TECHNICAL MEMO

Prepared By: Water Resources Management Division (WRMD)
Date: October 2023
Re: Reservoir Drawdown

Background

This memo is part of a series of documents on dam emergency interventions. The focus of this memo is to provide guidance on reservoir drawdown. Reservoir drawdown refers to the lowering of water levels in reservoirs in the event of emergencies or maintenance. It is only possible when the rate of outflow is greater than the inflow rate. Reservoir drawdown reduces and possibly eliminates the risk of dam failure in emergency situations (Dam Safety: Lake Drains, 2019):

1. Structural defects: cracks or slides in the dam
2. Overtopping of the dam due to clogged spillways
3. Excessive seepage that can produce piping failure (most common in an earthen dam)

Dams usually include spillways and/or outlets, with the purpose to reduce the water level. However, there are instances where the outlet is not functioning correctly or the spillway's capacity is insufficient. In these cases, it is crucial to implement temporary drawdown methods to control the water level of the reservoirs to prevent dam failure. If dam failure cannot be prevented, reservoir drawdown will reduce the amount of water released during breach of the dam (Courtnadge, Gosden, & Brown, 2017).

The two most common types of emergency drawdown methods are siphoning and pumping. The following criteria must be taken into consideration when choosing the most appropriate drawdown method for a dam (Guidelines for use of pumps and siphons for emergency reservoir drawdown, 2012):

1. Site accessibility and power source
2. Condition of inlets and outlets, depth of water and debris
3. Slope stability
4. Height of crest
5. Depth of drawdown
6. Discharge flowrate
7. Amount of time available

Temporary Drawdown Methods

1. *Siphon*

a. Overview

Siphons are pipes that use atmospheric pressure to pump water from the reservoir over the dam's crest to the discharge point, which is at a lower elevation than the reservoir (see Figure 1). The pipes must first be primed (filled) to produce the siphoning effect and operated at full capacity. Both the inlet and outlet must be submerged to prevent air entrainment in the siphon.

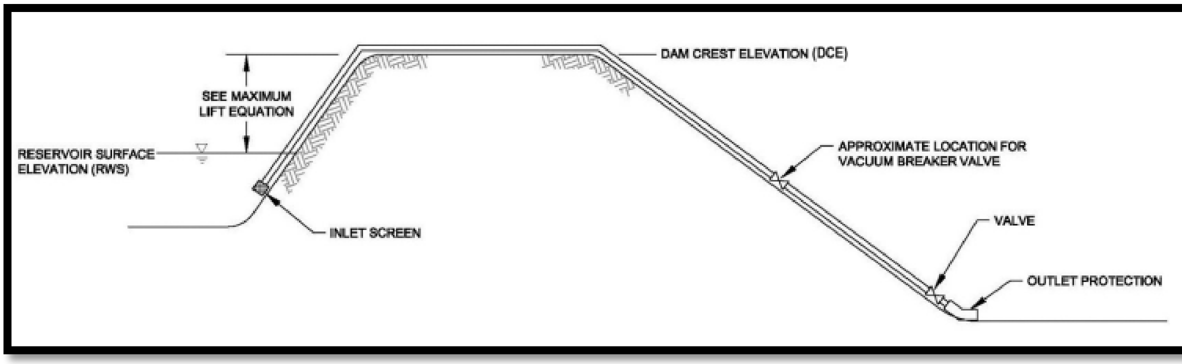

Figure 1: Siphon over Dam (Guidelines for use of pumps and siphons for emergency reservoir drawdown, 2012)

The water flowing out of the pipe at the discharge point produces a vacuum at the dam's crest while the inlet experiences atmospheric pressure. The pressure difference in the pipe forces the water up. The atmospheric pressure limits the maximum lift of the siphon. On the dam's downstream side, the water flows through gravity. When the height of the crest exceeds the maximum lift of the siphon, no siphoning effect is produced and the pipes may break. In this case, the tubes may be buried through the crest to reduce the maximum height (Guidelines for use of pumps and siphons for emergency reservoir drawdown, 2012). Figure 2 depicts an example of reducing lift.

Figure 2: Creating a groove to reduce lift for siphon (Guidelines for use of pumps and siphons for emergency reservoir drawdown, 2012)

b. Determining the maximum lift of the siphon

The maximum siphon lift equation determines the maximum height through which the atmospheric pressure can push the water. The two essential components of the equation are the Dam Crest Elevation (DCE) and the minimum Reservoir Water Surface (RWS). The difference between DCE and RWS is equal to the maximum height, H_{max}. The maximum siphon lift equation is as shown below: (Guidelines for use of pumps and siphons for emergency reservoir drawdown, 2012)

$$DCE \;- RWS \leq 20' - \frac{RWS}{1000}$$

$$H_{max} \leq 20' - \frac{RWS}{1000}$$

The water surface elevation decreases and the height difference increases as water is drawn out of the reservoir. The siphon will only work when the equation is considered for the minimum RWS to be attained. If the height difference is greater than the maximum lift, the siphon will stop working (Guidelines for use of pumps and siphons for emergency reservoir drawdown, 2012).

c. Determining the siphon flow capacity

The predicted siphon flowrate equation calculates the flow capacity. The flow capacity helps determine the size and number of siphons required. However, the equation is valid only for (Guidelines for use of pumps and siphons for emergency reservoir drawdown, 2012):

i. Dams
ii. The elevation difference is less than the maximum siphon lift
iii. Absence of vacuum

The equation is as shown below: (Guidelines for use of pumps and siphons for emergency reservoir drawdown, 2012)

$$Q = 0.0438D^{2.5}H^{0.5}(12fL + KD + D)^{-0.5}$$

$$f = 425({n^2}/{D^{0.33}})$$

Where,
Q = (flow in ft^3/second)
D = siphon diameter (inches)
H = Elevation difference between the outlet and water surface elevation (feet)
f = friction factor, dimensionless
n = Manning's constant
L = Total length of pipe (feet)
K = Hydraulic losses coefficient

The values for Manning's constant, n, and Hydraulic losses coefficient, k, are provided in the following two tables.

Table 1: Manning's n value (Houghtalen, Akan, & Hwang, 1996)

Type of Pipe	Manning's n	
	Minimum	Maximum
Brass	0.009	0.013
Cast Iron	0.011	0.015
Cement mortar surfaces	0.011	0.015
Cement rubble surfaces	0.017	0.030
Clay drainage tile	0.011	0.017

Concrete, precast	0.011	0.015
Copper	0.009	0.013
Corrugated metal (CMP)	0.020	0.024
Ductile Iron (cement mortar lined)	0.011	0.013
Glass	0.009	0.013
High-density polyethylene	0.009	0.011
Polyvinyl Chloride (PVC)	0.009	0.011
Steel, commercial	0.010	0.012
Steel, riveted	0.017	0.020
Vitrified sewer pipe	0.010	0.017
Wrought iron	0.012	0.017

Table 2: Hydraulic loss coefficient, K (Guidelines for use of pumps and siphons for emergency reservoir drawdown, 2012)

Component	"K" value
Entrance Loss	0.8
45º Bend	0.3
Gate Valve (Fully open)	0.2
Ball Valve (fully open)	10.0
Butterfly valve (fully open)	0.2
Check Valve	10.0
Exit Loss	1.0

d. Siphon Components

i. Pipe Dimension and Material

There are different materials available for pipes, such as HDPE, PVC, steel and aluminum pipes. However, the chosen material must resist the negative vacuum pressure developed by the siphoning effect. Other factors to consider when selecting materials are the availability in the local market and access to the site. It is recommended to use pipe diameters between 50 to 200 mm (2 to 8 inches). Using multiple pipes to increase the siphoning capacity is more economical than using a single large diameter pipe. The supplier can provide more information in selecting the appropriate size and material for the tubes. (Guidelines for use of pumps and siphons for emergency reservoir drawdown, 2012)

ii. Inlet

The intake should be completely submerged to prevent air from entering the pipes and disrupting the siphoning. The pipes should be immersed around 0.6 metres (2 feet) below the desired water surface elevation. If the tube is less dense than water, weights should be attached to the pipe to make it sink. A debris gate is also required to prevent debris from entering the tube. (Guidelines for use of pumps and siphons for emergency reservoir drawdown, 2012).

A vortex can form when the water surface is less than 0.6 metres (2 feet) from the inlet. It is seen as a depression on the water's surface and water swirl. Vortexing occurs when the suction force is substantial relative to the submerged depth of the inlet, and it results in air entrainment. The formation of a vortex can be prevented by changing the velocity of water entering the pipe and is attained by using plywood or large floating balls. (Proper submergence of inlet to avoid vortex, 2021)

iii. Outlet

The outlet should also be submerged in a plunged basin to prevent air from entering the pipe and disrupting the siphoning effect. The outlet should be at a lower elevation compared to the reservoir water surface. When the outlet is not submerged, it must be ensured that the pipes are at full capacity, and valves are placed at the top (crest of the dam) to release air. Also, unsubmerged pipes may cause erosion and care must be taken to ensure sufficient erosion protection for dam stability. (Guidelines for use of pumps and siphons for emergency reservoir drawdown, 2012)

iv. Priming the siphon

Priming the siphon requires both ends of the pipe to be closed using either a gate or butterfly valve. The latter is used to control the flow during and after priming. The pipes are filled through a fitting at the crest of the dam and it should be large to allow air to escape. Once filled, the fitting is closed with an airtight cap and the discharge valves are opened. (Guidelines for use of pumps and siphons for emergency reservoir drawdown, 2012)

v. Air vacuum breaker valve

An air vacuum breaker is usually mounted on the dam's downstream side, requiring vacuum or column protection. The valve allows air to enter the pipes stopping the outflow, and helps to prevent the pipe from collapsing. (Guidelines for use of pumps and siphons for emergency reservoir drawdown, 2012)

2. <u>Pump</u>

Pumping is an effective method to drawdown water from a reservoir. Establishing a pumping system requires proper consideration to select the appropriate size and type of pipes, pump, valves, and outlet erosion protection. (Guidelines for use of pumps and siphons for emergency reservoir drawdown, 2012)

a. Inlet Pipe

The pipe size is a crucial factor in establishing an efficient pumping system. The appropriate size is the one that results in the minimum friction and traditional losses. The table below summarizes the approximate diameter for different types of flows: (Guidelines for use of pumps and siphons for emergency reservoir drawdown, 2012)

Table 3: Pipe diameter for different flows (Guidelines for use of pumps and siphons for emergency reservoir drawdown, 2012)

Flow up to (gallons per min)	Pipe diameter
300	4 inches (100 mm)
600	6 inches (150 mm)
1100	8 inches (200 mm)
1700	10 inches (250 mm)
2500	12 inches (300 mm)

b. Pump and power source

There are different pump choices, such as the centrifugal pump and the positive displacement pumps. Still, the centrifugal pump is most commonly used since it is cheaper, efficient, and simple to operate. A power source must be available on-site to power the pump, and it can be either electricity or fuel. Additionally, the pump needs consistent monitoring during the operation. The chosen size and type of pump must overcome the elevation difference between the reservoir water surface and the dam's crest. Pump manufacturers usually provide information on their performance and pump curves.

Another important consideration is to prevent the formation of siphoning effect in a pump system. When placed at appropriate locations, air vacuum valves will break the water seal and stop the siphoning effect.

Another factor to consider is the Net Positive Suction Head (NPSH). It is the difference in the total head at the inlet and the vapour pressure inside the pump. It can also be defined as the total amount of suction available by the pump. If the available NPSH is less than the required NPSH, cavitation can occur. Cavitation is the process when liquid pressure reaches vapour pressure and water starts to boils. The impact of cavitation can be disastrous to the pumping system.

Site access is another factor when choosing pumps as they can be heavy and require transportation to the dam. Another factor to account for is the downtime of the pump due to maintenance and failure. (Guidelines for use of pumps and siphons for emergency reservoir drawdown, 2012)

c. Outlet Pipe

The release of water at the outlet can cause erosion, which may result in serious stability problems. The outlet should be placed far away and have sufficient scour protection to prevent stability problems. (Guidelines for use of pumps and siphons for emergency reservoir drawdown, 2012)

d. Combination of Air Valves, Air Release Valves and Air Vacuum Breaker Valves

Air in a pumping system is a significant concern and reduces the efficiency of the system. Air can enter the system from the inlet and accumulate at the high point. Therefore, air valves should be present at those high points to allow the air to escape. The air valve can be either automatic or manual. A vacuum breaker valve is required when column separation is expected. Column separation occurs when the liquid pressure reduces to vapour pressure and bubbles of air are formed. The vacuum breaker must be at a high point which allows atmospheric air to counteract the formation of the vacuum. The absence of a vacuum breaker can cause siphoning, which may lead to cavitation and pipes to collapse. (Guidelines for use of pumps and siphons for emergency reservoir drawdown, 2012)

Advantages & Disadvantages of Siphons and Pumps

The table below summarizes the advantages and disadvantages of siphons.

Table 4: Advantages and disadvantages of siphon

Advantages	Disadvantages
Cost-effective and easy to build	Limited to 20ft lift at mean sea level [Usually 15 ft as the atmospheric pressure decreases with increasing height]
Materials are readily available.	
Lower maintenance compared to pumps [Fewer people are required.]	
No power source is required.	
Reusable	

The following table lists the advantages and disadvantages of pumps.

Table 5: Advantages and disadvantages of pumps

Advantages	Disadvantages
Easy to set-up	Difficult to transport due to size and weight
Handle significant elevation lift [any required lift]	Costly
Fast process	Significant lead time
	Require an energy source
	Must be monitored and maintained regularly
	Severe damage to pumps can occur due to cavitation

Drawdown System Selection

Site characteristics are the major factors in selecting between pumps and siphons. The figure below illustrates a flowchart to help choose a drawdown method.

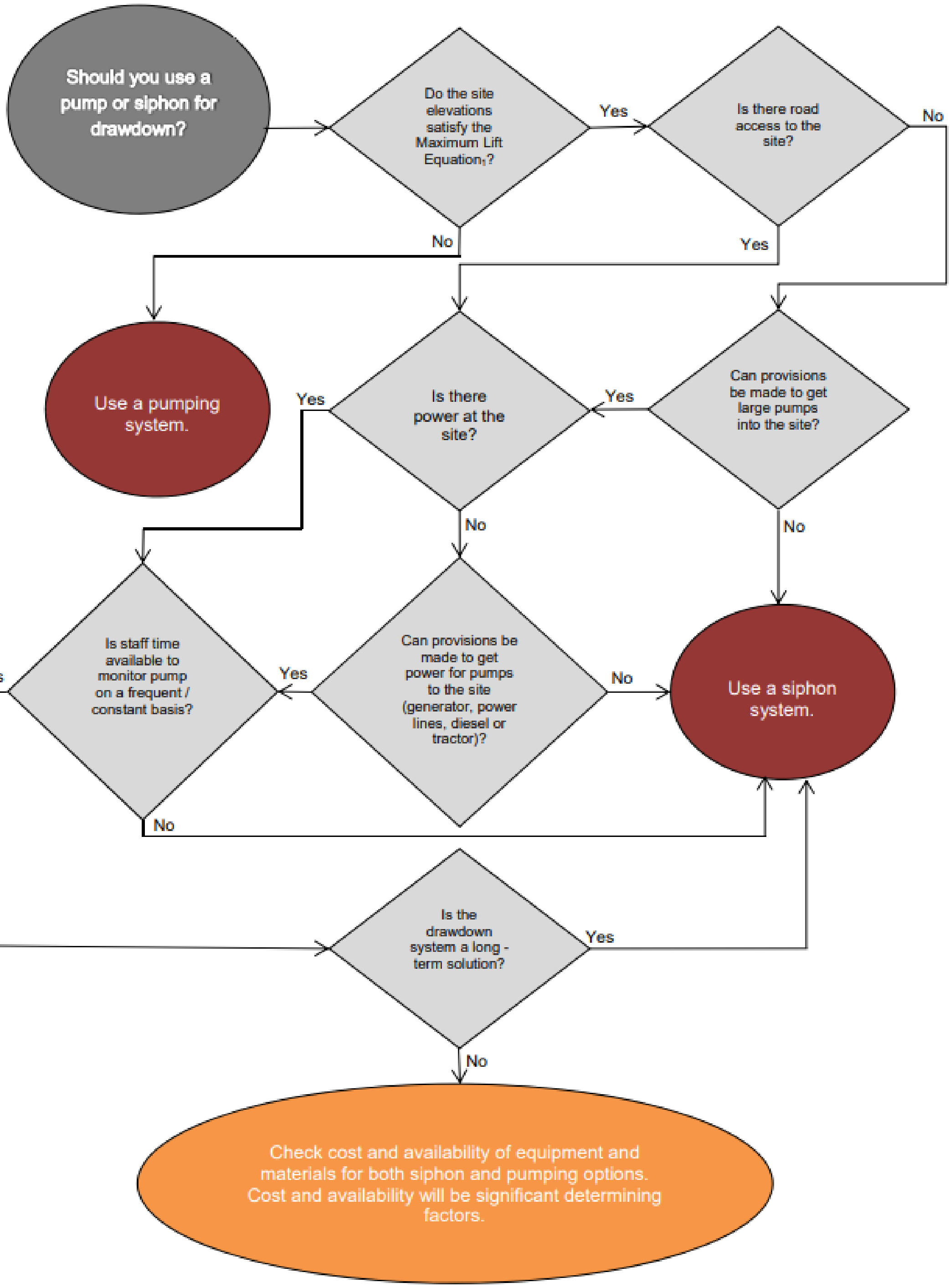

Figure 2: Drawdown method selection flowchart (Guidelines for use of pumps and siphons for emergency reservoir drawdown, 2012)

Other Considerations

Reservoir drawdown changes the hydrostatic pressure against the slope and affects the slope stability—a rapid drawdown can result in slope failure. The rapid decrease in water level changes the side slope's stress, which alters the pore water pressure. When the resulting pore water pressure is not in equilibrium with the boundary condition, the slope fails. A drawdown rate of 0.1 m/day is typical, while a drawdown of 0.5 m/day is high. A 1.0 m/day rate is a rapid drawdown, and dam condition must be carefully evaluated before implementation. (Alonso & Pinyol, 2009)

Recommendations:

1. Reservoir drawdown is an emergency fallback measure only and not a permanent solution to dams in poor condition.
2. The dam owner must appoint a professional engineer if the need arises.
3. An experienced engineer should assess the adequacy of the drawdown methods.
4. A pump supplier and professional engineer can adequately design a pumping system with the appropriate pump, type and dimension of pipes and the different valves.

References

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