# FINAL

## TECHNICAL MEMORANDUM NO. 5
## GROUNDWATER INFLOW MITIGATION PLAN

Water Treatment Plant #4 – Jollyville Transmission Main — B&V Project 167760
Phase B – Final Design — B&V File D-1.2
CIP ID: 6935.016

**To:** Stacie Long, P.E. – Project Manager, City of Austin

**From:** Dennis Allen, P.E. – Project Manager, Black & Veatch

**Date:** May 12, 2011 (replaces all previous versions)

### 1. Introduction

The proposed Jollyville Transmission Main (JTM) tunnel will convey finished water via a pipeline installed from Water Treatment Plant No. 4 (WTP4) to the Jollyville Reservoir (JR) for distribution by the City of Austin (COA). Any tunnel constructed in water bearing rock will experience groundwater inflow. In general, this water can be managed in the tunnel by the contractor. However, excessive groundwater infiltration adversely affects tunnel excavation. Additionally, the JTM tunnel will pass beneath environmentally sensitive springs and Bull Creek where shaft and tunnel construction impacts on groundwater must be avoided or minimized. The purpose of Technical Memorandum (TM) No. 5 is to present a avoidance and mitigation plan for groundwater inflow encountered during the construction of the shafts and tunnel.

### 2. Tunnel Design Parameters and Requirements

This TM is based on the tunnel alignment from WTP4 to the JR as presented in the Preliminary Engineering Report and as presented in TM No. 11 (Evaluation of Alternative Tunneling Concepts) dated September 22, 2010. Figure 1 shows the proposed horizontal alignment and shaft locations. The alignment and shaft locations were confirmed during detailed design. Figure 2 shows the proposed vertical alignment and direction of tunneling that was presented as Alternative 2 in TM No. 11. This vertical alignment or tunnel profile was adjusted as additional geotechnical information was gathered and reviewed during detailed design. The tunnel was lowered approximately 50 feet to zones of lower permeability in the Glen Rose formation near the Parks and Recreation Department (PARD) shaft site and Jollyville Reservoir (JR) shaft site. Figure 3 shows the final tunnel profile.

Other design parameters and requirements used in the development of the TMs and Basis of Design Report that were confirmed during detailed design, include the following:

**Table 1**
**JTM Tunnel Design Parameters**

| No. | Design Parameter | Description and Rationale |
|---|---|---|
| 1 | Tunnel Horizontal Alignment | Alignment as presented in the PER and subsequent TM No. 11 (Evaluation of Alternative Tunneling Concepts). See Figure 1. |
| 2 | Design, Bid Documents, and Contract Execution Schedule | Design, sealed, and bid-ready 100% contract documents completed by April 29, 2011, with an anticipated notice to proceed for Construction in Fall 2011. |
| 3 | Construction Schedule | The tunneled pipeline must be finished by Spring 2014 when WTP4 is scheduled to be operational. This schedule only allows a total of approximately 30 months for construction, requiring the need for two tunnel boring machines (TBMs). |
| 4 | Working Shafts | Working shafts approximately 40 feet excavated diameter will be located at Jollyville Reservoir (JR) and Four Points Area (FPA), and will be approximately 350 and 270 feet, deep respectively. |
| 5 | TBM Retrieval Shafts | TBM retrieval shafts approximately 20 to 30 feet excavated diameter will be located at the WTP4 and Parks and Recreation Department (PARD) sites, and will be approximately 200 feet and 125 feet deep, respectively. Construction Manager-at-Risk (CMAR) has requested that |

**Table 1**
**JTM Tunnel Design Parameters**

| No. | Design Parameter | Description and Rationale |
|---|---|---|
| | | the WTP4 site be used as a retrieval shaft only to minimize congestion at the site with the planned construction work. Pipe installation and grouting will be undertaken at the WTP4 and PARD sites to achieve completion of the project within the required timeframe. |
| 6 | Tunnel Construction | The tunnel will be approximately 10 feet in excavated diameter and 34,600 feet in length. Tunneling will be advanced upgradient from the JR shaft to the PARD shaft and from the FPA shaft to the WTP4 shaft. Tunneling will be advanced downgradient from the FPA shaft to the PARD shaft. |
| 7 | Minimal Environmental Impacts | No or minimal construction and operations impact objectives must be targeted for sensitive environments, including protected endangered or threatened species, karst impacts, and other critical groundwater and surface water resources. |
| 8 | Ventilation Shafts | No ventilation shafts have been permitted or provided in the design. |
| 9 | Working Hours | Acceptable working hours will be 12 hours per day from 7:00 a.m. to 7:00 p.m., Monday through Friday, excluding subterranean tunnel boring. Muck hauling outside the limits of the shaft sites will be 9:00 a.m. to 4:00 p.m. All muck hauling outside the limits of the PARD site will be 9:00 a.m. to 3:00 p.m. due to school drop-off and pickup times. Maintenance work will be allowed at the shaft sites from 8:00 a.m. to 5:00 p.m. on Saturdays, as approved by the COA. No work will be allowed on Sundays and major holidays. |

**Table 1**
**JTM Tunnel Design Parameters**

| No. | Design Parameter | Description and Rationale |
|---|---|---|
| | | |
| 10 | Noise | Noise at the shaft sites will comply with the COA Code of Ordinances, Chapter 9-2-3 (General Restrictions),which prohibits (a) noise audible to an adjacent business or residence between 10:30 p.m. and 7:00 a.m. and (b) operation of a machine that separates, gathers, grades, loads, or unloads sand, rock, or gravel within 600 feet of a residence, church, hospital, hotel, or motel between 7:00 p.m. and 6:00 a.m., except for the installation of concrete as authorized under Section 9-2-15 (Permit for Concrete Installation During Non-Peak Hour Periods). Contractor will be required to prepare and implement a noise monitoring plan, and if necessary to conform to the noise ordinance, implement noise abatement. |
| 11 | Truck Loads | Contractor may use maximum capacity trucks as allowed by the road limits for muck removal. |

## 3. Background and Objectives

This TM outlines the mitigation steps to reduce potential impacts to surface water and groundwater during tunnel and shaft construction and presents guidelines for preparation of the contract documents, including the Geotechnical Baseline Report. The purpose of this groundwater mitigation plan is to identify and design groundwater and surface water avoidance and mitigation strategies. Additionally, the plan presents contingency measures that will be implemented when and if groundwater inflow impacts the environment during shaft and tunnel construction.

## 4. Project Area Geology and Hydrogeology

The JTM project area lies within the dissected edge of the Edwards Plateau physiographic province. The general geology of the JTM alignment corridor includes a thin veneer of soil overlying carbonate (limestone and dolomite) bedrock. Soils are generally comprised of clay and silty clay, and commonly contain gravel size fragments of the underlying bedrock. The bedrock is comprised of a series of Cretaceous carbonate rocks that have been divided into four geological formations. From top to bottom, or youngest to oldest, these formations are the Edwards, Comanche Peak, Walnut, and Glen Rose. The tunnel will be excavated entirely within the Glen Rose formation.

There are two groundwater flow regimes present in the project area: an upper flow regime in the Edwards and Walnut formations, and a lower flow regime in the Glen Rose formation.

Precipitation generally enters the Edwards as recharge, where the formation crops out throughout the Edwards Plateau, and moves downward through the Edwards until encountering a less permeable layer. It then moves laterally, primarily discharging as springs and seeps along the hillsides found in the Project Area. Many of the springs and seeps occur at the Edwards/Walnut contact and at Walnut bedding planes. Springs that are present in the upper Glen Rose Formation are also considered to be part of the shallow flow system.

Groundwater flow is primarily away from the topographic highs in the shallow flow system. Dye tracing conducted by the City of Austin staff indicated estimated groundwater flow velocities on the order of tens of feet per day, indicating that flow in this shallow flow system is typical of a karst system.

The second groundwater flow regime is the deep flow system within the Glen Rose Formation, which is largely hydrologically disconnected, by either the Walnut Formation or the upper Glen Rose Formation, from the shallow groundwater flow system within the Edwards Limestone. A downward hydraulic gradient is observed within the deep flow system. Estimated hydraulic conductivities in the Glen Rose are low: the upper 50 feet of the Glen Rose appears to be more permeable, but below this zone the Glen Rose is consistently very tight, often yielding estimated hydraulic conductivities too low to be measured during packer tests.Hydraulic conductivity in the Glen Rose formation, as measured by packer tests, ranges from $<1x10^{-7}$ cm/s to $3x10^{-3}$ cm/s. Packer tests generally measure horizontal hydraulic conductivity. Vertical hydraulic conductivity is often one to two times lower than horizontal hydraulic conductivity. Groundwater movement in the Glen Rose is through discontinuities in the rock mass (joints, shears, faults and bedding planes) and vugs.

## 5. Groundwater Inflow

Potential sources of water inflow are as described in the previous section. Water inflows are generally expected throughout the alignment, but will vary along the alignment according to the hydraulic conductivity and storativity of the rock surrounding the tunnel. Packer testing has identified areas along the east and west ends of the alignment where there are areas of generally higher hydraulic conductivity in the Glen Rose formation. These areas are coincident with areas where there is Edwards and Walnut formations present above the Glen Rose. A central zone, generally associated with the BCP and lowlands area near Bull Creek and its tributaries has noticeably lower hydraulic conductivity, corresponding to areas where the Edwards and Walnut formations have been eroded away.

## 6. Groundwater Inflow Estimates

Analyzing potential groundwater inflows from fractured and vuggy rock has its inherent limitations. The high variability in the spacing, connectivity and character of rock mass discontinuities add uncertainty to estimating where inflows may occur and the sustainability of those inflows into the tunnel.

The radial flow equation was used to calculate inflows using modifications suggested by Heuer (1995, 2005) to calculate groundwater inflow. Heuer's method uses a 1/8$^{th}$ reduction factor (based on empirical evidence) for radial steady state flow (continuous recharge). This is similar to the 1/10$^{th}$ factor suggested by some investigators for assessing long term inflows (Schmidt, 1999). Also, the heading factors suggested by Heuer were used, varying from 1 for low permeability to 4 for high permeability rock. The two groundwater inflow conditions to be considered are initial heading flush inflow and long term steady state inflow. The long term, steady state inflow condition is reached with time and the distance from the face. The time between the initial heading inflow condition and the long term, steady state inflow condition may vary from a day to a month depending on the ground and recharge conditions. The calculated flows represent average groundwater inflow assuming instantaneous excavation without any mitigation techniques.

The following is a description of the steps taken to assess the groundwater inflow into the tunnel:

1. Lugeon tests were performed in most of the exploration boreholes. Except for the first test at the bottom of each boring, the tests were done with a straddle packer system spanning a length of 12 to 17 feet. Generally, each test had 5 steps, with pressures ranging from ½ to 1 psi per foot of depth to the center of the test interval. Overlapping tests were run throughout the Glen Rose formation.

2. Lugeon tests were analyzed using the Houlsby method (Houlsby, 1976) to choose the representative apparent hydraulic conductivity for each test interval.

3. The thickness of limestone/dolomite interbedding was too thin compared to the length of the test intervals to allow a separate calculation for each lithology.

4. Groundwater inflow was calculated based on Heuer's method, as described above, for both sustained and heading flush flow.

The inflows shown below are for unmitigated conditions, meaning that no measures are taken to reduce inflows during construction. Inflows were estimated along distinct reaches of tunnel as follows:

- Reach 1 – From WTP4 shaft to FPA shaft
- Reach 2 – From FPA shaft to PARD shaft
- Reach 3 – From PARD shaft to JR shaft

| Reach | Average Unmitigated Steady-State Inflow (gpm) | Maximum Unmitigated Flush Flow (gpm) |
|---|---|---|
| 1 | 80 | 120 |
| 2 | 370 | 630 |
| 3 | 510 | 980 |

These reaches correspond with proposed shafts, and with variations seen in the hydraulic conductivity data, which is presented in the GDM. It was observed from the data collected that there is lower hydraulic conductivity in the Glen Rose formation through the BCP where the Edwards and Walnut have been eroded off exposing the Glen Rose. Higher hydraulic conductivity was observed on both ends of the tunnel alignment in the upper portions of the Glen Rose.

Shaft inflow was calculated using the Thiem Equation for steady state radial flow in an unconfined aquifer.

$$Q=K(\pi(b_2^2-b_1^2))/\ln(r_2/r_1)$$

Hydraulic conductivity values from the boring adjacent to each shaft location were used for this analysis. Flush flows were calculated as three times the steady state inflow. The inflows for unmitigated flows into the shafts are as follows:

| Shaft | Unmitigated Steady-State Inflow (gpm) | Maximum Unmitigated Flush Flow (gpm) |
|---|---|---|
| WTP4 (R-1) | 65 | 260 |
| FPA (W-1) | 85 | 255 |
| PARD (R-2) | 50 | 150 |
| JR (W-2) | 60 | 240 |

## 7. Inflow Mitigation Techniques

There are numerous mitigation measures that have been used to decrease the groundwater inflow into tunnels and shafts. The mitigation measures chosen depend on ground conditions, inflow estimates, tunnel/shaft diameter, tolerance for dewatering, allowable inflow, tunnel/shaft depth, and access to the surface for construction activities. Based on these factors for the JTM tunnel and shaft, the following mitigation techniques were evaluated:

- Avoidance techniques
- Probing (drilling ahead of advancing tunnel face), the results of which may trigger mitigation
- Pre-excavation grouting from the TBM ahead of tunnel face or from the surface for shafts
- Gasketed liner plates
- Bolted, gasketed, pre-cast concrete segments in the tunnel
- Contact and consolidation grouting around the final lining of the tunnel and shafts
- Post-excavation remedial grouting
- Steel Liner

Each of these methods is described below, along with their application to the Jollyville Transmission Main.

Avoidance Techniques. These mitigation techniques include:

- Avoid tunneling in formations that feed springs necessary for the Jollyville Plateau Salamander. This has been accomplished by keeping the entire tunnel alignment within the Glen Rose formation, and at an elevation at least 100 feet below nearby springs.

- Confine tunneling to an aquifer that is not a major part of the spring aquifer system. The confined Glen Rose aquifer is believed to be separated by the argillaceous limestone in the middle and lower Walnut formation from the overlying unconfined aquifer of the Edwards and upper Walnut, which feed most of the springs.

- Provide sufficient cover over the tunnel beneath Bull Creek and its tributaries to protect against a possible vertical conduit that might allow direct impacts to the creek. A minimum of 100 feet of cover has been established by the preferred vertical alignment.

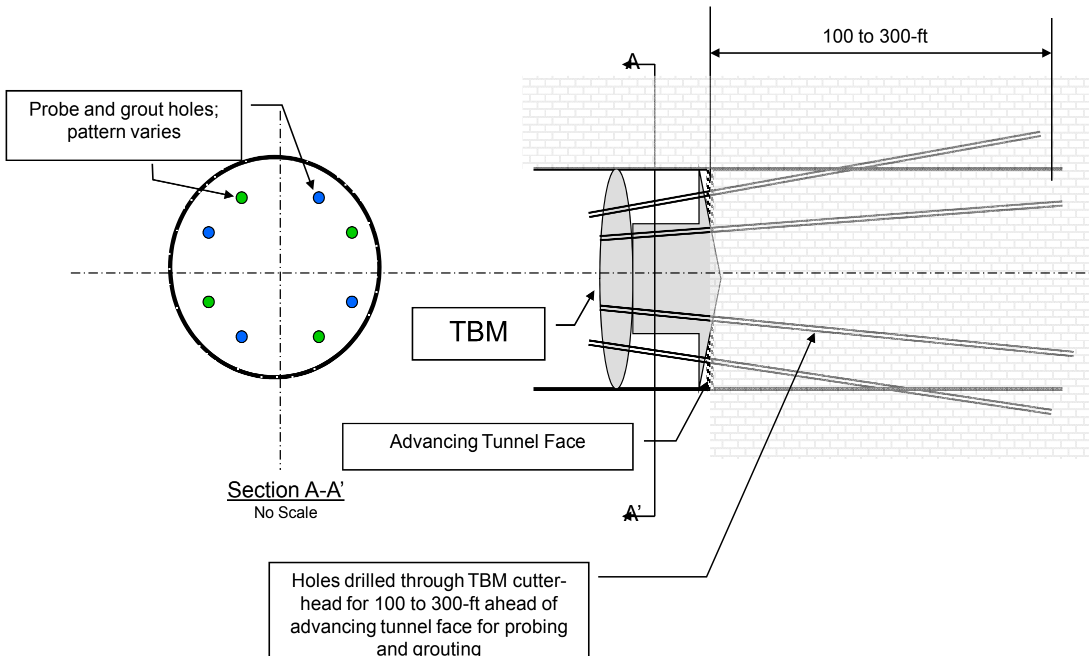
- Avoid indentified zones of high hydraulic conductivity. This has been accomplished by adjusting the vertical alignment to minimize excavation in a relatively high hydraulic conductivity zone in the upper portion of the Glen Rose identified by packer testing (see Figure 3-45 in the GDM).

- Place shafts as far away as possible from known springs. This has been accomplished by moving the Four Points Area Shaft (FPA W-1) to the west end of the property, and by moving the PARD Shaft (R-2) as far from the nearby Bull Creek tributary as possible.

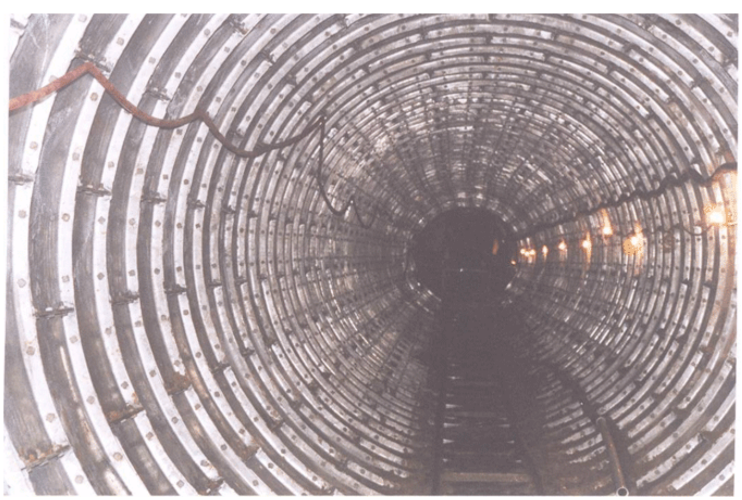
Probing. This method entails drilling a near horizontal boring 100 to 300 foot long ahead of the TBM along the tunnel alignment to determine if zones of high hydraulic conductivity are about to be encountered by the advancing TBM. The hydraulic conductivity can be estimated by packer testing the hole, or measuring flow out of the hole. This method is as a trigger for utilizing a mitigation technique, such as pre-excavation grouting. Probing is a reasonable tool for the JTM due to the overall low hydraulic conductivity, which would preclude mitigating the entire length of the tunnel.

This method would allow areas targeted as environmentally sensitive, recognized as likely having high hydraulic conductivity, or when a predetermined base level of inflow has been reached to be tested and mitigated prior to excavation. Excavation is stopped during probing and testing of the probe hole. This slows progress and increases costs, so the length of areas to be probed must be weighed against the cost.

Pre-excavation Grouting from the TBM Ahead of Tunnel Face. This method involves drilling near horizontal holes ahead of the active tunnel face and pressure grouting the holes to reduce rock mass hydraulic conductivity prior to excavation. The drill holes are drilled through the TBM while it is not actively mining, and are fanned out, generally less than $10^{o}$, from the centerline axis of the tunnel creating a cone as seen in the figure below. In conditions such as the JTM, with an overall low hydraulic conductivity, pre-excavation grouting is done only where geologic features have been identified that will likely have increased transmissivity (for instance fault zones) or is used in combination with probing through sensitive areas of the alignment. Pre-excavation grouting of this sort is expensive because it stops the progress of the TBM, and that is exacerbated for the JTM due to its small diameter (likely 10 feet excavated diameter) making work conditions difficult.




Gasketed Liner Plates. These are steel plates that bolt together to form a complete ring inside the excavated tunnel or shaft as shown below. The rim of each plate has gaskets to help seal the tunnel from inflows. Following installation, the annular space between the liner plate and the excavated rock surface is filled with grout to further limit inflows and help distribute rock and groundwater loads on the liner. It is likely that liner plates designed for this project could be installed by hand, but the contractor may elect to include a hydraulic erector to facilitate installation.



Contact and Consolidation Grouting. These techniques are generally done in combination with liner plates, pre-cast segments as described above, or cast in place concrete. Contact grouting is targeted at the annular space between the liner and tunnel perimeter, and the rock very close to the excavation surface. Consolidation grouting is targeted at fractured rock outside the contact grouting ring out to a distance dependent on rock and groundwater conditions.

Post Excavation Remedial Grouting. This method targets areas of high inflow after the TBM has passed. Grout holes are drilled to intersect the observed flow pathway out some distance from the tunnel perimeter, and grout is injected under pressure to fill the open fracture or vuggy zone and thereby reduce the flow rate. Hydrophobic polyurethane grouts have been used with success in this application, as have traditional cement grouts.

Steel Liner. Although this is a post-construction phase mitigation method, it is important to note that there will be a continuous steel liner installed in the tunnel which will prevent groundwater infiltration after construction is completed. It is also noteworthy that the higher inflow sections of Reach 1 and Reach 3 will have the steel liner installed before completion of the Reach 2 section. Thus, any potential impacts to groundwater levels in Reach 1 and 3 will be recovering before the project is completed.

### 7.1 Monitoring

Monitoring will be a key aspect of the groundwater inflow management program for the JTM. The following locations will require monitoring during construction:

- Piezometers installed as part of the design investigation
- Additional piezometers deemed necessary to be installed by the contractor prior to excavation, based on the results of groundwater modeling results, and at locations particularly sensitive to groundwater drawdown
- Bull Creek – at multiple points along the route
- Key springs – depending on accessibility to be worked out with BCP personnel, and private citizens
- Tunnel inflow – at each working shaft

The monitoring plan will be developed by the Environmental Commissioning Team, who will determine the monitoring points, monitoring parameters, and the responsible party for performing the monitoring.

### 7.2 Contract Documents

The contact documents will have provisions to specify the contractor's monitoring responsibility, specify triggers for groundwater inflow mitigation techniques to be performed during construction; and specify areas where mitigation techniques are required. At a minimum, the contract documents will address the following:

- Specifications
  - Will include requirements for monitoring tunnel inflows. This will include the locations, schedule, duration, method and reporting of monitoring required of the contractor, or the CMAR.
  - Will include any requirements that the TBM must have to perform inflow mitigation techniques that may be used.
  - Will specify the mitigation techniques selected for use during construction.
- Drawings – will include details and plans with locations for monitoring, and details of mitigation techniques.
- Geotechnical Baseline Report (GBR) – will provide our understanding of the groundwater system in the area, unmitigated baseline inflow rates for tunnel and shaft excavation, trigger points, and responses to trigger points.

### 7.3 Tunnel Water Treatment and Discharge

Tunnel water treatment and discharge is discussed in detail in TM No. 6 (Tunnel and Shaft Construction Water Treatment and Discharge).

## 8. Conclusions and Basis of Design

The economics of tunnel excavation using a TBM is predicated on rapid and uninterrupted machine advance. Large uncontrolled inflows and/or the stoppage of or delay of the tunnel drive for probe drilling and grouting are disadvantageous to TBM progress and performance. Therefore, one of the tasks of the geological and hydrogeological studies is to determine an estimate of inflows along the length of the tunnel, the impacts of the inflows to critical habitats and identify if there are any segments of the tunnel where mitigation would be required based on areas of high hydraulic conductivity or in areas near sensitive environmental resources.

With our current understanding of the groundwater systems in the area, estimation of tunnel inflow, and distribution of hydraulic conductivity in the Glen Rose, the following inflow mitigation plan is recommended:

- Piezometers – a schedule for monitoring each piezometer should be developed based on the location of the piezometer in comparison to construction activities
- Bull Creek flow – This data should be monitored weekly at the USGS gauge station, until the tunnel excavation approaches Bull Creek, and then data should be reviewed daily. The possibility of adding an additional gauge station closer to the project site should be investigated.
- Key Springs – a depth gauge should be installed at each spring and read daily, along with a visual description of water clarity when tunneling is within 1000 feet of the spring.
- Tunnel Inflow – All water pumped out of the tunnel should be run through a flow meter with continuous data recording during tunnel excavation, pipelaying and grouting. Data should be downloaded weekly.

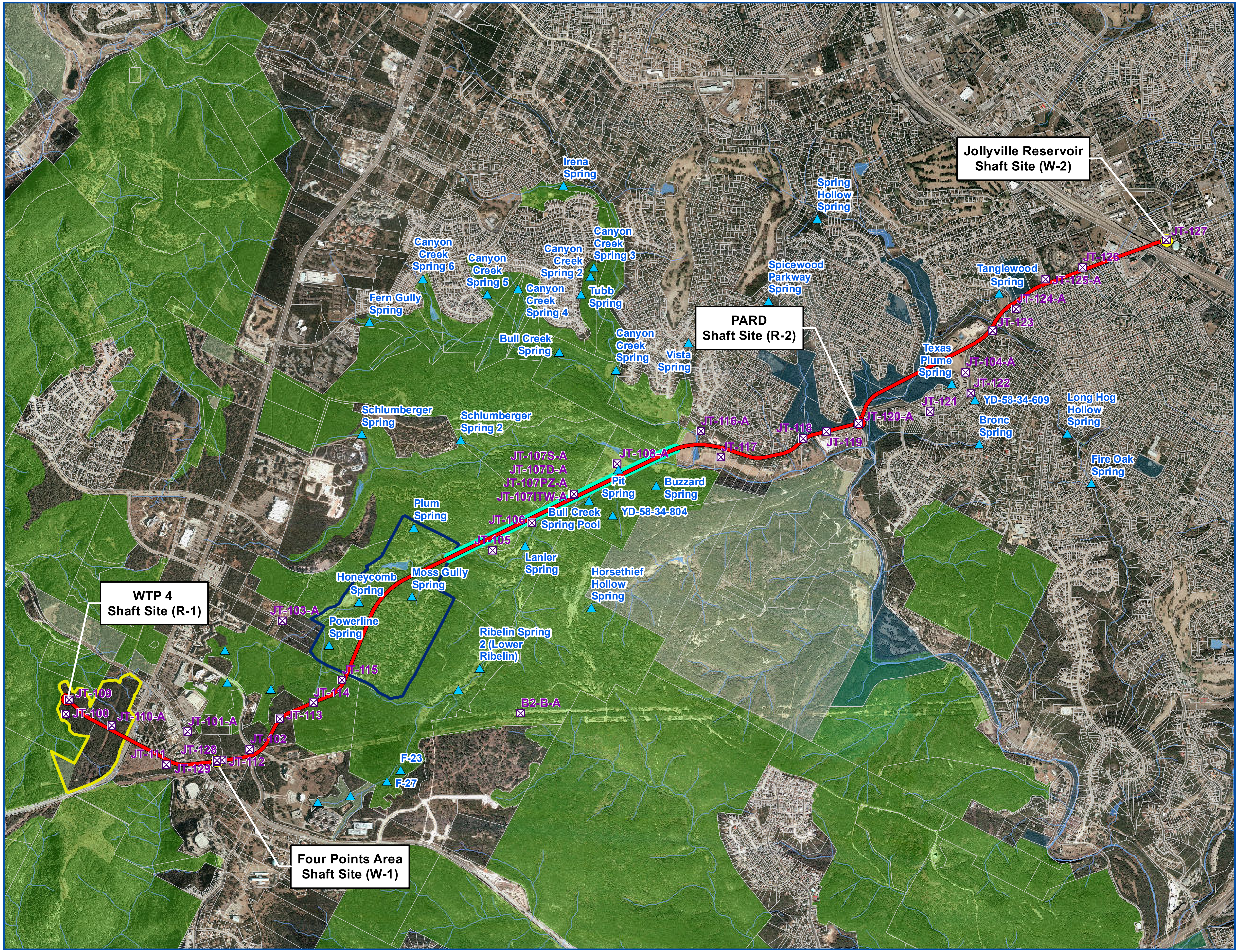
The strategies for protecting groundwater and Bull Creek flows along the JTM alignment have been coordinated closely with the results of the groundwater modeling study (summarized in the Preconstruction Groundwater Assessment dated December 2010), as well as the City of Austin, and the Environmental Commissioning team.

As noted in previous paragraphs, piezometers and flow gauges will be established at specific locations along the JTM alignment and all tunnel inflow will be pumped through a flow meter.

Two levels of triggers have been established for requiring the installation of liner plates within the tunnel to stem inflow depending on the environmental sensitivity of the area. When the steady state inflow trigger levels for any tunnel reach is exceeded, tunnel excavation will be stopped and tunnel groundwater inflow mitigation will be implemented. The baselines for steady-state and flush inflows are mandatory parameters established in the GBR and the specifications.

Additionally, if spring flows or creek base flows are reduced with a corresponding increase in tunnel inflow while tunneling in close proximity, adaptive management procedures will be put in place to develop a strategy for removing adverse impacts to the spring or creek. Adaptive management will be a corroborative effort between the Contractor, Owner, Engineer, and the Environmental Commissioning Team.

Three of the shafts (WTP4, FPA and JR) will be partially excavated through the Edwards Formation. In order to maintain existing flow pathways in these shafts, the annular space between installed liner plates and the rock will be filled with gravel where apparent hydraulic conductivity is present in the surrounding rock, and with grout where the rock appears tight (low or no hydraulic conductivity). The gravel will allow passage of water around the perimeter of the shaft to reconnect with existing flow pathways, while the grout will prevent vertical movement of water. The number and location of these permeable rings are baselined in the GBR, and specified in the technical specifications.




# City of Austin, Texas

## Water Treatment Plant 4

Jollyville Transmission Main

March 04, 2011

**LEGEND**

- Monitoring Springs
- Retrieval Shafts
- Working Shafts
- Boreholes
- Proposed Alignment
- Infrastructure Corridor
- Reservoir and WTP 4
- Old WTP 4 Site
- BCP
- Potential Future BCP
- City of Austin Parks
- Creeks
- Water
- ROW/Property Lines

N
W E
S

0 1,250 2,500

Feet

1 inch = 2,500 feet

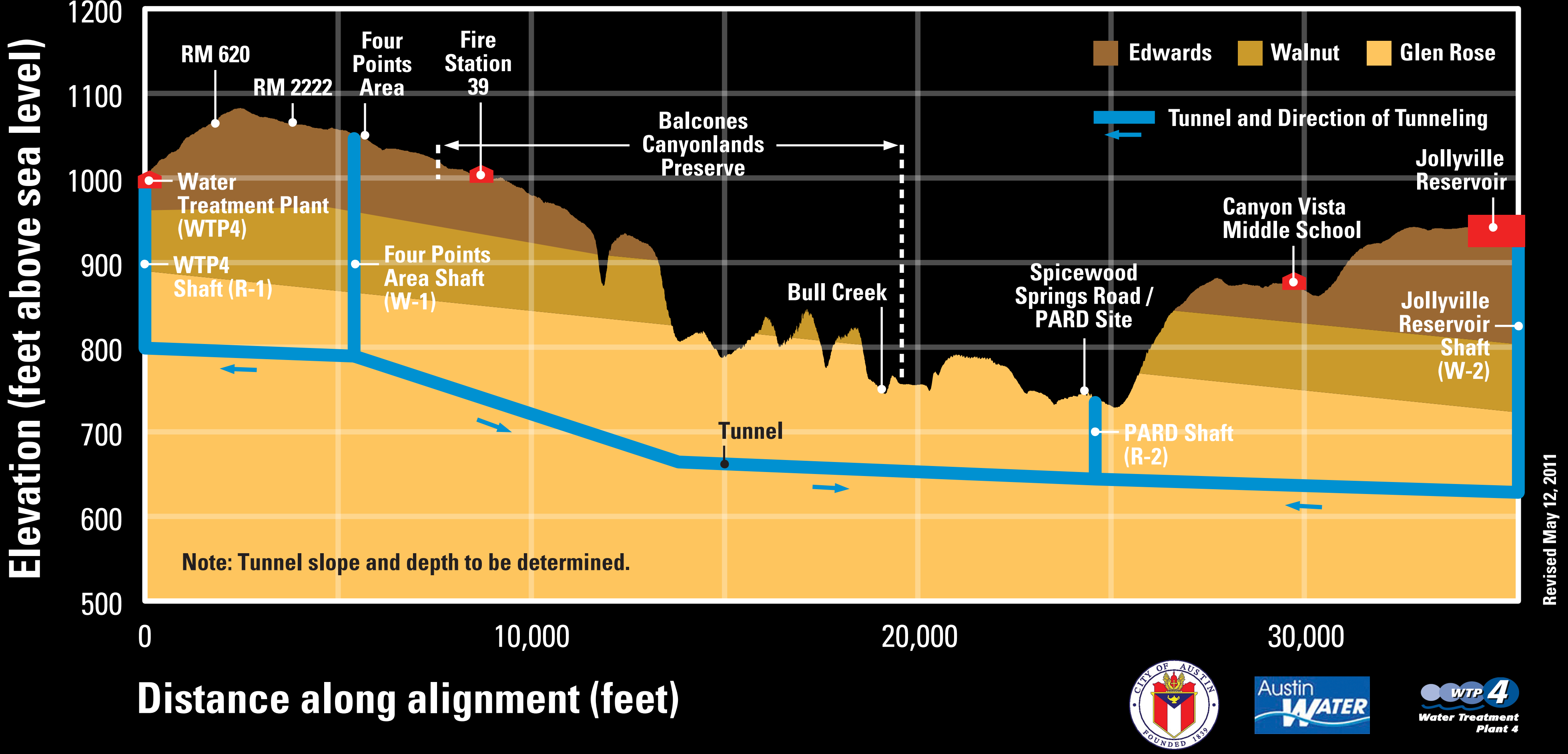
## Figure 1

Proposed Horizontal Alignment

ProposedHorizontalAlignment | J.Steurer | 3/4/2011

Data source: BV, City of Austin, CAPCOG, ESRI

# Figure 2
# Jollyville Transmission Main
# Proposed Vertical Alignment



# Figure 3
# Jollyville Transmission Main
# Final Tunnel Profile