Post-Audit of a Groundwater Model Used in Designing a Remediation System

Jason Early, PG, William Smith, PG,

Robert Kondelin, PG, and Christopher Hine

Environmental Alliance, Inc.
Ashland, VA and Wilmington, DE

ENVIRONMENTAL ALLIANCE

Outline

- Introduction/Background
- Post-Audit Methods
- Site Conditions
- GW Model Design
- Quantitative Comparison of Heads
- Qualitative/Graphical Comparison of Flowlines
- Conclusions
- Importance of Study

Introduction

- Along with field measurements and pilot testing, models are a useful tool in evaluating remedial scenarios for design purposes
- Much time spent developing and calibrating models, but rarely verified after implementing chosen remedial scenarios
- Post-auditing a model provides a means for evaluating the model's predictions:
  - Were the predictions accurate?
  - Should the model and/or the remedial design be modified?

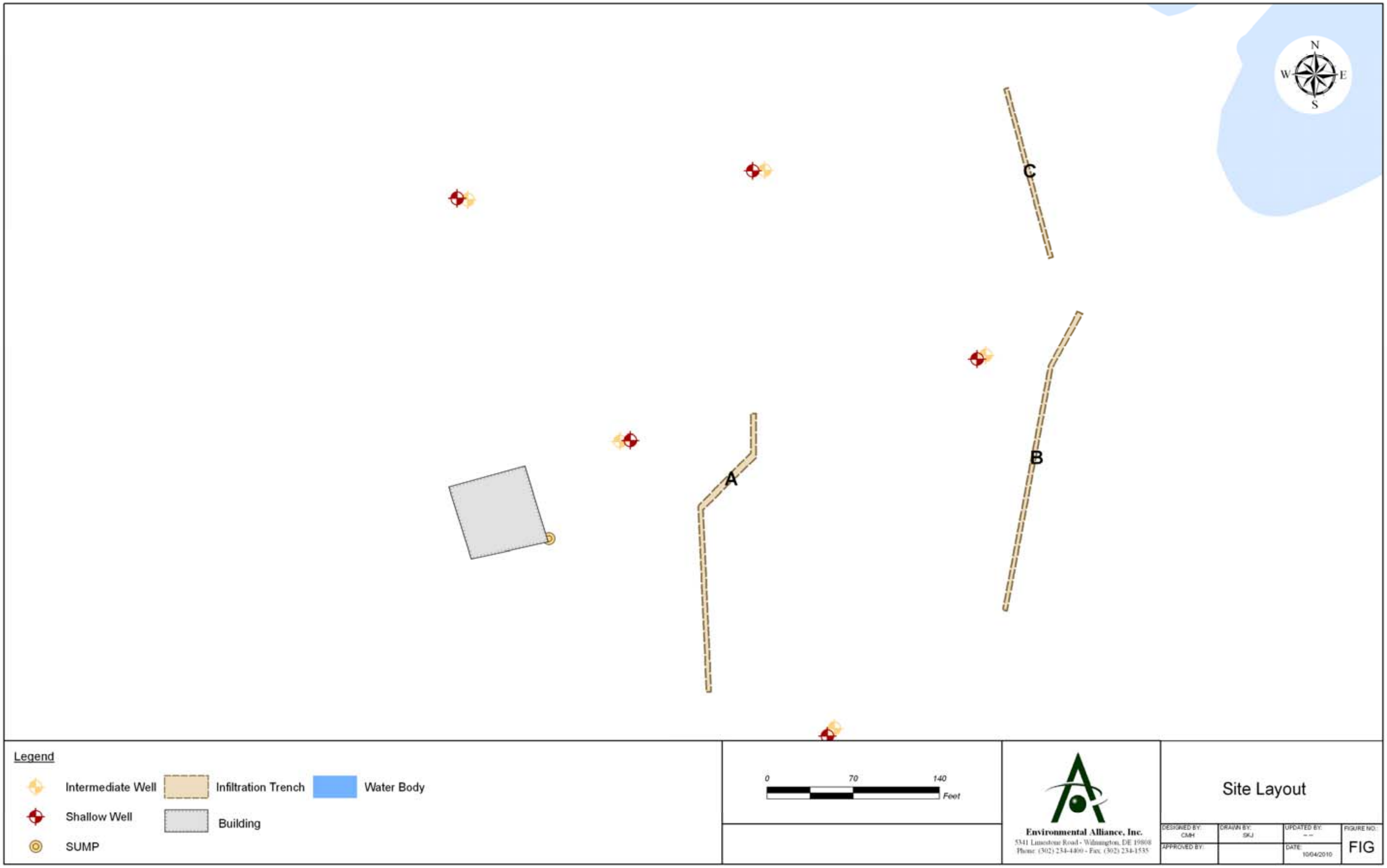
Environmental Alliance

Methods

- Post-audit performed for a design-phase steady-state MODFLOW/MODPATH model
- Model developed to select optimum placement and flow rates for a GW recirculation system
- System consists of 3 infiltration trenches located upgradient from a basement sump extracting at ~22.5 gpm
- Substrate amendment added to extracted and treated GW before infiltration, designed to spread substrate across site
- Infiltration distributed to trenches:
  - ~30% of flow directed to Trench A
  - ~50% of flow directed to Trench B
  - ~20% of flow directed to Trench C

ENVIRONMENTAL ALLIANCE

Site Layout



N
W
E
S
C
B
A
Legend
Intermediate Well
Shallow Well
SUMP
Infiltration Trench
Building
Water Body
0
70
140
Feet
Environmental Alliance, Inc.
5341 Limestone Road - Wilmington, DE 19808
Phone: (302) 234-4400 - Fax: (302) 234-1535
Site Layout
DESIGNED BY: CMH
DRAWN BY: SKJ
UPDATED BY: -- --
APPROVED BY:
DATE: 10/04/2010
FIGURE NO.: FIG

Methods (cont.)

- Model revised from original design-phase version to match the final as-built system construction and operating flows
- Revised model predictions then compared:
  1. Quantitatively: statistical comparison of simulated and observed heads
  2. Qualitatively: graphical comparison of simulated and projected flowlines mapped from field-measured heads
- Head data collected over 12 quarters used in analysis

Site Conditions

- Surficial WT aquifer consisting of Quaternary sands, silts and gravels underlain by sands
- Dense silty clay aquitard at base of surficial aquifer
- GW generally flows from east to west under natural conditions and due to sump operation
- Site in area of wet/dry seasons with high/rapid recharge events
- WT exhibits fluctuations of ~ 6.5 feet

ENVIRONMENTAL ALLIANCE

Model Design

- 2-Layer, steady-state MODFLOW flow model: top = coarser; bottom = finer
- BCs:
  - No-flow at base (aquitard)
  - Fire ponds (in connection with GW) as specified heads
  - Sump and infiltration trenches as specified flows
- MODPATH particles placed along trenches to trace predicted flowlines

ENVIRONMENTAL ALLIANCE

Model Design

- 2-Layer, steady-state MODFLOW flow model: top = coarser; bottom = finer
- BCs:
  - No-flow at base (aquitard)
  - Fire ponds (in connection with GW) as specified heads
  - Sump and infiltration trenches as specified flows
- MODPATH particles placed along trenches to trace predicted flowlines

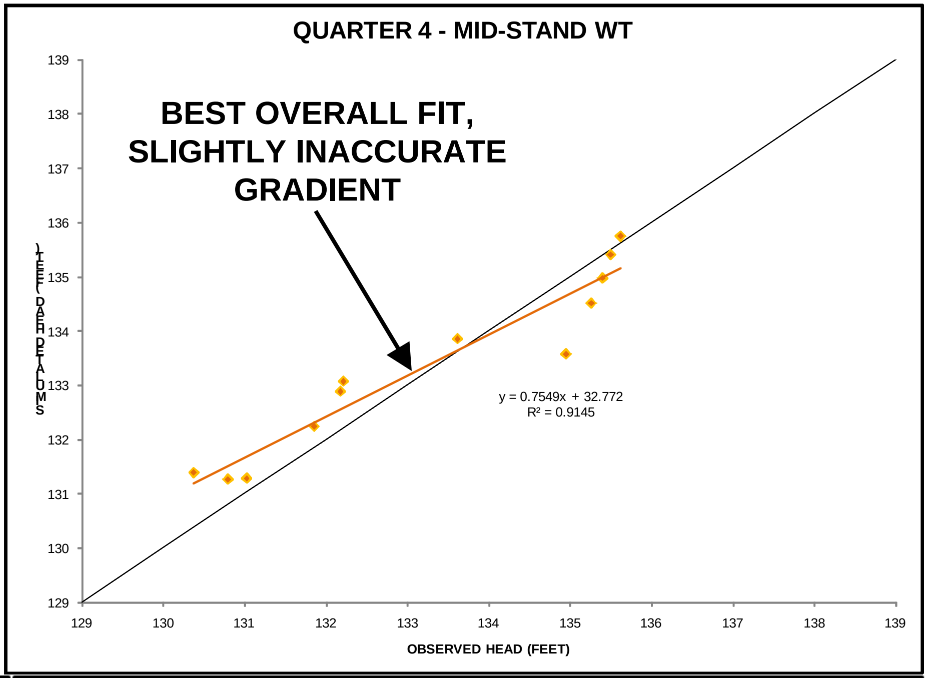
ENVIRONMENTAL ALLIANCE

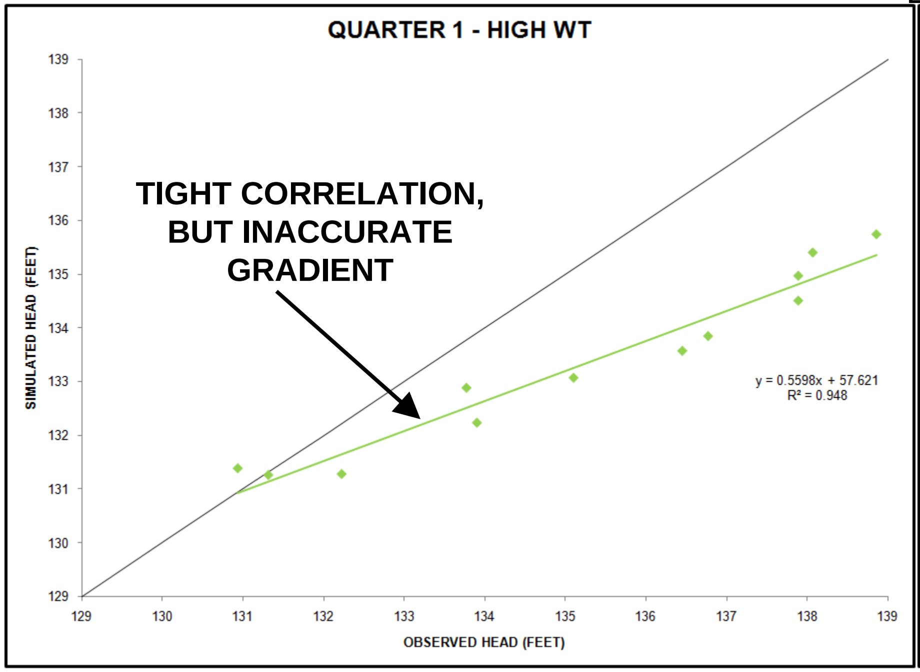
Statistical Comparison of Heads

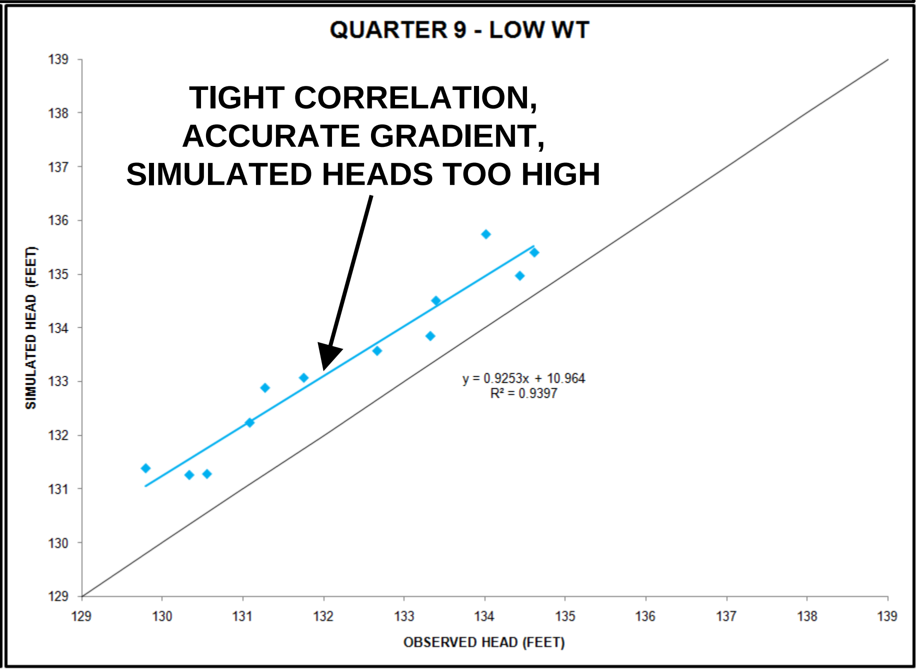
Dataset	Quarter 4	Quarter 1	Quarter 9
Hydrogeologic Condition	Mid-stand WT	High WT	Low WT
Statistic	Value	Value	Value
Mean Obs. Head	133.24	135.26	132.27
Mean Residual	0.11	-1.92	1.08
Abs. Mean Residual	0.55	1.99	1.08
Residual Std. Dev.	0.69	1.28	0.41
Residual Sum of Squares	5.33	62.23	15.91
n	12	12	12
Obs. Head Range	5.24	7.93	4.82
Root Mean Squared Error	0.67	2.28	1.15
Normalized RMS	12.7%	28.7%	23.9%
Correlation Coefficient	0.956	0.974	0.969
Interpretation	**Best Overall Fit, Slightly Inaccurate Gradient**	**Tight Correlation, Inaccurate Gradient**	**Tight Correlation, Accurate Gradient, Simulated Heads Too High**

ENVIRONMENTAL ALLIANCE

Scatter-Plot Comparison of Heads







Results: Quantitative Comparison of Heads

- Model produced accurate predictions of heads during average or mid-stand WT conditions
- Model gradients less accurate during high WT conditions, attributed to specified head boundary conditions (ponds)
- Model gradients accurate during low WT conditions despite over-predicted heads, also attributed to specified head boundary conditions (ponds)
- Model calibration to heads may be non-unique

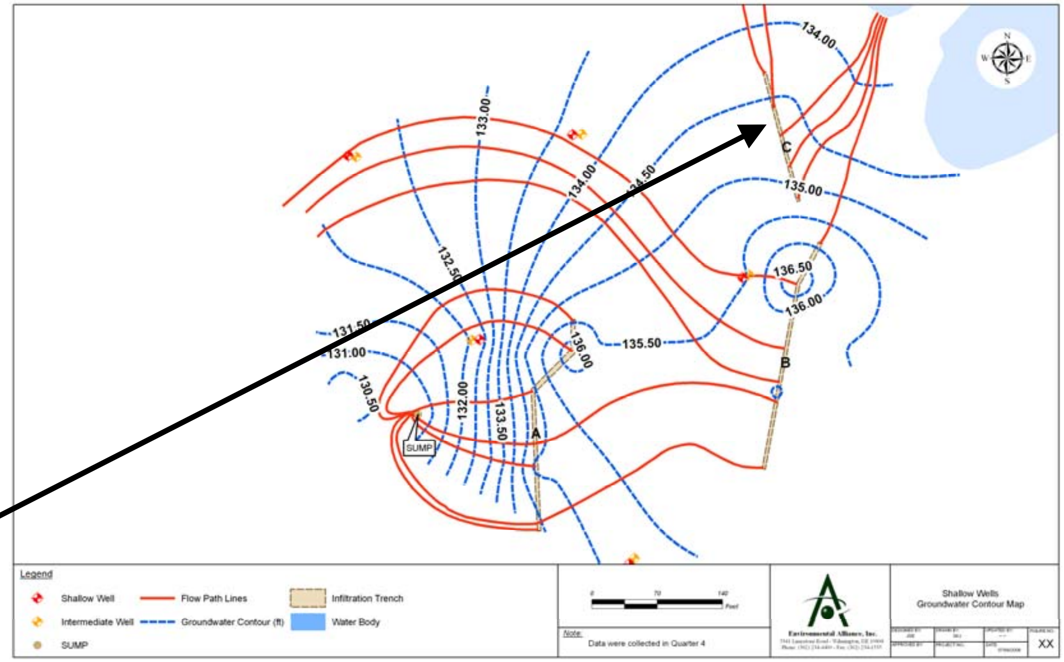
ENVIRONMENTAL ALLIANCE

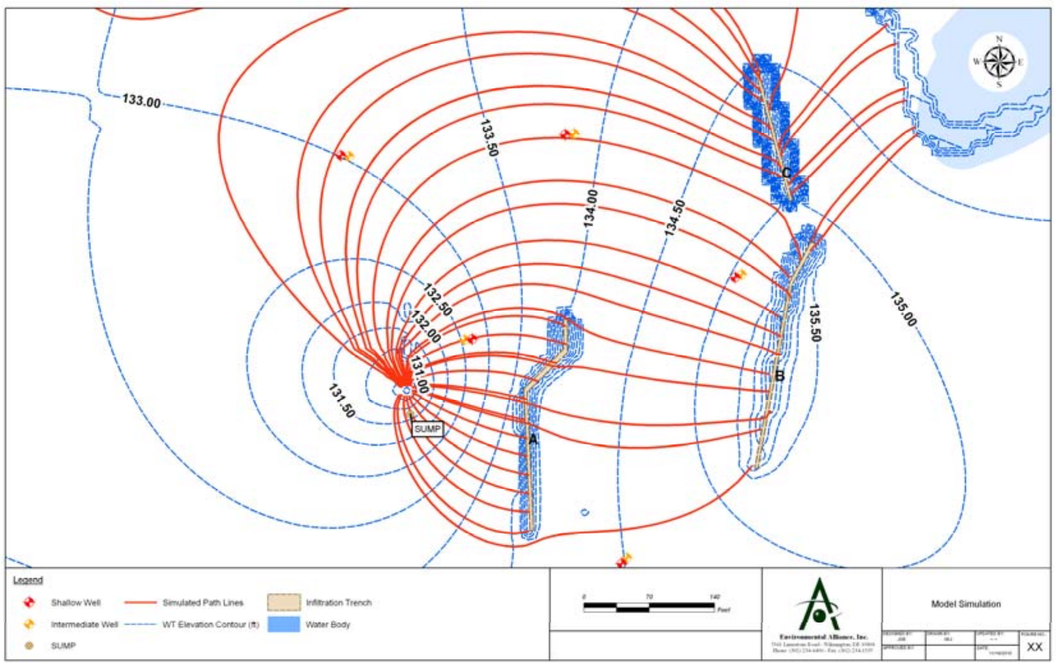
Results: Quantitative Comparison of Heads

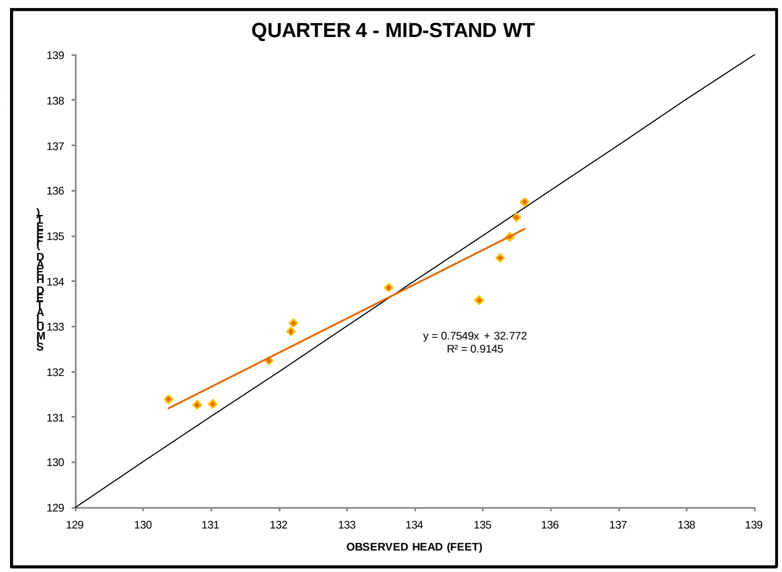
- Model could be improved by:
  - Increasing domain area to include natural hydrologic boundaries
  - Allowing specified heads at ponds to fluctuate
  - Evaluating different recharge conditions in model simulations

Graphical Comparison of Flowlines Quarter 4 (Mid-stand WT, Best Overall Fit, Slightly Inaccurate Gradient)

ALL FLOWLINES FROM TRENCH C PROJECT BACK TO PONDS

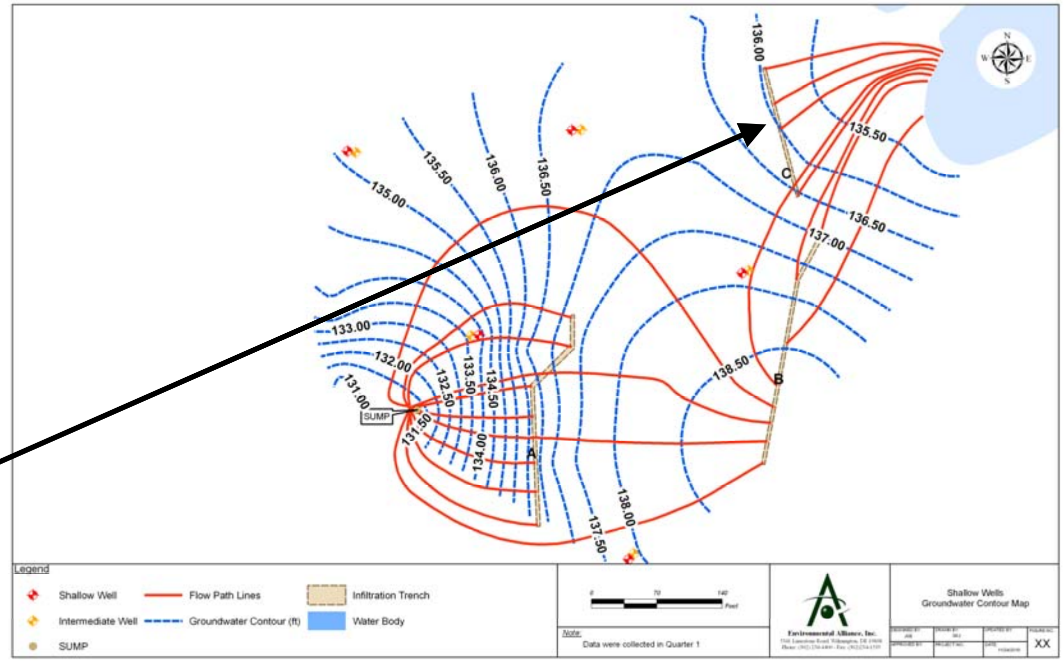


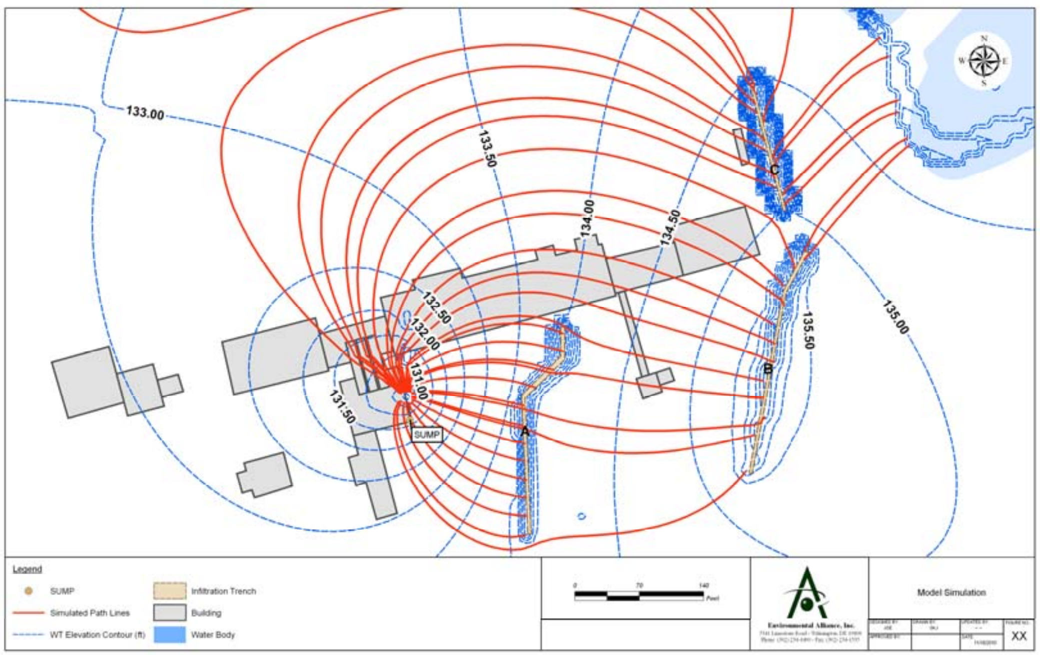


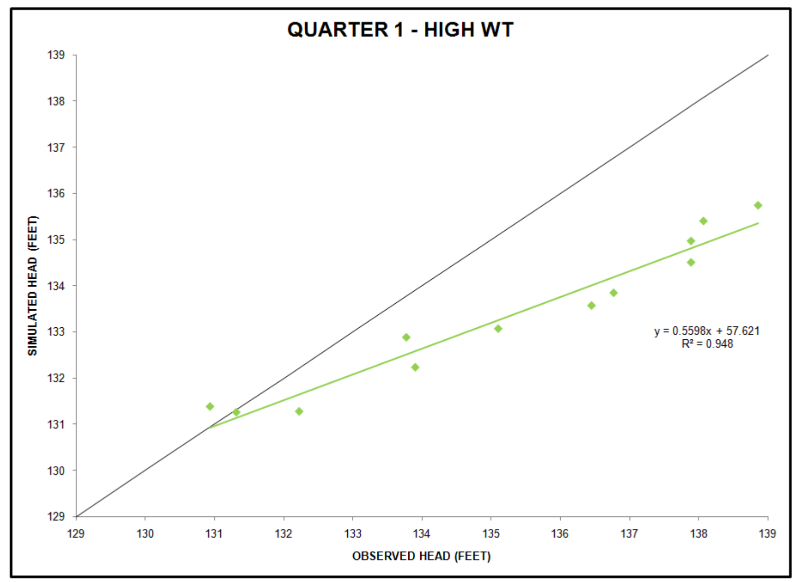


Graphical Comparison of Flowlines Quarter 1 (High WT, Tight Correlation but Inaccurate Gradient)

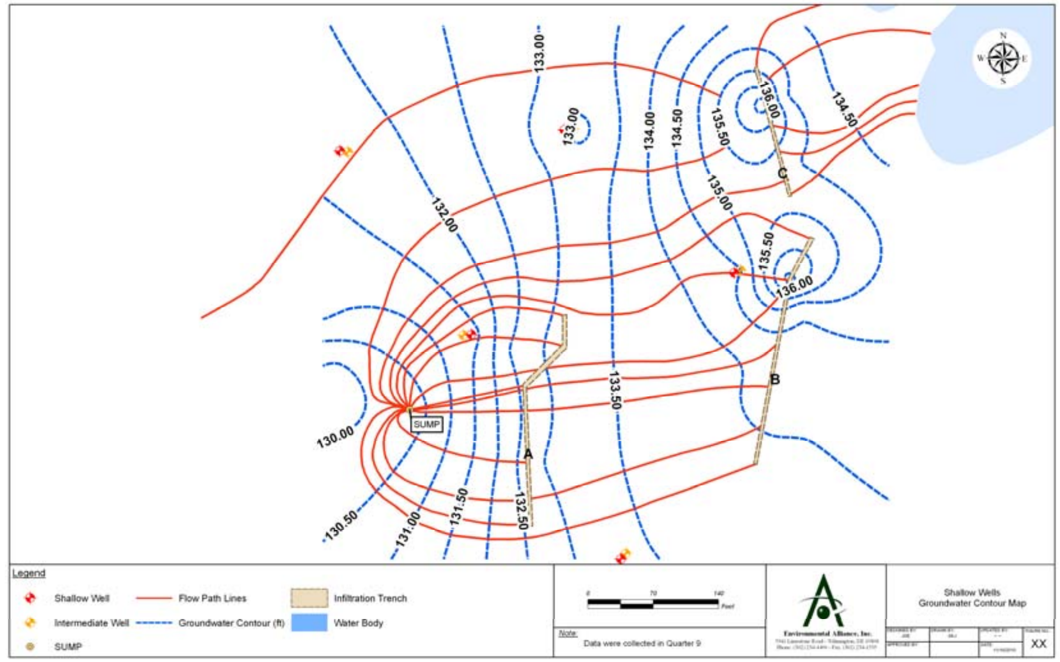
ALL FLOWLINES FROM TRENCH C PROJECT BACK TO PONDS

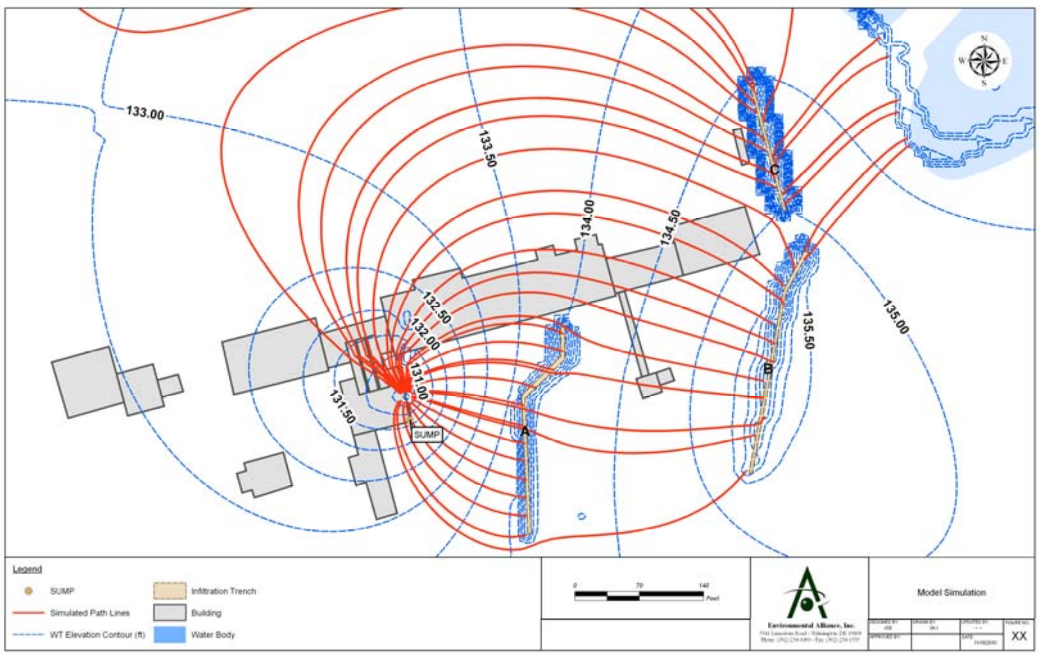


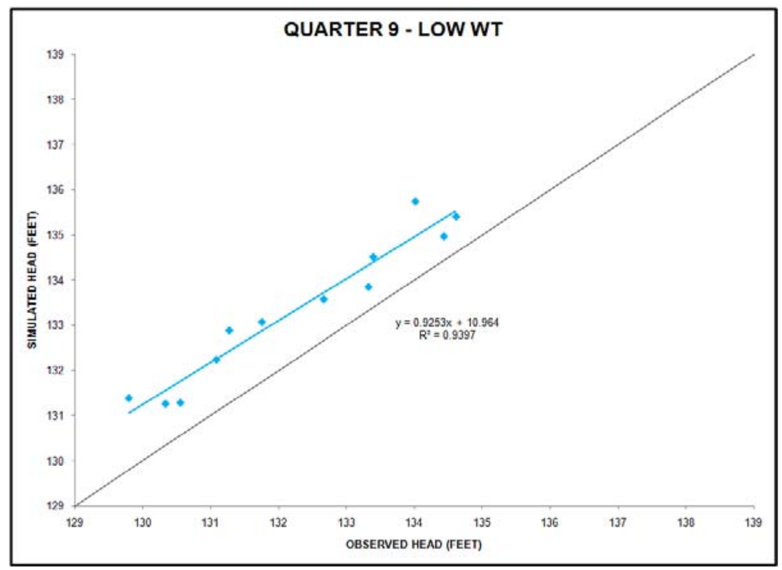




Graphical Comparison of Flowlines Quarter 9 (Low WT, Accurate Gradient but Simulated Heads too High)







Results: Graphical Comparison of Flowlines

- Overall, general flow directions predicted by model matched by field-based flownets:
  - Best fit to model corresponded to low WT, which also showed most accurate gradient despite simulated heads being too high
  - Reasonable match for mid-stand of WT
  - Worst fit to model corresponded to high WT, which also showed inaccurate gradient despite tight heads correlation

ENVIRONMENTAL ALLIANCE

Conclusions

- Because directions of GW flow (gradients) are more important than heads in evaluating recirculation system performance:
  - Model generally accurate in predicting groundwater flow directions and system treatment areas
  - Model more accurate during low to mid-stand WT conditions
  - Model less accurate during high WT conditions
  - Could be improved by increasing model recharge to simulate high WT conditions
  - Difficult to simulate high/rapid recharge events, generally calibrate model to average conditions

ENVIRONMENTAL ALLIANCE

Study Illustrates Importance of:

1. Performing post-audits to confirm model predictions
2. Modeling large enough area to allow simulation of natural hydrologic boundaries far from areas of induced stresses
3. Evaluating post-audit results in terms most relevant to model purpose:
    - i.e., GW flow directions and corresponding treatment areas more important than heads
4. Having more piezometers/MWs to map GW flow from field data

ENVIRONMENTAL ALLIANCE

Questions?

?

ENVIRONMENTAL ALLIANCE