HYDROLOGY G14/D31

G14/D31

2 PLANS

G14/D31

REX NORTON ARCHITECTS

June 7,1977

DRAINAGE STUDY

"Wendy's Old Fashioned Hamburgers" is situated on a tract of land comprising .586 acres,located on the Northwest corner of 4th St. and Fitzgerald St. NW.
The land at its present state is in a natural state which consist of sandy soil and poor grass.Presently the site drains from SE corner to the NW corner with less than a .4% slope.
It is the plan of this report to show that the runoff after the development will not exceed the natural runoff from property.

The following equations were taken from Glen Yrjaninen and Alan W. Warren article entitled,"A simple Method for Retention Basin Design",Water and Sewage Works,Dec.,1973.

OUTFLOW

$V_o = 40\ Q_o T$,where Q_o is a fixed maximum outflow @ peak storm

INFLOW

$$V_n = \frac{10500\ T}{T + 25} - V_o$$

TIME

$$T = -25 + \frac{6562.5}{Q_o}$$

DESIGN METHOD

1. $C_{nat} = .20$

   $C_{dev} = .7$ (weighted average)

   $I = 5.4$ In/Hr

   $A = ..586$ Acres

2. Maximum Allowable Outflow $= C_{nat} IA = .632$

3. $Q_o = \frac{\text{Max. All. Outflow}}{C_{dev}\ A} = \frac{.632}{.4102} = 1.54$

4. $T = -25 + \frac{7087.5}{Q_o} = 42.84$

5. $V_s = \frac{11340\ T}{T + 25} - V_o = \frac{485805.6}{67.84} - 2638.9 = 4522.1$

6. $V_t = V_s\ C_{dev}\ A = 1854.9$ cu. ft.

7. To hold this runoff,we will pond 2000cu. ft. of water in a area @ the West end

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of the site 8,000 sq. ft. x 3". We will discharge the water through 2-4"x3" orfice in a 3" high damn (speed bump).

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A simple method for retention basin design

By Glen Yrjonainen and Alan W. Warren*

Because the development of land for agrarian, residential, commercial or industrial use continues to increase, the temporary storage of storm runoff in an onsite retention basin has become essential due to inadequate outlets for the increased storm runoff created by development. In most cases, and primarily for economic reasons, adequately designed collector storm water systems (capable of handling the storm runoff from ultimate development) lag behind the development increases. Because of ever increasing construction costs and the infeasibility of installing large-diameter storm drains, the concept of ultimate design or improvement of collector storm water systems is impractical. The retention basin that meters or restricts flow is here to stay.

DESIGN METHODS. One method of retention basin design used by many design engineers is to use the rational formula to calculate the peak volume of retention required. The inflow volume for an incremental time of the storm is charted, then used to determine the depth of retention and hence the outflow over the increment of time selected. The same procedure is followed for the next time increment until the peak volume of retention is found.

One disadvantage of this method is that it requires a trial volume and area of retention to be selected by the designer in order to determine the incremental depth of retention and its corresponding outflow. Another disadvantage of this method is that the outflow over the time increment is only an average approximation, and not the instantaneously changing outflow that actually does occur with an outlet dependent upon changing head. Finally, this method is time consuming, tedious and may involve more than one trial if a poor selection for approximate volume and area is made by the designer.

Another method of retention basin design used by design engineers is graphical. It involves obtaining a synthetic hydrograph for the particular design storm and development in question. The volume of retention is then obtained by calculating the area between the bell shaped hydrograph curve and the superimposed allowable outflow curve, and then converting this area into a volume.

One disadvantage of this method is that the designer has no accurate method of selecting the duration of the storm for which to plot the hydrograph. Another disadvantage is that it is difficult to obtain an outflow curve for an instantaneously changing outflow to superimpose on the hydrograph. Other disadvantages are that a graphical solution is not that accurate and is sometimes awkward to obtain.

CALCULUS. What is needed is a straightforward, uncomplicated mathematical method of designing a retention basin. If the basin were to have no outlet, all of the storm runoff would have to be ponded. The fact is that most basins do have an outlet, with the outflow depending upon the amount of water that is ponded and the depth of retention. The outflow is instantaneously changing as the head varies. This type of outlet can be analyzed by applying basic calculus to the controlling outflow equation. If the outflow is at a constant rate, i.e., a pump, the analysis is easier. The volume of storm water into the retention basin can be determined by the rational formula. The required storage volume is the volume of runoff that flows into the basin minus that which flows out.

An equation can be obtained that relates volume of storage to allowable outflow using the time of the storm as a parameter. This equation can then be maximized by basic calculus to find the peak storage time, which in turn can be used to calculate the maximum volume of storage required. The one assumption in this method is that storm water rises in the retention basin at a constant rate to fill the basin to the peak volume, and that the maximum allowable outflow is reached only at this peak volume.

The derivations of retention equations for retention basins with a gravity flow, changing rate orifice outlet, and a constant rate pump outlet follow. These derivations are for a ten year frequency storm in the Oakland county, Michigan area. Retention equations for different year frequency storms and other areas can be obtained in the same manner.

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DEFINITION OF TERMS

- A = Contributing acreage
- a = Cross-sectional area of outflow pipe (ft^2)
- C = Coefficient of imperviousness
- c = Coefficient of contraction for an orifice
- g = Acceleration due to gravity (32.2 ft/sec^2)
- h = Head, defined as the distance from the water surface to the centerline of the outflow pipe (ft)
- I = Rainfall intensity (175/T + 25)
- K_1 = Constant (h/t)
- K_2 = Constant (ca $\sqrt{2gK_1}$)
- Qi = Instantaneously changing outflow (CFS)
- Qo = Maximum outflow per acre imperviousness (CFS/AC)
- T = Storage time, defined as the instant storage begins until the peak storage is attained (min)
- t = Instantaneous time of storage (min)
- Vn = Volume of water flowing into the retention basin per acre imperviousness (ft^3/AC)
- Vo = Volume of water flowing out of the retention basin per acre imperviousness (ft^3/AC)
- Vs = Maximum volume of water stored in the retention basin per acre imperviousness (ft^3/AC)
- Vt = Maximum volume of water stored in the retention basin (ft^3)

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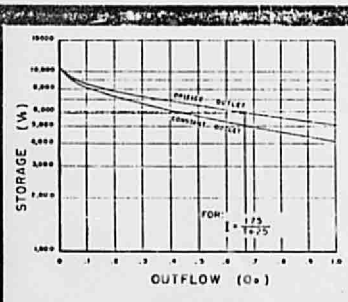


Type of Outlet	Peak Storage Time (Min)	Maximum Storage Volume (Vs)
Orifice with head	$T = -25 + \sqrt{\frac{6562.5}{Qo}}$	$Vs = \frac{10500T}{T+25} - 40QoT$
Constant Flow (Pump)	$T = -25 + \sqrt{\frac{4375}{Qo}}$	$Vs = \frac{10500T}{T+25} - 60QoT$

gravity system has to head up before it will reach the maximum rate. It is possible to have a gravity system that will head up at a rapid rate at the beginning of the storm, and at a slower rate at the end of the storm, but it is not possible for a gravity system to require less storage than the constant rate system for a given size outlet.

Retention basin design

DESIGN METHOD

1. Determine the amount of acreage (A) contributing runoff to the retention basin and its runoff coefficient (C).
2. Determine the maximum allowable outflow in CFS from the local municipal government regulations and/or the existing outlet conditions if there are no government regulations.
3. Calculate Qo = $\frac{\text{Allowable Outflow}}{\text{Acreage} \times \text{Runoff Coefficient}}$
4. Determine the type of outlet that will be used. (orifice or pump)
5. Calculate the maximum storage time (T) from the storage time equation corresponding to the type of outlet selected in Step 4.
6. Calculate the maximum storage (Vs) from the storage equation corresponding to the type of outlet selected in Step 4. (Vs will be in $\frac{\text{Ft}^3}{\text{Acres} \times \text{Runoff Coefficient}}$
7. Calculate the total volume of storage required for the entire site (Vt = Vs × C × A).

8a. If the outlet is to be an orifice operating under a head, select a depth of retention and a corresponding outflow pipe that will yield an outflow in CFS equal to the maximum allowable as determined in step 2 operating under the head as determined by the depth of retention.

8b. If the outlet is to be a pump, select a depth of retention and a pump that will yield an outflow in CFS equal to the maximum allowable as determined in step 2.

EXAMPLE PROBLEM: to illustrate the use of the equations and graphs derived in this report.

Design criteria

A 50 acre parcel of land is to be developed into a residential subdivision with a runoff coefficient of 0.30. An open ditch drain is available adjacent to this 50 acre parcel of land, and can accept storm runoff at a rate of no greater than 10 CFS from the proposed subdivision. Sufficient grade is available to allow 6.5 ft. depth of retention and a gravity flow orifice outlet. Determine (1) the volume of retention required, and (2) the size of outflow pipe required.

Solution

1. From the design criteria, calculate Qo

$$Qo = \frac{\text{Allowable outflow}}{\text{acreage} \times \text{runoff coefficient}}$$

$$Qo = \frac{10\ \text{CFS}}{50\ \text{ac} \times 0.30} = 0.667\ \frac{\text{CFS}}{\text{acre imperviousness}}$$

2. Calculate the time in min that the maximum volume of storage will occur from the orifice outlet storage time equation.

$$T = -25 + \sqrt{\frac{6562.5}{Qo}}$$

$$T = -25 + \sqrt{\frac{6562.5}{0.667}}$$

$$T = 74.22\ \text{min}$$

3. Calculate the maximum volume of storage per acre imperviousness from the orifice outlet storage equation.

$$Vs = \frac{10500\ T}{T + 25} - 40\ QoT$$

$$Vs = \frac{10500\ (74.22)}{74.22 + 25} - 40\ (0.667)\ (74.22)$$

$$Vs = 5875.18\ \text{ft}^3/\text{acre imperviousness}$$

4. Calculate the total volume of storage required for the entire site.

$$Vt = Vs \times \#\ \text{acres} \times \text{runoff coefficient}$$

$$Vt = 5875.18\ (50)\ (0.30)$$

$$Vt = 88{,}127.76\ \text{ft}^3$$

5. Because of sufficient grade available, the design depth of retention is 6.5 ft. Now select an outflow pipe from the orifice formula that will yield the allowable outflow of 10 CFS under a head of 6.5 ft.

$$Q = 0.62a\ \sqrt{2\ gh}$$

$$\text{Area} = \frac{Q}{0.62\ \sqrt{2\ gh}} = \frac{10\ \text{CFS}}{0.62\ \sqrt{64.4\ \frac{\text{ft}}{\text{sec}^2}\ (6.5\ \text{ft})}}$$

$$\text{Area} = 0.785\ \text{ft}^2$$

Select a 12 in.-diameter outflow pipe

6. Plot the storage required per acre imperviousness (Vs) versus the outflow per acre imperviousness (Qo) on the orifice outlet graph. One will see that it falls exactly on the curve. ■

Derivation for an Orifice Outlet

OUTFLOW

$$Qi = ca\sqrt{2gh} \quad \text{(Orifice formula)}$$

Assume that the storm that fills the basin to the peak volume causes the water level to rise at a constant rate. ($h = K_1 t$)

$$Qi = ca\sqrt{2gK_1 t}$$

$$\text{Let } K_2 = ca\sqrt{2gK_1}$$

$$Qi = K_2 t^{1/2}$$

$$Vo = 60\int_0^T Qi\,dt$$

A conversion factor of 60 sec/min is required because Qi is in cfs and t is in minutes.

$$Vo = 60\,K_2\int_0^T t^{1/2}\,dt$$

$$Vo = 60\,K_2(2/3)\,T^{3/2}$$

$$Vo = 40\,K_2\,T^{1/2}\,(T)$$

Assume the maximum outflow occurs only at the end of the peak storm such that $Qo = K_2\,T^{1/2}$

$$Vo = 40\,Qo\,T$$

INFLOW

$$Qn = CIA \text{ Rational Formula}$$

$$\text{Let } C = 100\%$$

$$A = 1 \text{ Acre}$$

$$I = \frac{175}{T + 25}$$

$$Qn = (100\%)\frac{175}{T + 25} \quad (1)$$

$$Qn = \frac{175}{T + 25}$$

$$Vn = Qn \times T \times 60 \text{ sec/min}$$

$$Vn = \frac{10500\,T}{T + 25}$$

STORAGE

$$Vs = Vn - Vo$$

$$Vs = \frac{10500\,T}{T + 25} - 40\,Qo\,T$$

Since Qo is a fixed maximum outflow that will only occur for the peak storm, it is necessary to find the time from the instant the storage begins until the instant the peak storage is attained. This can be done by taking the first derivative of the storage volume equation and setting it equal to zero.

$$\frac{dVs}{dT} = \frac{d\,\frac{10500\,T}{T + 25}}{dT} - \frac{d\,(40\,QoT)}{dT}$$

$$\frac{dVs}{dT} = \frac{(T + 25)(10500) - (10500\,T)(1)}{(T + 25)^2} - 40\,Qo$$

$$\frac{dVs}{dT} = \frac{262500}{T^2 + 50T + 625} - 40\,Qo = O$$

$$T^2 + 50T + 625 - \frac{262500}{40\,Qo} = O$$

This is a quadratic equation which may be reduced to the form:

$$ax^2 + bx + c = O$$

where x is T, a = 1, b = 50 and $c = 625 - \frac{262500}{40\,Qo}$

The general solution is:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$T = \frac{-50 \pm \sqrt{(50)^2 - 4(1)\left(625 - \frac{262500}{40\,Qo}\right)}}{2(1)}$$

$$T = \frac{-50 \pm \sqrt{2500 - 2500 + \frac{26250}{Qo}}}{2}$$

$$T = -25 + \frac{\sqrt{6562.5}}{Qo}$$

Derivation for a Constant Rate Outlet

A basin with a constant outflow device, such as a pump, is simpler to derive. The constant outlet rate implies that the total outflow is merely the rate multiplied by the duration of the storm.

$$Vo = 60\,Qo\,T$$

$$Vs = Vn - Vo$$

$$Vs = \frac{10500\,T}{T + 25} - 60\,Qo\,T$$

$$\frac{dVs}{dT} = \frac{(T + 25)(10500) - 10500\,T(1)}{(T + 25)^2} - 60\,Qo$$

$$\frac{dVs}{dT} = \frac{262500}{T^2 + 50T + 625} - 60\,Qo$$

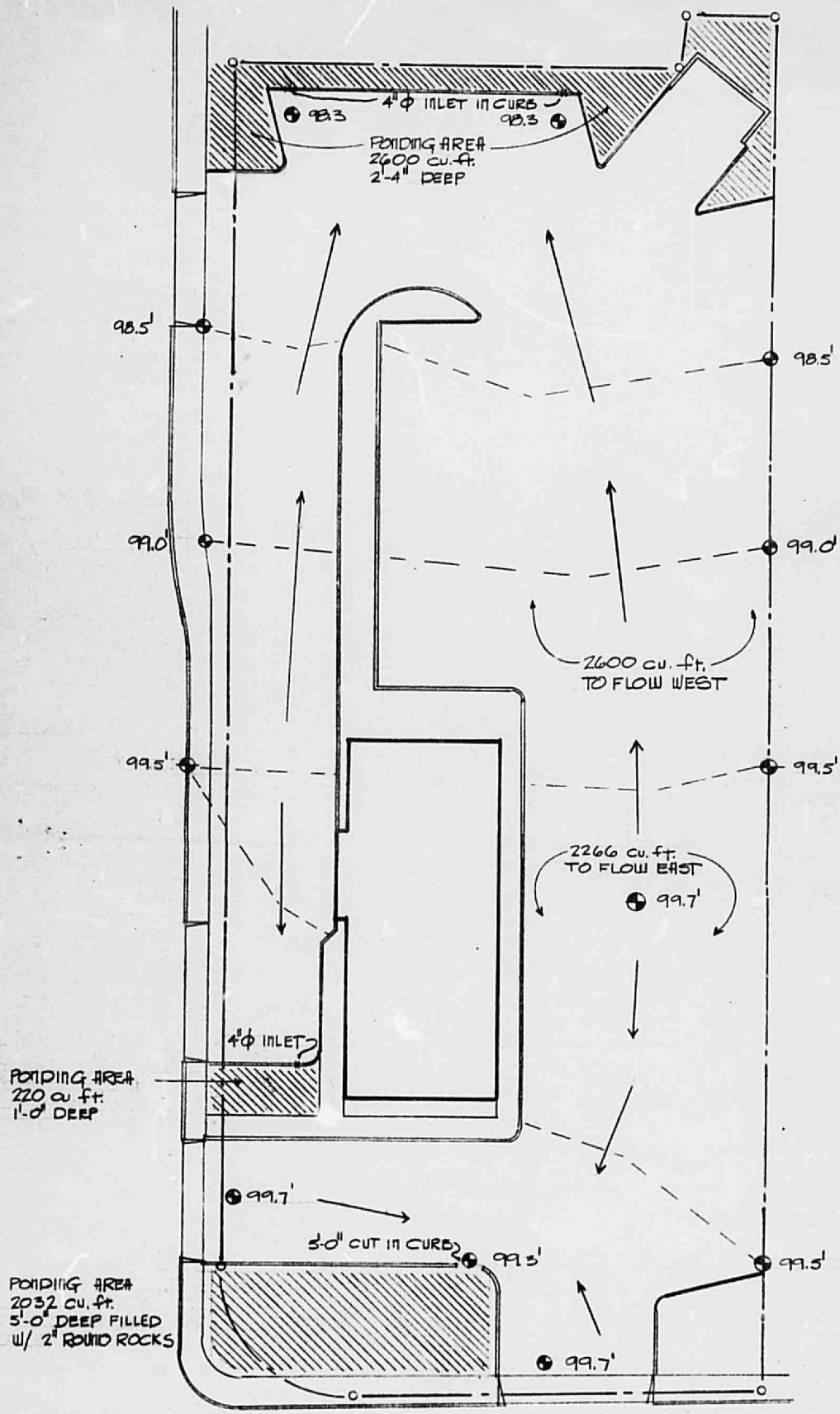
$$T^2 + 50T + 625 - \frac{262500}{60\,Qo} = O$$

$$T = -25 + \sqrt{\frac{4375}{Qo}}$$

GRAPH. In both outlet situations the duration of the storm to fill the basin to its maximum can be found as a function of the maximum outflow. The peak storage volume can then be found by substituting the duration time into the storage volume equation, reducing the storage volume equation to an equation with only one independent variable. This makes it possible to draw a graph of storage volume as a function of the maximum outflow rate. The included graph shows that as the outlet gets larger, the required storage volume decreases. The ideal basin will fall at a point on its respective curve. A basin that is oversized will fall at a point above its respective curve, and as a result, it will not reach its maximum outflow rate during the storm. An inadequate basin will fall at a point below its curve, and will rise above the design depth, producing more than the design outflow and possibly causing flooding. It should be pointed out that the constant rate system allows the least storage for a given size outlet. This is due to the fact that it functions at the maximum rate throughout the storm, while a

(Continued on p. 42)

** 10-year Frequency storm equation developed by Hubbell, Roth & Clark, Inc. for Oakland County, Michigan



REVISED DRAINAGE
& DRAINAGE STUDY 1"=20'-0"

$\frac{2.2 \times 26,536 ft^2}{12} = 4864.$ cu. ft.