# BULL RUN WATERSHED
# STORMWATER MANAGEMENT PLAN

## SECTION VI
## STORMWATER MANAGEMENT TECHNIQUES

### INTRODUCTION

One of the key features of the Stormwater Management Act 167 is its mandate to implement comprehensive stormwater runoff control practices. The Act requires stormwater planning at the watershed level in such a manner that adverse impacts of storm runoff are prevented, both at a particular site and at every potential flood prone location downstream from the watershed. Therefore, any stormwater management technique must consider runoff impacts on the watershed.

Studies in recent years have identified a number of methods of reducing the impact of development on storm peaks. Many management practices indicate the ingenuity of the planning, engineering and regulatory agencies. In particular, the publications of Soil Conservation Service (SCS) of Department of Agriculture (USDA), U.S. Environmental Protection Agency (EPA) and American Public Works Association (APWA) are quite comprehensive and aid in expanding some of the management practices reported in this section.

The present-day emphasis on detention or reduction of urban runoff within the contributing source area represents a remarkable shift in runoff control strategy that has occurred only just recently [Kibler and Aron, 1980]. This trend toward on-site runoff abatement includes control measures that either reduce the runoff directly at the source or delay the arrival of runoff contributions at some critical points downstream. Attesting to the strength of this trend is the large and growing number of publications describing various on-site control measures. Notable contributions in this regard include those by Poertner [1974, 78] on stormwater detention practices; Becker et al. [1973] on rooftop storage; Aron et al. [1976] on general runoff abatement measures including infiltration trench design; Montgomery County Soil Conservation District on storage detention ponds; ASCE, The Urban Land Institute, and the National Association of Homebuilders [1976] on residential runoff abatement measures; and Field [1978] and Field and Lager [1975] for comprehensive reviews of structural and nonstructural measures.

Methods applicable to almost all watersheds are based on the principles of velocity reduction, infiltration enhancement, detention and retention storage, etc. However, site-specific conditions in a given watershed may lead to the development of innovative control measures. All the methods are designed to control sediment, pollution and stormwater within the watershed. Although the design of stormwater control facilities is usually completed by engineers and landscape architects, key policy questions should first be answered by local officials. Preferences of local residents concerning level of protection, aesthetics, maintenance responsibilities, and cost allocation should be assessed by local officials, not professionals. After community stormwater management policies have been established, detailed design or design review of particular controls and measures can be carried out [Clinton River Watershed Council, 1984]. Where practical, control measures should be designed to exploit the beneficial uses of the stormwater such as recreational and aesthetic benefits and recharge of underground aquifers. In many cases this can be the decisive factor in approval of a new land development. The intent of this chapter is to review the existing storm water management techniques and make recommendations on their applicability, from many different perspectives such as suitability for the study watershed, cost, effectiveness, advantages, disadvantages and maintenance etc.

## CONCEPT OF STORMWATER MANAGEMENT

Early stormwater management efforts concentrated on transporting the runoff as quickly as possible from a storm location, by routing it through storm sewer systems. As the urban development increased in the watershed, such a flood control effort resulted in the worst flooding conditions downstream, due to increased total flow, peak flow rate, stream velocity and flow depth. Land development causes an increase in the rate of runoff from the site, resulting in an increased peak flow rate. Changing a natural channel to a concrete-lined ditch or a storm sewer system increases the velocity and reduces the travel time to downstream locations. A reduction in the travel time may make the peak flow rate from one watershed, to contribute or in the worst case to coincide with the peak flow rate of some other watershed(s). This again results in an increased peak flow rate. Detaining the storm water and releasing the maximum rate over a longer period of time may also induce the same adverse effect.

It is now recognized due to above mentioned problems that, the most logical and effective approach to control the storm runoff is to maintain the natural runoff flow characteristics. This can be accomplished in general by maximizing natural infiltration processes, reducing impervious surfaces, preserving floodplains, and controlling storm runoff in the watershed. There are numerous, technically acceptable techniques which have varying degrees of applicability in the study area, depending on the site and watershed characteristics. Some of the most widely used ones will be described here, along with a brief discussion of their key features, advantages and disadvantages, and typical costs. It will be up to each individual developer to select the techniques that are most appropriate to the project and site. It is most likely that in most situations, a combination of on-site controls will be the most appropriate and least costly stormwater management system. Nevertheless, some alternatives must be carefully analyzed. For example, when several detention basins are used, their interaction must be considered, since a combination of the timing of their releases could aggravate downstream flooding rather than alleviating it. Also, the efficiency and costs of many of management alternatives vary from one location to another. Many of the alternatives, such as on site storage basins, erosion control, and flow reduction alternatives, may be feasible only for areas of new development [Kibler, 1982].

To determine the most appropriate set of techniques for a particular site, several factors should be evaluated:

1. Soil characteristics (i.e. soil permeability, erodibility)
2. Topography
3. Subsurface conditions
4. Drainage patterns (i.e. proximity to stream flooding problems)
5. Proposed land uses
6. Costs
7. General advantages and disadvantages of each technique.

## STORMWATER RUNOFF PROBLEMS

### FLOODING

During high intensity, or long duration storms the existing infiltration capacity of soils may be exceeded and surface storage filled to capacity. Once this happens, runoff occurs in the form of overland and channel flow. During some high runoff and relatively infrequent storm events, if the existing watercourses have insufficient capacity to convey surface flows, they get flooded. Natural floodplains provide some benefits by serving as reservoirs, natural recharge basins, collectors of pollutants, wildlife habitats etc. As floodplain or upstream areas are developed, this natural beneficial phenomenon, becomes a disaster due to its increased frequency and magnitude. Thus, new developments increase the flood problems and damage downstream as compared to predevelopment.

There are many ways to reduce the impact of new development on flooding. Some general concepts to consider in determining which solutions are applicable to a study area are listed below:

1. Limit development of floodplains and prohibit development in floodways
2. Increase infiltration
3. Reduce runoff rates
4. Store precipitation and runoff where it falls and release it slowly
5. Keep water confined in adequate pipes or channels

6. Protect areas subject to flood damages

7. Build flood control measures

8 Limit erosion and sediment transport

## EROSION AND SEDIMENTATION

When raindrops hit bare soil, the cumulative effect is the splashing of the hundreds of tons of soil into the air. Some particles are washed into streams or downstream areas unless the velocity is very low or the soil is protected by some means. This phenomenon is called erosion. The runoff from new land developments can result in erosion both on-site and off-site. Once soil erosion begins, the soil particles transported by runoff and water currents begin to settle down in downstream drainage ways, which is called sedimentation. Sedimentation may result in blockages of natural watercourses, plugging of culverts and storm sewers, smothering of vegetation, filling of reservoirs, etc. The sedimentation occurs at increased rates during and following land development because graded areas are left in an unprotected state. Data collected by Brandt [1972] shows that erosion rates on land undergoing development can be 2,000 times the erosion rate of forested lands. General concepts to be followed for minimizing erosion and sedimentation include the following:

1. Protect the soil surface to withstand effects of rainfall and runoff

2. Limit soil erosion through site management practices

3. Store rainfall and runoff where it originates and release it slowly

4. Catch sediment before it enters natural drainage channels

## POLLUTANT TRANSPORT

Runoff from developed areas contains more pollutants than from natural watersheds. These pollutants include heavy metals, BOD, and high concentration of suspended solids. Heavy metals and BOD generally increase as the area is developed and reach a plateau when the development has stabilized. Suspended solids increase during first two years following the disturbance of land for development. The impacts of these pollutants depend on the existing quality and use of the receiving waters. If the newly developed area drains into a supply reservoir, an increase in the amount of pollutants could be very significant. In other cases, the impacts may be difficult to determine and are often long-term, subtle, and persuasive rather than immediate.

## ON-SITE STORM WATER MANAGEMENT

Many methods are available to alleviate the impact of urbanization on runoff. Maryland Interim Watershed Management Policy [APWA, 1981] states, "When engineering a site for stormwater management, two overall concepts must be considered: 1) the perviousness of the system should be maintained or enhanced, and 2) the rate of runoff should be slowed. Land development methods which tend to reduce the volume of runoff are preferred over methods which tend to increase the volume of runoff." Many of the steps taken to reduce flooding also have significant effects in reducing erosion, sedimentation and stream pollution and may reduce the need for capital-intensive storm sewer systems.

All things considered, the most advantageous means of controlling stormwater runoff from new developments is by minimizing the amount of increased runoff volumes produced. If it were possible to complete the new development in a manner such that there would be no change in either the volume or peak rate of discharge after development, there would be essentially no stormwater related impacts. While it is recognized that, in most cases, it may not be possible to accomplish the goal of making <u>both</u> post-development runoff volumes and peak rates of runoff match pre-development conditions, reasonable efforts should be made to minimize increases in total runoff volumes prior to the design of supplemental controls designed to control peak discharge rates.

It is recommended that land developers be encouraged to take reasonable and applicable steps to incorporate features into their developments which will serve to minimize increases in stormwater runoff volumes.

### RUNOFF VOLUME REDUCTION MEASURES

Following are brief descriptions of measures which may be taken to limit increases in total runoff volumes resulting from new developments. The applicability of these measures is highly site specific and dependent upon the nature of the development. However, it is recognized that the potential application of these techniques be seriously considered early in the design of land development activities.

#### Limit the Amount of Land Disturbed

The added volume of runoff produced as a result of the development of "virgin" land is directly related to the amount of land cover changed from its natural state to a more impervious condition (usually paved). Consequently, increases in runoff volumes can be minimized to the extent that land cover disturbances can be minimized. Individuals involved in land development activities, should, therefore, be encouraged to optimize their development activities from the standpoint of accomplishing the basic objectives of the development while minimizing the amount of paved areas used and natural areas disturbed.

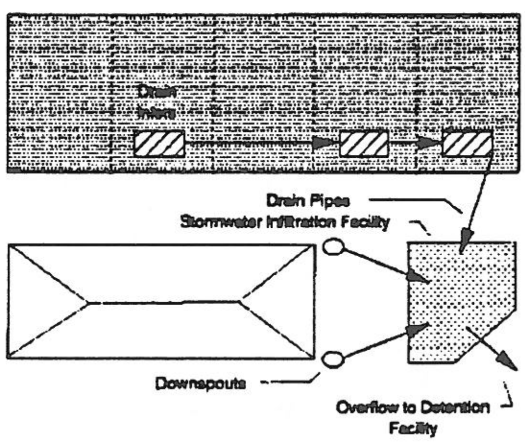
### Utilize Terraces, Contoured Landscapes, Runoff Spreaders, Diversions and Grassed or Rock-Lined Waterways

These measures increase the time of concentration by increasing length of overland flow, and thus lowering the flood peak. They will provide the additional benefit of reducing total runoff by infiltration if the site has well-drained soils. Runoff spreaders spread runoff or direct it into a system of terraces. Terraces are more suitable for reducing erosion from agricultural and non-urban areas and conserving soil moisture. They reduce effective slope length and runoff concentration. About 90% of the soil that is moved is deposited in the terrace channels. In contouring, crop rows follow field contours to prevent erosion and runoff. It can reduce average soil loss by 50% on moderate slopes and less on steep slopes. It must be supported by terraces on long slopes. There are no soil or climatic limitations on practicing contouring, but it is not feasible on very irregular topography. Grassed waterways or swales stabilize vegetation on drainage channels. For velocities of up to 8 ft/sec runoff is reduced by grass channels, if correctly graded and stabilized. Detailed design information for this category of alternatives can be obtained from the Soil Conservation Service's Engineering Field Manual for Conservation Practices.

### Use of Infiltration Devices

Infiltration devices are used to reduce flood peaks by releasing all or part of the stored runoff into the groundwater. The infiltrated water may appear a short distance downstream as surface water at a later time. However, the runoff hydrograph at the outlet point should be much lower and drawn out in time than that from runoff delay techniques [Aron, 1975]. An example application of infiltration storage techniques is provided in Figure VI-1.

Figure VI-1
Example Application of Roof
and Parking Lot Infiltration Facility



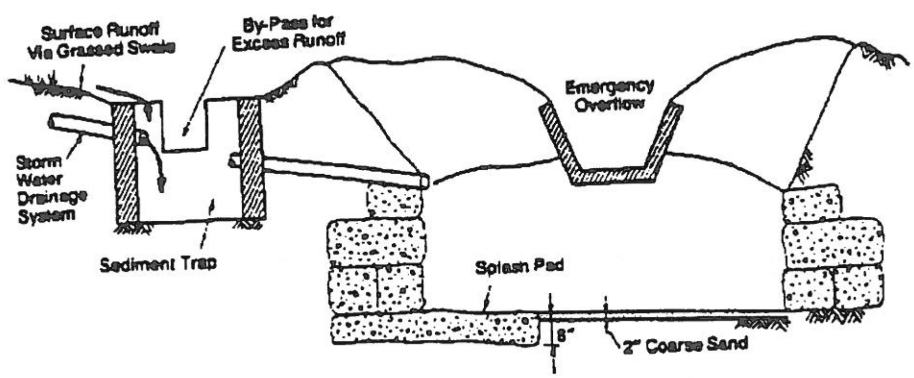
Soils comprised of sands and/or silty sands have high infiltration capacities, and therefore are well suited for infiltration storage. Soils comprised of fine silts and clays have low infiltration capacities and therefore, are not suitable for constructing infiltration devices over them. Deep soil sampling should be performed to assess the feasibility of water loading the various geological strata for purposes of stormwater disposal. Percolation tests, pumping tests, and soil sampling should provide useful data about the depth, size, and location where subsurface storage is practical. In the Bull Run Watershed the predominant soils are slowly permeable and limestone derived, thus sinkholes and depressions may occur if infiltration rates are increased. Therefore, infiltration storage alternatives should be used with extreme caution. If this method is proposed as the primary means to reduce runoff for large development sites or for sites located in landslide-prone soil locations, a soil engineer's report should be obtained. Generally, infiltration systems should not be used where there is a reasonable probability the runoff may be contaminated (e.g. industrial sites, commercial parking lots, etc.).

The following techniques for stormwater control based on the principle of infiltration storage.

Seepage or Recharge Basins

Figure VI-2 shows a typical design of a seepage or recharge basin. In this method, runoff is collected in various storm drainage systems and then passed into large excavations called seepage or recharge basins designed to allow a large percentage of annual rainfall to recharge an underlying aquifer. In addition to reducing runoff volumes, this method offers to put the stormwater to beneficial use by allowing a large percentage of runoff to recharge an aquifer.

Figure VI-2
Seepage or Recharge Basin



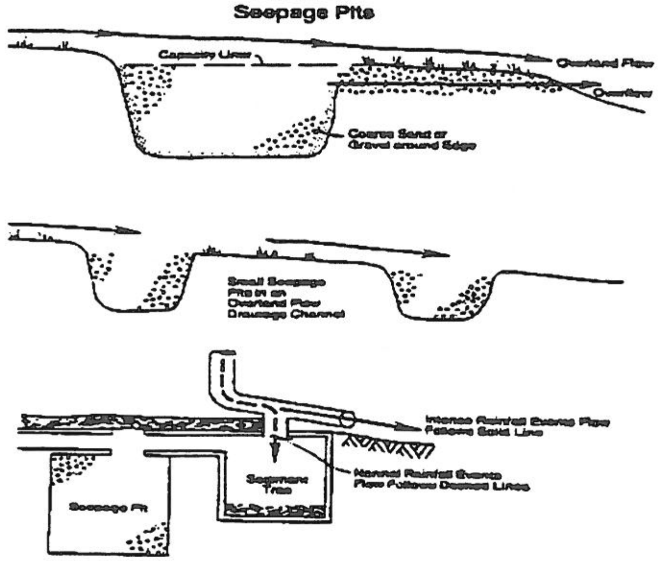
Generally, the basins must be located in aquifer recharge areas, but they may be used whenever the water table is more than 48" below the ground surface. If they are used as the only means of stormwater control, their size must be able to store the area's maximum design rainfall from all paved areas. However, they are economically more feasible if designed to recharge a certain percentage of the annual rainfall and control flood peaks by overflowing early during intense rainfall events. When using seepage basins there is a need to consider the impacts of the type and quality of runoff being infiltrated; e.g., water quality impacts on groundwater, possibility of the pit being sealed by the salts in the water. In order to maintain good infiltration rates, the bottom of the basin should be kept silt free by using a sediment trap. In addition, an emergency overflow structure is required to bypass excess runoff.

Seepage Pits or Dry Wells

Seepage pits are small excavations designed to overflow during intense storms, but reduce flood peaks by infiltration storage. They can be effectively used at the sites where soil permeability is over 0.15 ft/day and water table is more than 48" below the bottom of the pit.

There are two important design considerations associated with seepage pits: (1) the minimum size (which depends on porosity of the soil and design storm) should be sufficient to maintain predevelopment infiltration rate; (2) side area should be at least two times larger than the bottom area. Figure VI-3 shows three seepage pit designs each with an alternative overflow mechanism.

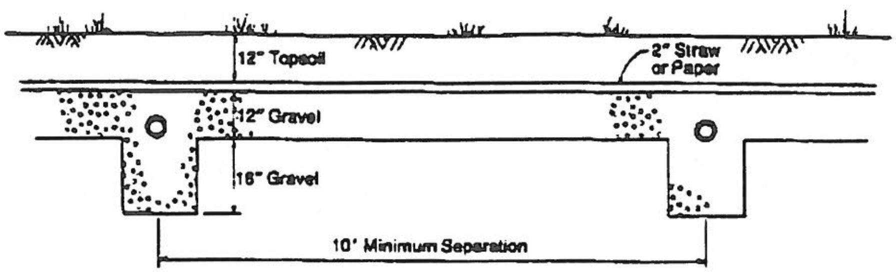
**Figure VI-3**
**Seepage Pits**



Seepage Beds or Ditches

Seepage beds dispose of runoff by infiltrating it into the soil through a system of perforated pipes laid in ditches. The runoff should be allowed to pass through a sediment trap as shown in Figure 1, with a bypass structure to drain runoff from extreme rainfall events. They are not suitable for sites with water tables less than 48" deep and extremely low permeability. A typical design of a seepage bed is shown in Figure VI-4.

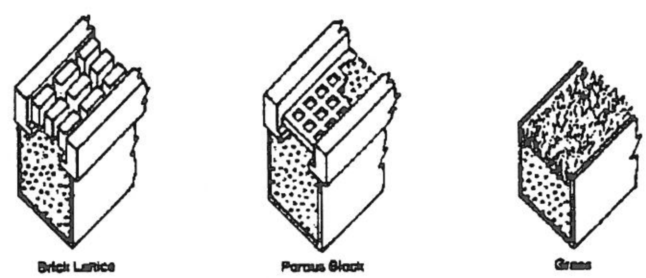
Figure VI-4
Seepage Bed




Dutch Drains

Dutch drains are employed in residential developments. They are simply ditches either filled entirely with gravel or covered with top soil and seeded. Very wide drains are usually covered with brick lattice or porous block as shown in Figure VI-5. The drains may either be located directly under the roof eaves along the length of a building, or runoff can be routed from downspouts to the dutch drain.

Figure VI-5
Dutch Drains



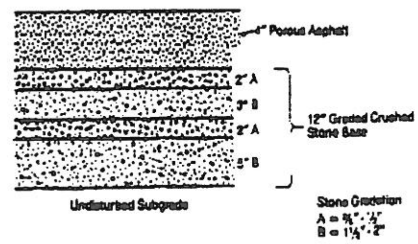

If dutch drains are the only means of stormwater disposal in a development, they should be able to drain the area's design rainfall alone, and therefore their size will be quite large. More often two to four feet drains are combined with other control alternatives for partial stormwater management using dutch drains.

Porous Pavement

Porous pavement is a special asphalt mixture designed to pass water at a high rate to a specially prepared subbase. The special subbase is thicker than a normal gravel subbase and is composed of coarse graded stone supplying large void spaces to store infiltrated runoff. Figure VI-6 shows a typical porous pavement cross-section. The base aggregate is designed to have about 40% voids ratio.

Regardless of design traffic number (DTN), a minimum surface thickness of 4" should be provided. Also, the combined surface and base thickness should not be less than anticipated frost penetration. Porous pavements have shown very positive results in regard to permeabilities, wear resistance and freezing - thawing effects. However, the main problem with porous pavements is that of pore clogging by muddy tires.

Figure VI-6
Typical Cross Section of Porous Pavement




PEAK DISCHARGE CONTROL DEVICES

Peak discharge control devices are those which control peak discharge rates by either lengthening the runoff path of the storm water or storing it and releasing it at a controlled rate. The runoff delay may vary between 15 to 30 minutes for very small areas to several hours for drainage basins of larger extent. A common goal of delay devices is, however, the disposal of all stored water before a second storm might hit. The stored water must be allowed to release at a flow rate that is designed not to cause harm.

Delay of runoff is accomplished by two basic principles of detention and retention. Detention is defined as detaining a large portion of the runoff from a storm, for a time period approximately equal to the natural runoff duration. Retention, on the other hand, is defined as holding of runoff for some time period longer than the natural runoff period. The following alternatives are available based on the principle of runoff delay.

There are a number of on-site locations for temporary storage of precipitation and runoff. The temporary sites that are generally considered are:

1. Storage in ponds and lakes

2. Rooftop storage
3. Underground storage
4. Parking lot storage
5. Blue-green storage
6. Multiple use storage areas

In planning on-site storage methods, one should consider existing physical, social and economic limitations of the area. What may be a good solution at one site, may be inappropriate at another.

Detention and Retention Basins

Detention and retention basins take a variety of forms. Some are wet (filled with water all of the time) and some are dry (filled with water only during storms).

Some are designed as a continuation of a stream or river (on-stream basins) while others are separate from the river (off-site basins). Off-stream basins are usually connected to the water course by pipes or swales. Figure VI-7 shows the storage concept and the difference between the operation of detention and retention basins.

Dry Ponds

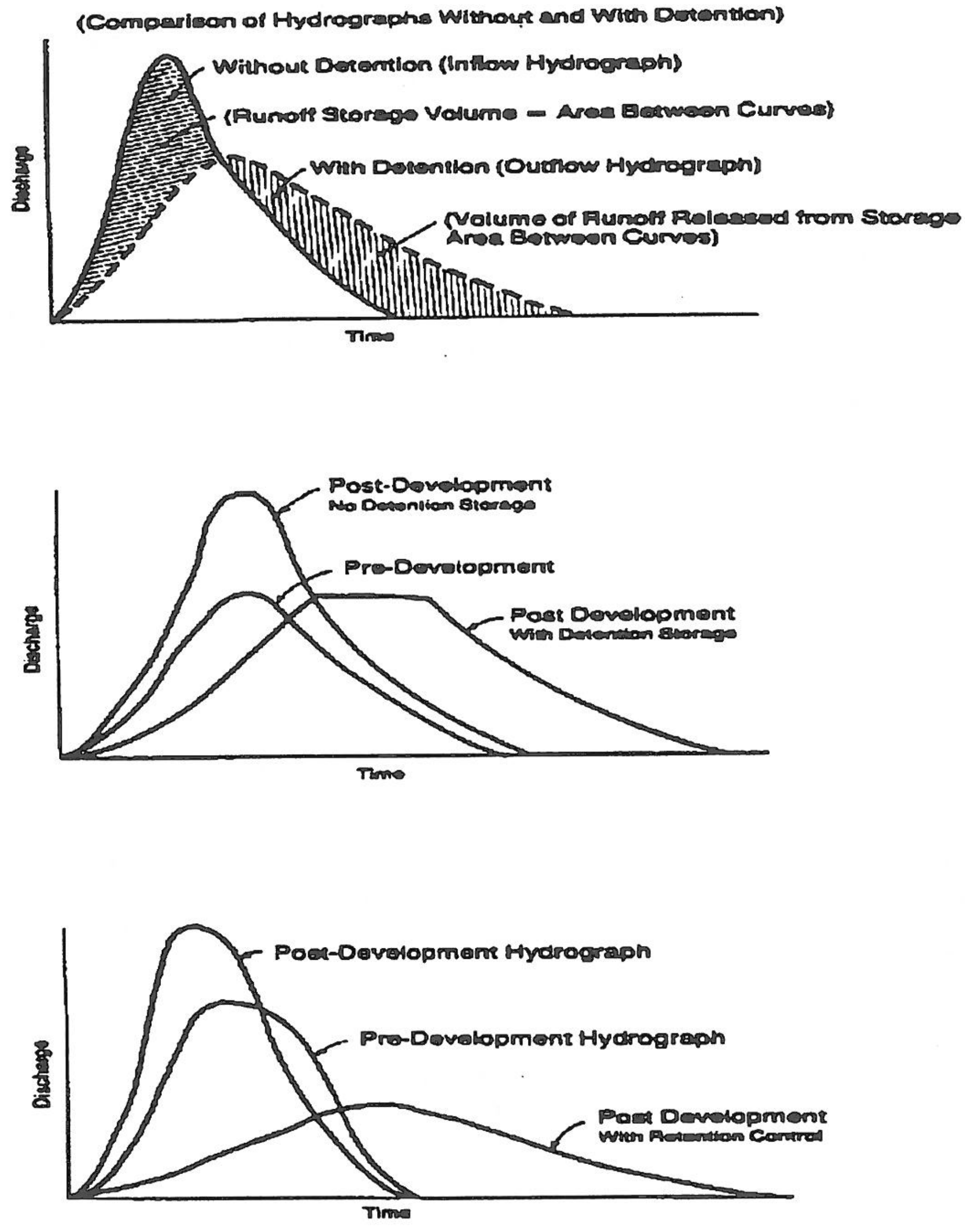
As the name implies, dry ponds are designed to be normally dry with the ability to store a portion of the stormwater during a storm event and then release the stored volume slowly and safely.

Typically they are used in areas where runoff volume has been increased and it is desirable to reduce the runoff rate.

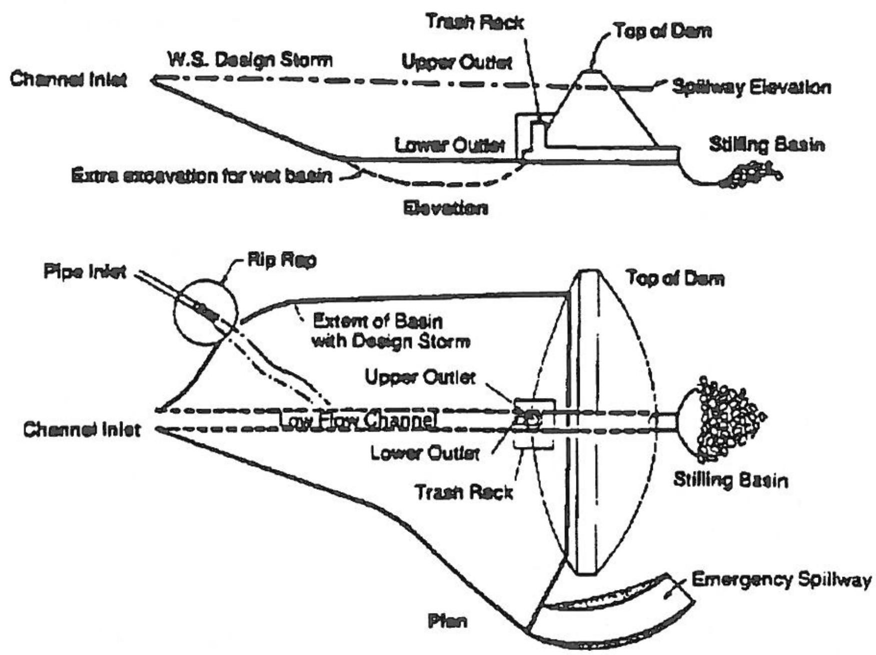
Retention basins are used when extreme limits on downstream flow rate or velocity are required. The outflow rate will be relatively low and extended over a longer period of time as compared to the outflow period of detention basin. This requires large amounts of storage for detaining stormwater for periods greater than 24 hours. Figure VI-8 shows a typical detention basin design. One detention basin can be designed to control the stormwater from 2, 10, 25 and 100-year design storm events, by constructing multi-stage outlet structures. The outlet flow discharge rate from the basin will depend on the return period of the design storm.

The outflow schedule of a pond can be extremely important as far as flood control efficiency is concerned. Some ponds could fill up with the early flush of the storm runoff and be ineffective by the time the flood peak arrives. To overcome this problem, a reservoir bypass option is employed. It allows an undisturbed sewer flow of 50 to 60 percent of capacity, beyond which the excess flow would be diverted into the reservoir.

## Figure VI-7
## Storage Concept for
## Detention and Retention Basins



## Figure VI-8
## Typical Detention Basin Design




As shown in Figure V-8 the detention basin is built right around the storm sewer. It allows the normal low to moderate flow to continue undiminished. As the discharge approaches full flow conditions (or any desired percentage thereof) water can spill through the holes in the top. If the bypass is only 50 percent or less, a half pipe or channel can be substituted for the full pipe. The reservoir will then be filled and not release any water until the water level in the reservoir is higher that in the pipe, at which time one-way flap gates will open and the reservoir will be gradually emptied for the next storm.

### Rooftop Retention

Rooftop retention utilizes the built-in structural capabilities of rooftops to store a certain amount of rainfall that falls on them. In many cases, existing roof structures require little modification to function as retention structures. On flat rooftops, drains must be designed with proper outlet capacities to control release rates to the design level. Overflow mechanisms should be provided to preclude danger from overloading.

Special considerations of roof water tightness may be necessary when water is to be detained for longer time periods or where frequent freezing and thawing are prevalent. Figure VI-9 illustrates several types of rooftop retention devices. On sloping roofs, the retention can be achieved by providing findams. Findams are actually about 4" high gravel ridges at 15 to 30 ft spacing as shown in Figure VI-10. Individual wedge-shaped ponds would build up behind these "minidikes". Through laboratory studies it was found that a series of five dikes of 1/4 inch gravel placed on roofs of 1% slope will cut the peak runoff rate by 50% and extend the runoff time by about 30 minutes [Aron, 1975]. Finer gravel would naturally delay the runoff further. The effectiveness of the rooftop storage is a function of the actual area affected by such storage. It is most effective when used as an integral part of a larger stormwater runoff control plan. Additional maintenance should be anticipated on roofs subject to leaf accumulation.

Figure VI-9
Rooftop Retention Devices

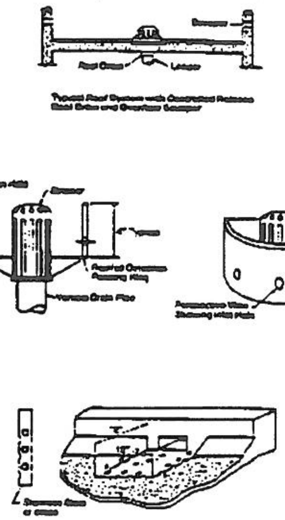
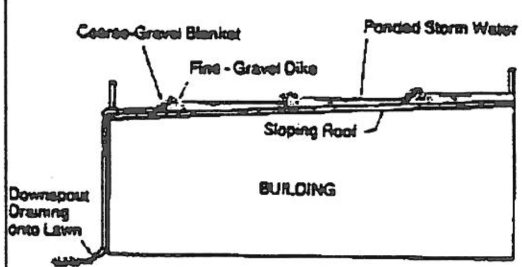


Figure VI-10
Roof Ponding With Gravel Dikes




Wet Ponds

Permanent or wet ponds are detention/retention structures filled with water all the time with adequate detention capacity to store the design floods above normal ponds level. Overflow spillways must be provided to bypass or discharge flows into floodways on the peripheries of the ponds so that safe water-storage elevations are not exceeded nor banks breached.

For extremely large ponds, adequate design precautions should be taken to minimize possible shoreline erosion due to ice, wind and wave action. Sediment accumulation and water pollution due to roadside accumulations of salts, copper, and asbestos from brake linings, grease, oil, and heavy metals, are the disadvantages associated with wet ponds. Such deleterious material should be screened out from the drainage system by interception and disposition before it reaches stormwater storage ponds. In some locations municipal, state or federal safety standards regarding the depth and volume of water will have to be met. These ponds are unquestionably more aesthetically appealing than a typical dry detention basin. In addition, they can be designed to provide some recreational benefits. North Park Lake is an example of a permanent pool. Figure 10 shows some suitable locations in a site plan for a residential development [Becker et al., 1973].

The main difficulty with wet ponds lies in the frequent unavailability of land. Dry ponds can be made rather inconspicuous as an integral part of the landscaping or as lawn areas for office buildings. For example, depressed front lawn areas can be designed to detain runoff from intense storms and to serve as building's green space in dry season. They can be used heavily by people at lunch time. The outlet pipes allow the ponds to drain in 12 to 24 hours, and a certain amount of water undoubtedly filters into the ground [Aron, 1975].

Parking Lot Detention

Parking lots cover a major portion of commercial developments and are, therefore, large contributors of stormwater runoff. Stormwater runoff can be detained on parking lot sites by shallow basins or swales. If properly designed, this measure can be quite effective; however, it is also quite a nuisance to shoppers trying to get into and out of their cars. Initial construction costs implementing these measures are only a small percentage above the construction cost of conventional parking lots. Arrangements of areas in a parking lot to accept ponding should be planned so that pedestrians are inconvenienced as little as possible. A 7" design depth is not unreasonable for parking locations in the remote areas of lots [APWA, 1981]. The facility should be designed to drain completely and avoid formation of ice.

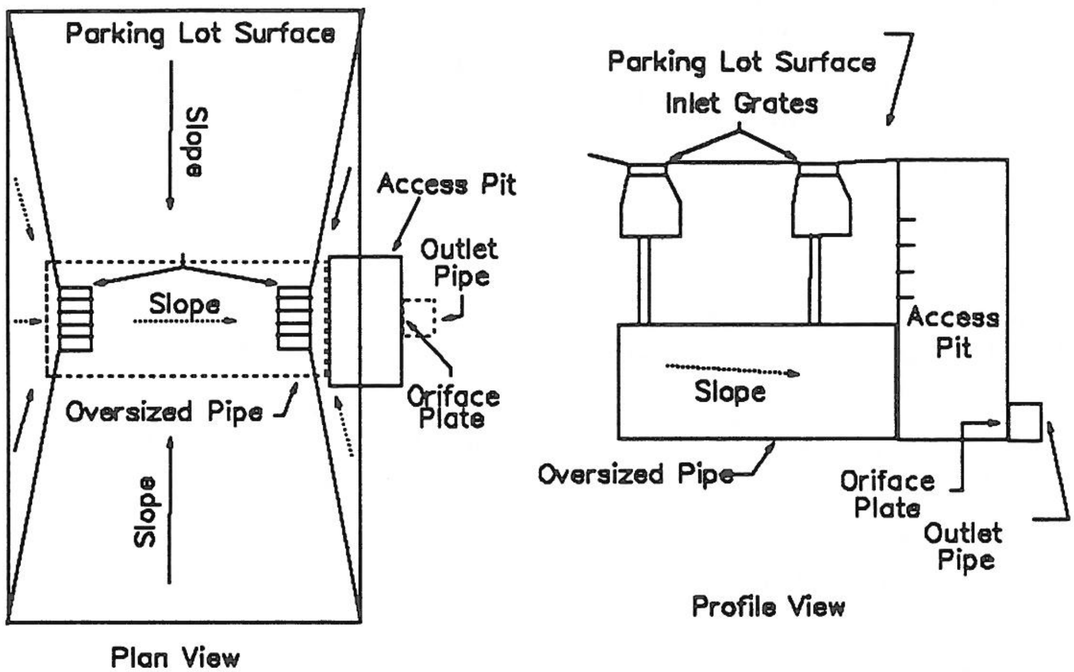
Design considerations should recognize the possible use of porous asphalt, provided the subgrade has an adequate infiltration capability. Expansive and/or collapsing type soils may preclude this solution.

An alternative to impervious paving of parking areas is the substitution of grassy strips. The ground surface of the planting strip is depressed and driving lanes are graded to direct the storm runoff into the depressions. The strips should be filled with pervious soil to allow a maximum of infiltration, and planted with a Fescue-type grass which is both resistant to occasional swamping and dry soil conditions. The strips are oriented perpendicular to the parking lot slope and surrounded by broken curbs to protect them from being overrun by cars.

Underground Detention Tanks

This alternative involves the underground construction of a holding tank or large size pipe as a means of providing controlled runoff from the site. In areas where land is expensive or surface topography is not suitable, these tanks can serve the same function as basins, but they conserve the land area. Outflow control devices may consist of small gravity pipes, oriface plates, or weirs. In some applications pumping may be required to discharge the stored runoff. This method is expensive because of high material construction costs and possible pumping requirements. A example of a typical underground storage facility installation is provided in Figure 11.

Figure VI-11
Underground Detention Facility

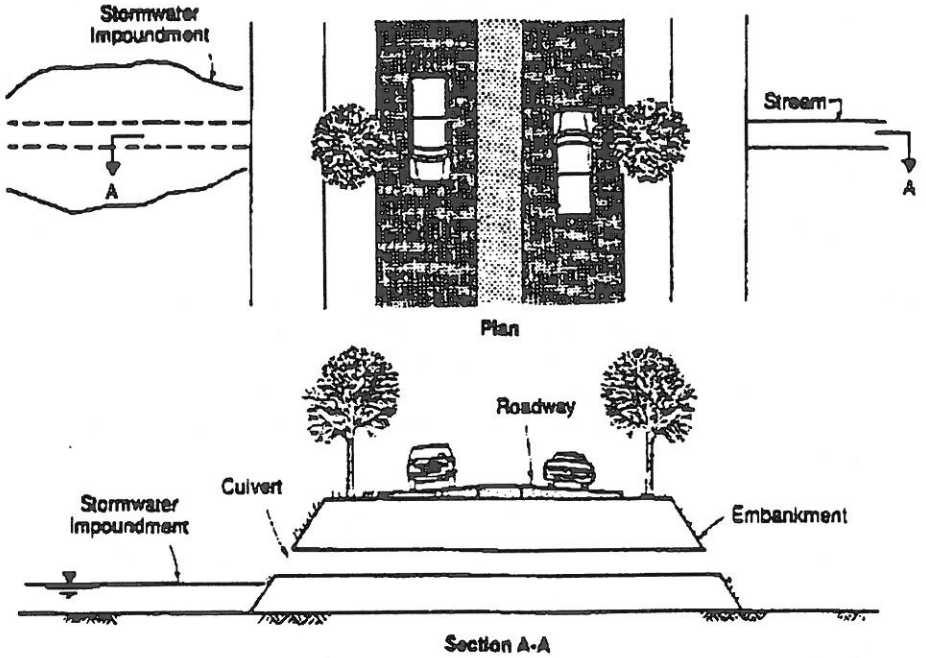



Blue-Green Storage

Incorporation of stormwater storage in urban drainage ways traversing roadways is a version of detention ponding that has been identified as the Blue-Green concept. Topographical characteristics of many land areas adjacent to roadway embankments make them very much adaptable for use as detention facilities. This can be achieved by designing the culverts to pond where appropriate, as shown in Figure VI-12. Many drainage structures can be designed to operate in this fashion. Roadway embankments at control points should be stabilized and protected to minimize erosional effects of retained water.

Figure VI-12

Road Embankment Stormwater Detention




## Detention within Pedestrian Plazas and Malls

On-site detention in heavily congested areas can be incorporated effectively in the design of pedestrian plazas, malls, and other similar type developments. The ponding requirement can be accomplished at selected locations with very shallow depths (1 to 3 in) to avoid public inconvenience. Frequent maintenance and suitable discharge control devices designed to satisfy the architectural objectives of the land development are necessary in developments of this type.

## Multiple Use Impoundment Areas

These areas utilize sites having primary functions other than runoff control. In new developments, such multiple use should be incorporated into the primary design. For example, open space and grassed areas provided in the land development to enhance the aesthetic appeal can also be used as stormwater detention facilities.

This can be accomplished by providing stormwater release controls such as weirs, orifices, small diameter pipes and gates etc.

A hard-surface basketball or tennis court can be designed to drain adjacent grassed or paved areas. The stormwater would collect in grass swales around the edge of the court, seep through a gravel drain to retain the sediment load, and discharge onto a porous asphalt surface. Some type of emergency drain should be provided. Positive drainage toward the control devices is essential to avoid the swampy conditions, weed growth and increased maintenance costs. For optimum operation of control structures it is also essential to screen out the floating debris from the inlet stormwater.

## RELATIVE ADVANTAGES AND DISADVANTAGES

Table VI-1 gives a brief summary of principal urban runoff abatement practices and relative advantages and disadvantages. As was expressed previously, the runoff volume reduction measures which simultaneously reduce runoff peaks offer significant advantages from the perspective of both local and watershed wide effects. However, since there are limitations inherent in the volume reduction techniques, it is likely that an overall stormwater control plan will include a combination of applicable volume reduction features and peak discharge control features (i.e. detention and/or retention facilities).

Selection of the best combination of techniques to be used in a particular instance should be made by the developer in consultation, or at least with the concurrence, of the municipal reviewer.

## EROSION AND SEDIMENTATION CONTROL MEASURES

The ability of storm water runoff to transport material is a function of flow velocity and the erosion resistance of the material. As stormwater runoff flow rates increase, the flow velocity increases and more eroded material is transported. As the water travels down the watershed, channel gradients reduce flow velocity and sediment begins to be deposited in streams and storm sewers. This process, known as sedimentation, continues as the flow rate and flow velocity reduces. New developments further increase the sedimentation problem by removing natural vegetation and making the bare ground susceptible to erosion.

The following principles should be practiced for urban soil erosion and sedimentation control.

1. Keep disturbed areas small: Areas vulnerable to erosion should be disturbed the minimum amount possible. As much natural cover as possible should be retained and protected. The construction plan should be phased whenever possible in small units and in sequence such that only the area being developed is exposed. All other areas should have a good cover of vegetation or mulch.

TABLE VI-1

ADVANTAGES AND DISADVANTAGES OF ON-SITE CONTROL METHODS

| METHOD | ADVANTAGES | DISADVANTAGES |
|---|---|---|
| REDUCTION OF RUNOFF / INFILTRATION STORAGE | | |
| Dutch Drains | - Reduces the total volume of runoff.<br>- Reduces the peak runoff discharge rate.<br>- Enhances the groundwater supply.<br>- Provides additional water for vegetation in the area.<br>- Reduces the size of down-slope stormwater control facilities. | - Looses efficiency if intensive storms follow in rapid succession.<br>- Subject to clogging by sediment.<br>- Limited to application for small sources of run-off only, i.e., roof drains, small parking lots, tennis courts.<br>- Maintenance is difficult when the facility becomes clogged.<br>- Limited application in poor infiltration soils. |
| Porous Pavement | - Reduces the total volume of runoff.<br>- Reduces the peak runoff discharge rates.<br>- Enhances the groundwater supply.<br>- Provides additional water for vegetation in the area.<br>- Reduces the size of down-slope stormwater control facilities.<br>- Less costly than conven-tional pavements for most applications.<br>- Safety features - superior skid resistance and visi-bility of pavement markings.<br>- Provides pavement drainage without contouring. | - More prone to water stripping than conven-tional mixtures.<br>- Subject to clogging by sediment.<br>- Water freezing within the pores takes longer to thaw and limits infiltration.<br>- Motor oil drippings and gasoline spillage may pollute groundwater.<br>- Limited application in poor infiltration soils.<br>- recent studies suggest that porous pavement's advantage will reduce with time. |

TABLE VI-1

ADVANTAGES AND DISADVANTAGES OF ON-SITE CONTROL METHODS

| METHOD | ADVANTAGES | DISADVANTAGES |
|---|---|---|
| | - Prevents puddling on the surface. | |
| Seepage/Recharge Basins | - Reduces the total volume of runoff.<br>- Reduces the peak runoff discharge rates.<br>- Enhances the groundwater supply.<br>- Construction borrow pits often can be converted to a large seepage basin to serve multiple areas. | - Must be fenced and regularly maintained.<br>- If porosity is greatly reduced, it may be necessary to bore seepage holes or pits in the base.<br>- No filtering supplied by the topsoil.<br>- Usefulness limited in poor infiltrations soils. |
| Seepage Pits | - Reduces the total volume of runoff.<br>- Reduces the peak runoff discharge rates.<br>- Enhances the groundwater supply.<br>- Provides additional water for vegetation in the area.<br>- Reduces the size of down-slope stormwater control facilities. | - Looses efficiency if intensive storms follow in rapid succession.<br>- Subject to clogging by sediment.<br>- Maintenance is difficult when the facility becomes clogged.<br>- Limited utility in poor soils. |
| Seepage Beds/Ditches | - Reduces the total volume of runoff.<br>- Reduces the peak runoff discharge rates.<br>- Enhances groundwater supply.<br>- Reduces the size of down-slope stormwater control facilities.<br>- Distributes stormwater over a larger area than other infiltration | - More expensive than other infiltration techniques.<br>- Replacement of entire system if clogging by sediment should occur.<br>- Maintenance of sediment traps must be frequent and consequently more expensive. |

TABLE VI-1

ADVANTAGES AND DISADVANTAGES OF ON-SITE CONTROL METHODS

| METHOD | ADVANTAGES | DISADVANTAGES |
|---|---|---|
| | techniques.<br>- May be placed under paved areas if the bearing capacity of the paved area is not affected.<br>- Safer than seepage or recharge basins. | |
| Terraces, Diversions, Runoff Spreaders, Grassed Waterways, and Contoured Land-scapes | - Increases the overland flow time, increasing the time of concentration and allowing for increased infiltration.<br>- Vegetative swales are less expensive than curb and gutter systems. | - On poorly drained soils, these techniques may leave ground waterlogged for extended periods after storms.<br>- vegetative channels may require more maintenance than curb and gutter systems.<br>- Roadside swales become less feasible as the number of driveway entrances requiring culverts increase. |
| DELAY OF RUNOFF | | |
| Rooftop Retention | - No additional land requirements.<br>- Not unsightly or a safety hazard.<br>- May be adapted to existing structures. | - Leaks may cause damage to buildings and contents.<br>- Stored runoff will greatly increase the load imposed on structural support. This increased construc-tion expense may be greater than the savings resulting from reducing the size of downslope stormwater management facilities. |

TABLE VI-1

ADVANTAGES AND DISADVANTAGES OF ON-SITE CONTROL METHODS

| METHOD | ADVANTAGES | DISADVANTAGES |
|---|---|---|
| Parking Lot Detention | - Adaptable to both existing and proposed parking facilities.<br>- Parking lot storage is usually easy to incorporate into parking lot design and construction. | - May cause an inconvenience to people.<br>- Ponding areas are prone to icing, requiring more frequent maintenance. |
| Multiple Use | - Serves more than one purpose. Employing areas of grass, a certain amount of stormwater will infiltrate and improve the quantity of water recharged by natural filtering processes.<br>- If porous pavement is used on basketball or tennis courts, additional infiltration will be provided. | - Difficult to maintain the porosity of multi-use areas. |
| Detention/Retention Basins | - Offers design flexibility for adapting to a variety of uses.<br>- Construction of ponds is relatively simple.<br>- May allow significant reduction in the size of downslope stormwater management facilities.<br>- May have some recreational and aesthetic benefits if runoff is not carrying heavy sediment loads. | - Facilities that empty out completely can have an unsightly nature and be a detriment to the developments.<br>- Difficulty in establishing a regular maintenance program.<br>- In a residential development, it may be difficult to determine whose responsibility it is to pay for the maintenance program.<br>- Consumes land area which could be used for other purposes. |

TABLE VI-1

ADVANTAGES AND DISADVANTAGES OF ON-SITE CONTROL METHODS

| METHOD | ADVANTAGES | DISADVANTAGES |
|---|---|---|
| Permanent Ponds | - Will provide both a reduction in peak runoff rates and a source of recreation in any residential area.<br>- Only minor modifications may be required to adapt an existing pond for use as a permanent stormwater management facility.<br>- Wildlife habitat and wetlands may be preserved | - Stormwater runoff having a high sediment or pollutant load should not be controlled in existing ponds because of its adverse impact on the natural conditions. |
| Underground Retention/ Detention Tanks | - Minimal interference with traffic or people.<br>- Can be used in existing as well as newly developed areas.<br>- Potential for using storm-water for nonpotable uses. | - Subsurface excavation could be extremely expensive depending upon the type and amount of rock encountered.<br>- Access for maintenance may be difficult if proper design features are not provided. |

2. Stabilize and Protect Disturbed Areas: Mechanical and/or structural methods and vegetative methods are available for stabilizing disturbed areas. These methods include seeding, mulching, sodding, retaining walls, terracing, use of chemical stabilizers, and others.

3. Keep Runoff Velocities Low: Removal of existing vegetative cover and the resulting increase in impermeable surface during development increase both the volume and velocity of runoff. Short slopes, low gradients and the preservation of natural vegetation cover help to keep stormwater velocities low and thus limit soil erosion.

4. Protect Disturbed Areas from Runoff: Protective measures that can be utilized to prevent water from entering and running over disturbed areas are diversions, waterways, structures etc.

5. Retain Sediment within the Site Area: Sediment can be retained by two methods: filtering runoff as it flows, and detaining sediment laden runoff for a period of time large enough to allow the soil particles to settle. Sediment basins, vegetative filter strips, terraces and sediment barriers may be used to retain sediment. However one should not rely solely upon vegetation filter strips, since sediment may rapidly render such areas useless by killing the vegetation.

6. In-stream Control: After precipitation and runoff has concentrated, an outlet channel is needed for safe release of the water off the site. This outlet channel needs to be protected from erosion. A wide, shallow grassed water way can be a very good method. Channels with steeper gradients need structural protection along with, or instead of vegetative measures. Typical structural measures include: earth dams with a full flow pipe through the fill, weirs, flood gates, and check dams. In designing such facilities, it is important to consider the effects of the dam or embankment on upstream properties. The design must include safety features in the form of spillways and bypasses to prevent overtopping which can cause embankment failure.

The details on the design and implementation of practices described above and many others can be obtained from the Soil Conservation Service and the County Conservation District.

## STORMWATER POLLUTION CONTROL MEASURES

The net result of runoff control problems is the potential degradation in quality of receiving waters. Flooding, erosion and sedimentation cause streams, ponds and lakes to fill with debris, pollutants and sediment. The principal water quality of impact of stormwater runoff from land development activities in the Bull Run

Watershed is related to erosion and sedimentation. The proper application of proven soil erosion and sedimentation control requirements currently enforced coupled with the stormwater quantity requirements recommended by this plan can serve to minimize the stormwater related impacts of land development on receiving water quality.

The use of sediment basins can have a significant impact on water quality. A theoretical study performed by The Northeastern Illinois Planning Commission found that approximately 40% of the biological oxygen demand (BOD) could be removed through detention facilities, without the use of chemical coagulants. A report of U.S. Environmental Protection Agency (1977) states that, by sedimentation storage alone, suspended soils in urban stormwater could be reduced by 20 to 60 percent and BOD by 30 percent. This report stated that settleable solids could be reduced by 90 to 95 percent. The Soil Conservation Service encourages 10 hours or more of detention, with longer times urged to protect downstream water quality.

The control of nonpoint receiving water pollution is of growing concern in many areas. However there is relatively sparse field data with which to evaluate the pollution reduction from stormwater detention. Chapter 12 of the Special Report No. 49 of APWA (1981) reviews the empirical work which has been undertaken and which may serve as a basis for evaluating pollution abatement.

This plan does not impose any additional water quality requirements other than routine erosion and sedimentation control requirements.

## SOIL CHARACTERISTICS VERSUS STORMWATER MANAGEMENT ALTERNATIVES

It was mentioned earlier that the soil characteristics at the development site, such as soil permeability, water capacity, frost penetration etc. play an important role in the selection of stormwater management alternatives. This section gives specific soil information for the Bull Run Watershed and discusses the soil characteristics and their impact on alternative stormwater management techniques.

Soil information for Union County can be obtained from the publications, "Soil Survey of Union County, Pennsylvania". These publications are prepared by Soil Conservation Service of U.S. Department of Agriculture. The survey for each county has a general soil map showing in color, the soil associations in the county. A soil association is a landscape that has a distinct pattern of soils in defined proportions. The soil association map should not be used to determine the soil type, for selecting stormwater water management alternatives. The reason is that, a general soil map is intended to be a general guide in evaluating large areas such as a watershed, or in county-wide planning for community development. It is not a suitable map for selecting a site for locating a stormwater detention or retention facility. For example, this map can be used to establish a generalized idea, that Edom soils constitute a major soil association in the Bull Run. Also, the survey tells that these soils have bedrock at a depth of 3.0 to 6.0 feet, thus having limited application for infiltration storage. Thus, a general rule can be established that infiltration storage alternatives may be approved in the Edom soils, unless the presence of bedrocks at low depths has been identified by on site engineering tests. Table VI-2 presents some relevant properties of the Bull Run soils significant to the use of various stormwater management techniques. Table VI-3 indicates the suitability of the soils for stormwater management alternatives.

## OPERATION AND MAINTENANCE CONSIDERATIONS

Most stormwater control facilities or systems must be monitored and maintained regularly following construction to assure effective operation, long life and compatibility with the local setting. Table VI-4 contains a summary of key operation and maintenance considerations for the stormwater management alternatives discussed previously.

As is indicated in Table VI-4, there is a range of operation / maintenance items which must be performed depending upon the type of stormwater management techniques employed. It is recommended that the enumeration of specific recommended operation and maintenance activities be required to be outlined by the design engineer at the time applications for permit approval are made. This set of recommended operation and maintenance activities should then be used as the basis of an on-going operation and maintenance plan. Also, provisions should be made in the appropriate ordinances or regulations to provide for effective mechanisms through which the completion of critical maintenance can be assured.

## PUBLIC ACCEPTANCE OF ON-SITE DETENTION

On-site detention, also has the disadvantage of not having wide spread public acceptance. This is mostly because the individuals have to spend extra dollars to satisfy the runoff control regulations. Also, they are concerned about the safety of their children also, which are usually attracted toward the ponds. Therefore, it is highly recommended to employ multi-purpose use of detention facilities. In the minds of a community, the multi-purpose use of such a detention facility greatly improves the perception that such a facility is a justifiable expense by the public or by the private developer [APWA, 1981]. Detention ponds are excellent examples of multi-purpose adaptability. When conceived and designed artistically, they can support different kind of activities throughout the year, such as, water sports and fishing. During winter months, shallow detention ponds with a permanent pool of water provide opportunities for ice skating in some parts of the country. A detention basin that is dry between runoff events can be used for field sports such as football, soccer, baseball, and various passive recreational pursuits such as badminton, model airplane operation, shuffleboard, croquet, and picnicking. Some detention basins may double as tennis or baseball courts. It might be difficult to convince some developers that the benefits derived from recreation outweighs the cost of the land plus construction costs. However, should the recreation area be redesigned as a multi-purpose recreational/detention basin, the cost would ook insignificant compared to the cost of upgrading a storm drainage system or the amount of potential flood damages.

## TABLE VI-2
## BULL RUN WATERSHED
## RELEVANT SOIL PROPERTIES

| Soil Name | Depth To Water Table (Feet) | Depth To Bedrock (Inches) | Permeability (Inches/Hour) |
|---|---|---|---|
| Albrights | 0.5 – 3.0 | >60 | 0.2 – 2.0 |
| Allenwoods | >6.0 | >60 | 0.6 – 6.0 |
| Alvira | 0.5 – 1.5 | >60 | 0.06 – 2.0 |
| Barbour–Linden | 3.0 – 6.0 | >60 | 0.6 – 20.0 |
| Basher | 1.0 – 3.0 | >60 | 0.2 – 6.0 |
| Calvin Klinesville | >6.0 | 10 – 40 | 2.0 – 6.0 |
| Edom Complex | >6.0 | 30 – 40 | 0.2 – 2.0 |
| Elliber | >6.0 | >60 | 0.6 – 6.0 |
| Evendale | 0.5 – 1.5 | 48 – 64 | 0.06 – 2.0 |
| Hagerstown | >6.0 | 40 – 72 | 0.6 – 6.0 |
| Holly | 0 – 0.5 | >60 | 0.2 – 6.0 |
| Kreamer | 1.5 – 3.0 | >60 | 0.06 – 2.0 |
| Leck Kill | >6.0 | 40 – 56 | 0.6 – 6.0 |
| Monongahela | 1.5 – 3.0 | >60 | 0.06 – 2.0 |
| Opequon | >6.0 | 12 – 30 | 0.2 – 2.0 |
| Shelmadine | 0 – 0.5 | >60 | 0.06 – 2.0 |
| Washington | 1.5 – 3.0 | >60 | 0.2 – 2.0 |
| Watson | 1.5 – 3.0 | >60 | 0.06 – 2.0 |
| Weikert | >6.0 | 10 – 20 | 2.0 – 6.0 |
| Wheeling | >6.0 | >60 | 0.6 – 20.0 |
| Wyoming | >6.0 | >60 | 6.0 – 20.0 |

## TABLE VI–3
## BULL RUN WATERSHED
## SUITABILITY OF SOILS FOR STORMWATER MANAGEMENT ALTERNATIVES

| Soil Name | Ponds | Embankments | Features Affecting Grassed Waterways, Terraces & Diversions |
|---|---|---|---|
| Albrights | Not favorable due to slope. | Very unfavorable: Wetness and susceptible to piping. | Wetness and rooting depth. |
| Allenwoods | Very unfavorable due to seepage. | Not favorable: Susceptible to piping. | Features favorable. |
| Barbour–Linden | Very unfavorable due to seepage. | Very unfavorable: Susceptible to piping. | Soil erodes easily. |
| Basher | Very unfavorable due to seepage. | Very unfavorable: Susceptible to piping. | Wetness. |
| Calvin–Klinesville | Very unfavorable due to shallow depth to rock and slope. | Very unfavorable: seepage and thin layer. | Slope, droughty, and depth to rock. |
| Edom Complex | Not favorable due to seepage, slope, and depth to rock. | Not favorable: thin layer of soil. | Features mainly favorable. Slope. |
| Elliber | Very unfavorable due to seepage. | Very unfavorable: seepage. | Large stones and droughty. |
| Evendale | Not favorable due to slope. | Very unfavorable: soil is hard to pack and has very high wetness. | Percs slowly and wetness. |
| Hagerstown | Very unfavorable due to slope. | Not favorable: soil hard to pack and only a thin layer. | Slope. |
| Holly | Very unfavorable due to seepage. | Very unfavorable: seepage, susceptible to piping, and wetness. | Wetness and too sandy. |
| Kreamer | Not favorable due to slope. | Very unfavorable: susceptible to piping. | Wetness and percs slowly. |
| Leck Kill | Very unfavorable due to slope and seepage. | Not favorable: only a thin layer of soil. | Features favorable, may be affected by slope. |

TABLE VI–3
BULL RUN WATERSHED
SUITABILITY OF SOILS FOR STORMWATER
MANAGEMENT ALTERNATIVES

| Soil Name | Ponds | Embankments | Features Affecting Grassed Waterways, Terraces & Diversions |
|---|---|---|---|
| Monongahela | Not favorable due to slope and seepage. | Very unfavorable: susceptible to piping. | Soil erodes easily, rooting depth, percs slowly, and high wetness. |
| Opequon | Very unfavorable due to slope and depth to rock. | Very unfavorable: hard to pack; only a a thin layer. | Slope, depth to rock, erodes easily, and droughty. |
| Shelmadine | Favorable for ponds. | Very unfavorable: wetness. | Wetness, rooting depth, and percs slowly. |
| Washington | Not favorable due to slope. | Very unfavorable: susceptible to piping and wetness. | Features favorable; wetness may affect terraces and diversions. |
| Watson | Not favorable due to slope and seepage. | Very unfavorable: susceptible to piping and wetness | Wetness, rooting depth, erodes easily, and percs slowly. |
| Weikert | Very unfavorable due to slope, depth to rock, and seepage. | Very unfavorable: seepage, susceptible to piping and thin layer. | Slope, droughty, and depth to rock. |
| Wheeling | Not favorable due to slope and seepage. | Very unfavorable: susceptible to piping. | Features favorable; slope in some areas. |
| Wyoming | Very unfavorable due to seepage. | Very unfavorable: susceptible to piping. | Large stones, droughty, and too sandy. |

## Table VI-4
## Operation and Maintenance Considerations

| | Dredging | Debris / Sedimentation Removal | Weed Control | Insect Control | Mechanical Maintenance | Mowing | Cleaning | Bottom Retilling | Repair | Inspection |
|---|---|---|---|---|---|---|---|---|---|---|
| Detention/Retention Basins | | ● | ● | ● | | ● | | | ● | ● |
| Detention/Retention Tanks | | | | ● | ● | | ● | | ● | ● |
| Ponds | ● | ● | ● | ● | | | | | ● | ● |
| Parking Lot Detention | | | | | | | ● | | ● | ● |
| Roof-top Retention | | | | | | | ● | | ● | ● |
| Open Space Detention | | ● | | | | ● | | | | ● |
| Road Embankment Detention | | ● | ● | ● | | | ● | | ● | ● |
| Seepage Basins | | ● | ● | ● | | ● | | ● | | ● |
| Infiltration Beds * | | ● | | | | | ● | | | ● |
| Porous Pavement | | | | | | | ● | | ● | ● |
| Open Channels | | ● | ● | | | ● | | | | ● |
| Pipe Systems | | ● | | | | | ● | | ● | ● |

* Includes dutch drains, seepage pits and seepage beds.

Detention facilities may also contribute to the protection and preservation of wildlife habitats and other natural resources. One example is a 602 ha (244 ac) tract in Chester County, Pennsylvania, where 315 homes were to be constructed. Approximately 84 ha (34 ac) of open space were provided containing two detention ponds designed to store runoff from the 100-year rainstorm. One year following the completion of the detention ponds, wildlife was observed returning to its former habitat. Geese have nested and fish have returned to the streams and newly constructed channels. The dual purpose utilization of stormwater detention facilities as wetlands represents a potential useful means of coping with the increasingly stringent wetland protection requirements and associated wetland replacement activities.

Although multiple uses are a better alternative for securing the community acceptance, maintenance costs for such facilities may be higher. Therefore, when considering multiple uses, it is important to look at all the associated costs and intangible benefits, to determine if it is practical to proceed with the multiple use concept.

## SAFETY CONSIDERATIONS

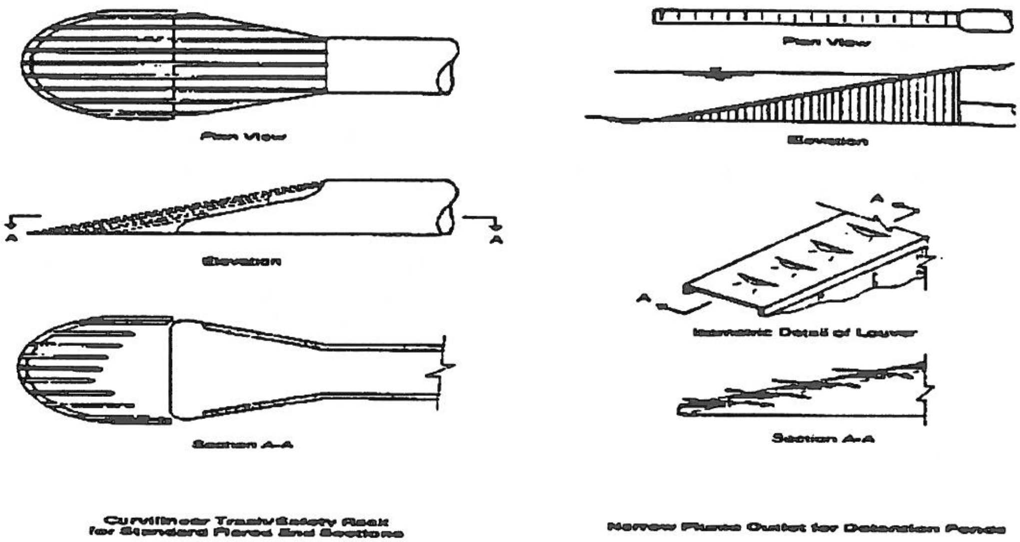
A survey conducted by APWA in 1980, based on 325 respondents, revealed that there have been two drownings reported at the detention facilities. It is therefore, very essential to take precautions in design and selection of storm water management alternatives, to minimize hazards. Embankment slopes, railings, fencing and other features are obvious considerations. The importance of designing and constructing outflow structures and dams with safety considerations in mind should never be ignored. In general, the approaches that can be used to promote safety are [APWA, 1981]:

1. Keep people off the detention facility site
2. Provide escape aids
3. Make the onset of the hazards gradual
4. Eliminate the hazards

The designers and reviewers of stormwater control facilities, particularly those using detention / retention facilities should pay particular attention to incorporating appropriate safety features in the design of the facilities.

Special attention must be given to the design of outflow structures to satisfy the safety considerations. Water currents constitute a distinct hazard to persons who enter a detention pond or basin during periods when stormwater is being discharged. The force of the currents may push a person into an outflow structure or may hold a victim under the water where a bottom discharge is used. Several features designed to either eliminate or reduce such hazards are illustrated in Figures VI-13 and VI-14.

## Figure VI-13
## Suggested Safety Features for Non-Submerged Outlets




## Figure VI-14
## Suggested Safety Features for Submerged Outlets

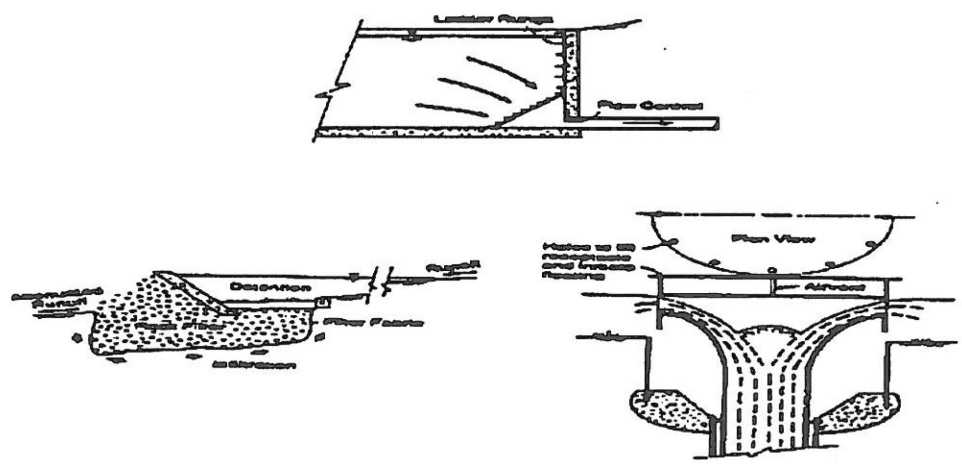


Figure VI-13 illustrates two versions of designs for non-submerged outlets: 1) curvilinear trash/safety racks for standard flared end sections and 2) narrow flume outlets. Both of these designs represent methods which tend to reduce the potential for persons to be drawn into or trapped against the outlet devices.

Figure VI-14 presents suggested safety features for submerged outlets: 1) outflow velocities and hence the associated hazards can be reduced through the use of a porous dam type of outlet facility; and 2) the illustrated safety rack for submerged outlets reduces the entrapment potential and provides a means of egress from the basin. As is also illustrated in Figure VI-14, drowning hazards can also be reduced by using a floating inlet for a basin outlet structure. The floating inlet reduces the drowning hazard by eliminating the water force which could trap a person at the outflow structure.

## DISTRIBUTED STORAGE

### GENERAL

The stormwater management techniques discussed thus far have been geared primarily to on-site control methods. It is likely that on-site controls will be the predominant form of stormwater management in the Bull Run watershed. Off-site, distributed storage is, however, an alternative or adjunct to on-site control techniques which should be recognized and considered for use where appropriate. Simply defined, distributed storage is the process of utilizing the most suitable site or sites for regional detention facilities.

The combination of on-site detention and distributed storage approaches may significantly improve the capability of land developers and communities to control stormwater on a watershed basis. Distributed storage may also offer a means of accommodating relatively dense commercial development in a manner which minimizes total costs and optimizes land utilization through the sharing of a single, strategically located detention or retention facility. Finally, the use of distributed storage may increase the feasibility of dual or multi-purpose facilities. For example, certain recreation areas might easily be used to provide temporary stormwater storage; natural or artificial ponds and lakes can serve both recreation and stormwater management objectives; and stormwater management facilities may be constructed as replacement wetlands.

### SELECTING DISTRIBUTED STORAGE LOCATIONS

There are two general methods for selecting appropriate or candidate sites for distributed storage facilities. These are: 1) selection to accommodate dense commercial development; and 2) selection based upon hydraulic factors. The first basis of selection is highly dependent upon existing and anticipated future commercial development conditions in specific locations in the watershed, the spatial distribution and timing of the development activities and the availability of suitable sites. This method of selection should be used and considered on an on-going basis by each municipality as the potential for significant strip type development is recognized.

Selection of candidate sites based upon hydraulic factors employs an analysis of storm flow routing in the watershed. The key under this approach is the selection of sites that are hydraulically most advantageous for off-site (regional) storage. The final determination of which, if any, storage area is ultimately constructed should be made by subsequently assessing the need for regional storage, the economics of this alternative and the associated advantages and disadvantages of distributed storage in specific locations.

To assist in future considerations of the potential use of distributed storage, candidate distributed storage locations have been identified based upon an analysis of basin hydraulics. These candidate locations are listed in Table VI-5. The subbasins listed in Table VI-5 refer to those identified previously in Plate IV-1, introduced in Section IV of this Plan.

Locations for distributed storage were determined by analyzing the flow routing in the watershed and selecting spots where streams join (confluences), and where peak runoff rates from two subbasins pass at approximately the same time. Areas where distributed storage would be most effective in terms of potential stream flow reductions are those where the timing of the peak discharges and the peak discharge rates are nearly equal.

Delaying one of the subbasins by using a detention pond or some other delaying facility would separate the peak runoff rates passing the confluence point would result in a decrease in the combined peak rate of stream flow at the downstream locations.

Locations for distributed storage were determined by analyzing the 100-year/24-hour output from the Penn State Runoff Model (PSRM) for all subbasins. The following procedures were followed in order to identify the locations presented in Table VI-5.

1. A list was made of all of the subbasins which have two or more upstream channels entering them (confluences). According to the inherent numbering convention of PSRM, these subbasins will always be immediately downstream from the dummy subbasins.

2. From the list, those subbasins where peak runoff rates form upstream subbasins pass at the same time (peak time ratio = 1.0) were identified. These areas should be given the highest priority in selecting distributed storage locations. Delaying the runoff from one of the tributary areas by using a detention pond (or some other delaying facility) will separate the peak runoff rates passing the confluence subbasins.

TABLE VI–5
BULL RUN WATERSHED
ANALYSIS FOR THE POTENTIAL FOR EFFECTIVE DISTRIBUTED STORAGE

| Downstream Watershed No. | Upstream Watershed No. | Peak Discharge (cfs) | Peak Time (minutes) | Potential for Effective Distributed Storage | Downstream Watershed No. | Upstream Watershed No. | Peak Discharge (cfs) | Peak Time (minutes) | Potential for Effective Distributed Storage |
|---|---|---|---|---|---|---|---|---|---|
| 5 | | 1116 | 780 | High | 29 | | 2439 | 1010 | Low |
| | 2 | 632 | 780 | | | 25 | 2398 | 985 | |
| | 4 | 484 | 780 | | | 27 | 325 | 840 | |
| 10 | | 1439 | 860 | Low | 34 | | 2762 | 945 | Low |
| | 6 | 1169 | 820 | | | 29 | 2439 | 1010 | |
| | 8 | 277 | 780 | | | 32 | 645 | 900 | |
| 15 | | 1951 | 945 | Moderate | 42 | | 455 | 825 | High |
| | 10 | 1439 | 860 | | | 38 | 169 | 785 | |
| | 13 | 537 | 850 | | | 40 | 226 | 785 | |
| 19 | | 2398 | 975 | Low | 46 | | 460 | 865 | Moderate |
| | 15 | 2021 | 945 | | | 42 | 455 | 825 | |
| | 17 | 974 | 780 | | | 44 | 295 | 780 | |
| 25 | | 2398 | 985 | Low | 48 | | 2926 | 1050 | Low |
| | 19 | 2021 | 975 | | | 36 | 2816 | 1020 | |
| | 23 | 974 | 865 | | | 46 | 640 | 865 | |

In order to select some more subbasins, subbasins where peak runoff rates from upstream subbasins with a peak time ratio of greater than one were identified. The subbasins with smaller peak time ratios were given relatively higher priority in the selection process.

3. For all of the subbasins identified above, compute the ratio of the peak runoff from the tributary subbasins. Again, the subbasins with lower ratios were given high priority in the selection process.

4. Combine (sum) the ratios of step 2 and 3 for the final selection. The lowest combined ratio subbasin is the best distributed storage location, and vice-versa. Finally, the combined ratios were used to categorize all distributed storage locations into three groups: high, moderate, and low. The lowest combined ratio was subtracted from the highest combined ratio and the result was divided by three, thus creating three groups.

   For the Bull Run Watershed, the grouping ratios were as follows:

   A. High, if combined ratio was 2.3 to 4.4
   B. Moderate, if combined ratio was 4.5 to 6.5
   C. Low, if combined ratio was 6.6 to 8.6

5. The final selection will depend on site specific geographical, socioeconomic, and political factors.

The resulting identified potential distributed storage locations represent those points in the watershed that the construction of distributed storage facilities are most likely to economically reduce downstream peak discharges. As such, they represent primary locations to be considered if the feasibility of the application of the distributed storage approach comes under consideration at points throughout the watershed. However, in the event that the identified candidate points prove unacceptable, the search for an acceptable location could be broadened to consider other locations which may offer less favorable timing and evenly divided stream discharge characteristics.