Development and Design of Cost-Effective, Real-Time Implementable Sediment and Contaminant Release Controls

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Executive Summary

Alternative design options for integrated storm water and sediment control systems were developed and evaluated for Outfalls 008, 011 and 015 of the Paducah Gaseous Diffusion Plant. The remedial options were required to be cost effective and implementable in a relatively short timeframe. Additionally, construction activities were to minimize earth disturbance, especially with respect to excavation.

The current database for storm water and effluent sediment concentration was assessed for the three outfalls. It was concluded that there was a significant lack of data and recommendations for monitoring equipment were provided to initiate a comprehensive surface water and sediment data acquisition system.

Modeling was completed for current conditions. Peak flow, runoff volume, peak sediment concentration and storm sediment load were modeled for storm events, ranging from 0.5 inches (12.7mm) to 3.0 inches (76.2mm). Predicted peak flows ranged from 2.5 cfs (0.071 m^3/s) for Outfall 011 and a 0.5 inches (12.7mm) storm to 210 cfs (5.95 m^3/s) for Outfall 008 and a 3.0 inches (76.2mm) storm. Additionally, the 100-yr 24-hr NRCS Type II storm was modeled. Storm sediment loads, for the corresponding outfalls and storm events, ranged from 0.1 to 9.0 tons (8.18 tonnes).

Retention ponds were designed and evaluated for each of the three outfalls. The ponds had a dual function; 1) contain the storm runoff volume for smaller storm events and 2) passively treat and discharge runoff that was in excess of the pond's storage capacity. Stored runoff was transferred to alternative secondary treatment systems. The expected performance of these treatment systems was evaluated.

The performance of the outfall ponds was evaluated for storm events ranging from 0.5 inches (12.7mm) to 4.0 inches (101.6mm). Outfall 011 has a watershed of 33.3 acres. Pond 011 (Outfall 011) has the largest storage capacity of the three outfalls, and therefore the highest potential for effective treatment. The predicted sediment trapping efficiency for a 4.0 in (101.6mm) 24-hour storm was 99.7% with an initial empty pond condition. Stored runoff is expected to be transferred to the treatment plant located near Outfall 010. A 4-in storm event accounts for approximately 97% of the average annual precipitation.

Pond 015 is relatively small due to the non-excavation restriction. Ninety eight percent and 72.3% sediment trap efficiencies were predicted for a 1.5 in and 3.0 in 24-hour storm; based on the pond being empty at the start of the storm and retained runoff being transferred to one of the secondary treatment systems. A 3-in storm event accounts for approximately 92% of the average annual precipitation.

The watershed area of Pond 008 is 113.6 acres and the storage capacity is only 0.92 ac-ft. Sediment trap efficiencies of 96.7%, 77.2% and 67.6% were predicted for storms of 1, 1.5 and 2 inches, respectively. Thus, nearly a 70+% sediment trap efficiency is predicted for storm events of 2 inches or less; accounting for 82% of the average annual precipitation.

The approximate quantity of runoff that can be retained and pumped to a secondary treatment system was determined on a storm and annual basis. On an annual basis, Ponds 008, 011 and 015 are expected to retain 20.2%, 83.1% and 34.7% of the generated runoff, respectively.

Retained runoff will be pumped to alternative treatment systems. The alternative treatment systems designed and evaluated are: 1) evapotranspiration-only, 2) evapotranspiration - infiltration and 3) a combination weep berm – grass filter control system. The evapotranspiration-only method would result in complete treatment of the runoff transferred from the retention pond. The evapotranspiration - infiltration technique is expected to result in treatment through filtration and natural attenuation of soil and associated constituents. Both drip and micro-sprinklers were evaluated for the first two listed treatment systems.

Outfall 015 was used to illustrate the evaporation –only and evapotranspiration – infiltration secondary treatment methods. Based on a 5 acre site and a very conservative evapotranspiration rate, i.e. a low value of 0.10 in/day, a completely full Pond 015 would take approximately 10 days to empty by the drip irrigation system design. For a 25 acre site, the dewatering time would, of course, be 2 days. For the micro-sprinkler irrigation system 8 and 1 ¾ days would be required for the 5 acre and 25 acre sites, respectively.

When the evapotranspiration – infiltration treatment system was employed the drip irrigation system, based on a 5 acre site, would take 2 days to dewatering Pond 015; 1/10 of the evapotranspiration-only method. For the micro-sprinklers, with a 5 acre site the dewatering time would be 1 ¾ days.

A comprehensive irrigation design was completed for each alternative scenario and a listing of all major system components was provided.

Outfall 008 was used to illustrate the combination weep berm – grass filter treatment system. Such a system has proven to be very effective at other applied research and at international hard rock mines. Design considerations were provided encompassing dewatering pumping rate, sediment load and concentration, soil type, weep berm characteristics and grass filter length and infiltration rates.

The expected performance of a combination weep berm – grass filter system design was illustrated through a detailed example and SEDCAD modeling. The retention pond – weep berm – grass filter, for the illustrated example, resulted in a peak effluent sediment concentration at the end of the grass filter of 2 mg/L, essentially providing 100% treatment of the transferred (pumped) runoff.

1. Background

The Department of Energy (DOE) and its contractors, the regulatory community, stakeholders and the public have placed a high priority on treatment of contaminated storm water and sediment from the Paducah Gaseous Diffusion Plant (PGDP). There are presently a number of industry-standard engineering approaches that have been considered at the PGDP to address releases of contaminated surface water and sediment from industrial and environmental restoration. However, those standard engineering approaches generally involve large expenditures of capital and a long implementation timeframe. The Biosystems and Agricultural Engineering Department of the University of Kentucky has been contracted to:

- evaluate the adequacy and expected performance of existing storm water controls
- develop alternative storm water and sediment treatment systems that should be considered for implementation, and
- assess and provide recommendations for identified storm water and sediment remedial options that will be cost effective and able to be implemented in a relatively short timeframe.

The potential efficacy of alternative treatment systems will be evaluated through modeling. These activities are to be performed for Outfalls 011, 015 and 008.

2. Cooperators

Design options for an integrated storm water and sediment control system were developed and analyzed for Outfalls 011, 015 and 008 of the Paducah Gaseous Diffusion Plant. Prior to developing alternative scenarios for on-site controls, rainfall, evaporation, existing site maps, and current water quality data were thoroughly reviewed. AutoCAD site drawings were reviewed and an on-site inspection was conducted. Numerous meeting were conducted with Mr. Steve Hampson, University of Kentucky, Water Resources Research Institute, Radiation Control Project to determine the applicability of alternative control design philosophies and to discuss the potential effectiveness of various systems. Additionally, extensive discussions were held with KRCEE participants at quarterly meetings.

3. Assessment of Current Conditions

3.1 Watershed Characteristics

Outfalls 011, 015 and 008 were identified from AutoCAD drawings of the PGDP. Individual sheets (drawings) were assembled and from topographic maps and surface and subsurface drainage systems, watershed boundaries were delineated for each outfall. Watershed boundaries are shown in Figure 1 for Outfall 011 and Figure 2 for Outfalls 015 and 008. Watershed areas are 33.3 acres, 55.5 acres and 113.6 acres, for Outfalls 011, 015 and 008, respectively. For Outfall 011, the entire drainage area consisted of buildings, paved areas and gravel parking lots. The percent impervious area for Outfalls 015 and 008 was 90.8 % and 95.6 %, respectively. The remaining watershed land use for these two outfalls is grass. Flow conveyance for all watersheds is accomplished by storm water inlets and an associated piping network and open channels primarily consisting of trapezoidal or parabolic grass waterways. Hence, a rapid hydrologic response is expected for all outfalls.

There are no current controls that significantly attenuate peak flow or enable settling of sediment. There exists a culvert at each outlet.

3.2 Summary of Outfall Current Conditions Database

Authorization was given and a password provided to the Data Warehouse and Paducah IMS Viewer on 10/31/06. During the next few days, numerous attempts were made to access constituent datasets for Outfalls 008, 011 and 015 via the Paducah IMS Viewer using both Internet Explorer and Mozilla Firefox browsers with no success. Using the Data Warehouse access site was more successful, but this site was still difficult to interpret which "Location" corresponded to the outfalls in question due to the lack of descriptive information and similar site nomenclature. Steve Cordiviola of the Kentucky Geological Survey assisted in obtaining the datasets used for this analysis. Datasets were downloaded on 11/10/06.

The three datasets contained sampling records ranging between 10/13/87 and 01/23/06, with no consistency between the date ranges. Other inconsistencies noted in the datasets include apparent gaps in recorded samples. For example, records indicate that samples were taken at regular intervals and yet extensive gaps (in some cases more than a year between recorded samples) occurred multiple times. There was no obvious pattern to the collection of the constituents analyzed.

Hourly precipitation data for Paducah for the dates ranging from October 1, 1987 through January 30, 2006 was acquired from the National Climatic Data Center of the National Oceanic & Atmospheric Administration (http://www.ncdc.noaa.gov/oa/climate/climatedata.html). The precipitation data was sorted and reorganized to allow for better correlation to PGDP constituent datasets. Representative storm events were selected at random from dates that corresponded to "Suspended Solids" sampling data collected at the three outfalls and analyzed. For collection dates where rainfall was not evident, the most recent rainfall event was noted. Selected events were used for SEDCAD modeling at each of the three

Figure 1. Outfall 011

Figure 2. Outfalls 015 and 008

outfall locations. The events and their corresponding "Suspended Solids" values are presented in Appendix A. While not specifically listed in the downloaded datasets, records were taken for "Suspended Solids". It was assumed that these values were TSS values. It was also assumed that samples recorded were simply grab samples. The range of TSS values for Outfalls 008, 011 and 015 are 4 to 60, 4 to 125 and 5 to 850 mg/L, respectively. TSS values primarily correspond with baseflow conditions. The values in the higher range may correspond with storm flow conditions but are of marginal usefulness for the purpose of this contract.

3.3 Gap Analysis of Outfall Current Database

This contract was focused on runoff and sediment at Outfalls 011, 015 and 008. The lack of information, at these outfalls, for these constituents was noteworthy. No on-site rainfall data was found. No flow data was found. Such a lack of basic data is deemed unacceptable. At a minimum, it would be expected that monitoring equipment would be located in watersheds and at outfalls throughout the facility consisting of:

1) recording rain gauges (such as tipping bucket),
2) flow control devices (such as flumes or compound weirs) at each outfall,
3) automatic continuous recording water level (such as a pressure transducer) at each outfall, and
4) flow-activated automatic pumped samplers.

3.4 Modeling Current Conditions

Hydrologic modeling was conducted using Sediment, Erosion and Discharge by Computer Aided Design (SEDCAD version 4.0), Warner et al. 1998. A composite runoff curve number (CN) of 92 was assigned for impervious areas, building, paved and gravel areas. For grassed areas, a CN of 79 was input based on hydrologic soil group C. Since the watershed drainage consists of a highly integrated network of pipes and open channels, a time of concentration of 0.126 was assigned. A fast unit hydrograph response function was assigned to the impervious areas and a medium unit response shape was used for the grassed areas.

Similarly, erosion parameters were assigned to both impervious and grassed areas. From the USDA soil survey (Figure 3), the predominant soil series are Henry-Grenada-Calloway. The erodibility (K-factor), based on soil texture classification, was 0.28. Representative slope lengths and gradients were taken from PGDP site drawings and topographic maps. For impervious areas, a representative slope length of 150 ft and slope gradient of 1% were assigned. Similarly, for the grassed areas, the representative slope length and gradient were 100 ft and 4%, respectively. The grassed areas in the watersheds for Outfalls 008 and 015 were observed to be well established with approximately 80% ground cover and were therefore assigned a cover factor (C-factor) of 0.013. Imperious areas were assigned a C-factor of 0.02, primarily due to existence of the gravel areas.

Figure 3. Soils Series at the Paducah Gaseous Diffusion Plant

Prediction of current conditions with respect to peak flow, runoff volume, peak sediment concentration and storm sediment load was conducted for design storms. Storms were developed from the rainfall data for each TSS data entry, appendix A, recorded at the Paducah airport located approximately 3 miles from the Paducah Gasification and Diffusion Site. Since, the TSS data was simply based on grab samples, and the purpose of this contract was to model the expected performance of alternative sediment controls, the TSS data was not found to be useful. Natural Resources Conservation Service (NRCS) Type II design storm events of 0.5, 0.75, 1.0, 1.5, 2.0, 3.0 and 6.8 (100-yr 24- hr) inches were modeled, at each of the three outfalls.

3.5 Modeling Results

Peak flow, runoff volume, peak sediment concentration and storm sediment load for the design storms are listed in Table 1. A typical SEDCAD computer analysis printout, for each outfall is provided in Appendix C. Due to the high density of impervious areas and the well established grass cover, the predicted sediment load and concentrations are low for all three outfalls. For small storms, such as a 0.5 to 1.0 in events, the peak sediment concentrations ranged from 430 mg/L to 550 mg/L for the three outfalls. Peak runoff, for Outfall 015, ranged from 2.5 cfs to 63.1 cfs for 0.5 to 3.0 in storm events. The runoff volume is a critical component for the design of retention ponds and alternative sediment control systems. The range of runoff volume, for Outfall 015, was 0.37 ac-ft to 9.58 ac-ft for 0.5 to 3.0 in storm events.

Table 1. Hydrologic and Sedimentologic Response for Modeled Storm Events – Current Conditions

Attribute	Outfall 011	Outfall 015	Outfall 008
Storm 0.50 inches			
Peak flow (cfs)	2.5	3.8	8.2
Runoff volume (ac-ft)	0.25	0.37	0.80
Peak sediment conc. (mg/L)	430	450	490
Sediment load (tons)	0.1	0.1	0.2
Storm 0.75 inches			
Peak flow (cfs)	7.00	10.60	22.84
Runoff volume (ac-ft)	0.64	0.97	2.08
Peak sediment conc. (mg/L)	460	490	530
Sediment load (tons)	0.2	0.3	0.7
Storm 1.00 inches			
Peak flow (cfs)	12.3	18.7	40.3
Runoff volume (ac-ft)	1.12	1.72	3.67
Peak sediment conc. (mg/L)	480	500	550
Sediment load (tons)	0.4	0.6	1.4
Storm 1.50 inches			
Peak flow (cfs)	24.4	37.7	80.4
Runoff volume (ac-ft)	2.22	3.47	7.36
Peak sediment conc. (mg/L)	510	540	590
Sediment load (tons)	0.8	1.3	3.0
Storm 2.00 inches			
Peak flow (cfs)	37.2	58.0	123.0
Runoff volume (ac-ft)	3.43	5.42	11.41
Peak sediment conc. (mg/L)	530	560	610
Sediment load (tons)	1.3	2.1	4.9
Storm 3.0 inches			
Peak flow (cfs)	63.1	99.8	210
Runoff volume (ac-ft)	6.00	9.58	20.05
Peak sediment conc. (mg/L)	560	600	650
Sediment load (tons)	2.3	4.0	9.0
100-yr 24-hr Storm 6.8 in			
Peak flow (cfs)	160.3	258.4	538.2
Runoff volume (ac-ft)	16.25	26.47	54.84
Peak sediment conc. (mg/L)	620	670	717
Sediment load (tons)	6.9	12.0	26.9

4. Alternative Storm Water and Sediment Control Systems

4.1 Overview

The primary function of the on-site treatment system is to provide retention in ponds followed by secondary treatment. Retained runoff will be pumped to alternative treatment systems. Control/treatment will focus on small to medium storms that would not have the benefit of dilution associated with larger storms. The first flush of larger storm events will also be detained. The dilution capacity provided by runoff occurring after the first flush and by the natural fluvial system will further reduce the concentration of constituents for the larger, infrequent storm events. Although analysis is focusing on sediment, it should be noted that a portion of radionucleides and metals are linked to the finer fraction of sediment. Additionally, the secondary treatment systems are addressing both suspended and dissolved fractions.

The design of detention ponds focused on retention of small to medium storm events and passage of the 100-yr 24-hr design storm over the emergency spillway. The primary purpose of the ponds is to retain runoff that will then be pumped to secondary treatment systems.

The alternative secondary treatment systems that are addressed include: 1) irrigation (drip or micro-sprayers) and 2) a weep berm with passive treatment. The design of retention ponds and secondary treatment systems are based on the premise that earthwork activities will be minimized; that is, control systems will be placed on the surface without excavation, thus reducing generation of fugitive dust. For Outfall 011, construction of the retention pond could occur in conjunction with the scheduled real-time channel remediation.

It should be noted that there has not been an on site assessment of primary sources of pollutants. Such an assessment is needed to focus resources on reduction of predominant pollution sources. Storm water from impervious areas primarily enters storm water inlets and then is conveyed to a pipe network and/or directly flows to grass waterways. The placement of a geocomposite (HDPE, bentonite clay, geotextile) or geosynthetic clay liners (bentonite clay imbedded between two geotextile sheets) along the waterways would eliminate any (or many?) constituents that may otherwise be eroded or resuspended from the channel bed or sideslopes. Such liner systems will eliminate infiltration along the channels. Porous check dams, located in the channels, were investigated but due to the shallow channel slope and small cross-sectional area, peak flow reduction was minimal. Thus, use of porous rock check dams along the channels is deemed not cost effective.

4.2 Retention Pond Design

Retention ponds were designed for each outfall. The primary function of the ponds was to contain the entire runoff volume of smaller storms and retain a portion of larger storm events. Stored runoff could be transferred (pumped) to a secondary treatment system or alternatively, in place treatment could be accomplished. Only the secondary treatment systems are addressed herein.

For each outfall, locations were identified for retention ponds and corresponding embankments. A geocomposite liner or geosynthetic clay liner could be placed on the ground surface to preclude infiltration from the pond. For Outfall 011, there would be only nominal earthwork for the construction of the drop inlet spillway since Patrol Road 3 serves as both the embankment and emergency spillway. The drop inlet could be connected to the existing culvert (Figure 4). For Outfalls 015 and 008, clearing of trees and brush would be needed prior to placement of the geocomposite liner. Such clearing could be conducted in conjunction with a real-time stream channel remediation program. An embankment is required to be built for Outfalls 015 and 008, Figures 5 and 6, respectively.

No excavation was considered for any of the ponds. If excavation is deemed an acceptable measure, additional storage capacity would be provided and a larger portion of the annual runoff volume would be afforded secondary treatment.

The invert of the emergency spillway was set to accommodate the 100-yr 24-hr design storm. A 36-inch drop inlet structure was located 2 feet below the invert of the emergency spillway. The drop-inlet could be fabricated as a perforated riser, fitted with one of more vertical dewatering valve(s), to accommodate controlled release of stored water from various elevations within the pond.

The pond capacity, below the principle spillway (invert of the drop inlet), for Outfalls 011, 015 and 008 are 3.66, 097 and 0.92 ac-ft, respectively. Pond capacity was determined without excavation. A summary of embankment and pond attributes is provided as Table 2 below.

Table 2. Pond and Embankment Attributes

Attribute	Outfall 011	Outfall 015	Outfall 008
Embankment Crest Elevation (ft)	377.5	365	363
Emergency Spillway			
Invert (ft)	377	363	361
Width (ft)	60	25	25
Drop Inlet			
Invert (ft)	375	361	359
Diameter (in)	36	36	36
Pond Capacity (ac-ft)			
@ Top of Dam	6.67	3.51	3.03
@ Emergency Spillway	5.92	2.03	1.70
@ Principle Spillway	3.66	0.97	0.92
100yr 24hr Freeboard (ft)	0.0	0.17	Overflows

Figure 4. Outfall 011 Pond

Figure 5. Outfall 015 Pond

Figure 6. Outfall 008 Pond

The watershed area of Outfall 011 is 33.3 acres. It is the smallest drainage area of the three outfalls analyzed. The pond for Outfall 011 (Pond 011) has the largest capacity of the three outfall ponds and therefore has the highest potential for effective treatment of inflow. Additionally, the pond is easily constructed due to the existence of Patrol Road 3, which functions as an embankment, and has a culvert that can be fitted with a gated perforated riser and/or floating siphon. The culvert becomes the barrel of the discharge system. Thus, control of runoff, sediment and associated water quality constituents is highly feasible for Outfall 011.

4.3 Retention Pond Performance – Design Storm Basis

4.3.1 Outfall 011

The expected performance of Pond 011 was conducted using SEDCAD with the initial condition of being empty at the beginning of the storm event (Appendix D). It was anticipated that runoff contained in the pond would be pumped to the treatment system located near Outfall 010 and then discharged at that outfall. With a storage capacity of 3.66 ac-ft, Pond 011, if empty at the start of a storm, could completely contain a 2-in rainfall event (3.43 ac-ft), as shown in Table 3. For larger storm events, with an initial condition of empty, the predicted reduction in peak flow (in versus out), peak sediment concentration and sediment trap efficiency ((tons in – tons out)/tons in) X 100) was conducted using SEDCAD (Table 3). The 3-in storm would discharge 0.25 ft above the invert of the principle spillway, reduce the peak flow from 63 to 5 cfs and have approximately 100 % sediment trapping (Table 3). Even for the 4-in storm, the predicted performance is excellent, achieving 99.7 % sediment trapping. Thus, it can be concluded, with respect to sediment, that with transfer of contained runoff to the treatment plant located at Outfall 010, the performance of Outfall's 011 pond is predicted to be excellent; essentially trapping all entering sediment for storm events less than 4 inches. A 4-in storm has approximately a 10 year recurrence interval. A 4-in storm event accounts for approximately 97 % of the average annual precipitation (Appendix B).

4.3.2 Outfall 015

The storage volume for Pond 015 is much smaller than Pond 011 and the watershed area is greater, 55.5 versus 33.3 acres. It should be noted that the storage capacity could be increased through excavation, if feasible, or increasing the berm height along the sideslopes of the pond in the vicinity of the embankment.

Without excavation and starting empty, Pond 015 could completely contain a ¾-in rainfall event. A 1.5-in storm is predicted to have 98.2 % sediment trap efficiency. Again, the 98.2 % efficiency is based on the pond being empty at the start of the storm and the retained runoff being transferred to one of the secondary treatment systems described in the Alternative Secondary Treatment Systems section of this report. For 2- and 3-in storms, the sediment trap efficiency is predicted to be 85.5 and 72.3 %, respectively. Thus, a 70+% sediment trapping efficiency is predicted for storm events of 3 inches or less. A 3-in storm event accounts for approximately 92 % of the average annual precipitation (Appendix B).

Table 3 Pond Inflow – Outflow Analysis

Parameter	Outfall 011		Outfall 015		Outfall 008	
Storm 0.5 in						
Peak flow (cfs)	In	Out	In	Out	In	Out
	2.50		3.79		8.16	
Peak Stage (ft)	368.0		358.9		358.7	
Peak Sediment Conc. (mg/L)	In	Out	In	Out	In	Out
	430		450		490	
Sediment (tons)	In	Out	In	Out	In	Out
	0.1		0.1		0.2	
Trap Efficiency (%)	Completely contained		Completely contained		Completely contained	
Storm 1.0 in						
Peak flow (cfs)	In	Out	In	Out	In	Out
	12.32		18.71	1.62	40.23	26.25
Peak Stage (ft)	371.5		361.08		359.92	
Peak Sediment Conc. (mg/L)	In	Out	In	Out	In	Out
	480		500	100	550	47
Sediment (tons)	In	Out	In	Out	In	Out
	0.4		0.6	<0.01	1.4	<0.05
Trap Efficiency (%)	Completely contained		99.9		96.7	
Storm 1.5 in						
Peak flow (cfs)	In	Out	In	Out	In	Out
	24.42		37.72	20.80	80.38	57.79
Peak Stage (ft)	3.73		361.78		361.46	
Peak Sediment Conc. (mg/L)	In	Out	In	Out	In	Out
	510		540	30	590	175
Sediment (tons)	In	Out	In	Out	In	Out
	0.8		1.3	0.02	3.0	0.7
Trap Efficiency (%)	Completely contained		98.2		77.2	
Storm 2.0 in						
Peak flow (cfs)	In	Out	In	Out	In	Out
	37.17		58.03	40.90	122.96	118.53
Peak Stage (ft)	374.7		362.47		361.97	
Peak Sediment Conc. (mg/L)	In	Out	In	Out	In	Out
	530	.	570	120	610	237
Sediment (tons)	In	Out	In	Out	In	Out
	1.3	.	2.1	0.3	4.9	1.6
Trap Efficiency (%)	Completely contained		85.5		67.6	
Storm 3.0 in						
Peak flow (cfs)	In	Out	In	Out	In	Out
	63.09	5.08	99.80	87.30	209.98	204.21
Peak Stage (ft)	375.25		363.73		362.56	
Peak Sediment Conc. (mg/L)	In	Out	In	Out	In	Out
	560	0	600	193	650	292
Sediment (tons)	In	Out	In	Out	In	Out
	2.3	0	4.0	1.1	9.0	3.5
Trap Efficiency (%)	~100		72.3		61.3	
Storm 4.0 in						
Peak flow (cfs)	In	Out	In	Out	In	Out
	88.94	26.84	141.8	136.2	297.08	289.59
Peak Stage (ft)	377.04		364.10		363.04	
Peak Sediment Conc. (mg/L)	In	Out	In	Out	In	Out
	580	13	623	238	670	324
Sediment (tons)	In	Out	In	Out	In	Out
	3.5	~0.0	6.0	1.9	13.5	5.6
Trap Efficiency (%)	99.7		67.5		58.1	
Storm 6.8 in	**100 year – 24 hour Design Storm**					
Peak flow (cfs)	In	Out	In	Out	In	Out
	160.29	127.24	258.4	252.2	538.2	525.49
Peak Stage (ft)	377.51		364.83		364.38	
Peak Sediment Conc. (mg/L)	In	Out	In	Out	In	Out
	615	130	670	300	720	370
Sediment (tons)	In	Out	In	Out	In	Out
	6.9	1.1	12.0	4.7	26.9	12.4
Trap Efficiency (%)	83.5		61.1		53.8	

4.3.3 Outfall 008

The watershed area of Outfall 008 is 113.6 acres which exceeds Outfall 015 by more than a factor of two. The pond capacity, below the principle spillway, is 0.92 ac-ft which is approximately the same as for Outfall 015. Pond 008, starting empty, can contain a ½-in rainfall event without discharging. The predicted sediment trapping efficiencies for the 1-in, 1.5- in and 2-in storms are 96.7, 77.2 % and 67.6%, respectively (Table 3). An example SEDCAD analysis is provided in Appendix D. These pond efficiencies are predicted to be achieved based on the retained runoff volume being pumped to a secondary treatment system. Thus, nearly a 70+% sediment trapping efficiency is predicted for storm events of 2 inches or less. A 2-in storm accounts for approximately 82 % of the average annual precipitation (Appendix B).

4.4 Retention Pond Performance – Annual Basis

The approximate amount of annual runoff that could be contained and subsequently treated by a secondary treatment system was determined for each outfall. An analysis of Paducah airport daily precipitation data for the period from 1971 through 2000 was completed. The assessment was conducted to determine the average number and size of storm events that can be expected throughout the year. A cumulative rainfall curve was developed by multiplying storm size (midpoint) by the probability of occurrence (Appendix B). The majority of rainfall is due to small to medium storm events, with 24 %, 40%, 52%, 62%, 70%, 82% and 92% of the annual rainfall being accounted for by storms less than ½, ¾, 1, 1.25, 1.5, 2 and 3 inches, respectively. Larger storms, although containing more rainfall, are relatively rare events and as such, contribute to a lesser degree to the annual rainfall than the more frequent small to medium storm events.

Storm analysis was completed for ponds at each outfall. The runoff associated with storms having a daily rainfall between 0.1 and 5.50 inches were analyzed to determine the size of storm that would be completely contained and the portion of runoff from larger storms that would be contained if the initial condition was an empty pond. It was assumed that the stored pond water would be transferred to a secondary treatment system or treated and released prior to a subsequent storm. For Outfalls 011, 015 and 008 the largest storm size that could be completed contained is approximately 2, 3/4 and 1/2 inches, respectively.

For storms larger than the completely contained storm, the portion of runoff that would be contained was determined (Table 4). From Appendix B, the probability of occurrence for incrementally increasing storm events was determined and is presented in column 2 of Table 4. The portion of runoff that would be retained in each pond (SEDCAD analysis) and probability of occurrence (Appendix B) were combined and summed to estimate the annual amount of runoff that could be transferred to a secondary treatment system (Table 4). Based on this analysis, the estimated annual volume of runoff that could be treated in a secondary treatment system for Outfalls 011, 015 and 008 is 83.1 %, 34.7% and 20.2 %, respectively. These percentages would be somewhat reduced due to consecutive storms that occur prior to accomplishing transfer of stored runoff to the secondary treatment system.

Table 4. Estimated Percent of Storm and Annual Runoff Contained in Retention Ponds

Rainfall (in)	Rainfall midpoint	Probability	Outfall 011 Runoff * (%)	Outfall 015 Runoff * (%)	Outfall 008 Runoff * (%)
0.10-0.25	0.175	5.32	100	100	100
0.25-0.50	0.375	15.02	100	100	100
0.50-0.75	0.625	15.94	100	100	66
0.75-1.00	0.875	11.67	100	73	32
1.00-1.25	1.125	10.23	100	46	20
1.25-1.50	1.375	7.93	100	32	14
1.50-1.75	1.625	5.61	100	25	11
1.75-2.00	1.875	6.09	100	20	9
2.00-2.25	2.125	3.88	100	16	7
2.25-2.50	2.375	2.09	84	14	6
2.50-2.75	2.625	1.77	73	12	6
2.75-3.00	2.875	2.33	64	11	5
3.00-3.25	3.125	1.00	58	10	4
3.25-3.50	3.375	1.14	52	9	4
3.50-3.75	3.625	0.73	48	8	4
3.75-4.00	3.875	1.83	44	7	3
4.00-4.50	4.25	0.84	39	6	3
4.50-5.00	4.75	0.95	34	5	3
5.00-5.50	5.25	0.71	30	5	2
Annual containment in ponds			**83.1%**	**34.7%**	**20.2%**

* Runoff volume contained in ponds

Design professionals often simply address the 10-yr 24-hr design storm. Unfortunately, focusing on such a large and infrequent storm event results in construction of control facilities that are costly to design, operate, maintain and subsequently decommission. The focus of this contract was on developing a cost-effective control system that can be readily implemented and that would treat a significant portion of the annual runoff. Frequent small storm events would be completely retained, medium storms would be effectively treated and the few rare, large storms would be partially retained and discharged flows would enter a stream system that provides dilution.

4.5 Alternative Secondary Treatment Systems

Alternative design options are detailed herein. Runoff stored in the retention ponds is pumped to the secondary treatment systems. Designs have been developed for: 1) irrigation (drip or micro-sprayers) and 2) a weep berm with passive treatment.
The approach taken was to illustrate, by detailed example, the design, evaluation and performance of alternative control systems and options. This approach was taken to

provide an on-site contractor with a great deal of flexibility in implementing these control systems. Treatment options are integrated with topographic conditions and spatial constraints.

Specifically, to illustrate these alternative secondary treatment systems, the irrigation alternatives were applied to Outfall 015 and the weep berm system utilizing Outfall 008.

Outfall 011 has a treatment process located near Outfall 010. The stored runoff from Outfall 011 could be transferred to Outfall 010's treatment facility or flocculation could be used to enhance performance within Pond 011. The alternative secondary treatment systems can be applied to any of the Outfalls as long as sufficient area is available.

4.6 Design Alternative Secondary Treatment Systems for Outfall 015

4.6.1 Overall Methods

Two primary methods were investigated: 1) evapotranspiration of applied water and 2) evapotranspiration and infiltration of applied water. The advantage of restricting the application rate to match the evapotranspiration rate is that the vast majority of water applied will be treated without the potential for groundwater contamination. Hence, nearly 100% treatment of transferred water is expected. The disadvantage is the requirement for a larger treatment area and/or a pond water removal rate (pumping rate) that may not enable dewatering the retained pond water prior to the occurrence of a subsequent storm thereby reducing the overall volume of runoff receiving secondary treatment. The advantages of an evapotranspiration-infiltration system are the ability to have a higher applications rate, longer duration of application and thus, treatment of a greater volume of water compared to the evapotranspiration method. Additionally, natural removal of pollutants within the soil matrix can be realized. Determining the removal efficiency through natural attenuation was beyond the scope of this contract. The potential disadvantage is that a portion of the applied water may migrate to groundwater.

The two irrigations systems being considered are: 1) drip and 2) micro-sprinklers.

4.6.2 Evapotranspiration Method

A simple water balance is shown in Table 5, based on average monthly precipitation and evapotranspiration (ET) from an established turf area located in Paducah, Kentucky. Table 5 lists monthly precipitation and ET amounts. Also shown is the monthly difference between precipitation and ET. The average monthly differences are shown in Figure 7. As expected, in the hotter months, ET exceeds precipitation resulting in a negative water balance. Also calculated, for each month, is the average daily ET value. As seen in Table 5, monthly ET ranges from a low of 0.01 to a high of 0.24 inches per day. The high value corresponds with the irrigation rule-of-thumb of about ¼-inch needed for irrigating turf during high water demand periods.

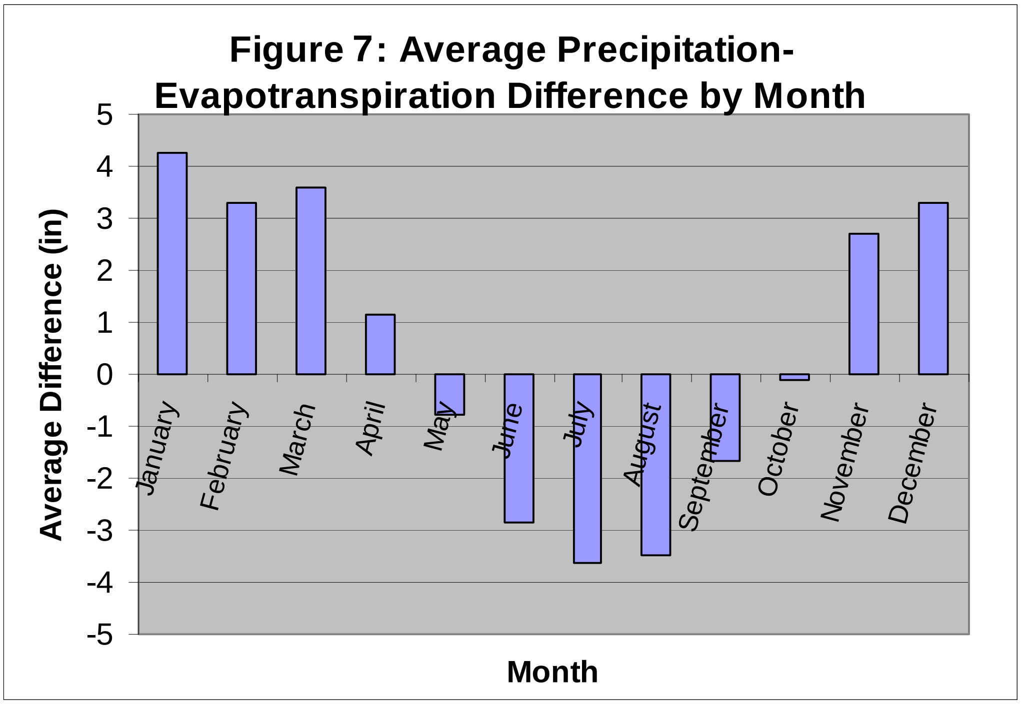

Table 5. Monthly Water Balance, USLE 'R-factor' and Daily Evapotranspiration

Month	Average Precipitation (in)	Average ET (in)	Average Difference (in.)	Ave. Daily ET (in/day)	Monthly R value (%)	Cumulative R value (%)
January	4.66	0.41	4.25	0.013	1	1
February	3.87	0.58	3.29	0.021	5	6
March	5.02	1.43	3.59	0.046	6	12
April	4.13	3.00	1.13	0.100	9	21
May	4.21	4.97	-0.76	0.160	10	31
June	3.86	6.71	-2.85	0.224	12	43
July	3.97	7.61	-3.64	0.245	14	57
August	3.39	6.87	-3.48	0.222	14	71
September	3.06	4.71	-1.65	0.157	10	81
October	2.61	2.73	-0.12	0.088	7	88
November	3.79	1.09	2.70	0.036	5	93
December	3.81	0.52	3.29	0.017	4	97
TOTAL	46.38	40.63	5.75	0.111		

4.6.2.1 Drip Irrigation System – Evapotranspiration Method

A 5-acre irrigation system is used to illustrate the capabilities of this method (Figure 8). This drip irrigation system is designed to apply water to the soil at such a rate as to evapotranspirate all, or the vast majority of, applied water. Application of water to the areas adjacent to and up-gradient of the retention pond 015 is illustrated in Figure 9. Use

Figure 8. Typical 5-Acre Drip and Micro-sprinkler Irrigation System Layout

Figure 9. Drip and Micro-sprinkler Irrigation System - Outfall 015

of such a simple irrigation system enables extending the period of vegetal establishment throughout most of the year. Obviously, any water evapotranspirated reduces the quantity of water discharged from Outfall 015.

System components include a pump, filter, piping system, drip line and fittings, controller and solenoid valves and either a rainfall sensor or a soil moisture sensor. Figure 8 shows an established turf area of approximately 5 acres that can potentially be used for drip irrigation. The area could potentially be expanded to approximately 25 acres.

The average daily evapotranspiration is 0.11 inches. Thus, for 5 acres, 0.55 ac-in (0.046 ac-ft) of water could be evapotranspirated. Since the retention pond of Outfall 015 has a capacity of 0.972 ac-ft, it would take approximately 21 days to treat the entire stored volume, assuming that the pond was initially full to capacity. There is an average of 75 runoff producing rainfall events per year, or approximately 1 per 5 days throughout the year (Appendix B). Based on the incremental rainfall values and cumulative frequency, shown in Appendix B, 36 % of runoff producing events (greater than 0.1 inch/day) would only partially fill Pond 015 storage capacity.

The average daily evapotranspiration rate for June through August is approximately 0.23 inches. For May and September it is approximately 0.16 inches and for April and October it is approximately 0.10 inches. Thus for one-half of the year, the 0.10 inch/day rate can be equaled or exceeded. It is noteworthy that during the highest stress period for fish and aquatic invertebrates (June through August; due to temperature), the evapotranspiration rate is twice the design rate of 0.11, used in the above calculations. Thus, during these high stress periods, a completely full retention pond could be emptied in approximately 10 days.

Alternatively, if the entire 25 acre potential irrigation area was utilized, then the 0.972 ac-ft pond storage capacity could be treated through evapotranspiration (at 0.11 inch/day) in approximately 4 days. Again, during the high stress period of June through August, the complete pond capacity could be emptied in approximately 2 days.

4.6.2.2 System Components

For a 5 acre system, designed in five 1-ac zones, the required pump capacity, based on 36 gpm with a head of approximately 120 ft (depending on filter type and irrigation system layout) is approximately a 2 BHP (Figure 8).

Each acre requires approximately 11,000 ft of drip line (based on a 4-ft spacing). The flow rate is 36 gpm/ac. For a 5-ac system, the main pipe would be either 1 ½ or 2-inch and the submain would be 1 to 1 ¼ inch in diameter. A 6-zone irrigation controller (5-station controllers are not manufactured) will be needed to automatically transition from zone to zone and apply water for user specified times. Each zone would need a 1 ½ inch solenoid valve.

For the 25 ac system, segmented into five 5-ac zones, a 10 BHP pump would be required (Figure 10). The main pipe would be 4-inches and submains 2 to 3 inches in diameter. Three inch valves would be needed for each zone.

To apply 0.1 in/day to an acre of land will require approximately 1 ¼ hours for each zone or a daily run time of approximately 6 hours. The controller should be programmed for multiple application times throughout the 6 hour timeframe. Such a pulse water application method will enhance evapotranspiration. For instance, each 1-ac zone could be programmed to be irrigated using three 25 minute periods or five 15 minute periods.

Two alternative sensors could be considered for use: 1) rain or 2) soil moisture. The rain sensor simply over-rides the irrigation controller when a pre-set rainfall amount is contained in a sensor cup. The soil moisture sensor is inserted into the soil such that the current soil moisture condition is used to control the irrigation controller. If soil conditions are too wet, then irrigation will not be applied to that zone.

4.6.2.3 Micro-sprinklers Irrigation System – Evapotranspiration Method

Micro-sprinklers are small rotating spray heads that have a radius of approximately 15 ft and a flow capacity of approximately 1 gpm. The micro-sprinkler is relatively close to the ground compared to standard impact sprinklers. Therefore, evaporation benefits are realized with limited exposure to drift. The evaporation rate of the spray is expected to be approximately 20% of the application rate. Additionally, compared to drip irrigation, spatial coverage is better so evapotranspiration can be expected to be more uniform. Micro-sprinklers have a higher irrigation application rate, so operating times are much less than drip system.

Micro-sprinklers are spaced to achieve head-to-head coverage; that is, a 15-ft radius implies 15-ft spacing between sprayers. A 15-ft radius sprayer has a flow rate of approximately 1 gpm. The application rate, based on 15-ft square spacing, is 0.43 in/hr. To meet the evapotranspiration rate of 0.11 inch/day, the micro-sprinklers would only have to operate for 15 minutes/day. For 0.22 inch/day, the micro-sprayers would operate 30 minutes/day. If spray evaporative losses are accounted for, then the operating time would be 18 minutes for a loss of 0.13 inch/day, and 36 minutes for a loss of 0.26 inch/day. Approximately 200 micro-sprayers are required per acre.

A 5-ac system is capable of dewatering Pond 015 in approximately 8 days. A 25-ac system can dewater the pond in approximately 1 ¾ days.

The 5-ac plot could be separated into twenty ¼ acre zones each with a flow rate of approximately 50 gpm (Figure 11). The 20 zone irrigation system would operate for approximately 5 hours/day to meet the 0.13 inch/day evapotranspiration rate and 10 hours/day for 0.26 inch/day. The size of irrigation components depends upon the layout of the irrigation system.

Figure 10. 25-Acre Drip and Micro-sprinkler Irrigation System Layout

Figure 11. 5-Acre Micro-sprayer Irrigation System Layout

Typical component sizing is illustrated in Figure 11 for a 5-ac micro-sprinkler system that is separated into twenty 0.25-ac zones with 50 sprinkler heads per zone. For such a layout, the main would be 2 to 2 ½ inches in diameter; the submains would be 1 ¼ to 2 ½ inches in diameter, with ½ in laterals and 1 ½ in solenoid valves. The pump would be approximately 3 BHP for such a 5-ac system.

A 25-ac design, based on 25 1-ac zones with a flow rate of 200 gpm/zone, is illustrated in Figure 12. Each zone would require 200 micro-sprinklers. For the layout shown in Figure 12, the main would be 4 inches in diameter, with 3 to 4 inch submains, ¾ in laterals and 1 ½ to 2 in solenoid valves. The pump would be approximately 12 BHP.

The 25 zone irrigation system would operate for approximately 6 ¼ hours/day to meet the 0.13 inch/day evapotranspiration rate and 12 ½ hours/day for 0.26 inch/day. The size of irrigation components depends upon the layout of the irrigation system.

It should be noted that the presented irrigation layouts are meant to provide typical system layouts and associated irrigation components. The actual irrigation system design and layout will be site-specific and components sized according to topography and zones. Alternative designs should be evaluated to determine the most cost-effective configuration.

Figure 12. 25-Acre Micro-sprayer Irrigation System Layout

4.6.3 Evapotranspiration/Infiltration Method

4.6.3.1 Drip Irrigation System – Evapotranspiration/Infiltration Method

A preliminary estimate of the soil infiltration rate is solely based on soil texture. The approximate steady state infiltration rate, for a hydrologic soil group 'C' category soil, ranges from 0.05 to 0.15 in/hr. Due to macropores, the infiltration rate may be substantially higher. The initial infiltration rate can be 0.4 to 0.5 inch/hour and short duration irrigation application rates can exceed 0.6 in/hr without runoff.

Based on the conservative value of a steady state infiltration rate of 0.1 in/hr, a 10-hour irrigation duration, and a 5 acre site, 0.42 ac-ft could be infiltrated within a day. Adding evapotranspiration (0.11 inch/day), the resultant quantity of water that can be treated is approximately 0.46 ac-ft. Thus a 5-ac site could dewater a Pond 015 sized completely full retention pond in approximately 2 days. This length of time, using only 5 acres, is approximately 1/10 of the time required for a 5-ac evapotranspiration-only drip irrigation system.

It should be noted that the capacity of the silty loam soil to remove pollutants at such an infiltration rate has not be evaluated. Obviously, increasing the area that receives irrigated water enables reduction of the application rate and the corresponding daily loading rate; therefore increasing the removal efficiency of the soil matrix. Alternatively, soil amendments could be applied to the surface to enhance removal of pollutants.

4.6.3.2 System Components

The drip irrigation system design to meet the steady state infiltration and evapotranspiration rate is similar to the of the evapotranspiration-only drip irrigation design, except that a 3-ft spacing between drip lines would be used (4-ft for evapotranspiration-only) and the entire system would be operated for 10 hours/day, thus precluding the use of zoning used in the evapotranspiration-only method. Hence, a larger pump would be required (240 gpm @ 120 ft head ~ 13 BHP). The main pipe would be 4-inches in diameter and submains would be 2 to 3-inches in diameter, depending upon system layout.

4.6.3.3 Micro-sprayer Irrigation System – Evapotranspiration/ Infiltration Method

Based on an application rate of 0.43 inch/hour, the micro-sprayers would be operated multiple times during the day so as not to exceed the steady-state infiltration capacity. This type of operation is known as the pulse irrigation method. For a 5-ac site to accommodate 1.0 inch daily infiltration, or 1.3 inch/day (including evapotranspiration and evaporative losses during spraying), 0.54 ac-ft would be applied on a daily basis. The length of time to dewater Pond 015 would be approximately 1 3/4 days.

The number of zones would have to be reduced from twenty 1/4-ac zones (evapotranspiration-only method) to five 1-ac zones to enable having enough time per day to apply irrigation water. Thus, pump capacity would be increased from 50 gpm to

200 gpm. Each 1-ac zone of micro-sprayers would operate for approximately 3 hours/day. Most likely, multiple application cycles of ½ hour each would be utilized. The total operating time for the 5 zones would be 15 hours per day to achieve the 1.3 inch/day rate.

Alternatively, micro-sprinklers could be replaced by spray heads that have a 15-ft radius and a flow rate of 3.7 gpm (versus 1 gpm for micro-sprinklers) and an application rate of 1.83 in/hr (versus 0.43 in/hr for micro-sprinklers). The zone operating time would be reduced from 3 hours per day to about 45 minutes per day. If 9 hours per day is considered the available operating time, then 12 zones would be utilized. The pump capacity would be approximately 300 gpm.

4.7 Design Alternative Secondary Treatment Systems for Outfall 008

A combination weep berm-grass filter is being considered as secondary treatment system for Outfall 008.

4.7.1 Combined Weep Berm – Grass Filter Characteristics

A combined weep berm – grass filter system, illustrated in Figures 13 and 14, is a low cost, easily constructed and highly effective passive treatment system that works synergistically with the down-gradient riparian zone *and* blends into the natural landscape. A weep berm is simply an earthen berm that temporarily detains water that is slowly and passively discharged through pipes or weep outlets, to the down-gradient grass filter. Further treatment and infiltration occurs along the grass filter prior to any residual runoff re-entering Outfall 008's retention pond.

The combination weep berm-grass filter reduces the sediment concentration. Runoff is first detained in the weep berm where sediment and other particulate-based pollutants settle up-gradient of the weep berm. Additionally, metals in solution will infiltrate through the earthen berm which can be modified to further capture pollutants. Discharge from the weep berm occurs in three ways:

1) through a large number of equally spaced small pipes or weep outlets
2) infiltration through the earthen berm and
3) into the underlying soil.

If the infiltration rate up-gradient of the weep berm is considered to be too high for natural attenuation of specific water quality constituents within the near-surface soil matrix, then a geocomposite can be incorporated into the design to preclude such infiltration. Further treatment is achieved through interception and detention by the vegetation and infiltration within the grassed filter.

4.7.2 Expected Performance

The expected performance of a combination weep berm-grass filter treatment system can be gleaned from a research project conducted on a construction site near Atlanta, GA. A weep berm– forested riparian area was used to retain sediment, reduce peak flow and infiltrate runoff at an active construction site at Alpharetta, Georgia (Warner and Collins-Camargo, 2001). Monitoring was conducted only immediately up and down-gradient of the weep berm since, by design, most discharge emanating from the weep berm infiltrated within the forested area. The monitored effectiveness of the weep berm system, with respect to storm water and sediment control, was excellent; reducing effluent sediment from approximately 50,000 mg/l entering the weep berm to approximately 300 mg/l prior to achieving another 90-plus percent reduction in effluent concentrations through the adjacent down-gradient riparian zones to less than 30 mg/l discharged to the stream.

In another project, a weep berm – grass filter control system was installed down-gradient of two elongated gradient sediment ponds placed in series at a site receiving sediment-laden flow in the mountains of Peru. The ponds were equipped with a flocculation system that was used during the wet season for larger storm events to enhance sediment-trapping efficiency. The reported effluent sediment concentration entering the adjacent stream was always below 50 NTU and averaged approximately 15 NTU during storm events. The passive weep berm – grass filter system was viewed as a control system that successfully achieved effluent requirements of the project (Warner and Torrealba, 2003).

4.7.3 Design Considerations for Combination Weep Berm –Grass Filter Control System

The design of a combination weep berm – grass filter control system to remove sediment and associated constituents is based on both weep berm and grass filter attributes. Design parameters include the pumping rate from Pond 008, sediment load and concentration, desired treatment efficiency, soil type, height and length of the weep berm, location, type and configuration of the outlets, and internal check dam spacing and height, if utilized. The design discharge rate from the weep berm to the down-gradient grass filter is a function of the infiltration rate and length (in the flow direction) of the grass filter and the desired systems effectiveness. The highest efficiency is often a function of the amount of discharged water that is infiltrated within the filter. Generally, system performance is increased with a longer grass filter and higher infiltration rate in the grass filter. Removal efficiency is also a function of the filtering action of the riparian material.

5. DESIGN METHODOLOGY AND MODELED PERFORMANCE

The treatment system consists of retention Pond 008, the transfer pump, the weep berm and the grass filter (Figure 13). Pond 008 has a storage capacity of 0.92 ac-ft.

There is a relationship among pumping rate, length of the weep berm, discharge rate through the weep berm and overall system treatment effectiveness. As an illustration, a pumping rate of 450 gpm (~ 1 cfs) was used to dewater Pond 008. A pump operating for 6 hours/day will transfer 0.5 ac-ft. Thus, a completely full (to the invert of the principle spillway) Pond 008 can be emptied in approximately two days.

The weep berm is to be placed on the contour. It is 450 ft in length and has a height of 2 ft. Assuming approximately a 5 % land slope up-gradient of the weep berm the storage capacity, corresponding to the top of the berm, is approximately 0.275 ac-ft .The berm is grassed and the top of the berm functions as a very wide emergency spillway. One inch PVC pipes are placed at 10 ft intervals along the weep berm. The invert of the pipe is 1 ft above the ground level. The stage-discharge values are listed in Appendix D, SEDCAD file entitled Pond 008 Combined Weep Berm – Grass Filter.

Analysis was conducted for a 0.7-in storm event. The peak stage, 358.97 ft, is slightly lower than the principle spillway, 359 ft. Retained runoff is pumped to the weep berm at 450 gpm. The weep berm reaches a steady state condition at a stage of 1 ¾ ft above the ground surface, ¼ freeboard, and discharges over a 7 hour period prior to reaching the invert of the weep berm pipes. The approximate sediment trap efficiency of the weep berm is an additional 36 %. The peak sediment concentration emanating from the weep berm is predicted to be 88 mg/l.

The natural grass filter is 450 ft in width (same as the weep berm), 250 ft in length and has a 4 % slope. The steady state grass filter infiltration rate is 0.1 in/hr. The majority of water infiltrates into the soils of the weep berm. The grass filter reduces the sediment concentration to near zero (predicted 2 mg/L). Hence, the treatment system consisting of Pond 008 and the combination weep berm – grass filter achieve an overall efficiency of nearly 100 %. It should be make clear that the 100 % treatment efficiency is for the runoff retain in Pond 008 and subsequentially treated by the combined weep berm – grass filter.

Figure 13. Overview of Outfall 008 Treatment System

6. GENERAL FINDINGS

- The retention pond for Outfall 011 has a predicted sediment trap efficiency of 99.7% for a 4-in 24-hr storm, if the pond is initially empty and retained runoff is pumped to the treatment plant at Outfall 010 prior to release.
- Retention Pond 015 has a predicted sediment trap efficiency of 72.3% for a 3-in 24-hr storm, if the pond is initially empty and retained runoff is pumped to one of the alternative secondary treatment systems.
- Retention Pond 008 has a predicted sediment trap efficiency of 67.6% for a 2-in 24-hr storm, if the pond is initially empty and retained runoff is pumped to one of the alternative secondary treatment systems.
- The approximate average annual runoff that can be retained in ponds and pumped to secondary treatment systems is 20.2%, 83.1% and 34.7% for Outfalls 008, 011 and 015, respectively.
- For the secondary treatment method, consisting of an evapotranspiration-only treatment system, a drip irrigation system and a micro-sprinkler irrigation system can dewater Pond 015, entirely full, within 2 days and 1 ¾ days, respectively when a 25 ac site is used.
- For the secondary treatment method, consisting of an evapotranspiration-infiltration treatment system, a drip irrigation system and a micro-sprinkler irrigation system can dewater Pond 015, entirely full, within 2 days and 1 ¾ days, respectively when a 5 ac site is used.
- The predicted performance of a combination weep berm – grass filter system to process retained runoff from Pond 008, when completely full, is essentially 100%; reducing effluent concentration to 2 mg/L.

7. REFERENCES

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