TECHNICAL MEMORANDUM

To File TOWN OF SILVER CITY/RECHARGE October 15, 2009

From Dave M. Romero, P.H. and Casey W. Cook, P.E.

Subject GROUNDWATER RECHARGE ANALYSIS AND ESTIMATE OF RECHARGE OPTION COSTS

Introduction

The Town of Silver City (the Town) is interested in assessing groundwater recharge options at its municipal wellfields. In March of 2009, the Town retained Balleau Groundwater, Inc. (BGW) to evaluate the general hydrology of a prospective groundwater recharge program. The evaluation involves an overall assessment of the hydrologic system that has been historically influenced by regional groundwater development in conjunction with an assessment of how the system can be expected to change in the future with managed groundwater recharge. Water for use by the Town is supplied by Frank's wellfield (three wells in production), the Gabby Hayes well, the Anderson well and the Woodward wellfield (five wells in production) (Figure 1).

The Town is interested in initially recharging groundwater in the area of Frank's wellfield. General options under consideration include infiltration along natural intermittent channels and an injection well system. Recharge water is expected to come from the Gila River. The elevation change between the Gila River and the Town wellfields is approximately 1,690 feet. If it is feasible to use existing facilities for water conveyance, the existing pipeline that runs from Bill Evan's lake to Tyrone Mine is suitable for routing water part of the way to the Town wellfields. Additional pipeline would be necessary to route water from the existing pipeline to Frank's wellfield. A proposed route of new pipeline and an estimate of costs is included herein. A recharge project is considered feasible after permitting requirements are satisfied.

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Purpose and Scope

This work is intended to enhance the understanding of the regional aquifer system with an emphasis on hydrologic effects caused by the Town wellfields, regional water use, and managed groundwater recharge. The area of interest is shown on Figure 1. We assess the hydrologic system and characterize the extents of groundwater captured by the Town wells. This technical memorandum describes our analysis, which is based on a water accounting model that integrates MODFLOW-2000 (Harbaugh and others, 2000) and Geographic Information System (ArcGIS, 2009) techniques with data and results from previous studies. The objectives of the assessment are to (1) characterize the region of groundwater captured by the Town wells, (2) assess hydrologic effects from managed groundwater recharge operations, and (3) propose preliminary sites and estimated costs for development of a groundwater recharge program.

Technical Approach

BGW developed a model of the aquifer system in the region of the Mangas Trench (Trauger, 1972, p. 22) that accounts for the water in the area influenced by Town wellfields and for regional water use of others. The boundary of the model is the area of interest shown on Figure 1. The New Mexico Office of the State Engineer (OSE) has developed two earlier versions of groundwater flow models in generally the same area; Hathaway (1986) and Johnson (2000) each developed two-dimensional models to assess hydrologic effects from proposed transfers of groundwater rights. The new model builds on the previous work of the OSE. We developed a three-dimensional model to account for shallow and deep recharge operations within the aquifer system. The model provides a mathematical simulation method for examining the change in aquifer conditions resulting from historical groundwater development and for calculating the projected effects of proposed future water-management actions in the basin. The model is based on the U.S. Geological Survey (USGS) MODFLOW 2000 program (Harbaugh and others, 2000). The model was calibrated to approximately match predevelopment water levels and estimated flow conditions, and 64 years of historical groundwater development from 1945 to 2009. Pre-development water-level statistics and

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historical water-level hydrographs for the Town wells are included in Appendix A. The model is in development; however, it is in a form suitable for the analysis described herein.

Hydrogeologic Setting

Geology in the area has been reported by others (Paige, 1916; Koopman and others, 1969; Trauger, 1972; Cunningham, 1974; Hedlund, 1978a; Hedlund, 1978b; Hanson and others, 1994; and Hawley and others, 2000). A geology map of the area is shown on Figure 2 (adapted from Hawley and others, 2000). The dominant geologic feature in the area of interest is a northwest-trending structure described as the Mangas Trench (Trauger 1972, p. 22) and also known as the Mangas and San Vicente Subbasins (Hawley and others, 2000). The eastern boundary of the trench is marked by a fault trend along the Silver City Range. The western edge is bounded by the Precambrian uplift of the Burro Mountains.

The principal aquifer that supplies the Town water system is the late Tertiary to early Quaternary Upper Gila Group (Woodward wellfield area) and the late Tertiary Middle Gila Group (Frank's wellfield area) (Hawley and others, 2000, Plate 1). The Town wells yield water ranging from 230 to 950 gallons per minute (gpm) with transmissivity (near the well screen) ranging from about 850 to 2600 feet squared per day (ft^2/d) (BGW, 2006, Table 1).

The continental divide runs through the area of interest and is the topographic divide between the Gila and Mimbres basins. Northwest of the continental divide is the Gila Basin. The principal drainage of the Gila basin is Mangas Creek, which is intermittent along most of its course until it becomes perennial at Mangas Spring located about 12 miles from the continental divide, or four miles away from the Gila River. Surface-water flow measurements on Mangas Creek below the spring indicate that the creek gains flow along the perennial segment below the spring.[1] Southeast of the continental divide, the principal drainage in the Mimbres Basin is San Vicente Arroyo, which is intermittent throughout the area of interest.

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[1] Trauger (1972, p.47) reports that flow below the spring increases with an average of about 1.6 cubic feet per second (1,200 acre feet per year) ¼-mile below the spring and an average of 1.8 cubic feet per second (1,300 acre feet per year) about ¾-mile further downstream.

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Others have estimated the quantity of groundwater flow through the Mangas Trench region. Based on the transmissivity of wells in the Warmsprings, Faywood and Whitewater areas and on regional aquifer head gradients, Trauger (1972, p.64) estimates the amount of groundwater moving southeast into the Deming Basin from the San Vicente watershed to be 10,800 acre feet per year (AFY); an independent estimate by Hawley and others (2000, p. 39) is 10,000 AFY. Northwest in the Gila Basin along Mangas Creek near Mangas Spring, Trauger (1972, p. 64) estimates 3,000 to 4,000 AFY moving through the basin fill until it eventually discharges to the Gila River. The OSE model (Johnson, 2000) of groundwater flow through the Mangas Trench derives quantities that are comparable to the aforementioned estimates of Trauger (1972) and Hawley and others (2000); about 9,800 AFY of groundwater flow to the Mimbres Basin and 6,100 AFY discharging to Mangas Spring and the Gila River. These works provide a basis for a groundwater recharge rate of approximately 16,000 AFY in the region of the Mangas Trench with about 60 percent flowing toward the Mimbres Basin and 40 percent flowing toward the Gila Basin.

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Hydrogeologic Model

We compiled data from other sources (Trauger, 1972; Cunningham, 1974; Hedlund, 1978a; Hedlund, 1978b; Hawley and others, 2000) to provide a basis for the construction of a three-dimensional hydrogeologic unit solids model (Figure 3). The solids model provides a framework for specifying hydrologic parameter zones within the water accounting model and provides a basis for using the Hydrogeologic Unit Flow (HUF) package that works with MODFLOW-2000 (Anderman and Hill, 2003). The HUF package provides flexibility in the water accounting model in that as new information provides improved or alternative hydrogeologic interpretations, they can be readily incorporated into the model.

The model simulates hydrologic features or an average annual basis that define the interaction of the local aquifer system: regional aquifer subsurface flow, natural recharge, stream channels, and riparian evapotranspiration (ET). The model-derived water flow budget is illustrated on Figure 4; it represents natural conditions of the 1940s prior to significant development of groundwater. The modeled budget of water flow results in 17,400 AFY of recharge that leaves the model as 7,000 AFY southeast to the Mimbres Basin, 4,400 AFY northwest to Mangas Creek (2,000 AFY) and to the Gila River (2,400 AFY) and 6,000 AFY to model-wide ET, which is consumed predominantly along riparian vegetation at Mangas Creek. The results are compatible with other estimates described above. The modeled predevelopment water-levels are shown on Figure 5. The predevelopment hydrologic setting serves as an initial condition for the model scenarios.

Model Scenarios

The model scenarios are intended to analyze how the regional geohydrology influences water-level changes as groundwater has been developed historically and as it may be developed and managed in the future. We simulated four model scenarios: (1) a historical simulation from 1945 to 2009, (2) a future 40-year baseline simulation, (3) the future baseline with injection wells to provide managed recharge, and (4) the future baseline with infiltration to provide managed recharge. Scenarios (3) and (4) assume that managed recharge water is available at a continuous rate of 1.0 cubic foot per second (cfs) for 365.25 days per year, or about 725 AFY. The scenarios are described below.

Scenario 1: Historical Simulation

The historical simulation requires specifying groundwater diversions model-wide. For the Town well diversions, we specified pumping based on meter records on file with the Town and as described in BGW (2006, Figure 11). The Town has a wastewater treatment plant (WWTP) that discharges water to San Vicente arroyo in the Mimbres Basin. We estimate that the WWTP provides about 1,000 AFY of recharge to groundwater in the Mimbres Basin (BGW, 2006, Figure 12). We added the Town WWTP return flow to the historical simulation to account for return flow to the Mimbres Basin aquifer. Regional groundwater diversions for water users other than the Town are based on withdrawal data compiled in the OSE model of the Mangas Trench (Johnson, 2002) that has been updated to include regional groundwater pumping data on file at the OSE District III office in Deming, NM. The updated model does not include

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individual domestic well use. We compiled information on domestic wells[2] and added it to the model herein so that regional domestic well water use would be accounted for.

The modeled water-level condition at the end of the historical period is shown on Figure 6. The change in water levels over the 64-year period from 1945 to 2009 is shown on Figure 7. The largest degree of water-level change (decline) occurs at the Town well field and at Tyrone mine. Also apparent on Figure 7 is water-level rise associated with return flow from the Town WWTP. Figure 8 shows the historical extents of groundwater captured by the Town wellfield since the 1940's; the yellow streaks represent the distances over which groundwater has been captured by individual Town wells since they began pumping. Wellfield capture areas are within a few miles of the Town's wells.

Scenario 2: Future 40-Year Baseline Simulation

The baseline simulation runs 40 years into the future from 2009 to 2049. Groundwater use by the Town is assumed to grow at a rate of 0.5 percent per year. Regional groundwater diversions for water users other than the Town are assumed to remain constant. The future 40-year water-level condition resulting from assumed levels of groundwater use is shown on Figure 9. The baseline simulation serves to provide a condition upon which the two future groundwater recharge scenarios (injection and infiltration) can be superimposed.

Scenario 3: Future 40-Year Recharge Scenario with Injection Wells

The projected 40-year recharge scenario with injection wells is the same as the baseline scenario except for including injection of 1.0 cfs distributed equally in two wells. The injection wells are assumed to be 1,000 feet deep and to have completions compatible with Frank's wells 5, 6 and 7 (BGW, 2006, Table 1 and Figure 6). Figure 10 shows the water-level build-up associated with 1.0 cfs (725 AFY) injected into the Gila Group aquifer for 40 years. The build-up of water levels is relative to the 40-year baseline condition shown on Figure 9. Figure 10 also shows the extents to which injection water travels over the 40-year period. For the

[2] New Mexico Office of the State Engineer Water Administration Technical Engineering Resource System database: data accessed May, 2009.

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conditions assumed in the 40-year scenario, none of the injected water reaches individual wells in Frank's wellfield (i.e. none of the recharge water is produced by existing Town wells); however, that result is dependent on the magnitude of future water use, the magnitude of injected water and the location of injected water relative to existing wells.

Scenario 4: Future 40-Year Recharge Scenario with Infiltration

The projected 40-year recharge scenario assumes recharge water is infiltrated into the ground along an existing arroyo south of Frank's wellfield. The recharge rate is constant at 1.0 cfs of water for 365.25 days per year, or 725 AFY for 40 years. As with Scenario 3, the scenario is the same as the baseline with the exception of infiltration recharge water. Figure 11 shows the build-up of water levels relative to the 40-year baseline condition on Figure 9; the extent to which infiltrated water travels is also shown. As opposed to Scenario 3, some of the infiltrated water reaches other wells in Frank's wellfield within the 40-year time frame (i.e. the wellfield eventually produces water that is a mixture of Gila Group aquifer water with managed recharge water).

The results of Scenarios 3 and 4 indicate that there is notable difference between the extent of water travelled and the extent of water-level build-up. The extents of water-level build-up reach substantially farther away from the recharge water source than the distance that recharge water travels.

Example Recharge Projects and Estimated Costs

If the Town plans to move forward with groundwater recharge operations, there are a number of factors to consider that are beyond the scope of this document. This document is not intended to address all project aspects; however, for planning purposes, we have compiled information regarding two example groundwater recharge options that involve new infrastructure to convey water to Frank's wellfield, including a general estimate of project costs. Prior to moving forward with an actual groundwater recharge program, a detailed assessment of infrastructure development and analysis of more-specific costs would be required.

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In this section, we provide two examples of full scale, operating projects the Town might undertake for aquifer recharge. Example recharge sites near Frank's wellfield are shown on Figure 12. Options for recharge by injection and infiltration are described, including general infrastructure requirements and estimated costs. Both injection and infiltration recharge options require the construction of a new pipeline to deliver water to the recharge site. Existing infrastructure that delivers Gila River water from Bill Evans Lake to Tyrone Mine may be available for use by the Town to deliver water part way to recharge sites. New infrastructure will be needed to convey water the rest of the way, to treat water and provide for direct injection, and to control and monitor recharging water. The following sections describe existing and new infrastructure needed, estimated costs, and foreseeable permitting issues. Table 1 outlines estimated costs for injection and infiltration projects.

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Existing and Required New Infrastructure

The Southwestern New Mexico Regional Water Plan (DBS&A, 2005 p. 8-103) describes existing diversion and conveyance facilities from the Gila River to Tyrone Mine operated for mine-water purposes. The diversion location and the conveyance alignment are shown in Figure 12. Diversions up to 40 cfs are made from the Gila River and pumped to Bill Evans Lake, which has 2,100 AF storage capacity. Water is conveyed from the lake to the mine by two pumping stations through 22 miles of 27-inch diameter pipe at rates up to 21 cfs. Part of the existing infrastructure may be available for use by the Town for recharge operations.

Conveying water to prospective recharge sites requires a new pumping station and new pipeline. Figure 12 shows one possible tie-in point and alignment for new pipeline to convey water from the existing pipe to the recharge sites. About eight miles of new pipeline is needed for either recharge option. Elevation change is 1,690 feet from the Gila River to the recharge sites; about 1,000 feet of that is along the new pipeline. We estimate that a 400-horsepower pump station is needed to convey one cfs (about 500 gpm) from the tie-in with existing pipe eight miles and 1,000 vertical feet to the recharge site, assuming new pipe is eight-inch diameter. Capital cost of the pump and pipeline is estimated at about $4.2 million (Table 1), which is necessary for both recharge options (injection and infiltration). A description of the basis for estimated costs is appended to this technical memorandum (Appendix B).

Managed Injection of Recharge Water

The injection project involves directly recharging water to the regional aquifer by gravity feed through one or several wells. Proposed locations of injection wells are shown on Figure 12. Gila River surface water to be used for injection is expected to require treatment, which would happen at an on-site facility prior to injection. Treatment involving filtration and disinfection is necessary to protect the aquifer and prevent well-screen fouling. In the example project herein, two injection wells are proposed to be constructed in the area of Frank's Wellfield at depths of 600 and 1,100 feet (Figures 13 and 14) corresponding to shallow and deep completions in Town wells at Frank's wellfield. The injection wells would be equipped with a drop pipe and orifice to prevent cascading water, and valves and gages to monitor and control pipeline pressure and injection rates. A separate nested observation well with piezometers screened at the injection zones is recommended to monitor shallow and deep aquifer conditions (Figure 15). Injection wells and observation piezometers would be instrumented with pressure transducers to measure and record water levels.

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Table 1 summarizes estimated capital and annual costs for the example injection project. Annual costs include pumping and treating water, and rehabilitating wells to remove scale and restore capacity. The annualized cost of the example injection project is estimated at about $1.1 million per year and the unit cost at $1,400 per AF.

Managed Infiltration of Recharge Water

We propose to use in-channel infiltration at local arroyos near the Town's wellfield for managed recharge. Two arroyo locations are shown in Figure 16; anywhere along the arroyo lengths indicated is prospective for infiltration. The feasibility of recharging water in arroyos has been demonstrated by Hernandez and others (1984, p.70), who report that discharge from a 1982 three-day pumping test of Frank's Well 7 was routed to one such arroyo (Figure 16). The resulting flow of 1.35 cfs infiltrated into the arroyo bed over a distance of less than 2,000 feet, or an infiltration rate of over three cfs per mile. In a separate project, the Town is presently monitoring recharge of wastewater effluent discharged to San Vicente Arroyo (BGW, 2009). In that area, effluent infiltrates into the arroyo bed at a rate of approximately three cfs per mile and it has occurred since the current WWTP began operating in 1979.

For the example project, untreated water from the new pipeline would be discharged into one or two natural drainage areas near Frank's Wellfield. As with the injection approach, a new pump and pipeline are necessary to convey water to the recharge site. The pipeline outlet would be equipped with valves and totalizing flow meters to control and monitor discharge rates. Discharge to the arroyo at one cfs is expected to flow about 2,000 feet before fully infiltrating. No preparation of the arroyo bed prior to beginning operations is necessary, but periodic treatment of the bed may be need to remove algae or other clogging materials. An instrument nest (Figure 17) would be installed in each recharge drainage to monitor percolation of water through the vadose zone. A second nest may be installed above the wetted reach to monitor background conditions. A series of temperature and moisture-content sensors in each nest will track percolation of water from the surface down to the regional water table. A 450-foot deep monitor well screened across the water table and instrumented with a pressure transducer would monitor water-table conditions.

Estimated costs for the example infiltration recharge project are summarized in Table 1 and detailed in the Appendix B. The annualized cost is estimated at about $0.8 million per year and the unit cost at about $1,000 per AF.

The annualized costs for larger recharge projects involving, for example, two cfs would be higher than the smaller example projects at $1.8 and $1.2 million per year for injection and infiltration, but unit costs would be lower at $1,100 and $700 per acre foot.

Administrative Issues

We understand the source of recharge water for the Town may be Gila River water leased from the mine. A water-transfer application to the OSE is needed to change the place and purpose of use of mine water to recharge water. The application will need to be advertised and may be protested. A protested application with an administrative hearing may take two to

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three years for a decision, with uncertain outcome; however, an application for groundwater recharge may have more appeal administrative then other applications typically submitted to the OSE. We understand OSE permits are not needed for drilling instrument nests if the borehole does not intersect a water-bearing unit, but the monitor well may need a permit. Injection wells will require drilling permits.

A NMED groundwater discharge permit is not expected to be required for the infiltration approach, but likely will be needed for injection. Federal NPDES requirements, which control point discharge to surface water bodies, may or may not come into play with infiltration. With either recharge approach, we recommend the Town first submit a Notice of Intent to NMED that describes the program, the water source and recharge method and location, monitoring program and water quality sampling results. On that basis NMED can advise whether and what permitting is required.

Recommended Pilot Program

Although the three-day aquifer test associated with Frank's Well 7 provided information on local infiltration rates, it would be prudent to conduct a pilot test for a longer period of time to confirm conditions suitable for the full scale project. We recommend the Town undertake a short-term recharge pilot project that would involve pumping one or more of the Town's supply wells and conveying water to an arroyo at a reasonably constant rate for several months. The program would demonstrate technical and hydrologic feasibility of recharging water through arroyos prior to moving forward with the $4.2 million cost of installing the infrastructure to import water from the Gila River. The rate and duration may depend on available well capacity and Town water-service demands, but a minimum of 0.5 cfs (220 gpm) for three to five months is recommended. The test could be conducted through the fall, winter or spring months when municipal demand is lowest. We recommend at least one subsurface instrument nest installed along the wetted reach to track recharge progress.

If possible, water from the wells could be routed through the Town's existing water supply line to a tee fitting that directs water to the head of the recharge reach. A few hundred feet of temporary PVC may be needed to convey water to the site, which can be buried in a

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shallow trench for security and to prevent freezing. The pipe would include a pressure gage, rate control valve and totalizing meter to track and control discharge. The cost of buying and installing equipment for the example setup would be about $10,000 to $20,000 for the outlet pipe and valves and about $40,000 for an instrument nest, or a total of up to $60,000.

Administrative and permitting issues for a short pilot test with State agencies are uncertain, but may be relatively minor. Water for the project would come from the Town's OSE-permitted quantities and wells, and would be used within the Town's permit place of use. The Town may want to confirm with their water attorney whether use of the water for recharge is within permitted purposes of use. A Notice of Intent to OSE for the project may be needed. The Town should also plan to submit a Notice of Intent to NMED, but we understand a groundwater discharge permit usually is not required for temporarily discharging groundwater from a well directly to the ground surface.

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Conclusions

1. The hydrogeologic model provides a suitable tool for assessing the hydrologic effects of groundwater development and management in the region of the Mangas Trench. The model is capable of simulating hydrologic conditions observed in the field and it may be used to understand the performance of the hydrologic system and to assist with future planning of local regional water use and management alternatives.

2. Historical groundwater pumping has resulted in water-level declines at the Town of Silver City wells. The extent of groundwater captured by the Town wells is within a few miles of the wellfields.

3. Managed recharge options available to the Town of Silver City include direct injection to the aquifer with wells and infiltration along natural channels. Managed recharge in the wellfield area would reduce the amount of future drawdown that otherwise would occur and it is expected to provide a means to replenish aquifer storage historically consumed.

4. Long-term injection operations at the locations described herein will eventually result in the Town wells capturing recharge water. The timing and degree of capture depends on the amount and locations of recharge and on the magnitude of wellfield pumping.

5. Assuming existing infrastructure is available for conveying water, we estimate a recharge project involving infiltration of 800 acre feet per year of Gila River water would have an annual cost of about $0.8 million per year, or a unit cost of $1,000 per acre foot. The same amount of recharge water with direct injection into the aquifer (injection wells) costs more, or about $1.1 million per year with a unit cost of $1,400 per acre foot. A recharge project with more water than 800 acre feet per year has higher annualized costs, but lower unit costs in terms of cost per acre foot.

6. A pilot program to confirm infiltration performance in existing intermittent channels near Frank's wellfield would cost about $60,000 to set up. The test would run for a few months.

Recommendation

1. If the Town decides to move forward with recharge operations, undertake a pilot program involving several months of piping the Town of Silver City well water to a local intermittent channel to demonstrate hydrologic feasibility of infiltration recharge. Install a vadose zone temperature and moisture-content instrument nest to track recharge progress. Findings will assist with decisions on moving forward.

Attachments: Table 1
Figures (17)

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References

Anderman, E.R. and Hill, M.C., 2003, MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model—Three Additions to the Hydrogeologic-Unit Flow (HUF) Package: Alternative Storage for the Uppermost Active Cells (SYTP Parameter Type), Flows in Hydrogeologic Units, and the Hydraulic-Conductivity Depth-Dependence (KDEP) Capability: U.S. Geological Survey Open-File Report 03-347.

ARC GIS, 2009, Geographical Information System: ESRI, http://www.esri.com/software/arcgis/arcinfo/index.html.

Balleau Groundwater, Inc., 2009, Installation of Monitoring System for Tracking Subsurface Thermal Water Movement: Consultant's Unpublished Report.

Balleau Groundwater, Inc., 2006, Supplement on Water Use and Wellfield Service-a 40-Year Water Plan for the Town of Silver City, New Mexico: Consultant's Unpublished Report.

Cunningham, J.E., 1974, Geologic Map and Sections of Silver City Quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources.

Daniel B. Stephens & Associates, Inc., 2005, Southwest New Mexico Regional Water Plan Volume 1: Report Text, Appendix A.

Hanson, R.T., McLean, J.S. and Miller, R.S., 1994, Hydrogeologic Framework and Preliminary Simulation of Ground-Water Flow in the Mimbres Basin, Southwestern New Mexico: U.S. Geological Survey Water-Resources Investigations Report 94-4011.

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.

Hathaway, D.L., 1986, Hydrogeologic Evaluation of Proposed Transfer of Water from the Gila River to Tyrone by the Phelps Dodge Corporation: New Mexico Office of the State Engineer.

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Hawley, J.W., Hibbs, B.J., Kennedy, J.F., Creel, B.J., Remmenga, M.D., Johnson, M., Lee, M.M. and Dinterman, Phil, 2000, Trans-International Boundary Aquifers in Southwestern New Mexico.

Hedlund, D.C., 1978a, Geologic Map of the Wind Mountain Quadrangle, Grant County, New Mexico: U.S. Geological Survey, Map MF-1031.

Hedlund, D.C., 1978b, Geologic Map of the White Signal Quadrangle, Grant County, New Mexico: U.S. Geological Survey, Map MF-1041.

Hernandez, J.W., Hines, W.G. and Trauger, F.D., 1984, Evaluation of a Municipal Water Supply for the Silver City Area Using Ground Water Recharge of Water from Conner Reservoir on the Gila River.

Johnson, M.S., 2000, Hydrologic Evaluation of Application GSF-1745 into GSF-1014 for Permit to Change Location of Well and Place or Purpose of Use in the Gila-San Francisco Underground Water Basin Grant County, New Mexico: New Mexico Office of the State Engineer Hydrology Report 00-3.

Johnson, M.S., February 6, 2002 Technical Memorandum "Modifications to the OSE Silver City Ground-Water Flow Model": New Mexico Office of the State Engineer.

Koopman, F.C., Trauger, F.D and Basler, J.A., 1969, Water Resources Appraisal of the Silver City Area New Mexico: New Mexico Office of the State Engineer Technical Report 36.

Paige, S., 1916, Description of the Silver City Quadrangle, New Mexico: U.S. Geological Survey Atlas, Folio 1999, 19 pp.

Trauger, F.D., 1972, Water Resources and General Geology of Grant County, New Mexico: New Mexico State Bureau of Mines and Mineral Resources Hydrologic Report 2.

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GROUNDWATER RECHARGE

TABLE 1. ESTIMATED CAPITAL AND ANNUAL COSTS FOR EXAMPLE INJECTION AND FOR INFILTRATION PROJECTS

Element	Cost per unit	Unit	No. of Units	Totals
Injection				
Capital Costs				
Pumping station	-	-	-	$210,000
Pipeline	$500,000	mi	8	$4,000,000
Treatment Plant	$1,200	AF	800	$960,000
1100-ft injection well	$250	ft	1100	$275,000
600-ft injection well	$250	ft	600	$150,000
Well appurtenances	$50,000	each	2	$100,000
Observation well	$150	ft	1100	$165,000
			Total	$5,860,000
			Ten Percent Annualized[1]	$586,000
O&M Costs				
Pumping water	$460	AF	800	$370,000
Water Treatment	$150	AF	800	$120,000
Well rehabilitation	$15,000	each	2	$30,000
			Total	$520,000
			Total Annual Cost for Water Injection	$1,106,000
			Unit Cost ($/AF)[2]	$1,400
Infiltration				
Capital Costs				
Pumping station	-	-	-	$210,000
Pipeline	$500,000	mi	8	$4,000,000
Monitor Well	$100	ft	450	$45,000
Instrumentation nests	$42,500	nest	2	$85,000
			Total	$4,340,000
			Ten Percent Annualized[1]	$434,000
O&M Costs				
Pumping water	$460	AF	800	$368,000
Arroyo bed rehabilitation	$5,000	acre	2	$10,000
			Total	$378,000
			Total Annual Cost for Water Infiltration	$812,000
			Unit Cost ($/AF)[2]	$1,000

[1]Equivalent to annual payments for 20 years at 8 percent interest.

[2]Rounded to nearest $100

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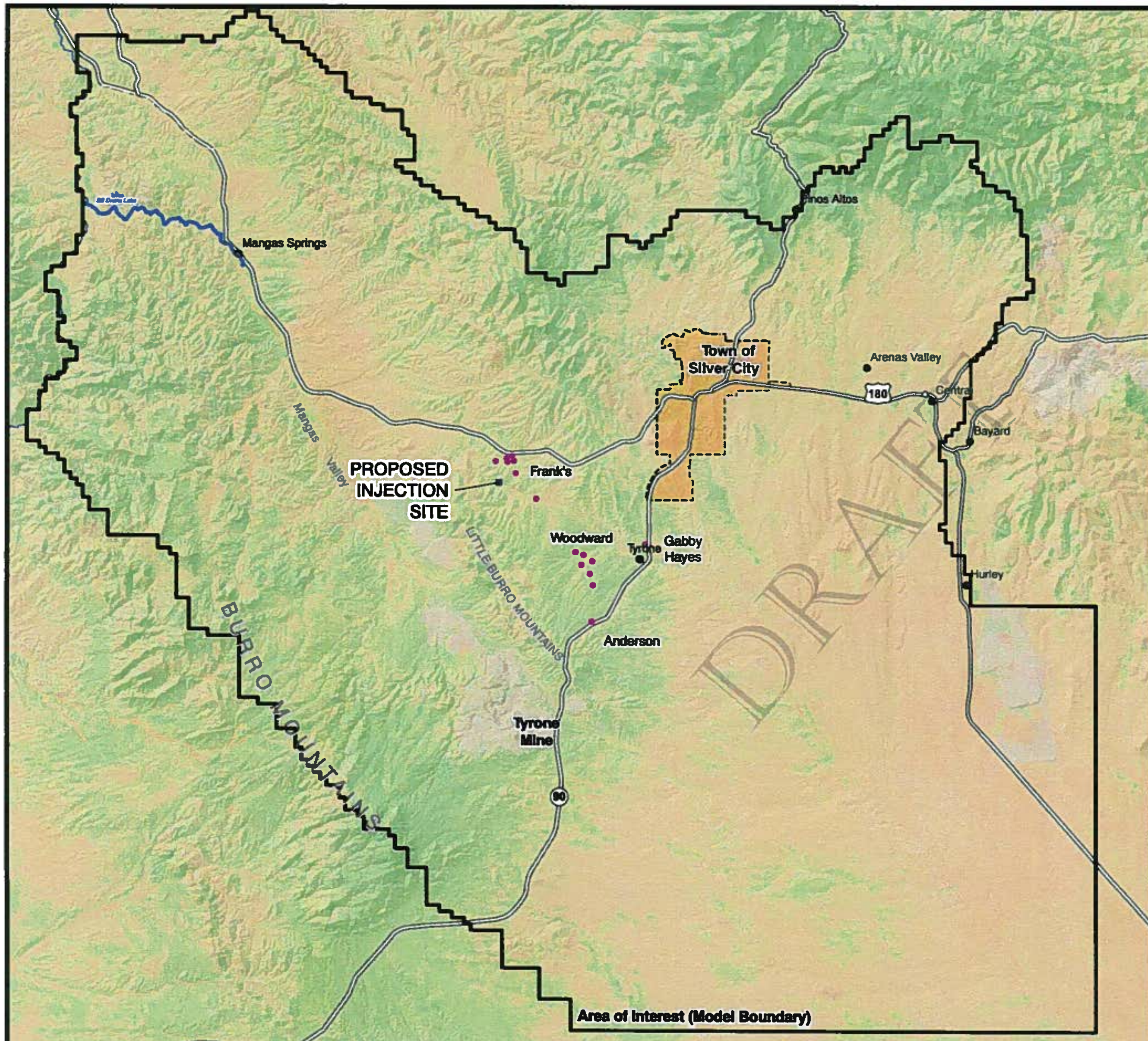
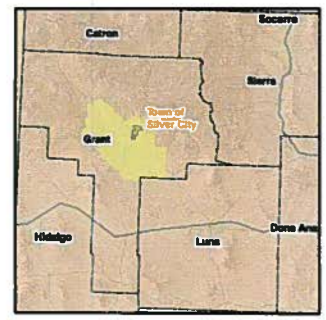


0 5 Miles

Map Projection: New Mexico West, NAD83.



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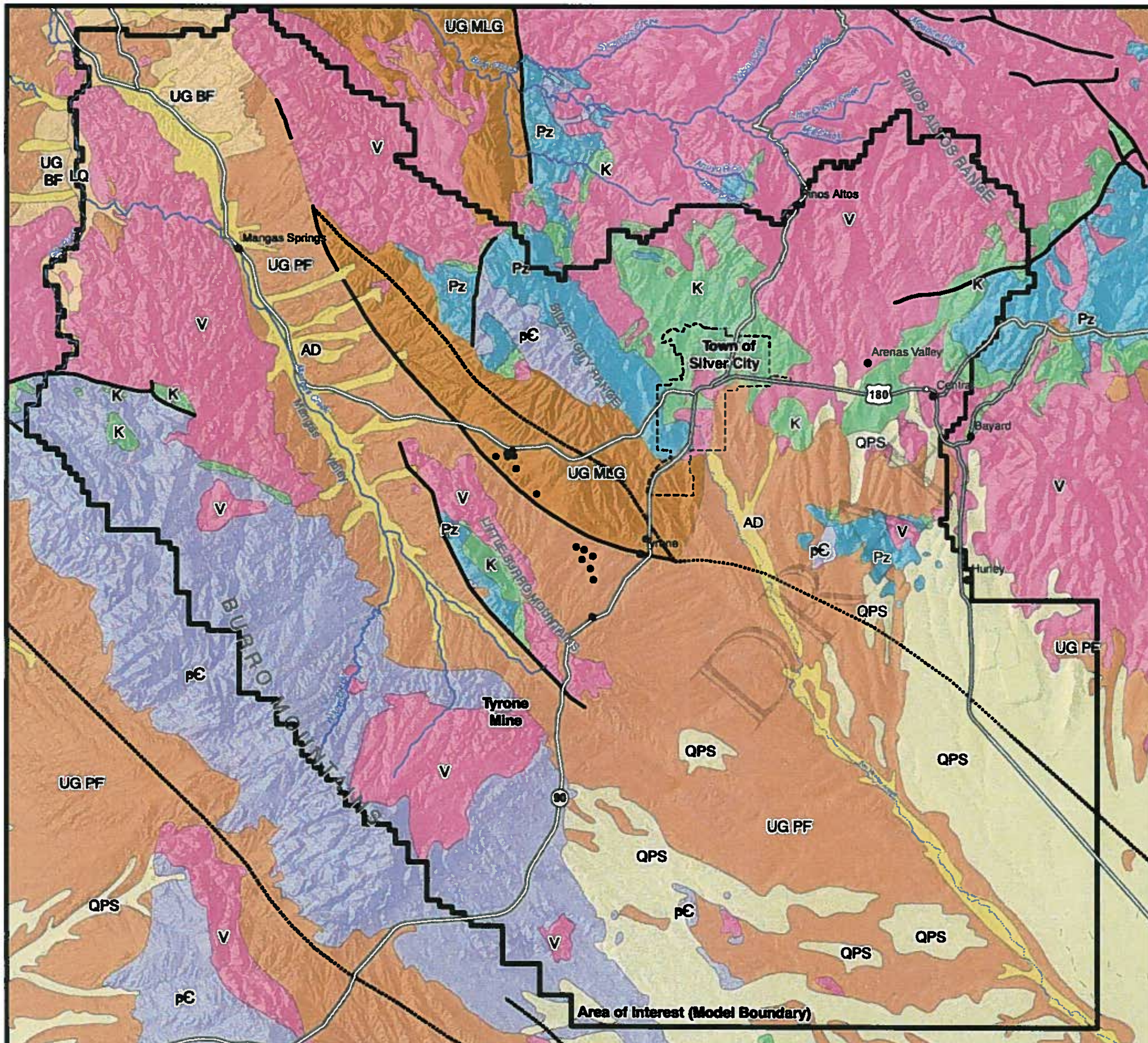
TOWN OF SILVER CITY / GROUNDWATER RECHARGE

LOCALITY AND AREA OF INTEREST

FIGURE 1

BALLEAU GROUNDWATER, INC.



EXPLANATION

- AD Alluvial deposits of major ephemeral streams
- QPS Quaternary piedmont slope hydrostratigraphic units
- LQ Late Quaternary fluvial hydrostratigraphic units
- UG BF Upper Gila Group hydrostratigraphic units - Basin-floor facies
- UG MLG Upper Gila Group hydrostratigraphic units - Middle and Lower Gila
- UG PF Upper Gila Group hydrostratigraphic units - Piedmont facies
- K Cretaceous rocks
- Pz Paleozoic rocks
- pЄ Pre-Cambrian
- V Volcanics
- Fault (dashed where approximated)

Adapted from:
Hawley, J.W., Hibbs, B.J., Kennedy, J.F., Creel, B.J., Remmenga, M.D., Johnson, M., Lee, M.M. and Dinterman, P., 2000, Trans-International Boundary Aquifers in Southwestern New Mexico (Plate 1 – Surface Geology and Hydrostratigraphic Units of the Southwestern New Mexico Region) New Mexico Water Resources Research Institute, Technical Completion Report.

0 — 5 Miles

Map Projection: New Mexico West, NAD83.

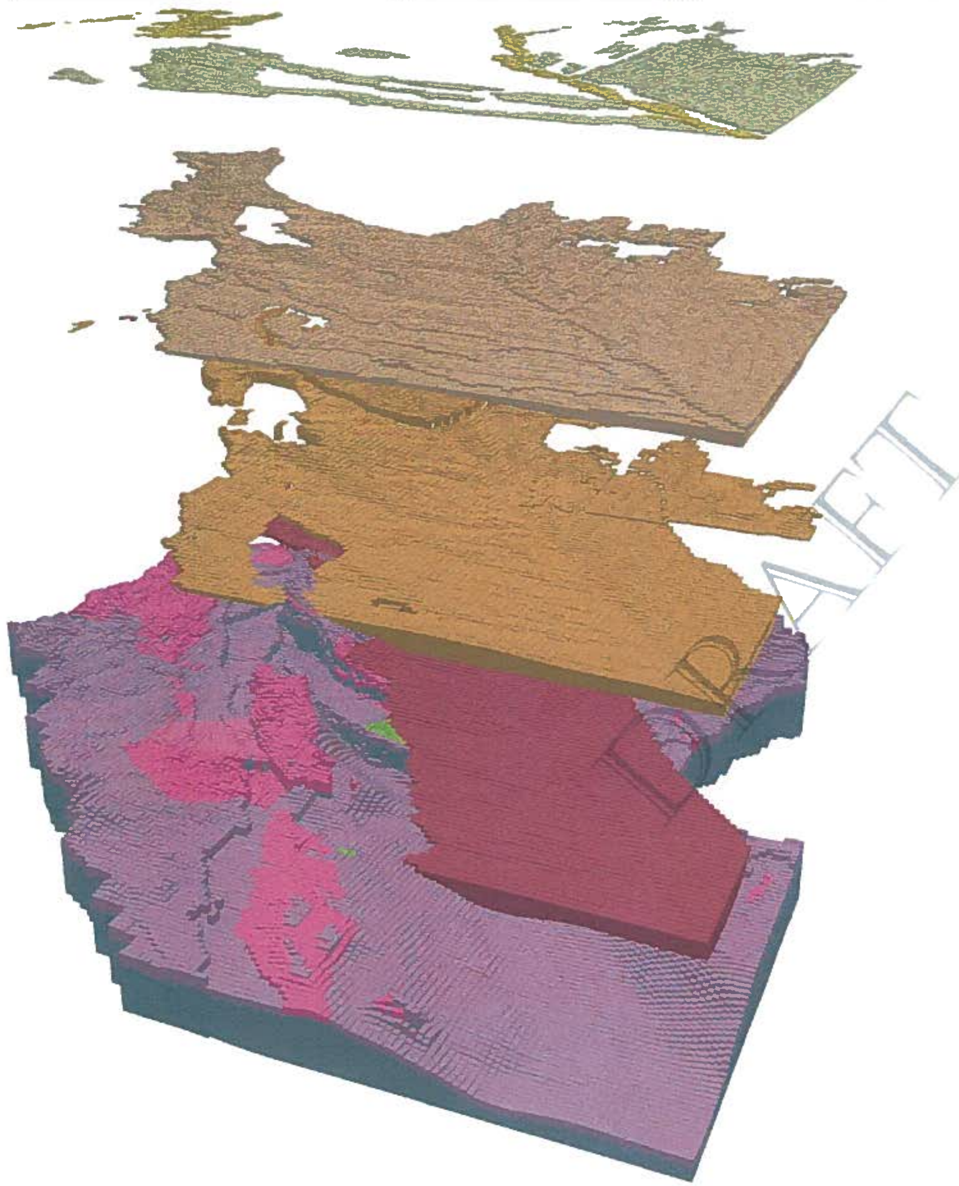
N / E / S / W

TOWN OF SILVER CITY / GROUNDWATER RECHARGE

GEOLOGY OF SILVER CITY AREA

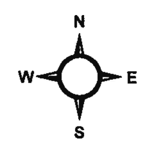
FIGURE 2

BALLEAU GROUNDWATER, INC.



EXPLANATION

- AD Alluvial deposits
- QPS Quaternary piedmont slope hydrostratigraphic units
- UG BF Upper Gila Group hydrostratigraphic units
- UG MLG Middle and Lower Gila Group hydrostratigraphic units (upper)
- UG MLG Middle and Lower Gila Group hydrostratigraphic units (lower)
- pC Pre-Cambrian and other bedrock hydrostratigraphic units
- V Volcanics and other bedrock hydrostratigraphic units

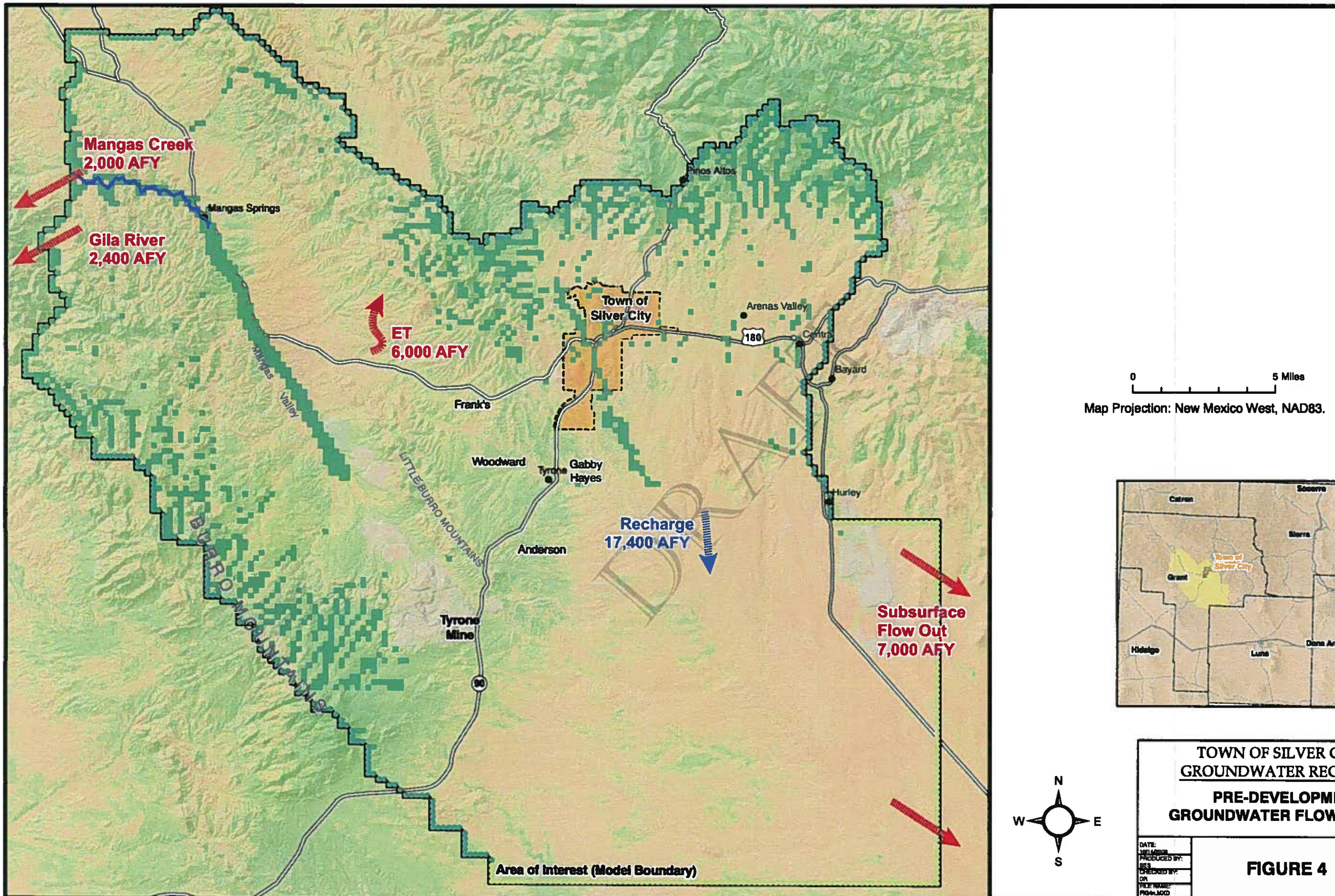


TOWN OF SILVER CITY / GROUNDWATER RECHARGE

THREE-DIMENSIONAL MODEL STRUCTURE

FIGURE 3

BALLEAU GROUNDWATER, INC.

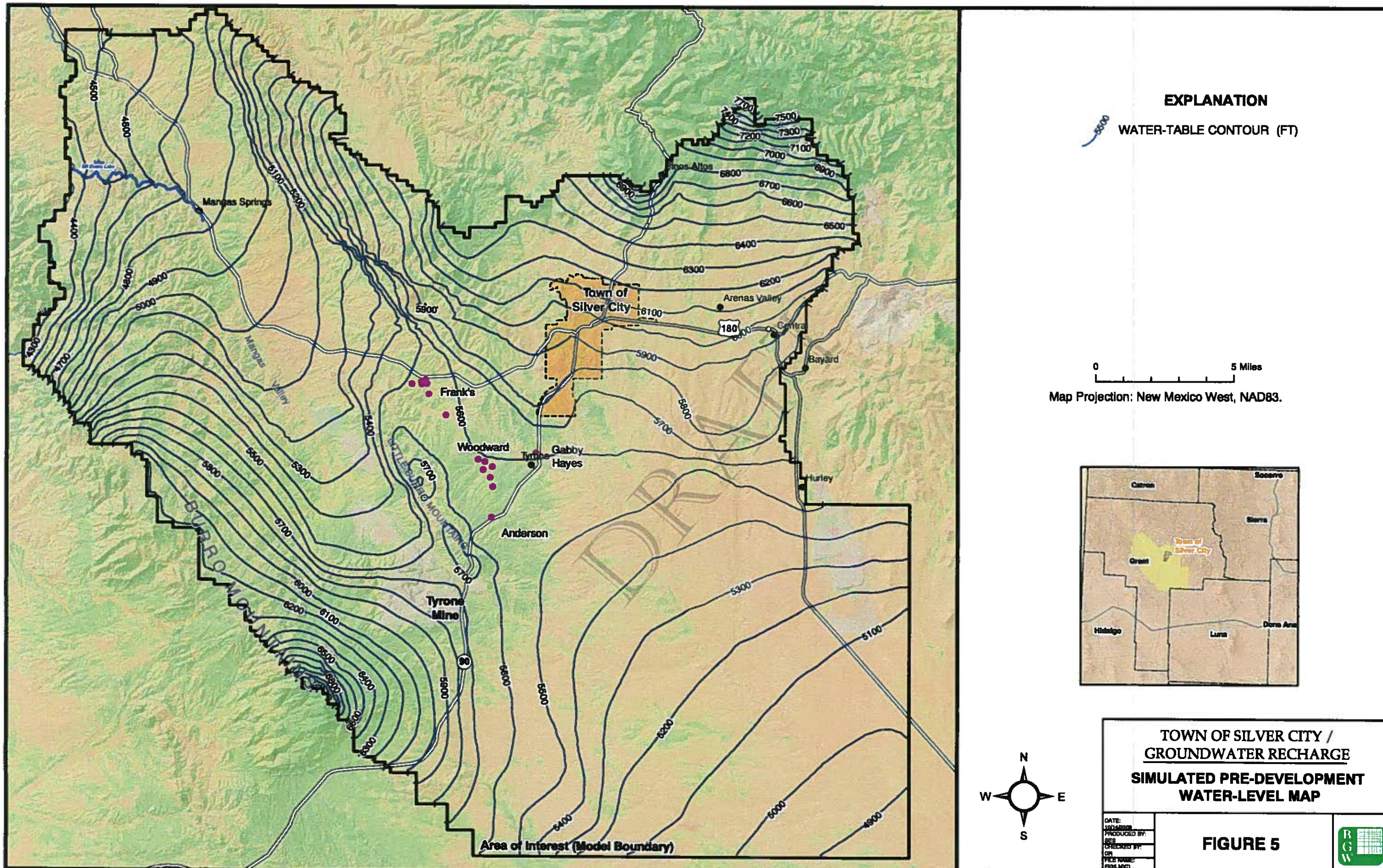


TOWN OF SILVER CITY /
GROUNDWATER RECHARGE

PRE-DEVELOPMENT GROUNDWATER FLOW BUDGET

FIGURE 4

BALLEAU GROUNDWATER, INC.

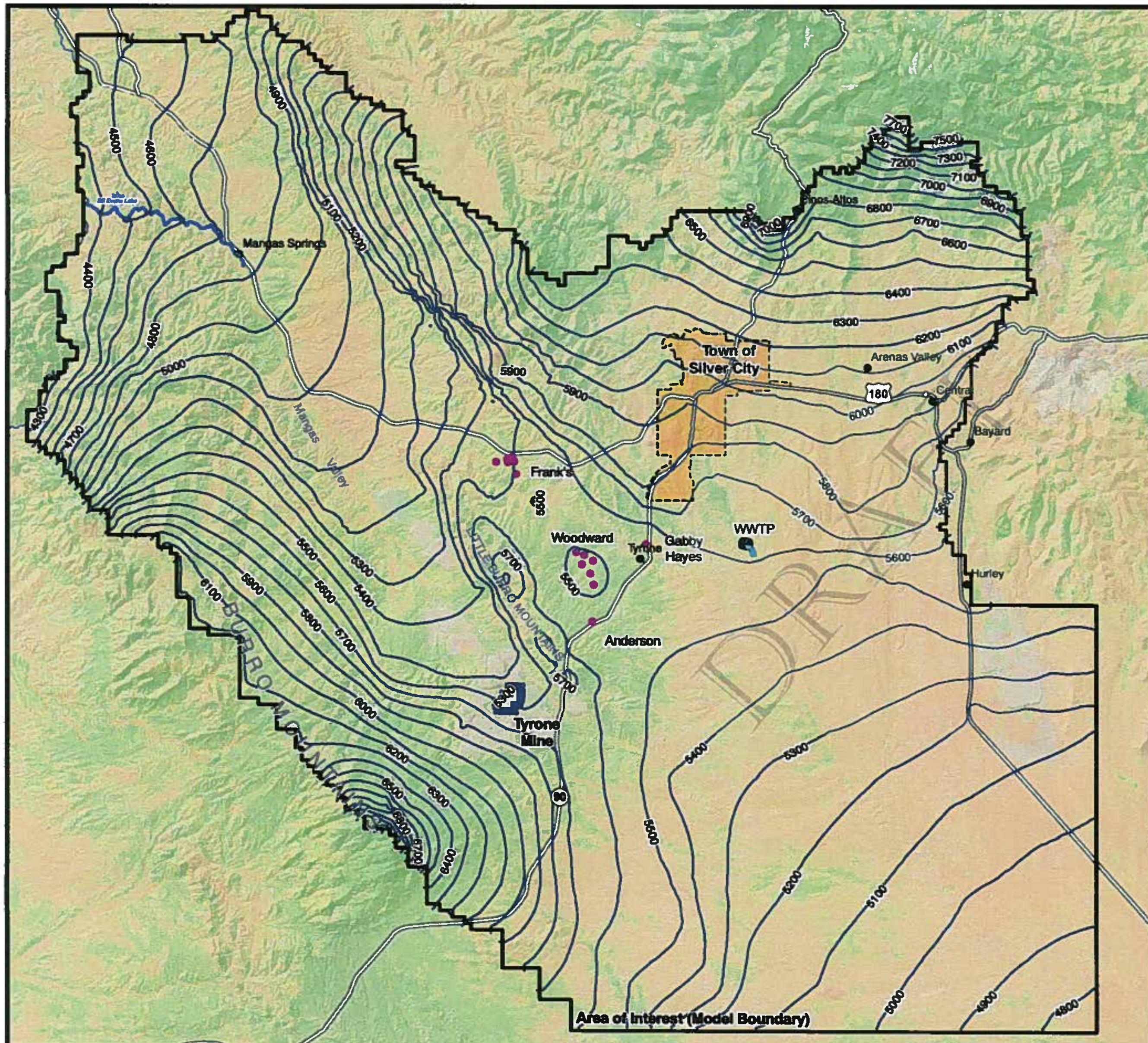


TOWN OF SILVER CITY / GROUNDWATER RECHARGE

SIMULATED PRE-DEVELOPMENT WATER-LEVEL MAP

FIGURE 5

BALLEAU GROUNDWATER, INC.



EXPLANATION

WATER-TABLE CONTOUR (FT)

0 — 5 Miles

Map Projection: New Mexico West, NAD83.

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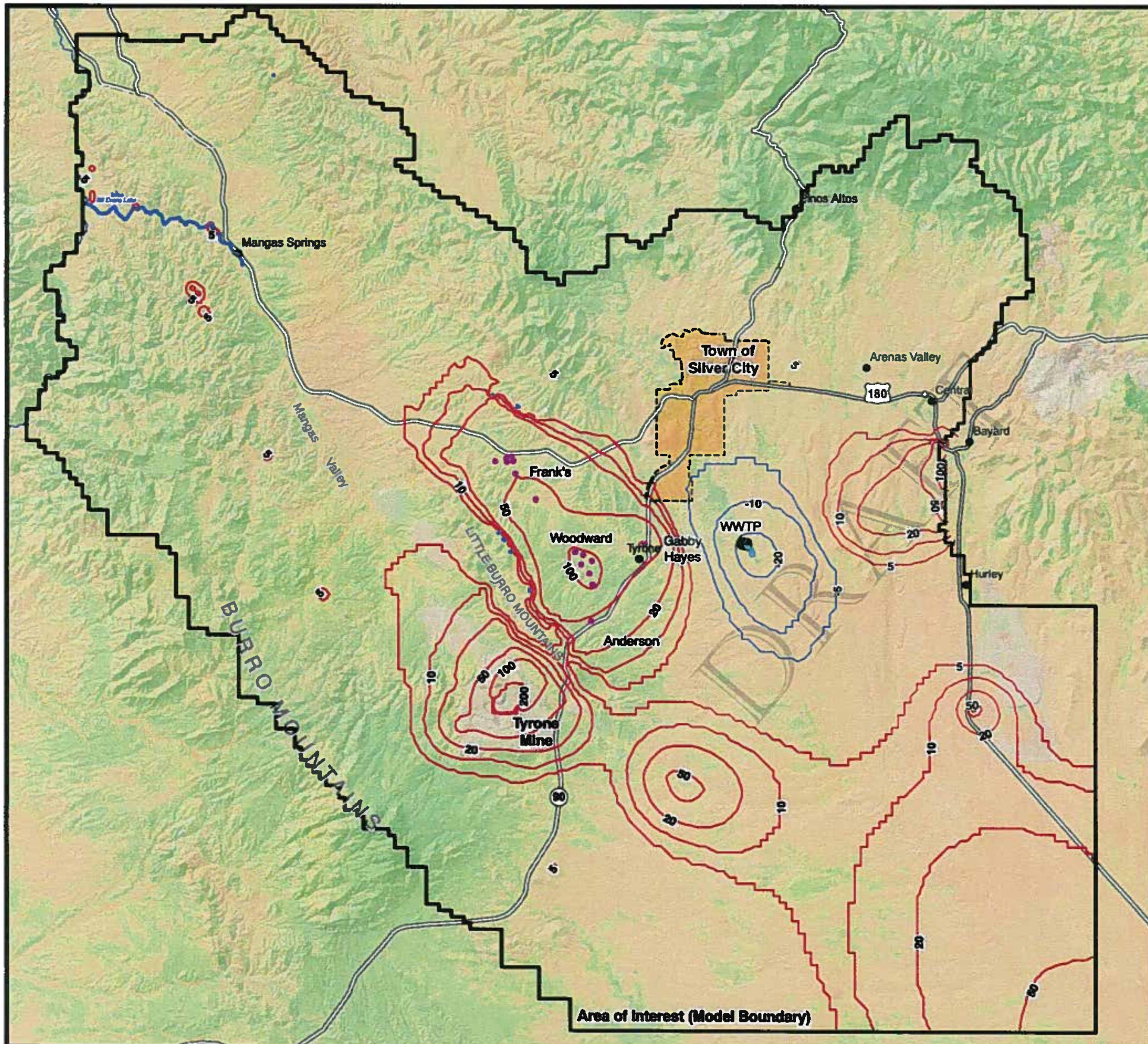
TOWN OF SILVER CITY / GROUNDWATER RECHARGE

YEAR 2009 WATER-LEVEL MAP

FIGURE 6

BALLEAU GROUNDWATER, INC.



EXPLANATION

WATER-TABLE BUILD-UP (FT)

WATER-TABLE DRAWDOWN (FT)

0 5 Miles

Map Projection: New Mexico West, NAD83.

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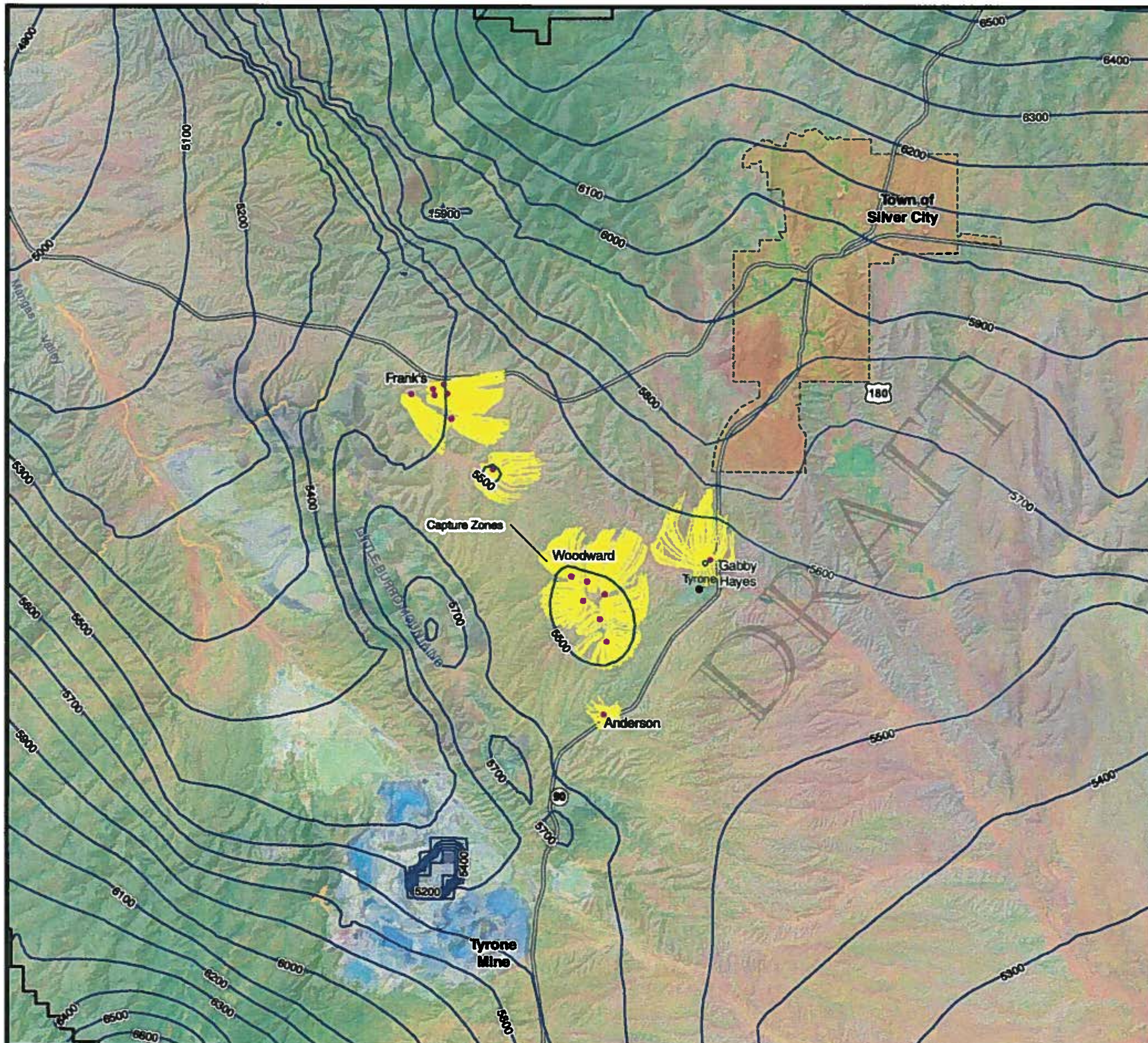
TOWN OF SILVER CITY /
GROUNDWATER RECHARGE

HISTORICAL WATER-LEVEL CHANGE

DATE:
PRODUCED BY:
CHECKED BY:
DR
FILE NAME:
FIG8A.MXD

FIGURE 7

BALLEAU GROUNDWATER, INC.



EXPLANATION

WATER-TABLE CONTOUR (FT)

0 5 Miles

Map Projection: New Mexico West, NAD83.

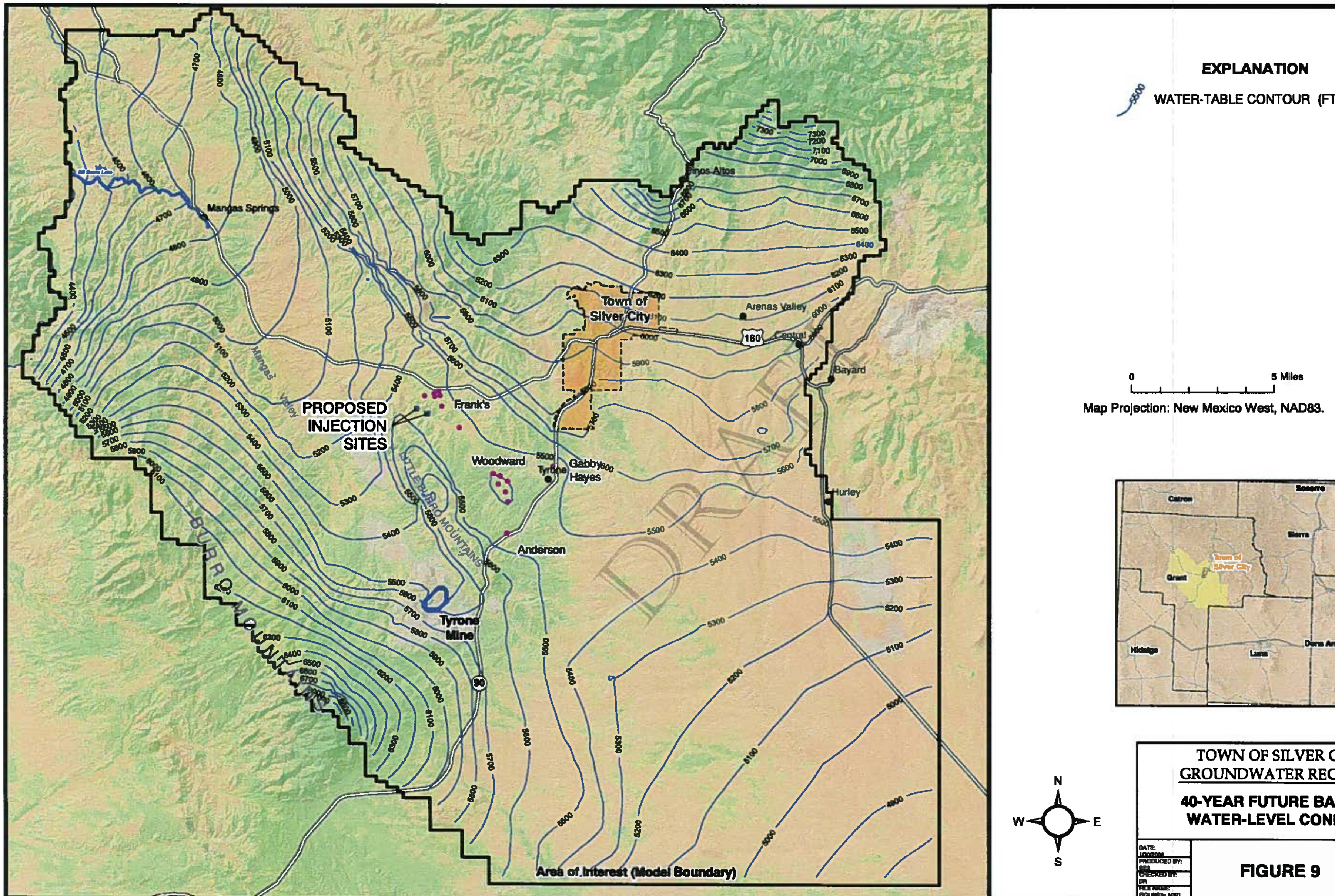
N W E S

TOWN OF SILVER CITY /
GROUNDWATER RECHARGE

HISTORICAL EXTENTS OF GROUNDWATER CAPTURED BY TOWN WELLFIELD

FIGURE 8

BALLEAU GROUNDWATER, INC.

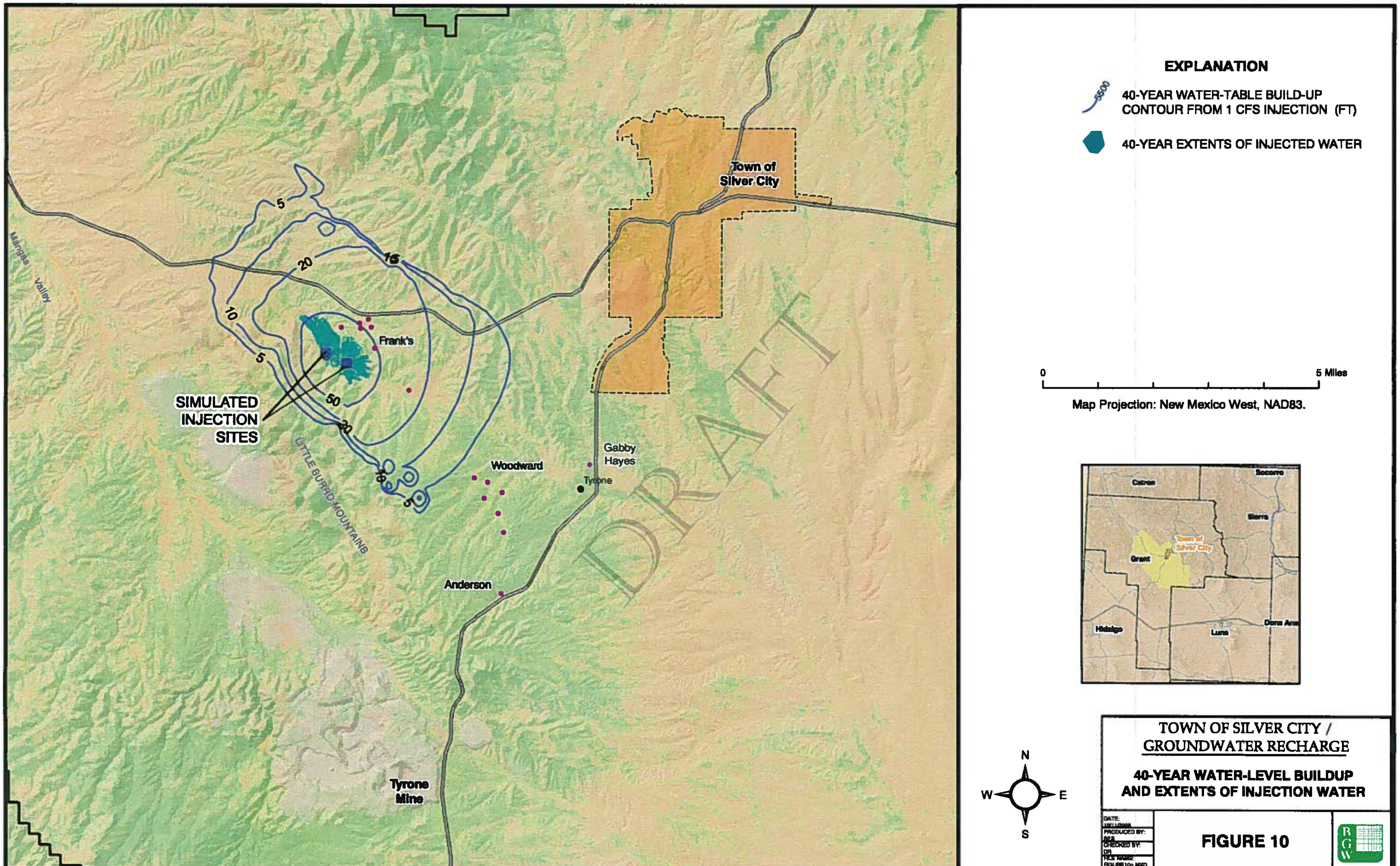


TOWN OF SILVER CITY /
GROUNDWATER RECHARGE

40-YEAR FUTURE BASELINE WATER-LEVEL CONDITION

FIGURE 9

BALLEAU GROUNDWATER, INC.

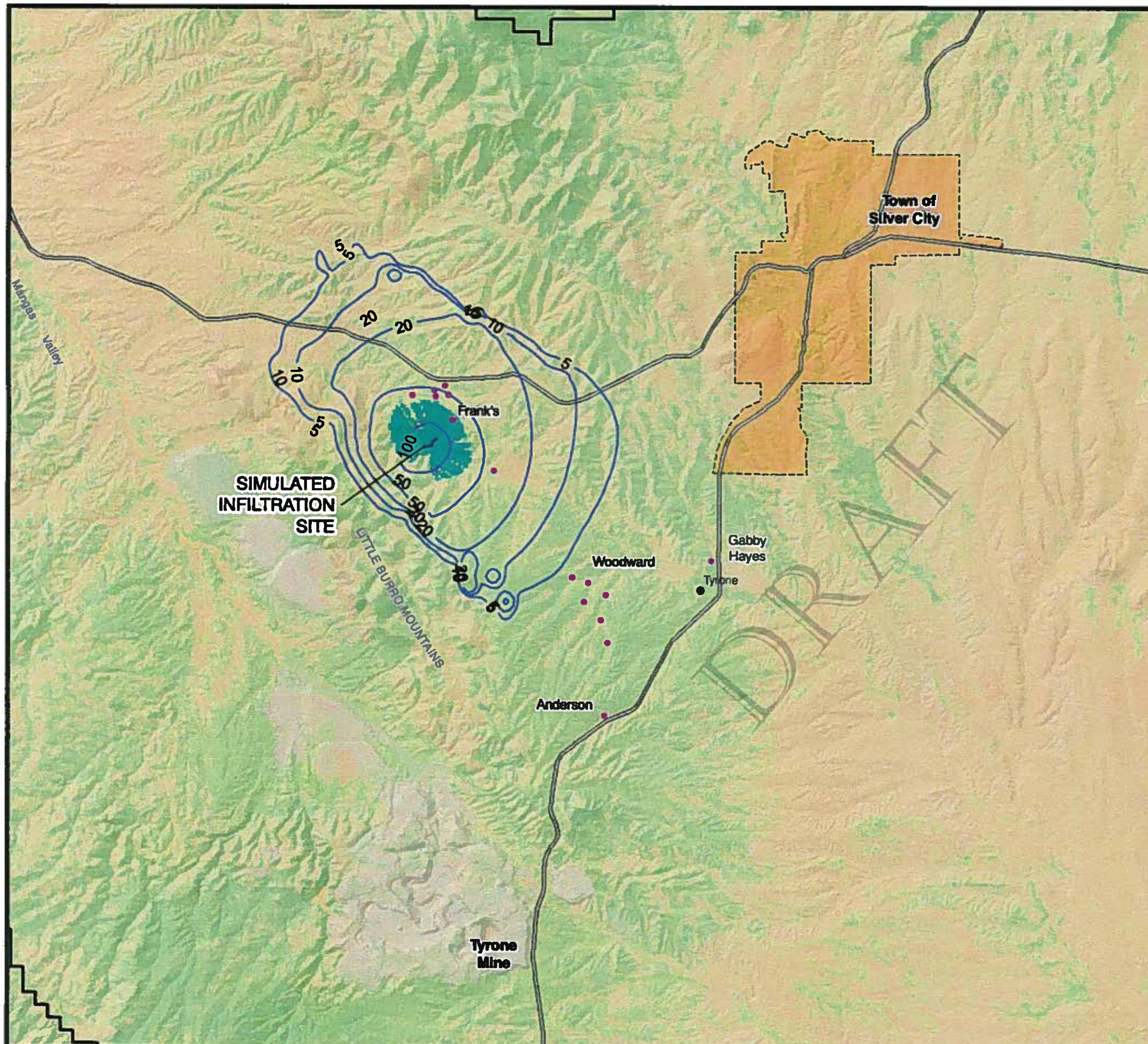


TOWN OF SILVER CITY / GROUNDWATER RECHARGE

40-YEAR WATER-LEVEL BUILDUP AND EXTENTS OF INJECTION WATER

FIGURE 10

BALLEAU GROUNDWATER, INC.



EXPLANATION

40-YEAR WATER-TABLE BUILD-UP CONTOUR FROM 1 CFS INFILTRATION (FT)

40-YEAR EXTENTS OF INFILTRATED WATER

0 — 5 Miles

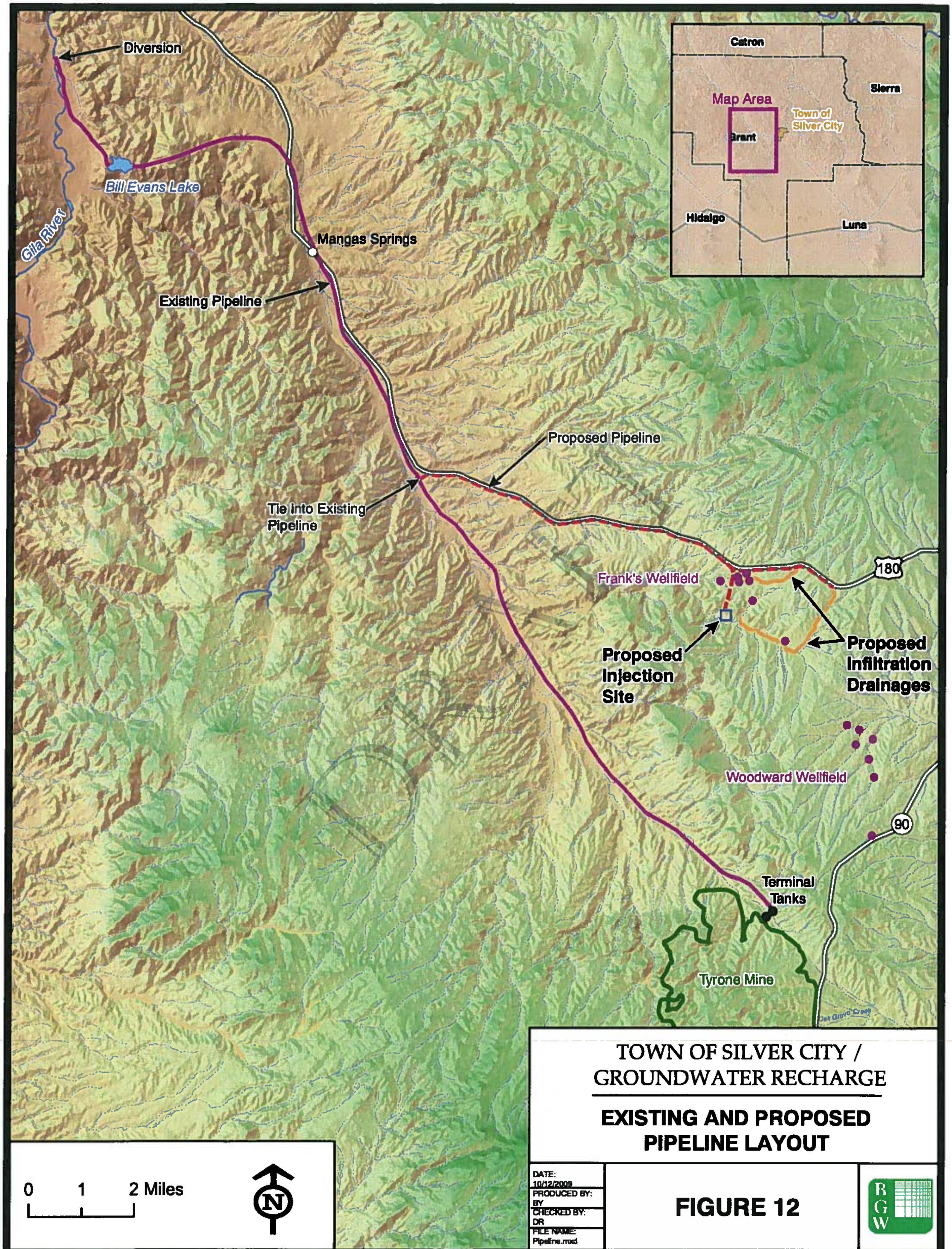
Map Projection: New Mexico West, NAD83.

TOWN OF SILVER CITY /
GROUNDWATER RECHARGE

40-YEAR WATER-LEVEL BUILDUP AND EXTENTS OF INFILTRATED WATER

FIGURE 11

BALLEAU GROUNDWATER, INC.

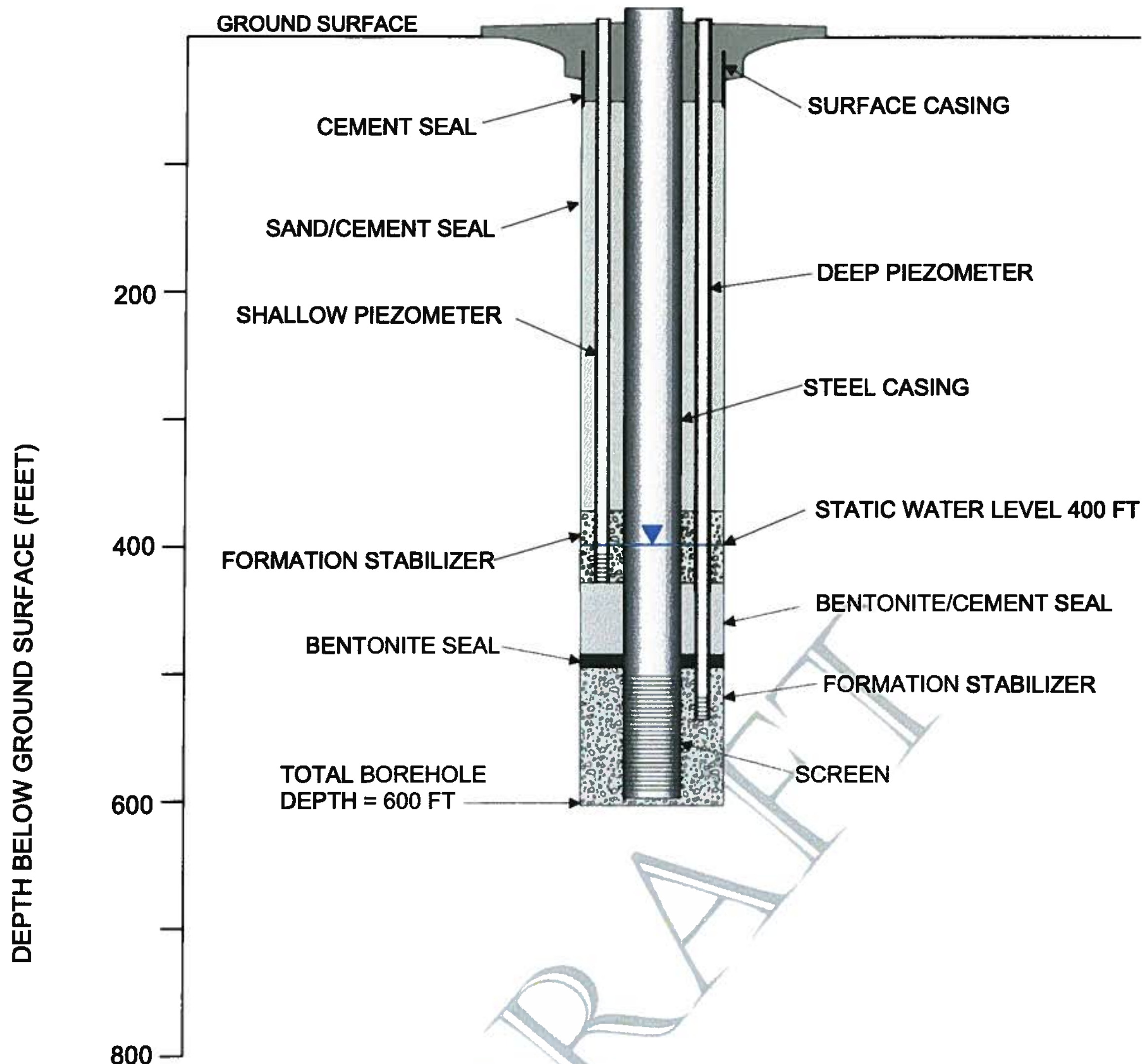


TOWN OF SILVER CITY / GROUNDWATER RECHARGE

EXISTING AND PROPOSED PIPELINE LAYOUT

FIGURE 12

BALLEAU GROUNDWATER, INC.



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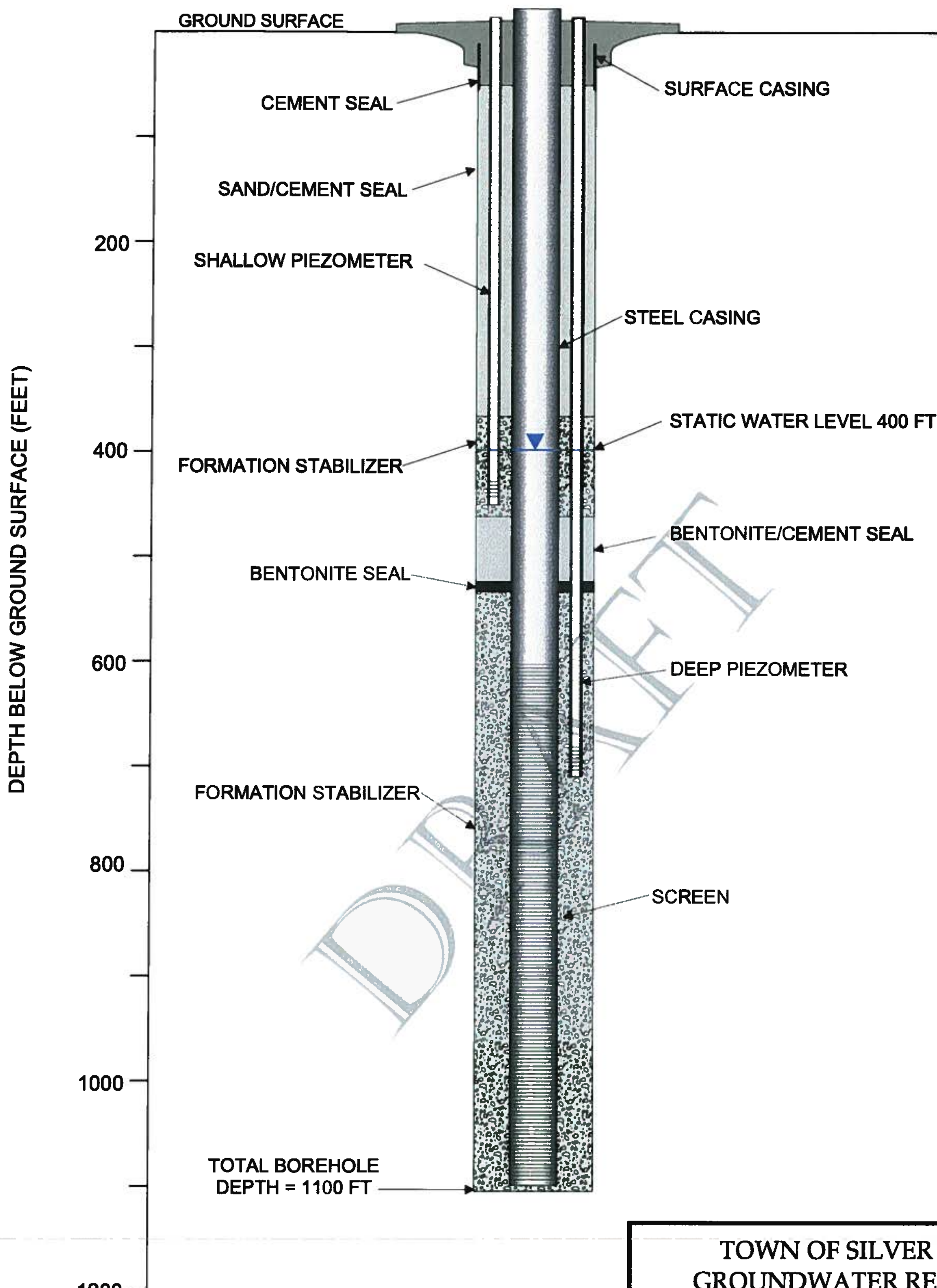
TOWN OF SILVER CITY / GROUNDWATER RECHARGE

EXAMPLE SHALLOW INJECTION WELL

Date: 10/14/2009
Produced By: BY
Checked By: CC
Filename: injwell_plan600.dsf

FIGURE 13

BALLEAU GROUNDWATER, INC.



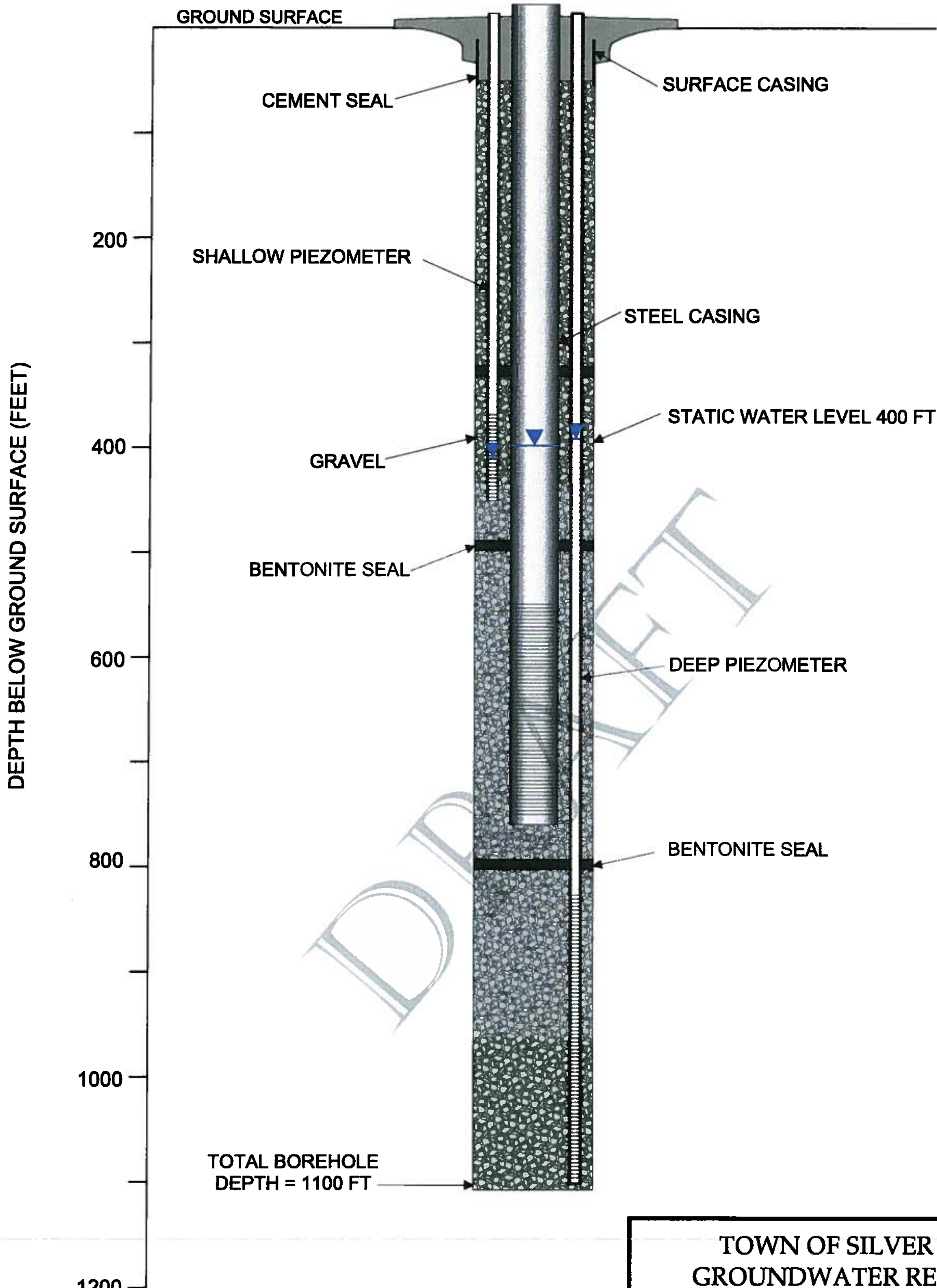
TOWN OF SILVER CITY / GROUNDWATER RECHARGE

EXAMPLE DEEP INJECTION WELL

Date: 10/14/2009
Produced By: BY
Checked By: CC
Filename: injwell_plan2.dsf

FIGURE 14

BALLEAU GROUNDWATER, INC.



TOWN OF SILVER CITY /
GROUNDWATER RECHARGE

EXAMPLE OBSERVATION WELL

Date: 10/14/2009	**FIGURE 15**
Produced By: BY	
Checked By: CC	
Filename: obswell_plan2.dsf	

BALLEAU GROUNDWATER, INC.

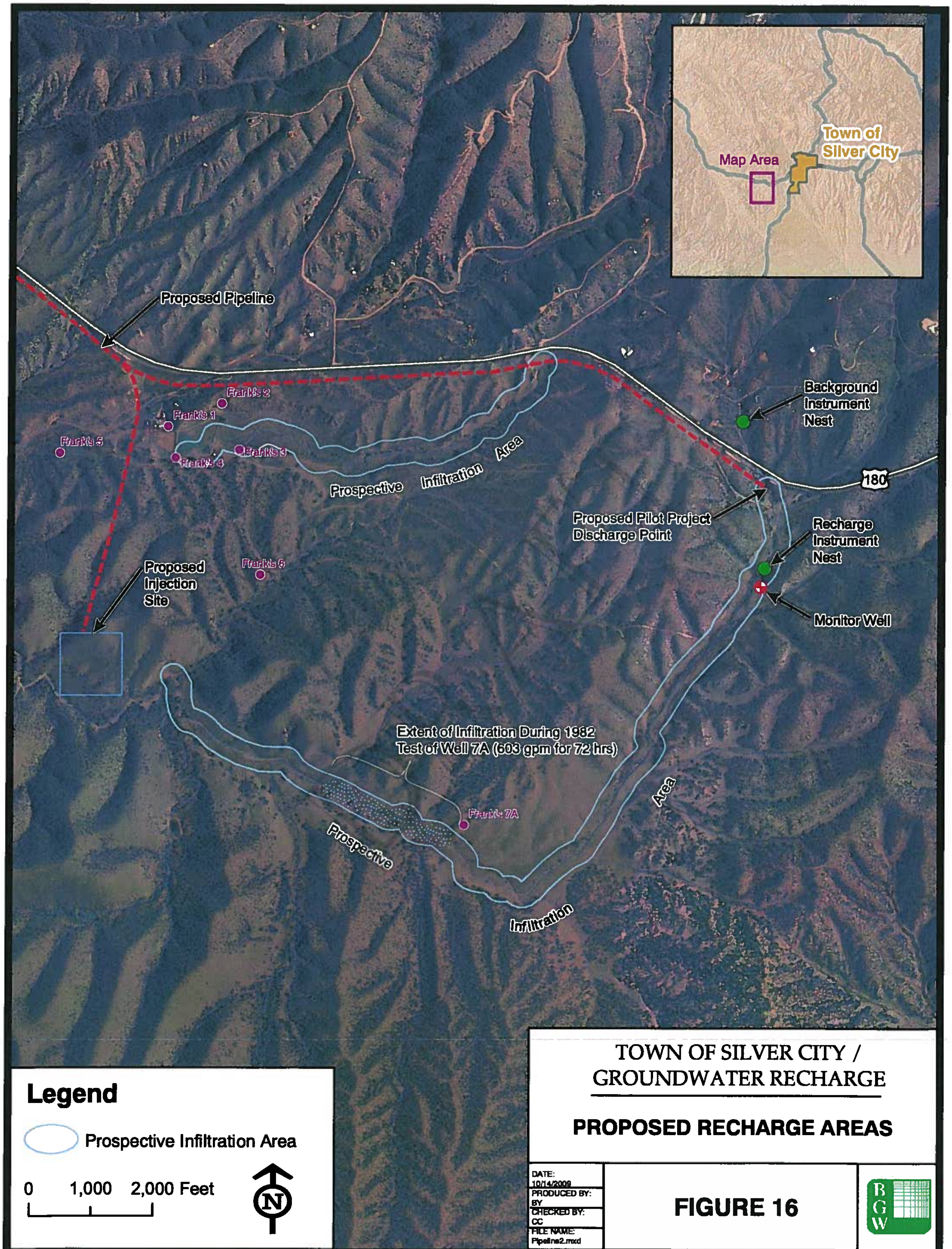
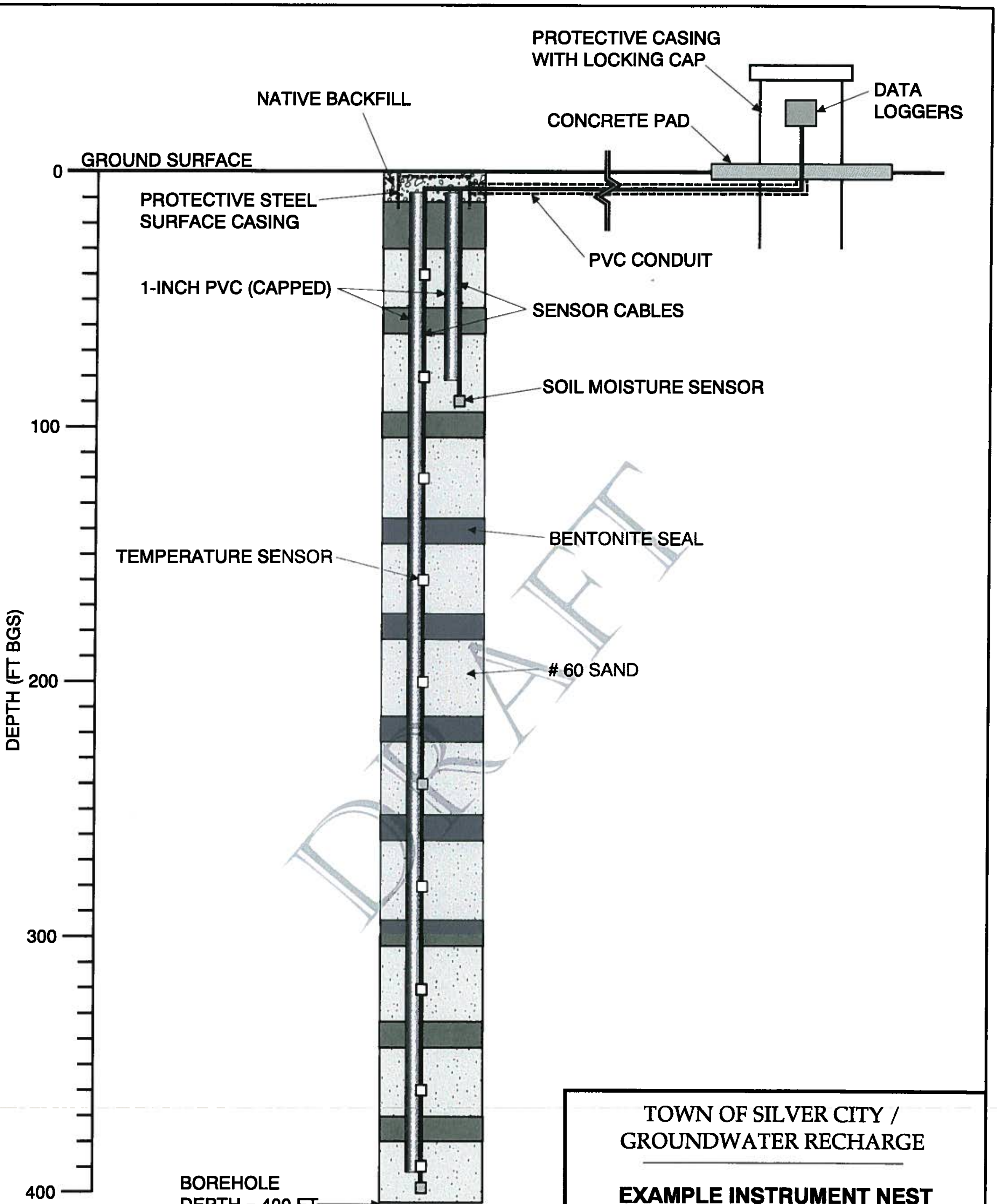


FIGURE 16

BALLEAU GROUNDWATER, INC.



TOWN OF SILVER CITY /
GROUNDWATER RECHARGE

EXAMPLE INSTRUMENT NEST

Date: 2/2/09 Produced By: BY Checked By: DR Filename: IN-A As-Built.dsf	**FIGURE 17**

BALLEAU GROUNDWATER, INC.

APPENDIX A

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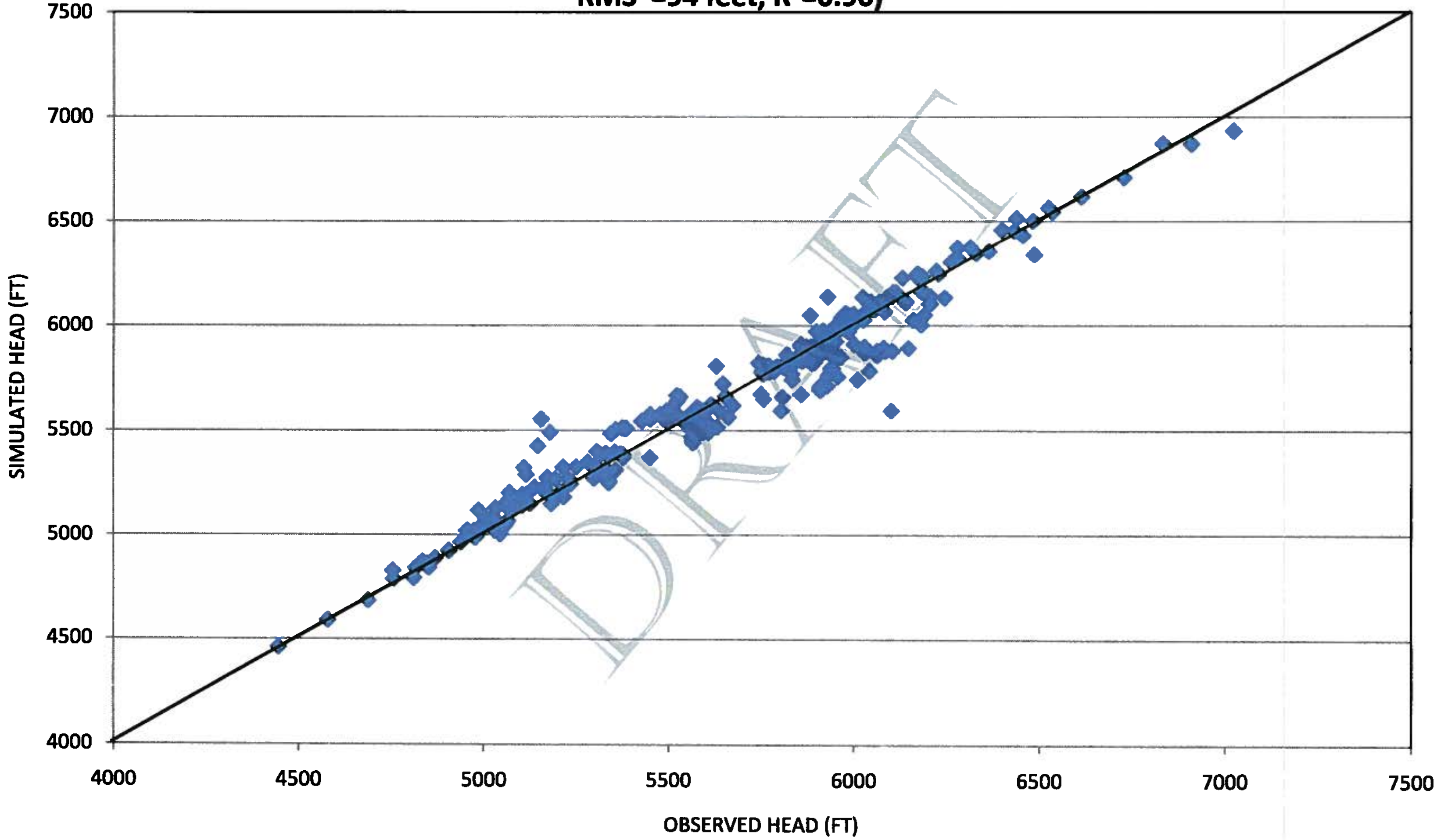
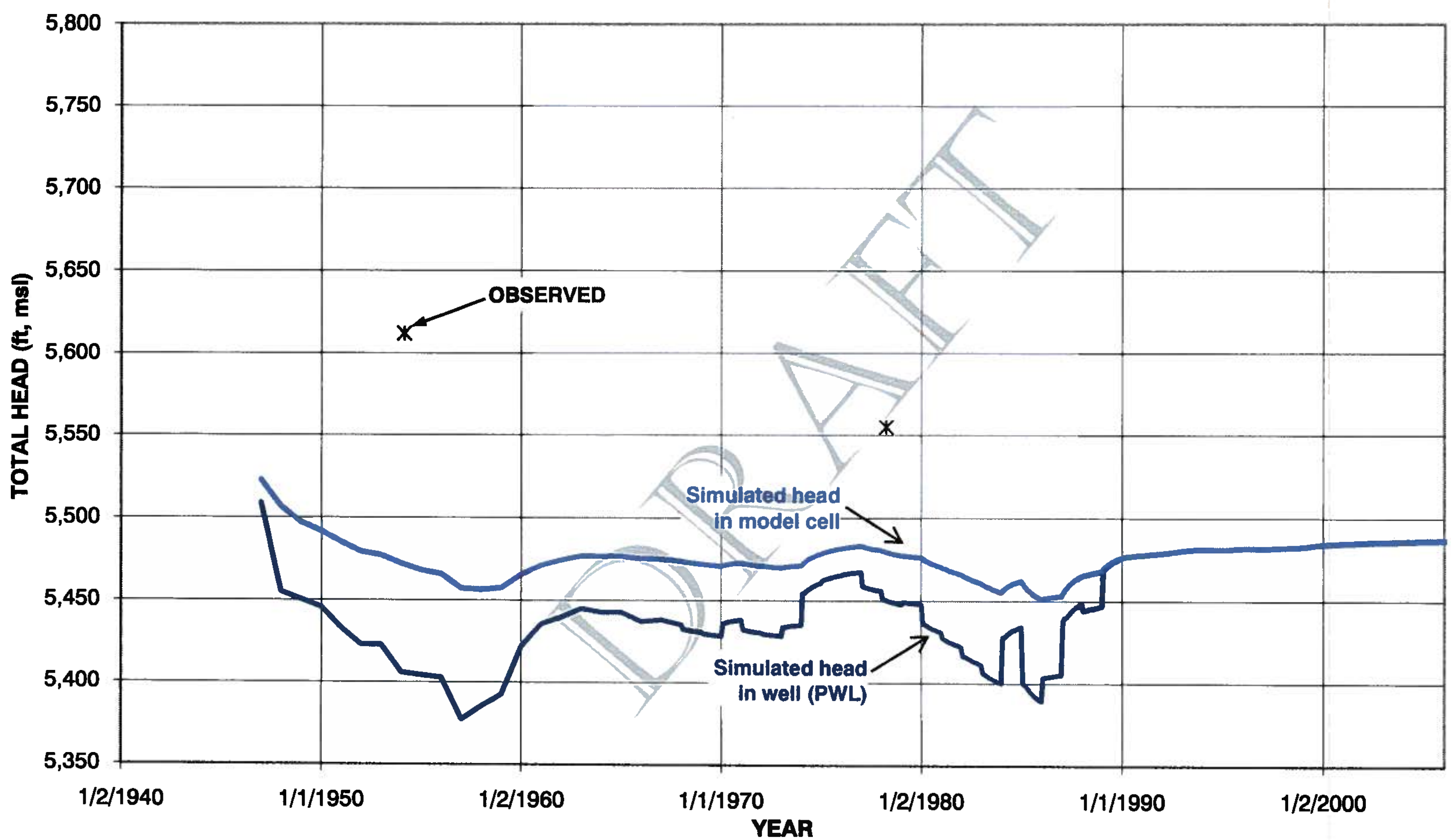
FIGURE A-1
OBSERVED-SIMULATED HEADS (1938-1958 GWSI DATA, PRE-GW PUMPING MODEL HEADS, RMS =94 feet, R^2=0.96)



hds.xls
SES
10/15/2009

FIGURE A-2
OBSERVED AND SIMULATED WATER LEVELS AT FRANK'S 1



hgr.xlsb
DMR
10/15/2009

FIGURE A-3
OBSERVED AND SIMULATED WATER LEVELS AT FRANK'S 2

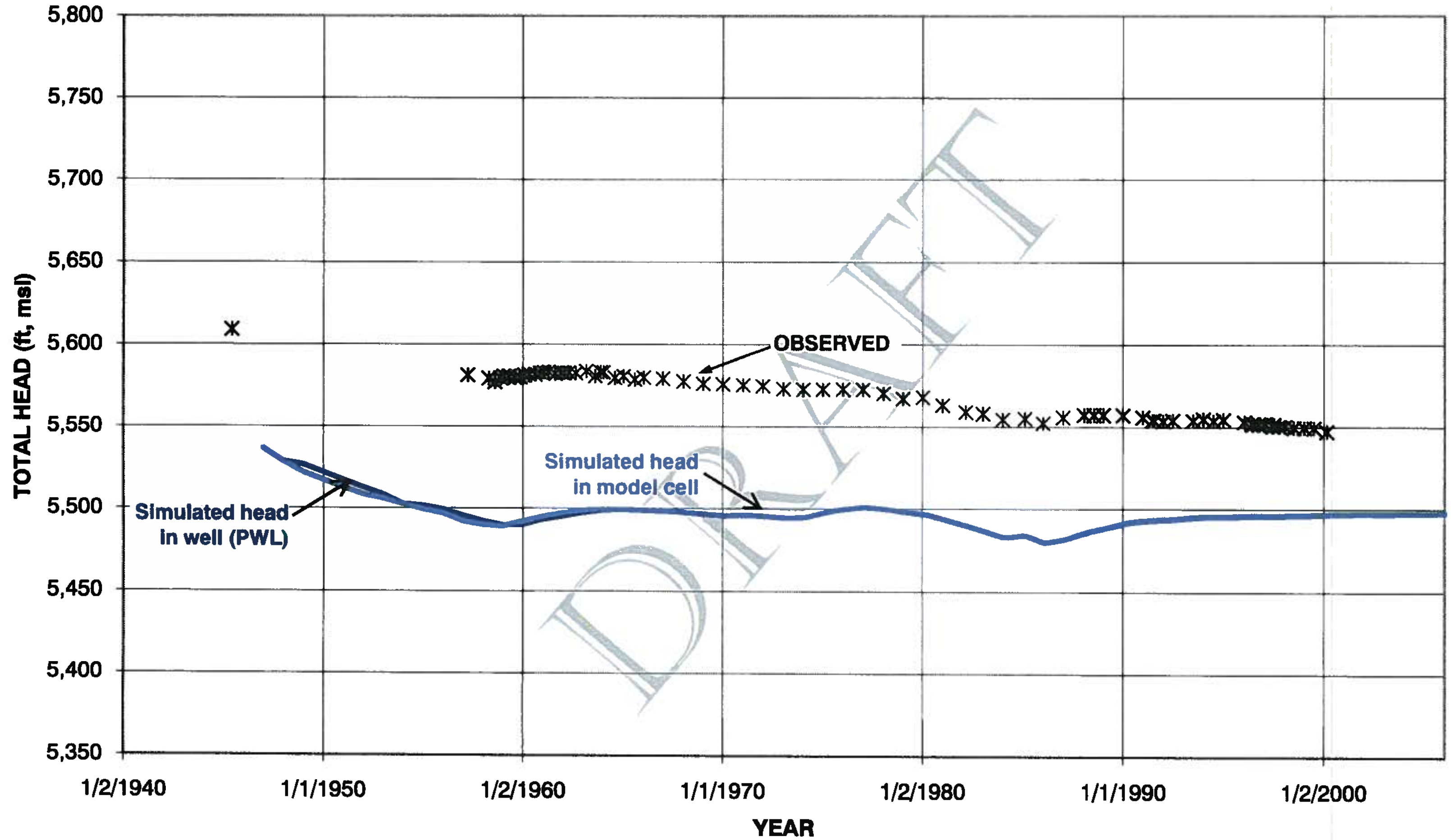
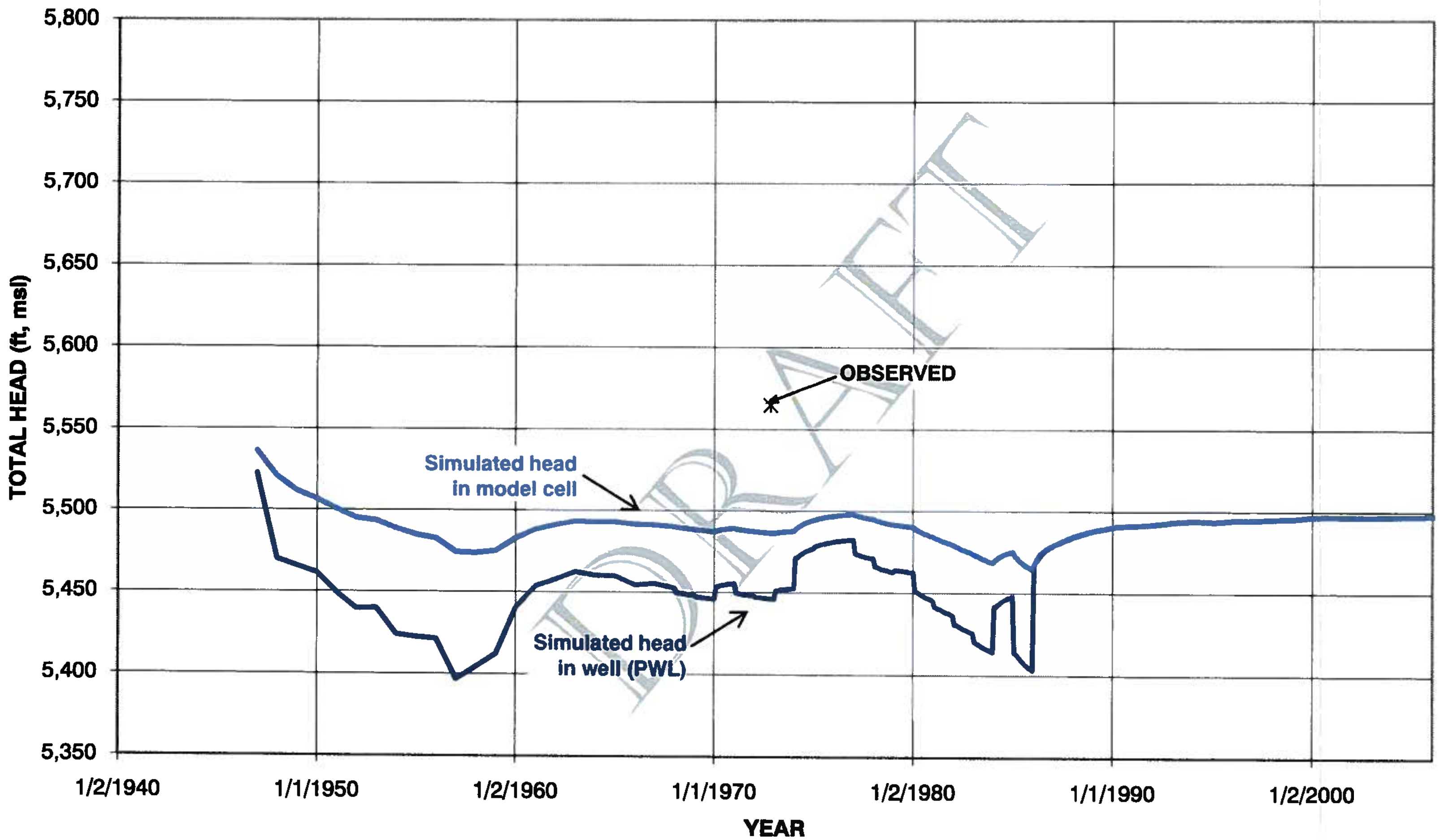


FIGURE A-4
OBSERVED AND SIMULATED WATER LEVELS AT FRANK'S 3



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DMR
10/15/2009

FIGURE A-5
OBSERVED AND SIMULATED WATER LEVELS AT FRANK'S 4

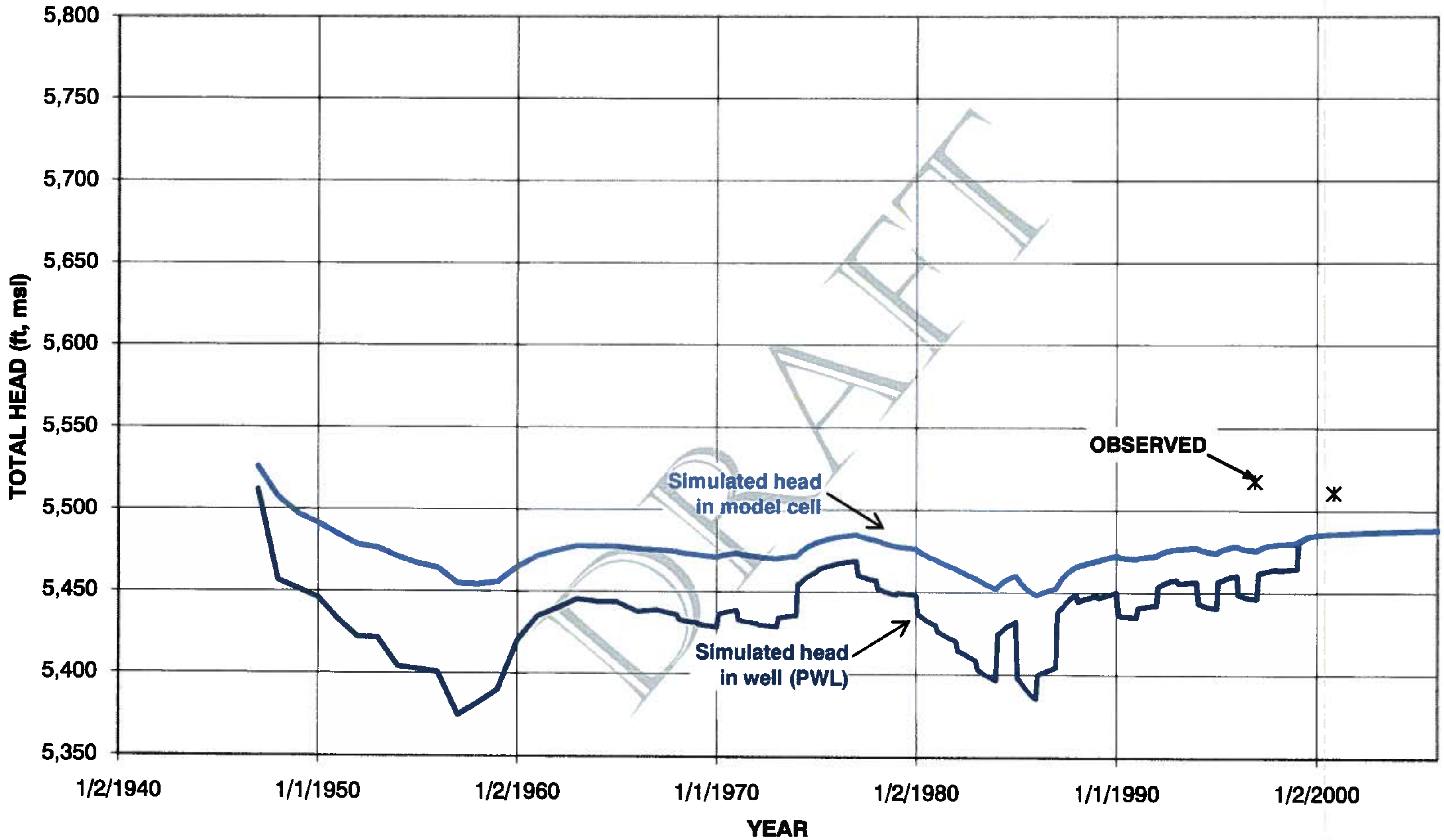

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FIGURE A-6
OBSERVED AND SIMULATED WATER LEVELS AT FRANK'S 5

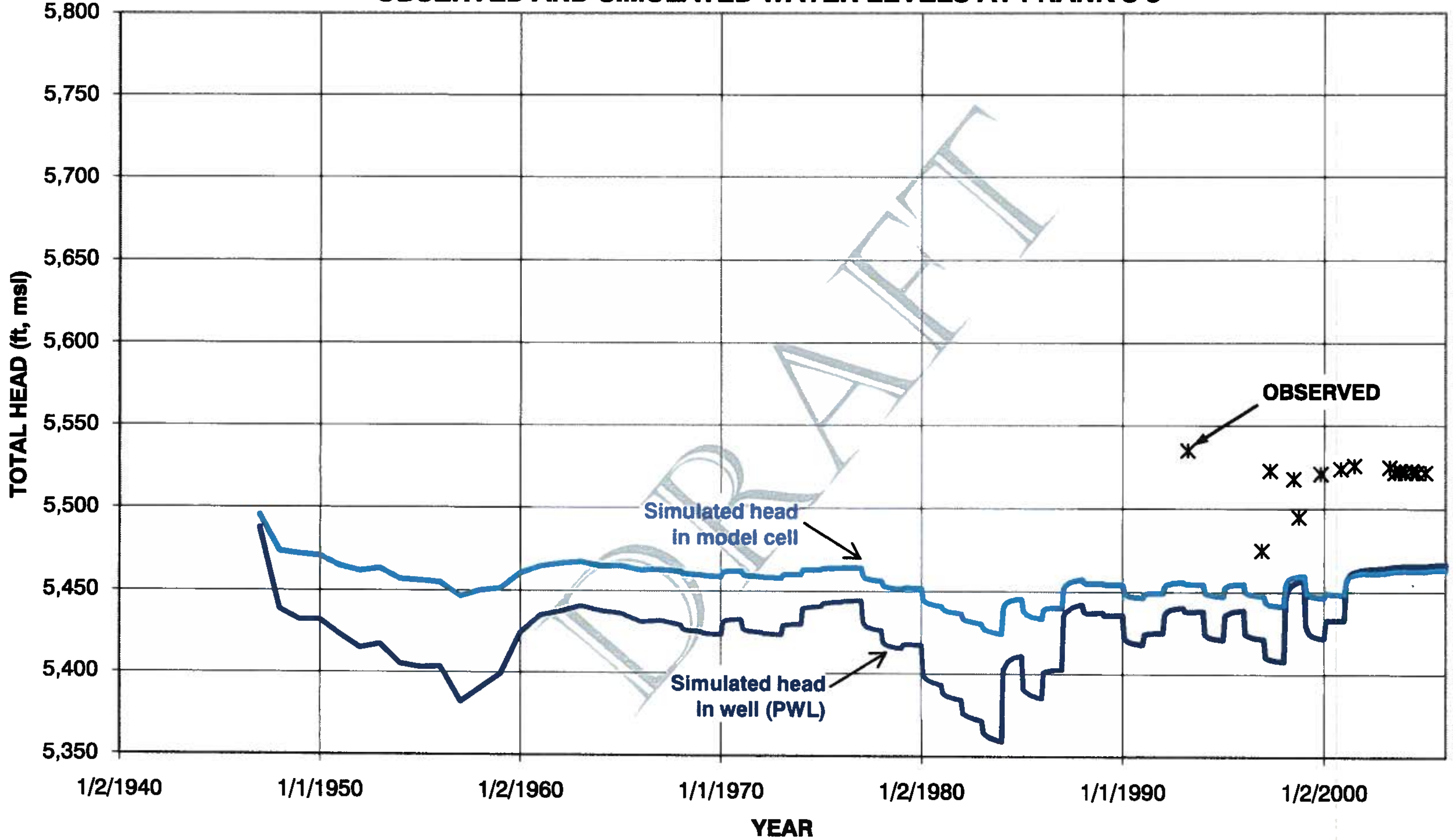

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FIGURE A-7
OBSERVED AND SIMULATED WATER LEVELS FRANK'S 6

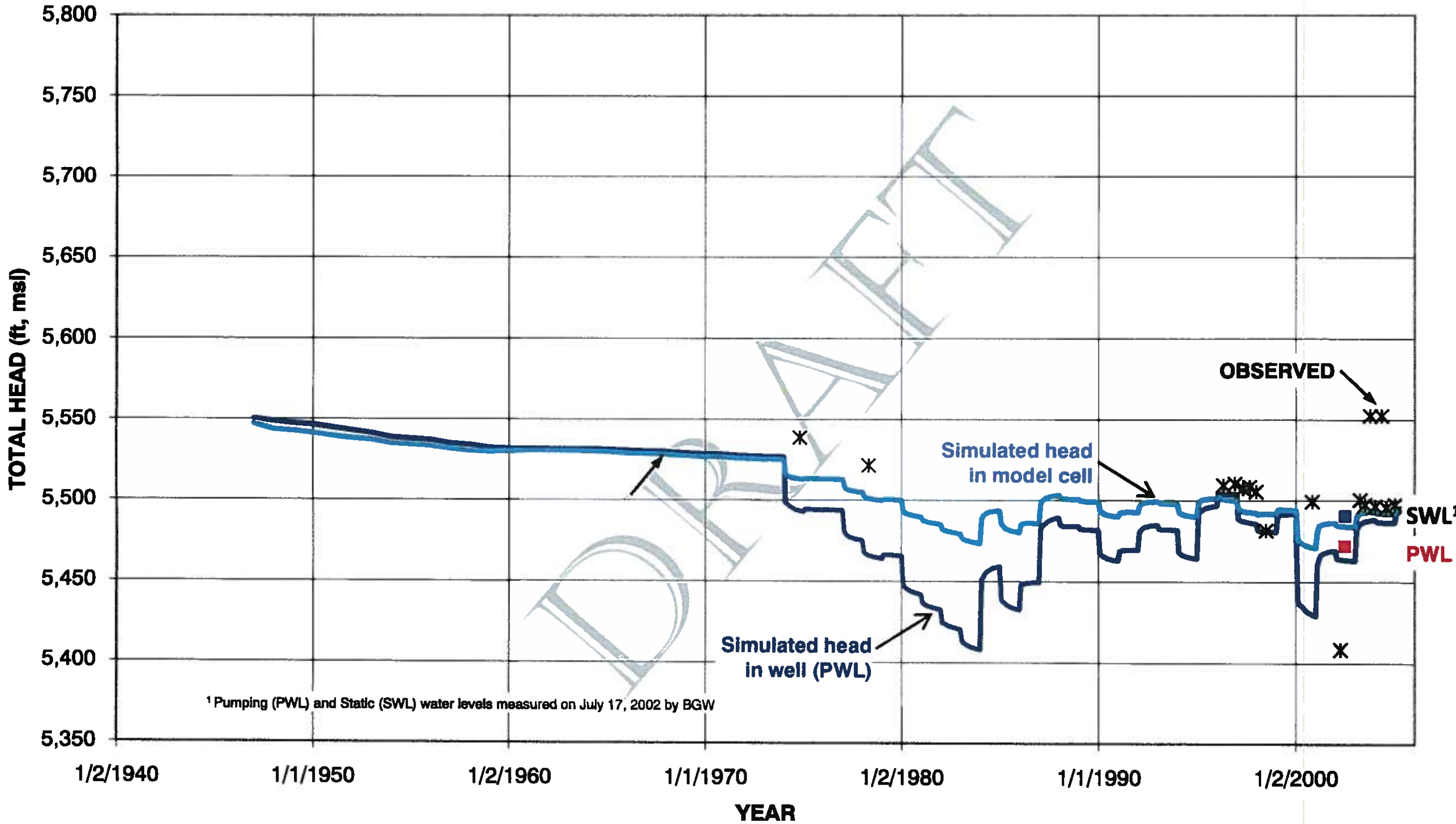
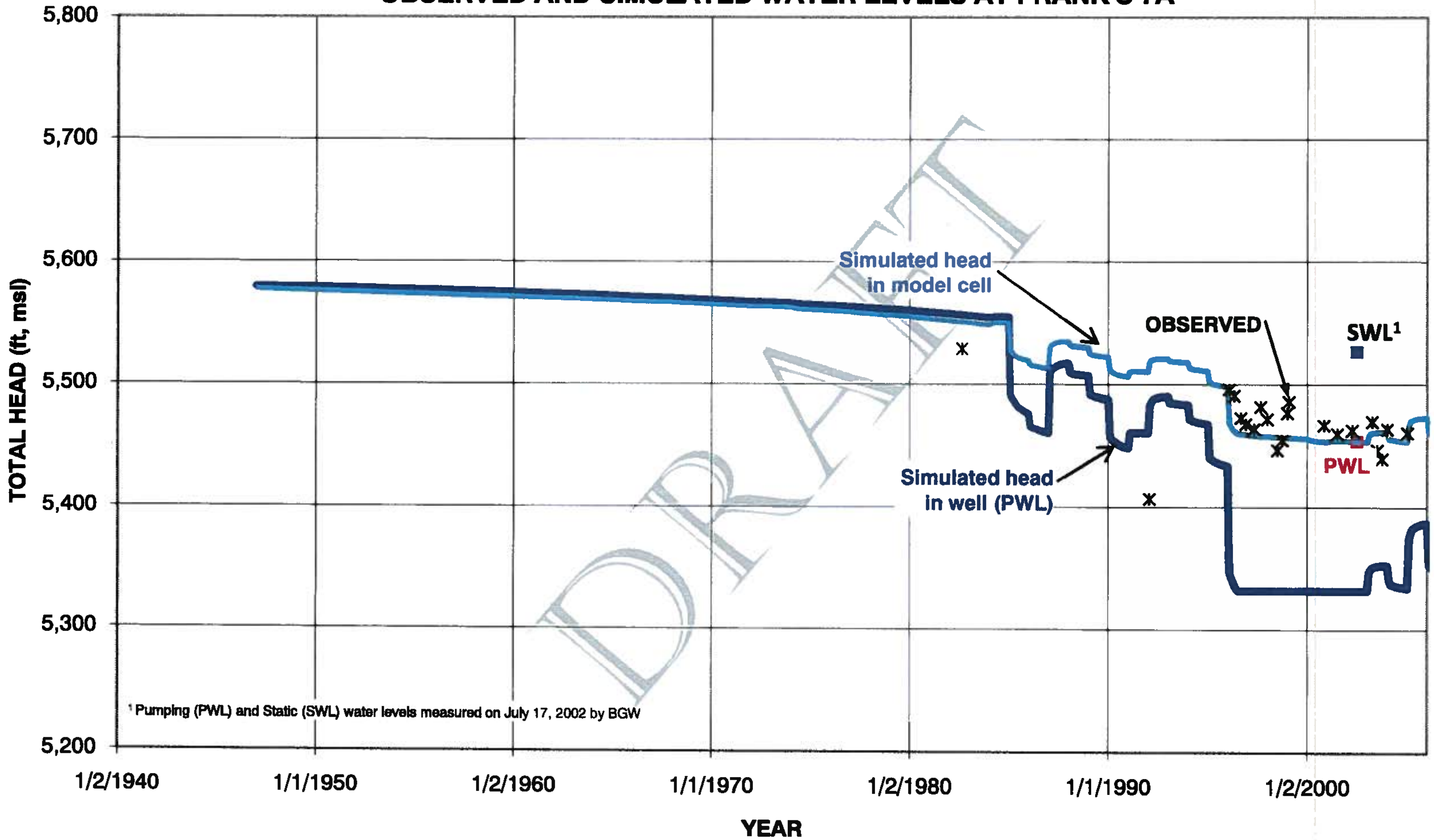


FIGURE A-8
OBSERVED AND SIMULATED WATER LEVELS AT FRANK'S 7A



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DMR
10/15/2009

FIGURE A-9
OBSERVED AND SIMULATED WATER LEVELS AT WOODWARD 1

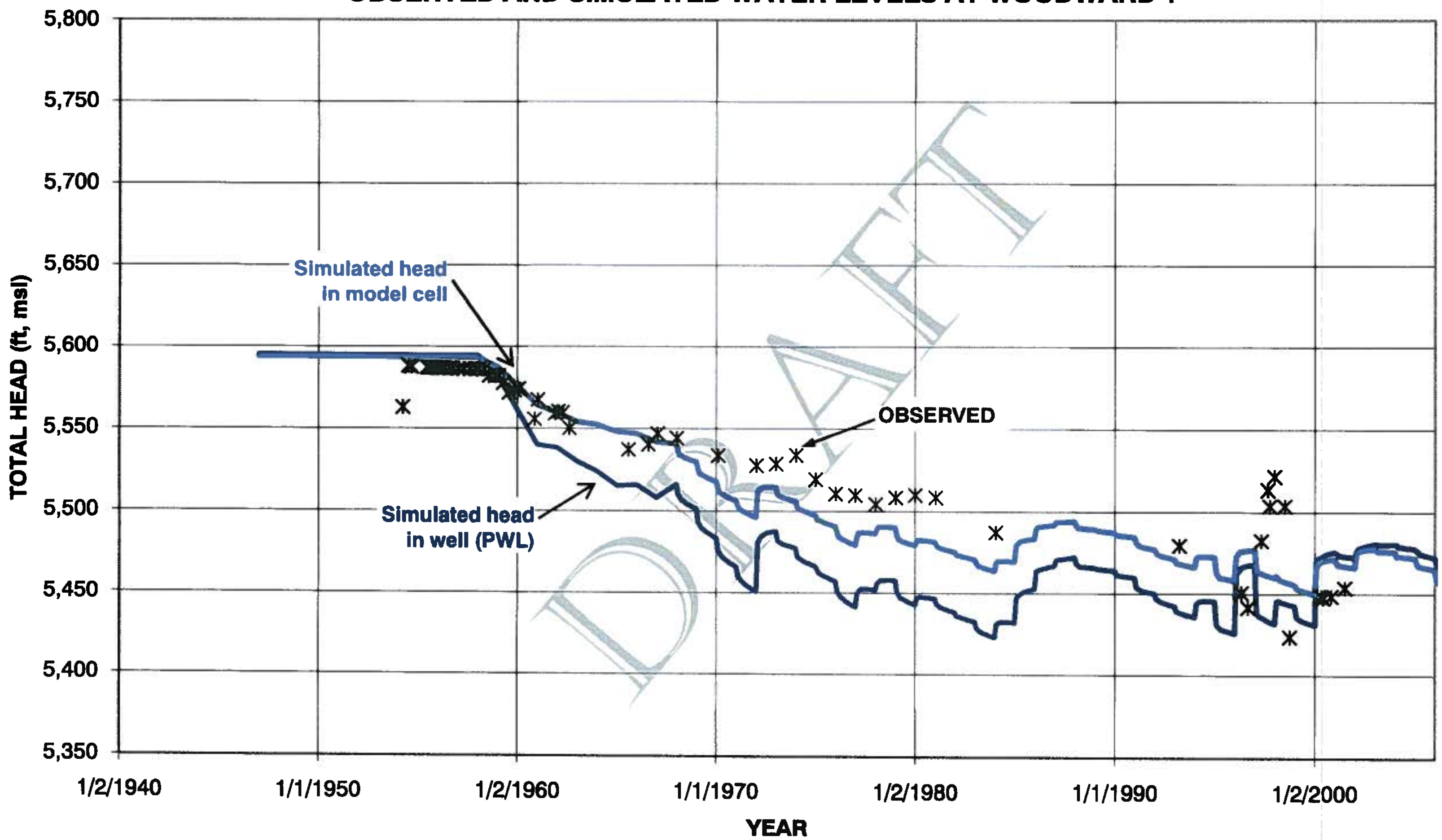

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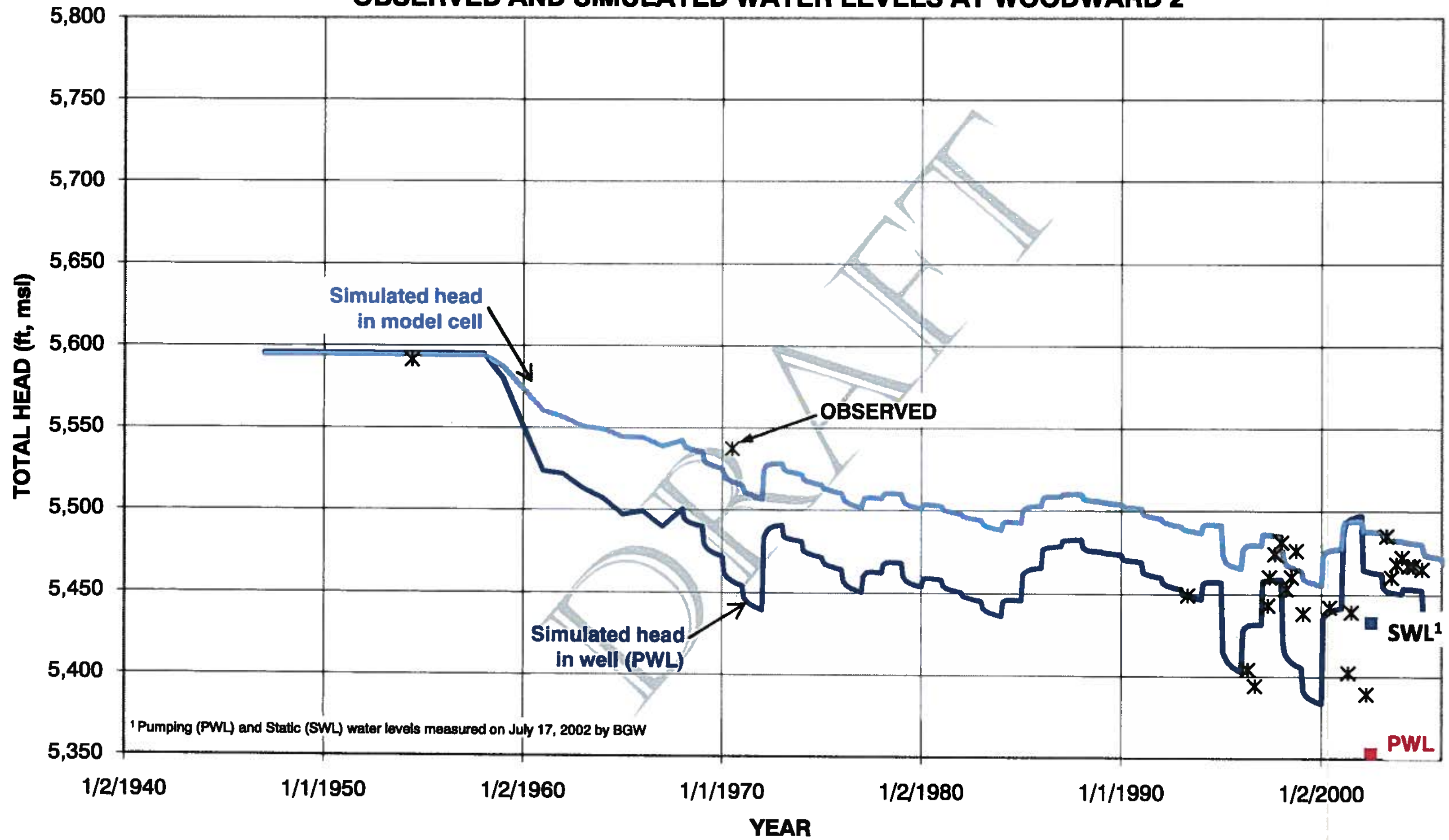
FIGURE A-10
OBSERVED AND SIMULATED WATER LEVELS AT WOODWARD 2



[1] Pumping (PWL) and Static (SWL) water levels measured on July 17, 2002 by BGW

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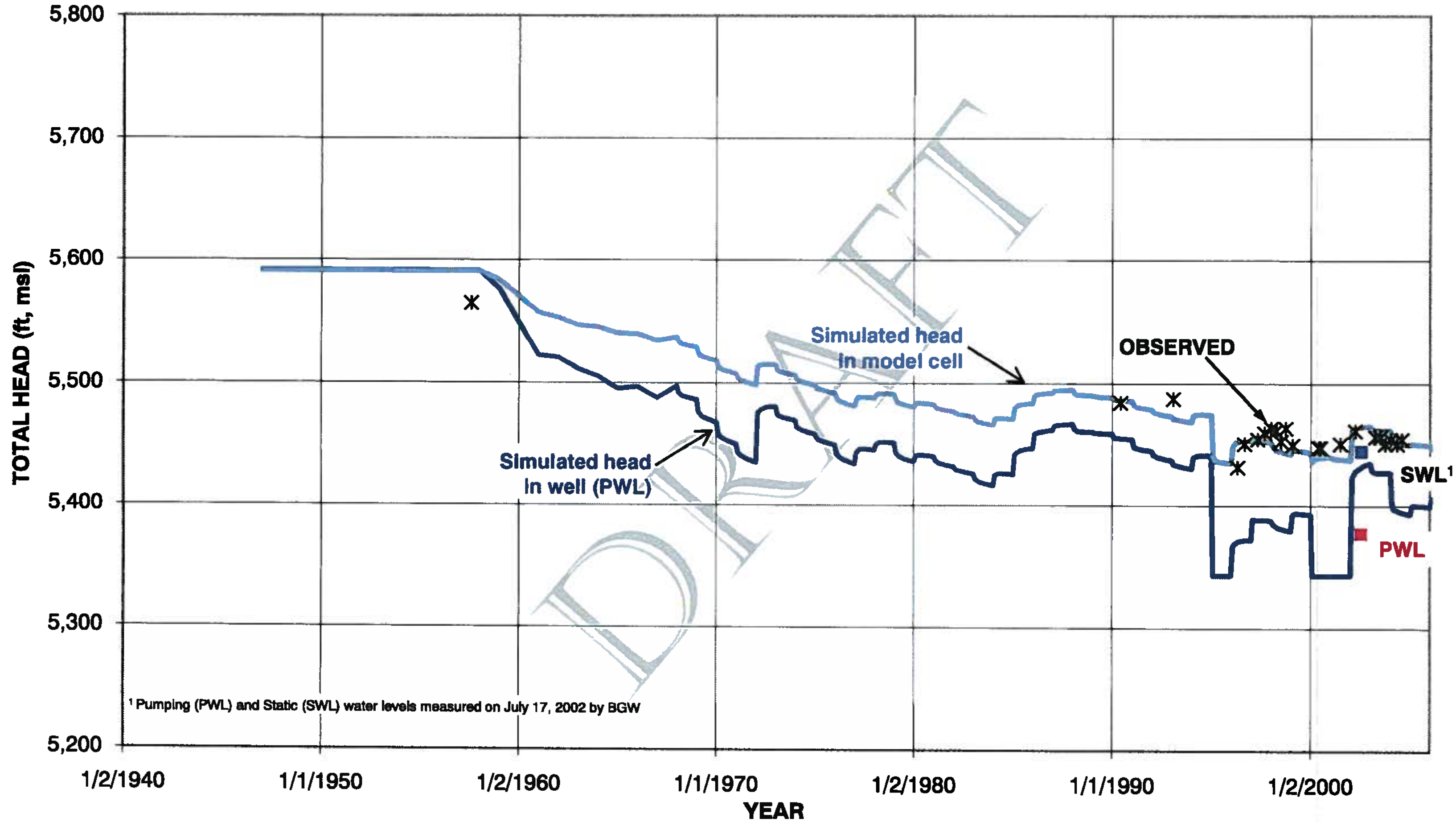
FIGURE A-11
OBSERVED AND SIMULATED WATER LEVELS AT WOODWARD 3



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10/15/2009

FIGURE A-12
OBSERVED AND SIMULATED WATER LEVELS AT WOODWARD 4

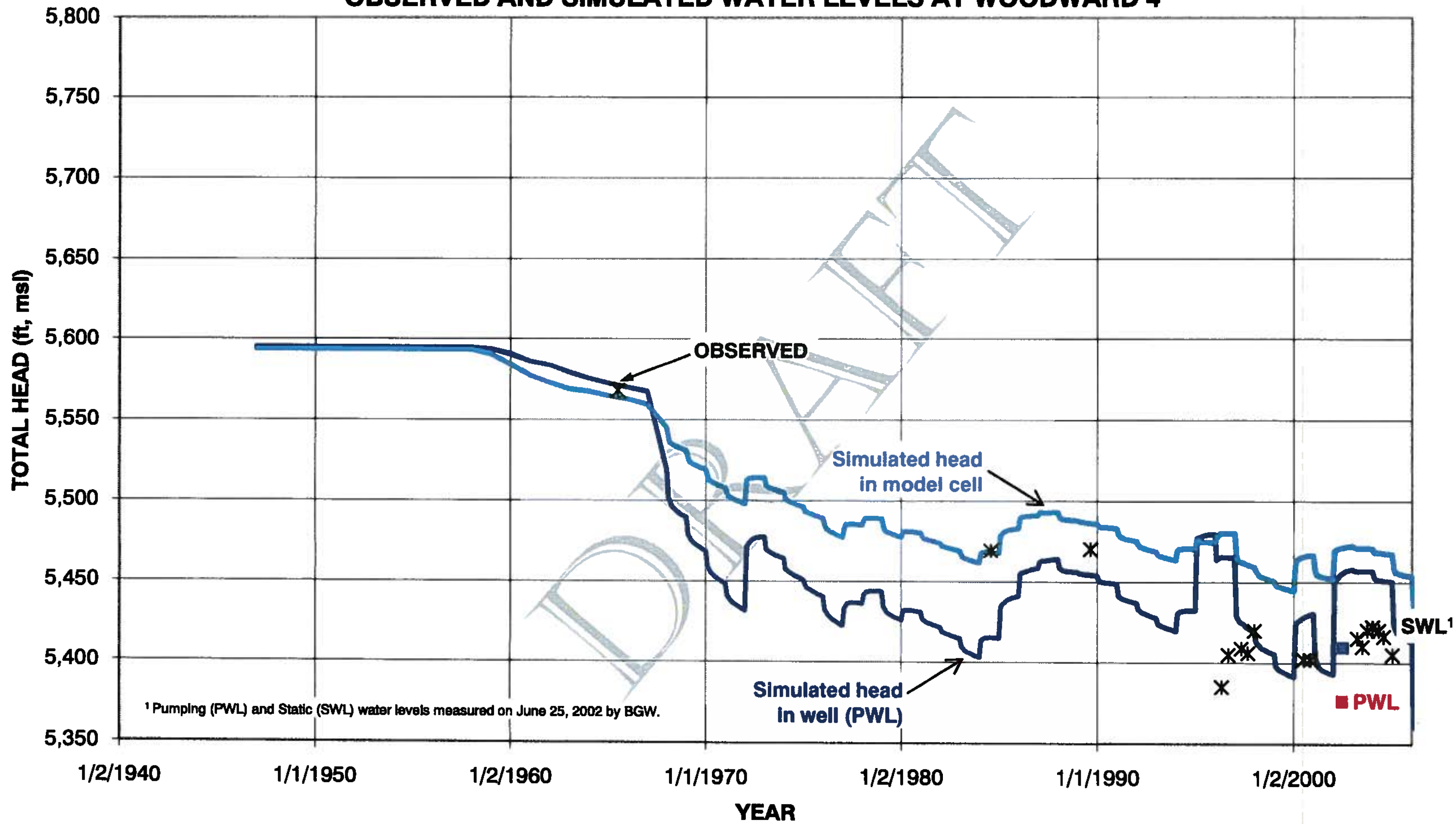

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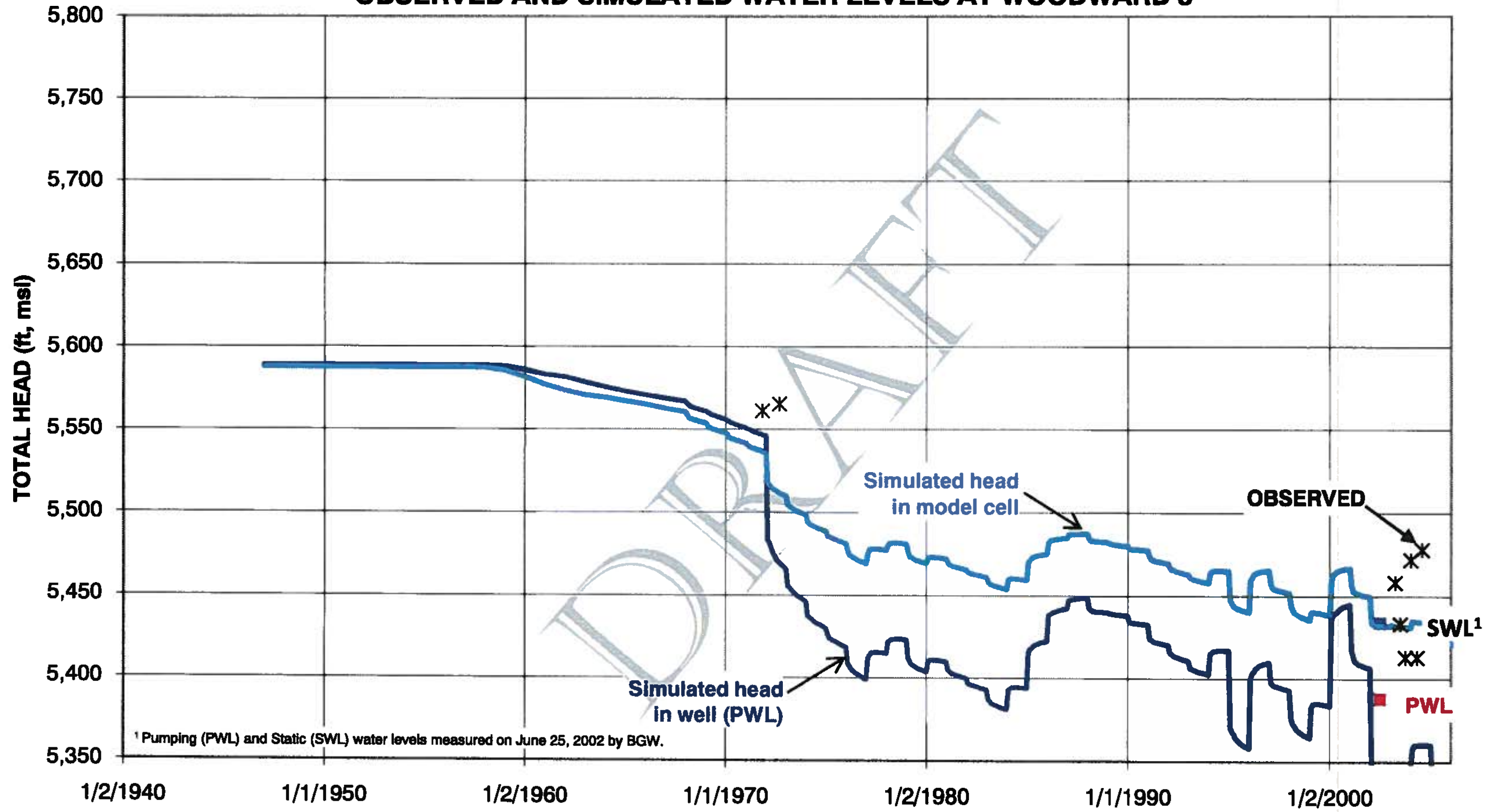
FIGURE A-13
OBSERVED AND SIMULATED WATER LEVELS AT WOODWARD 5



[1] Pumping (PWL) and Static (SWL) water levels measured on June 25, 2002 by BGW.

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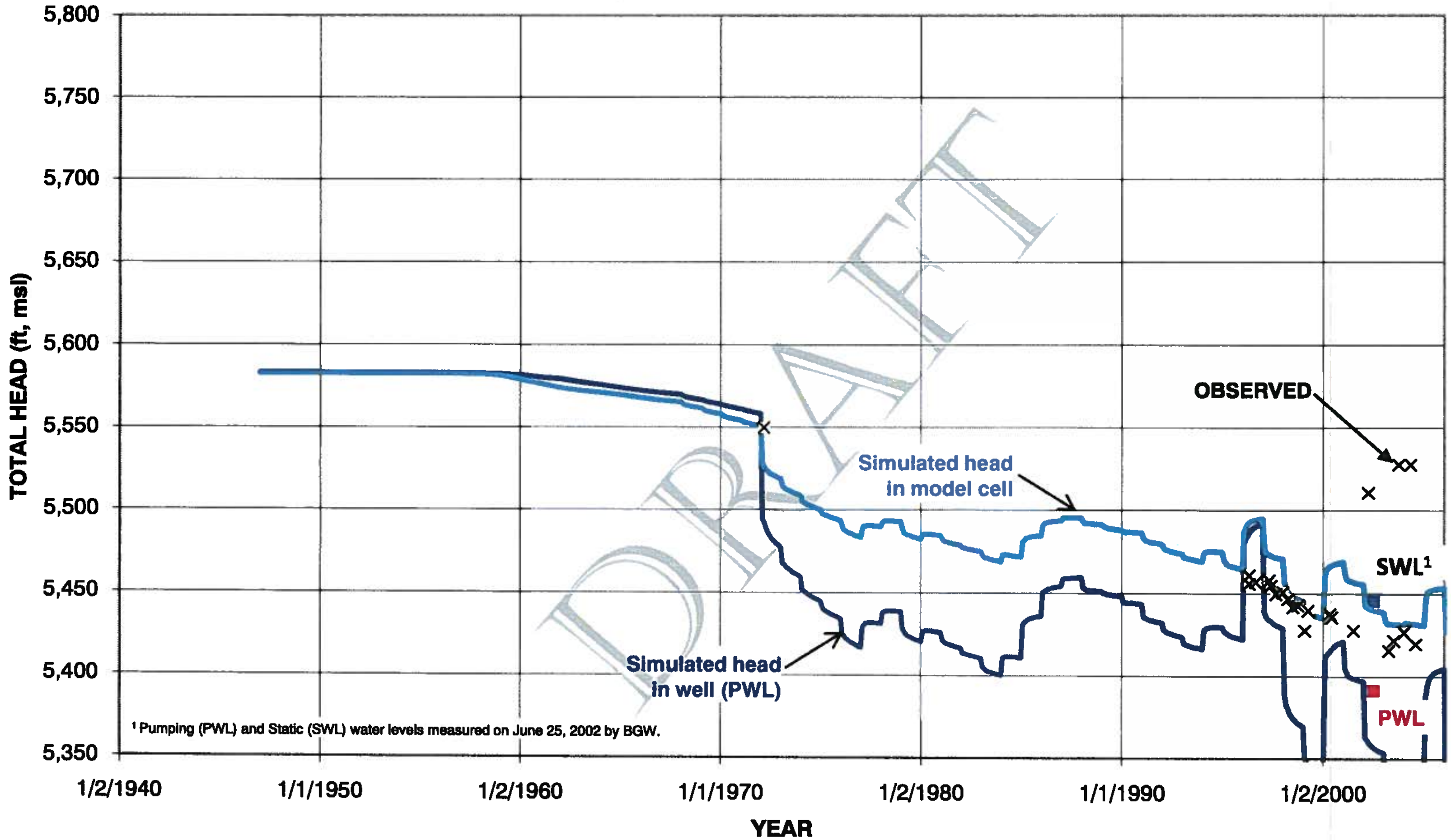
10/15/2009

FIGURE A-14
OBSERVED AND SIMULATED WATER LEVELS AT WOODWARD 6



[1] Pumping (PWL) and Static (SWL) water levels measured on June 25, 2002 by BGW.

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FIGURE A-15
OBSERVED AND SIMULATED WATER LEVELS AT GABBY HAYES WELL

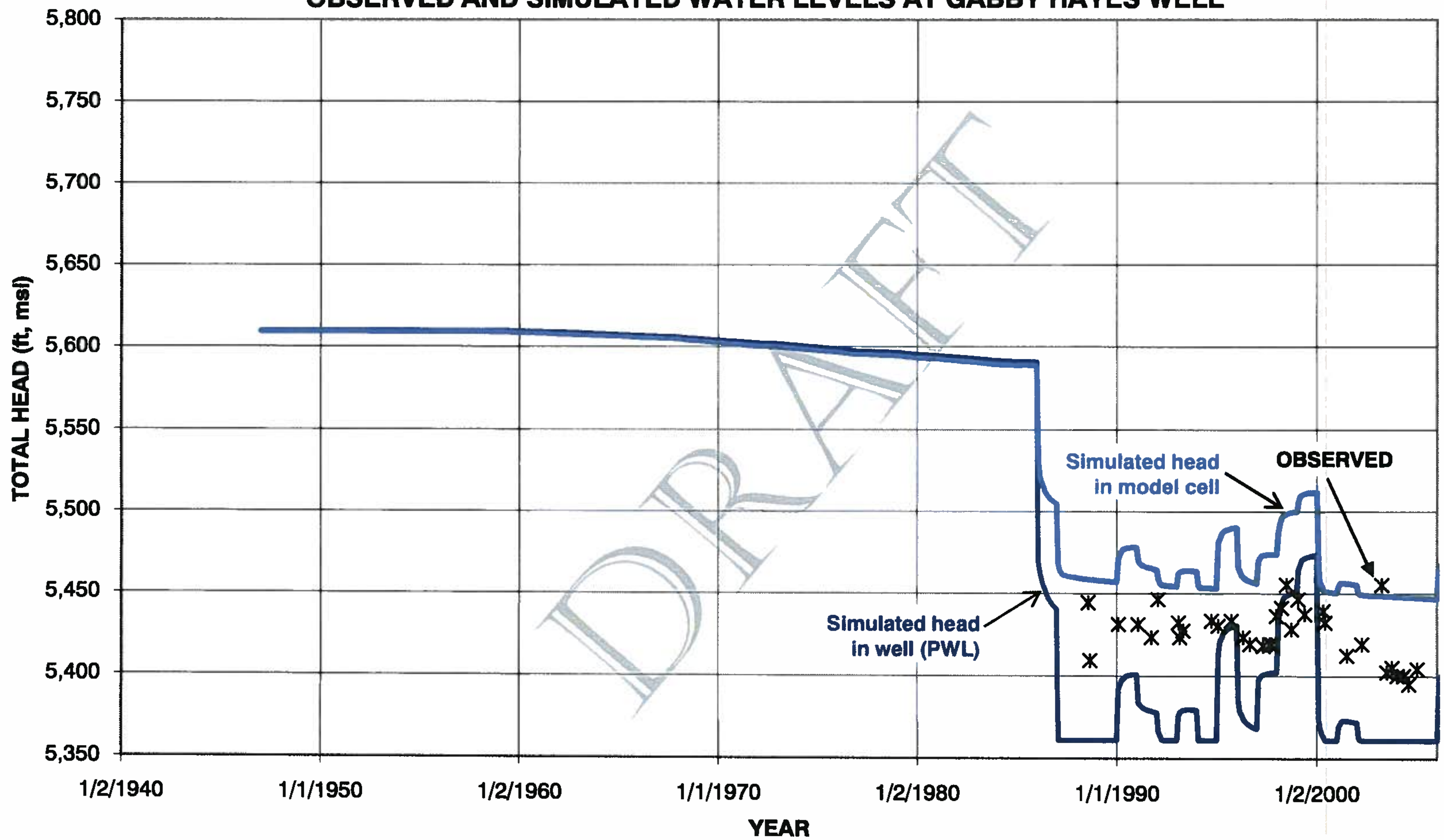
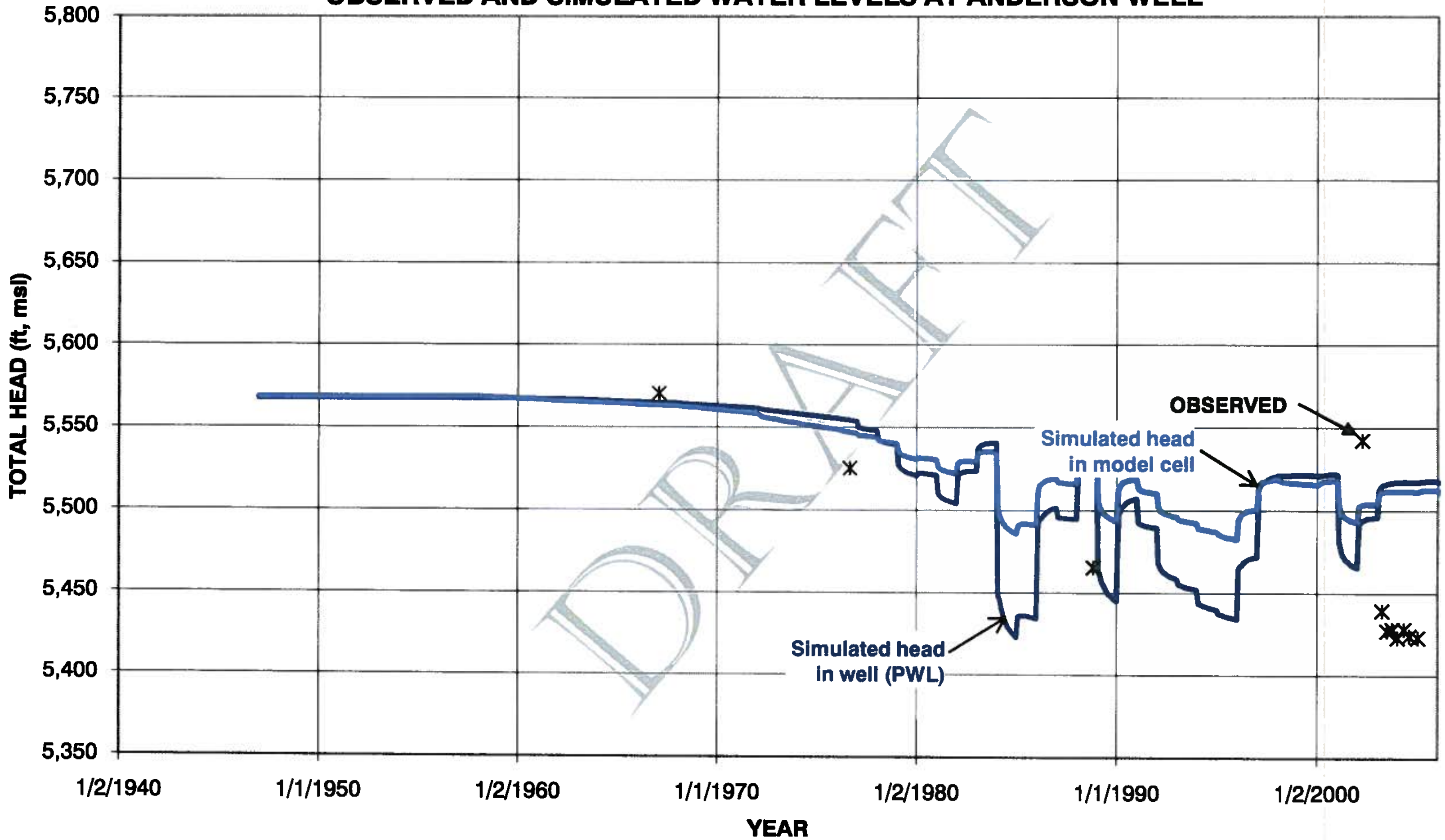


FIGURE A-16
OBSERVED AND SIMULATED WATER LEVELS AT ANDERSON WELL



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10/15/2009

APPENDIX B

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APPENDIX B

This Appendix describes the basis for estimated costs for example recharge projects in Technical Memorandum Table 1. Table B-1 summarizes the factors used to estimate costs for each approach.

Capital costs for recharge with the example injection approach involves a pumping station and pipeline, a water treatment plant, injection wells and appurtenances, and an observation well. Operation and maintenance costs are expected to include water pumping, water treatment and well rehabilitation.

An eight-inch diameter pipeline is assumed to cost $0.5 million per mile, including construction, material and acquiring rights' of way. We estimate an eight-mile pipeline would cost $4 million. For comparison, a recent feasibility study[1] for a pipeline from the Estancia Basin to City of Santa Fe estimated pipeline construction at $0.45 million to $0.8 million per mile for 24-inch pipe.

The cost of a pumping station depends on the size pump required. We estimate a 400-horsepower pump is needed to lift 500 gallons per minute through eight miles of pipe with 1,000 feet of elevation change, including about 200 feet of friction head loss. The estimate incorporates a combined pump and motor efficiency of 50 percent.

The cost of the pump station is based on a formula for a variable speed turbine pump in Wilbert and others (undated);

$$85{,}000\ (HP/100)^{0.65}$$

[1] Ryan, M., CDM, 2004, Letter to R. Carpenter, Water Resources Project Coordinator, City of Santa Fe: Estancia Basin Supply Project Feasibility Study Draft Report.

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GROUNDWATER RECHARGE

Based on the formula, a 400-horsepower pump would cost $210,000. The annual power cost to pump the water from the Gila River to the recharge site through existing and new pipeline, based on the foregoing factors and electricity rate of $0.1065/kWh[2], is $460 per acre foot or $370,000/year for the example 800 acre feet per year (AFY).

We anticipate that water for recharge through injection wells will require treatment to protect the target aquifer and to minimize screen clogging. Treatment methods are expected to be similar to conventional treatment of surface water for drinking purposes, specifically removal of suspended solids and disinfection. Environmental Protection Agency (EPA) (1979, Table 185) provides an estimated cost for a small-scale conventional treatment plant. Converting the EPA total estimated capital cost to a unit cost per AFY capacity and accounting for three percent inflation since 1979, we estimate constructing a treatment facility will cost $1,200 per AFY capacity. A plant capable of treating 800 AFY will cost about $960,000. The annual cost of operating the treatment plant is adapted from EPA (1979) Table 186, and adjusted for inflation. The resulting unit cost ($150 per acre foot treated) implies $120,000 per year to treat 800 acre feet.

Injection well drilling costs are adapted from recent drillers' estimates of similarly-constructed wells (12-inch casing with two nested piezometers) at $250 per foot. The example deep and shallow injection wells (1100 and 600 feet deep) are estimated to cost $275,000 and $150,000.

The example observation well has nested completions matching shallow and deep injection zones to monitor aquifer conditions during testing and operation. From recent drillers' estimates, we expect such a well to cost $150 per foot, or $165,000 for an 1100-foot well.

Well appurtenances including drop pipe, orifice, valves and gages for controlling and monitoring injection water flow and pressure are estimated to cost $50,000 for each well.

[2] Public Service Company of New Mexico TNMP Services, 2009, Services Rate Schedule, Second Revised Rate No. 12 Canceling First Rate No. 12. Schedule MPS Municipal Power Service.

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GROUNDWATER RECHARGE

Injection wells will likely require rehabilitation each year, involving scale removal (acidation and brushing), disinfection and redevelopment. The cost of rehabilitating one well is estimated at $15,000 each time based on past drillers' estimates for similar work.

The infiltration method of recharge also will require a pump and pipeline to convey water to the recharge site with the same expected upfront costs. However, water treatment prior to recharge is not needed, as any suspended solids and bacteria will be filtered by travel through the vadose zone. Other expected costs are associated with constructing and installing subsurface instrumentation nests and wells for monitoring. These costs, and annual costs for pumping and arroyo bed rehabilitation, are described below.

The cost of instrumenting the vadose zone below the recharge basin is estimated from similar equipment installed for the Town in San Vicente Arroyo below the treatment plant. A nest up to 400 feet deep with ten to 12 sets of soil moisture and temperature probes and associated loggers will cost $4,500 for equipment and $38,000 for installation with a drill rig, or $42,500 for each nest.

A water table monitor well is expected to cost $100 per foot to drill and construct, or $45,000 for a 450-foot well.

Arroyo bed rehabilitation may be needed each year to remove clogging from sediments and algae. Based on a factor of $3/yd^3 for dirt work, treatment of each acre to one-foot depth is estimated at $5,000, or $10,000 per year for a two-acre area along the recharge reach.

Attachment: Table B-1

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TABLE B-1. FACTORS FOR ESTIMATING RECHARGE PROJECT COSTS

Factor	Injection	Infiltration
Rate (gpm)	500	500
Annual Volume (AF)	800	800
Existing Pipeline Distance (miles)	12	12
New Pipeline Distance (miles)	8	8
New Pipeline Elevation Change (ft)	1000	1000
Total Pipeline Elevation Change (ft)	1690	1690
Pipe Diameter (in)	8	8
Pump-Motor Combined Efficiency	50%	50%
Cost of Electricity ($/kWh)	0.1065	0.1065
Water Treatment Required	Filter/disinfect	None

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