Authors

Clay E. Haynes, M.S., P.E. [1], is a Project Engineer with Black & Veatch Corporation. On the Nacimiento Water Project, he authored the tunnel and shaft related specifications and drawings in Contract Package 01 for the intake structure at Lake Nacimiento. Mr. Haynes has more than 20 years experience in design of shafts and tunnels for water projects. He holds a M.S. in Civil Engineering from University of Missouri-Columbia and a B.S. in mining engineering from the University of Missouri-Rolla.

John R. Hollenbeck, P.E.[2], is the Nacimiento Project Manager within the Public Works Department of San Luis Obispo County, California. He is the full-time manager of the project through the design, bidding and construction phases. Mr. Hollenbeck has been engaged in the evaluation, design, and construction management for hydraulic structures since graduating from Kansas State University with a B.S. and a M.S. degree in Civil Engineering in 1984 and 1986, respectively.

Christopher G. Mueller, Ph.D., P.E.[3], is the Project Geotechnical Engineer with Black & Veatch Corporation. On the Nacimiento Water Project, he authored the Geotechnical Baseline Report included in Contract Package 01 for the intake structure at Lake Nacimiento. Mr. Mueller has more than 20 years experience in design of shafts and tunnels for water projects. He holds a M.S. in Civil Engineering from Northwestern University and a Ph.D. in Civil (Geotechnical) Engineering from the University of Illinois.

[1] in Missouri, Texas and California
[2] in Kansas and California
[3] in Missouri

Nacimiento Lake Tap

Clay Haynes, P.E., John R. Hollenbeck, P.E., and Chris Mueller, Phd., P.E.

ABSTRACT

In 2005, Black & Veatch Corporation began designing a raw water conveyance system for San Luis Obispo County from Lake Nacimiento to the city of San Luis Obispo. The first element of the water transfer system will be a raw water pump station and lake tap. The wetwell of the pump station will consist of a concrete lined shaft approximately 180 feet deep constructed in the very incompetent sandstone of the Vacqueros Formation. The lake will be wet tapped at approximately 172 feet below grade using a slurry earth pressure balance tunnel boring machine. The 48 to 72-inch finished diameter microtunnel will be approximately 500 feet in length. Construction is scheduled to begin in the Winter of 2007.

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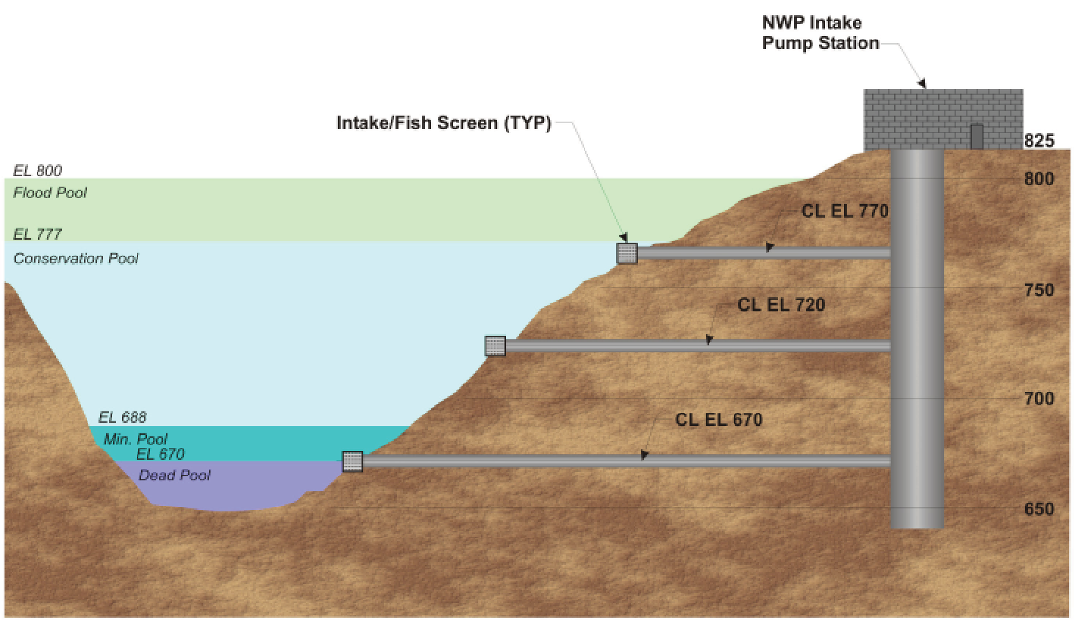
Introduction

Located in the central coast of California, the San Luis Obispo County Flood Control and Water Conservation District (District) is implementing the Nacimiento Water Project (NWP), a raw water conveyance system to deliver 15,750 acre-feet annually from Lake Nacimiento to participating agencies including the City of Paso Robles, City of San Luis Obispo, Atascadero Mutual Water Company, and the Templeton Community Services District and County Service Area 10, Zone A (Figure 1).

In 2005, Black & Veatch Corporation, Irvine, California, was selected to perform preliminary and final design of the $185 million project, which is scheduled to be in operation by 2010. A key element of the Project is the NWP Intake, consisting of a 20-foot diameter, 180-foot deep, concrete-lined vertical shaft connected to the Lake via a single 500-foot long, 48-inch to 72-inch diameter micro tunnel with a lake tap. A surface-mounted sloping intake with seven ports will allow water to be drawn from various reservoir depths for optimal water quality. Construction is scheduled to begin winter of 2007.

Figure 2. NWP Intake Configuration in the EIR



Source: Black & Veatch Corporation, December 2005

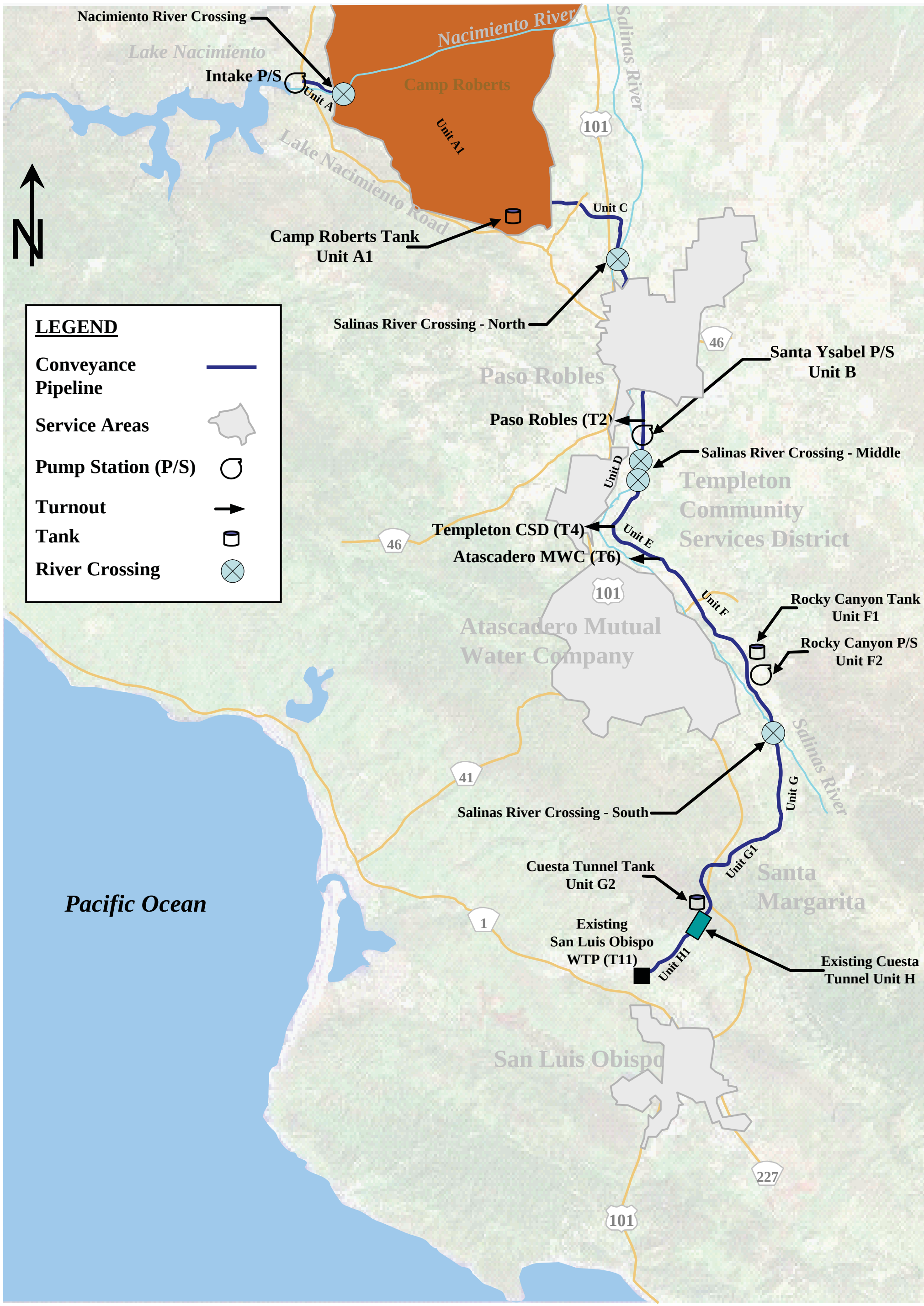
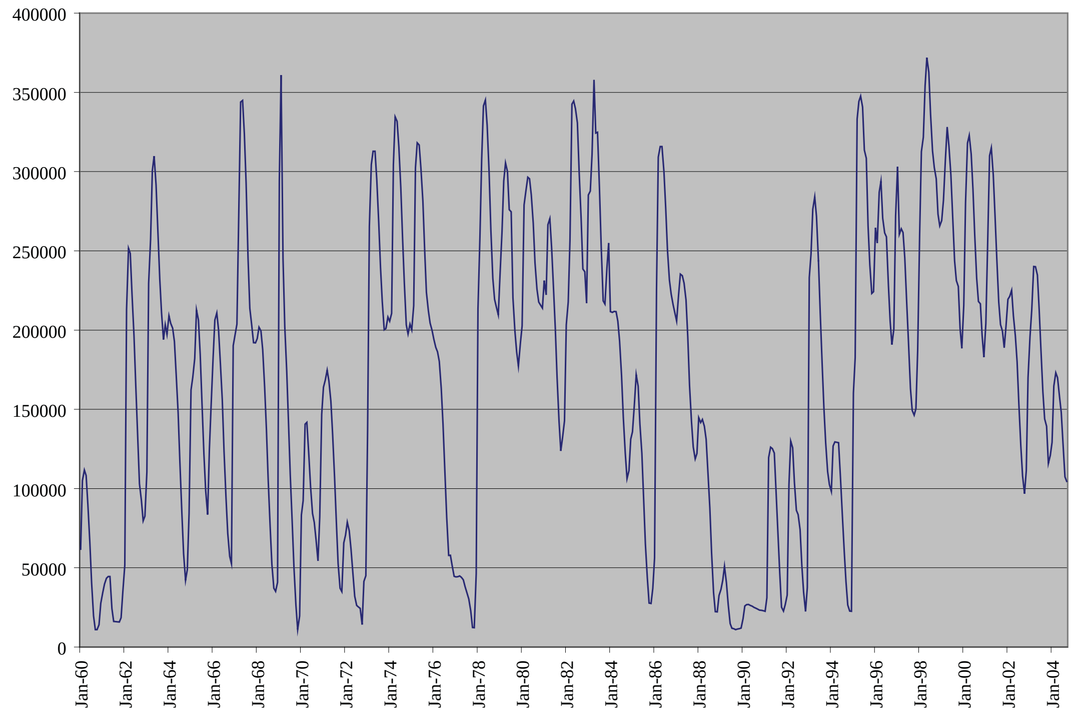


Figure 1. Nacimiento Water Project, San Luis Obispo County, California



Source: California Department of Water Resources

Figure 3. Nacimiento Storage Levels, Acre-Feet (1960 to 2004)

NWP Intake Alternatives

The Nacimiento Water Project Final Environmental Impact Report (FEIR), December 2003, represented the conceptual design of the intake facility as a fixed three-port lake intake, with each port connected to the lake via a 72-inch diameter inlet tunnel (Figure 2). As design development progressed, it became clear that the fixed-port intake did not offer enough flexibility to withdraw raw water from varying lake levels (Figure 3) sufficient to optimize the water quality in combination with the participants' treatment processes. A water quality investigation and review of intake alternatives was subsequently conducted by Black & Veatch in December 2005.

A technical memorandum (TM) was prepared to summarize the existing lake water quality data and to provide recommendations on intake port depths, chemical feed options for the raw water supply, and water quality monitoring. Black & Veatch reviewed water quality data for Nacimiento Reservoir obtained from the District, as well as historical water levels, for the purpose of analyzing the following lake characteristics:

- Determining the position of the thermocline in the water column;
- Describing water quality in the epilimnion and hypolimnion and identifying locations (depths) where water quality changes occur; and
- Identifying additional water quality

data and monitoring needs.

Figure 3, obtained from the California Department of Water Resources website, shows historical reservoir storage volumes based on acre-feet of storage, which was converted to reservoir elevations for the analysis.

As expected, the water quality data indicated that during the winter months the temperature profiles in the reservoir are fairly uniform and stratification is not present. Beginning in February or March, the surface waters start to warm and a thermocline starts to form. Usually during May, epilimnion, thermocline, and hypolimnion areas become distinct. The surface waters reach their highest temperatures in July and August and then start to cool. As the surface water cools, the thermocline erodes and the temperature profiles again become uniform. Stratification disappears as early as October or as late as December.

During the periods of a well established thermocline (May through September), the top of the thermocline was observed to be at depths of 15 to 30 feet and the bottom of the thermocline was at depths of 30 to 55 feet. The thermocline was usually 15 to 25 feet thick.

Based on the water quality data results, the number and spacing of intake ports were also reviewed as part of this TM. Ultimately, the decision was made to incorporate seven intake ports spaced at approximately 20 feet vertically in order to provide the flexibility to withdraw optimal water quality for any operating lake level. Figure 4 shows a schematic of the intake configuration accepted for final design.

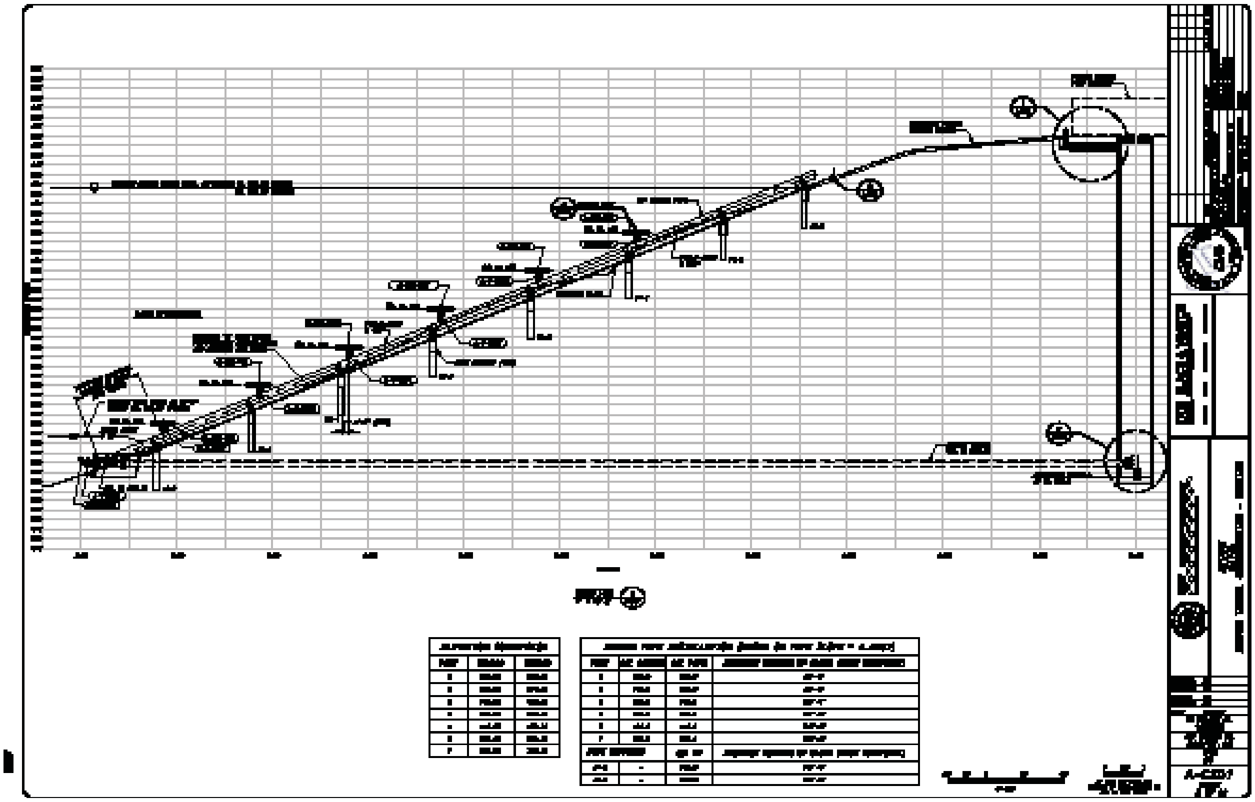
NWP Intake Design

Final design of the NWP Intake focused on construction of the four principal features of the intake, namely, vertical shaft, intake tunnel, sloping intake and intake ports, and marine works. The following discusses the considerations involved with each part.

Geologic & Geotechnical Considerations

The intake site is located in the central California Coast Ranges Geomorphic Province, characterized by moderately rugged terrain and north-northwest trending ridges and intervening alluvial valleys. The site is located in a tectonically and seismically active region dominated by the San Andreas Fault System.

As outlined in the Geotechnical Baseline Report (GBR) for the intake, the intake shaft is located upstream of the existing Nacimiento Dam and adjacent to the north abutment and spillway. Geologic mapping indicates shaft and tunnel construction will take place in the Vaqueros Formation consisting of moderately lithified, massive, poorly- to well-graded sandstone. The formation is predominantly quartz with minor constituents that include feldspar and clay minerals. The formation can include conglomerates and granitic boulders, as well as thin partings of clay, claystone, or siltstone that separate the massive sandstone beds.



Source: Black & Veatch Corporation, 2007

Figure 4. NWP Intake Configuration Accepted for Final Design

The Vaqueros Formation observed at the boring locations varies significantly in strength, hardness, and quality. In general, the formation consists of fine- to medium-grained sandstone whose mineral constituents are dominated by hard, abrasive minerals such as quartz and feldspar. Significant clay minerals ranging from clay-size to silt- and fine-sand size particles are also present in the formation.

One of the most significant characteristics of the Vaqueros Formation as relates to shaft and tunnel construction is the presence of hard, abrasive minerals. Published literature indicates quartz content of 50 percent to more than 90 percent. Grain size analyses on samples of the sandstone indicate the presence of significant clay-, silt- and fine-sand size particles, ranging from between 10 and 25 percent passing the No. 200 sieve. Much of this fraction of “fine” material, however, includes quartz and feldspar.

The structure of the Vaqueros Formation includes both bedding planes and two orthogonal sets of joints. As shown in Figure 5, the bedding dips steeply into the slope (north-northeast) at angles of 50 to 78 degrees. The nature of the bedding planes is highly variable which typifies sedimentary deposits. In general, the bedding planes are characterized by very thin (< 1mm) partings containing silt and clay. Elsewhere, the silt and clay can be absent entirely.

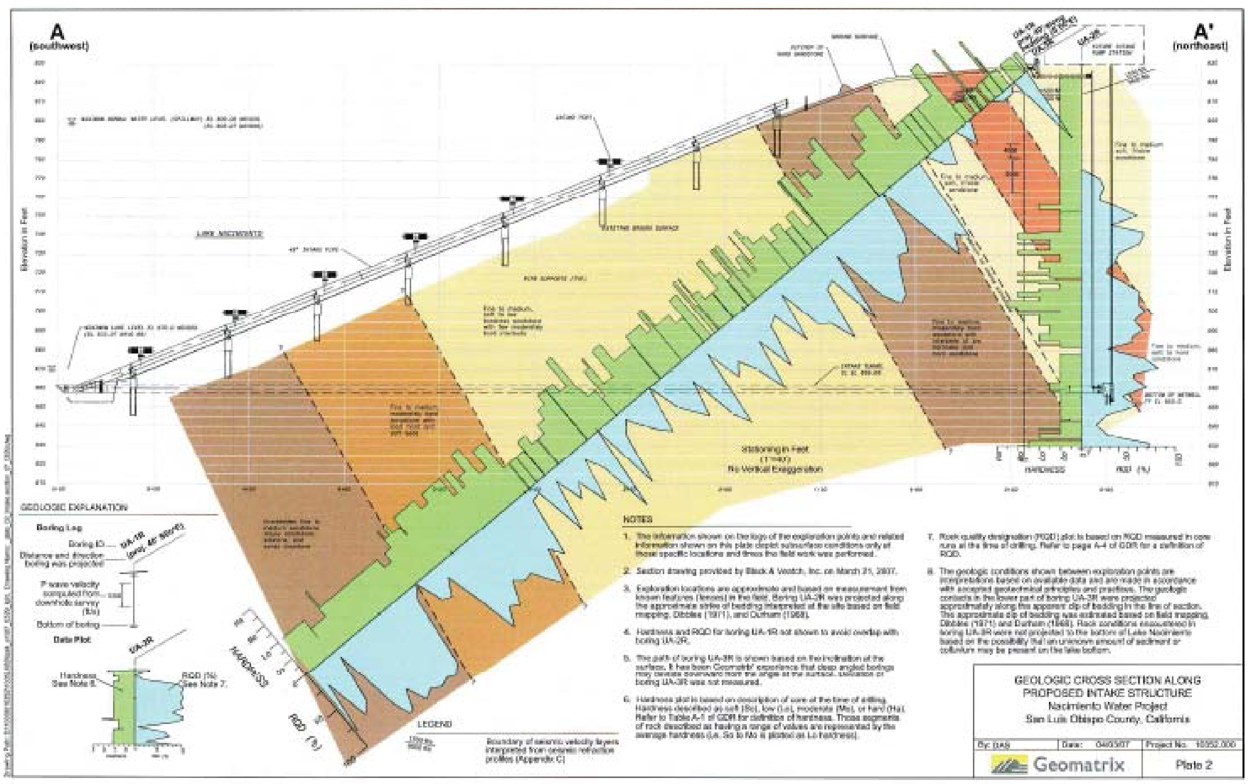
Joints are typically widely spaced, tight, and contain either precipitates of calcium carbonate ("healed") or evidence of weathering. Joints dip steeply from near vertical to between 45 and 80 degrees.

The intact strength of the rock varies between extremely weak and weak to moderately strong. Measured rock strength typically ranges from several hundred to several thousand pounds per square inch (psi), although lower and higher strengths were measured. The lowest measured uniaxial compressive strength was about 10 psi, while the largest measured values were on the order of 7,000 psi.

Ground water levels at the site will vary substantially with seasonal variations in precipitation within the watershed and with reservoir levels.

Shaft Design

Excavation for the intake shaft will extend approximately 180 ft ± below ground surface and will require excavation through a combination of fill, residual soil and weathered rock, and weak to moderately strong, intact rock. Plans for the project require a finished interior shaft diameter of 16- to 20-feet, with an excavated shaft diameter to be determined by the general contractor



Source: Black & Veatch Corporation, Intake GBR, 2007

Figure 5. Geologic Section through NWP Intake

based on structural requirements shown in the contract documents and means and methods used for initial support.

Design of initial support for the shaft excavation will be the responsibility of the contractor. Initial support may consist of liner plate and steel ribs, slurry panel walls, secant piles, or casing installed using drilling methods, such as blind auger drilling. Since slurry panel walls, secant piles, and blind auger drilling provide pre-support of the ground prior to substantial excavation, these systems offer significant advantages over support systems requiring excavation prior to installation, including improved management of ground water inflows and significant reductions in excavation volumes.

Due to the unfavorable orientation of bedding planes within the Vaqueros Formation and the generally weak nature of the rock, the material is expected to squeeze and fast ravel within a cycle of bench excavation and erection of initial support. Thus, excavation volumes 35 percent greater than those corresponding to a “neat” line would be anticipated for support systems requiring excavation prior to installation. In addition, for liner plate and/or steel rib installations, ground water inflows and corresponding requirements for treatment and disposal must be considered. Sustained ground water inflows of 500 gpm are projected.. Flush flows of up to 2,000 gpm are possible and if encountered are to be grouted to reduce total flows into the shaft to a 500 gpm threshold.

A mechanism was provided in the contract to mitigate excessive groundwater inflows into the shaft excavation. The first line of defense consisted of probe holes drilled in front of (below) the excavation face to detect any water bearing strata. The second line of defense consisted of drilling grout holes; connecting pumping equipment to the grout holes; and pumping grout into water bearing strata to reduce its permeability. The third line of defense was to provide a concrete protection system that would protect the shaft lining concrete from erosion and washout during placement and hydration.

Microtunneling

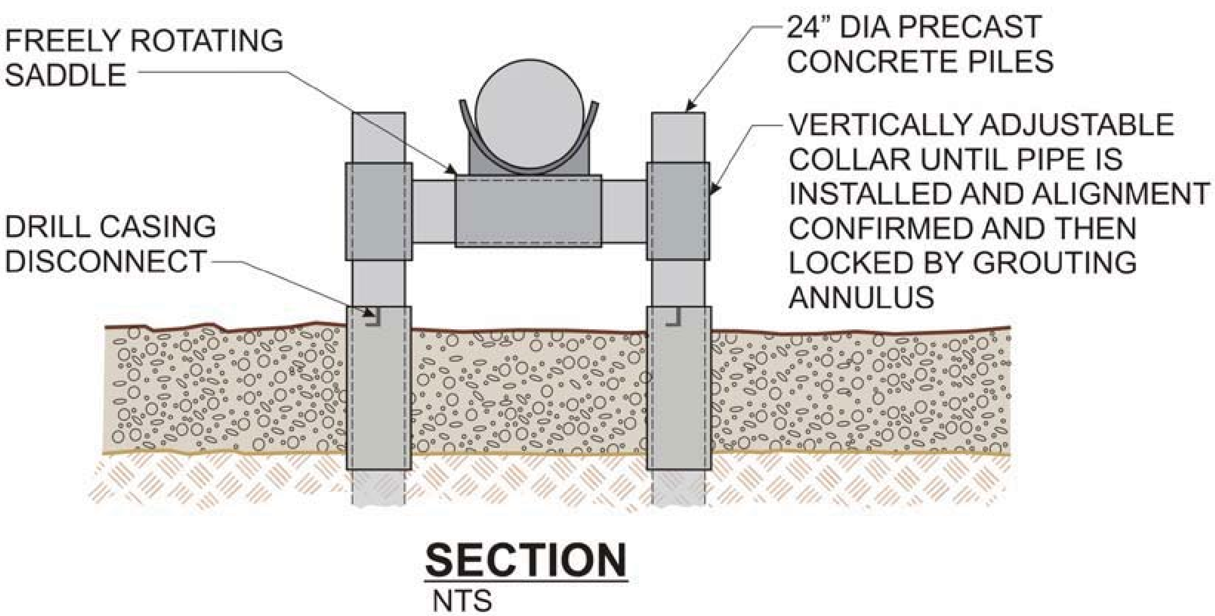
A single 500-foot long microtunneled intake tunnel will connect the shaft to the lake with a lake tap. The construction method will involve jacking a steel pipe casing following a microtunnel boring machine (MTBM), with the casing serving as initial support and final liner. Plans for the project require a finished intake tunnel diameter of 48- to 72-inches, with the actual diameter to be determined by the general contractor based on MTBMs available at bid time and allowable jacking space resulting from the selected shaft diameter. The contractor will be responsible for selection of the appropriate MTBM and casing thickness to carry the thrust of jacking forces and other loads.

The MTBM will be driven from the shaft to the reservoir and retrieved “in the wet.” The retrieval of the MTBM will be staged from an excavation into the slope of the reservoir side wall that will be prepared prior to initiation of microtunneling.

The MTBM will be a closed, pressurized face, steerable, laser-guided, articulated tunnel shield capable of exerting continuous, controlled pressure at the tunnel face to prevent uncontrollable groundwater inflows and ground movements into the cutter chamber, with a reversible cutterhead drive system to minimize rotation of pipe during installation. It will also be capable of handling the various anticipated ground conditions to minimize loss of ground during tunneling and steerable and capable of controlling the advance of the heading to maintain line and grade within the specified tolerances. It will include a system to inject lubricant over and around the rear of the MTBM to reduce jacking friction and a slurry system to balance ground and groundwater pressure up to 140 feet of hydrostatic head.

The MTBM will be equipped with drag picks for weaker ground and disc cutters for harder rock. Additionally, the MTBM will be equipped with a crushing chamber for rock fragments that are not "chipped" by the cutters.

The overall tunneling system will also include a casing jacking system; launch seal affixed to the shaft wall and through which the MTBM and steel pipe passes; equipment to maintain proper air quality in case the contractor selects manned microtunnel operations during construction; and lighting fixtures in watertight enclosures. The steel casing pipe will be either all welded steel pipe or

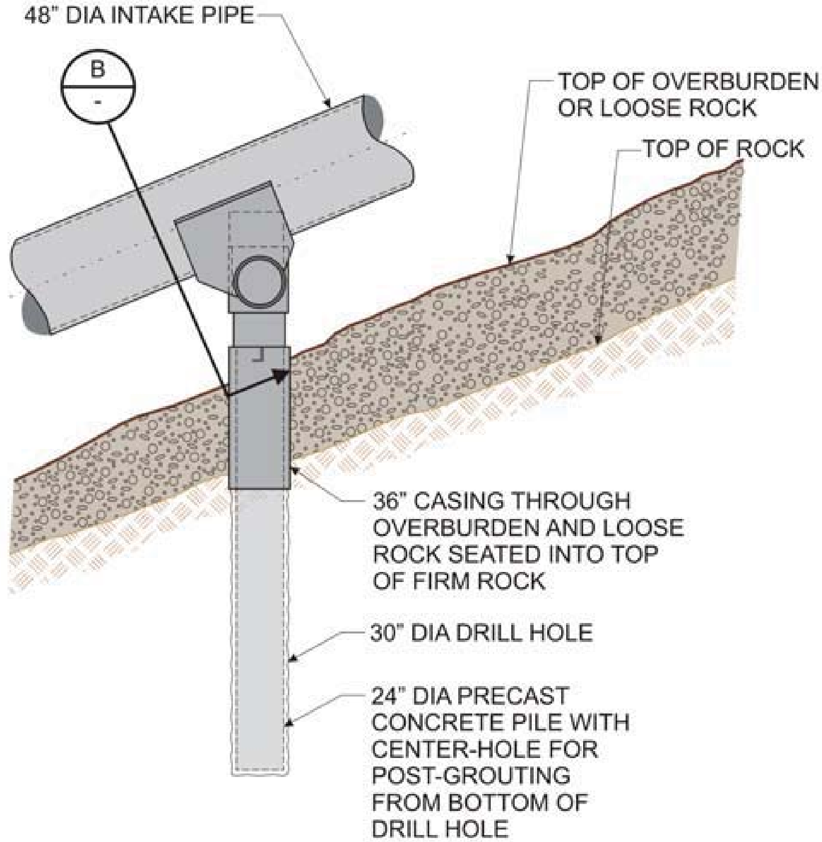


Source: Ben C. Gerwick, Inc., December 2006

Figure 6. Section through Intake Pipeline Saddle Support

Source: Ben C. Gerwick, Inc., December 2006

Figure 7. Pipe Support Foundations for NWP Intake Pipeline



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Permalok pipe with gasketed joints.

The final push of the MTBM into the reservoir, the "lake tap," is expected to be the riskiest part of the job. During lake tap operations, the contractor's principal focus will be on safety of the work and personnel. The contractor will select his means and methods for performing the lake tap, including the type of removable bulkheads and/or flood valves to be used to ensure that the work is protected from flooding and unexpected water inflows given the relatively high head working conditions.

Sloping Intake and Intake Ports

The seven-port sloping intake was selected to maximize the District's ability to withdraw water from the best locations depending on actual reservoir water surface elevation and time of year. The inlet ports are uniformly spaced vertically at 20-foot centers. The intake consists of an approximately 400-foot long, 48-inch diameter, free-standing pipeline anchored on pipe supports; 24-inch diameter inlet ports with isolation butterfly valve and screen; and hydraulic system for intake valve operation.

A key construction planning activity focused on how to quickly and efficiently install the pipe supports and pipeline segments underwater from the lake surface. As shown in Figures 6 and 7, the intake design team, including underwater specialists from Ben C. Gerwick, Inc., devised a pipe support system that involves construction of cased drilled holes, followed by insertion of precast concrete piers and subsequent grouting to solidly lock the piers in-place. The individual pipeline segments (50 foot each) will be connected into 100-foot lengths and lowered down onto the pipe supports and connected to the pier tops with a fabricated steel pipe saddle. The means and methods and final installation sequencing will be left to the installing contractor.

Marine Construction

Marine construction activities will support the installation of the sloping intake and retrieval of the MTBM. Associated with the marine construction will be the replacement / relocation of the existing log boom in the intake / spillway area.
Marine construction will involve establishing a floating marine operation with barge/crane and access to shore; diving operations; fuel transfer; underwater excavation; placement of tremie concrete; underwater construction of pipe supports; and underwater placement of pipeline segments, valves and screens.

Summary

Through preliminary and final design, the NWP Intake facility has evolved from an originally-conceived three-port tunneled intake facility to a surface-mounted sloping intake with seven ports to allow water to be drawn from various depths of the reservoir for optimal water quality control.

The District considers construction of the NWP Intake to be one of the riskier elements of the NWP. With detailed construction planning and the use of a geotechnical baseline report (GBR) in the construction contract documents, the risks to both the District and contractor become shared.
Construction of the NWP Intake is scheduled to commence in late 2007.

References

Black & Veatch Corporation, Nacimiento Water Project Technical Memorandum (TM) 8, Water Quality Investigations, January 2006 (Final).

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Marine Research Specialists, Nacimiento Water Project, Environmental Impact Report (Final), December 2003, prepared for the San Luis Obispo County Department of Planning and Building

NOTES