Lower Grand River Watershed

Stormwater Management for Stream Protection:

Development of Michigan Statewide Rating Curves for Extended Detention Control of the Stream Protection Volume

MDEQ Tracking Code #2007-0137

May 2009
Project No. G080017

Fishbeck, Thompson, Carr & Huber
engineers • scientists • architects • constructors

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LIST OF ABBREVIATIONS/ACRONYMS

ac-ft	acre-feet
cfs	cubic feet per second
cfs/ac	cubic feet per second per acre
ft^3	cubic feet
ft^3/ac	cubic feet per acre
CN	Curve Number
Ep	Erosion Potential
FTC&H	Fishbeck, Thompson, Carr & Huber, Inc.
HSG	Hydrologic Soil Group
LID	Low Impact Development
MDE	Maryland Department of Environment
MDEQ	Michigan Department of Environmental Quality
PGCM	Prince George's County, Maryland

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INTRODUCTION

The focus of this study is the impact that urban development has on the stability of stream channels. More specifically, the intent of this paper is to compare the erosion potential of several common storm water management approaches for stream protection to ensure that effective controls are being requested by local units of government within the Lower Grand River Watershed. The use of extended detention and the increasing use of Low Impact Development (LID)-based retention are common in local rules and ordinances. However, specific criteria varies. In addition, several Michigan Department of Environmental Quality (MDEQ) watershed studies have indicated the need for stricter controls (Fongers 2004). This paper presents a uniform and straightforward approach based on runoff Curve Number (CN) to determine allowable release rates and storage volumes for effective extended detention control. A design tool, in the form of a series of rating curves, was developed that can be used by local government and site-work engineers to implement recommended stream protection criteria within the Lower Grand River Watershed. The rating curves were also expanded to include each climactic region throughout the State of Michigan. Recommendations relating to storm water management for stream protection are based on the nationally-known studies and empirical research referenced in the bibliography, and on the hydrologic analysis (case study) completed by Fishbeck, Thompson, Carr & Huber, Inc. (FTC&H) in this paper and prior watershed management plans (Gun River, Anchor Bay, and Rabbit River).

BACKGROUND

Receiving water bodies may experience a variety of effects from urbanization including declining water quality, increased temperature, diminished groundwater recharge, degradation of stream channels, increased overbank flooding, and floodplain expansion (MDE 2000). At some threshold, these impacts can affect the quality of life, health, public safety and property of watershed residents, the environment and the economics of a region. Those involved in watershed management seek to improve, preserve and protect these values, but require practical measures and tools to do so. This paper presents one such tool and provides recommendations to protect receiving streams from channel degradation due to urban development. A basic understanding of the relationship between urbanization, altered hydrology and channel erosion is necessary prior to discussing approaches to mitigate the impacts of development.

URBAN DEVELOPMENT AND ALTERED HYDROLOGY

Urban development significantly alters the local hydrologic cycle and, as a result, can have a pronounced effect on the quality of a region’s rivers and streams. Woods, meadows, and agricultural lands that intercept, absorb and transpire rainfall are removed and replaced with impervious surfaces. Natural depressions that encourage evaporation of rainfall are replaced with smoothly draining surfaces. Soils compacted by construction equipment no longer have the infiltration capacity present before development. Natural drainage ways are “improved” with free draining structures such as curb/gutter systems and storm sewers. The result is that a greater volume of rainfall runs off from the developed site. Furthermore, this runoff occurs more quickly resulting in greater peak discharges and volumes.

One measure of the impact of development is the percentage of impervious cover. As the impervious cover increases, so does the rate and volume of storm water discharge. It has been noted that the threshold for urban stream stability is around 10% impervious cover (Schueler 1995).

URBAN DEVELOPMENT AND CHANNEL EROSION

Increases in stormwater runoff rate and volume associated with development have a marked influence on the geometry of stream channels. Natural channel form is controlled by the frequency and magnitude of storm events. Higher stream discharges during storm events results in higher velocities and shearing stresses along the stream bank. These higher shearing stresses cause erosion resulting in the transport of greater amounts of sediment downstream. Large, infrequent events may cause a great amount of erosion but smaller events are usually more significant because, over time, more sediment is transported due to the higher frequency of the event. The discharge that is most effective at doing work that results in the average morphological characteristics of the channel is referred to as the bankfull discharge (Dunne and Leopold 1978). Many studies have indicated that this discharge has a frequency of about once every 1.5 years (Rosgen 1996). The impact from development is that this bankfull discharge occurs more frequently and with longer durations, significantly altering the stream.

Streams that are exposed to erosive flows more frequently and for longer periods of time respond by increasing their ability to convey water. This usually results in an enlargement of the cross sectional area of flow. The flow area is increased by either widening, down cutting, or both. This results in channel instability, stream bank erosion and habitat degradation (Schueler 1996).

EROSION POTENTIAL

The critical issue for channel stability is not the magnitude of the shear stresses, but the amount of erosive work done by the shear stresses. The erosive work is a function of both shearing stress and time. This can be quantified using the Erosion Potential.

The Erosion Potential (Ep) is a measure of the increase in erosive work associated with a change in the flood hydrograph due to development. The erosive work is calculated by taking the shear stress multiplied by the velocity in excess of some critical velocity and integrating it over the duration of the storm (FTC&H 2006, 2008). Ep is then defined as the post-development erosive work divided by the pre-development erosive work. (See Appendix 2 for a development of the equation for Erosion Potential). A value of 1 or less implies no negative impact associated with the new development. Values larger than 1 are an indicator of potential stream instability.

EVALUATION

The evaluation conducted during this study included a review and comparison of storm water management approaches for stream protection to demonstrate the relative effectiveness of an extended detention approach with appropriate criteria. A case study was used to demonstrate numerically the effectiveness of each approach in terms of the Erosion Potential.

A COMPARISON OF APPROACHES TO MITIGATE THE IMPACT OF DEVELOPMENT ON CHANNEL EROSION

Various approaches have been used by engineers and policy makers over the years to mitigate the impact of development on channel erosion. The three basic approaches to stream protection are reviewed in this paper:

- Detention for 2-year peak discharge control, including one variation.
- Extended detention, including three variations.
- LID-based retention for 2-year volume control.

Variations are evaluated based on their application in the Lower Grand River Watershed and in Michigan.

DETENTION

An early approach to stream protection was to provide it as part of the storm water detention typically required in new developments for flood control. As early as 1968, peak rate control by detention of the 1.5- to 2-year event was recognized as a way to mitigate the effect of urbanization on streams (Leopold 1968). Stream protection control took the form of a dual-stage outlet from the detention basin to hold the runoff from a 2-year storm event after development to the predevelopment rate. The 2-year event was considered to be the upper limit of bankfull discharge. By controlling the 2-year event, it was assumed that control would be effective for higher frequency events as well. This approach maintained peak bank shearing stress at predevelopment levels, but because a larger volume of water was being released these peak discharges were held at a high level for a longer period of time, thereby increasing the erosive potential of the discharge. In the end, the detention approach is not at all sufficient to protect streams from accelerated erosion due to increased imperviousness and subsequent runoff volumes.

YIELD METHOD

The Yield Method was suggested by the MDEQ (Fongers and Fultcher 2002, Fongers 2004) as an improvement on the 2-year peak discharge approach described above. The watershed yield is defined as the peak discharge for a particular event divided by the area of the watershed or sub-watershed. The yield method specifies the peak detention basin release rate for a 2-year rainfall event at the pre-development watershed yield value for that same event. So, instead of holding the post-development 2-year discharges for the site to pre-development levels for the site they are held to pre-development levels for the larger watershed. Since the watershed yield decreases as the size of the watershed increases, it is necessary to define the controlling watershed before a yield value can be specified. This can be a somewhat arbitrary decision. Furthermore, if the controlling watershed is small relative to the size of the development this approach is reduced to the 2-year peak discharge approach defined above. While the calculation of watershed yield is very useful for analysis of hydrologic impacts by subwatershed, it does not directly translate into a practical design criteria methodology.

EXTENDED DETENTION

A second approach is the use of extended detention. Extended detention restricts the outflow from a detention basin to a rate lower than that of the 2-year pre-developed peak discharge. This allows the larger, post development volume to be released at rates well below the rates that contribute to stream erosion. Several variations exist, each using different design criteria for specifying the peak release rate and the amount of detention storage required. Three of these are discussed in the following paragraphs.

MARYLAND METHOD

The Center for Watershed Protection located in Prince George’s County, Maryland (PGCM) and the State of Maryland have been forerunners in innovative storm water management. In their landmark Stormwater Design Manual (MDE 2000) the State of Maryland took an extended detention approach to provide for stream protection from site developments. They decided to focus on very slow release of more frequent events allowing larger, less frequent events to quickly pass through the detention basin. As a result, runoff from the more common events is released so slowly that no stream erosion occurs. When larger events do occur, the peaks pass through the detention basin quickly leaving less time for the high shear stresses to do much damage. Their criterion is to design the detention to hold a 1-year event in storage for a 24-hour period. Technically this means that the inflow and outflow hydrograph centroids are separated by at least 24 hours.

This method differs from the yield method in that the discharge criterion is based on post-development condition of the site instead of the pre-development condition of the larger watershed. This allows the method to be implemented without having to study the larger watershed and it makes it a more uniform standard over a larger geographic region. The details of implementation of this method can be found in Appendix D.11 of the Maryland Stormwater Design Manual (MDE 2000).

SIMPLIFIED IMPERVIOUS AREA METHOD (0.05/5000)

This method is currently in use in Ottawa, Allegan, Montcalm, Mecosta, Oceana, Van Buren, and Newaygo Counties. It is essentially a simplification of the Maryland method. The primary differences are that it uses a 1.5-year event instead of a 1-year event, and it assumes that the pervious areas of the site have average runoff CN associated with soils of average infiltration characteristics (between Hydrologic Soil Group [HSG] B and C). The criteria was determined by FTC&H in 2001 by running many different simulations and calculating average conditions. The criteria states that the peak detention release rate will be 0.05 cfs per impervious acre and the detention volume will be 5,000 cfs per impervious acre. It should also be noted that the Kent County storm water rules and model ordinance presently specify 0.05 cfs per acre (versus per *impervious* acre), which has the effect of dramatically increasing the allowable release rate for all but the most highly impervious sites. The main objection to this method is that it was designed for developments with an average hydrologic soil condition (HSG between B and C). The method includes the inherent assumption that sites with sandier soils (HSG type A) will infiltrate the runoff volume as recommended in the respective storm water criteria. If this is not the case, a more restrictive release rate would be required to meet the 1-year, 24-hour condition. Sites with heavier soils (HSG type D) would require larger detention volumes. A more universal method accounts for the types of soils present in the development, which is exactly what the CN method is designed to do.

CN METHOD

The CN method is also a simplification of the Maryland method. This is the method recommended in this paper for designing extended detention for stream protection. It was first presented in a hydrologic and hydraulic study of the Gun River Watershed in Allegan County, Michigan (FTC&H 2004). Its basis, like Maryland's, is a 24-hour detention of the 1-year rainfall event. The specific design criteria are determined by way of multiple hydrologic simulations using standard hydrologic modeling software. The technical details behind this method are described next.

This analysis uses the fact that the unit peak discharge (i.e. peak discharge per unit drainage area per inch of surface runoff) is a function of the initial abstraction divided by precipitation depth, Ia/P, and the time of concentration, Tc. In addition, there is a direct relationship between unit peak discharge and the peak detention basin outflow to inflow ratio corresponding to a 24-hour detention time and a set of assumed basin parameters. Multiple numerical simulations were used to establish these two relationships. The simulations used seven somewhat arbitrary combinations of drainage area, varying from 67 to 775 acres, and Curve Number, CN, varying from 65 to 98, which, along with a single precipitation depth value, resulted in seven Ia/P values. For each of these Ia/P combinations, several simulation runs were made with Tc values varying from 15 to 480 minutes. For each simulation, the detention basin outlet orifice diameter was adjusted to achieve the 24-hour detention time. The simulation results then give the peak detention outflow to inflow ratio as well as the detention storage volume to inflow volume ratio as functions of Ia/P and tc. These functions were then averaged over the range of Tc values since it was observed that there was little variation for a given Ia/P and the full range of tc.

Given any value of CN, the 1-year, 24-hour rainfall depth for any one of the 10 Michigan climatic zones and a unit drainage area (i.e. 1 acre), Ia/P, the runoff volume, and peak discharge can be computed. Using the relationships described above the required detention peak discharge and storage volume can be computed. The peak discharge and required storage volumes can then be plotted for a range of CN values to give the rating curve for the particular Michigan climatic zone.

Rating Curves

The rating curves to determine maximum allowable release rate and storage volume for 24-hour extended detention of the 1-year, 24-hour rainfall event are shown in Figures 1 and 2. These figures give the results for all climatic zones in Michigan. Rating curves for each individual climatic zone are provided in Appendix 1. Figure A-1 shows the 10 climatic zones. Figure A-2 through Figure A-11 are the extended detention design charts tailored to each climatic zone. These charts require calculation of the weighted average CN (including impervious areas) for the portion of the site contributing to the detention basin. The maximum 1-year release rate is then provided in units of cfs/acre. The size of the detention basin is also provided in units of ft^3/acre. Table 1 gives the climatic zones for the eight counties in the Lower Grand River Watershed.

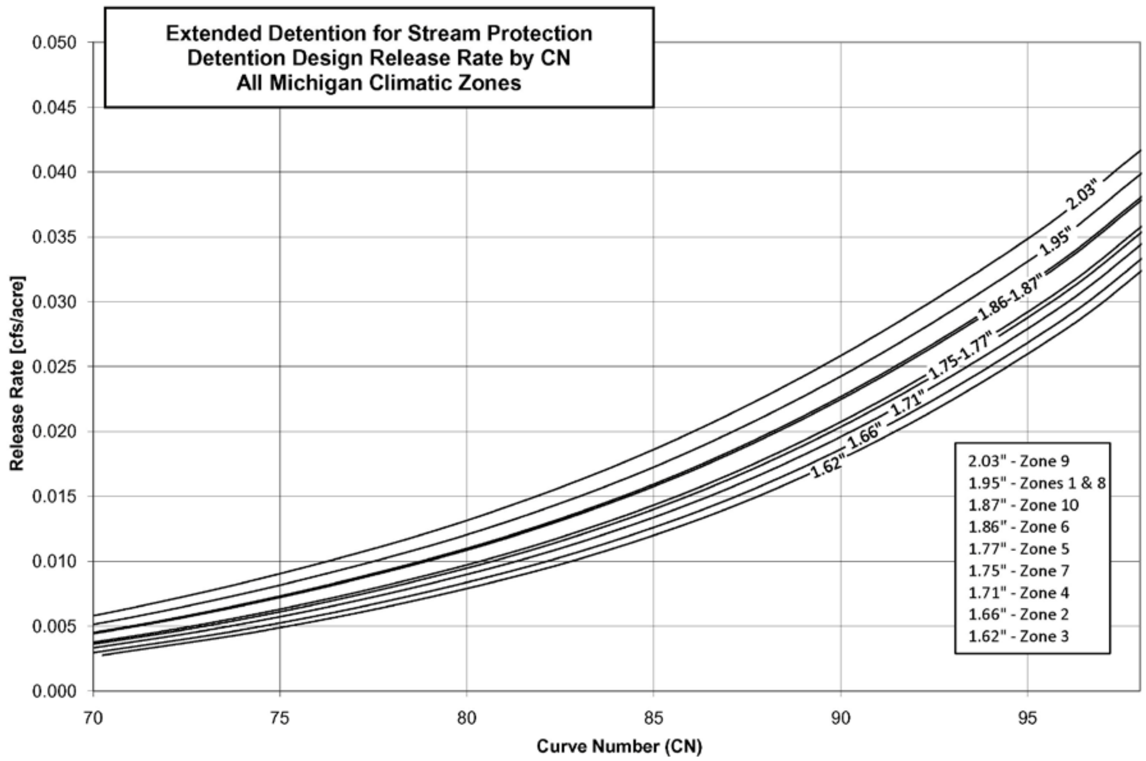

Figure 1 Extended Detention Release Rates

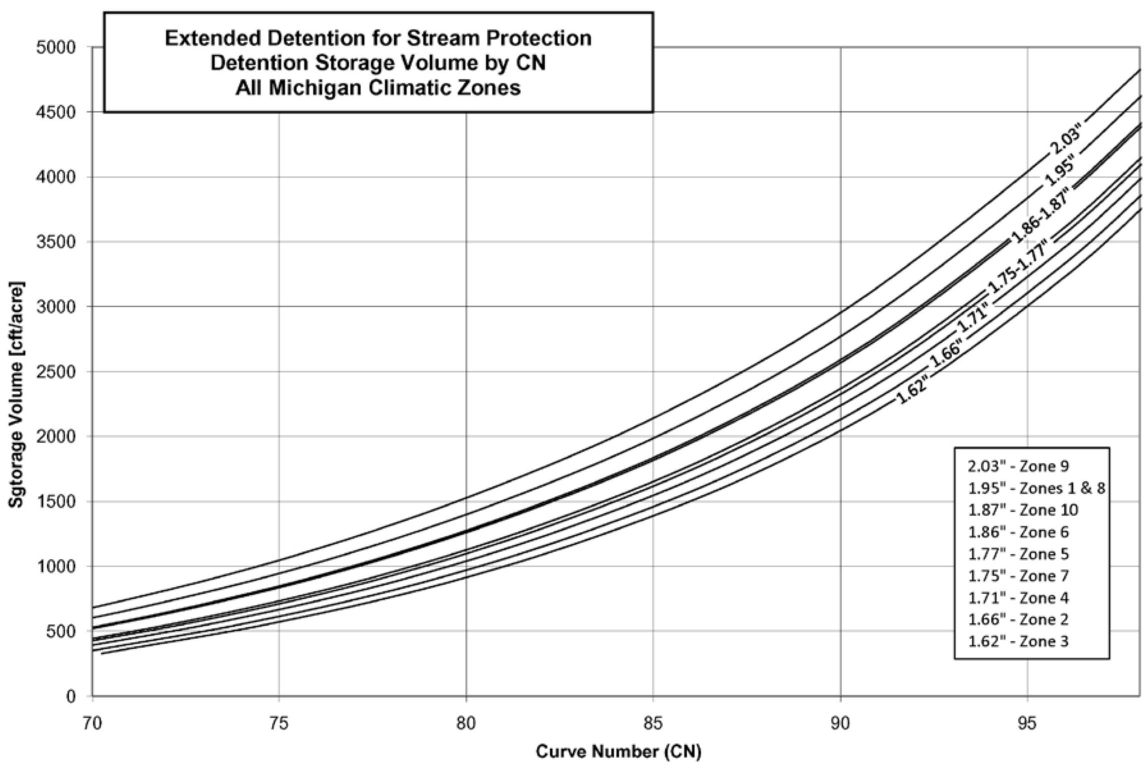

Figure 2 Extended Detention Storage Volumes

Table 1: Lower Grand River Watershed Climatic Zones

Zone	Counties
5	Muskegon, Newaygo
6	Montcalm
8	Kent, Ottawa
9	Barry, Eaton, Ionia

LID-Based Retention

The third approach to stream protection mentioned above is LID-based retention for 2-year volume control. The shortcomings of detention with 2-year peak discharge control is that a greater volume of water is discharged after development causing high velocities and subsequent shearing stresses to occur over a longer period of time. The way to solve this problem is to limit post-development runoff volumes to pre-development levels, or volume control. In other words, if a site can be designed so that there is no increase in runoff volume, it should have no negative impact on the receiving water body. Volume control can be accomplished using site level LID procedures.

LID is a method of land development that seeks to maintain or restore the natural hydrologic character of the site. LID practices allow development of a site that mimics the predevelopment site hydrology by using site design techniques that store (collect and reuse), infiltrate, intercept, evaporate and detain runoff (PGCM 1999). Use of these techniques helps to reduce off-site runoff and ensure adequate groundwater recharge. Various LID management practices include green roofs, infiltration trenches, rain gardens, open swales instead of storm sewers, and porous pavement. The goal of storm water management practices for new developments should be to limit and then retain as much of the increased runoff volume as possible."Low Impact Development Manual for Michigan: A Design Guide for Implementers and Reviewers" includes a recommended volume control for stream protection, which seeks to maintain pre-settlement runoff conditions for all storms up to the 2-year, 24-hour event.

It may not always be possible to retain all of the increased runoff volume associated with a new development. If this is the case, extended detention using the CN method (as described above) may be used separately or in combination with volume control.

CASE STUDY

A case study is used to better illustrate the three basic approaches to stream protection and their effect on channel erosional processes. Five scenarios were evaluated in the case study:

- Pre-development

- Post-development with no storm water management control
- Post-development with detention for 2-year peak discharge control
- Post-development with extended detention of the 1-year volume using the CN method
- Post-development with LID-based retention for 2-year volume control

Although separate analysis was completed for several watersheds (Gun River, Anchor Bay and Rabbit River) using actual subcatchment and downstream river reach data, a hypothetical case is presented here to compare results between the three storm water management approaches.

Site details are as follows:

- Site area = 40 acres
- Soils are predominately in HSG C
- Pre-development land use is Meadow resulting in CN=71
- Pre-development time of concentration is 45 minutes.
- Post-development imperviousness = 25%
- Post-development pervious land use is Open (good condition) for a pervious CN=74
- Post-development time of concentration is 30 minutes.

The runoff volume from the site can be calculated using:

$$A\frac{\left(P-0.2\left(\frac{1000}{CN}-10\right)\right)^2}{P+0.8\left(\frac{1000}{CN}-10)\right)}$$

where *A* is the drainage area, *P* is the precipitation depth in inches, and *CN* is the runoff Curve Number.

PRE- AND POST-DEVELOPMENT RESULTS

For a 1-year precipitation event (1.95 inches in Kent County), this formula (after units conversion) gives a value of 0.82 ac-ft for the pre-development condition and 2.25 ac-ft for the post-development condition. The 2-year runoff volumes (2.37 inches of rain) are 1.43 and 3.13 ac-ft respectively for the pre- and post-development conditions. Figure 3 shows the pre- and post-development hydrographs for the 2-year event. Note that the peak discharge increases from 8.52 cfs to 25.3 cfs.

As mentioned earlier, the Ep is a measure of the erosive impact associated with a change in the flood hydrographs. To calculate an Ep value, some assumptions are needed about the receiving stream in this case study.

- The stream carries flows from the site only (no off-site contributions).

- The stream has a rectangular cross section and is at bankfull for the pre-development 2-year storm.
- It has a slope of 0.1%, a Manning's n of 0.35, and a width of 3.7 feet.
- It is assumed that erosive velocities start when the depth reached 50% of the bankfull depth.

Primarily because of the higher velocities, Ep for the 2-year event with no discharge controls is 3.0. Ep for the 1-year event is 10.3. Both are well above the neutral value of 1. All of the Ep results are summarized in Table 2.

DETENTION RESULTS

The 2-year peak discharge control approach seeks to match the pre-development 2-year peak discharge with the same value under post-development conditions. A detention pond was designed to do this. The pond has side slopes of 4:1, a peak depth of 4 feet and volume of 1.04 ac-ft. Figure 4 shows the results. The detention basin peak discharge matches the pre-development condition of 8.52 cfs. But, the duration of high velocity flows is much longer than for the pre-development case. The calculated Ep for this case is 3.0, no different than no discharge controls at all. Figure 5 shows the results when a basin designed under the 2-year control approach experiences a 1-year rainfall event. Note that now the peak detention basin discharge is above the peak pre-development discharge for this event. Likewise, the Ep for this case is calculated as 8.3, well above the neutral value of 1 and only slightly less than no discharge controls at all.

EXTENDED DETENTION RESULTS

Extended detention based on the CN method seeks to detain the 1-year rainfall event for a 24-hour period. We find the detention basin parameters using Figure A-9 (for Climatic Zone 8). The average CN for the developed site is $0.25(98)+0.75(74)=80$. From Figure A-9, the peak discharge rate is 0.012 cfs/ac or 0.48 cfs for the 40 acre site. The detention basin size is 1400 ft^3/ac or 56,000 ft^3 or 1.28 ac-ft. The basin was designed for a peak depth of 4 feet during the 1-year event. Figure 6 shows the result for a 1-year rain event. The peak discharges are now well below the level that would cause erosion resulting in an Ep of zero. The centroid of the inflow hydrograph (labeled "Developed without controls") is at 12.75 hours. The centroid of the detention basin outflow hydrograph is at 42.10 hours resulting in a 29 hour detention time.

If a larger rain event occurs, inflows in excess of the one-year rate will pass through an overflow weir or a second level of basin control. Assuming that there is a second orifice located at the 4-foot elevation with a much larger (100 times) area, the resulting hydrographs for the 2-year event are shown in Figure 7. Note that for a short period the discharge from the detention basin is elevated above the slow release rate. The Ep associated with this case is 0.2, well below the neutral value of 1.

LID-BASED RETENTION RESULTS

Volume control is a better approach to managing the negative impacts of development. Here the goal is to develop a site so that the timing and volume of runoff match from pre-development to post-development. In our case study the post-development time of concentration is increased to the pre-development level of 45 minutes. This is done using measures such as replacing storm drains with swales and by increasing the flow length. The 2-year runoff volume is kept at the predevelopment level using retention practices. This means that 3.13 – 1.43 = 1.70 ac-ft of retention is needed. The resulting hydrologic model assumes that retention practices will take all of the runoff until they are full. Once full, runoff will proceed at post-development rates (PGCM 2000). Figure 8 shows the hydrographs associated with 2-year volume control during a 2-year rainfall event. Note that the resulting "Developed with retention" hydrograph mimics the pre-development hydrograph. The calculated Erosion Potential is 0.4. Figure 9 shows the result when a 1-year rainfall event occurs on a site designed for 2-year volume control. Note that very little runoff occurs from the site at all resulting in an Ep of zero.

COMBINED LID-BASED RETENTION AND EXTENDED DETENTION

In some cases it may not be possible to find enough retention storage volume on site. In this case study the retention storage was reduced from 1.7 to 1.1 ac-ft with the time of concentration remaining at 45 minutes. Figure 10 shows the results for a 2-year event. The "Developed with retention" hydrograph starts when the retention volume is full. It then follows the hydrograph that would have occurred if there were no controls. Since the retention volume is limited, it fills earlier resulting in higher peak discharges. Ep for this case is 1.4, slightly higher than the neutral value of 1. A similar result occurs for the 1-year rainfall event shown with two of the curves in Figure 11. The "Developed with retention" curve is the hydrograph that results from the limited retention volume. Again the peak discharge with limited retention exceeds the pre-development case resulting in an Ep of 1.9, again somewhat higher than the neutral value of 1.

In the case where there is not enough retention storage available, extended detention may be used as a supplement. In this example the post development runoff volume for the 1-year event is 2.25 ac-ft. This is reduced to 1.15 ac-ft by the 1.1 ac-ft of retention storage. So, the CN method detention criteria should be applied to $\frac{1.15}{2.25} = 51\%$ of the 40 acres. The result is a peak detention discharge of 0.25 cfs and a detention volume of 0.67 ac-ft. So, a detention pond with 0.67 ac-ft of storage is added to further control the runoff from this site. Figure 11 shows the results. The "Developed with retention" curve (described above) represents the excess discharge from the retention storage devices which is then routed *into* the 0.67 ac-ft detention pond. The “Developed with detention” curve is the pond discharge and the resulting outflow from the entire site. The inflow and outflow detention basin hydrograph centroids are separated by 31 hours and Ep is reduced to zero.

LIMITATIONS

It should be noted that the numerical results given here are for a hypothetical case study. The case study is primarily intended to show how these methods work. The effectiveness of the CN method and LID-based retention (as given by the Ep values listed in Table 2) are made more dramatic by the assumption that the receiving stream receives all of its flows from the developing site (i.e., no off-site contributions).

Similar hydrologic modeling of urban build-out has been completed previously in actual watersheds (Gun River, Anchor Bay, and Rabbit River). Prior analysis included evaluation of the impacts on a selection of field-measured channel reaches of varying downstream distances from the study area. Each of these studies yielded distinct conclusions for the respective watershed based on the specific stream protection criteria evaluated. However, the results of these studies directed the selection of the more effective criteria for extended detention (1-year with CN method) and retention (2-year with pre-settlement land use conditions), which were used in the numerical evaluated in the case study presented here.

Table 2: Case Study Summary

Stream Protection Approach	Storm water Management Criteria: Peak Detention Discharge for Design Event [cfs]	Storm water Management Criteria: Detention Storage Volume Required [ac-ft]	Storm water Management Criteria: Retention Storage Volume Required [ac-ft]	Interpretation of Results: Erosion Potential (Ep): 1-Year Rainfall	Interpretation of Results: Erosion Potential (Ep): 2-Year Rainfall
None	——	——	——	10.3	3.0
Detention with 2-year peak discharge control	8.52	1.04	——	8.3	3.0
Extended detention using the CN method (detain 1-year hydrograph for 24 hours)	0.48	1.28	——	0	0.2
LID-based retention with 2-year volume control	——	——	1.70	0	0.4
LID-based retention with less than 2-year volume control	——	——	1.10	1.9	1.4
Combined LID-based retention and extended detention	0.25	0.67	1.1	0	0

Note:
Ep < 1 indicates less erosion potential than existing condition (Ep = 1)
Ep > 1 indicates greater erosion potential than existing condition (Ep = 1)

CONCLUSIONS AND RECOMMENDATIONS

Developments within a watershed generally increase the amount of impervious surface resulting in a greater runoff volume and peak discharge rate. This can destabilize receiving streams by elevating bank shearing stresses to higher levels for longer durations. This paper shows that both extended detention of the 1-year frequency rainfall based on the CN approach and LID-based retention of the 2-year frequency rainfall can be effective ways to reduce the impact that development has on stream stability. Furthermore, both of these approaches are better than 2-year discharge control using detention.

The Ep is a measure of the impact of these approaches in a way that accounts for both shear stress magnitude and the duration of elevated shear stresses. Extended detention works well because the shear stresses acting on the stream banks during a flood event are kept at a low enough level that the extended duration of flood flows has no significant impact. LID-based retention works well and should be considered the better approach because it maintains the watershed's response to storms up to the channel-forming condition. The two methods can be used in combination to effectively manage storm water runoff for stream protection as illustrated by the numerical results in Table 2.

Recommendation: *Local storm water rules and ordinances for site development should require a LID-based retention approach as a first priority consistent with guidelines in the "Michigan LID Manual" and allow extended detention based on the CN method when it is shown that retention of the stream protection volume cannot wholly be achieved onsite.*

The rating curves developed here and presented in Appendix 1 are convenient tools for sizing extended detention for stream protection. These can be used for an extended-detention-only approach or for a combined LID and extended detention approach. They have been developed for all 10 climatic zones in Michigan.

Recommendation: *The rating curves for extended detention of the stream protection volume should be included in local storm water rules and ordinances.*

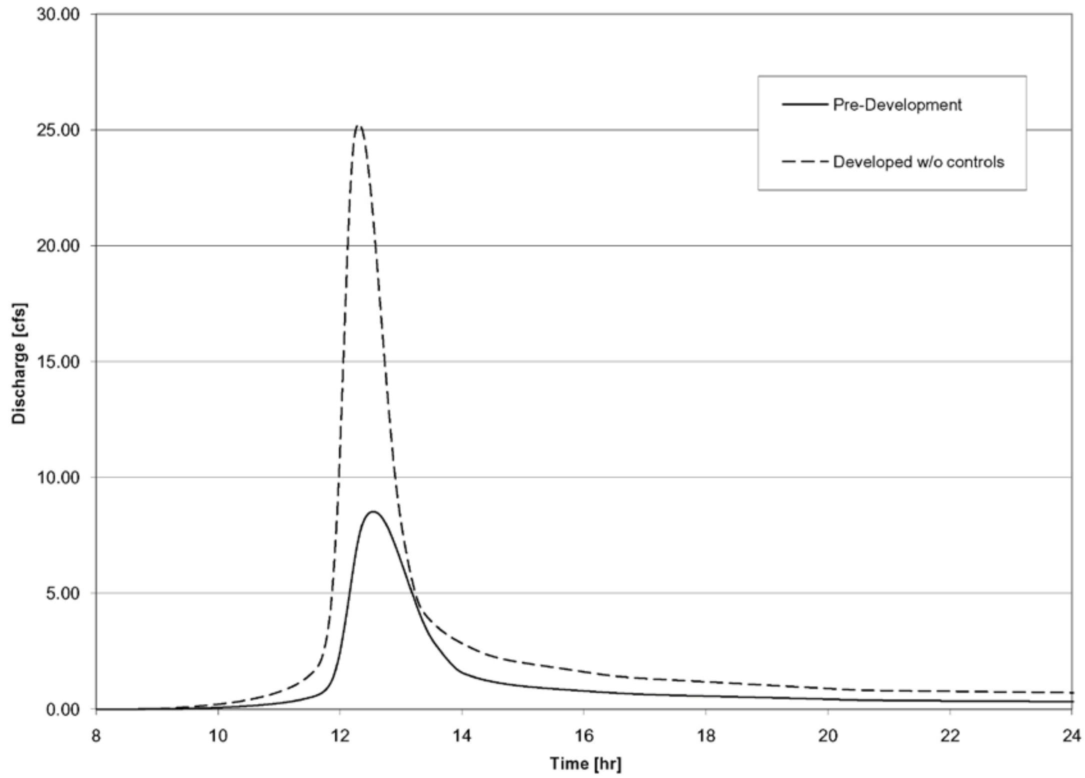

Figure 3: Pre- and Post-Development Hydrographs for 2-Year Rainfall Event

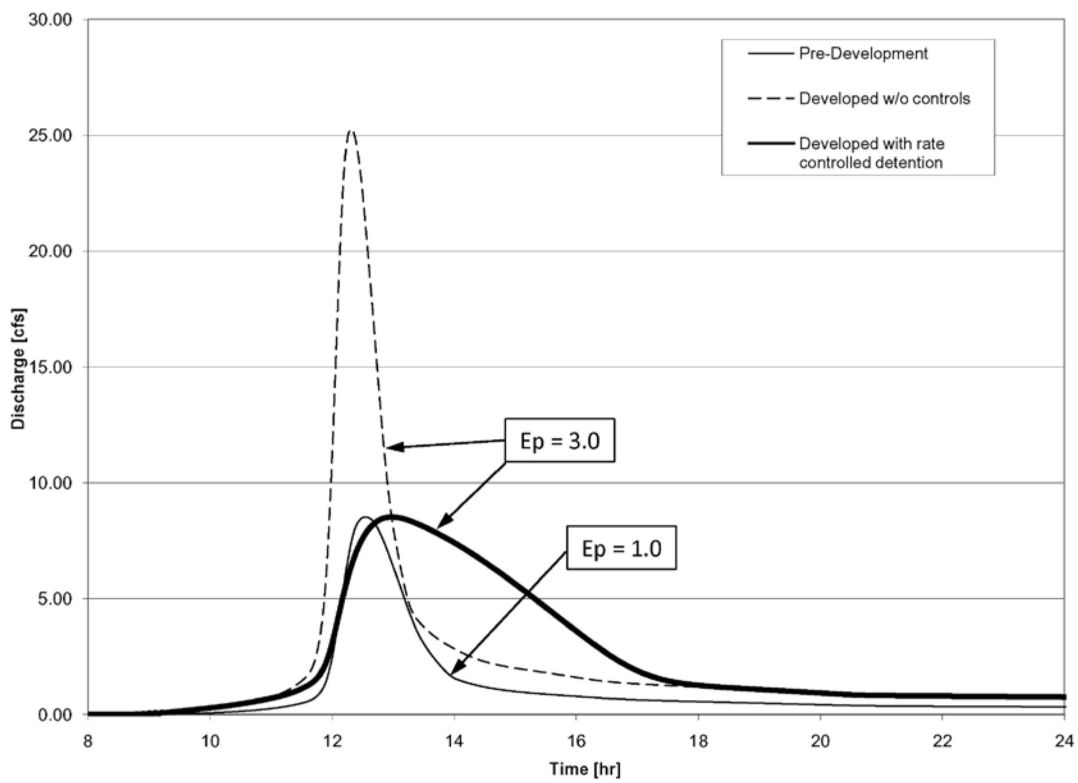

Figure 4: 2-Year Detention Control for a 2-Year Rainfall Event

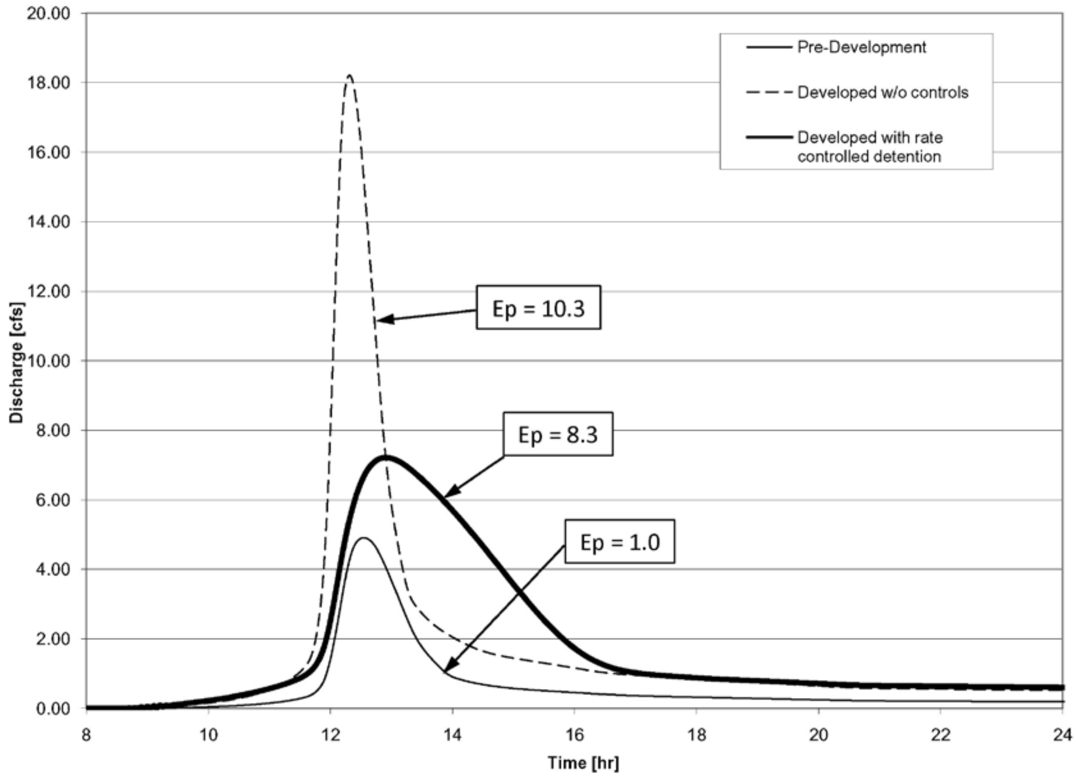

Figure 5: 2-Year Detention Control for a 1-Year Rainfall Event

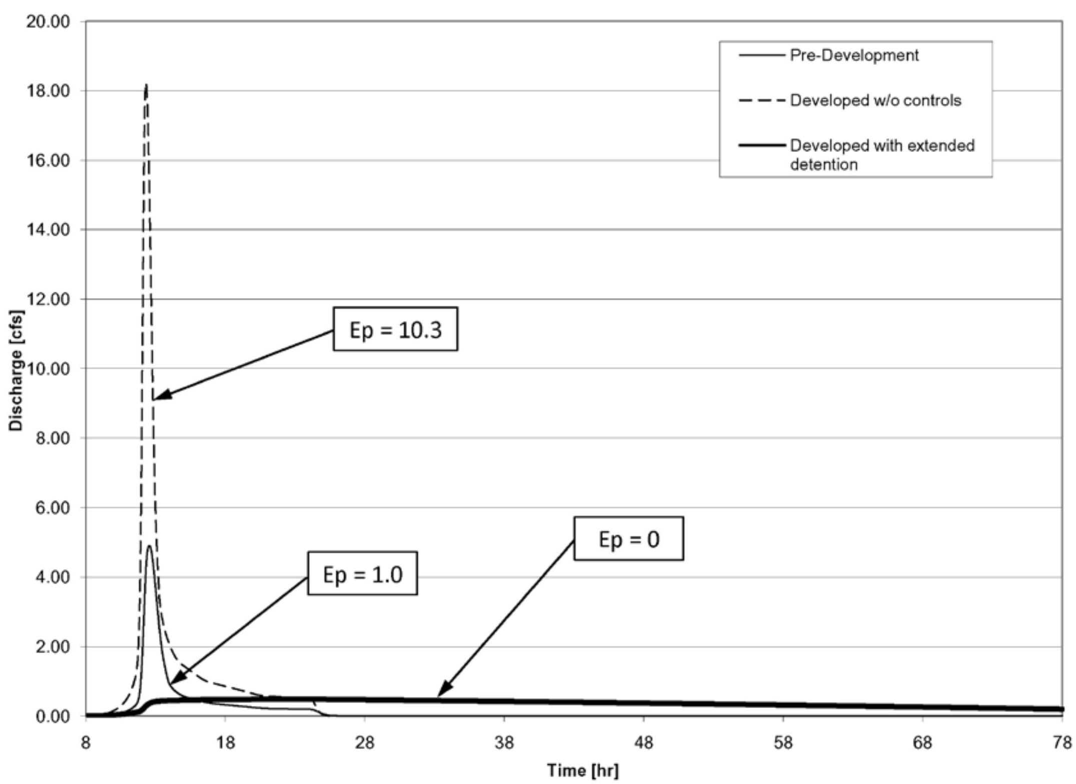

Figure 6: 1-Year Extended Detention Control for 1-Year Rain Event

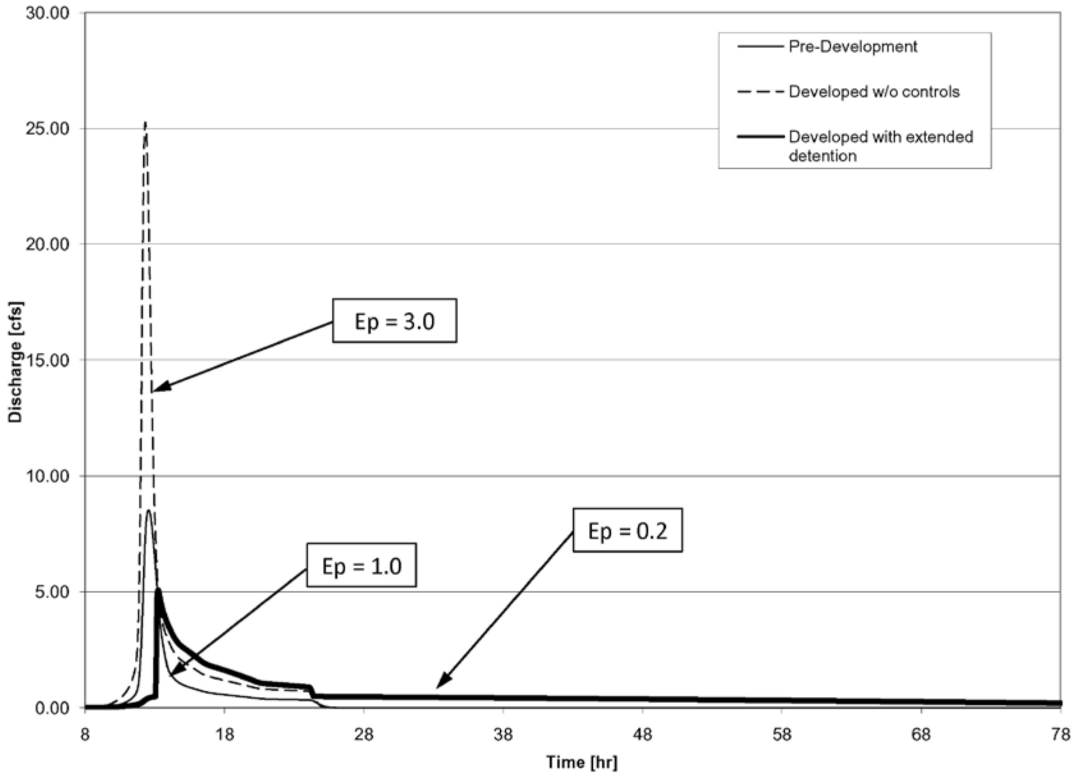

Figure 7: 1-Year Extended Detention Control for 2-Year Event

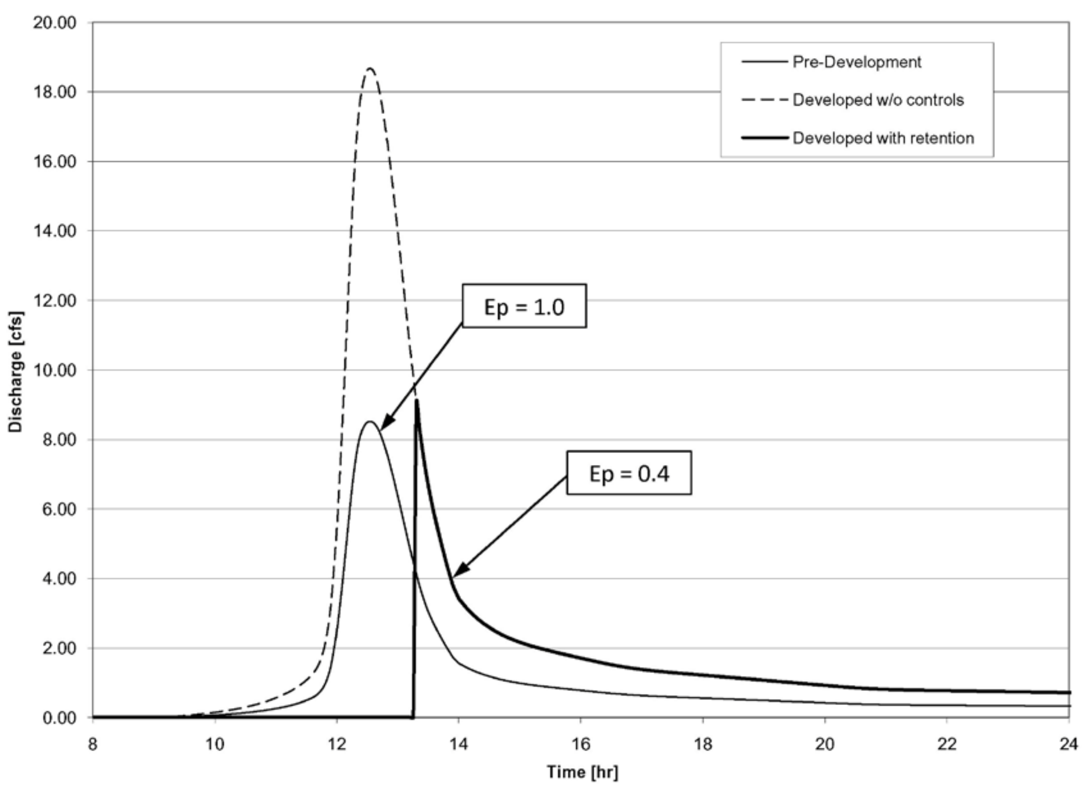

Figure 8: 2-Year Volume Control for 2-Year Rainfall Event

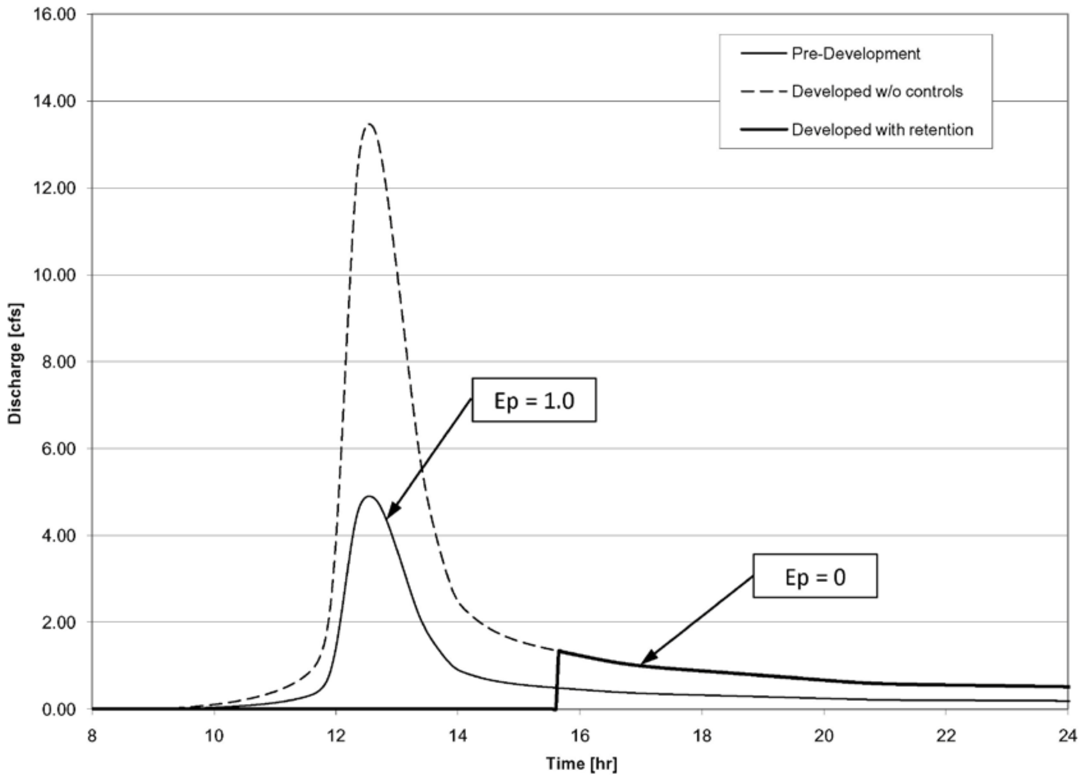

Figure 9: 2-Year Volume Control for 1-Year Rainfall Event

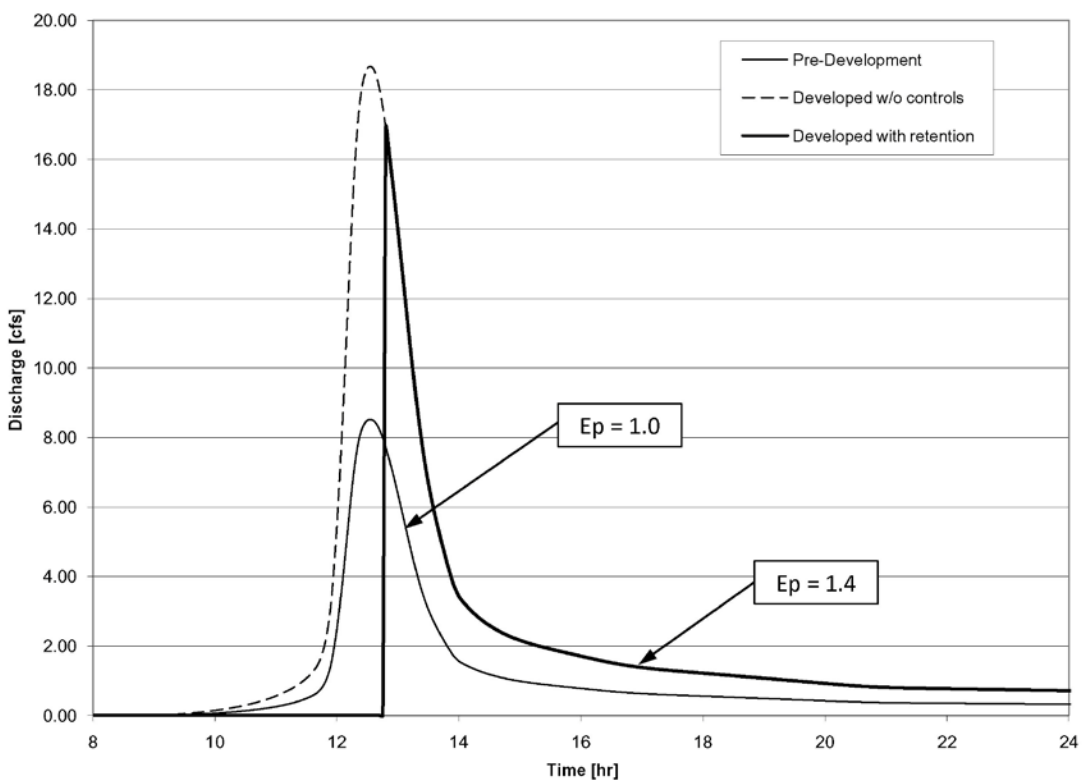

Figure 10: Limited Retention Volume Control for 2-Year Event

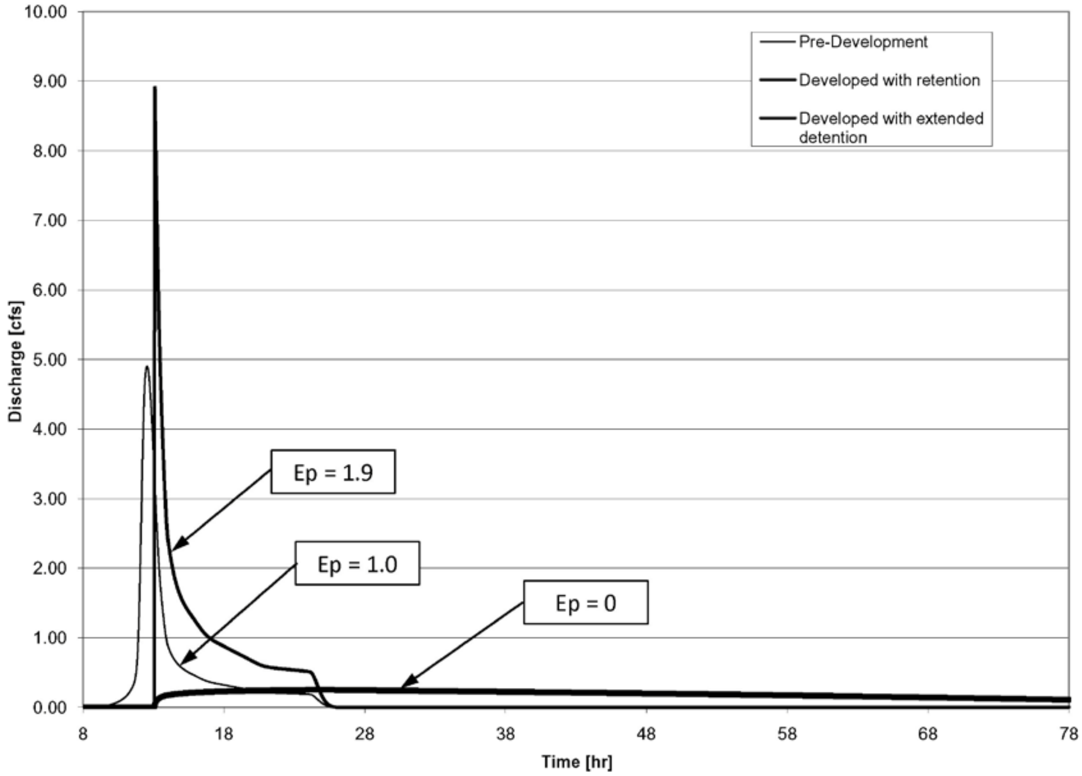

Figure 11: Both Retention and Detention Controls for 1-Year Event

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Appendix 1

Appendix 1 – CN Method Charts for Specifying Extended Detention Design Parameters

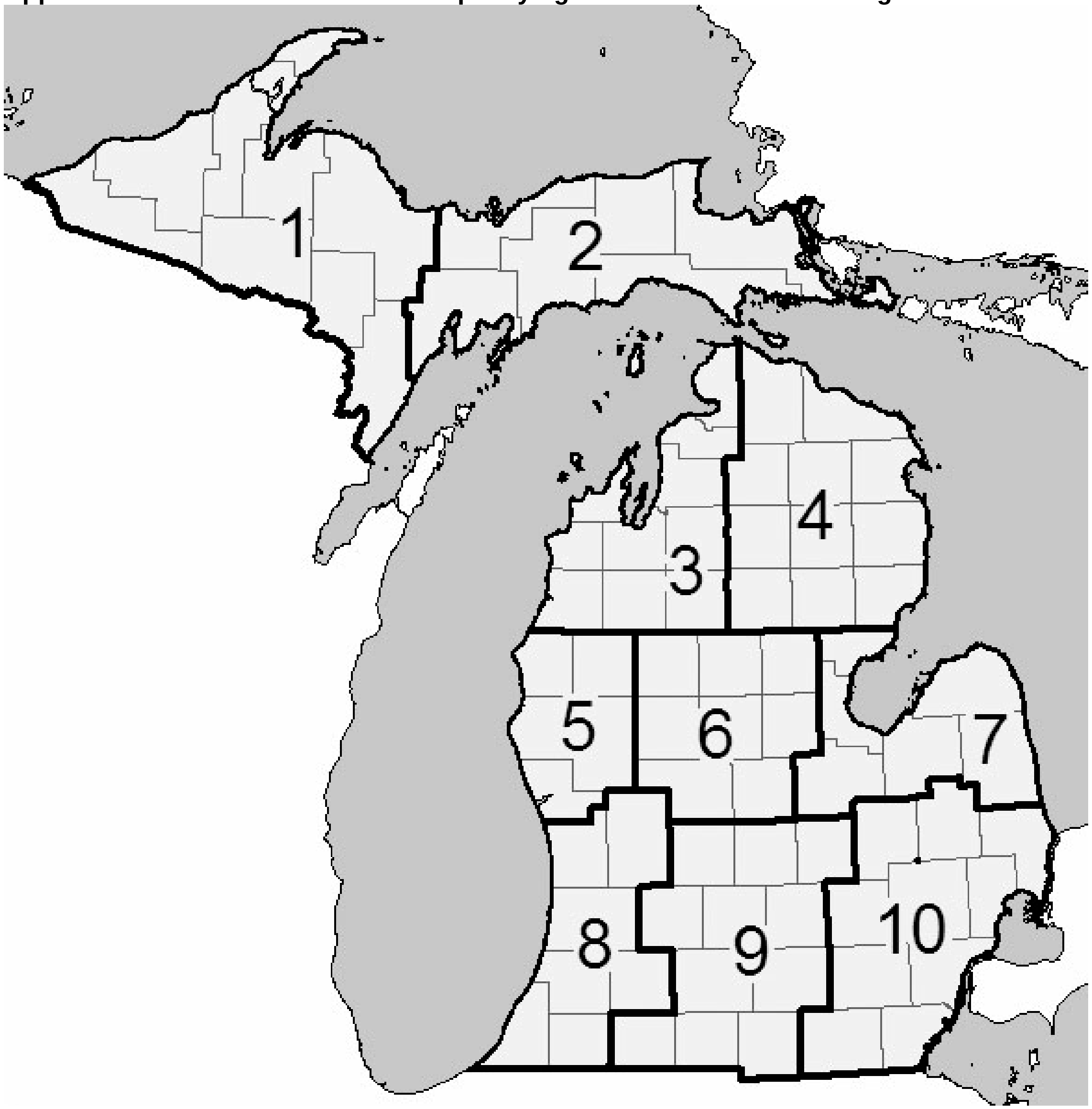

Figure A-1 Michigan Climatic Zones

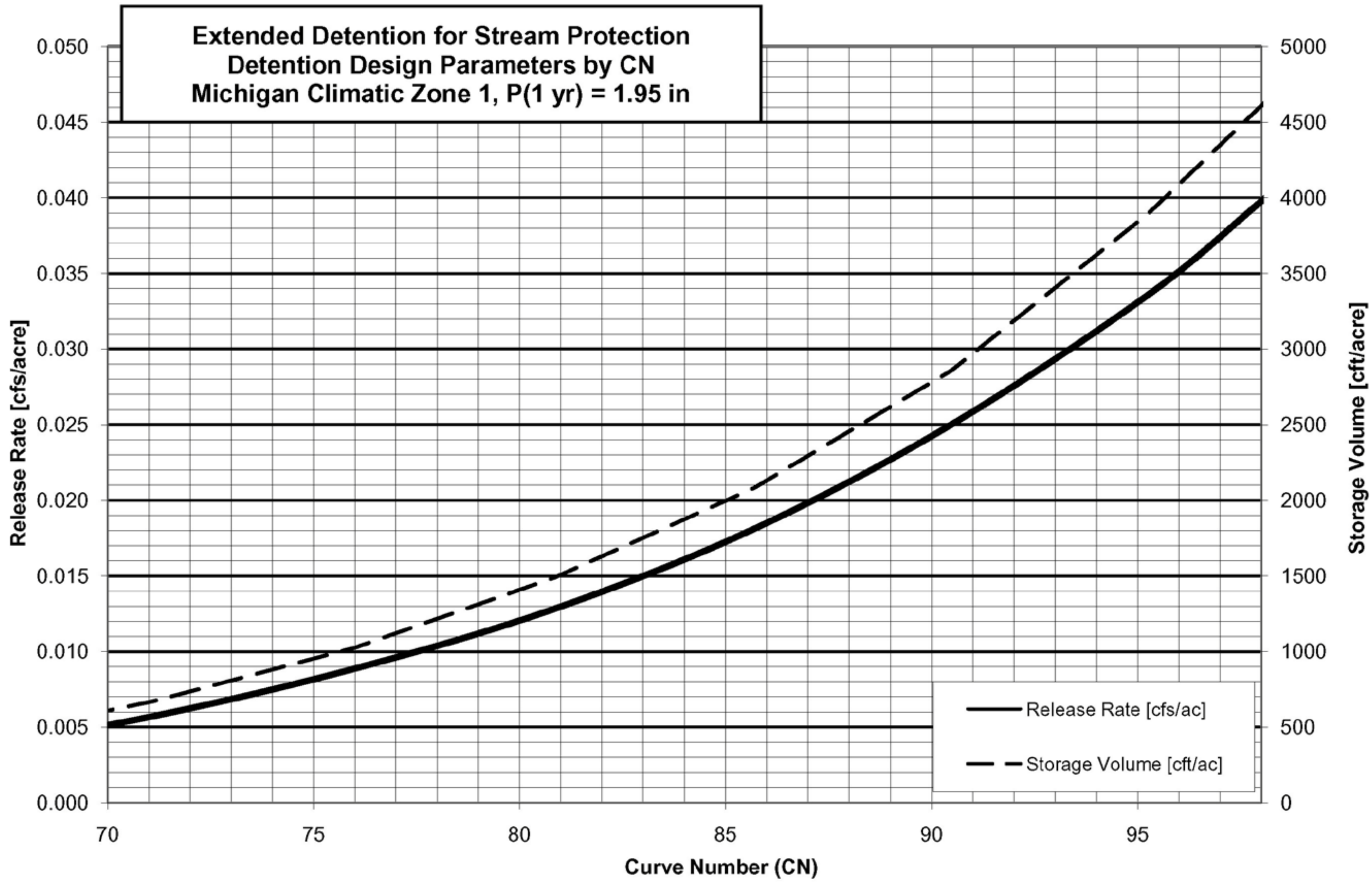

Figure A-2 Detention Rating Curve for Michigan Climatic Zone 1

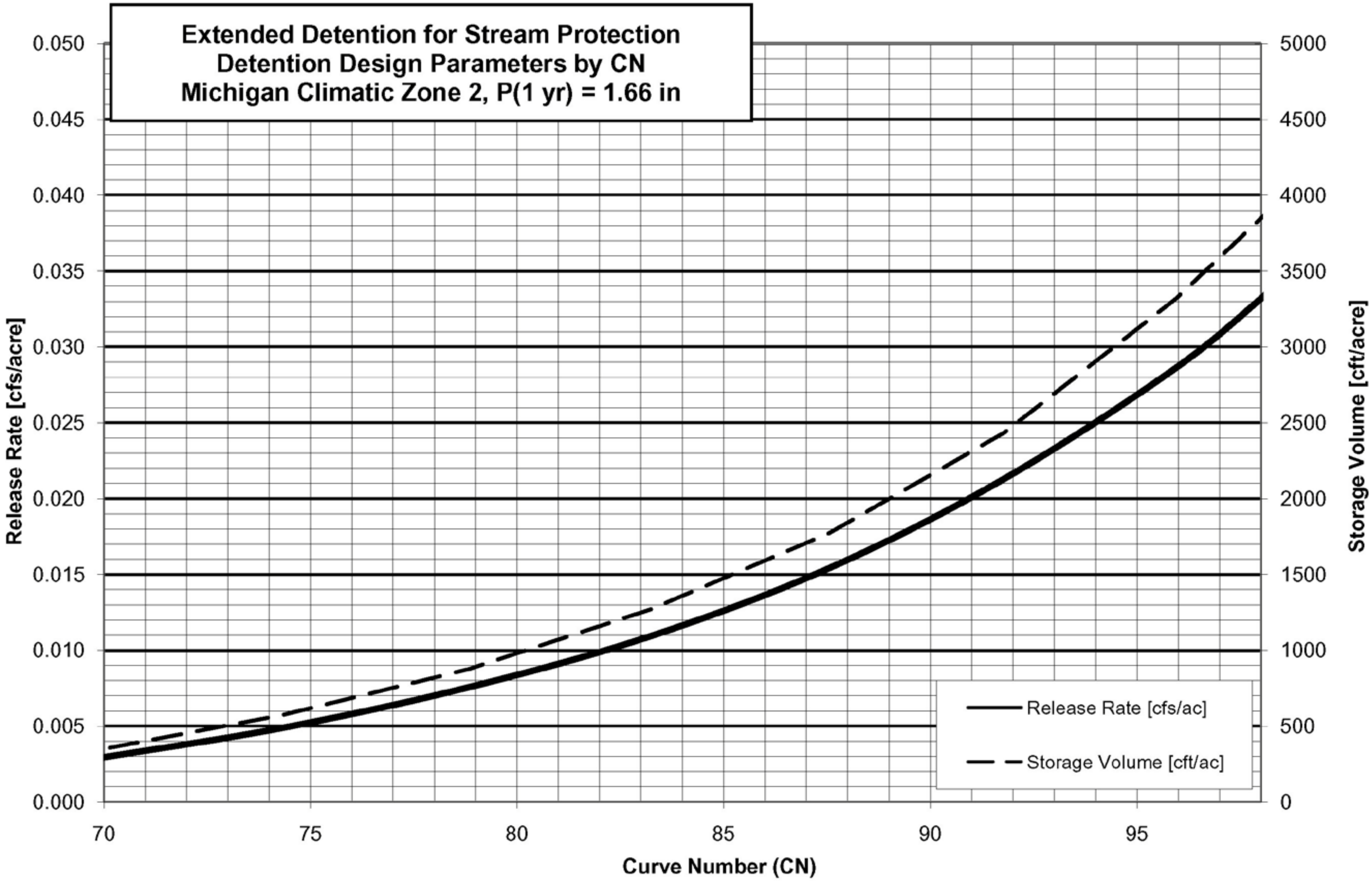

Figure A-3 Detention Rating Curve for Michigan Climatic Zone 2

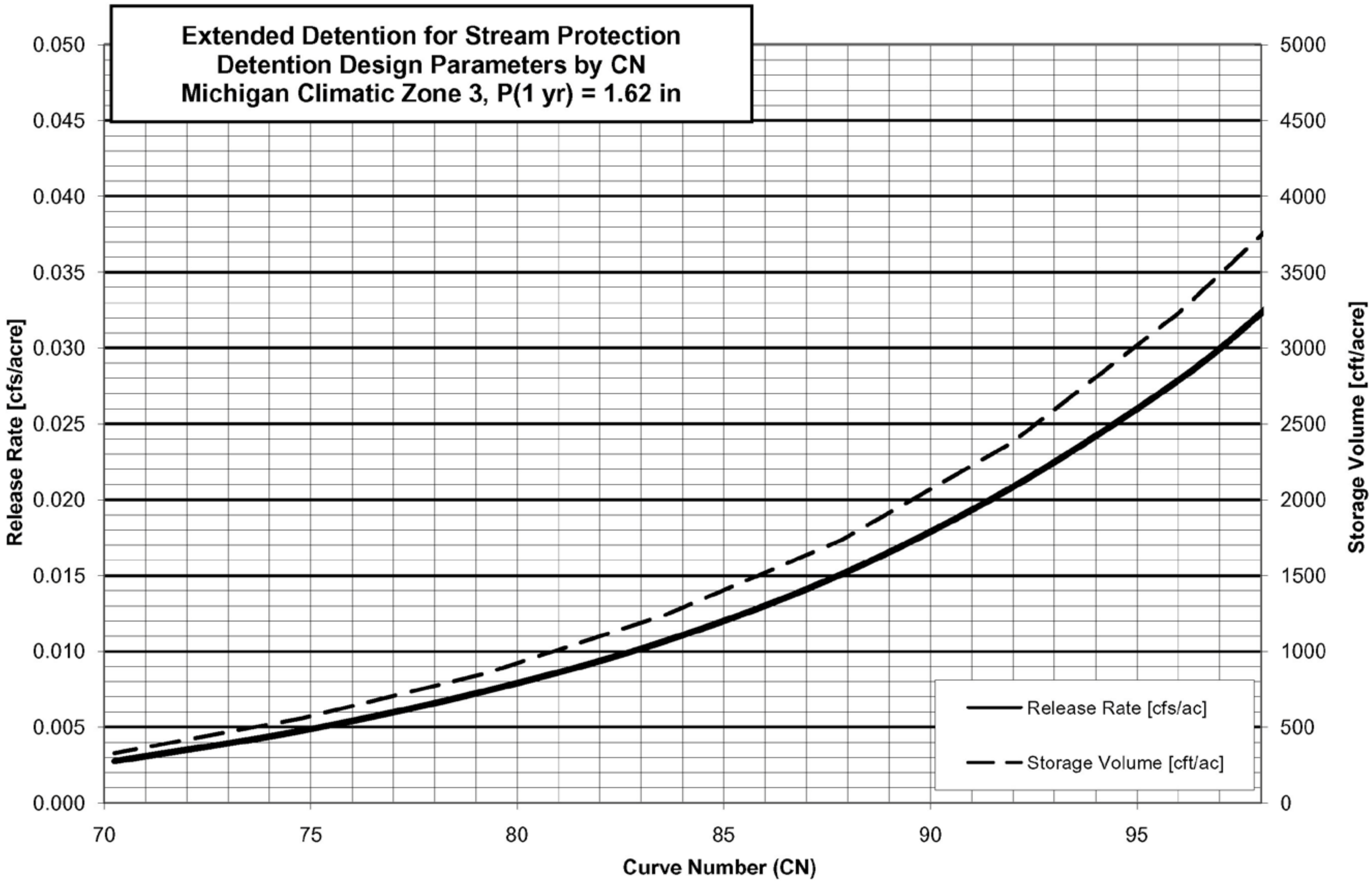

Figure A-4 Detention Rating Curve for Michigan Climatic Zone 3

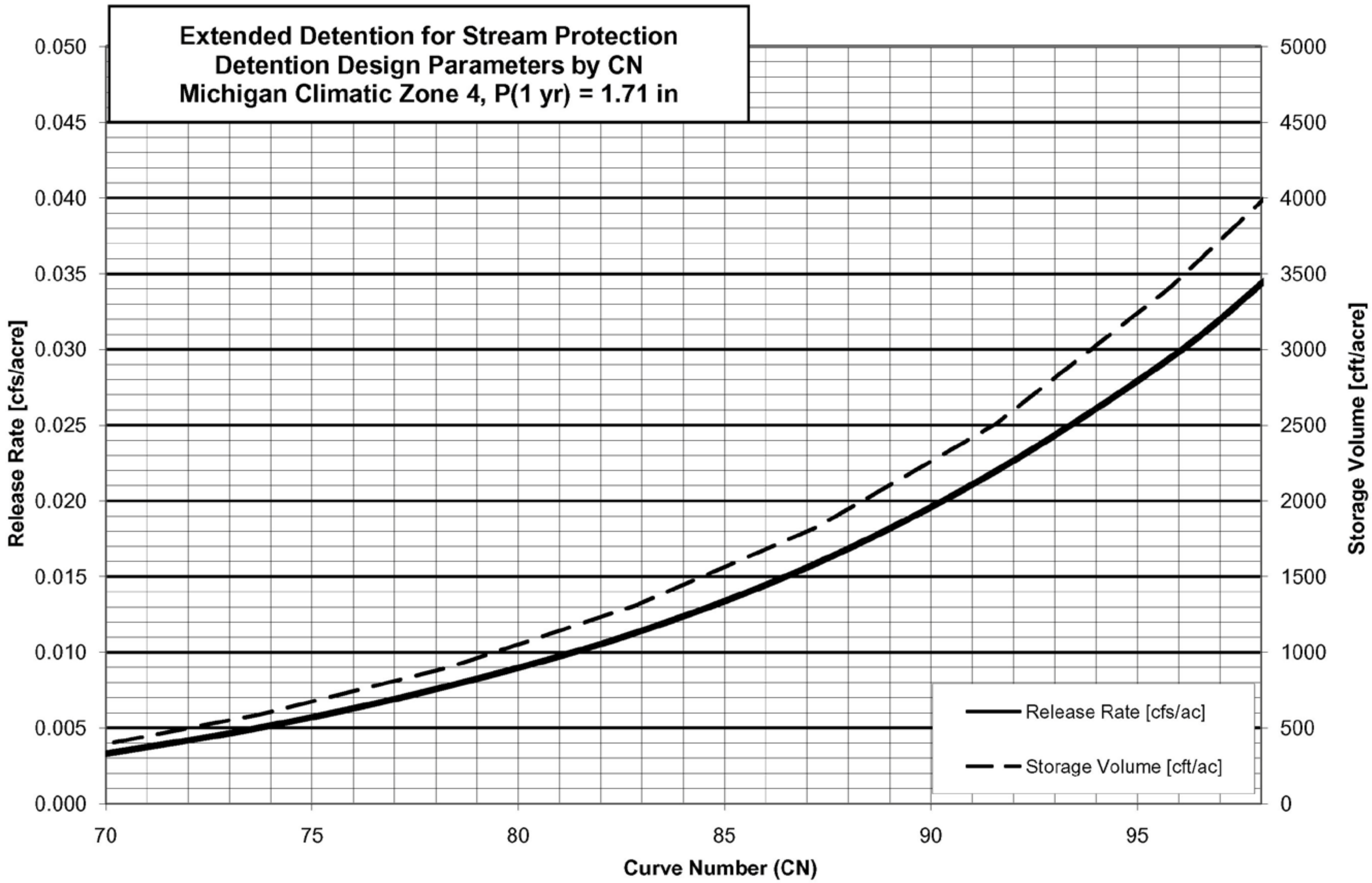

Figure A-5 Detention Rating Curve for Michigan Climatic Zone 4

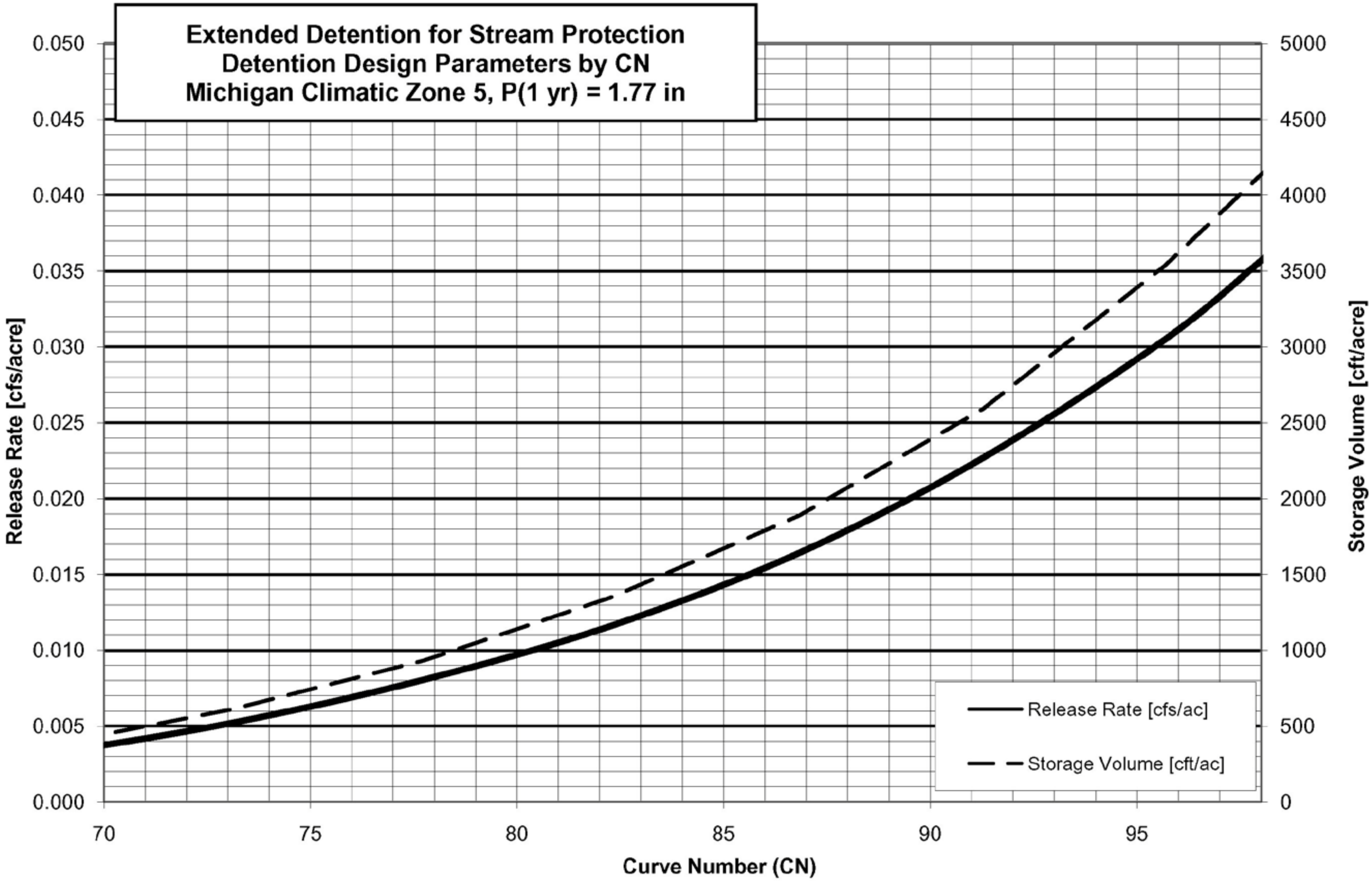

Figure A-6 Detention Rating Curve for Michigan Climatic Zone 5

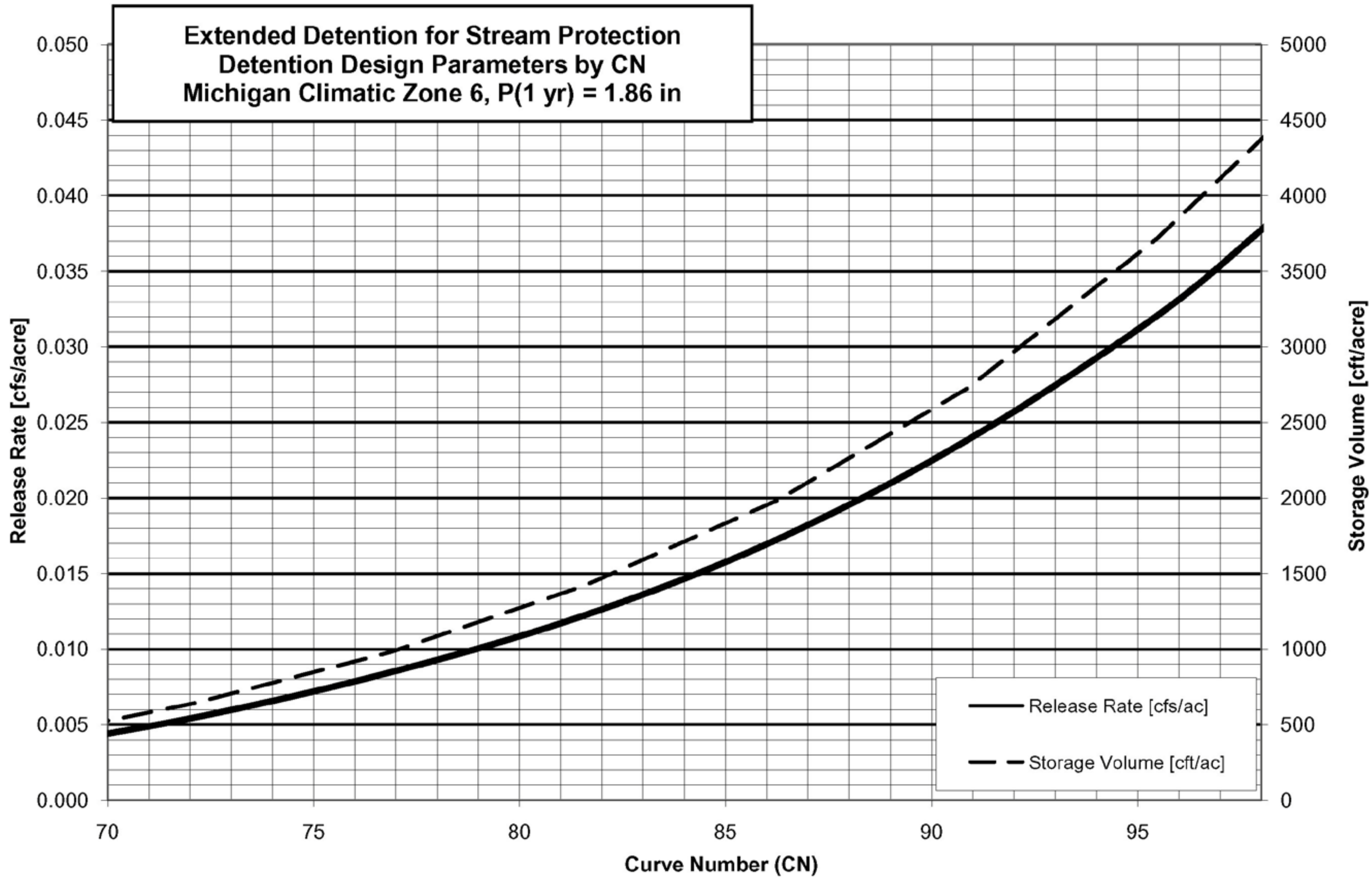

Figure A-7 Detention Rating Curve for Michigan Climatic Zone 6

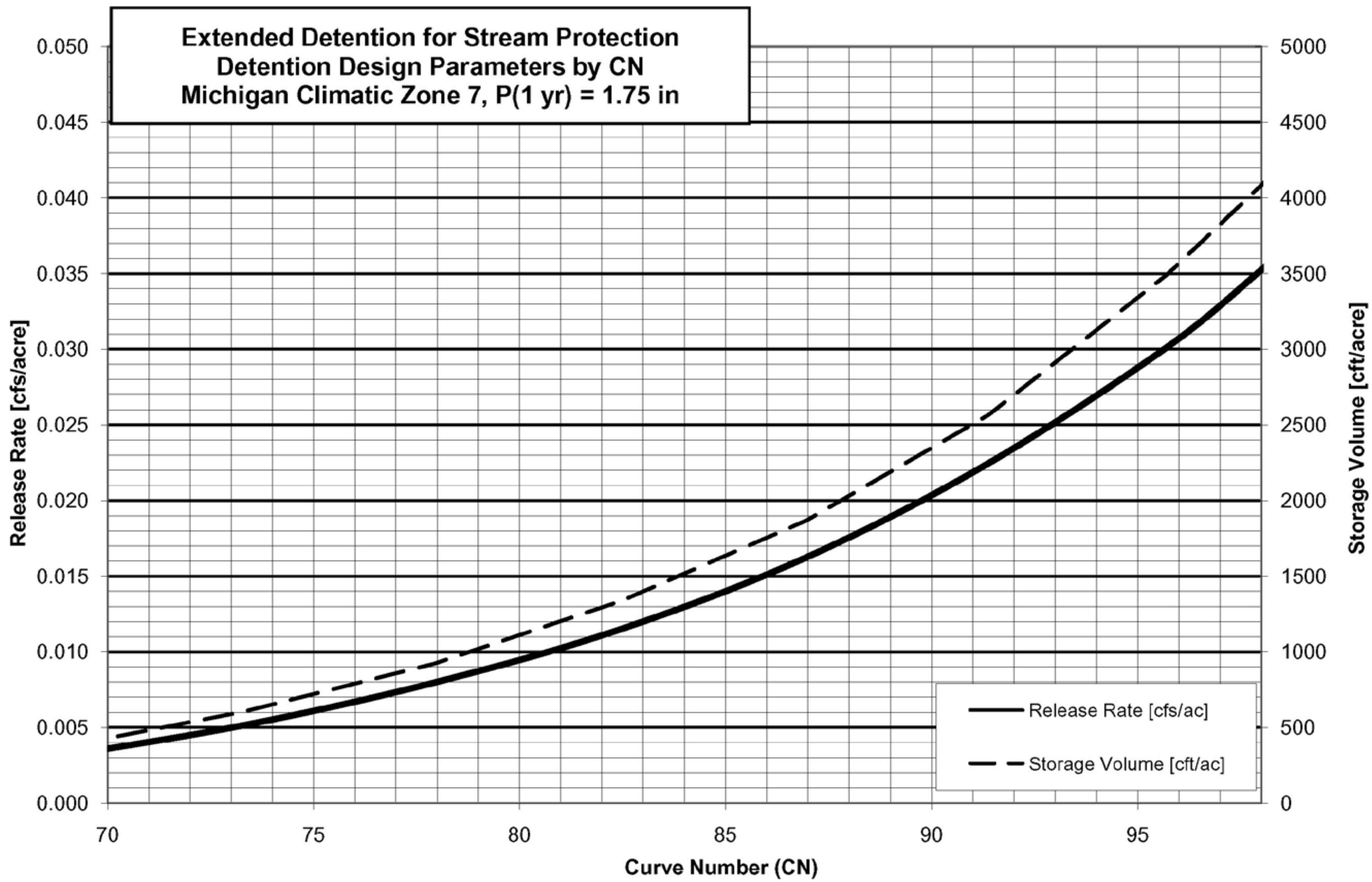

Figure A-8 Detention Rating Curve for Michigan Climatic Zone 7

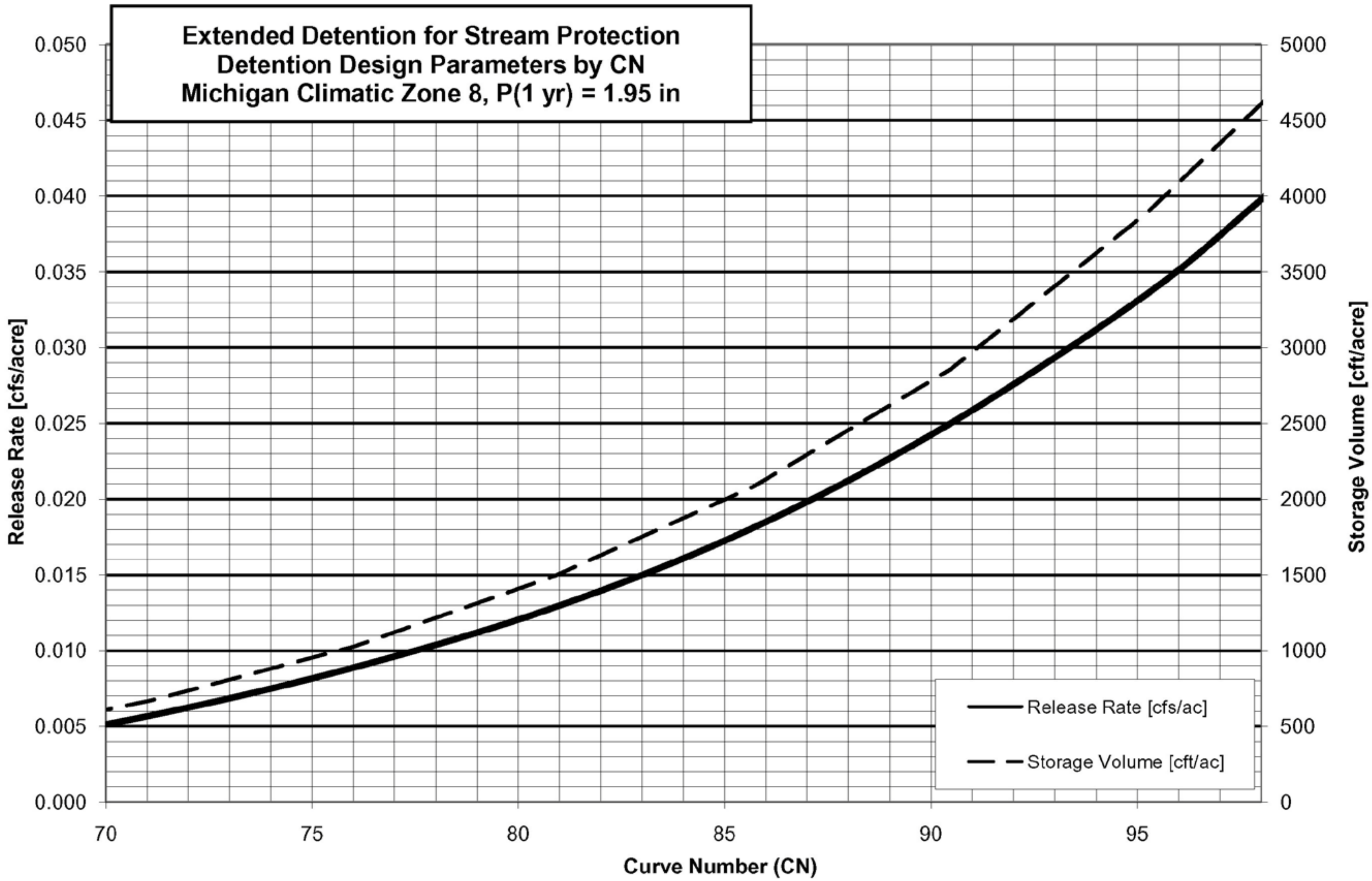

Figure A-9 Detention Rating Curve for Michigan Climatic Zone 8

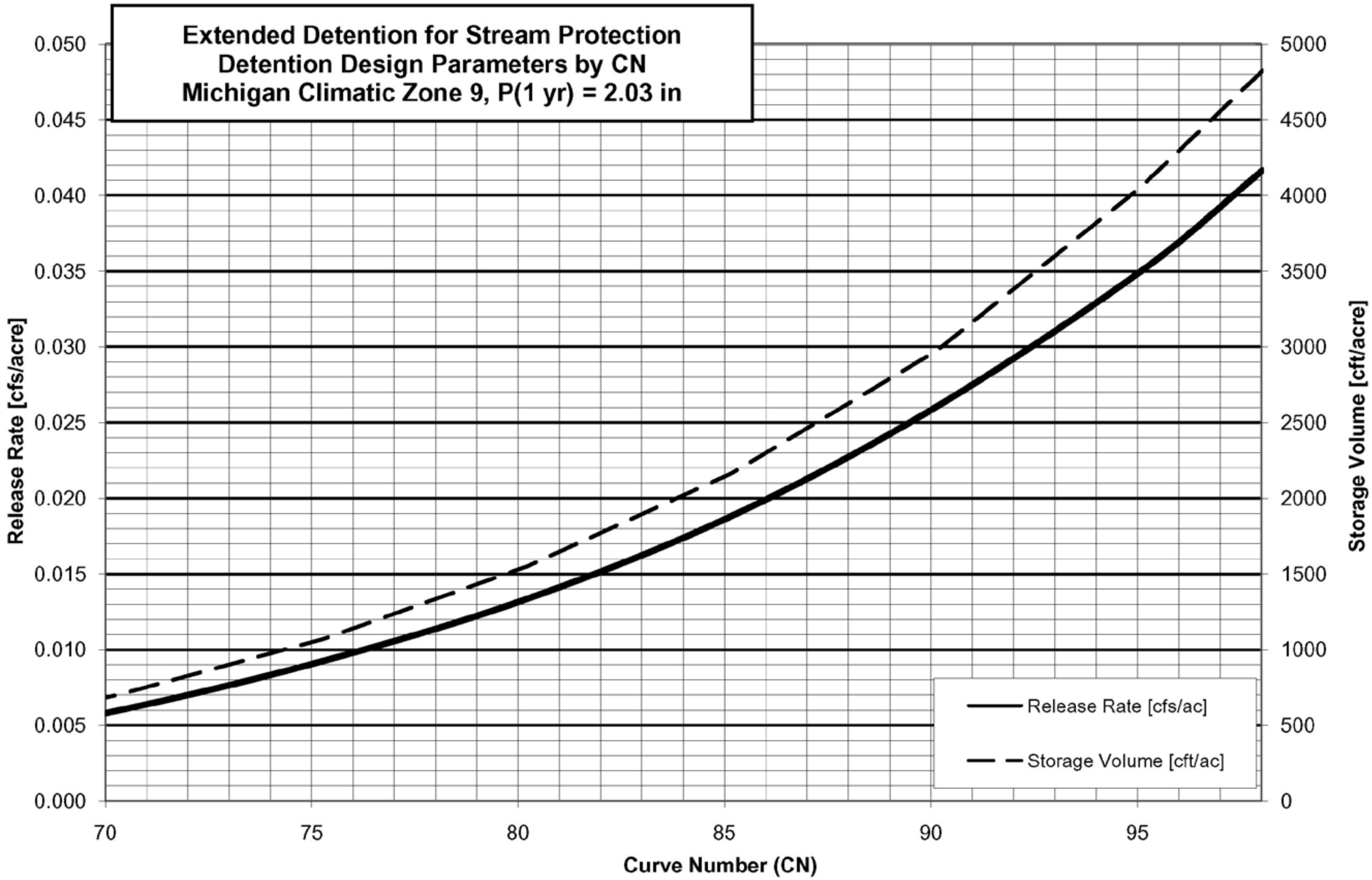

Figure A-10 Detention Rating Curve for Michigan Climatic Zone 9

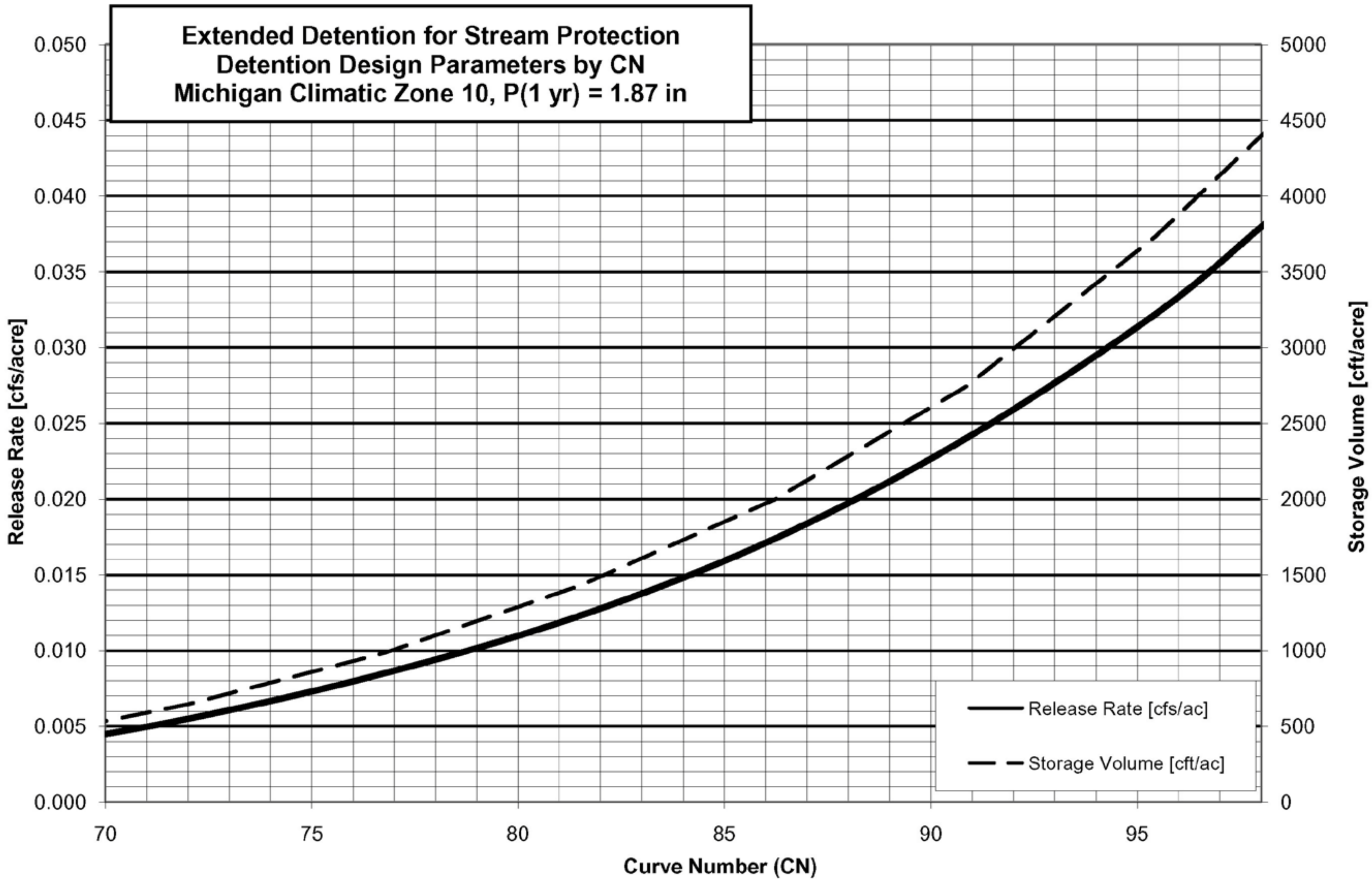

Figure A-11 Detention Rating Curve for Michigan Climatic Zone 10

Appendix 2

Appendix 2 – Erosion Potential

The bank shear stress can be computed as $\tau = \gamma d s_o$ where γ is the unit weight of water, *d* is the depth of flow, and s_o is the stream bed slope. Streambank erosion begins when the shear stress exceeds some critical value, τ_c, often referred to as the critical shear stress for bed mobility. The erosive power for per unit area of stream bank is $P = (\tau - \tau_c)V$, where V is the stream velocity. The erosive work is the erosive power integrated over the duration of the flood event or

$$W = \int_{Flood} P dt = \int_{Flood} (\gamma d s_o - \tau_c)^e V dt$$

In this equation, *e* is an exponent between 1 and 2.5 (MacRae 1992, 1996). An alternative is to write the equation in terms of the critical depth for bed mobility, d_c. The critical shear stress can then be computed as $\tau_c = \gamma d_c s_o$. When this is substituted into the above equation for erosive work the following results:

$$W = \int_{Flood} \gamma s_o (d - d_c)^e V dt$$

The generally accepted exponent, e, for this equation is 1, which gives equal weight to the magnitude of flow changes above a critical depth and to changes in the duration of higher flows. Assuming the unit weight and channel slope are constants:

$$W = \gamma s_o \int_{Flood} (d - d_c)^e V dt$$

The Erosion Potential, E_P, used in this report is the ratio of the erosive work after development to the erosive work prior to development,

$$E_P = \frac{W_{Post-development}}{W_{Pre-development}}$$

A value of 1 or less implies no negative impact associated with the new development. Values greater than 1 are in indicator of potential stream instability.

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