Evapotranspiration Measurement and Simulation due to Poplar Trees at a Phytoremediation Site

Eric M. Panhorst

Thesis submitted to the faculty of Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

CIVIL & ENVIRONMENTAL ENGINEERING

Committee Members:

Mark A. Widdowson, Chairman
  John T. Novak
  G.V. Loganathan

May 29, 2000
Blacksburg, VA

Copyright 2000, Eric M. Panhorst
Evapotranspiration Measurement and Simulation due to Poplar Trees at a Phytoremediation Site

Eric M. Panhorst

(Abstract)

A railroad yard in Oneida, Tennessee was contaminated with creosote in the 1950s and 1960s through cross tie treatment. The problem was discovered in 1990 and phytoremediation in combination with an interception trench was chosen as the remediation strategy. Hybrid poplar trees (1,036) were planted in 1997 within 0.7 acres. The goals of the phytoremediation system are to prevent migration of the contaminant off the site and clean up the contaminant in-situ. This study is focused on quantifying the rate of evapotranspiration of the phytoremediation system and then determining the effect on groundwater flow. This will be accomplished by quantifying evapotranspiration using a water budget, applying White’s Equation, comparing groundwater recession curves, creating a groundwater flow model, and examining water table elevations obtained at the site. Calculations of water use by the poplar trees in early September 1999 ranged from 0.62 to 1.34 gal/day/tree. The volume of evapotranspiration calculated for the trees during 1999 is 140,292 gallons. Total evapotranspiration determined by the water budget for 1998 is 1,570,064 gallons. Evaluation of the water level data over a period of several years shows significant lowering of the water table (fluctuations of up to four feet) during the summer and fall months due to evapotranspiration. Although calculated evapotranspiration rates are not as high as seen in the literature, continued monitoring of the site should show large increases in evapotranspiration rates in the future as the poplar trees mature.
# Table of Contents

1 Introduction ............................................................................................................. 1

2 Literature Review ................................................................................................... 3

   2.1 Water Table Fluctuations .................................................................................. 3
       2.1.1 Water Table Fluctuations due to Evapotranspiration ......................... 3
       2.1.2 Water Table Fluctuations due to Barometric Pressure Changes ....... 6
       2.1.3 Water Table Fluctuations due to Temperature Changes ................. 9
       2.1.4 Water Table Fluctuations due to a Recharge Event ...................... 10

   2.2 Quantifying Evapotranspiration ...................................................................... 10

   2.3 Poplar Trees ..................................................................................................... 13

3 Method of Data Collection ..................................................................................... 14

   3.1 General Site Information ................................................................................. 14

   3.2 Materials and Methods .................................................................................... 14
       3.2.1 Weather Station ...................................................................................... 16
       3.2.2 Other Weather Data Sources ................................................................. 16
       3.2.3 Continuous Water Level Monitoring .................................................... 18
       3.2.4 Discrete Water Level Measurements .................................................... 19
       3.2.5 Bouwer and Rice Slug-Test ................................................................. 19
       3.2.6 Interception Trench ............................................................................... 20

   3.3 Discussion of White’s Equation ........................................................................ 20

   3.4 Discussion of Groundwater Recession Method ............................................. 25

4 Water Budget for Oneida ...................................................................................... 27
4.1 Water Budget Components ........................................................................... 27
  4.1.1 Rainfall ................................................................................................. 27
  4.1.2 Groundwater Flow In/Out ................................................................. 29
  4.1.3 Interception Trench ............................................................................. 29
  4.1.4 Runoff .................................................................................................. 30
  4.1.5 Evapotranspiration .............................................................................. 31
  4.1.6 Change in Storage of the Aquifer ....................................................... 32

4.2 Water Budget Results .................................................................................. 33

4.3 Sensitivity Analysis .................................................................................... 36

5 Transpiration Results for Poplar Trees at Oneida .................................... 39
  5.1 Results of White’s Equation .................................................................... 39
  5.2 Results of Groundwater Recession Method ........................................ 40

6 Spatial and Temporal Behavior of Water Table ....................................... 42

7 Groundwater Model .................................................................................... 46
  7.1 Model Grid and Parameters .................................................................... 47
    7.1.1 Model Grid ......................................................................................... 47
    7.1.2 Initial Conditions and Recharge ....................................................... 47
    7.1.3 Boundaries ......................................................................................... 49
    7.1.4 Bedrock Elevations .......................................................................... 50
    7.1.5 Hydraulic Conductivity .................................................................... 50
    7.1.6 Specific Yield ..................................................................................... 50
    7.1.7 Interception Trench .......................................................................... 51
7.1.8 Poplar Trees

7.2 Model Calibration Procedure and Results

7.2.1 Calibration of 2/28/00 – 3/8/00

7.2.2 Verification of 1/31/00 – 2/8/00

7.2.3 Application of Model to Tree Use

8 Summary and Conclusions

8.1 Comparison of Tree Consumption Methods

8.2 Phytoremediation System Water Use

8.3 Conclusions

8.4 Future Considerations

9 References

Appendix A: Weather Data
Appendix B: Pressure Transducers
Appendix C: Discrete Water Level Measurements
Appendix D: Groundwater Flow Model Parameters
Appendix E: Bouwer and Rice Slug-Test
Appendix F: Trench Data
List of Figures:
Figure 2.1: Water levels in a thicket of willow trees in Utah .................................................. 7
Figure 2.2: Water levels in a field of pickleweed in Utah .............................................................. 7
Figure 2.3: Walter White’s evaporation vs. depth experiment ..................................................... 8
Figure 2.4: Example of application of White’s Equation at Oneida in September 1999 .................. 12
Figure 3.1: Oneida, Tennessee site map ....................................................................................... 15
Figure 3.2: Plot of rainfall and pressure transducer data from 6/15/99 – 3/15/00 ......................... 17
Figure 3.3: Application of White’s Equation, September 5, 1999 .............................................. 22
Figure 3.4: Application of White’s Equation, October 15, 1999 ................................................ 22
Figure 3.5: Plot of potential errors in using White’s Equation ..................................................... 24
Figure 3.6: Application of White’s Equation, November 6, 1999 .............................................. 24
Figure 3.7: Comparison of summer and winter MW6 water level data ........................................ 26
Figure 4.1: Monthly rainfall data for Oneida (April 1997 – February 2000) ................................. 28
Figure 4.2: Comparison of ET from water budget and from Thornthwaite Method .................... 34
Figure 4.3: Water level data for P4 and P6 from October 1997 – March 2000 ............................. 37
Figure 6.1: July 1999 water level data and contours ................................................................. 43
Figure 6.2: March 2000 water level data and contours ............................................................... 44
Figure 7.1: Model grid ............................................................................................................... 48
Figure 7.2: Steady state model results simulating December 1997 ............................................. 54
Figure 7.3: Steady state model results simulating August 1999 ................................................. 55
Figure 7.4: March 2000 calculated heads compared with observed heads ............................... 59
Figure 7.5: February 2000 calculated heads compared with observed heads ............................ 59
Figure 7.6: September 1999 calculated heads compared with observed heads ......................... 62
Figure 7.7: August 1999 calculated heads compared with observed heads ............................... 62
Figure 8.1: Recommendation plot ............................................................................................ 67

List of Tables:
Table 4.1: 1998 monthly water withdrawal from interception trench at Oneida ..................... 30
Table 4.2: 1998 monthly change in head and storage of aquifer at Oneida .............................. 33
Table 4.3: Detailed 1998 water budget ....................................................................................... 35
Table 4.4: Results of sensitivity analysis ...................................................................................... 38
Table 5.1: Results using White’s Equation ..................................................................................... 40
Table 5.2: Results using Groundwater Recession Method ......................................................... 41
Table 6.1: Comparison of extreme water elevations and gradients for data .............................. 45
Table 7.1: Steady state model calibration statistics ................................................................. 53
Table 7.2: Steady state model water budget ................................................................................. 56
Table 7.3: Transient model calibration statistics ......................................................................... 58