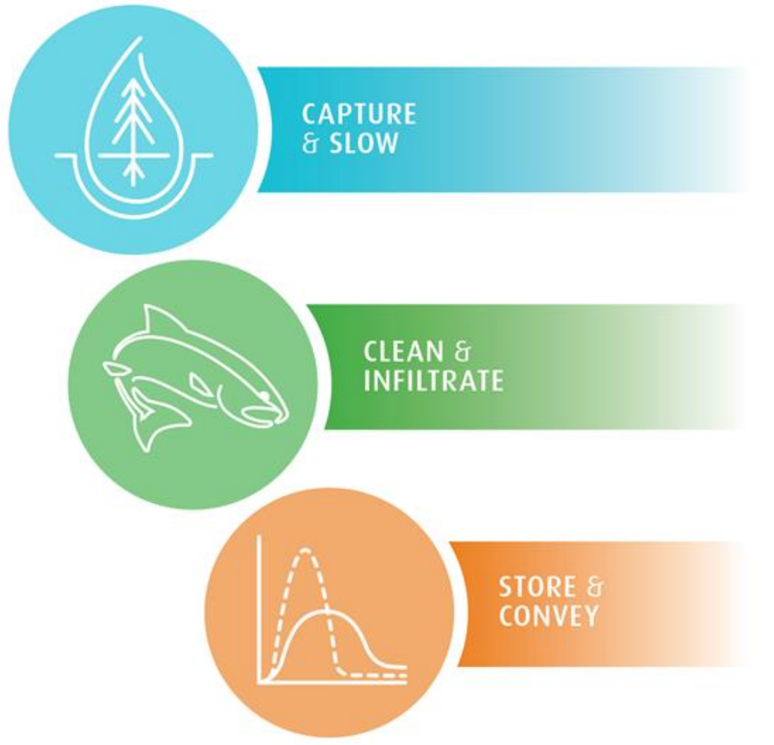

APPENDIX I – CONSTRUCTED WETLANDS, WET PONDS & DRY PONDS

Green Stormwater Infrastructure Design Guidelines for the Capital Region

SPRING 2019

Constructed Wetlands, Wet Ponds & Dry Ponds[1]

Description

Constructed wetlands and detention ponds are open areas of shallow water designed so the water level can rise to provide temporary storage for excess water during rainfall events. The water level rises temporarily when it rains. Equally as important, they provide valuable environmental benefits by helping to remove pollution from surface water runoff. Ponds are similar to wetlands but have a greater focus on storing excess water whereas wetlands have a greater focus on treatment of pollution.

Figure 1 Constructed wetland at Peers Creek. Photo Credit: District of Saanich

Constructed wetlands are man-made, engineered wetland areas created through excavation and/or berming. They typically differ from natural or restored wetlands in that they are located in areas where no wetland existed before. Wetlands collect, detain and treat stormwater runoff during storm events and release it into the receiving environment. Properly constructed wetland systems provide a high level of contaminant removal through sedimentation and biological uptake. Wetlands can also provide benefits for flood protection, stream erosion, habitat creation and protection.

Figure 2 Dry pond University of Victoria

Constructed wetlands consist of a series of shallow ponds connected by an engineered marsh system designed to treat contaminated stormwater through the biological processes associated with emergent aquatic plants and via sedimentation. They are similar in nature and application to wet ponds, except that wetlands are normally relatively shallow

[1] Authored by: Opus International Consultants (Canada) Limited
Original design guidelines source: Stormwater Best Management Practices Guide Volume 1, Part 1-3, Greater Vancouver Sewerage and Drainage District (1999)
http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/BMPVol1a.pdf#search=%22BMP%22
http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/BMPVol1b.pdf#search=%22BMP%22
http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/BMPVol2c.pdf#search=%22BMP%22
Design guidelines drawings by: Kerr Wood Leidal Associates Ltd.

and typically include emergent vegetation and marshy areas - suitable for controlling runoff flow rates and for removing particulate and dissolved contaminants. Some infiltration may also occur. Constructed wetlands can have the added benefit of creating habitat for aquatic and terrestrial wildlife.

Figure 4 Stormwater management wetland with invasive species "Parrot's Feather" (*Myriophyllum aquaticum*). Photo Credit: Town of View Royal

Detention ponds provide extended detention storage of runoff. Extended detention refers to the dry or active storage provided by these facilities. Extended detention ponds reduce the rate of stormwater discharge by storing the stormwater runoff temporarily and releasing it at a controlled rate. Water quality treatment is provided through enhanced settling and biological processes. As such, extended detention storage provides benefits related to water quality, erosion protection, and flooding potential. There are several types of detention ponds that function similarly but differ in design and operation. Dry ponds fill during storm events and slowly release runoff at a predetermined rate until empty. They may be incorporated into sports fields, parks, rooftops or parking lots. Wet ponds maintain a minimum level of water and store runoff above the minimum level, releasing it at a predetermined rate. Wet ponds require a large enough contributing area to maintain the wet pool and prevent it from becoming stagnant. They may accommodate special recreational or aesthetic uses centred around the permanent pool.

Figure 3 Stormwater management pond with invasive species "Parrot's Feather" (*Myriophyllum aquaticum*). Photo Credit: Town of View Royal

Selection, Application and Limitations

- Constructed wetlands and ponds can be land intensive because they are shallow facilities. The land requirements limit their use in highly urbanized areas.
- Constructed wetlands and ponds can provide effective flood control, streambank erosion control, removal of particulate and soluble contaminants, and limited groundwater recharge (depends on soil conditions).
- Location should be chosen to ensure a large enough catchment for continual flow though the dry season (June-September) so as not to allow stagnation.

- Constructed wetlands and ponds should be designed to mimic natural systems (varying depths, islands, high marsh peninsulas).
- Dry ponds are designed to impound run-off in catchment during large storms and gradually release it. Dry ponds mainly provide runoff rate control as opposed to water quality control.
- Wet Ponds control peak flow, protect streambank erosion, enhance water quality, and enhance the community (recreation, aesthetic value).
- Dry ponds are not as aesthetically pleasing as wet ponds and constructed wetlands.
- Dry ponds' limited effectiveness in removing soluble contaminants is an important factor in considering their application.
- Dry ponds are more expensive than vegetated swales/grassed channels, but less expensive than wet ponds and engineered wetlands.
- Wet ponds may not be appropriate, or may require specialized design, where receiving water temperatures are a concern.
- Some safety concerns are associated with side slopes and water pooling.

Mosquito Control

Mosquitoes complete their development in standing aquatic environments in 8 to 10 days. Unlike other vegetated facilities that are designed to infiltrate the water in 3 days or less, detention facilities such as constructed wetlands and wet ponds are designed to always have surface water, thus require mosquito control measures.

Mosquito control is undertaken to protect public health and maintain expected quality of life. Best management practice for control of mosquito production within constructed wetlands and ponds can be accomplished by a combination of source reduction techniques, such as vegetation management, and utilizing design features such as deep water zones that reduce mosquito production, application of mosquito control agents (where permitted), along with public education.

General Design Guidelines

1. Detailed design requirements should be evaluated for each individual application based on site-specific constraints and objectives.
2. Follow all applicable federal, provincial and municipal regulations.
3. Geo-technical investigations are recommended with soil permeability testing being the minimum requirement for design. Advice from a professional engineer for design is recommended.
4. Analysis should be completed or reviewed by a professional engineer.
5. Detailed designed requirements should be evaluated for each individual application based on site-specific constraints and objectives.
6. Select plant species for survival rather than contaminant uptake. Use a professional to determine the correct plants for each of the zones (wet to dry).
7. Minimize flow velocities to minimize sediment re-entrainment and erosion.

8. Minimum 65% of the pond should be less than 450 mm deep allowing for vegetation growth and contaminant uptake. Depths should vary (25% >1.2 m deep, 65% <450 mm deep, 35% <150 mm deep).
9. Length to width ratio of 3:1 to 5:1.
10. Recommended side slopes 5:1 (H:V) or flatter.
11. Permanently wetted area should hold capture target.
12. See Supplemental 1, Planting Templates & Plant Lists for planting considerations.
13. Volumetric water quality criteria for data collected in Ontario are presented in Table 1. The values are based on a 24-hour drawdown time and will vary based on climate.

Table 1 Water Quality Storage Requirements based on Receiving Waters[2]

Protection Level	Type	Storage Volume (m^3/ha) for Impervious Level			
		35%	**55%**	**70%**	**85%**
Enhanced 80% long-term suspended solids removal	Wet Pond	140	190	225	250
	Wetland	80	105	120	140
Normal 70% long-term suspended solids removal	Wet Pond	90	110	130	150
	Wetland	60	70	80	90
Basic 60% long-term suspended solids removal	Wet Pond	60	75	85	95
	Dry Pond	90	150	200	240
	Wetland	60	60	60	60

Vegetation and Landscaping Guidelines

1. Consider using landscape architect to integrate facility into the community.
2. Use vegetated buffers to discourage small children from approaching pool and post warning signs.

Wet Pond Sizing

1. Wet ponds are designed to meet specific water quality and/or discharge rate objectives.
2. Wet ponds designed to control peak discharge rates only do not normally provide optimum water quality enhancement. Flood control or peak flow control wet ponds are typically designed to control the large infrequent event storms.
3. The permanent pool is designed for water quality only – design additional live storage above permanent pool for streambank erosion protection and/or flood control.

[2] Environmental design criteria (Chapter 3), Ontario Stormwater Management Planning and Design Manual (2003) https://www.ontario.ca/document/stormwater-management-planning-and-design-manual/environmental-design-criteria

4. The Washington State Department of Ecology recommends the runoff from the 24-hour, 6 month event as the water quality volume.[3]

5. One design approach is to size the permanent pool volume to hold the runoff from the design water quality storm.

6. Sedimentation forebay with a volume equal to 10% of the total design volume is recommended for extended detention basins. Pre-treatment is achieved in the sediment forebay.

7. Typically, sediment may have to be removed from the forebay once every 10 years or after 50% of total forebay capacity has been lost.

8. Alternatively, size the storage pool volume based on the "volume ratio" as follows:

   Volume Ratio = V_B/V_R, where:
   V_B = permanent pool volume
   V_R = volume of runoff from the long-term average storm
   King County recommends V_B/V_R = 3 for 80% removal of suspended solids and V_B/V_R = 4.5 for 50% removal of total phosphorus.[4]

   Note that in the Seattle area where the long-term average storm is about 12 mm, ponds sized for the 6-month, 24-hour (30 mm) storm have a V_B/V_R of about 2.5.

9. Dispersion length = $\frac{8Q}{dV_f}$

   Where:
   Q = inflow (m³/s)
   d = depth (m)
   V_f = velocity (m/s)

10. Forebay Length = $(\frac{rQ_p}{V_s})^{1/2}$

    Where:
    r = length-to-width ratio of forebay
    Q_p = peak flow rate from pond during quality design storm (m³/s)
    V_s = settling velocity (m/s)

11. Average pond depth 1 m to 2 m, maximum pond depth 2.5 m to prevent anaerobic conditions.

12. Minimum 300 mm freeboard.

13. Include 2 or more distinct cells and baffles if necessary to minimize short-circuiting.

14. Minimum length to width ratio 3:1, preferably up to 5:1.

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[3] Stormwater Management Manual for Western Washington, 2012 https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/Stormwater-permittee-guidance-resources/Stormwater-manuals

[4] Surface Water Design Manual, King County, Washington https://www.kingcounty.gov/services/environment/water-and-land/stormwater/documents/surface-water-design-manual.aspx

15. Maximum side slope 3:1.
16. Benches: 150 mm to 300 mm drop.
17. Maintenance access maximum grade 8% to 10%.

Dry Pond Sizing

1. Size storage and outlet structure according to design objectives for flood control, streambank erosion control, or contaminant removal.
2. Typical detention times for the design runoff event as follows:
    a. Conventional dry pond for flood control – 1 to 2 hours.
    b. Extended dry pond for streambank protection – 24 hours.
    c. Extended dry pond basin for contaminant removal – 24 to 72 hours.
3. Allow an additional 20% storage volume to allow for sediment accumulation.
4. For contaminant removal, provide an outlet to empty less than 50% of the design volume during the first 33% of the emptying period.
5. Minimum length to width ratio of 4:1 to 5:1.
6. Two-stage basin recommended for extended detention – design volume of lower stage (micropool) should be 15% to 25% of total design volume with depth 1.1 m to 2.7 m, upper stage 0.6 m to 1.8 m deep with bottom sloping 2% toward low flow (pilot) channel – lower stage reduces standing water and sediment deposition in the rest of the basin and helps to prevent re-suspension of settled sediments and clogging of the low flow orifice.
7. Maximum basin side slopes 3:1 (preferably 4:1) for slope stability, ease of maintenance and safety.
8. Maintenance access maximum grade 8% to 10%.
9. Minimum 600 mm freeboard.
10. Inlet minimum diameter: 450 mm.

Constructed Wetland Sizing

Wetland design should be specific to the particular location. Most of the design elements discussed in the wet ponds section are applicable to constructed wetlands. The exceptions to the wet ponds guidelines are related to the depth and distribution of aquatic vegetation.

1. Wetlands should comprise of a mixture of water depths. Water levels greater than 1 m should be limited to a maximum of 20% of the wetland surface area. A minimum of 30% should be 0.5 m – 1.0 m deep and a minimum of 50% should be 0.0 m – 0.5 m deep.
2. Where wetlands are designed for flow attenuation, the temporary storage above the permanent water level should not exceed 1.5 m.

3. Peak outflow during quality design storm controlled by weir:

   $Q_p = C \times b \times H^{1.5}$

   Where:
   Q_p=flow (m^3/s)
   C = weir coefficient
   b = crest length (m)
   H = maximum height above crest (m)

4. Dispersion length = $\frac{8Q}{dV_f}$

   Where:
   Q = inflow (m^3/s)
   d = depth (m)
   V_f = velocity (m/s)

5. Forebay Length = $(\frac{rQ_p}{V_s})^{1/2}$

   Where:
   r = length-to-width ratio of forebay
   Q_p = peak flow rate from pond during quality design storm (m^3/s)
   V_s = settling velocity (m/s)

6. The flow path to width ratio should be greater than 3:1 (CIRIA, 2007). A length to width ratio of 5:1 is preferred, with a minimum ratio of 2:1 to enhance water quality benefits. The longer length allows more travel time and opportunity for infiltration, biofiltration and sedimentation.[5]

7. Maximum side slope 3:1.

8. Benches: 150 mm to 300 mm drop.

9. Maintenance access maximum grade 8% to 10%.

Guideline Specifications

Materials shall meet Master Municipal Construction Document 2009 (MMCD) requirements.

Construction Practices shall meet MMCD requirements, **and**:

1. The bottom and the side slopes of the pond, including any benches, should be carefully constructed to ensure that they are structurally sound.

2. Backfilling against inlet and outlet structures needs to be controlled to minimize settlement and erosion.

3. If an impermeable liner is used, care should be taken to ensure that it is not damaged during construction.

[5] The Sustainable Drainage Systems (SuDS) manual, CIRIA, London 2007
https://www.ciria.org/Resources/Free_publications/SuDS_manual_C753.aspx

Constructed Wetland Design Example

Scenario Description

This example provides forebay and wetland size calculations for a 4-hour 25-mm rainfall event (Saskatoon, 2014).

The following parameters are known:

- Q = Peak Inflow = 0.690 m^3/s
- C = weir coefficient = 1.5 (broad crested weir)
- b = crest length = 0.12 m
- H = maximum height above crest = 0.20 m
- d = depth = 1.0 m
- V_f = velocity = 0.4 m/s
- r = length to width ratio of the forebay = 3:1
- V_s = settling velocity = 0.0003 m/s
- Catchment area = 7.7 ha
- Percent impervious = 85%

Forebay Sizing

Determine the peak outflow during the quality design storm controlled by the weir:

$$Q_p = C \times b \times H^{1.5}$$

$$Q_p = 1.5 \times 0.12\,m \times (0.20\,m)^{1.5}$$

$$Q_p = 0.016\,\frac{m^3}{s}$$

Next, find the minimum forebay dispersion length:

$$Forebay\ (dispersion) Length = \frac{8Q}{dV_f}$$

$$Forebay\ (dispersion) Length = \frac{8 \times 0.690\,\frac{m^3}{s}}{1.0\,m \times 0.4\,\frac{m}{s}}$$

$$Forebay\ (dispersion) Length = 13.8\,m$$

Chosen forebay dispersion length = 15.0 m
Design width = 5.0 m
Length-to-width ratio: 3:1

Wetland Sizing

Required storage volume (80% long-term S.S. removal) = 140 m^3/ha (Table 1)
Total volume required = 1,078 m^3
Extended detention (40 m^3/ha) = 308 m^3
Permanent pool = total volume – extended detention
Permanent pool = 770 m^3

Example Hydraulic Components

- **Inlet**: Existing ditch with riprap at entry.
- **Outflow**: Two weirs with a 100-mm diameter pipe each.

Example Operation and Maintenance

- Mow to keep grass in the active growth phase, remove clippings to prevent clogging of outlets, and remove trash and debris.
- Replace dead plants, as required.
- Remove accumulated sediment.

GSI Driver Effectiveness – Runoff Reduction and Pollutant Removal

International Stormwater BMP Database http://www.bmpdatabase.org/ is a recommended resource for performance summaries of GSI facilities and latest research.

Ponds and constructed wetlands can achieve pollutant removal through a variety of physical, biological, and chemical treatment processes. Although conventional dry ponds do not significantly remove pollutants, extended dry ponds can remove pollutants at similar rates to those of wet ponds. The pollutant removal efficiency can be increased or decreased based on the design components and what pollutants are being targeted for reduction. The following table shows the typical effectiveness of wet ponds, extended dry ponds, and constructed wetlands for pollutant removal.

Table 2 Runoff Reduction and Contaminant Removal

Constructed Wetlands, Wet Ponds and Dry Ponds GSI Facilities			
GSI Driver	*Estimated Effectiveness or typical % Reduction and Removal		
	Wet Ponds[1]	Extended Dry Ponds[2]	Constructed Wetlands[3]
Slow – Volume Runoff Reduction	Depends on Size		
Store – Rate Control Delay Peak	Depends on Size		
Clean – Water Quality Treatment			
Copper	57%	-	40%
Lead	73%	75-90%	-
Zinc	51%	30-60%	44%
Nitrate	24%	-	67%
Total Phosphorus	47%	20-40%	49%
Total Nitrogen	30%	20-40%	30%
Total Suspended Solids	77%	50-70%	76%
Hydrocarbons	83%	50-70%	-
Bacteria	65%	50-90%	-

Note: * Performance of individual GSI facilities will vary depending on site-specific contexts and facility design.

Sources:

1: Schueler, 1997b. Bacterial Levels in Urban Stormwater. Watershed Protection Techniques 3(1)

2: Horner, R.R., J.J. Skupien, E.H. Livingston, and H.E. Shaver, 1994. Fundamentals of Urban Runoff Management: Technical and Institutional Issues. Terrene Institute, Washington, DC.

3: Pennsylvania Stormwater Manual, 2006 http://www.stormwaterpa.org/from-the-foreword.html

Maintenance

A maintenance plan is recommended for ponds and constructed wetlands which would include the scope, schedule, record keeping, and responsibilities related to the facility.

Inspection Checklist

Activity	Schedule	Facilities
Inspect function during wet weather	Periodically during the winter or other wet periods	Wet Ponds Dry Ponds
Inspect hydraulic and structural facilities	Annually	Wet Ponds Dry Ponds
Inspect at outset of rainy season and after each significant storm – remove floatables, correct erosion problems, unclog outlet structures	As required	Dry Ponds

Routine Maintenance

Most of the routine maintenance procedures are related to the removal of accumulated sediment.

ACTIVITY	SCHEDULE	Facilities
Mow side-slopes, embankments and spillways to prevent woody growth and weeds, manage remaining buffer as meadow or forest	Annually or as required	Wet Ponds Constructed Wetlands
Clean sediment forebay	Every 5-7 years or when 50% of capacity has been lost (CWP et al., 1997)	Wet Ponds Constructed Wetlands
Remove accumulated sediments from pond bottom	When 10% to 20% of pool volume is lost – typical volume loss to sedimentation 1% per year	Wet Ponds Constructed Wetlands
Remove floatables, correct erosion problems, unclog outlet structures	At the outset of the rainy season and after each significant rainstorm	Wet Ponds Dry Ponds
Remove sediments from lower stage	Every 5-15 years, as required	Dry Ponds

Non-routine Maintenance

The majority of the non-routine maintenance activities involve managing insects and vegetation.

ACTIVITY	SCHEDULE	Facilities
Control nuisance insects and weeds	As required	Wet Ponds Constructed Wetlands
Vegetation on the pond fringes may have to be harvested the clippings removed	As required	Wet Ponds Constructed Wetlands
Routine mowing – maintain irrigated grass to 50-100 mm tall and non-irrigated native grasses to 100-150 mm tall	Regularly, as required	Dry Ponds

Recommended Inspection and Maintenance Resources:

Inspection and Maintenance Guide for Stormwater Management of Ponds and Constructed Wetlands, 2016, Toronto and Region Conservation and CH2M Hill Canada Ltd.

http://www.sustainabletechnologies.ca/wp/wp-content/uploads/2016/06/SWMFG2016_Guide_June2016.pdf

Stormwater Pond Maintenance and Anoxic Conditions Investigation FINAL REPORT, 2011, Lake Simcoe Region Conservation Authority.

http://www.sustainabletechnologies.ca/wp/wp-content/uploads/2015/01/LSRCA-Stormwater-Maintenance-and-Anoxic-Conditions-2011.pdf

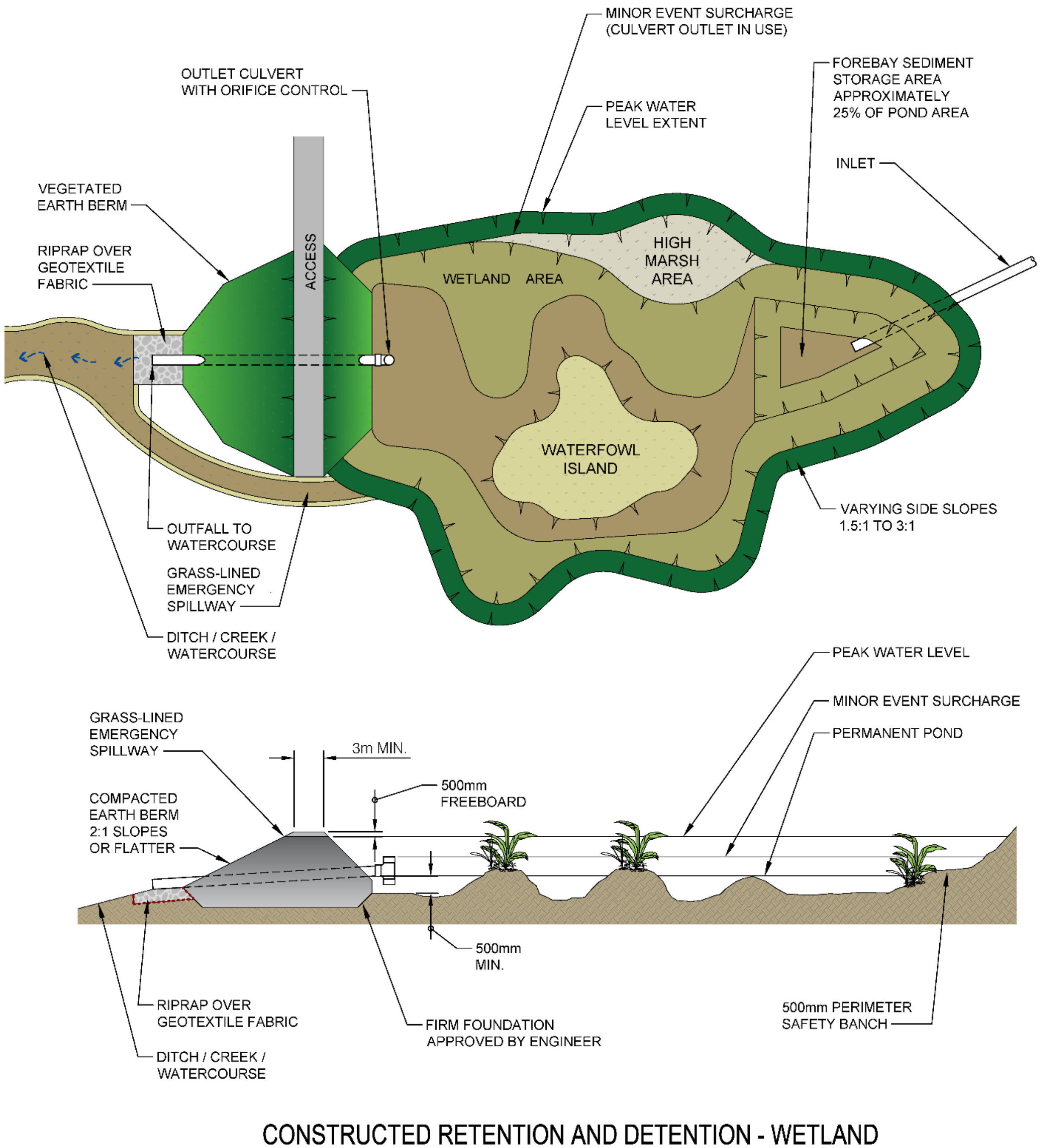

Figure 5 Constructed Retention and Detention – Wetland

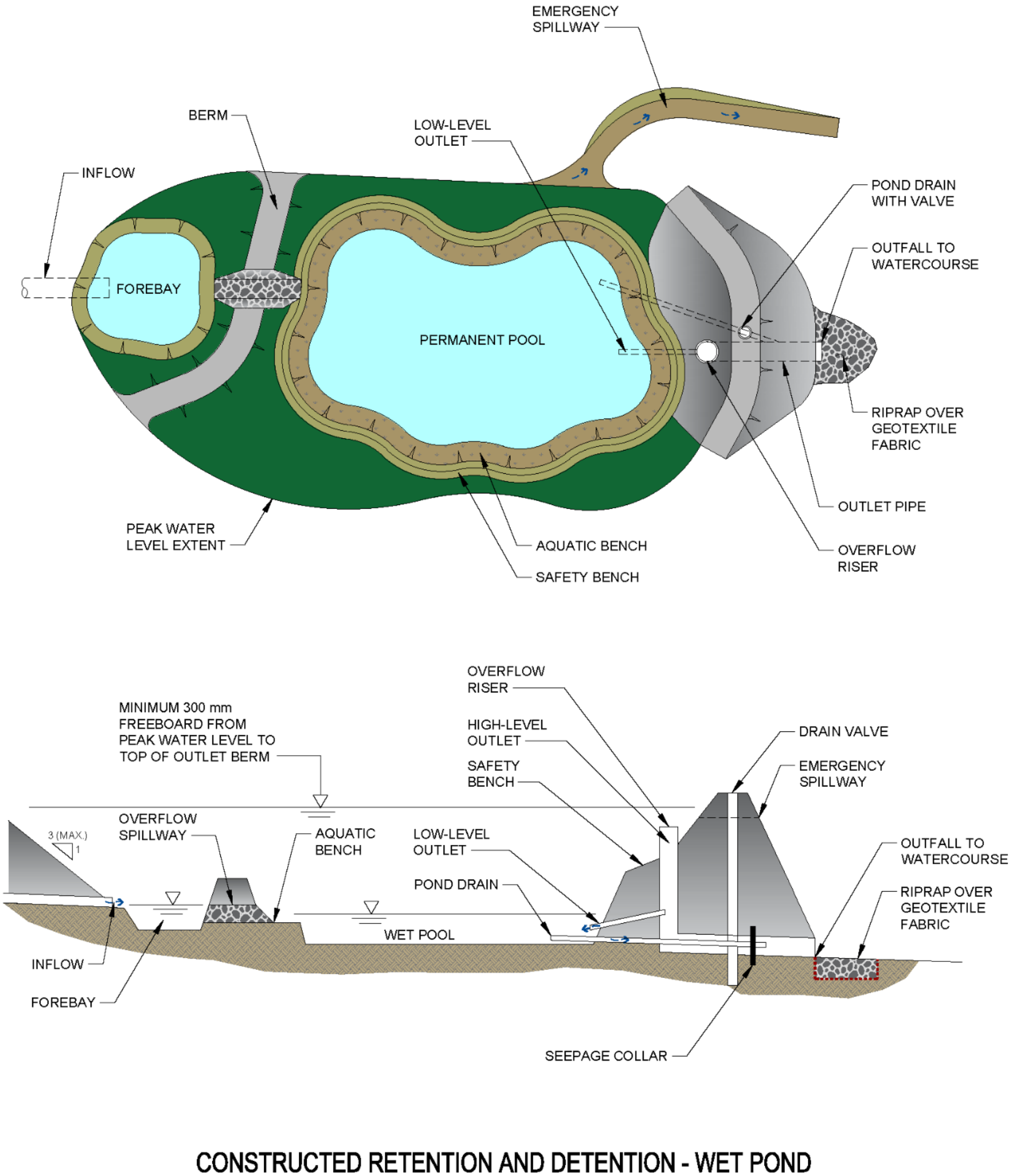

Figure 6 Constructed Retention and Detention – Wet Pond

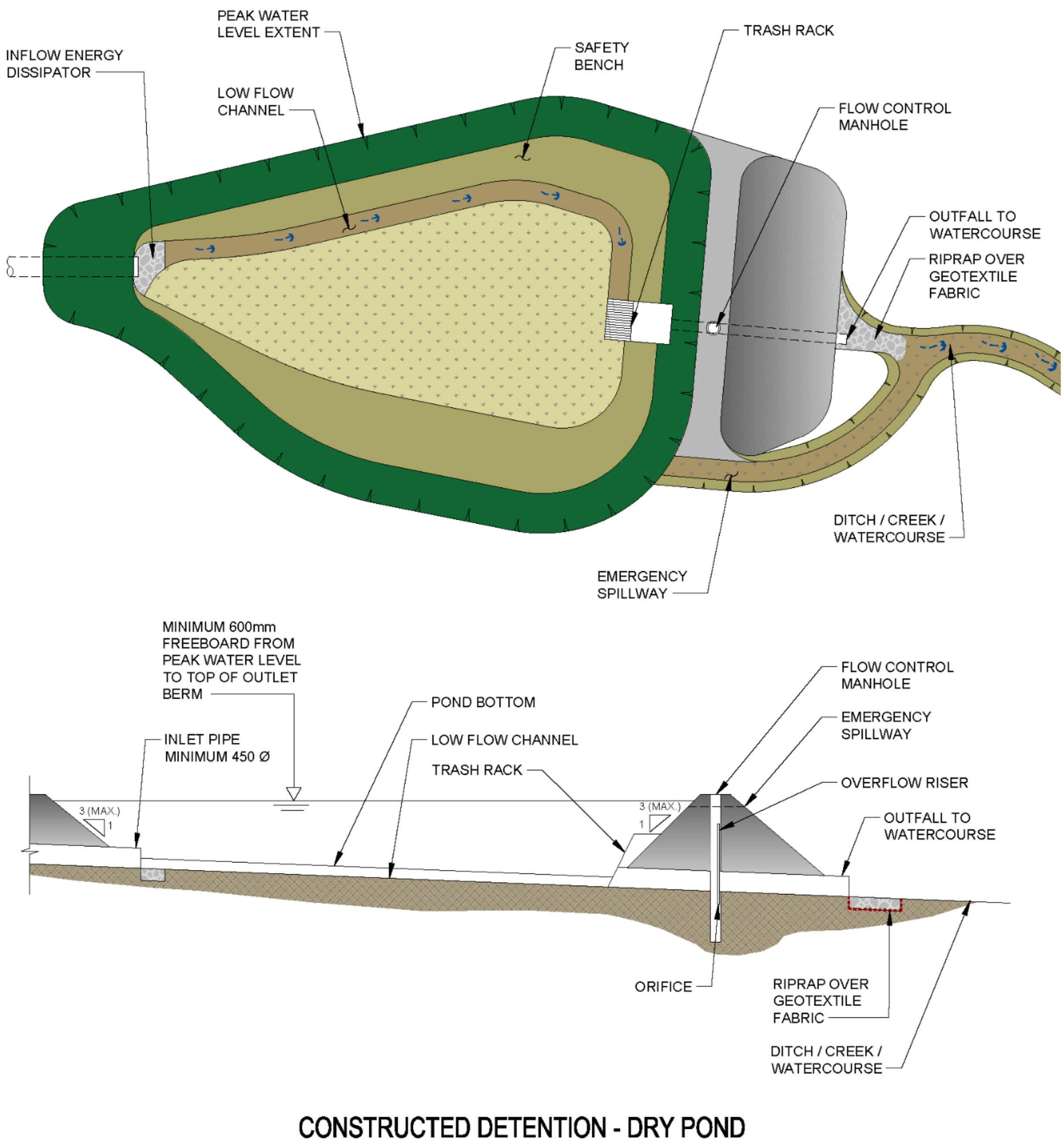

Figure 7 Constructed Detention – Dry Pond