

## Chapter 5

# The Regional Stormwater Detention Concept in Urban Drainage System

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This chapter uses a case study to demonstrate a regional stormwater detention concept which can be applied to solve flooding problems in urban areas. The stormwater detention concept has been implemented for more than thirty years in the United States with some success. However, local stormwater regulation and permitting lead to small detention ponds individually provided without a regional prospective. Individual detention facilities may successfully control the local peak flow. Nevertheless, the downstream reach may still suffer from flood damage due to the surface runoff rate and volume that results from increased regional addition of impervious areas.

The Lincoln Creek watershed in Milwaukee, Wisconsin has been selected for this case study. Approximately 1500 residential homes experienced flood damage in this nineteen square mile watershed. The Army Corps of Engineers computer programs, HEC-1 and HEC-2, were utilized to analyze detention and watercourse improvement alternatives.

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Evaluations of potential detention or retention locations preceded estimates of storage volumes at each site. Various channel improvements, including different shapes, dimensions, and bank protection materials, were evaluated on a reach-by-reach basis. Iterative HEC-1 and HEC-2 techniques served to evaluate carefully-selected alternatives with channel storage that would mitigate the existing flooding problems and minimize adverse impacts downstream. The preparation of hydrographs at each sensitive location facilitated easy graphical comparisons.

The preliminary results show that, by using the combination of retention and detention ponds throughout the project area and various channel improvements, existing flood-prone areas can be protected from damage by the 100-year storm event. This regional approach ensures that solving a problem at one place does not create a problem somewhere else.

## **5.1 Introduction**

This chapter demonstrates how a regional stormwater detention concept can be applied to solve an urban drainage flooding problem. The main discussion relates to stormwater quantity in terms of peak and volume. The discussion of the channel improvement and wet detention pond options briefly describes the issues related to water quality.

Even though stormwater detention has been provided for years, urban flooding problems remain. Most of the local regulations require a site development to provide its own detention storage, limiting the outflow to its pre-development condition. In general, a developer will provide a detention facility to reduce the potential peak flow to the maximum runoff under existing conditions. Although the peak flow is abated, the runoff volume will be increased due to the addition of impervious areas. In a certain period of time, the additional runoff, which exceeds pre-development runoff, will return to the drainage system. The accumulated runoff may adversely affect downstream properties in a different time period.

A regional stormwater detention approach addresses the drainage problems from a broad perspective. It may not necessarily be a large watershed boundary. There are no clear definitions of how large a region should be. However, it is important to recognize the spatial and temporal distribution of rainfall over a large watershed. Generally, a regional approach should look for solutions that can be applied to a selected area with minimum impacts to its surrounding environment. Contrary to an individually-designed detention system, which is only applicable to a

solution at its outlet, the regional approach evaluates an area at which point the impact is no longer significant. By re-visiting the basic stormwater detention concept, we hope that a regional approach can correct the shortcomings of the individual detention solution and enhance the overall performance of the drainage system.

The basic rainfall-runoff relation, water surface computation, channel and/or reservoir routing concept that applies to the case study can be found in engineering hydrology handbooks (Viessman et al., 1989; Urbonas and Stahre, 1993). Most of the findings in this chapter came from the Lincoln Creek watershed study in Milwaukee, Wisconsin. A discussion section presents technical results as well as non-structural solutions and recommendations.

## 5.2 Existing Practice

The essential question is: why do individually-designed detention not always prevent flooding after development. With proper design, the detention storage should have abated the peak flow, previously increased due to additional imperviousness. Let us review the fundamental storage routing concept using a hypothetical hydrograph at a given station. As shown in Figure 5.1, Hydrograph A represents a time series of discharge under pre-developed conditions. Hydrograph B shows the peak and

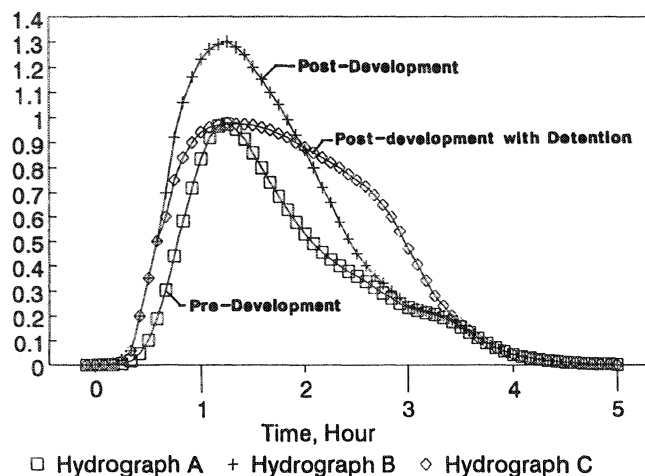


Figure 5.1  
Detention Storage Routing.

volume increase due to the development assuming no detention storage is provided. If detention storage was provided to reduce the peak flow impact, the hydrograph will usually be similar to Hydrograph C. In general, stormwater regulations do not require Hydrograph C (post-development) to match Hydrograph A (pre-development) exactly. Most regulations only require that the peak flow does not exceed existing conditions. So, engineers effectively design the detention pond to meet the peak reduction requirement.

The problem begins when small volume increases accumulate downstream. As shown in Figure 5.2, even though the peak flow at each individual outlet was restrained, the accumulated peak flow can exceed its existing condition at a different time period.

Other drainage problems come from mismanagement of the watershed in the past. Over-development may take place in low-lying areas. Building levees in the floodplain constrains flows into narrower waterways. Construction of concrete channels accommodate quick flow conveyance downstream. Within the framework of a limited budget, short-sighted solutions address the relief of immediate local problems. The cumulative effect of intervention with natural watercourses over a long period of time now causes loss of human life and property. *As last summer's rampaging Mississippi River has shown, the safety of flood control is not perfect -- it provides more years between floods but will not prevent the worst* (Graves, 1993).

### **5.3 Study Area Description**

The Lincoln Creek watershed in Milwaukee County, Wisconsin has been almost fully urbanized. The 19 square mile (49 square kilometer) watershed consists of single family residential and some industrial development. About 90% of 8.6 miles (13.8 kilometers) of waterway has been straightened and/or paved. Erosion control measures such as check weirs, drop structures, and stone and concrete linings can be found throughout the channel. Flood damage potential exists for approximately 1500 residential homes at about the center of the watershed. Over-developing, insufficient detention storage, and structure (bridge/culvert) constrictions lead to the main cause of flooding. The ongoing feasibility study evaluates a solution that can mitigate the existing flooding problems as well as rehabilitate the waterway to a natural state. The major alternatives studied include channel improvement, bank protection, bridge rehabilitation,

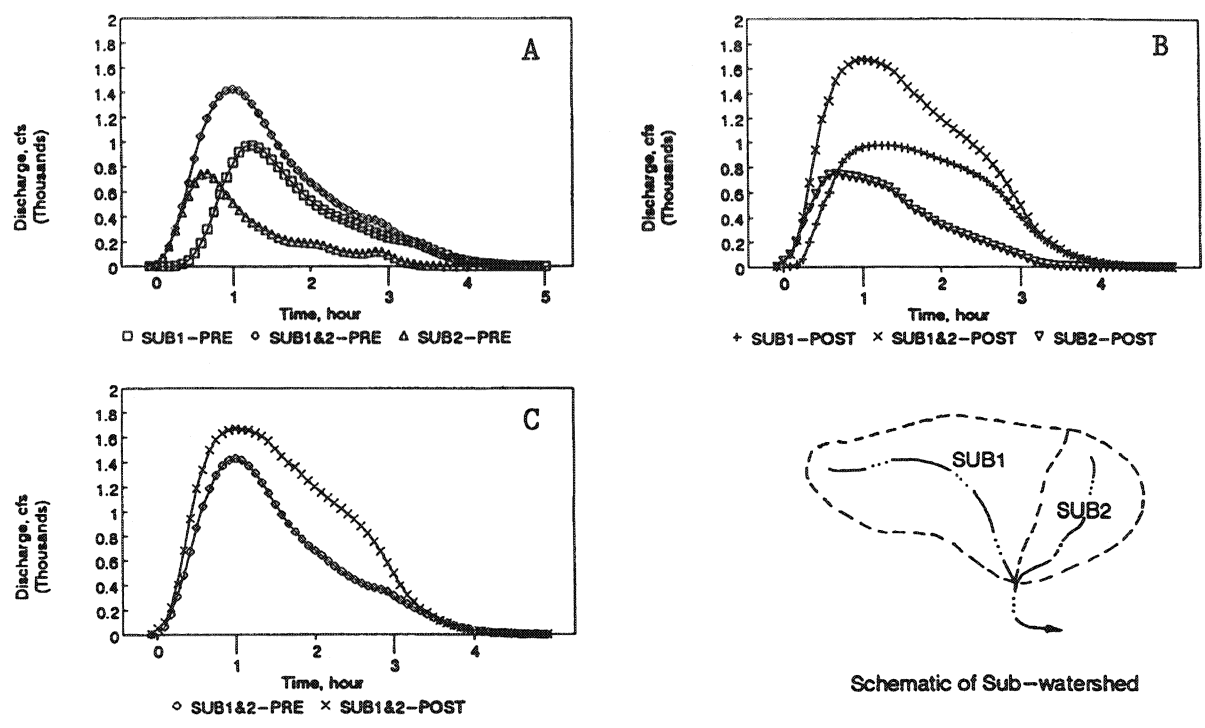


Figure 5.2 Accumulation of hydrographs.

detention, retention, wetland, embankment, pump station, and non-structural solutions such as setting a stringent release rate and relocating residential homes.

Lincoln Creek discharges into the west fork of the Milwaukee River. At the confluence, a recreational park was developed after a major Milwaukee River channelization project. Estabrook Dam was constructed about 1.1 miles (1.8 kilometers) downstream. The control gates open during winter session, and close during the rest of year to create pools for recreation. The backwater submerges Lincoln Creek to about 1.3 miles (2.1 kilometers) upstream of the confluence. From this point up, a concrete lined section at the lower portion of the channel prevents bank erosion. Riparian vegetation, rock and/or stone line the channel further upstream. The installation of the grade control measures such as check weirs and drop structures presently function well. The creek is substantially stabilized, and there is no significant degradation and aggradation at this time.

Channel improvement considerations include shape, dimension, and bank protection materials. A proposal to carry low flow through a meandering channel section seeks to re-establish marine life. The normal flow channel is designed to convey flows within the channel about 95% of the time. An overbank section similar to the existing floodplain could be added to the normal channel to convey the design flow (100-year return interval). An additional consideration is the replacement of the concrete channel with soil bioengineering materials. The vegetated channel reach can be improved by a selected woody variety that provides lower resistance and higher protection.

Fifty potential detention and/or retention sites were initially appraised with respect to storage volume and practicality. Both the forest preserve and the parkway system locations along the creek served as the major storage areas. These areas are inundated during major storms and are predominantly located in the floodplain. Relocation of residential homes to provide storage is politically and/or economically unacceptable. Five alternative major sites can accommodate sufficient storage for the purpose of flood detention. The rest of the smaller storage areas were considered as potential wet detention sites for water quality improvement.

## **5.4 Modeling Technique**

The U.S. Army Corps of Engineers (USACE), Detroit District, constructed the base-condition models. The selected models include

HEC-1 (US Army Corps of Engineers, 1990a) and HEC-2 (US Army Corps of Engineers, 1990b) to simulate future land use under the existing channel condition.

The HEC-1 model uses the basic data from a TR-20 model developed by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) in 1990 (ibid, 1990). Important enhancements include:

1. A set of updated Huff rainfall distributions (Huff, 1990) that has four different quartiles for various rainfall durations to replace the previous rainfall distribution.
2. A set of rainfall isohyetal maps (Huff and Angel, 1992) recently prepared for the midwest States.
3. A selected rainfall duration (3-, 6-, 12-, and 24-hour storms) has been evaluated to identify the critical peak flows for nine frequency events (2-, 5-, 10-, 25-, 50-, 75-, 100-, 200-, and 500-year).

The HEC-2 model was developed by connecting the original eleven SEWRPC reaches into one model with additional bridge and culvert data. Other changes include:

1. Revision of Manning's  $n$  values.
2. Additional cross sections and high water elevation data.
3. Change of starting elevations. USACE use the slope-area method to determine start elevation. A modification was made to consider the backwater effect from the Estabrook Dam.

Calibration (with respect to high water marks) of the two models ensured consistent results across five selected routing locations. Assessment of alternative solutions to the flooding problems along Lincoln Creek utilized these base condition models.

In the search for a regional solution to the Lincoln Creek flooding problems, evaluation was needed for both detention storage and channel conveyance alternatives. When the hydraulic analysis is performed with a steady-state flow model like HEC-2, the computation does not include the channel storage effects in the routing. Modifications such as channelization, floodplain encroachment, bridge removal, and levee construction, generally change the floodplain storage. Significant storage change will alter the shape and time of the flood wave as it passes through the modified reach. To simulate the modification in the floodplain, USACE developed an iterative procedure (US Army Corps of Engineers, 1990c) to estimate the impact of the change in storage. This iterative

procedure with HEC-1 and HEC-2 is implemented for evaluating each alternative as follows:

1. Compute peak flows using HEC-1. A range of peak flows is determined. (Note: HEC-1 uses a cross-section method, roughly estimating channel storage at these runs).
2. Execute HEC-2 with multiple profiles option using flow values covering the range of flow. The profile computation provides the storage-outflow data for the reach specified.
3. HEC-1 is executed with the multiple rainfall events to generate peak flows with channel storage that represent an array of flood events.
4. The routed peak flows are then transferred back into the HEC-2 data set at the appropriate downstream section for each sub-reach. HEC-2 computes the final water surface profile for the peak discharges.
5. The stage information at modified reaches from both HEC-1 and HEC-2 were checked against each other to determine whether additional iteration is required.

Usually, one round of iteration gives sufficiently accurate results (e.g. within 0.5 feet (0.15 m)).

## **5.5 Evaluation and Discussion**

The analysis started with evaluation of channel improvement alternatives, assuming that several major bridges will be replaced. As soon as these bridge obstructions were removed, the downstream flows increased dramatically. In order to mitigate the flooding near the center of the watershed, about 3.0 miles (4.8 kilometers) of channel between the flooding area and confluence will receive a higher peak. The magnitude of flow increase can be represented at the mouth of Lincoln Creek. The peak flow increased from about 8,000 cfs (230 cms) to about 14,000 cfs (400 cms). A significant conveyance increase was required to accommodate these additional flows. A larger channel cross section and lower flow resistance were necessary to increase conveyance. The attempt to improve channel conveyance without additional detention failed. The major reasons were that the right of way is limited for channel widening; only a very small increase in conveyance can be accomplished over the existing concrete channel; and the starting water surface elevation cannot be lowered due to the backwater from Estabrook dam.

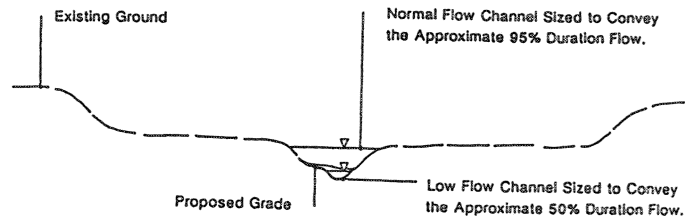
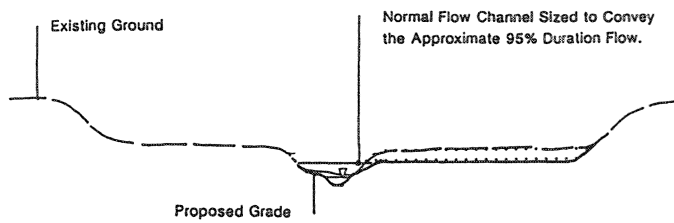
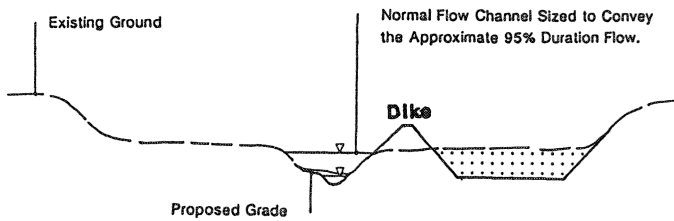
When analyzing regional watersheds that have flooding problems, typically most of the storage areas are not available where needed. The areas that are desirable for detention storage usually are also desirable for development. Additional detention storage is easier to find in the upper reach of Lincoln Creek watershed. Unfortunately, this storage is too far away from the flooding area. And, the outflow from the upper reach has been restricted by several undersized structures. The storage near and immediately upstream from the flooding area that provides the most efficient detention is very limited because the whole area was built up. The available parcels are park land and parkways near the creek. Most of the parkway areas in the floodplain are currently reserved for recreational use.

The evaluation of the parkway land determined that if the open area can be dredged to a lower elevation, several hundred acre-feet of needed storage can be gained. The computer simulation shows that if this flood fringe storage is allowed to be filled without control, it will reduce the flood stage only a few inches. A closer evaluation of results finds that this on-stream storage was filled before the flood peak arrived. A dike can be provided to separate the additional parkway storage from normal flow channel as shown in Figure 5.3. The dike can be designed to eliminate the requirement of gate structures and reduce maintenance. If the peak flow is allowed to spill over a side channel into the detention storage, the peak flow would be lowered more efficiently. Figure 5.4 illustrates the results of this storage added to the floodplain. Figure 5.5 illustrates the results of this storage if separated from the normal flow of the channel. The shaded area in each figure represents where the detention storage was used.

An additional benefit of providing a dike between the parkway detention and channel is reduced frequency of submergence. If additional storage is provided in the floodplain without control, the area will be inundated more frequently because of the lower ground. By controlling inflow to the parkway detention at higher elevation, the recreational use of the parkway can be preserved. The proposed detention ponds in the parkway will be activated once every 10 to 50 years depending on the location and size.

The preliminary results show that by using the combination of retention and detention ponds throughout the project area, and various channel improvements in different reaches, the existing flood-prone areas can be protected from damage by the 100-year storm event.

Water quality improvement is also a major objective when dealing with stormwater management. Wet detention is one of the best management practices to improve water quality.

**Proposed channel improvement with existing storage****Proposed additional floodplain storage****Proposed dike to separate detention storage**

**Figure 5.3**  
**Schematic of adding storage to the parkway.**

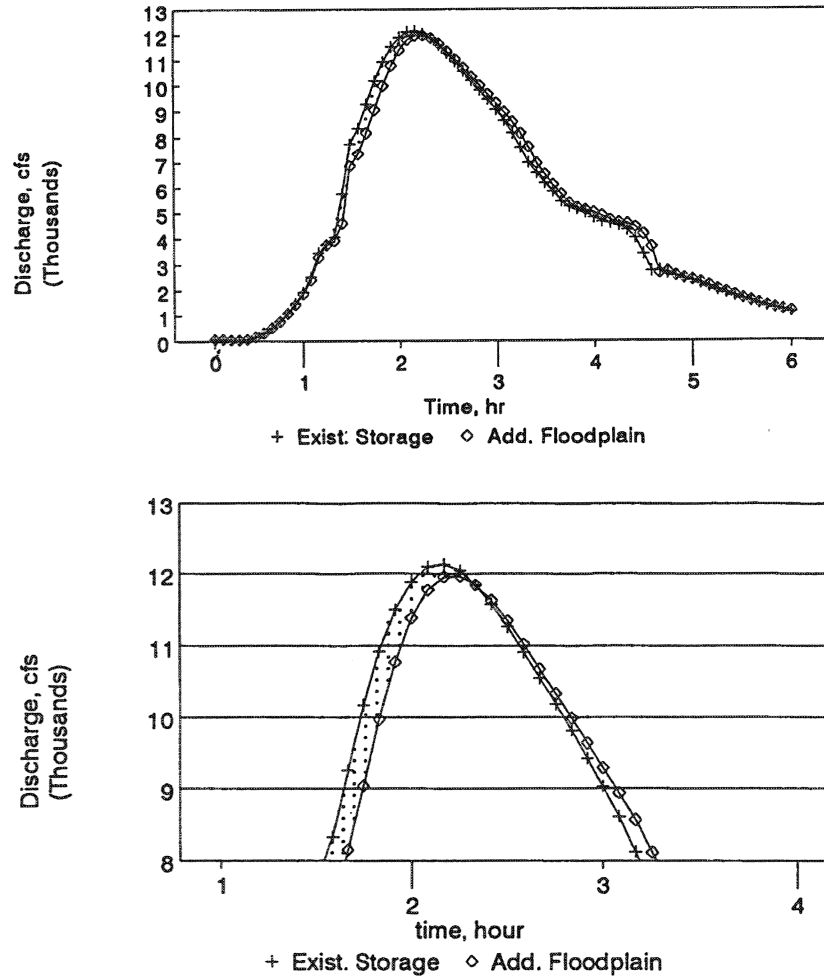


Figure 5.4  
Routing through additional floodplain storage.

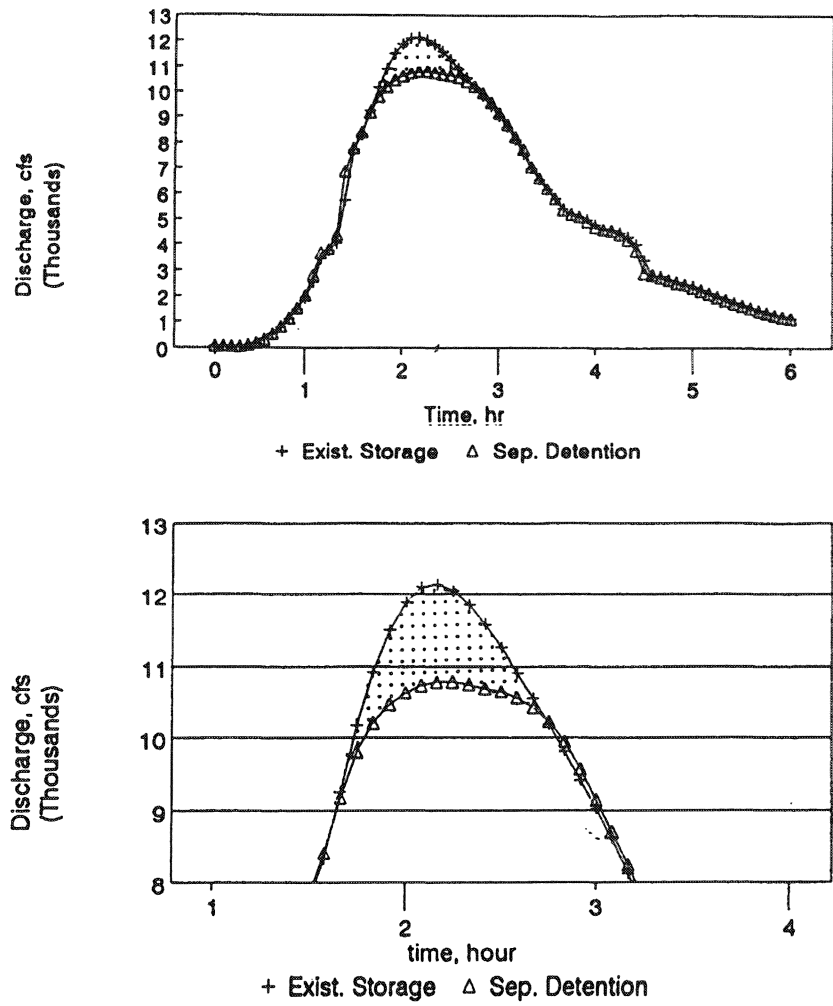


Figure 5.5  
Routing through a separated detention storage.

There is an interesting finding related to distributing wet detention throughout the watershed. Even if a regional watershed has numerous local wet detention ponds, the impact on the peak flow is minor. The Lincoln Creek watershed follows this pattern. The potential storage provided by wet detention was evaluated for each of 18 sub-watersheds. The storage was considered as diversion in the model and the time of concentration was adjusted for each sub-watershed. The simulation results show that the potential 170 ac-ft (210,000 m<sup>3</sup>) can reduce only about 4% of the peak flow at the mouth of Lincoln Creek. As a result, local wet detention ponds are not an effective flood control measure. While it is not dramatic, the reduction is valuable at certain critical locations.

This also leads us to look broadly at the solution. Can we reduce surface runoff by other non-structural approaches? Stormwater regulations may reduce the overall surface runoff, and thus lower the cost of flood control structures. The following are practical examples of stormwater regulations:

1. Set a stringent release rate for new developments or re-developments.
2. Eliminate rooftop runoff that directly discharges onto the driveway or storm sewer.
3. Collect discharge fees based on impervious surfaces to promote a runoff reduction.

How can we correct the previous mistakes with minimum cost and provide the whole system with long term benefits? This becomes a new challenge for the engineer. The growing trend in the midwest states is to provide regional solutions to a watershed. Flooding issues have entered the political arena as demonstrated by recent establishment of regional stormwater management commissions. The concept of the regional approach ensures that solving a problem at one place does not create a problem somewhere else.

## 5.6 Conclusion

Stormwater management has historically been provided in conjunction with new development. As these developments have typically been fragmented, stormwater management has also been limited in scope and scale. The results of this approach from a regional perspective have been disappointing. The current trend is towards a broader, more regional approach. Often, the region in question is already experiencing flooding

problems. As demonstrated by the Lincoln Creek case study, mitigation of flood impacts is more difficult to achieve with numerous individual detention facilities and requires creativity and innovative use of available modeling tools for regional analyses. The benefits, however, of this approach are clear: downstream constraints are fully considered, and more efficient use is made of floodplain storage with peak flow reductions that are beneficial to the impacted areas.

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