



Feasibility of a regional trail underpass beneath General Jim Moore Boulevard in Del Rey Oaks, CA

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The Watershed Institute

School of Natural Sciences
California State University
Monterey Bay

<http://ccows.csumb.edu/pubs/>

100 Campus Center, Seaside, CA
93955-8001

Anna Conlen
Elizabeth Eichorn
Nicole Inglis
Fred Watson (instructor)

Senior author contact details:
fwatson@csumb.edu

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Executive Summary

The Fort Ord Rec Trail and Greenway (FORTAG) is a proposed 30-mile network of paved recreational trails and greenways aimed at connecting communities to open space in the Monterey Bay area on the Central Coast of California. The trail network will expand opportunities for people of all ages and abilities to safely travel between home, work, open space and commercial areas by foot, bike or wheelchair. Some segments will also be open to equestrian use.

The purpose of this study was to assess the feasibility of a pedestrian underpass beneath General Jim Moore Boulevard (GJMB) on the eastern border of Frog Pond Wetland Preserve in the City of Del Rey Oaks. If determined feasible, the underpass will serve as a key connection between the Monterey Bay Coastal Recreation Trail, the Laguna Grande trail network, Canyon del Rey, Ryan Ranch, eastern Seaside and Fort Ord National Monument. Our primary goals were to determine current topographical conditions of the GJMB roadbed and adjacent terrain between Highway 218 and South Boundary Road (SBR), assess the hydrologic conditions of the tributary directly south of SBR that passes under GJMB and determine the space available for an underpass in this area given basic requirements for such a structure. This report is intended for an audience of engineers, land use planners and interested community members.

We performed a high resolution topographical survey of the study site using a three-arcsecond Nikon NPR-362 Total Station with Immaterial MNI Prisms and a Real Time Kinematic (RTK) global positioning system (GPS) with Spectra Precision Epoch 50 GNSS receivers. We transformed the survey data into a digital elevation model (DEM) using ArcGIS and fused it with pre-existing LiDAR data. The DEM was then used to create a two-dimensional schematic of approximate underpass design using the R Software Package and a three-dimensional rendering using Google SketchUp. We monitored hydrologic conditions of the South Boundary tributary and Frog Pond using In-Situ Level TROLL 500 Data Loggers and pond surface elevation was determined by a longitudinal survey using the Total Station. All data were collected between February and April 2018.

Due to GJMB road runoff, South Boundary tributary flows fluctuate sharply during rain events. Changes of up to one foot in water depth were observed directly downstream of the box culvert that passes under GJMB. We found that the flashboard at the southern terminus of Frog Pond, a proxy for maximum Frog Pond water level, is located 78 ft above sea level while the base of the existing cement culvert has an elevation of 83 ft.

This five-foot difference in elevation makes it unlikely that the proposed underpass will flood due to Frog Pond backwater effects.

Applying minimum bike/pedestrian trail standards, underpass design standards and the maximum elevation of Frog Pond, we determined that there is sufficient space (approximately 13 vertical feet assuming a deck thickness of four feet) within the existing landscape to accommodate an underpass that encompasses the natural course of the South Boundary tributary and a Class I trail without altering the existing road gradient. We recommend moving ahead with further exploration of a bridge span underpass at General Jim Moore Boulevard with special attention paid to designs that would ensure habitat connectivity, continuity of open-space experience and human safety.

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1 Introduction

1.1 Background

The Fort Ord Rec Trail and Greenway (FORTAG) is a proposed 30-mile network of paved recreational trails and greenways aimed at connecting various communities to open space in the Monterey Bay area on the Central Coast of California. Project benefits will be far reaching but the cities that are expected to benefit most are Monterey, Seaside, Marina and Del Rey Oaks as they contain the majority of the trail network. FORTAG will expand opportunities for safe transport of all ages and abilities between home, work, open space and commercial areas by foot, bike or wheelchair. Some segments will be designated for equestrian use.

In 2012, portions of the former Fort Ord military base were designated as Fort Ord National Monument (FONM), managed by the Bureau of Land Management, opening 83 contiguous miles of trail and 14,658 acres of open space to the public (BLM 2012). In November 2016, Monterey County voters approved \$20 million in funding for implementation of FORTAG as part of the countywide Transportation Investments and Safety Plan, enabled by Measure X, which will provide connectivity between the national monument, nearby cities and the Monterey Bay Coastal Recreation Trail. In February of this year, the Transportation Agency for Monterey County Board of Directors approved an additional \$1 million in state funding and issued a Request for Proposals for FORTAG environmental review and preliminary engineering designs.

Del Rey Oaks is a small city that covers 0.45 square miles and has a population of under 2,000 people. The city limits are bounded by the City of Seaside to the north, the City of Monterey to the south and southwest, and the former Fort Ord to the east (Denise Duffy & Associates 1997). Highway 218, an important commuting connector between Highway 1 to the west and Highway 68 to the southeast, bisects the city and has a very limited amount of safe pedestrian crossings.

Frog Pond Wetland Preserve (FPWP), managed by Monterey Peninsula Regional Park District (MPRPD), is a popular open space area in north eastern Del Rey Oaks with direct access from the Cities of Del Rey Oaks and Seaside, as well as Ryan Ranch. The park is divided by General Jim Moore Boulevard (GJMB) with 17 ac located to the west and approximately 20 ac located to the east. It is home to various plants and animals typical

of seasonal wetlands such as willows, oaks, riparian understory vegetation, frogs, deer, small mammals, birds and reptiles.

Following the closure of Fort Ord, MPRPD negotiated (MPRPD 1999) and acquired (2009) approximately 20 acres of land to the east of GJMB with the intent that it be managed as a connected open space area contiguous to the western parcel. The 1996/97 Fort Ord Reuse Plan provides for MPRPD parking and trailhead facilities abutting the eastern edge of the combined MPRPD parcels. A 1998 letter from MPRPD requests a “below-grade tunnel” under GJMB connecting the parcels to facilitate safe, accessible east-west travel, and references an existing east-west trail, 300 feet north of Highway 218 (MPRPD 1998). The MPRPD re-affirmed this intent in 2017 with board resolution supporting FORTAG, and specifically that the FORTAG alignment would run through Frog Pond Wetland Preserve with an under-crossing at GJMB (MPPRD 2017).

The development of FORTAG in the Del Rey Oaks area realizes a key connection between the Monterey Bay Coastal Recreation Trail, the Laguna Grande trail network, Ryan Ranch, Canyon del Rey, eastern Seaside and Fort Ord National Monument. Specifically, existing FPWP trails are proposed to be used as a connector between Canyon del Rey and FONM. Essential to this effort is enabling safe pedestrian crossings near FPWP’s main entrance on Highway 218 and at GJMB to the east. The feasibility of these crossings has yet to be assessed, warranting this preliminary study of a proposed underpass beneath GJMB.

1.2 Study Site

The study site is located at the Southern terminus of General Jim Moore Boulevard 600 ft from Highway 218 Canyon Del Rey Boulevard in Del Rey Oaks, California (Fig. 1). The underpass should be located at the current site of the South Boundary tributary culvert under GJMB. The South Boundary tributary consists of primarily subsurface flow, however vegetation patterns indicate the occasional presence of standing water (Geisler et al. 2015) and running water has been recorded during high rainfall events. The South Boundary tributary drains from an undeveloped area of the former Fort Ord army base through sandy, highly pervious soils (Geisler et al. 2015). It travels through a cement box culvert beneath GJMB before draining into Frog Pond and then Arroyo del Rey. Downstream of FPWP, Arroyo del Rey passes through a culvert feeding the Laguna Grande and Roberts Lake system before eventually draining into Monterey Bay National Marine Sanctuary (Geisler et al. 2015).

The proposed FORTAG trail system follows the South Boundary tributary creek bed starting about 1,300 ft upstream of the GJMB crossing. After the crossing, the trail follows the southern boundary of FPWP alongside Highway 218.

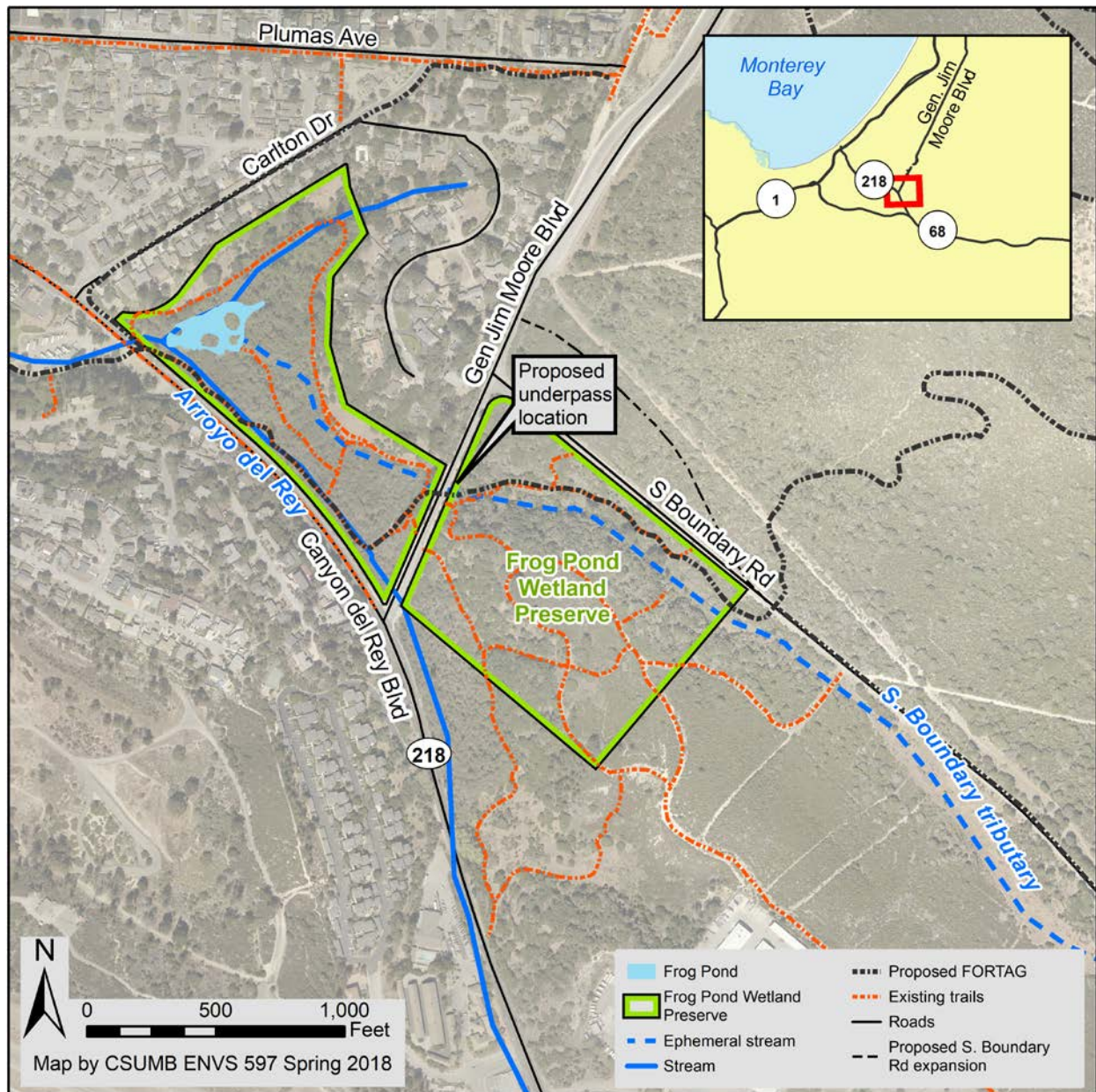


Figure 1. Location of the Frog Pond Wetland Preserve in Del Rey Oaks, California and the study site location on adjacent General Jim Moore Boulevard.

1.3 Project Description

The goal of the project was to conduct a preliminary study on the feasibility of a recreational trail underpass beneath General Jim Moore Boulevard (GJMB) by:

- a. Creating a terrain model based on detailed field survey
- b. Calculating maximum available vertical trail clearance i.e. between underlying natural canyon topography and the base of a potential future bridge beam
- c. Calculating the maximum horizontal bridge span that would be required to span the natural canyon topography without substantial intrusion of bridge supports into the natural shape of the canyon
- d. Estimating potential need to allow for trail flooding by stream flow or Frog Pond backwater, by:
 - a. Measuring water flow, if any, in drainages entering the Frog Pond
 - b. Measuring Frog Pond water levels
- e. Determining – based on the above calculations – if there is sufficient vertical and horizontal cross-sectional space for a safe, accessible multi-purpose trail under GJMB, along with space for movement and dispersal of wildlife, plants, and water.

The results of the study are intended be informative to engineers, land use planners and community members.

2 Methods

We collected data for this study between February and April 2018. We performed a high resolution topographical survey of the existing road geometry of General Jim Moore Boulevard and valley conditions along the South Boundary tributary, transformed the survey data into a digital elevation model (DEM) layer in ArcGIS and estimated the hydrological conditions of the South Boundary tributary as it pertains to the proposed underpass and Frog Pond. This information was compiled to inform a two-dimensional and three-dimensional depiction of a potential underpass design and to determine the feasibility of the proposed project.

2.1 High Resolution Topographical Survey

2.1.1 Topographical survey

We surveyed a swath approximately 30 m to the east and 20 m to the west of a 65 m section of General Jim Moore Boulevard between Canyon del Rey Boulevard and South Boundary Road in Del Rey Oaks, California to create an accurate, detailed digital elevation model of the study area.

The survey involved a combination of instruments, including a total station (TS), two RTK GPS systems, and pre-existing LIDAR data. We used TS for most of our survey because it is effective under trees, unlike GPS, LiDAR, or drone-photogrammetry, which only work well in open areas with minimal tree canopy cover. We supplemented the TS survey with RTK GPS over open areas like GJMB, and with pre-existing LiDAR data in areas outside our primary study area.

We installed and surveyed a rebar benchmark into order to be able to link the different survey systems together and create a unified survey referenced to an established geodetic datum.

We used a total station (TS) (Three-arcsecond Nikon NPR-362 with Immaterial MNI Prisms) to conduct the primary survey. We installed a number of temporary wooden-stake control points (CP) and deployed the TS at most of these CPs, such that the entire survey area was visible from at least one TS deployment. One CP was placed on the eastern side of the road and two were placed on the western side. The location of each CP was determined using RTK GPS. Using the TS, we measured the location of terrain points organized in a rough grid pattern determined in the field, with more points taken in locations where slopes changed abruptly and fewer points taken where slopes changed gradually. We determined the locations of all trees larger than 15 cm in diameter at breast height (DBH) within the study area by direct measurement also using the Total Station. We used a Forestry Suppliers Inc. DBH tape to measure the diameter of trees that met our criteria within the study site (Fig. 2).

We used an RTK GPS system (Spectra Precision Epoch 50 GNSS receivers) to survey road locations not obscured by the tree canopy. This was done in approximately 15 transects perpendicular to GJMB to capture the topography of western and eastern road banks, curbs, sidewalks and the road's centerline. Transects were approximately ten feet apart

and consisted of five to ten GPS points depending on how thick vegetation was on either end of the transect.

A colleague (K. Nitayangkul) used a second RTK GPS system (Leica Viva GS16 Self-Learning GNSS Smart Antenna, corrected to regional GPS corrections via SIM card in real time) to accurately survey the location of our primary benchmark. This allowed the entire survey to be accurately tied to a known geodetic datum. Prior to this, we attempted to do the same thing with our own RTK GPS, by uploading our data to the National Oceanic and Atmospheric Administration's (NOAA) Online Positioning User Service (OPUS) to relate our survey points to high-accuracy National Spatial Reference System (NSRS) coordinates. But this operation could not be completed when we discovered that our survey did not fall within the bounds of NSRS reference stations.

We used Microsoft Excel to collate and correct all survey data.

The resulting data set provided much more detailed, precise, and accurate information on the terrain of the site than was previously available. The best prior data set would probably be the 2010 Monterey County LIDAR data, which is unreliable under dense tree canopies like those at Frog Pond.

2.1.2 Longitudinal survey

We conducted a longitudinal profile survey to relate the surface water elevation of Frog Pond to our topographic survey (Fig. 3). Beginning at the base station (Fig. 2), we used three landmarks on the northern shoulder of Highway 218 to conduct a Total Station traverse from GJMB to Frog Pond. We collected survey points of Frog Pond water elevation and flashboard elevation just north of Frog Pond's confluence with Arroyo del Rey. The

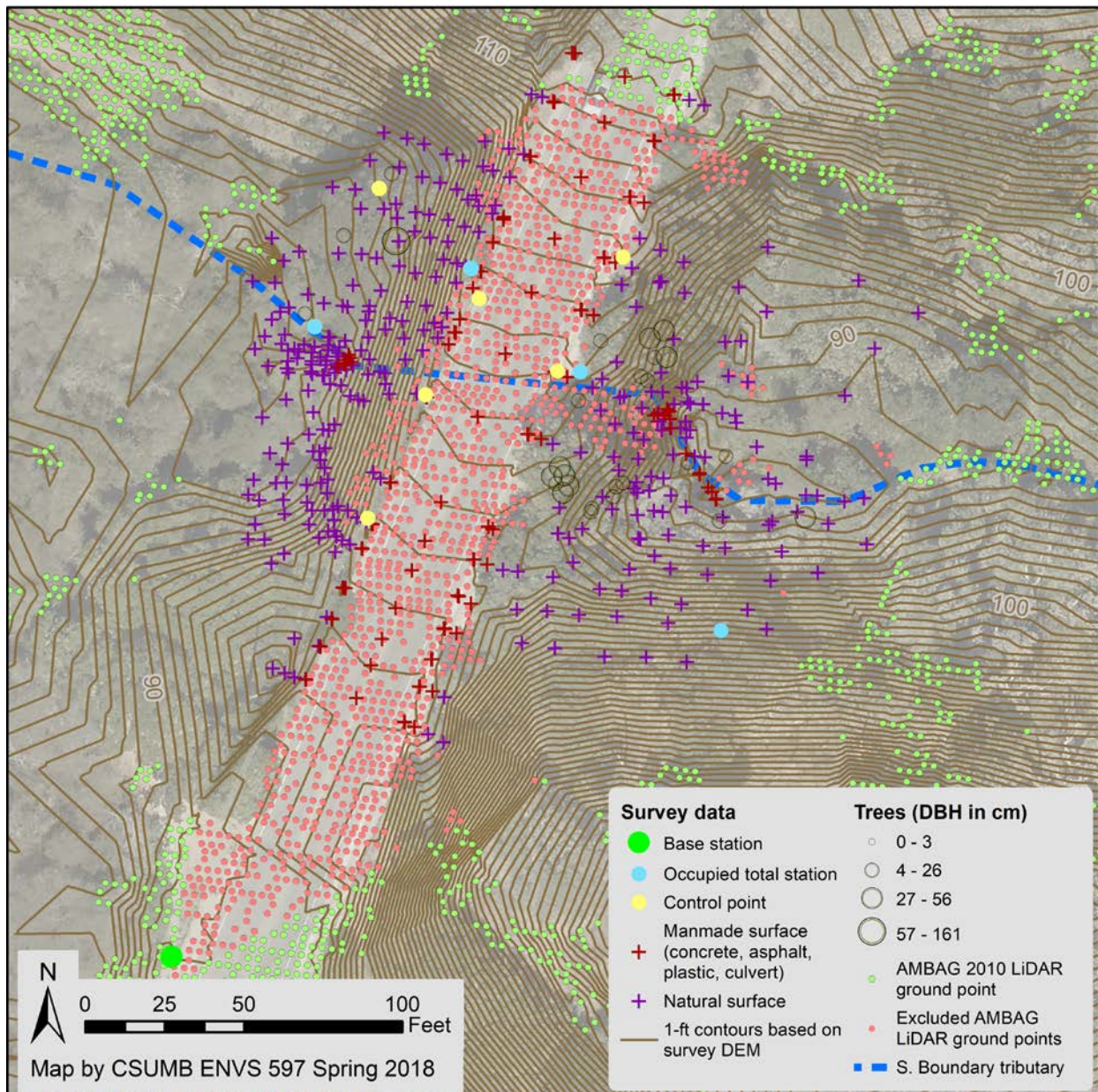


Figure 2. Survey map showing locations of control points, survey points, existing road infrastructure, the course of South Boundary tributary and locations of culvert inlet and outlet.

flashboard elevation was used as a proxy for the highest water elevation the pond would be expected to reach.

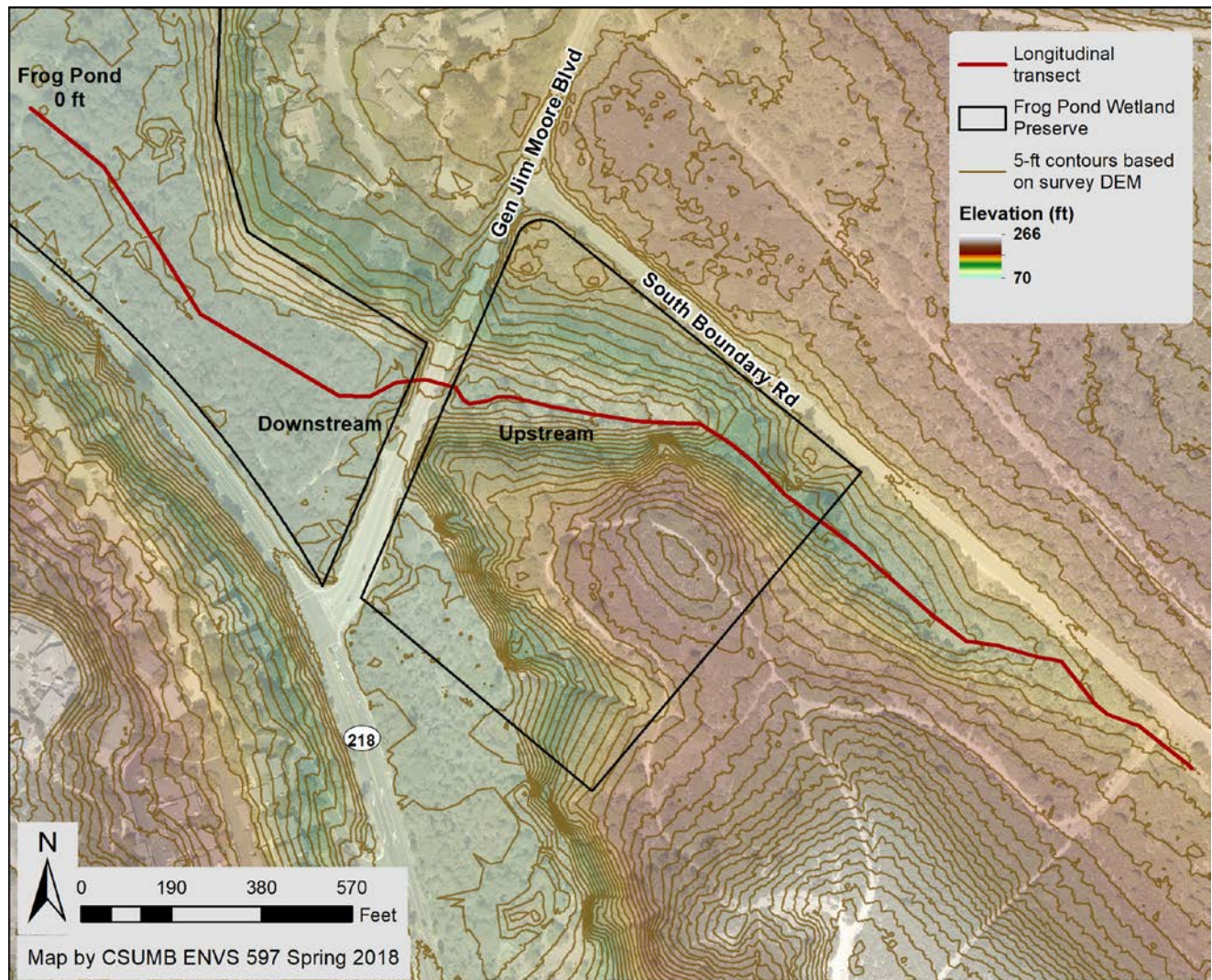


Figure 3. Transect location used to inform the longitudinal profile schematic.

2.2 Digital Elevation Model Layer Creation

Using ArcGIS 10.6, R 3.3.2 (R Core Team 2016) and Microsoft Excel, we visualized, cleaned and processed survey data into a digital elevation model. In Excel we:

- Merged Total Station and RTK survey points, classified, converted to feet and removed points marked in the survey notes as erroneous shots
- Corrected data by easting, northing and elevation based on updated base station survey

- Categorized (survey, trees (DBH), control points) for import into ArcMap and R

We used R to examine the data as it was collected for quality control. We used the interactive plot function `scatter3D()` to visualize the data in 3D.

We created a DEM of the study area from corrected survey points using the following steps in ArcMap. Most of the process was automated in ModelBuilder (Appendix I). We:

- Imported survey points as XY data (Import XY Data) in GCS_NAD_1983 datum
- Created a shapefile (Export Data)
- Projected the point shapefile into California State Plane Zone 4 (Project Tool)
- Explored various interpolation options (Natural Neighbor, Spline, Kriging, Create Tin tools), determining that a TIN raster best captured the geometry of the survey area.
- Created a raster of the survey TIN (TIN to Raster tool)
- Explored the points, TIN and the TIN raster for anomalies in ArcMap and ArcScene
- Qualitatively compared the survey points to AMBAG 2010 LiDAR grounds points to check for accuracy (Identify)
- Through comparisons to photos and knowledge of the survey area, identified and removed anomalies such as protrusions or sinks in the TIN (Edit Features)

To merge the AMBAG LiDAR data into the survey data and create a seamless DEM of the study area, we:

- Converted the AMBAG LiDAR ground points to a multipoint shapefile (LAS to Multipoint tool)
- Exploded the multipoint to single point features (Multipart to Singlepart tool)
- Clipped the point dataset to the extent of the study area (Clip tool)
- Added elevation data to the attribute table (Add Z Information tool)
- Created a hole in the LiDAR shapefile that was the same extent as the survey data:
 - Multiplied the survey TIN raster by zero to create a one-value raster of the survey area (Raster Calculator tool)
 - Converted the resulting raster to integer format (Int tool)
 - Created a polygon that traced the outline of the survey area (Raster to Polygon tool)
 - Erased the survey extent from the LiDAR shapefile (Erase tool)

- Merged the survey point data and the LiDAR point data (Merge tool)
- Created a TIN, raster and contours of the combined data set (Create Tin tool, TIN to Raster tool, Contour tool)
 - Raster was created using a resolution of one foot

2.3 Hydrological Conditions Estimation

2.3.1 Flow evaluation of select Frog Pond tributaries

The flow rates of the various tributaries flowing directly into Frog Pond are not routinely monitored. During a storm on 20 Mar 2018, we measured the flow rates of Frog Pond's five main tributaries using the velocity area method between 3:00 and 4:00 PM. The California Irrigation Management Information System (CIMIS) Laguna Seca Station 229 registered a 0.72 in rain event that day with no rain having fallen for three days prior. These were the only flow estimations made over the duration of the study.

2.3.2 Monitoring changes in Frog Pond tributary depths

In an effort to estimate fluctuations in South Boundary tributary water depth, which the proposed underpass would have to accommodate, we installed an In-Situ Level TROLL 500 Data Logger above and below the existing culvert (Fig 4). The upstream logger was placed above the GJMB road runoff outlet (Fig. 5 (A)). The downstream logger was placed underneath the walking bridge directly west of the culvert outlet and therefore monitored the cumulative flow from the South Boundary tributary drainage and runoff



Figure 4. Pressure transducer placement above (A) and below (B) the GJMB box culvert (C). Pictured here is the downstream culvert outlet. The black pipe transports road runoff from the western half of GJMB and the largely submerged cement box culvert transports South Boundary tributary flow and runoff from the eastern half of GJMB.

from both sides of GJMB (Fig. 5 (B)). Two more loggers were installed, one below the viewing deck in Frog Pond and another under the bridge in the tributary that drains from Carlton Drive (Fig. 5, (C) and (D) respectively), to provide context for the changes in depth registered by the South Boundary tributary loggers. Loggers were in place between 14 March and 30 April 2018 save for the one installed in the Carlton Drive tributary which was in place for a shorter amount of time. All were programmed to collect depth of surface water measurements every three minutes and data were downloaded in the field

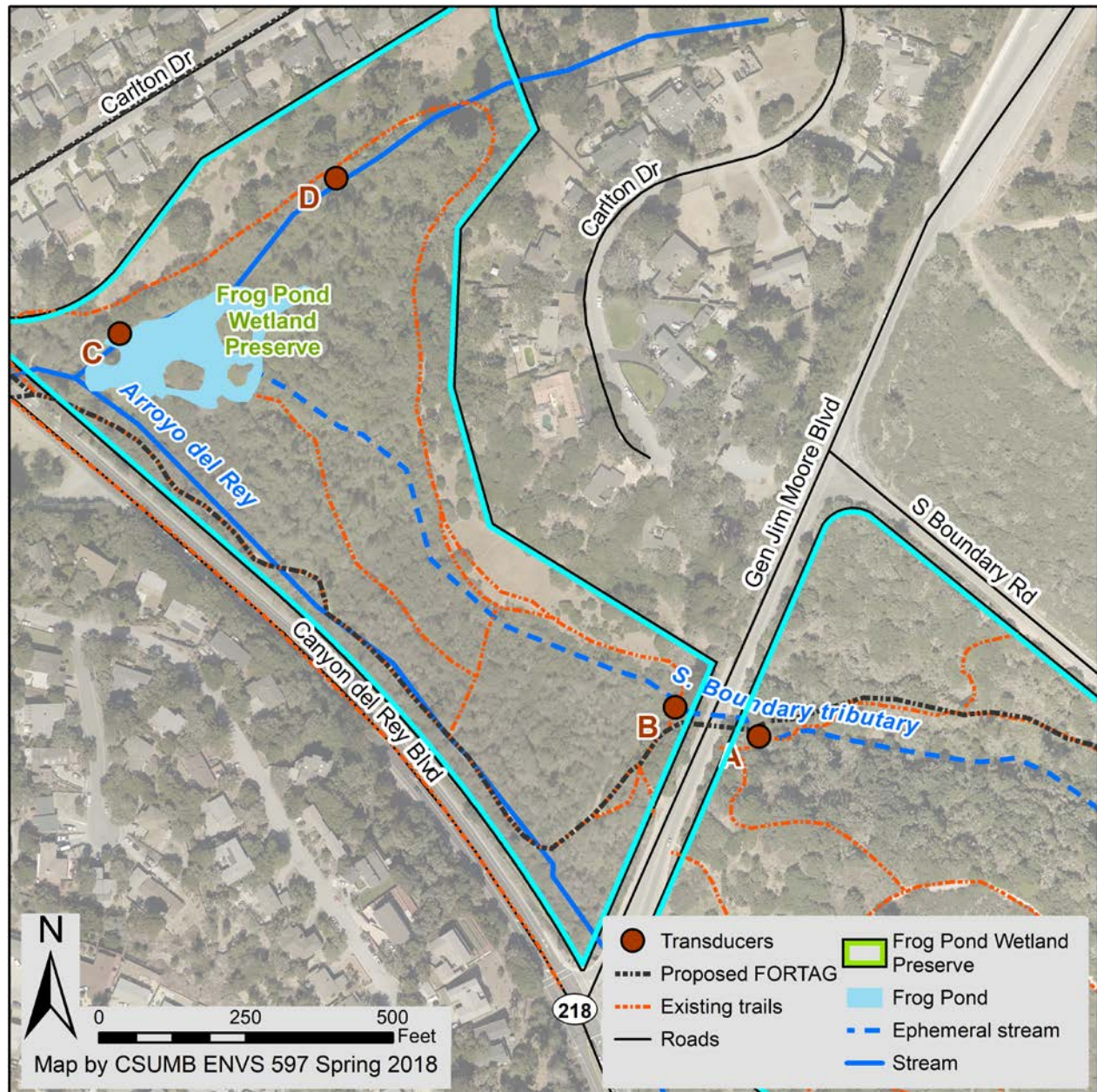


Figure 5. In-Situ Level TROLL 500 Data Logger approximate placement locations.

periodically using Win-Situ 5 software at which time Frog Pond staff plate readings were also taken.

2.3.3 Frog Pond water elevation

We surveyed Frog Pond water elevation and flashboard elevation during a longitudinal Total Station survey on 4 April 2018 (Fig. 6). We read the Frog Pond staff plate as 2.30 at 11:45 AM, coinciding with the shot that recorded the water elevation. We determined the maximum Frog Pond elevation based on the flashboard height (78 ft) and used this elevation to inform our two-dimensional underpass schematic that included current culvert locations to determine the risk and effects of Frog Pond backwater flow.



Figure 6. Frog Pond flashboard at the time of the longitudinal survey on 4 April 2018. The water from Frog Pond flows under the footbridge on the left and into Arroyo del Rey.

2.4 Two-Dimensional Underpass Design

We used RStudio to draw a spatially accurate two-dimensional model of the GJMB underpass design (RStudio Team 2016). We extracted cross-sections from the study area DEM to incorporate existing terrain into the design (Fig. 7). We extracted five cross-sections for use in the underpass design: one along the centerline of GJMB (0 ft), two upstream of GJMB (-70 ft, -120 ft), and two downstream of GJMB (70 ft, 120 ft). We chose distances of 70 ft and 120 ft upstream and downstream of the GJMB centerline to avoid a berm upstream of GJMB and accurately represent elevational changes in the study area. We manually adjusted the cross-sections' lateral distances so that '0 ft' was in the thalweg. We compiled pedestrian/bike trail standards and requirements to create a realistic portrayal of the GJMB underpass.

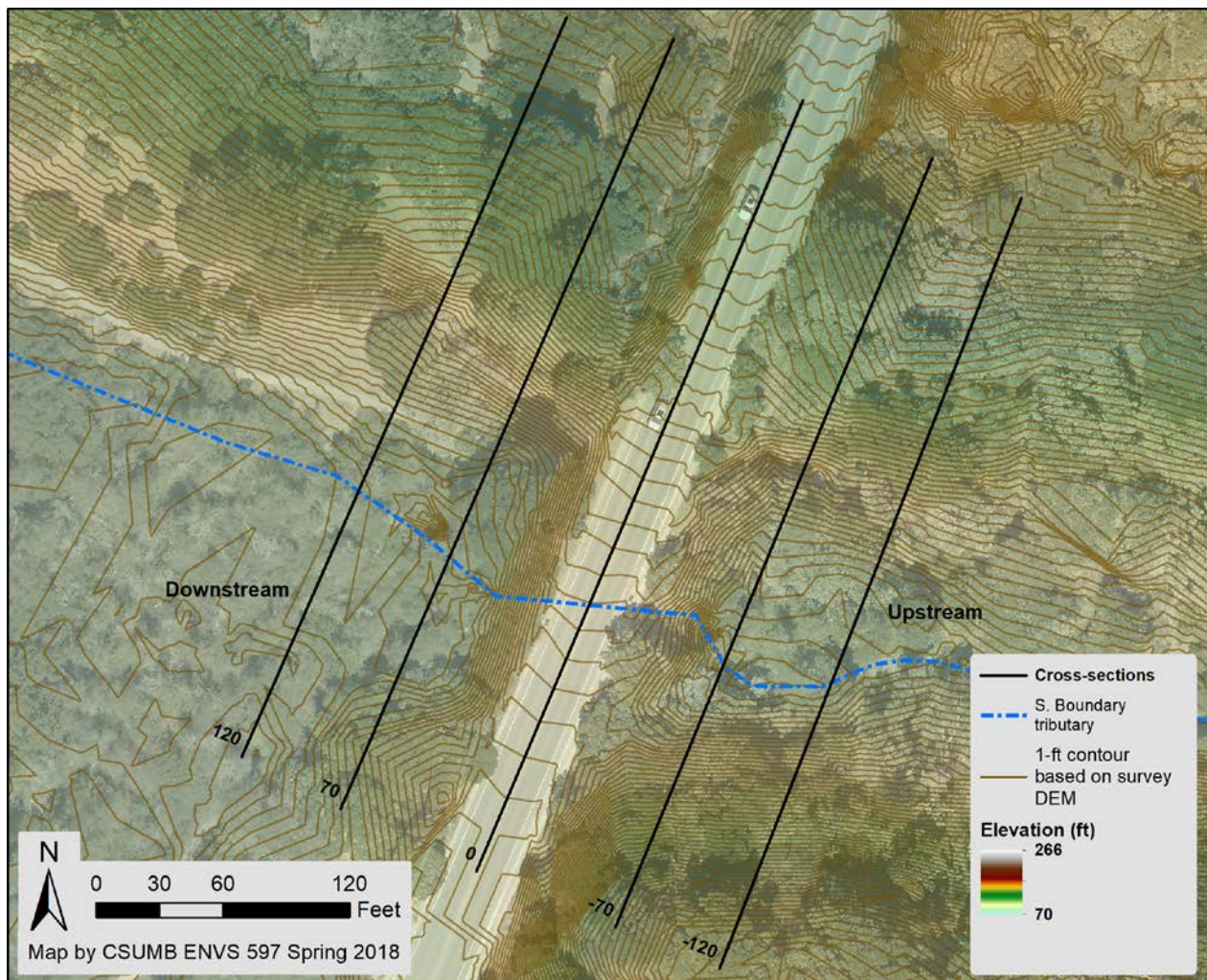


Figure 7. Cross-sections used to inform the two-dimensional underpass design.

The underpass met the following Caltrans requirements for a two-way Class I bikeway (CDT 2017):

- 8 ft minimum paved width, 10–12 ft recommended
- Minimum 2 ft wide shoulder adjacent to path with 2% slope
- 10 ft minimum vertical clearance

We modeled the bridge deck from existing conditions of GJMB and design parameters of similar projects. There is no standard bridge thickness for a two-lane road; bridge deck thickness is project-specific and dependent on many factors like bridge length, width, and load. We modeled deck thickness in the 2D schematic from engineering bridge plans from the City of Santa Cruz, including the Dakota Bridge, Lee Street Bridge and Market Street Bridge (Amelia Conlen, email message, April 16, 2018). The maximum bridge thickness from these plans is 4 ft, which we applied to our schematic. Professional bridge engineering expertise is required for actual design dimensions.

2.5 Three-Dimensional Underpass Design

We created a three-dimensional rendering using Google Sketchup to help the community and engineers visualize what an underpass could look like, given the desire to maintain a continuous, safe open space experience.

We imported the results of our topological survey into Google SketchUp by importing the DEM into R using the 'rgl' library to render the terrain in a display window, exporting the contents of that window to an STL file (writeSTL()) and then importing the .STL file into SketchUp.

In Google Sketchup, we created a tunnel matching the dimensions of the 2D design, placed it through terrain where the underpass would be and carved out the terrain inside the tunnel. Stream and trail components were draped over the terrain inside the tunnel. We added natural features and examples of human use to simulate the potential natural environment and ambiance of the underpass.

3 Results

3.1 Survey and DEM Creation

We sewed the topographic survey points into existing LiDAR data to create a seamless DEM of the study area (Figs. 8 and 9). The resulting DEM has a horizontal resolution of one foot. We created contour lines at one, five and ten-foot intervals.

Examination of the topography indicates that Arroyo del Rey and the S. Boundary tributary once cut natural, continuous canyons into the landscape. Construction of GJMB required building a causeway that cuts through the S. Boundary tributary drainage and partially through the Arroyo del Rey Canyon. Restoring this area to its natural topographic state would involve restoring original canyon walls and converting the causeway into a bridge, creating a continuous open-space experience for trail users and a renewed connectivity for plants and wildlife.

3.2 Hydrology

3.2.1 Flow evaluation of select Frog Pond tributaries

Flow estimations of the main Frog Pond tributaries revealed that the pond was receiving an approximate total of 2 cfs at the time it was monitored during a 0.72 in precipitation event (Table 1). It was not determined if the tributaries were monitored before, during or after the peak of the storm. We observed that the majority of the runoff (1.67 cfs) was coming from the tributary that drains from Carlton Drive and inputs from GJMB runoff were limited (0.12 cfs) with negligible flow input from the upper South Boundary tributary (0.000036 cfs). Though we cannot correlate precipitation amounts to total water expected to enter Frog Pond for any given storm from these data, our observations serve as rough indicators of the proportionality of flows during storm events.

In the planned event that upper portions of the South Boundary tributary watershed are developed, changes in impervious surface could alter the observed flow patterns in the South Boundary drainage. However, land use restrictions require that development in the upper watershed includes a plan to capture stormwater to prevent erosion and siltation of ephemeral drainages downstream (USFWS 2005, FORA & DRO 2006). With such a plan

in effect, South Boundary tributary flows would likely not change dramatically, but if such a plan failed to be implemented, an in-depth hydrological review would be warranted to understand potential impacts to the drainage, Frog Pond and any downstream infrastructure.

Table 1. Summary of Frog Pond tributary stream flow estimates recorded on 20 Mar 2018 between 3:00 and 4:00 PM. Streams were monitored in a clockwise manner starting from the main Frog Pond pull-out parking area using the velocity area method (VAM).

Time	Site	Description	Method	Wet/Dry	Stage (ft)	Flow (cfs)
15:31	Stream 1	Bridge and stream	VAM	Wet		0.404
15:33	Stream 2	Bridge and stream (~50 ft later)	VAM	Dry		NA
15:34	Frog Pond	Viewing deck (Fig. 5C)	Staff plate	Wet	2.25	NA
15:42	Stream 3	Bridge and stream (drains Carlton Drive, Fig. 5D)	VAM	Wet		1.667
15:47	Stream 4	Bridge and stream at the redwoods	VAM	Wet		0.001
15:58	Stream 5 Dwn	South Boundary tributary, downstream of GJMB (Fig. 5B)	VAM	Wet		0.119
16:03	Stream 5 Up	South Boundary tributary, upstream of GJMB, upstream of GJMB road runoff (Fig. 5A)	VAM	Wet		0.000036

3.2.2 Depth variation in Frog Pond and its tributaries

Data retrieved from the loggers placed below the GJMB culvert and in the Carlton Drive tributary showed sharp peaks of up to one foot in changed water depth about half a day after peak rain events, while data for Frog Pond showed more gradual water level rise and subsidence following storms (Fig. 10). The logger placed above the GJMB culvert in the South Boundary tributary channel malfunctioned and its data were unusable. Some abrupt changes were observed in Frog Pond surface water depth which were likely due to wrack build up or changes in flashboard management (Fig. 10D). We surveyed the Frog Pond water surface elevation and collected a simultaneous staff plate reading during our longitudinal TS survey on 4 April 2018. A staff plate reading of 2.30 ft corresponds to a water surface elevation of 77.64 ft above sea level.

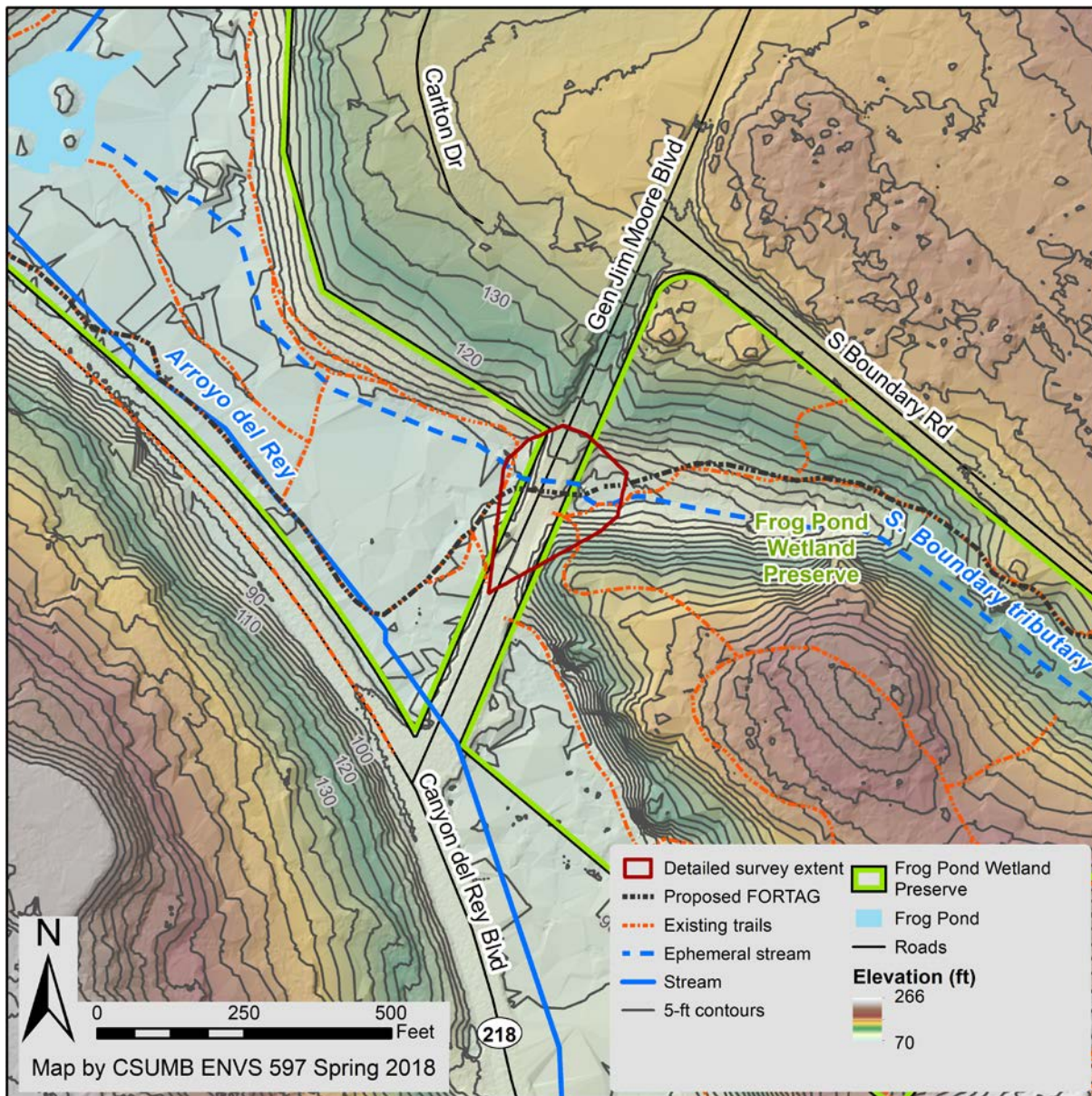


Figure 8. Digital elevation model product with five-foot contour lines.

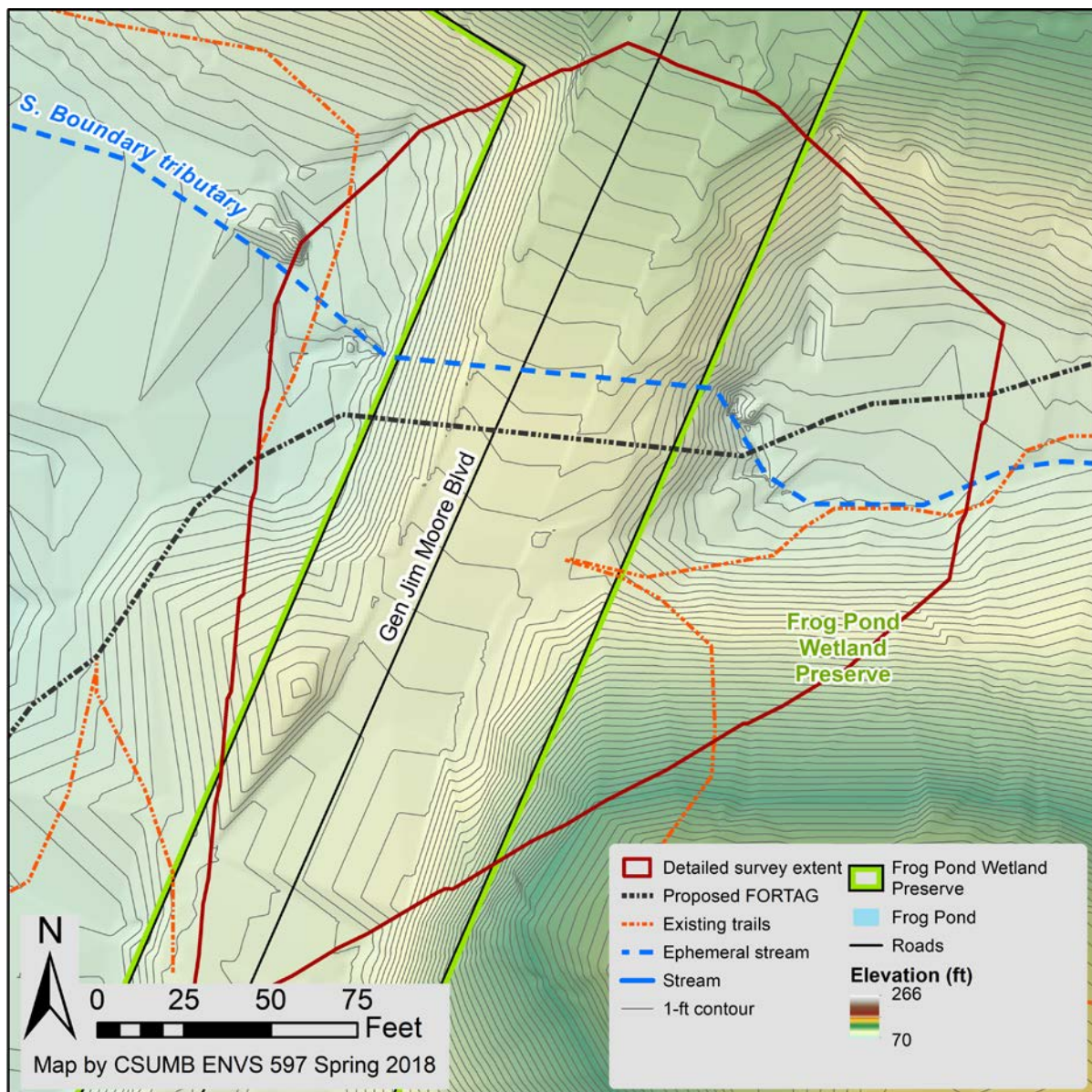


Figure 9. Survey area detail of digital elevation model product with one-foot contour lines.

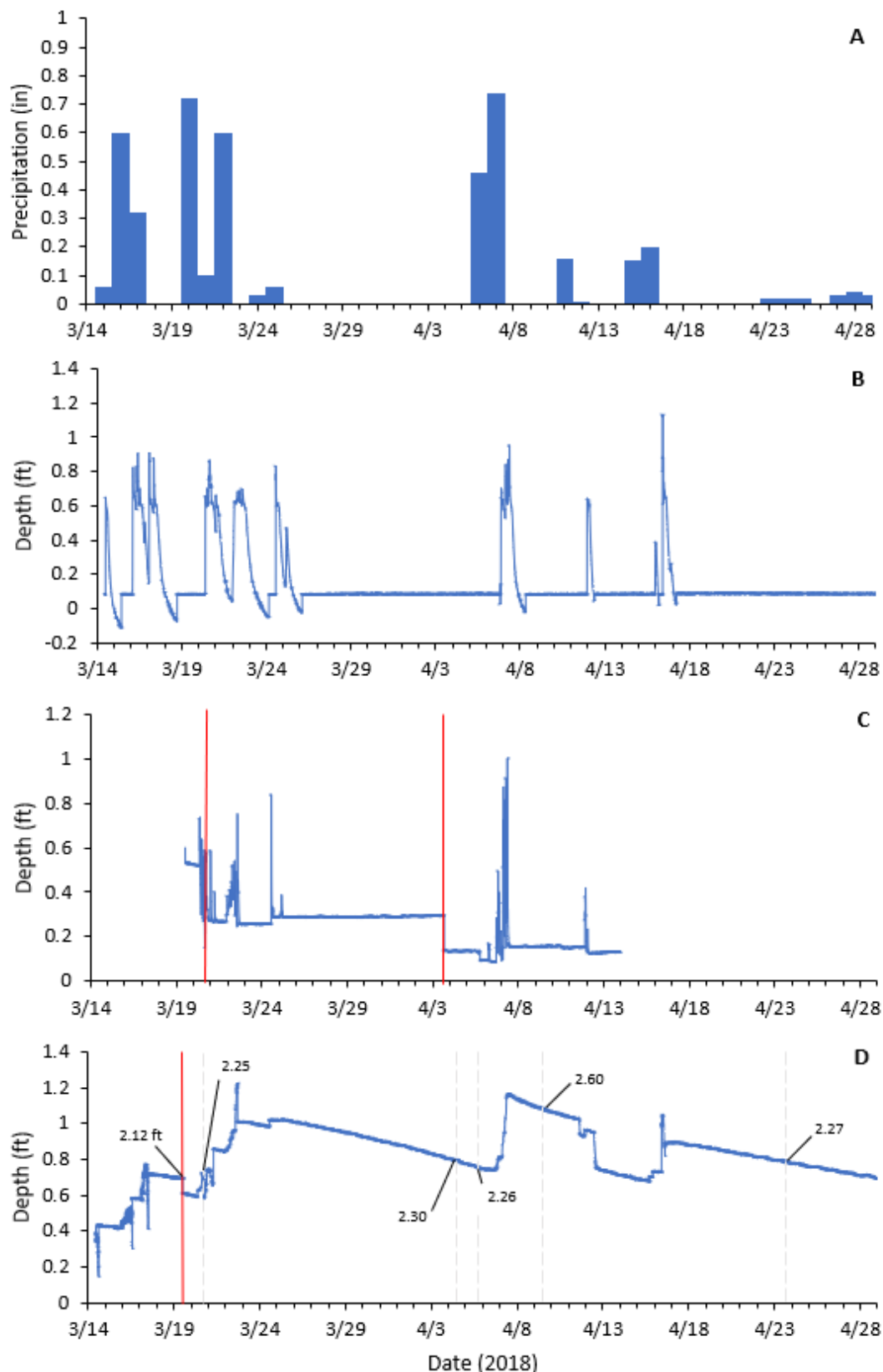


Figure 10. Comparison of CIMIS Station 229 precipitation data (A) to changes in water depth (relative to arbitrary datums) in the S. Boundary tributary below GJMB culvert (B), Carlton Drive tributary (C) and Frog Pond (D) from mid-March to the end of April 2018. Vertical red lines indicate when a logger was moved. Grey dotted lines show when a staff plate reading was taken. Corresponding staff plate readings are listed.

3.3 2D Cross-Section Drawing

We created a 2D cross-section drawing of the GJMB underpass to visualize the feasibility of the trail underpass within the pre-existing natural environment, assessing vertical and horizontal clearance and flood risk by the South Boundary tributary. Applying minimum bike/pedestrian trail standards, underpass design standards, and the maximum elevation of Frog Pond, we determined that there is sufficient space within the existing landscape to safely accommodate the underpass and Class I trail (Fig. 11).

Based on our 2D drawing, we found there is adequate vertical clearance for the trail within the pre-existing canyon. Our drawing preserved the existing road elevation and assumed a bridge deck thickness of 4 feet. We surveyed the upstream and downstream culvert bottom elevations and estimated the trail surface elevation as an average of the two. This led to a 13 ft clearance, which is substantially more than the 10 ft minimum standard.

Our design indicates there is substantial horizontal clearance to accommodate the trail while maintaining a natural, open, and safe feeling of passage. Class I designs recommend a minimum trail width of 12 ft. The maximum desired horizontal span is between opposite pre-existing canyon walls. This span varies between approximately 100 and 150 ft depending on elevation and west (downstream) – east (upstream) location. From the standpoint of the trail user, the ideal bridge over the canyon has a span of 60 ft or more and a thickness of not more than 4 ft.

We found that the South Boundary Tributary is very unlikely to flood the trail at the GJMB underpass. We never observed more than a barely detectable trickle (ounces per hour), even when other inputs to Frog Pond were flowing strongly (as much as a cubic foot per second). South Boundary Tributary drainage is mainly highly permeable sand with low water retention capacity (Geisler et al. 2015). Sand produces low runoff volumes, reducing the likelihood of high flows in the tributary. Development in the upper South Boundary watershed must capture and direct on-site stormwater to reduce runoff and pollution (USFWS 2005). This mitigation feature implies that runoff in the South Boundary Tributary watershed will increase minimally with increased development, maintaining the current, low risk of flooding.

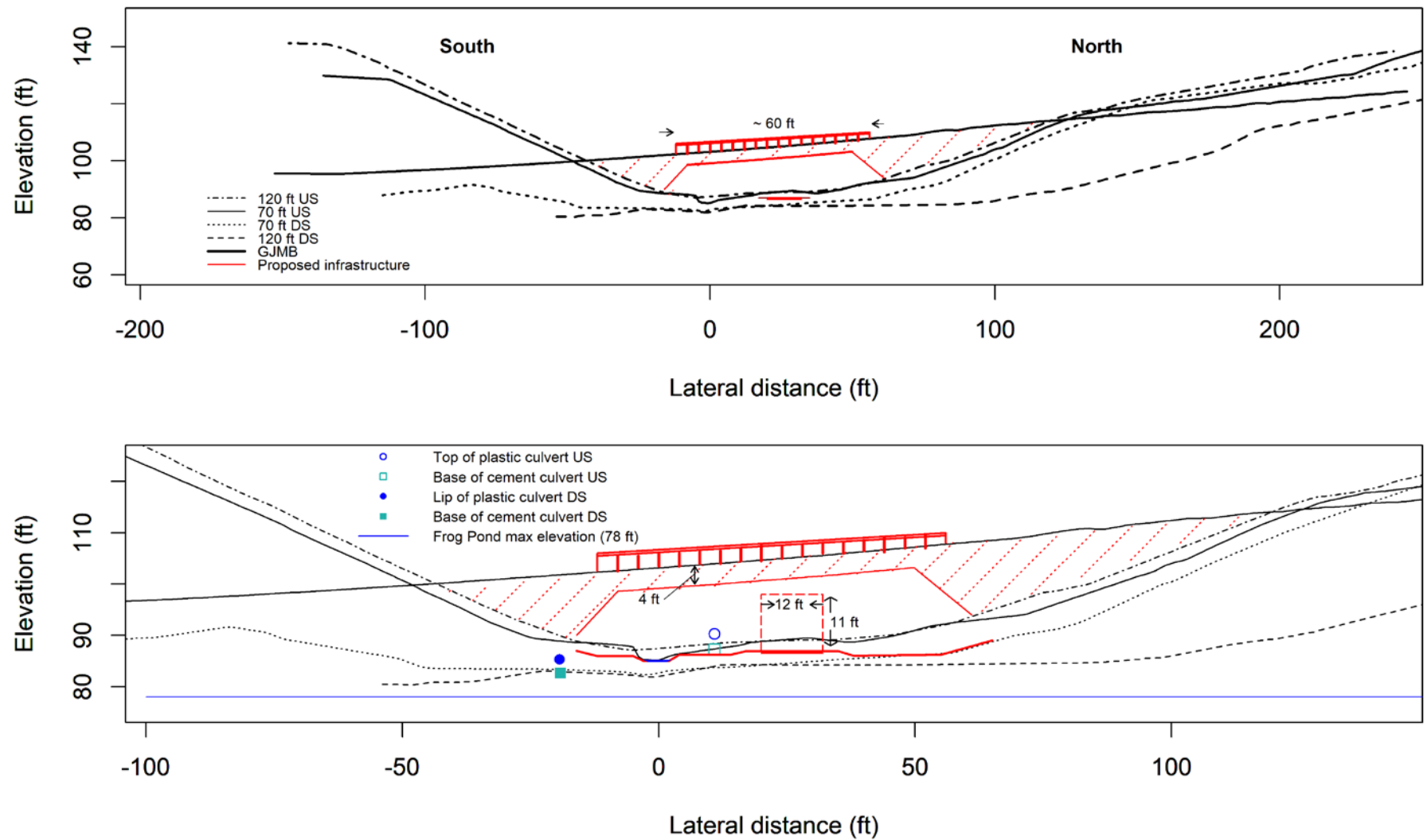


Figure 11. Two-dimensional depiction of a possible underpass design.

Frog Pond backwater is unlikely to flood the GJMB underpass. We surveyed the elevation of the flashboards at Frog Pond as 78 ft, which is well below the elevation of the most downstream culvert (~83 ft). This five-foot difference in elevation makes it unlikely that the trail will flood due to Frog Pond backwater effects (Fig. 12).

3.4 3D Design Model

We created a 3D rendering to illustrate how the vision of a continuous, open-space natural experience is feasible within the existing terrain (Fig. 13). This 3D model depicts wide underpass with ample room for an 8-ft wide natural trail surface and nearby South Boundary Tributary stream bed or linear wet meadow, depending on hydrology. A natural surface can cover the ground around the trail and streambed, creating a seamless natural experience for trail users and encouraging use by plants and wildlife. From the west side of GJMB, FORTAG takes a gentle curve toward the underpass, allowing ample visibility and natural light. On the east side, the trail extends straight out from the underpass into a stand of willow and oak trees. This open design enhances safety, perception of safety and the connectivity of the natural environment.

As depicted in this rendering, the underpass supports the FORTAG vision as supported by the MPRPD; namely the facilitation of active transport, wildlife, natural landscapes and aesthetics and the connection of open space (MPRPD 2017).

It also addresses known safety and environmental concerns that prompted MPRPD officials to request a project of this nature 20 years ago (MPRPD 1998).

These images are meant to serve as a visualization of potential underpass attributes and ambience so that the community, engineers and planners can engage in an informed planning and decision-making process.

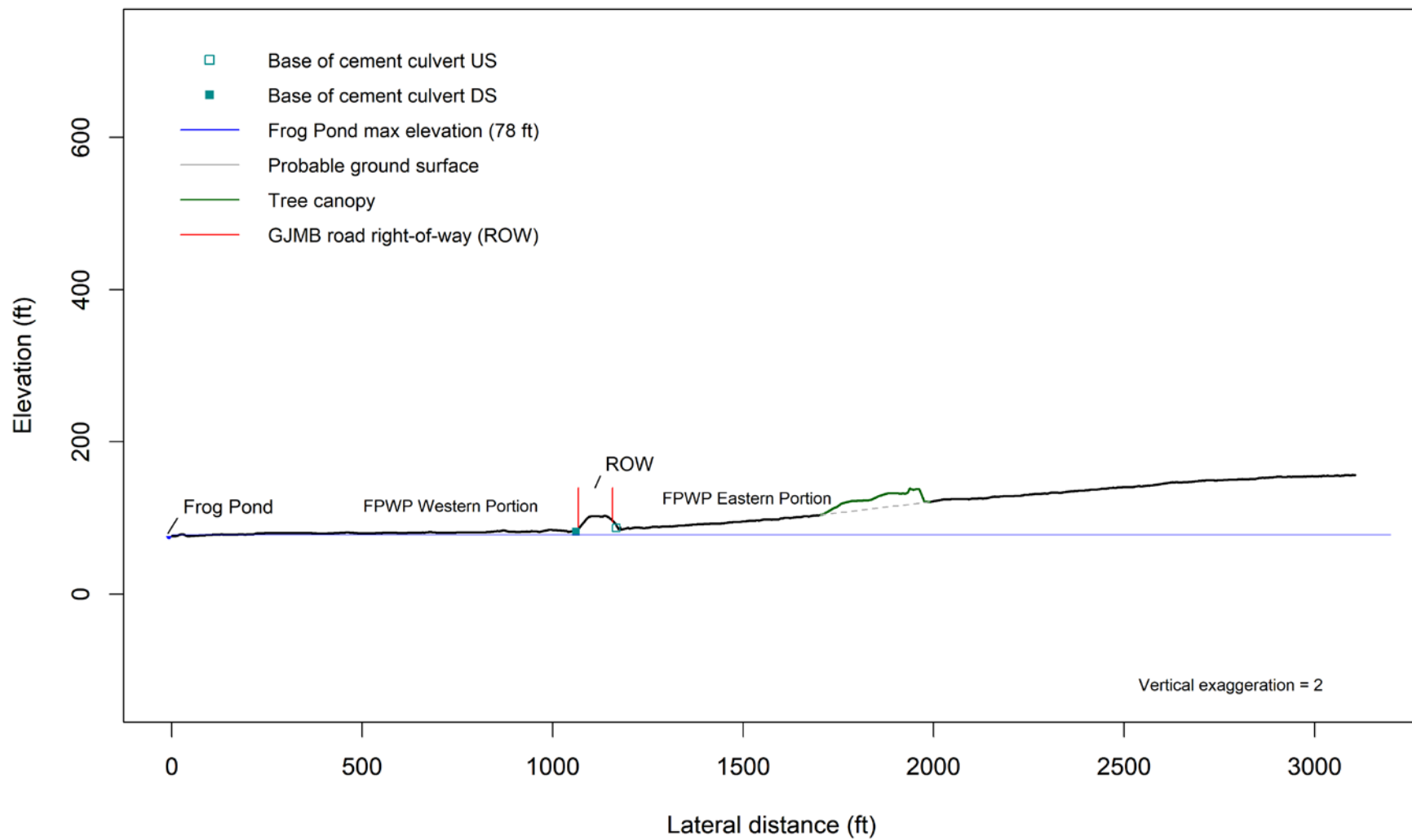


Figure 12. Longitudinal profile schematic showing the elevational relationship between the existing culvert and maximum Frog Pond elevation.



Figure 13a. Three-dimensional depiction of a possible underpass design.



Figure 13b. Three-dimensional depiction of a possible underpass design.



Figure 13c. Three-dimensional depiction of a possible underpass design.

4 Discussion

Caltrans released a draft of its first bicycle and pedestrian plan in 2017 which outlined how to increase bicycling and walking and reduce bicycle and pedestrian fatalities in California. The plan states its goal of doubling the number of walking trips and tripling the number of cycling trips by 2020 (Caltrans 2017). FORTAG and the GJMB underpass directly support these goals from Caltrans by promoting increased connectivity and safe passage for cyclists and pedestrians throughout Monterey County.

4.1 Ideal Design Components

The underpass at General Jim Moore Boulevard will help connect trails at Frog Pond Wetland Preserve to the extensive trail network in Fort Ord, allowing residents of Del Rey Oaks and other cities to access these outdoor spaces. The ideal underpass will provide safe crossing under GJMB while preserving the open, natural feel of the surrounding landscape and promoting habitat connectivity for wildlife.

4.1.1 Habitat connectivity for wildlife and plants

The main goals of the recreational trail and greenway GJMB underpass is to allow safe crossing of GJMB and connect people to two trail systems, though it will also benefit wildlife connectivity and native plant dispersal. FPWP provides rich wetland habitat for migratory birds, small and large mammals, amphibians and reptiles (Geisler et al. 2015) and notable native plant species (MPRPD 2018).

Surrounding Frog Pond itself, the park's habitat includes abundant Arroyo Willow riparian habitat, oak woodlands, Monterey Pines, grasslands and planted redwood trees (Geisler et al. 2015; MPRPD 2018).

California red legged frogs (*Rana draytoni*), listed as threatened under the Endangered Species Act, have not been recorded within the park, however the habitat there has been identified as suitable for potential colonization (Anderson 2013). In addition, officials have identified a potential breeding site for the federally-listed California tiger salamander (CST) on the FPWP parcel on the east side of GJMB (USFWS 2005). GJMB cuts off this site from continuity with the rest of the FPWR wetland habitat and poses a roadkill risk to salamanders (USFWS 2005). An underpass would connect and enhance critical habitat for these endangered amphibians.

Underpasses that allow for water flow, such as the one proposed in this report, can serve to encourage proper function and connection between riparian habitats. Depending on how they are designed, these structures may be amenable to the passage of small and large mammals, amphibians and reptiles, semi-aquatic species and semi-arboreal species (FHWA 2011).

Riparian habitat continuity should be maintained throughout the underpass, and cover can be provided in the form of woody debris, rocks and brush to encourage use by amphibians and small mammals (FHWA 2011). Natural vegetation at the approach and entrance of the underpass are essential for small and medium size mammals and will serve to benefit the overall aesthetic of the project (Cavallaro et al. 2005).

It is recommended for wildlife crossing that underpasses conform to natural topography and be constructed to minimize traffic noise and light (DOT 2011). Large, open underpasses are recommended for wildlife for increased visibility, to provide sight distances and to avoid the 'tunnel effect' which is often avoided by larger species (Ruediger 2001). We propose an open bridge span design that provides ample light to encourage growth of native vegetation inside the underpass and the atmosphere of a natural environment, creating a seamless habitat for wildlife of all sizes.

4.1.2 Human use

Primarily, the underpass should encourage a safe and seamless open-space experience for humans. An underpass would vastly increase the safe connectivity of the existing trail system and support the vision and goals of the FORTAG proposal.

Currently, a trail system connecting FPWP to South Boundary Road crosses General Jim Moore Boulevard at our study site. Pedestrians and bicyclists aiming to continue along the trail east of Frog Pond must dismount bikes and cross a busy two-lane road (MPRPD 1998). On GJMB there is a blind hill that crests just before the crossing, making it difficult for drivers to see pedestrians and vice versa, causing a safety threat. The advent of an underpass would increase the safety of people utilizing this trail system. The underpass was originally requested for these safety reasons by MPRPD in 1998 during the initial study for the GJMB (formerly North-South road)/Highway 218 improvement project (MPRPD 1998).

Bicycle and pedestrian underpasses provide the community with increased access to nature and safe road crossing, but certain design components can dictate whether people find the trail appealing and safe to use. If an underpass does not have an open

design, it may be avoided by bikers and pedestrians (MN DOT 2007). Vertical clearance for the underpass should be maximized to increase natural light, visibility and the perception of safety. In this study, GJMB is a constraint on trail vertical clearance, though the 2D model of the trail shows there is sufficient clearance for the trail without lowering the path or altering the existing roadbed. Appropriate decision sight distances are critical for safety and to give cyclists time to adjust to avoid potential crashes (UDFCD 2016). GJMB is a two-lane road, so the underpass will be shorter and require minimal lighting. Longer underpasses require greater illumination; tunnels longer than 50 ft are recommended to have 24-hour lighting (MN DOT 2007). The GJMB underpass has the capacity to provide a relatively short, open trail for safe travel by people and wildlife.

4.3 Limitations

4.3.1 Project costs

We did not specifically consider cost when determining the feasibility of the GJMB underpass. In general, underpasses are a less costly alternative to overpasses, however project costs can vary widely (MN DOT 2007). The City of Elk Grove, CA recently projected the cost of undercrossings (not including design costs) as between approximately \$250,000 to \$1 million (City of Elk Grove 2014). A recent Santa Clara pedestrian undercrossing and approach ramp, completed in 2017, had a final cost of \$13.8 million. This undercrossing extended 80 feet below three Union Pacific Railroad tracks (SCVTA 2017).

The \$40M FORTAG budget prepared for Measure X anticipated the GJMB underpass cost as \$2.88M, assuming an area of 18 ft x 80 ft at \$2,000/ft² (Wood Rogers 2015). Bridge length in our design is much longer, around 60 ft, increasing total cost. A 2017 CalTrans comparison of bridge costs cites much lower prices per square foot, ranging from \$150–\$420/ft² for high end projects (DOT 2017). The GJMB underpass project is considered high cost due to its environmental and aesthetic constraints. These costs are general, and do not include the cost of removing the existing road and berm. There is currently \$2.9M of FORTAG's budget allocated to the GJMB underpass; additional engineering cost estimates are required for a more accurate project cost.

4.3.2 Equestrian use

Equestrian use may require accommodations beyond the scope of our study. According to state regulations, pavement required for bicycle travel is not suitable for horses and

bicycles and horses should be separated from one another to avoid potentially dangerous encounters (CDT 2017). Equestrian access requires a separate natural surface trail and a barrier between horses and bicyclists. Equestrians and bicyclists should be separated by as much space as possible, and good visibility of approaching bicyclists should be maintained along the equestrian path to avoid sudden appearances that may spook horses (CDT 2017). If equestrian access is to be considered, additional research should be conducted on how this use can be accommodated to meet state regulations and guidelines.

4.3.3 Land use and future development

Although we only observed a maximum change in depth of one foot in the South Boundary Tributary below the existing GJMB culvert, the hydrology of the upper tributary needs to be assessed in greater detail as very little is known about its hydrological patterns during large storm events. The precipitation events that occurred during our study were similar to previous ones recorded by the Laguna Seca CIMIS Station since 1 October 2017 (Fig. 14), but further analysis is needed to relate this year's rain and streamflow patterns to wetter years.

Development in the upper watershed of the South Boundary tributary is required to control storm water and runoff to preserve CST habitat through a Memorandum of Agreement (MOA) between the Fort Ord Reuse Authority (FOR A) and the City of Del Rey Oaks (FOR A 2004). Developers in this area must capture and filter storm water and prevent erosion and downstream sedimentation. This mitigation is mandated in the

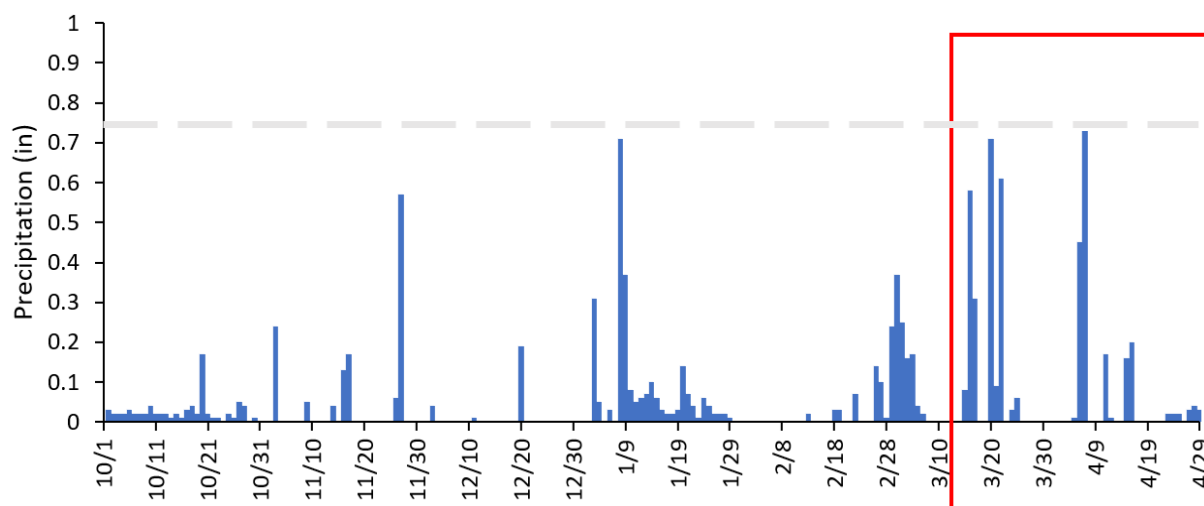


Figure 14. Precipitation events between 1 October 2017 and 30 April 2018 as recorded by CIMIS Station 229. The red box indicates the duration of this study.

framework of species protection but has the added benefit of protecting the GJMB underpass from future flood risk. An increase in upstream impervious cover could increase flow rates and sediment transport due to runoff, potentially compromising the underpass and causing more frequent flooding of the trail. The MOA expressly requires the retention of runoff from upstream development, reducing the likelihood of altered hydrologic function and GJMB trail/underpass flooding.

4.4 Recommendations

We recommend moving ahead with preliminary engineering design and cost estimation of a bridge span underpass at Highway 218 and General Jim Moore Boulevard. This report offers initial insights into the feasibility of the project and guidelines for design components. We recommend that relevant governing agencies hire an engineering consulting firm to continue the study and design of an underpass with the following attributes aforementioned in this report:

- A bridge span underpass approximately 60 ft wide that allows space for the 12 ft wide FORTAG trail (Class I Bikeway), a minimum vertical clearance of 10 ft, a bridge thickness of 4 ft and the flow of the South Boundary tributary at maximum water levels.
- Minimal rerouting of the FORTAG trail to accommodate a wide curve into the underpass from the west side to improve sightlines through the tunnel.
- As amenable as possible to wildlife connectivity for large and small wildlife including: ungulates, mesocarnivores, small mammals, semi-aquatic and semi-arboreal species. This requires attention to the continuity of habitat and natural features to encourage use by wildlife.

4.4.1 Areas of future study

- Comprehensive cost analysis of the underpass, including cost estimates for design, construction and maintenance. Comparison to similar projects and optional pricing tiers should be discussed.
- Increased and long-term monitoring of South Boundary tributary flow to determine annual hydrograph and recurrence intervals of high-flow events. This will offer a baseline against which to measure potential future impacts.

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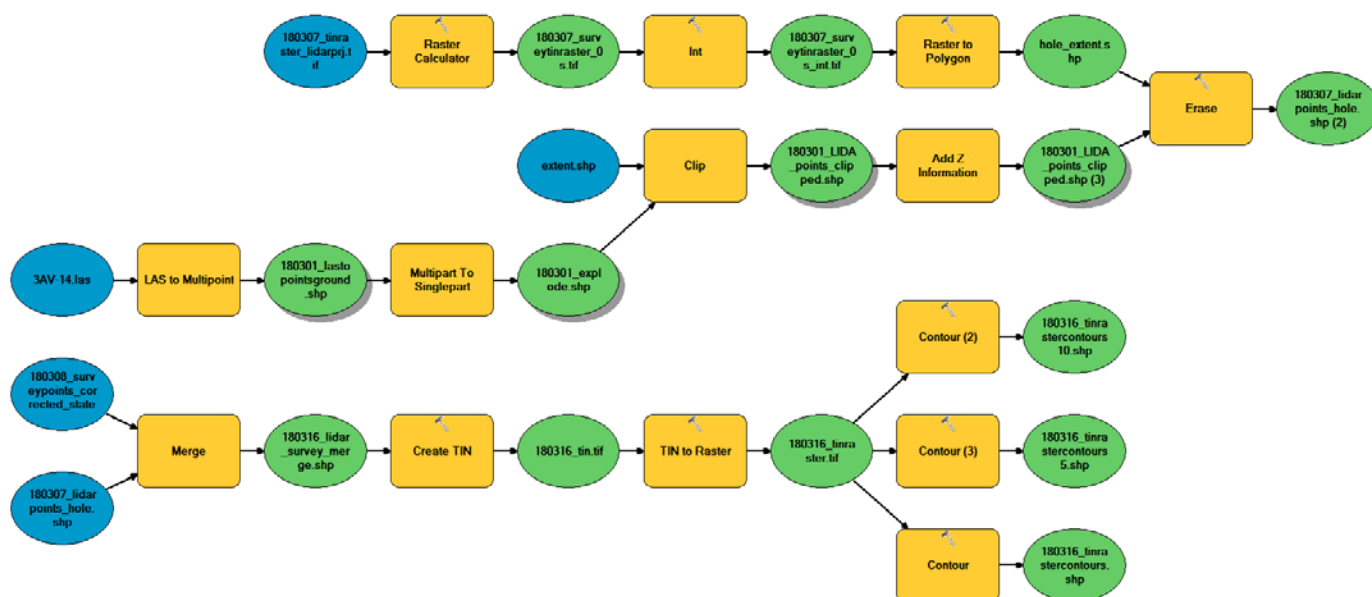
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7 Appendix

Appendix I: ArcGIS workflow



Appendix II: R code for Longitudinal Profile

```

# FORTAG longitudinal transect of S. Boundary tributary to Frog Pond

setwd("C:\\output")

rm(list=ls())
graphics.off()

xlim=c(0,3150)
ylim=c(0,600)
xlab="Lateral distance (ft)"
ylab="Elevation (ft)"

#set windows size and set margins
#windows(10,5);
par(mai=c(0.9,0.9,0.2,0.2))

#Long xsection
Long=read.csv("Long_Xsection.csv")
plot(Long, type="l",lty=1,xlim=xlim, ylim=ylim,col="black",lwd=1.5,xlab=xlab,
ylab=ylab,asp=2)
par(new=TRUE)
#Probable canopy
canopy=read.csv("canopy.csv")
plot(canopy,type="l",lty=1,xlim=xlim,ylim=ylim,col="darkgreen",lwd=1.5,xlab=xlab,
ylab=ylab,asp=2)
  
```

```

par(new=TRUE)

#Location of probable terrain
t.x=1703
t.y=104
t2.x=1990
t2.y=121
segments(x0=t.x,y0=t.y,x1=t2.x,y1=t2.y,col="darkgrey",lty=2)

#US culvert locations
#Bottom of cement
points(1167,87,type="p",pch=0,col="darkcyan",cex=0.7)

#DS culvert locations
#Base of cement
points(1061,82,type="p",pch=15,col="darkcyan",cex=0.7)

#Frog Pond
coords=rbind(c(0,76),c(-5,72),c(-10,72),c(-15,76))
polygon(coords,col="blue",border=NA,denstiy=NULL)
segments(x0=-10,y0=80,x1=15,y1=100,col="black",lwd=1)
text(x=-8,y=114,"Frog Pond",pos=4,col="black",cex=0.8)

#GJMB
segments(x0=1111,y0=140,x1=1125,y1=155,col="black",lwd=1)
text(x=1100,y=170,"ROW",pos=4,col="black",cex=0.8)
segments(x0=1067,y0=88,x1=1067,y1=140,col="red",lwd=1)
segments(x0=1157,y0=95,x1=1157,y1=140,col="red",lwd=1)

#Frog Pond flashboard elevation *corrected data
FP.elev=rbind(c(0,78),c(3200,78))
lines(FP.elev,lwd=0.5,col="blue")

legend(0,750,legend=c("Base of cement culvert US", "Base of cement culvert
DS","Frog Pond max elevation (78 ft)","Probable ground surface","Tree
canopy","GJMB road right-of-way
(ROW)"),pch=c(0,15,NA,NA,NA,NA),col=c("darkcyan","darkcyan","blue","darkgrey"
,"darkgreen","red"),lty=c(NA,NA,1,1,1,1),bg="transparent",box.lty=0,cex=0.8,y
.intersp=0.9)
text(x=2500,y=-120,"Vertical exaggeration = 2",pos=4,col="black",cex=0.7)
text(x=1000,y=115,"FPWP Western Portion",pos=2,col="black",cex=0.7)
text(x=1250,y=125,"FPWP Eastern
Portion",pos=4,col="black",adj=c(0.5,0.5),cex=0.7)

```

Appendix III: R code for 2D Underpass Schematic

```

# FORTAG cross-sectional schematic of trail undercrossing at General Jim
Moore Blvd

setwd("C:\\output")

rm(list=ls())
graphics.off()

```

```

xlim=c(-55,100)
ylim=c(60,150)
xlab="Lateral distance (ft)"
ylab="Elevation (ft)"
xlim.zm=c(-55,100)
ylim.zm=c(75,125)

#set windows size and set margins
#windows(10,5);
par=par(mfrow=c(2,1))
par(mai=c(0.9,0.9,0.2,0.2))

#GJMB center line
GJ<-read.csv("profile_CLa.csv")
plot(GJ, type="l",lty=1,xlim=xlim, ylim=ylim,col="black",lwd=1.5,xlab=xlab,
ylab=ylab, asp=1)
par(new=TRUE)

#profiles 70, 120ft upstream and downstream
xs_70_ds=read.csv("profile_70.csv")
xs_120_ds=read.csv("profile_120.csv")
xs_70_us=read.csv("profile_-70.csv")
xs_120_us=read.csv("profile_-120.csv")

plot(xs_70_ds, type="l", lty=3, xlim=xlim,
ylim=ylim,col="black",lwd=1.5,xlab=xlab, ylab=ylab, asp=1)
par(new=TRUE)
plot(xs_120_ds, type="l", lty=2, xlim=xlim,
ylim=ylim,col="black",lwd=1.5,xlab=xlab, ylab=ylab, asp=1)
par(new=TRUE)
plot(xs_70_us, type="l", lty=1, xlim=xlim,
ylim=ylim,col="black",lwd=1.5,xlab=xlab, ylab=ylab, asp=1)
par(new=TRUE)
plot(xs_120_us, type="l", lty=4, xlim=xlim,
ylim=ylim,col="black",lwd=1.5,xlab=xlab, ylab=ylab, asp=1)
par(new=TRUE)
legend(-185,95,legend=c("120 ft US","70 ft US", "70 ft DS", "120 ft DS",
"GJMB", "Proposed
infrastructure"),col=c("black","black","black","black","black","red"),bg="tra
nsparent",lty=c(4,1,3,2,1,1),lwd=c(1,1,1,1,1.5,1),box.lty=0,cex=0.6,y.intersp
=0.4,x.intersp=0.5,seg.len=1.5)
par(new=TRUE)
text(x=-100,y=140,"South",pos=4,col="black",cex=0.8,font=2)
text(x=150,y=140,"North",pos=2,col="black",cex=0.8,font=2)
par(new=TRUE)

##underpass
deck=read.csv("GJ_deck2.csv")
plot(deck,type="l", lty=1, col="red",xlim=xlim, ylim=ylim,lwd=1.5,xlab=xlab,
ylab=ylab, asp=1)
par(new=TRUE)

S.culv=rbind(c(-16,90),c(-8,98.6))
lines(S.culv,col="red",lwd=1)
N.culv=rbind(c(50,103),c(61,94))
lines(N.culv,col="red",lwd=1)

```

```

#underpass polygon
coords=rbind(c(-14,88),c(-
42,99),c(56,108),c(70,109),c(119,114),c(61,94),c(50,103),c(-8,98))
polygon(coords,col="red",border=NA,density=12,lty=3,angle=45)

#12' wide trail
#13' vertical clearance
y.pave.trail=87
x.pave.trail=20
xy=rbind(
  c(x.pave.trail,y.pave.trail),
  c(x.pave.trail+12,y.pave.trail))
lines(xy,col="red",lwd=1)
xy=rbind(
  c(x.pave.trail,y.pave.trail-.5),
  c(x.pave.trail+12,y.pave.trail-.5))
lines(xy,col="red",lwd=1)
coords1=rbind(c(20,86.5),c(20,87),c(32,87),c(32,86.5))
polygon(coords1,col="red",border=NA,density=-5,lty=1,angle=50)

segments(x0=-18,y0=110,x1=-15,y1=110,col="black",lwd=0.5)
segments(x0=61,y0=113,x1=59,y1=113,col="black",lwd=0.5)
arrows(x0=-15,y0=110,x1=-13,y1=110,length=0.05,col="black",code=2,lty=1)
arrows(x0=59,y0=113,x1=57,y1=113,length=0.05,col="black",code=2,lty=1)
text(x=10,y=113,"~ 60 ft",pos=4,col="black",cex=0.6)

#2%, 3' slope L shoulder
xy=rbind(
  c(x.pave.trail,y.pave.trail),
  c(x.pave.trail-3,y.pave.trail-0.06))
lines(xy,col="darkred",lwd=1)

#2%, 3' slope R shoulder
xy=rbind(
  c(x.pave.trail+12,y.pave.trail),
  c(x.pave.trail+15,y.pave.trail-0.06))
lines(xy,col="darkred",lwd=1)

#Bridge railing
b.rail=rbind(c(-12,102.5),c(-12,106))
lines(b.rail,col="red",lwd=1.3)
b.rail=rbind(c(-8,102.5),c(-8,105.5))
lines(b.rail,col="red",lwd=2)
b.rail2=rbind(c(52,107),c(52,109.5))
lines(b.rail2,col="red",lwd=2)
b.rail2=rbind(c(56,108),c(56,110))
lines(b.rail2,col="red",lwd=1.3)
top.rail=rbind(c(-12,106),c(56,110))
lines(top.rail,col="red",lwd=1.3)
top.rail2=rbind(c(-12,105.5),c(56,109.5))
lines(top.rail2,col="red",lwd=1.3)
segments(x0=-4,y0=103.25,x1=-4,y1=105.5,col="red",lwd=2)
segments(x0=0,y0=103.5,x1=0,y1=106,col="red",lwd=2)
segments(x0=4,y0=103.5,x1=4,y1=106,col="red",lwd=2)
segments(x0=8,y0=104,x1=8,y1=106.5,col="red",lwd=2)
segments(x0=12,y0=104,x1=12,y1=106.5,col="red",lwd=2)

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segments(x0=16,y0=104.5,x1=16,y1=107,col="red",lwd=2)
segments(x0=20,y0=104.5,x1=20,y1=107.5,col="red",lwd=2)
segments(x0=24,y0=105,x1=24,y1=107.5,col="red",lwd=2)
segments(x0=28,y0=105.5,x1=28,y1=107.5,col="red",lwd=2)
segments(x0=32,y0=106,x1=32,y1=108,col="red",lwd=2)
segments(x0=36,y0=106,x1=36,y1=108,col="red",lwd=2)
segments(x0=40,y0=106.5,x1=40,y1=108.5,col="red",lwd=2)
segments(x0=44,y0=106.25,x1=44,y1=109,col="red",lwd=2)
segments(x0=48,y0=107,x1=48,y1=109,col="red",lwd=2)

#Plot 2 zoom
plot(GJ, type="l",lty=1,xlim=xlim.zm,
ylim=ylim.zm,col="black",lwd=1,xlab=xlab, ylab=ylab, asp=1)
par(new=TRUE)

plot(xs_70_ds, type="l", lty=3, xlim=xlim.zm,ylim=ylim.zm,xlab=xlab,
ylab=ylab, asp=1)
par(new=TRUE)
plot(xs_120_ds, type="l", lty=2, xlim=xlim.zm, ylim=ylim.zm,xlab=xlab,
ylab=ylab, asp=1)
par(new=TRUE)
plot(xs_70_us, type="l", lty=1, xlim=xlim.zm,ylim=ylim.zm,xlab=xlab,
ylab=ylab, asp=1)
par(new=TRUE)
plot(xs_120_us, type="l", lty=4, xlim=xlim.zm, ylim=ylim.zm,xlab=xlab,
ylab=ylab, asp=1)
par(new=TRUE)

plot(deck,type="l", lty=1, col="red",xlim=xlim.zm,ylim=ylim.zm,xlab=xlab,
ylab=ylab, asp=1)
par(new=TRUE)

S.culv=rbind(c(-16,90),c(-8,98.6))
lines(S.culv,col="red",lwd=1)
N.culv=rbind(c(50,103),c(61,94))
lines(N.culv,col="red",lwd=1)

#underpass polygon
coords=rbind(c(-14,88),c(-
42,99),c(56,108),c(70,109),c(119,114),c(61,94),c(50,103),c(-8,98))
polygon(coords,col="red",border=NA,density=12,lty=3,angle=45)
segments(x0=7,y0=100,x1=7,y1=103.5,col="black",lwd=0.5)
arrows(x0=7,y0=100,x1=7,y1=103.5,col="black",code=3,length=0.05,lty=1)
segments(x0=7,y0=102,x1=1,y1=97,col="black",lwd=0.5)
text(x=3,y=97,"4 ft",col="black",cex=0.6,pos=2)

#12' wide trail
#13' vertical clearance
y.pave.trail=87
x.pave.trail=20
xy=rbind(
  c(x.pave.trail,y.pave.trail),
  c(x.pave.trail+12,y.pave.trail))
lines(xy,col="red",lwd=1)
xy=rbind(
  c(x.pave.trail,y.pave.trail-.5),
  c(x.pave.trail+12,y.pave.trail-.5))

```

```

lines(xy,col="red",lwd=1)
coords1=rbind(c(20,86.5),c(20,87),c(32,87),c(32,86.5))
polygon(coords1,col="red",border=NA,density=-5,lty=1,angle=50)

#2%, 3' slope L shoulder
xy=rbind(
  c(x.pave.trail,y.pave.trail),
  c(x.pave.trail-3,y.pave.trail-0.06))
lines(xy,col="darkred",lwd=1)

#2%, 3' slope R shoulder
xy=rbind(
  c(x.pave.trail+12,y.pave.trail),
  c(x.pave.trail+15,y.pave.trail-0.06))
lines(xy,col="darkred",lwd=1)

#Bridge railing
b.rail=rbind(c(-12,102.5),c(-12,106))
lines(b.rail,col="red",lwd=1.3)
b.rail=rbind(c(-8,102.5),c(-8,105.5))
lines(b.rail,col="red",lwd=2)
b.rail2=rbind(c(52,107),c(52,109.5))
lines(b.rail2,col="red",lwd=2)
b.rail2=rbind(c(56,108),c(56,110))
lines(b.rail2,col="red",lwd=1.3)
top.rail=rbind(c(-12,106),c(56,110))
lines(top.rail,col="red",lwd=1.3)
top.rail2=rbind(c(-12,105.5),c(56,109.5))
lines(top.rail2,col="red",lwd=1.3)
segments(x0=-4,y0=103.25,x1=-4,y1=105.5,col="red",lwd=2)
segments(x0=0,y0=103.5,x1=0,y1=106,col="red",lwd=2)
segments(x0=4,y0=103.5,x1=4,y1=106,col="red",lwd=2)
segments(x0=8,y0=104,x1=8,y1=106.5,col="red",lwd=2)
segments(x0=12,y0=104,x1=12,y1=106.5,col="red",lwd=2)
segments(x0=16,y0=104.5,x1=16,y1=107,col="red",lwd=2)
segments(x0=20,y0=104.5,x1=20,y1=107.5,col="red",lwd=2)
segments(x0=24,y0=105,x1=24,y1=107.5,col="red",lwd=2)
segments(x0=28,y0=105.5,x1=28,y1=107.5,col="red",lwd=2)
segments(x0=32,y0=106,x1=32,y1=108,col="red",lwd=2)
segments(x0=36,y0=106,x1=36,y1=108,col="red",lwd=2)
segments(x0=40,y0=106.5,x1=40,y1=108.5,col="red",lwd=2)
segments(x0=44,y0=106.25,x1=44,y1=109,col="red",lwd=2)
segments(x0=48,y0=107,x1=48,y1=109,col="red",lwd=2)

#US culvert locations
#Top of black plastic
points(10.9,90.28,type="p",pch=1,col="blue")
#Bottom of cement
points(10.9,87.27,type="p",pch=0,col="lightseagreen")
legend(-60,130,legend=c("Top of plastic culvert US","Base of cement culvert
US", "Lip of plastic culvert DS","Base of cement culvert DS","Frog Pond max
elevation (78 ft)"),pch=c(1,0,16,15,NA),col=c("blue","lightseagreen",
"blue","lightseagreen","blue"),lty=c(NA,NA,NA,NA,1),bg="transparent",box.lty=
0,cex=0.6,y.intersp=0.6)

#DS culvert locations
#S lip of black plastic

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points(-19.3,85.3,type="p",pch=16,col="blue")
#Base of cement
points(-19.2,82.67,type="p",pch=15,col="lightseagreen")

#Frog Pond flashboard elevation *corrected data
FP.elev=rbind(c(-100,78),c(150,78))
lines(FP.elev,lwd=0.5,col="blue")

#Proposed trail elevation
trail.coords=rbind(c(-16,87),c(-12,86),c(-5,86),c(-
3,85),c(2,85),c(4,86.25),c(14,86.25),c(17,86.94),c(35,86.94),c(38,86.04),c(55
,86.25),c(65,89))
lines(trail.coords,col="red",lwd=1.5)
coords2=rbind(c(-3,85.25),c(-2,84.75),c(1.5,84.75),c(2.5,85.25))
polygon(coords2,col="blue",density=-5,border=NA)

#trail tunnel box
coords3=rbind(c(20,87),c(20,98),c(32,98),c(32,87))
polygon(coords3,col="red",lty=5,density=0,border="red")
segments(x0=20,y0=96,x1=22.5,y1=96,col="black",lwd=0.5)
segments(x0=29.5,y0=96,x1=32,y1=96,col="black",lwd=0.5)
arrows(x0=20,y0=96,x1=22.5,y1=96,length=0.05,col="black",code=2,lty=1)
arrows(x0=32,y0=96,x1=29.5,y1=96,length=0.05,col="black",code=2,lty=1)
text(x=31,y=96,"12 ft",pos=2,col="black",cex=0.6)
segments(x0=x.pave.trail+13.5,y0=y.pave.trail+1,x1=x.pave.trail+13.5,y1=y.pav
e.trail+4,col="black",lwd=0.5)
segments(x0=x.pave.trail+13.5,y0=y.pave.trail+7.5,x1=x.pave.trail+13.5,y1=y.p
ave.trail+10.5,col="black",lwd=0.5)
arrows(x0=x.pave.trail+13.5,y0=y.pave.trail+4,x1=x.pave.trail+13.5,y1=y.pave.
trail+1,length=0.05,angle=60,col="black",code=2,lty=1)
arrows(x0=x.pave.trail+13.5,y0=y.pave.trail+7.5,x1=x.pave.trail+13.5,y1=y.pav
e.trail+10.5,length=0.05,angle=60,col="black",code=2,lty=1)
text(x=x.pave.trail+10.5,y=y.pave.trail+5.5,"11
ft",pos=4,col="black",cex=0.6)

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