ENGINEERING PLANNING SURVEYING CONSTRUCTION SERVICES

# Flood Control District of Maricopa County Alternatives Analysis for Water Quality Enhancement of Detention Basin Effluent

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# 1. Introduction

The Environmental Protection Agency (EPA) has introduced new rules in the Clean Water Act (CWA) that require municipal separate storm sewer systems (MS4's) to obtain a National Pollution Discharge Elimination System (NPDES) permit covering all of their stormwater discharges. Currently the EPA is not imposing numerical limits on the quality of the stormwater discharged. In lieu of numerical limits the requirements will be that the MS4's implement Best Management Practices (BMP's) to reduce the amount of pollutants in the discharge.

The Flood Control District of Maricopa County (FCDMC) has constructed many floodwater storage basins and is in the process of planning several new basins. The discharge from many of these basins may be conveyed through facilities owned and operated by other agencies or cities, each required to obtain an NPDES permit or to obtain a joint permit (depending on the population of the agency or city). Therefore, the quality of stormwater that is collected or conveyed inter-jurisdictionally may be a concern. An MS4 owner/operator which accepts inter-jurisdictional runoff can reduce its potential liability by requiring the contributing agency to provide selected BMP's for pollutant reduction before continued acceptance of runoff will be permitted.

The purpose of this study is to evaluate alternative methods of improving the quality of stormwater released from detention basins. This can be accomplished by using BMP's approved by the EPA. These types of alternatives are usually classified as major structural controls. Also, there are many BMP's that address the improvement of the stormwater quality before it is received by the detention basins. The BMP's have been classified in three different types as follows:

- Institutional and Non-Structural Controls: Examples include such programs as spill revention ordinances, recycling programs, increased street sweeping, increased cleaning of storm drains, and increased maintenance of existing stormwater facilities.
- Minor Structural Controls: Examples include using gravel berms strategically placed to filter runoff, construction of vegetated overland flow areas to filter the stormwater before discharge, installation of porous pavement to reduce and filter runoff, construction of parking lot oil and grease separators. These types of controls are very site specific, and are intended to prevent pollutants from entering the major conveyance systems by control at the source..

- Major Structural Controls: Examples include construction of modifications to detention basins, man-made and natural wetland areas, chlorination facilities, and other capital intensive pollutant reduction options. Major controls are typically used to treat stormwater after it has reached a primary conveyance system.

The type of BMP's that are needed for major conveyance system discharges are primarily major structural controls. These types of controls are effective at meeting the NPDES permit requirements of the EPA. However, it may be less expense to examine the minor and non-structural controls that may be applied. These types of controls reduce discharges at the source and reduce the pollutant loading to major conveyance systems. A literature survey of these three types of BMP's is presented in Appendix A. This survey briefly describes each process and the cost of each process. Each process is ranked in terms of pollutant reduction efficiencies, capital costs, operation and maintenance (O&M) costs, and land requirements.

In order to compare each treatment process in a meaningful way, a design basis was needed for application to each alternative. Rainfall data taken over the past 50 years from the Phoenix Airport was analyzed to determine a reasonable first flush storm. This data was used to project a runoff volume per acre of contributing area to be applied to each alternative. Water quality parameters were estimated from stormwater sample data taken by various local agencies in the Phoenix Metro area from 1990 through 1995. This data was used for predicting stormwater quality to apply to each alternative in order to appropriately size each facility. Section 2.0 presents the design basis development.

Of the technical literature search of BMP's presented in Appendix A, an analysis was made of each alternative in regard to its pollutant reduction capability for detention basin effluent and physical applicability to Maricopa County. Ten alternative BMP's were chosen by PBS&J and presented to FCDMC for evaluation in the form of brief narratives of each process and process flow diagrams. FCDMC, in cooperation with the Salt River Project (SRP), evaluated these alternatives and chose five processes to examine in more detail. They are as follows:

- Subsurface Wetlands
- Sand Filtration Basins
- Dry Pond Retention Basins
- Modified Dry Wells
- Infiltration Trenches

Section 3.0 of this study presents design criteria, standard details, and specifications that were developed for each selected process. These criteria represent typical procedures currently used in industry for process design.

All five stormwater quality enhancement alternatives are compared side by side in Section 4.0. Design and cost parameters for each alternative are put into comparable units and presented in tabular form to aid in the comparison of each alternative. Each alternative is compared on a per acre served basis where possible so an evaluation can be made regarding any size drainage area. The per 50 acres served criteria is used throughout the analysis to aid in determining land requirements, size of facility, construction and O&M costs.

# 2. Design Basis

## 2.1 Introduction

To effectively compare stormwater enhancement technologies in terms of effectiveness and applicability a common design basis must be developed. This entails an understanding of the size and distribution of storm events, as well as any water quality data that has been accumulated. Knowledge of the total volume of storm runoff and pollutant concentrations can provide an estimate of total pollutant load. The data made available for this study by FCDMC includes 50 years of historic precipitation data taken at the Phoenix Sky Harbor Airport and water quality data from storm events collected by FCDMC and other surrounding authorities from 1990 through 1995.

The goal of this analysis is to estimate the depth and water quality of a "first flush" storm. The concept of first flush is traditionally defined as the depth of rainfall required to transport 90% of the contaminants predicted to be in the runoff from a given watershed. This criteria is a function of many variables such as the velocity of the runoff, the intensity of the storm and the contaminant being transported. The current water quality data available from the county does not provide ample information to correlate contaminant transport with rainfall depth. Discrete samples taken throughout the duration of a storm and analyzed separately for concentration will show the fluctuation in contaminant levels throughout the duration of runoff from a storm. This type of data, along with information about the duration and size of the storm, time between sampling events, and drainage area will predict a first flush parameter based on contaminant transport. The goal of this study is to provide guidelines for capturing and improving the quality of the stormwater runoff from 90% of the typical rainfall events in Maricopa County (excluding infrequent storms.

The focus of Stormwater flood control is with the peak flow rates from large and infrequent storm events. These storm events are not the focus of stormwater quality control because in terms of quality frequent small storms have much more of an impact in total pollutant loading than infrequent storms large. The premise is that storms that occur once every 5, 10, or 25 years will not transport any more pollutants than a frequent event. Small volumes of water running across a watershed will show higher concentrations of pollutants. From the standpoint of design, two parameters must be defined: the quantity of stormwater and the quality of stormwater.

## 2.2 Stormwater Quantity

### 2.2.1 Statistical Evaluation

The storm used as a design parameter in this study is the event whose precipitation depth is equal to or greater than 90% of all the rainfall events recorded at Sky Harbor for the last fifty years. A summary of this data is found in Appendix A. The purposes of this study the storms that are considered significant are those that produce runoff. According to the Drainage Design Manual, Vol. 1, of Maricopa County the expected Surface Retention Loss (or Initial Abstraction, IA) for pavement is 0.05 inches. Since paved surfaces typically have the lowest surface retention of the various land uses and are the first ones to produce runoff, it follows that storms less than or equal to 0.05 inches in depth will not produce runoff from any of the watershed's surfaces. Therefore the statistical analyses performed for this study neglected all rainfall events of 0.05 inches or less. Based on this assumption, of the total number of rainfall events which occurred over 50 years (3085), only 36% (1114) produced significant runoff.

Further analysis of the data shows an interesting trend in the distribution of storm events in the Phoenix area. At each extreme of storm depths, the data is very skewed. As an example, the lesser 50% of the storm events yielded only 4% of the total rainfall. On the other extreme, only

1.5% (46) of the storm events were greater than one inch in depth, yet these lower frequency-greater magnitude storms were responsible for 16% of the total rainfall. This means that the 34.5% (1069 events) which measured between 0.05 inches and 1.0 inches produced 84% of the long term average annual runoff. This is the target group for stormwater quality enhancement proposed by this report.

Since there are over 3,000 observations, the rainfall data was analyzed assuming that it follows a normal distribution. The Central Limit Theorem states that as long as the number of observations is large, it is reasonable to assume a normal distribution for purposes of parameter estimation. A discussion of this theorem is found in the Hienes and Montgomery text (Ref. #). Also, a measurement to determine the regularity of a set of data is to examine the difference between the median and the mean. This value is used to calculate the skewness which defines the lack of symmetry in a data set.

The following is a list of statistical factors derived from the data:

$$\text{Median Depth} = d_{50} \text{ (inches)}$$

$$\text{Average Depth} = d_{ave} \text{ (inches)}$$

$$\text{Standard Deviation, } S = \sqrt{\frac{\sum d_i^2}{n} - d_{ave}^{\ 2}}$$

$$d_{90} = d_{ave} + S$$

$$\text{Skew} = \frac{3\left(d_{ave} - d_{50}\right)}{S}$$

The same type of analysis was performed on three groups of the rainfall data for comparison purposes. The first group contains all of the rainfall events, the second group contains all of the rainfall events producing runoff (as above) and the third group contains all of the events producing runoff but less than 1 inch of rainfall. By excluding all the events greater than one inch, only 1.5% of all the storms are excluded. This case was selected in an attempt to eliminate both extremes of large and small storms. From a water quality standpoint, the larger storms are so infrequent and provide so much dilution, that it is reasonable to exclude them from the analysis. In addition, the cost of processing these infrequent events becomes very expensive but little provides gain in average annual pollutant reduction loading. The following table summarizes the results:

**Table 2-1: Rainfall Depth Statistical Analysis Comparison**

| Parameter | All Rain Events | >0.05 | 1.00 > i < 0.05 in |
|---|---|---|---|
| n | 3085 | 1181 | 1068 |
| $d_{50}$ | 0.01 | 0.21 | 0.20 |
| $d_{ave}$ | 0.12 | 0.32 | 0.27 |
| s | 0.164 | 0.306 | 0.214 |
| Skew | 2.01 | 1.08 | 0.78 |
| $d_{90}$ | 0.34 | 0.71 | 0.55 |

Source: Adapted from Appendix 3, Ref. 12

The design storm chosen for this study is 0.55 inches. Given that the goal of this study is to identify feasible ways to improve runoff quality rather than to retain runoff, the assumption of neglecting storms over 1 inch is reasonable. As mentioned, the excluded storms represent only 1.5% of the total storms over the past 50 years. The skewness of the data is reduced by eliminating the extremes of the data. In this way, parameters estimated from this data will be more significant and funds can be spent to develop BMP's which address only the storm events of concern.

### 2.2.2 Runoff Calculations

Runoff volumes were calculated in units of acre feet, by using a modifies form of the rational method. The Rational Equation is based on the assumption that the application of a steady uniform rainfall is uniformly distributed over the drainage area. The Rational Equation gives a peak runoff rate for a given watershed. It can be rewritten to give an approximate total runoff volume by substituting precipitation depth (P) for rainfall intensity (i) and solving for runoff volume (V) instead of peak flow rate (Q). It should be noted that although the Rational Equation is an empirical equation whose units do not balance (cfs=(in/hr) (ac.)) the volume this version of the equation does balance:

$$ac - ft = \left(\frac{in}{12in/ft}\right)(ac)$$

$$V = C\left(\frac{P}{12}\right)A$$

Where:
V = Volume of Runoff, acre - ft
C = Runoff coefficient, dimensionless
P = Depth of rainfall, inches
A = Acea of watershed, acres

All of the major structural BMP's require a storage facility for the runoff. In some cases the quality enhancement requirements can be combined with attenuation requirements so one storage facility will serve both processes. The following describes the assumptions used to size the storage facility.

The simulated drainage area for this study is 50 acres. All design costs and enhancement system sizing are based on runoff from a 50 acre watershed. This size of area will provide a reasonable scaling factor when estimating larger or smaller drainage areas. The average runoff coefficient used was 0.75. The facility size is based on a typical retention basin design per Section 8 of the District's Drainage Design Manual, Volume II. The design includes the use of a square basin. Based on these assumptions the following parameters were used for design comparisons:

**Table 2-2: Design Storm Parameters.**

| | |
|---|---|
| Design Storm For Study | 0.55 inch 90% Storm |
| Storage Volume for 50 acre watershed. | 1.72 acre-ft |
| Acres Required for Storage Facility | 0.90 ac. |

Source: Appendix F

## 2.3 Stormwater Quality

The prediction of the expected quality of stormwater is very site specific and dependent upon many variables. Generally, the most important variables are the land use of the drainage area, the time between storm events, and the duration of the storm event. Each type of contaminant potentially contained in the runoff has different transport rates and conditions under which they will be transferred from the land surface to the runoff. Also, once set in motion by the stormwater, each will travel to the final point of collection at varying rates and concentrations, depending on such factors as the solubility of the contaminant, the velocity of the runoff, and the concentration of the contaminant in the runoff. Obtaining sufficient data to define each of these variables individually so that they can be mixed and matched as the situation arises is certainly not a practical goal in an arid climate. That would be a monumental task both in terms of manpower and the number of years necessary to collect meaningful data. Therefore this study uses generalizations based on existing data to estimate the expected water quality of the runoff.

### 2.3.1 Stormwater Quality Modeling Methods

Contaminant movement over the ground surface from a storm event, through piping networks, into storage and quality enhancement units, and finally to receiving waters is a very complex process. The FCDMC has been collecting stormwater quality data and compiling data from other municipalities since 1990. This data could be applied to the EPA's Stormwater Management Model (SWMM) to simulate a continuous time analysis for large drainage areas within the County. Continuous time analysis can provide an optimum design for storage and enhancement facilities based on long term historical weather patterns. The application of this or any other water quality model is dependent on good data for calibration. Accurate data on the washoff rates of pollutants for each land use within a basin is needed. In addition, the accumulation rate of pollutants should be determined to allow estimation of containment loads accentuated between rainfall events. Application of the SWMM model is beyond the scope of this analysis, but should be recognized as a valuable stormwater management tool.

### 2.3.2 Historical Water Quality Data vs. Gila River Standards

The data used to estimate the quality of the stormwater runoff was taken from a report by the FCDMC dated December 31, 1995. This report contains data collected by FCDMC from 1990 through mid-year 1995, and presents a statistical summary of the pollutants which were detected at least once.

The data is divided into three categories of land use: residential, commercial, and industrial. Within those land use categories, particularly industrial, there can be a great variation of stormwater quality depending on the nature of the industry. Certain industrial operations, such as hazardous waste treatment and disposal facilities, are already required by the EPA to have pollution prevention plans that regulate their stormwater runoff. Commercial runoff quality can be affected by the type of business within that watershed, but most of the runoff will come from large parking lots and roof tops. Residential stormwater quality can vary by economic demographics and type of landscaping. Desert landscaping will produce a higher suspended solids load while traditional grass landscaping will produce higher nutrient and herbicide loading.

The time between storm events can also affect the quantity of a particular contaminant in stormwater runoff. As the time between storm events increases, the deposition of contaminants also increases. Frequent events will flush the surface of the watershed more thoroughly and reduce the overall concentration of contaminants in the runoff but typically will not reduce annual loadings.

Average values for contaminant concentration are based on a report produced by FCDMC dated December 31, 1995 which summarizes the data collected to date. For this analysis representative contaminants were chosen to simplify the comparison of alternative processes. It is important to note that no significant conclusions about stormwater quality can be drawn from this data, and it is presented for comparison purposes only. The following table lists representative contaminants and applied influent conditions for each land use type. These values are compared to the designated use of the Gila River as warm water aquatic and wildlife (A&Ww). These standards are found in the Arizona Administrative Code, Title 18, Chapter 11. A copy of these standards is found in Appendix B.

**Table 2-3: Estimated Contaminant Concentrations vs. Gila River Standards**

| Type | Specific Compound | Residential | Commercial | Industrial | Gila River Discharge Standard (A&Ww) |
|---|---|---|---|---|---|
| $BOD_5$ | | 35 mg/l | 55 mg/l | 130 mg/l | NNS[1,2] |
| Coliform | Fecal | 15,200 cfu/ml | 4,200 cfu/ml | 8,000 cfu/ml | 4,000 cfu/ml |
| Suspended Solids | Silt | 136 mg/l | 132 mg/l | 345 mg/l | NNS[2] |
| Nutrients | T. Nitrogen | 1.0 mg/l | 1.2 mg/l | 1.5 mg/l | 2.0 ug/l |
| Dissolved Solids | TDS | 142 ml/l | 167 mg/l | 154 mg/l | NNS[2] |
| Volatile Organic Compounds | Xylene | 3 ug/l | 3 ug/l | 3 ug/l | NNS[2] |
| Chlorinated Organic Compounds | Aldrin (chlorinated pesticide) | 17 ug/l | 17 ug/l | NS | 2.0 ug/l |
| Semi-Volatile Organics | Acetone | 34 ug/l | 39 ug/l | 25 ug/l | NNS[2] |
| Oil and Grease | | 130 mg/l | 45 mg/l | 80 mg/l | Narr. Std./ (15 mg/l)[3] |
| Dissolved Metals | Lead | 8.9 ug/l | 5.8 ug/l | 15 ug/l | 0.6 ug/l R/C<br>3.5 ug/l I[4] |
| Acid/Base Neutrals | Phenols | 20 ug/l | 45 ug/l | 50 ug/l | 7,000 ug/l |

[1]Minimum Dissolved Oxygen A&Ww Std. is 6.0 mg/l for the receiving body of water.
[2]NNS indicate no numerical standard has been specified. However, the acceptable limit may be determined by toxicity testing.
[3]Currently, the EPA is writing a narrative standard into their NPDES stormwater permits indicating that any oil and grease discharge may not produce a visible sheen. The EPA existing standard for industrial stormwater discharges currently under the NPDES program is 15 mg/l.
[2]A&Ww Std. is based on hardness. The residential/commercial (R/C) number is based on an average 25 mg/l hardness, and the industrial (I) is based on and average 100 mg/l hardness. Note that under EPA test method 7421, the minimum detection level is 2 ug/l.

Source: FCDMC Report dated 12/31/95, Appendix C.

### 2.3.3 Water Quality Data Discussion

As mentioned earlier, the data used for these comparisons must be considered inconclusive due to the nature of the sampling. However, some obvious trends warrant discussion. First, the occurrence of coliform in the residential areas appears to be higher than industrial or commercial areas. In general, there are more landscaped areas in residential developments that will attract a variety of wildlife such as ducks and geese, and other wild birds. Coupled with domestic animals (such as horses, dogs and cats) and the general increase of landscaped areas, this may account for the increased coliform count in the residential areas.

Another trend noted is the increase of oil and grease in the residential areas. This could be due to traffic pattern differences in this type of area. Slower traffic and a higher amount of unoperated, parked cars may contribute to increased oil and grease accumulation. There is a discussion of how to manipulate traffic patterns to mitigate such found in Appendix A. Also, there is more of an opportunity for the "shade tree" mechanic to contribute to potential grease and oil runoff. One illicit discharge of an oil change can contribute greatly to the contamination of runoff. A public education program is best suited to mitigate this type of discharge.

The data in Table 2-3 above also shows a higher amount of suspended solids originating from industrial areas. In general, industrial areas are more impermeable than residential or commercial areas. This will not only contribute to a higher volume of runoff but also a higher runoff velocity. This higher velocity could be picking up more solids and accounting for the higher suspended solids in this type of drainage area.

## 2.4 Effluent Target Standards

The EPA recommends using best management practices instead of numerical quality based effluent limits for stormwater enhancement in MS4's. The goal of the MS4 program is to reduce pollutant loadings to receiving waters. Monitoring the quality of receiving waters will show the effectiveness of the MS4 program. According to the EPA, there is not enough information on the characteristics of stormwater to justify numerical limits, and therefore they recommend the use of BMP's, as addressed in this study. However, some criteria must be initially selected to provide a gauge of effectiveness and necessity for the design of BMP alternatives. Based on the brief comparison in Table 2-3, it is appears that the compounds of concern are dissolved metals, coliform, and pesticides.

Through discussion with the FCDMC and SRP, it was decided that full body contact standards be used to compare the effectiveness of the BMP's, however the ultimate receiving water for all of Maricopa county drainage is the Gila River governed by warm water Aquatic and Wildlife standards.

# 3. Selected Management Processes

## 3.1 Introduction

This chapter presents five management processes deemed to be suitable by the FCDMC and SRP. These five processes were selected in the narrative analysis submittal. Each process has very different characteristics and therefore different design concerns are discussed for each one. The standard stormwater design basis developed in Section 2.0 is applied to each one so an evaluation can be made of their effectiveness and cost of managing stormwater.

### 3.2 Subsurface Wetlands

#### 3.2.1 Process Overview

A wetland is an area classified by the EPA and other regulatory agencies as an area in which the water table is at or above the ground long enough each year to sustain growth of vegetation indigenous to saturated ground. Naturally occurring wetlands are highly regulated and would be difficult to use as stormwater management facilities, but man-made wetlands constructed specifically to treat a waste stream have been shown to be an effective treatment process.

The process of subsurface wetlands works through plants that absorb oxygen through their leaves and above ground stems in the wetland environment. The oxygen is carried throughout the plant resulting in aerobic conditions surrounding the root of the plant. Some of this oxygen will be supplied to microbes that will consume nutrients in the water. This is the major process for pollutant removal in a wetland. In addition, water flowing slowly through the submerged wetland media will encourage sedimentation. Many pollutants, including heavy metals, adhere to soil particles and will be removed by this process.

Because the submerged portion of the plant plays such a major role in transferring oxygen to the soils, the root penetration of the plants should be a factor in crop selection. Two of the most common wetland plants are bulrush and cattails. The root penetration of the bulrush can be up to 30 inches, while the cattail has roots to 12 inches. Studies have shown that bulrush are capable of removing up to 3 times more nitrogen than cattails in wetlands. Also, bulrush have been shown to be hearty plants that can withstand short periods of heavy loading.

Subsurface flow wetlands consist of a trench filled with highly permeable media and sometimes lined with an impermeable membrane to prevent seepage. The media includes crushed rock, gravel, and various soils. It is different from a free surface flow type of wetland because the water flow occurs in the root zone of the plants. This subsurface zone is continually saturated and is mostly anaerobic except in the areas of the plant roots where oxygen transfer takes place. Advantages of this type of system is that odors are less likely to occur and mosquitoes are less likely to develop.

Wetlands are usually designed on the basis of $BOD_5$ and nutrient removal. Most organic materials are biodegradable and require oxygen to break down. Biochemical oxygen demand is not a specific contaminant, rather it is the amount of oxygen required to degrade the organics contained in water. The degradation is a biochemical process as opposed to COD (chemical oxygen demand) that exists when inorganic compounds use (or demand) the oxygen. A $BOD_5$ value of 100 mg/l means that if this water were allowed to degrade for 5 days (not limited by the need for nutrients) it would require 100 mg of dissolved oxygen per liter of water over the 5 day period.

The design of a wetland system is a complex process with many variables to consider. Presented in this section are some typical design criteria that can be used to determine the major components of a subsurface flow wetland. The typical parameters presented are geared toward climatic conditions in Maricopa County, the design basis presented on Section 2.0, and the availability of a supplemental water supply.

### 3.2.2 Contaminants Removed

Wetlands have shown $BOD_5$ removal rates as high as 250 pounds per acre per day during warm periods. During these warmer periods, the amount of bacterial structure on the roots of the plants is at its highest. During cooler periods, the $BOD_5$ removal performance decreases because of slower metabolic activity of the bacteria or plant die off. Suspended solids are removed at just about the same rate as $BOD_5$. Bacterial nitrification and denitrification processes are the principle mechanisms for nitrogen removal. A properly designed wetland will be particularly effective at reduction of organic contaminants due to these processes.

Wetlands have not been shown to efficiently remove significant amounts of dissolved metals since bacteria cannot metabolize dissolved metals effectively. Most metals in stormwater are attached to soil particles and therefore end up in the sediment layer in the wetland with some dissolved metals being assimilated by the plants. It has been theorized that the plants can be harvested regularly to prevent the buildup of toxic metals and the release of nutrients during the decay process.

### 3.2.3 Supplemental Water Needs

The wetlands will not have a continuous supply of stormwater so an alternate water supply must be available to keep the wetland operating. The evapotranspiration rate is an important factor in planning water supply needs by constructing a water balance of the wetland. It is recommended that average values for the most severe month be used rather than a yearly average. Properly designed and healthy wetlands can take short periods of dry weather with no detrimental effects.

The Arizona Department of Environmental Quality, Engineering Bulletin No. 11 provides guidance on estimating evaporation rates for evaporation pond design. Excerpts are found in Appendix C. The evapotranspiration rate from a plant crop can be higher due to increased surface area of the plants and other factors inherent to a particular species. Based on this observation, the value recommended in the ADEQ publication is increased by 30%. For the Phoenix area, the maximum monthly evaporation rate occurs in June and July at an average rate of 0.3 inches per day. By applying the 30% increase factor, the wetland will need approximately 1,420 cubic feet of water per day per acre of wetland to account for evapotranspiration losses.

The Table below summarizes the water requirements of a subsurface wetland in the Maricopa County climate.

Table 3-1:Estimated Supplemental Water Requirement a Subsurface Wetland

| Description | $ft^3$ water per day per acre of wetland |
|---|---|
| Water Surface Evaporation | 1,089 |
| Plant Transpiration (30% of Water Surface) | 327 |
| Total: | 1,416 |

Source: Adapted from ref. 3

This equates to a maximum daily flow rate of about 7.4 gallons per minute per acre of wetland to replace evapotranspiration water losses during the driest months.

### 3.2.4 Typical Design Parameters

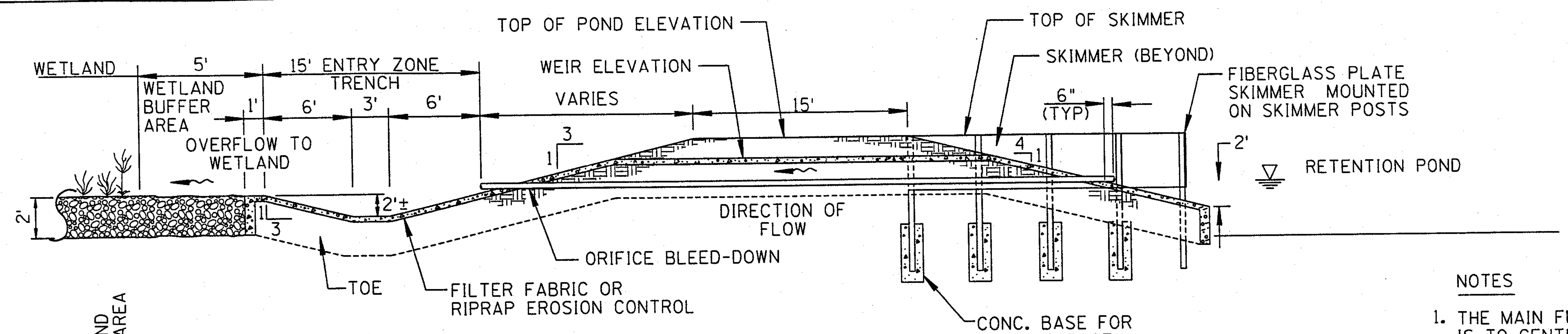
For a subsurface wetland, the hydraulic loading on the system determines the length of the intake weir, and the level of quality enhancement desired dictates the width parallel to the flow line. The following table summarizes the typical design criteria for subsurface flow wetlands.

**Table 3-2:Subsurface Wetland Typical Design Parameters**

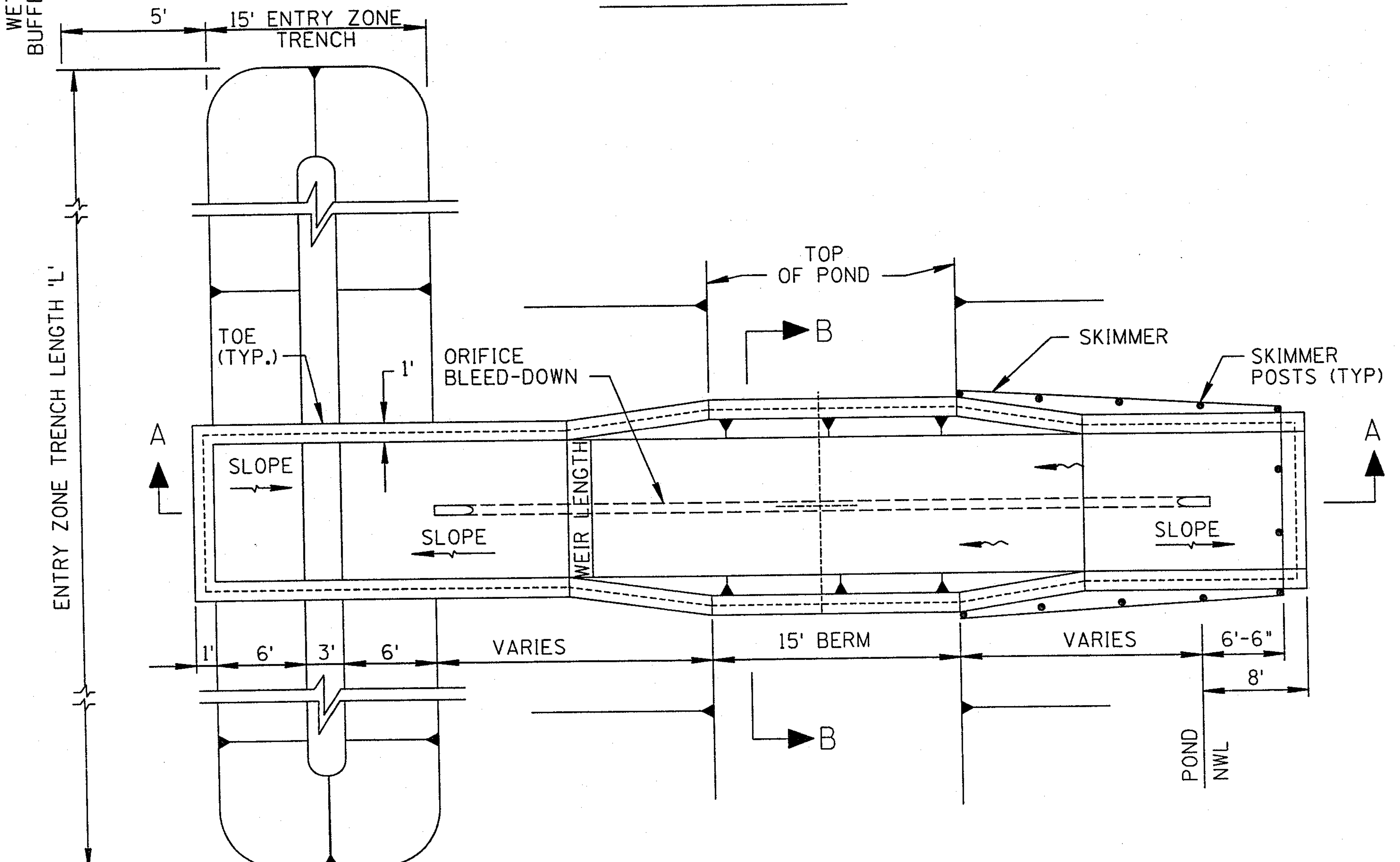
| Parameter | Units | Typical Range. |
|---|---|---|
| Hydraulic Detention Time, θ | days | 4-15 |
| Organic Loading Rate | lbs. BOD/(acre day) | <60lbs/acre day |
| Hydraulic Loading Rate | MG/(acre day) | 0.15 - 0.05 |
| Bed Porosity, n | %, unitless | 35 - 45 |
| Bed Aspect Ratio | Length/Width | not applicable |
| Water Depth, d | inches | 12 to 30 |
| Inlet Trench Length | feet/acre served | 40-50 |

Source: Adapted from refs. 2, 3,14 using assumptions in Section 2.0.

A large aspect ratio is not necessary for the subsurface flow wetlands since plug flow is achieved in all subsurface flow. The width of the wetlands is controlled by desired removal efficiency. More often than not the bed inlet exceeds the bed length. The size of the inlet structure is controlled by hydraulics and is independent of the reactions in the system. The unit velocity, flow per unit area, should not exceed 25 ft/day to avoid disruption of the root rhizomes or shearing of the bacteria film on the roots. The velocity in a subsurface system is a function of the porous media. Also, a portion of it is taken up by the root system. The approximate required entry zone trench length per acre of drainage area served is 50 feet.



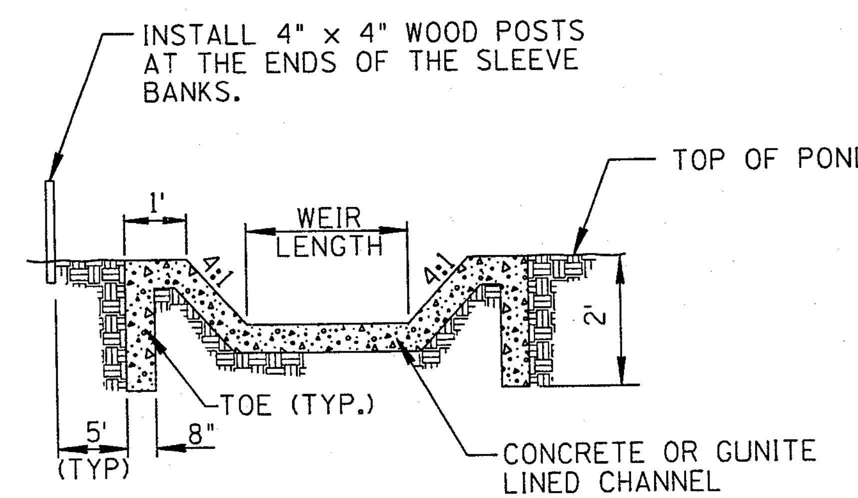

SECTION A-A




PLAN VIEW

NOTES

1. THE MAIN FUNCTION OF THE SPREADER IS TO GENTLY FEED CAPTURED FLOWS INTO THE WETLAND. MODIFICATION WILL HAVE TO BE MADE FOR MULTIPLE CELL WETLANDS.
2. THIS SPREADER SWALE REPRESENTS A TYPICAL WETLAND ENTRANCE STRUCTURE FROM A FIRST FLUSH CAPTURE BASIN. ALL DETAILS AND ORIENTATION OF THE STRUCTURE ARE SUBJECT TO MODIFICATION DEPENDING ON INDIVIDUAL PRODUCT REQUIREMENTS.
3. THE MAIN FUNCTION OF THE SKIMMER IS TO PREVENT FLOATING DEBRIS FROM ENTERING THE WETLAND.




SECTION B-B

FIGURE 1

| Job Number: | Designed By: | Drawn By: | Title: |
|---|---|---|---|
| 54014 | MM | PJO'C | SPREADER SWALE TYPICAL DETAILS |
| Sheet Number: FIGURE 1 | Checked By: TB | Date: 04/97 | |

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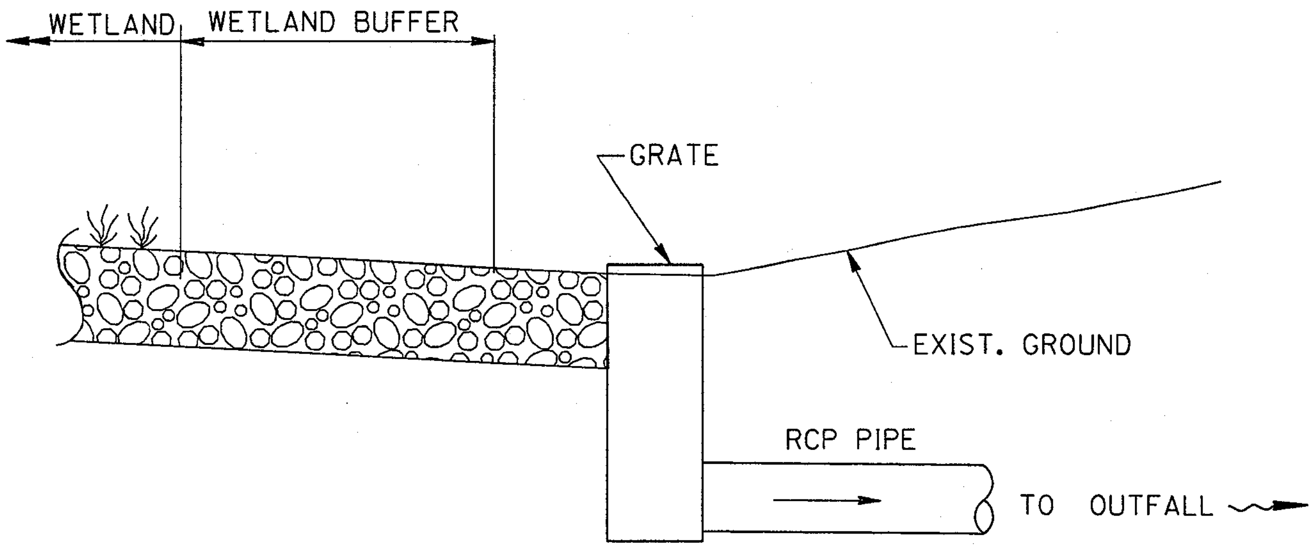


## OUTFALL STRUCTURE TYP. DETAIL

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NOTE: FLOW CONTROL MUST BE ON INLET.

FIGURE 2

Title:

# SUBSURFACE FLOW WETLAND TYPICAL OUTFALL STRUCTURE

| Job Number: | Designed By: | Drawn By: |
|---|---|---|
| 54014 | MM | LLW |
| Sheet Number: | Checked By: | Date: |
| FIGURE 2 | TB | 04/97 |

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FIG2 .dgn
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10:51:59

### 3.2.5 Inlet Structure

The stormwater must be applied to the wetland basin in such a way as to ensure uniform distribution of stormwater into the entry zone of the treatment bed. Typical details are presented in Figures 1 and 2. This can be done using a spreader swale leading into a trench filled with crushed rock, 5 to 10 feet wide, along the entire width of the wetland basin. The crushed rock should be 2 to 4 inches in diameter. The stormwater can be applied to the entry zone using a V-notched weir or similar method to ensure even distribution. The entry zone is also planted with similar plants as used in the wetland basin. The weir crest should be placed about 1 to 2 feet above the surface of the entry zone to allow for accumulation of floatables such as oil, grease and debris. The outlet of the wetland is typically sloped drain tile placed in a crushed rock zone with an adjustable outlet weir for water level control. Flow through the subsurface wetland is similar to groundwater flow. The headloss across the wetland can be estimated using Darcy's Law as follows:

$$v = -K\frac{\Delta h}{\Delta l}$$

Where:

$v$ = velocity of flow through the wetland, ft / d

K = hydraulic conductivity of the subsurface media, ft / d

$\frac{\Delta h}{\Delta l}$ = hydraulic gradient across the wetland, ft / ft

### 3.2.6 Wetland Treatment Area

Constructed wetlands can be considered to be attached-growth biological reactors. The approach to design of the wetland cell is much like that of a trickling filter, described with first-order, plug-flow kinetics. Plug-flow reactors are ideally mixed in the lateral direction and unmixed longitudinally. $BOD_5$ degradation is a function of temperature, influent concentration, desired effluent concentration, and time.

The following first order, $BOD_5$ removal equation is for use with a subsurface flow type of wetland:

$$\frac{C_{out}}{C_{in}} = e^{-K\theta}$$

Where:
$C_{out}$ = $BOD_5$ Concentration in the Effluent, mg / l
$C_{in}$ = $BOD_5$ Concentration in the Influent, mg / l
K = First order Rate Constant, $days^{-1}$
$\theta$ = Detention Time, days

The detention time is the variable that will determine the area of wetland. The actual detention time in a subsurface flow wetland follows similar rules of groundwater flow as follows:

$$\theta = \frac{L}{k_s S}$$

Where:
$L$ = Basin Length, feet
$k_s$ = hydraulic conductivity, $ft^3 / ft^2 \cdot d$
S = Slope of the Basin, ft / ft

### 3.2.7 Operation and Maintenance Requirements

Successful operation of a wetland includes proper frequent monitoring of water level, water application rates, and general plant health. With frequent monitoring during the start-up phase, and adjusting the operating parameters accordingly, a healthy wetland can be developed. Although each wetland is different depending on the siting of the wetland and the size, the following is a list of recommended monitoring:

**Table 3-3: Recommended O&M Schedule for Subsurface Wetlands**

| Item | Frequency |
|---|---|
| Inflow and Outflow | Daily |
| Recycle Flow | Daily |
| Evaporation Data | Daily |
| Rainfall Data | Daily |
| General Plant Health | Weekly |
| Nutrient Loading | Weekly |
| Nutrient Effluent | Weekly |
| Coliform Count | Monthly/or per Permit |
| Sediment Levels | Monthly or after storm event |
| Plant Harvesting | Yearly |
| Media Maintenance | Yearly |

Source: Refs. 2 & 14.

The Arizona Guidance Manual for Constructed Wetlands for Water Quality Improvements has an extensive chapter on operation and maintenance requirements of a constructed wetlands.

## 3.3 Sand Filtration

### 3.3.1 Process Overview

The filtration process has been shown to be an effective means to reduce contaminant levels in stormwater runoff. First flush runoff or design storm flows are collected and applied to the sand filter. The stormwater is applied to the top of the filter bed and as the water filters through the granular medium, the suspended matter in the water is removed by a variety of physical and chemical means.

During the first stages of filtration in a clean sand filter, most of the suspended material is removed by means of straining through the granular sand medium, but after some time of operation the particles removed increase the straining process and the head loss in the filter starts to build up and the flow rate through the filter slows. At some point, depending on the solids loading of the filter bed, the top layer of the filter media must be replaced to restore the porosity of the filter. The removal efficiency of a sand filter generally increases as it operates and rapidly declines as clogging or breakthrough occurs.

### 3.3.2 Contaminants Removed

Sand filters are most efficient at removing suspended solids, but other contaminants are also removed during the filtration process. Metals that are adsorbed to the suspended solids are removed, and fecal coliform bacteria concentrations can be reduced this way. Over the course of filtration, biological activity can develop in the sand media that is effective at removing BOD and other organic contaminants. Hydrocarbons and nutrients may also removed. Due to the physical nature of the sand filter process, however, sand filters are generally inefficient at removal of dissolved contaminants, such as dissolved metals or nitrates.

The following table shows representative removal efficiencies for a typical stormwater sand filter basin. These numbers will vary depending on the frequency and quality of maintenance of the filter as well as the influent concentrations of each contaminant. The estimated removal rates are from data collected by the Naval Facilities Engineering

Service Center from various municipalities. The data includes sand filter systems with different land uses and varying drainage area sizes.

**Table 3-4: Estimated Removal Efficiencies for Sand Filters**

| Contaminant | Percent Removal |
|---|---|
| Fecal Coliform | 76% |
| Total Suspended Solids (TSS) | 70% |
| $BOD_5$ | 70% |
| Total Organic Carbon (TOC) | 48% |
| Total Kjeldahl Nitrogen (TKN) | 46% |
| Iron | 45% |
| Lead | 45% |
| Zinc | 45% |
| Total Phosphorous | 33% |
| Total Nitrogen | 21% |
| Nitrate (as Nitrogen) | 0% |

Source: Ref. 20

### 3.3.3 Types of Sand Filter Designs

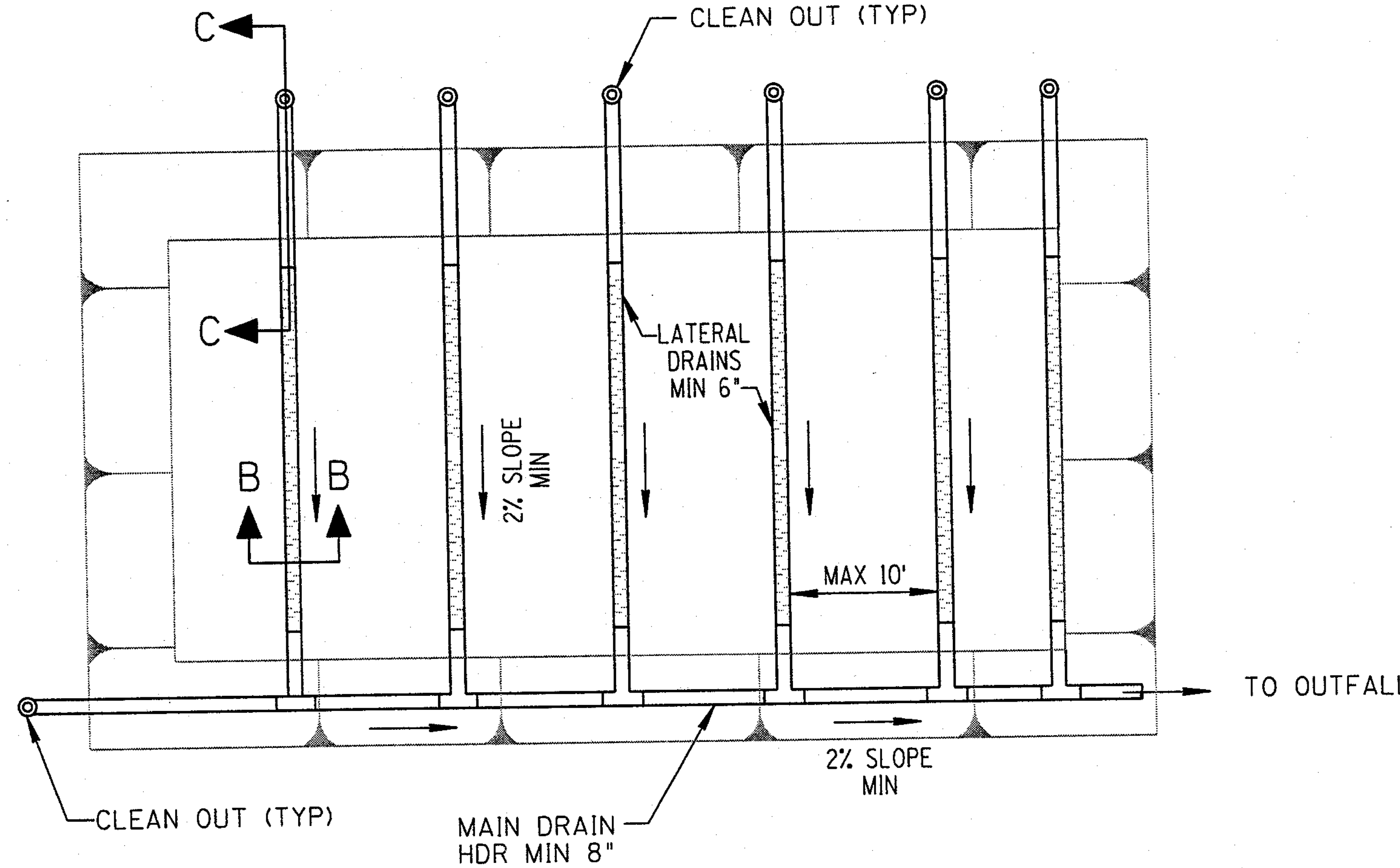
Sand filters used for stormwater quality control and runoff management can be designed many different ways depending on the location of the filter, land availability, level of treatment required, or capital availability. Types of designs available include surface sand filter basins, underground vault sand filter, or double trench sand filter. Surface sand filter basins are usually as large as a wet pond treatment system, depending on the drainage area served. They are designed to hold large amounts of runoff while filtration occurs. They are actually adaptable as a combined storage and treatment facility.

Underground vault sand filters are used in highly urbanized areas where land availability is at a premium. These types of filters are usually more complex in structure and therefore more expensive to build, but they are just as effective as a surface sand filter. This type of filter can be used to treat runoff, for example, at the boundary of an established, urban industrial complex.

The double trench sand filter is generally a smaller system meant to be used on drainage areas less than 5 acres. It provides a higher level of treatment by using two stage filtration. The first stage of the filtration process removes the larger particles and some of the floatables. The second stage is a polish step with finer filtration media. A higher level of treatment is achieved because the second step can contain a finer media than a single stage filter. The type of sand filter discussed in this section is the surface sand filter basin somewhat analogous to the slow sand filter used in drinking water treatment. A typical sand filter is found in Figure 3.

GENERAL DESIGN NOTES

1. DRAIN PIPE SHALL BE A MINIMUM OF 6" SDR 26 PVC. PIPE SHALL BE SLOTTED, NOT PERFORATED WITH A MINIMUM SLOT SPACING OF 0.75 INCHES AND A MINIMUM OF 50 SLOT SCREEN SIZE. HYDRAULIC REQUIREMENTS WILL DICTATE FINAL SCREEN DESIGN.
2. PEA GRAVEL SHALL CONFORM TO ASTM D1863, SIZE 67 OR 17A GRADATION STANDARD.
3. FILTER FABRIC SHALL BE USED TO SEPARATE THE MEDIA. TYPICALLY IT IS A NONWOVEN POLYPROPOLENE FABRIC WITH A MINIMUM PERMEABILITY OF 0.30 CM/SEC.
4. FILTER SAND LAYER SHALL BE MEDIUM TO FINE SAND 1.0mm TO 0.5mm IN SIZE.
5. COARSE SAND TOP LAYER SHALL BE 2.0mm TO 4.0mm IN SIZE.




BASIN PLAN
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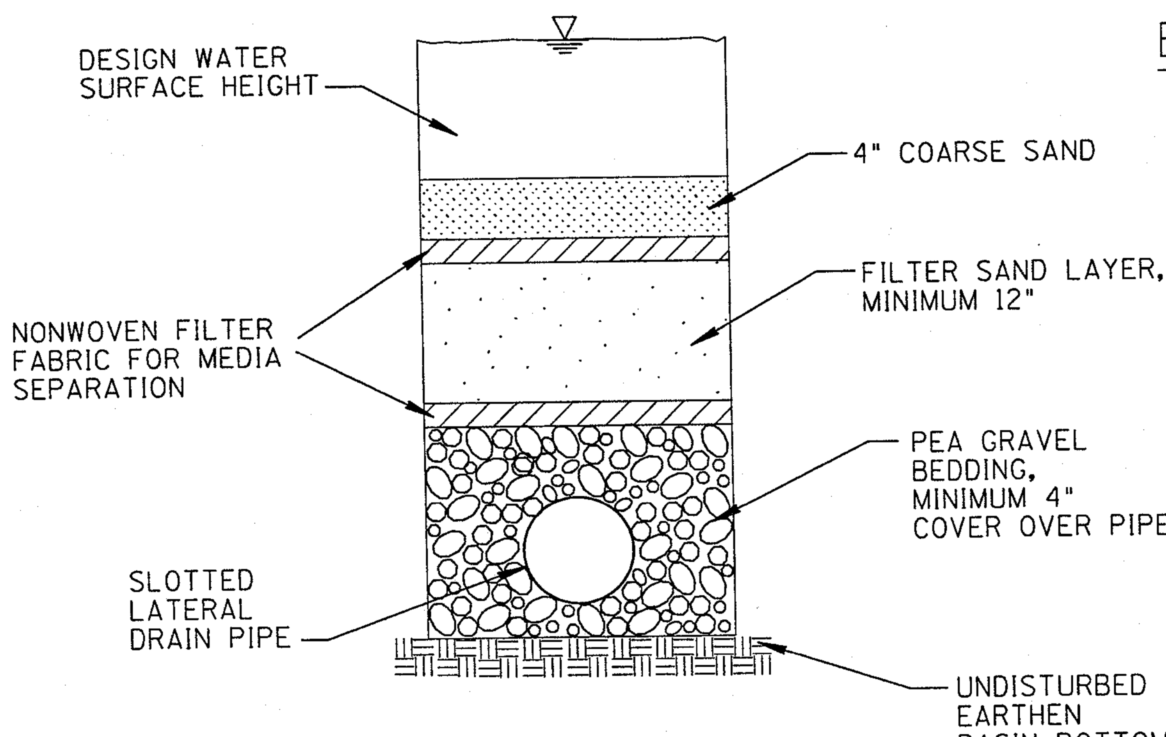


SECTION B-B
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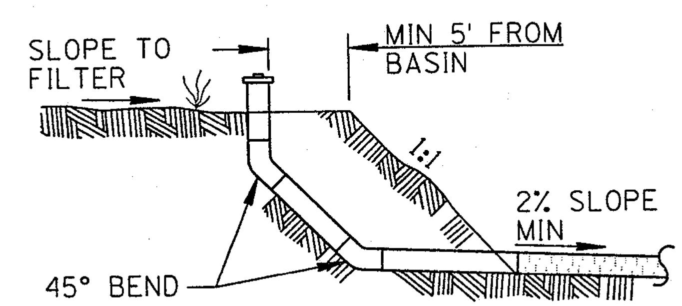


SECTION C-C
NTS

FIGURE 3

| Job Number: | Designed By: | Drawn By: | Title: |
|---|---|---|---|
| 54014 | MM | LLW | TYPICAL SAND FILTER AND UNDERDRAIN LAYOUT |
| Sheet Number: FIGURE 3 | Checked By: TB | Date: 04/97 | |

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### 3.3.4 Typical Design Parameters

The design parameters discussed below are for a deep bed, unstratified media, surface sand filter basin. Typical properties of this type of filter are as follows:

**Table 3-5 : Sand Filter Typical Design Parameters**

| Parameter | Value |
|---|---|
| Sand Depth | 36 to 72 inches |
| Effective Grain Size | 2 to 3 mm |
| Filtration rate | 2 to 5 gpm/ft$^2$ |
| Free Board Requirements | 3 to 6 feet |

Source: Ref. 14,18.

An appropriate under drain system requires other design considerations. The purpose of the underdrain system is to collect the treated stormwater and convey it to the point of discharge. It can also serve to keep the treated water from reaching the groundwater table. Appropriate hydraulic design methods should be applied to the system in determining the need for transfer sumps into or out of the sand filter.

### 3.3.5 Underdrain System

The underdrain system can be designed a variety of ways depending on the complexity of the stormwater collection requirements. Perforated drain tile should be laid in the trenches and covered with enough crushed rock to cover the pipe plus a foot of cover. The porous rock should be covered with permeable filter fabric to prevent the fine sand from clogging the underdrain system. All fabric filters used should be resistant to ultraviolet light. The top of the fine sand layer should also be covered with a permeable filter liner to catch fine silt and to aid in maintenance. Cleanouts installed on the underdrain pipes will allow for unclogging the buried drain tile should it become necessary.

### 3.3.6 Filter Run Time

After the sand filter has been in operation for sometime, it will eventually need to be cleaned. As the solids build up in the upper layer of the filter media, the head loss through the filter will increase. If the filter is not properly maintained, the head loss across the filter will become so great that the filter will fail to function. The filtration rate will drop substantially and more head will be required to force the water through the filter at a reasonable rate. Proper design of a stormwater sand filter includes estimating the amount of head loss the filter can sustain before it requires cleaning.

The type of filtration proposed for the stormwater sand filter is a variable head-constant rate design. This procedure involves having the filter process a constant flow of stormwater, but as the filter becomes clogged, the water level above the filter media builds up to force the stormwater through the filter at the same rate. Once the water level above the filter media reaches a certain point, the filter must be taken out of service and cleaned. The water level capacity above the filter media is controlled by the amount of freeboard in the filter basin design.

The level of water above the filter can be predicted by using one of the many mathematical models available. These models are similar to those used for groundwater flow. Table 3-6 contains a summary of formulas governing the flow of clean water through a granular medium.

## Table 3-6 : Clean Water Head Loss Equations

**Carmen-Kozeny:**

$$h = \frac{f}{\phi}\frac{1-\alpha}{\alpha^3}\frac{L}{d}\frac{v^2}{g}$$

$$f = 150\frac{1-\alpha}{N_r} + 1.75$$

$$N_r = \frac{\phi d v \rho}{\mu}$$

**Fair-Hatch:**

$$h = ckS^2\frac{(1-\alpha)^2}{\alpha^3}\frac{L}{d^2}\frac{v}{g}$$

**Rose:**

$$h = \frac{1.067}{\phi}C_d\frac{1}{\alpha^2}\frac{L}{d}\frac{v^2}{g}$$

$$C_d = \frac{24}{N_r} + \frac{3}{\sqrt{N_r}} + 0.34$$

**Hazen:**

$$h = \frac{1}{C}\frac{60}{1.8T+42}\frac{L}{d_{10}^2}v$$

**Variable Definitions:**

$h$ = headloss (L)
$f$ = friction factor (unitless)
$\alpha$ = porosity (unitless)
$\phi$ = shape factor (unitless)
$v$ = filtration velocity (L / T)
g = acceleration due to gravity ($L / T^2$)
$N_r$ = ReynoldsNumber
$\rho$ = density ($M / L^3$)
d = grain diameter (L)
c = filtration constant (unitless)
k = kinematic viscosity ($L^2 / T$)
$C_d$ = coefficient of drag (unitless)
C = coefficient of compactness (unitless)
T = temperature
$d_{10}$ = effective grain diameter (L)

Source: Refs. 14, 18.

### 3.3.7 Operation and Maintenance Requirements

Regular operation and maintenance is critical to the successful operation of a sand filter in order to achieve maximum removal rates. Since influent contaminant concentrations vary with the specific land uses of each watershed, it is difficult to set a regular schedule of O&M that will apply to every situation. As the sand filter is operated in each area, a regular schedule of maintenance should be developed.

The major component of maintenance for a sand filter is regular cleaning. The permeable filter fabric and the upper layer of sand should be removed and replaced when the infiltration rate across the filter becomes slow. Other maintenance activities include inspection of the underdrain system (and cleaning if necessary), and general site inspections to make sure everything will function properly during a storm event. Additional maintenance activities may be required and will be site specific.

## 3.4 Dry Pond Retention Basins

### 3.4.1 Process Overview

Dry pond retention basins temporarily store stormwater runoff for up to 36 hours (most jurisdictions) and gradually the stormwater percolates into the ground. The slow percolation of the stormwater removes sediment and silt from the stormwater and any other contaminants that are bound to the sediments. The basin is dry between storm events, i.e., it has no standing water. Typically, the primary function of these basins is to control stormwater flows during a storm event, treatment of the stormwater to lessen pollutants is a secondary function.

### 3.4.2 Contaminants Removed

The settling action that occurs in the dry pond retention basin during percolation periods is the main means of removing contaminants. Silts, suspended solids, and oil and grease concentrations can be reduced by this percolation action. The concentrations of metals that may be bound to the suspended solids material will also be reduced as a result of percolation and/or settling. Additional treatment means may include biological action that can occur in the sedimentary layer in the bottom of the basin. Also, basins with sodded surfaces will often provide a natural microbe population that may contribute to degradation of organics in the stormwater.

### 3.4.3 Typical Design Parameters

Each municipal jurisdiction has different design criteria for sizing retention/detention facilities. Maricopa County has summarized its design procedures in the Drainage Design Manual, Volume II, Hydraulics. For the purposes of this study, the design basis presented in Section 3.0 will be used in this discussion of dry retention basin design. While the design procedure is the same for each jurisdiction, the design storm parameters and detention volume regulations can vary significantly. Table 3-7 summarizes design criteria for the dry pond retention basin and Figure 4 shows typical details.

**Table 3-7 : Dry Pond Retention Basin Typical Design Parameters**

| | |
|---|---|
| Maximum Side Slope | 3:1 |
| Typical Ponding Depth | 3 feet |
| Inlet Protection | Riprap or Concrete Splash Pad |
| Side Slope Protection | Sod, Riprap, Geonetting |

Source: Adapted from Ref. 7.

### 3.4.4 Soil Percolation

The above criteria is based solely on retention requirements. However, the percolation rate in the soil below may be the controlling factor in design. A slow percolation rate may require the basin size to be larger than that necessary to retain all the stormwater. After the retention basin site has been determined, a percolation test should be performed to determine the soil percolation rate. The area of the basin necessary to retain the stormwater should be compared to the area required to drain the stormwater within 36 hours. Although the percolation rate is a function of the available head, the area required to drain the basin can be estimated from the following equation:

$$A_b = \frac{12}{P_r}\frac{D}{t}$$

Where:

$A_b$ = Area of Basin Bottom, $ft^2$

$P_r$ = Percolation Rate, $in / ft^2 \cdot hr$

D = Depth of Water in Basin, ft

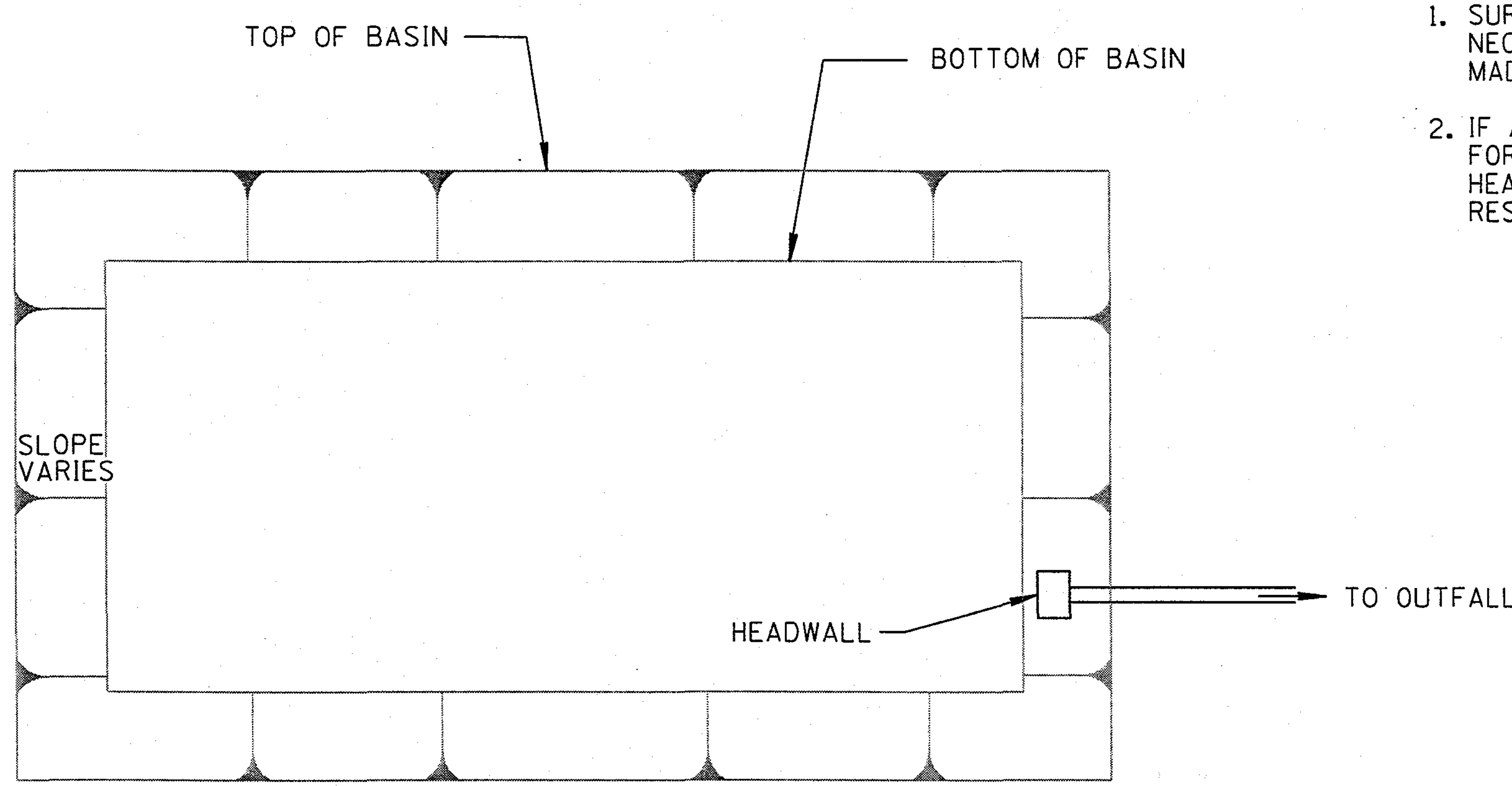
$t$ = Time for Basin to Drain, hr

### 3.4.5 Inlet Structures

An appropriate inlet structure for a dry pond retention basin will be necessary to convey runoff into the facility. The type of inlet will depend on the expected flow rate to the basin and the required basin geometry, but it's main function is to direct the inflow down a slope into the storage area. This inlet should be designed in such a way as to minimize erosion around the inlet. Also, an inlet that minimizes the velocity of incoming water will greatly enhance the safety of the basin. Control measures should be applied to inlet structures to insure that they do not become attractive for activities such as skateboarding or biking. Rough finished surfaces, fencing, and bump strips may deter such activities. All inlet piping should be covered with a bar rack small enough to prevent small animals and children from entering. Design guidelines for inlet structures can be found in Chapter 6 of the Drainage Design Manual for Maricopa County, Volume II, Hydraulics.

NOTES

1. SURFACE OF BASIN CAN BE SODDED IF NECESSARY, PROVISIONS SHOULD BE MADE FOR A SPRINKLER SYSTEM.
2. IF A RECREATIONAL USE IS PLANNED FOR THE FACILITY ACCESS TO THE HEADWALL STRUCTURE SHOULD BE RESTRICTED.

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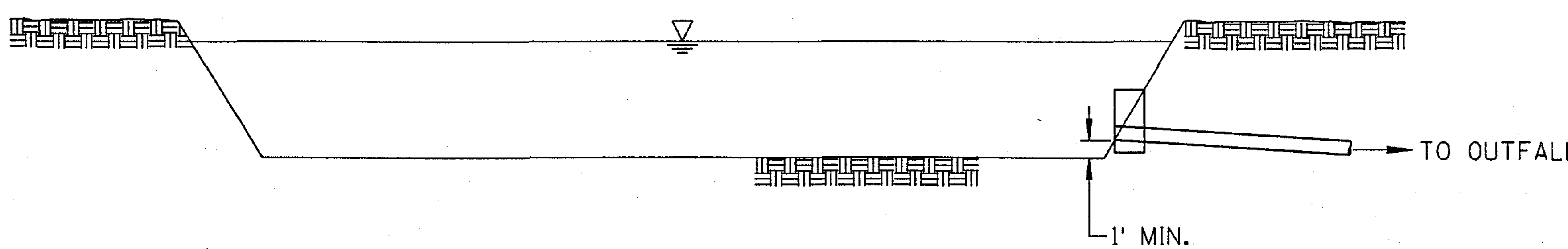


SECTION
NTS

FIGURE 4

| Job Number: | Designed By: | Drawn By: | Title: |
|---|---|---|---|
| 54014 | MM | LLW | TYPICAL DRY RETENTION/DETENTION SETTLING BASIN |
| Sheet Number: FIGURE 4 | Checked By: TB | Date: 04/97 | |


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### 3.4.6 Multi-Use Options

A large enough detention basin will have the ability to be developed for recreational or social uses. If funds are available for landscaping and development, the basins can be developed as parks or athletic fields. These multi-use options can bring added social benefits to a community, as well as public support for maintenance of the basins. Table 3-8 lists the dimensions necessary for possible athletic uses for a dry pond retention basin. The required dimensions presented are the necessary bottom dimension that must be available for each use.

**Table 3-8 : Multi-Use Options for Dry Pond Retention Basins**

| Multi-Use Option | Basin Bottom Dimensions (ft) / (acres) | Cost* |
|---|---|---|
| Football Field | 450 x 200 / 2.0 ac | $ 40,000 |
| Soccer Field | 350 x 225 / 1.8 ac | $ 35,000 |
| Softball Field | 350 x 350 / 2.8 ac | $ 50,000 |
| Basketball Court | 120 x 250 / 0.7 ac | $ 35,000 |
| Tennis Courts (2) | 150 x 150 / 0.5 ac | $ 40,000 |
| Racquetball Courts (6) | 100 x 100 / 0.3 ac | $ 30,000 |
| Park Area w/ Swings | 50 x 50 / 0.06 ac (min) | $ 5,000 |

*Costs include sod, sprinkler system, lighting (except fields), and fencing
Source: Adapted from Ref. 26.

### 3.4.7 Operation and Maintenance Requirement

The operation and maintenance requirements for a dry pond sedimentation basin will vary according to location, storm frequency, and any multi-use options that are selected for the basin. Access roads for maintenance vehicles should be kept in good condition. Sediment removal should be performed on a regular schedule depending upon the season of the year. All landscaping should be regularly mowed and fertilized. Weed growth should be controlled, however the extensive use of herbicides in this type of facility should be avoided. Any inlet structures, such as riprap or splash pads should be kept free of debris. Inlet pipes should be free of debris to prevent clogging. Any irrigation system in the basin should be regularly inspected for leakage and broken or misdirected sprinklers. All signage in the basin area should be kept in good repair and clear of graffiti.

## 3.5 Modified Dry Wells

### 3.5.1 Process Overview

Dry wells are a means of disposal for stormwater and provide a minimal level of filtration with their main function being disposal of stormwater into the subsurface soil. The filtration of the stormwater through the surrounding soil formation is the only means of enhancement. However, the modified dry well has a column filled with granular activated carbon (GAC) through which the water is filtered before disposal. Disposal of the groundwater occurs in the same way as a regular dry well, except that the GAC removes dissolved organic contaminants before it is injected into the ground. The treated water can be run through the dry well by gravity or it can be injected into the ground by pumping.

The GAC removes dissolved organic contaminants through the process of adsorption. Adsorption of the contaminants dissolved in the water occurs on the surface of the GAC and the contaminants are removed from the water stream. Since the GAC is a non-polar medium and water is a polar medium, the non-polar dissolved organics are more attracted to the GAC and come out of solution onto the GAC surface. The GAC surface is made up of many adsorption "sites" on which the dissolved organics accumulate. When these sites are full, the GAC is spent and must be replaced.

### 3.5.2 Contaminants Removed

The GAC will remove any dissolved organic contaminant provided there is enough residence time in the column. The residence time is the period when the water is in contact with the GAC. Adsorption is a selective process, with certain types of compounds being adsorbed preferentially over other types of compounds. Also, because of the physical filtration process, some sediments and fines will be removed taking anything that happens to be bound to them such as metals or other inorganics.

In Maricopa County, each jurisdiction has regulations on the construction of dry wells and some jurisdictions disallow them completely. The design parameters and guidelines presented here are from the FCDMC. It is suggested that the specific jurisdiction be contacted for specific guidelines of design and construction of the dry well. The GAC modification should be part of the proposal to that jurisdiction.

### 3.5.3 Typical Design Parameters

All the same parameters that apply to dry well design apply to the modified dry well design. The important difference is determining the required diameter and depth of the carbon column. The diameter of the carbon column is a function of the desired flow into the well, and the depth of carbon is a function of the level of contaminant removal required. Some contaminants, such as the heavier semi-volatiles, are not feasible for GAC treatment.

It is assumed that the dry well design parameters presented here are for the filtration and disposal of a first flush capture storm event. Even though the sediment load to the dry well will be reduced somewhat due to the settling action in the first flush basin, a settling chamber area is provided in the dry well. A telescoping valve is placed in the settling chamber that can be manually or automatically operated. This allows the heavier solids in the stormwater to settle at the bottom of the settling chamber while the clearer water at the top is drawn into the well.

There are many factors that make up the total water acceptance rate of a site. Basing hydraulic application rates for disposal based on soil classification alone is not good practice. Because the presence of fine soil particles, or silts, soil permeabilities can be highly variable. The best way to estimate the hydraulic acceptance capacity of a site is to install a test well. Figure 5 shows typical details.

### 3.5.4 Operation and Maintenance Requirements

Operation and maintenance on a modified dry well is similar to that of a non-modified dry well. In order for the well to function at an optimal level, the sediment must be removed regularly from the primary settling chamber. Removal of this sediment will vary according to the amount of runoff received by the well. An effective cleaning schedule will be flexible to follow a large rainfall event. The activated carbon section in the dry well should be changed at least twice yearly. If the modified dry well is receiving runoff from a known source of pollutants, the frequency of changing the activated carbon should be adjusted accordingly.

The sediment and activated carbon can be removed with a typical vacuum truck. There are many services that will send the truck out to change the carbon, supply the well with fresh carbon, and dispose of the old carbon. The truck will simply vacuum out the sediment in the primary settling chamber, open the cleanout, remove the screen, and vacuum out the activated carbon in the well column. New carbon will be added to the well and the screens and clean out cap replaced.

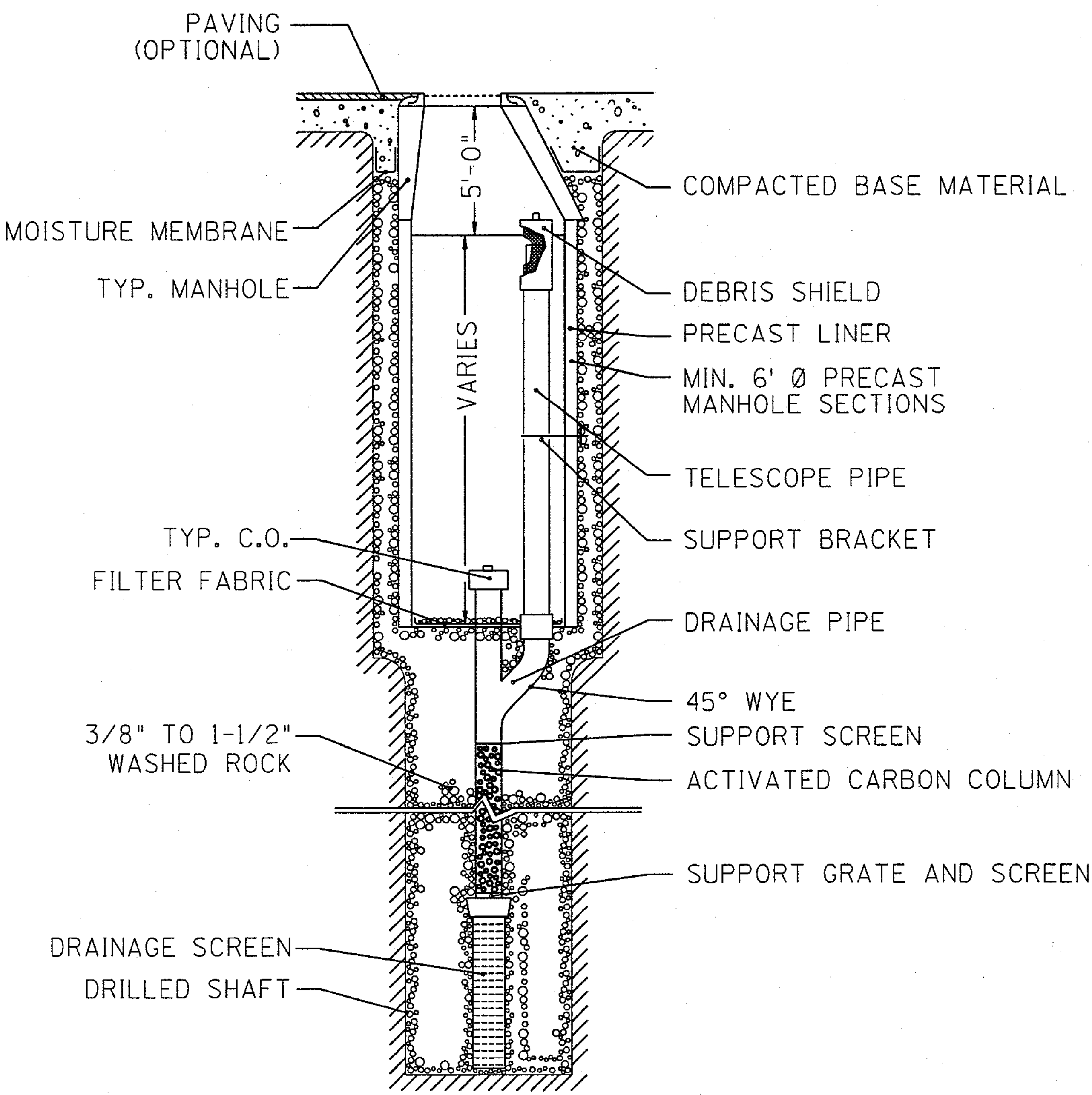


FIGURE 5

Title:

MODIFIED DRYWELL

| Job Number: | Designed By: | Drawn By: |
|---|---|---|
| 54014 | MM | PJO'C |
| **Sheet Number:** | **Checked By:** | **Date:** |
| FIGURE 6 | TB | 01/97 |

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## 3.6 Infiltration Trenches

### 3.6.1 Process Overview

Infiltration trenches, as compared to complex structural treatment schemes, are an inexpensive way to enhance the quality of collected stormwater. Infiltration trenches can be strategically placed to intercept stormwater runoff from specific areas. For example, they can be constructed surrounding a parking lot on the low sides to intercept runoff. The gravel in the trenches provides the filtration action that reduces pollutants in the stormwater. By placing a vegetated filter strip before the entrance to the trench, the filtration action can be enhanced; however, there are no certain removal performance data for the trenches.

Infiltration trenches are backfilled with pea gravel or stone to create an underground reservoir. Stormwater that is diverted to the trenches fills the trenches quickly and is filtered as it is discharged to a sloped drain tile or gradually seeps into the surrounding soil. Native soil conditions should have good percolation rates for the trenches to be effective. Pretreatment using grass filter strips can increase efficiency and reduce clogging. Trenches are prone to clogging if not properly maintained.

Infiltration trenches can be an inexpensive alternative for improving the quality of stormwater. Land requirements are less than that of dry ponds and trenches can be placed in multiple locations to divert stormwater flow. However, right-of-way requirements for the trenches are more dependent upon the physical features of the drainage basin and may offer less flexibility.

### 3.6.2 Contaminants Removed

Infiltration trenches are most efficient at removing suspended solids from water, but other contaminants can also be removed during the filtration process. Metals that are adsorbed to the suspended solids are removed, and fecal coliform bacteria concentrations can be reduced this way. Over the course of filtration, biological activity can develop in the sand media that may be effective at removing BOD and other organic contaminants. Infiltration trenches are not effective at removal of dissolved contaminants, such as dissolved metals or nitrates.

The removal efficiencies for a typical infiltration trench will vary depending on the frequency of the storm events and the influent concentrations of each contaminant. An infiltration trench can be designed to remove a higher percentage of suspended particulates by using a finer filtration media. Fine sand will provide removal efficiencies much in line with that of sand filters, and a coarser media, such as pea gravel, will only remove large debris and provide only moderate straining.

### 3.6.3 Typical Design Parameters

The major design parameters of infiltration trenches are a function of; the volume of flow to be intercepted per unit length of trench, the level of filtration desired, the anticipated concentrations of pollutants, the proximity to a drainage outfall, and existing soil conditions.

The top width of a trench is governed by the flow volume per unit length of trench and by the size of the filter media. The width is directly proportional to the flow volume and inversely proportional to the grain size of the trench filter media. The depth of the trench is governed by the level of filtration desired. The deeper the trench, the more filter media can be used. Also, finer filter media can be used to get a higher level of filtration providing there is enough hydraulic head to push the stormwater through it.

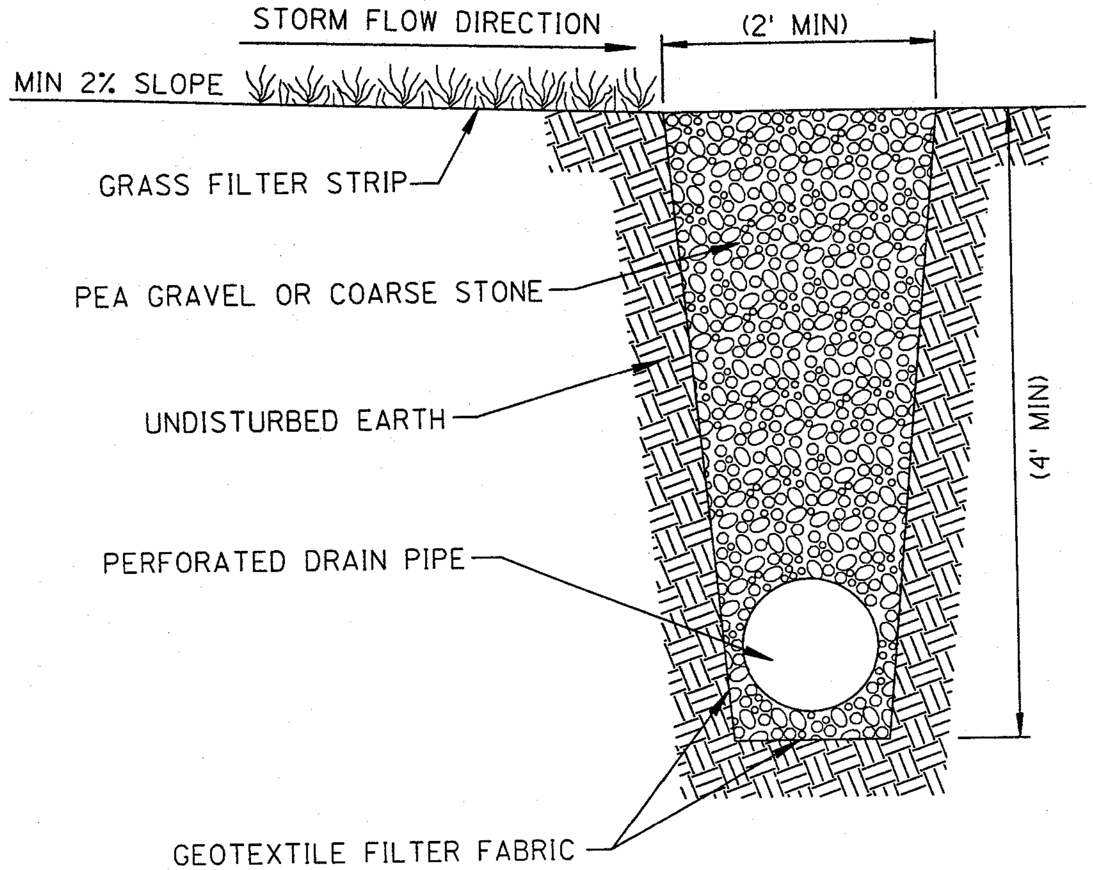
The primary application of this technique is along the perimeter of a developed site or structure. They can be placed in landscaped areas, in medians, or parking lot islands. They are not suitable, however, for intercepting and filtering large flows. Some typical design parameters for infiltration trenches are listed below:

**Table 3-9 : Infiltration Trench Typical Design Criteria**

| Parameter | Value |
|---|---|
| Grass Strip Width | 2 to 5 feet |
| Trench Top Width | 2 to 8 feet |
| Effective Grain Size of Media | 0.25 to 0.50 inch |
| Application Rate | 1 gpm/ft$^2$ |
| Trench Depth | 3 - 6 feet |

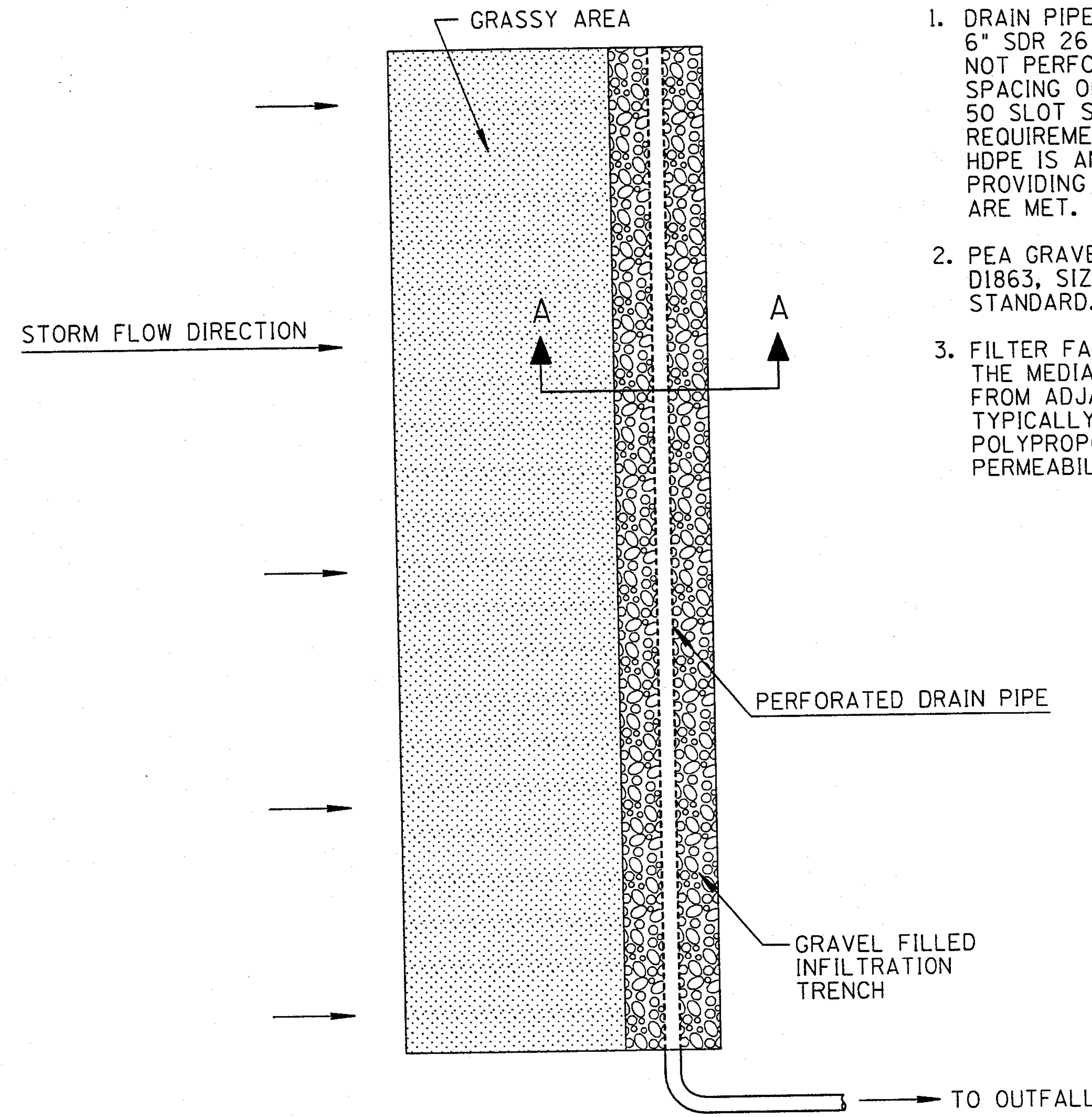
Source: Adapted from Refs. 5, 16.

Applying the standard design basis, as developed in Section 2.0, the length of trench required to serve 50 acres of drainage area is approximately 98 feet. This calculation does not take into account geographical conditions; however, it only assumes that the entire 50 acres drains into the top of a typical two foot wide trench. This calculation was made only to provide a means of comparison to other alternatives. In reality, each area drained to a trench will probably be smaller. Also, the perimeter of the trench may also have to be larger than is hydraulically required in order to capture all of the runoff. An analysis of the drainage subbasin for the area to be served by the trench must be made to determine proper placement of the trench. Typical design details are shown in Figure 6.




SECTION A-A

NTS




PLAN

NTS

GENERAL DESIGN NOTES

1. DRAIN PIPE SHALL BE A MINIMUM OF 6" SDR 26 PVC. PIPE SHALL BE SLOTTED, NOT PERFORATED WITH A MINIMUM SLOT SPACING OF 0.75 INCHES AND A MINIMUM OF 50 SLOT SCREEN SIZE. HYDRAULIC REQUIREMENTS WILL DICTATE FINAL DESIGN. HDPE IS AN ACCEPTABLE ALTERNATIVE PROVIDING ALL OTHER MINIMUM CRITERIA ARE MET.

2. PEA GRAVEL SHALL CONFORM TO ASTM, D1863, SIZE 67 OR 17A GRADATION STANDARD.

3. FILTER FABRIC SHALL BE USED TO PROTECT THE MEDIA FROM CLOGGING WITH SILT FROM ADJACENT UNDISTURBED EARTH, TYPICALLY IT IS A NONWOVEN POLYPROPOLENE FABRIC WITH A MINIMUM PERMEABILITY OF 0.30 CM/SEC.

FIGURE 6

| Job Number: 54014 | Designed By: MM | Drawn By: PJO'C | Title: INFILTRATION TRENCH TYPICAL DETAILS |
|---|---|---|---|
| Sheet Number: FIGURE 5 | Checked By: TB | Date: 04/97 | |

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**Figure 6 : Infiltration Trench Typical Details**

### 3.6.4 Operation and Maintenance Requirements

Operation and maintenance requirements for infiltration trenches are minimal, but critical to the smooth functioning of the trenches. If there is a vegetated filter strip laid out before the entrance to the trench, that vegetation must be watered and landscaped regularly. If allowed to wither and die, the filter strip could begin to contribute heavily to the sediment load of the trench. The top of the trench must be kept free and clear of debris. Regular visual inspections should be scheduled to ensure this. Also, depending on the quality of stormwater entering the trench, the gravel media should be replaced every 10 years.

## 3.7 Permitting Issues

### 3.7.1 Facility Operation Permit

The Arizona Administrative Code, Title 18, Environmental Quality, regulates treatment facilities. Specifically, the facilities regulated are for treatment of wastewater. Currently, there is no language in Title 18 that specifically addresses stormwater management facilities. If future stormwater management facilities are classified the same as wastewater treatment facilities under the current law, all of the processes discussed in this report will be subject to the same rules as wastewater treatment facilities. For example, a dry well does not need to have an aquifer protection permit, but if it is installed as a "treatment" process, modified with activated carbon, it will require an aquifer protection permit according to ADEQ even if the same quality runoff is being diverted to that well. Given the nature of stormwater, this may not be appropriate. Therefore, it is suggested that the FCDMC negotiate some amendments to Title 18 with the ADEQ to specifically separate municipal stormwater management from wastewater treatment. Currently, Aquifer Protection Permits are not required for "stormwater management facilities". This is a generalization that includes facilities designed to manage all stormwater, not the selected first flush storm that this report addresses.

Current regulations governing the APP process of dry wells entails first establishing the Applicability Permit with the ADEQ for the dry well. An example permit form and assistance pamphlets published by the ADEQ that aid in completing the Applicability Permit as well as the regular APP permit are found in Appendix F. This information includes a Best Management Practices Plan (BMPP) published by the ADEQ as guidance for dry well permitting and operation.

### 3.7.2 Construction Permit Requirements

Each municipality will have its own site specific requirements for construction of stormwater management facilities. Local agencies should be contacted for construction approval of the facility. If the facility will be located on or near any natural wetlands, or any other feature which the U.S. Army Corps of Engineers claims jurisdiction of, a Clean Water Act (CWA) Section 404 permit may be necessary. An Aquifer Protection Permit (APP) may be required depending on the characteristics of the drainage basin. Should the sand filter plant require an area of greater than 5 acres, a CWA section 402 permit will be required which includes the preparation of a pollution prevention plan that covers activities during construction. Also, if the location of the plant will affect any endangered plant or animal species, the Endangered Species Act may require a Habitat Conservation Plan. Compliance with Arizona Native Plant Law will be necessary. If any cultural resources are found on the site, the National Historical Preservation Act will set fourth requirements. Most of these permit requirements regulate the construction of the facility rather than the operation.

# 4. Process Comparison Summary

The following Table 4-1 summarize the costs of each treatment process discussed in this report. Table 4-2 presents a comparison of stormwater treatment efficiencies for each process with regard to different pollutants. Their purpose is to present decision making tools that provides an order of magnitude comparisons between processes. Supporting calculations can be found in Appendix B.

**Table 4-1 : Cost Comparison Summary**

| | Subsurface Flow Wetland | Sand Filtration | Dry Pond Retention Basin | Modified Dry Wells | Infiltration Trench |
|---|---|---|---|---|---|
| First Flush Retention Land Requirement | 0.9 Acres | 0.9 Acres | 0.9 Acres | 0.9 Acres | N/A |
| Treatment System Land Requirement | 3 Acres | 0.3 Acres | N/A | N/A | Varies[2] |
| Total Land Requirement | 3.9 Acres | 1.2 Acres | 0.9 Acres | 0.9 Acres | Varies[2] |
| Capital Costs[1] (per 50 acres served) | $420,000 | $200,000 | $56,000 | $106,000[4] | $15,600[3] |
| Operation and Maintenance Cost | $150,000 | $75,000 | $5,000 | $9,000 | $5,000 |

[1]Capital costs above do not include the cost of land. Note that the Total Land Requirement in Table 4-1 above is the sum of the 90% storm retention requirement and the treatment system land requirement. All costs are based on facilities designed to treat the stormwater from the 90% storm within 48 hours. The 90% storm design basis is defined in Section 2.0.

[2]Land Requirements for this Process are not significant and are impossible to determine generally. However, right-of-ways or minimal strips of land must be purchased.
[3]Assumes 195 feet of trench at $80/ft.
[4]Assumes 2 wells, each 100 feet deep with 20 ft. deep settling chambers.

**Table 4-2 : Treatment Efficiency Comparison Summary**

| | Subsurface Flow Wetland | Sand Filtration | Dry Pond Retention Basin | Modified Dry Wells | Infiltration Trench |
|---|---|---|---|---|---|
| BOD5 | H | H | M | M | L |
| Fecal Coliform | H | M | M | M | L |
| Suspended Solids | H | H | M | M | M |
| Nutrients | H | M | M | M | L |
| Silt | M | H | M | M | L |
| Dissolved Solids | H | M | L | L | NR |
| Organic Compounds | H | L | M | H | L |
| Chlorinated Organic Compounds | M | L | L | H | NR |
| Oil and Grease | H | H | M | M | M |
| Total Metals | H | M | M | M | L |
| Dissolved Metals | M | NR | NR | L | NR |

Ranking Key:
H: 70% to 100% removal expected
M: 40% to 70% removal expected
L : up to 40% removal expected
NR: No removal expected

The prediction of removal rates is not an exact science; however, knowledge of the treatment process in other situation can be used to predict future results. Removal rates expressed in percent can be misleading if not applied properly. For example, BOD that is reduced from 10,000 mg/l to 500 mg/l represents a 95% removal where BOD that is reduced from 50 mg/l to 20 mg/l only represents 60% removal. Percentage types of removal rates are only significant when judging the potential effectiveness of a process and cannot provide any predictions for specific effluent concentrations unless some assumptions are made about influent conditions. The above ranks were assigned to each process based on expected influent conditions outlined in the design basis in Section 2.0.

# Appendix A

## Discussion of Available BMP's

# APPENDIX A. DISCUSSION OF AVAILABLE BMP'S


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# A. Discussion of Available BMP's

## A.1. General

This chapter presents an overview of available Best Management Practices (BMP's) found in the literature search. Some of the BMP's presented here were presented as narratives to FCDMC. The purpose to this literature survey is to examine many available stormwater treatment alternatives. Each BMP discussion is divided into three headings; description, pollutants reduced, costs. At the end of each section, there are tables comparing each alternative side by side in terms of cost and efficiency.

### A.1.1. Best Management Practices Overview

BMP's are structural and non-structural measures used to control and improve the quality of stormwater runoff to receiving waters. Non-structural BMP's are geared toward source prevention through government policies, ordinances, and programs. Non-structural source controls include street sweeping, maintenance of existing stormwater facilities, public education programs, and littering ordinances. Structural BMP's consist of building or constructing some type of treatment facility or structure to enhance treatment of stormwater. Minor structural controls are low-cost controls designed for source reduction and treatment; especially of sediments, particulates, and litter. These controls include exfiltration trenches, infiltration trenches, porous pavement, and grassed swales. Major structural controls are designed for physical, biological, and/or chemical treatment of large stormwater flows after leaving the pollution source. Major structural controls include detention ponds, retention ponds, and chemical treatment systems.

## A.1.2. Cost Basis

The construction, operating, and maintenance costs in this report, unless otherwise noted, are based on a study sponsored by the American Public Works Association, entitled "A Study of Nationwide Costs to Implement Municipal Stormwater Best Management Practices", released in May 1992. This study surveyed municipalities, consultants, and contractors to identify appropriate BMP's and their associated costs for each of nine geographic areas (rainfall zones). These costs have been adjusted for the Phoenix, Arizona metropolitan area using similar methodologies (published historical and city cost indices). Construction and O&M costs are presented as unit costs to assist in planning and evaluation. It is important to note that they do not include land acquisition, engineering, administration, contingencies, or permitting. These costs could increase the total cost by 30 to 50 percent.

In general, non-structural BMP's have lower pollutant removal efficiencies than structural BMP's. Likewise, capital, operation and maintenance costs increase as the degree of treatment increases. There are a wide range of BMP's available for selection. The type of BMP applicable to a situation will depend on the application. Treatment efficiency and total life-cycle cost will vary with BMP type and site selection.

## A.2.Non-Structural Best Management Practices

### A.2.1. Litter Control Ordinances and Programs

**Descripition**

Litter-free areas encourage users of the land to maintain a clean and aesthetically pleasing environment. Elements of a complete litter control program include:

- Comprehensive garbage collection program
- Recyclable resource recovery system
- Ordinances covering collection and disposal of garbage, recyclables, and yard wastes
- Laws that prohibit littering and impose rigid fines on violators
- Enforcement to ensure compliance

**Pollutants Reduced**

Litter is the visible trash commonly found along roadways. A large majority of litter is biodegradable and as such will impose an oxygen demand if it decomposes in water. Oxygen demanding substances consume the available oxygen in water and can cause fish kills and algae blooms in lakes and streams. Litter also acts as a means of conveyance for other pollutants such as metals, fertilizers, pesticides, oils, and grease.

**Costs**

Capital cost is $20 per trash receptacle to increase the number of trash receptacles in the community. O&M cost is $16 per acre per year. Capital cost is $20,000 for staff time to adopt and publicize litter control ordinances. O&M cost is $30,000 per year for materials and 20 man-hours/week of labor. Fines may recover some or all of the O&M costs associated with monitoring, continued marketing, and enforcement.

### A.2.2.Chemical Use and Storage Ordinances

**Description**

Chemical use and storage ordinances can control pollutant discharges by presenting industrial users with incintives to control their own discharges. Fines and other disincentives may provide some funding, however the goal is to get them to reduce the potiontial of careless spills that could lead to contaminated stormwater runoff. These types of ordinances can be specific to the type of industry in the area, and development involves planning that will ensure the maximum impact of the ordinaces.

**Pollutants Reduced**

The use, storage, and disposal of pesticides, herbicides, fertilizers, petroleum distillates, and other household and industrial chemicals have a definite impact on the quality of stormwater runoff. Nutrients and oxygen demanding substances can be just as toxic to fish and wildlife as harmful chemicals and hazardous wastes.

**Costs**

Capital cost is $20,000 for staff time to adopt and publicize ordinances. O&M cost is $30,000 per year for materials and 20 man-hours/week of labor. Fines may recover some or all of the O&M costs associated with monitoring and enforcement.

## A.2.3. Illicit Discharge Elimination Program

### Description

Urban runoff can be impacted significantly by illicit storm drain connections and illegal dumping. Elimination of these pollution sources through water quality screening, storm sewer system monitoring, and ordinance adoption and enforcement will result in improvement of stormwater discharge quality.

### Pollutants Reduced

The pollutants removed or reduced with this type of program will vary with the type of illicit discharge activity. Often, large amounts of oil and other wastes are improperly discarded within storm and conveyances

### Costs

Capital cost is $5 per acre served for program start-up, including staff time to adopt and publicize ordinances, and for purchase of monitoring equipment. O&M cost is $50 per acre served per year for TV inspection of storm sewers, assuming one monitor for every square mile and inspection of each pipeline once every four years. Fines may recover some or all of the O&M costs associated with ordinance monitoring and enforcement.

## A.2.4. Facility Inspection and Enforcement

### Description

Review of a facility for proper stormwater management (or proper application of the stormwater pollution prevention plan) is a key element of any stormwater management program. The inspection program will identify the level of awareness that a given facility has regarding the potential impact its activities and materials have on the quality of stormwater discharging from the site. This component is the most important element of public education relative to business and industry. Follow-up compliance checks and enforcement, when needed, are very important to making facilities aware of the concerns relative to all discharging entities within the catchment area.

**Pollutants Reduced**

The type of pollutants reduced with this type of program will vary according to the type of industry.

**Costs**

Capital costs include staff time that may be incurred for additional data collection, analysis, and reporting. Capital cost is approximately $20,000 for staff time to adopt and publicize ordinances. O&M cost is $30,000 per year for materials and 20 man-hours/week of labor.

## A.2.5. Public Education

**Description**

Education programs can serve many different purposes and many different groups. Educating the public about the origins of stormwater and stormwater runoff leads to an understanding of its potential effects on the environment. Understanding leads to awareness of stormwater issues that affect cities and their surroundings. Awareness gains citizen support for current and future stormwater management programs. Public education has the greatest bearing on the ability of non-structural control measures to reduce stormwater pollution. This component directly impacts all other aspects of any pollution control program.

Education programs suited to the regulated community (developers, contractors, inspectors, etc.) should focus on an understanding of stormwater regulations in order to increase compliance and efficiency in the permitting process. Workshops and seminars can be conducted in association with professional groups and incorporated into their meetings and conferences.

For the general public, an understanding of the need for, and the logic behind, stormwater regulations, programs, and projects is necessary for continued cooperation and future support. Each citizen needs to know how their everyday activities contribute the their stormwater problems, and how he/she can be a part of the solution. The collective benefit of many individual contributions must be emphasized.

**Pollantants Reduced**

Pollantants Reduced will vary according to the type of public education program. Increased awareness in the residential section will help reduce careless disposal of toxic household chemicals, such a cleaners and degreasers, that can contribute to stormwater pollution. Public education can also affect workers the

**Costs**

Capital cost is $200,000 for staff and consultants time to prepare a marketing plan which includes news releases, public service announcements, school programs, billing inserts, and education pamphlets. O&M cost is $260,000 per year for continued operation and monitoring.

### A.2.6.Increased Street Sweeping

**Description**

Increased street sweeping is a reasonably effective way to reduce the amount of particlates in stormwater runofff by keeping them clear of the street. The removal efficiency of this method is a function of sweeping frequency, number of passes, sediment gradation and accumulation, pollutant characterization, pavement conditions, and type of sweeper used. Overall particle removal efficiency is considered to be 50%, which is comprised primarily of larger sized particles. However, a large percentage of the pollutants are attached to the smaller particles, thus lowering the total pollutant removal efficiency of the process.

**Pollutants Reduced**

Streets are collectors of a wide variety of pollutants including garbage, oil, grease, heavy metals, urban wastes, fertilizers, pesticides, and other constituents, which may be reduced with increased street sweeping.

**Costs**

This BMP only increases the level of existing maintenance and the capital cost is zero. O&M cost is $ 0.83 per acre per year, assuming 0.04 curb miles per acre.

## A.2.7.Increased Storm Drain System Maintenance

**Description**

Storm sewer maintenance includes monitoring, cleaning, and repair of pipes and pump systems. Early identification of problems can prevent costly repairs at a later time. Removal of sewer solids and growths can reduce pollutant loads in both storm sewer and combined sewer systems. Decomposition by-products can deteriorate concrete and metal pipes, causing cracks and ruptures. Pipe failure and subsequent storm sewer system failure, can cause overflows of water and pollutants, and can contaminate groundwater supplies.

**Pollutants Reduced**

Increased mantainence of stormwater sewers can reduce the overall pollutant discharge load by providing a clear conveyance of strom water to the point of treatment or discharge.

**Costs**

This BMP only increases the level of existing maintenance; therefore the capital cost is zero. O&M cost is about $20 per acre served depending on the condition of the existing system.

## A.2.8. Traffic Flow Regulation

**Description**

The deposition of pollutants on the roadways is inversely related to the average travel speed of vehicular traffic. It has been demonstrated that slow moving traffic deposits more pollution than does faster moving traffic. Additional incentives for efficient traffic flow include energy resource preservation, cleaner air, and subsequently cleaner rainfall and runoff.

**Pollutants Reduced**

Better traffic flow may reduce the amount of grease and oil deposited on the roadways and therefore lessen the load in the stormwater runoff.

**Costs**

Capital and O&M costs are assumed to be assignable to existing agencies and departments. However, staff time may be incurred for additional data collection, analysis, and reporting.

## A.2.9.Design of a Non-Structural Program

The EPA has set forth some guidlines for implementation of a non-structural BMP program. In general, the program shall follow good engineering practices. The program shall be documented in narrative form, including explainations of how the program is to be implemented, what pollutants are targeted for reduction, and how the targeted pollutants will be reduced. The narrative form of the BMP program should be clearlyl described, and submitted with the NPDES permit application for review. Once approved, the narrative becomes a guide for maintaining the program.

Table 1.

Estimated Pollutant Reduction Efficiency For Selected Non-Structural BMP's

| Stormwater BMP | Susp. Solids | Nutrients | O2 Demand |
|---|---|---|---|
| Street Sweeping | M | L | L |
| Litter Control Laws | L - M | L - M | M |
| Public Education | L - M | L - M | L - M |
| Traffic Flow Regulation | L | L | L |
| Poisons and Fertilizers Use | L | H | M |
| Facility Inspection & | H | M | M |
| Improved Maintenance | M | M | M |
| Removal of Illicit Connections | M - H | M - H | M - H |
| Recycling Program | L | L | L |

L - low M - moderate H - high

# A.3. Minor Structural Best Management Practices

## A.3.1. Overview

Minor structural controls are more direct measures of treatment than non-structural controls. Their use is usually site specific in the sense that they must be placed in strategic locations to intercept runoff. Minor structural controls usually consist of treatment measures that do not directly treat a specific collected volume of stormwater, but that reduce the contaminant load in the runoff by intercepting the stormwater during a storm event usually by applying some sort of filtration process to it. Also, they can be combined with major structural controls to provide an additional level of treatment.

By siting a minor structural control near the outlet of a known stormwater runoff pollutant generator, such as a parking lot or an industrial site, the overall pollutant load at the discharge location can be lessened. Minor structural controls are less costly than major treatment facilities. They do require regular maintenance to function effectively, but the cost is minimal.

## A.3.2.Swales and Channels

**Description**

A swale is a shallow ditch system with relatively flat slopes and low velocities (< 2-4 fps). They are usually vegetated to provide additional attenuation and treatment. Grassed swales are often used in conjunction with other BMP's as a means of pre-treatment and stormwater conveyance. Channels are larger in size and flow capacity (5-8 fps), are further stabilized with riprap and/or gabions, and are designed primarily for flood control conveyance, with some storage benefit.

Other characteristics of grassed swales are as follows:

- Most efficient for flat slopes, wide bottoms, and permeable soils
- Velocities should be < 2-4 feet per second
- Requires minimal land area
- Allows deposition and subsequent binding of pollutants to sediments and surface soils (as opposed to curb and gutter entrapment)
- Retrofit options are limited due to water quantity capacity

**Pollutants Reduced**

Grassed swale systems have moderate success at removing particulate and trace metals. Additional treatment can be provided by swale blocks (small, mid-channel berms), to improve the removal efficiency of soluble pollutants.

**Costs**

Capital cost for excavation, not including seeding/sodding, is $200 per acre served. O&M costs, not including summer irrigation, are $12 per acre served per year. Capital cost for riprap and gabions is $40 per cu. yd. and $4-$10 per sq. ft., respectively. Existing inspection techniques and frequency reduce O&M cost to zero.

## A.3.3. Improve and Maintain Existing Swales and Channels

### Description

Vegetation of existing swales and channels can provide sideslope stabilization and erosion control as well as the pollutant removal benefits obtained from vegetated filter strips. Riprap, gabions, and other structural materials can provide stabilization and erosion protection for sideslopes and pipe/channel outlets. Gravel filter berms can filter stormwater flow while reducing velocity. Fencing can prevent windblown trash and illegal dumping from clogging and polluting open channels. Sediment and debris removal can improve capacity, aesthetics, and wildlife habitat.

### Pollutants Removed

Adding vegitation can remove a low to moderate amound to sediment in storm water runoff. The filtering action can also remove some floatables as well.

### Costs

Capital cost for vegetative establishment is $2,500 per acre served. O&M cost is $250 per acre served per year. Capital cost for riprap gabions is $40 per cubic yard and $4 to $10 per square foot, respectively. Existing inspection techniques and frequency eliminates additional O&M costs. Capital cost for fence material and construction is $7 per linear foot. No maintenance is require for this option. Capital cost for sediment and debris removal equipment is $4,000 per acre served. O&M costs are $3 per acre served per year.

### A.3.4. Vegetated Filter Strips

**Description**

Vegetated filter strips are typically located adjacent to streets and highways. This pollutant removal technique is used to reduce runoff velocity and promote infiltration. Runoff is encouraged to spread out in a wide sheet flow pattern onto adjacent vegetated land or into a vegetated swale, ditch, or pipe conveyance. Additional characteristics of filter strips are as follows:

- Use of this method is limited by slope, soil characteristics, water table depth, type of vegetation, and runoff flow characteristics.
- Use and retrofit in urban settings is limited due to land and traffic constraints.
- Selected vegetation should be drought tolerant, effective against erosion, compatible with soils, durable, and relatively easy to maintain.
- Generally 150 - 250 feet of overland flow length (minimum of 50 feet) is necessary for adequate treatment of stormwater, depending on site-specific characteristics.
- Maintenance is generally low to moderate. Increased maintenance may be required after large storm events to repair erosion scours.

**Pollutants Removed**

Filter strips have moderate to high removal rates of pollutants through sedimentation, vegetative filtering, biological assimilation, and infiltration mechanisms

**Costs**

Capital cost is $2,500 per acre served for grading and vegetative establishment. O&M cost is $250 per acre served per year. Irrigation, which may be required in arid regions, will increase capital and O&M costs.

## A.3.5.Water Quality Inlets (Oil/Water, Oil/Grit, Sediment/Grease Separators)

### Description

A water quality inlet is a three-stage underground concrete retention system designed to remove sediments and oils from stormwater. Sediments sink to the bottom while hydrocarbons float to the top of the treatment chamber. Use is limited to small areas (< 2 acres) with high pollutant loads, large areas (< 20 acres) as part of the treatment train, and for potential spill areas. Other characteristics of the water quality inlet are as follows:

- In-line treatment of storm sewer flows
- Use normally limited to smaller sites such as parking lots and gas stations (< 2 acres)
- Moderate maintenance required to maintain performance
- Oil and sediments must be disposed of properly
- Re-suspension of pollutants during larger storm events is possible
- Retrofit capability is generally limited to replacement of existing manholes

### Pollutants Removed

Moderate removal of oils and sediments is expected with water quality inlets. Total metals may also be reduced as a secondary effect of reducing sediment.

### Costs

Capital cost ranges from $2,000 to $3,000 per acre served. O&M cost is $2,000 per acre served per year. These costs assume installation of one unit for every five acres served.

## A.3.6.Underground Storage

### Description

Where land is unavailable for storage and/or treatment, underground basins allow the land above, as well as the collected stormwater runoff, to be reclaimed to be reclaimed for economic or aesthetic uses. Stormwater runoff may be routed to either on-site of off-site storage areas, with the additional benefit of protecting collected water from evaporation, contamination and disease-carrying vectors.

Examples include large diameter (96") pipe under Arizona's Price and Santan freeways for underground routing and storage of collected stormwater. Direct recharge into the many underground caverns that exist in the southwest and construction of gravel wells under parking lots and sand-covered playgrounds are excellent options for natural and man-made underground storage. Design considerations for underground basins include:

- Locate basins away from building foundations, leaching fields, and steep cut or fill
- Avoid passing raw stormwater through porous pavement or sand mulch unless sediment pretreatment is used
- Use drainage inlets with perforated walls to direct water down and into the basin
- Use open-graded storm wrapped in filter fabricate maximize void space, maintain strength and stability, and prevent sedimentation
- Slope the basin floor downward toward the inlet bottom for stormwater reclamation and sediment removal access.

**Pollutants Removed**

Temporary storage of storm water runoff can reduce the sediments. If a skimmer is applied before the water is stored, floatables, such as oil and grease, can be reduced.

**Costs**

Capital costs will vary greatly with the size of facility. If an underground storage area can be combined with another project, capital costs could be lessened. Maintainence costs include periodic inspection and sediment removal.

## A.3.7. Artificial Ponds and Waterfalls

**Description**

Artificial ponds and waterfalls in urban areas provide the function of stormwater management and the aesthetics of aquatic landscaping. When incorporated into the building's landscape plan or as part of the physical plant, ponds and waterfalls are used to store and convey water to on-site areas of later use.

As an example, the Greenwood Plaza office park near Denver, Colorado captures stormwater runoff and excess landscape irrigation several small ponds prominently located at read intersections and building facades. Landscaping is designed to tolerate fluctuations in water level through the use of rocks, flat slopes, and drought-tolerant plants at the pond's edges. Pumps, spillways, and irrigation pipes convey water it where it's needed for storage and/or irrigation.

Other benefits include water's on the mind and body. The sight and sound of water had calming and soothing effects on the psyche. Evaporation has s cooling and humidifying effect on the surrounding environment as will. Parks, recreation facilities, and other public use areas are enhanced by large or small bodies or water. These benefits are especially important when air, noise and thermal pollution take their toll on a city's inhabitants.

Rooftop and parking lot storage of stormwater is a variation of cistern storage that, like artificial ponds and waterfalls, is specific to and part of the building or structure. Suitable for existing or new construction, storage of stormwater in highly impervious areas reduces or eliminated the associated large stormwater flows and pollutant loads. When needed, water is conveyed by gravity, reducing equipment and energy requirements. The stored water can be used to irrigate surrounding pervious areas or to supplement water requirements where water quality is not a concern.

### A.3.8. Water Reuse

A technologically and economically feasible method for supplementing the water supply is the reuse of stormwater. Water reuse techniques range form policy and program initiatives to construction of advanced wastewater treatment plants for wastewater reclamation. The wastewater industry has developed numerous techniques for treating wastewater effluent for safe, reliable, and economical reuse. The paper, textile, chemical, electronics, and mining industries have also done much toward water reuse. Much of the research and application of water/wastewater reclamation can be applied to stormwater relaxation as well. Depending on the degree of treatment, reclaimed waters can e used for landscape irrigation, crop irrigation, industrial cooling and boiler feed and recreational ponds and lakes. Reused water can supplement or replace current water supplies and can be further recycled if necessary. Afterwards, indirect and/or natural recharge or surface and ground waters can return reclaimed waters to the portable water supply.

Public health and economics are the primary factors in the design, development, and operation of water reuse projects. Local, state, and federal regulations must be met. Treatment and distribution facilities must be constructed or expanded. These are obstacles which wastewater reclamation projects must overcome, but are much less of an issue with stormwater reuse as treatment requirement and flows are usually lower for stormwater than for wastewater reuse. In either case, the construction of water reclamation facilities can be justified through consideration of the following:

- Reclaimed water quality and quantity
- Current and future water quality and quantity supply
- Current and future water quality and quantity demand
- Collection, treatment, storage, and distribution costs
- Expected benefit and/or projected revenue

Landscape and small-scale crop irrigation puts reclaimed stormwater to use. Many techniques for water harvesting and reuse have been developed, most notable in Arizona and Colorado, where demand exceeds supply for irrigation water. During the summer months,. Landscape irrigation can account of up to 85 percent of portable water use. Public and private stormwater reclamation projects have provided irrigation for lawns, gardens, shrubs and fruit and shade trees. Even projects that reclaim stormwater for irrigation may also reclaim the irrigation runoff for direct use.

Runoff with higher pollutant loading, or runoff to be used for irrigation of edible vegetation may require chemical and biological pre-treatment. On the other hand, stormwater runoff that is high in nutrients such as nitrogen and phosphorus may be more desirable. Of greatest concerns is the transmission of pathogens to food crops, especially near harvest time.

In industrial operations, chemical quality is often the controlling criteria while bacteriological quality might not warrant consideration. Physical treatment may also be required to remove the potentially large sediment load found in stormwater runoff. However, even wastewater treatment plant effluent can be used successfully for general plant application, cooling water, and for boiler feedwater if properly treated. Cooling and boiler feedwater accounts for almost fifty percent of all industrial water use. Stormwater runoff can at least provide make-up water for these and other industrial operations.

Adoption of water politics and programs can encourage water reuse by domestic, agricultural, and industrial consumers. These could include reduced water and sewer rates for reclaimed water, pollution credits for internal water reuse, to be used to offset costs and treatment requirements for other consumptive uses and discharges, financial assistance for water reuse projects, ordinances discouraging stormwater discharge without reuse, and public education initiatives to elicit and maintain community support. Water reuse policies and programs should incorporate rate stormwater management, harvesting, and reuse into current state and local water laws and regulations.

# A.4. Major Structural Controls

## A.4.1. Overview

Major structural controls include stormwater detention, stormwater retention, filtration, and chemical/biological treatment. These facilities, if properly installed and maintained, will provide additional aesthetic and functional value beyond efficient pollutant removal. One major disadvantage of major structural controls is the cost and difficulty of property or right-of-way acquisition, especially in developed areas.

Detention ponds are designed to detain stormwater so pollutants can settle out into the pond. Retention ponds are designed to retain stormwater and allow it to percolate into the soil. Stormwater ponds have good particulate and moderate soluble pollutant removal capabilities. In addition, biological action will remove nutrients and oxygen demanding substances. Pollutant removal efficiency is contingent upon soil infiltration rate, depth to water table, treatment volume available per unit of watershed area, and level of maintenance. The decision on the type of stormwater pond to use is often dictated by site conditions.

Filtration systems use excavated areas backfilled with a filter media to strain out pollutants and pollutant-laden particulates The filter media can be gravel, sand, filter fabric, or a combination. Filtration systems provide discharge attenuation and temporary storage of runoff, while improving stormwater runoff quality.

Chemical treatment includes chlorination for microorganism removal and alum or lime injection for solids and soluble metals removal. Although very expensive, these methods are highly effective and versatile in retrofit applications.

## A.4.2.Dry Infiltration Basins

### Description

Where land is available for a sufficiently large open basin and secondary use of the basin area can be made, dry infiltration basins can have a dual benefit. For example, football or soccer fields in low-drying area can retain stormwater for flood and pollution control, as will as for turf irrigation. Beams and depression areas, collectively landscape into small rolling hills, can also have dual functional and aesthetic benefits.

To maintain the dry conditions required, a design methodology and equations have been recently developed. Some considerations for dry basin design include:

- All inflows and outflows should be designed using only the basin floor area and should not include infiltration along the sideslopes.
- The infiltration rate is that of the most limiting soil horizon beneath the basin floor.
- For unvegetated basins, use a factor of safety of 0.5 for infiltration rate.
- To protect vegetated basins form flooding, use a factor of safely of 0.05 to 0.25 for infiltration rate, depending on basin floor slope and depth to the most limiting soil.

### Pollutants Removed

Dry basins are best at removing sediments in the storm water. Total metals may also be reduced as a secondary effect of reducing sediment.

### Costs

Capital cost is $100,000 per million gallons of stormwater stored. Capital cost covers basin excavation, control structure installation, and landscaping. Some installations may require an impermeable flexible membrane liner at additional cost. O&M cost is $1,000 per million gallons of stormwater stored per year. O&M cost covers landscape maintenance and sediment removal.

### A.4.3.Extended (Dry) Detention Pond

**Description**

A dry detention pond temporarily detains stormwater runoff for at least 24 hours after a storm, thus allowing sediments to settle out. Discharge from the pond occurs gradually through a fixed opening, thereby reducing the risk of localized flooding. The pond is dry between storm events and has no permanent standing water.

Other characteristics of this technique include:

- Contributing watershed area should be > 10 acres
- Not appropriate for high visibility areas unless frequently maintained
- Water table should be > 2 feet below pond bottom
- Space requirements limit use in urban areas
- Re-suspension of previously deposited pollutants can occur
- Minimum detention time is six to twelve hours
- Clogging of drawdown device is common
- Works most efficiently with smaller treatment volumes
- Provides very little wildlife habitat value

- Pollutant removal efficiency highly dependent on design treatment volume, pond configuration, and maintenance frequency
- Often used as a retrofit option such as for dry stormwater ponds or at drainage conveyance confluences

**Pollutants Removed**

Dry detention provides a moderate but variable removal of particulate pollutants. It does not remove soluble pollutants.

**Costs**

Capital cost is $100,000 per million gallons of stormwater stored. Capital cost covers basin excavation, control structure installation, and landscaping. Some installations may require an impermeable flexible membrane liner at additional cost. O&M cost is $1,000 per million gallons of stormwater stored per year. O&M cost covers landscape maintenance and sediment removal.

### A.4.4.Extended (Wet) Detention Pond

**Description**

A wet detention pond is a stormwater treatment and storage method consisting of a permanent pool of water located below a control structure release or overflow elevation. The permanent pool provides additional physical and biological treatment. The minimum detention time is twenty-four hours. Other characteristics of wet detention ponds include:

- Requires regular sediment removal to provide continued pollutant removal efficiency
- Requires frequent maintenance to preserve aesthetics and function
- Contributing watershed area must be > 10 acres or a reliable baseflow is needed to prevent pool stagnation
- Pond must be carefully located and designed in order to reduce adverse downstream impacts from pond discharge
- Pretreatment by sediment sump is needed
- Provides good fish and wildlife habitat value
- Can be used to serve large developed sites and can double as a recreational facility
- Potential for thermal polluted and oxygen depleted discharge if improperly designed
- Space limitations in urban areas
- High retrofit capability for improperly functioning dry ponds. Commonly used in conjunction with wetlands and other wet detention ponds
- Pond must be located below the groundwater table in well-drained soils

**Pollutants Removed**

Wet detention ponds provide moderate to high removal efficiencies of particulate and soluble pollutants as well as peak flow attenuation. Removal rates are effective when the permanent pools are designed with volumes of 0.5 to 1.0 inch of runoff from the contributing impervious watershed area

**Costs**

Capital cost is $100,000 per million gallons of stormwater stored. Capital cost covers basin excavation, control structure installation, and landscaping. Some installations may require an impermeable flexible membrane liner at additional cost. O&M cost is $1,000 per million gallons of stormwater stored per year. O&M cost covers landscape maintenance and sediment removal.

## A.4.5. Off-Line Retention Pond

### Description

An off-line retention pond is designed to divert a "first flush" of volume out of the normal stormwater runoff conveyance system. Treatment is normally provided by infiltration. Stormwater from the latter portions of the storm are presumed cleaner and are discharged directly to the receiving system. Other characteristics of off-line retention systems are as follows:

- Drainage basin should be < 10 acres, depending on impervious area and distribution
- Maintenance requirements are moderate and sediment and particulate removal, mowing, and control structure maintenance are regularly required
- Sediment sump at inflow can restrict extent of sediment load
- Use in urban areas highly dependent on land availability and soils suitability
- Seasonal high water table should be > 3 feet below pond bottom
- Soils should have an infiltration rate > 0.5 inch/hour
- Retrofit capability dependent on land availability and water quantity requirements
- Requires short time period (48 to 72 hours) to infiltrate to provide storage for next storm event
- Provides source of groundwater recharge

### Pollutants Removed

The pollutant removal of these systems is considered high and is accomplished by infiltration, straining, and sedimentation processes

### Costs

Capital cost is $30,000 per million gallons of stormwater stored. Capital cost covers basin excavation, control structure installation, and landscaping. O&M cost is $1,000 per million gallons of stormwater stored per year. O&M cost covers landscape maintenance and sediment removal.

## A.4.6.On-line Retention Pond

### Description

On-line retention treatment is similar to extended dry detention with the exception that the control structure release is elevated, thereby providing an available volume of retainage that can discharge the pond via infiltration only. Other characteristics of on-line retention treatment include:

- Drainage basin should be < 50 acres
- Maintenance requirements are moderate and sediment and particulate removal, mowing, and control structure maintenance are regularly required
- Sediment sump at inflow can restrict extent of sediment load

- Use in urban areas highly dependent on land availability and soils suitability
- Seasonal high water table should be > 3 feet below pond bottom
- Soils should have an infiltration rate > 0.5 inch/hour
- Retrofit capability dependent on land availability and water quantity requirements
- Requires short time period (48 to 72 hours) to infiltrate to provide storage for next storm event
- Provides source of groundwater recharge

**Pollutants Removed**

On-line retention ponds have moderate to high pollutant removal capabilities that entail sedimentation, infiltration, and straining by vegetation and/or the discharge structure.

**Costs**

Capital cost is $30,000 per million gallons of stormwater stored. Capital cost covers basin excavation, control structure installation, and landscaping. O&M cost is $1,000 per million gallons of stormwater stored per year. O&M cost covers landscape maintenance and sediment removal.

## A.4.7. Natural/Constructed Treatment Wetlands

**Description**

Wetlands are areas inundated or saturated by surface or groundwater at a frequency and duration sufficient to support a prevalence of vegetation adapted to saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas. Wetland flora and fauna, including microbial species, provide the mechanisms of pollutant removal.

In addition to providing predictable, consistent, and energy-efficient water quality improvement, other benefits include wildlife habitat creation and public education and recreation opportunities. Wetlands also have aesthetic value in suburban, public park, and nature preserve settings. Fishing in wetlands can be accommodated if considered early in the design process. Such secondary benefits may be of importance during permitting and public review.

**Pollutants Removed**

Wetlands physically and biologically remove hydrocarbons, metals, bacteria, suspended solids, nutrients, and oxygen-demanding pollutants from treated wastewater or stormwater flows to produce a high quality effluent.

**Costs**

Costs can vary widely and are greatly dependent on wetland size, design, use, and operation. According to the "Arizona Guidance Manual for Constructed Wetlands for Water Quality Improvement" (as referenced in the bibliography), capital costs are $3,500 per wetland acre per million gallons per day treated for a medium-sized wetland (100-200 acres). O&M costs for medium-sized wetlands is $200 per wetland acre per million gallons per day treated per year.

## A.4.8.Swirl Concentrators

**Description**

A swirl concentrator uses the velocity of stormwater runoff entering the unit to separate pollutants from stormwater. Flow enters tangentially and the geometry of the concentrator causes the water to swirl in a vortex pattern. The cyclonic action allows the clarified water to pass through the top of the unit while the heavier solids exit through the bottom. At reduced velocities, all flow exits through the bottom.

Another benefit is reduction of peak flow in conveyance systems and/or where there is limited land available for detention/retention ponds. A self-regulating device with no moving parts or energy consumption, the vortex formed in the swirl concentrator builds up back pressure as discharge increases. Discharge rates can be reduced 60 to 90 percent over discharge through a straight pipe or orifice. Other features include ease of installation and retrofit, and low maintenance requirement which involves only cleaning and inspection. Maintenance requirements are low, and involve cleaning and inspection only. As there are no moving parts, maintenance costs are low and equipment life is high.

**Pollutants Removed**

Swirl concentrators have the potential, alone or as part of a total treatment system, to remove a high percentage of particulate pollutants and the contaminants bound to them, such as metals. They are also indicated for microorganism removal and separation of floatables, such as certain oils and greases, and a moderate percentage of soluble pollutants.

**Costs**

Capital cost is $12,000 per million gallons per day treated for installation and connection to inflow and outflow pipes. O&M cost is $1,000 per million gallons treated per year for annual inspection and periodic sediment and debris removal.

## A.4.9.Infiltration/Exfiltration Trench

### Description

An infiltration trench is a shallow trench that has been backfilled with gravel to create a reservoir to provide for temporary storage and infiltration of stormwater runoff. An exfiltration trench consists of a perforated pipe wrapped with a suitable filter fabric installed in a sand or fine aggregate backfill. An exfiltration trench may overlay a rock bed or dry well to limit silting. Other characteristics of infiltration/exfiltration trenches are as follows:

- Requires sediment sump and/or vegetated filter strip to prevent sediments from clogging the system.
- Maintenance can be relatively high, consisting of regular removal of particulate and settled matter and mowing
- Potential impact to groundwater from such soluble constituents as nitrates and metals
- Contributing drainage area should not exceed five acres
- Not recommended for high water table locations
- Use is limited to soils with infiltration rates greater than 0.5 inch/hour
- Not recommended for drainage areas with high sediment loads and/or steep slopes
- Provides good groundwater recharge

### Pollutants Removed

Trench systems have the potential, as part of a total treatment system, to remove a high percentage of particulate pollutants and a moderate percentage of soluble pollutants. To maintain performance, materials that will clog the filter media (settleable solids, oil, grease, and debris) should be removed before water enters the trench.

**Costs**

Capital cost is $4,000 per acre served for excavation of a two to ten foot deep trench, optional pipe, and backfill. O&M cost is $1,500 per acre served per year for annual inspection and periodic sediment and debris removal.

## A.4.10.Sand Filters

### Description

A sand filter is comprised of a contained bed of sand surrounding perforated discharge pipe(s). The first flush of stormwater is captured, diverted to the sand bed, strained through the sand, collected in the perforated discharge pipe, and conveyed to the receiving water system. Additional characteristics of sand filters include the following:

- Maintenance is high due to accumulation of particulate matter at straining surface. May require periodic removal of sand media where high sediment loads occur
- Improved efficiency if used as an off-line system
- Pretreatment sediment sump is recommended
- Watershed drainage area limited to < 5 acres
- Pressure head for flow should preferably be > 2 feet
- Commonly used in area-limited urban settings
- Provides no wildlife habitat value
- High water table must be below discharge pipe invert
- Retrofit capabilities possible for instances of limited space and off-line layout

### Pollutants Removed

The pollutant removal efficiency for sand filters is high for particulate and trace metals and low to moderate for soluble nutrients. Pollutant removal is achieved by straining and settling

### Costs

Capital cost is $4,000 per acre served for excavation, pipe, and backfill. O&M cost is $1,500 per acre served per year for annual inspection and periodic sediment and debris removal.

### A.4.11.Porous Pavement

**Description**

Porous and grid pavements are alternatives to conventional asphalt pavement surfaces. Concrete grid pavement consists of concrete blocks with voids filled with pervious materials, overlaying a sand or gravel base. Porous pavement generally is poured over a gravel layer. Stormwater infiltrates the pavement into the gravel layer, where it then exfiltrates into the surrounding soil. Other characteristics of porous and grid pavements include the following:

- High maintenance requirement for quarterly vacuum sweeping and/or jet hosing
- Lack of maintenance reduces treatment efficiency and increases imperviousness
- Drainage areas usually < 10 acres
- Soil must have infiltration rate > 0.5 inch/hour
- Slope should be < 5 percent
- High water table should be > 3 feet below pavement surface
- Not suitable for large truck traffic or frequently used parking areas
- Limitations include little to no sediment inputs from adjacent lands and/or traffic
- Use in urban areas is limited to select sites with suitable soils and acceptable land uses
- Possible transport of toxic chemicals into groundwater
- Good groundwater recharge
- Retrofit capabilities are severely limited

**Pollutants Removed**

Pollutant removal efficiency is good for sediment, nutrients, and trace metals. Runoff and pollutant loading is reduced, thus reducing or eliminating the need for other treatment methods (storm sewers, swales, filter strips).

**Costs**

Capital cost is $100,000 per acre of pavement installed. Capital cost is for installation of porous pavement, which may require twice as much paving material as asphalt to achieve the same strength. O&M cost is $200 per acre of pavement installed per year. O&M cost is for quarterly vacuum sweeping and/or jet hosing.

## A.4.12. Coagulation and Flocculation

**Description**

Coagulant treatment is a process used in water and wastewater treatment for removing suspended matter. Coagulation is the addition and rapid mixing of a chemical reagent to combine with non-settleable and slow-settleable solids. Flocculation is the gentle mixing and aggregation of the floc particles to promote settling and/or precipitation.

The most widely used coagulants for stormwater treatment are aluminum sulfate (alum), ferric sulfate, and hydrated lime. The injection system consists of a pump, a chemical holding tank, a flow measurement device, and a feed hose. Dosage is controlled by flow rate and chemical concentration. The stormwater and coagulant are rapidly mixed by passing through a pipe before discharge.

Studies using alum as a coagulant have found that up to 90 percent phosphorus, 50 to 80 percent of nitrogen, and 80 percent of suspended solids can be removed. Other characteristics of coagulant treatment include the following:

- Moderate maintenance requirement, primarily for floc removal
- Semi-automatic and automatic operation possible
- Minimum alkalinity of 25 mg/L and a pH of 6.0 required during flocculation
- Can be used as pretreatment for filtration treatment systems
- Can be used in place of land-intensive detention basins
- Flexible in applicability and retrofit

**Pollutants Removed**

Suspended solids, nutrients, microorganisms, and metals are among the pollutants removed by this process.

**Costs**

Capital cost is estimated to be from $800,000 to $1,100,000 per million gallons per day of stormwater runoff treated. O&M cost, primarily for chemical addition and sediment removal, is $70,000 per million gallons of stormwater runoff treated per year

### A.4.13. Modified Dry Wells

**Description**

Dry wells are an existing technology for stormwater detention. However a dry well can be retrofitted with filtration material such as sand or activated carbon that filters the stormwater as it infiltrates into the ground. The filtration process will remove suspended sediments while the activated carbon will removed dissolved contaminants.

Advantages include low land requirements, it can be implemented in-line with an existing storm sewer, and it can be implemented in the bottom of an existing detention basin. Since the filter media is located near the bottom of the dry well, maintenance could be difficult, and sampling the treated effluent could be difficult depending on the depth of the well

**Pollutants Removed**

Pollutant removal in modified dry wells can be very good. Sediments are removed in the primary sedimentation chamber. The activated carbon section of the dry well can effectively remove dissolved organics. Also, the filtration action of the granular carbon will remove finer sediments.

**Costs**

On a per well basis, the approximate base capital costs is $5,000. Depending on how deep the well is, add $120 per foot for installation. Operation and Maintenence requirements include sediment removal in the primary chamber and removal and replacement of the activated carbon in the filtration column. On a per well basis, that equates to $3,500 per year.

## A.5.Comparison Summary

The following tables summarize selected BMP's discussed in this section. This data was tabulated from a variety of references and represents the general characteristics of each BMP. This data is meant to be used for comparison purposes only, rather than design parameters.

Table 2.
Selected Structural BMP Characteristics

| Stormwater BMP | Area (acres) | Soil Infiltration Requirement | High Water Table Limitations | Sediment Load Limitations | Relative Space Requirement | Maintenance Frequency | Construction Cost |
|---|---|---|---|---|---|---|---|
| Extended Dry Detention | > 10 | none | probable | possible | high | moderate | low |
| Wet Detention | > 10 | none | none | possible | mod. to high | moderate | mod. to high |
| Sediment Sump | none | none | none | none | moderate | mod. to high | low |
| Extended Wet Detention | > 10 | none | none | possible | mod. to high | moderate | mod. to high |
| Stormwater Wetlands (created) | > 2 | none | none | possible | mod. to high | high to mod. | high |
| Extended Wetland Detention | > 10 | none | none | possible | mod. to high | high to mod. | high |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Natural Wetlands | none | none | none | possible | low | moderate | low |
| Pond/Wetland Systems | > 10 | none | none | possible | mod. to high | moderate | high |
| Infiltration Systems Trenches | < 10 | rapid | probable | definitely | mod. to high | mod. to high | low to mod. |
| Infiltration Systems Basins | < 25 | rapid | probable | definitely | high | moderate | low |
| Stormwater Filters | < 5 | rapid | probable | definitely | low to mod. | high | moderate |
| Porous Pavement | < 10 | rapid | definitely | definitely | low | mod. to high | mod. to high |
| Concrete Grid Pavement | < 10 | rapid | definitely | probable | low | moderate | moderate |
| Swales | < 5 | mod. to rapid | probable | probable | low to mod. | low | low |
| Water Quality Inlets | < 2 | none | none | probable | low | low | low |
| Off-Line Retention | < 5 | none | seldom | possible | mod. to high | moderate | mod. to high |
| On-Line Retention | < 10 | none | possible | possible | moderate | moderate | low |
| Overland Flow - Grass | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Overland Flow - Grass/Soil | < 5 | rapid | seldom | probable | low | low | low |

Table 3.

Estimated Percent Pollutant Reduction For Selected Structural BMP's

| Stormwater BMP Technique | Suspended Solids | Nutrients | | $BOD_5$ |
|---|---|---|---|---|
| | | Total P | Total N | |
| Extended Dry Detention | 55 | 30 | 30 | 50 |
| Wet Detention | 65 | 50 | 35 | 40 |
| Sediment Sump | N/D | N/D | N/D | N/D |
| Extended Wet Detention | 80 | 65 | 55 | 35 |
| Stormwater Wetlands (created) | 70 | 40 | 25 | 20 |
| Extended Wetland Detention | 60 | 25 | 20 | N/D |
| Natural Wetlands | 90 | 60 | 40 | 80 |
| Pond/Wetland Systems | 75 | 55 | 40 | 40 |
| Infiltration Systems Trenches | 90 | 65 | 60 | 85 |
| Infiltration Systems Basins | 90 | 65 | 60 | 85 |
| Stormwater Filters | 85 | 70 | 45 | 90 |
| Porous Pavement | 80 | 60 | 80 | N/D |
| Concrete Grid Pavement | N/D | N/D | N/D | N/D |
| Swales | 85 | 65 | 40 | 10 |
| Water Quality Inlets | 15 | N/D | N/D | N/D |
| Off-Line Retention | 95 | 95 | 95 | 95 |
| On-Line Retention | 70 | 60 | N/D | 65 |
| Overland Flow - Grass | 30 | N/D | N/D | N/D |
| Overland Flow - Grass/Soil | 90 | N/D | N/D | N/D |

"N/D" indicates no data available

Table 4

Listing Of BMP's Discussed

| Non-Structural BMP's | Minor Structural BMP's | Major Structural BMP's |
|---|---|---|
| Litter Control Programs | Swales and Channels | Dry Basins |
| Chemical Use and Storage Ordainence | Improvement of Existing Swales and Channells | Extended Dry Detention |
| Illicit Discharge Elimination Program | Vegitated Filter Strips | Extended Wet Detention |
| Facility Inspection and Enforcement | Water Quality Inlets | Off-Line Retention |
| Public Education | Underground Storage | On-Line Retention |
| Increased Street Sweeping | Artificial Ponds and Waterfalls | Wetlands |
| Increased Storm Drain System Maintenance | Water Reuse Programs | Swirl Concentrators |
| Traffic Flow Regulation | | Infiltration Systems Trenches |
| | | Sand Filters |
| | | Porous Pavement |
| | | Coagulation and Flocculation |
| | | Modified Dry Wells |

# Appendix B

## Summary of Historical City of Phoenix Rainfall Data

City of Phoenix Rainfall Data
1945-1995

3085.00 Total Events
1114.00 Events > 0.05 inch
1068.00 1.0 inch<Events>0.05 inch

380.21 Total Rain (in)
351.68 Rain > 0.05 inch
289.82 1.0 inch<Rain>0.05 inch

| Rainfall (in) | Discrete Events | Total Rain (in) | Cumulativ Events | Cumulative Percent | Cumulative Rain (in) | Cumulative Percent Rain | Cumulative Events (>0.05) | Cumulative % Events (>0.05) | Cumulative Rain (>0.05) | Cumulative % Rain (>0.05) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.01 | 1561 | 15.61 | 1561 | 50.60 | 15.61 | 4.11 | | | | |
| 0.02 | 150 | 3 | 1711 | 55.46 | 18.61 | 4.89 | | | | |
| 0.03 | 115 | 3.45 | 1826 | 59.19 | 22.06 | 5.80 | | | | |
| 0.04 | 78 | 3.12 | 1904 | 61.72 | 25.18 | 6.62 | | | | |
| 0.05 | 67 | 3.35 | 1971 | 63.89 | 28.53 | 7.50 | | | | |
| 0.06 | 76 | 4.56 | 2047 | 66.35 | 33.09 | 8.70 | 76 | 6.82 | 4.56 | 1.30 |
| 0.07 | 51 | 3.57 | 2098 | 68.01 | 36.66 | 9.64 | 127 | 11.40 | 8.13 | 2.31 |
| 0.08 | 52 | 4.16 | 2150 | 69.69 | 40.82 | 10.74 | 179 | 16.07 | 12.29 | 3.49 |
| 0.09 | 51 | 4.59 | 2201 | 71.35 | 45.41 | 11.94 | 230 | 20.65 | 16.88 | 4.80 |
| 0.10 | 40 | 4 | 2241 | 72.64 | 49.41 | 13.00 | 270 | 24.24 | 20.88 | 5.94 |
| 0.11 | 29 | 3.19 | 2270 | 73.58 | 52.60 | 13.83 | 299 | 26.84 | 24.07 | 6.84 |
| 0.12 | 31 | 3.72 | 2301 | 74.59 | 56.32 | 14.81 | 330 | 29.62 | 27.79 | 7.90 |
| 0.13 | 33 | 4.29 | 2334 | 75.66 | 60.61 | 15.94 | 363 | 32.59 | 32.08 | 9.12 |
| 0.14 | 36 | 5.04 | 2370 | 76.82 | 65.65 | 17.27 | 399 | 35.82 | 37.12 | 10.56 |
| 0.15 | 25 | 3.75 | 2395 | 77.63 | 69.40 | 18.25 | 424 | 38.06 | 40.87 | 11.62 |
| 0.16 | 29 | 4.64 | 2424 | 78.57 | 74.04 | 19.47 | 453 | 40.66 | 45.51 | 12.94 |
| 0.17 | 27 | 4.59 | 2451 | 79.45 | 78.63 | 20.68 | 480 | 43.09 | 50.10 | 14.25 |
| 0.18 | 21 | 3.78 | 2472 | 80.13 | 82.41 | 21.67 | 501 | 44.97 | 53.88 | 15.32 |
| 0.19 | 19 | 3.61 | 2491 | 80.75 | 86.02 | 22.62 | 520 | 46.68 | 57.49 | 16.35 |
| 0.20 | 25 | 5 | 2516 | 81.56 | 91.02 | 23.94 | 545 | 48.92 | 62.49 | 17.77 |
| 0.21 | 25 | 5.25 | 2541 | 82.37 | 96.27 | 25.32 | 570 | 51.17 | 67.74 | 19.26 |
| 0.22 | 25 | 5.5 | 2566 | 83.18 | 101.77 | 26.77 | 595 | 53.41 | 73.24 | 20.83 |
| 0.23 | 12 | 2.76 | 2578 | 83.57 | 104.53 | 27.49 | 607 | 54.49 | 76.00 | 21.61 |
| 0.24 | 16 | 3.84 | 2594 | 84.08 | 108.37 | 28.50 | 623 | 55.92 | 79.84 | 22.70 |
| 0.25 | 14 | 3.5 | 2608 | 84.54 | 111.87 | 29.42 | 637 | 57.18 | 83.34 | 23.70 |
| 0.26 | 16 | 4.16 | 2624 | 85.06 | 116.03 | 30.52 | 653 | 58.62 | 87.50 | 24.88 |
| 0.27 | 20 | 5.4 | 2644 | 85.71 | 121.43 | 31.94 | 673 | 60.41 | 92.90 | 26.42 |
| 0.28 | 14 | 3.92 | 2658 | 86.16 | 125.35 | 32.97 | 687 | 61.67 | 96.82 | 27.53 |
| 0.29 | 9 | 2.61 | 2667 | 86.45 | 127.96 | 33.66 | 696 | 62.48 | 99.43 | 28.27 |
| 0.30 | 16 | 4.8 | 2683 | 86.97 | 132.76 | 34.92 | 712 | 63.91 | 104.23 | 29.64 |
| 0.31 | 14 | 4.34 | 2697 | 87.42 | 137.10 | 36.06 | 726 | 65.17 | 108.57 | 30.87 |

## City of Phoenix Rainfall Data
## 1945-1995

3085.00 Total Events
1114.00 Events > 0.05 inch
1068.00 1.0 inch<Events>0.05 inch

380.21 Total Rain (in)
351.68 Rain > 0.05 inch
289.82 1.0 inch<Rain>0.05 inch

| Rainfall (in) | Discrete Events | Total Rain (in) | Cumulativ Events | Cumulative Percent | Cumulative Rain (in) | Cumulative Percent Rain | Cumulative Events (>0.05) | Cumulative % Events (>0.05) | Cumulative Rain (>0.05) | Cumulative % Rain (>0.05) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.32 | 18 | 5.76 | 2715 | 88.01 | 142.86 | 37.57 | 744 | 66.79 | 114.33 | 32.51 |
| 0.33 | 16 | 5.28 | 2731 | 88.53 | 148.14 | 38.96 | 760 | 68.22 | 119.61 | 34.01 |
| 0.34 | 14 | 4.76 | 2745 | 88.98 | 152.90 | 40.21 | 774 | 69.48 | 124.37 | 35.36 |
| 0.35 | 13 | 4.55 | 2758 | 89.40 | 157.45 | 41.41 | 787 | 70.65 | 128.92 | 36.66 |
| 0.36 | 15 | 5.4 | 2773 | 89.89 | 162.85 | 42.83 | 802 | 71.99 | 134.32 | 38.19 |
| 0.37 | 4 | 1.48 | 2777 | 90.02 | 164.33 | 43.22 | 806 | 72.35 | 135.80 | 38.61 |
| 0.38 | 16 | 6.08 | 2793 | 90.53 | 170.41 | 44.82 | 822 | 73.79 | 141.88 | 40.34 |
| 0.39 | 10 | 3.9 | 2803 | 90.86 | 174.31 | 45.85 | 832 | 74.69 | 145.78 | 41.45 |
| 0.40 | 7 | 2.8 | 2810 | 91.09 | 177.11 | 46.58 | 839 | 75.31 | 148.58 | 42.25 |
| 0.41 | 9 | 3.69 | 2819 | 91.38 | 180.80 | 47.55 | 848 | 76.12 | 152.27 | 43.30 |
| 0.42 | 7 | 2.94 | 2826 | 91.60 | 183.74 | 48.33 | 855 | 76.75 | 155.21 | 44.13 |
| 0.43 | 4 | 1.72 | 2830 | 91.73 | 185.46 | 48.78 | 859 | 77.11 | 156.93 | 44.62 |
| 0.44 | 9 | 3.96 | 2839 | 92.03 | 189.42 | 49.82 | 868 | 77.92 | 160.89 | 45.75 |
| 0.45 | 8 | 3.6 | 2847 | 92.29 | 193.02 | 50.77 | 876 | 78.64 | 164.49 | 46.77 |
| 0.46 | 9 | 4.14 | 2856 | 92.58 | 197.16 | 51.86 | 885 | 79.44 | 168.63 | 47.95 |
| 0.47 | 6 | 2.82 | 2862 | 92.77 | 199.98 | 52.60 | 891 | 79.98 | 171.45 | 48.75 |
| 0.48 | 8 | 3.84 | 2870 | 93.03 | 203.82 | 53.61 | 899 | 80.70 | 175.29 | 49.84 |
| 0.49 | 4 | 1.96 | 2874 | 93.16 | 205.78 | 54.12 | 903 | 81.06 | 177.25 | 50.40 |
| 0.50 | 8 | 4 | 2882 | 93.42 | 209.78 | 55.17 | 911 | 81.78 | 181.25 | 51.54 |
| 0.51 | 12 | 6.12 | 2894 | 93.81 | 215.90 | 56.78 | 923 | 82.85 | 187.37 | 53.28 |
| 0.52 | 7 | 3.64 | 2901 | 94.04 | 219.54 | 57.74 | 930 | 83.48 | 191.01 | 54.31 |
| 0.53 | 3 | 1.59 | 2904 | 94.13 | 221.13 | 58.16 | 933 | 83.75 | 192.60 | 54.77 |
| 0.54 | 2 | 1.08 | 2906 | 94.20 | 222.21 | 58.44 | 935 | 83.93 | 193.68 | 55.07 |
| 0.55 | 5 | 2.75 | 2911 | 94.36 | 224.96 | 59.17 | 940 | 84.38 | 196.43 | 55.85 |
| 0.56 | 5 | 2.8 | 2916 | 94.52 | 227.76 | 59.90 | 945 | 84.83 | 199.23 | 56.65 |
| 0.57 | 5 | 2.85 | 2921 | 94.68 | 230.61 | 60.65 | 950 | 85.28 | 202.08 | 57.46 |
| 0.58 | 7 | 4.06 | 2928 | 94.91 | 234.67 | 61.72 | 957 | 85.91 | 206.14 | 58.62 |
| 0.59 | 9 | 5.31 | 2937 | 95.20 | 239.98 | 63.12 | 966 | 86.71 | 211.45 | 60.13 |
| 0.60 | 1 | 0.6 | 2938 | 95.24 | 240.58 | 63.28 | 967 | 86.80 | 212.05 | 60.30 |
| 0.61 | 2 | 1.22 | 2940 | 95.30 | 241.80 | 63.60 | 969 | 86.98 | 213.27 | 60.64 |
| 0.62 | 2 | 1.24 | 2942 | 95.36 | 243.04 | 63.92 | 971 | 87.16 | 214.51 | 61.00 |

3085.00 Total Events
1114.00 Events > 0.05 inch
1068.00 1.0 inch<Events>0.05 inch

380.21 Total Rain (in)
351.68 Rain > 0.05 inch
289.82 1.0 inch<Rain>0.05 inch

| Rainfall (in) | Discrete Events | Total Rain (in) | Cumulativ Events | Cumulative Percent | Cumulative Rain (in) | Cumulative Percent Rain | Cumulative Events (>0.05) | Cumulative % Events (>0.05) | Cumulative Rain (>0.05) | Cumulative % Rain (>0.05) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.63 | 6 | 3.78 | 2948 | 95.56 | 246.82 | 64.92 | 977 | 87.70 | 218.29 | 62.07 |
| 0.64 | 4 | 2.56 | 2952 | 95.69 | 249.38 | 65.59 | 981 | 88.06 | 220.85 | 62.80 |
| 0.65 | 3 | 1.95 | 2955 | 95.79 | 251.33 | 66.10 | 984 | 88.33 | 222.80 | 63.35 |
| 0.66 | 3 | 1.98 | 2958 | 95.88 | 253.31 | 66.62 | 987 | 88.60 | 224.78 | 63.92 |
| 0.67 | 6 | 4.02 | 2964 | 96.08 | 257.33 | 67.68 | 993 | 89.14 | 228.80 | 65.06 |
| 0.68 | 4 | 2.72 | 2968 | 96.21 | 260.05 | 68.40 | 997 | 89.50 | 231.52 | 65.83 |
| 0.69 | 6 | 4.14 | 2974 | 96.40 | 264.19 | 69.49 | 1003 | 90.04 | 235.66 | 67.01 |
| 0.70 | 6 | 4.2 | 2980 | 96.60 | 268.39 | 70.59 | 1009 | 90.57 | 239.86 | 68.20 |
| 0.71 | 3 | 2.13 | 2983 | 96.69 | 270.52 | 71.15 | 1012 | 90.84 | 241.99 | 68.81 |
| 0.72 | 1 | 0.72 | 2984 | 96.73 | 271.24 | 71.34 | 1013 | 90.93 | 242.71 | 69.01 |
| 0.73 | 7 | 5.11 | 2991 | 96.95 | 276.35 | 72.68 | 1020 | 91.56 | 247.82 | 70.47 |
| 0.74 | 1 | 0.74 | 2992 | 96.99 | 277.09 | 72.88 | 1021 | 91.65 | 248.56 | 70.68 |
| 0.76 | 3 | 2.28 | 2995 | 97.08 | 279.37 | 73.48 | 1024 | 91.92 | 250.84 | 71.33 |
| 0.77 | 1 | 0.77 | 2996 | 97.12 | 280.14 | 73.68 | 1025 | 92.01 | 251.61 | 71.55 |
| 0.78 | 2 | 1.56 | 2998 | 97.18 | 281.70 | 74.09 | 1027 | 92.19 | 253.17 | 71.99 |
| 0.79 | 4 | 3.16 | 3002 | 97.31 | 284.86 | 74.92 | 1031 | 92.55 | 256.33 | 72.89 |
| 0.80 | 4 | 3.2 | 3006 | 97.44 | 288.06 | 75.76 | 1035 | 92.91 | 259.53 | 73.80 |
| 0.81 | 3 | 2.43 | 3009 | 97.54 | 290.49 | 76.40 | 1038 | 93.18 | 261.96 | 74.49 |
| 0.83 | 2 | 1.66 | 3011 | 97.60 | 292.15 | 76.84 | 1040 | 93.36 | 263.62 | 74.96 |
| 0.84 | 3 | 2.52 | 3014 | 97.70 | 294.67 | 77.50 | 1043 | 93.63 | 266.14 | 75.68 |
| 0.85 | 1 | 0.85 | 3015 | 97.73 | 295.52 | 77.73 | 1044 | 93.72 | 266.99 | 75.92 |
| 0.86 | 4 | 3.44 | 3019 | 97.86 | 298.96 | 78.63 | 1048 | 94.08 | 270.43 | 76.90 |
| 0.87 | 1 | 0.87 | 3020 | 97.89 | 299.83 | 78.86 | 1049 | 94.17 | 271.30 | 77.14 |
| 0.88 | 2 | 1.76 | 3022 | 97.96 | 301.59 | 79.32 | 1051 | 94.34 | 273.06 | 77.64 |
| 0.89 | 2 | 1.78 | 3024 | 98.02 | 303.37 | 79.79 | 1053 | 94.52 | 274.84 | 78.15 |
| 0.90 | 1 | 0.9 | 3025 | 98.06 | 304.27 | 80.03 | 1054 | 94.61 | 275.74 | 78.41 |
| 0.91 | 4 | 3.64 | 3029 | 98.18 | 307.91 | 80.98 | 1058 | 94.97 | 279.38 | 79.44 |
| 0.92 | 3 | 2.76 | 3032 | 98.28 | 310.67 | 81.71 | 1061 | 95.24 | 282.14 | 80.23 |
| 0.93 | 2 | 1.86 | 3034 | 98.35 | 312.53 | 82.20 | 1063 | 95.42 | 284.00 | 80.76 |
| 0.95 | 1 | 0.95 | 3035 | 98.38 | 313.48 | 82.45 | 1064 | 95.51 | 284.95 | 81.03 |
| 0.96 | 2 | 1.92 | 3037 | 98.44 | 315.40 | 82.95 | 1066 | 95.69 | 286.87 | 81.57 |

3085.00 Total Events
1114.00 Events > 0.05 inch
1068.00 1.0 inch<Events>0.05 inch

380.21 Total Rain (in)
351.68 Rain > 0.05 inch
289.82 1.0 inch<Rain>0.05 inch

| Rainfall (in) | Discrete Events | Total Rain (in) | Cumulativ Events | Cumulative Percent | Cumulative Rain (in) | Cumulative Percent Rain | Cumulative Events (>0.05) | Cumulative % Events (>0.05) | Cumulative Rain (>0.05) | Cumulative % Rain (>0.05) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.98 | 2 | 1.96 | 3039 | 98.51 | 317.36 | 83.47 | 1068 | 95.87 | 288.83 | 82.13 |
| 0.99 | 1 | 0.99 | 3040 | 98.54 | 318.35 | 83.73 | 1069 | 95.96 | 289.82 | 82.41 |
| 1.00 | 1 | 1 | 3041 | 98.57 | 319.35 | 83.99 | 1070 | 96.05 | 290.82 | 82.69 |
| 1.01 | 1 | 1.01 | 3042 | 98.61 | 320.36 | 84.26 | 1071 | 96.14 | 291.83 | 82.98 |
| 1.02 | 3 | 3.06 | 3045 | 98.70 | 323.42 | 85.06 | 1074 | 96.41 | 294.89 | 83.85 |
| 1.03 | 3 | 3.09 | 3048 | 98.80 | 326.51 | 85.88 | 1077 | 96.68 | 297.98 | 84.73 |
| 1.04 | 1 | 1.04 | 3049 | 98.83 | 327.55 | 86.15 | 1078 | 96.77 | 299.02 | 85.03 |
| 1.05 | 3 | 3.15 | 3052 | 98.93 | 330.70 | 86.98 | 1081 | 97.04 | 302.17 | 85.92 |
| 1.06 | 1 | 1.06 | 3053 | 98.96 | 331.76 | 87.26 | 1082 | 97.13 | 303.23 | 86.22 |
| 1.07 | 1 | 1.07 | 3054 | 99.00 | 332.83 | 87.54 | 1083 | 97.22 | 304.30 | 86.53 |
| 1.12 | 1 | 1.12 | 3055 | 99.03 | 333.95 | 87.83 | 1084 | 97.31 | 305.42 | 86.85 |
| 1.15 | 1 | 1.15 | 3056 | 99.06 | 335.10 | 88.14 | 1085 | 97.40 | 306.57 | 87.17 |
| 1.17 | 1 | 1.17 | 3057 | 99.09 | 336.27 | 88.44 | 1086 | 97.49 | 307.74 | 87.51 |
| 1.18 | 1 | 1.18 | 3058 | 99.12 | 337.45 | 88.75 | 1087 | 97.58 | 308.92 | 87.84 |
| 1.19 | 1 | 1.19 | 3059 | 99.16 | 338.64 | 89.07 | 1088 | 97.67 | 310.11 | 88.18 |
| 1.20 | 1 | 1.2 | 3060 | 99.19 | 339.84 | 89.38 | 1089 | 97.76 | 311.31 | 88.52 |
| 1.21 | 1 | 1.21 | 3061 | 99.22 | 341.05 | 89.70 | 1090 | 97.85 | 312.52 | 88.86 |
| 1.22 | 1 | 1.22 | 3062 | 99.25 | 342.27 | 90.02 | 1091 | 97.94 | 313.74 | 89.21 |
| 1.24 | 1 | 1.24 | 3063 | 99.29 | 343.51 | 90.35 | 1092 | 98.03 | 314.98 | 89.56 |
| 1.25 | 1 | 1.25 | 3064 | 99.32 | 344.76 | 90.68 | 1093 | 98.11 | 316.23 | 89.92 |
| 1.32 | 1 | 1.32 | 3065 | 99.35 | 346.08 | 91.02 | 1094 | 98.20 | 317.55 | 90.30 |
| 1.33 | 1 | 1.33 | 3066 | 99.38 | 347.41 | 91.37 | 1095 | 98.29 | 318.88 | 90.67 |
| 1.35 | 1 | 1.35 | 3067 | 99.42 | 348.76 | 91.73 | 1096 | 98.38 | 320.23 | 91.06 |
| 1.36 | 1 | 1.36 | 3068 | 99.45 | 350.12 | 92.09 | 1097 | 98.47 | 321.59 | 91.44 |
| 1.37 | 1 | 1.37 | 3069 | 99.48 | 351.49 | 92.45 | 1098 | 98.56 | 322.96 | 91.83 |
| 1.43 | 1 | 1.43 | 3070 | 99.51 | 352.92 | 92.82 | 1099 | 98.65 | 324.39 | 92.24 |
| 1.46 | 1 | 1.46 | 3071 | 99.55 | 354.38 | 93.21 | 1100 | 98.74 | 325.85 | 92.66 |
| 1.50 | 1 | 1.5 | 3072 | 99.58 | 355.88 | 93.60 | 1101 | 98.83 | 327.35 | 93.08 |
| 1.52 | 1 | 1.52 | 3073 | 99.61 | 357.40 | 94.00 | 1102 | 98.92 | 328.87 | 93.51 |
| 1.54 | 1 | 1.54 | 3074 | 99.64 | 358.94 | 94.41 | 1103 | 99.01 | 330.41 | 93.95 |
| 1.58 | 1 | 1.58 | 3075 | 99.68 | 360.52 | 94.82 | 1104 | 99.10 | 331.99 | 94.40 |

3085.00 Total Events
1114.00 Events > 0.05 inch
1068.00 1.0 inch<Events>0.05 inch

380.21 Total Rain (in)
351.68 Rain > 0.05 inch
289.82 1.0 inch<Rain>0.05 inch

| Rainfall (in) | Discrete Events | Total Rain (in) | Cumulativ Events | Cumulative Percent | Cumulative Rain (in) | Cumulative Percent Rain | Cumulative Events (>0.05) | Cumulative % Events (>0.05) | Cumulative Rain (>0.05) | Cumulative % Rain (>0.05) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.59 | 1 | 1.59 | 3076 | 99.71 | 362.11 | 95.24 | 1105 | 99.19 | 333.58 | 94.85 |
| 1.66 | 2 | 3.32 | 3078 | 99.77 | 365.43 | 96.11 | 1107 | 99.37 | 336.90 | 95.80 |
| 1.69 | 1 | 1.69 | 3079 | 99.81 | 367.12 | 96.56 | 1108 | 99.46 | 338.59 | 96.28 |
| 1.73 | 1 | 1.73 | 3080 | 99.84 | 368.85 | 97.01 | 1109 | 99.55 | 340.32 | 96.77 |
| 1.90 | 1 | 1.9 | 3081 | 99.87 | 370.75 | 97.51 | 1110 | 99.64 | 342.22 | 97.31 |
| 1.98 | 1 | 1.98 | 3082 | 99.90 | 372.73 | 98.03 | 1111 | 99.73 | 344.20 | 97.87 |
| 2.32 | 1 | 2.32 | 3083 | 99.94 | 375.05 | 98.64 | 1112 | 99.82 | 346.52 | 98.53 |
| 2.43 | 1 | 2.43 | 3084 | 99.97 | 377.48 | 99.28 | 1113 | 99.91 | 348.95 | 99.22 |
| 2.73 | 1 | 2.73 | 3085 | 100.00 | 380.21 | 100.00 | 1114 | 100.00 | 351.68 | 100.00 |

# Appendix C

## Surface Water Quality Standards
## (Title 11, Chapter 18, Appendix A)

## APPENDIX A. Numeric Water Quality Criteria

**Table 1. Human Health and Agricultural Designated Use Numeric Water Quality Criteria**

| PARAMETER | CAS[1] NUMBER | DWS[2] (µg/L) | FC[2] (µg/L) | FBC[2] (µg/L) | PBC[2] (µg/L) | AgI[2] (µg/L) | AgL[2] (µg/L) |
|---|---|---|---|---|---|---|---|
| Acenaphthene | 83-32-9 | 420 | 2600 | 8400 | 8400 | NNS | NNS |
| Acenaphthylene | 208-96-8 | NNS | NNS | NNS | NNS | NNS | NNS |
| Acrolein | 107-02-8 | 110 | 750 | 2200 | 2200 | NNS | NNS |
| Acrylonitrile | 107-13-1 | 0.06 | 0.64 | 2.6 | NNS | NNS | NNS |
| Alachlor | 15972-60-8 | 2 | NNS | 1400 | 1400 | NNS | NNS |
| Aldrin | 309-00-2 | 0.002 | 0.0003 | 0.08 | 4.2 | k | k |
| Ammonia | 7664-41-7 | NNS | NNS | NNS | NNS | NNS | NNS |
| Anthracene | 120-12-7 | 2100 | 6300 | 42000 | 42000 | NNS | NNS |
| Antimony (as Sb) | 7440-36-0 | 6 T | 140 T | 56 T | 56 T | NNS | NNS |
| Arsenic (as As) | 7440-38-2 | 50 T | 1450 T | 50 T | 50 T | 2000 T | 200 T |
| Asbestos | 1332-21-4 | a | NNS | NNS | NNS | NNS | NNS |
| Atrazine | 1912-24-9 | 3 | NNS | 4900 | 4900 | NNS | NNS |
| Barium (as Ba) | 7440-39-3 | 2000 T | NNS | 9800 D | 9800 D | NNS | NNS |
| Benzene | 71-43-2 | 5 | 120 | 48 | NNS | NNS | NNS |
| Benzidine | 92-87-5 | 0.0002 | 0.002 | 0.006 | 420 | 0.01 | 0.01 |
| Benz (a) anthracene | 56-55-3 | 0.003 | 0.00008 | 0.12 | NNS | NNS | NNS |
| Benzo (a) pyrene | 50-32-8 | 0.2 | 0.002 | 0.2 | NNS | NNS | NNS |
| Benzo (ghi) perylene | 191-24-2 | NNS | NNS | NNS | NNS | NNS | NNS |
| Benzo (k) fluoranthene | 207-08-9 | 0.003 | 0.00001 | 0.12 | NNS | NNS | NNS |
| 3,4-Benzofluoranthene | 205-99-2 | 0.003 | 0.00004 | 0.12 | NNS | NNS | NNS |
| Beryllium (as Be) | 7440-41-7 | 4 T | 0.21 T | 4 T | 700 T | NNS | NNS |
| Bis (2-chloroethoxy) methane | 111-91-1 | NNS | NNS | NNS | NNS | NNS | NNS |
| Bis (2-chloroethyl) ether | 111-44-4 | 0.03 | 1.4 | 1.3 | NNS | NNS | NNS |
| Bis (2-chloroisopropyl) ether | 108-60-1 | 280 | 15000 | 5600 | 5600 | NNS | NNS |
| Boron (as B) | 7440-42-8 | 630 | NNS | 12600 | 12600 | 1000 T | NNS |
| Bromodichloromethane | 75-27-4 | TTHM | 22 | 100 | 2800 | NNS | NNS |
| p-Bromodiphenyl ether | 101-55-3 | NNS | NNS | NNS | NNS | NNS | NNS |
| Bromoform | 75-25-2 | TTHM | 80 | 180 | 2800 | NNS | NNS |
| Bromomethane | 74-83-9 | 9.8 | 7500 | 200 | 200 | NNS | NNS |
| Butyl benzyl phthalate | 85-68-7 | 1400 | 5000 | 28000 | 28000 | NNS | NNS |

**Table 1. Human Health and Agricultural Designated Use Numeric Water Quality Criteria**

| PARAMETER | CAS[1] NUMBER | DWS[2] (µg/L) | FC[2] (µg/L) | FBC[2] (µg/L) | PBC[2] (µg/L) | AgI[2] (µg/L) | AgL[2] (µg/L) |
|---|---|---|---|---|---|---|---|
| Cadmium (as Cd) | 7440-43-9 | 5 T | 41 T | 70 T | 70 T | 50 T | 50 T |
| Carbofuran | 1563-66-2 | 40 | NNS | 700 | 700 | NNS | NNS |
| Carbon tetrachloride | 56-23-5 | 5 | 5.5 | 11 | 98 | NNS | NNS |
| Chlordane | 57-74-9 | 2 | 0.001 | 2 | 8.4 | NNS | NNS |
| Chlorine (total residual) | 7782-50-5 | NNS | NNS | 14000 | 14000 | NNS | NNS |
| Chlorobenzene | 108-90-7 | 100 | 500 | 2800 | 2800 | NNS | NNS |
| p-Chloro-m-cresol | 59-50-7 | NNS | NNS | NNS | NNS | NNS | NNS |
| 2-Chloroethyl vinyl ether | 110-75-8 | NNS | NNS | NNS | NNS | NNS | NNS |
| Chloroform | 67-66-3 | TTHM | 590 | 230 | 1400 | NNS | NNS |
| Chloromethane | 74-87-3 | NNS | NNS | NNS | NNS | NNS | NNS |
| Chloronapthalene beta | 91-58-7 | 560 | 13000 | 11000 | 11000 | NNS | NNS |
| 2-Chlorophenol | 95-57-8 | 35 | 2100 | 700 | 700 | NNS | NNS |
| 4-Chlorophenyl phenyl ether | 7005-72-3 | NNS | NNS | NNS | NNS | NNS | NNS |
| Chromium (as Cr III) | 16065-83-1 | NNS | 67000 T | 140000 T | 140000 T | NNS | NNS |
| Chromium (as Cr VI) | 18540-29-9 | NNS | 3400 T | 700 T | 700 T | NNS | NNS |
| Chromium (Total as Cr) | 7440-47-3 | 100 T | NNS | NNS | NNS | 1000 T | 1000 T |
| Chrysene | 218-01-9 | 0.003 | .0001 | 0.12 | NNS | NNS | NNS |
| Copper (as Cu) | 7440-50-8 | 1000 D | NNS | 5200 D | 5200 D | 5000 T | 500 T |
| Cyanide | 57-12-5 | 200 T | 210000 T | 2800 T | 2800 T | NNS | 200 T |
| Dibenz (ah) anthracene | 53-70-3 | 0.003 | 0.00003 | 0.12 | NNS | NNS | NNS |
| Dibromochloromethane | 124-48-1 | TTHM | 12 | 17 | 2800 | NNS | NNS |
| 1,2-Dibromo-3-chloropropane (DBCP) | 96-12-8 | 0.2 | NNS | NNS | NNS | NNS | NNS |
| 1,2-Dibromoethane (EDB) | 106-93-4 | 0.05 | NNS | 1.6 | NNS | NNS | NNS |
| Dibutyl phthalate | 84-74-2 | 700 | 2300 | 14000 | 14000 | NNS | NNS |
| 1,2-Dichlorobenzene | 95-50-1 | 600 | 2800 | 13000 | 13000 | NNS | NNS |
| 1,3-Dichlorobenzene | 541-73-1 | 94 | 2000 | 1880 | 1880 | NNS | NNS |
| 1,4-Dichloroenzene | 106-46-7 | 75 | 1200 | 1880 | 1880 | NNS | NNS |
| 3,3'-Dichlorobenzidine | 91-94-1 | 0.08 | 0.09 | 3.1 | NNS | NNS | NNS |
| p,p'-Dichlorodiphenyldichloroethane (DDD) | 72-54-8 | 0.15 | 0.0009 | 5.8 | NNS | 0.001 | 0.001 |
| p,p'-Dichlorodiphenyldichloroethylene (DDE) | 72-55-9 | 0.1 | 0.0006 | 4.1 | NNS | 0.001 | 0.001 |
| p,p'-Dichlorodiphenyltrichloroethane (DDT) | 50-29-3 | 0.1 | 0.0005 | 4.1 | 70 | 0.001 | 0.001 |

**Table 1. Human Health and Agricultural Designated Use Numeric Water Quality Criteria**

| PARAMETER | CAS[1] NUMBER | DWS[2] (µg/L) | FC[2] (µg/L) | FBC[2] (µg/L) | PBC[2] (µg/L) | AgI[2] (µg/L) | AgL[2] (µg/L) |
|---|---|---|---|---|---|---|---|
| 1,1-Dichloroethane | 75-34-3 | NNS | NNS | NNS | NNS | NNS | NNS |
| 1,2-Dichloroethane | 107-06-2 | 5 | 120 | 15 | NNS | NNS | NNS |
| 1,1-Dichloroethylene | 75-35-4 | 7 | 4.5 | 7 | 1300 | NNS | NNS |
| 1,2-cis-Dichloroethylene | 156-59-2 | 70 | NNS | NNS | NNS | NNS | NNS |
| 1,2-trans-Dichloroethylene | 156-60-5 | 100 | 13000 | 2800 | 2800 | NNS | NNS |
| Dichloromethane | 75-09-2 | 5 | 480 | 190 | 8400 | NNS | NNS |
| 2,4-Dichlorophenol | 120-83-2 | 21 | 810 | 420 | 420 | NNS | NNS |
| 2,4-Dichlorophenoxyacetic acid (2,4-D) | 94-75-7 | 70 | NNS | 1400 | 1400 | NNS | NNS |
| 1,2-Dichloropropane | 78-87-5 | 5 | NNS | NNS | NNS | NNS | NNS |
| 1,3-Dichloropropene | 542-75-6 | 0.2 | 6.6 | 7.8 | 42 | NNS | NNS |
| Dieldrin | 60-57-1 | 0.002 | 0.0002 | 0.09 | 7 | k | k |
| Diethyl phthalate | 84-66-2 | 5600 | 110000 | 110000 | 110000 | NNS | NNS |
| Di(2-ethylhexyl) phthalate | 117-81-7 | 6 | 7.4 | 100 | 2800 | NNS | NNS |
| 2,4-Dimethylphenol | 105-67-9 | 140 | 2200 | 2800 | 2800 | NNS | NNS |
| Dimethyl phthalate | 131-11-3 | 70000 | 2800000 | 1400000 | 1400000 | NNS | NNS |
| 4,6-Dinitro-o-cresol | 534-52-1 | 2.7 | 120 | 55 | 55 | NNS | NNS |
| 2,4-Dinitrophenol | 51-28-5 | 14 | 5400 | 280 | 280 | NNS | NNS |
| 2,4-Dinitrotoluene | 121-14-2 | 14 | 163 | 280 | 280 | NNS | NNS |
| 2,6-Dinitrotoluene | 606-20-2 | NNS | NNS | NNS | NNS | NNS | NNS |
| Di-n-octyl phthalate | 117-84-0 | NNS | NNS | NNS | NNS | NNS | NNS |
| 1,2-Diphenylhydrazine | 122-66-7 | 0.04 | 0.25 | 1.8 | NNS | NNS | NNS |
| Endosulfan sulfate | 1031-07-8 | 0.35 | 0.78 | 7 | 7 | NNS | NNS |
| Endosulfan (Total) | 115-29-7 | 42 | 110 | 840 | 840 | NNS | NNS |
| Endrin | 72-20-8 | 0.2 | 1.1 | 40 | 40 | 0.004 | 0.004 |
| Endrin aldehyde | 7421-93-3 | 2.1 | 0.81 | 420 | 420 | NNS | NNS |
| Ethylbenzene | 100-41-4 | 700 | 110000 | 14000 | 14000 | NNS | NNS |
| Ethyl chloride | 75-00-3 | NNS | NNS | NNS | NNS | NNS | NNS |
| Fluoranthene | 206-44-0 | 280 | 130 | 5600 | 5600 | NNS | NNS |
| Fluorene | 86-73-7 | 280 | 580 | 5600 | 5600 | NNS | NNS |
| Fluorine | 7782-41-4 | 4000 | NNS | 8400 | 8400 | NNS | NNS |
| Heptachlor | 76-44-8 | 0.4 | 0.0002 | 0.4 | 70 | NNS | NNS |

**Table 1. Human Health and Agricultural Designated Use Numeric Water Quality Criteria**

| PARAMETER | CAS[1] NUMBER | DWS[2] (µg/L) | FC[2] (µg/L) | FBC[2] (µg/L) | PBC[2] (µg/L) | AgI[2] (µg/L) | AgL[2] (µg/L) |
|---|---|---|---|---|---|---|---|
| Heptachlor epoxide | 1024-57-3 | 0.2 | 0.0001 | 0.2 | 2 | NNS | NNS |
| Hexachlorobenzene | 118-74-1 | 1 | 0.002 | 1 | 280 | NNS | NNS |
| Hexachlorobutadiene | 87-68-3 | 0.45 | 0.52 | 18 | NNS | NNS | NNS |
| Hexachlorocyclohexane alpha | 319-84-6 | 0.006 | 0.03 | 0.22 | NNS | NNS | NNS |
| Hexachlorocyclohexane beta | 319-85-7 | 0.02 | 0.02 | 0.78 | NNS | NNS | NNS |
| Hexachlorocyclohexane delta | 319-86-8 | NNS | NNS | NNS | NNS | NNS | NNS |
| Hexachlorocyclohexane gamma (lindane) | 58-89-9 | 0.2 | 0.02 | 1 | 42 | NNS | NNS |
| Hexachlorocyclopentadiene | 77-47-4 | 50 | 550 | 1000 | 1000 | NNS | NNS |
| Hexachloroethane | 67-72-1 | 2.5 | 4.8 | 100 | 140 | NNS | NNS |
| Indeno (1,2,3-cd) pyrene | 193-39-5 | 0.003 | 0.000003 | 0.12 | NNS | NNS | NNS |
| Isophorone | 78-59-1 | 36.8 | 2300 | 1500 | 28000 | NNS | NNS |
| Lead (as Pb) | 7439-97-1 | 50 T | NNS | NNS | NNS | 10000 T | 100 T |
| Manganese (as Mn) | 7439-96-5 | 4900 T | NNS | 19600 T | 19600 T | 10000 | NNS |
| Mercury (as Hg) | 7439-97-6 | 2 T | 0.6 T | 42 T | 42 T | NNS | 10 T |
| Methoxychlor | 72-43-5 | 40 | NNS | 700 | 700 | NNS | NNS |
| Naphthalene | 91-20-3 | NNS | NNS | NNS | NNS | NNS | NNS |
| Nickel (as Ni) | 7440-02-0 | 100 T | 730 T | 2800 T | 2800 T | NNS | NNS |
| Nitrate (as N) | 14797-55-8 | 10000 | NNS | 224000 | 224000 | NNS | NNS |
| Nitrite (as N) | 14797-65-0 | 1000 | NNS | 14000 | 14000 | NNS | NNS |
| Nitrate/Nitrite (as Total N) | | 10000 | NNS | NNS | NNS | NNS | NNS |
| Nitrobenzene | 98-95-3 | 3.5 | 600 | 70 | 70 | NNS | NNS |
| o-Nitrophenol | 88-75-5 | NNS | NNS | NNS | NNS | NNS | NNS |
| p-Nitrophenol | 100-02-7 | NNS | NNS | NNS | NNS | NNS | NNS |
| N-nitrosodimethylamine | 62-75-9 | 0.0007 | 2.1 | 0.03 | NNS | NNS | NNS |
| N-nitrosodiphenylamine | 86-30-6 | 7.1 | 14 | 290 | NNS | NNS | NNS |
| N-nitrosodi-n-propylamine | 621-64-7 | 0.005 | 0.51 | 0.2 | NNS | NNS | NNS |
| Pentachlorophenol | 87-86-5 | 1 | 8.2 | 11.7 | 2000 | NNS | NNS |
| Phenanthrene | 85-01-8 | NNS | NNS | NNS | NNS | NNS | NNS |
| Phenol | 108-95-2 | 4200 | 6500000 | 84000 | 84000 | NNS | NNS |

**Table 1. Human Health and Agricultural Designated Use Numeric Water Quality Criteria**

| PARAMETER | CAS[1] NUMBER | DWS[2] (µg/L) | FC[2] (µg/L) | FBC[2] (µg/L) | PBC[2] (µg/L) | AgI[2] (µg/L) | AgL[2] (µg/L) |
|---|---|---|---|---|---|---|---|
| Polychlorinatedbiphenyls (PCBs) | 1336-36-3 | 0.5 | 0.00009 | 0.5 | NNS | 0.001 | 0.001 |
| Pyrene | 129-00-0 | 210 | 1100 | 4200 | 4200 | NNS | NNS |
| Selenium (as Se) | 7782-49-2 | 50 T | 9000 T | 700 T | 700 T | 20 T | 50 T |
| Silver (as Ag) | 7440-22-4 | NNS | NNS | NNS | NNS | NNS | NNS |
| Styrene | 100-42-5 | 100 | NNS | 28000 | 28000 | NNS | NNS |
| Sulfides | | NNS | NNS | NNS | NNS | NNS | NNS |
| 2,3,7,8-Tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) | 1746-01-6 | 0.0000003 | 0.000000004 | 0.00009 | NNS | NNS | NNS |
| 1,1,2,2-Tetrachloroethane | 79-34-5 | 0.17 | 11 | 7 | NNS | NNS | NNS |
| Tetrachloroethylene | 127-18-4 | 5 | 11 | 35 | 1400 | NNS | NNS |
| Thallium (as Tl) | 7440-28-0 | 2 T | 41 T | 12 T | 12 T | NNS | NNS |
| Toluene | 108-88-3 | 1000 | 90000 | 28000 | 28000 | NNS | NNS |
| Toxaphene | 8001-35-2 | 3 | 0.0008 | 3 | NNS | 0.005 | 0.005 |
| 1,2,4-Trichlorobenzene | 120-82-1 | 70 | 155 | 1400 | 1400 | NNS | NNS |
| 1,1,1-Trichloroethane | 71-55-6 | 200 | NNS | NNS | NNS | NNS | NNS |
| 1,1,2-Trichloroethane | 79-00-5 | 5 | 31 | 25 | 560 | NNS | NNS |
| Trichloroethylene | 79-01-6 | 5 | NNS | NNS | NNS | NNS | NNS |
| 2,4,6-Trichlorophenol | 88-06-2 | 3.2 | 4.9 | 130 | NNS | NNS | NNS |
| 2-(2,4,5-Trichlorophenoxy) proprionic acid (2,4,5-TP) | 93-72-1 | 50 | NNS | 1120 | 1120 | NNS | NNS |
| Trihalomethanes, Total | | 100 | NNS | NNS | NNS | NNS | NNS |
| Uranium (as Ur) | 7440-61-1 | 35 D | NNS | NNS | NNS | NNS | NNS |
| Vinyl chloride | 75-01-4 | 2 | 620 | 80 | NNS | NNS | NNS |
| Xylenes (Total) | 1330-20-7 | 10000 | NNS | 280000 | 280000 | NNS | NNS |
| Zinc (as Zn) | 7440-66-6 | 2100 T | 22000 T | 42000 T | 42000 T | 10000 T | 25000 T |

**Historical Note**

Appendix A repealed, new Appendix A, Table 1 adopted effective April 24, 1996 (Supp. 96-2).

**APPENDIX A. Numeric Water Quality Criteria**

**Table 2. Aquatic & Wildlife Designated Use Numeric Water Quality Criteria**

| PARAMETER | CAS[1] NUMBER | A&Wc Acute3 (µg/L) | A&Wc Chronic4 (µg/L) | A&Ww Acute3 (µg/L) | A&Ww Chronic4 (µg/L) | A&Wedw Acute3 (µg/L) | A&Wedw Chronic4 (µg/L) | A&We Acute3 (µg/L) | A&We Chronic4 (µg/L) |
|---|---|---|---|---|---|---|---|---|---|
| Acenaphthene | 83-32-9 | 850 | 550 | 850 | 550 | 850 | 550 | NNS | NNS |
| Acenaphthylene | 208-96-8 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Acrolein | 107-02-8 | 34 | 30 | 34 | 30 | 34 | 30 | NNS | NNS |
| Acrylonitrile | 107-13-1 | 3800 | 250 | 3800 | 250 | 3800 | 250 | NNS | NNS |
| Alachlor | 15972-60-8 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Aldrin | 309-00-2 | 2.0 | NNS | 2.0 | NNS | 2.0 | NNS | 4.5 | NNS |
| Ammonia | 7664-41-7 | b | b | b | b | NNS | NNS | NNS | NNS |
| Anthracene | 120-12-7 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Antimony (as Sb) | 7440-36-0 | 88 D | 30 D | 88 D | 30 D | 1000 D | 600 D | NNS | NNS |
| Arsenic (as As) | 7440-38-2 | 360 D | 190 D | 360 D | 190 D | 360 D | 190 D | 440 D | 230 D |
| Asbestos | 1332-21-4 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Atrazine | 1912-24-9 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Barium (as Ba) | 7440-39-3 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Benzene | 71-43-2 | 2700 | 180 | 2700 | 180 | 11000 | 700 | NNS | NNS |
| Benzidine | 92-87-5 | 1300 | 89 | 1300 | 89 | 1300 | 89 | 10000 | 640 |
| Benz (a) anthracene | 56-55-3 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Benzo (a) pyrene | 50-32-8 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Benzo (ghi) perylene | 191-24-2 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Benzo (k) fluoranthene | 207-08-9 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| 3,4-Benzofluoranthene | 205-99-2 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Beryllium (as Be) | 7440-41-7 | 65 D | 5.3 D | 65 D | 5.3 D | 65 D | 5.3 D | NNS | NNS |
| Bis (2-chloroethoxy) methane | 111-91-1 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Bis (2-chlorethyl) ether | 111-44-4 | 120000 | 6700 | 120000 | 6700 | 120000 | 6700 | NNS | NNS |
| Bis (2-chloroisopropyl) ether | 108-60-1 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Boron (as B) | 7440-42-8 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Bromodichloromethane | 75-27-4 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| p-Bromodiphenyl ether | 101-55-3 | 180 | 14 | 180 | 14 | 180 | 14 | NNS | NNS |
| Bromoform | 75-25-2 | 15000 | 10000 | 15000 | 10000 | 15000 | 10000 | NNS | NNS |
| Bromomethane | 74-83-9 | 5500 | 360 | 5500 | 360 | 5500 | 360 | NNS | NNS |
| Butyl benzyl phthalate | 85-68-7 | 1700 | 130 | 1700 | 130 | 1700 | 130 | NNS | NNS |

**Table 2. Aquatic & Wildlife Designated Use Numeric Water Quality Criteria**

| PARAMETER | CAS[1] NUMBER | A&Wc Acute3 (µg/L) | A&Wc Chronic4 (µg/L) | A&Ww Acute3 (µg/L) | A&Ww Chronic4 (µg/L) | A&Wedw Acute3 (µg/L) | A&Wedw Chronic4 (µg/L) | A&We Acute3 (µg/L) | A&We Chronic4 (µg/L) |
|---|---|---|---|---|---|---|---|---|---|
| Cadmium (as Cd) | 7440-43-9 | c D | c D | c D | c D | c D | c D | c D | c D |
| Carbofuran | 1563-66-2 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Carbon tetrachloride | 56-23-5 | 18000 | 1100 | 18000 | 1100 | 18000 | 1100 | NNS | NNS |
| Chlordane | 57-74-9 | 2.4 | 0.004 | 2.4 | 0.21 | 2.4 | 0.21 | 3.2 | 0.45 |
| Chlorine (total residual) | 7782-50-5 | 11 | 5.0 | 11 | 5.0 | 11 | 5.0 | NNS | NNS |
| Chlorobenzene | 108-90-7 | 9800 | 620 | 9800 | 620 | NNS | NNS | NNS | NNS |
| p-Chloro-m-cresol | 59-50-7 | 15 | 4.7 | 15 | 4.7 | 15 | 4.7 | 48000 | 15000 |
| 2-Chloroethyl vinyl ether | 110-75-8 | 180000 | 9800 | 180000 | 9800 | 180000 | 9800 | NNS | NNS |
| Chloroform | 67-66-3 | 14000 | 900 | 14000 | 900 | 14000 | 900 | NNS | NNS |
| Chloromethane | 74-87-3 | 270000 | 15000 | 270000 | 15000 | 270000 | 15000 | NNS | NNS |
| Chloronapthalene beta | 91-58-7 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| 2-Chlorophenol | 95-57-8 | 2200 | 150 | 2200 | 150 | 2200 | 150 | NNS | NNS |
| 4-Chlorophenyl phenyl ether | 7005-72-3 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Chromium (as Cr III) | 16065-83-1 | d D | d D | d D | d D | d D | d D | d D | d D |
| Chromium (as Cr VI) | 18540-29-9 | 16 D | 11 D | 16 D | 11 D | 16 D | 11 D | 34 D | 23 D |
| Chromium (Total as Cr) | 7440-47-3 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Chrysene | 218-01-9 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Copper (as Cu) | 7440-50-8 | e D | e D | e D | e D | e D | e D | e D | e D |
| Cyanide | 57-12-5 | 22 T | 5.2 T | 41 T | 9.7 T | 41 T | 9.7 T | 84 T | 19 T |
| Dibenz (ah) anthracene | 53-70-3 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Dibromochloromethane | 124-48-1 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| 1,2-Dibromo-3-chloropropane (DBCP) | 96-12-8 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| 1,2-Dibromoethane (EDB) | 106-93-4 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Dibutyl phthalate | 84-74-2 | 470 | 35 | 470 | 35 | 470 | 35 | 1100 | 84 |
| 1,2-Dichlorobenzene | 95-50-1 | 790 | 300 | 1200 | 470 | 1200 | 470 | 5900 | 2300 |
| 1,3-Dichlorobenzene | 541-73-1 | 2500 | 970 | 2500 | 970 | 2500 | 970 | NNS | NNS |
| 1,4-Dichlorobenzene | 106-46-7 | 560 | 210 | 2000 | 780 | 2000 | 780 | 6500 | 2500 |
| 3,3'-Dichlorobenzidine | 91-94-1 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| p,p'-Dichlorodiphenyldichloroethane (DDD) | 72-54-8 | 1.1 | 0.001 | 1.1 | 0.02 | 1.1 | 0.02 | 1.1 | 0.02 |
| p,p'-Dichlorodiphenyldichloroethylene (DDE) | 72-55-9 | 1.1 | 0.001 | 1.1 | 0.02 | 1.1 | 0.02 | 1.1 | 0.03 |

**Table 2. Aquatic & Wildlife Designated Use Numeric Water Quality Criteria**

| PARAMETER | CAS[1] NUMBER | A&Wc Acute3 (µg/L) | A&Wc Chronic4 (µg/L) | A&Ww Acute3 (µg/L) | A&Ww Chronic4 (µg/L) | A&Wedw Acute3 (µg/L) | A&Wedw Chronic4 (µg/L) | A&We Acute3 (µg/L) | A&We Chronic4 (µg/L) |
|---|---|---|---|---|---|---|---|---|---|
| p,p'-Dichlorodiphenyltrichloroethane (DDT) | 50-29-3 | 1.1 | 0.001 | 1.1 | 0.001 | 1.1 | 0.001 | 1.1 | 0.006 |
| 1,1-Dichloroethane | 75-34-3 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| 1,2-Dichloroethane | 107-06-2 | 59000 | 41000 | 59000 | 41000 | 59000 | 41000 | NNS | NNS |
| 1,1-Dichloroethylene | 75-35-4 | 15000 | 950 | 15000 | 950 | 15000 | 950 | NNS | NNS |
| 1,2-cis-Dichloroethylene | 156-59-2 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| 1,2-trans-Dichloroethylene | 156-60-5 | 68000 | 3900 | 68000 | 3900 | 68000 | 3900 | NNS | NNS |
| Dichloromethane | 75-09-2 | 97000 | 5500 | 97000 | 5500 | 97000 | 5500 | NNS | NNS |
| 2,4-Dichlorophenol | 120-83-2 | 1000 | 88 | 1000 | 88 | 1000 | 88 | NNS | NNS |
| 2,4-Dichlorophenoxyacetic acid (2,4-D) | 94-75-7 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| 1,2-Dichloropropane | 78-87-5 | 26000 | 9200 | 26000 | 9200 | 26000 | 9200 | NNS | NNS |
| 1,3-Dichloropropene | 542-75-6 | 3000 | 1100 | 3000 | 1100 | 3000 | 1100 | NNS | NNS |
| Dieldrin | 60-57-1 | 2.5 | 0.002 | 2.5 | 0.002 | 2.5 | 0.005 | 4 | 0.9 |
| Diethyl phthalate | 84-66-2 | 26000 | 1600 | 26000 | 1600 | 26000 | 1600 | NNS | NNS |
| Di(2-ethylhexyl) phthalate | 117-81-7 | 400 | 360 | 400 | 360 | 400 | 360 | 3100 | 360 |
| 2,4-Dimethylphenol | 105-67-9 | 1000 | 310 | 1000 | 310 | 1100 | 310 | 150000 | 43000 |
| Dimethyl phthalate | 131-11-3 | 17000 | 1000 | 17000 | 1000 | 17000 | 1000 | NNS | NNS |
| 4,6-Dinitro-o-cresol | 534-52-1 | 310 | 24 | 310 | 24 | 310 | 24 | NNS | NNS |
| 2,4-Dinitrophenol | 51-28-5 | 110 | 9.2 | 110 | 9.2 | 110 | 9.2 | NNS | NNS |
| 2,4-Dinitrotoluene | 121-14-2 | 15000 | 970 | 15000 | 970 | 15000 | 970 | NNS | NNS |
| 2,6-Dinitrotoluene | 606-20-2 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Di-n-octyl phthalate | 117-84-0 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| 1,2-Diphenylhydrazine | 122-66-7 | 130 | 11 | 130 | 11 | 130 | 11 | NNS | NNS |
| Endosulfan sulfate | 1031-07-8 | 0.22 | 0.06 | 0.22 | 0.06 | 0.22 | 0.06 | 3.0 | 1.5 |
| Endosulfan (Total) | 115-29-7 | 0.22 | 0.06 | 0.22 | 0.06 | 0.22 | 0.06 | 3.0 | 1.5 |
| Endrin | 72-20-8 | 0.18 | 0.002 | 0.2 | 0.08 | 0.2 | 0.08 | 0.7 | 0.3 |
| Endrin aldehyde | 7421-93-3 | 0.18 | 0.002 | 0.2 | 0.08 | 0.2 | 0.08 | 0.7 | 0.3 |
| Ethylbenzene | 100-41-4 | 23000 | 1400 | 23000 | 1400 | 23000 | 1400 | NNS | NNS |
| Ethyl chloride | 75-00-3 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Fluoranthene | 206-44-0 | 2000 | 1600 | 2000 | 1600 | 2000 | 1600 | NNS | NNS |

**Table 2. Aquatic & Wildlife Designated Use Numeric Water Quality Criteria**

| PARAMETER | CAS[1] NUMBER | A&Wc Acute3 (μg/L) | A&Wc Chronic4 (μg/L) | A&Ww Acute3 (μg/L) | A&Ww Chronic4 (μg/L) | A&Wedw Acute3 (μg/L) | A&Wedw Chronic4 (μg/L) | A&We Acute3 (μg/L) | A&We Chronic4 (μg/L) |
|---|---|---|---|---|---|---|---|---|---|
| Fluorene | 86-73-7 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Fluorine | 7782-41-4 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Heptachlor | 76-44-8 | 0.52 | 0.004 | 0.52 | 0.004 | 0.58 | 0.013 | 0.9 | 0.1 |
| Heptachlor epoxide | 1024-57-3 | 0.52 | 0.004 | 0.52 | 0.004 | 0.58 | 0.013 | 0.9 | 0.1 |
| Hexachlorobenzene | 118-74-1 | 6.0 | 3.7 | NNS | NNS | NNS | NNS | NNS | NNS |
| Hexachlorobutadiene | 87-68-3 | 45 | 8.2 | 45 | 8.2 | 45 | 8.2 | NNS | NNS |
| Hexachlorocyclohexane alpha | 319-84-6 | 1600 | 130 | 1600 | 130 | 1600 | 130 | 1600 | 130 |
| Hexachlorocyclohexane beta | 319-85-7 | 1600 | 130 | 1600 | 130 | 1600 | 130 | 1600 | 130 |
| Hexachlorocyclohexane delta | 319-86-8 | 1600 | 130 | 1600 | 130 | 1600 | 130 | 1600 | 130 |
| Hexachlorocyclohexane gamma (lindane) | 58-89-9 | 2.0 | 0.08 | 3.4 | 0.28 | 7.6 | 0.61 | 11 | 0.9 |
| Hexachlorocyclopentadiene | 77-47-4 | 3.5 | 0.3 | 3.5 | 0.3 | 3.5 | 0.3 | NNS | NNS |
| Hexachloroethane | 67-72-1 | 490 | 350 | 490 | 350 | 490 | 350 | 850 | 610 |
| Indeno (1,2,3-cd) pyrene | 193-39-5 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Isophorone | 78-59-1 | 59000 | 43000 | 59000 | 43000 | 59000 | 43000 | NNS | NNS |
| Lead (as Pb) | 7439-97-1 | f D | f D | f D | f D | f D | f D | f D | f D |
| Manganese (as Mn) | 7439-96-5 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Mercury (as Hg) | 7439-97-6 | 2.4 D | 0.01 D | 2.4 D | 0.01 D | 2.6 D | 0.2 D | 5.0 D | 2.7 D |
| Methoxychlor | 72-43-5 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Naphthalene | 91-20-3 | 1100 | 210 | 3300 | 600 | 3300 | 600 | NNS | NNS |
| Nickel (as Ni) | 7440-02-0 | g D | g D | g D | g D | g D | g D | g D | g D |
| Nitrate (as N) | 14797-55-8 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Nitrite (as N) | 14797-65-0 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Nitrate/Nitrite (as Total N) | | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Nitrobenzene | 98-95-3 | 1300 | 850 | 1300 | 850 | 1300 | 850 | NNS | NNS |
| o-Nitrophenol | 88-75-5 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| p-Nitrophenol | 100-02-7 | 4100 | 3000 | 4100 | 3000 | 4100 | 3000 | NNS | NNS |
| N-nitrosodimethylamine | 62-75-9 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| N-nitrosodiphenylamine | 86-30-6 | 2900 | 200 | 2900 | 200 | 2900 | 200 | NNS | NNS |
| N-nitrosodi-n-propylamine | 621-64-7 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Pentachlorophenol | 87-86-5 | h | h | h | h | h | h | h | h |

**Table 2. Aquatic & Wildlife Designated Use Numeric Water Quality Criteria**

| PARAMETER | CAS[1] NUMBER | A&Wc Acute3 (µg/L) | A&Wc Chronic4 (µg/L) | A&Ww Acute3 (µg/L) | A&Ww Chronic4 (µg/L) | A&Wedw Acute3 (µg/L) | A&Wedw Chronic4 (µg/L) | A&We Acute3 (µg/L) | A&We Chronic4 (µg/L) |
|---|---|---|---|---|---|---|---|---|---|
| Phenanthrene | 85-01-8 | 30 | 6.3 | 30 | 6.3 | 54 | 6.3 | NNS | NNS |
| Phenol | 108-95-2 | 5100 | 730 | 7000 | 1000 | 7000 | 1000 | 180000 | 26000 |
| Polychlorinatedbiphenyls (PCBs) | 1336-36-3 | 2.0 | 0.01 | 2.0 | 0.02 | 2.0 | 0.02 | 11 | 2.5 |
| Pyrene | 129-00-0 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Selenium (as Se) | 7782-49-2 | 20 T | 2.0 T | 20 T | 2.0 T | 50 T | 2.0 T | 33 T | 2.0 T |
| Silver (as Ag) | 7440-22-4 | i D | NNS | i D | NNS | i D | NNS | i D | NNS |
| Styrene | 100-42-5 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Sulfides | | 100 | NNS | 100 | NNS | 100 | NNS | 100 | NNS |
| 2,3,7,8-Tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) | 1746-01-6 | 0.01 | 0.005 | 0.01 | 0.005 | 0.12 | 0.01 | 0.1 | 0.01 |
| 1,1,2,2-Tetrachloroethane | 79-34-5 | 4700 | 3200 | 4700 | 3200 | 4700 | 3200 | NNS | NNS |
| Tetrachloroethylene | 127-18-4 | 2600 | 280 | 6500 | 680 | 6500 | 680 | 15000 | 1600 |
| Thallium (as Tl) | 7440-28-0 | 700 D | 150 D | 700 D | 150 D | 700 D | 150 D | NNS | NNS |
| Toluene | 108-88-3 | 8700 | 180 | 8700 | 180 | 8700 | 180 | NNS | NNS |
| Toxaphene | 8001-35-2 | 0.73 | 0.0002 | 0.73 | 0.02 | 0.73 | 0.02 | 11 | 1.5 |
| 1,2,4-Trichlorobenzene | 120-82-1 | 750 | 130 | 1700 | 300 | NNS | NNS | NNS | NNS |
| 1,1,1-Trichloroethane | 71-55-6 | 2600 | 1600 | 2600 | 1600 | 2600 | 1600 | NNS | NNS |
| 1,1,2-Trichloroethane | 79-00-5 | 18000 | 12000 | 18000 | 12000 | 18000 | 12000 | NNS | NNS |
| Trichloroethylene | 79-01-6 | 20000 | 1300 | 20000 | 1300 | 20000 | 1300 | NNS | NNS |
| 2,4,6-Trichlorophenol | 88-06-2 | 160 | 25 | 160 | 25 | 160 | 25 | 3000 | 460 |
| 2-(2,4,5-Trichlorophenoxy) proprionic acid (2,4,5-TP) | 93-72-1 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Trihalomethanes, Total | | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Uranium (as Ur) | 7440-61-1 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Vinyl chloride | 75-01-4 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Xylenes (Total) | 1330-20-7 | NNS | NNS | NNS | NNS | NNS | NNS | NNS | NNS |
| Zinc (as Zn) | 7440-66-6 | j D | j D | j D | j D | j D | j D | j D | j D |

Footnotes

a - The standard to protect this use is 7 million fibers (longer than 10 micrometers) per liter.

b - Values for ammonia are contained in separate tables located at the end of Appendix A.

c - Cadmium A&Wc acute standard: $e^{(1.128\,[\ln(\text{Hardness})]\,-\,3.828)}$
A&Wc chronic standard: $e^{(0.7852\,[\ln(\text{Hardness})]\,-\,3.490)}$
A&Ww acute standard: $e^{(1.128\,[\ln(\text{Hardness})]\,-\,2.0149)}$
A&Ww chronic standard: $e^{(0.7852\,[\ln(\text{Hardness})]\,-3.490)}$
A&Wedw acute standard: $e^{(1.128\,[\ln(\text{Hardness})]\,-\,2.0149)}$
A&Wêdw chronic standard: $e^{(0.7852\,[\ln(\text{Hardness})]\,-\,3.490)}$
A&We acute standard: $e^{(1.128\,[\ln(\text{Hardness})]\,-\,0.9691)}$
A&We chronic standard: $e^{(0.7852\,[\ln(\text{Hardness})]\,-\,3.490)}$
(See Footnote 5)

d - Chromium III A&Wc acute standard: $e^{(0.8190\,[\ln(\text{Hardness})]\,+\,3.688)}$
A&Wc chronic standard: $e^{(0.8190\,[\ln(\text{Hardness})]\,+\,1.561)}$
A&Ww acute standard: $e^{(0.8190\,[\ln(\text{Hardness})]\,+\,3.688)}$

A&Ww chronic standard: $e^{(0.8190 [\ln(Hardness)] + 1.561)}$
A&Wedw acute standard: $e^{(0.8190 [\ln(Hardness)] + 4.9361)}$
A&Wedw chronic standard: $e^{(0.8190 [\ln(Hardness)] + 1.561)}$
A&We acute standard: $e^{(0.8190 [\ln(Hardness)] + 3.688)}$
A&We chronic standard: $e^{(0.8190 [\ln(Hardness)] + 1.561)}$
(See Footnote 5)

e -Copper A&Wc acute standard: $e^{(0.9422 [\ln(Hardness)] - 1.464)}$
A&Wc chronic standard: $e^{(0.8545 [\ln(Hardness)] - 1.465)}$
A&Ww acute standard: $e^{(0.9422 [\ln(Hardness)] - 1.464)}$
A&Ww chronic standard: $e^{(0.8545 [\ln(Hardness)] - 1.465)}$
A&Wedw acute standard: $e^{(0.9422 [\ln(Hardness)] - 1.464)}$
A&Wedw chronic standard: $e^{(0.8545 [\ln(Hardness)] - 1.465)}$
A&We acute standard: $e^{(0.9422 [\ln(Hardness)] - 1.1514)}$
A&We chronic standard: $e^{(0.8545 [\ln(Hardness)] - 1.1448)}$
(See Footnote 5)

f - Lead A&Wc acute standard: $e^{(1.2730 [\ln(Hardness)] - 1.460)}$
A&Wc chronic standard: $e^{(1.2730 [\ln(Hardness)] - 4.705)}$
A&Ww acute standard: $e^{(1.2730 [\ln(Hardness)] - 1.460)}$
A&Ww chronic standard: $e^{(1.2730 [\ln(Hardness)] - 4.705)}$
A&Wedw acute standard: $e^{(1.2730 [\ln(Hardness)] - 1.460)}$
A&Wedw chronic standard: $e^{(1.2730 [\ln(Hardness)] - 4.705)}$
A&We acute standard: $e^{(1.2730 [\ln(Hardness)] - 0.7131)}$
A&We chronic standard: $e^{(1.2730 [\ln(Hardness)] - 3.9518)}$
(See Footnote 5)

g - Nickel A&Wc acute standard: $e^{(0.8460 [\ln(Hardness)] + 3.3611)}$
A&Wc chronic standard: $e^{(0.8460 [\ln(Hardness)] + 1.1644)}$
A&Ww acute standard: $e^{(0.8460 [\ln(Hardness)] + 3.3611)}$
A&Ww chronic standard: $e^{(0.8460 [\ln(Hardness)] + 1.1644)}$
A&Wedw acute standard: $e^{(0.8460 [\ln(Hardness)] + 3.3611)}$
A&Wedw chronic standard: $e^{(0.8460 [\ln(Hardness)] + 1.1644)}$
A&We acute standard: $e^{(0.8460 [\ln(Hardness)] + 4.4389)}$
A&We chronic standard: $e^{(0.8460 [\ln(Hardness)] + 2.2417)}$
(See Footnote 5)

h - Pentachlorophenol A&Wc acute standard: $e^{(1.005 (pH) - 4.830)}$
A&Wc chronic standard: $e^{(1.005 (pH) - 5.290)}$
A&Ww acute standard: $e^{(1.005 (pH) - 4.830)}$
A&Ww chronic standard: $e^{(1.005 (pH) - 5.290)}$
A&Wedw acute standard: $e^{(1.005 (pH) - 4.830)}$
A&Wedw chronic standard: $e^{(1.005 (pH) - 5.290)}$
A&We acute standard: $e^{(1.005 (pH) - 3.4306)}$
A&We chronic standard: $e^{(1.005 (pH) - 3.9006)}$
(See Footnote 6)

i - Silver A&Wc acute standard: $e^{(1.72 [\ln(Hardness)] - 6.52)}$
A&Ww acute standard: $e^{(1.72 [\ln(Hardness)] - 6.52)}$
A&Wedw acute standard: $e^{(1.72 [\ln(Hardness)] - 6.52)}$
A&We acute standard: $e^{(1.72 [\ln(Hardness)] - 6.52)}$
(See Footnote 5)

j - Zinc A&Wc acute standard: $e^{(0.8473 [\ln(Hardness)] + 0.860)}$
A&Wc chronic standard: $e^{(0.8473 [\ln(Hardness)] + 0.761)}$
A&Ww acute standard: $e^{(0.8473 [\ln(Hardness)] + 0.860)}$
A&Ww chronic standard: $e^{(0.8473 [\ln(Hardness)] + 0.761)}$
A&Wedw acute standard: $e^{(0.8473 [\ln(Hardness)] + 0.860)}$
A&Wedw chronic standard: $e^{(0.8473 [\ln(Hardness)] + 0.761)}$
A&We acute standard: $e^{(0.8473 [\ln(Hardness)] + 3.1342)}$
A&We chronic standard: $e^{(0.8473 [\ln(Hardness)] + 3.0484)}$
(See Footnote 5)

k - The standard to protect this use is 0.003 ug/l aldrin/dieldrin.

1 - Chemical Abstract System (CAS) number is a unique identification number given to each chemical.

2 - The numeric standards to protect this use shall not be exceeded.

3 - Determination of compliance with acute standards shall be as prescribed in R18-11-120.C.

4 - Determination of compliance with chronic standards shall be as prescribed in R18-11-120.C.

5 - Hardness, expressed as mg/L $CaCO_3$, is inserted into the equation where it says "Hardness". Hardness is determined according to the following criteria:

a. If the receiving water body has an A&Wc or A&Ww designated use, then hardness is based on the hardness of the receiving water body from a sample taken at the same time that the sample for the metal is taken, except that the hardness may not exceed 400 mg/L $CaCO_3$.

b. If the receiving water body has an A&Wedw or A&We designated use, then the hardness is based on the hardness of the effluent from a sample taken at the same time that the sample for the metal is taken, except that the hardness may not exceed 400 mg/L $CaCO_3$.

6 - The pH is inserted into the equation where it says "pH". pH is determined according to the following criteria:

a. If the receiving water body has an A&Wc or A&Ww designated use, then pH is based on the pH of the receiving water body from a sample taken at the same time that the sample for pentachlorophenol is taken.

b. If the receiving water body has an A&Wedw or A&We designated use, then the pH is based on the pH of the effluent from a sample taken at the same time that the sample for pentachlorophenol is taken.

µg/L -micrograms per liter
NNS - No numeric standard.
D - Dissolved
T -Total recoverable
TTHM -Indicates that the chemical is a trihalomethane. See Trihalomethanes, Total for DWS standard.

# Appendix D

## Evaporation Rate Data

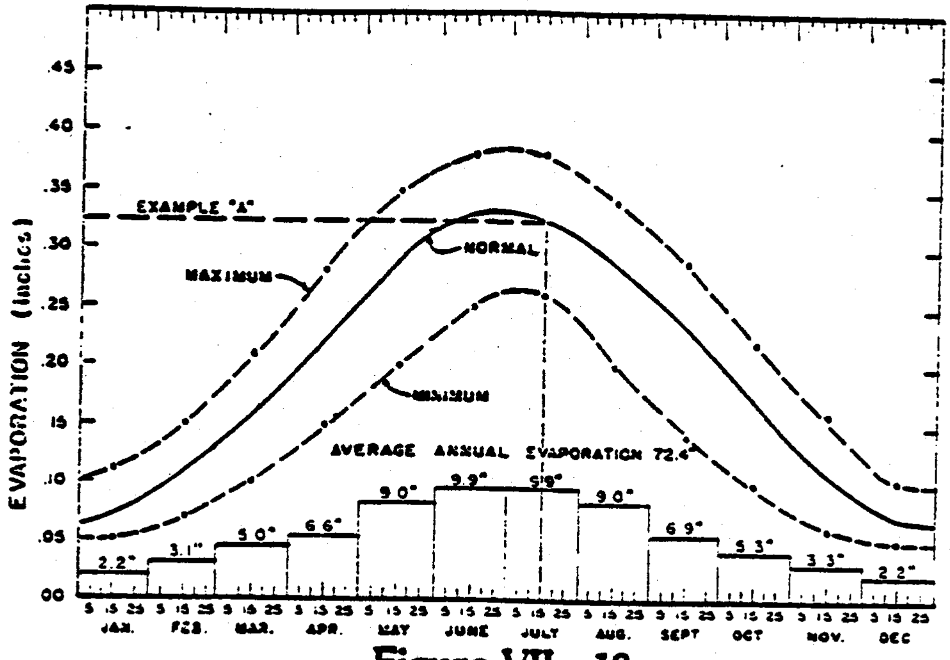


**Figure VII - 19**

**Maximum, Normal and Minimum Daily Evaporation and Average Monthly Evaporation From Open Water Surfaces (Adjustment Factor = 1.00)**

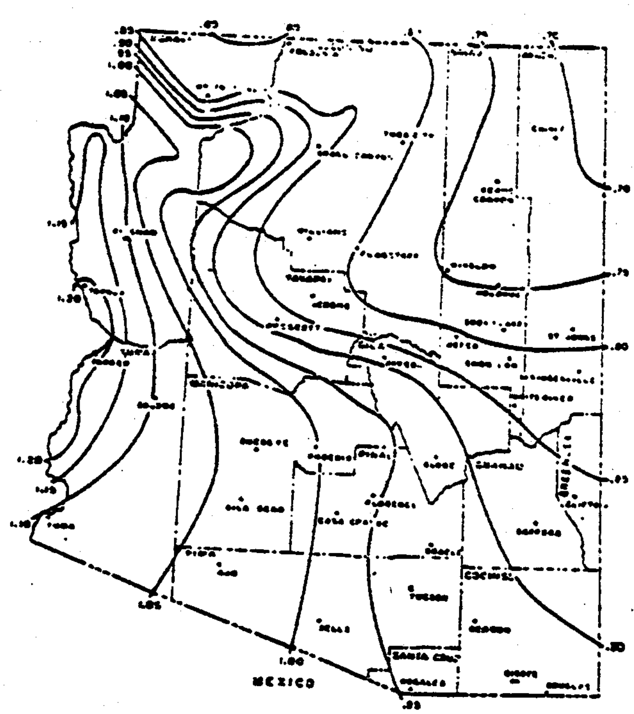


***Figure VII* - 20**

**Evaporation Adjustment Factors for Arizona**

# Appendix E

## ADEQ Dry Well Permit Information

*Arizona Department of Environmental Quality*

DRY WELL PROGRAM

## Aquifer Protection Permit Determination of Applicability
## For Dry Well(s) Revised 11-19-96

**For ADEQ Use Only**

| | |
|---|---|
| **Registration Numbers:**<br>- - through | ☐ **Incomplete.** Please submit this form with the additional information requested (see items circled below) within 30 days of |
| **Reviewed by**__________ Date________<br>Water Protection Approvals & Permits Section<br>Industrial and Dry Well Unit<br>Telephone No. (602) 207-4686 | **APP required.**<br>☐ Complete and submit the enclosed APP application within 90 days of ________. (APP application packet attached)<br>☐ A future APP application will be required. ADEQ will notify owner/operator at least 90 days before application is due. |

☐ On ________, you were notified that additional information is required to complete the applicability form. If information requested in this form is not submitted within 45 days of ________, your facility will be **referred to compliance for further action.**

☐ **Closure plan approval required. Submit closure plan within 90 days of** ______. (please contact ADEQ at 207-4686 for guidance.)

☐ **Additional sampling data** is required (see the attached ADEQ Dry Well Investigation Guidelines). Please submit the following sampling data within 60 days of__________ for sediment in the dry well settling chamber for ☐ TPH by 418.1, ☐ TPH by EPA modified 8015, ☐ eight total RCRA metals, ☐ four priority pollutant metals (Sb, Tl, Be, Ni), ☐ VOCs, ☐Semi-VOCs, ☐ RCRA metals by TCLP.

☐ **APP not required.** Operators who use, store, load, or treat hazardous substances in the vicinity of the dry well(s) shall follow the attached approved copy of your best management practices plan (BMPP), or the approved operational practices described on this form to prevent any discharge from entering the dry well(s).

The Dry Well Program of the Arizona Department of Environmental Quality (ADEQ) is charged with the regulation of activities and processes which may have an impact on the quality of waters of the state. To determine which, if any, regulatory programs may apply to your operations and whether your facility activity is subject to an Aquifer Protection Permit for the dry well(s) located on the premises, please answer all of the following questions and include detailed explanations where needed. Attach additional information and reference sheets as needed. Also, please attach any design plans, site plans, maps, etc., that may assist the department in this review.

A. **Responsible Party For Completing the Following Information:**

Project/Facility Name________________________

Contact Person________________ Title________________

Address ________________________

________________________ Zip Code____________

Phone Number (______)____________

**Nature of Business**

____(03) Warehouse/Offices
____(04) Manufacturing/Offices
____(05) Industrial/Agriculture Processing
____(06) Mining/Milling
____(07) Chemical & Fuel Storage
____(08) Vehicular Service Facilities
____(09) Schools, Churches & Recreational Facilities with vehicular maintenance operations.
____(10) Other________________

C. How long has the facility operation or activity been at its present location?________________

D. Depth to groundwater beneath site (below ground surface)____________ Date of measurement __________

Source of data ________________________

(May be obtained from Arizona Department of Water Resources, (602) 255-1543.)

E. Include a site plan and vicinity map showing:

1. The location of <u>all</u> on-site dry wells and/or retention basins.
2. Dry well number (as designated in Section G) and the delineation of each drainage area, including surface drainage patterns (use arrows for surface flow directions), location of floor drains draining to a dry well, water supply or monitoring wells, underground or above ground storage tanks, and chemical storage and waste storage areas. Identify any other areas where hazardous substances are used, stored, loaded, or treated.

## F. FACILITY INFORMATION AND IDENTIFICATION NUMBERS

| TYPE | | ID NUMBER/PERMIT |
|---|---|---|
| FEDERAL | RCRA ID NUMBER | AZ |
| | NPDES NUMBER | AZ |
| | OTHER | EXPLAIN: |
| STATE | TREATMENT, STORAGE AND DISP | |
| | AIR QUALITY | |
| | WATER QUALITY | |
| | OTHER | EXPLAIN: |
| LOCAL | AIR QUALITY | |
| | WATER QUALITY (INDUSTRIAL) | |
| | OTHER | EXPLAIN: |

| TYPE OF FACILITY OPERATION(S) check each one that applies. | √ |
|---|---|
| Fuel storage greater than 55 gallons. | |
| On-site industrial wastewater treatment and/or disposal. | |
| Release/application/storage of waste fluid or chemicals to a ditch, pit, pond, or land surface. | |
| Bioremediation | |
| Truck or car washing. | |
| Aircraft or automobile servicing. | |
| Printing | |
| Manufacturing | |
| Photographic processing | |
| Food preparation | |
| Dry cleaning | |
| Painting or paint stripping | |
| Other (explain) | |

| G. SPECIFIC DRY WELL INFORMATION | Submit copies of driller's logs, if available. Note: refer to dry well registration form for numbering of dry wells as listed below. |
|---|---|

| DRY WELL NUMBER | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Dry well completion date. Month/year | | | | | | | | | | |
| Total depth of hole drilled (feet) | | | | | | | | | | |
| Drilling Firm (If known) | | | | | | | | | | |

| | Y/N | DRY WELL NUMBER(S) If yes, refer to dry well number above |
|---|---|---|
| Do dry wells drain areas where hazardous substances are used, stored, loaded, or treated? . | | |
| Have dry wells received any unauthorized discharges? e.g. spill, leaks, disposal, etc. | | |
| Has an investigation of any dry wells ever been performed? If, yes, please provide locations, depths, sampling results and any other relevant information. Attach appropriate information as necessary. | | |

H. If the facility has a Best Management Practices Plan (BMPP), please submit a copy of the plan along with this questionnaire.

If the facility does not have a BMPP but does have a Pollution Prevention Plan (PPP) on file with the department, please give the ID number of the PPP:______________________________

Does the PPP address the dry well(s)? Yes ( ) No ( )

- If **no**, please submit a BMPP addressing the dry wells
- If **yes**, please send the applicable section of the plan to this office for review.

If you have neither plan that addresses the dry well(s), please describe how your facility or operation addresses each of the following items. Please use additional sheets as necessary to provide adequate details for each item. A copy of the BMPP guidelines developed by ADEQ is attached for your reference.:

1. Facility Description - Describe general details of the operation

______________________________

______________________________

2. Spill Containment/Control Measures

a. Engineered structures used to prevent accidental spills from entering dry well(s):

______________________________

______________________________

______________________________

b. Actions and specific methods used to control spills, leaks of fluids and waste waters other than stormwater runoff for each facility:

______________________________

______________________________

______________________________

c. Procedures for handling wastes collected from cleanup process. Verify that applicable federal, state, county/city disposal requirements will be followed:

______________________________

______________________________

2. Waste Management Procedures

Describe the housekeeping program as it relates to the following:

a. Inventory of generated waste and products:

______________________________

______________________________

______________________________

b. Waste minimization plan and spent solvent recycling/reuse feasibility:

______________________________

______________________________

______________________________

c. Collection of waste in approved waste receptacles:

__________________________________________________________________________________________________________

d. Handling procedures for transportation of waste off-site by a certified waste hauler, and destination for final disposal:

__________________________________________________________________________________________________________

3. Describe Operational Practices

Daily or periodic inspection of your facility activity as related to minimizing waste spill and proper storage and handling of waste/chemicals:

__________________________________________________________________________________________________________

4. Employee Training

Training plan for new employees and periodic training for workers handling chemicals or waste:

__________________________________________________________________________________________________________

The owner and facility operator should fill out this form as accurately and completely as possible. If you are unable to complete one or more items for any reason, a written explanation should be attached with this form to assist the department in the applicability determination.

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision to assure that the information submitted was properly gathered and checked by qualified personnel. Based upon my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information submitted, the information is, to my knowledge, true, accurate, and complete. I am aware there are significant penalties for submitting false information.

| | |
|---|---|
| Signature (Property Owner) | Date |
| Name (Please Print) | Title |
| Signature (Facility Operator) | Date |
| Name (Please Print) | Title |

# DRILLING LOG

| Please describe materials encountered during drilling. Include color, grain size, and moisture content. | | Draw a diagram of the dry well as built, indicating materials used, cross section with dimensions including diameters and depths. |
|---|---|---|
| **DEPTH** | **SOIL DESCRIPTION** | |
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Remarks:

Date Drilled: ____________________

Driller's logs completed by: ______________________________

☐Owner ☐Driller ☐Other ____________________

*Arizona Department*
*of*
*Environmental Quality*

# Guidance for Design, Installation, Operation, Maintenance, and Inspection of DRY WELLS

*August 25, 1995*

**In the event of a non-stormwater or non-surface runoff discharge that has the potential to impact groundwater quality, the facility owner or operator should notify the ADEQ in writing within 30 calendar days from the date of occurrence or date of discovery, and report the action taken to mitigate the impact.**

## GENERAL:

1. Dry wells should be installed to dispose of only stormwater and urban surface run-off as defined in this guidance.

2. No dry well should be installed closer than 100 feet from any water well, underground storage tank, or fuel loading area.

3. Dry wells should not be installed where hazardous or toxic materials are used, stored, loaded, or treated, or where a spill of such materials would drain into the dry well system.

4. Dry wells should be completed at least 10 feet above water table. In the event perched water tables are encountered, drywell systems may be constructed by an installer licensed by the Arizona Department of Water Resources as long as the perching formation is sealed per ADWR requirements.

5. Dry well installers should meet the licensing requirements of the State Registrar of Contractors and the Arizona Department of Water Resources.

6. If the above conditions cannot be met, Please consult with ADEQ.

## DEFINITIONS:

**"Stormwater"** means runoff resulting from rainfall.

**"Urban Surface Runoff"** means other common water discharges such as fire hydrant flushing; potable water system releases; foundation or footing drains that are not contaminated by pollutants; naturally occurring seeps, springs, wetlands or riparian area; non-agricultural irrigation water; individual vehicle washing; evaporative cooler discharge; air conditioning condensate; swimming pool releases; water well backflushing; and dust control watering.

**"Drainage System"** means all or any part of storm drains, basins, ditches, pipes, gutters, catch basins, interceptors and drywells that are used for collecting, retaining, treating, conveying or disposing stormwater or urban surface runoff.

**"Effective Settling Capacity"** means the volume resulting from the distance between the bottom of a settling chamber to the height of the overflow outlet.

**"Heavy Use/Industrial"** means areas exposed to manufacturing and industrial operations or large drainage areas which would generate additional sediment or debris loading to a drainage system. This includes high truck traffic and loading areas such as public right-of-ways, shipping facilities and truck docks except where hazardous materials are used, handled or stored.

## DESIGN AND INSTALLATION IN GENERAL AREAS:

1. For drainage systems draining PAVED AREAS - a minimum of one standard drywell shall be installed for each 6,000 cubic feet (cf). of drainage volume.*

2. For drainage systems draining LANDSCAPED AREAS - a minimum of one standard drywell shall be installed for each 15,000 cf of drainage volume.*

3. The standard drywell system shall be a MaxWell Type IV or approved equal and have a minimum effective settling capacity of 1,000 gallons per chamber. (Effective settling capacity = distance from bottom of settling chamber to the height of overflow outlet. For a 4 feet ID chamber this would be the equivalent of a 16 feet deep chamber inclusive of 5 feet of freeboard.)

4. Systems are to use a shielding device to enhance separation of petrochemicals from water by gravity differentials. Such devices are to be vented to prevent siphoning or skimming of floating petrochemicals.

5. Systems are to use a hydrophobic petrochemical absorbent with a minimum capacity of at least 128 ounces.

6. A device to screen floating debris such as paper, leaves and other trash must be used to retain such material within the settling chamber.

7. The system must be accessible from the surface for maintenance and inspection. Standard minimum opening is a 24 inch diameter nominal size cast iron grating or manhole cover bolted in at least two locations. All inlets are to be marked in raised cast letters **"STORM WATER ONLY"**.

8. Excavation and/or drilling is to be performed in a manner to maintain and protect the integrity of drainage soils.

9. A minimum penetration of 10 continuous feet into permeable porous soils is recommended for standard installations. In unstable sandy, gravely soils where "belling out" is a problem, an equivalent of 200 square .feet (sf). of sidewall area is acceptable (bottom area is not to be included). If such penetration is not achieved or if the required design performance rate is greater than 0.25 cubic feet per second (cfs), a constant head percolation test on the completed system will be required to determine performance.

10. Drywell inlets should be located at least 20 feet from retention basin surface inlets.

11. Multiple drywells should be spaced a minimum of 100 feet apart center to center.

12. Inlet connecting pipes to drywell systems should be a maximum of 6 inches in diameter.

13. Drywell surface grates should be raised a minimum of 3 inches above bottom of landscaped retention basins.

14. During construction, dry well inlets (including any remote inlets) should be sealed with two layers of U.V. protected geotextile fabric to prevent sediments from entering the dry wells until paving and landscaping are complete.

* *Calculations are based on using the Rational formula for a 10 year design storm with a 2 hour duration.*

## DESIGN AND INSTALLATION IN HEAVY USE/INDUSTRIAL AREAS

1. A MaxWell Plus System* or equivlent design utilizing a pretreatment interceptor should be installed as a standard drywell system for the following drainage area applications:

   - When draining public right-of-ways or heavy use areas such as trucking facilities or maintenance areas.
   - When draining areas impacted by industrial or manufacturing operations (except where hazardous chemicals are used, handled or stored).
   - When more than one acre and up to a maximum of two acres of paved surface drains to a single drywell.
   - When more than 2.5 acres and up to a maximum of 5 acres of landscaped surface drains to a single drywell.

2. The interceptor should be a sealed unit with an effective settling capacity of at least 500 gallons and a maximum outflow capacity of 0.25 cfs.

3. Systems should use shielding devices to enhance separation of petrochemicals from water by gravity differentials.

4. Systems should use hydrophobic petrochemical absorbents with a minimum capacity of at least 256 ounces per chamber.

5. A device to screen floating debris such as paper, leaves and other trash should be used to retain such material within the settling chambers.

6. The system should be accessible from the surface for maintenance and inspection. Standard minimum opening is a 24 inch diameter nominal size cast iron grating or manhole cover bolted in at least two locations. All inlets should be marked in raised cast letters **"STORM WATER ONLY"**.

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* Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not constitute endorsement by the ADEQ.

7. During construction, dry well inlets (including any remote inlets or connected catch basins) should be sealed with two layers of U.V. protected geotextile fabric to prevent sediments from entering the dry wells until paving and landscaping are complete.

8. A solid manhole cover should be installed on the drywell to insure flow is through the interceptor inlet only. The cover should be bolted in at least two locations and marked in raised cast letters **"STORM WATER ONLY"**.

9. Best management practices (BMPPs) should be followed for dry wells in heavy use industrial areas where hazardous substances are used, stored, loaded, or treated. A separate BMPP guidance manual is available from ADEQ.

## MAINTENANCE:

1. The drainage system including settling chambers and interceptors should be inspected annually.

2. Removal of deposited silt and sediment may be performed with the annual inspection, or at a minimum as follows:

   - In paved areas - when the sediment level fills 10% of the effective settling capacity.
   - In landscaped areas - when the sediment level fills 25% of the effective settling capacity.
   - When ownership of the property changes.
   - When material not resulting from stormwater or urban surface runoff enters the drainage system interceptor or drywell settling chamber.

3. Maintenance should include removal of all sediment, cleaning of all filters and screens and replacement of chemical absorbents.

   Removed material should be disposed of at a acceptable landfill or facility.

## INSPECTION:

1. Inspection should be performed annually or if water remains standing on the surface of the drainage area or retention basin for longer than 36 hours.

2. Activities performed within the drainage area should be reviewed to ensure that chemicals are not used, handled or stored within that area. Visual observations should be made for non-stormwater discharges such as unusual stain or pavement discoloration surrounding the drywell, residue coating the inlet grate or within dry well sediments, or the presence of unusual odors in the settling chamber.

3. Settling chambers and interceptor compartments should be visually inspected for type and quantity of debris and condition of drainage components. Remove debris and sediment as required under "Maintenance".

4. If chemical absorbents are discolored and/or submerged beneath the water surface, they should be replaced.

5. The ADEQ recommends a copy of each annual inspection, if performed, be kept on file at the drainage property's location.

6. An inspection checklist is available from ADEQ which may be helpful when performing annual inspections.

**For additional information please call the ADEQ Water Quality Division, Aquifer Protection Program Section, Industrial & Dry Well Unit at (602) 207-4686, or 1-800-234-5677.**

# BEST MANAGEMENT PRACTICES PLAN (B.M.P.P.) GUIDANCE FOR DRY WELLS DRAINING AREAS ASSOCIATED WITH INDUSTRIAL ACTIVITIES THAT USE, STORE, LOAD, OR TREAT HAZARDOUS SUBSTANCES

**DRAFT**
**August 21, 1996**

**Arizona Department of Environmental Quality**

**Water Quality Division**
**Water Protection Approvals & Permits Sections**

**OFR 96-16**

DRAFT

# BEST MANAGEMENT PRACTICES PLAN (B.M.P.P.) GUIDANCE FOR DRY WELLS DRAINING AREAS ASSOCIATED WITH INDUSTRIAL ACTIVITIES THAT USE, STORE, LOAD, OR TREAT HAZARDOUS SUBSTANCES

## OBJECTIVE

Provide guidance for developing Best Management Practices Plans (BMPPs) in order to minimize the possibility of soil, groundwater, or surface water contamination resulting from contaminated runoff from automotive service facilities, manufacturing facilities, industrial warehouses, and other industrial operations draining into dry wells and/or basins.

## CONTAMINATED WATER FROM FACILITY

Surface runoff drained from vehicular service stations, warehouses storing hazardous or toxic materials, manufacturing and other industrial processing facilities may drain into dry well(s). Many of the wastes and chemicals generated from or stored at these facilities may be considered hazardous. These wastes/chemicals can pose a significant threat to groundwater quality. Such discharges to dry wells are not authorized by Federal and state laws. Discharge of any contaminant causing a violation of any Aquifer Water Quality Standard is prohibited under state law. Alternative waste stream management practices are available that can effectively reduce the threat of groundwater contamination from potentially hazardous or toxic waste or waste constituents. A Best Management Practices Plan (BMPP) can be developed to eliminate contaminants from entering a drywell in a retention basin. Areas draining non-industrial runoff such as parking lots, roof areas and landscaped areas are excluded from these requirements.

## BEST MANAGEMENT PRACTICES PLAN (BMPP) DEVELOPMENT

A BMPP should be developed in accordance with good engineering and good housekeeping practices. Under no circumstances, should leaks and spills of fluids that may be considered as contaminants under Federal and state laws and regulations, flow into dry wells in a retention basin. If a facility already has an ADEQ approved pollution prevention plan (PPP) and the PPP has addressed all the BMPP concerns, the plan will be considered adequate as a BMPP. The BMPP should generally contain the following information:

### 1. FACILITY PLANS AND DESCRIPTION

Include a general description of the facility operations indicating what and how chemicals are used in each of the operations, and how the wastes are generated from the operation. The facility plans should include surface drainage patterns, location of floor drains, dry wells, and chemical and waste storage areas, etc. Factors to be considered in developing facility plans for new or remodeled facilities include:

- Locate dry wells so as to prevent unauthorized discharges,
- Analyze drainage areas for potential sources of pollutants,
- If a dry well is located in a retention basin, consider preliminary stilling or settling

basins upstream, to trap contaminated sediments, and

- Future modifications at the site should include a review of the potential impact from on-site operations on soil, groundwater, and surface water prior to implementation.

## 2. DESIGN PLANS

Include storm water drainage system design and construction details such as retention/detention basins, dry wells, and the associated pre-treatment components.

## 3. SPILL CONTAINMENT/CONTROL MEASURES

Include engineering structures used to prevent accidental spills from entering a dry well and/or retention basin. List actions and specific methods that will be utilized to control chemical spills, fluids leaks, and waste waters from each facility. Waste disposal of materials collected from clean-up processes should follow applicable federal, state, and county/city disposal requirements. Specific considerations should include:

- Where dry wells and/or basins receive runoff from industrial/commercial sites, no chemicals should be stored in areas exposed to rainfall,
- No releases of industrial process waters or wastes should be permitted in the dry well/basin drainage area,
- Any spill or leak of substances other than "normal urban runoff" in the dry well/basin drainage area should be contained, cleaned up, and disposed of in accordance with local, state, and federal regulations and guidelines, and
- Where parks or other facilities are located within a retention basin, no chemicals or equipment containing pollutants should be stored within the basin or its drainage area.

## 4. WASTE MANAGEMENT PROCEDURES

A housekeeping program should be in place, and should include the following:

- Maintain an up-to-date inventory of generated waste and products,
- A waste minimization plan and a spent solvent recycling/reuse feasibility analysis,
- All wastes or solvents that are not recycled should be disposed of through companies licensed to handle such materials,
- Have a pollution prevention plan in place,
- Provide for collection of waste in approved waste receptacles,
- Establish handling procedures for transportation of waste off-site by a certified waste hauler to final destination for disposal, and
- The operator of any facility located within the drainage area of a dry well that is located in a retention basin should not allow hazardous wastes or other materials which may contribute to the contamination of soil, groundwater, or surface water to accumulate in the basin or in the drainage area.

## 5. OPERATIONAL PRACTICES

The facility should maintain the following activities to ensure that the dry well functions propertly.

- Daily or periodic inspection of facility operation, as related to minimizing waste spills and proper handling of waste/chemicals, should take place,
- Use of toxic/hazardous materials, including but not limited to pesticides, herbicides, and fertilizers, within a dry well in a retention basin should be in accordance with manufacturers' instructions, including restricting quantity of application to minimum effective levels,
- Where non-toxic alternatives are available, they should be used in lieu of toxic substances,
- Accumulations of sediments should be removed from settling basins as necessary so as to preserve their operability and capacity; accumulations within the detention/retention basin itself should be removed so as to prevent entry into any dry wells which may be present there, and
- Dry wells should be maintained according to state guidelines.

## 6. EMPLOYEE TRAINING

The facility should maintain a waste management training program at the site that includes the following:

- Include a training plan for new employees and periodic training for workers that are involved in handling of chemicals or waste,
- Employees that work around waste and chemical storage areas should be informed of the procedures for control of accidental spills and releases,
- Where employees are involved in the application of pesticides, herbicides, or fertilizers, to the surfaces of retention basins, they should be trained in the proper application of those substances within basins or areas draining to basins and/or dry wells, and
- Employees responsible for removal and disposal of contaminated sediments should be trained in proper handling of hazardous materials.

The BMPP including the above details should be maintained at the facility at all times. It should be amended whenever there is a change in facility design, construction, operation, or maintenance which may cause unauthorized discharges of hazardous or toxic pollutants into a dry well and/or retention basin.

## SAMPLING REQUIREMENTS/A.P.P. APPLICATIONS

Pursuant to A.A.C. R18-9-102.A, the Aquifer Protection Permit program requirements may apply to dry wells that drain areas where hazardous substances are used, stored, loaded, or treated. Facility operators should demonstrate that the storm water drainage facilities do not have the potential to impact aquifer water quality through on-site operations. An APP applicability form including the sampling results obtained according to the state Dry Well Investigation Guidelines may be required by ADEQ to determine program requirements.

## ALTERNATIVE DRAINAGE OPTIONS

If the facility chooses one of the following options, a determination of applicability for an APP may be required.

(1) **Pretreatment**

Prior to final discharge into a retention basin or dry well, a pretreatment structure or interceptor such as an **Envibro®** System may be installed that initially receives the runoff from the industrial area. The system should be substantially effective in removing hazardous substances from the water before discharge into the retention basin or dry well. Such systems should at a minimum incorporate gravity separation, filtration, coalescing separation, absorption or adsorption as part of the treatment process. If installed below grade, the system should be of watertight construction and be accessible from the surface for inspection and maintenance.

(2) **Impermeable Sump**

An impermeable sump with double liners can be built where storm runoff from areas possibly contaminated with hazardous wastes, toxic materials, or other contaminants may be routed. The sump may be equipped with a manual pump connected to other storm water drainage facilities including on-site dry wells or retention basins

The dry well that is replaced with a sump should be properly closed according to the ADEQ's dry well decommissioning guidelines prior to installation of the sump. The facility should demonstrate clean closure prior to abandonment of the dry well.

(3) **Evaporation Basin**

Possible contaminated storm runoff may be directed into an evaporation basin. The basin should be properly designed and should meet the APP program BADCT guidelines for surface impoundment's, and approved by the state and local agencies.

(4) **Sanitary Sewer**

The local governments will define pretreatment requirements and limitations of drainage volumes before discharge to the sanitary sewer system.

If a sanitary sewer is available, then the runoff from areas that may be contaminated by wastes or toxic materials may be routed to the sewer, with proper hook-up meeting the local governmental requirements. It must be completed in accordance with all federal, state, and local requirements. The operator should follow the monitoring and reporting requirements under all federal, state, and local laws. The dry well should be properly closed according to the ADEQ's dry well decommissioning Guidelines.

## CLOSURE OF EXISTING FACILITIES

Closure of stormwater dry wells should meet state guidelines and local governmental requirements, if any. A determination of applicability for an APP may be required. If the facility can demonstrate clean closure of the dry well, an APP is not required. However, the facility needs to submit a closure plan to ADEQ for Approval.

CLC:bmpp.doc(8/21/96)

Arizona Department of Environmental Quality
Water Quality Division

# Fact Sheet

3033 N. Central Ave., Phoenix, AZ 85012

October 1, 1996

## DRY WELL INFORMATION

**What is a dry well?**

A dry well is a bored, drilled, or driven shaft or hole whose depth is greater than its width and is designed and constructed specifically for the disposal of storm water.

**Who needs to register the dry wells ?**

A person who owns an existing dry well which is or has been used for disposal shall register the dry well with ADEQ. They must be registered by completing a form supplied by ADEQ, and submitting a registration fee of $10 per dry well. Registration is generally not required for drywells used in conjunction with golf course maintenance, and they are exempted from regulation under the dry well program. However, vadose zone injection wells (including dry wells) that receive storm water mixed with reclaimed wastewater or groundwater, or both, from manmade bodies of water associated with golf courses, parks, and residential areas must be registered. In this situation, a general permit is issued by statute in lieu of an individual permit, provided that six criteria, including registration, are met (Arizona Revised Statute (A.R.S.) 49 - 245.02).

**How are dry wells regulated ?**

Dry wells are regulated by A.R.S. 49-331 through 336, and Aquifer Protection Permit (APP) statutes and rules. Specific rules regarding dry wells have not yet been developed. Program guidance documents are listed below, and should be followed for dry well construction, maintenance, siting, investigation, decommissioning, and closure.

**When do APP program requirements apply to dry wells ?**

APP program requirements apply to certain dry wells and injection wells for operation and closure. ADEQ may provide an APP Determination of Applicability for Dry Wells form for dry wells in areas where hazardous substances are used, stored, loaded, or treated. The completed form will be reviewed by ADEQ to determine if the dry well(s) are subject to regulation under the APP program.

As indicated above, in the second paragraph, general APPs are issued to certain dry wells, as provided for in A.R.S. 49 - 245.02. In addition, certain discharges to dry wells in combination with stormwater are exempt from the APP requirements. Eight types of discharges other than stormwater are listed in statute (A.R.S. 49-250.23).

**What about dry wells in drainage areas where there are hazardous substances ?**

The APP requirements apply to dry wells that drain areas where hazardous substances are used, stored, loaded, or treated. Generally, for existing facilities, at a minimum, a sediment sample from the settling chamber of the drywells should be tested initially for TPH, total metals, and volatile organic compounds. However, constituents analyzed should be representative of the chemicals or wastes that are or have been used at the site. An APP is required to ensure that best management practices are followed, and hazardous substances are kept from entering the drywells by using the proper engineering design structures, physical barriers, and procedural controls.

**What about dry wells in other areas ?**

APP program requirements apply to a facility which adds a pollutant to a dry well provided that it meets the criteria to be classed as an injection well. If your drywell does not drain an area where hazardous substances are used, stored, loaded, or treated, APP program requirements may not apply. However, you should contact the ADEQ Industrial & Dry well Unit at (602) 207-4686 if hazardous substances have been detected in the dry well or any unauthorized disposal or spill of hazardous substances has occurred.

A dry well that is used for industrial wastewater disposal either solely or in conjunction with stormwater discharge is an injection well, and APP program requirements apply to operation or closure.

**What if I want to close a dry well ?**

Closure should be achieved by following ADEQ's Dry Well Decommissioning Guidelines. If "clean closure" (as defined in A.R.S. 49-201.5) is demonstrated, closure approval can be made by ADEQ without the issuance of an APP.

**Drywell documents available for distribution:**

1. Dry Well Registration form
2. Dry Well Decommissioning Guidelines
3. Dry Well Investigation Guidelines
4. Arizona Stormwater Dry Well Installers list
5. Guidance for Design, Installation, Operation, Maintenance, and Inspection of Dry Wells
6. Best Management Practice Plan (BMPP) Guidance for Dry Wells at Industrial Areas
7. Aquifer Protection Permit for Clean Closure
8. APP Determination of Applicability form for Dry Wells
9. Annual Dry Wells Inspection Checklist
10. Copies of the above referenced regulatory requirements

**Please contact ADEQ regarding updates and additions to the above referenced list of available documents, or any questions you may have about the dry well program at (602) 207-4686.**

*Arizona Department of Environmental Quality*

# *DRAFT*
# *DRY WELL DECOMMISSIONING GUIDELINES*

**8/22/96**

Prior to decommissioning, all dry wells must be registered with the ADEQ, Aquifer Protection Permit Program. Please call the ADEQ, Water Protection Approvals & Permits Section for the necessary registration form at 207-4686 or write to:

Arizona Department of Environmental Quality
Water Protection Approvals & Permits Section
3033 North Central Avenue
Phoenix, AZ 85012

The following procedures are recommended for closure of dry wells used to receive storm water runoff.

1. Only an experienced dry well drilling contractor should perform the dry well decommissioning.

2. Remove sediments and any drainage components such as stand pipes and screens from the dry well's settling chamber.

3. The top of the dry well, including the upper settling chamber, should be removed to at least six feet below the land surface. This can be accomplished using a backhoe or other acceptable excavation equipment.

4. The remaining settling chamber should be filled in with clean, mechanically compacted silt, clay or similar engineered material, or ABC slurry.

5. A cement grout plug should be set from four feet below the land surface to a minimum of six feet below the land surface.

6. The remainder of the dry well should be backfilled to the land surface with clean silt, clay or engineered material and mechanically compacted. A water settling procedure should not be allowed.

7. All fill should be placed in the well in such a manner as to eliminate any void space. Materials containing hazardous substances must not be used.

8. If procedures other than the above were applied to the decommissioning, it must be demonstrated that there will be no fluid migration from the surface to aquifer.

9. Within 30 days of decommissioning, written verification of the closure procedures must be sent to this office with the dry well registration number or the registration form. The letter should state the reason for the decommissioning, the materials and methods used to abandon the dry well(s), the name of contractor did the closure, the completion date, and any sampling data collected from the dry well investigation, if required by ADEQ. If a sump is constructed to replace the abandoned dry well, sump construction details must be included.

If the dry well drained an area where hazardous substances were used, stored, loaded, or treated, an investigation of groundwater impacts beneath the site must be completed to demonstrate that Aquifer Water Quality Standards (AWQS) has/will not be exceeded at the applicable point of compliance and that clean closure can be achieved pursuant to Arizona Revised Statutes (A.R.S.) 49-201.5 and 252. A closure plan for clean closure must be submitted in order for the director to issue a letter of approval to the owner or operator. If the ADEQ determines that post-closure monitoring in the groundwater is necessary at the site, an Aquifer Protection Permit will be required.

# Appendix F

## Supporting Calculations

Subject: ESTIMATED COST AND DESIGN OF TMT ALTERNATIVES (FCD #98-48)

CALC TREATMENT VOLUME OF 90% STORM 50 AC Area

$$V = C\left(\frac{P}{12}\right)A$$

$P_{90\%} = 0.55$ in.
$C = 0.75$
$A = 50$ AC
} PER Sec 2.2.2

$$V = (0.75)\left(\frac{0.55}{12}\right)(50) = \underline{1.72 \text{ ac}\cdot\text{ft}}$$

APPLY A 48 hr. PROCESSING TIME TO STANDARDIZE A FLOW RATE

$$1.72 \text{ ac-ft} \times \frac{43560 \text{ ft}^2}{1 \text{ AC}} \times \frac{7.48 \text{ gal}}{1 \text{ cf}} \times \frac{\text{per}}{48 \text{ h}} \times \frac{1 \text{ h}}{60 \text{ m}} =$$

$$Q_{AVE} = \underline{195 \text{ gpm}}$$

THIS REPRESENTS A STANDARDIZED CAPACITY CALCULATOR IN ORDER TO COMPARE ALTERNATIVES ON AN EQUIVALENT BASIS.

**PBS&J** POST, BUCKLEY, SCHUH & JERNIGAN, INC.

COMP. BY: MM
CHK. BY: TAB
DATE: 3/18/97
SHEET NO.: 2
JOB NO.: 54014

Subject: ESTIMATED COST AND DESIGN OF TMT ALTERNATIVES (FCD# 98-48)

## FIRST FLUSH RETENTION REQUIREMENTS

ASSUMPTIONS:

(1) BASIN IS SQUARE
(2) SIDE SLOPES ARE 3:1
(3) MAX WATER DEPTH IS 3 ft. W/1 ft. FREEBOARD
(4) BASIN IS SIZED TO HOLD 90% STORM
(5) 10' WIDE ACCESS ROAD IS PROVIDED AROUND PERIMETER

(1) $$\forall_W = \left[\frac{b^2 + (6z+b)^2}{2}\right] \cdot d$$

(2) $$A_T = (8z+b)^2$$

WHERE:

$\forall_W$ = volume of water
$z$ = 3:1 side slope
$b$ = basin botom width
$d$ = depth of water, 3 ft
$A_T$ = Top area required with 1 ft. of freeboard

SOLVE EQ 1 FOR $b$ FOR $\forall_W = 1.72$ ac-ft:

$$b = 149 \text{ ft}$$

$$A_T = (8z + 10' \text{ access road} \times 2 + 149)^2$$

$$A_T = 37{,}249 \text{ ft}^2 \times \frac{1 \text{ AC}}{43560 \text{ ft}} = 0.86 \text{ AC}$$

USE 0.9 ACRES

**PBSJ** POST, BUCKLEY, SCHUH & JERNIGAN, INC.

COMP. BY: MM
CHK. BY: TAB
DATE: 3/18/97
SHEET NO.: 3
JOB NO.: 54014

Subject: ESTIMATED COST AND DESIGN OF TMT ALTERNATIVES (FCD #95-48)

ESTIMATE SIZE OF SSF WETLAND

$$Q_{AVE} = 195\ gpm \times \frac{1\ MGD}{694.3\ gpm} = 0.28\ MGD$$

SIZE RANGE DUE TO TYP. HYDRAULIC LOADING

TYP = 0.15 to 0.05 MGD/AC

$A_{REQ}$ = 1.9 AC to 5.6 AC

CHECK ORGANIC LOADING RATE

USE COMMERCIAL AVE ≐ 55 mg/L

LR = 55 mg/L × 0.28 MGD × 8.354 ≐ 129 lb/day

MAX LR = 60 lb/AC-d

MINIMUM AC REQ'D = $129 \frac{lb}{d} \times \frac{1\ AC\cdot d}{60\ lb}$ = 2.15 AC

CHECK HYDRAULIC RETENTION TIME

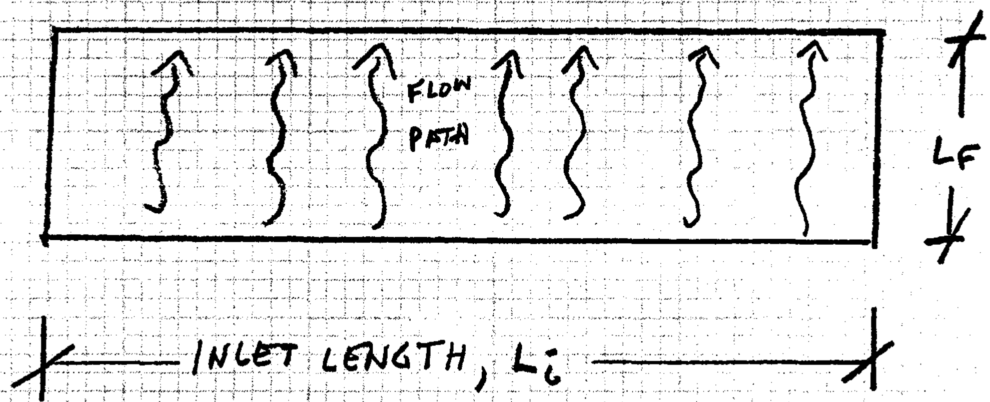
USE: BED POROSITY = 40%

BED DEPTH = 24"

FIND: REQ'D ACRES FOR 4 DAY MIN. RETENTION

MAXIMUM PORE VELOCITY, $V = 25$ f/d

FLOW LENGTH, $L_F = 25\frac{f}{d} \times 4\,d = 100$ ft.




(1) $Q = A \cdot V$ where:

$V$ = velocity, 25 f/d

$A$ = AREA OPEN TO FLOW

(2) $A = n \cdot d \cdot L_i$ where:

$n$ = media POROSITY, 40%

$d$ = MEDIA DEPTH, 24"

$L_i$ = INLET LENGTH

solve for $L_i$:

$$L_i = \frac{Q}{n \cdot d \cdot V} = \frac{280{,}000 \text{ gal/day}}{(.40)\left(\frac{24''}{12}\right) \cdot 25\frac{ft}{day}} \times \frac{1 \text{ cf}}{7.48 \text{ gal}}$$

$L_i$ = 1,872 feet

PBSJ POST, BUCKLEY, SCHUH & JERNIGAN, INC.

COMP. BY: MM
CHK. BY: TAB
DATE: 3-18-97
SHEET NO.: 5
JOB NO.: 54014

Subject: ESTIMATED COST AND DESIGN OF TMT ALTERNATIVES (FCD #95-48)

$$\text{AREA} = L_F \cdot L_i = 100\,ft \times 1872\,ft \times \frac{1\,AC}{43{,}560\,ft^2}$$

AREA = 4.3 AC

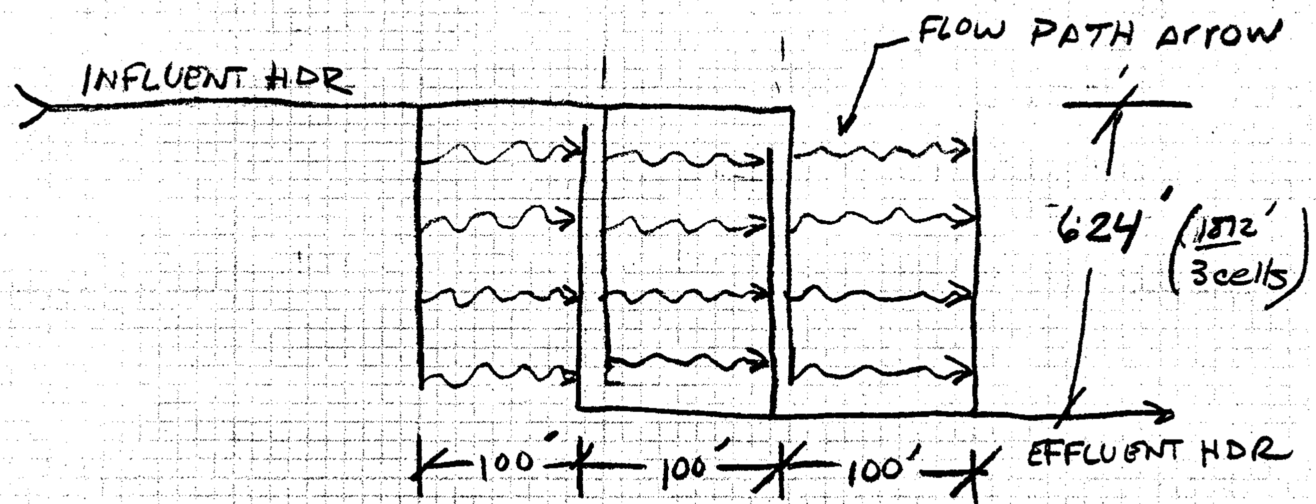
**COMPARE PREVIOUSLY CALCULATED CRITERIA**

ORGANIC LR AREA = 2.15 AC < 4.3 AC OK.

TYP. HYDRAULIC AREA = 1.9 to 5.6 AC ⇒ 4.3 = OK

MINIMUM RETENTION TIME IS MET ∴ USE 4.3 AC

* NOTE THAT FLOW CAN BE ADDED TO THE WETLAND BY HEADER CREATING CELLS. THESE CELLS CAN BE CONFIGURED TO FIT A PARCEL OF LAND



## SAND FILTER SIZING

Q = 195 gpm (FOR 50 ACRES SERVED)

FROM SEC 3.3.4, Table 3-5: FILTER RATE = 2-5 $gpm/ft^2$

AREA OF FILTER REQ'D = $\frac{195 \text{ gpm}}{2 \text{ gpm}/ft^2} = 97.5 \ ft^2$

ADD 10% FOR APPURTENANCES

AREA = $(1.1)(97.5 \ ft^2) = 107 \ ft^2$

ASSUME MINIMUM PARCEL TO ACCOMMODATE SAND FILTER IS 60' × 60' ≈ 0.08 ACRES

## DRY POND BASIN SIZING

THE DRY POND IS ASSUMED TO BE THE SAME STRUCTURE AS THE FIRST FLUSH RETENTION BASIN. IN REAL DESIGN, HOWEVER, IT IS RECOMMENDED THAT THE PERCOLATION RATES BE ADEQUATE TO DRAIN THE BASIN WITHIN 48 HOURS OR WITHIN THE TIME SPECIFIED IN LOCAL CODES.

$\forall_{BASIN}$ = 0.9 ACRES (SEE p2)

## COST OF WETLAND

CAP COST: $109,000/AC OF WETLAND
O & M COST: $500,000/MGD/yr
} ref. 2

$109,000/AC × 4.3 AC ≐ $470,000 CAP COST

$500,000/MGD × 0.28 MGD ≅ $140,000/year O & M

## COST OF SAND FILTER

CAP COST: $715,000/MGD
O & M COST: $250,000/MGD/yr
} ref. 13

$715,000/MGD × 0.28 ≐ $200,000 CAP COST

$250,000/MGD × 0.28 ≐ $70,000/yr O & M COST

## COST OF DRY BASIN

CAP COST: $200,000/MG
O & M COST: $2,000/MG/yr
} ref. 13

$200,000/MG × (.28) = $56,000 CAP COST

2,000/MG × (.28) = $5,600/yr O & M COST

## MODIFIED DRY WELLS SIZING

IT IS ASSUMED THAT THE DRY WELLS WILL BE LOCATED IN THE BOTTOM OF THE FIRST FLUSH RETENTION BASIN. THEREFORE, NO LAND REQUIREMENT IS ASSUMED.

ASSUMPTIONS:

(1) EACH WELL WILL TAKE APPROXIMATELY 100gpm. FOR ANTICIPATED FLOWS OVER 50 gpm/WELL, A SOILS TEST IS RECOMMENDED.

(2) EACH WELL HAS A 20' DEEP SETTLING CHAMBER.

(3) EACH WELL HAS 100' OF DISPOSAL SHAFT.

(4) COSTS DO NOT REFLECT ANY WATER METERING, SAMPLING DEVICES, OR TELEMETRY

**PBSJ** POST, BUCKLEY, SCHUH & JERNIGAN, INC.

COMP. BY: MM
CHK. BY: TAB
DATE: 3/25/97
SHEET NO.: 9
JOB NO.: 54014

Subject: ESTIMATED COST AND DESIGN OF TNT ALTERNATIVES (FCD #95-18)

| ITEM | QTY | COST | EXTENDED |
|---|---|---|---|
| (1) 5' DIAM DRILLED HOLE SET W/WELL SCREEN AND PACKING | 100' | 230/LF | $23,000 |
| (2) PREFAB, 6' MH SET 20' DEEP, CONC. RING/COVER | 1 | 9,300/EA | $9,300 |
| (3) 6" PVC - TELESCOPE PIPING WITHIN WELL | 1 | 4,600/WELL | $4,600 |
| (4) ACTIVATED CARBON ASSEMBLY | 1 | 5,500/WELL | $5,500 |
| (5) 25% CONTINGENCY | | | $10,600 |
| | | | $53,000/WELL |

AT 2 WELLS PER 50 ACRES,

ESTIMATED COST ~ $106,000 /50 ACRES

Ref:

(1) LONGMOIR DRILLING SERVICE, MESA AZ
(2) CITY OF PHOENIX BID PRICES, 1994
(3) RS MEANS, 1996
(4) ART, INC, KALAMAZOO, MI

PBSJ POST, BUCKLEY, SCHUH & JERNIGAN, INC.

COMP. BY: MM
CHK. BY: TAB
DATE: 3/25/97
SHEET NO.: 10
JOB NO.: 54014

Subject: ESTIMATED COST AND DESIGN OF TMT ALTERNATIVES (FCD #95-48)

## INFILTRATION TRENCH

ASSUMPTIONS: 1 - RECOMMENDED APPLICATION RATE IS 1 gpm/SF OF TRENCH TOP AREA
2 - TRENCH IS 2' WIDE, 8' DEEP w/ 4' GRASS FILTER STRIP
3 - NO COSTS ARE INCLUDED FOR UTILITY CONFLICTS OR ASPHALT REMOVAL/REPLACEMENT

| Item No | ITEM | QTY | PRICE | EXT. |
|---|---|---|---|---|
| 1 | DIG TRENCH - MED HARD COND. | 98 LF | $27/LF | 2,646 |
| 2 | PEA GRAVEL | 60 CY | $89/CY | 5,340 |
| 3 | SOD FILTER | 390 SF | $5/SF | 1,950 |
| 4 | DIRT DISPOSAL | 72 CY | $20/CY | 1,440 |
| | | | | 11,376 |
| 5 | 25% CONTINGENCY | | | 2,844 |
| | | | | $14,220 |

CALCS:

$195 \text{ gpm} \times \frac{1 \text{ sf}}{1 \text{ gpm}} \times \frac{1 \text{ LF TRENCH}}{2 \text{ SF TRENCH}} = 97.5 \text{ LF}$

4 FT SOD x 97.5 LF = 390 SF

$\text{VOLUME} = 97.5 \times 8' \text{ DEEP} \times 2' \text{ WIDE} = \frac{1560 \text{ cf}}{27 \text{ cf/cy}} = 58 \text{ cy}$

# Appendix G

## Glossary

**90% Storm** - A storm event that caused a total rainfall depth larger than 89% of the storms expected to occur and smaller than 10% of the storms expected to occur.

**adsorption** - The adherance of a dissolved chemical or liquid to the surface of a solid.

**aerobic** - Indicates the presence oxygen.

**algae bloom** - The uncontrolled growth of algae in a body of water due to an excess amount of available nutrients

**anerobic** - Indicated no oxygen is present.

**aspect ratio** - The ratio of lenght to width.

**attatched-growth biological reactor** - A treatment process in which the microbes that will digest the pollutants in water are fixed to an inert media and function as the water flows by.

**Best Management Practice** - A method accepted by the EPA as one that is suitable for use in managing a program of pollution control.

**breakthrough** - A condition in a sand filter in which the constituent that was being removed appears in the treated water in higher than acceptable concentrations.

**Central Limit Theorem** - States that if the number of observations is large enough, methods used assuming a Normal distribution can reasonably predict furture observations.

**clean water head loss** - The pressure required to force clean water through a clean sand filter.

**dissolved metals** - All the metal that can be recovered from a sample after it has been filtered and any solids are removed.

**evapotranspiration rate** - The rate of water transpiration of water by plants.

**fecal coliform** - Bacteria that is associated with the fecal matter of warm-blooded animals.

**first flush** - The first part of the runoff arriving to a collection point that contains most of the pollutants washed from the land.

**flexible membrane liner (FML)** - A flexible liner that separates two areas.

## Glossary

**granular activated carbon (GAC)** - A highly porous carbon material in a granular form that has a surface that attracts non-polar materials.

**hydraulic detention time** - The theoretical time it take a a hydraulic slug to enter then leave a reactor.

**impermeable membrane** - A liner material that separated two areas and completely prevents any mixing or seepage between the two areas.

**mean** - The total of all observations divided by the number of observations.

**median** - The point in a distribution which divids the total observations into two parts, one higher in value and one lower in value, containing equal numbers of observations.

**microbes** - Living organisms that cannot be seen with the naked eye, including bacteria and protozoa.

**nutrients** - Elements that are essential for the growth of plants and animals, usually referring to nitrogen and phosphorus.

**oxygen demand** - The oxygen necessary for a carbon based substance to degrade.

**plug flow** - A flow condition where ideally no mixing or dispersion occurs.

**plug flow kinetics** - The mathematics that describes degredation rates under plug-flow conditions.

**polar** - Overall charged either positivly or negatively.

**pollutant** - Any chemical or parameter regulated by the EPA or Arizona Administrative Code with regard to surface water discharge.

**reactor** - Any volume that defines where a reaction is taking place.

**runoff** - Water that flows over the land due to a storm event.

**semi-volitile organic** - A carbon based compound that generally has a heavy molecular weight and a medium to low evaporation rate.

**skew** - A measure of a the lack of symmetry in a data set.

**standard deviation** - A measure of the variability of a data set.

**total Kjeldahl nitrogen (TKN)** - This represents the organic nitrogen plus the ammonia nitrogen. It is essentially represents all nitrogen except the nitrates and nitrites.

# Glossary

**total metals** - All the metal that can be recovered from a sample.

**treatment efficency** - A measure of the pollutant removal rate, in percent, of a treatment process.

**trickling filter** - A traditional method of biological domestic wastewater treatment that commonly uses rocks as the inert media and functions as an attached-growth biological reactor.

**vegetation** - Grass, low growing ground cover, and plants.

**volitile organic** - A carbon based compound that generally has a light molecular weight and a high evaporation rate.

# Appendix H

## Bibliography

# Bibliography


1. American Society of Civil Engineers, *Proceedings: 1991 National Conference on Hydraulic Engineering*, Nashville, TN, 1991.

2. Arizona Department of Environmental Quality, "Arizona Guidance Manual for Constructed Wetlands for Water Quality Impovement", May, 1995.

3. Arizona Department of Environmental Quality, "Minimum Requirements for Design, Submission of Plans and Specifications of Sewage Works", Engineering Bulletin No. 11, July 1978.

4. Clup, et. al., *Handbook of Advanced Wastewater Treatment*, Second Ed., Van Nostrand Reinhold Company, New York, 1978.

5. Dennison, M., *Storm Water Discharges: Regulatory Compliance and Best Management Practices*, Lewis Publishers, New York, 1996.

6. Fergison and Debo, *On-site Stormwater Management*, Von Nostrand Reinhold, New York, NY, 1992.

7. Flood Control District of Maricopa County, *Drainage Design Manual for Maricopa County, Arizona,* Volume I, Hydrology, 1992.

8. Flood Control District of Maricopa County, "Detention Basins for Water Quality Enhancement".

9. Flood Control District of Maricopa County, "Wetlands for Water Quality Enhancement".

10. Freeze, R., and J.A. Cherry, *Groundwater*, Prentice Hall, New Jersey, 1979.

11. French, R., *Open-Channel Hydraulics*, McGraw Hill Book Company, New York, 1895.

12. Hines, William W., and Douglas Montgomery, *Probability and Statistics in Engineering and Management Science*, John Wiley & Sons, New York, 1980.

13. JMM Engineers, "Study of Nationwide Costs to Implement Municipal Stormwater Best Management Practices", American Public Works Association Southern California Chapter, May 1992.

14. Metcalf & Eddy, *Wastewater Engineering, Treatment, Disposal, Reuse*, Third Ed., McGraw Hill, New York, 1991.

15. Means, *Site Work and Lanscaping Cost Data*, R.S. Means, Inc., Kingston, MA, 1996.

16. Moffa, P., *The Control and Treatment of Industrial and Municipal Stormwater*, Van Nostrand Reinhold, New York, 1996.

17. Reed, S., et. al., *Natural Systems for Waste Management and Treatment*, McGraw Hill Book Company, New York, 1988.

18. Tchobanoglous, G., and E. Schroeder, *Water Quality Characteristics, Modeling, Modification*, Addison-Wesley Publishing Company, Reading, Massachusetts, 1987.

19. Wanielista and Yousef, *Stormwater Management*, J. Wiley & Sons, New York, NY, 1993.

20. Seelye, Elwyn E., *Design Data Book for Civil Engineers*, J. Wiley & Sons, New York, NY, 1960.