# How Proper Trunk Line Construction Maximizes the Longevity of Reservoir Floating Covers

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## ABSTRACT

The Los Angeles Department of Water and Power (LADWP) designed and constructed the Green Verdugo Floating Cover Replacement Project to comply with the Environmental Protection Agency's (EPA) Long Term 2 Enhanced Surface Water Treatment Rule. LADWP incorporated best practices utilizing data from computational fluid dynamic modeling, installing remotely operated hydraulic actuated valves, and relocating trunk lines to beneath the reservoir floor to maximize the longevity of the floating cover. The construction of the project was subject to two California regulatory agencies. Tie-in connection work was done within the footprint of the dam leading to increased structural requirements. Reinforced concrete encasement and additional steel thickness to the trunk line added to the longevity of the pipe while also providing corrosion protection. The project had a hybrid delivery process through a partnership with LADWP's in-house construction division and a specialized geosynthetics contractor. All regulatory requirements have been met and Green Verdugo Reservoir is expected to go back into service in February 2024.

## INTRODUCTION

The Los Angeles Department of Water and Power (LADWP) is the largest municipal utility in the United States serving over 4 million residents and businesses net dependable capacity of 8019 megawatts of power and an average of 435 million gallons (MG) of water per day within the City of Los Angeles. With a network spanning over 7000 miles of pipelines comprising of both smaller distribution lines and large diameter pipes known as trunk lines, the core objective of LADWP's Water System is to provide reliable, safe, high quality water to its customers.

The federal Environmental Protection Agency (EPA) and the California Division of Drinking Water (DDW) are among the agencies that regulate LADWP's ability to serve potable water to the public. In accordance with the EPA's Long Term 2 Enhanced Surface Water Treatment Rule, all finished water storage facilities for public consumption must be covered to prevent contamination from animal waste, human activity, algal growth, insects and airborne deposition. Animal waste, particularly from birds, is a significant source of contamination and may contain *salmonella*, *mycobacterium*, *cryptosporidium* and *giardia* among other pathogens. Algal growth, also called an algae bloom, is caused by aquatic photosynthetic microorganisms in environments with adequate nutrients, sunlight, warm temperatures and slow-moving water. The microorganisms include cyanobacteria (blue-green algae) that can produce cyanobacterial toxins and disinfection byproduct formations that negatively affects human health when consumed. The taste and odor of the water is also affected. A floating cover acts as a physical barrier to mitigate sunlight exposure on the water while also preventing debris, insects and airborne contaminants from entering the water. By installing the floating cover complying with the EPA mandate, LADWP is able reduce to illnesses linked to microbial pathogens in drinking water.

Acceptable covers above the water surface may be a flexible membrane material or of rigid construction. Rigid covers are typically the roofing structures on standard tanks or in buried reservoirs. Flexible covers tend to be more cost effective for outdoor uncovered reservoirs with a large surface area. The cover installation is similar to that of a residential pool cover. Given that the material comes into direct contact with potable water in the reservoir, the Division of Drinking Water under the State Water Resources Control Board imposes supplementary regulatory stipulations. All products that come into contact with potable water must be NSF 61 certified. LADWP specifies the utilization of chlorsulfonated polyethylene (CSPE), a type of NSF 61 approved synthetic rubber known for its resistance to heat, chemicals and ultraviolet rays. These types of resistances are well matched in the application to outdoor reservoirs in California with water treatment involving chemical injection. LADWP has CSPE floating covers at its Santa Ynez, Elysian, Eagle Rock, Lower Franklin, Upper Stone Canyon and Green Verdugo reservoirs. CSPE floating covers have an expected service life of 25 years which is achieved thru the proper design and construction of the floating cover and all its appurtenances including the pipelines within the reservoir.

## RESERVOIR OPERATIONS

The Green Verdugo Reservoir is a 32 million gallon reservoir formed by an earth fill dam covering 3.23 acres in Sunland, California. First placed in service in September 1953, the reservoir serves the Sunland-Tujunga area in the northeast region of the LADWP service area. The previous floating cover installed in 1989 had reached the end of its useful service life and was due for replacement when the La Tuna Canyon wildfire occurred in September 2017. The wildfire burned the cover, necessitating the reservoir to be unexpectedly removed from service due to compromised water quality. The Water Engineering and Technical Services (WETS) Division led the efforts to improve the reservoir design and replace the floating cover in a capital improvement project, the Green Verdugo Reservoir Floating Cover Replacement Project, for LADWP's Water System.

The original reservoir inlet pipe extended from the Green Verdugo Pump Station, located on the Green Verdugo Reservoir property, and terminated above ground within the reservoir. The inlet pipe was comprised of a combination of 456 LF of 36" ID x 3/8" thick welded steel pipe (WSP) and 172 LF of reinforced concrete cylinder pipe (RCCP) for a total length of 628 LF. The WSP inlet pipe extended through the face of the dam on the western side of the reservoir, entered the reservoir beneath the reservoir floor and then daylighted onto the reservoir floor as shown in the profile of the inlet highlighted in blue in Figure 1**.** The 36" RCCP portion of the inlet line was supported by concrete piers along the reservoir floor before terminating on the east side of the reservoir as shown in the plan view in Figure 2. The inlet line is highlighted in blue and the outlet line in green.

Water from the reservoir enters the distribution system to the Sunland-Tujunga service area through the 484 LF of 36" ID x 3/8" thick WSP outlet line. The outlet line parallels the inlet line thru the face of the dam on the western side of the reservoir and originally connected to an outlet tower structure. The outlet tower structure served as the means to convey water out of the reservoir into the distribution system and had three valves at different elevations as shown in

Figure 3. These valves were opened sequentially to feed the outlet line and played a secondary role in enhancing water quality by promoting internal mixing of the water within the reservoir. The maximum high water level (HWL) and spillway elevation (EL.) in the reservoir is EL. 1400. Valve 212 would be opened first and lowered the water level to EL. 1379. Valves 213 and 214 would lower the reservoir elevation to EL. 1366 and El. 1352 respectively. The original reservoir floor stood at EL. 1345, resulting in a residual of 7 feet of water that necessitated manual pumping with external equipment through a hatch on the floating cover in order to achieve complete drainage of the reservoir. Improvements to the outlet design sought by Water Operations during the planning process aimed to streamline the draining process at the Green Verdugo Reservoir.

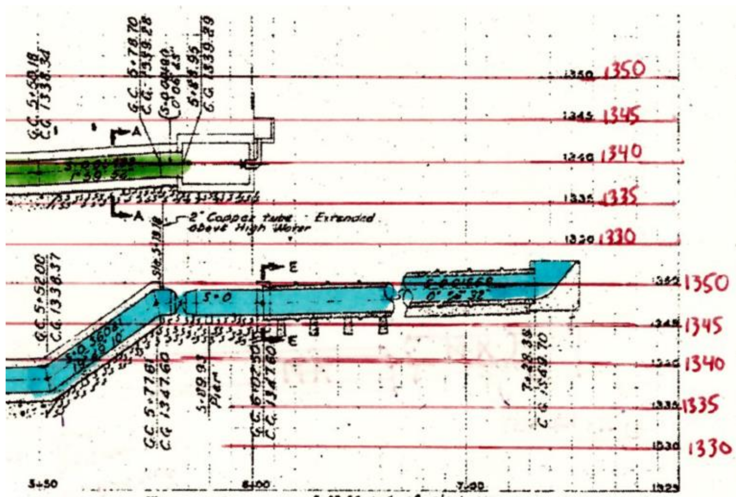


**Figure 1: Original Profile of Inlet and Outlet Trunk Lines (1953)**

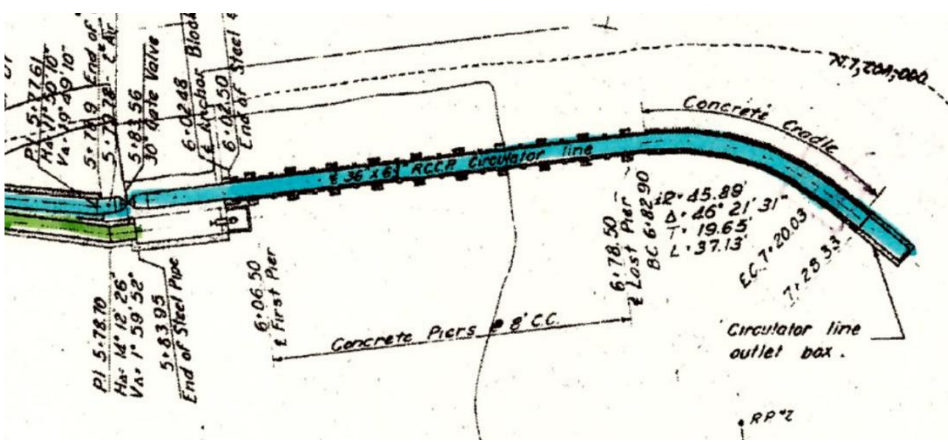


**Figure 2: Plan View of Original Trunk Line Design (1953)**

In preparation for the replacement of the aging floating cover at the Green Verdugo Reservoir, the scope of work prepared by WETS Planning engineers encompassed various elements aimed at enhancing the design and operation of the reservoir. The overarching goal of these improvements was to increase operational flexibility and prolong the longevity of the floating cover. When designed and installed in accordance with industry standards, a floating cover typically has a life expectancy of 25 years. This longevity is contingent upon proper design and installation to ensure optimal performance and durability throughout its operational lifespan.

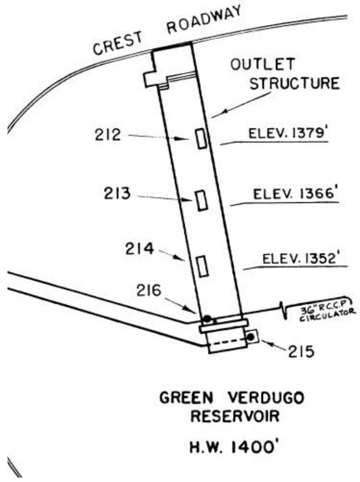


**Figure 3: Original Outlet Tower at Green Verdugo Reservoir (1953)**

The original inlet line was positioned on top of the reservoir floor and supported by concrete piers as illustrated in blue in Figure 2. Adjacent to the inlet line were a pair of steel mixer cages that housed mixer blades utilized for blending water and disinfection chemicals to maintain water quality standards. These above ground appurtenances on the reservoir floor exerted additional stress to the floating cover. This stress was exacerbated by the inability of the cover to lay flat on the reservoir floor when the reservoir was fully drained leading to the formation of pinholes and tears over the floating cover's service life. To address these issues, the trunk lines and mixers were relocated underground beneath the reservoir floor.

The relocation of the mixers to a new vault beneath the reservoir floor presented the opportunity to select a more advantageous position that would not interfere with the cover. LADWP enlisted a consultant to conduct computational fluid dynamics (CFD) modeling to evaluate the different options for enhancing water quality by eliminating stagnant areas. The ANSYS CFX CFD software utilized simulates three-dimensional fluid flow and analyzed the flow conditions across various scenarios related to location of the mixer vault, blade size and rotational speeds. Based on the consultant's report, the recommended design called for a 16,000 gallon per minute (gpm) mixer in the location depicted in Figure 4. This mixer vault placement aligned with the flow originating from the end of the inlet pipe where water enters the reservoir at the inlet manifold. Velocity contours taken at different elevations of the proposed mixer design indicated the elimination of all dead zones except for the perimeter wall at the top of the reservoir. The final design integrated the consultant's recommendations for optimal mixer placement beneath the reservoir floor to ensure compatibility with the cover and eliminate interference.

## DESIGN OF THE TRUNK LINE

The trunk line portion of the Green Verdugo Reservoir Floating Cover Replacement Project was designed internally by the WETS Trunk Line Design Group, maintaining the original 36 inch inlet and outlet pipe diameter size based on hydraulic modeling analysis performed by Planning engineers. The required thickness of the WSP pipe wall was determined considering internal pressure, outside diameter of the pipe excluding coatings and the allowable stress. When designing for internal pressure, the thickness of the pipe is selected to limit the hoop stress. Based on the American Water Works Association (AWWA) Manual of Water Supply Practices M11 Barlow equation (Eq. 1), it was calculated that the minimum pipe wall thickness for the inlet and outline lines would be 0.055 inches. Taking into consideration, external loadings such as soil, concrete slurry backfill, vehicular loading, the 52 foot column of water when the reservoir is at capacity, buckling and deflection, the pipe wall thickness was determined to be 0.50 inches. The new reservoir elevation ranges from EL. 1348 feet to EL. 1400 feet.

$$t = \frac{pD_o}{2s} \tag{1}$$

Where: $t =$ pipe wall thickness for internal pressure, in.
$p =$ internal pressure, psi
$D_o =$ outside diameter of steel pipe cylinder (not including coatings), in.
$s =$ allowable design stress, psi

After establishing the minimum thickness using the Barlow equation (Eq. 1), external dead load conditions were considered. The AWWA M11 guidelines treat trench dead load as a prism load (Eq. 2).

$$W_c = wH_c \frac{D_c}{12} \tag{2}$$

Where:
$W_c =$ prism load = dead load on the pipe, lb/lin ft of pipe
$w =$ unit weight of fill, lb/ft$^3$
$H_c =$ Height of fill above top of pipe, ft
$D_c =$ outside diameter of coated pipe, ft

Following the consideration of external dead loads, the project accounted for external live loads, specifically designed for H-20 vehicular loading (Eq. 3). This loading condition would occur during the construction phase of the project when pipe sections would be backfilled upon completion to support vehicular traffic on the reservoir floor.

$$W_{LL} = LL \frac{D_c}{12} \tag{3}$$

Where:
$W_{LL} =$ Weight of Live load on the pipe, lb/lin ft of pipe
$LL =$ unit weight of live load, lb/ft$^2$
$D_c =$ outside diameter of coated pipe, ft

The allowable pipe deflection, $\Delta_A$, must be greater than the calculated pipe deflection, $\Delta_x$. Therefore $\Delta_A > \Delta_x$. According to the AWWA M11, the pipe deflection is calculated as shown below in Eq. 4.

$$\Delta_x = D_l \frac{KWr^3}{EI + 0.061E'r^3} \tag{4}$$

Where:
$\Delta_x$= predicted horizontal deflection of pipe, in
$D_l$ = Deflection lag factor (1.0 when prism load is used)
$K$ = bedding constant (0.1)
$W$ = load per unit of pipe length, lb/lin in.
$r$ = mean radius of the pipe, in.
$E'$ = modulus of soil reaction of the embedment material, psi
$EI$ = pipe wall stiffness, lb in.
The allowable pipe deflection is calculated as seen below in Eq. 5.

$$\Delta_A = D_{OD} * 0.02 \tag{5}$$

Where:
$\Delta_A$= allowable deflection, in.
$D_{OD}$ = Outside diameter, in.

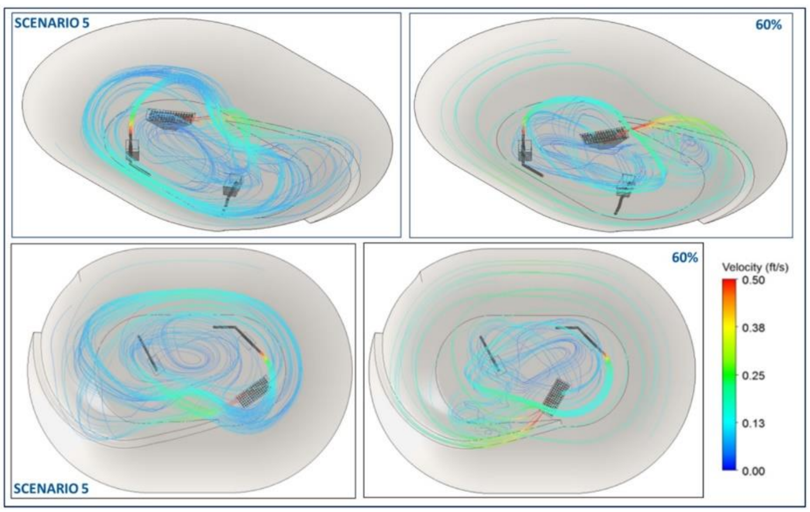


**Figure 4: CFD Model Flow Path**

The inlet and outlet lines inside the reservoir were encased in reinforced concrete for additional protection. The 36 inch diameter pipes was surrounded by 66 inches of concrete in both directions and #5 rebar spaced every 12 inches. This additional layer of reinforced concrete is intended to add a layer of protection to the reservoir against potential pipe failure.

During the as-built investigation of the original reservoir design and its components, an existing 6-inch steel subdrain system was found beneath the reservoir floor. This subdrain system contributes to the dam's stability by directing groundwater through a drain to a seepage vault. The existing subdrain elevation coincided with the elevation of the proposed inlet and outlet lines, creating a conflict in the design. Due to the nature of the existing gravity fed subdrain system, relocating or rerouting it was not feasible. Consequently, the new 36-inch inlet and outlet lines had to dip under the subdrain at intersecting locations, resulting in low points in these lines. To address this, the maintenance holes inside the vaults would facilitate access for future maintenance and allow for manual pumping with a sump pump to remove water from low points in the pipes as shown in Figures 5 and 6.

Per the recommendation of the floating cover design team, the 36-inch inlet terminus daylights at a 45-degree angle to reduce the strike angle against the underside of the floating cover. The 45-degree angle was the most optimal to reduce wear and tear of the cover at the entry point of the water, known as the inlet manifold, shown at station 3+00 in Figure 5.

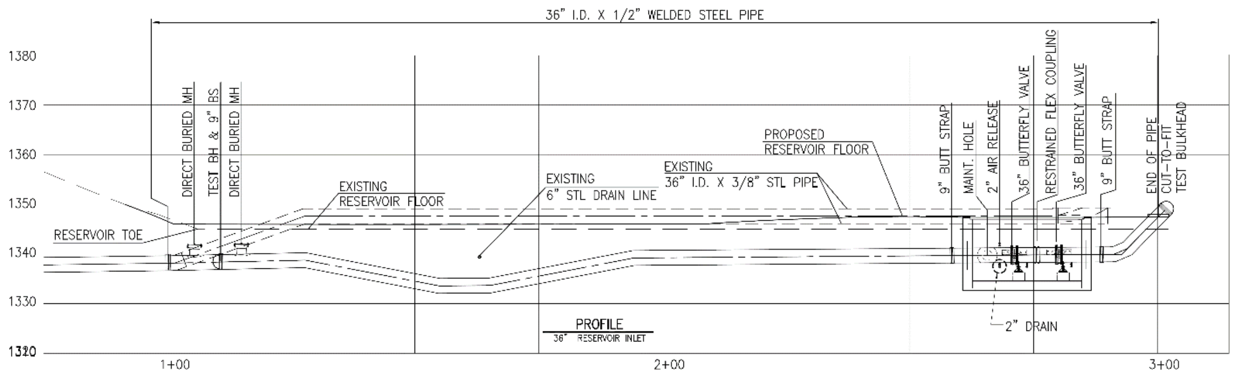


**Figure 5: Profile of New Inlet Line and Inlet Vault (2018)**

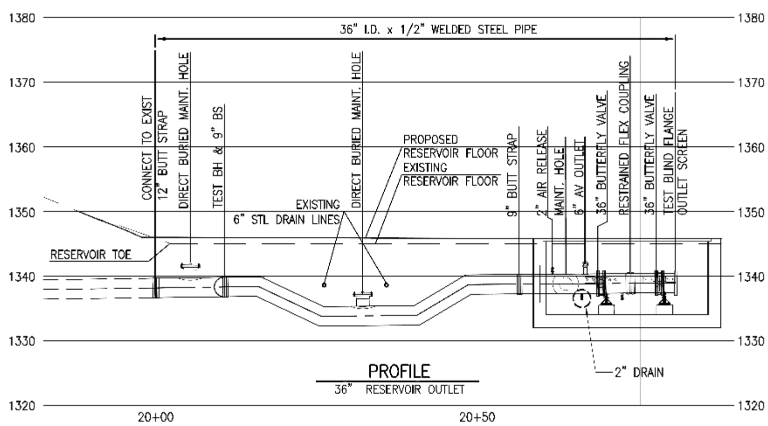


**Figure 6: Profile of New Outlet Line and Outlet Vault (2018)**

The scope of work for the Green Verdugo FCRP included the installation of four butterfly valves on the inlet and outlet lines to facilitate future shutdowns and maintenance. The valves are controlled remotely from a hydraulic control panel within the Control Building located outside the reservoir on the property. Each of the inlet and outlet vaults was designed for two 36-inch butterfly valves. To meet safety and redundancy standards, LADWP requires a double-block and bleed condition on its large diameter pipelines. This requirement pairs two valves performing similar functions together to monitor a potential leak or failure of the first valve.

Extensive research was conducted on underground utilities to locate suitable positions for these valves along the existing inlet and outlet lines outside of the reservoir and away from the dam limit. However, the presence of numerous underground chemical and power lines conflicts made it impractical to install the valves in these locations. Additionally, relocation of these lines would have necessitated a lengthy shutdown of the chlorination and ammoniation stations, which was not operationally feasible. As a result, the decision was made to submerge the valves within the reservoir in concrete vaults and design them to be hydraulically actuated. The hydraulically operated butterfly valves are powered with a gear box and double acting cylinder. These actuators are designed to provide on-off function of the valves. Auxiliary controls are provided to direct hydraulic power to the cylinder and regulate its operating speed.

The valve's placement within concrete vaults enables operators to access them via a hatch on the floating cover to perform maintenance and future replacement. The inlet and outlet pipes within the vaults are equipped with sideways maintenance access holes featuring hinged blind flanges for interior pipe access. Due to clearance constraints, a typical maintenance hole on top of the pipe was not feasible. The sideways maintenance hole configuration offers other benefits such as easier access for personnel to crawl into the pipe rather than dropping in, a lower elevation requiring a shorter ladder and enhanced safety with hinged blind flanges. This eliminated the need to drop or set the flanges on the floor of the vault.

Corrosion protection plays a critical role in extending the lifespan of the welded steel pipe, with the sacrificial anodes implemented to absorb the effects of corrosion in lieu of the pipe. Analysis has shown that the WSP inlet and outlet lines are sufficiently protected using an impressed current. The WSP was coated with an epoxy dielectric coating directly on the steel before the cement mortar coating was applied. Utilizing cathodic protection to safeguard the steel not only reduces maintenance needs but also minimizes access needs on the floating cover, thereby reducing stress on the cover and enhancing its longevity.

## REGULATORY REQUIREMENTS BY DIVISION OF SAFETY OF DAMS (DSOD)

During the review of the drawing set at 90% design, DSOD requested the inclusion of an air and vacuum valve on the outlet line in the outlet vault. An air and vacuum valve, commonly referred to as air-vac, serves crucial purposes in pipelines. Prior to filling, pipelines may be assumed to be devoid of water but still contain a volume of air, necessitating consideration during filling to prevent pressure surges. It is essential to exhaust air in a smooth and uniform manner to prevent such surges from occurring in the pipeline. Additionally, the valve allows air to re-enter the pipeline in response to negative pressure, preventing a vacuum from forming and ensures efficient drainage. Exclusion of an air-vac could potentially lead to a catastrophic pipe collapse, a condition where the pipe "deflates" inelastically. This in turn would cause serious pipe damage requiring massive repair efforts involving the removal of the floating cover and excavation within reservoir. A 6-inch steel air vac was deemed sufficient to prevent pipe collapse in the event of a failure downstream. Furthermore, it provides operational flexibility, enabling the outlet line to serve as an inlet line when necessary, such as during initial disinfection to return the reservoir back in service.

The braced shoring system designed for installing the pipeline beneath the reservoir floor underwent thorough review by DSOD, with stricter conditions imposed due to its proximity to the dam limit at the toe of the reservoir. Limited space at the bottom of the reservoir made open excavation infeasible due to the required depth of the excavations and the anticipated number of construction vehicles needed. A braced shoring system designed with the structural analysis software RISA-3D called for structural HP soldier piles set at a standard spacing of 8 feet 4 inch with 1 inch thick steel plates in between. The tie in connection to the existing system was located within the footprint of the dam itself, leading to a reduced shoring spacing of 4 foot 4 inch. Typical shoring deflections permitted for projects of this nature is a half inch at the top of the soldier pile. However, given the location beyond the dam limit within the footprint of the dam, stable conditions and minimal movement were imperative. The allowable deflection was reduced to a quarter inch with survey crews monitoring each soldier pile on a weekly basis. DSOD imposed restrictions on the removal of soldier piles located beyond the dam limit due to the potential risk of causing dam instability. As a mitigation measure, sacrificial beams beyond the dam limit were cut three feet below the reservoir floor elevation and backfilled with the entire excavation. This approach ensured compliance with safety standards while maintaining the integrity of the dam.

DSOD also required the trunk line inlet and outlet lines inside the reservoir to be encased by reinforced concrete. This would further protect the reservoir and dam from any potential adverse impact caused the steel pipe. The reinforced concrete encasement was designed internally by the Civil Structural Group at LADWP.

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## HYBRID PROJECT DELIVERY

The project had a hybrid delivery process through an internal partnership with the LADWP Power Construction and Maintenance (PC&M) Division and general contractor specializing in geosynthetic material fabrication and installation.

PC&M, the in-house construction division, was responsible for the installation of the 36” WSP trunk line, new concrete structures, mechanical equipment and new electrical controls systems. The team utilized the construction management online software platform, Procore, to collaborate among project engineers and the PC&M construction crews. Procore served as the central hub for all project documentation and written communications, including drawings, photos, requests for information (RFI) and meeting minutes. Meeting minutes distributed through Procore recorded discussions between the crew and project engineers during the weekly construction meetings held in the on-site construction trailer. These topics included safety, material procurement status updates, upcoming schedule review, necessary drawing revisions, planned site visits by regulatory agency representatives and staffing needs for equipment testing procedures. The crew primarily consisted of the General Construction, Electrical Construction and Pipefitter trades while Structural Steel Fabricators, Boilermakers, Plumbers, Roofers and Painters also contributed to the success of the project. Leads from each of the primary trades were present for each weekly construction meeting and communicated with the discipline specific design engineer directly to address questions and clarify information. This provided a more effective communication channel as construction superintendents and site foremen were not relied on to serve as the liaisons between the crews and the engineers. A Resident Engineer was present on the site from the Construction Management Group throughout the project. The Resident Engineer coordinated with the crew on site daily and represented the project engineering team in communicating needs and requests.

Key differences from traditional design bid build projects existed in this type of alternative construction process due to its internal nature. Project drawings listed all specifications as notes and material choices were called out in details. The design engineers were responsible for the procurement of all specialized materials that the crews did not have readily available. This included all the 36” WSP trunk line. The trunk line design engineers began the procurement process two years prior to the anticipated start of construction through the LADWP Supply Chain Service’s electronic request-solicit-procure procedure. Lay sheet submittals from the selected pipe manufacturer were approved by the trunk line design engineers prior to an in person inspection of the fabricated pipe at the manufacturer’s factory. Delivery of the pipe was received by PC&M and stored at the lay down area within the reservoir site before the necessary pieces were sequentially moved into the reservoir excavation for installation. All trunk line installations were completed and the excavations were backfilled, enabling PC&M to demobilize from the reservoir interior. This cleared the way for the installation of the floating cover.

The geosynthetics contractor assumed the role of a general contractor for the fabrication and installation of the CSPE floating cover. The contractor also oversaw subcontractors for specialty asphalt paving within the reservoir and installation of the rainwater removal system. The rainwater removal system consists of four pumps located in troughs directly on the floating cover. Ponding of rainwater negatively affects floating cover performance and adds additional stress to the material that may lead to tears. The rainwater removal system is programmed to automatically detect water on the cover and initiate pumping operations to remove water during rain events as well as operational cover washing by personnel.

## CONCLUSION

The design of the trunk line plays a crucial role in determining the frequency of floating cover replacement, while allowing the floating cover the potential to achieve its full expected 25 year lifespan. The extensive relocation of the reservoir appurtenances facilitates future reservoir shutdowns for floating cover replacement, potentially shortening the duration to approximately six months. Increased pipe thickness, rebar encasement and corrosion protection contribute to prolonged trunk line service life, thereby minimizing maintenance requirements and the necessity for replacement. By integrating advancing methodologies and meeting regulatory requirements in its project design, LADWP continues to ensure the highest water quality and reliability for its customers. Through collaboration with internal and external partners, the project has achieved its objectives and is set to bring Green Verdugo Reservoir back into service in February 2024.

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