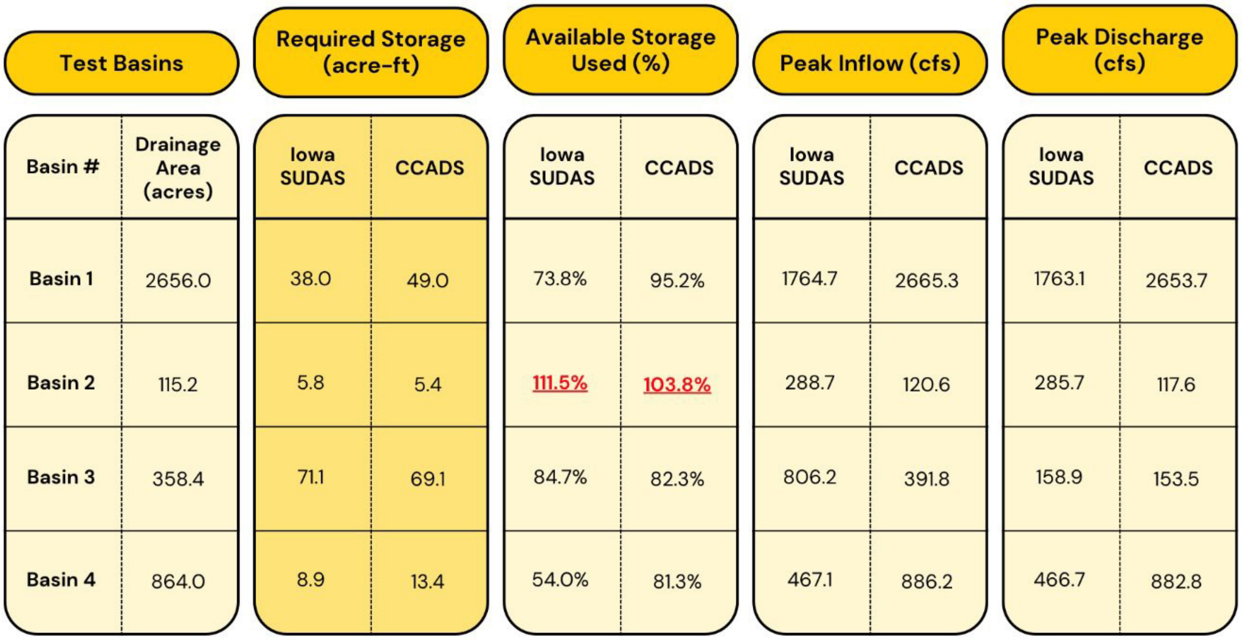


Action	Description	Frequency
Detention Basin Model	Phase 1: Test all basins with Climate Change Adjusted Design Storm.	Initially
	Phase 2: Monitor design storm prediction.	Significant Change in Climate Predictions
Land Cover Study	Evaluate the land cover changes and calculate new curve numbers within the watershed.	10 years OR Significant Land Development
Inspection: Upstream and Downstream	Integrity inspection of reaches upstream and downstream of the detention basin.	10 years OR Heavy Rainfall Event (>1 in/hr for at least 1 hr)
Inspection: Field	Field inspection of the basin and hydraulic structure.	5 years
Maintenance: Structural	Address erosion and hydraulic structure issues.	Late Summer - Annual
Maintenance: Debris	Seasonal cleanup of debris at the basin.	Early Spring and Late Fall - Semiannual
Amend Design Standards	Amend storm sewer design standards to require an overland route capable of conveying the 500-year event.	Initially

Extrapolation

The basin study completed highlights valuable data collected from basins of varying sizes and applications shown in Table 5.

Table 5. Basin in study tested against the 100-year 24-hour storm (Iowa SUDAS) and the 100-year 6-hour storm (Climate Change Adjusted Design Storm)



Test Basins		Required Storage (acre-ft)		Available Storage Used (%)		Peak Inflow (cfs)		Peak Discharge (cfs)	
Basin #	Drainage Area (acres)	Iowa SUDAS	CCADS	Iowa SUDAS	CCADS	Iowa SUDAS	CCADS	Iowa SUDAS	CCADS
Basin 1	2656.0	38.0	49.0	73.8%	95.2%	1764.7	2665.3	1763.1	2653.7
Basin 2	115.2	5.8	5.4	111.5%	103.8%	288.7	120.6	285.7	117.6
Basin 3	358.4	71.1	69.1	84.7%	82.3%	806.2	391.8	158.9	153.5
Basin 4	864.0	8.9	13.4	54.0%	81.3%	467.1	886.2	466.7	882.8

The smaller basins (less than 500 acres) tend to use the most amount of available storage when simulated with both storms. Basin 2 fails during both storm simulations while Basin 3 uses about 80% of available storage. Generally, a detention basin is designed to use 100% of available storage during the Iowa SUDAS storm if the basin is constructed after the implementation of the Iowa SUDAS Design manual. Basin 2 and Basin 3 show susceptibility to land cover changes that either require more or less storage, respectively. An additional observation on the less than 500-acre basins is the use of available storage is relatively the same when simulating the two storms.

The larger basins (greater than 500 acres) display a robust design given the use of available storage is minimal for the SUDAS storm. Given the size of the drainage area, larger detention ponds may be located within large commercial and industrial areas, or could be upstream of large populous centers. Regardless of environment, a significant amount of investment went into a larger basin to handle the largest catastrophes. Other captivating data are the peak inflow and discharges are larger for the higher intensity storm (CCADS) when compared to the SUDAS storm. These observations are significant because of the potential exploitation of basins that have an imbalance between the attenuation and storage as mentioned in Basin Risks and Vulnerabilities section. Furthermore, a case study should be completed on the orientation of specific drainage areas that have a particularly dominant West-to-East orientation rather than North-to-South because of local weather movements that display the same trajectory. Table 6 shows the data collected and analyzed in four basins that can be extrapolated to other basins located within the Dubuque area.

Table 6. Data extrapolation for the Dubuque stormwater detention basin system
using the Iowa SUDAS Design Storm and the Climate Change Action Design Storm (CCADS)

Drainage Area	Average Available Storage Used	Average Change in Peak Flows from SUDAS Design Storm to CCADS
Less than 500 acres	Iowa SUDAS: 98.1%	Inflow Change: −54.8%
	Climate Change Adjusted Design Storm: 93.1%	Outflow Change: −31.1%
Greater than 500 acres	Iowa SUDAS: 63.9%	Inflow Change: +70.4%
	Climate Change Adjusted Design Storm: 88.2%	Outflow Change: +69.8%

The results from Table 6 show the relationship between a more intense rainfall and the size of drainage area. The nature of these results is not entirely clear, so we recommend comparing the evaluation of additional basins to see if the trend continues. One applicable design consideration is the performance of drainage areas less than 500 acres is similar for both storms when considering the available storage used. Ideally, the Iowa SUDAS Design Storm should use 100% available storage if designed after the implementation of the Iowa SUDAS standards. In contrast, a decrease in inflow and outflow is observed. For drainage areas larger than 500 acres, the Climate Change Action Design Storms uses 24% more available storage and increases the inflow and outflow of the basin by 70%.

Given the observations made, we recommend designing all basins to the Climate Change Adjusted Design Storm. The data displays the potential for an early emergency spillway activation during the Iowa SUDAS event which may create unprecedented damage during an unsuspecting time.