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

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Background

• High priority on treatment of contaminated storm water and sediment from PGDP

• Industry-standard engineering approaches have been considered

• Involve
  – Large expenditures of capital
  – Long implementation timeframe
Objectives

• Evaluate the adequacy and expected performance of existing storm water controls

• Develop alternative storm water and sediment treatment systems

• Assess and provide recommendations for identified storm water and sediment remedial options
  – cost effective
  – able to be implemented in a short timeframe
Assessment of Current Conditions - Watershed Characteristics

- Outfall 011 - Area Calculated: 33.3 acres
- Percent impervious area: 100%
- Flow conveyance for all watersheds
  - Storm water inlets
  - Associated piping network
  - Open channel waterways
Assessment of Current Conditions - Watershed Characteristics

- Areas calculated:
  - Outfall 015: 55.5 acres
  - Outfall 008: 113.6 acres
- Percent impervious area:
  - Outfall 015: 90.8%
  - Outfall 008: 95.6%
- Remaining land use is grass.
Assessment of Current Conditions – Modeling Current Conditions

• SEDCAD version 4.0 (Warner et al. 1998)

• Curve Numbers
  – 92 for impervious areas, buildings, paved and gravel areas
  – 79 for grassed areas (hydrologic soil group C)

• Time of concentration – 0.126

• Unit hydrograph response functions assigned
  – Fast for impervious areas
  – Medium for grassed areas
Modeling Current Conditions

• Erosion parameters similarly assigned
• Predominant soil series are:
  – Henry-Grenada-Calloway
• K-factor (erodibility) – 0.28
Modeling Current Conditions

- **Representative slope lengths and gradients**
  - Impervious areas
    - Slope length – 150 ft.
    - Slope gradient – 1%
  - Grassed areas
    - Slope length – 100 ft.
    - Slope gradient – 4%

- **C-factor (cover factor)**
  - Impervious areas – 0.02
  - Grassed areas – 0.013
Assessment of Current Conditions - Modeling Results

• Predicted sediment load and concentrations are low for all three outfalls
  – high density of impervious areas
  – well established grass cover

• Storms (0.5 to 3 in) Outfall 015
  – peak sediment concentrations ranged from 450 – 600 mg/L
  – peak runoff – 3.8 – 99.8 cfs
  – runoff volume - 0.37 ac-ft. to 9.58 ac-ft.
Alternative Storm Water and Sediment Control Systems

• Retention Pond Performance – Design Storm Basis
  – Outfall 011
  – Outfall 015
  – Outfall 008

• Retention Pond Performance – Annual Basis

• Alternative Secondary Treatment Systems
### Retention Pond & Embankment Design

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Outfall 011</th>
<th>Outfall 015</th>
<th>Outfall 008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embankment Crest Elevation (ft)</td>
<td>377.5</td>
<td>365</td>
<td>363</td>
</tr>
<tr>
<td>Emergency Spillway</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Invert (ft)</td>
<td>377</td>
<td>363</td>
<td>361</td>
</tr>
<tr>
<td>Width (ft)</td>
<td>60</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Drop Inlet</td>
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<td></td>
</tr>
<tr>
<td>Invert (ft)</td>
<td>375</td>
<td>361</td>
<td>359</td>
</tr>
<tr>
<td>Diameter (in)</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Pond Capacity (ac-ft)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@ Top of Dam</td>
<td>6.67</td>
<td>3.51</td>
<td>3.03</td>
</tr>
<tr>
<td>@ Emergency Spillway</td>
<td>5.92</td>
<td>2.03</td>
<td>1.70</td>
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<tr>
<td>@ Principle Spillway</td>
<td>3.66</td>
<td>0.97</td>
<td>0.92</td>
</tr>
<tr>
<td>100yr 24hr Freeboard (ft)</td>
<td>0.0</td>
<td>0.17</td>
<td>Overflows</td>
</tr>
</tbody>
</table>
Retention Pond Performance
– Design Storm Basis: Outfall 011

• Initial condition – empty at beginning of storm event
• Runoff contained in the pond - pumped to the treatment system located near Outfall 010
• Completely contain a 2-in rainfall event (3.43 ac-ft)
• 3-in storm –
  – reduce the peak flow from 63 to 5 cfs
  – ~100 % sediment trapping
• Performance of Outfall’s 011 pond is predicted to be excellent; essentially trapping all entering sediment for storm events less than 4 inches
Retention Pond Performance
– Design Storm Basis: Outfall 015

• Storage volume for Pond 015 much smaller than Pond 011

• Watershed area is greater: 55.5 vs. 33.3 acres

• Without excavation and starting empty, Pond 015 completely contain \( \frac{3}{4} \)-in storm

• Predicted sediment trap efficiency
  – 1.5-in storm - 98.2 %
  – 2.0-in storm - 85.5 %
  – 3.0-in storm - 72.3 %
Retention Pond Performance
– Design Storm Basis: Outfall 008

- Watershed area of 113.6 acres - exceeds Outfall 015 by more than a factor of two
- The pond capacity, below the principle spillway, is 0.92 ac-ft, ~ the same as Outfall 015
- Contain a ½-in storm without discharging
- Predicted sediment trapping efficiencies
  - 1.0-in, 96.7%
  - 1.5-in, 77.2%
  - 2.0-in, 67.6%
Retention Pond Performance – Annual Basis

• Analyzed Paducah airport daily precipitation data 1971 to 2000

• Cumulative rainfall curve

<table>
<thead>
<tr>
<th>Rainfall (in)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>24</td>
</tr>
<tr>
<td>0.75</td>
<td>40</td>
</tr>
<tr>
<td>1.0</td>
<td>52</td>
</tr>
<tr>
<td>1.25</td>
<td>62</td>
</tr>
<tr>
<td>1.5</td>
<td>70</td>
</tr>
<tr>
<td>2.0</td>
<td>82</td>
</tr>
<tr>
<td>3.0</td>
<td>92</td>
</tr>
<tr>
<td>Rainfall (in)</td>
<td>Rainfall midpoint</td>
</tr>
<tr>
<td>--------------</td>
<td>------------------</td>
</tr>
<tr>
<td>0.10-0.25</td>
<td>0.175</td>
</tr>
<tr>
<td>0.25-0.50</td>
<td>0.375</td>
</tr>
<tr>
<td>0.50-0.75</td>
<td>0.625</td>
</tr>
<tr>
<td>0.75-1.00</td>
<td>0.875</td>
</tr>
<tr>
<td>1.00-1.25</td>
<td>1.125</td>
</tr>
<tr>
<td>1.25-1.50</td>
<td>1.375</td>
</tr>
<tr>
<td>1.50-1.75</td>
<td>1.625</td>
</tr>
<tr>
<td>1.75-2.00</td>
<td>1.875</td>
</tr>
<tr>
<td>2.00-2.25</td>
<td>2.125</td>
</tr>
<tr>
<td>2.25-2.50</td>
<td>2.375</td>
</tr>
<tr>
<td>2.50-2.75</td>
<td>2.625</td>
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<td>2.75-3.00</td>
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<td>3.375</td>
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<tr>
<td>3.50-3.75</td>
<td>3.625</td>
</tr>
<tr>
<td>3.75-4.00</td>
<td>3.875</td>
</tr>
<tr>
<td>4.00-4.50</td>
<td>4.25</td>
</tr>
<tr>
<td>4.50-5.00</td>
<td>4.75</td>
</tr>
<tr>
<td>5.00-5.50</td>
<td>5.25</td>
</tr>
</tbody>
</table>

**Annual containment in ponds**

83.1% 34.7% 20.2%

* Runoff volume contained in ponds
<table>
<thead>
<tr>
<th>Outfall</th>
<th>Largest Storm</th>
<th>Outfall</th>
<th>Annual Runoff Volume (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>011</td>
<td>2</td>
<td>011</td>
<td>83.1</td>
</tr>
<tr>
<td>015</td>
<td>3/4</td>
<td>015</td>
<td>34.7</td>
</tr>
<tr>
<td>008</td>
<td>1/2</td>
<td>008</td>
<td>20.2</td>
</tr>
</tbody>
</table>
Alternative Secondary Treatment Systems

• Designs:
  – irrigation (outfall 015)
    • evapotranspiration (ET)
      – drip
      – micro-sprayers
    • evapotranspiration-infiltration (ET-I)
      – drip
      – micro-sprayers
  – weep berm (outfall 008)
Design Alternative: ET

• Advantage of restricting application rate to match ET rate:
  – vast majority of water applied will be treated without the potential for groundwater contamination

• Disadvantage
  – slower dewatering rate of pond
  – primarily applicable April - October
Design Alternative: ET-I

- **Advantages: evapotranspiration-infiltration system:**
  - ability to have a higher applications rate
  - longer duration of application -> treatment of a greater volume of water compared to the evapotranspiration method

- **Disadvantage:** portion of the applied water may migrate to groundwater
Figure 7: Average Precipitation - Evapotranspiration Difference by Month
Evapotranspiration Considerations

• Daily ET
  – > 0.10 in (April - Oct)
  – > 0.16 in (May – Sept)
  – > 0.23 in (June – Aug)

• ET applicable ~ 7 months/yr
Drip Irrigation System

5-Acre Drip Irrigation System
(Evapotranspiration Design)

Sensor
Controller (6-stations)
Pump
Filter

36 gpm
120 ft. head
~ 2 BHP

Main (1 1/2 - 2 in.)
Subriser (1-1 1/4 in.)

1 acre zone
11,000 ft. 5/8 in. dripline
4 ft. row spacing
8-in. emitter spacing

PR - pressure regulator (10 psi)

1 1/2 in solenoid valve
Evapotranspiration Method
– Drip Irrigation System

• Dewatering Time (daily ET 0.11)
  – 21 days (5 ac)
  – 4 days (25 ac)

• Dewatering Time (daily ET 0.22) – June - August
  – 10 days (5 ac)
  – 2 days (25 ac)
Infiltration Assumptions

- Soil infiltration rate based - soil texture
- Steady state infiltration rate (hydrologic soil group ‘C’) 0.05 to 0.15 in/hr
- Due to macropores, the infiltration rate may be substantially higher.
- Initial infiltration rate - 0.4 to 0.5 in/hr and short duration irrigation application rates can exceed 0.6 in/hr without runoff.
Evapotranspiration/Infiltration Method
– Drip Irrigation System

• Assumed
  – steady state infiltration rate of 0.1 in/hr
  – 10-hour irrigation duration

• Dewatering Time
  – 2 days (5 ac)
Micro-sprinkler Irrigation System

- Micro-sprinklers:
  - small rotating spray heads
  - radius ~ 15 ft
  - 1 gpm

- Close to the ground

- Limited exposure to drift

- Evaporation rate of spray ~ 20% of application rate

- Spatial coverage is better than drip - ET more uniform

- Higher irrigation application rate than drip - operating times are reduced
Evapotranspiration Method
– Micro-sprinkler Irrigation System

• Head-to-head coverage spacing: 15-ft spacing between sprayers
• ~ 200 micro-sprayers /ac
• Application rate - 0.43 in/hr
• Operation time/zone:
  – ET rate of 0.11 inch/day: 15 minutes/day
  – ET rate of 0.22 inch/day: 30 minutes/day.
5-Acre Micro Sprinkler Irrigation Design

Sensor

Controller (6-stations)

Pump

Filter

50 gpm
140 ft. head
~ 3 BHP

Main (2 - 2 1/2 in.)

Submain (1 1/4 in.)

50 ft. 1/2 in PE
5 micro-sprinklers / row
15 ft. micro-sprinkler spacing
10 rows
15 ft. row spacing

1 1/2 in. solenoid valve

1/4 in. pressure regulator

PR - pressure regulator (10 psi)
Evapotranspiration Method  
– Micro-sprayer Irrigation System

- Operate on a pulse irrigation method
- 1.0 inch daily infiltration (1.3 in/day)
- 0.54 ac-ft/day applied
- Each 1-ac zone - operate ~ 3 hrs/day
- Total operating time (5 zones): 15 hours/day

- Time to dewater Pond 015:
  - 8 days (5 ac)
  - ~1 ¾ days (25 ac)
25-Acre Micro Sprinkler Irrigation Design

Controller (25-stations)
  Sensor
  Pump
  Filter

Main (4 in.)

Submains (3 - 4 in.)

1-1 1/2 in solenoid valve

For each 1-acre plot:
~3,000 ft. 3/4 in. PE
10 micro-sprinklers / row
15 ft. micro-sprinkler spacing
20 rows
15 ft. row spacing

200 gpm
130 ft. head
~ 12 BHP
Evapotranspiration/Infiltration Method
– Micro-sprayer Irrigation System

• Operate on a pulse irrigation method

• 5-ac site
  – 1.0 inch daily infiltration (1.3 in/day)
  – 0.54 ac-ft/day applied

• Each 1-ac zone - operate ~ 3 hrs/day

• Total operating time (5 zones): 15 hours/day

• Time to dewater Pond 015: ~ 1 3/4 days (5 ac)
Combined Weep Berm – Grass Filter

- A weep berm - simply an earthen berm that temporarily detains water that is slowly and passively discharged through multiple pipes, to the down-gradient grass filter.
- Low cost, easily constructed, and highly effective
- Further treatment and infiltration occurs along the grass filter prior to any residual runoff re-entering Outfall 008’s retention pond.
- Works synergistically with the down-gradient riparian zone and blends into the natural landscape
- A combination weep berm-grass filter reduces sediment concentration
Seep Berm Design

- Height
- Spillway Configuration
- Removal Efficiency

Outlet Structures

- Fixed Siphon
- Geotextile Wrap
- Porous Rock Outlet
- Drop Inlet / Perforated Riser

- Weep Berm
- Straight Pipe
Combined Weep Berm – Grass Filter

• **Weep Berm Design Parameters**
  - length – 450 ft
  - height – 2 ft
  - storage capacity – 0.275 ac-ft
  - 1-in PVC pipes at 10 ft spacing and 1 ft invert
  - pumping rate from Pond 008 – 450 gpm
  - pump operating time – 6 hr/day

• **Dewatering time for Pond 008 ~ 2 days**
Combined Weep Berm – Grass Filter

- Grass Filter Design Parameters
  - length – 250 ft
  - slope – 4 %
  - steady-state infiltration rate – 0.1 in/hr
  - grass – existing vegetation
Weep Berm – Grass Filter Performance

- Storm – 0.7 in
- Weep berm steady state stage – 1 ¾ ft
- Freeboard – ¼ ft
- Sediment trap efficiency of weep berm – additional 36%
- Peak effluent – 88 mg/L
- Sediment trap efficiency of grass filter - ~ 100 %
- Peak effluent - 2 mg/L
### Findings - Sediment Trap Efficiency of Ponds

<table>
<thead>
<tr>
<th>Outfall</th>
<th>Sediment Trap Efficiency (%)</th>
<th>Storm Size (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>011</td>
<td>99.7</td>
<td>4</td>
</tr>
<tr>
<td>015</td>
<td>72.3</td>
<td>3</td>
</tr>
<tr>
<td>008</td>
<td>67.6</td>
<td>2</td>
</tr>
</tbody>
</table>
## Findings - Annual Runoff Volume Treated by Secondary System

<table>
<thead>
<tr>
<th>Outfall</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>011</td>
<td>83.1</td>
</tr>
<tr>
<td>015</td>
<td>34.7</td>
</tr>
<tr>
<td>008</td>
<td>20.2</td>
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## Findings – Dewatering Time Pond 015

<table>
<thead>
<tr>
<th>Treatment System</th>
<th>ET</th>
<th>ET-Infiltration</th>
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<tbody>
<tr>
<td></td>
<td>Drip</td>
<td>Micro</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1 3/4</td>
</tr>
<tr>
<td></td>
<td>5 ac</td>
<td>25 ac</td>
</tr>
<tr>
<td></td>
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</table>
General Findings – Weep Berm-Grass Filter

- Pond 008
- ~ 100% sediment retention