5.0 REQUIREMENTS FOR STORMWATER MANAGEMENT

5.0.1 ARTICLE SUMMARY

When **development** occurs, the natural or existing conveyance and storage capacity of land is reduced or even eliminated, and the resulting **stormwater runoff** can adversely impact adjacent and downstream properties by increasing **flood** elevations or decreasing **flood** conveyance capacity. The goal of **stormwater** management is to minimize the potential of these adverse impacts.

To achieve this goal, **stormwater** management must be designed and incorporated into the **development** to ensure the resulting **stormwater runoff** does not increase **flooding**. **Stormwater** management includes controlling of the rate and volume of **stormwater runoff**. The **WMO** requires several **stormwater** management practices to be incorporated into the **development** to mitigate potential **flooding** impacts including:

- **Runoff**
- Volume control
- Detention

The **WMO** establishes the following standards for **development** and **stormwater** management:

- General **Development** and **Stormwater** Management Requirements (§501)
- **Runoff** Requirements (§502)
- Volume Control Requirements (§503)
- Detention Requirements (§504)
- **Development** and **Redevelopment** Tributary to **Existing Detention Facilities** (§505)

This section of the **TGM** provides guidance on performing a hydrologic and hydraulic analysis to calculate the quantity of **stormwater runoff** from a **development**, and design guidelines for a **stormwater** management facility to comply with the **WMO stormwater** management requirements. Detailed examples are provided at the end of each section.

NOTE: All bold words are defined in Appendix A of the WMO and the TGM.

5.1 GENERAL DEVELOPMENT AND STORMWATER MANAGEMENT REQUIREMENTS

5.1.1 GENERAL DEVELOPMENT REQUIREMENTS

§501.1 of the **WMO** establishes the following standards to ensure **stormwater runoff** from **development** does not:

- Increase **flood** elevations or decrease **flood** conveyance capacity upstream or downstream of the **property holdings**;
- Pose any increase in **flood** velocity or impairment of the hydrologic and hydraulic functions of streams and **floodplains** unless a **water resource benefit** is realized;
- Unreasonably or unnecessarily degrade surface or **groundwater** quality; or
- Result in any new or additional expense to any **person** other than the **applicant** as a result of **stormwater** discharge.

5.1.2 GENERAL STORMWATER MANAGEMENT REQUIREMENTS

§501.2 of the **WMO** regulates **stormwater** management based on the type of **development** and the size of the **property holdings**. (Table 2 in §501.2 of the **WMO**) summarizes the applicable **stormwater** management requirements.

It is important to note the following items for Table 5.1:

- **Single-Family Homes** are exempt from all **stormwater** management requirements.
- **Stormwater** management requirements do not apply to **demolition** or **maintenance activities**.
- **Volume control** and **detention** must be provided for **right-of-way development** when the new **impervious area** is greater than or equal to 1.0-acre where practicable. These types of **development** are often limited by public **right-of-way** constraints. If the **stormwater** management requirements are not provided in full, the **applicant** must demonstrate the **right-of-way development** has complied with the **stormwater** management requirements to the maximum extent possible.

TABLE 5.1 SUMMARY OF STORMWATER MANAGEMENT REQUIREMENTS

Development Type (See Appendix A for definitions)	**§502** Runoff Requirements[1,2]	**§503** Volume Control Requirements[1,2]	**§504** Detention Requirements[1,2]
Single-Family Home	Exempt	Exempt	Exempt
Residential Subdivision on **property holdings**	≥ 1 acre	≥ 1 acre	≥ 5 acres
Multi-Family Residential on **property holdings**	≥ 0.5 acre	≥ 0.5 acre	≥ 3 acres‡
Non-Residential on **property holdings**	≥ 0.5 acre	≥ 0.5 acre	≥ 3 acres‡
Open Space on **property holdings**	≥ 0.5 acre	Not Applicable	Not Applicable
Right-of-Way when new **impervious area**	≥ 1 acre	≥ 1 acre†	≥ 1 acre†

1 **Stormwater** management requirements do not apply to **demolition** or **maintenance activities**.

2 Requirements are applicable when a **Watershed Management Permit** is required under §201 of the **WMO**.

† Where practicable.

‡ Starting the effective date of the **WMO**, any new **development** within the **property holdings** that totals either individually or in the aggregate to greater than or equal to one-half (0.5) of an acre.

§501.3 of the **WMO** allows **development** that incorporates in-kind replacement with **green infrastructure** to be considered **non-qualified development**. For this provision, a **volume control practice** used to comply with the volume control requirements of the **WMO** is not considered **green infrastructure**. Therefore, the **non-qualified development** area can only be excluded from the detention requirements of the **WMO** when **green infrastructure** is not used to comply with the volume control requirements of the **WMO**. The following examples are provided:

- A **development** that replaces a traditional paved parking lot with permeable pavers can be considered **non-qualified development** provided the permeable paver system is not used to comply with the **volume control requirements** of the **WMO**.
- A **development** proposes a **building**, **sanitary sewer**, and permeable paver parking lot on a property that has never been developed. The permeable paver system is not considered **non-qualified development** since it is a new parking lot and not in-kind replacement.
- A **development** replaces an existing **building** with a new **building** that includes a green roof. The **building** replacement is not considered **non-qualified development** since the **WMO** does not consider any **building** replacement as in-kind replacement.

§501.4 of the **WMO** allows, under certain circumstances, a **Watershed Management Permit** to be issued without the **applicant** providing detention for the undeveloped area within the **property holdings**. This situation typically occurs when the **development** only takes place on a small portion of the larger undeveloped **property holdings**. If detention is only provided for the **development**, and not the entire **property holdings**, then the following items apply:

- The **applicant** must submit Schedule L along with a plat of survey (Exhibit A) for the **property holdings**. Exhibit A must include a legal description and include all PINs. Schedule L and Exhibit A will be recorded with the **Cook County** Recorder of Deeds as an encumbrance against the entire parcel; and

- A special condition, requiring **detention** to be provided for any future **development** within the **property holdings**, will be made a part of the **Watershed Management Permit**.

5.2 RUNOFF REQUIREMENTS

5.2.1 GENERAL RUNOFF REQUIREMENTS

§502.1 of the **WMO** regulates **runoff** based on the type of **development** and the size of the **property holdings** being developed. Table 5.1 (refer to 5.1.2) summarizes when **runoff** requirements are applicable.

It is important to note the following items:

- **Single-Family Homes** are exempt from **runoff** requirements.
- **Stormwater** management requirements do not apply to **demolition** or **maintenance activities**.

5.2.2 TRANSFER OF STORMWATER RUNOFF BETWEEN WATERSHEDS

Stormwater runoff from a **development** should remain within the existing **watershed**. §502.2 of the **WMO** prohibits **development** that results in the transfer of **stormwater** between **watersheds**, unless the transfer does not violate the provisions of §501.1. For this provision, the following items apply:

- "**Watershed**" refers to the **tributary area** to a body of water; and
- "Transfer of **stormwater**" refers to the diversion of **stormwater runoff** or stream flow from one **watershed** to a different **watershed** by overland flow paths or **storm sewer** systems.

Prior to **development**, some sites may contain a ridgeline that results in the site being tributary to multiple **watersheds**. To demonstrate compliance with §502.2, the existing and proposed site must be evaluated. The proposed grading plan should preserve the natural drainage boundaries that define the **watersheds**. The following resources are available to evaluate the site:

- The drainage boundaries of the **watersheds** are available online and can be viewed with the **District's Stormwater** Inundation Mapping Application at the following link:
  gispub.mwrd.org/swima
- USGS topographic maps are available online and can be viewed with the topoView application at the following link:
  ngmdb.usgs.gov/topoview/
- **Cook County** topography maps are available online and can be viewed with the CookViewer Map Application at the following link:
  maps.cookcountyil.gov/cookviewer/

If the proposed **development** revises the **watershed** drainage boundaries, the **applicant** must submit plans and calculations to demonstrate it will not increase **flood** elevations, velocities or flow rates, or decrease **flood** conveyance capacity to upstream, downstream, or adjacent property. Computation of flows must be completed using the methodology required for **major stormwater systems**.

5.2.3 CONCENTRATED DISCHARGES

§502.3 of the **WMO** requires concentrated discharges from **stormwater facilities** enter conveyance systems that are:

- Contained within a **right-of-way** or a public easement; or
- Capable of carrying the **design runoff rate** without increasing **flood** or **erosion** damages downstream or on adjacent property for the 2-year, 10-year, and 100-year **storm events**.

Concentrated discharges from the **development's stormwater facilities** may enter a conveyance system that is not located within a **right-of-way** (e.g., on adjacent private property). In general, if the **development** maintains the existing drainage patterns and discharge rates, the discharge from the **development** will likely not cause **flood** or **erosion** damages to downstream or adjacent property. However, if the **development** modifies the existing drainage pattern or increases flow rates, the **applicant** must submit plans and calculations to demonstrate the discharge from the **development** does not cause **flood** or **erosion** damages to downstream or adjacent property. The following must be considered:

- When concentrated flow is discharged into an overland conveyance system, energy dissipation and permanent **erosion control practices** must be used;
- When concentrated flow is discharged into a **minor stormwater system**, calculations must demonstrate that it can collect and convey **stormwater runoff** from the 10-year **storm event** by gravity, with the hydraulic grade line below the crown of the sewer; and
- When concentrated flow is discharged into a **major stormwater system**, calculations must demonstrate that it can collect and convey the **design runoff rate** determined by a **critical duration analysis** and comply with the **building** protection standards described in 5.2.7.7.

5.2.4 MINOR STORMWATER SYSTEM

Minor stormwater systems are comprised of **storm sewers** and **structures** (inlets, catch basins, manholes, curb and gutter, etc.) that are designed to collect and convey **stormwater runoff** from minor **storm events**. These systems prevent **stormwater** from ponding on sidewalks, roadways, and properties during more frequent, less intense **storm events**.

5.2.4.1 MINOR STORMWATER SYSTEM DESIGN CONSIDERATIONS

§502.4 of the **WMO** requires the **minor stormwater system** be sized to collect and convey **stormwater runoff** from the **tributary area** under fully developed conditions consistent with the design requirements of the local jurisdiction or existing **stormwater** system. If the local jurisdiction does not regulate the design requirements of **minor stormwater systems**, they should be designed, at a minimum, to collect and convey **stormwater runoff** from the 10-year **storm event** by gravity, with the hydraulic grade line (HGL) below the crown of the sewer. The **applicant** may be required to submit design calculations for the **minor stormwater system**.

5.2.4.2 MINOR STORMWATER SYSTEM DESIGN PROCEDURE

The Rational Method and Manning's Equation can be used together to design a **minor stormwater system**. The procedure to design a **minor stormwater system** is:

1. Select a design **storm event** to be collected and conveyed within the system.
2. Determine the size and type of land surface for the **tributary area** to calculate the composite **runoff** coefficient, C (5.6.2.2).
3. Calculate the time-of-concentration, T_c (5.6.1.2), for the **tributary area**.
4. Determine the rainfall intensity, i (5.6.7), from the calculated T_c and selected design **storm event**.
5. Use the Rational Method (5.6.3) to calculate the peak **stormwater runoff**, Q, for the **tributary area**.
6. Use Manning's Equation (5.6.13) to calculate the required dimensions of the **minor stormwater system** to convey the peak **stormwater runoff**, Q, for the **tributary area**.

5.2.5 MAJOR STORMWATER SYSTEM

Major stormwater systems are comprised of overland flow routes (roadways, swales, etc.) that collect and convey **stormwater runoff** from major **storm events** when the capacity of the **minor stormwater system** is exceeded. These systems prevent **flooding** and **erosion** damages to adjacent and downstream properties during less frequent, more intense **storm events**.

5.2.5.1 MAJOR STORMWATER SYSTEM DESIGN CONSIDERATIONS

§502.5 of the **WMO** requires the **major stormwater system** be sized to collect and convey the **design runoff rate** during the critical 100-year **storm event** for the **tributary area**. The **design runoff rate** must also consider flows from the **tributary areas** upstream of the point of design without increasing **flood** or **erosion** damages downstream or on adjacent properties.

In general, the design of **major stormwater systems** must consider all onsite and offsite **tributary areas** under fully developed conditions. In cases where the **tributary area** is undeveloped or partially developed, local zoning maps and information should be evaluated.

The **applicant** must submit calculations for the **design runoff rate** and the **major stormwater system** capacity. The plans must delineate and label the flow path of all **major stormwater systems** to the receiving system on the appropriate plan sheets (grading plan, **stormwater** management exhibit) by using flow arrows. When **storm sewers** are sized to convey the **design runoff rate**, they must be uniquely identified on the appropriate plan sheets (utility plan, **stormwater** management exhibit). An overland **major stormwater system** must be provided when the receiving sewer system is not designed to convey the **design runoff rate**. Cross-sections of the **major stormwater system** indicating the hydraulic grade line (HGL) may be requested.

The following items must also be considered for the **major stormwater system**:

- **Building** protection standards described in 5.2.7.7;
- HGL calculations must consider tailwater conditions (due to **BFE**, HWL, etc.) at the downstream end of the system;
- A gravity system must be used whenever practicable. A system that incorporates a **stormwater** pump station may only be used after all other alternatives have been exhausted. When a **stormwater** pump station is used to convey the design flow rate, it should comply the requirements of a **sanitary sewer** pump station described in Section 7 of this **TGM**;
- Open channel conveyance systems should incorporate the following:
    - Energy dissipation is essential to avoid transferring scour and stability problems downstream. Sufficient energy dissipation must be provided where flow enters the channel to prevent scouring of the streambank, bed, or downstream land. Armoring of the channel should not be considered in lieu of energy dissipation;
    - To the extent possible, deep-rooted vegetated side slopes, and inverts with velocities sufficiently limited must be used to prevent scouring;
    - Reasonable side slopes given the engineering properties of the materials. A 3:1 side slope typically provides adequate stability in an earth channel and a mowable slope. A 4:1 or shallower side slope is desirable. Deviations from the minimum value should be justified by appropriate calculations (e.g., slope stability calculations) and **maintenance** plans that do not require mowing.
    - Best management practice (BMP) standards. These standards are published in the **Illinois Urban Manual** and can be viewed at the following link: aiswcd.org/illinois-urban-manual/

5.2.5.2 MAJOR STORMWATER SYSTEM CONVEYANCE METHODS

The type of **major stormwater system** selected to collect and convey the **design runoff rate** will depend on the required conveyance route, existing adjacent and downstream elevations, and the type of **development**. Typically, an open channel conveyance system or **storm sewer** system is selected for the **major stormwater system**. When a **detention facility** is provided, the emergency overflow and downstream conveyance route to the receiving system are also part of the **major stormwater system**.

5.2.5.3 MAJOR STORMWATER SYSTEM DESIGN PROCEDURE

NRCS TR-55 methodology and an event hydrograph method can be used together to determine the **design runoff rate** for **major stormwater systems**, which are sized using Manning's Equation. The procedure to design a **major stormwater system** is:

1. Determine the size and type of land surface for the **tributary area** to calculate the composite **runoff** curve number, *CN* (5.6.2.1).
2. Calculate the time-of-concentration, T_c (5.6.1.1), for the **tributary area**.
3. Perform a **critical duration analysis** (5.2.6.1) to determine the **design runoff rate**, *Q*.
4. Use Manning's Equation (5.6.13) to calculate the required dimensions of the appropriate **major stormwater system** to convey the **design runoff rate**, *Q*, for the **tributary area**.

5.2.6 DESIGN RUNOFF RATE

§502.9 of the **WMO** requires the **design runoff rate** for **major stormwater systems** be calculated using an event hydrograph method described in 5.6.4 and a **critical duration analysis**.

The **applicant** must submit calculations and/or a summary of the model output for the **design runoff rate**. The **applicant** may be required to submit the full model results. An **applicant** may use other proprietary software (e.g., *HydroCAD*, *PondPack*, etc.) to calculate the **design runoff rate** provided the assumptions described in 5.6.4 are incorporated. However, the **District** will review the calculations using an event hydrograph method described in 5.6.4 and will not accept a lesser **design runoff rate** when proprietary software is used for the calculations.

5.2.6.1 CRITICAL DURATION ANALYSIS

A **critical duration analysis** is a study that determines which **storm event** duration results in the greatest peak **runoff** rate. This peak **runoff** rate is the **design runoff rate** for **major stormwater systems** and the emergency overflow conveyance system from the **detention facility** to the receiving **stormwater** conveyance system. The **critical duration analysis** must include the 1-, 2-, 3-, 6-, 12-, 24-, and 48-hour storm durations to determine the critical storm duration that results in the greatest peak **runoff** rate.

A **critical duration analysis** is recommended for all **developments**; however, it is only required for the **developments** listed below. Any **development** that does not require a **critical duration analysis** is not exempted from determining the **design runoff rate**. For these **developments**, the Rational Method (5.6.3) may be used to calculate the **design runoff rate** provided the time-of-concentration is less than 60-minutes. A **critical duration analysis** is required for the following:

- **Development** greater than 20-acres;
- When the ratio of offsite **tributary area** to onsite **tributary area** is 5:1 or greater; or
- When there are clear conveyance issues that may contribute to **site flooding** or **flooding** to adjacent and downstream properties.

The **critical duration analysis** must incorporate the following assumptions:

- **Storm sewers** as part of the **minor stormwater system** are not available to convey flow; and
- When a **detention facility** is part of the **development**, the detention volume is not available and the **control structure** is plugged.

5.2.7 ADDITIONAL RUNOFF CONSIDERATIONS

This section covers additional items that must be considered and incorporated into the **development** to comply with the **runoff** requirements of the **WMO**. Although a **development** may not contain all these items, applicable items must be incorporated.

5.2.7.1 GENERAL ITEMS

- Any **development** that proposes to discharge **stormwater** into a private **stormwater facility** must obtain written permission from the private **owner** (§502.13). The letter must be submitted to the **District** prior to permit issuance.
- Any **development** that proposes offsite construction on private property must obtain written permission from the private property **owner** and obtain any required easements (§502.14). The letter must be submitted to the **District** prior to permit issuance.
- All **runoff** from rooftops and parking lots that does not discharge into a **detention facility** should be directed onto pervious surfaces to the maximum extent practicable (§502.15).
- A separate **sanitary sewer** and **storm sewer** must be provided within the **property holdings** (§502.16).

- **Development** located within the **combined sewer area** must collect, route, and discharge **stormwater** into either a **waterway** or a **stormwater facility** tributary to a **waterway** if (§502.17):
  - Any boundary of the **project** is within one eighth (1/8) of a mile of the **stormwater facility**; or
  - Any boundary of the **project** is within one quarter (1/4) of a mile of the **stormwater facility**, if practicable.
- The **applicant** must procure all required federal, state, or local permits for **stormwater** discharges to a **waterway** (§502.18).

5.2.7.2 DRAIN TILE

§502.10 of the **WMO** requires existing drain tile located within the **property holdings** be safely routed through or around the **development** based on its existing capacity and capability to convey **groundwater** and upstream flows. When drain tile is found during the design or construction of the **development** the following items apply:

- Any modifications to drain tile must not cause damage to upstream and downstream **structures**, land uses, or existing **stormwater facilitates**;
- Any drain tile that receives **upstream tributary flow** must remain in service during construction and, if applicable, until the new **stormwater facilities** are permanently installed and operational to convey the flow;
- Any drain tile that serves adjacent or upstream properties must be properly reconnected to the downstream system and located within a **right-of-way** or a public easement and shown on the **record drawings**; and
- Any drain tile shall not be tributary to **sanitary sewers**, **combined sewers**, or **storm sewer** tributary to **District** facilities.

When the **development** modifies the existing drain tile system, the **applicant** must submit the following:

- Calculations demonstrating the proposed modifications will not cause damage to upstream or downstream **structures**, land uses, or existing **stormwater facilities**. Calculations should be based on the drain tile size and slope. When slope is unknown, a reasonable assumption can be made provided supporting justification is submitted;
- When the drain tile system serves adjacent or upstream properties, the easement must be delineated and be labeled with appropriate information on the plans;

- **Record drawings** submitted to the **District** must show the drain tile and, if applicable, delineate the recorded easement and be labeled with appropriate information; and

- The drain tile must be investigated to determine the receiving system. If the receiving system is tributary to a **sanitary sewers**, **combined sewer**, or **storm sewer** tributary to **District** facilities, they must be disconnected and properly routed to discharge overland or into a system that is tributary to a **waterway**.

5.2.7.3 EASEMENTS

§502.8 of the **WMO** requires **major stormwater systems** to be located within a **right-of-way** or public easement explicitly providing public access for **maintenance**. This is particularly important when the **development** includes a **major stormwater system** that conveys **stormwater runoff** from adjacent or upstream properties. The easement must:

- Be appropriately sized to allow access to perform necessary **maintenance**; and

- Be recorded on all legal documents of all properties containing the easement.

A minimum of 10-feet should be dedicated over any **major stormwater system**; however, consideration should be given to the type of conveyance system and the necessary access to undertake any required **maintenance**. It is also recommended that areas up to 10-feet beyond the established high water level (HWL) of a **stormwater detention facility** be placed within a public easement. Easement language should include **maintenance** access provisions for all **stormwater facilities**.

When the **development** includes a **major stormwater system** that serves adjacent or upstream properties, the following items apply:

- The plans must delineate the proposed or existing easement and be labeled with appropriate information; and

- **Record drawings** submitted to the **District** must delineate the recorded easement and be labeled with appropriate information.

5.2.7.4 UPSTREAM TRIBUTARY FLOWS

§502.7 of the **WMO** requires **upstream tributary flows** to be considered for all **projects** and be safely routed around or through the **project** in the following manner:

- Where detention is not required per §504.1 of the **WMO**, the **applicant** shall demonstrate that the **development** will not increase velocities or flows downstream or on adjacent properties for the 2-year, 10-year, and 100-year **storm events**, at a minimum, using **critical duration analysis** and the methodology provided in §502.9 of the **WMO**; and

- Where detention is required per §504.1 of the **WMO**, the requirements of §504.10 of the **WMO** apply.

A **development** could potentially impact existing drainage patterns and discharge rates from **upstream areas**. These **upstream tributary flows** cannot be blocked and must be either routed around or through the **development**. The **design runoff rate**, determined by **critical duration analysis**, should consider the **upstream area** under fully developed conditions to ensure the **major stormwater system** is not undersized and can adequately collect and convey the **upstream tributary flow**. When detention is required for the **development**, the **upstream tributary flows** can be either bypassed or stored within the **detention facility**. Refer to 5.4.6 for additional information.

5.2.7.5 DEPRESSIONAL STORAGE

Depressional storage is an aboveground storage area without a traditional outlet and drains by evaporation and infiltration, or when the water surface exceeds the highest closed-contour elevation. These **depressional storage** areas reduce the rate of **stormwater runoff** leaving the site since **stormwater runoff** is retained onsite.

§502.8 of the **WMO** requires the storage function of **depressional storage** areas be preserved. When the **development** alters the **depressional storage** area, the **depressional storage** must be compensated in the following manner:

- When detention is not required in §504.1 of the **WMO**, the **applicant** shall demonstrate that the **development** will not increase velocities, flows, or **flood** elevations downstream nor on adjacent properties for the 2-year, 10-year, and 100-year **storm events** of a 24-hour duration and the methodology provided in §502.9 of the **WMO**; and

- When detention is required in §504.1 of the **WMO**, the requirements of §504.6 of the **WMO** apply.

The hydrologic model must consider the following items to determine the **runoff** rate for the **depressional storage** area:

- All onsite and offsite **tributary areas**; and

- Discharge rates for any drain tile outlets or overflow weirs must be included as a component of the total release rate.

The following **runoff** rates must be considered:

- When **stormwater** detention is not required for the **development**, the proposed **runoff** rate must be less than or equal to the existing **runoff** rate;

- When **stormwater** detention is required for the **development** and the existing **runoff** rate is less than the **gross allowable release rate** in §504.3, then the **net allowable release rate** and corresponding detention volume must be based on the existing **runoff** rate; and

- Existing and proposed stage-storage-discharge relationship tables must be provided for comparison purposes showing no increase in flows and **flood** elevations.

When the **depressional storage** area is located within the **development** site, a complete topographic survey with 1-foot contour intervals should be used to determine the stage-storage relationship table to be used in the hydrologic model. When the **depressional storage** area extends offsite, topographic maps may be used to determine the stage-storage relationship table. If the **depressional storage** area extends into adjacent counties, the county or USGS topographic maps can be used to complete a stage-storage relationship table. The following resources are available to determine the offsite stage-storage relationship:

- **Cook County** topography maps are available online and can be viewed with the CookViewer Map Application at the following link:
  maps.cookcountyil.gov/cookviewer/

- USGS topographic maps are available online and can be viewed with the topoView application at the following link:
  ngmdb.usgs.gov/topoview/

The **applicant** must submit existing and proposed storage and discharge calculations for the **depressional storage** area. The drainage exhibit must delineate and label the **depressional storage** area, and all onsite and offsite **tributary areas** with their respective **runoff** curve number and associated acreage. The drainage exhibit must also delineate any outlet from the **depressional storage** area with relevant dimensional and elevation information indicated.

Note that if the **depressional storage** area is mapped as a **floodplain** on the **FIRM** maps, the **floodplain** provisions of Article 6 of the **WMO** apply.

5.2.7.6 MAXIMUM STORMWATER RUNOFF INUNDATION DEPTHS

§502.11 of the **WMO** limits the **stormwater runoff** inundation depth on roads and parking lots to a maximum of 12-inches. This also includes **stormwater detention** inundation depths.

Stormwater detention inundation depths within truck docks may exceed the 12-inch maximum depth, provided the following items are submitted to the **District**:

- The **Permittee's** written approval of the inundation depth; and

- The **Co-Permittee's** written acknowledgement and acceptance of the inundation depth and the potential **flooding** hazard and **flood** damages.

5.2.7.7 BUILDING PROTECTION STANDARDS

§502.12 of the **WMO** requires the **lowest floor** of new **buildings** or additions to existing **buildings** be elevated to prevent the entry of surface **stormwater**. The **lowest floor** of a **building** includes the **basement**. If the **lowest floor** cannot be elevated to comply with the required protection elevation, the **building** must be **floodproofed** or protected such that the **lowest entry elevation** complies with the required protection elevation. The **lowest floor** or the **lowest entry elevation** must be elevated to a minimum of one (1) foot above the following **stormwater** elevations:

- The design water surface elevation (hydraulic grade line, HGL) associated with the **design runoff rate** for the **major stormwater system** as designed in §502.5;
- The design water surface elevation (high water elevation, HWL) associated with the 100-year detention volume of the **detention facility** as designed in §504.13;
- The design water surface elevation (hydraulic grade line, HGL) associated with the **detention facility** overflow path as designed in §504.13.D; and
- The **BFE** or any other tailwater conditions must be incorporated into the design water surface elevations (HGL and/or HWL) indicated above.

In addition, the following must also be considered and incorporated into the **development**:

- The **lowest floor** and/or **lowest entry elevations** for existing **buildings** located within the **property holdings** that are not part of the **development** should comply with the **building** protection standards described above. When the protection standards cannot be provided for the existing **building**, the **Co-Permittee's** written acknowledgement and acceptance of the potential **flooding** hazard and **flood** damages must be submitted to the **District**. The letter must be submitted to the **District** prior to permit issuance; and
- The **lowest floor** and/or **lowest entry elevations** for **buildings** located on adjacent private property and outside the **property holdings** must comply with the **building** protection standards described above.

To demonstrate compliance with the **building** protection elevation standards, the **applicant** must indicate the **lowest floor** and/or **lowest entry elevations** and detail any **floodproofing** measures on the plans. Calculations for the water surface elevation associated with the HGL and/or HWL adjacent to **building lowest entry elevation** must be submitted. Cross-sections with the HGL and/or HWL and the **lowest floor** and/or **lowest entry elevations** shown must also be submitted.

In general, pavement ridgelines and storm **structure** rim elevations should maintain 18-inches of separation from the **lowest floor** and/or **lowest entry elevation** to ensure that the **building** protection standards are met. Additionally, it is recommended that a minimum setback distance of 10-feet from the HGL and/or HWL to the **lowest floor** and/or **lowest entry elevations** is maintained.

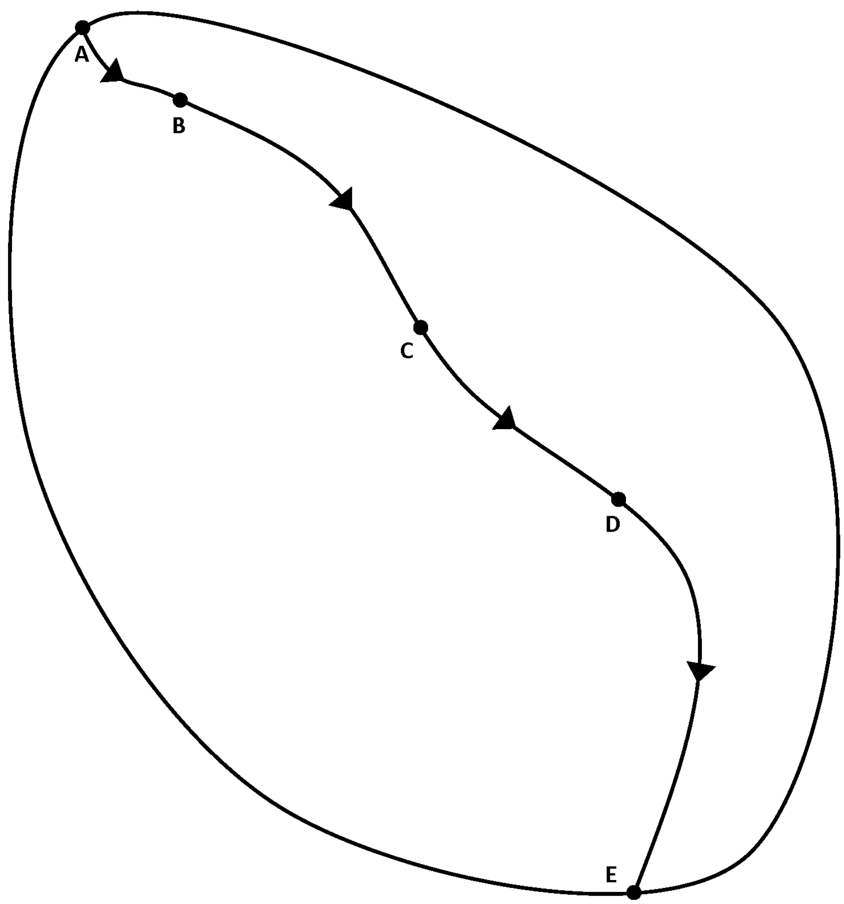
5.2.8 RUNOFF EXAMPLES

EXAMPLE 1

The flow path of from the most hydraulically distant point (A) to the outlet (E) for a **watershed** is shown in the figure and described in the table below. Determine the time-of-concentration, T_c, for the **watershed** using **NRCS** TR-55 methodology.

WATERSHED INFORMATION

Flow Segment	Flow Type	Surface Type	Flow Length (ft)	Surface Slope (ft/ft)	Flow Area (ft^2)	Wetted Perimeter (ft)
AB	Sheet	Dense Grass	100	0.030	-	-
BC	Shallow Concentrated	Unpaved	1,400	0.020	-	-
CD	Shallow Concentrated	Paved	800	0.010	-	-
DE	Open Channel	Unpaved	1,200	0.005	32.25	24.15



WATERSHED FLOW PATH (NOT TO SCALE)

Step 1. Using the T_c Calculator, enter the information provided for each flow segment corresponding to the respective flow type. Use Table 5.8 to obtain Manning's *n* for dense grass sheet flow. Use Table 5.14 to obtain the 2-year, 24-hour rainfall depth. Use Table 5.9 to obtain Manning's *n* for unpaved open channel flow.

Answer: The T_c for **watershed** is 34.16-minutes.

NRCS TIME OF CONCENTRATION (T_c) OR TRAVEL TIME (T_t)

PROJECT: Runoff Example 1 **PERMIT NUMBER:**

LOCATION: **DATE:**

CONDITION (SELECT FROM DROP-DOWN)

X PROPOSED CONDITION ___ EXISTING CONDITION

SHEET FLOW								
1. Segment ID		AB						
2. Surface description		Dense Grass						
3. Manning's roughness coefficient, *n*		0.24						
4. Flow length, *L* (≤ 100 ft)		100	ft					
5. 2-year, 24-hr rainfall, P_2		3.34	in					
6. Land slope, *s*		0.030	ft/ft					
7. Travel time, T_t	$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5}s^{0.4}}(60)$	11.88	+		=	11.88	min
SHALLOW CONCENTRATED FLOW								
8. Segment ID		BC		CD				
9. Surface description (drop-down list)		Unpaved		Paved				
10. Flow length, *L*		1400	ft	800				
11. Watercourse slope, *s*		0.020	ft/ft	0.010				
12. Average velocity, *V*		2.28	fps	2.03				
13. Travel time, T_t	$T_t = \frac{L}{60V}$	10.23	+	6.56	=	16.79	min
OPEN CHANNEL FLOW								
14. Segment ID		DE						
15. Cross-sectional flow area, *A*		32.25	ft^2					
16. Wetted Perimeter, P_w		24.15	ft					
17. Hydraulic radius, *R*		1.34	ft					
18. Flow Length, *L*		1200	ft					
19. Channel slope, *S*		0.005	ft/ft					
20. Manning's roughness coefficient, *n*		0.035						
21. Average velocity, *V*	$V = \frac{1.486}{n}R^{\frac{2}{3}}S^{\frac{1}{2}}$	3.64	fps					
22. Travel time, T_t	$T_t = \frac{L}{60V}$	5.49	+		=	5.49	min
TIME-OF-CONCENTRATION (T_c) OR TRAVEL TIME (T_t)								
23. Time-of-Concentration, *Tc*, or Travel Time, *Tt*	$T_c, T_t = \sum T_t$				=	34.16	min

EXAMPLE 2

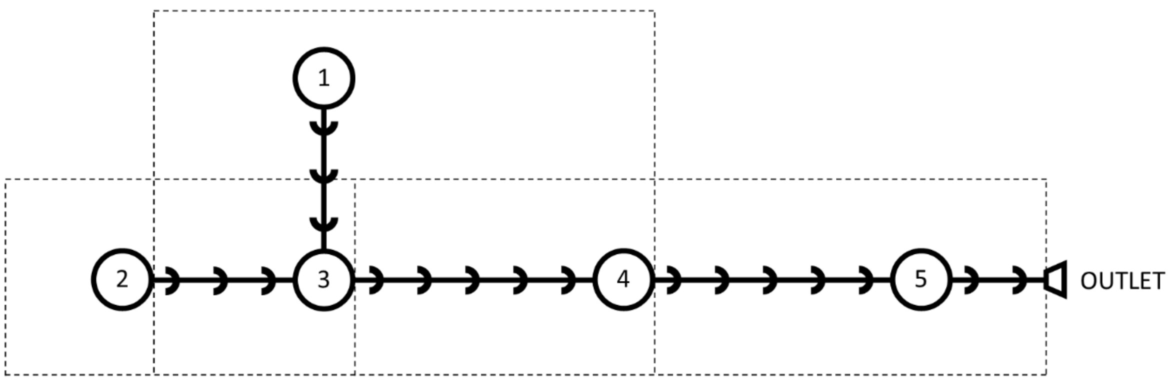
Information for a **storm sewer** system and **tributary areas** are provided in the tables below. Determine the required diameters of the **storm sewer** system to convey the **runoff** from the 10-year **storm event** with the hydraulic grade line below the crown of the sewer.

TRIBUTARY AREA INFORMATION

Inlet	Incremental Tributary Area (acres)	Runoff Coefficient, *C*	Travel Time to Inlet (min)
1	2.5	0.70	5
2	1.0	0.60	5
3	2.0	0.65	10
4	2.0	0.80	10
5	3.0	0.75	5

SEWER INFORMATION

Sewer	Length (ft)	Slope (ft/ft)
1-3	200	0.020
2-3	200	0.030
3-4	400	0.004
4-5	300	0.004
5-OUT	100	0.002



MINOR STORMWATER SYSTEM AND DRAINAGE AREAS (NOT TO SCALE)

Answer: In this example, a spreadsheet with the Rational Method and a Manning's equation is used to determine the diameters of the proposed **storm sewer** system. Note that the ratio in Column 20 was determined using the calculated ratio of Column 19 and a circular channel ratio chart that is available in most hydraulics reference manuals. If an **applicant** is using proprietary software (e.g., Hydraflow, StormCAD, etc.) to design the **storm sewer system**, the hydraulic grade line (HGL) must be plotted to ensure it's below the crown of the sewer. Since Manning's equation assumes full-pipe conditions, the HGL is equal to the crown of the sewer and no other HGL calculations are required to be submitted.

STRUCTURE ID		DRAINAGE AREA		DRAINAGE AREA X RUNOFF COEFFICIENT		TIME OF CONCENTRATION		RAINFALL - RUNOFF		STORM SEWER											
FROM (1)	TO (2)	INCREMENT (acres) (3)	C (4)	INCR. X C (5)	TOTAL (6)	INLET (min) (7)	SYSTEM (min) (8)	RAINFALL INTENSITY (in/hr) (9)	DESIGN FLOW (cfs) (10)	MINIMUM DIAMETER (in) (11)	SELECTED DIAMETER (in) (12)	LENGTH (ft) (13)	SLOPE (ft/ft) (14)	MATERIAL (15)	MANNING'S RUNOFF COEFFICIENT (16)	FULL FLOW CAPACITY (cfs) (17)	FULL FLOW VELOCITY (ft/sec) (18)	DESIGN FLOW --------- FULL FLOW CAPACITY (19)	ACTUAL VELOCITY --------- FULL FLOW VELOCITY (20)	ACTUAL VELOCITY (ft/sec) (21)	FLOW TIME (min) (22)
1	3	2.50	0.70	1.750	1.750	5.00	5.00	7.44	13.02	17.1	18	200	0.020	RCP	0.013	14.86	8.41	0.88	1.13	9.48	0.35
2	3	1.00	0.60	0.600	0.600	5.00	5.00	7.44	4.46	10.6	12	200	0.030	RCP	0.013	6.17	7.86	0.72	1.09	8.56	0.39
3	4	2.00	0.65	1.300	3.650	10.00	10.00	6.48	23.65	29.0	30	400	0.004	RCP	0.013	25.94	5.28	0.91	1.13	5.99	1.11
4	5	2.00	0.80	1.600	5.250	10.00	11.12	6.27	32.92	32.8	36	300	0.004	RCP	0.013	42.18	5.97	0.78	1.11	6.60	0.76
5	OUT	3.00	0.75	2.250	7.500	5.00	11.90	6.13	45.98	42.3	48	100	0.002	RCP	0.013	64.24	5.11	0.72	1.09	5.56	0.30

STORM SEWER DESIGN SPREADSHEET

EXAMPLE 3

A 30-acre upstream area is tributary to a proposed 2-acre **development**. Determine the **design runoff rate** that must be bypassed through the **development** using the information below.

AREA INFORMATION

	Area (acres)	Area (mi^2)	CN	T_c (min)
Development Area	2	0.003125	84	10
Upstream Area	30	0.046875	90	20

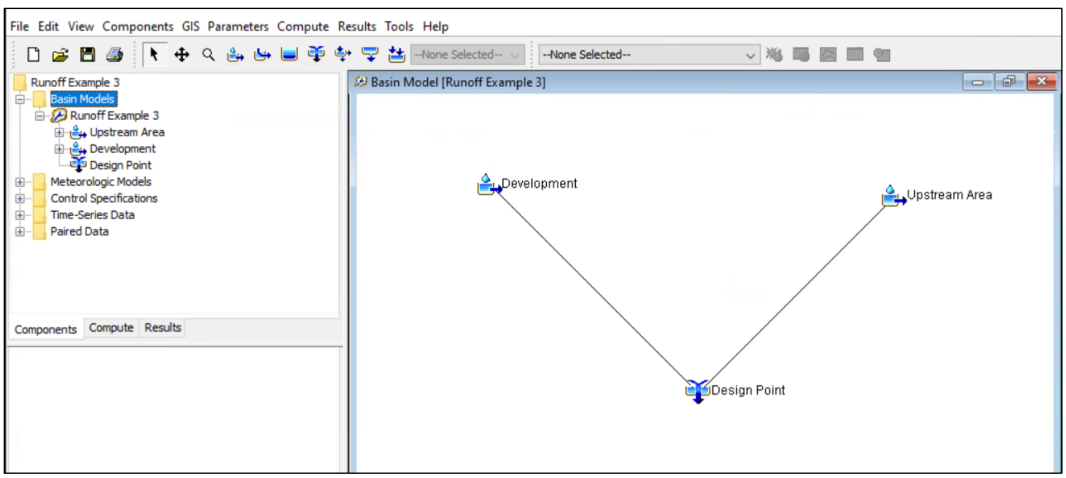
Step 1. Calculate the lag time for each area to be entered into the HEC-HMS model:

$$Lag\ Time = 0.60T_c$$

$$Lag\ Time_{develop} = (0.60)(10\text{ min}) = 6\ min$$

$$Lag\ Time_{offsite} = (0.60)(20\text{ min}) = 12\ min$$

Step 2. Using HEC-HMS, create a subbasin for the 2-acre (0.003125 mi^2) **development** area with a composite CN of 84, a subbasin for the 30-acre (0.046875 mi^2) upstream **tributary area** with a composite CN of 90, and the design point junction.



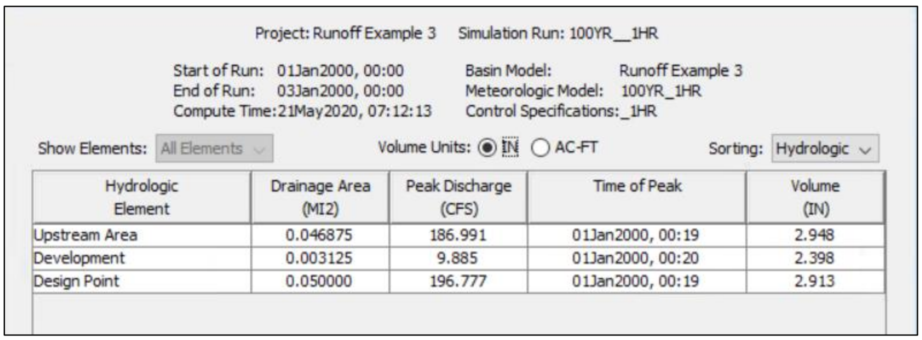
Step 3. Enter the 100-year, 1-hour through the 100-year, 48-hour rainfall depths from Table 5.14 into the *Meteorologic Models* component of the model.

Step 4. Enter the time distributions of rainfall for the 1-hour through the 48-hour storm durations from Table 5.19 into the *Time-Series Data* component of the model.

Step 5. Enter the length of time the model should run along with data output intervals for the 1-hour through the 48-hour storm durations into the *Control Specifications* component of the model.

Step 6. Create and compute S*imulation Runs* for the 100-year, 1-hour through the 100-year, 48-hour storm durations.

Answer: The **design runoff rate** determined from the **critical duration analysis** is 196.78 cfs. The *Global Summary Results* for the 100-year, 1-hr **storm event** is shown below. HEC-HMS does not provide a summary for the various simulations; therefore, the results of the **critical duration analysis** are summarized in the table below.



Project: Runoff Example 3 Simulation Run: 100YR__1HR

Start of Run: 01Jan2000, 00:00 Basin Model: Runoff Example 3
End of Run: 03Jan2000, 00:00 Meteorologic Model: 100YR_1HR
Compute Time: 21May2020, 07:12:13 Control Specifications: _1HR

Show Elements: All Elements Volume Units: IN AC-FT Sorting: Hydrologic

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (IN)
Upstream Area	0.046875	186.991	01Jan2000, 00:19	2.948
Development	0.003125	9.885	01Jan2000, 00:20	2.398
Design Point	0.050000	196.777	01Jan2000, 00:19	2.913

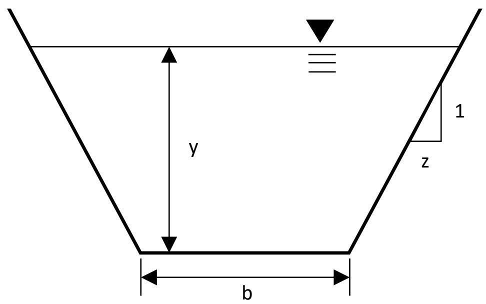
Storm Event	Peak Flow Rate (cfs)
100-year, 1-hour	196.78
100-year, 2-hour	144.17
100-year, 3-hour	114.79
100-year, 6-hour	73.22
100-year, 12-hour	41.05
100-year, 18-hour	29.74
100-year, 24-hour	23.81
100-year, 48-hour	15.94

EXAMPLE 4

Determine the required size of a **major stormwater system** to convey the design flow rate of 196.78 cfs determined from Example 3 using the information below.

MAJOR STORMWATER SYSTEM INFORMATION

Channel type	Grass lined channel
Channel slope	0.01 ft/ft
Side slopes	4:1
Maximum flow depth	0.75
Manning's roughness coefficient	0.035



MAJOR STORMWATER SYSTEM (NOT TO SCALE)

Step 1. Calculate the hydraulic radius, *R*, from the channel parameters using Equation 5.25:

$$R = \frac{A}{P_w}$$

$$= \frac{y(b+zy)}{b+2y\sqrt{1+z^2}}$$

Step 2. Input the channel area, hydraulic radius, and other known parameters into Equation 5.24 (Manning):

$$Q = \frac{1.486}{n} A R^{2/3} S^{1/2}$$

$$= \frac{1.486}{n} \left((b+zy)y\right) \left(\frac{(b+zy)y}{b+2y\sqrt{1+z^2}}\right)^{2/3} S^{1/2}$$

Answer: Through an iterative process, the width of the channel is 74-feet.

5.3 VOLUME CONTROL REQUIREMENTS

5.3.1 GENERAL VOLUME CONTROL REQUIREMENTS

§503.1 of the WMO regulates volume control based on the type of **development** and the size of the **property holdings**. Table 5.1 (refer to 5.1.2) summarizes when volume control requirements are applicable.

It is important to note the following items:

- **Single-Family Homes**, **open space development**, **demolition**, **maintenance activities**, and **non-qualified development** are exempt from the volume control requirements;

- **Right-of-way development** must comply with the volume control requirements when the new **impervious area** is greater than or equal to 1-acre where practicable. If the volume control requirements are not provided in full, the **applicant** must demonstrate the **right-of-way development** complies with the volume control requirements to the maximum extent possible.

5.3.2 VOLUME CONTROL STORAGE

§503.2 of the **WMO** defines the **volume control storage** as the first inch of **stormwater runoff** from the **impervious area** of the **development**. **Impervious areas** include pavement, compacted gravel, and **buildings** excluding green roof areas. Porous pavement, non-compacted gravel, railroad ballast, and synthetic turf fields are not considered **impervious areas** for volume control requirements. The **volume control storage** is calculated with the following equation:

$$V_c = d\ A_i\ U_c \quad (5.1)$$

Where:
- V_c = **volume control storage**, acre-feet
- d = 1-inch, requirement for volume control
- A_i = **impervious area**, acres
- U_c = 1-ft / 12-inch, unit conversion factor from inches to feet

Equation 5.1 may be simplified to the following by multiplying the volume control requirement and unit conversion.

$$V_c = \frac{A_i}{12} \quad (5.2)$$

5.3.3 VOLUME CONTROL PRACTICES

§503.3 of the **WMO** requires **volume control practices** to capture the **volume control storage**. **Volume control practices** are designed to retain and infiltrate the **volume control storage**. The purpose of these practices is to reduce the volume of **stormwater runoff** discharged from the **development**. In addition to the volume reduction, **volume control practices** often provide water quality enhancement through interception, evapotranspiration, nutrient uptake, filtration, and adsorption of pollutants such as fine **sediment**, nutrients, bacteria, and organic materials from initial (first flush) **stormwater runoff**.

Volume control practices include both **retention-based practices** and **flow-through practices**. **Retention-based practices** provide water quality benefits and reduce the volume of **stormwater runoff** discharged from the **development** since the practice has quantifiable storage. When the **volume control storage** is retained by a **retention-based practice**, it is able to infiltrate into the underlying soils, dissipate through evapotranspiration, and attenuate flows draining into the **minor stormwater system**. **Flow-through practices** also provide water quality benefits; however, since they do not contain quantifiable storage space, the reduction of **stormwater runoff** is negligible.

It is important to note the following items:

- **Volume control practices** are required to be provided when the **impervious area** of the **development** is greater than or equal to 0.10-acre.
- **Volume control practices** should be provided when the **impervious area** of the **development** is less than 0.10-acre where practicable.
- When detention is required for the **development**, credit for **retention-based practices** may be applied toward the detention requirements.

§503.4 of the **WMO** requires **volume control practices** to be provided in the following hierarchy:

1. Onsite **retention-based practices** with quantifiable storage capacity;
2. **Offsite retention-based practices** when the **applicant** can demonstrate that **site constraints** prevent the **development** from providing onsite **retention-based practices** to retain the full **volume control storage**;
3. If all means of providing onsite and **offsite retention-based practices** are technically infeasible and documented, then the alternatives described in 5.3.3.3 may be utilized.

5.3.3.1 ONSITE RETENTION-BASED PRACTICES

Onsite **retention-based practices** must be provided for **developments** that do not contain a **site constraint**. If the **applicant** can demonstrate that a **site constraint** is present only on a portion of the **property holdings**, **retention-based practices** should be used in the non-constrained area to comply with the volume control requirements. When it is not possible to provide onsite **retention-based practices** due to a **site constraint**, the **applicant** must explore whether **offsite retention-based practices** can be utilized to comply with the volume control requirements.

5.3.3.2 EXPLORATION OF OFFSITE RETENTION-BASED PRACTICES

When the **District** determines that a **development** qualifies for a **site constraint**, the **applicant** must explore whether **offsite retention-based practices** can be utilized to comply with the volume control requirements. The **applicant** must pursue the following:

- If possible, construct a **retention-based practice** on a property where the **volume control storage** for the **development** is tributary to the practice, or construct an **offsite retention-based practice** within the same **watershed planning area** to be utilized for **impervious area** trading;
- Contact the **District** for a list of permitted **offsite retention-based practices** within the same **watershed planning area** as the **development**; and
- Contact the local **municipality** and adjacent **municipalities** within the same **watershed planning area**, to determine whether **offsite retention-based practices** can be utilized for **impervious area** trading.

If the **applicant** can utilize **offsite retention-based practices**, the **applicant** must submit the following documentation:

- **Watershed Management Permit** number for the **offsite retention-based practice**;
- Letter from the **owner** of the **offsite retention-based practice** approving the use of the practice by the **development** and the quantity of traded volume; and
- Copy of the agreement for the perpetual **maintenance** of the **offsite retention-based practice** between all parties.

If the **applicant** is unable to utilize **offsite retention-based practices**, the **applicant** must submit documentation to the **District** summarizing their efforts to utilize **offsite retention-based practices** and provide an alternative compliance solution.

5.3.3.3 ALTERNATIVES TO OFFSITE RETENTION-BASED PRACTICES

When an **applicant** submits sufficient documentation to the **District** summarizing that an **offsite retention-based practice** could not be utilized for the **development**, the following compliance alternatives may be utilized:

- The **volume control storage** may be reduced by five-percent (5%) for every one-percent (1%) of reduced **impervious area**. Therefore, the required **volume control storage** for the **development** can be provided by reducing the existing **impervious area** by 20%;
- When the **development** is tributary to a **combined sewer** system or **storm sewer** system tributary to **District water reclamation facilities**, detention volume equivalent to the **volume control storage** must be provided in the following manner depending on whether detention is required:
    - When detention is not required for the **development**, a **detention facility** must be provided for the **volume control storage**. The release rate from the **detention facility** should be attenuated and similar to a **retention-based practice**. The **applicant** must submit design calculations and include details of the **detention facility** on the plans. Note that an overflow conveyance route must be incorporated into the design of the **detention facility**.
    - When detention is required for the **development**, detention volume equivalent to the **volume control storage** must be detained in addition to the **required detention volume**.
- When the **development** is tributary to a **waterway**, including when located in the **combined sewer area**, **flow-through practices** must be provided and sized to pretreat the **volume control storage** as it passes through the practice.

5.3.4 VOLUME CONTROL PRACTICE DESIGN CONSIDERATIONS

The following items must be considered when determining the type and location of **volume control practices**:

- Whether a **site constraint** exists
- Estimated seasonal high **groundwater** table
- Infiltration rate of the underlying soils and whether bedrock is present
- **Volume control storage** conveyance route to the practice
- Overflow route from the practice to the main drainage system
- Practices should not be installed on slopes greater than 5:1

- Practices should not be installed above soils that are considered fill
- Practices should maintain the following separation distances:
    - 10-feet from a **building** foundation (unless waterproofed)
    - 20-feet from a gravel shoulder for a road to prevent frost heaving
    - 100-feet from potable water wells, septic tanks, or other underground storage tanks
- The practice must incorporate a backflow prevention device and be located downstream of the **underdrain** when tributary to a **combined sewer** or **storm sewer** tributary to **District facilities**
- Practices in proximity of a **sanitary sewer** or **combined sewer** must:
    - Maintain a horizontal separation of 10-feet. If local conditions prevent this separation, then the sewer must be constructed with water main quality material/joints;
    - Not be located above the sewer. If local conditions prevent relocation of the practice or sewer, then the sewer must be constructed with water main quality material/joints and be encased in a carrier pipe with the ends sealed; and
    - The sewer must not be located within the practice.

5.3.4.1 OVERFLOW ROUTE FOR VOLUME CONTROL PRACTICES

An overflow route must be incorporated into the design of the **volume control practice** to convey **stormwater runoff** from the practice into the main drainage system. The overflow route is required and must be designed to prevent structural damage to the **volume control practice** from localized **flooding** in the event it cannot drain fast enough to prevent an overflow. An overflow can occur as a result of clogging or during long-duration, high-intensity **storm events** that can exceed that capacity of the practice or saturate the underlying soils to the extent that impedes infiltration. The design of the overflow route must convey excess flows through a stabilized discharge point that allows flow to be directed back into the main drainage system in a controlled manner that will not cause scour.

5.3.4.2 PROTECTION DURING CONSTRUCTION

Volume control practices are susceptible to failure during construction, therefore; it is important that staging, construction means/methods, and **erosion and sediment control practices** all be considered during installation. To protect the long-term functionality of **volume control practices**, the following measures must be considered and incorporated into the construction sequencing and the **soil erosion and sediment control** plan:

- **Volume control practices** should be installed toward the end of the construction schedule;
- The **tributary area** must be stabilized prior to the installation of the **volume control practice**;
- Soil compaction must be minimized to the maximum extent possible. Appropriate measures (e.g., fencing) should be used to prevent heavy construction equipment traffic from accessing the area;
- **Volume control facilities** must be protected by a double-row silt fence, coir logs, or equivalent measure during construction; and
- In general, **volume control facilities** should not be used as temporary **sediment** traps during construction. Where this is not practicable, that **applicant** must provide additional construction notes and/or details on the plans demonstrating measures to protect the functionality of the facility.

5.3.5 RETENTION-BASED PRACTICE FEASIBILITY ASSESSMENT

A feasibility assessment is required to determine the appropriate approach and type of **retention-based practice** to comply with the volume control requirements. Soil infiltration capacity, estimated seasonal high **groundwater** table, presence of contaminated soils, and the type of **development** must all be considered when choosing the type and design of the **retention-based practice**.

The **applicant** must submit a geotechnical report, signed and sealed by a **Professional Engineer**, to assess whether the underlying soils are appropriate for **retention-based practice**. The report must indicate the type of soil in the location of the **retention-based practice** and the elevation of the estimated seasonal high **groundwater** table. The report must also indicate the infiltration capacity of the soil when an **underdrain** is not incorporated into the **retention-based practice**.

Soil borings should be taken in the location of the proposed **retention-based practice** to verify soil particle size distribution. An adequate number of borings should be taken to determine soil conditions. The minimum depth of the borings must extend seven (7) feet below grade and must extend a minimum of five (5) feet below the bottom elevation of the proposed **retention-based practice** to determine the elevation of the estimated seasonal high **groundwater** table and whether bedrock is present.

When an **underdrain** is not incorporated into the proposed **retention-based practice**, an infiltration test must be conducted at the proposed bottom elevation of the **retention-based practice**. The infiltration test must use a double-ring infiltrometer and comply with the requirements of ASTM D3385. For sites where the double-ring infiltrometer test is impractical, the single-ring infiltrometer test may be used, provided the testing follows the procedure contained within the City of Chicago **Stormwater** Management **Ordinance** Manual.

5.3.5.1 SOIL SUITABILITY

Retention-based practices require soils with adequate infiltration capacity. The infiltration rate of soil is strongly influenced by the proportion of sand, silt, and clay. Predominately clay soils have infiltration rates that are not sufficient to accommodate the **volume control storage** and predominately sandy soils can infiltrate it too rapidly and adversely impact **groundwater**. In addition to infiltration capacity the soils must be free of contaminants which can also adversely impact **groundwater**.

Retention-based practices should be located on soils that have sufficient infiltration capacity to infiltrate the **volume control storage** and drain within 72-hours. The infiltration capacity of soil should be between 0.50 inch/hour and 2.41 inch/hour. Soils with poor infiltration rates (less than 0.50 inches/hour) are common throughout **Cook County**, but do not prevent the use of **retention-based practices**. If the infiltration capacity of the soil is less than 0.50 inch/hour the design of the **retention-based practice** must incorporate an **underdrain** system that freely outlets overland or into the receiving **stormwater facility**. Soils with poor infiltration rates are not considered a **site constraint**.

If a natural depression is proposed to be used as a **retention-based practice**, the **applicant** must provide the following:

- Infiltration capacity of the soils under existing conditions (inch/hour);
- Existing drawdown time for the high water level and a natural overflow elevation; and
- Operation of the natural depression under post-**development** conditions mimics the hydrology of the system under pre-**development** conditions.

5.3.5.2 SITE CONSTRAINTS

A **site constraint** is a condition within the **development** that limits the use of **retention-based practices**. **Site constraints** include:

- Contaminated soils
- Estimated seasonal high **groundwater** table
- Shallow depth to bedrock
- **Floodway**
- Existing **wetlands** or **riparian environments**

When only a portion of the **property holdings** contains a **site constraint**, **retention-based practices** must be used in the non-constrained area to comply with the volume control requirements to the maximum extent possible. An **applicant** must submit supporting documentation and an exhibit delineating the limits of the **site constraint** for consideration.

Retention-based practices are prohibited within the **floodway** due to the risk of washout and loss of functionally from **flood** waters. **Retention-based practices** may be located within the **floodplain**; however, appropriate measures should be incorporated into the design to ensure it remains functional.

5.3.5.2.1 GROUNDWATER ANALYSIS

The geotechnical report must indicate the elevation of the estimated seasonal high **groundwater** table (ESHGWT) in the location of the proposed **retention-based practice**. The ESHGWT is not the **groundwater** elevation encountered during drilling operations. The minimum separation distances in Table 5.2 must be maintained between the ESHGWT and the bottom of the **retention-based practice** to allow treatment of the **volume control storage** and avoid **groundwater** contamination.

When the minimum distance between the ESHGWT and the bottom of the proposed **retention-based practice** and cannot be maintained, the practice must be relocated or redesigned. If the **applicant** can demonstrate that the minimum separation distance cannot be maintain anywhere within the **property holdings**, then the **development** may qualify for a **site constraint** and the use of **offsite retention-based practices** or alternative compliance solutions, may be utilized to comply with the volume control requirements.

TABLE 5.2 SEPARATION DISTANCE FOR VOLUME CONTROL PRACTICE AND ESTIMATED SEASONAL HIGH GROUNDWATER TABLE

Stormwater Tributary to	Minimum Separation Distance
Waterway	2.0-feet
MWRD Facilities	3.5-feet

5.3.5.2.2 CONTAMINATED SOIL

A **development** may occur on a property where the current or historical uses have contaminated the soil. These types of properties typically include aboveground or underground storage tanks for gasoline, petroleum, or other chemicals. The land use of a new **development** may also potentially contaminate the soil and **groundwater**. These types of **developments** typically include gas stations and chemical storage facilities.

If that the **applicant** can demonstrate that the property contains contaminated soil, then the **development** may qualify for a **site constraint** and the use of **offsite retention-based practices** or alternative compliance solutions may be utilized to comply with the volume control requirements.

An **applicant** must submit an environmental report with supporting documentation and an exhibit delineating the limits of the contaminants for **site constraint** consideration. Also, it must be noted that if only a portion of the property contains contaminants, **retention-based practices** can be used in the non-contaminated area to comply with the volume control requirements.

5.3.6 FLOW-THROUGH PRACTICES

Flow-through practices are designed to provide water quality benefits by filtering pollutants from the **volume control storage**. Many **flow-through practices** allow some infiltration, however; since they do not have quantifiable storage, the reduction of **stormwater runoff** discharged from the **development** is negligible.

Typical **flow-through practices** include:

- Vegetated filter strips
- Bio-swales
- Constructed **wetlands**
- Storm **structure** inserts (sumps, hoods, trash racks)
- Mechanical **structures** (e.g., oil/grit separators, pollutant removal devices)

Flow-through practices that use deep-rooted vegetation can trap suspended **sediments** and incorporate nutrients into their biomass as **stormwater runoff** flows through the practice. When storm **structure** inserts or mechanical **structures** are used, captured **sediments** must be removed as part of regular **maintenance**.

5.3.6.1 FLOW-THROUGH PRACTICE DESIGN CONSIDERATIONS

Flow-through practices must be sized to allow sufficient contact time with the treatment practice (shallow water depths, low velocities) for pollutant removal to occur. The contact time is critical to the effectiveness of pollutant removal and it should be maximized to provide adequate treatment of the **volume control storage**. Refer to the **Illinois Urban Manual** for additional design considerations.

Providing vegetated **flow-through practices** may be difficult in many **redevelopment** areas due to the lack of soils capable of supporting hearty vegetative growth. Many soils have undergone significant compaction and nutrient loss, which can limit root **development** and proper drainage. **Flow-through practices** can also have the potential to interfere with existing infrastructure and their design should be considered accordingly.

5.3.7 RETENTION-BASED PRACTICES

Retention-based practices are designed to capture, retain and infiltrate the **volume control storage**, have quantifiable storage volume, and provide water quality benefits.

Typical **retention-based practices** include:

- Infiltration trenches and basins
- Bioretention facilities
- Porous/permeable pavement
- Dry-wells
- Bioswale with check dams
- Storage below the outlet of a **detention facility**
- Constructed **wetlands** that have forebays, deepwater zones, and micropools
- Green roofs

5.3.7.1 PRETREATMENT OF STORMWATER RUNOFF

§503.4.A(2) of the **WMO** requires pretreatment of **stormwater runoff** to protect the functionality of **retention-based practices** where necessary. Pretreatment is critical to prevent **retention-based practices** from clogging. This reduces long-term **maintenance** of the practice and also provides an added level of protection against **groundwater** contamination.

Flow-through practices, such as vegetated swales or filter strips, should be used to comply with the pretreatment requirement. In some cases, the use of trash racks, sumps, and snouts/hoods will also comply with the pretreatment requirements as these measures prevent debris from entering the **retention-based practice**. Additionally, upstream drainage areas should be properly stabilized both during and after construction to reduce **erosion** and minimize **sediment** loads entering the practice. Table 5.3 provides a summary of pretreatment measures that may be used for various **volume control practices**. It should also be noted that pretreatment is not required for **stormwater runoff** originating from roofs.

5.3.7.2 RETENTION-BASED PRACTICE DESIGN CONSIDERATIONS

Retention-based practices must be designed to capture the **volume control storage** (first flush of **stormwater runoff**), have quantifiable storage, completely drain within 72-hours, and maintain a separation distance with the estimated seasonal high **groundwater** table. When deep rooted vegetation is incorporated into the practice, emergent plantings tolerant of wet-dry cycles must be selected to ensure long-term performance of the practice (refer to **IDOT** seed mixes). Sod is not recommended for areas subject to surface water inundation. Additionally, an overflow route must be incorporated to convey **stormwater runoff** from the practice into the receiving system.

5.3.7.2.1 QUANTIFIABLE STORAGE VOLUME

Retention-based practices must have quantifiable storage volume. Depending on the type of practice, storage volume may consist of surface storage (ponding), storage in the voids of growing media, and storage in the voids of coarse aggregate.

Volume provided above the ground surface is limited to 12-inches of **wetland** ponding. To obtain storage credit for surface ponding, it must occur above deep-rooted vegetation. Ponding depths above 12-inches are not considered volume control and considered **impervious area**. The average-end-area method must be used to calculate the surface storage of the **retention-based practice**.

Volume provided within the voids of the growing media and coarse aggregate is based on the porosity and whether **underdrain** is incorporated into the practice. The growing media should be comprised of 50% sand, 30% organics (e.g., aged composted leaf mulch), and 20% high quality topsoil. Other growing media mixes are allowed provided they comply with the composition indicated in Table 5.4. Coarse aggregate must comply with **IDOT** CA-1, CA-3, or CA-7 gradation. Other types of coarse aggregate may be allowed, provided it is crushed angular stone that is clean and free of fines (no more than 10% passing the No. 4 sieve).

When test data is not available, the porosity for growing media and coarse aggregate is provided in Table 5.5. To calculate the void volume of the **retention-based practice**, the volume of material is multiplied by its porosity. Void volume credit depends on whether an **underdrain** is part of the practice and is summarized in Table 5.6.

TABLE 5.3 PRETREATMENT MEASURES FOR RETENTION-BASED PRACTICES

Retention-Based Practice	Pretreatment Measures
Bioretention Facility	• Level spreader must be installed where runoff enters as shallow concentrated flow to distribute runoff over entire facility. • Vegetated filter strip, grass-lined channel, or sump must be installed upstream to filter sediment and floatable materials. • Where inflow velocities are greater than 3 ft/s, a vegetated filter strip or rock outlet protection must be installed to prevent erosion and distribute flows across the facility. • Vegetated portions of the contributing drainage area must be stabilized.
Bioswale	• Level spreader must be installed where runoff enters as shallow concentrated flow to distribute runoff over entire facility. • Vegetated portions of the contributing drainage area must be stabilized.
Constructed Wetlands	• Where inflow velocities are greater than 3 ft/s, rock outlet protection should be provided to prevent erosion and distribute the flows into the facility. • Vegetated portions of the contributing drainage area must be stabilized. • Sediment forebay must be installed upstream of the facility.
Dry Well	• Filter screens must be installed on all roof drains directed toward the facility. • For facilities that include inflow pipes, sump and/or trash rack must be installed at manhole immediately upstream of facility.
Green Roof	• No pretreatment measures required.
Infiltration Trench	• Level spreader must be installed where runoff enters as shallow concentrated flow to distribute runoff over entire facility. • Vegetated filter strip, grass-lined channel, or sump must be installed upstream to filter sediment and floatable materials. • Where inflow velocities are greater than 3 ft/s, a vegetated filter strip or rock outlet protection should be provided to prevent erosion and distribute flows across the facility. • Vegetated portions of the contributing drainage area must be stabilized.
Permeable Pavement/Pavers	• Vegetated filter strip, grass-lined channel, or sump must be installed upstream to filter sediment and floatable materials. • Vegetated portions of the contributing drainage area must be stabilized.
Storage Below Detention Facility Outlet	• Where inflow velocities are greater than 3 ft/s, rock outlet protection should be provided to prevent erosion and distribute the flows into the facility. • Vegetated portions of the contributing drainage area must be stabilized. • Sediment forebay must be installed upstream of the facility.
Water Reuse System	• Filter screens must be installed on all roof drains directed toward the facility. • For facilities that include inflow pipes, sump and/or trash rack must be installed at manhole immediately upstream of facility.
Filter Strip (Flow-through practice)	• Level spreader must be installed where runoff enters as shallow concentrated flow to distribute runoff over entire facility. • Vegetated portions of the contributing drainage area must be stabilized.

TABLE 5.4 GROWING MEDIA MIX BASED ON UNDERLYING SOIL

Underlying Soil	Growing Media Mix
Any	50% sand 30% organic 20% high quality topsoil
Clay	50% Sand 50% District composted biosolids or any other compost (incorporate into top 4-inches)
Sandy	40% high quality topsoil 60% District composted biosolids or any other compost (incorporate into top 4-inches)
Loamy	25% Sand 75% District composted biosolids or any other compost (incorporate into top 4-inches)

TABLE 5.5 POROSITY FOR MATERIALS USED IN RETENTION-BASED PRACTICES

Material	Porosity
CA-1, CA-3, CA-7	0.36
CA-16, Pea Gravel	0.25
Growing Media	0.25

TABLE 5.6 RETENTION-BASED PRACTICE STORAGE VOLUME CREDIT

Underdrain	Volume Credit
Surface Storage (up to 12-inches above deep-rooted vegetation)	100%
Above Underdrain Invert (including volume of underdrain)	50%
Below Underdrain Invert (limited to 12-inches)	100%
No underdrain (soil test infiltration rate > 0.50 in/hour)	100%

5.3.7.2.2 UNDERDRAIN

A perforated **underdrain** is required for all **retention-based practices** unless an infiltration test is submitted indicating the infiltration capacity of the soil is greater than or equal to 0.50 inch/hour. This is due to the prevalence of soils with poor infiltration rates throughout **Cook County**. Additionally, the practice must drain from the high water elevation (HWL) to an elevation 2-inches above the bottom of the practice within 72-hours to provide:

- Wet-dry cycling between **storm events**
- Storage for frequent **storm events**
- Suitable habitat for vegetation
- Aerobic conditions
- Unsuitable mosquito breeding habitat

The bedding for the **underdrain** must be a minimum of 2-inches and a maximum of 12-inches of coarse aggregate. The **underdrain** should be no larger than 4-inches in diameter to encourage retention, installed at zero slope with perforations directed downward, and connect to the drainage system or upstream of the **control structure** when detention is provided. A “sock” should not be installed on the **underdrain** when predominantly clay soils are present. When multiple runs of **underdrains** are installed, they should also be spaced at no more than 30-feet on center.

5.3.7.2.3 FILTER FABRIC

The use of filter fabric must be considered for **retention-based practices**. When the practice includes both growing media and coarse aggregate, a layer of filter fabric or choking stone must separate them to prevent the practice from clogging due to soil migration. Non-woven filter fabric must be placed to separate the practice from native soils and is not recommended along the bottom of the practice. The **Illinois Urban Manual** contains specifications for filter fabrics and the type and location for where they should be placed. Refer to the **Illinois Urban Manual** for additional guidance on filter fabric (geotextile).

5.3.7.2.4 OBSERVATION WELL

Retention-based practices should be designed to have direct access to perform **maintenance** and must incorporate an observation well. The observation well is required to visually monitor the drawdown rate of water and ensure the practice is functioning as designed. One observation well is required for every 6,000 ft^2 of practice surface area. The observation well should be flush against the ground with 12-inches of topsoil/aggregate surrounding the cap.

5.3.8 OFFSITE RETENTION-BASED PRACTICES

Offsite retention-based practices may be utilized when the **applicant** demonstrates a **site constraint** prevents the **development** from providing onsite **retention-based practices**. The **offsite retention-based practice** must be approved under a **Watershed Management Permit** and located within the same **watershed planning area** as delineated in Appendix E of the WMO. The **offsite retention-based practice** may or may not be the same **owner** as the **development** site.

The **offsite retention-based practice** must retain an equivalent existing **impervious area**, which is not expected to be redeveloped and not subject to volume control requirements under a **Watershed Management Permit**. **Impervious area** tributary to an **offsite retention-based practice** cannot have its **volume control storage** captured more than once, and therefore, cannot comply with the volume control requirements for multiple locations (its own and offsite). Additionally, any volume provided within the **offsite retention-based practice** in excess of its required **volume control storage** cannot be traded (utilized by a **development**) since it is not capturing an existing **impervious area**.

The existing **impervious area** tributary to the **offsite retention-based practice** must be greater than or equal to the **impervious area** of **development** not captured by onsite **retention-based practices**. Multiple **offsite retention-based practices** may be utilized to comply with the **volume control storage** requirement.

Prior to a **development** utilizing an **offsite retention-based practice** all the following requirements must be satisfied:

- The **offsite retention-based practice** must be approved under a **Watershed Management Permit**;
- The **offsite retention-based practice** must function prior to the submittal of the Request for Final Inspection (RFI) for the **development**;
- A letter must be submitted from the **owner** of the **offsite retention-based practice** approving of the use of the practice by the **development** and the quantity of volume allocated for the **development**;
- A copy of the agreement must be submitted for the perpetual **maintenance** of the **offsite retention-based practice** between all parties; and
- When the **development** is tributary to a **waterway**, **flow-through practices** must be provided to capture and pretreat the **volume control storage**.

Note that local **green infrastructure** may not qualify as a **retention-based practice**. **Green infrastructure** refers to any practice designed to mimic hydrologic functions and does not need to capture **stormwater runoff** from **impervious areas** or comply with the design requirements of **retention-based practices**. Only **retention-based practices** approved under a **Watershed Management Permit** complying with the volume control requirements may be used as an **offsite retention-based practice**.

5.3.9 EXAMPLES OF VOLUME CONTROL PRACTICES

Additional details and specifications for the design of **volume control practices** are provided in Appendix C of the **TGM**, the **WMO** website at mwrd.org/wmo, and the **Illinois Urban Manual**. This section provides information on commonly used **volume control practices**.

5.3.9.1 PERMEABLE PAVERS/PAVEMENT

Permeable pavers/pavement is a **retention-based practice**. This practice allows **stormwater runoff** to infiltrate into and through the surfaces of parking lots, streets, and other traditional impervious surfaces. Benefits of this practice include **stormwater** infiltration, reduction of surface **runoff** volume, reduction in **runoff** velocity, and water quality benefits. Porous pavements are particularly beneficial in filtering first flush pollutants (car oil, gasoline, trash, road salt, and suspended solids) observed at the beginning of a **storm event**. Regular **maintenance**, including removal of organic material and **sediments** with street-sweeping vacuums, brushes and water to clear out voids, is necessary to ensure long-term functionally. The design of this practice should consider freeze-thaw cycles, de-icing, snow removal, subgrade compaction, and infiltration capacity of underlying soils.

5.3.9.2 DRY WELL

Dry wells are a **retention-based practice**. This practice consists of an excavated area which is backfilled with aggregate to retain and infiltrate **stormwater runoff** from rooftops. Their typical application is for residential **buildings**. Benefits of this practice include **stormwater** infiltration, reduction of **runoff** volume, and water quality benefits. This practice should be located an adequate distance away from a **building** so that it does not cause **basement** seepage, **flooding**, or surface ponding. Additionally, the drainage area (1-acre maximum) and infiltration capacity of underlying soils should be considered.

5.3.9.3 BIORETENTION FACILITY

Bioretention facilities are a **retention-based practice**. This practice is a landscape feature incorporating deep-rooted vegetation that is designed to retain, infiltrate, and store **stormwater runoff**. A permeable soil layer (growing media) allows **stormwater runoff** to infiltrate to a layer of coarse aggregate, where **stormwater** can be stored in the void space of the aggregate. Bioretention facilities provide surface storage (ponding), storage in the voids of growing media, and storage in the voids of coarse aggregate. Benefits of this practice include **stormwater** infiltration, reduction of **runoff** volume, reduction in **runoff** velocity, and water quality benefits.

5.3.9.4 WATER REUSE SYSTEMS

Water reuse systems are a **retention-based practice**. This practice consists of **structures** that are designed to capture and temporarily store **stormwater runoff**. Typical water reuse systems include rain barrels, cisterns, and aboveground or underground storage tanks. The storage system must include a water reuse application to qualify as a **retention-based practice**. Benefits of this practice include reuse of **stormwater runoff** for irrigation and reduction of **runoff** volume. When a pump is used to dewater the system, an operation plan must be provided describing the dewatering schedule.

5.3.9.5 GREEN ROOF

Green roofs are a **retention-based practice**. This practice consists of a conventional rooftop that includes a vegetated cover that acts like a pervious surface instead of an impervious surface. Green roofs include a planting layer (native vegetation), growing media layer, geotextile fabric, drainage layer, insulation, membrane protection and root barrier, and structural supports. The green roof can be either extensive or intensive depending on the depth of the growing media. Extensive green roofs include a shallow growing media layer (≤ 4-inches) and support vegetation with shallow root systems, such as herbs, grasses, moss, and sedum. Intensive green roofs include a deeper growing medium layer (> 4-inches) that can support vegetation with deeper root zones, including trees and shrubs. Intensive green roof systems are generally limited to flat roofs and require significantly more **maintenance** than extensive green roof systems.

Green roofs provide quantifiable storage volume within the void space of the growing media and drainage layers. Therefore, the curve number and **runoff** coefficient are a function of the total media depth which includes both growing medium and drainage layers. Table 5.11 in 5.6.2.1and Table 5.13 in 5.6.2.2 provide a summary of parameters to be used for green roofs.

The design of a green roof must have the load-bearing capacities verified by a licensed structural engineer. A minimum setback of two (2) feet is required from the roof perimeter and all roof penetrations. Careful attention and additional **maintenance** are necessary during the first two growing seasons to ensure establishment and proper function as a **retention-based practice**. For additional details, specifications, and selection of vegetation refer to ASTM E2400, *Selection, Installation, and **Maintenance** of Plants for Vegetative (Green) Roof Systems*.

5.3.9.6 FILTER STRIP

Filter strips are a **flow-through practice**. This practice consists of vegetated sections of land that provides treatment of **stormwater runoff** from tributary **impervious areas**. The primary benefit of this practice is removal of pollutants and **sediment** from **runoff** prior to discharging into the receiving **stormwater facility**.

Filter strips are suitable for draining areas that are less than 5-acres. The minimum length may be determined by the type of vegetative cover, infiltration capacity of the underlying soil, and slope of the filter strip. In general, filter strips should be no less than 30-feet in length and should not exceed 150-feet in length to prevent **erosion**. The longitudinal slope should be uniform and less than 15%.

5.3.9.7 VEGETATED SWALE

Vegetated swales are a **flow-through practice**. This practice consists of a shallow earthen channel that provides treatment of **stormwater runoff** from tributary **impervious areas** and promote limited infiltration. The primary benefit of this practice is removal of pollutants and **sediment** from **runoff** prior to discharging into the receiving **stormwater facility**. In general, the wetted perimeter should be maximized. Side slopes of 4:1 or flatter are recommended. Longitudinal slopes should range from 0% to 4% as drainage permits. Slopes greater than 4% can be used if check **dams** are used to reduce flow velocity.

Vegetated swales may be combined with non-infiltration related storage volume to treat the **volume control storage**. For example, an underground storage vault may capture the **volume control storage**. This vault may be dewatered and discharge into a vegetated swale. For configurations such as these, the vault provides storage volume, while the vegetated swale provides pollutant removal and limited infiltration.

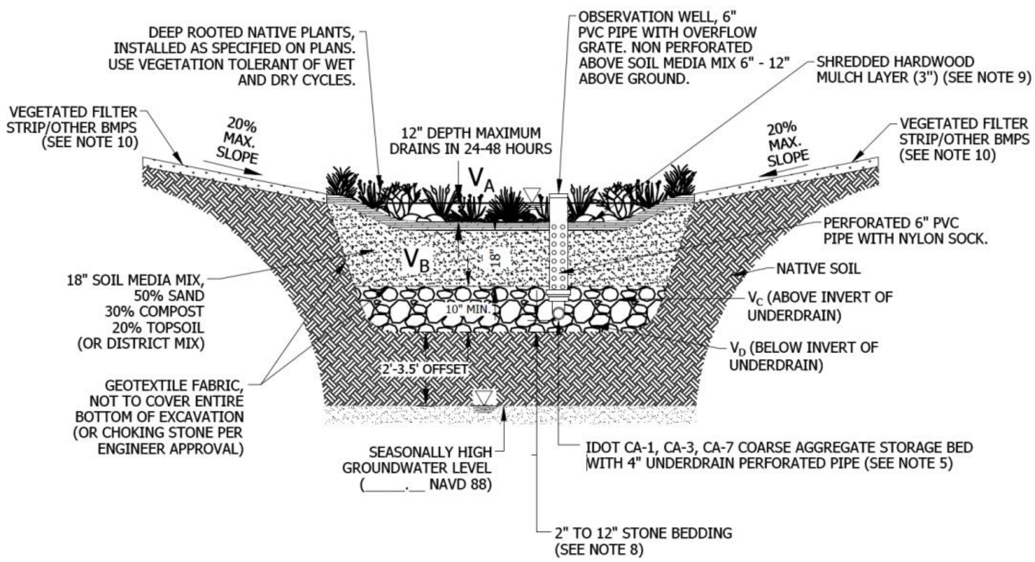
5.3.10 VOLUME CONTROL EXAMPLES

EXAMPLE 1

A **development** will capture the **volume control storage** by a bioretention facility. Information for the **development** is provided in the table below. Determine the required **volume control storage** and surface area of the bioretention facility.

DEVELOPMENT INFORMATION

Development Area	2.78 acres
Impervious Area Proposed	2.32 acres
Site Constraints	None



Step 1. Calculate the **volume control storage** using Equation 5.1:

$$V_c = d\ A_i\ U_c$$

$$= (1\ in)(2.32\ ac)\left(\frac{1\ ft}{12\ in}\right)$$

$$= 0.194\ ac\text{-}ft$$

Step 2. Calculate the area of the bioretention facility. For this example, the facility is designed to provide 0.194 ac-ft of storage volume with 12-inches of surface ponding, 18-inches of aggregate and growing media, 6-inches of aggregate above the **underdrain**, and the **underdrain** is 12-inches above the bottom of the facility. The area is calculated to be 5160 ft^2 (0.12-acre).

Answer: The **volume control storage** of 0.194 ac-ft is captured by the bioretention facility with a surface area of 5160 ft^2 (0.12-acre). Storage volume information is provided below.

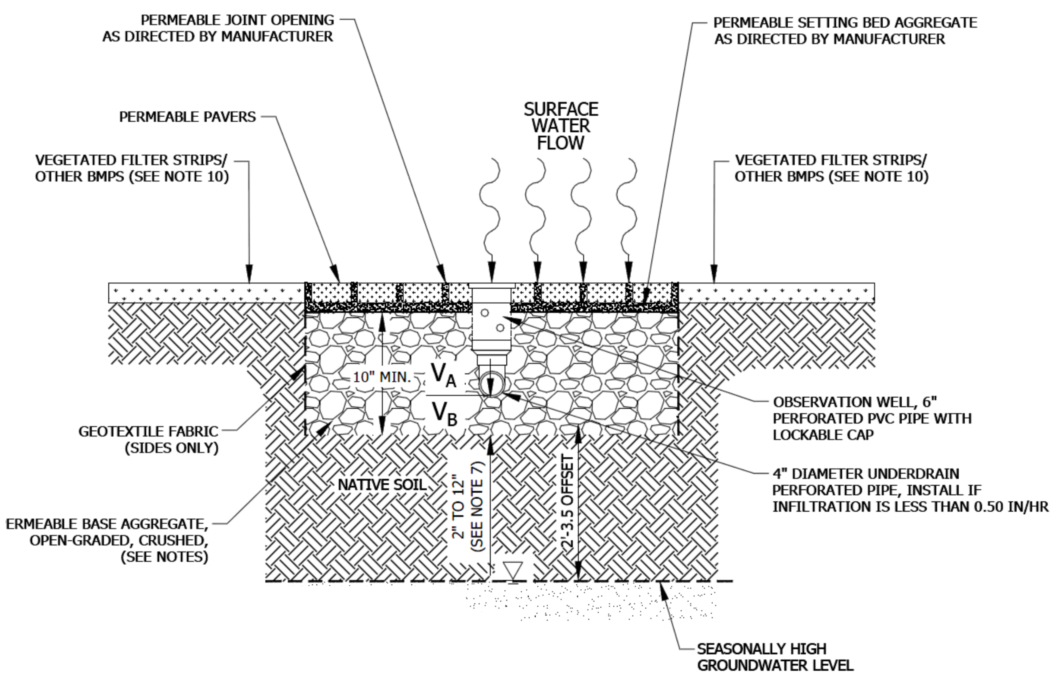
Volume Type	Surface Area	Depth	Porosity	Storage Volume	Volume Provided
V_A: Surface Storage	0.12 ac	1.0 ft	1.00	(1.00)(V_A)	0.120 ac-ft
V_B: Soil Media Mix	0.12 ac	1.5 ft	0.25	(0.50)(0.25)(V_B)	0.022 ac-ft
V_C: Coarse Aggregate (above invert)	0.12 ac	0.5 ft	0.36	(0.50)(0.36)(V_C)	0.011 ac-ft
V_D: Coarse Aggregate (below invert)	0.12 ac	1.0 ft	0.36	(0.36)(V_D)	0.043 ac-ft
				Total:	**0.194 ac-ft**

EXAMPLE 2

A **development** occurs with contaminated soils located only on a portion of the site. Permeable pavers are proposed in the non-contaminated area to capture the **volume control storage**. There are no **offsite retention-based practices** available. Information for the **development** is provided below. Determine the **volume control storage** considering the reduction of **impervious area**.

DEVELOPMENT INFORMATION

Development Area	2.25 acres
Impervious Area Proposed	1.54 acres
Site Constraints	Contaminated Soils
Impervious Area Reduction	10%



Step 1. Calculate the gross **volume control storage** using Equation 5.1:

$$V_c = d\ A_i\ U_c$$

$$= (1\ in)(1.54\ ac)\left(\frac{1\ ft}{12\ in}\right)$$

$$= 0.128\ ac\text{-}ft$$

Step 2. Calculate the required **volume control storage** considering the reduction of **impervious area**:

$$V_C = 0.128\ ac\text{-}ft - (10\%)\left(\frac{5\%}{1\%}\right)(0.128\ ac\text{-}ft)$$

$$= 0.064\ ac\text{-}ft$$

Answer: The **volume control storage** of 0.064 ac-ft must be captured by the permeable pavers.

EXAMPLE 3

A **non-residential development** will capture the **volume control storage** in a **retention-based practice** that is incorporated into the underground **detention facility**. Pretreatment of the **volume control storage** will be provided by a sump and hood upstream of the facility. Information for the **development** is provided below. Determine the required **volume control storage**.

DEVELOPMENT INFORMATION

Development Area	9.00 acres
Impervious Area Proposed	5.84 acres
Site Constraints	None

Step 1. Calculate the gross **volume control storage** using Equation 5.1:

$$V_c = d\ A_i\ U_c$$

$$= (1\ in)(5.84\ ac)\left(\frac{1\ ft}{12\ in}\right)$$

$$= 0.487\ ac\text{-}ft$$

Step 2. Calculate the storage volume provided within the **retention-based practice**. Storage volume is provided in voids at the bottom of the vault. The facility has volume available 2-feet of above and 1-foot below the **underdrain**. No volume is provided around the sides of the vault. The facility is 0.41-acres and the volume provided within the **retention-based practice** is 0.493 ac-ft.

Answer: The **volume control storage** of 0.493 ac-ft is captured by the **retention-based practice**. The storage information is provided below:

Volume Type	Surface Area	Depth	Porosity	Storage Volume	Volume Provided
V_A: Vault Storage (above invert*)	0.41 ac	1.5 ft	1.00	$(1.00)(0.50)(V_A)$	0.308 ac-ft
V_B: Coarse Aggregate (above invert)	0.41 ac	0.5 ft	0.36	$(0.50)(0.36)(V_B)$	0.037 ac-ft
V_C: Vault Storage (below invert)	0.41 ac	N/A	1.00	$(1.00)(V_C)$	0.000 ac-ft
V_D: Coarse Aggregate (below invert)	0.41 ac	1.0 ft	0.36	$(0.36)(V_D)$	0.148 ac-ft
*Below Detention Outlet				**Total:**	**0.493 ac-ft**

EXAMPLE 4

A **project** will construct a **retention-based practice** to capture 4.87-acres of existing **impervious area** to be utilized as an **offsite retention-based practice**. The existing **impervious area** did not previously require volume control and is not expected to be redeveloped in the future. Determine the **volume control storage** captured by the **retention-based practice** that is available for trading.

Step 1. Calculate the gross **volume control storage** using Equation 5.1

$$V_c = d\ A_i\ U_c$$

$$= (1\ in)(4.87\ ac)\left(\frac{1\ ft}{12\ in}\right)$$

$$= 0.406\ ac\text{-}ft$$

Answer: The **offsite retention-based practice** has 0.406 ac-ft of **volume control storage** available for trading.

Note that when this **offsite retention-based practice** is utilized by a **development**, the following must be submitted:

- The **applicant** for the **development** must demonstrate a **site constraint** prevents the use of onsite **retention-based practices**
- A letter from the **owner** of the **offsite retention-based practice** approving of the use of the facility by the **development** and the quantity of traded **volume control storage**
- A copy of the agreement for the perpetual **maintenance** of the **offsite retention-based practice** between all parties

5.4 DETENTION REQUIREMENTS

5.4.1 GENERAL DETENTION REQUIREMENTS

§504.1 of the WMO regulates detention based on the type of **development** and the size of the **property holdings**. Note that unlike other regional or local regulators, the **WMO** detention requirements are not based on new **impervious area** created by **development**. Table 5.1 (refer to 5.1.2) summarizes when detention requirements are applicable.

It is important to note the following items:

- **Single-Family Homes**, **open space development**, **demolition**, **maintenance activities**, and **non-qualified development** are exempt from the detention requirements.
- **Multi-family residential** and **non-residential development** require detention when the **property holdings** is greater than or equal to 3-acres and the new **development** either individually or in the aggregate is greater than or equal to 0.50-acre after the effective date of the **WMO**.
- **Right-of-way development** must comply with the detention requirements when the new **impervious area** is greater than or equal to 1-acre where practicable. If the detention requirements are not provided in full, the **applicant** must demonstrate the **right-of-way development** complies with the detention requirements to the maximum extent possible.
- When detention was deferred for previous **development** within the **property holdings**, the previously deferred area must be included as part of the detention requirements for the current **development**.
- **Development** that discharges **stormwater** to a **stormwater facility** tributary to Lake Michigan may be exempt from the detention requirements. Refer to 5.4.10 for additional information.

When a **project** includes **development** or **redevelopment** that will utilize an **existing detention facility**, the detention requirements are provided in Section 5.5 of this **TGM**.

5.4.2 RELEASE RATE

§504.2 through §504.7 of the **WMO** defines various release rates for **development** that must be considered and incorporated into the design of the **detention facility**. These release rates and considerations are described in the sections below.

5.4.2.1 GROSS ALLOWABLE RELEASE RATE

The **gross allowable release rate** is the maximum allowable release rate from a **development** during the 100-year **storm event**. This includes all release rates from restricted, unrestricted, and **depressional storage** areas of the **development**. The **gross allowable release rate** is determined by the **watershed** specific release rate of the **watershed planning area** where the **development** is located and summarized in Table 5.7. **Watershed** specific release rates are also specified in Appendix B of the **WMO** and **watershed planning areas** are delineated in Appendix E of the **WMO**.

TABLE 5.7 WATERSHED SPECIFIC RELEASE RATES

Watershed Planning Area	Gross Allowable Release Rate
Calumet Sag Channel	0.30 cfs/acre
Little Calumet River	0.25 cfs/acre
Lower Des Plaines	0.20 cfs/acre
North Branch	0.30 cfs/acre
Poplar Creek	0.25 cfs/acre
Upper Salt Creek	0.20 cfs/acre

5.4.2.2 NET ALLOWABLE RELEASE RATE

The **net allowable release rate** is the maximum allowable release rate from the **control structure** of a **detention facility**. This release rate is calculated by adjusting the **gross allowable release rate** due to **unrestricted flows** and existing flow rates of **depressional storage** areas of the **development**. The **actual release rate** must not exceed the **net allowable release rate**.

5.4.2.3 UNRESTRICTED FLOW

A **development** should maximize the amount of area tributary to the **detention facility**. Areas that are not tributary (unrestricted areas) produce **unrestricted flow**. This **unrestricted flow** must be either mitigated or deducted from the **gross allowable release rate**. Additionally, the **applicant** must demonstrate that it does not cause damage to downstream or adjacent property.

In general, if the **development** maintains the existing drainage patterns and discharge rates, the **unrestricted flow** from the **development** will likely not cause **flood** or **erosion** damages to downstream or adjacent property. However, if the **development** modifies the existing drainage pattern or increases flow rates, the **applicant** must submit plans and calculations to demonstrate the discharge from the **development** does not cause **flood** or **erosion** damages to downstream or adjacent property.

Unrestricted flow may be mitigated by onsite trading. The unrestricted area is traded with a hydrologically equivalent area not part of the proposed **development** that is tributary to the **detention facility**. The traded area must be located within the **property holdings** and not subject to the detention requirements under the **WMO** or **Sewer Permit Ordinance**. Typically, this accomplished when there is existing **upstream tributary flow** that can be routed into the **detention facility**. When onsite trading is used to mitigate the unrestricted area, the **gross allowable release rate** is based on the **development** area (restricted and unrestricted areas). The **required detention volume** is based on the hydrologically equivalent area (refer to 5.4.8) and the restricted **development** area.

Unrestricted flow may be mitigated by creating a **native planting conservation area**. The unrestricted area must be planted with deep-rooted vegetation, placed within an easement, and maintained in perpetuity. **Native planting conservation areas** are considered **non-qualified development**. When a **native planting conservation area** is used to mitigate the unrestricted area, the **gross allowable release rate** excludes this area from the **development** area.

Unrestricted flow may also be mitigated by deducting it from the **gross allowable release rate**. The **unrestricted flow** rate is calculated considering the 100-year **storm event** with a 24-hour duration using an event hydrograph method described in 5.6.4.

5.4.2.4 DEPRESSIONAL STORAGE

Depressional storage areas reduce the rate of **stormwater runoff** leaving the site since **stormwater runoff** is retained onsite. When the existing **runoff** rate for the **depressional storage** area is less than the **gross allowable release rate**, then the **net allowable release rate** for the **development** must be based on the existing **runoff** rate. Additionally, any **unrestricted flow** created by the **development** must also be deducted and further reduces the **net allowable release rate**.

The existing **runoff** rate for the **depressional storage** area must be calculated for the 100-year **storm event** with a 24-hour duration using an event hydrograph method described in 5.4.3.3.

5.4.2.5 ACTUAL RELEASE RATE

The **actual release rate** is the release rate from the **control structure** of a **detention facility** at the 100-year high water elevation (HWL) where the **required detention volume** is provided. The **actual release rate** must not exceed the **net allowable release rate**. When a **development** includes multiple **detention facilities** with **control structures** discharging offsite in multiple locations, the sum of all individual **actual release rates** must not exceed the **net allowable release rate**. Refer to 5.6.14 for **control structure** types and discharge rate calculations.

5.4.3 DETENTION VOLUME

§504.8 through §504.10 **WMO** defines various detention volume requirements for the **development** that must be considered and incorporated into the design of the **detention facility**. The **required detention volume** is based on **Bulletin 75** rainfall data (refer to 5.6.7) for the 100-year **storm event** with a 24-hour duration and must be calculated using the **actual release rate** of the **detention facility**. The **required detention volume** may be calculated by either the nomograph method or an event hydrograph method utilizing **NRCS** curve number methodology (refer to 5.6.2.1) and an outlet control routing option. Additionally, storage volume provided within onsite **retention-based practices** may be credited toward the **required detention volume**.

The **required detention volume** may be calculated by either the nomograph method or an event hydrograph method. The nomograph method is not meant to address complex hydrology or hydraulics and may not be used in any of the following scenarios:

- The **development** is greater than or equal to 20-acres;
- The **net allowable release rate** is affected by **depressional storage**;
- There is **upstream tributary flow** through the **control structure** of the **detention facility**;
- The **BFE** or any other tailwater conditions affect the **actual release rate**; or
- Non-traditional or composite **control structures**.

The average-end-area method must be used to calculate the detention volume provided within the **detention facility**.

5.4.3.1 DETENTION VOLUME CREDIT FOR RETENTION-BASED PRACTICES

Storage volume provided within **retention-based practices** may be credited toward the **required detention volume** when they are located within the same **property holdings** as the **detention facility**. To qualify for this credit, all of the following must be satisfied:

- The storage volume of the **retention-based practice** is accessed during the 100-year **storm event**; and
- The outlet of the **retention-based practice** is tributary to and located upstream of the **control structure** for the **detention facility**.

Credit is provided for **retention-based practices** by using an adjusted **runoff** curve number (CN_{ADJ}) to calculate the **required detention volume**. CN_{ADJ} is calculated using the **NRCS runoff** equation by reducing the total **runoff** volume of the **development** by the storage provided within the **retention-based practice**. When CN_{ADJ} is used, the storage associated with **retention-based practices** must not be included in the stage-storage-discharge relationship for the **detention facility**. Refer to 5.6.5 for CN_{ADJ} *and t*he **District** provides a CN_{ADJ} calculator that can be found on the **WMO** website at mwrd.org/wmo.

5.4.3.2 NOMOGRAPH METHOD

The nomograph method calculates the **required detention volume** by inputting the proposed **runoff** curve number (*CN*) for the **development** and the **actual release rate**. When volume control is provided by a **retention-based practice**, CN_{ADJ} should be used. When CN_{ADJ} is used, the storage associated with **retention-based practices** must not be included in detention volume calculations.

A nomograph that incorporates **Bulletin 75** rainfall data and curves for various release rates is provided to determine the **required detention volume**. When an **actual release rate** does not align with the provided curve, the **applicant** may use the next lower release rate or interpolate between the provided curves. Refer to 5.6.6 for the nomograph and the **District** provides a Nomograph Calculator that can be found on the **WMO** website at mwrd.org/wmo.

5.4.3.3 EVENT HYDROGRAPH METHOD

The event hydrograph method, described in 5.6.4, with outlet control routing is used to calculate the **required detention volume** for the 100-year storm event with a 24-hour duration. The stage-storage-discharge relationship for the **detention facility** and **control structure** must be incorporated into the model to demonstrate the 100-year HWL at the **required detention volume** does not exceed the **net allowable release rate**. When volume control is provided by a **retention-based practice**, CN_{ADJ} should be used. When CN_{ADJ} is used, the storage associated with **retention-based practices** must not be included in the stage-storage-discharge relationship for the **detention facility**.

The **applicant** must submit calculations and/or a summary of the model output for the **detention facility**. The **applicant** may be required to submit the full model results. An **applicant** may use other proprietary software (e.g., *HydroCAD*, *PondPack*, etc.) provided the assumptions described in 5.6.4 are incorporated. However, the **District** will review the calculations using an event hydrograph method described in 5.6.4 and will not accept a lesser **required detention volume** or a higher **actual release rate** when proprietary software is used for the calculations.

5.4.4 CONTROL STRUCTURE

The **control structure** (i.e. restrictor) is the **structure** that controls the release rate of the **detention facility** such that the **required detention volume** is provided. The **actual release rate** from the **control structure** must not exceed the **net allowable release rate**. The **control structure** must be designed to operate by gravity. A **control structure** that incorporates a pump may only be used when all other alternatives have been exhausted.

5.4.4.1 GRAVITY CONTROL STRUCTURE

Control structures that discharge by gravity include the following:

- Storm **structure** with an orifice plate or baffle wall
- Restrictor pipe (**storm sewer**)
- Weir
- Vortex restrictor

Refer to 5.6.14 for calculating the **actual release rate** from the **control structure**. When a vortex restrictor is used as the **control structure**, the **applicant** must submit the manufacturer stage-discharge relationship for the **actual release rate**.

5.4.4.2 PUMPED CONTROL STRUCTURE

Control structures that discharge by pump may only be used when a gravity outlet is not possible. In addition to the items indicated in 5.4.4.3, the following items must be considered and incorporated into the pump design:

- A backup pump must be provided;
- Individual pumps must be designed not to exceed the **net allowable release rate**;
- The programmable logic controller (PLC) must be designed to prohibit simultaneous operation of pumps that exceed the **net allowable release rate**. Note that the **applicant** may be required to submit PLC schematics;

- The plan set must include a detail for the **control structure** with all relevant dimensions, elevations, and pump operation (on/off) elevations;
- The **applicant** must submit relevant calculations including pump and system curves for the full and empty conditions of the **detention facility**; and
- The **co-permittee** must submit a letter detailing the plan to provide backup power to the pumps in the event of primary power outage.

5.4.4.3 DESIGN CONSIDERATIONS

The **control structure** must incorporate all requirements depicted and noted on the standard details provided by the **District**. Standard details for **control structures** are provided in Appendix C of this **TGM** and on the **WMO** website at mwrd.org/wmo. Additionally, the following items must be considered and incorporated into the design of the **control structure**:

- The **control structure** (and emergency overflow **structure**) must be located within the **property holdings**;
- The restrictor within the **control structure** must be durable and permanently installed and must not contain any plastic or removable/adjustable gates;
- The restrictor within the **control structure** must be visible and readily accessible for **maintenance** and inspection;
- The restrictor must be located on the downstream side of the **control structure**;
- The **control structure** must be designed to be self-cleaning;
- The **control structure** must incorporate a backflow prevention device when tributary to a **combined sewer** or **District water reclamation facilities**;
- The **control structure** must be a minimum 4-foot diameter manhole or a **structure** with equivalent internal clearance;
- The restrictor within the **control structure** must be constructed with a steel plate, concrete, or pipe complying with the material specifications in the **District's** general notes provided in Appendix C of this **TGM**; and

- The **actual release rate** of a restrictor must not exceed the **net allowable release rate**; therefore, there is no minimum restrictor diameter. Note that **maintenance** increases with small diameter restrictors and it is recommended that alternative restrictors (vortex restrictor, weir) be used whenever possible to avoid multiple restrictors or designs that include high head. When a restrictor less than 4-inches is proposed, a clogging prevention device should be installed (sumps, hoods, trash racks, etc.). Vortex restrictors should not be used when a 4-inch diameter or larger orifice can be used.

5.4.5 DETENTION FACILITY

The **detention facility** is designed to provide the **required detention volume** (100-year **storm event** with a 24-hour duration) at the **actual release rate**. When the volume control requirements apply to the **development**, a **retention-based practice** may also be incorporated into the **detention facility**. Typical **detention facilities** include:

- Wet and/or dry detention basins
- Underground systems (concrete vaults, prefabricated systems, etc.)
- Surface ponding (parking lots)

§504.15 of the **WMO** requires the **detention facility** be provided within the **property holdings**. When all means of providing the **required detention volume** onsite is technically infeasible and documented, an **offsite detention facility** may be utilized in the following hierarchy:

1. Offsite in a **detention facility** where the **development** conveys the 100-year **storm event** to the **detention facility**;
2. Partially onsite in a **detention facility** with supplemental storage in an **offsite detention facility** where the **offsite detention facility** is located in accordance with the following hierarchy:
    a. Upstream or hydrologically equivalent to the **development** within the same **watershed planning area**; or
    b. Within the same **watershed planning area**.

5.4.5.1 ONSITE DETENTION FACILITIES

Onsite **detention facilities** must be provided for **developments** that do not contain a site limitation. If the **applicant** can demonstrate a site limitation is present only on a portion of the property, **detention facilities** should be used in the non-limited area to comply with the detention requirements. When it is not practicable to provide onsite **detention facilities** due to a site limitation, the **applicant** must explore whether **offsite detention facilities** can be utilized to comply with the detention requirements.

5.4.5.2 SITE LIMITATIONS

A site limitation is a condition within the **development** that limits the use of a **detention facility**. Site limitations that prevent the construction of an onsite **detention facility** must be present in order to pursue the use of **offsite detention facilities**. Site limitations include:

- **Floodway**
- Shallow bedrock
- Extreme topography
- Existing, fully-developed **property holdings** without at-grade or underground space

If the **applicant** believes a potential site limitation exists, they may submit supporting documentation and an exhibit delineating the extent of the potential limitation for consideration.

5.4.5.3 EXPLORATION OF OFFSITE DETENTION FACILITIES

When the **District** determines a **development** contains a site limitation, the **applicant** must explore whether **offsite detention facilities** can be utilized to comply with the detention requirements. The **applicant** must pursue providing the **required detention volume** for the **development** in accordance with the following hierarchy:

1. In a detention facility where the 100-year storm event from the development is conveyed to the detention facility;
2. In an **offsite detention facility** within the same **watershed planning area** that captures a hydrologically equivalent area upstream of the **development**;
3. In an **offsite detention facility** within the same **watershed planning area** that captures a hydrologically equivalent volume.

If the **applicant** utilizes an **offsite detention facility**, the **applicant** must submit documentation to the **District** summarizing their efforts to comply with the hierarchy above. Refer to 5.4.9 for additional information on **offsite detention facilities**.

5.4.5.4 EMERGENCY OVERFLOW

An emergency overflow **structure** must be incorporated into the design of the **detention facility**. This **structure** protects the **detention facility** from overtopping and safely conveys **stormwater** to the receiving system if the **control structure** fails. The emergency overflow **structure** of the **detention facility** and conveyance route to the receiving system is considered a **major stormwater system**. These components must be designed and provide sufficient capacity to convey the **design runoff rates** for the **upstream tributary flow** and the detained area. If the **design runoff rate** is less than 1 cfs/acre, the emergency overflow **structure** and conveyance route must have the capacity to convey a minimum of 1 cfs/acre. Typically, the overflow **structure** is a weir constructed as part of the **detention facility**. Refer to 5.6.14.3 for calculating the capacity of a weir.

The invert elevation of the emergency overflow **structure** may be placed at the 100-year high water level (HWL) of the **detention facility**. The design water surface elevation (hydraulic grade line, HGL) associated with the emergency overflow **structure** must maintain at least one (1) foot of separation from the **lowest entry elevation** of any **buildings** located within or adjacent to the **development**. Refer to 5.2.7.7 for additional information on **building** protection standards.

5.4.5.5 DESIGN CONSIDERATIONS

The following items must be considered and incorporated into the design of the **detention facility**:

- The **detention facility** must be accessible and maintainable:
  - Aboveground earthen **detention facilities** should be accessible to **maintenance** equipment (lawn mowers, trucks, etc.)
  - Underground detention systems should have a minimum of two (2) access points (manholes) at opposite ends of the system large enough for **maintenance** equipment. Access points should be located near all at inlets/outlets to the system
- The **detention facility** must function with a gravity outlet wherever possible;
- The **detention facility** must function without human intervention and under tailwater conditions;
- Include an emergency overflow **structure** and overflow route that can safely convey the **design runoff rate** and no less than 1 cfs/acre;
- The maximum **stormwater** detention inundation depth on parking lots must not exceed 12-inches and the inundation hazard must be clearly posted;

- Earthen **detention facilities** must be provided with:
    - Side slope stabilization
    - Stabilization and armoring (riprap, concrete, or other durable material) when erosive forces may cause soil **erosion** or washout at inlets/outlets (flared end sections) and the emergency overflow
- **Stormwater** inundation depths and limits resulting from the 100-year high water elevation of the **detention facility** must be located within the **property holdings**.

5.4.6 UPSTREAM TRIBUTARY FLOW

Upstream tributary flow includes **stormwater runoff** or **groundwater** flow from an area upstream of the **development**. This flow can occur from areas located within (non-**development** area) or outside the **property holdings** and is calculated using the same methodology as the **design runoff rate** described in 5.2.6. §504.11 of the **WMO** requires these **upstream tributary flows** to be safely routed around or through the **detention facility**. Methods to address **upstream bypass flow** are described in the following sections.

5.4.6.1 BYPASS UPSTREAM TRIBUTARY FLOW

It is recommended that **upstream tributary flows** be bypassed around the **detention facility**, however; the routing method depends on the ratio of the upstream area to the detained area. When **upstream tributary flows** bypass the **detention facility**, the **detention facility** provides the **required detention volume** for the **development** at the **actual release rate**.

When the ratio of the upstream area to the detained area is less than 5:1, **upstream tributary flow** may be routed through the **detention facility** using the emergency overflow **structure**. The emergency overflow **structure** of the **detention facility** is considered a **major stormwater system** and must be designed and have sufficient capacity to convey the **design runoff rates** for the **upstream tributary flow** and the detained area. The **applicant** must also submit calculations for the drawdown time of the **detention facility**. When the drawdown time is greater than 72-hours, **upstream tributary flow** should be bypassed around the **detention facility**.

When the ratio of the upstream area to the detained area is greater than or equal to 5:1, **upstream tributary flow** must be routed around the **detention facility**. Typically, an open channel conveyance system or **storm sewer** system is selected to bypass the flow around the **detention facility**. The bypass system is considered a **major stormwater system** and must be designed and have sufficient capacity to convey the **design runoff rate** for the **upstream tributary flow**.

5.4.6.2 PROVIDE DETENTION FOR THE UPSTREAM TRIBUTARY FLOW

If **upstream tributary flow** is detained within the **detention facility**, the **detention facility** provides the **required detention volume** for both the **development** and the upstream area. The **actual release rate** used to determine the **required detention volume** depends on the location of the **upstream tributary flow**. If the upstream area is located outside of the **property holdings**, the **actual release rate** is based on the **development** area only. If the upstream area is located within the **property holdings**, the **actual release rate** may be based on the **development** and upstream area.

5.4.6.3 PROVIDE STORAGE FOR THE UPSTREAM TRIBUTARY FLOW

If **upstream tributary flow** is stored within the **detention facility**, the **detention facility** provides the **required detention volume** for both the **development** and the upstream area at an **actual release rate** that does not cause damage to adjacent or downstream properties. The **applicant** must demonstrate that the **actual release rate** does not increase velocities or flows downstream or on adjacent properties for the 2-year, 10-year, and 100-year **storm events**, at a minimum, using a **critical duration analysis**. The minimum **required detention volume** for the **detention facility** must be based on the **actual release rate** for the **development** without considering the upstream area.

5.4.7 TAILWATER CONDITIONS

§504.12 of the **WMO** requires the **BFE** or any other tailwater conditions to be considered in the calculations for the **actual release rate** and **required detention volume**.

A tailwater condition reduces the **actual release rate** due to the elevation of the downstream hydraulic grade line being above the invert elevation of the **control structure**. These tailwater conditions typically occur when **detention facilitates** discharge into **floodplains**, downstream **detention facilities**, **depressional storage** areas, or other **stormwater facilities**.

To protect the **development** against overflows and **flooding**, the calculation of the **required detention volume** must consider the tailwater elevation. The release rate from the **control structure** is zero until the high water elevation of the **detention facility** is greater than the downstream hydraulic grade line. The **detention facility** must be designed to comply with the following:

- The **actual release rate** must not exceed the **net allowable release rate** assuming no tailwater effect (free-flow condition),
- The **required detention volume** must be calculated at the **actual release rate** assuming zero release below the tailwater elevation (submerged release)

The tailwater elevation due to a **floodplain** must be the **BFE** shown on the effective **FIS** and **FIRM** or a **project**-specific **100-year flood elevation** as described in §601.4 and §601.5 of the **WMO**. The tailwater elevation due to a downstream **detention facility** is the 100-year high water elevation of the facility. The tailwater elevation due to a **depressional storage** area should be the elevation resulting from the 100-year **storm event** with a 24-hour duration.

Note that if the **detention facility** is located within an area mapped as a **floodplain** on the effective **FIRM**, the **floodplain** provisions of Article 6 of the **WMO** apply.

5.4.8 HYDROLOGIC EQUIVALENT TRADING

Hydrologic equivalent trading can be used to mitigate **unrestricted flows** created by **development** (onsite trading) or when an **offsite detention facility** (offsite trading) is utilized to comply with the detention requirements. Areas are considered hydrologically equivalent when the **stormwater runoff** volume from them are equivalent.

Equation 5.3 is used to calculate the **stormwater runoff** volume of an area. This equation is modified from Equation 2.1 of the **NRCS** TR-55 manual. The **District** provides a **Runoff** Volume Calculator that can be found on the **WMO** website at mwrd.org/wmo. The equations to calculate the **runoff** volume are:

$$V_R = \frac{(P-0.2S)^2}{(P+0.8S)}\,(A)\left(\frac{1}{12\frac{in}{ft}}\right) \tag{5.3}$$

$$S = \frac{1000}{CN} - 10 \tag{5.4}$$

Where:
- V_R = **runoff** volume, ac-ft
- P = 100-year, 24-hour rainfall depth, inches (use Table 5.14)
- S = potential maximum retention after **runoff** begins, inches
- CN = composite **runoff** curve number
- A = area, acres

5.4.9 OFFSITE DETENTION FACILITIES

Offsite detention facilities may be utilized when the **applicant** demonstrates a site limitation prevents the **development** from providing detention onsite and calculations are provided demonstrating the **development** will comply with §501.1 of the **WMO**. The **offsite detention facility** must be approved under a **Watershed Management Permit** and located within the same **watershed planning area** as delineated in Appendix E of the **WMO**. The facility may or may not have the same ownership as the **development** site.

The **offsite detention facility** must provide detention for a hydrologically equivalent area, which is not expected to be redeveloped and not subject to the detention requirements under the **WMO** or **Sewer Permit Ordinance**. Additionally, the **offsite detention facility** must provide detention for an area that is not currently detained. Refer to 5.4.8 for hydrologically equivalent trading.

Prior to a **development** utilizing an **offsite detention facility** all the following requirements must be satisfied:

- The **offsite detention facility** must be approved under a **Watershed Management Permit**;
- The **offsite detention facility** must be functional prior to the submittal of the Request for Final Inspection (RFI) for the **development**;
- A letter must be submitted from the **owner** of the **offsite detention facility** approving the use of the facility by the **development** and the quantity of traded volume; and
- A copy of the agreement must be submitted for the perpetual **maintenance** of the **offsite detention facility** between all parties.

It is important to note that when undeveloped areas that are detained within the **offsite detention facility** are subsequently developed and subject to the detention requirements, the area can no longer be used as a hydrologically equivalent area and the **required detention volume** must be provided for the original **development**. This can be accomplished by providing a **detention facility** for the original **development** utilizing the **offsite detention facility** or by a trade with another **offsite detention facility**.

5.4.10 DISCHARGES TO LAKE MICHIGAN

§504.18 of the **WMO** exempts **development** from the detention requirements when all of the following conditions are satisfied:

- The **development** discharges **stormwater** to a **stormwater facility** tributary to Lake Michigan;
- The **stormwater facility** conveying **stormwater** to Lake Michigan has adequate capacity determined by the governing **municipality**;
- The **development** complies with the volume control requirements; and
- The **development** intercepts and treats all **stormwater runoff** to improve water quality prior to discharge.

Improvements to the water quality of **stormwater runoff** may be provided by a treatment train of various systems or a mechanical **structure** (hydrodynamic separator) with a settling/separation unit to remove **sediments**, hydrocarbons, and other pollutants. The characteristics and volume of **stormwater runoff** must be considered when determining the type of system to be used.

Water quality benefits are satisfied by demonstrating the following **stormwater runoff** pollutant removal standards:

- 80% total suspended solids (TSSS), defined by OK-110 particle size distribution (PSD);
- 80% of free floatable hydrocarbons; and
- 100% of floatables (trash, debris).

Providing a water quality system does not preclude the **applicant** from obtaining any necessary federal, state, or local permits for discharges into Lake Michigan.

Water quality systems must have capacity to treat the peak **runoff** volume for the 2-year **storm event** with a 24-hour duration (first flush). Additionally, the system must contain an overflow system that can safely bypass flows in excess of the 2-year **storm event** with a 24-hour duration. A typical detail of a mechanical **structure** is provided in Appendix C of the **TGM** and the **WMO** website at mwrd.org/wmo.

5.4.11 DETENTION EXAMPLES

EXAMPLE 1

A **non-residential development** consists of a **building**, permeable paver parking lot, landscaped vegetation, and a **detention facility**. The **volume control storage** will be captured by and provided within the permeable paver parking lot. Information for the **development** is provided below. Determine the size of the **control structure** and the **required detention volume** using the nomograph method.

DEVELOPMENT INFORMATION

Watershed Planning Area	Poplar Creek Watershed (0.25 cfs/acre)
Development Area	3.00 acres
Unrestricted Area	None
Upstream Tributary Area	None
Tailwater Conditions	None
Site Constraints (volume control)	None
Site Limitations (detention)	None
Hydrologic Soil Group (HSG)	D

DEVELOPMENT AREA INFORMATION

Surface Type	Area (acres)	Curve Number, *CN* *(HSG D)*
Building	0.78	98
Landscaping	0.72	80
Permeable Pavers	1.25	91
Wet-Bottom Detention Basin	0.25	100
TOTAL	3.00	-

DETENTION FACILITY INFORMATION

	Elevation (ft)
High Water Elevation (HWL)	605.00
Normal Water Elevation (NWL)	600.00
Control Structure Invert (Orifice Plate, C_d = 0.61)	600.00

Step 1. Calculate the **gross allowable release rate**:

$$Q_{gross\ allowable} = A_{development}Q_{watershed\ specific\ releade\ rate}$$

$$= (3\ acres)(0.25\ cfs/acre)$$

$$= 0.75\ cfs$$

Step 2. Calculate the **net allowable release rate**:

$$Q_{net\ allowable} = Q_{gross\ allowable} - Q_{unrestricted}$$

$$= 0.75\ cfs - 0\ cfs$$

$$= 0.75\ cfs$$

Step 3. Calculate the diameter of the orifice plate restrictor for the **control structure**. For this example, the maximum diameter will be used. This occurs when the **actual release rate** is equal to the **net allowable release rate** of 0.75 cfs. Using either Equation 5.28 or the Orifice Calculator, the diameter is 3.58-inches. Refer to 5.4.4.3 for additional information regarding **maintenance** for small diameter restrictors.

ORIFICE DISCHARGE RATE

PROJECT: Detention Example 1 **PERMIT NUMBER:**

LOCATION: **DATE:**

RESTRICTOR INFORMTION

1.	Orifice Number	1		
2.	Orifice diameter, *d*	3.58	in	
3.	Discharge Coefficient, C_d	0.61		
4.	Invert Elevation	600.00	ft	
5.	High Water Elevation, HWL	605.00	ft	
6.	Tail Water Elevation		ft	

ACTUAL RELEASE RATE

6.	Free Flow Actual Release Rate at HWL	0.75	cfs	
7.	Submerged Actual Release Rate at HWL		cfs	

STAGE-DISCHARGE TABLE CONDITION (SELECT FROM DROP-DOWN)

Free-flow

STAGE-DISCHARGE TABLE

Elevation (ft)	Orifice 1 (cfs)	Orifice 2 (cfs)	Total (cfs)	
600.00	0.00		0.00	
600.50	0.20		0.20	
601.00	0.32		0.32	
601.50	0.40		0.40	
602.00	0.47		0.47	
602.50	0.52		0.52	
603.00	0.58		0.58	
603.50	0.63		0.63	
604.00	0.67		0.67	
604.50	0.71		0.71	
605.00	0.75		0.75	HWL
605.50	0.79		0.79	
606.00	0.83		0.83	

Step 4. Calculate the composite **runoff** curve number. Using either Equation 5.12 or the Composite *CN* Calculator, the composite *CN* is 90.93.

COMPOSITE RUNOFF CURVE NUMBER (*CN*)

PROJECT: Detention Example 1 **PERMIT NUMBER:** ______

LOCATION: ______ **DATE:** ______

TYPE OF AREA (SELECT WITH DROP-DOWN)

X DETAINED AREA

__ MAJOR STORMWATER SYSTEM

__ UNRESTRICTED AREA

__ OTHER: ______

__ UPSTREAM AREA

CONDITION (SELECT WITH DROP-DOWN)

X PROPOSED CONDITION

__ EXISTING CONDITION

RUNOFF CURVE NUMBER

Surface Description	Hydrologic Soil Group (HSG)	CN	Area (acres)	Product (CN)(Area)
Building	D	98	0.78	76.44
Landscaping	D	80	0.72	57.60
Permeable Pavers	D	91	1.25	113.75
Wet-Bottom Detention Basin	D	100	0.25	25.00
		TOTALS:	3.00	272.79

COMPOSITE RUNOFF CURVE NUMBER

$$\text{Composite CN} = \frac{\text{Total Product}}{\text{Total Area}} = \frac{272.79}{3.00} \rightarrow \textbf{Composite CN} = \textbf{90.93}$$

Step 5. Calculate the adjusted **runoff** curve number, CN_{ADJ}. For this example, assume the storage provided within the permeable paver parking lot is equal to the **volume control storage**. Using the CN_{ADJ} Calculator, CN_{ADJ} is equal to 88.77.

ADJUSTED COMPOSITE RUNOFF CURVE NUMBER (CN_{ADJ})

PROJECT: Detention Example 1 **PERMIT NUMBER:**

LOCATION: **DATE:**

DEVELOPMENT INFORMTION			
1. Area Detained, *A*		3.000	acres
2. Total Impervious Area		0.780	acres
3. Composite CN		90.93	
4. Volume Control Storage Provided, VC_P		0.065	ac-ft
5. Depth of Rainfall, *P*		8.57	inches
RUNOFF VOLUME (NRCS EQUATIONS)			
6. Maximum Retention, *S*	$S = \frac{1000}{CN} - 10$	1.00	inches
7. Runoff Depth, Q_D	$Q_D = \frac{(P - 0.2S)^2}{(P + 0.8S)}$	7.48	inches
8. Runoff Volume, V_R	$V_R = Q_D A \left(\frac{1}{12\frac{in}{ft}}\right)$	1.87	ac-ft
VOLUME CONTROL STORAGE			
9. Volume Control Storage Required, VC_R		0.065	ac-ft
10. Additional Volume Control Storage Provided		0.000	ac-ft
ADJUSTED RUNOFF VOLUME			
11. Adjusted Runoff Volume, V_{ADJ}	$V_{ADJ} = V_R - VC_P$	1.805	ac-ft
12. Adjusted Runoff Depth, Q_{ADJ}		7.22	inches
13. Adjusted Maximum Retention, S_{ADJ}		1.26	inches
ADJUSTED COMPOSITE RUNOFF CURVE NUMBER			
14. Adjusted Runoff Curve Number, CN_{ADJ}		88.77	

Step 6. Using the **actual release rate** of 0.75 cfs and CN_{ADJ} of 88.77, calculate the **required detention volume.** Using the nomograph, the **required detention volume** for the **development** is 1.101 ac-ft.

NOMOGRAPH: BULLETIN 75 RAINFALL DATA

PROJECT: Detention Example 1 **PERMIT NUMBER:**

LOCATION: **DATE:**

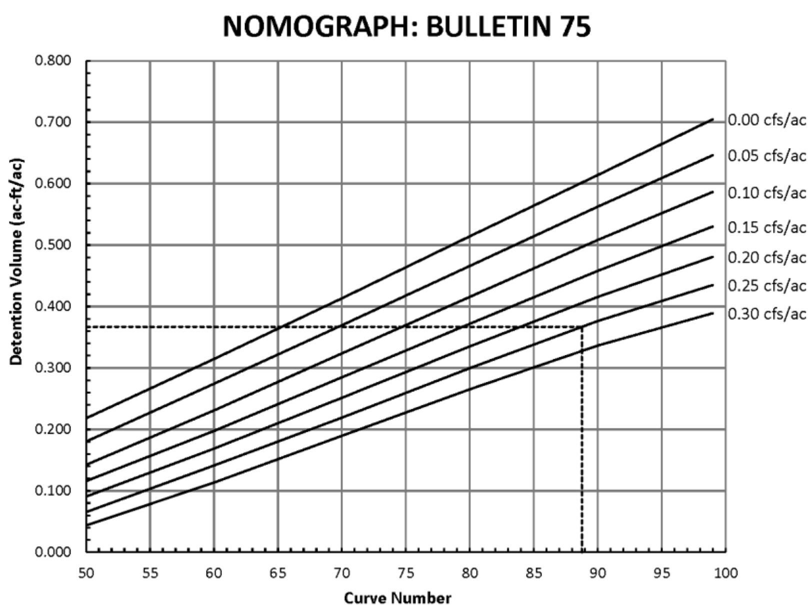
DEVELOPMENT INFORMATION

1. Detained Area	3.000	acres
2. Curve Number	88.77	
3. Actual Release Rate	0.750	cfs

REQUIRED DETENTION VOLUME

4. Required Detention Volume	1.101	ac-ft

NOMOGRAPH



Answer: The **control structure** is a 3.58-inch diameter orifice plate and the **required detention volume** is 1.101 ac-ft.

EXAMPLE 2

A **non-residential development** required detention and an upstream area to be bypassed, and a **detention facility**. The **volume control storage** will be captured by and provided by a bioretention facility. Information for the **development** is provided below. Determine the following:

1. The size of the **control structure** and **required detention volume** using HEC-HMS**.**
2. The **design runoff rate** using HEC-HMS and the size of the emergency overflow weir.

DEVELOPMENT INFORMATION

Watershed Planning Area	North Branch Watershed (0.30 cfs/acre)
Development Area	4.5 acres
Unrestricted Area	0.5 acres
Upstream Tributary Area	1.2 acres
Time of Concentration (all areas)	10-minutes
Tailwater Conditions	None
Site Constraints (volume control)	None
Site Limitations (detention)	None
Hydrologic Soil Group (HSG)	D

DEVELOPMENT AREA INFORMATION

Surface Type	Area (acres)	Curve Number, *CN* *(HSG D)*
Building	1.55	98
Landscaping	0.65	80
Unrestricted Area	0.50	80
Parking Lot	1.40	98
Wet-Bottom Detention Basin	0.40	100
TOTAL	4.50	-

UPSTREAM TRIBUTARY AREA INFORMATION

Surface Type	Area (acres)	Curve Number, *CN* *(HSG D)*
Paved path	0.20	98
Landscaping	1.00	80
TOTAL	1.20	-

DETENTION FACILITY INFORMATION

	Elevation (ft)
High Water Elevation (HWL)	646.50
Normal Water Elevation (NWL)	641.00
Control Structure Invert (Orifice Plate, C_d = 0.61)	641.00

PART 1 SOLUTION

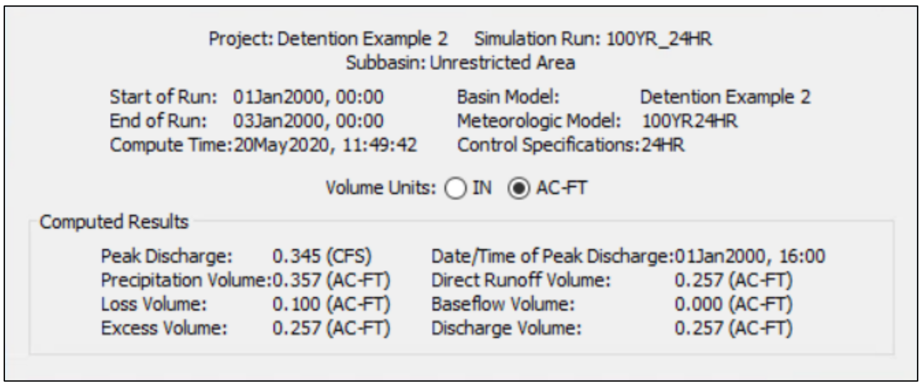
Step 1. Calculate the **gross allowable release rate**:

$$Q_{gross\ allowable} = A_{development} Q_{watershed\ specific\ releade\ rate}$$

$$= (4.5\ acres)(0.30\ cfs/acre)$$

$$= 1.35\ cfs$$

Step 2. Calculate the **unrestricted flow** using HEC-HMS by creating a subbasin for the 0.50-acre (0.00078125 mi^2) unrestricted area with a *CN* of 80 and a lag time of 6-minutes (60% of 10-minute T_c). The **unrestricted flow** rate is 0.35 cfs.



Step 3. Calculate the **net allowable release rate**:

$$Q_{net\ allowable} = Q_{gross\ allowable} - Q_{unrestricted}$$

$$= 1.35\ cfs - 0.35\ cfs$$

$$= 1.00\ cfs$$

Step 4. Calculate the diameter of the orifice plate restrictor for the **control structure**. For this example, the maximum diameter will be used. This occurs when the **actual release rate** is equal to the **net allowable release rate** of 1.00 cfs. Using either Equation 5.28 or the Orifice Calculator, the diameter is 4.03-inches. For this example, a 4.00-inch restrictor plate will be used. Refer to 5.4.4.3 for additional information regarding **maintenance** for small diameter restrictors.

Step 5. Calculate the composite **runoff** curve number using Equation 5.12:

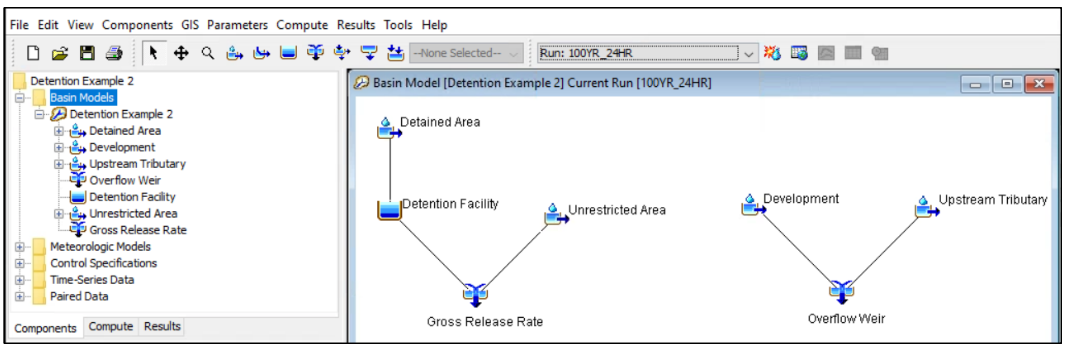
$$CN = \frac{CN_1A_1+CN_2A_2+\ldots+CN_nA_n}{\sum A}$$

$$= \frac{(100)(0.40)+(98)(1.40+1.55)+(80)(0.65)}{4.00}$$

$$= 95.28$$

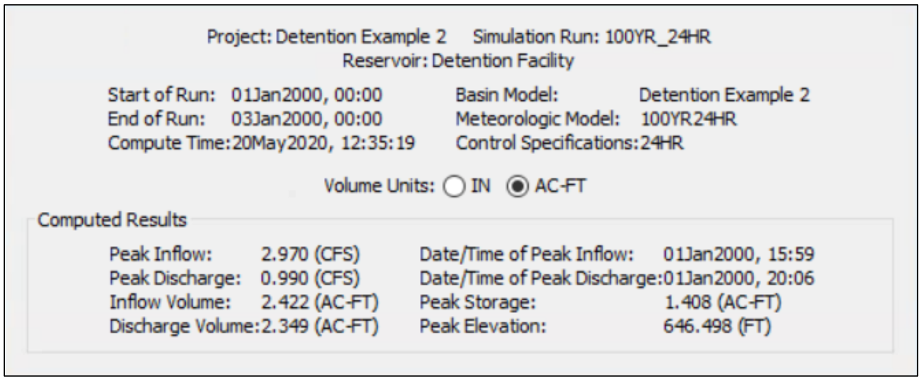
Step 6. Calculate the adjusted **runoff** curve number, CN_{ADJ}. For this example, assume the storage provided within the bioretention facility is equal to the **volume control storage**. Using the CN_{ADJ} Calculator, CN_{ADJ} is equal to 89.15.

Step 7. Using HEC-HMS, create a subbasin for the 4.0-acre (0.00625 mi^2) detained area with a *CN* of 89.15 and a reservoir for the proposed **detention facility**. Using the known elevations of the **detention facility** and the **actual release rate** of the **control structure**, a stage-storage-discharge relationship is iteratively determined to provide adequate volume to store the 100-year **storm event** with a 24-hour duration. The basins shown on the right side of the image are used for Part 2 of this example.



Answer: The **control structure** is a 4.00-inch diameter orifice plate restrictor. The **required detention volume** is 1.41 ac-ft at the HWL of 646.50 ft with an **actual release rate** of 0.99 cfs. The resulting stage-storage-discharge relationship followed by the model output for the **detention facility** is below. Note that the HEC-HMS model template for this **development** is provided on the **District** website at mwrd.org/wmo.

Elevation (ft)	Storage (ac-ft)	Discharge (cfs)
641.00	0.000	0.00
642.00	0.172	0.39
643.00	0.378	0.58
644.00	0.622	0.72
645.00	0.904	0.84
646.00	1.230	0.94
646.50	1.409	0.99


Project: Detention Example 2 Simulation Run: 100YR_24HR
Reservoir: Detention Facility

Start of Run:	01Jan2000, 00:00	Basin Model:	Detention Example 2
End of Run:	03Jan2000, 00:00	Meteorologic Model:	100YR24HR
Compute Time:	20May2020, 12:35:19	Control Specifications:	24HR

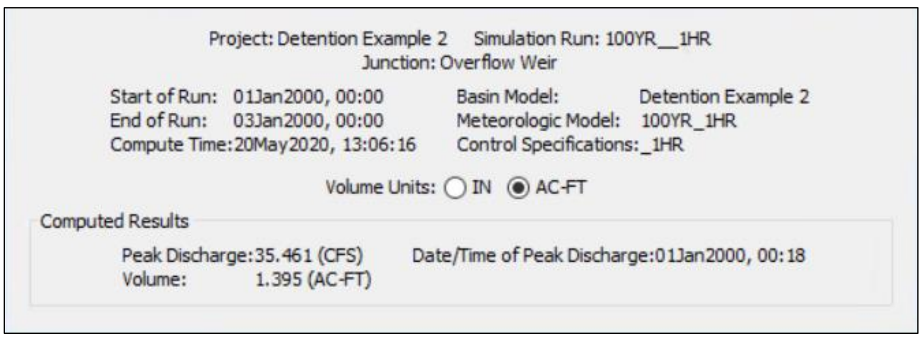
Volume Units: IN AC-FT

Computed Results

Peak Inflow:	2.970 (CFS)	Date/Time of Peak Inflow:	01Jan2000, 15:59
Peak Discharge:	0.990 (CFS)	Date/Time of Peak Discharge:	01Jan2000, 20:06
Inflow Volume:	2.422 (AC-FT)	Peak Storage:	1.408 (AC-FT)
Discharge Volume:	2.349 (AC-FT)	Peak Elevation:	646.498 (FT)

PART 2 SOLUTION

Step 1. Calculate the **design runoff rate** from both the detained area and the upstream area tributary to the **detention facility** emergency overflow weir. Using HEC-HMS, create a subbasin for the 1.2-acre (0.001875 mi^2) upstream area with a composite *CN* of 83.00 and a subbasin for the 4.0-acre (0.00625 mi^2) detained area with a composite *CN* of 95.28. The **design runoff rate** resulting from the **critical duration analysis** is 35.46 cfs.


Project: Detention Example 2 Simulation Run: 100YR__1HR
Junction: Overflow Weir

Start of Run:	01Jan2000, 00:00	Basin Model:	Detention Example 2
End of Run:	03Jan2000, 00:00	Meteorologic Model:	100YR_1HR
Compute Time:	20May2020, 13:06:16	Control Specifications:	_1HR

Volume Units: IN AC-FT

Computed Results

Peak Discharge:	35.461 (CFS)	Date/Time of Peak Discharge:	01Jan2000, 00:18
Volume:	1.395 (AC-FT)		

Step 2. Calculate the dimensions of the emergency overflow weir to convey the **design runoff rate**. To comply with the **building** protection standards of the **WMO**, the maximum hydraulic grade line of the weir is 647.00 ft. Additionally, the breadth of the weir crest is 3-feet. Calculate the length of the broad-creased weir using Equation 5.30:

$$Q = CLH^{\frac{3}{2}}$$

$$L = \frac{35.46}{(2.63)\left(0.5^{\frac{3}{2}}\right)}$$

$$= 38.14\ ft$$

Answer: The emergency overflow weir is broad-crested with a length of 38.14 ft with the hydraulic grade line 0.50 ft above the crest.

EXAMPLE 3

The **detention facility** in Example 2 is discharging into the **floodplain** with the **BFE** of 644.00 ft. Determine the **required detention volume** using HEC-HMS.

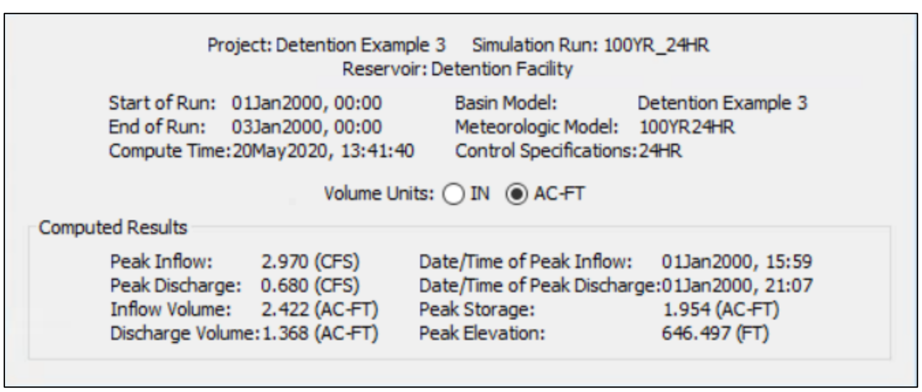
Step 1. Create a new stage-discharge relationship of the **control structure** for the submerged condition. The resulting stage-discharge relationship is below.

Elevation (ft)	Discharge (cfs)
641.00	0.00
642.00	0.00
643.00	0.00
644.00	0.00
645.00	0.43
646.00	0.60
646.50	0.68

Step 2. Using HEC-HMS, determine the required volume to store the 100-year **storm event** with a 24-hour duration.

Answer: The **required detention volume** is 1.954 ac-ft. The resulting stage-storage-discharge relationship followed by the model output for the **detention facility** is below.

Elevation (ft)	Storage (ac-ft)	Discharge (cfs)
641.00	0.000	0.0000
642.00	0.257	0.0001
643.00	0.554	0.0002
644.00	0.895	0.0003
645.00	1.281	0.4300
646.00	1.718	0.6000
646.50	1.955	0.6800


Project: Detention Example 3 Simulation Run: 100YR_24HR
Reservoir: Detention Facility

Start of Run: 01Jan2000, 00:00 Basin Model: Detention Example 3
End of Run: 03Jan2000, 00:00 Meteorologic Model: 100YR24HR
Compute Time: 20May2020, 13:41:40 Control Specifications: 24HR

Volume Units: IN AC-FT

Computed Results

Peak Inflow: 2.970 (CFS) Date/Time of Peak Inflow: 01Jan2000, 15:59
Peak Discharge: 0.680 (CFS) Date/Time of Peak Discharge: 01Jan2000, 21:07
Inflow Volume: 2.422 (AC-FT) Peak Storage: 1.954 (AC-FT)
Discharge Volume: 1.368 (AC-FT) Peak Elevation: 646.497 (FT)

EXAMPLE 4

A **project** will modify an **existing detention facility** that was previously approved under a **Watershed Management Permit** to be utilized, in part, as an **offsite detention facility**. The existing **right-of-way** (ROW), adjacent to the facility, did not require detention under the original permit and will now be detained. Information for the ROW is provided below. Determine the **runoff** volume from the ROW that will be available for hydrologic equivalent trading.

PROJECT INFORMATION

Watershed Planning Area	Little Calumet River (0.25 cfs/acre)
ROW Area	3.75 acres
Hydrologic Soil Group (HSG)	D

ROW ACREAGE INFORMATION

Surface Type	Area (acres)	Curve Number, *CN* *(HSG D)*
Pavement	3.25	98
Pervious Area	0.50	80

Step 1. Calculate the composite **runoff** curve number. Using either Equation 5.12 or the Composite *CN* Calculator, the composite *CN* is 95.60.

Step 2. Calculate the **runoff** volume. Using either Equation 5.3 or the Runoff Volume Calculator, the **runoff** volume is 2.51 ac-ft.

RUNOFF VOLUME CALCULATOR

PROJECT: Detention Example 4 **PERMIT NUMBER:**

LOCATION: **DATE:**

DEVELOPMENT INFORMTION			
1. Area, *A*		3.75	acres
2. Curve Number, *CN*		95.60	
3. 100-year, 24-hr Rainfall Depth, *P*		8.57	inches
RUNOFF DEPTH (NRCS RUNOFF EQUATIONS)			
4. Maximum Retention, *S*	$S = \frac{1000}{CN} - 10$	0.46	inches
5. Runoff Depth, Q_D	$Q_D = \frac{(P - 0.2S)^2}{(P + 0.8S)}$	8.04	inches
RUNOFF VOLUME			
6. Runoff Volume, V_R	$V_R = Q_D A \left(\frac{1}{12\frac{in}{ft}}\right)$	2.51	ac-ft

Answer: The **runoff** volume available for hydrologic equivalent trading is 2.51 ac-ft.

Note that modifications to the **control structure** and the **existing detention facility** to provide the **required detention volume** for the original **development** and the newly detained ROW may be required and are not covered in this example.

EXAMPLE 5

A **non-residential development** consists of three (3) **buildings**, parking lot, and landscaped vegetation. The **applicant** provided documentation indicating the presence of shallow bedrock throughout the **property holdings** to qualify as a **site constraint** (volume control) and site limitation (detention). Additionally, the **applicant** provided calculations demonstrating the **development** will comply with §501.1 of the **WMO** without providing detention onsite. The **development** will provide a mechanical **flow-through practice** to comply with the volume control requirements. The **development** will utilize the **offsite detention facility** in Example 4 (same **Watershed Planning Area**) to comply with the detention requirements. Information for the **development** is provided below. Determine the **runoff** volume from the **development** that must be traded and available within **offsite detention facility**.

DEVELOPMENT INFORMATION

Watershed Planning Area	Little Calumet River (0.25 cfs/acre)
Development Area	3.15 acres
Unrestricted Area	None
Upstream Tributary Area	None
Tailwater Conditions	None
Site Constraints (volume control)	Shallow Bedrock
Site Limitations (detention)	Shallow Bedrock
Hydrologic Soil Group (HSG)	C

DEVELOPMENT ACREAGE INFORMATION

Surface Type	Area (acres)	Curve Number, *CN* *(HSG C)*
Buildings	0.75	98
Pavement	0.60	98
Landscaping	1.80	74
TOTAL	3.15	-

Step 1. Calculate the composite **runoff** curve number. Using either Equation 5.12 or the Composite *CN* Calculator, the composite *CN* is 84.29.

Step 2. Calculate the **runoff** volume generated by the **development**. Using either Equation 5.3 or the Runoff Volume Calculator, the **runoff** volume is 1.75 ac-ft.

Answer: The **runoff** volume that must be captured and detained within the **offsite detention facility** is 1.75 ac-ft. Since the **offsite detention facility** in Example 4 has 2.51 ac-ft of **runoff** volume available to trade with this **development**, 0.76 ac-ft of **runoff** volume is available for future trading.

Note that the **applicant** must submit the following:

- A letter from the **owner** of the **offsite detention facility** approving of the use of the facility by the **development** and the quantity of traded **runoff** volume; and

- A copy of the agreement for the perpetual **maintenance** of the **offsite detention facility** between all parties.

5.5 DEVELOPMENT AND REDEVELOPMENT TRIBUTARY TO EXISTING DETENTION FACILITIES

5.5.1 GENERAL DEVELOPMENT AND REDEVELOPMENT REQUIREMENTS

§505 of the **WMO** regulates **development** and **redevelopment** tributary to **existing detention facilities**. Many of these facilities were designed with outdated rainfall data and various release rate methodologies to comply with the requirements at the time they were permitted by the **District** or constructed. The intent of the **WMO** is to gradually update **existing detention facilities** by providing incremental detention volume for **development** and/or **redevelopment** using current rainfall data and release rate requirements. Therefore, the **existing detention facility** may need to be revised to provide additional detention volume and modify the **control structure** to comply with new release rate requirements proportionally with the area of the **development** and/or **redevelopment**. Note that only the **development** and/or **redevelopment** area must comply with the current rainfall data and release rate requirements. However, the **existing detention facility** may be updated to fully comply with the detention requirements of Section 5.4 of this **TGM** rather than following the **redevelopment** methodologies of this section.

When any individual **redevelopment** of the entire **detention service area** occurs, excluding the **existing detention facility**, it must comply with the detention requirements of §504 of the **WMO**. The **detention service area** includes all areas accounted for when calculating the **gross allowable release rate** and the **required detention volume**. This includes all **tributary areas** and **unrestricted flows** (unrestricted area) considered in the design of a **detention facility**.

§505.1 of the **WMO** considers incidental disturbance to an **existing detention facility** to provide additional detention volume to be **non-qualified development**. This also includes restoring an **existing detention facility** to comply with the **required detention volume**.

§505.2 of the **WMO** allows an **existing detention facility** to be used to provide the **required detention volume** for a **development** and/or **redevelopment** when all the following are satisfied:

- The existing **control structure** is verified to comply with the release rate requirements in effect at the time the **control structure** was constructed under this **Ordinance** or the **Sewer Permit Ordinance**. The **control structure** may be modified as part of the proposed work to comply with the release rate requirements;
- The existing detention volume is verified to comply with the **required detention volume** in effect at the time the **existing detention facility** was constructed under this **Ordinance** or the **Sewer Permit Ordinance**. The **existing detention facility** may be modified as part of the proposed work to comply with the **required detention volume**;
- Adequate capacity is provided to convey **stormwater runoff** to the **existing detention facility** for all storms up to and including the 100-year **storm event**; and
- **Volume control practices** are provided to treat the **volume control storage** as required in §503 of the **WMO**.

Verification of the **control structure** and **existing detention facility** must be based on a recent survey signed and sealed by either a **Professional Engineer** or **Professional Land Surveyor** for each **redevelopment**. The verification of the **control structure** must include the invert elevation, diameter, and any other relevant information. The verification of the volume within the **existing detention facility** must be based on information collected within the previous 5 years. The **applicant** must submit relevant calculations and incorporate survey information into the plan set. Alternative verification methods (e.g. **Cook County** topography, LiDAR, aerial photography, **record drawings**) may be accepted by the **District**.

When an **existing detention facility** is used for **development** and/or **redevelopment**, the **applicant** should request a copy of the issued permit from the **District**. To request a copy of an issued permit, please email the Permit Inquiry Inbox at mwrdpi@mwrd.org. This email must include a location map of the area in question along with the contact **person** and phone number.

5.5.2 RELEASE RATE REQUIREMENTS

§505.4.B and §505.4.C of the **WMO** defines the release rate that must be considered and incorporated for **development** and/or **redevelopment** using an **existing detention facility**. This release rate and other considerations are described in the sections below.

5.5.2.1 COMPOSITE RELEASE RATE

A composite **gross allowable release rate** must be calculated for the **detention service area** based on the **watershed** specific release rate of the **development** and/or **redevelopment**, specified in Appendix B of the **WMO**, and the pro-rated share of the existing **gross allowable release rate** for the remaining non-redeveloped area. The composite **net allowable release rate** is then calculated by adjusting the composite **gross allowable release rate** due to any existing and newly created **unrestricted flows** (unrestricted areas) and any existing flow rates due to **depressional storage** areas.

When the **development** and/or **redevelopment's** existing **gross allowable release rate** is less than the **watershed** specific release rate, specified in Appendix B of the **WMO**, the existing **gross allowable release rate** must be used to calculate the composite **gross allowable release rate**.

5.5.2.2 CONTROL STRUCTURE MODIFICATION

To avoid frequent changes to a **control structure** for each incremental **redevelopment**, the **WMO** allows the **control structure** to remain in place until significant **redevelopment** of the **detention service area** occurs. The **control structure** must be modified to comply with the composite **net allowable release rate** described in 5.5.2.1 when any **redevelopment**:

- Is greater than or equal to 25% of the **detention service area**; or
- Results in the aggregate **development** and/or **redevelopment** of the **detention service area** greater than or equal to the following milestones: 40%, 80%, or 100%.

The percent **redevelopment** is determined by dividing the individual or aggregate **redevelopment** area by the **detention service area**. The **detention service area** must consider any newly added or removed areas.

Note that modifications to the **control structure** may also be required if the release rate at the 100-year HWL of the **detention facility** exceeds the existing **net allowable release rate**. This may occur when the **required detention volume** for the **redevelopment** is provided by adjusting the 100-year HWL or when areas are removed from the **detention service area**.

5.5.3 DETENTION VOLUME FOR REDEVELOPMENT

§505.4.A of the **WMO** requires detention volume to be provided for **redevelopment** tributary to an **existing detention facility**. The **required detention volume** for the **redevelopment** must be calculated using **Bulletin 75** rainfall data (refer to 5.6.7) and the lesser of the **watershed** specific release rate for the **redevelopment** or the **actual release rate** of the **control structure**.

It is important to note the following items:

- **Redevelopment** may require additional detention volume due to updated rainfall data and release rates requirements regardless of the net change to **impervious area**.
- The **required detention volume** for **redevelopment** is determined by the incremental detention volume based only on the area of **redevelopment**.
- When detention volume is provided in a manner that increases the existing 100-year HWL and the **control structure** is not modified, the new **actual release rate** must comply with the existing **net allowable release rate**.
- Storage volume provided within onsite **retention-based practices** may be credited toward the **required detention volume**, provided the **retention-based practice** complies with the requirements of 5.4.3.1.
- If detention was deferred for previous **development** within the **property holdings**, the previously deferred area must be included as part of the detention requirements for the **redevelopment**.

The methodology used to calculate the **required detention volume** depends on whether the **existing detention facility** was approved under a **Sewerage System Permit** or a **Watershed Management Permit**. If the **existing detention facility** was <u>not</u> approved under a **District** permit, the methodology used to calculate the **required detention volume** is based on the **District's** requirements in effect at the time the **existing detention facility** was constructed. Note that if the **existing detention facility** was constructed on or after May 1st, 2014 effective date of the **Watershed** Management **Ordinance** and <u>not</u> approved under a **Watershed Management Permit**, the requirements of Section 5.4 of this **TGM** apply.

5.5.3.1 EXISTING DETENTION FACILITIES PERMITTED UNDER THE SPO

Redevelopment tributary to an **existing detention facility** subject to the **Sewer Permit Ordinance** (**SPO**) and approved under a **Sewerage System Permit** may use the Modified Rational Method to calculate the **required detention volume**. Storage volume within **retention-based practices** may be credited toward the **required detention volume** when located within the same **property holdings** as the **detention facility** provided it complies with the requirements 5.4.3.1.

The procedure to determine the new **required detention volume** resulting from **redevelopment** located within the **detention service area** of an **existing detention facility** is:

1. Calculate the existing **required detention volume** based on the **runoff** coefficient for the area to be **redeveloped**, the **actual release rate** of the **control structure** pro-rated for the area, and the existing rainfall data used under the approved permit.

2. Calculate the **required detention volume** of the **redevelopment** based on the proposed **runoff** coefficient, the lesser of the **watershed** specific release rate or the **actual release rate** of the **control structure** pro-rated for the area, and **Bulletin 75** rainfall data.

3. Calculate the required incremental detention volume for the **redevelopment** by subtracting the existing **required detention volume** (Step 1) from the **required detention volume** (Step 2).

4. Calculate the new **required detention volume** for the **detention service area** by adding the incremental detention volume (Step 3) to the previously approved **required detention volume**.

5.5.3.2 EXISTING DETENTION FACILITIES NOT PERMITTED UNDER THE SPO

The **SPO** did not require detention for **projects** in the **combined sewer area** or when a **project** did not comply with specified acreage thresholds when located within the **separate sewer area**. However, a local **ordinance** may have required detention to be provided for these **projects**. When **development** and/or **redevelopment** is tributary to an **existing detention facility** constructed prior to the May 1, 2014 effective date of the **Watershed** Management **Ordinance** and not approved under a **Sewerage System Permit** (**SPO** permit), the Modified Rational Method (refer to 5.6.12) may be used to calculate the **required detention volume**.

The **existing detention facility** must be verified to comply with (or modified as part of the current work) the **stormwater** detention requirements of the **Sewer Permit Ordinance**. The procedure to verify the **existing detention facility** is:

1. Calculate the longest time-of-concentration, T_c (5.6.1.2), for the undeveloped, natural condition of the **detention service area**. If undeveloped grades are unavailable, T_c may be calculated assuming the longest diagonal at 1% slope.

2. Calculate the existing **gross allowable release rate** (5.6.12.1) for the 3-year **storm event** with a duration equal to T_c.

3. Calculate the existing **net allowable release rate** for the **detention service area** by accounting for any **unrestricted flows**. **Unrestricted flows** must be calculated using the 100-year **storm event**. The **actual release rate** of the existing **control structure** must be less than or equal to the **net allowable release rate**. Note that modification to the **control structure** may be required.

4. Calculate the existing **required detention volume** (5.6.12.2) of the **detention service area** based on the composite **runoff** coefficient, **actual release rate** of the existing **control structure**, and Technical Paper 40 rainfall data (5.6.9).

5. Calculate the new **required detention volume** for the **detention service area** utilizing the existing **required detention volume** of the **detention service area** (Step 4) and the previously permitted **required detention volume** using the procedure in 5.5.3.1.

5.5.3.3 EXISTING DETENTION FACILITIES PERMITTED UNDER THE WMO

Redevelopment tributary to an **existing detention facility** approved under a **Watershed Management Permit** (**WMO** permit) may use either the nomograph method or an event hydrograph method with **NRCS** curve number methodology and outlet control routing to calculate the **required detention volume**. Storage volume within **retention-based practices** may be credited toward the **required detention volume** when they are located within the same **property holdings** as the **detention facility** provided it complies with the requirements of 5.4.3.1. Credit toward the **required detention volume** is provided by adjusting the **runoff** curve number (CN_{ADJ}). When CN_{ADJ} is used, the storage associated with **retention-based practices** must not be included in detention volume calculations.

5.5.3.3.1 NOMOGRAPH METHOD

The nomograph method, described in 5.4.3.2, may not be used to calculate the **required detention volume** in any of the following scenarios:

- The **detention service area** is greater than or equal to 20-acres;
- The **allowable release rate** is affected by **depressional storage**;
- There is **upstream tributary flow** through the **control structure**; or
- The **BFE** or any other tailwater conditions affect the **actual release rate**.

When the nomograph method is used, the procedure to determine the new **required detention volume** resulting from **redevelopment** located within the **detention service area** of an **existing detention facility** is:

1. Calculate the existing **required detention volume** based on the curve number for the area to be **redeveloped**, the **actual release rate** of the **control structure** pro-rated for the area, and the existing rainfall data used under the approved permit.

2. Calculate the **redevelopment's detention volume** based on the proposed **runoff** curve number, the lesser of the **watershed** specific release rate or the **actual release rate** of the **control structure** pro-rated for the area, and **Bulletin 75** rainfall data.

3. Calculate the required incremental detention volume for the **redevelopment** by subtracting the existing **required detention volume** (Step 1) from the **redevelopment**'s **detention volume** (Step 2).

4. Calculate the **required detention volume** for the **detention service area** by adding the incremental detention volume (Step 3) to the previously approved **required detention volume**.

5.5.3.3.2 EVENT HYDROGRAPH METHOD

An event hydrograph method, described in 5.4.3.3, must be used to calculate the **required detention volume** when:

- The **detention service area** is greater than or equal to 20-acres;

- The **control structure** is modified and an **event hydrograph method** was used for the **existing detention facility**;

- There is **upstream tributary flow** through the **control structure**; or

- The **BFE** or any other tailwater conditions affect the **actual release rate**.

When the event hydrograph method is used, the procedure to determine the new **required detention volume** resulting from **redevelopment** located within the **detention service area** of an **existing detention facility** is:

1. Create sub-basins for the **redeveloped** and the remaining non-redeveloped **tributary areas**.

2. The **redeveloped** sub-basin must consider the proposed **runoff** curve number and **Bulletin 75** rainfall data with appropriate time distribution of rainfall.

3. The remaining non-redeveloped sub-basin must consider the **runoff** curve number for the area and the existing rainfall data with the time distributions under the approved permit.

4. Develop a new stage-storage-discharge relationship that incorporates the composite release rate based on the lesser of the **watershed** specific release rate or the **actual release rate** for the **redevelopment area** and **actual release rate** pro-rated for the remaining non-redeveloped area.

5. Determine the new **required detention volume** for the **existing detention facility** from the new stage-storage-discharge relationship (developed in Step 4).

5.5.3.4 DETENTION VOLUME FOR DEVELOPMENT ADDED TO A DETENTION SERVICE AREA

§505.4.A of the **WMO** requires detention volume to be provided for **redevelopment** added to the **detention service area** of an **existing detention facility**. When the **detention service area** is increased, the existing **gross allowable release rate** may be increased by the lesser of the **watershed** specific release rate or the existing **gross allowable release rate** pro-rated for the area. All existing and any newly created **unrestricted flows** (unrestricted areas) must be considered when calculating the composite **net allowable release rate**. Any modifications to the **control structure** must comply with the composite **net allowable release rate** described in 5.5.2.

The procedure to determine the new **required detention volume** resulting from **development** added to the **detention service area** of an **existing detention facility** is:

1. Calculate the **required detention volume** of the proposed **development** based on either the proposed curve number or **runoff** coefficient, the lesser of the **watershed** specific release rate or the portion of the **actual release rate** allocated to the proposed **development**, and **Bulletin 75** rainfall data.

2. Calculate the new **required detention volume** for the new **detention service area** by adding the **required detention volume** of the **development** (Step 1) to the previously approved **required detention volume**.

5.5.3.5 DETENTION VOLUME FOR DEVELOPMENT REMOVED FROM A DETENTION SERVICE AREA

Development may be removed from the **detention service area** of an **existing detention facility**. **Development** removed from a **detention service area** is subject to the requirements of Section 5.4 of this **TGM**. The existing **gross allowable release rate** of the **detention service area** must be decreased proportional to the area removed. Any removed **unrestricted flows** (unrestricted areas) must be considered when decreasing the **net allowable release rate**. The existing **control structure** may be required to be modified to comply with the decreased **net allowable release rate**. Additionally, the **existing detention facility** must provide the **required detention volume** for the revised **detention service area** and incorporate modifications to the **control structure**.

5.5.4 REDEVELOPMENT EXAMPLES

EXAMPLE 1

A **redevelopment** is located within the **detention service area** of an **existing detention facility** permitted under the **SPO**. This is the first **redevelopment** since the **SPO** permit was issued. The **redevelopment** does not create any new or modify any existing unrestricted areas of the **detention service area**. Onsite **retention-based practices** are provided as part of the **redevelopment** to comply with the volume control requirements. Information for the **redevelopment** and the **existing detention facility** are provided below. Determine the following:

1. Whether the **control structure** is required to be modified to comply with the new composite **net allowable release rate**. If so, design a new **control structure**.

2. The **required detention volume** for the **redevelopment**.

REDEVELOPMENT INFORMATION

Watershed Planning Area	Calumet Sag Channel Watershed (0.30 cfs/acre)
Redevelopment Area	2.00 acres

REDEVELOPMENT AREA INFORMATION

	Impervious (acres)	Pervious (acres)	Total Area (acres)	Runoff Coefficient, *C*
Existing Area	0.67	1.33	2.00	0.60
Proposed Area	1.55	0.45	2.00	0.80

EXISTING DETENTION FACILITY INFORMATION

Detention Service Area	17.00 acres
Unrestricted Area	0.45 acre
Detained Area	16.55 acres
Gross Allowable Release Rate	4.13 cfs
Unrestricted Release Rate	1.74 cfs
Net Allowable Release Rate	2.39 cfs
Actual Release Rate at HWL	2.39 cfs
Control Structure	6.25-inch (C_d=0.61) @ 620.00 ft
High Water Elevation	625.50 ft
Required Detention Volume	3.61 ac-ft @ 2.39 cfs
Provided Detention Volume	3.61 ac-ft @ 625.50 ft

PART 1 SOLUTION

Step 1. Calculate the percentage of **redevelopment** with respect to the **detention service area**:

$$\% = \left(\frac{Redevelopment\ Area}{Detention\ Service\ Area}\right)(100\%)$$

$$= \left(\frac{2.00\ acres}{17.00\ acres}\right)(100\%)$$

$$= 11.76\ \%$$

Answer: The individual **redevelopment** is less than 25% of the **detention service area**. Also, the aggregate **redevelopment** is less than 40% since this is the first **redevelopment** of the **detention service area**. Therefore, the **control structure** is not required to be modified as part of the **redevelopment**.

PART 2 SOLUTION

The **required detention volume** for the **redevelopment** is calculated using **Bulletin 75** rainfall data and the lesser of the **watershed** specific release rate for the **redevelopment** or the **actual release rate** of the **control structure**.

Step 1. Calculate the per acre **actual release rate** of the detained area to determine whether it is less than the Calumet Sag Channel **watershed** specific release rate 0.30 cfs/acre. The **actual release rate** from the approved permit is used for the calculation.

$$Q_{actual/acre} = \left(\frac{Q_{actual}}{Detained\ Area}\right)$$

$$= \left(\frac{2.39\ cfs}{16.55\ acre}\right)$$

$$= 0.14\ cfs/acre$$

The per acre **actual release rate** of 0.14 cfs/acre is less than the 0.30 cfs/acre **watershed** specific release rate and the **control structure** is not modified. Therefore, the per acre **actual release rate** must be used to determine the **required detention volume**. Note that if the per acre **actual release rate** was greater than the **watershed** specific release rate, the **watershed** specific release rate must be used to determine the **required detention volume**.

Step 2. Calculate the existing **required detention volume** based on the permitted **runoff** coefficient for the area to be **redeveloped**, the **actual release rate** of the **control structure** pro-rated for the area, and the existing rainfall data used under the approved permit.

Using the Modified Rational Method Calculator, the existing **required detention volume** is 0.304 ac-ft.

MODIFIED RATIONAL METHOD: TP-40 RAINFALL DATA

PROJECT: Redevelopment Example 1 **PERMIT NUMBER:**

LOCATION: **DATE:**

DEVELOPMENT INFORMTION

1. Detained Area	2.000	acres
2. Runoff Coefficient	0.600	
3. Actual Release Rate	0.280	cfs

REQUIRED DETENTION VOLUME

4. Required Detention Volume	0.304	ac-ft

CALCULATION TABLE

Storm Duration	Rainfall Intensity (in/hr)	Inflow Rate (cfs)	Stored Rate (cfs)	Required Storage (ac-ft)	
10 min	7.60	9.12	8.84	0.122	
20 min	5.50	6.60	6.32	0.174	
30 min	4.40	5.28	5.00	0.207	
40 min	3.70	4.44	4.16	0.229	
50 min	3.20	3.84	3.56	0.245	
1 hr	2.80	3.36	3.08	0.255	
1.5 hr	2.10	2.52	2.24	0.278	
2 hr	1.70	2.04	1.76	0.291	
3 hr	1.20	1.44	1.16	0.288	
4 hr	1.00	1.20	0.92	0.304	←
5 hr	0.84	1.01	0.73	0.301	
6 hr	0.73	0.88	0.60	0.296	
7 hr	0.65	0.78	0.50	0.289	
8 hr	0.58	0.70	0.42	0.275	
9 hr	0.53	0.64	0.36	0.265	
10 hr	0.49	0.59	0.31	0.255	
11 hr	0.46	0.55	0.27	0.247	
12 hr	0.43	0.52	0.24	0.234	
13 hr	0.40	0.48	0.20	0.215	
14 hr	0.38	0.46	0.18	0.204	
15 hr	0.36	0.43	0.15	0.188	
16 hr	0.34	0.41	0.13	0.169	
17 hr	0.33	0.40	0.12	0.163	
18 hr	0.31	0.37	0.09	0.137	
19 hr	0.30	0.36	0.08	0.126	
20 hr	0.29	0.35	0.07	0.112	
21 hr	0.28	0.34	0.06	0.097	
22 hr	0.27	0.32	0.04	0.080	
23 hr	0.26	0.31	0.03	0.061	
24 hr	0.25	0.30	0.02	0.040	

Step 3. Calculate the **required detention volume** of the **redevelopment** based on the proposed **runoff** coefficient, the **actual release rate** of the **control structure** pro-rated for the area, and **Bulletin 75** rainfall data.

Using the Modified Rational Method Calculator, the **required detention volume** for the **redevelopment** is 0.732 ac-ft.

MODIFIED RATIONAL METHOD: BULLETIN 75 RAINFALL DATA

PROJECT: Redevelopment Example 5 **PERMIT NUMBER:**

LOCATION: **DATE:**

DEVELOPMENT INFORMTION

1. Detained Area	4.200	acres
2. Composite Runoff Coefficient	0.700	
3. Actual Release Rate	0.630	cfs

REQUIRED DETENTION VOLUME

4. Required Detention Volume	1.268	ac-ft

CALCULATION TABLE

Storm Duration	Rainfall Intensity (in/hr)	Inflow Rate (cfs)	Stored Rate (cfs)	Required Storage (ac-ft)	
5 min	12.36	36.34	35.71	0.246	
10 min	10.80	31.75	31.12	0.429	
15 min	9.28	27.28	26.65	0.551	
20 min	8.04	23.64	23.01	0.634	
30 min	6.34	18.64	18.01	0.744	
40 min	5.28	15.52	14.89	0.821	
50 min	4.55	13.38	12.75	0.878	
1 hr	4.03	11.85	11.22	0.927	
1.5 hr	3.03	8.91	8.28	1.026	
2 hr	2.49	7.32	6.69	1.106	
3 hr	1.83	5.38	4.75	1.178	
4 hr	1.48	4.35	3.72	1.230	
5 hr	1.25	3.68	3.05	1.258	
6 hr	1.07	3.15	2.52	1.248	
7 hr	0.96	2.82	2.19	1.268	←
8 hr	0.86	2.53	1.90	1.255	
9 hr	0.79	2.32	1.69	1.259	
10 hr	0.72	2.12	1.49	1.229	
11 hr	0.67	1.97	1.34	1.218	
12 hr	0.62	1.82	1.19	1.183	
18 hr	0.45	1.32	0.69	1.031	
24 hr	0.36	1.06	0.43	0.850	

Step 4. Calculate the required incremental detention volume for the **redevelopment** by subtracting the existing **required detention volume** from the **required detention volume**:

$$V_{inc} = (V_{req'd}) - (V_{exist\ for\ redev})$$

$$= (0.732\ ac\text{-}ft) - (0.304\ ac\text{-}ft)$$

$$= 0.428\ ac\text{-}ft$$

Step 5. Calculate the new **required detention volume** for the **detention service area**. Since an onsite **retention-based practice** is provided as part of the **redevelopment**, the volume provided within the onsite **retention-based practice** may be credited toward the new **required detention volume**. In this example, 0.129 ac-ft of storage volume, equal to the required **volume control storage**, is provided within the **retention-based practice**. Therefore, the **required detention volume** for the **redevelopment** is:

$$V_{req'd for\ DSA} = (V_{exist}) + (V_{inc}) - (V_{VC})$$

$$= (3.610\ ac\text{-}ft) + (0.428\ ac\text{-}ft) - (0.129\ ac\text{-}ft)$$

$$= 3.909\ ac\text{-}ft$$

Answer: The new **required detention volume** for the **detention service area** is 3.91 ac-ft. The **existing detention facility** is proposed to be expanded to provide the additional detention volume (0.278 ac-ft) for the **redevelopment**. All additional volume is provided below the existing HWL of 625.50 ft.

EXAMPLE 2

A **redevelopment** is located within the **detention service area** of an **existing detention facility** permitted under the **WMO**. This is the first **redevelopment** since the **WMO** permit was issued. The existing onsite **retention-based practices** are used to comply with the volume control requirements and new unrestricted areas are not created. Information for the **redevelopment** and **existing detention facility** are provided below. Determine the following:

1. Whether the **control structure** is required to be modified to comply with the new composite **net allowable release rate**. If so, design a new **control structure**.

2. The **required detention volume** for the **redevelopment**.

REDEVELOPMENT AREA INFORMATION

Watershed Planning Area	Lower Des Plaines Watershed (0.20 cfs/acre)
Redevelopment Area	4.40 acres
Hydrologic Soil Group (HSG)	D

REDEVELOPMENT AREA INFORMATION

	Impervious (acres)	**Pervious (acres)**	**Total Area (acres)**	**Curve Number, *CN***
Existing Area	2.28	2.12	4.40	89.33
Proposed Area	1.96	2.44	4.40	88.02

EXISTING DETENTION FACILITY INFORMATION

Detention Service Area	10.20 acres
Detained Area	10.20 acres
Gross Allowable Release Rate	3.06 cfs
Net Allowable Release Rate	3.06 cfs
Actual Release Rate at HWL	3.06 cfs
Control Structure	7.00-inch (C_d=0.61) @ 600.00 ft
High Water Elevation	605.75 ft
Required Detention Volume	2.32 ac-ft @ 3.06 cfs
Provided Detention Volume	2.32 ac-ft @ 605.75 ft

PART 1 SOLUTION

Step 1. Calculate the percentage of **redevelopment** with respect to the **detention service area**:

$$\% = \left(\frac{Redevelopment\ Area}{Detention\ Service\ Area}\right)(100\%)$$

$$= \left(\frac{4.40\ acres}{10.20\ acres}\right)(100\%)$$

$$= 43.14\ \%$$

The individual **redevelopment** is greater than 25% of the **detention service area**. Therefore, the **control structure** must comply with the composite **net allowable release rate** and may be required to be modified as part of the **redevelopment**.

Step 2. Calculate the per acre **actual release rate** of the detained area to determine whether it is less than the Lower Des Plaines **Watershed** specific release rate 0.20 cfs/acre. The **actual release rate** from the approved permit is used for the calculation.

$$Q_{actual/acre} = \left(\frac{Q_{actual}}{Detained\ Area}\right)$$

$$= \left(\frac{3.06\ cfs}{10.20\ acre}\right)$$

$$= 0.30\ cfs/acre$$

The per acre **actual release rate** of 0.30 cfs/acre is greater than the 0.20 cfs/acre **watershed** specific release rate. Therefore, the **control structure** is required to be modified.

Step 3. Calculate the composite **gross allowable release rate** for the **detention service area** based on the Lower Des Plaines **watershed** specific release rate of 0.20 cfs/acre and the pro-rated share of the existing **gross allowable release rate** for the remaining non-redeveloped area:

$$Q_{comp\ gross} = (A_{redev})\left(Q_{watershed\ sp\ cific\ release\ rate}\right) + (A_{non\text{-}redev})(Q_{ext})$$

$$= (4.40\ acres)(0.20\ cfs/acre) + (5.80\ acres)(0.30\ cfs/acre)$$

$$= 2.62\ cfs$$

The composite **gross allowable release rate** for the **detention service area** is 2.62 cfs. Unrestricted areas are not created; therefore, the composite **net allowable release rate** is equal to the composite **gross allowable release rate**. However, if they were the composite **net allowable release rate** would be calculated by subtracting the **unrestricted flows** from the **gross allowable release rate**.

Step 4: Determine the design parameters for the new **control structure**. For this example, the existing **control structure** invert elevation of 600.00 ft and the existing HWL of 605.75 ft will be maintained. Therefore, the existing 7.00-inch diameter orifice plate will need to be replaced with a smaller diameter orifice plate to comply with the new composite **net allowable release rate** of 2.62 cfs. Note that if the HWL was modified to provide additional detention volume, the resulting **actual release rate** at the modified HWL must be used to calculate the **required detention volume**.

Answer: Using the Orifice Calculator, a 6.48-inch diameter orifice plate will be installed.

ORIFICE DISCHARGE RATE

PROJECT: Redevelopment Example 2 **PERMIT NUMBER:**

LOCATION: **DATE:**

RESTRICTOR INFORMTION

1. Orifice Number	1		
2. Orifice diameter, *d*	6.48	in	
3. Discharge Coefficient, C_d	0.61		
4. Invert Elevation	600.00	ft	
5. High Water Elevation, HWL	605.75	ft	
6. Tail Water Elevation		ft	

ACTUAL RELEASE RATE

6. Free Flow Actual Release Rate at HWL	2.62	cfs	
7. Submerged Actual Release Rate at HWL		cfs	

STAGE-DISCHARGE TABLE CONDITION (SELECT FROM DROP-DOWN)

Free-flow

STAGE-DISCHARGE TABLE

Elevation (ft)	Orifice 1 (cfs)	Orifice 2 (cfs)	Total (cfs)	
600.00	0.00		0.00	
600.50	0.54		0.54	
601.00	0.96		0.96	
601.50	1.24		1.24	
602.00	1.47		1.47	
602.50	1.67		1.67	
603.00	1.85		1.85	
603.50	2.01		2.01	
604.00	2.17		2.17	
604.50	2.31		2.31	
605.00	2.44		2.44	
605.50	2.56		2.56	
605.75	2.62		2.62	HWL

PART 2 SOLUTION

The **required detention volume** for the **redevelopment** is calculated using **Bulletin 75** rainfall data and new **actual release rate** of the modified **control structure**.

Step 1. Calculate the existing **required detention volume** based on the **runoff** curve number for the area to be **redeveloped** and the existing **actual release rate** of the **control structure** pro-rated for the area.

The existing adjusted **runoff** curve number (CN_{ADJ}) is first calculated since volume control is provided by an existing onsite **retention-based practice**. Using the CN_{ADJ} Calculator, CN_{ADJ} for the existing area is 84.89.

ADJUSTED COMPOSITE RUNOFF CURVE NUMBER (CN_{ADJ})

PROJECT: ____________ PERMIT NUMBER: ____________

LOCATION: ____________ DATE: ____________

DEVELOPMENT INFORMTION			
1. Area Detained, A		4.400	acres
2. Total Impervious Area		2.280	acres
3. Composite CN		89.33	
4. Volume Control Storage Provided, VC_P		0.190	ac-ft
5. Depth of Rainfall, P		7.58	inches
RUNOFF VOLUME (NRCS EQUATIONS)			
6. Maximum Retention, S	$S = \frac{1000}{CN} - 10$	1.19	inches
7. Runoff Depth, Q_D	$Q_D = \frac{(P - 0.2S)^2}{(P + 0.8S)}$	6.31	inches
8. Runoff Volume, V_R	$V_R = Q_D A \left(\frac{1}{12\frac{in}{ft}}\right)$	2.32	ac-ft
VOLUME CONTROL STORAGE			
9. Volume Control Storage Required, VC_R		0.190	ac-ft
10. Additional Volume Control Storage Provided		0.000	ac-ft
ADJUSTED RUNOFF VOLUME			
11. Adjusted Runoff Volume, V_{ADJ}	$V_{ADJ} = V_R - VC_P$	2.125	ac-ft
12. Adjusted Runoff Depth, Q_{ADJ}		5.80	inches
13. Adjusted Maximum Retention, S_{ADJ}		1.78	inches
ADJUSTED COMPOSITE RUNOFF CURVE NUMBER			
14. Adjusted Runoff Curve Number, CN_{ADJ}		84.89	

The existing **required detention volume** is then calculated by using the existing CN_{ADJ} and the existing **actual release rate** of the **control structure** pro-rated for the area.

Using the Nomograph Calculator, the **required detention volume** for existing the **redevelopment** is 0.935 ac-ft.

NOMOGRAPH: BULLETIN 70 RAINFALL DATA

PROJECT: Redevelopment Example 2 **PERMIT NUMBER:**

LOCATION: **DATE:**

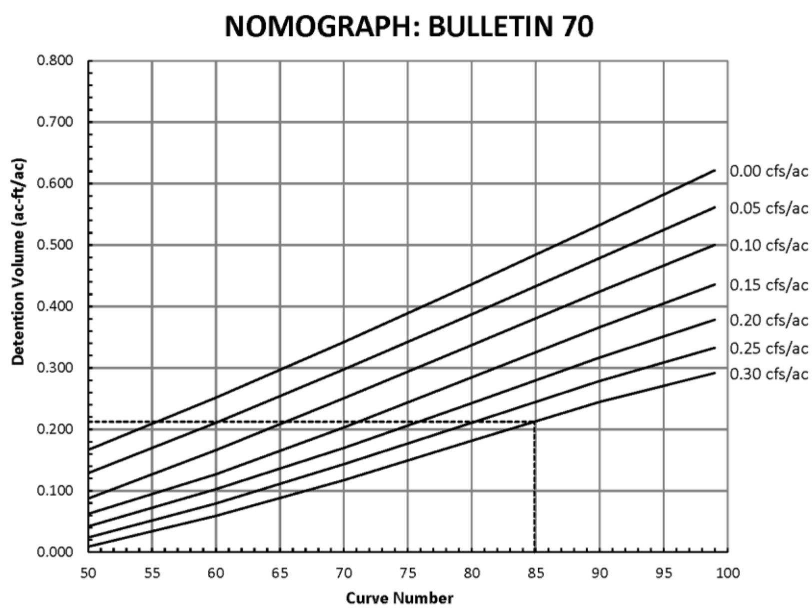
DEVELOPMENT INFORMATION

1. Detained Area	4.400	acres
2. Curve Number	84.89	
3. Actual Release Rate	1.320	cfs

REQUIRED DETENTION VOLUME

4. Required Detention Volume	0.935	ac-ft

NOMOGRAPH



Step 2. Calculate the **required detention volume** of the **redevelopment** based on the proposed curve number, the **watershed** specific release rate pro-rated for the area, and **Bulletin 75** rainfall data.

The proposed adjusted **runoff** curve number (*CN_{ADJ}*) is first calculated since volume control is provided by an existing onsite **retention-based practice**. Since the required **volume control storage** for the **redevelopment** area is now reduced due to the reduction of **impervious area**, additional storage volume within the existing onsite **retention-based practice** can be applied to further reduce *CN_{ADJ}*. Using the *CN_{ADJ}* Calculator, *CN_{ADJ}* for the existing area is 83.72.

The **required detention volume** is then calculated by using the proposed *CN_{ADJ}* and the **watershed** specific release rate pro-rated for the area. Using the Nomograph Calculator with an area of 4.40-acres, *CN_{ADJ}* of 83.72, and **actual release rate** of 0.88 cfs, the **required detention volume** for the **redevelopment** is 1.509 ac-ft.

NOMOGRAPH: BULLETIN 75 RAINFALL DATA

PROJECT: Redevelopment Example 2 **PERMIT NUMBER:**

LOCATION: **DATE:**

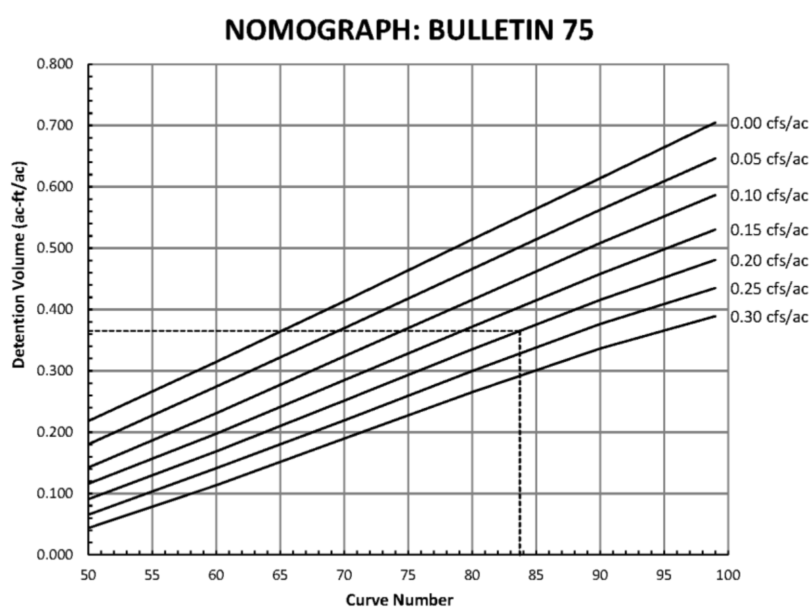
DEVELOPMENT INFORMATION

1. Detained Area	4.400	acres
2. Curve Number	83.72	
3. Actual Release Rate	0.880	cfs

REQUIRED DETENTION VOLUME

4. Required Detention Volume	1.606	ac-ft

NOMOGRAPH



Step 3. Calculate the required incremental detention volume for the **redevelopment** by subtracting the existing **required detention volume** from the **required detention volume**:

$$V_{inc.} = (V_{req'd}) - (V_{exist\ for\ redev})$$

$$= (1.606\ ac\text{-}ft) - (0.935\ ac\text{-}ft)$$

$$= 0.671\ ac\text{-}ft$$

Step 4. Calculate the new **required detention volume** for the **detention service area** by adding the incremental detention volume to the previously permitted **required detention volume**:

$$V_{req'd for\ DSA} = (V_{exist}) + (V_{inc.})$$

$$= (2.320\ ac\text{-}ft) + (0.671\ ac\text{-}ft)$$

$$= 2.991\ ac\text{-}ft$$

Answer: The existing pond is proposed to be expanded to provide the additional 0.671 ac-ft for the **redevelopment**. All additional volume is provided below the existing HWL of 605.75 ft.

EXAMPLE 3

A **development** will be added to the **detention service area** of an **existing detention facility** permitted under the **WMO**. Onsite **retention-based practices** are provided as part of the **development** to comply with the volume control requirements. Information for the **development** and the **existing detention facility** are provided below. Determine the following:

1. Whether the **control structure** is required to be modified to comply with the new composite **net allowable release rate**. If so, design a new **control structure**.

2. Determine the **required detention volume** for the **development** using the nomograph method.

DEVELOPMENT INFORMATION

Watershed Planning Area	Little Calumet River Watershed (0.25 cfs/acre)
Development Area	2.98 acres
Hydrologic Soil Group (HSG)	D

DEVELOPMENT AREA INFORMATION

	Impervious (acres)	Pervious (acres)	Curve Number, *CN*
Development Area	2.10	0.88	94.02

EXISTING DETENTION FACILITY INFORMATION

Detention Service Area	10.85 acres
Unrestricted Area	0 acres
Detained Area	10.85 acres
Gross Allowable Release Rate	3.26 cfs
Net Allowable Release Rate	3.26 cfs
Actual Release Rate at HWL	3.24 cfs
Control Structure	7.95-inch (C_d=0.61) @ 600.00 ft
High Water Elevation	604.00 ft
Required Detention Volume	2.42 ac-ft @ 3.24 cfs
Provided Detention Volume	2.42 ac-ft @ 604.00 ft

PART 1 SOLUTION

Step 1. Calculate the percentage of **development** with respect to the sum of the **detention service area** under the approved permit and the **development** area:

$$\% = \left(\frac{Redevelopment\ Area}{Existing\ DSA + Development\ Area}\right)(100\%)$$

$$= \left(\frac{2.98\ acres}{10.85\ acres + 2.98\ acres}\right)(100\%)$$

$$= 21.5\ \%$$

Answer: Since the individual **development** is less than 25% and no other **development** has occurred to exceed an aggregate milestone, the **control structure** is not required to be modified as part of the **development**.

PART 2 SOLUTION

The **required detention volume** for the added **development** is calculated using **Bulletin 75** rainfall data and new **actual release rate** allocated for the added **development**.

Step 1. Calculate the **required detention volume** using the nomograph method using the **actual release rate** assigned to the **development**. Since the proposed **development** was not included as part of the original detention calculations, the **development** does not have an existing **actual release rate** assigned to the area. Therefore, the **required detention volume** must be determined at 0 cfs/acre. However, if the **control structure** is modified, a new release rate may be assigned to the new **development**. To avoid providing detention volume at 0 cfs/acre, the **control structure** will be modified.

Step 2. Calculate the composite **gross allowable release rate** for the **detention service area** is based on the lesser of the **watershed** specific release rate or the **existing gross allowable release rate**. The Little Calumet River **watershed** specific release rate of 0.25 cfs/acre will be used for the **development** area, while the **existing gross allowable release rate** will be used for the remaining area.

$$Q_{comp\ gross} = (A_{dev})\left(Q_{watershed\ specific\ release\ rate}\right) + (A_{non\text{-}dev})\left(Q_{ext.\ gross}\right)$$

$$= (2.98\ acres)(0.25\ cfs/acre) + (10.85\ acres)(0.30\ cfs/acre)$$

$$= 4.00\ cfs$$

The composite **net allowable release rate** for the **detention service area** is calculated by subtracting any new or existing **unrestricted flow** (unrestricted area) from the composite **gross allowable release rate**. Since there are not any newly created or existing unrestricted areas, the composite **net allowable release rate** is equal to the composite **gross allowable release rate**.

$$Q_{comp\ net} = Q_{comp\ gross} - Q_{unrestricted}$$

$$= 4.00\ cfs - 0.00\ cfs$$

$$= 4.00\ cfs$$

Step 3. Calculate the diameter of the orifice plate restrictor for the **control structure**. For this example, the maximum diameter will be used. This occurs when the **actual release rate** is equal to the **net allowable release rate** of 4.00 cfs. Additionally, the existing invert elevation of 600.00 ft and HWL of 604.00 ft will be maintained. Using either the Equation 5.28 or the Orifice Calculator, the diameter of the orifice plate restrictor is 8.87-inches. Note that a release rate exhibit must be submitted delineating the release rate assigned to the added **development** and remaining areas.

Step 4. Calculate the **required detention volume** for the **development** based on the proposed adjusted **runoff** curve number (CN_{ADJ}), the **actual release rate** assigned to the **development** area, and **Bulletin 75** rainfall data.

CN_{ADJ} is first calculated since volume control will be provided by an onsite **retention-based practice**. Using the CN_{ADJ} Calculator, CN_{ADJ} for the **development** is 88.17

The **required detention volume** is then calculated by using CN_{ADJ} and the **actual release rate** assigned to the **development** area. Using the Nomograph Calculator, the **required detention volume** for the **development** is 1.080 ac-ft.

Step 5. Calculate the new **required detention volume** for the **detention service area** by adding the **required detention volume** for the **development** to the previously permitted **required detention volume**:

$$V_{req'd for\ DSA} = (V_{exist}) + (V_{added})$$

$$= (2.42\ ac\text{-}ft) + (1.08\ ac\text{-}ft)$$

$$= 3.50\ ac\text{-}ft$$

Answer: The **existing detention facility** will be expanded to provide the additional 1.08 ac-ft for the **development**. All additional volume is provided between 600.00 ft and the existing HWL of 604.00 ft.

EXAMPLE 4

A **redevelopment** is within the **detention service area** of an **existing detention facility** permitted under the **WMO**. The previously permitted onsite **retention-based practices** are used to comply with the volume control requirements for the **redevelopment** and new unrestricted areas are not created. Information for the **redevelopment** and the **existing detention facility** are provided below. The **control structure** will be modified as part of the **project**. Determine the following:

1. Whether the **control structure** is required to be modified to comply with the new composite **net allowable release rate**. If so, design a new **control structure**.
2. The **required detention volume** for the **redevelopment** by creating a stage-storage-discharge relationship for the **detention facility**.

REDEVELOPMENT INFORMATION

Watershed Planning Area	Upper Salt Creek Watershed (0.20 cfs/acre)
Redevelopment Area	9.00 acres
Hydrologic Soil Group (HSG)	D

DETENTION SERVICE AREA (DSA) INFORMATION

	Impervious (acres)	Pervious (acres)	Unrestricted (acres)	Curve Number, *CN*
Existing DSA	25.14	7.36	0.50	93.92
Proposed DSA	21.75	10.75	0.50	92.05

REDEVELOPMENT AREA AND REMAINING AREA INFORMATION

	Impervious (acres)	Pervious (acres)	Unrestricted (acres)	Curve Number, *CN*
Redeveloped	3.89	5.11	0.00	87.78
Remaining	17.86	5.64	0.50	93.68

EXISTING DETENTION FACILITY INFORMATION

Detention Service Area	33.00 acres
Unrestricted Area	0.50 acres
Detained Area	32.50 acres
Gross Allowable Release Rate	9.90 cfs
Unrestricted Flow	0.35 cfs
Net Allowable Release Rate	9.55 cfs
Actual Release Rate at HWL	9.50 cfs
Control Structure	11.60-inch (C_d=0.61) @ 598.00 ft
High Water Elevation	605.47 ft
Required Detention Volume	7.33 ac-ft @ 9.50 cfs
Provided Detention Volume	7.36 ac-ft @ 605.50 ft

PERMITTED/VERIFIED DETENTION FACILITY INFORMATION

Elevation (ft)	Cumulative Volume (ac-ft)	Discharge (cfs)	Notes
598.00	0.00	0.00	Bottom of Pond
599.00	0.75	2.58	
600.00	1.56	4.42	
601.00	2.44	5.70	
602.00	3.40	6.74	
603.00	4.43	7.64	
604.00	5.54	8.44	
605.00	6.74	9.17	
605.50	7.36	9.52	HWL
606.50	8.69	10.17	Overflow

PART 1 SOLUTION

Step 1. Calculate the percentage of **redevelopment** with respect to the **detention service area**:

$$\% = \left(\frac{Redevelopment\ Area}{Detention\ Service\ Area}\right)(100\%)$$

$$= \left(\frac{9\ acres}{33\ acres}\right)(100\%)$$

$$= 27.3\ \%$$

The individual **redevelopment** is greater than 25% of the **detention service area**. Therefore, the **control structure** is required to be modified as part of the **redevelopment**.

Step 2. Calculate the per acre **actual release rate** of the detained area to determine whether it is less than the Upper Salt Creek **Watershed** specific release rate 0.20 cfs/acre. The **actual release rate** from the approved permit is used for the calculation.

$$Q_{actual/acre} = \left(\frac{Q_{actual}}{Detained\ Area}\right)$$

$$= \left(\frac{9.50\ cfs}{32.50\ acre}\right)$$

$$= 0.29\ cfs/acre$$

The per acre **actual release rate** of 0.29 cfs/acre is greater than the 0.20 cfs/acre **watershed** specific release rate. Therefore, the **control structure** is required to be modified.

Step 3. Calculate the composite **gross allowable release rate** for the **detention service area** based on the Upper Salt Creek **watershed** specific release rate of 0.20 cfs/acre and the pro-rated share of the existing **gross allowable release rate** for the remaining non-redeveloped area:

$$Q_{comp\ gross} = (A_{redev})\left(Q_{watershed\ specific\ release\ rate}\right) + (A_{non\text{-}redev})(Q_{exist})$$

$$= (9\ acres)(0.20\ cfs/acre) + (24\ acres)(0.30\ cfs/acre)$$

$$= 9.00\ cfs$$

The composite **gross allowable release rate** for the **detention service area** is 9.00 cfs. The existing unrestricted area is not part of the **redevelopment** and no new unrestricted areas are created; therefore, the composite **net allowable release rate** is:

$$Q_{comp\ net} = Q_{comp\ gross} - Q_{unrestricted}$$

$$= 9.00\ cfs - 0.35\ cfs$$

$$= 8.65\ cfs$$

Step 4. Calculate the diameter of the orifice plate restrictor for the **control structure**. This occurs when the **actual release rate** is equal to the **net allowable release rate** of 8.65 cfs. Using either Equation 5.28 or the Orifice Calculator, the maximum diameter of the orifice plate restrictor is 10.68-inches. For this example, a 10.65-inch orifice plate restrictor will be used. Note that a release rate exhibit must be submitted delineating the release rate assigned to the added **development** and remaining areas.

Answer: Determine the design parameters for the new **control structure**. For this example, the existing **control structure** invert elevation of 598.00 ft and a new HWL of 606.50 ft will be used to minimize grading work to the **existing detention facility**. Therefore, the existing 11.60-inch diameter orifice plate will be replaced with a 10.65-inch diameter orifice plate to comply with the new composite **net allowable release rate** of 8.65 cfs.

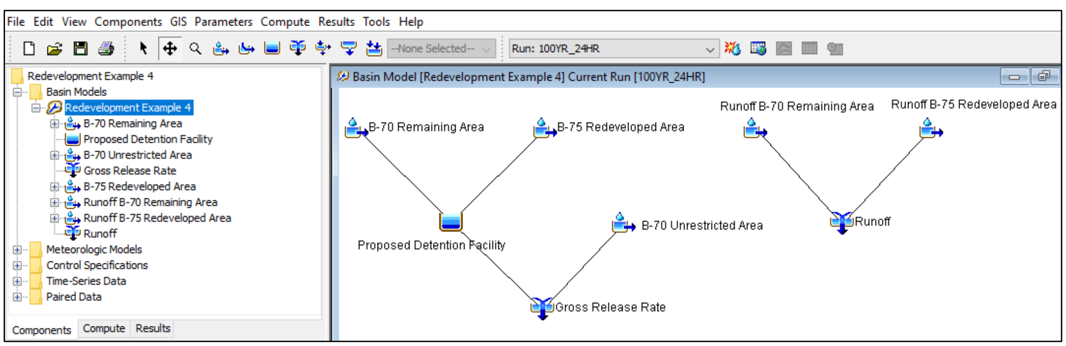
PART 2 SOLUTION

The **required detention volume** for the **detention facility** is determined by an event hydrograph method using **Bulletin 75** for the **redevelopment** area, **Bulletin 70** for the non-redeveloped area, and the new **actual release rate** of the modified **control structure**. HEC-HMS will be used for this example.

Step 1. Calculate new **runoff** curve numbers for the **redevelopment** and non-redeveloped areas. The adjusted **runoff** curve number (CN_{ADJ}) is calculated for each area. Since the required **volume control storage** for the **redevelopment** area is now reduced due to the reduction of **impervious area**, additional storage volume within the existing onsite **retention-based practice** can be applied to further reduce CN_{ADJ}. Of the 2.10 ac-ft of storage provided within the existing onsite **retention-based practice**, 0.61 ac-ft is provided for the **redevelopment** and 1.49 ac-ft is provided for the non-redeveloped area.

Using the CN_{ADJ} Calculator with detained area of 9.00-acres, total **impervious area** of 3.89-acres, composite *CN* of 87.78, 0.610 ac-ft provided volume control, and 8.57-inches of rainfall, CN_{ADJ} for the redeveloped area is 81.04.

Using the CN_{ADJ} Calculator with detained area of 23.50-acres, total **impervious area** of 17.86-acres, composite *CN* of 93.68, 1.490 ac-ft provided volume control, and 7.58-inches of rainfall, CN_{ADJ} for the non-redeveloped area is 87.21.



Step 2. Calculate the new **required detention volume** for the **detention service area** based on the adjusted curve numbers, the updated stage-storage-discharge relationship for the modified **detention facility** and **control structure**, **Bulletin 75** for the **redevelopment** area, and **Bulletin 70** for the non-redeveloped area. Since the **detention facility** has available volume above the HWL, it will be used to provide the **required detention volume**. Note that if the existing HWL was maintained, the **detention facility** would need to be expanded.

PROPOSED STAGE-STORAGE-DISCHARGE RELATIONSHIP FOR THE DETENTION FACILITY

Elevation (ft)	Cumulative Volume (ac-ft)	Discharge (cfs)	Notes
598.00	0.00	0.00	Bottom of Pond
599.00	0.75	2.26	
600.00	1.56	3.78	
601.00	2.44	4.84	
602.00	3.40	5.71	
603.00	4.43	6.46	
604.00	5.54	7.14	
605.00	6.74	7.75	
605.50	7.36	8.04	
606.19	8.29	8.43	HWL
606.50	8.69	8.60	Overflow

Project: Redevelopment Example 4 Simulation Run: 100YR_24HR
Reservoir: Proposed Detention Facility

Start of Run: 01Jan2000, 00:00 Basin Model: Redevelopment Example 4
End of Run: 03Jan2000, 00:00 Meteorologic Model: 100YR_24HR
Compute Time: 21May2020, 14:09:54 Control Specifications: _24HR

Volume Units: IN AC-FT

Computed Results

Peak Inflow: 23.70 (CFS) Date/Time of Peak Inflow: 01Jan2000, 15:04
Peak Discharge: 8.43 (CFS) Date/Time of Peak Discharge: 01Jan2000, 19:18
Inflow Volume: 16.59 (AC-FT) Peak Storage: 8.29 (AC-FT)
Discharge Volume: 16.51 (AC-FT) Peak Elevation: 606.187 (FT)

Answer: The **required detention volume** for the **detention service area** is 8.29 ac-ft at the HWL of 606.19 ft with an **actual release rate** of 8.43 cfs. Note that the HEC-HMS model template for this **redevelopment** is provided on the **District** website at mwrd.org/wmo.

EXAMPLE 5

A **redevelopment** is tributary to an **existing detention facility** that was constructed in 1994. Since the **existing detention facility** is located within the **combined sewer area**, it was not permitted under the **SPO**. Onsite **retention-based practices** are provided as part of the **redevelopment** to comply with the volume control requirements of the **WMO**. Information for the **redevelopment** and the **existing detention facility** are provided below. Determine the following:

1. Whether the **existing detention facility** complies with the requirements of the **SPO**.
2. Whether the **control structure** is required to be modified to comply with the existing or new composite **net allowable release rate**. If so, design a new **control structure**.
3. The **required detention volume** for the **redevelopment**.

REDEVELOPMENT INFORMATION

Watershed Planning Area	Little Calumet River Watershed (0.25 cfs/acre)
Redevelopment Area	4.20 acres

ORIGINAL DEVELOPMENT AREA INFORMATION

	Impervious (acres)	Pervious (acres)	Total Area (acres)	Runoff Coefficient, *C*
Tributary Area	11.06	4.49	15.55	0.77
Unrestricted Area	0.22	0.23	0.45	0.67

REDEVELOPMENT AREA INFORMATION

	Impervious (acres)	Pervious (acres)	Total Area (acres)	Runoff Coefficient, *C*
Existing Area	2.99	1.21	4.20	0.77
Proposed Area	2.33	1.87	4.20	0.70

EXISTING CONTROL STRUCTURE INFORMATION

Invert Elevation (ft)	HWL (ft)	Diameter (inch)	Type / Discharge Coefficient
630.00	635.00	6.43	Bottom of Pond

EXISTING DETENTION FACILITY INFORMATION

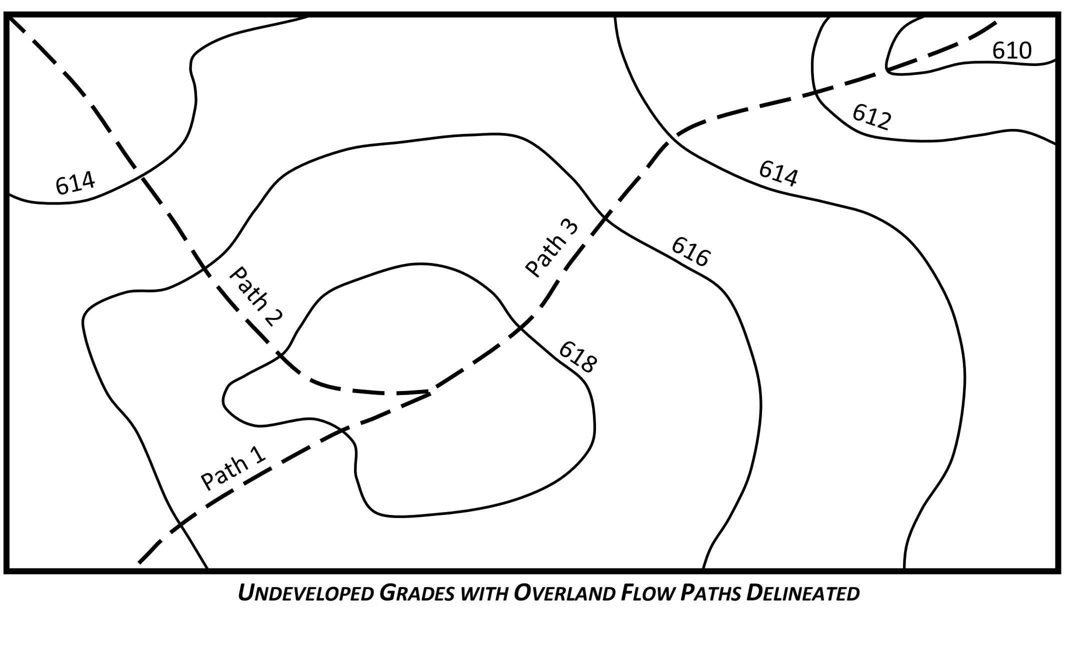
Elevation (ft)	Cumulative Volume (ac-ft)	Notes
630.00	0.00	Bottom of Pond
631.00	0.23	
632.00	0.71	
633.00	1.49	
634.00	2.44	
635.00	3.49	HWL/Overflow
636.00	4.68	

PART 1 SOLUTION

Step 1. Calculate the longest time-of-concentration, T_c, for the undeveloped, natural condition of the **detention service area**.

The undeveloped, natural grades of the property were obtained from the original plans for the **development**. The exhibit below shows the undeveloped, natural grades with several overland flow paths delineated. There is no channelized flow within the property. Information for the overland flow paths are provided in the table below.

Note that undeveloped grades may be obtained from USGS topography or other sources. If all resources have been exhausted to obtained undeveloped grades, T_c may be calculated assuming the longest diagonal at 1% slope.



UNDEVELOPED GRADES WITH OVERLAND FLOW PATHS DELINEATED

ORIGINAL DEVELOPMENT AREA INFORMATION

Overland Flow Path	High Elevation (ft)	Low Elevation (ft)	Length (ft)	Slope (ft/ft)
1	619.25	615.65	305	0.012
2	619.25	613.15	625	0.010
3	619.25	609.05	715	0.003

Equation 5.10 is used to calculate T_c since the overland flow paths are less than 1,000-feet. If an overland flow path was greater than or equal to 1,000-feet, Equation 5.11 must be used. The SPO T_c Calculator is used for Flow Path 3.

SPO TIME OF CONCENTRATION (T_c)

PROJECT: Redevelopment Example 5 **PERMIT NUMBER:**

LOCATION: **DATE:**

OVERLAND FLOW

1. Segment ID		3	
4. Flow length, *L*		715	ft
6. Land slope, *s*		0.003	ft/ft
7. Travel time, T_t		45.05	min

OPEN CHANNEL FLOW

14. Segment ID			
15. Cross-sectional flow area, *A*			ft^2
16. Wetted Perimeter, P_w			ft
17. Hydraulic radius, *R*			ft
18. Flow Length, *L*			ft
19. Channel slope, *S*			ft/ft
20. Manning's roughness coefficient, *n*			
21. Average velocity, *V*	$V = \frac{1.486}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$		fps
22. Travel time, T_t	$T_t = \frac{L}{3600V}$		min

TIME-OF-CONCENTRATION (T_c)

23. Time-of-Concentration, *Tc*	$T_c = \sum T_t$	45.05	min

The table below summarizes the T_c for each overland flow path. The longest T_c is 45.05-minutes.

TIME-OF-CONCENTRATION SUMMARY

Overland Flow Path	*Time-of-concentration, T_c* (min)
1	21.90
2	31.94
3	45.05

Step 2. Calculate the existing **gross allowable release rate** for the 3-year **storm event** with a duration equal to T_c using Technical Paper No. 40 rainfall data.

The **gross allowable release rate** is calculated using the Rational Method formula with the undeveloped **runoff** coefficient of 0.15 and the 3-year rainfall intensity of 2.00 in/hr (based on the longest T_c of 45.05-minutes):

$$Q_{gross\ allow} = C_{undev}\ i_3\ A$$

$$= (0.15)(2.00\ in/hr)(16\ acres)$$

$$= 4.80\ cfs$$

Step 3. Calculate the existing **net allowable release rate** by subtracting the **unrestricted flow** rate from the **gross allowable release rate**.

The **unrestricted flow** rate is calculated considering the developed condition of the unrestricted area and its T_c for the 100-year **storm event**. The **unrestricted flow** rate is typically calculated considering a T_c of 10-minutes unless supporting calculations are submitted. The **unrestricted flow** rate is:

$$Q_{unrestricted} = C_{dev}\ i_{100}\ A$$

$$= (0.67)(3.45\ in/hr)(0.45\ acres)$$

$$= 2.29\ cfs$$

The existing **net allowable release rate** is then calculated by subtracting the **unrestricted flow** rate from the **gross allowable release rate**:

$$Q_{net\ allow} = Q_{gross\ allow} - Q_{unrestricted}$$

$$= (4.80\ cfs) - (2.29\ cfs)$$

$$= 2.51\ cfs$$

Step 4. Calculate the existing **required detention volume** of the **detention service area** based on the composite **runoff** coefficient, **actual release rate** of the existing **control structure**, and Technical Paper 40 rainfall data.

The existing **required detention volume** and the **actual release rate** of the existing **control structure** is determined using both the Orifice and Modified Rational Method Calculators the through an iterative process. The existing **required detention volume** is 3.165 ac-ft at the HWL of 635.00 ft and the **actual release rate** is 2.40 cfs.

ORIFICE DISCHARGE RATE

PROJECT: Redevelopment Example 2 **PERMIT NUMBER:**

LOCATION: **DATE:**

RESTRICTOR INFORMTION

1.	Orifice Number	1		
2.	Orifice diameter, *d*	6.48	in	
3.	Discharge Coefficient, C_d	0.61		
4.	Invert Elevation	600.00	ft	
5.	High Water Elevation, HWL	605.75	ft	
6.	Tail Water Elevation		ft	

ACTUAL RELEASE RATE

6.	Free Flow Actual Release Rate at HWL	2.62	cfs	
7.	Submerged Actual Release Rate at HWL		cfs	

STAGE-DISCHARGE TABLE CONDITION (SELECT FROM DROP-DOWN)

Free-flow

STAGE-DISCHARGE TABLE

Elevation (ft)	Orifice 1 (cfs)	Orifice 2 (cfs)	Total (cfs)	
600.00	0.00		0.00	
600.50	0.54		0.54	
601.00	0.96		0.96	
601.50	1.24		1.24	
602.00	1.47		1.47	
602.50	1.67		1.67	
603.00	1.85		1.85	
603.50	2.01		2.01	
604.00	2.17		2.17	
604.50	2.31		2.31	
605.00	2.44		2.44	
605.50	2.56		2.56	
605.75	2.62		2.62	HWL

MODIFIED RATIONAL METHOD: TP-40 RAINFALL DATA

PROJECT: Redevelopment Example 5 **PERMIT NUMBER:**

LOCATION: **DATE:**

DEVELOPMENT INFORMTION

1. Detained Area 15.550 acres
2. Runoff Coefficient 0.770
3. Actual Release Rate 2.400 cfs

REQUIRED DETENTION VOLUME

4. Required Detention Volume 3.165 ac-ft

CALCULATION TABLE

Storm Duration	Rainfall Intensity (in/hr)	Inflow Rate (cfs)	Stored Rate (cfs)	Required Storage (ac-ft)
10 min	7.60	91.00	88.60	1.220
20 min	5.50	65.85	63.45	1.748
30 min	4.40	52.68	50.28	2.078
40 min	3.70	44.30	41.90	2.309
50 min	3.20	38.32	35.92	2.473
1 hr	2.80	33.53	31.13	2.572
1.5 hr	2.10	25.14	22.74	2.820
2 hr	1.70	20.35	17.95	2.968
3 hr	1.20	14.37	11.97	2.967
4 hr	1.00	11.97	9.57	3.165 ←
5 hr	0.84	10.06	7.66	3.164
6 hr	0.73	8.74	6.34	3.144
7 hr	0.65	7.78	5.38	3.114
8 hr	0.58	6.94	4.54	3.005
9 hr	0.53	6.35	3.95	2.935
10 hr	0.49	5.87	3.47	2.865
11 hr	0.46	5.51	3.11	2.825
12 hr	0.43	5.15	2.75	2.726
13 hr	0.40	4.79	2.39	2.567
14 hr	0.38	4.55	2.15	2.488
15 hr	0.36	4.31	1.91	2.368
16 hr	0.34	4.07	1.67	2.210
17 hr	0.33	3.95	1.55	2.179
18 hr	0.31	3.71	1.31	1.951
19 hr	0.30	3.59	1.19	1.872
20 hr	0.29	3.47	1.07	1.772
21 hr	0.28	3.35	0.95	1.653
22 hr	0.27	3.23	0.83	1.514
23 hr	0.26	3.11	0.71	1.355
24 hr	0.25	2.99	0.59	1.177

Answer: The **actual release rate** of 2.40 cfs is less than the existing **net allowable release rate** is 2.51 cfs. Also, the **existing detention facility** provides 3.49 ac-ft at an elevation of 635.00 ft, which is greater than existing **required detention volume** of 3.165 ac-ft. Therefore, the **existing detention facility** complies with the **stormwater** detention requirements of the **SPO**. Note that if the **exiting detention facility** did not comply with the **SPO** requirements, it must be modified as part of the **redevelopment** to comply with the requirements.

PART 2 SOLUTION

Step 1. Calculate the percentage of **redevelopment** with respect to the **detention service area**:

$$\% = \left(\frac{Redevelopment\ Area}{Detention\ Service\ Area}\right)(100\%)$$

$$= \left(\frac{4.2\ acres}{16.0\ acres}\right)(100\%)$$

$$= 26.25\ \%$$

The individual **redevelopment** is greater than 25% of the **detention service area**. Therefore, the **control structure** may be required to be modified as part of the **redevelopment**.

Step 2. Calculate the per acre **actual release rate** of the detained area to determine whether it is less than the Little Calumet River **Watershed** specific release rate of 0.25 cfs/acre. The **actual release rate** from the approved permit is used for the calculation.

$$Q_{actual/acre} = \left(\frac{Q_{actual}}{Detained\ Area}\right)$$

$$= \left(\frac{2.40\ cfs}{15.55\ acre}\right)$$

$$= 0.15\ cfs/acre$$

Answer: The per acre **actual release rate** of 0.15 cfs/acre is less than the 0.25 cfs/acre **watershed** specific release rate. Therefore, the **control structure** is not required to be modified.

PART 3 SOLUTION

The **required detention volume** for the **redevelopment** is calculated using **Bulletin 75** rainfall data and the lesser of the **watershed** specific release rate for the **redevelopment** or the **actual release rate** of the **control structure**. Part 2 above determined the per acre **actual release rate** of 0.15 cfs/acre is less than the 0.30 cfs/acre **watershed** specific release rate. Therefore, the per acre **actual release rate** must be used to determine the **required detention volume**

Step 1. Calculate the existing **required detention volume** based on the permitted **runoff** coefficient for the area to be **redeveloped**, the **actual release rate** of the **control structure** pro-rated for the area, and the existing rainfall data used under the approved permit.

Using the Modified Rational Method Calculator, the existing **required detention volume** is 0.862 ac-ft.

Step 2. Calculate the **required detention volume** of the **redevelopment** based on the proposed **runoff** coefficient, the **actual release rate** of the **control structure** pro-rated for the area, and **Bulletin 75** rainfall data.

Using the Modified Rational Method Calculator, the **required detention volume** for the **redevelopment** is 1.268 ac-ft.

Step 3. Calculate the required incremental detention volume for the **redevelopment** by subtracting the existing **required detention volume** from the **required detention volume**:

$$V_{inc.} = \left(V_{req'd}\right) - \left(V_{exist\ for\ redev}\right)$$

$$= (1.268\ ac\text{-}ft) - (0.862\ ac\text{-}ft)$$

$$= 0.406\ ac\text{-}ft$$

Step 4. Calculate the new **required detention volume** for the **detention service area** by adding the incremental detention volume to the previously permitted **required detention volume**.

Since an onsite **retention-based practice** is provided as part of the **redevelopment**, the storage provided within the onsite **retention-based practice** may be credited toward the new **required detention volume**. In this example, 0.194 ac-ft of storage, equal to the required **volume control storage**, is provided within the **retention-based practice**. Therefore, the new **required detention volume** for the **detention service area** is:

$$V_{req'dfor\ DSA} = (V_{exist}) + (V_{inc}) - (V_{VC})$$

$$= (3.165\ ac\text{-}ft) + (0.406\ ac\text{-}ft) - (0.194\ ac\text{-}ft)$$

$$= 3.38\ ac\text{-}ft$$

Answer: The **existing detention facility** provides 3.49 ac-ft at an elevation of 635.00 ft, which is greater than existing **required detention volume** is 3.38 ac-ft. Therefore, the **existing detention facility** complies with the **stormwater** detention requirements of the **WMO**.

5.6 STORMWATER MANAGEMENT REFERENCE DATA AND EQUATIONS

This section of the **TGM** includes reference data and equations used to perform a hydrologic and hydraulic analysis to comply with the **stormwater** management requirements of the **WMO**.

5.6.1 TIME-OF-CONCENTRATION

The time-of-concentration, T_c, is defined as the time it takes **stormwater runoff** to travel from the most hydraulically distant point in a **watershed** to the point of analysis. The methodology used to calculate T_c are described in the sections below. The **District** provides a T_c Calculator at mwrd.org/wmo.

5.6.1.1 WMO METHODOLOGY

NRCS TR-55 methodology is used to calculate T_c under the **WMO**. T_c is the sum of all individual travel times, T_t, for consecutive components of the **stormwater** conveyance system. T_t is the time that **stormwater runoff** travels as sheet flow, shallow concentrated flow, or open channel flow. In general, when **development** occurs, T_c decreases and **stormwater runoff** increases.

Sheet flow is the first segment of a flow path. It consists of very shallow flow depths (less than 0.10 ft) and is limited to a maximum of 100-feet. Manning's kinematic solution (Overton and Meadows, 1976) is used to calculate the travel time, T_t, for sheet flow. Manning's roughness coefficients for sheet flow are shown in Table 5.8 (Table 3.1 from the **NRCS** TR-55 Manual). Manning's kinematic solution is:

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5}s^{0.4}}\left(\frac{60\ min}{hr}\right) \quad (5.5)$$

Where:
- T_t = travel time, min
- n = Manning's roughness coefficients (use Table 5.8)
- L = flow length, ft
- P_2 = 2-year, 24-hr rainfall (use Table 5.14)
- s = slope of hydraulic grade line (land slope), ft/ft

After 100-feet, sheet flow transitions to shallow concentrated flow. The travel time, T_t, for shallow concentrated flow is from Equation 3.1 of the **NRCS** TR-55 Manual. The equation to calculate travel time for shallow concentrated flow is:

$$T_t = \frac{L}{60V} \quad (5.6)$$

Where:
- T_t = travel time, min
- L = flow length, ft
- V = average velocity, ft/sec
- 60 = conversion factor from seconds to min

The average velocity, *V*, in Equation 5.6 is calculated separately and is based on whether the surface is paved or unpaved. Once the average velocity is calculated, travel time, T_t, can be calculated using Equation 5.6. The average velocity for shallow concentrated flow is calculated using Equation 5.7 for paved surfaces, or Equation 5.8 for unpaved surfaces:

$$V_{paved} = 20.3282(s)^{1/2} \tag{5.7}$$

$$V_{unpaved} = 16.1345(s)^{1/2} \tag{5.8}$$

Where: V = average velocity, ft/sec
s = slope of the hydraulic grade line (watercourse slope), ft/ft

Stormwater runoff may flow through an area as open channel flow (e.g., creeks, ditches, **storm sewers**). The travel time, T_t, for open channel flow can be determined using velocity calculated in Equation 5.9, with average flow velocities based on Manning's Equation assuming bank-full elevation. Average flow velocity for open channel flow in **storm sewers** can be assumed to be 2 ft/sec. Manning's roughness coefficients for open channel flow are shown in Table 5.9. Manning's Equation to calculate average flow velocity, *V*, is:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2} \tag{5.9}$$

Where: V = average flow velocity, ft/sec
n = Manning's roughness coefficient (use Table 5.9)
R = hydraulic radius of the sewer or channel, ft
S = slope of the sewer or channel (energy gradient), ft/ft

In general, when land is developed, the speed of **stormwater runoff** increases and the T_c decreases. The shape of **runoff** hydrographs is affected by the length of T_c. A short T_c produces a steep **runoff** hydrograph with a higher peak flow, while a long T_c will flatten the shape of the **runoff** hydrograph and the peak flow will be lower. For many **developments**, the T_c will be short, and a minimum value of 10-minutes should be used.

TABLE 5.8 MANNING'S ROUGHNESS COEFFICIENTS FOR SHEET FLOW (TABLE 3-1 FROM NRCS TR-55)

Surface Type	**Manning's Roughness Coefficient, n**
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated Soils:	
Residue cover ≤ 20%	0.06
Residue cover ≥ 20%	0.17
Grass:	
Short prairie grass	0.15
Dense grass	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods:	
Light underbrush	0.40
Dense Underbrush	0.80

TABLE 5.9 MANNING'S ROUGHNESS COEFFICIENTS FOR OPEN CHANNEL FLOW (CHOW, 1959)

Surface Type	**Manning's Roughness Coefficient, *n***
Paved channels (asphalt, concrete, pipes)	0.013
Unpaved channels	0.035

5.6.1.2 SPO METHODOLOGY

The **SPO** required the longest T_c to be determined for the undeveloped, natural condition of the **detention service area**. Several flow paths must be delineated within the **detention service area** to determine the longest T_c.

The equation (Kerby, 1959) used to calculate T_c when the flow path is less than 1,000-feet is:

$$T_C = 0.827\left(\frac{Lr}{\sqrt{S}}\right)^{0.467} \tag{5.10}$$

Where:
- L = overland flow length, ft
- s = average slope, ft/ft
- r = 0.40, Kerby retardance coefficient for average grass

The equation (FAA Airport Drainage, 1970) used to calculate T_c when the flow path is greater than or equal to 1,000-feet is:

$$T_C = 1.8\left(\frac{(1.1-c)L^{1/2}}{\sqrt[3]{100S}}\right) \quad (5.11)$$

Where: L = overland flow length, ft
s = average slope, ft/ft
c = 0.15, Manning's roughness coefficient for undeveloped land

When there is channelized flow within the **property holdings**, Manning's equation, detailed in 5.6.1.1 should be used to determine the T_c of the channel.

5.6.2 HYDROLOGIC RUNOFF PARAMETERS

Hydrologic parameters are used to determine the quantity of **stormwater runoff** from an area. These parameters are described in the sections below.

5.6.2.1 RUNOFF CURVE NUMBER

The **runoff** curve number is a hydrologic parameter used to calculate the peak **stormwater runoff** from an area using the **NRCS** (formally known as SCS) **Runoff** Curve Number Method. The composite **runoff** curve number is the weighted average of the different surface types within the **tributary area**. The **District** provides a Composite **Runoff** Curve Number Calculator mwrd.org/wmo.

The composite **runoff** curve number must be calculated using the **runoff** curve numbers shown in Table 5.10. This table is a modified version of Table 2-2a from the **NRCS** TR-55 Manual. Factors affecting the **runoff** curve number are the hydrologic soil group, surface type, and antecedent **runoff** condition. The equation to calculate the composite **runoff** curve number, *CN*, is:

$$CN = \frac{CN_1A_1+CN_2A_2+\ldots+CN_nA_n}{\sum A} \quad (5.12)$$

Where: CN = composite **runoff** curve number
CN_n = **runoff** curve number for surface type (use Table 5.10)
A_n = area of surface, acres

TABLE 5.10 RUNOFF CURVE NUMBERS

Surface Type	Curve Numbers for Hydrologic Soil Group (Antecedent Runoff Condition II)	
	C	**D**
Impervious (roads, roofs, sidewalks, etc.)	98	98
Pervious Area (open space, mostly grassed areas)	74	80
Gravel (railroad yards, roads, parking lots)	89	91
Water Surface (open water)	100	100
Graded areas (pervious area only, no vegetation)	91	94
Native Plantings (deep-rooted vegetation)	70	77
Wetlands	91	94
Synthetic turf fields	91	91
Green Infrastructure:		
Non-compacted gravel areas	91	91
Porous/permeable pavement	91	91
Bioswale	63	70
Bioretention Facility	63	70
Rain Garden	63	70
Green Roof	(Refer to Table 5.11)	

TABLE 5.11 RUNOFF CURVE NUMBERS FOR GREEN ROOFS AS A FUNCTION OF DEPTH

Media Depth (inches)	Porosity	Reduced CN	Volume Control Storage (ft^3/ft^2)
0	-	98	-
2	0.25	94	0.042
4	0.25	90	0.083
6	0.25	85	0.125
9	0.25	79	0.188
12	0.25	72	0.250

The index of potential **runoff** before a **storm event** is called antecedent **runoff** condition (ARC). The variability in the **runoff** curve numbers are a result of rainfall intensity and duration, total rainfall, soil moisture conditions, cover density, stage of growth, and temperature. ARC is divided into three classes: I for dry conditions, II for average conditions, and III for wetter conditions. The **runoff** curve numbers shown in Table 5.10 are based on ARC II.

Soils are classified into hydrologic soil groups (HSG) based on the minimum infiltration rate at the surface of bare soil after prolonged wetting. Due to the general uniformity of low-infiltrating soils in **Cook County**, the curve numbers will be limited to HSG C and D as shown in Table 5.10. These are low-infiltrating soils that are in their native or post-**development** condition. Since the areas that contain high-infiltrating soils, HSG A and B, are extremely limited, the curve numbers for these soils will only be allowed where the native soils are intact and a soil test is performed to verify the infiltration capacity, and the infiltration capacity of the soils will be preserved under the developed condition. Site-specific soil information is available online through the **NRCS** website at websoilsurvey.sc.egov.usda.gov/App/HomePage.htm.

5.6.2.2 RUNOFF COEFFICIENT

The **runoff** coefficient is a hydrologic parameter used to calculate the quantity of **stormwater runoff** generated from an area. The **District** provides a Composite **Runoff** Coefficient Calculator at mwrd.org/wmo.

The composite **runoff** coefficient is a weighted average of the different types of surfaces within the **tributary area**. The composite **runoff** coefficient must be calculated using the **runoff** coefficients shown in Table 5.12. These **runoff** coefficients account for **stormwater runoff** infiltrating into the ground and for evapotranspiration. The equation to calculate the composite **runoff** coefficient, *C*, is:

$$C = \frac{C_1 A_1 + C_2 A_2 + \ldots + C_n A_n}{\sum A} \tag{5.13}$$

Where:
C = composite **runoff** coefficient
C_n = **runoff** coefficient for surface type (use Table 5.12)
A_n = area of surface, acres

TABLE 5.12 RUNOFF COEFFICIENTS

Surface Type	Runoff Coefficient, *C*
Impervious (buildings, pavement, compacted gravel)	0.90
Pervious	0.45
Gravel (loose, unbound)	0.75
Water Surface	1.00
Native Plantings	0.15
Wetlands	0.79
Synthetic Turf Fields	0.75
Green Infrastructure:	
Pervious Surfaces (non-compacted gravel, Permeable pavers/concrete)	0.75
Bioswale	0.10
Bioretention Facility	0.10
Rain Garden	0.10
Green Roof	(Refer to Table 5.13)

TABLE 5.13 RUNOFF COEFFICIENTS FOR GREEN ROOFS AS A FUNCTION OF DEPTH

Media Depth (inches)	Porosity	Reduced Runoff Coefficient, C	Volume Control Storage (ft^3/ft^2)
0	-	0.90	-
2	0.25	0.83	0.042
4	0.25	0.74	0.083
6	0.25	0.66	0.125
9	0.25	0.54	0.188
12	0.25	0.40	0.250
> 12	0.25	0.10	> 0.250

5.6.3 RATIONAL METHOD

The Rational Method is used to calculate the peak **stormwater runoff**, *Q*, of the design **storm event** for the **tributary area**. The Rational Method may be used to calculate the **design runoff rate** provided a **critical duration analysis** is not required per 5.2.6.1 of this **TGM**. The Rational Method formula is:

$$Q = C\ i\ A \tag{5.14}$$

Where:
- Q = peak **stormwater runoff**, cfs
- C = composite **runoff coefficient** (use Table 5.12)
- i = rainfall intensity, in/hr (use Table 5.15)
- A = area, acres

The Rational Method assumes the duration of the rainfall intensity, *i*, is equal to the T_c. **NRCS** TR-55 methodology must be used to calculate T_c (refer to 5.6.1.1). **Bulletin 75** rainfall data, shown in Table 5.15, must be used to calculate the peak **stormwater runoff**.

5.6.4 EVENT HYDROGRAPH METHODS

The **design runoff rate** can be calculated using one of the following event hydrograph methods:

- HEC-1 (**NRCS runoff** method);
- HEC-HMS (**NRCS runoff** method); or
- TR-20.

Other event hydrograph modeling methods not listed above may be used with approval from the **District**. All event hydrograph methods must incorporate the following:

- Antecedent **Runoff** Condition (ARC) II;
- **Bulletin 70** Northeast Sectional Rainfall Depths (Table 5.14); and
- Appropriate time distributions of rainfall (Table 5.21).

The District provides HEC-HMS model templates for development and redevelopment at at mwrd.org/wmo.

5.6.5 CN ADJUSTMENT

Storage volume provided within **retention-based practices** may be credited toward the **required detention volume** when they are located within the same **property holdings** as the **detention facility**. Credit is provided for **retention-based practices** by using an adjusted **runoff** curve number (CN_{ADJ}) to calculate the **required detention volume**. CN_{ADJ} is calculated using the **NRCS runoff** equation by reducing the total **runoff** volume of the **development** by the storage provided within the **retention-based practice**. Refer to 5.4.3.1 for additional information. The **District** provides a CN_{ADJ} Calculator at mwrd.org/wmo.

To calculate CN_{ADJ}, use the **NRCS runoff** equations to determine the **runoff** volume tributary to the **retention-based practice**:

$$S = \frac{1000}{CN} - 10 \tag{5.15}$$

$$Q_D = \frac{(P-0.2S)^2}{(P+0.8S)} \tag{5.16}$$

$$V_R = Q_D\ (A)\left(\frac{1}{12\frac{in}{ft}}\right) \tag{5.17}$$

Where:
- S = potential maximum retention after **runoff** begins, inches
- CN = composite **runoff** curve number
- Q_D = **runoff** depth, inches
- P = 100-year, 24-hour rainfall depth, inches (use Table 5.14)
- V_R = **runoff** volume, ac-ft
- A = area, acres

Calculate the adjusted **runoff** volume by subtracting the volume provided within the **retention-based practice** from the **runoff** volume:

$$V_{ADJ} = V_R - VC_P \tag{5.18}$$

Where: V_{ADJ} = adjusted **runoff** volume, ac-ft
VC_P = volume provided within **retention-based practice**, ac-ft

Use the adjusted **runoff** volume to solve for CN_{ADJ}:

$$V_{ADJ} = Q_{ADJ}\,(A)\left(\frac{1}{12\frac{in}{ft}}\right) \tag{5.19}$$

$$Q_{ADJ} = \frac{\left(P-0.2S_{ADJ}\right)^2}{\left(P+0.8S_{ADJ}\right)} \tag{5.20}$$

$$S_{ADJ} = \frac{1000}{CN_{ADJ}} - 10 \tag{5.21}$$

Where: S_{ADJ} = adjusted potential maximum retention after **runoff** begins, inches
CN_{ADJ} = adjusted composite **runoff** curve number
Q_{ADJ} = adjusted **runoff** depth, inches
P = 100-year, 24-hour rainfall depth, inches (use Table 5.14)
V_{ADJ} = adjusted **runoff** volume, ac-ft
A = area, acres

5.6.6 NOMOGRAPH METHOD

The nomograph method calculates the **required detention volume** by inputting the proposed **runoff** curve number (*CN*) for the **development** and the **actual release rate**. When volume control is provided by a **retention-based practice**, CN_{ADJ} should be used. When CN_{ADJ} is used, the storage associated with **retention-based practices** must not be included in detention volume calculations.

Separate nomographs are provided for **Bulletin 75**and **Bulletin 70** rainfall data and they include curves for various release rates. The **District** provides Nomograph Calculators at mwrd.org/wmo.

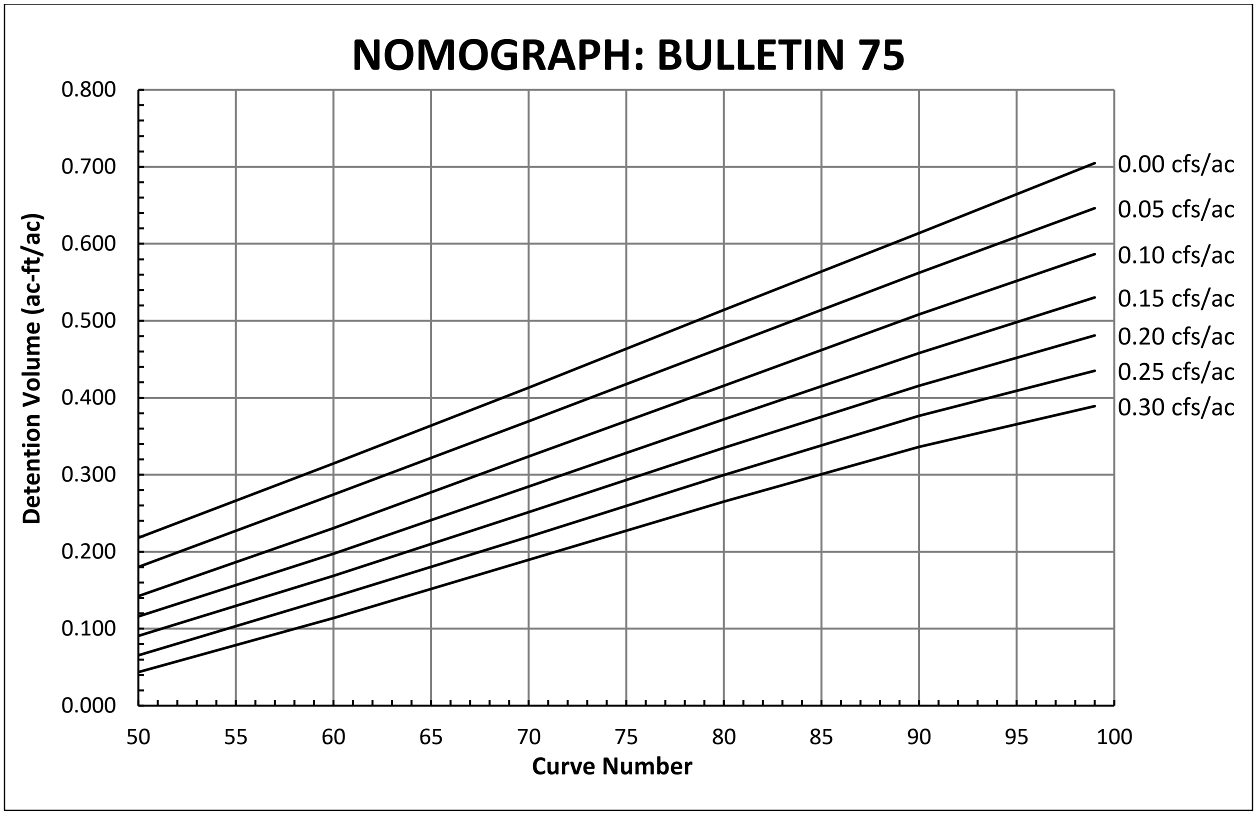


FIGURE 5.1: NOMOGRAPH FOR BULLETIN 75 RAINFALL DATA

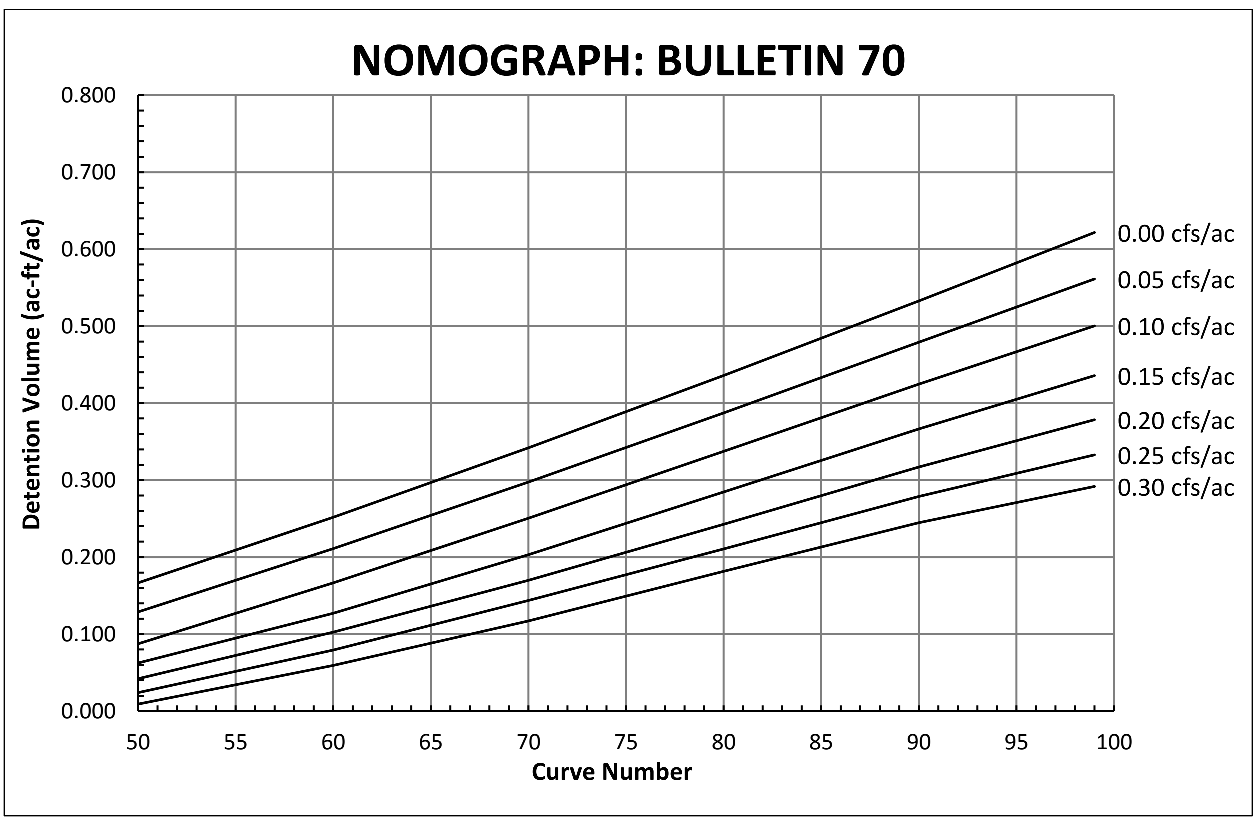


FIGURE 5.2 NOMOGRAPH FOR BULLETIN 70 RAINFALL DATA

5.6.7 BULLETIN 75 NORTHEAST SECTIONAL RAINFALL DATA

Bulletin 75 Northeast Sectional Rainfall Data is provided in Table 5.14 and Table 5.15.

TABLE 5.14 BULLETIN 75 NORTHEAST SECTIONAL RAINFALL DEPTH

Storm Duration	Rainfall Depth (in) per Storm Event Duration and Recurrence Interval						
	1-year	2-year	5-year	10-year	25-year	50-year	100-year
5-min	0.33	0.40	0.52	0.62	0.77	0.90	1.03
10-min	0.58	0.70	0.90	1.08	1.35	1.58	1.80
15-min	0.75	0.90	1.16	1.39	1.74	2.03	2.32
30-min	1.03	1.24	1.59	1.91	2.39	2.78	3.17
1-hour	1.30	1.57	2.02	2.42	3.03	3.53	4.03
2-hour	1.61	1.94	2.49	2.99	3.74	4.35	4.97
3-hour	1.77	2.14	2.75	3.30	4.13	4.80	5.49
6-hour	2.08	2.51	3.23	3.86	4.84	5.63	6.43
12-hour	2.41	2.91	3.74	4.48	5.61	6.53	7.46
18-hour	2.61	3.14	4.04	4.84	6.06	7.05	8.06
24-hour	2.77	3.34	4.30	5.15	6.45	7.50	8.57
48-hour	3.04	3.66	4.71	5.62	6.99	8.13	9.28
72-hour	3.30	3.97	5.08	6.05	7.49	8.64	9.85
120-hour	3.67	4.42	5.63	6.68	8.16	9.39	10.66
240-hour	4.65	5.60	7.09	8.25	9.90	11.26	12.65

TABLE 5.15 BULLETIN 75 NORTHEAST SECTIONAL RAINFALL INTENSITY

Storm Duration	Rainfall Intensity (in/hr) per Storm Event Duration and Recurrence Interval						
	1-year	2-year	5-year	10-year	25-year	50-year	100-year
5-min	3.96	4.80	6.24	7.44	9.24	10.80	12.36
10-min	3.48	4.20	5.40	6.48	8.10	9.48	10.80
15-min	3.00	3.60	4.64	5.56	6.96	8.12	9.28
30-min	2.06	2.48	3.18	3.82	4.78	5.56	6.34
1-hour	1.30	1.57	2.02	2.42	3.03	3.53	4.03
2-hour	0.81	0.97	1.25	1.50	1.87	2.18	2.49
3-hour	0.59	0.71	0.92	1.10	1.38	1.60	1.83
6-hour	0.35	0.42	0.54	0.64	0.81	0.94	1.07
12-hour	0.20	0.24	0.31	0.37	0.47	0.54	0.62
18-hour	0.15	0.17	0.22	0.27	0.34	0.39	0.45
24-hour	0.12	0.14	0.18	0.21	0.27	0.31	0.36
48-hour	0.06	0.08	0.10	0.12	0.15	0.17	0.19
72-hour	0.05	0.06	0.07	0.08	0.10	0.12	0.14
120-hour	0.03	0.04	0.05	0.06	0.07	0.08	0.09
240-hour	0.02	0.02	0.03	0.03	0.04	0.05	0.05

5.6.8 BULLETIN 70 NORTHEAST SECTIONAL RAINFALL DATA

Bulletin 70 Northeast Sectional Rainfall Data is provided in Table 5.16 and Table 5.17. This rainfall data may have been used to determine the **stormwater** detention requirements for **existing detention facilities** approved under a **WMO** permit.

TABLE 5.16 BULLETIN 70 NORTHEAST SECTIONAL RAINFALL DEPTH

Storm Duration	Rainfall Depth (in) per Storm Event Duration and Recurrence Interval						
	1-year	2-year	5-year	10-year	25-year	50-year	100-year
5-min	0.30	0.36	0.46	0.54	0.66	0.78	0.91
10-min	0.55	0.67	0.84	0.98	1.21	1.42	1.67
15-min	0.68	0.82	1.03	1.21	1.49	1.75	2.05
30-min	0.93	1.12	1.41	1.65	2.04	2.39	2.80
1-hour	1.18	1.43	1.79	2.10	2.59	3.04	3.56
2-hour	1.48	1.79	2.24	2.64	3.25	3.82	4.47
3-hour	1.60	1.94	2.43	2.86	3.53	4.14	4.85
6-hour	1.88	2.28	2.85	3.35	4.13	4.85	5.68
12-hour	2.18	2.64	3.31	3.89	4.79	5.62	6.59
18-hour	2.30	2.79	3.50	4.11	5.06	5.95	6.97
24-hour	2.51	3.04	3.80	4.47	5.51	6.46	7.58
48-hour	2.70	3.30	4.09	4.81	5.88	6.84	8.16
72-hour	2.93	3.55	4.44	5.18	6.32	7.41	8.78
120-hour	3.25	3.93	4.91	5.70	6.93	8.04	9.96
240-hour	4.12	4.95	6.04	6.89	8.18	9.38	11.14

TABLE 5.17 BULLETIN 70 NORTHEAST SECTIONAL RAINFALL INTENSITY

Storm Duration	Rainfall Intensity (in/hr) per Storm Event Duration and Recurrence Interval						
	1-year	2-year	5-year	10-year	25-year	50-year	100-year
5-min	3.60	4.32	5.52	6.48	7.92	9.36	10.92
10-min	3.30	4.02	5.04	5.88	7.26	8.52	10.02
15-min	2.72	3.28	4.12	4.84	5.96	7.00	8.20
30-min	1.86	2.24	2.82	3.30	4.08	4.78	5.60
1-hour	1.18	1.43	1.79	2.10	2.59	3.04	3.56
2-hour	0.74	0.90	1.12	1.32	1.63	1.91	2.24
3-hour	0.53	0.65	0.81	0.95	1.18	1.38	1.62
6-hour	0.31	0.38	0.48	0.56	0.69	0.81	0.95
12-hour	0.18	0.22	0.28	0.32	0.40	0.47	0.55
18-hour	0.12	0.15	0.18	0.22	0.27	0.31	0.37
24-hour	0.10	0.13	0.16	0.19	0.23	0.27	0.32
48-hour	0.06	0.07	0.09	0.10	0.12	0.14	0.17
72-hour	0.04	0.05	0.06	0.07	0.09	0.10	0.12
120-hour	0.03	0.03	0.04	0.05	0.06	0.07	0.08
240-hour	4.12	4.95	6.04	6.89	8.18	9.38	11.14

5.6.9 TECHNICAL PAPER NO. 40 RAINFALL DATA

Technical Paper No. 40 Rainfall Data is provided in Table 5.18. This rainfall data is applicable to determine the **stormwater** detention requirements for **existing detention facilities** approved under a **Sewerage System Permit** (**SPO** permit) or constructed prior to the May 1, 2014 effective date of the **Watershed** Management **Ordinance** and not permitted under a **Sewerage System Permit** (**SPO** permit).

TABLE 5.18 TECHNICAL PAPER NO. 40 RAINFALL DATA

Storm Duration	Rainfall Intensity (in/hr) per Storm Event Duration and Recurrence Interval	
	3-year	100-year
10-min	4.30	7.60
20-min	3.00	5.50
30-min	2.45	4.40
40-min	2.15	3.70
50-min	1.85	3.20
1-hr	1.67	2.80
1.5-hr	1.27	2.10
2-hr	1.00	1.70
3-hr	0.73	1.20
4-hr	0.58	1.00
5-hr	0.48	0.84
6-hr	0.42	0.73
7-hr	0.37	0.65
8-hr	0.33	0.58
9-hr	0.30	0.53
10-hr	0.27	0.49
11-hr	0.25	0.46
12-hr	0.23	0.43
13-hr	0.22	0.40
14-hr	0.20	0.38
15-hr	0.19	0.36
16-hr	0.18	0.34
17-hr	0.17	0.33
18-hr	0.16	0.31
19-hr	0.16	0.30
20-hr	0.15	0.29
21-hr	0.15	0.28
22-hr	0.14	0.27
23-hr	0.14	0.26
24-hr	0.13	0.25

5.6.10 BULLETIN 75 MEDIAN TIME DISTRIBUTIONS OF RAINFALL

Bulletin 75 median time distributions (Huff quartiles) of rainfall are shown in Table 5.21. These distributions are based on the size of the basin and expressed as cumulative percentages of storm duration and rainfall depth. Distributions are categorized as 1st-, 2nd-, 3rd- or 4th-quartile storms depending on whether the greatest percentage of total storm rainfall depth occurred during the first-, second-, third-, or fourth-quarter of the storm period. The appropriate quartile for a particular storm duration is shown in Table 5.22.

TABLE 5.19 BULLETIN 75 MEDIAN TIME DISTRIBUTIONS OF RAINFALL

Portion of the Storm	Area < 10 mi²				10 mi² < Area < 50 mi²				50 mi² < Area < 400 mi²			
	Quartile				Quartile				Quartile			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
0/24	0	0	0	0	0	0	0	0	0	0	0	0
1/24	8.36	2.29	2.05	2.31	6.41	1.48	1.33	1.48	4.59	0.88	0.72	0.90
2/24	17.73	4.82	4.31	4.79	15.69	3.57	3.02	3.34	13.49	2.38	1.85	2.29
3/24	28.11	7.78	6.67	7.12	27.45	6.39	5.13	5.72	25.94	4.93	3.47	4.36
4/24	38.33	11.33	9.12	9.78	38.91	10.02	7.53	8.56	39.17	8.52	5.57	7.10
5/24	47.45	15.79	11.71	12.53	49.34	14.71	10.01	11.69	51.04	13.19	8.28	9.93
6/24	55.50	21.39	14.36	15.23	58.55	20.89	12.65	14.19	60.79	19.59	10.96	12.84
7/24	62.25	28.41	16.91	17.91	65.88	28.91	15.24	17.19	69.26	27.46	13.79	15.46
8/24	67.22	36.44	19.64	20.33	71.10	37.55	18.17	19.69	74.80	37.17	16.35	17.83
9/24	70.82	45.29	22.78	22.83	74.92	46.86	21.46	22.27	78.74	47.77	19.66	20.12
10/24	74.17	54.35	26.33	25.41	78.30	56.25	25.36	24.81	82.20	58.18	23.46	23.12
11/24	76.97	62.38	30.93	28.35	81.16	64.84	29.90	27.46	85.13	67.64	28.07	25.76
12/24	79.81	69.76	36.35	31.25	83.75	72.90	35.60	30.33	87.38	75.86	34.06	28.26
13/24	82.55	75.48	43.92	33.90	86.20	79.07	43.42	32.42	89.58	82.04	42.30	30.99
14/24	85.18	80.38	52.11	36.33	88.64	83.97	52.18	34.28	91.45	86.92	52.02	33.68
15/24	87.40	84.70	61.02	38.61	90.81	87.58	61.88	36.89	93.35	90.33	62.76	36.12
16/24	89.47	87.81	69.89	41.24	92.58	90.67	71.81	39.73	94.80	93.09	72.80	39.07
17/24	91.17	90.22	78.19	45.08	93.99	92.76	80.43	43.85	95.99	94.82	82.27	42.93
18/24	92.70	92.17	84.92	51.29	95.19	94.59	87.25	49.87	96.94	96.25	89.19	48.98
19/24	94.03	93.81	89.74	59.31	96.35	95.97	92.01	58.93	97.70	97.34	93.60	59.22
20/24	95.36	95.29	93.11	69.19	97.27	97.10	95.04	69.85	98.35	98.21	96.33	71.66
21/24	96.56	96.57	95.34	80.05	98.03	97.99	96.90	82.36	98.86	98.83	97.97	85.18
22/24	97.74	97.74	97.06	89.71	98.74	98.72	98.22	92.59	99.28	99.30	98.98	94.64
23/24	98.85	98.84	98.56	96.04	99.37	99.39	99.21	97.96	99.66	99.67	99.58	98.77
24/24	100	100	100	100	100	100	100	100	100	100	100	100

TABLE 5.20 QUARTILE FOR STORM DURATION

Quartile	1st				2nd	3rd		4th			
Storm Duration	1-hr	2-hr	3-hr	6-hr	12-hr	18-hr	24-hr	48-hr	72-hr	120-hr	240-hr

5.6.11 CIRCULAR 173 MEDIAN TIME DISTRIBUTIONS OF RAINFALL

Circular 173 median time distributions (Huff quartiles) of rainfall are shown in Table 5.21 and are to be used with **Bulletin 70** rainfall data. These distributions are based on the size of the basin and expressed as cumulative percentages of storm duration and rainfall depth. Distributions are categorized as 1st-, 2nd-, 3rd- or 4th-quartile storms depending on whether the greatest percentage of total storm rainfall depth occurred during the first-, second-, third-, or fourth-quarter of the storm period. The appropriate quartile for a particular storm duration is shown in Table 5.22.

TABLE 5.21 CIRCULAR 173 MEDIAN TIME DISTRIBUTIONS OF RAINFALL

Cumulative Percent of Storm	Area < 10 mi²				10 mi² < Area < 50 mi²				50 mi² < Area < 400 mi²			
	Quartile				Quartile				Quartile			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
05	16	03	03	02	12	03	02	02	08	02	02	02
10	33	08	06	05	25	06	05	04	17	04	04	03
15	43	12	09	08	38	10	08	07	34	08	07	05
20	52	16	12	10	51	14	12	09	50	12	10	07
25	60	22	15	13	62	21	14	11	63	21	12	09
30	66	29	19	16	69	30	17	13	71	31	14	10
35	71	39	23	19	74	40	20	15	76	42	16	12
40	75	51	27	22	78	52	23	18	80	53	19	14
45	79	62	32	25	81	63	27	21	83	64	22	16
50	82	70	38	28	84	72	33	24	86	73	29	19
55	84	76	45	32	86	78	42	27	88	80	39	21
60	86	81	57	35	88	83	55	30	90	86	54	25
65	88	85	70	39	90	87	69	34	92	89	68	29
70	90	88	79	45	92	90	79	40	93	92	79	35
75	92	91	85	51	94	92	86	47	95	94	87	43
80	94	93	89	59	95	94	91	57	96	96	92	54
85	96	95	92	72	96	96	94	74	97	97	95	75
90	97	97	95	84	97	97	96	88	98	98	97	92
95	98	98	97	92	98	98	98	95	99	99	99	97

TABLE 5.22 QUARTILE FOR STORM DURATION

Quartile	1st				2nd	3rd		4th			
Storm Duration	1-hr	2-hr	3-hr	6-hr	12-hr	18-hr	24-hr	48-hr	72-hr	120-hr	240-hr

5.6.12 *MODIFIED RATIONAL METHOD (SPO METHODOLOGY)*

The Modified Rational Method was used to determine the detention requirements for a **project** subject to the **Sewer Permit Ordinance** and issued under a **Sewerage System Permit**. This methodology may be used to determine the **stormwater** detention requirements for an **existing detention facility** constructed prior to the May 1, 2014 effective date of the **Watershed** Management **Ordinance** and not permitted under a **Sewerage System Permit**.

5.6.12.1 *GROSS ALLOWABLE RELEASE RATE*

The **gross allowable release rate**, Q_{allow}, was determined for the undeveloped, natural condition of the **property holdings**. The Rational Method is used to calculate Q_{allow}, for the 3-year **storm event** with a duration equal to the longest T_c described in 5.6.1.2. Technical Paper No. 40 rainfall data in Table 5.18 is used to calculate Q_{allow}. The equation used to calculate Q_{allow} is:

$$Q_{allow} = C_{undev}\, i_3\, A \qquad (5.22)$$

Where:
Q_{allow} = **gross allowable release rate**, cfs
C_{undev} = 0.15, undeveloped **runoff** coefficient
i_3 = 3-year rainfall intensity based on the longest time-of-concentration for the undeveloped, natural condition, in/hr (use Table 5.18)
A = area, acres

5.6.12.2 *REQUIRED DETENTION VOLUME*

The **required detention volume** was based on the critical 100-year **storm event** and is calculated by subtracting the **actual release rate** of the **control structure** from the maximum **stormwater runoff** rate of the detained area considering all storm durations published in Technical Paper No. 40. The equation used to calculate the **required detention volume** is:

$$V_{req} = (C_{dev}\, i_{100}\, A) - Q_{act} \qquad (5.23)$$

Where:
V_{req} = **required detention volume**, ac-ft
C_{dev} = developed **runoff** coefficient (use Table 5.12)
i_{100} = 100-year rainfall intensity for all storm durations
A = detained area, acres
Q_{act} = **actual release rate** (constant for all storm durations), cfs

5.6.13 MANNING'S EQUATION

Manning's Equation can be used to determine the minimum dimensions of a sewer system or other open channel conveyance systems. Manning's roughness coefficients are shown in Table 5.9 for open channels and Table 5.23 for sewers. Manning's Equation to calculate the flow rate, *Q*, is:

$$Q = \frac{1.486}{n} A\, R^{2/3}\, S^{1/2} \quad (5.24)$$

Where:
Q = flow capacity, cfs
n = Manning's roughness coefficient (Table 5.9 or Table 5.23)
A = cross-sectional area of the pipe or channel flow, ft^2
R = hydraulic radius of the pipe or channel, ft
S = slope of the pipe or channel (energy gradient), ft/ft

The hydraulic radius, *R*, is calculated with the following equations:

$$R = \frac{A}{P_w} \quad (5.25)$$

$$R = \frac{D}{4} \quad \text{(only when circular pipe is flowing full)} \quad (5.26)$$

Where:
A = cross-sectional area of the pipe or channel flow, ft^2
P_w = wetted perimeter of pipe or channel flow, ft
D = diameter of circular pipe, ft

TABLE 5.23 MANNING'S ROUGHNESS COEFFICIENTS FOR PIPE FLOW

Pipe Material	Manning's Roughness Coefficient, *n*
Concrete, ductile iron	0.013
Plastic pipe:	
Smooth interior	0.011
Corrugated interior	0.022

Manning's Equation can be written to calculate the minimum pipe diameter, *D*, assuming the pipe is flowing full:

$$D = \left(\frac{2.159\, Q\, n}{S^{1/2}}\right)^{3/8} \quad (5.27)$$

Where:
D = diameter of pipe, ft
Q = flow capacity, cfs
n = Manning's roughness coefficient (use Table 5.23)
S = slope of the pipe or channel (energy gradient), ft/ft

5.6.14 CONTROL STRUCTURE

A **control structure** is a device used to control the rate of **stormwater runoff**. Common **control structures** are described in this section.

5.6.14.1 ORIFICE DISCHARGE

An orifice can be used to control the release rate from a **detention facility**. The equation to calculate the discharge rate, *Q*, from an orifice is:

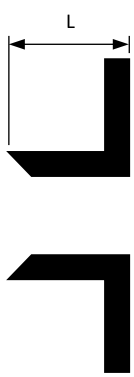
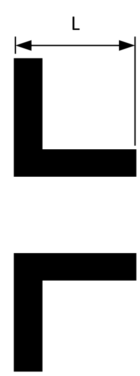
$$Q = C_d A\sqrt{2gH} \tag{5.28}$$

Where:

Q = discharge rate, cfs
C_d = discharge coefficient
A = area of orifice, ft^2
g = gravitational acceleration, 32.2 ft/sec^2
H = head from water surface elevation to centerline of orifice or differential head if orifice is submerged, ft

The discharge coefficient, C_d, depends on whether there is a projection of the orifice and the length of projection. Table 5.24 provides a summary of orifice discharge coefficients.

TABLE 5.24 ORIFICE DISCHARGE COEFFICIENTS, C_d (MWRDGC, 1978)

Type:	Projecting Sharp Edge	Projecting Square Edge	Sharp Edge	Square Edge Wall/Plate	Short Tube Wall/Plate
Flow Direction →					
Length, *L*	1/2d to d		<2d		2d to 3d
C_d	0.52		0.61		0.82

5.6.14.2 PIPE DISCHARGE

A pipe can be used to control the release rate from a **detention facility**. Pipe restrictors are classified as either short or long.

5.6.14.2.1 SHORT PIPE

A pipe is considered short when the length is 2-feet. A short pipe restrictor is typically installed within a **storm sewer** downstream of the **detention facility**. The short pipe must be permanently secured within the **storm sewer** by filling the annular space with 2-feet on non-shrink concrete.

Table 5.24 is used to calculate the discharge rate, *Q*, from a short pipe restrictor. The discharge coefficient, C_d, for a short tube restrictor is 0.82.

5.6.14.2.2 LONG PIPE

A pipe is considered long when the length is greater than 2-feet. A long pipe restrictor is typically the outlet **storm sewer** of the **detention facility**.

The equation to calculate the discharge rate, *Q*, from a long pipe is derived from the Bernoulli equation and Manning's equation:

$$Q = A\left[\frac{H}{\frac{K_e+K_O}{2g}+\frac{2.87n^2L}{D^{4/3}}}\right]^{1/2} \tag{5.29}$$

Where:

Q = discharge rate, cfs
A = area of pipe, ft^2
H = head from water surface elevation to the top of pipe, ft
Ke = entrance loss coefficient, 0.43, dimensionless
Ko = exit loss coefficient, 1.0, dimensionless
g = gravitational acceleration, 32.2 ft/sec^2
n = Manning's roughness coefficients (use Table 5.23)
L = length of pipe, ft
D = diameter of pipe, ft

5.6.14.3 WEIR DISCHARGE

A weir is a **structure** used to control **stormwater runoff**. The edge over which **stormwater** flows is called the crest of the weir.

A sharp-crested weir, shown in Figure 5.3, is generally used as a restrictor or is part of the **control structure** of a **detention facility**. The sharp edge causes the flow to spring clear of the weir crest. A broad-crested weir, shown in Figure 5.6, is generally part of a **detention facility** and used to control the flow path of **stormwater** when it overtops the **detention facility**. Since the crest is long in the direction of flow, the flow lays on the crest rather than springing clear.

The equation to calculate the free-flow discharge, Q, from any weir is:

$$Q = CLH^{3/2} \tag{5.30}$$

Where:
- Q = discharge rate, cfs
- C = discharge coefficient (refer to 5.6.14.3.1 or 5.6.14.3.2)
- L = effective length of weir (refer to 5.6.14.3.1), ft
- H = head above crest, ft
- H_c = height of weir crest, ft

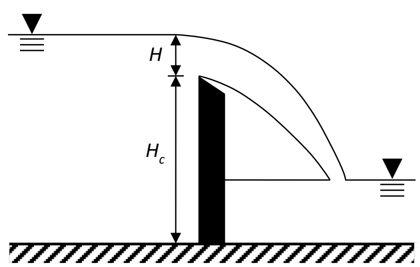


FIGURE 5.3 SHARP-CRESTED WEIR (FREE-FLOW CONDITION)

When the weir is submerged, shown in Figure 5.4, the discharge rate will be less than the free-flow condition. The equation to calculate the discharge rate, Q_s, of a submerged weir is:

$$Q_s = Q\left[1-\left(\frac{H_{\text{downstream}}}{H_{\text{upstream}}}\right)^{x}\right]^{0.385} \quad (5.31)$$

Where:
- Q_s = submerged discharge rate, cfs
- Q = unsubmerged discharge rate, cfs
- x = 3/2 for sharp crested weir, 5/2 for triangular weir
- $H_{upstream}$ = upstream head above crest, ft
- $H_{downstream}$ = downstream head above crest, ft
- H_c = height of weir crest, ft

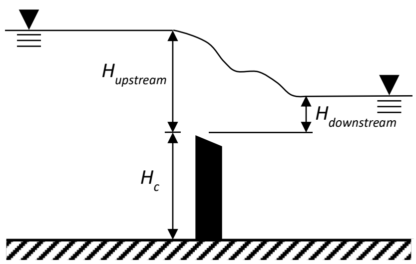


FIGURE 5.4 SUBMERGED WEIR

5.6.14.3.1 SHARP-CRESTED WEIR

The effective length of a sharp-crested weir is reduced by end contractions. A weir is suppressed (no end contractions) when the length of the weir opening is the same as the width of the upstream flow. A weir is contracted (with end contractions) when the length of weir opening is less than the width of the upstream flow. Figure 5.5 shows a suppressed weir (n=0) and contracted weir (n =2).

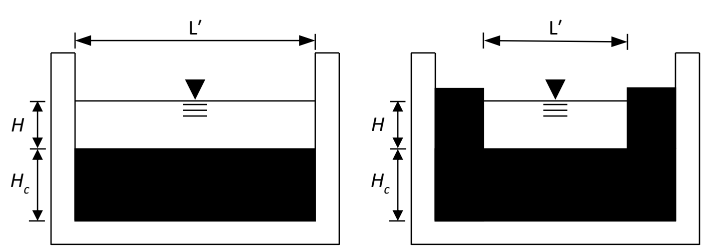


FIGURE 5.5 SUPPRESSED (LEFT) AND CONTRACTED (RIGHT) SHARP-CRESTED WEIRS

The equation to calculate the effective length of the weir, *L*, is:

$$L = L' - 0.1nH \qquad (5.32)$$

Where:
L = effective length of weir, ft
L' = measured length of weir, ft
n = number of contractions
H = head above crest, ft

The discharge coefficient, *C*, for a sharp-crested weir depends on the ratio of H/H_c. When H/H_c is less than or equal to 0.30, *C* = 3.33 as shown in Equation 5.33. When H/H_c is greater than 0.30, the discharge coefficient, *C*, is calculated by Equation 5.34.

$$C = 3.33 \qquad when \left(\frac{H}{H_c}\right) \leq 0.30 \qquad (5.33)$$

$$C = 3.27 + 0.40\left(\frac{H}{H_c}\right) \qquad when \left(\frac{H}{H_c}\right) > 0.30 \qquad (5.34)$$

Where:
Q = discharge rate, cfs
C = discharge coefficient
H = head above crest, ft
H_c = height of weir crest, ft

5.6.14.3.2 BROAD-CRESTED WEIR

A weir is considered broad-crested when the breadth of the crest, *b*, is greater than half of the head, *H*. A broad-crested weir, is shown in Figure 5.6.

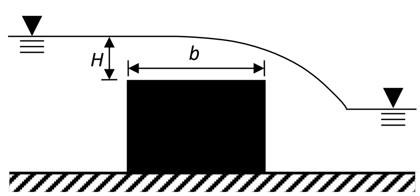


FIGURE 5.6 BROAD-CRESTED WEIR

The discharge coefficient, *C*, is influenced by the head above the weir crest and the breadth of the weir. Use Table 5.25 to determine the discharge coefficient, *C*. When the broad-crested weir has sharp corners, a minimum *C* of 2.6 should be used. When the broad-crested weir has rounded corners, a C of 3.0 is usually appropriate. If the head is greater than twice the breadth, the weir operates as a sharp-crested weir (Brater and King, 1976).

TABLE 5.25 BROAD-CRESTED WEIR COEFFICIENTS, C (Brater and King, 1976)

Head, *H* (ft)	**Breadth of Weir Crest, *b* (ft)**										
	0.50	**0.75**	**1.00**	**1.50**	**2.00**	**2.50**	**3.00**	**4.00**	**5.00**	**10.00**	**15.00**
0.2	2.80	2.75	2.69	2.62	2.54	2.48	2.44	2.38	2.34	2.49	2.68
0.4	2.92	2.80	2.72	2.64	2.61	2.60	2.58	2.54	2.50	2.56	2.70
0.6	3.08	2.89	2.75	2.64	2.61	2.60	2.68	2.69	2.70	2.70	2.70
0.8	3.30	3.04	2.85	2.68	2.60	2.60	2.67	2.68	2.68	2.69	2.64
1.0	3.32	3.14	2.98	2.75	2.66	2.64	2.65	2.67	2.68	2.68	2.63
1.2	3.32	3.20	3.08	2.86	2.70	2.65	2.64	2.67	2.66	2.69	2.64
1.4	3.32	3.26	3.20	2.92	2.77	2.68	2.64	2.65	2.65	2.67	2.64
1.6	3.32	3.29	3.28	3.07	2.89	2.75	2.68	2.66	2.65	2.64	2.63
1.8	3.32	3.32	3.31	3.07	2.88	2.74	2.68	2.66	2.65	2.64	2.63
2.0	3.32	3.31	3.30	3.03	2.85	2.76	2.27	2.68	2.65	2.64	2.63
2.5	3.32	3.32	3.31	3.28	3.07	2.89	2.81	2.72	2.67	2.64	2.63
3.0	3.32	3.32	3.32	3.32	3.20	3.05	2.92	2.73	2.66	2.64	2.63
3.5	3.32	3.32	3.32	3.32	3.32	3.19	2.97	2.76	2.68	2.64	2.63
4.0	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.70	2.64	2.63
4.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.74	2.64	2.63
5.0	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.64	2.63
5.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.64	2.63

5.6.14.3.3 TRAPEZOIDAL WEIR (CIPOLLETTI WEIR)

A trapezoidal weir is essentially a rectangular weir with a triangle weir on each side. When the side slopes are at 1:4 (H:V) the weir is known as a Cipolletti Weir and shown in Figure 5.7. Although this weir is contracted, the discharge behaves as though its end contractions were suppressed. The discharge through the triangular portions of the weir make up for the end contractions that would reduce the flow over a rectangular weir. The equation to calculate the discharge rate, *Q*, for a Cipolletti Weir is:

$$Q = 3.367LH^{3/2} \quad (5.35)$$

Where: Q = discharge rate, cfs
H = head above crest, ft
L = effective length of weir, ft

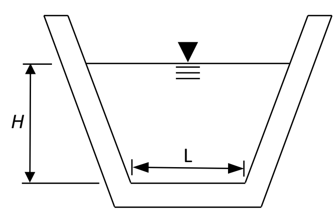


FIGURE 5.7 CIPOLLETTI WEIR

5.6.14.3.4 TRIANGULAR WEIR

The triangular weir, or v-notch weir, is shown in Figure 5.8. The equation to calculate the discharge rate, *Q*, from a triangular weir is:

$$Q = 2.5 \tan\left(\frac{\theta}{2}\right) H_1^{5/2} \quad (5.36)$$

Where:
Q = discharge rate, cfs
θ = Angle of v-notch, degrees
H = head above crest, ft

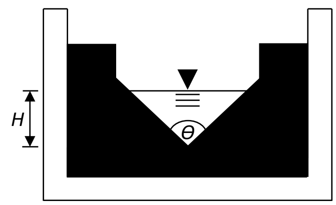


FIGURE 5.8 TRIANGULAR WEIR

ARTICLE 5 REFERENCES

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ARTICLE 5 REVISION TABLE

No.	Revision Description	Date
0	Original TGM	5/1/2014
1	Schedule applicability, sole permittee requirements, flowchart/checklist updates	8/1/2015
2	5/16/2019 WMO amendment update, rewrite, revision table	10/7/2019
3	5/7/2020 WMO amendment update, Bulletin 75 rainfall data	5/26/2020