

US EPA ARCHIVE DOCUMENT

**FLORENCE COPPER, INC.
UIC PERMIT APPLICATION
FLORENCE COPPER PROJECT – PRODUCTION TEST FACILITY**

ATTACHMENT N – CHANGES IN INJECTED FLUID

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N.1 Introduction

This Attachment N has been prepared in support of an application (Application) by Florence Copper, Inc. (Florence Copper) to the United States Environmental Protection Agency (USEPA) for issuance of an Underground Injection Control Class III (Area) Permit (UIC Permit) for the planned Production Test Facility (PTF), to be located at the Florence Copper Project (FCP) in Pinal County, Arizona. As required for Attachment N under USEPA Form 7520-6, this document includes a description of the changes that are anticipated to occur in the injected fluids between the time of injection and recovery. Specifically, this Attachment addresses the expected changes in pressure of the injected fluid, displacement of native fluid, and the direction of movement of the injected fluid.

N.2 Background

The PTF proposed by Florence Copper will consist, in part, of a closely spaced array of Class III injection and recovery wells that will extract copper from a highly fractured porphyry copper oxide deposit located in the upper portion (oxide zone) of the bedrock beneath the FCP site. The oxide zone is located below the water table at a depth of approximately 450 feet below ground surface.

The oxide zone consists of a fractured bedrock mass overlain by approximately 400 feet of alluvial sediments that become increasingly consolidated with depth. Silt and clay strata within the alluvial sediments are contiguous and sufficiently extensive to create confined to semi-confined aquifer conditions within the oxide zone. The ambient groundwater elevation is between 200 and 230 feet above the top of the oxide zone. At a minimum, the uppermost 40 feet of the oxide zone is excluded from injection to inhibit the vertical migration of injected fluid into overlying alluvial sediments. Core holes drilled in 2011 at the PTF well field site indicate that the top of the planned injection interval (500 feet bgs) will be as much as 70 feet below the top of the oxide zone. The core holes drilled in 2011 (CMP11-05 and CMP11-06) were abandoned after samples were collected. Detailed cross sections showing the oxide zone and the distribution of alluvial sediments are included in Attachment F of this Application.

The array of injection and recovery wells will be arranged in a five-spot pattern that effectively surrounds each injection well with four recovery wells. The injection wells will be used to inject a dilute sulfuric acid solution (lixiviant) into the oxide zone to dissolve the copper oxide minerals and liberate the copper into solution. The resulting copper-laden solution, referred to as pregnant leach solution (PLS), will be pumped from the formation by the recovery wells. Copper will be recovered from the PLS by means of a solvent extraction/electrowinning (SX/EW) process. Once copper has been recovered, the chemistry of the “barren” PLS solution (raffinate) will be adjusted and the solution will be re-injected as lixiviant back into the oxide zone.

Injection and recovery flow rates will be carefully balanced to ensure that more fluid is recovered than injected, thereby ensuring an inward hydraulic gradient within the injection zone. The aggregate flow rate from the recovery wells will be controlled to meet the requirements of Aquifer Protection Permit (APP) No. 106360 issued to Florence Copper for PTF operations by the Arizona Department of Environmental Quality (ADEQ). Recovery rates will be greater than the aggregate flow rate of injected solutions and approximately equal to the 300 gallon per minute (gpm) nominal design capacity of the PTF infrastructure. The number of active wells in service at any given time during PTF operations is anticipated to be constant.

The injection pressure will be closely controlled such that it remains below the fracture pressure of the rock within the oxide zone, but high enough to overcome ambient hydrostatic pressure and drive the injected solution toward the recovery wells. With the exception of a relatively small make-up stream and a small bleed steam, the injected solution will be recycled for the duration of PTF operations.

The proposed PTF design and operation are closely based on data and observations generated by BHP Copper Inc. (BHP Copper), a previous owner of the FCP site, during its construction and operation of a limited pilot-scale injection and recovery test. The test was conducted at the site from late 1997 to early 1998 for the purpose of demonstrating the feasibility of hydraulic control of injected solutions. The test successfully demonstrated that hydraulic control could be maintained.

N.3 Changes in Pressure of Injected Fluid

Maximum allowable injection pressures will be calculated for each well by multiplying a pre-determined factor (described in Attachment I of this Application) by the depth from the top of casing at ground surface to top of the injection interval. Because of variations in depth of the oxide zone from ground surface, the depth of the injection interval will vary from well to well, which in turn means the maximum allowable injection pressures will vary from well to well. Although the maximum allowable injection pressures will vary, the injection flow rate at each well is expected to remain approximately uniform relative to the length of the injection interval. Planned injection rates and pressures for PTF operations are presented in Attachment H of this Application.

As described above, each injection well will be paired with four recovery wells arranged in a five-spot pattern. The recovery wells will be located approximately 71 feet from the injection well. The aggregate pumping rate at the recovery wells will exceed the aggregate injection rate to ensure that hydraulic control will be maintained at all times. Because each injection well will be surrounded by nearby recovery wells pumping at carefully controlled rates, the three dimensional pressure influence generated by injection at a typical injection well will attenuate rapidly.

UIC Permit No. AZ396000001, obtained by BHP Copper for the FCP site, allowed injection at pressures up to 0.65 pounds per square inch per foot (psi/ft) of depth from top of casing to the top of the injection interval. Florence Copper proposes to apply the same fracture gradient value of 0.65 psi/ft to PTF operations. However typical injection pressures are expected to be somewhat lower due to the favorable hydraulic conductivity characteristics of the oxide zone. The hydraulic conductivity of the oxide zone is great enough that, during the 1997-1998 test, BHP Copper was able to inject at their design flow rate of 40 gpm without fully filling the injection well casing with lixiviant or pressurizing the well heads above atmospheric pressures.

The pressure generated at the top of the injection zone during the 1997-1998 test was generated exclusively by the equilibrium weight of the column of lixiviant standing inside the well casing with no supplementary mechanical pressure applied. Because a column of lixiviant generates pressures equivalent to approximately 0.45 psi/ft of depth, filling the casing completely with lixiviant alone will not generate enough pressure to reach the 0.65 psi/ft limit without additional mechanical pressure being applied.

N.3.1 Groundwater Model

In order to simulate the change in pressure of the injected fluid between a typical injection well and the associated recovery wells, Florence Copper constructed a computer-based numerical groundwater flow model using MODFLOW (Harbaugh et al., 2000). MODFLOW is a modular, finite-difference, three-dimensional groundwater flow modeling code originally developed by the United States Geological Survey.

The groundwater flow model was built using geologic information, formation characteristics, and hydrologic properties of the oxide zone that were measured during characterization of the oxide zone by BHP Copper. The model assumes homogeneous and isotropic conditions within the oxide zone, and so cannot be used to predict fluid migration within discrete, unidentified flow paths within the oxide zone.

The groundwater model was configured to match the number, distribution, and mode (injection or recovery) of the wells proposed for the PTF and is consistent with the model used to support the APP application, and determination of the Area of Review (AOR) described in Attachment A of this Application.

The groundwater flow model was configured with four injection wells and nine recovery wells, all located within a 200-foot by 200-foot area. The model also explicitly represents the three-dimensional location of the Sidewinder and Partyline faults, which have been parameterized to account for potential preferential flow pathways. Figures 9-1 and 9-2 both show the location of the Sidewinder fault as identified within the model for layer 10 (bottom of the Bedrock Oxide Zone) and across the broader Florence Copper property. Both Figures 9-1 and 9-2 also show cross-sections through the proposed PTF well field with the vertical extent and orientation of the Sidewinder fault at the location of the proposed PTF well field.

The model has also been configured to explicitly represent the Upper Basin Fill Unit (UBFU), Middle Fine-Grained Unit (MFGU), and Lower Basin Fill Unit (LBFU) with parameterization that is conceptually and numerically representative of the hydrologic properties of those alluvial units, as well as the hydraulic connections that exist between each of these units and the Bedrock Oxide Zone (model layers 6 through 10). In all current and previous versions of the FCP model, the LBFU was configured to be in full hydraulic communication with the Bedrock Oxide Zone. The only confining unit represented in any of the models prepared in conjunction with the FCP, past or current, is the MFGU.

Dispersive and diffusive effects have been included to account for migration potential beyond strictly advective fluxes. Model construction allows for advective flow in three dimensions, as well as dispersive and diffusive fluxes which are of a lesser magnitude within the PTF well field area due to close proximity pumping and injection conditions during PTF operations. Table N-1 lists the hydrologic properties of each model layer as represented in the FCP groundwater model.

Table N-1. Aquifer Parameter Value Ranges by Model Layer				
	Horizontal Hydraulic Conductivity Kx (feet/day)	Vertical Hydraulic Conductivity Kz (feet/day)	Anisotropy Ratio Kx/Kz (feet)	Porosity n (Unitless)
Layers 1 and 2 (UBFU)	20 to 130	2 to 13	10:1	0.13 to 0.2
Layer 3 (MFGU/UBFU)	1 to 130	0.01 to 13	100:1 – 10:1	0.15 to 0.2
Layers 4 and 5 (LBFU)	5 to 25	0.5 to 2.5	10:1	0.2
Layer 6 (Oxide Exclusion Zone)	1	1	1:1	0.08
Layer 7 (Oxide)	0.57	0.57	1:1	0.08
Layer 8 (Oxide)	0.57	0.57	1:1	0.08
Layer 9 (Oxide)	0.1	0.1	1:1	0.05
Layer 10 (Oxide)	0.1	0.1	1:1	0.05
Faults	2.51	2.51	1:1	0.1

The aquifer parameters and hydrostratigraphic unit descriptions were developed from data collected in support of Brown and Caldwell’s hydrogeologic study (1996) and were used to support the creation of a sub-regional groundwater flow model described in Brown and Caldwell (1996), as well as during the update and expanded calibration described in Appendix 14A of the Temporary APP application prepared by Brown and Caldwell (2012). These data include the results of 26 aquifer tests and 14 core hole packer tests, and remain the best available data describing hydrogeologic characteristics at the proposed PTF well field and surrounding vicinity. No significant additional hydrogeologic characterization activities have been conducted at the proposed PTF well field and surrounding vicinity since the Brown and Caldwell study (1996) was completed. Data developed in support of Brown and Caldwell’s study (1996) were used as direct input into the current PTF groundwater flow model. Hydrostratigraphic unit descriptions presented in the Brown and Caldwell study (1996) serve as the conceptual basis for hydrostratigraphic units represented in the FCP groundwater flow model.

The model configuration used to run simulations to demonstrate changes in injected fluid includes four injection wells operating at a uniform rate of 60 gpm (240 gpm total), the central recovery well operating at 60 gpm, and the remaining 240 gpm of recovery production distributed to the other nine recovery wells based on the ambient groundwater gradient and proximity to injection wells. Total simulated pumping is 300 gpm during the initial 14 months of the simulation. Simulated withdrawal rates are 125 percent of the injection rates. The time frame for simulated PTF operations is described in Table N-2.

Table N-2. Specifications of the FCP Groundwater Model	
Model Characteristics	Specifications
Simulation Time	Predictive: 6 years and 11 months (14 months with hydraulic control pumping at the PTF, 9 months formation rinsing pumping, and 5 years with no hydraulic control pumping during closure)
Stress Periods	Predictive Models: 7 stress periods of varying lengths as follows. The first two stress periods include 14 months of PTF operational pumping, and 9 months of PTF well field rinsing. The last five stress periods are 1 year in length and represent the 5-year closure period.

Model results indicate that injection at 60 gpm over an injection interval of approximately 700 feet (representing a flow rate less than 0.1 gpm per foot of interval) will generate a pressure of approximately 8.2 psi above ambient hydrostatic pressure at the top of the injection interval. Proposed PTF injection rates are 60 gpm per injection well, and each injection well will have as much as approximately 620 feet of well screen resulting in a flow rate of less than 0.1 gpm per foot of screen. An increase of 8.2 psi above hydrostatic pressure is sufficient to drive native groundwater upward approximately 19 feet if aquifer conditions were unconfined. However, the oxide zone and the LBFU are in mutual hydraulic communication with no confining formation between them, but exist in confined to semi-confined aquifer conditions because they are both below the MFGU. Because aquifer conditions are confined to semi-confined, no physical injection mound will be created at the water table. The 8.2 psi pressure response at the top of the injection interval adjacent to the injection well represents a dynamic piezometric response that will not translate into extensive vertical migration of injected fluids.

Model results also indicate that hydrostatic pressure at the recovery well will be reduced by 8.2 psi due to pumping at the recovery well; a drop sufficient to lower native groundwater levels by approximately 19 feet if aquifer conditions were unconfined. As with the pressure response at the injection well, this pressure drop at the recovery wells represents a dynamic piezometric effect that will result in a low pressure zone that will serve to draw injected fluid toward the recovery wells.

The total pressure differential between the typical injection and recovery well is approximately 16.5 psi, equivalent to a change in head of 38 feet over a horizontal distance of 71 feet. This change in pressure is a dynamic piezometric effect that will not result in elevation changes at the water table because aquifer conditions within the oxide zone are confined to semi-confined.

As noted below in Section N.4.1, the predicted hydrostatic effects and resulting head differential is limited to 40 feet, which corresponds to the thickness of the model layer used to simulate the exclusion zone. Additional detailed description of specific model scenarios and results are described in Attachment A of this Application.

N.4 Native Fluid Displacement

Native formation fluid within the oxide zone consists of groundwater residing in fractures and is of a quality generally suitable for irrigation and industrial uses. No drinking water wells exist within the oxide zone or the overlying alluvial sediments within the bounds of the Aquifer Exemption area.

At the commencement of injection and recovery, native groundwater will be withdrawn from the fractures of the oxide zone through the recovery wells and will be replaced with injected fluid. Consequently, at startup, displacement of native fluid will consist of extraction of native fluid and subsequent replacement by injected fluid.

Injection and recovery rates will be closely balanced to ensure full recovery of the injected fluid. The aggregate recovery rate will be slightly higher than the aggregate injection rate to ensure that more fluid is withdrawn than is injected, and to maintain the necessary inward hydraulic gradient until groundwater quality within the injection and recovery zone is restored to the level required by the UIC Permit. The inward hydraulic gradient will cause groundwater to flow toward the active portion of the PTF facility from surrounding areas.

Because injection and recovery rates will be closely balanced, net groundwater extraction within the PTF area will consist of the amount of groundwater pumped to maintain hydraulic control. During PTF operation, this volume of water will be approximately 60 gpm, when the full 300 gpm production capacity of the PTF SX/EW plant is attained. During PTF operations, withdrawal of the net 60 gpm of fluid (groundwater plus PLS) will be distributed across the PTF well field, an area measuring approximately 200 feet by 200 feet in size, resulting in a relatively modest groundwater flow rate into the perimeter of the active PTF area.

The Sidewinder fault is assumed to extend the entire distance over which it has been mapped without any discontinuity. However, the Sidewinder fault zone ranges in width from approximately 100 to 300 feet at locations where it has been identified in core logs. The Sidewinder fault was simulated in the groundwater flow model based on a geologic model that was constructed from core logs. Consequently where the fault zone thins, a reduced fault zone thickness is represented in the groundwater model. During construction of the groundwater flow model, an effort was made to ensure that at least two cells overlapped at any location where core logs showed that the Sidewinder fault thinned.

The Bedrock Oxide Zone is an extensively fractured mass of granodiorite and quartz monzonite. The fracturing is the result of regional scale extensional tectonic stresses that effectively pulled the rock mass apart, creating a series of faults and related fracturing throughout the rock mass. The difference between the observed faults and other fracturing is the noted evidence of displacement (i.e., slickensides, fault gouge, or observable offset). Fractures that do not show evidence of displacement are not logged as faults, while fractures that show evidence of displacement are logged as faults. Consequently, the mapped faults consist of fractures that have exhibited evidence of displacement with no regard to the degree and scale of fracturing.

The location of the plane of displacement shifts over time with changing tectonic stresses, resulting in an irregular and discontinuous fault plane at each principal shear zone. The observed faults do not exhibit discrete fault planes as inferred on cross sections prepared to accompany both APP and UIC permit application materials. Rather, the faults are characterized as fault zones consisting of numerous shear planes flanked by extensive related fracturing, which combined range in width from a few feet to several hundred feet on either side of the principal shear zone.

The shifting tectonic stresses affecting the rock mass beneath the FCP property have resulted in two significant and continuous faults (Sidewinder and Party Line), and numerous smaller, discontinuous faults which occur sub-parallel to the larger faults. The Sidewinder fault is the only significant and continuous fault that transects the PTF well field.

Based on one aquifer test conducted adjacent to the Party Line fault in 1995, it has been inferred that hydraulic conductivity adjacent and parallel to the larger faults is greater than that observed in the remainder of the fractured rock mass, and that hydraulic conductivity perpendicular to the faults is lower than the surrounding rock mass. Other than this single aquifer test, aquifer characterization studies conducted at the

FCP site made no attempt to segregate or characterize hydrologic properties of the numerous smaller and discontinuous faults and shear zones in relation to the surrounding highly fractured rock. The numerous small faults are too small and pervasive to individually characterize within the much larger and fully encompassing fractured bedrock framework.

Aquifer tests conducted at the FCP site generated data describing bulk rock hydrologic properties. All aquifer tests conducted in the Bedrock Oxide Zone demonstrate that the bedrock is so extensively fractured that the hydrologic properties are similar to an equivalent porous media. The many discontinuous small faults and shear zones have been characterized within the framework of the bulk aquifer properties developed from aquifer tests, including those conducted in the vicinity of the PTF well field. Review of core logs from core holes drilled within the footprint of the PTF well field show that the discontinuous evidence of displacement associated with the Rattlesnake and Thrasher faults is distributed over a relatively wide shear zone that spans nearly the entire distance between the two faults and the distance between these faults and the Sidewinder fault. The combined data generated from bulk properties aquifer tests, and the core logs suggests that the Bedrock Oxide Zone will behave as an equivalent porous media rather than a fault controlled hydrologic system. Therefore, small faults and shear zones, identified by evidence of displacement, were not simulated discretely within the highly fractured rock mass of the Bedrock Oxide Zone in the FCP groundwater model. Rather, the rock mass was assigned bulk hydrologic properties consistent with hydrologic data generated for the fractured rock mass, including small faults like the Rattlesnake and Thrasher faults.

N.4.1 Groundwater Model Simulation of Vertical Migration of Injected Fluid

Figures 9-1 and 9-2 provide cross-sectional views of the extent of vertical migration of injected fluid under steady state injection and recovery conditions at the end of a 14-month period of operations. As shown on Figure 9-1, which represents a west-facing cross-sectional view, injected fluid migrates upward approximately 40 feet into the exclusion zone after 14 months of operating conditions, and does not reach the LBFU along this transect. Figure 9-2 provides a north-facing cross sectional view of the extent of vertical migration at the end of PTF operations. Along this west-to-east transect, injected fluid is simulated to migrate upwards approximately 40 feet into the exclusion zone and does not reach the LBFU along this transect. In summary, model results indicate that mounding of injected fluid is limited to the simulated 40-foot thick exclusion zone, but trace concentrations of injected fluid occur in the LBFU above the injection area as a result of dispersive effects.

N.5 Direction of Movement of Injected Fluid

As explained above, each injection well will be surrounded by four recovery wells constructed to withdraw fluid at the same elevation within the oxide zone at which it is injected. The recovery wells will be evenly spaced in a square pattern around each injection well at a distance of approximately 71 feet from the injection well. The top of the injection interval will be a minimum of 40 feet below the top of the oxide zone. Core holes drilled in 2011 at the PTF well field site indicate that the top of the planned injection interval (500 feet bgs) will be as much as 70 feet below the top of the oxide zone. The core holes drilled in 2011 (CMP11-05 and CMP11-06) were abandoned after metallurgical samples were collected. Core hole drill and abandonment records are included in Exhibit C-1 to Attachment C of this Application.

The 1997-1998 test conducted by BHP Copper demonstrated that this proposed well design, pattern, and spacing can be used successfully to induce horizontal well-to-well flow within the oxide zone. The current groundwater model, constructed by Florence Copper using formation-specific geologic and hydrologic properties, also demonstrated that horizontal fluid flow could be induced between wells constructed in the oxide zone. Model results indicate that when injection and recovery rates are closely balanced, well-to-well horizontal flow will be induced with a dynamic vertical flow component of approximately 40 feet.

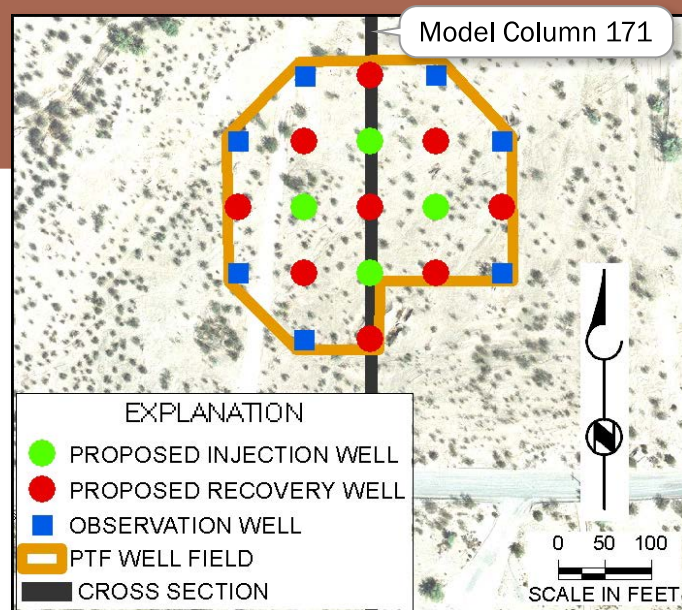
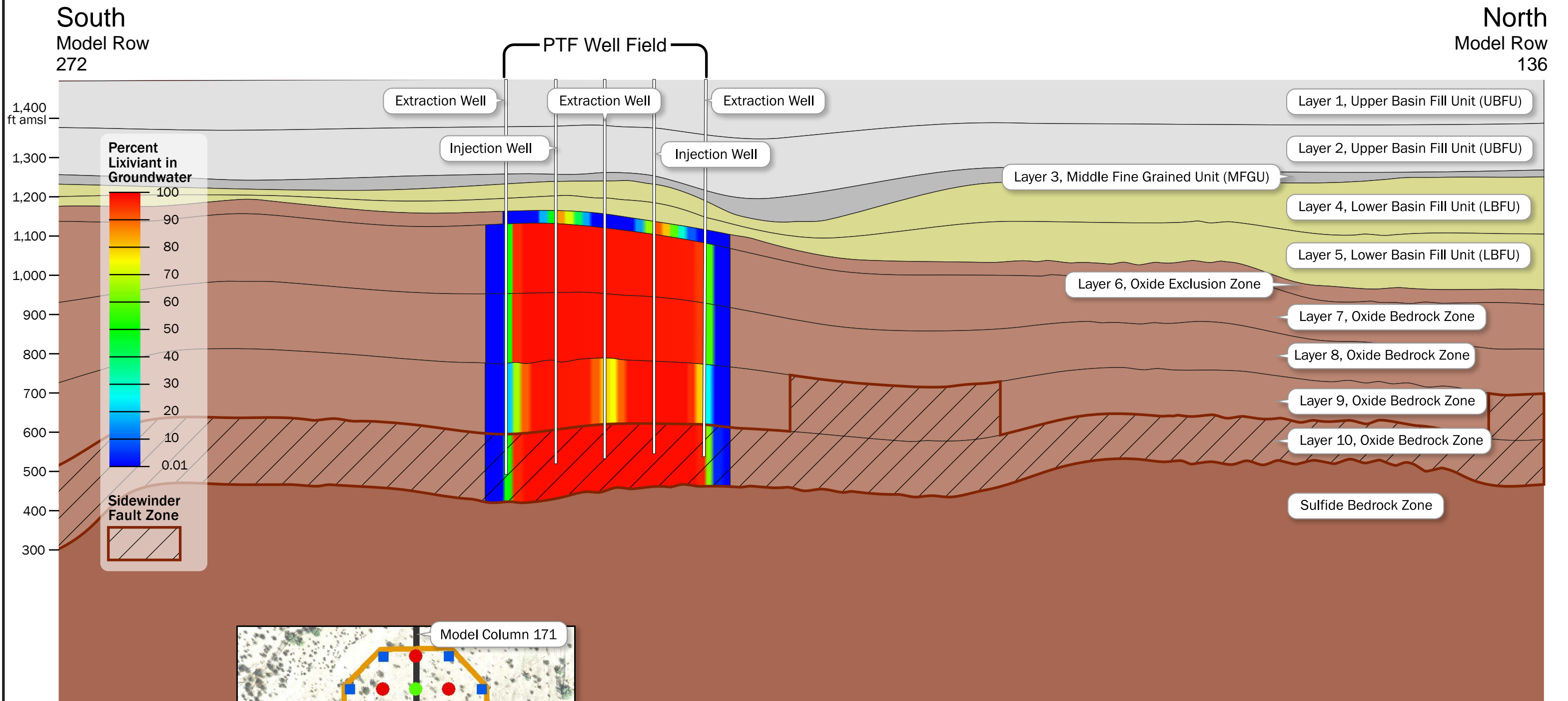
The bedrock underlying the oxide zone is effectively impermeable, so downward flow of injected solutions is not expected. The oxide zone is underlain locally by a zone of sulfide mineralization that occurs in the same quartz monzonite and granodiorite rocks that compose the oxide zone, and is of unknown lateral and vertical

extent. The fracture frequency and resulting permeability of the fracture network within the sulfide zone beneath the proposed PTF well field is significantly less than that observed in the overlying oxide zone. For this reason, no ambient downward flow of injected fluid is anticipated, and no recovery wells will be constructed in the sulfide zone to induce downward flow of injected fluid.

N.6 References

- Brown and Caldwell, 1996a. *Magma Florence In-Situ Project Aquifer Protection Permit Application, Volume IV of V, Modeling Report*. January 1996.
- Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G., 2000. *MODFLOW-2000, The U.S. Geological Survey Modular Ground-water Model – User Guide to Modularization Concepts and the Ground-water Flow Process*. U.S. Geological Survey Open-File Report 00-92.

Cross-Section along Model Column 171

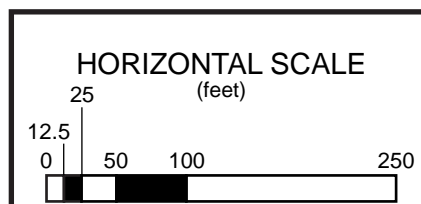


Scenario 8 Simulation Details and Variations from Base FCP Model:

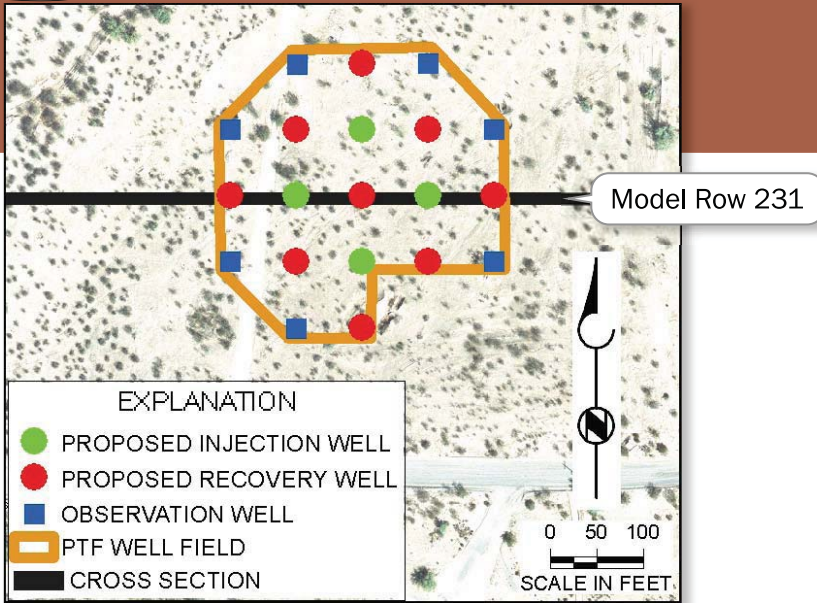
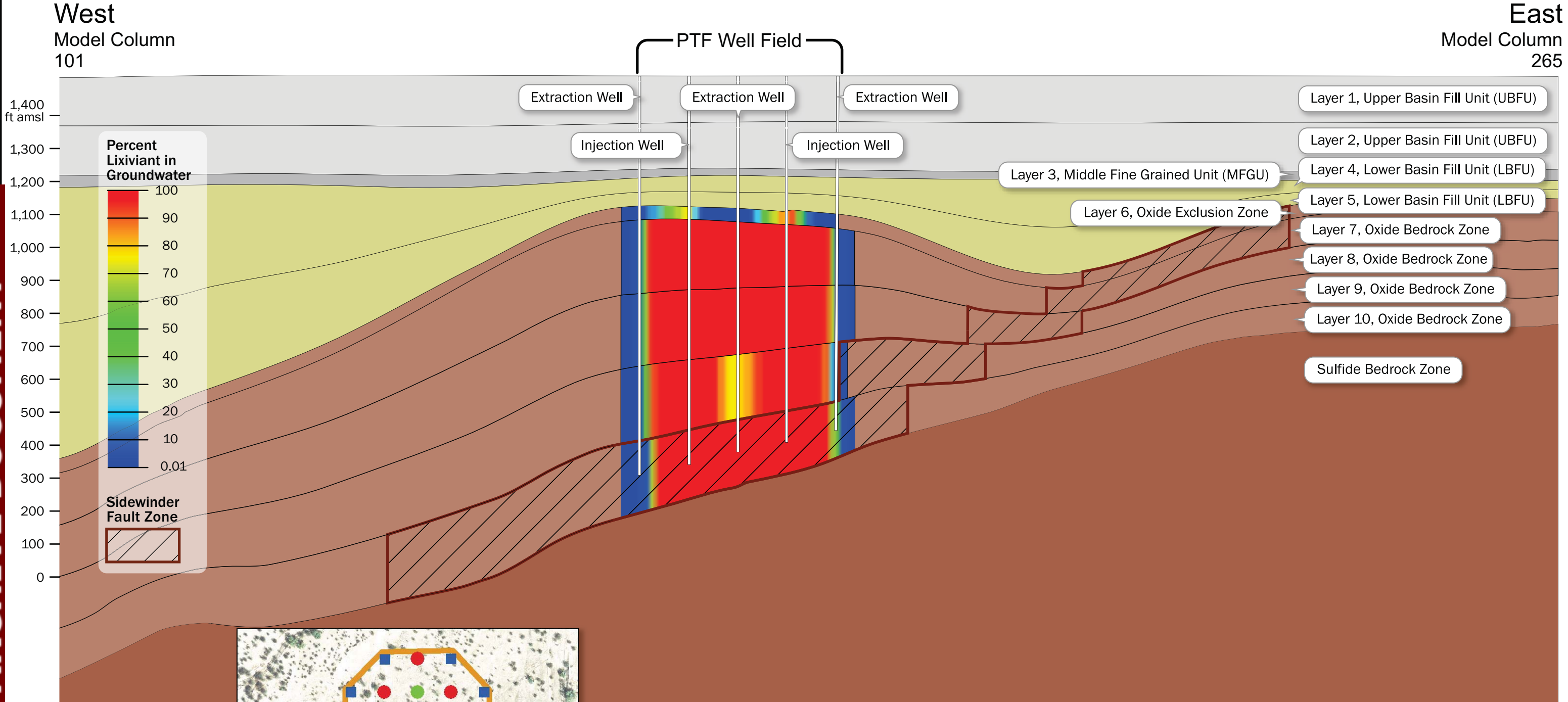
- 14 months simulation time
- 4 PTF wells injecting at 60 gpm each
- 9 PTF recovery wells pumping at 300 gpm total
- Hydrologic parameters same as base FCP Model (Table 10-1)

Figure 9-1
Model Predicted Migration of Lixiviant – Scenario 8
West-facing Cross Section
Florence Copper Project Groundwater Model

Brown AND Caldwell



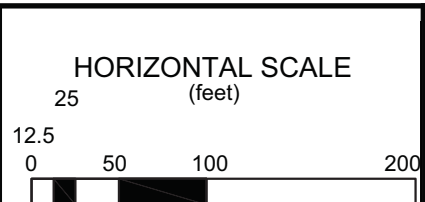
Cross-Section along Model Row 231



Scenario 8 Simulation Details and Variations from Base FCP Model:

- 14 months simulation time
- 4 PTF wells injecting at 60 gpm each
- 9 PTF recovery wells pumping at 300 gpm total
- Hydrologic parameters same as base FCP Model (Table 10-1)

Figure 9-2
 Model Predicted Migration of Lixiviant - Scenario 8
 North-facing Cross Section
 Florence Copper Project Groundwater Model



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