EXPLORATORY VELOCITY MEASUREMENTS IN IRON GATE RESERVOIR WITH AN ACOUSTIC DOPPLER CURRENT PROFILER

PREPARED FOR PACIFICORP

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Introduction

In 2008, a curtain was deployed at the log boom in Iron Gate Reservoir to determine if water quality improvements could be attained by isolating near surface waters to reduce entrainment of algae to the outlet tower (Figure 1). During the summer of 2009, velocities were measured along the log boom curtain and in the vicinity of the outlet tower to determine local hydraulic conditions. Measurements were completed September. The curtain and the log boom and outlet tower are shown in Figure 2 (a) and (b), respectively.

Figure 1. Outlet and trash rack (screen) and surface water entrainment (September 10, 2008).

To explore velocity conditions in the vicinity of these features an acoustic Doppler current profiler (ADCP) was employed. Specifically, a Workhouse Sentinel by Teledyne RD Instruments was used on a floating catamaran system and connected to an onboard computer (Figure 3). The ADCP uses the Doppler shift principle to measure velocities along four acoustic beams projected downward through the water column. The instrument emits precise acoustic signals which are reflected off particles in the water column. The Doppler shift of the backscattered signal is proportional to the velocity of the particles (Teledyne 2007a). Velocity measurements near the curtain provide information regarding the general movement of water along or under the curtain. Velocity measurements at the outlet tower provide important information on the local zone of influence regarding the withdrawal dynamics from the reservoir.

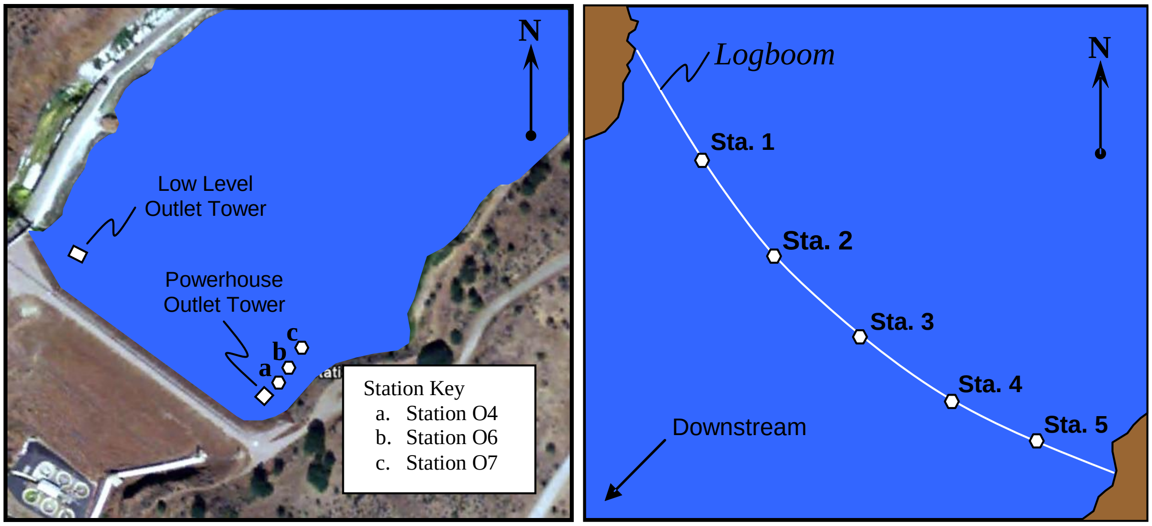
(a) (b)

Figure 2. Log boom curtain seen in Iron Gate Reservoir (looking north), (b) Main outlet tower at Iron Gate Reservoir showing log boom and trash rack (looking downstream)

Figure 3. Workhouse Sentinel acoustic Doppler current profiler (ADCP) by Teledyne RD Instruments, and cataraft used to deploy ADCP in reservoir (source: Teledyne Technologies (2007b)).

Approach

For the purpose of the study, the Workhouse Sentinel Acoustic Doppler Current Profiler (ADCP) was placed in a small catamaran raft and floated over multiple locations along the curtain and near the outlet tower to collect a series of discrete measurements. The ADCP was remotely operated and the data downloaded via laptop. Deployments occurred along the log boom at six distinct locations (Figure 4a). Another set of deployments were taken in front of the outlet tower (Figure 4b). Measurements were taken for multiple depths to examine water velocities through the water column. The data was downloaded and analyzed using WinSC and WinADCP, two post-processing programs provided by RD Instruments. Deployment locations are summarized in Table 1.



(a) (b)

Figure 4. Deployment of Workhouse ADCP (a) at the log boom, and (b) near outlet tower. (Note, log boom in aerial photo is located in a different position than during the September 2009 field work)

Results of the two areas explored in this study, the log boom and outlet tower, are presented below.

Table 1. Latitude and longitude of stations at log boom and outlet tower

Location	Map Symbol*	Latitude	Longitude
Station 1	Sta. 1	41° 56' 19.362" N	122° 25' 58.310" W
Station 2	Sta. 2	41° 56' 17.928" N	122° 25' 56.846" W
Station 3	Sta. 3	41° 56' 16.654" N	122° 25' 55.077" W
Station 4	Sta. 4	41° 56' 15.795" N	122° 25' 51.827" W
Station 5	Sta. 5	41° 56' 15.113" N	122° 25' 51.442" W
Station O4**	a	-	-
Station O6	b	41° 56' 3.506" N	122° 26' 4.920" W
Station O7	c	41° 56' 4.152" N	122° 26' 4.263" W

* Refer to Figure 4.

** Station O4 was between Station O6 and the outlet tower screen. No GPS point was obtained at this point.

Log Boom Curtain

The original intent of the log boom curtain was to isolate surface waters and reduce phytoplankton entrainment in the outlet tower. Specifically, the curtain would restrict the withdrawal envelop to deeper waters, thus entraining water with presumably lower concentrations of phytoplankton that are most prevalent in near-surface waters (e.g., photic zone), as shown in Figure 5.

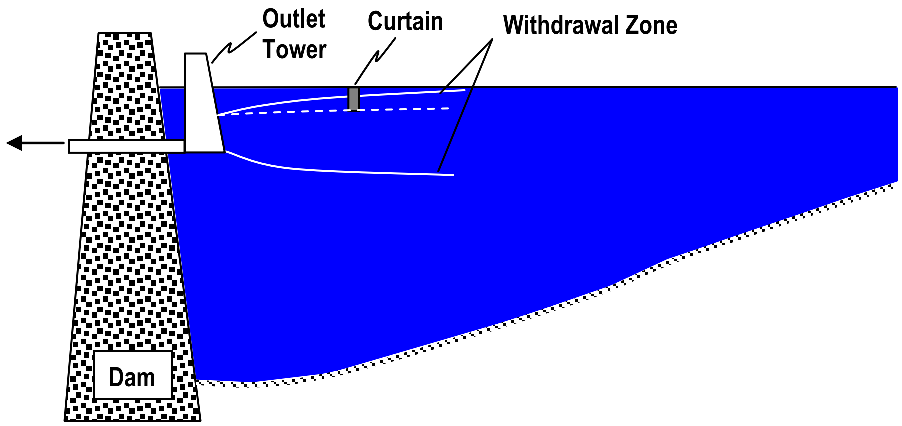


Figure 5. Conceptualization of reservoir outflow withdrawal zone (white line), curtain placement, and truncated withdrawal zone (dashed white line).

To assess velocities measured by the ADCP at the curtain (coordinates are included in Table 1 of the appendix), measurements at 0.5 m intervals were averaged for depths between 1 to 3 meters and 3 to 6 meters representing from near-surface to the bottom of the curtain and from the bottom of the curtain to six meters of depth, respectively. Velocity observations less than 1 meter were not available due to the close proximity to the surface of the ADCP. Observations were completed along the log boom at stationary position during each measurement. However, the log boom location is not static and can move depending on the wind direction or lack of wind. When the wind is out of the south or west, the log boom is displaced forming a concave arc upstream (Figure 6a). When the wind is out of the north or east, the opposite occurs (Figure 6b). During windless periods the log boom can occupy positions intermediate to these two extremes.

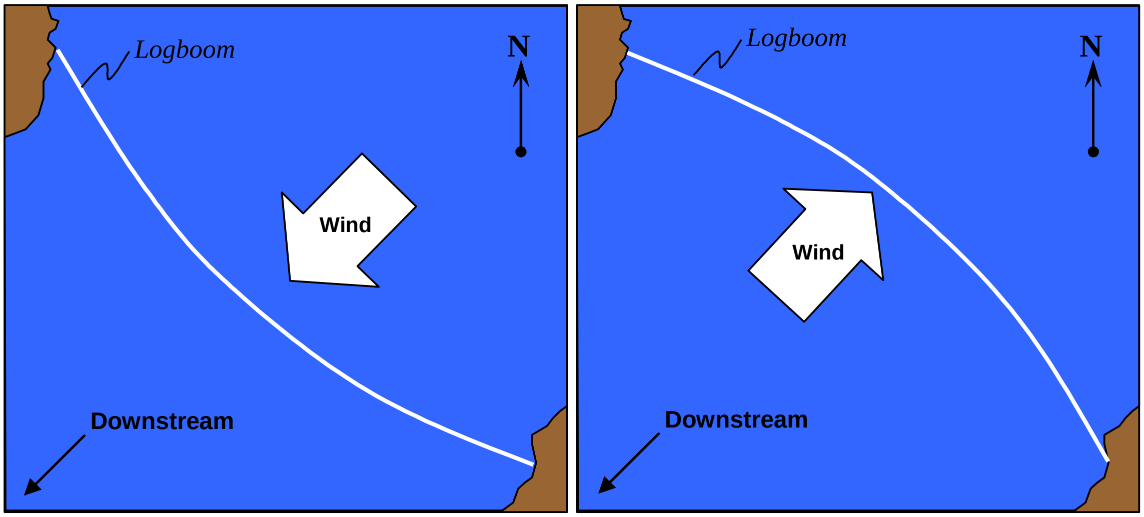


Figure 6. Log boom location based on wind direction

The primary action of wind over a lake surface is to apply a shear force wherein wind energy is transferred into water motion in approximately the same direction as the wind

(Kalff 2002). During the experiment, wind out of the northeast pushed the log boom to a downstream arc (Figure 6a). Wind induced surface currents, out of the northeast, were modified by the curtain that was suspended from the log boom. Near surface waters were redirected generally southward along the curtain.

Generally, velocities at depths of 1 to 3 meters were approximately parallel to the curtain (stations 1-2) or generally southward (stations 3-5). Velocities below the curtain suggest a more downstream direction (stations 1-3) with the exception of the southernmost stations where velocities were generally southward (stations 4-5).

This redirection of near surface current appeared to result in a net flow of water towards the south shoreline. At which point a decrease in reservoir depth, coupled with general downstream barotropic motion (i.e. wind driven) of surface water, resulted in water passing under the curtain in the vicinity of stations 4 and 5. Thus, under the conditions that occurred during the experiment, surface waters from the upstream side of the curtain were, at least in part, routed to the southern end of the curtain where the combination of barotropic and baroclinic (i.e. density driven) motion (Fischer et al. 1979) results in water passing under the curtain near the southern shore. These limited measurements suggest that the opposite condition may occur under a wind out of the south or west – that is, surface waters would move generally northward along the curtain.

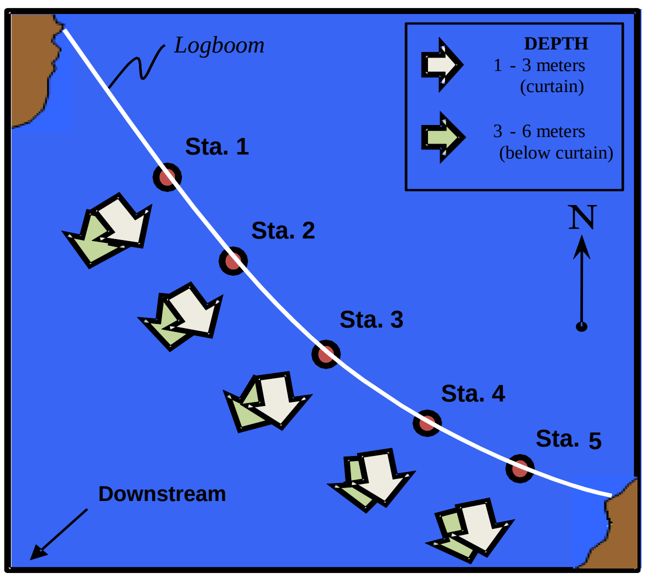


Figure 7. Direction and flow of water based on the average of ADCP measurements. Water depths of 1-3 meters are represented by the white arrow and water depths of 3-6 meters are represented by the green arrow.

The full range of implications of curtain placement, curtain depth, local wind conditions, thermal stratification, presence/absence of phytoplankton (including species present) and other factors were not explored. As a result, these initial findings represent only conditions available for a single sampling event. Nonetheless, it appears that the curtain placement did not have the intended effect of reducing phytoplankton entrainment at the intake tower. Factors playing a role in curtain performance included:

- Effects of the curtain on the withdrawal zone were small and readily overcome by wind driven factors.

- The curtain was placed too far from the outlet tower to have a notable effect, particularly given that outlet tower is screened to the water surface, and the areas between the log boom and the dam was considerable.

- Impacts of reservoir morphology, coupled with curtain placement and wind driven circulation, produced conditions that reduce the efficacy of the hypothesized performance (particularly under windy conditions).

Given these findings, the observations at the outlet tower provide further insight into potential control of phytoplankton in reservoir releases.   These data are summarized in Table 2.

Table 2. Average velocity of water with depth at stations at log boom

Location	Map Symbol*	Magnitude (m/s) (1 – 3 meters)	Magnitude (m/s) (3 – 6 meters)
Station 1	Sta. 1	0.050	0.041
Station 2	Sta. 2	0.050	0.036
Station 3	Sta. 3	0.060	0.033
Station 4	Sta. 4	0.055	0.045
Station 5	Sta. 5	0.038	0.037

* Refer to Figure 4.

Outlet Tower

The principal outlet works for Iron Gate Dam include an outlet tower located in the south east corner of the reservoir (Figure 8, Figure 4b), resting on a bench cut into the south wall of the reservoir (Figure 9). Other outlet works at Iron Gate dam include fish hatchery outlets, an emergency low level outlet, and a spillway. The upstream face of the outlet tower is approximately 16 feet wide and 45 feet tall. The tower is fully screened (trash rack) from the invert of the 12 foot diameter waterway outlet pipeline (elevation 2,293 ft msl) to well above the reservoir surface (Figure 2b). The waterway pipeline has a capacity of approximately 1,750 cfs (PacifiCorp 2002). At normal maximum water elevation (2,328 ft msl), the depth of water at the outlet tower flows is approximately 35 feet. Because of the full screened depth, the tower entrains surface waters as well as deeper waters. These ADCP measurements were intended to improve understanding of potential contributing flows at various depths and assess potential for surface entrainment of algae.

Figure 8. Iron Gate Reservoir outlet tower located adjacent to the dam and south bank of the reservoir. Photo is taken looking approximately westward.

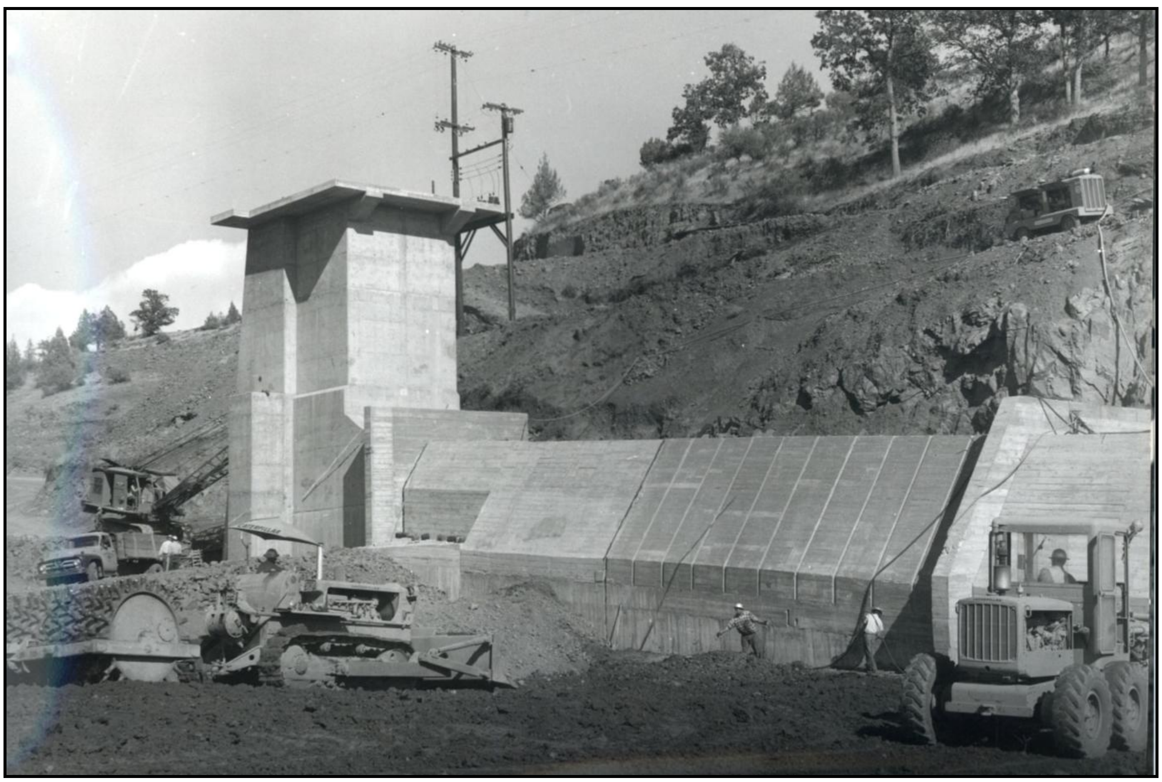
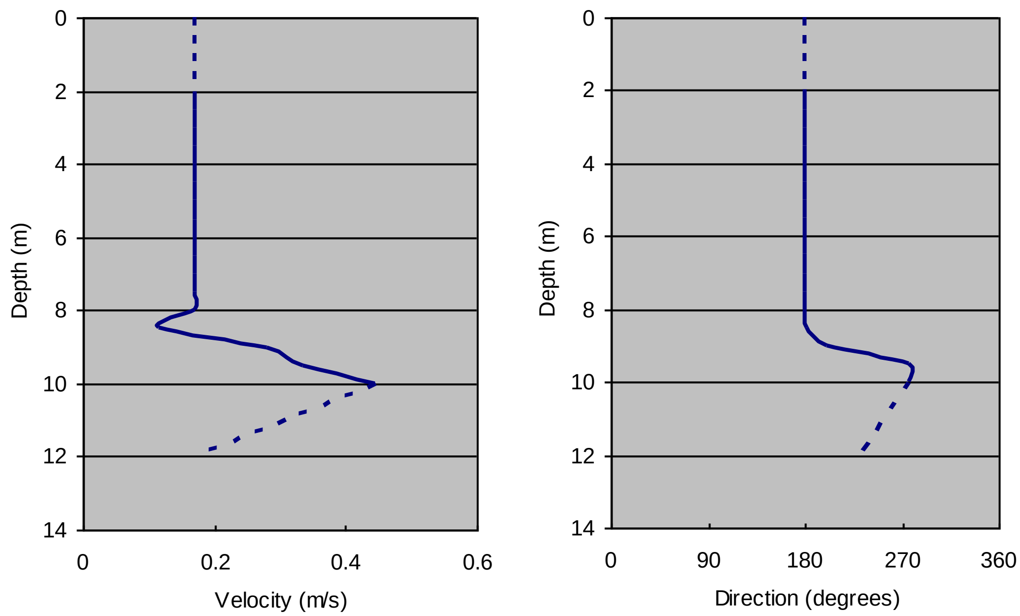


Figure 9. Outlet tower and waterway pipeline during construction (prior to control building construction. Picture is taken looking approximately to the southeast (source: PacifiCorp).

Measurements were taken at upstream end of the small log boom attached to the outlet tower and close to the intake tower screen. The depth of water at the outlet tower was approximately 33 feet (10 meters). These vertical velocity profiles resulted in three principal findings:

1) the vertical velocity distribution is asymmetrical, with a form that suggests larger contributions in the vicinity of the waterway pipeline. This finding suggests that although the tower is screened to the surface, surface contributions are smaller than those from deeper in the reservoir. Given that the tower is of uniform width and that velocities are notably larger in the vicinity of the waterway pipeline, deeper waters appear to contribute a proportionally larger fraction of the flow (Figure 10(a)).

2) through much of the vertical depth, waters enter the outlet tower perpendicular to the trash rack (i.e., parallel to the longitudinal axis of the reservoir and perpendicular to the trash rack). However, in the vicinity of the waterway pipeline the velocities enter at a notably larger angle (Figure 10(b)). These results suggest that the withdrawal dynamics are a function of outlet tower location. Geographically, the outlet tower is adjacent to the left bank with shallower waters towards shore and deeper waters towards the centerline of the reservoir. The physical boundary of the south reservoir bank limits the contributing area, creating an asymmetrical flow field at the bottom of the intake tower, wherein the majority of the water is drawn from the deeper waters located towards the centerline of the reservoir (Figure 11).



(a) (b)

Figure 10. ADCP data for (a) vertical velocity distribution and (b) direction of flow at the Iron Gate Outlet tower (180 degrees represents downstream flow into the outlet tower, i.e., parallel to the longitudinal axis of the reservoir and perpendicular to the trash rack). Dashed lines indicate potential velocities and direction of flow where measurements were unavailable.

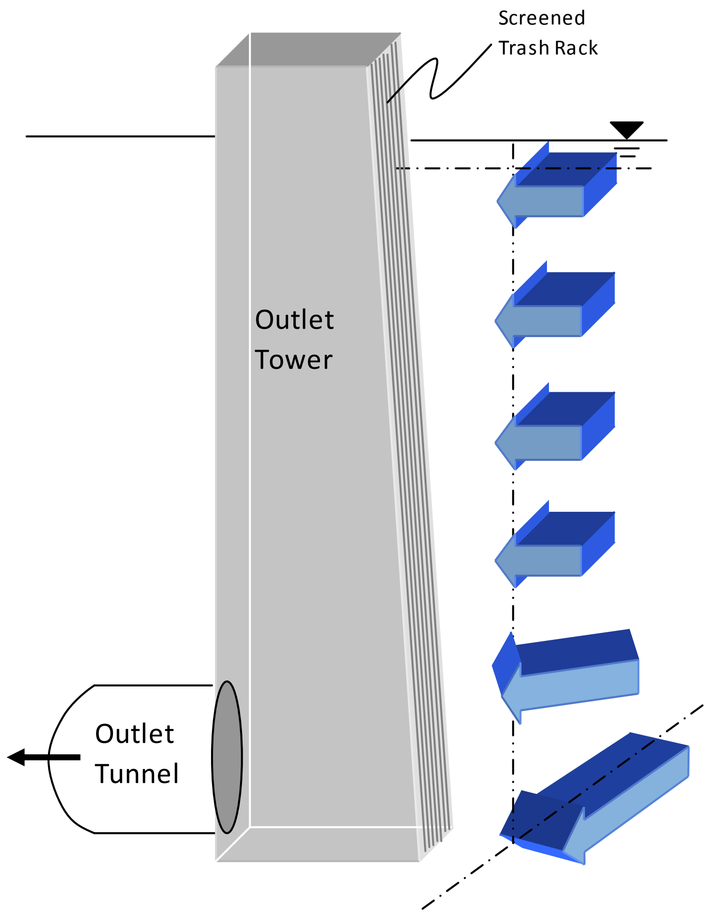


Figure 11. Direction and magnitude of upstream water entering the outlet tower, represented by blue arrows. (approximate scale)

3) Depth averaged velocities decrease notably as distance from the outlet tower increases (i.e. from Station O4 to Station O7). These data are summarized in Table 3.

Table 3. Average velocity of water with depth at stations at log boom and outlet tower

Location	Map Symbol*	Magnitude (m/s) (1 – 5 meters)	Magnitude (m/s) (5 – 10 meters)
Station O4	a	0.146	0.175
Station O6	b	0.129	0.143
Station O7	c	0.059	0.074

* Refer to Figure 4.

Recommendations

Based on the findings of this initial pilot study, several recommendations have been identified

- Placing a 3 m (approximately 10 ft) curtain at the log boom may be too far from the outlet tower to have the desired effect and/or may require a curtain of greater depth. Placing a curtain closer to the outlet tower may prove more effective. Exploring curtains of different lengths may be useful as well (e.g., 5 m or 7.5 m depths). If a curtain is to be placed in the future, recommend monitoring pre- and post-deployment to identify changes in velocity regime around the curtain.

- Consider placing a cover directly on the outlet tower trash rack. This cover would have a direct impact on reducing surface water entrainment and would overcome the problem of placing a curtain upstream at an appropriate distance and depth.

- Recommend (a) additional field observations (velocity profiles) at the outlet tower at several distances upstream from the tower, (b) using existing simulation models to assess potential impacts of outlet tower cover size, and (c) examine conditions at different times of years. Such an approach could lead to effective management of outlet tower, wherein a cover could be manipulated (e.g., raised, lowered, or removed) in response to water quality conditions in Iron Gate Reservoir.

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