Hastings Utilities Municipal Well 33

Particle Tracking and Localized Groundwater Model

Prepared for Hastings Utilities

Prepared by:

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August 9, 2011

HASTINGS UTILITIES

August 9, 2011

Marty Stange, P.E.
Environmental Supervisor
Hastings Utilities
1228 North Denver Avenue
Hastings, NE 68901

RE: Localized Well 33 Groundwater Model

Dear Mr. Stange, P.E.,

Hastings Utilities (HU) retained HDR Engineering, Inc. (HDR) to develop a localized and detailed groundwater flow model for the area near HU Well 33 in order to evaluate nitrate transport within the pumping well. Data collected from the Well 33 Spinner Flow Meter Survey (Layne, 2009) and the Well 33 Dual Pump Pilot Study (ongoing) clearly indicate that the highest concentrations of nitrates enter the water supply well near the top of the well screen, while the lowest concentrations of nitrates are observed near the bottom of the well. Nitrate sampling data collected from the aquifer indicate that the highest concentrations of nitrate are observed in the shallower portions of the sand and gravel aquifer in which the HU wells are constructed.

The objective of the Localized Well 33 Groundwater Model (Localized Model) was to develop a tool that could be used to provide graphics and animations that would help HU staff illustrate the nitrate transport that has been observed in Well 33. The following letter report describes the procedure used to construct the model and also summarizes the preliminary results. However, the primary deliverable associated with this project are the model visualizations developed to support future meetings with regulators and the Hastings Wellhead Protection Advisory group. Model visualizations will be provided to HU under separate cover.

Model Construction

The Localized Model was constructed using the most up to date version of the Phase I Adams County Sub-Regional Groundwater Model (Phase I Model) as a building block. The Phase I Model is a sub-regional model that was developed using the Eastern Model Unit of the Cooperative Hydrology Study (COHYST EMU) as the parent model, and was summarized in the *Hastings Utilities Groundwater Modeling Study* (HDR, 2010). The Phase I Model was developed using the Telescopic Mesh Refinement (TMR) process, a commonly used tool in groundwater flow modeling that allows for detailed model development in areas of previously developed regional models. The TMR process assigns hydraulic boundaries to the refined (daughter) model based on the mass balance of the regional (parent) model. HDR used the TMR approach in developing the Localized Model, with the Phase I Model used as the parent model. The parent model/daughter model relationship between the COHYST EMU, the Phase I Model, and the Localized Model is shown on Figure 1.

The objective of the Localized model was to evaluate the complex groundwater flow and nitrate transport conditions that occur near a pumping well. Achieving this objective required construction of a highly discretized model, both in the horizontal and vertical direction. The Localized Model was constructed to simulate groundwater flow conditions over an area that is approximately 1.5 miles by 1 mile, as shown on Figure 2. To increase the number of head calculations near the pumping well, the Localized Model was constructed using a grid size of 1 foot by 1 foot around Well 33 and included

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11 layers to simulate the single Pleistocene sand and gravel aquifer. Figure 3 presents a cross section extracted from the model column in which Well 33 is located. The Figure 3 cross section illustrates the geology of Well 33 and the model layer approach used to improve the calculation of vertical gradients in the model. Model layers 1 and 2 represent the unsaturated, low permeability silts and clays that overlie the Pleistocene sand and gravel aquifer. Layers 3 through 11 represent the sand and gravel aquifer with each unit having a uniform 15 foot layer thickness. Once completed, the Localized Model included a total of 2,592,810 active cells, or 235,710 active cells per model layer. By comparison, the Phase I model contained 164,742 active cells and the COHYST EMU contains 185,400 active cells.

Model Calibration Check

As previously stated, the Localized Model is based on the hydrogeologic data included in the COHYST EMU model, a well documented and publically accepted study and therefore no calibration was required for the Localized Model. However, to ensure that the hydraulic boundaries were properly assigned during the TMR process, a calibration check of the Localized Model was performed. The calibration check consisted of comparing the Phase I Model and Localize Model predicted groundwater elevations, with Well 33 operating at 1,200 gallons per minute (gpm). This comparison of model predicted groundwater elevations is presented as Figure 4. As shown, the predicted groundwater contours are similar between the two models. However, near Well 33, the Localized Model predicts a slightly different pattern to the potentiometric surface which shows more drawdown at the pumping well. The Localized Model also indicates a smaller cone of depression for Well 33. These differences are attributable to the differences in the model cell size near Well 33, which is one foot by one foot in the Localized Model, and is 100 foot by 100 foot in the Phase I Model.

An additional calibration check was performed on the Localized Model to ensure that it accurately reproduced observed drawdown conditions in Well 33. The drawdown of Well 33 was directly measured using an electronic water level meter during field work associated with the Spinner Flow Meter Study (Layne, 2008). At a pumping rate of 1,200 gpm, a drawdown of 23 feet was measured after approximately one hour of pumping. As a comparison, the model predicted drawdown within the cell in which Well 33 is located was 21 feet, after a pumping time of 6 days, which was the shortest pumping period in the model.

Predictive Model Runs

As previously stated, the primary purpose of the Localized Model was to provide illustrations and visualizations of the observed nitrate transport conditions in Well 33. The observed nitrate concentrations in Well 33, relative to the well screen, are summarized in Table 1. Well 33 is screened from 205 to 235 feet below ground surface (bgs). Nitrate concentrations as high as 19 mg/L have been detected as part of the Well 33 Dual Pump Pilot Study, with the pump suction located at 207 ft bgs.

Table 1
Well 33 Depth Specific
Nitrate Sample Results

Depth of Water Quality Sample (ft bgs)	Nitrate Concentration (mg/L)
205 13.9	
207 13.8	
220 4.1	
234 2.0	
Well Discharge (February 5, 2009)	**6.1**

To most accurately reproduce the pumping conditions in Well 33, the pumping rate was proportioned in the model to reflect the measured distribution of flow entering the well screen (Layne, 2009). During the spinner flow meter survey, measurements of flow velocity entering the well indicated that 50 percent of the well flow entered the well at a near uniform rate, from 210 to 235 feet bgs. The remaining 50 percent of well flow entered the pumping well from 205 to 210 feet bgs.

Model predictive simulations consisted of particle tracking using the United States Geological Survey (USGS) code MODPATH (Pollock, 1989). For these simulations, a row of 40 particles was placed upgradient of Well 33 and tracked forwards. Particles were placed in each model layer to evaluate where particles would enter the well screen and if the vertical starting location of a particle impacts where the particle enters the pumping well. Relating the concept to nitrate transport, it has been observed that the nitrate concentrations are highest in the shallow portion of the aquifer and that nitrate concentrations decrease vertically through the aquifer. Based on these observations and the data from Well 33, particles released in layers near the water table (layers 3, 4, and 5) should enter near the top of the well screen. Conversely, particles that are released near the base of the aquifer (layers 9, 10, and 11) should enter the well near the bottom of the well screen. The primary goal of the Localized Model was to test these hypotheses.

The results of the particle tracking simulations are presented on Figures 5 and 6. Figure 5 presents a plan view of the particle tracking simulations, the capture zone for Well 33, and also shows where the particles were released. Figures 6a and 6b illustrate the results of the particle tracking simulations in cross sectional view. The shallow near water table particles (layers 3, 4, and 5) are shown on Figure 6a, while the results of the deep aquifer (layers 9, 10, and 11) particle tracking are shown on Figure 6b.

Discussion of Results

As shown on Figures 6a and 6b, the vertical location of a groundwater particle impacts where the particle enters the screen interval of a pumping well. Because groundwater flow is perpendicular to the equipotential contours, evaluating the fate of a groundwater particle in the aquifer is simply a process of developing a flow net for that particle, which can be developed using the results presented on Figures 6a and 6b.

When applied to the transport of dissolved phased contaminants, which travel with water, the results of the modeling show that contaminants located in the upper portion of the aquifer (model layers 3 through 5) will enter the pumping well near the top of the well screen. This occurs because the step

groundwater gradients that occur near a pumping well introduce a strong vertical component to groundwater flow, as clearly illustrated on Figures 6a and 6b. This figure shows the bending of the equipotential lines which occurs near the top of the screen interval of Well 33. Near the bottom of the well screen (in layers 9 though 11) the equipotential lines are approximately vertical, indicating that groundwater flow is approximately horizontal. Because groundwater flow in the bottom of the aquifer remains nearly horizontal, particles released from the bottom of the aquifer enter the pumping well near the bottom of the well screen.

Conclusions

The results of the Localized Well 33 Groundwater Model closely match the observed vertical point of entry of nitrate contaminants observed in Well 33. Nitrate concentrations in the aquifer are highest near the water table and lowest near the base of the aquifer. With that understanding, the results of the groundwater flow modeling confirms that the reason the observed nitrate concentrations are higher near the top of a pumping well screen is related to the hydraulics of groundwater flow near a pumping well. The cross sectional particle tracking results developed to illustrate the results of the model (shown as Figure 6b) clearly show the equipotential contours bending and converging within the upper portion of the well screen. The results of the modeling show that the transport of nitrates near Well 33 can be evaluated by developing a flow net using particle tracking. These flow nets can be used as a graphical tool to explain nitrate transport near Well 33 to a technical audience. The model results were also used to develop several visualizations, submitted under separate cover, that can be used to help explain the concepts presented in this letter to less technical audiences.

HDR Engineering appreciates working with HU on this interesting project. If you have any questions regarding the proposed well modifications or specifications presented, please contact me at (816) 412-1322.

Very truly yours,

HDR ENGINEERING, INC.

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NE Professional Env. Engineer No. E-12739
NE Professional Geologist No. 0328

REFERENCES:

HDR, 2010. Hastings Utilities Groundwater Modeling Study. Prepared for Hastings Utilities. October.

Layne, 2009. Water Supply Well 33 Spinner Flow Meter Survey and Depth Specific Water Sampling. Prepared for Hastings Utilities. February.

Pollock, D.W. 1989. Documentation of Computer Programs to Compute and Display Pathlines Using Results from the U.S. Geological Survey Modular Three-Dimensional, Finite-Difference, Groundwater Flow Model. USGS Open File Report.

FIGURES

CUSTER

DAWSON

BUFFALO

Platte River

Phase I Model
Adams County Sub-Regional
Model Domain

Localized Well 33
Model Domain

HAMILTON

YORK

PHELPS

KEARNEY

ADAMS

CLAY

Little Blue River

HARLAN

FRANKLIN

WEBSTER

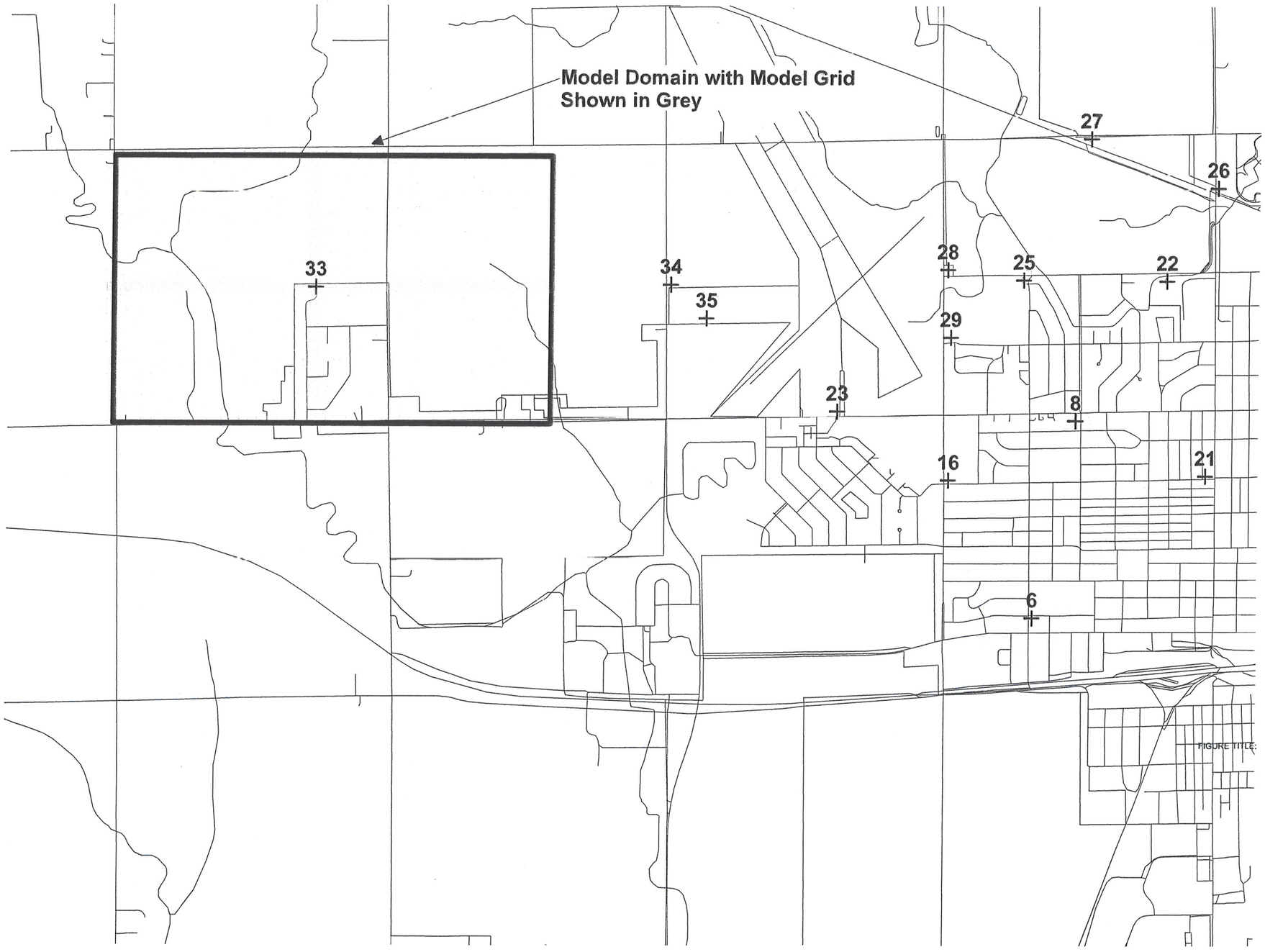
NUCKOLLS

Republican River

Note:
Figure 1: Compares the study areas of the COHYST EMU and the Adams County Sub-Regional Model and to the study area of the Well 33 Detailed Model. The sub-regional model boundaries and model grids are shown overlying Adams County.

FIGURE TITLE: Comparison of COHYST EMU/Adams County Sub-Regional Model/Well 33 Localized Model	FIGURE No: 1
	DATE: Aug 2011
	PREPARED BY: LD
DOCUMENT TITLE: Hastings Utilities Groundwater Modeling Study	CHECKED BY:
	PROJECT No: 149243

HDR



Legend:

33 HU Water Supply Well

Note:
1)Figure 2: Presents the Model Domain of the Localized Well 33 Groundwater Model.
2)Grid size is 1 ft x 1 ft in the area near Well 33.

MAP SCALE:
1 inch = 2,000 feet

0 2000 4000

FIGURE TITLE:

FIGURE TITLE: Localized Well 33 Groundwater Model Grid Location	FIGURE No: 2
	DATE: Aug 2011
	PREPARED BY: LD
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	PROJECT No: 149243

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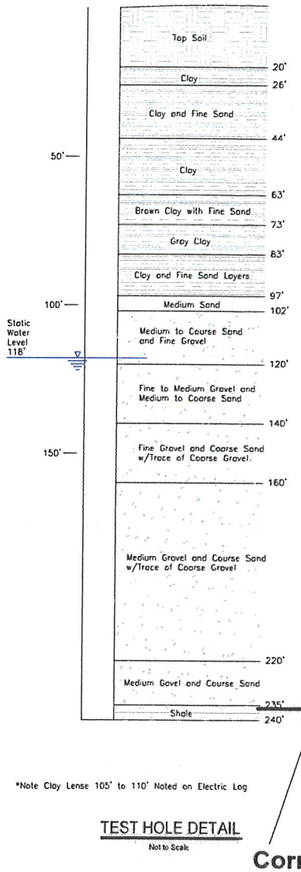
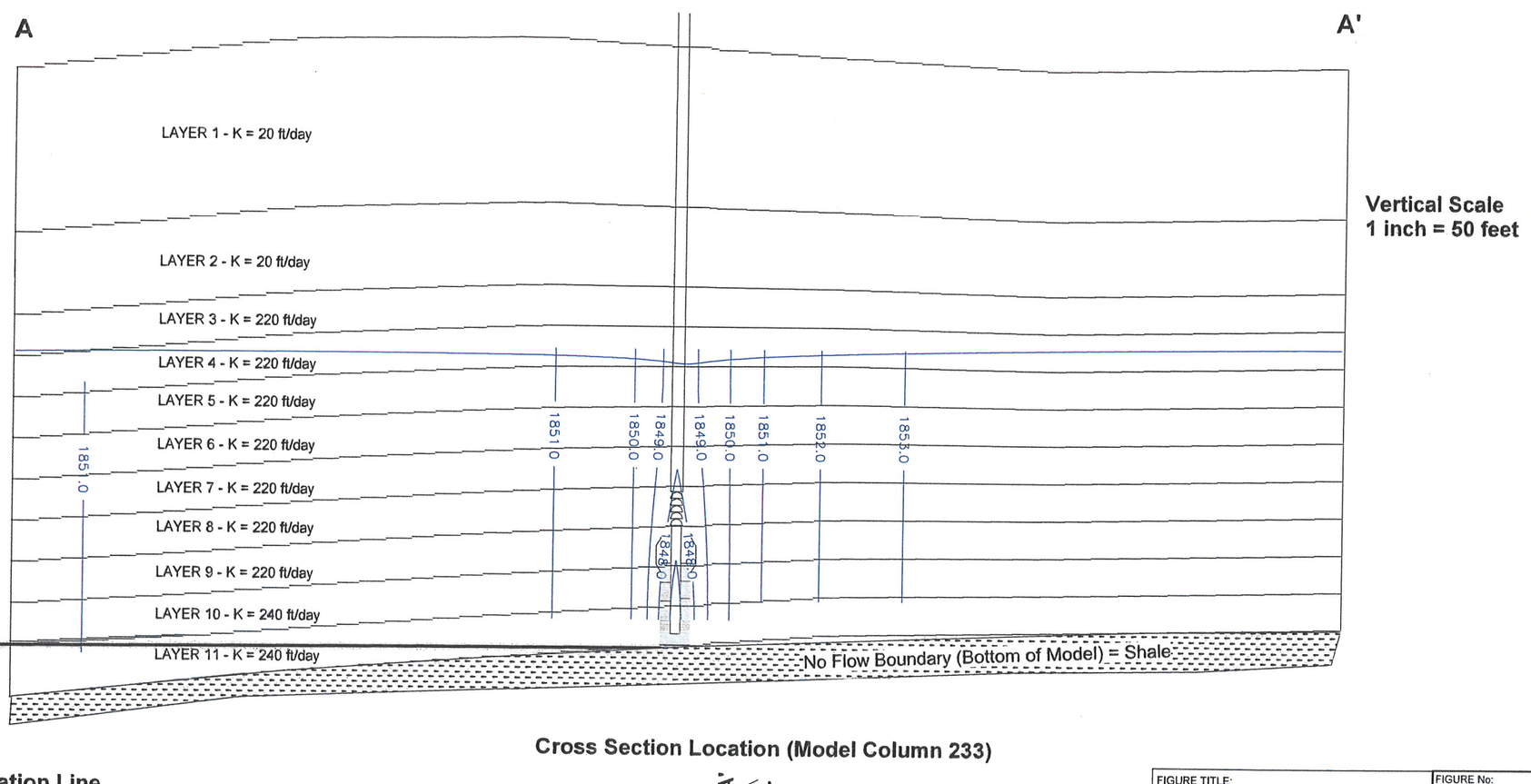
Geologic Log from Well 33



Cross Section Along Model Column 233



Vertical Scale
1 inch = 50 feet

Correlation Line

Cross Section Location (Model Column 233)

Note:
1)Model Layers 1 and 2 are unsaturated.
2) Hydraulic conductivity (K) values shown by model layer
3) Blue lines indicated model predicted groundwater elevations in ft msl. The model run included Well 33 pumping at 1,200 gpm.
4) Well 33 screen is located in Layers 9, 10, and 11.
5) Layers 3 through 11 are 15 feet thick.

FIGURE TITLE: Groundwater Model Cross Section and Well 33 Geologic Log	FIGURE No: 3
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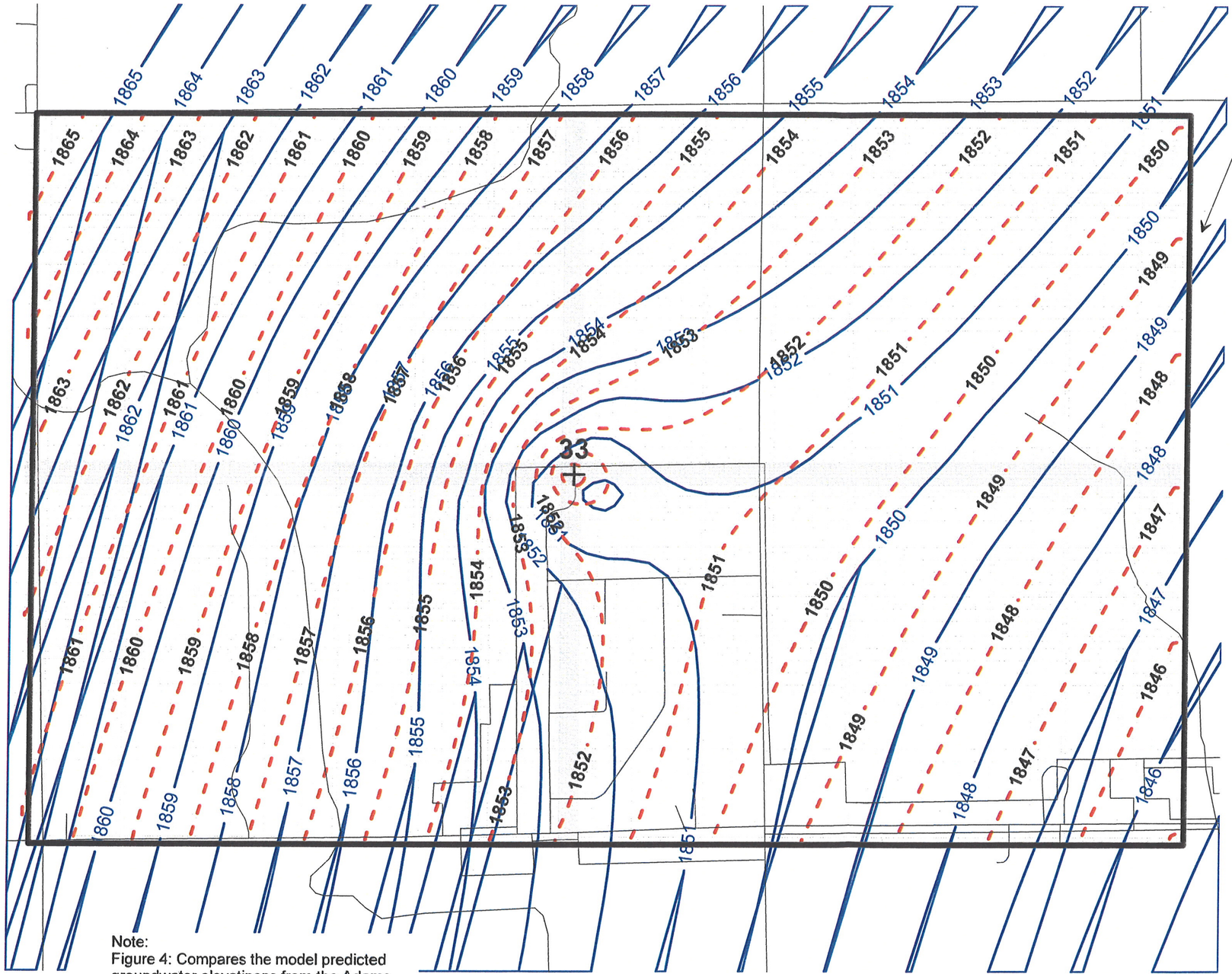

Model Domain

1857 — Predicted groundwater elevation (ft msl) - Well 33 Localized Model

1857 — Predicted groundwater elevation (ft msl) - Phase I Adams County Subregional Model

33 + HU Water Supply Well

Note:
1) Well 33 Detailed Model constructed using 11 Layers, 486 Rows and 485 Columns.
2) Minimium cell size = 1 ft x 1 ft. Maximum cell size = 23 ft x 31 ft.
3)■ Block represents to scale size of one cell in the Phase I model

Note:
Figure 4: Compares the model predicted groundwater elevatinons from the Adams County Sub-Regional model and the Well 33 Detailed Model.

MAP SCALE
1inch = 800 feet

0 500 1000 1500 2000

FIGURE TITLE: Comparison of Model Predicted Groundwater Elevations	FIGURE No: 4
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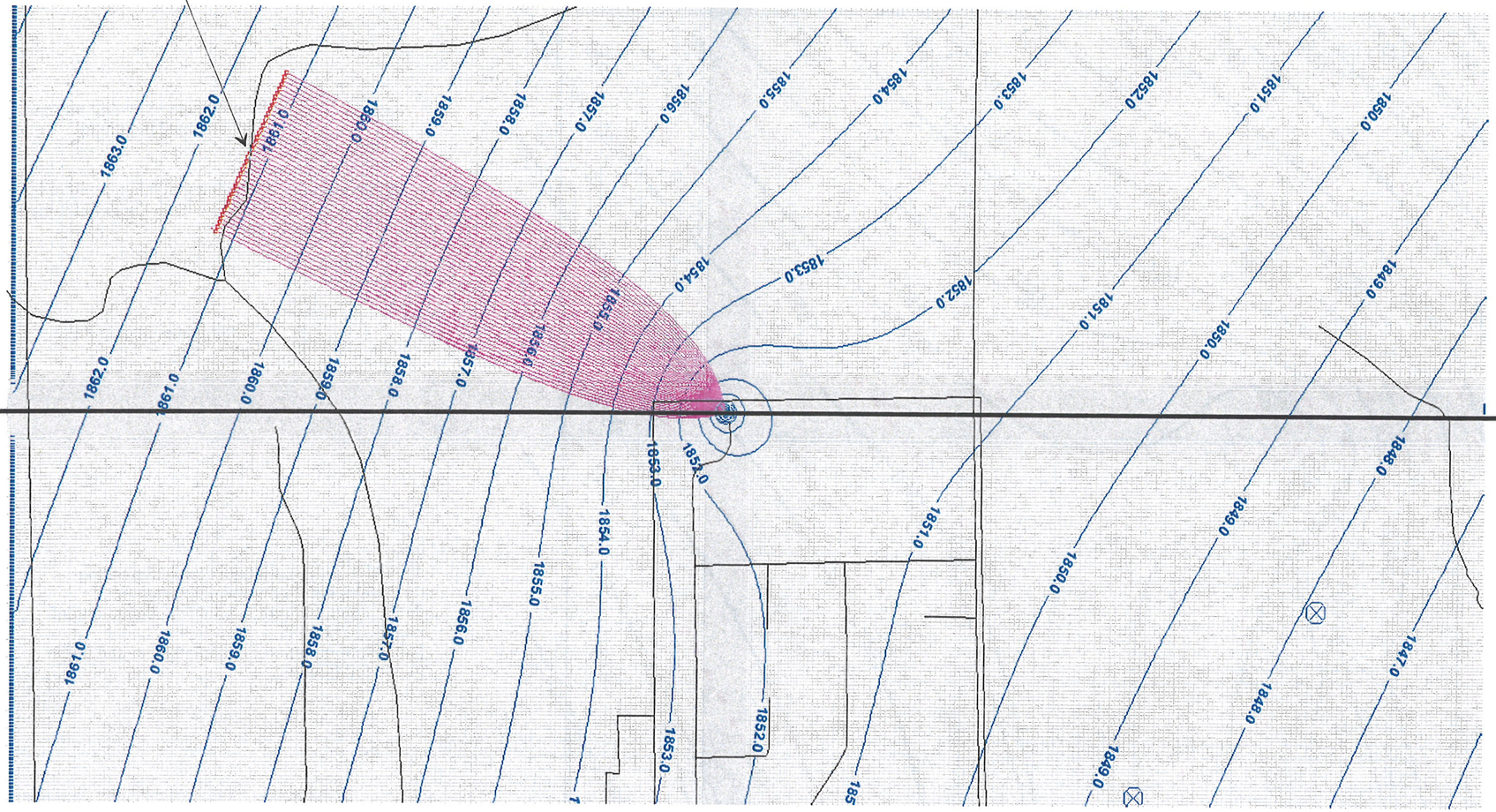
Particle Starting Locations
for All Model Simulations

Plan View Map of Partilces Starting Locations



Note:
1) Blue contour lines indicated model predicted groundwater elevations in ft msl. The model run included Well 33 pumping at 1,200 gpm.

Cross Section Location Map for Figures 6a and 6b (along model row 243)

Not To Scale

FIGURE TITLE: Plan View Map of Partilces Starting Locations	FIGURE No: 5
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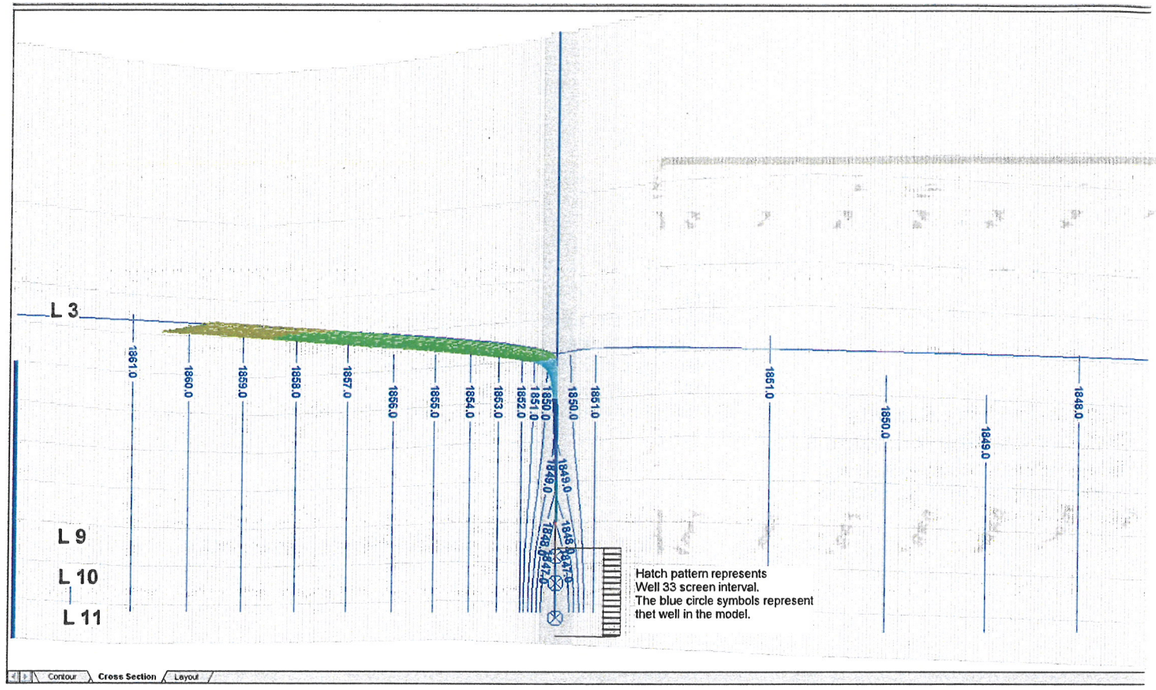
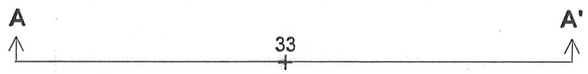


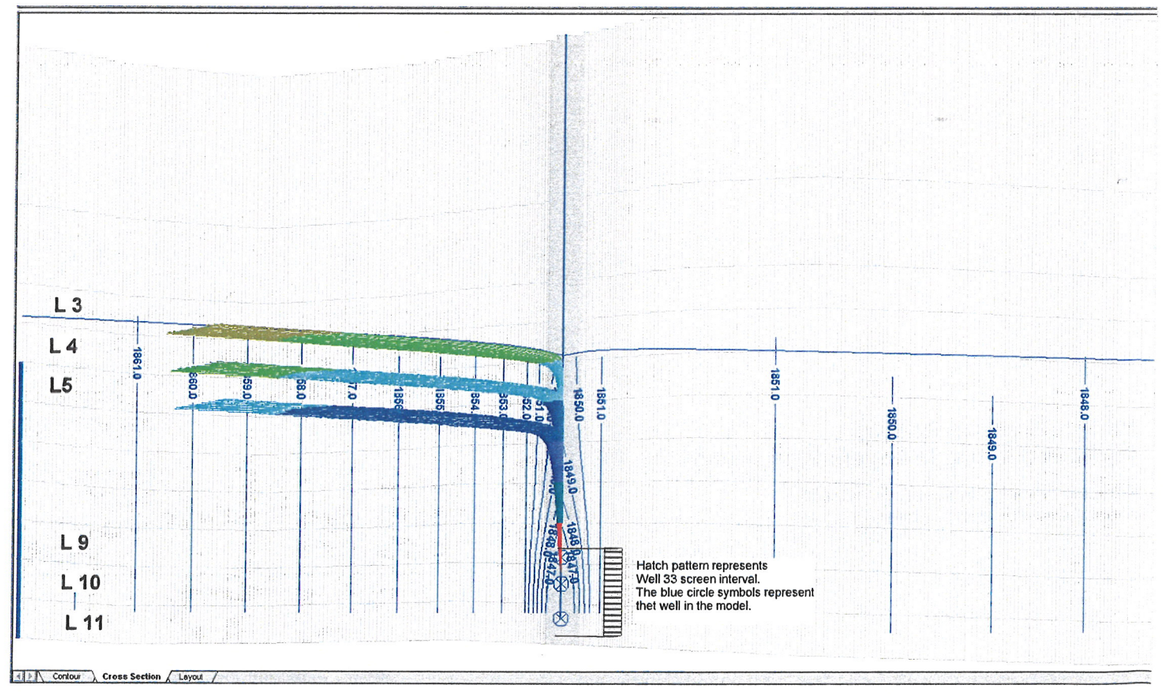
Particle Tracking Results
Partilces Starting in Layers 3

Note:
Particles released in Layer 3
enter the well screen in Layer 9.

Note:
1)Model Layers 1 and 2 are unsaturated.
2) Blue lines indicated model predicted groundwater elevations in ft msl. The model run included Well 33 pumping at 1,200 gpm.
4) Well 33 screen is located in Layers 9, 10, and 11.

Cross Section Location (Model Row 243)





Particle Tracking Results
Partilces Starting in Layers3, 4, and 5

Note:
Particles released in Layers 3, 4, and 5
enter the well screen in Layer 9.

FIGURE TITLE: Groundwater Model Cross Section and Particle Tracking	FIGURE No: 6a
	DATE: Aug 2011
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	PROJECT No: 149243

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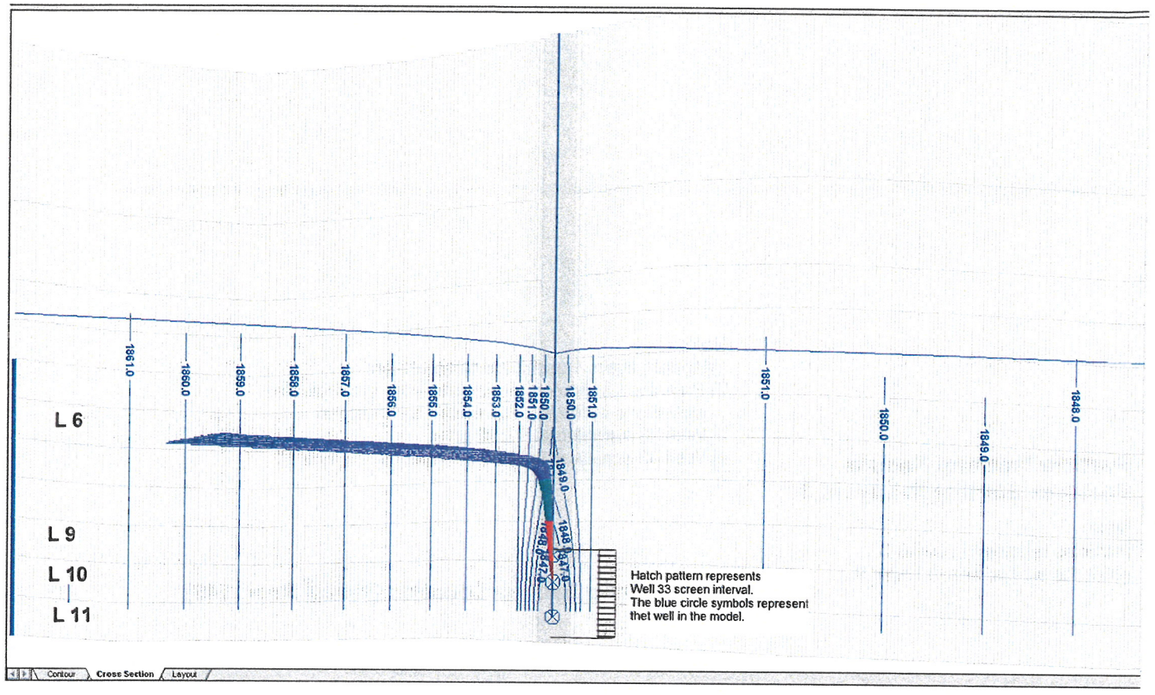
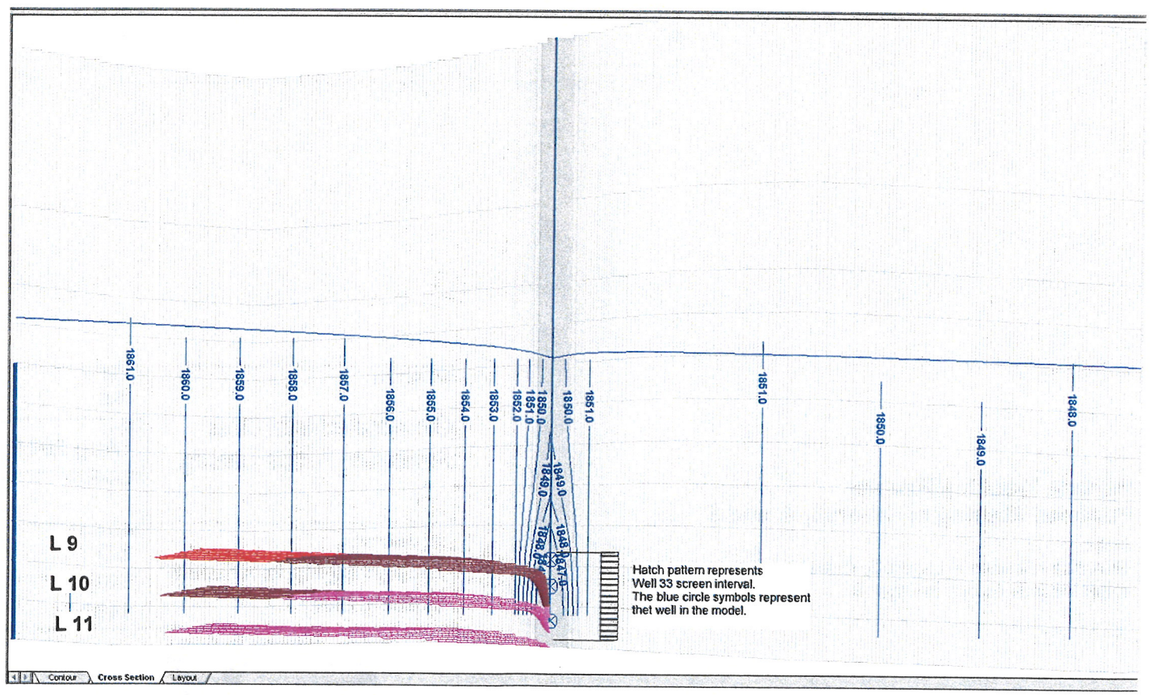


Particle Tracking Results
Partilces Starting in Layers 6

Particles released in Layer 6 enter the well screen in Layer 10, near the top of the layer.

Note:
1)Model Layers 1 and 2 are unsaturated.
2) Blue lines indicated model predicted groundwater elevations in ft msl. The model run included Well 33 pumping at 1,200 gpm.
4) Well 33 screen is located in Layers 9, 10, and 11.

Cross Section Location (Model Row 243)



Particle Tracking Results
Partilces Starting in Layers 9, 10, and 11

Particles released in Layers 9, 10, and 11 enter the well screen in Layer 11.

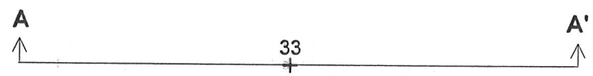


FIGURE TITLE: Groundwater Model Cross Section and Well 33 Geologic Log	FIGURE No: 6b
	DATE: Aug 2011
	PREPARED BY:
DOCUMENT TITLE: Hastings Utilities Groundwater Modeling Study	CHECKED BY: LD
	PROJECT No: 149243

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