Appendix B
Tunnel Feasibility Study

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Distribution

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Table of Contents

1 Introduction ...................................................................................................................................... 5
   1.1 Project Description ................................................................................................................... 5
   1.2 Purpose .................................................................................................................................... 5
   1.3 Definitions ............................................................................................................................... 5
   1.4 Organization ............................................................................................................................ 6
   1.5 Related Documents ................................................................................................................ 7
   1.6 Quality Assurance ................................................................................................................... 7
   1.7 Limitations ................................................................................................................................ 7

2 Previous Studies .................................................................................................................................. 8

3 Existing Conditions .............................................................................................................................. 9
   3.1 Chronology ............................................................................................................................ 9
   3.2 Observations and Interpretation ............................................................................................. 10

4 Functional Design Criteria .............................................................................................................. 12
   4.1 General Description ............................................................................................................... 12
   4.2 Hours of Operation ............................................................................................................... 12
   4.3 Ventilation and Lighting ....................................................................................................... 12
   4.4 Safety and Security .............................................................................................................. 13
   4.5 Fire Prevention and Suppression ......................................................................................... 13
   4.6 Emergency Access .............................................................................................................. 13

5 Rehabilitation Approach ................................................................................................................. 14
   5.1 Approaches to Tunnel Rehabilitation .................................................................................. 14
   5.2 Building Protection ............................................................................................................. 17
   5.3 Ventilation ............................................................................................................................ 17
   5.4 Lighting .................................................................................................................................... 17
   5.5 Fire Protection and Communication .................................................................................... 18
   5.6 Potential for Hazardous Waste ........................................................................................... 18
   5.7 Alto Tunnel Closure ............................................................................................................. 18

6 Feasibility Level Cost Estimate ...................................................................................................... 19
   6.1 Estimate Methodology .......................................................................................................... 19
   6.2 Estimate Summary ................................................................................................................ 20

7 Summary ........................................................................................................................................ 22

8 References ...................................................................................................................................... 23

9 Revision Log .................................................................................................................................... 24

Appendix A: Alto Tunnel Inspection by David Carroll Circa 1978 ..................................................... 36

Appendix B: Factored Construction Cost Estimate for Alto Tunnel based on Cal Park Hill Tunnel Bids ... 38
Table

Table 1. Descriptions of Rock Mass Structure............................................................................................................. 25

List of Figures

Figure 1. Location map of eastern Marin County, showing location of Alto Tunnel and Cal Park Hill Tunnel (modified from Google Maps, 2009, no scale)........................................................................................................... 26
Figure 2. Plan view of Alto Tunnel showing locations of geotechnical investigation ............................................... 27
Figure 3. North Portal layout (all lengths in feet) .............................................................................................................. 28
Figure 4. North Portal: East slope 50 feet north of the portal ......................................................................................... 29
Figure 5. North Portal: Rock mass quality in sandstone on east slope .......................................................................... 29
Figure 6. North Portal: Sandstone and shotcrete on east slope next to portal ............................................................... 30
Figure 7. North Portal: Shotcrete over shale on west slope next to portal ................................................................. 30
Figure 8. North Portal: Condition of bulkhead (left) and shotcrete (right) south of portal ........................................ 30
Figure 9. MMWD Water Pipe Tunnel: South Shaft view ................................................................................................. 31
Figure 10. South Portal: Typical condition of rock fill at South Portal .......................................................................... 31
Figure 11. Tunnel Alignment: Condition of rock mass in tunnel inferred from installed support ............................ 32
Figure 12. Tunnel Alignment: Rehabilitation profiles ...................................................................................................... 33
Figure 13. Tunnel Alignment: Portal approaches ........................................................................................................... 34
Figure 14. Tunnel Alignment: Typical cross section ....................................................................................................... 35
1 Introduction

1.1 Project Description

Marin County commissioned a corridor study of three specific bike/pedestrian routes connecting the cities of Mill Valley and Corte Madera. The scope of the study is to facilitate planning and conduct preliminary engineering and design work to identify the relative feasibility of each route. The three routes include: (1) the “Horse Hill/Casa Buena Route,” which follows a frontage road of U.S. 101, an existing bike path adjacent to the highway, and residential streets; (2) the Alto Tunnel route, which would follow the former Union Pacific Railroad alignment and would include reopening the Alto railroad tunnel; and (3) the Camino Alto/Corte Madera Avenue route, which follows existing roads winding through the hills to the west of the Alto Tunnel route. The Alto Tunnel is an abandoned and partially collapsed railroad tunnel, located in southeast Marin County, running parallel and west of Highway 101 (Figure 1). The North Portal is located in Corte Madera and the South Portal is in Mill Valley.

1.2 Purpose

This Tunnel Feasibility Study addresses the issues associated with the second option—reopening and rehabilitating the Alto Tunnel and developing new pedestrian/bicycle paths, which will be connected to existing bicycle/pedestrian paths. The following subtasks were undertaken by the Jacobs Associates team as a part of this study:

- Reviewed existing data, including the Alto Tunnel Scoping Study prepared by Jacobs Associates in 2001.
- Reviewed the Cal Park Hill Tunnel Rehabilitation design requirements and visited the construction site at critical milestones.
- Developed functional design criteria to frame the Alto Tunnel rehabilitation technical requirements.
- Developed a feasibility-level cost estimate for reopening the Alto Tunnel and developing it for bicycle/pedestrian use, based on recent construction bids for the Cal Park Hill Tunnel Rehabilitation.
- Developed a conceptual level cost estimate for abandoning the Alto Tunnel in lieu of bicycle/pedestrian path development.

1.3 Definitions

There are several terms used in this study that are unique to the tunnel construction industry. Definitions of selected tunneling terms are given below.

Face: Location in tunnel where excavation is taking place.
Ground Support: General term for the materials installed to stabilize the ground around a shaft or tunnel excavation.

Heading: Immediate area of tunnel adjacent to the face, including location where initial tunnel support is being installed.

Initial Support: Any combination of ground support elements installed prior to installation of a final lining.

Rock Bolt: Rock reinforcement element consisting of a tensioned steel bar with associated hardware and anchorage recommended by the manufacturer.

Rock Dowel: Rock reinforcement element consisting of an untensioned steel bar with associated hardware and anchorage recommended by the manufacturer.

Rock Reinforcement: A general term describing support systems that act in such a manner as to reinforce the rock mass, including rock bolts, rock dowels, steel straps, welded wire fabric, shotcrete, and other appurtenances, but excluding steel sets.

Stand-up Time: A general term describing the length of time the tunnel is anticipated to remain stable without any support.

Steel Set or Steel Rib: Structural steel member used for ground support, curved to match the theoretical shape of the tunnel or shaft excavation and uniformly blocked or expanded to the excavated surface.

Steel Strap: A long, flat steel plate or crimped steel mat for support of the ground between rock bolts or rock dowels.

Descriptions of rock mass conditions are given in Table 1.

1.4 Organization

This study is organized into the following sections:

- Section Two summarizes the previous studies on the Alto Tunnel.
- Section Three summarizes the existing conditions of the Alto Tunnel.
- Section Four presents the functional design criteria that define the general and operating requirements for the tunnel rehabilitation.
- Section Five presents approaches to rehabilitating the tunnel.
- Section Six presents the conceptual cost estimate for reopening and rehabilitating the tunnel.
- Section Seven summarizes the tunnel feasibility study.
• The appendices include selected correspondence, figures, and the feasibility study level cost estimate.

1.5 Related Documents

As part of Task 4.1, Jacobs Associates produced a *Geotechnical Study* report for the Alto Tunnel (August 2009). That report documents geotechnical investigations performed in support of the tunnel feasibility study. The following subtasks were undertaken by Jacobs Associates for the geotechnical study:

• Review of existing data, including published and unpublished geologic maps and geotechnical reports, as well as a review of the *Alto Tunnel Scoping Study* (2001).
• Geologic field reconnaissance above the tunnel, including mapping of portals and approaches to the portals, to gather data on rock properties such as joint orientations and rock mass classifications.
• Geomechanical interpretation of the anticipated rock mass conditions at the tunnel elevation.

These investigations showed that most of the tunnel is in sandstone and some shale (especially to the north), and rock-like mélange matrix (especially to the south). The rock mass conditions comprise a wide spectrum—from disintegrated rock with no stand-up time to massive rock with longer stand-up time and tough and abrasive excavation conditions. The majority of the rock is very blocky to blocky, with a stand-up time of several hours to several days, but in which block and wedge failure are likely upon the removal of the timber sets. Some minor cave-ins were mapped in the late 1970s, and a major cave-in was backfilled in 1982. Zones of the tunnel are anticipated to have very little stand-up time if unsupported. The North Portal is surrounded by very blocky to blocky sandstone and shale rock slopes overlaid by vegetated residual soil at the top. The South Portal is covered with rock and soil fill, but it is surrounded by very blocky to blocky sandstone, and potentially mélange matrix.

1.6 Quality Assurance

This memorandum was prepared by Mr. Blake Rothfuss and staff members of Jacobs Associates. Technical review was provided by Mr. Victor Romero of Jacobs Associates.

1.7 Limitations

This technical memorandum was prepared based on our current understanding of the Corte Madera to Mill Valley Corridor Bike and Pedestrian Study and an initial assessment of the Alto Tunnel, which is one of the routes being evaluated within the study. The Alto Tunnel was not available for an internal inspection; therefore, an assessment of the anticipated condition of the tunnel interior was developed based on previous inspection reports, limited geotechnical investigations as noted in Section 1.5 above, and comparisons with other tunnels of similar construction and age.
2 Previous Studies

Several studies and observations have been produced for the Alto Tunnel and the nearby Cal Park Hill Tunnel that are pertinent to the current feasibility study. These documents are summarized briefly below.

- *Alto Tunnel Scoping Study, Volume I—Background Information*
  This document contains a detailed history of the tunnel and summarizes all reference materials available at the date of the scoping study. This work was completed in August 2001.

- *Alto Tunnel Scoping Study, Volume II—Engineering Summary and Proposed Supplemental Investigation*
  This document provides a summary of the tunnel’s condition for each reach of the tunnel. This work was completed in August 2001.

- **Articles by John Palmer**
  Mr. John Palmer prepared a series of articles describing the Alto Tunnel history, the technical studies completed through 2003, and his opinion of the issues associated with reopening the tunnel.

- **Cal Park Hill Tunnel Documents**
  The Cal Park Hill Tunnel was built in 1884 as a single track railway tunnel. In 1924 it was widened to accommodate a double track and was converted back to a single track before it was abandoned. It is currently being rehabilitated for use as a pedestrian and bike pathway by the County of Marin, and also potentially as a commuter rail transportation corridor by the Sonoma Marin Area Rail Transit Agency (SMART). The Cal Park Hill Tunnel original construction was similar to that of the single track Alto Tunnel, and both tunnels were constructed in the same year.

  Cal Park Construction Contract Documents (including design drawings, specifications, and geotechnical reports) and construction observations were considered in the development of the Alto Tunnel feasibility study. Jacobs Associates is the Construction Manager for the Cal Park Hill Tunnel Rehabilitation and Appurtenances construction contract.
3 Existing Conditions

3.1 Chronology

The following is a summary chronology of Alto Tunnel events pertinent to this Tunnel Feasibility Study.

1884 The Alto Tunnel was constructed by Northwestern Pacific Railroad serving the Corte Madera to Sausalito communities. The 2,173-foot-long tunnel has a cross section 16 feet wide by 20 feet high. A single narrow-gauge track served the railroad. The Northwestern Pacific Railroad (RR) was a joint venture of Southern Pacific RR and Santa Fe RR.

1929 Southern Pacific RR became the sole owner of the Alto Tunnel.

1940 The Corte Madera–Sausalito line was closed to passenger rail traffic. Freight traffic continued along the line.

1950–1960s Construction of homes along the tunnel alignment encroached on the railroad’s rights-of-way.

1971 The Corte Madera–Sausalito line was closed to freight rail traffic. The Alto Tunnel was abandoned. At the time of the abandonment, heavy bulkheads were built at each end of the tunnel to prevent further access.

1972 The Golden Gate Transit District attempted to purchase the railroad’s right-of-way, including the Alto Tunnel, for use as a commuter rail line. Community concerns over land ownership, right-of-way, noise, and rail safety prevented the purchase.

Kaiser Engineers evaluated the condition of the tunnel for Golden Gate Transit and expressed its concerns about continued deterioration of the tunnel supports. Its recommendations were not implemented.

Late 1970s The County of Marin purchased additional right-of-way from Southern Pacific RR.

1975 At the North Portal, a lean concrete plug approximately 125 feet long was also installed to improve security.

1977 A private party offered to purchase the tunnel to use as a commercial enterprise. However, the sale was abandoned due to fee title issues.

1978 Mr. David Carroll accessed a portion of the tunnel from the South Portal area.

1979 Southern Pacific RR sealed and abandoned the Alto Tunnel.

1981 A portion of the tunnel near the South Portal collapsed and caused a large depression adjacent to Underhill Road. The depression destroyed a residence and underground utilities.
Some of the old rail right-of-way, excluding the Alto Tunnel, was converted to multipath use.

The County of Marin hired the firm of Copple Foreaker Associates to study the tunnel in anticipation of its possible purchase from Southern Pacific. The Foreaker Study, as it came to be known, described the tunnel as being in an advanced state of decay as a result of moisture and neglect.

1982  A depression and a portion of the tunnel were backfilled with gravel. In total 400 feet of the tunnel was filled with concrete or gravel. The Foreaker Study was updated to reflect the backfill work to fill the depression and tunnel. The dates of these events have not been confirmed.

1983  The County of Marin and the Northwestern Pacific Railroad Company entered into a 15-month option wherein the County would purchase a one-mile portion of the railroad right-of-way. The agreement was completed in part.

1994  The Marin County Department of Parks and Open Space hired Brady and Associates to explore the possibility of developing a bike path and reconstructing the Alto Tunnel.

2000  Safe Routes Marin sparked interest in evaluating the possibility of utilizing the Alto Tunnel as part its bike master plan.

The Marin County Department of Public Works researched and verified both the County’s and the railroads current rights-of-way. The portions of the tunnel yet to be donated included the 275-foot portion from the South Portal north, and the 490-foot section from the North Portal south.

2001  The Congestion Management Agency of the Marin County Department of Public Works commissioned a new feasibility study from the firms of Quincy Engineering, Jacobs Associates, and Parikh Consultants in order to evaluate the Alto Tunnel for its possible conversion to pedestrian and bicycle use.

An inspection team confirmed that access to the tunnel interior was blocked by a concrete plug.

2008  Marin County of Public Works commissioned the Corte Madera to Mill Valley Corridor Study to evaluate bicycle and pedestrian routes connecting Corte Madera and Mill Valley.

### 3.2 Observations and Interpretation

The Alto Tunnel is approximately 125 years old and has been abandoned for the last 38 years. The tunnel is in an advanced stage of disrepair and collapse. Portions of the tunnel have been backfilled in attempts to reduce the impacts of continued structural decay.

In the event that the Alto Tunnel is not developed for bicycle and pedestrian use, it is likely that existing tunnel supports will continue to deteriorate, and in areas where ground conditions are poor, this will likely lead to further instability and collapse in the tunnel. Such instability and collapse could propagate to the...
ground surface and impact or otherwise damage surface structures and utilities above and adjacent to the
tunnel alignment.

### 3.2.1 The North Portal Area

The North Portal is located between Tunnel Lane and Montecito Drive. Several residences are located
immediately adjacent to the portal structure. The abandoned rail bed is overgrown with vegetation and is
poorly drained. Access to the tunnel is prevented by an unvented structural steel bulkhead at Station (Sta.)
277+61.9. Due to inadequate drainage and ventilation, approximately 18 inches of standing water is often
present (confirmed by the 2001 inspection) between the steel bulkhead and the 124-foot-long concrete
tunnel plug, starting at approximately Sta. 276+12. Beyond the tunnel plug, there is a 170-foot-long zone
of uncompacted backfill material. Figures 3 through 8 present images of the existing conditions.

### 3.2.2 The Tunnel

From Sta. 273+18 to 258+64, the tunnel is supported by the remaining tunnel support (bracing) system,
which consists of redwood timber (10 by 14 inches) sets in a 7-segment and 5-segment configurations
spaced 1 to 5 feet apart. Wood lagging, spanning between the sets along both sides and the crown of the
tunnel, consists of split redwood approximately 2 inches thick and 5 to 8 inches wide. In this 1,454-foot
reach of tunnel, three localized collapses were found during inspections in the 1970s.

The concrete plug at the north end and the gravel bulkhead at the south end have almost completely cut
off air circulation in the tunnel. Reports of vent shafts to the Alto Tunnel have proven inaccurate. The
Marin Municipal Water District (MMWD) operates a short pipeline tunnel that is parallel to and above
the Alto Tunnel alignment (see Figure 9). Access hatches to this pipeline have been mistaken for vent
shafts for the Alto Tunnel. The lack of air circulation coupled with the water that seeps into the tunnel
create a highly humid atmosphere or possibly submerged conditions that have likely resulted in the
deterioration of the timber support system. It is also likely that additional localized collapses have
occurred during the past 30 years.

From Sta. 259+00 to the South Portal (Sta. 255+89), the tunnel is backfilled with pea gravel and concrete.
The tunnel section between the backfilled plugs is supported by 125-year-old timber supports that have
outlived their design life. Further instability and collapses in the tunnel are likely if no action is taken,
possibly leading to unacceptable ground settlement or even sinkholes to the ground surface, similar to
what was experienced at the Cal Park Hill Tunnel.

### 3.2.3 The South Portal Area

The South Portal was backfilled with cobbles and gravel above the top of the portal structure. Down
station from the portal, the rail bed is overgrown with vegetation and is a seasonal wetland. Figure 10
presents an image of the existing backfill at the tunnel portal.
4  Functional Design Criteria

The Functional Design Criteria define the general and operating features of the tunnel. When the functional criteria are confirmed, the technical design criteria can be developed during future design efforts. The following recommended features should be considered for the rehabilitation of the Alto Tunnel.

4.1 General Description

The potential pedestrian/bicycle path tunnel should have the following general characteristics:

- The 2,173-foot-long tunnel will be converted from a single track rail tunnel with interior dimensions of approximately 13 feet wide by 16 feet tall.
- There will be an unrestricted 12-foot-wide (approximate) access for pedestrian and bike traffic between Corte Madera and Mill Valley.
- The tunnel will be relined with steel sets or rock bolts and shotcrete; there will not be any timber or other combustibles remaining in the tunnel.
- The portals will include bollards/barricades that allow pedestrian, wheelchair, and bicycle access, but prevent nonemergency vehicle entry.
- The portals will be approximately 12 feet wide.

4.2 Hours of Operation

The pedestrian/bicycle path will be accessible to users from sunrise to sunset. A lockable security gate will be provided to prevent tunnel access during the night. Signs will notify users of the hours of operations, traffic controls, and alternate routes at the portals.

4.3 Ventilation and Lighting

Natural air ventilation is sufficient for the normal tunnel usage. Natural ventilation relies on weather (wind, temperature, and pressure difference due to elevation) to maintain air flow. Historically, tunnels shorter than about 2,500 feet and with noncombustible elements and usage can be ventilated naturally. However, a ventilation system can be installed to address the emergency scenario of a maintenance vehicle fire in the tunnel.

Low energy lighting will be provided just outside the portals as well as throughout the tunnel. Lighting will have a back-up power supply.
4.4 Safety and Security

In addition to ventilation and lighting, the following safety and security provisions are recommended:

- Radio communications (leaky coaxial cable, cell phones if possible) for public safety in the tunnel
- Emergency call stations at portals and at 200-foot increments in the tunnel
- A system for user notice when maintenance, emergency vehicle, or other blockage is present in tunnel
- Security cameras at portals and at approximate 300-foot increments in the tunnel
- Lockable portal gates
- Bollards at portals to block unauthorized vehicle entry
- Anti-graffiti coating of portal structures and tunnel walls (optional)

4.5 Fire Prevention and Suppression

The following fire safety provisions are recommended:

- Fire alarm pull stations at portals and at 200-foot increments in the tunnel
- Sprinkler system in the tunnel
- 1,000 gpm fire hydrants on the portal sides of the emergency access turnarounds and wet-standpipe fire hose connections at 200-foot increments in the tunnel

4.6 Emergency Access

The following incident response provisions are recommended:

- A 20-foot-wide traffic corridor from street to portals: 12-foot-wide paved path with 4-foot-wide compacted earth shoulder on either side
- Overhead clearance of 13 feet minimum
- A 16-foot-wide shunt or hammerhead vehicle turnaround as close as possible to each portal (225 feet from North Portal, 150 feet from South Portal)
- Pull-off parking near the portals for emergency vehicles
5 Rehabilitation Approach

5.1 Approaches to Tunnel Rehabilitation

Based on the information gathered during the site investigations and on an analysis of previous studies, an assessment was made of the anticipated geotechnical conditions that are likely to be found within the tunnel area. In the tunnel behavior characterizations given below, “stand-up time” refers to the minimum length of time the tunnel is anticipated to remain stable without any support. During tunnel rehabilitation, immediate resupport of the tunnel envelope will be required if there is a short stand-up time so that the tunnel does not collapse. This also implies that if the existing redwood timber supports (sets) have degraded (most likely due to rotting) and can no longer provide support to the rock, the tunnel in the sections with short stand-up time will collapse unless they are rehabilitated. Rock toughness and abrasivity refer to rock properties that are unfavorable to excavation because they provide greater resistance to excavation (in the case of tough rock) and cause higher equipment wear (in the case of abrasive rock). Both of these characteristics would require laboratory testing to determine the magnitude of excavation resistance (usually based on intact rock strength) and abrasivity to aid in selecting the most appropriate excavation methodology.

Four ground support types have been defined to address the range of ground conditions anticipated:

- Type I: excavation through portal concrete tunnel plug or cemented gravels and support with steel sets and shotcrete.
- Type II: excavation through portal and collapsed tunnel unconsolidated materials and support with steel sets and shotcrete.
- Type III: removal of existing timber sets and lagging and replacement with steel sets and shotcrete.
- Type IV: removal of existing timber sets and lagging and replacement with rock bolts and shotcrete.

The general distribution of these ground support types is given below. Reaches refer to those shown in Figure 11. Conceptual designs are presented in Figures 12, 13, and 14.

5.1.1 The North Portal Area—Sta. 277+61.9 to Sta. 273+17

Drainage improvements to the North Portal area will be required prior to rehabilitating the tunnel. Before any work is begun in the tunnel, geotechnical instrumentation should be installed in the portal vicinity to monitor for ground settlement and displacement. Additional environmental monitoring may be required based upon environmental impact studies.

Due to the proximity of houses on and adjacent to the tunnel alignment, surface settlement or movement caused by tunneling cannot be tolerated. The construction contractor should be required to utilize ground control methods that minimize the ground loss or convergence within the tunnel. In addition, building protection measures should be implemented before tunnel rehabilitation, as described below.
As noted in the 2001 *Alto Scoping Study*, excavation of the backfill plug would be most efficiently performed by roadheader equipment. Although excavation by drill-and-blast methods is technically feasible, the proximity of the tunnel to residential structures would probably preclude the use of explosives for environmental reasons. In addition, it is anticipated that excavation by a tunnel boring machine (TBM) would not be economically feasible for the lengths of excavation that would be involved. Although roadheaders come in a variety of sizes and configurations, most roadheaders consist of a rotary cutterhead equipped with picks that are attached to a hydraulically operated boom, which in turn is mounted on a base frame. Handling of excavated materials (i.e., muck) is usually accomplished by an apron loader that transfers muck onto a short conveyor. The conveyor can dump the materials into muck cars or haul trucks for transport out of the tunnel. The entire cutter, boom, frame, apron, and conveyor assemblies are usually mounted on either crawler tracks or rubber tires for propulsion.

This 445-foot-long section of the tunnel will likely require Types I, II, and III ground support. The gunite-lined section between the portal and the concrete plug (Type III support) and the concrete plug itself (Type I support) should have a long stand-up time; however, as the excavation approaches the original tunnel walls and crown, the work should proceed more carefully. As the concrete and remaining timber support are being excavated, steel sets with shotcrete lagging should be erected to support the tunnel. The spacing of the steel supports will depend on the actual ground conditions but is expected to be spaced at 3 to 4 foot centers. If the ground has a short stand-up time, a top heading (i.e., smaller excavation in the tunnel crown) and bench method could be utilized to first support the tunnel crown, then excavate and support the tunnel walls. The steel supports should be covered with shotcrete to strengthen the permanent support system, provide corrosion protection, and improve fire resistance.

As the heading approaches the interface between the concrete plug and the unconsolidated backfill, the excavation method should be adjusted to account for the looser material. Soft ground tunneling methods will be required to excavate through the unconsolidated backfill zone. This will likely require Type II ground support. This material could be removed by a traditional excavator and the ground immediately supported with steel sets and shotcrete. Depending on the integrity of the cemented pea gravel backfill, a top heading and bench excavation could be effective. If the excavation process jeopardizes the tunnel integrity, grouting the ground and the pea gravel prior to excavation could increase the stand-up time for support installation. The steel supports should be covered with shotcrete, as noted above.

Tunnel excavation and support can be carried out without having to condemn or acquire properties adjacent to the tunnel and portal. However, building protection measures will be necessary to prevent damage to occupied homes, as described below.

**5.1.2 The Tunnel—Sta. 259+00 to Sta. 273+17**

To rehabilitate the main tunnel in this section, the existing redwood timber sets and lagging should be carefully removed, the exposed rock scaled to remove loose material and immediately supported with steel sets, then shotcrete should be applied. From approximately Sta. 273+17 to 270+70, it is expected that the ground will be disturbed to very blocky sandstone or mélange matrix. This section may have deteriorated since the 1975 inspection, so Type II ground support is assumed.
In the following reaches, Type III ground support is assumed: Sta. 262+80 to Sta. 263+75, Sta. 270+20 to Sta. 270+70, and Sta. 271+75 to Sta. 273+17. These reaches generally range from blocky to massive sandstone with light ground loads. Records show these sections to be dry, so deterioration in the last 30 years is less likely.

From approximately Sta. 260+50 to Sta. 261+75, the “heavy” ground and closely spaced timber sets suggest that at least one fault or zone of weak ground is present. The records also note that the tunnel is “wetter” at the southern end. Groundwater may be entering the tunnel via sheared material within a fault. The heavier ground loads and the potential for groundwater may likely require Type III ground support.

From approximately Sta. 265+80 to Sta. 270+20, where the ground loads are “light” and the original timber support spacing was 5 feet, rock bolts and shotcrete (Type IV ground support) may be a cost-effective alternative to steel sets and shotcrete (Type III ground support).

The reaches not mentioned in this section (Sta. 259+00 to Sta. 260+50, Sta. 261+75 to Sta. 262+80, Sta. 263+75 to Sta. 265+80, and Sta. 270+70 to Sta. 271+75) contain known collapses, and the ground ranges from blocky to distributed sandstone or mélange matrix. These reaches will require Type II ground support.

In this section, the tunnel rehabilitation activities are not expected to initiate surface settlement or movement since the tunnel is 75 to over 200 feet below the surface. The MMWD pipeline tunnel located above demonstrates this stability, and the deeper Alto Tunnel would be less susceptible to surface ground movements due to the confinement provided at greater depth.

5.1.3 The South Portal Area—Sta. 255+89 to Sta. 259+00

This tunnel reach is the most technically challenging and will likely be the most expensive portion of the tunnel repair. The tunnel stability problems in this area have been recognized for many years. Soil and rock slope stability analyses should be performed and a portal excavation support scheme developed to safely construct a new portal at the south end.

Stabilizing the portal will require reducing the amount of water in the soil and rock. A combination of redirecting surface runoff from Underhill Drive, using the rehabilitated tunnel as a temporary drain, dewatering wells, and/or modifying the weak ground could be utilized. We anticipate that this portal would be stabilized both from the exterior (surface) and from within the tunnel. As with the North Portal, geotechnical instrumentation should be installed in the portal vicinity to monitor for ground settlement and displacement before stabilizing the slope and excavating the portal. Building protection of nearby homes is also recommended, as described below. Due to the proximity of houses on and adjacent to the tunnel alignment, surface settlement or movement caused by tunneling cannot be tolerated. The construction contractor should be required to utilize ground control methods that minimize the ground loss or convergence within the tunnel.

Soft ground tunneling methods will be required to excavate the pea gravel or cemented pea gravel zone. The unconsolidated backfill can be removed by a traditional excavator and the ground immediately
supported with steel sets and shotcrete. If the excavation process jeopardizes the tunnel integrity, grouting prior to excavation could increase the stand-up time for support installation.

Tunnel excavation and support can be carried out without having to condemn or acquire properties adjacent to the tunnel and portal. However, building protection measures will be necessary to prevent damage to occupied homes.

A reinforced concrete structure will be required for the permanent portal. This structure and the slope stability improvements will provide a stable access point to the tunnel.

5.2 Building Protection

To address concerns of settlement and stability during construction, building protection measures should be implemented for residential structures above the tunnel alignment in the portal areas that are within the zone of influence of tunnel rehabilitation activities. Such protection measures include structural underpinning, grouting, ground reinforcement, or other measures to protect surface structures from ground movement associated with construction. Geotechnical instrumentation and monitoring should be implemented to monitor ground and structure movements to ensure public safety and to verify that building protection measures are working effectively. Ground movement threshold limits will be set to trigger additional remedial measures to prevent damage to structures above the tunnel. This is a proactive approach to protect surface structures and prevent damage before it occurs.

5.3 Ventilation

The requirement for forced air tunnel ventilation depends primarily on the need for emergency vehicle operations within the tunnel. If only nonmotorized vehicles are permitted in the tunnel, and noncombustible materials are used for tunnel rehabilitation as recommended herein, then natural ventilation should provide a sustainable environment for pedestrians and bicycle riders.

If emergency vehicles must operate within the tunnel, the air quality requirements and the anticipated concentrations of air pollutants will be used to establish the ventilation requirements. The U.S. Environmental Protection Agency and the Federal Highway Administration have established the airborne contaminant concentration limits (primarily carbon monoxide) in vehicular tunnels. To remove airborne contaminants, a 3,000 cubic foot per minute (cfm) vane-axial fan would provide about 15 feet per minute of air movement through the Alto Tunnel. Approximately 12 fans would be required, spaced at about 200-foot intervals. The vane-axial fans do generate noise, although the fans system can be configured to operate in emergency (fire) situations only. To reduce operation and maintenance costs, the Alto Tunnel ventilation system should be similar to the system at the Cal Park Hill Tunnel.

5.4 Lighting

Lighting must meet the requirements for pedestrian and bicycle usage, as well as emergency access. Lights should be spaced approximately every 100 feet. High-efficiency lighting systems should be specified to properly illuminate the path while minimizing energy usage. Furthermore, the lighting should
be zoned into at least two sections: portal zones, where ambient daylight complements lighting, and a tunnel zone. A minimum lighting level should be maintained throughout the night and early morning hours when the tunnel is closed to traffic. To reduce operations and maintenance costs, the Alto Tunnel lighting system should be similar to the system at the Cal Park Hill Tunnel.

5.5 Fire Protection and Communication

Noncombustible materials can be used in the tunnel rehabilitation. Concrete and shotcrete provide excellent fire protection. Ventilation, lighting, and fire protection systems are comprised of semicombustible materials. Accordingly, fire pull stations and emergency phones should be located at each portal structure and at 200-foot intervals.

5.6 Potential for Hazardous Waste

During the tunnel rehabilitation, timber sets, steel rail, railroad ties, and ballast will be removed from the tunnel. The Alto and Cal Park Hill tunnels were constructed in the same era, and we have assumed that similar materials were used in both tunnels. Hazardous chemicals or contaminants were not found in recent testing of the Cal Park Hill Tunnel redwood sets or ballast. However, the railroad ties tested positive for creosote and required special handling and disposal.

The Alto Tunnel timber sets are redwood and may have some salvage value. The steel rail also can be salvaged. We expect that because of the standing water in the Alto Tunnel, ballast as well as railroad ties may be contaminated. Requirements to have these waste materials tested and properly disposed of in accordance with local, state, and federal regulations have been factored into the cost estimate.

5.7 Alto Tunnel Closure

If the Alto Tunnel is not developed for bicycle and pedestrian use, and the property owners wish to limit risk of further tunnel instability which could lead to surface impacts or damage, it is recommended that the Alto Tunnel be completely backfilled with stable material. This would involve boring multiple holes through the existing plugs with casing pipes. Following dewatering of the tunnel, a weak cement based material such as cellular concrete (also known a foamed concrete or foamed grout) could be used to backfill the entire tunnel. Bored holes from the ground surface would verify that backfill material had reached the central portions of the tunnel.
6 Feasibility Level Cost Estimate

6.1 Estimate Methodology

A feasibility study level opinion of probable construction cost was developed for the Alto Tunnel rehabilitation, and is presented in Appendix B. This estimate was prepared in conformance with the Association for the Advancement of Cost Engineering’s Cost Estimate Class 4 recommendations (AACE, 1997). For the Alto Tunnel, a stochastic “factored estimate” was produced by taking the cost of individual lump sum or unit price items for the recently bid Cal Park Hill Tunnel project in San Rafael and Larkspur, CA (see Figure 1), and adjusting this pricing for the Alto Tunnel, as applicable. This involves multiplying lump sum items by a factor, or using unit prices and applying them to Alto Tunnel estimated quantities. The Alto Tunnel was originally constructed with the same methods and Cal Park Hill Tunnel, in the same year (1884), and is currently in similar condition to the Cal Park Hill Tunnel, before the Cal Park Hill Tunnel underwent rehabilitation. Differences in the size and length of the two tunnels are accounted for by applying appropriate factors and quantities to the cost estimate. For elements of the proposed Alto Tunnel rehabilitation that were not part of the Cal Park Hill Tunnel rehabilitation, new items were added to the Alto Tunnel cost estimate. These items were based off labor estimates and material quotes for similar operations and projects. For an AACE Class 4 estimate, this factor estimate methodology is the most appropriate and accurate method for the current level of study.

The factored costs were developed as a base cost, and then modified for a “Lower Range” and “Upper Range” cost analysis, which reflects scope items that are uncertain, or design elements which may or may not be ultimately needed. In addition, due to the uncertainty associated with the condition of the Alto Tunnel between the concrete and fill plugs at each end of the tunnel, a sensitivity analysis was performed to bracket the potential range of costs associated with rehabilitating varying lengths of collapsed sections of the tunnel. The Lower Range reflects support and rehabilitation of collapse conditions as currently estimated, based on the last tunnel inspections between the current plugs (in the 1970’s and 1980’s), and assuming some deterioration into the present. The Upper Range assumes a much greater deterioration (i.e., greater lengths of collapse sections), and thus effectively shifts more of the Type III and Type IV tunnel support into the more conservative and costly Type II and Type III tunnel support categories.

The Lower and Upper Range costs were then adjusted for escalation into present dollars (Cal Park Hill Tunnel was bid in 2008), as well as contingency. For bid items directly dependent on the unconfirmed ground conditions a contingency allowance of 40% was used. Bid items with greater certainty included a contingency allowance of 20%. These factors reflect estimating accuracy commensurate with project design definition, and allowances for unknown ground conditions, in addition to contractor allowances for construction risk. We recommend that the amount of contingency expressed as a percentage of estimated escalated construction cost, be similar for each for each alternative under consideration.

The following assumptions and limitations should be considered when evaluating the range of probable construction costs:

- The Alto Tunnel has not been inspected recently to assess the accurate condition of the tunnel supports, rock integrity, and level of water intrusion.
- The planning and time horizon for the project has not been identified. The cost estimate is in 2009 dollars.
- The rehabilitation scope of work has not been fully developed or accepted.
The following project costs are not included in the cost estimate: planning, land acquisition and right-of-way, environmental evaluation and permitting, engineering and design, procurement assistance, construction management, and engineering support during construction.

The Alto Tunnel cost estimate was prepared for feasibility purposes, specifically for comparison with other bicycle/pedestrian routes being evaluated.

As an alternative to tunnel rehabilitation for bicycle and pedestrian use, a cost estimate was also produced for long-term tunnel closure, which involves complete backfill of the Alto Tunnel with a stable material. This estimate was based on labor estimates and material quotes for similar operations and projects.

6.2 Estimate Summary

A summary of the estimated cost of rehabilitating the Alto Tunnel is given below:

<table>
<thead>
<tr>
<th>Project Construction Costs</th>
<th>Opinion of Probable Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subtotal Construction Cost</td>
<td>$17,851,000 $21,762,000</td>
</tr>
<tr>
<td>Escalation, 1 yr @ 2%/1 358,000 436,000</td>
<td></td>
</tr>
<tr>
<td>Subtotal with Escalation</td>
<td>18,208,000 22,198,000</td>
</tr>
<tr>
<td>Construction Cost Contingency2 6,11,53 0,000</td>
<td></td>
</tr>
<tr>
<td>Total Construction Cost with Contingency</td>
<td>24,319,000 29,727,000</td>
</tr>
<tr>
<td>Cost Estimate Accuracy Allowance</td>
<td>$4,864,000 $5,946,000</td>
</tr>
<tr>
<td>Total Construction Cost with Contingency &amp; Accuracy Allowance</td>
<td>$29,182,000 $35,673,000</td>
</tr>
</tbody>
</table>

| Project Development Costs | |
| Survey, Technical Studies, and Engineering Design (15%) | $3,648,000 $4,460,000 |
| Environmental Analysis, Documentation, and Permits (10%) | 2,432,000 2,973,000 |
| Project Administration (10%) | 2,432,000 2,973,000 |
| Construction Management (10%) 2,432,000 2,973,000 |
| Allowance to Address Right of Way Issues3 | $500,000 $1,500,000 |
| Total Project Development Costs | $11,444,000 $14,878,000 |

Total Estimated Project Cost | $40,625,000 $50,550,000 |

When evaluating these costs with other routes, similar assumptions for year of estimate (2009 dollars) and contingency should be considered.

---

1 Escalation is applied to base construction costs only, and excludes contingencies
2 Contingency rates are 20% or 40% on some base items depending on certainty
3 A placeholder allowance developed by others
The estimated cost for completely backfilling the Alto Tunnel is $11.5 million (2009 dollars including costs for engineering, environmental, project and construction management with an average construction contingency of 37%).
7 Summary

Rehabilitating the Alto Tunnel is technically feasible and could be accomplished using methods similar to those employed on the Cal Park Hill Tunnel Project. Unfortunately, due to limited access to the Alto Tunnel, the current conditions within the tunnel have been extrapolated from past reports and observations.

The tunnel rehabilitation will include lighting, safety, and emergency response/communication features. Natural ventilation would provide a safe environment for pedestrians and bicycle riders. The rehabilitation costs are dependent on the current conditions within the tunnel. The feasibility study level estimate of construction costs, assuming a 40% contingency (weighted average) to reflect design definition and current uncertainties, ranges from $29.2 million to $35.8 million in 2009 dollars. To develop a higher confidence level in the cost estimate, access to the tunnel and a detailed tunnel inspection will be required.
8 References


## Revision Log

<table>
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<tr>
<th>Revision No.</th>
<th>Date</th>
<th>Revision Description</th>
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<td>A</td>
<td>4/22/09</td>
<td>Issued for project team review</td>
</tr>
<tr>
<td>B</td>
<td>5/1/09</td>
<td>Issued for discussion with TAP</td>
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<tr>
<td>C</td>
<td>7/30/09</td>
<td>Issued for project team review</td>
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<tr>
<td>D</td>
<td>8/18/09</td>
<td>Issued Administrative Draft</td>
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<tr>
<td>0</td>
<td>4/26/10</td>
<td>Issued Final Report</td>
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Table 1. Descriptions of Rock Mass Structure

<table>
<thead>
<tr>
<th>Structure</th>
<th>Description</th>
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<tr>
<td>Massive</td>
<td>Intact in situ rock with few widely spaced discontinuities.</td>
</tr>
<tr>
<td>Blocky</td>
<td>Well-interlocked undisturbed rock mass consisting of cubical blocks formed by three intersecting discontinuity sets.</td>
</tr>
<tr>
<td>Very Blocky</td>
<td>Interlocked, partially disturbed mass with multifaceted angular blocks formed by 4 or more joint sets.</td>
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<tr>
<td>Blocky/Disturbed</td>
<td>Folded with angular clocks formed by many intersecting discontinuity sets. Persistence of bedding planes or schistosity.</td>
</tr>
<tr>
<td>Disintegrated</td>
<td>Poorly interlocked, heavily broken rock mass with a mixture of angular and rounded rock pieces.</td>
</tr>
<tr>
<td>Laminated</td>
<td>Lack of blockiness due to close spacing of weak schistosity.</td>
</tr>
<tr>
<td>Sheared</td>
<td>Lack of blockiness due to close spacing of shear planes.</td>
</tr>
</tbody>
</table>

After Marinos et al. (2005).
Figure 1. Location map of eastern Marin County, showing location of Alto Tunnel and Cal Park Hill Tunnel (modified from Google Maps, 2009, no scale)
Figure 2. Plan view of Alto Tunnel showing locations of geotechnical investigation
Figure 3. North Portal layout (all lengths in feet)
Figure 4. North Portal: East slope 50 feet north of the portal

Figure 5. North Portal: Rock mass quality in sandstone on east slope
Figure 6. North Portal: Sandstone and shotcrete on east slope next to portal

Figure 7. North Portal: Shotcrete over shale on west slope next to portal

Figure 8. North Portal: Condition of bulkhead (left) and shotcrete (right) south of portal
Figure 9. MMWD Water Pipe Tunnel: South Shaft view

Figure 10. South Portal: Typical condition of rock fill at South Portal
Figure 11. Tunnel Alignment: Condition of rock mass in tunnel inferred from installed support
Figure 12. Tunnel Alignment: Rehabilitation profiles
Figure 13. Tunnel Alignment: Portal approaches
Figure 14. Tunnel Alignment: Typical cross section
Appendix A: Alto Tunnel Inspection by David Carroll Circa 1978

Email with Photo Attachment
Subject: condition of alto tunnel
Date sent: Thu, 9 Oct 2003 12:39:20 -0400
From: "David Carroll"
To: "Debbie at Marin Bike"

Hi;
I saw the article on reopening the alto tunnel, and regarding the question of the condition of the interior, I can relate my experience: In 1978 or so, I dug my way into the south entrance through the fill that had been placed there. I knew where to dig, because I grew up in Scott Valley, and played around and in the tunnel many times when it was still operational. First, it is full of water. I had to wade in water up to my chest until about a third of the way through, where the grade of the line raised out of the water. There is a very large collapsed section in the middle, which required that I pick my way over and around many large boulders that almost completely fill the tunnel. It was really quite a sight to see the enormous beams all broken and splintered. The roof of the tunnel was gone for about 25 feet, and in it's place was a "dome" cavity where the rock had been. I completed the exploration to the north end, and returned to where I entered, re-filling my excavation. There were no other caved in sections at that time.

The ventilation shaft is located near the top of the grade. It is a locked screened box, about 25 yards down the slope just off the top of Chapman drive. I considered rappelling down through it, and thought better of it. I've seen the inside enough.

Take care,
Dave.
Appendix B: Factored Construction Cost Estimate for Alto Tunnel based on Cal Park Hill Tunnel Bids
### Comparison of Cal Park Hill Tunnel and Alto Tunnel

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Item Description</th>
<th>Unit of Measure</th>
<th>Quantity</th>
<th>Average Unit Price</th>
<th>Average Amount Lower Range</th>
<th>Upper Range</th>
<th>Contingency Percent</th>
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<td>1.0</td>
<td>Mobilization</td>
<td>LS</td>
<td>1</td>
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<td>$941,450</td>
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<td>$37,829</td>
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<td>$16.76</td>
<td>$16.76</td>
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<td>$26,477</td>
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<td>20%</td>
</tr>
</tbody>
</table>

**Total Non-Construction Project Costs**

- Survey, Technical Studies, and Engineering Design: $3,839,471
- Environmental Analysis: $2,507,647
- Project Administration: $2,507,647
- Construction Management: $2,507,647
- Cost to address ROW issues: $500,000

**Total Project Costs:** $40,424,877

**Notes:**
1. In other estimates by Noble Engineers.
2. 10% indicates cost estimated based on selected components of Engineer's Estimate for Cal Park Hill Tunnel.
3. Lettered bid items were not part of Cal Park Hill Tunnel contract and were estimated as allowances for Alto Tunnel.
4. Environmental mitigation in contingency.
5. See Appendix B, Tunnel Feasibility Study for additional assumptions.