ECF-300FF5-17-0039
Revision 0

Analysis of Potential Land Development Approaches on Recharge and Groundwater Flow Near the Land Conveyance in the 300 Area

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

P.O. Box 1600
Richland, Washington 99352

Approved for Public Release;
Further Dissemination Unlimited

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Terms

AWLN	Automated Water Level Network
COC	Contaminant of Concern
DOE	U.S. Department of Energy
EA	Environmental Assessment
EAA	Enhanced Attenuation Area
ECF	Environmental Calculation File
EIS	Environmental Impact Statement
EMMA	Environmental Model Management Archive
GHB	General Head Boundary
GWFM	Groundwater Flow Model
HF	Hanford Formation
HSGFM	Hanford South Geologic Framework Model
HSU	Hydrostratigraphic Unit
MNA	Monitored Natural Attenuation
NEPA	National Environmental Policy Act
PRZ	Periodically Rewetted Zone
RET	Recharge Estimation Tool
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
RUM	Ringold Upper Mud
Rwie	Ringold E
TMR	Telescopic Mesh Refinement
TRIDEC	Tri-City Development Council

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1 Purpose

The National Defense Authorization Act of 2015 directed the U.S. Department of Energy (DOE) to transfer all rights, title, and interest of 1,641 acres of land formerly a part of the Hanford Site to the Tri-City Development Council (TRIDEC) for economic development purposes. As part of this transfer, the DOE was required to comply with the National Environmental Policy Act (NEPA), including an Environmental Assessment (EA). During the EA public review process, the potential for additional recharge to leach more contamination from the 300 Area into the Columbia River was raised. To address this concern, a range of conceptual potential development scenarios was developed using State of Washington stormwater management guidelines. These scenarios established potential changes in aquifer recharge from development, which were used with two groundwater models of the area to estimate how much water-levels could rise in areas of known uranium contamination, and how groundwater flow paths and rates could change near the 300 Area nitrate and uranium groundwater plumes. These metrics were used to qualitatively assess the potential for increased leaching of uranium.

2 Background

The 300 Area is in the southeastern Hanford Site; fabrication of nuclear fuel assemblies (1943 to 1987) and fuel-processing research (1950s to 1960s) occurred in the area (DOE/RL-2016-09, *Hanford Site Groundwater Monitoring Report for 2015*). Disposal of associated liquid effluent has resulted in groundwater contamination, with some residual contamination remaining in the vadose zone and aquifer (DOE/RL-2016-09). The Remedial Investigation/Feasibility Study (RI/FS) (DOE/RL-2010-99, DOE/RL-2010-99-ADD1, *Remedial Investigation/Feasibility Study for the 300-FF-1, 300-FF-2, and 300-FF-5 Operable Units, Addendum*) and Record of Decision (ROD) (EPA et al., 2013, *Hanford Site 300 Area Record of Decision for 300-FF-2 and 300-FF-5, and Record of Decision Amendment for 300-FF-1*) identify Contaminants of Concern (COCs) as uranium, gross alpha, TCE, cis-1,2-DCE, tritium, and nitrate. Residual uranium soil contamination is to be sequestered by phosphate application in the vadose zone, Periodically Rewetted Zone (PRZ), and aquifer top; Monitored Natural Attenuation (MNA) is the alternative for all other COCs. The area, known as the Stage A Enhanced Attenuation Area (EAA), to be treated with phosphate is near the southern end of the former 300 Area Process Trenches and North Process Pond (Figure 2-1). A nitrate plume is present near the 618-11 Burial Ground; however, there is nitrate in southern 300 Area groundwater from offsite agricultural and industrial activities not associated with the Hanford Site (DOE/RL-2016-09), and is not part of the 300-FF-5 OU.

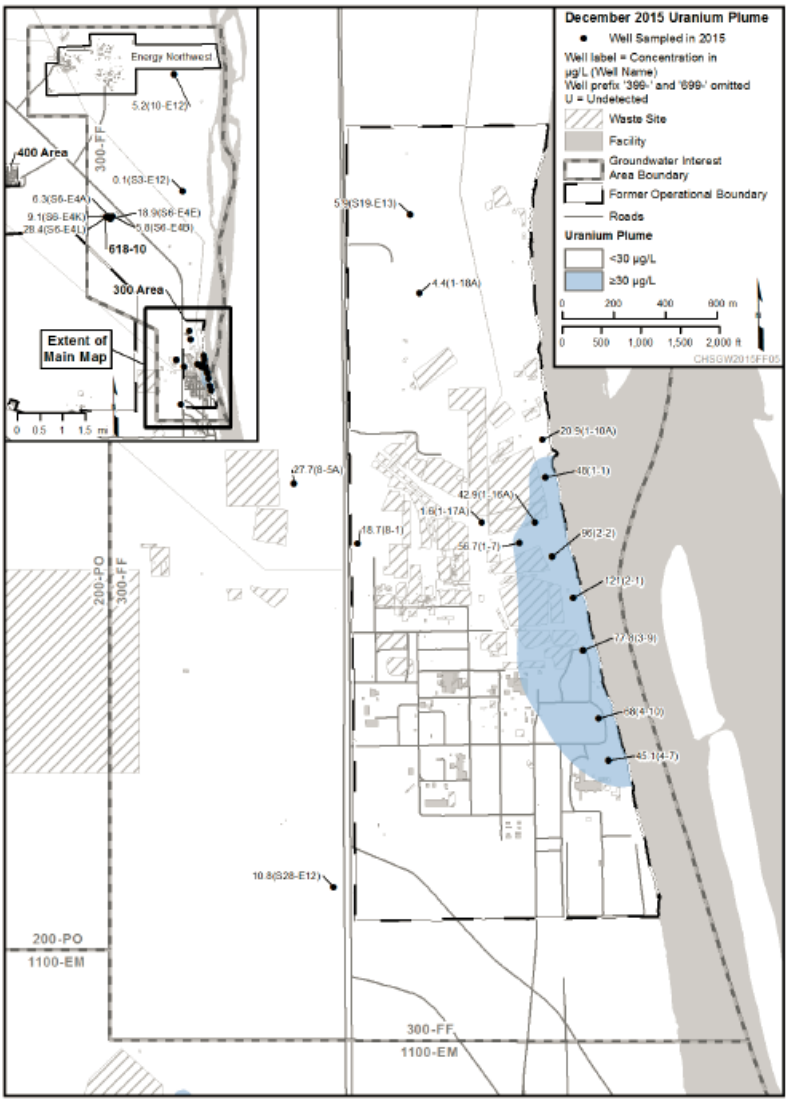


Figure 7-5. 300-FF Uranium Plume, Upper Part of Unconfined Aquifer, December 2015 (Low River Stage)

Figure 2-1. 300-FF Uranium Plume, Upper Part of Unconfined Aquifer, December 2015 (Low River Stage) (from DOE/RL-2016-09)

Groundwater in the unconfined aquifer in the 300 Area flows east to southeast towards the Columbia River, the groundwater discharge point (Figure 2-2). This direction is a consequence of converging overall southward regional flow. Near the uranium plume, the direction tends south-southeast, subparallel to the river (Figure 2-2). The hydraulic gradient is much lower approaching the river because of the presence of high-hydraulic conductivity Hanford formation at the water table. Near the Columbia River, groundwater levels respond strongly to river fluctuations; these fluctuations can raise the water table into the soil residual contamination, and a positive correlation exists between water-table elevation and uranium concentrations in the EAA (DOE/RL-2016-09).

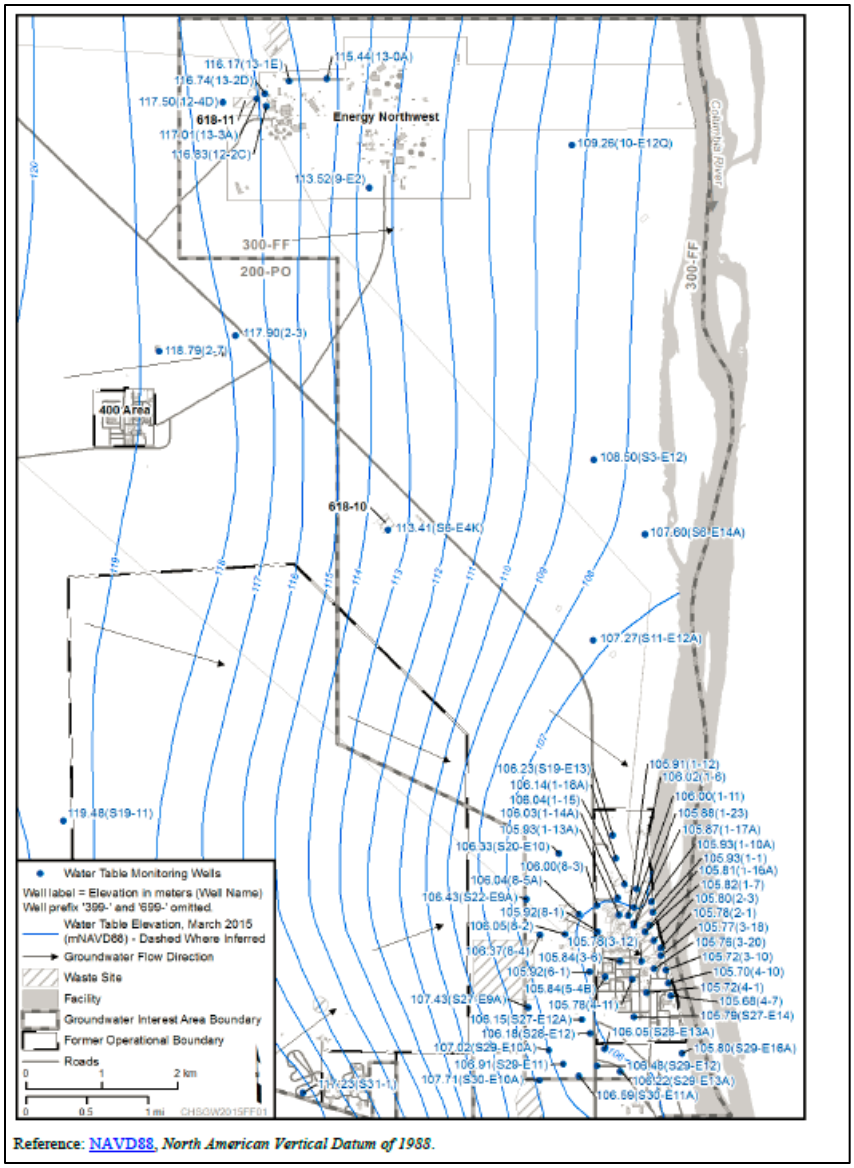


Figure 2-2. 300-FF Overview Map with Groundwater Flow (from DOE/RL-2016-09)

The City of Richland uses the North Richland wellfield and recharge basins as part of its water supply operations. Water from the Columbia River is pumped to the basin, infiltrated, and then pumped for water supply. The TC&WM EIS (DOE/EIS-0391, *Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site*) reports infiltration starting in 1981. This infiltration has created a groundwater mound, which affects the nitrate plume in the southern part of the 300 Area. Modeling analysis performed in 1989 found the effect of the mound between 1983 and 1988 (WHC-MR-0033, *Recharge to the North Richland Well Field*) had a significant impact on groundwater flow in the area. This feature is included in this analysis.

PNNL-17708, *Three-Dimensional Groundwater Models of the 300 Area at the Hanford Site*, developed a detailed groundwater flow and transport model near the 300 Area uranium plume. Key conceptual elements of a dynamic unconfined aquifer system were the influence of the Columbia River stage and high hydraulic conductivity of the Hanford formation. Hydraulic testing shows that the Hanford formation

hydraulic conductivity is 100 to 1,000 times higher than the underlying Ringold formation, with values near the EAA on the order of 3,800 and 40 m/d for the Hanford and Ringold formations, respectively.

3 Methodology

The following steps describe the calculations performed in this Environmental Calculation File (ECF). Section 3.1 pertains to the modeling based on the TC&WM EIS flow model (DOE/EIS-0391, Appendix L) and Section 3.2 discusses the site-specific model developed for the 300 Area.

3.1 EIS Sub-Model

1. Obtained a copy of the base case TC&WM Environmental Impact Statement (EIS) MODFLOW flow model (DOE/EIS-0391 Appendix L, *Groundwater Flow Field Development*) files from the Environmental Model Management Archive (EMMA).
2. Imported the EIS MODFLOW model into Groundwater Vistas™[1] (Rumbaugh and Rumbaugh, 2015).
3. Verified that the Groundwater Vistas™ model produced groundwater head elevations consistent with the original EIS model.
4. Used Groundwater Vistas™ Telescopic Mesh Refinement (TMR) to create a more refined model within a sub-region of a larger-scale EIS model.
5. Post-processed groundwater head output from the full-scale Groundwater Vistas™ model to extract groundwater head elevations along the north, south and west sides of the sub-model domain to use as boundary conditions for the refined model.
6. Ran the refined MODFLOW model with no stormwater retention ponds (base case) and for four development scenarios with stormwater retention ponds and reduced areal recharge outside the ponds.
7. Ran MODPATH for the base case model (no stormwater retention ponds) and for the four development scenarios to produce particle tracks through the 2015 uranium and nitrate plumes in the 300 Area.

3.2 Focus Groundwater Flow Model

The focus groundwater flow model (GWFM) uses same model domain and grid spacing as the EIS sub-model. However, the focus model was constructed to explicitly capture the interaction of the aquifer and Columbia River using site-specific data; the EIS model omitted wells within 600 m of the river, which includes much of the land transfer area. Thus, the focus model provides a more realistic representation of the aquifer system in the area of interest, and greater accuracy in representing the potential impacts from development stormwater management.

3.2.1 Parameter Estimation Framework

The PEST (Doherty, 2016) parameter estimation software was used to facilitate model calibration in concert with manual adjustments. The 2014 through December 2015 calibration dataset incorporated the following elements:

1. Stress-period averaged Automated Water Level Network (AWLN) water levels from 18 wells (1369 total data points). All of these AWLN wells are located within uranium and nitrate plume

[1] Groundwater Vistas is a registered trademark of Environmental Simulations, Inc.

footprint which is a small portion compared to the entire model domain. Therefore, hydraulic properties of the aquifer in this zone of high density observed data can be well calibrated using PEST.

2. 174 wells with low frequency manual water-level measurements (1,179 data points). These wells are spread out throughout the model domain with no coverage in few areas. Some wells were not added in the actual calibration due to the disagreement in well data with the surrounding wells and due to the well screen opened to the underlying Ringold Upper Mud aquitard (RUM).

The deviation between observed and simulated values (objective function) is mathematically minimized using singular value decomposition as described by Doherty (2016). The overall calibration process was as follows:

- Run the PEST software
- Review estimated model parameters and model fit to data for reasonableness and agreement
- Identify potential conceptual or parameter issues to be resolved and an approach
- Implement parameter, model setup, or other change
- Repeat

PEST provides several outputs of the process, including a file listing the residual (.res) between simulated and observed. This data was used to review goodness of fit. No absolute value of goodness of fit was set as a stopping criterion; an overall weight of evidence was considered including goodness of fit and plausibility of estimated parameters. Figure 3-1 shows the location of the calibration targets used in the model calibration.

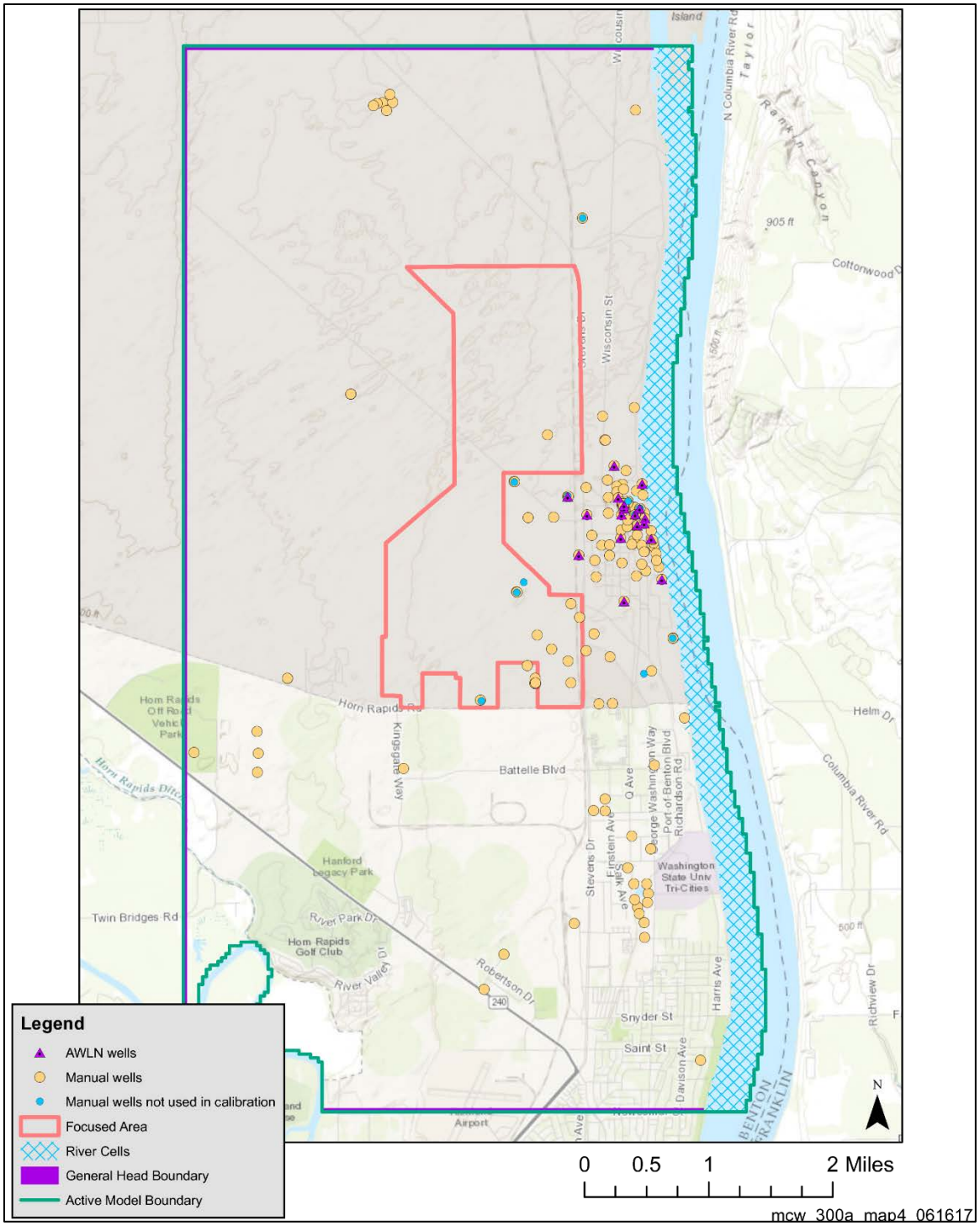


Figure 3-1. Location of the Calibration wells within the Focus GWFM

3.2.2 Predictive Model Setup

The predictive groundwater model for 300 Area uses the same parameters (e.g., hydraulic conductivity, boundary conditions) from the calibrated model. Time varying boundary conditions such as river, drain, and general head boundary are formed by reusing the calibrated boundary conditions (from 2014 to 2015)

as many times as needed. A 100-year predictive simulation, starting in 2016, was performed for the particle tracking analysis.

4 Assumptions and Inputs

Section 4.1 discusses the EIS Sub-Model and Section 4.2 the 300 Area site-specific model.

4.1 EIS Sub-Model

4.1.1 Assumptions

In general, the same assumptions that apply to the TC&WM EIS flow model (DOE/EIS-0391 Appendix L) apply to the EIS Sub-Model. Some of the principle assumptions include:

1) Columbia and Yakima River stages are modeled as unchanging with time. Because of this assumption, all wells within 600 meters of the Columbia River were removed from the calibration data set for the TC&WM EIS MODFLOW flow model to remove the periodic fluctuations in the river stage from the head observation data.

2) Groundwater flow at Hanford is through an unconfined, heterogeneous aquifer bounded at the bottom by an impermeable basalt surface.

3) The top of the model is open to the atmosphere and subject to natural recharge (precipitation) and anthropogenic recharge.

4) The site-wide natural recharge rate is 3.5 millimeters per year.

5) Hydraulic head values from the site-wide model provide adequate boundary conditions for the refined site model.

6) Infiltration from the stormwater ponds is based on infiltration modeling over a two-year period, 1995 through 1996, with 1996 being the wettest year on record (ECF-300FF5-17-0065, *Analysis of Stormwater Management from Potential Land Development Scenarios for the 300 Area Land Transfer*).

Additional assumptions can be found in DOE/EIS-0391 Appendix L.

4.1.2 Model Inputs

4.1.2.1 Discretization

<u>Spatial Discretization</u>

The TC&WM EIS flow model (DOE/EIS-0391 Appendix L) is a three-dimensional MODFLOW model that encompasses the entire Hanford Site and consists of 31 layers of uniform thickness across the entire model domain (See Figures L-16, L-17 and L-18 of DOE/EIS-0391, Appendix L). Grid cell dimensions for the site-wide EIS model are 200 m by 200 m, except along the northern, eastern, and southern edges where a single line of cells had reduced dimensions. Figure 4-1 shows the model domain of the TC&WM EIS flow model and the area selected for the 300 Area EIS Sub-Model, which extends from easting 588,400 m to 595,800 m and from northing 108,600 m to 122,400 m.

The EIS Sub-Model was extracted from the site-wide model using TMR in Groundwater Vistas™. Grid cells size was decreased from 200 by 200 m to 50 by 50 m. Figure 4-2 shows the EIS Sub-Model grid and the focused study area. Vertical discretization remains the same as the site-wide model.

Temporal Discretization

The TC&WM EIS flow model (DOE/EIS-0391 Appendix L, 2012) retrieved from EMMA had 65 stress periods covering a period from 1940 through 2200 (Table 4-1). For the EIS Sub-Model, the last stress period was reduced from 179 years to the 100-year performance period selected for analysis of stormwater pond effects. Otherwise, all stress periods and time stepping remained the same as for the site-wide model. Time units for the EIS Sub-Model are years to be consistent with the site-wide EIS model.

Table 4-1. Time Discretization for the TC&WM EIS MODFLOW Flow Model

Stress Period[a]	Period Length (yr)	Begin	End
1	4	1940	1943
2	1	1944	1944
3	1	1945	1945
4	1	1946	1946
5	1	1947	1947
...			
61	1	2003	2003
62	1	2004	2004
63	1	2005	2005
64	16	2006	2021
65	179[b]	2022	2200

Notes:

a. Stress periods 2 through 63 were all one year in length.

b. Stress period 65 was reduced to 100 years for the EIS Sub-Model.

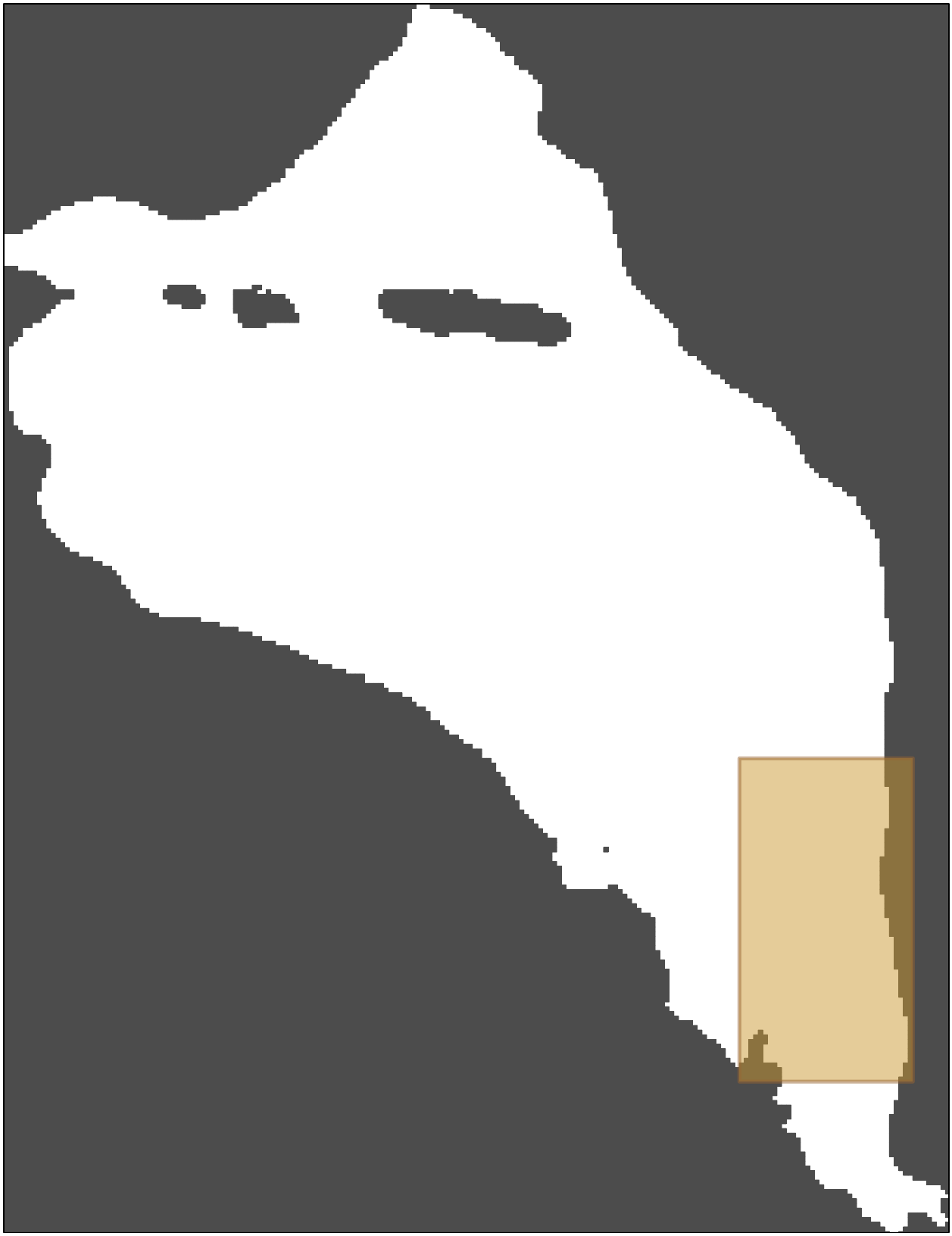


Figure 4-1. TC&WM EIS Flow Model Domain and the Area Selected for the 300 Area EIS Sub-Model

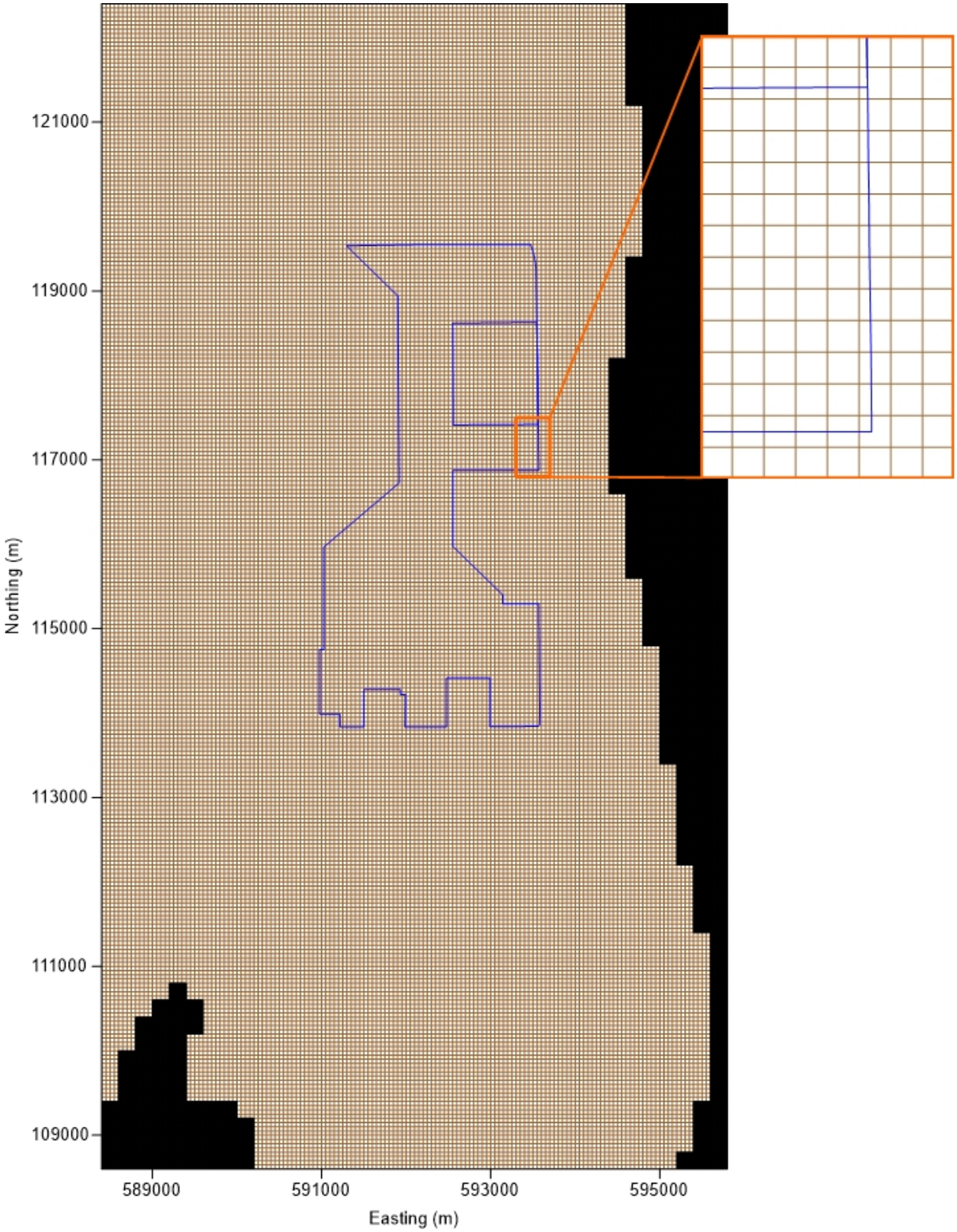


Figure 4-2. EIS Sub-Model Grid

4.1.2.2 Parameterization

Boundary Conditions

Boundary conditions for the site-wide TC&WM EIS flow model can be found in DOE/EIS-0391 Appendix L. For the EIS Sub-Model No Development scenario (base case), river and recharge boundary conditions remain the same as the site-wide model. For the four development scenarios, recharge conditions within the focused study area are modified, but river boundary conditions and recharge outside the focused study area remain the same as the site-wide model. A discussion of the development scenarios and associated recharge in the focused study area is provided in Section 6. River boundary cells are confined to layers 18 and 19 for the Yakima River and layer 21 for the Columbia River within the EIS Sub-Model domain.

The base of the TC&WM EIS flow model in the vicinity of the EIS Sub-Model is defined by the top of the basalt that underlies the unconfined aquifer. This boundary is assumed to be a no-flow boundary throughout the model.

Lateral boundary conditions along the north, south and west edges of the EIS Sub-Model were implemented using general head boundaries (GHBs) developed from the site-wide TC&WM EIS flow model. Time varying hydraulic head values for each stress period were extracted from the site-wide model for each boundary cell along the north, south and west edges of the EIS Sub-Model. These time varying hydraulic head values were then used to create GHBs for each cell along the north, south and west edges of the EIS Sub-Model. Figure 4-3 shows a plan view of the locations for the river and GHB cells.

Hydraulic Properties

Material properties defined for the TC&WM EIS flow model (DOE/EIS-0391 Appendix L) include horizontal and vertical hydraulic conductivity, storage coefficient and specific yield. Table L-15 of DOE/EIS-0391 Appendix L (reproduced herein as Table 4-2) lists horizontal and vertical hydraulic conductivity values for the base case TC&WM EIS flow model. Only a subset (highlighted in yellow in Table 4-2) of the material types listed are included in the EIS Sub-Model domain. Table 4-3 lists specific yield (the ratio of the volume of water that a saturated soil will yield by gravity to the total soil volume) values for the material types included in the EIS Sub-Model domain. The storage coefficient (specific storage S_s times saturated thickness b) is variable by material type and depth, and ranges from 0.0001 to 0.008. Figure 4-4 shows the material types for model layer 19, the water table layer for most of the focused study area.

Porosity was also required for particle tracking. Particle tracking for the TC&WM EIS flow model results used a value of 0.25 for all material types (DOE/EIS-0391 Appendix O). For consistency, the same value was used for these simulations.

Table 4-2. Hydraulic Conductivity Values (m/day) for the TC&WM EIS Flow Model (Recreated from Table L–15 of DOE/EIS-0391 Appendix L [2012])

Material Type (Model Zone)[d]	Hydraulic Conductivity (Kx)[a]	Hydraulic Conductivity (Ky)[b]	Hydraulic Conductivity (Kz)[c]
Hanford mud (1)	0.171	0.171	0.0171
Hanford silt (2)	6.8	6.8	0.68
Hanford sand (3)	123.6	123.6	12.36
Hanford gravel (4)	156.0	156.0	15.6
Ringold sand (5)	3.57	3.57	0.357
Ringold gravel (6)	19.2	19.2	1.92
Ringold mud (7)	1.514	1.514	0.1514
Ringold silt (8)	1.51	1.51	0.151
Plio-Pleistocene sand (9)	96.8	96.8	9.68
Plio-Pleistocene silt (10)	5.81	5.81	0.581
Cold Creek sand (11)	99.13	99.13	9.913
Cold Creek gravel (12)	62.7	62.7	6.27
Highly conductive Hanford formation (13)	3982.0	3982.0	398.2
Activated basalt (14)	0.001	0.001	0.0001

Notes:

a. Hydraulic conductivity with respect to the x axis, meters per day.

b. Hydraulic conductivity with respect to the y axis, meters per day.

c. Hydraulic conductivity with respect to the z axis, meters per day.

d. Material types included in the EIS Sub-Model domain are highlighted in yellow.

Table 4-3. Specific Yield Values for the EIS Sub-Model

Material Type	Specific Yield
Hanford sand (3)	0.26
Hanford gravel (4)	0.3
Ringold sand (5)	0.26
Ringold gravel (6)	0.15
Ringold mud (7)	0.2
Ringold silt (8)	0.18
Highly conductive Hanford formation (13)	0.3

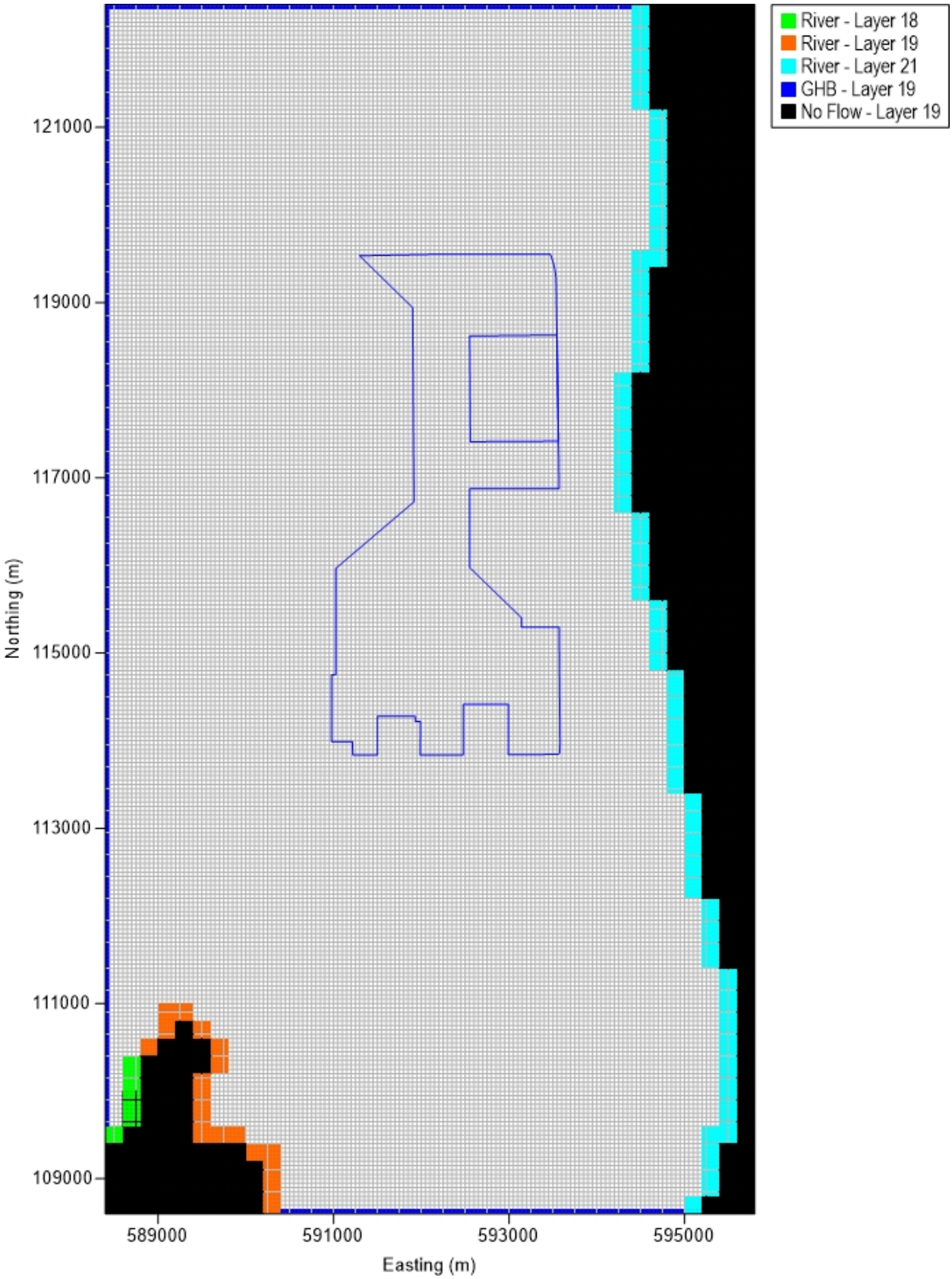


Figure 4-3. EIS Sub-Model Boundary Conditions

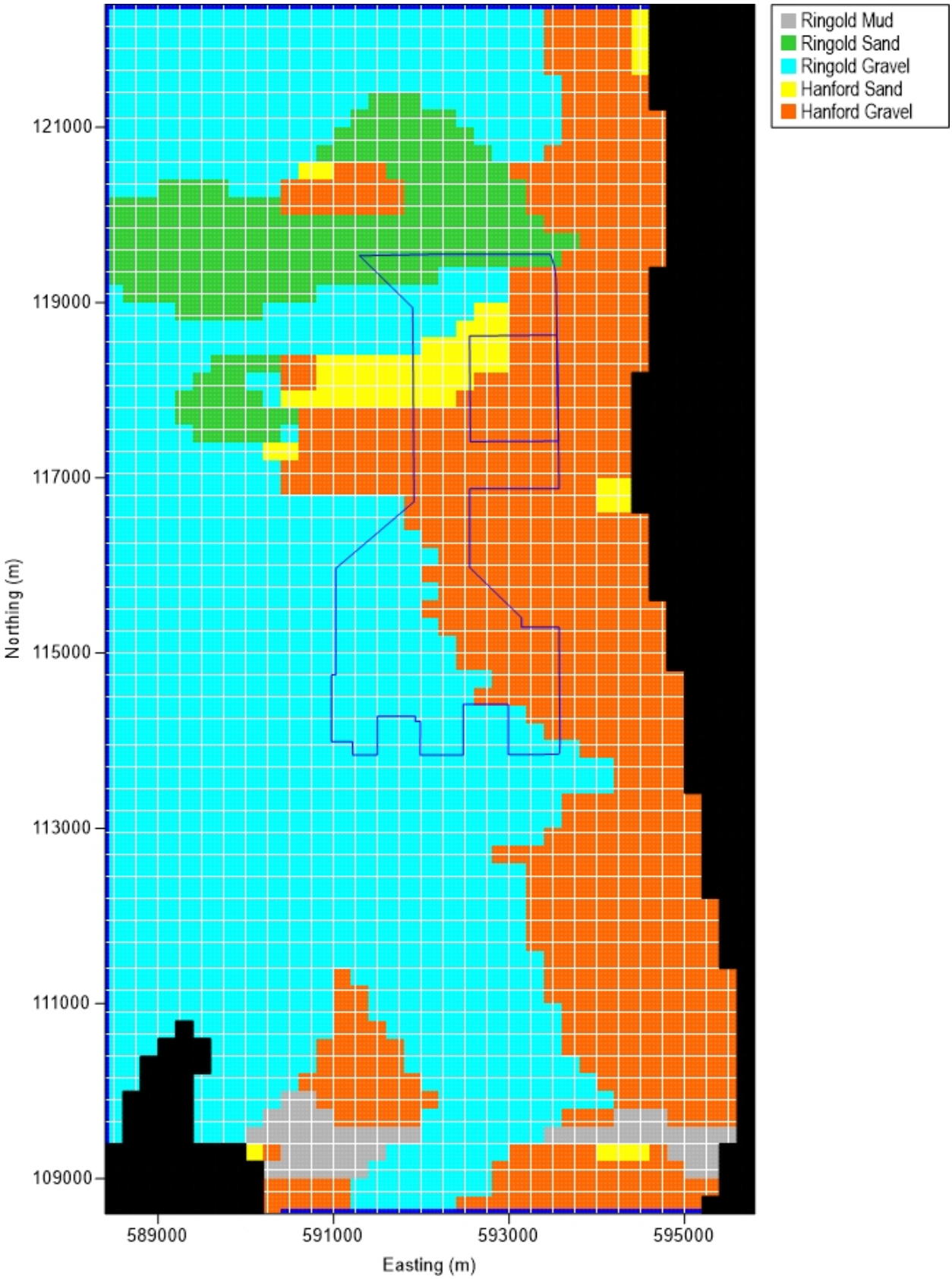


Figure 4-4. Material Types for Layer 19 of the EIS Sub-Model

4.2 Focus Groundwater Flow Model

4.2.1 Discretization

4.2.1.1 Temporal Discretization

Columbia River stage at the 300 Area river gauge is available from November 1991 to end of 2016. Water-level measurements between 1991 and 2003 were collected manually at a lower frequency, and automated water level measurement at the 300 Area river gauge commenced in 2004. Generally, Columbia River stage is relatively steady from October to March and fluctuates from April to September. All the AWLN wells in 300 Area are clustered near the Columbia River and the uranium plume footprint. A few AWLN wells have water-level measurement from 2009, but most of the AWLN wells started collecting data from 2014. Manual water-level measurements at wells that are spread out across the model domain are available with lower frequency. Additionally, 100-year predictive model simulation requires a different time discretization for efficiency. These factors dictated multiple temporal discretizations.

The focus groundwater flow model (GWFM) was implemented two different ways for distinct purposes as follows:

1. **Calibration** to river induced changes to establish aquifer hydraulic properties emphasizing the most recent and extensive data. This period was from January 2014 through January 2016 with stress periods ranging from 5 to 30 days. Care was taken to increase temporal discretization during periods of rapid river stage change to accurately capture the transient effects that provide information on hydraulic properties. Thus, a 5-day stress period length was used for April to September (i.e., rising limb to the peak river stage and falling limb from the peak river stage) of each year to capture this response, and a 30-day stress period length was used for October to March of each year. Figure 4-5 shows the comparison between hourly river stage and average river stage based on stress period length at 300 Area river gauge for January, 2014 to January, 2016.

2. Long-term **Predictive** model. A long-term predictive model is required to perform particle tracking analysis for estimating the travel time for nitrate and uranium plume to discharge to the Columbia River. A 30-day/31-day stress period length was used for 50 years beginning January 2016. For the last 50 years March 2014 was selected as an average condition and applied for 50 one-year stress periods. Figure 4-6 shows the comparison between daily river stage and average river stage based on stress period length at 300 Area river gauge for 2 years of the predictive model.

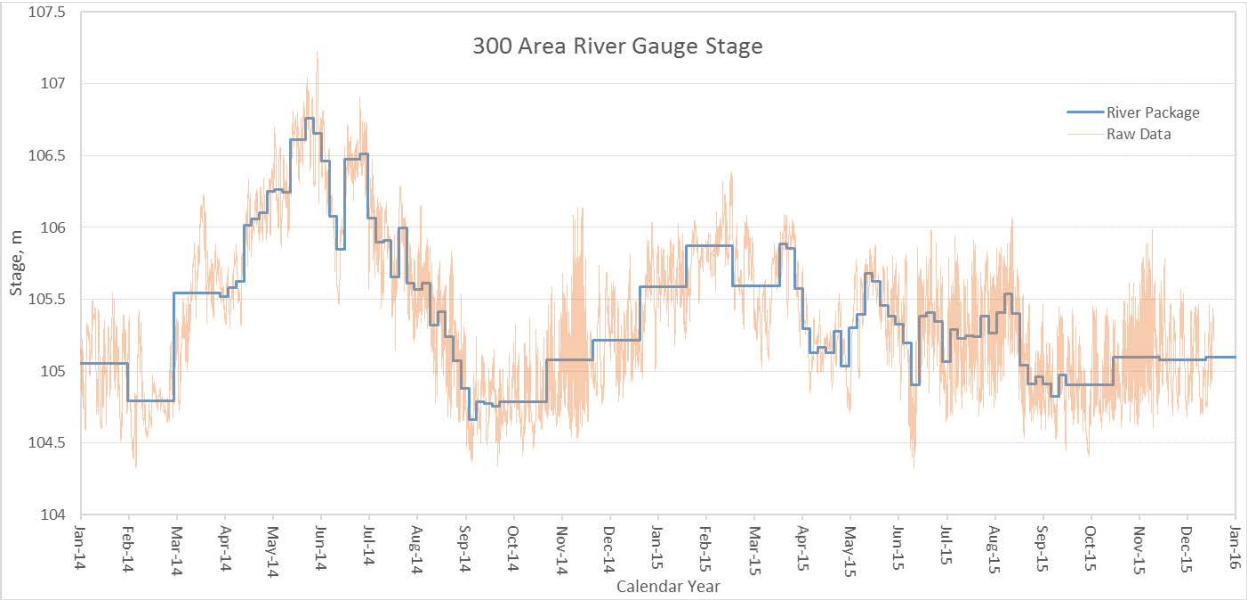


Figure 4-5. Comparison between daily river stage and average river stage based on stress period length at 300 Area River gauge for January, 2014 to December, 2015

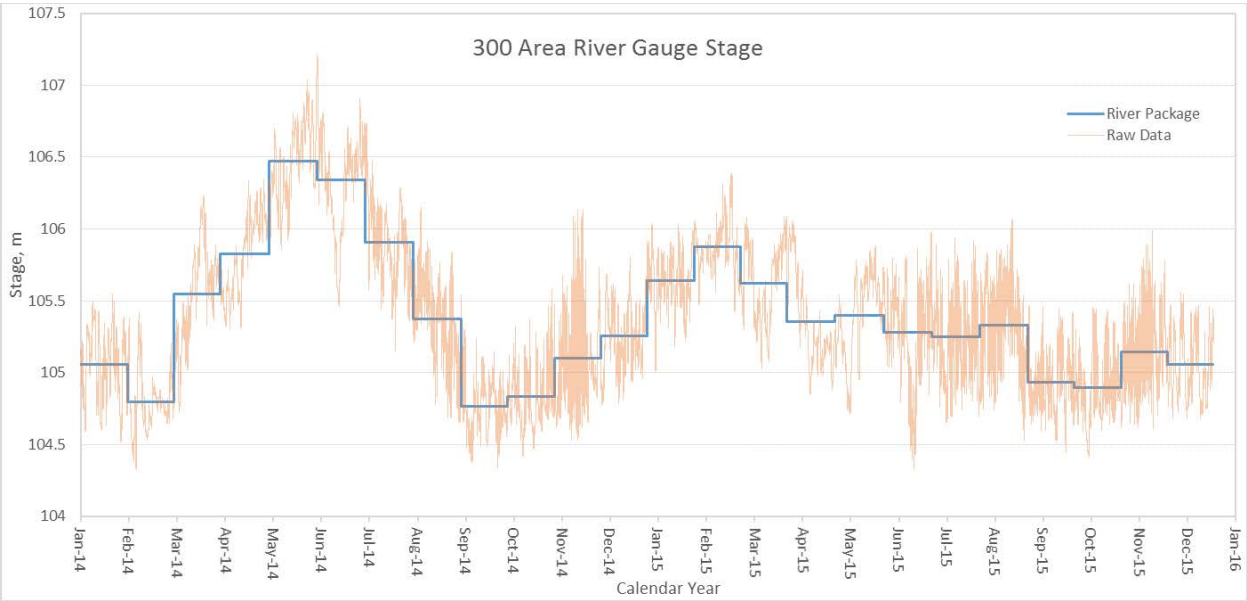


Figure 4-6. Comparison between daily river stage and average river stage based on stress period length at 300 Area River gauge for the predictive model

4.2.1.2 Spatial Discretization

Spatial discretization is the same for all models of the focus GWFM. A uniform grid spacing of 50 m was used for the entire model domain. The model consists of 276 rows, 162 columns, and 2 layers. A total of 89,424 cells are in the model, of which 73,688 are active. The model origin is at 588,400 m easting and 108,600 m northing in Washington South NAD83 HARN.

The focus GWFM extends to the Columbia River on the east side of the model and uses a general head boundary on the north, south, and west sides of the model. The Yakima River runs through the southwest

corner of the model followed by basalt above water table (no-flow) on the other side of the river. The Yakima River was not considered in the model because flow in that area is still east toward the Columbia River, and the affected area is south of the area of interest. Land surface along with Columbia River bathymetry is the top of the model, and the bottom of Ringold formation Unit E comprises the lower model boundary. However, the lower boundary dipped into the RUM in few areas to maintain a minimum of 2 m layer thickness. The focus GWFM is restricted to approximately center of the width of the Columbia River by a polyline lateral extent and is assigned no flow for the cells beyond the center line of the river. Features of the focus GWFM are shown in Figure 4-7.

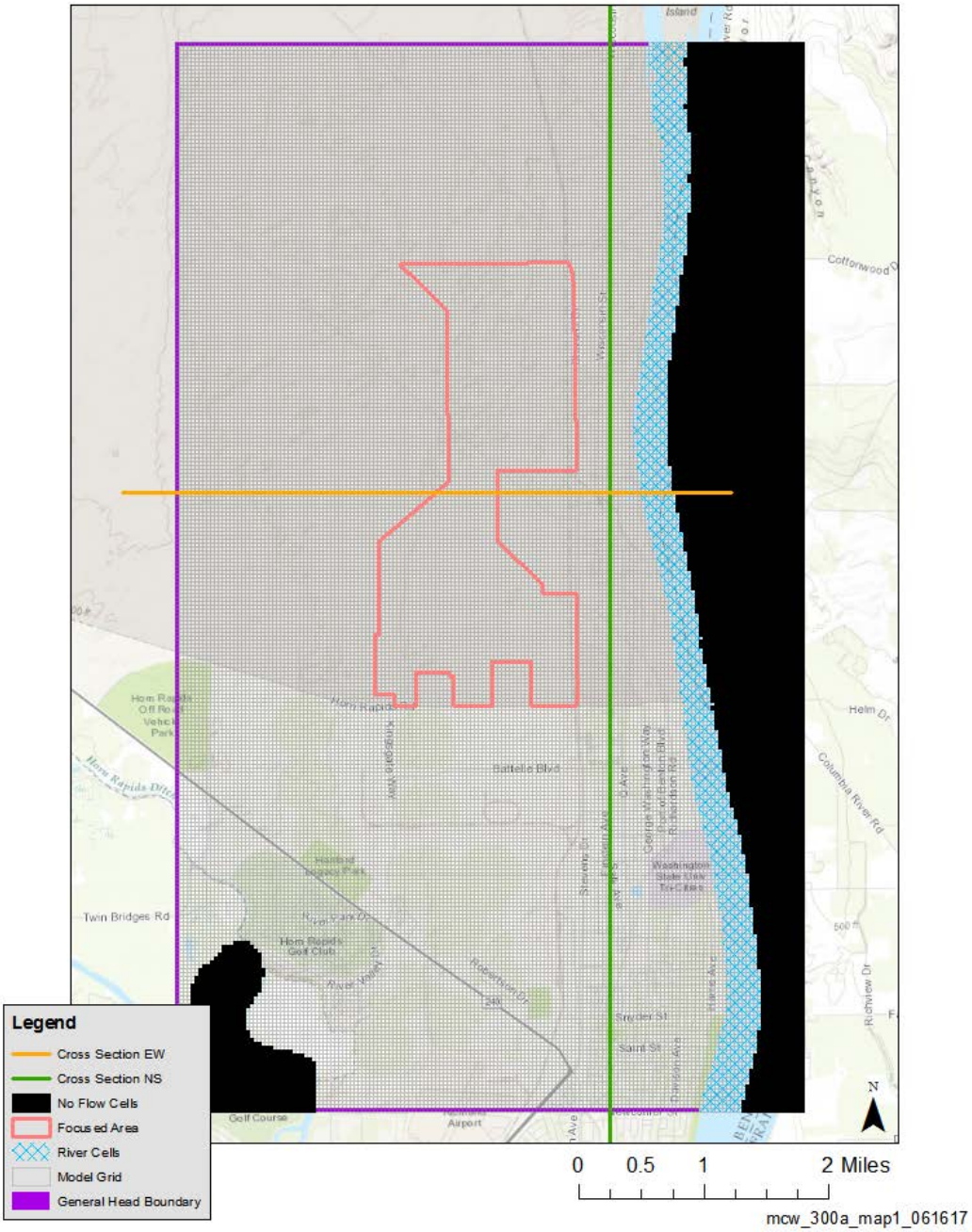


Figure 4-7. Focus Groundwater Flow Model Plan View Grid

Columbia River bathymetry (PNNL-19878) comprises the upper boundary surface of the broader Hanford South Geologic Framework Model (HSGFM) along the Hanford Reach within the model domain. This also applies to the 300 focus GWFM since it lies completely within the domain of the HSGFM. To create the original HSGFM upper boundary surface, high-resolution land surface LiDAR (Aero-Metric LiDAR, 2008) was mosaicked with the river bathymetry using GIS (ECF-HANFORD-13-0029, Rev.4).

The model boundary was selected to contain two key natural boundaries (e.g., river, no-flow), well locations with extensive data, and plume extents for uranium and nitrate within the 300 Area operable unit. The HSGFM use top of basalt as their lower boundary surfaces and are comprised (from land surface down) of the Hanford formation (HF), Ringold E (Rwie) and RUM hydro-stratigraphic units. Since the RUM is assumed to be a no flow boundary, only Hf and Rwie are utilized in the focus GWFM.

The MODFLOW grid for the focus GWFM was built using Groundwater Vistas software and FORTRAN utilities. The following procedures were performed to generate model grid and hydro-stratigraphic unit assignment at each cell of focus GWFM:

a. MODFLOW grid with 276 rows, 162 columns, and 2 layers was created using Groundwater Vistas.
b. Model cells to the east of approximately center of Columbia River were made inactive. Model cells within the Columbia River footprint are defined as river cells.
c. The surface with combination of land surface and Columbia River bathymetry is imported to Groundwater Vistas design as the upper boundary of the model.
d. A surface was generated by subtracting 3.5 m from the 2013 annual groundwater table map and was imported to Groundwater Vistas as the bottom elevation of layer 1. This allows at least 3.5 m saturated thickness in layer which is important in preventing wet-dry issues during MODFLOW model simulation.
e. Rwie and RUM contact surface was imported to Groundwater Vistas as the lower boundary of the model. In addition, model cells, where basalt pinches out above water table, were made inactive.
f. A FORTRAN utility was used to identify hydro-stratigraphic unit at each cell based on the contact surfaces extracted from HSGFM.

Figure 4-8 and Figure 4-9 show cross-sectional view of the HSGFM within the focus GWFM along with Columbia River and MODFLOW model layering.

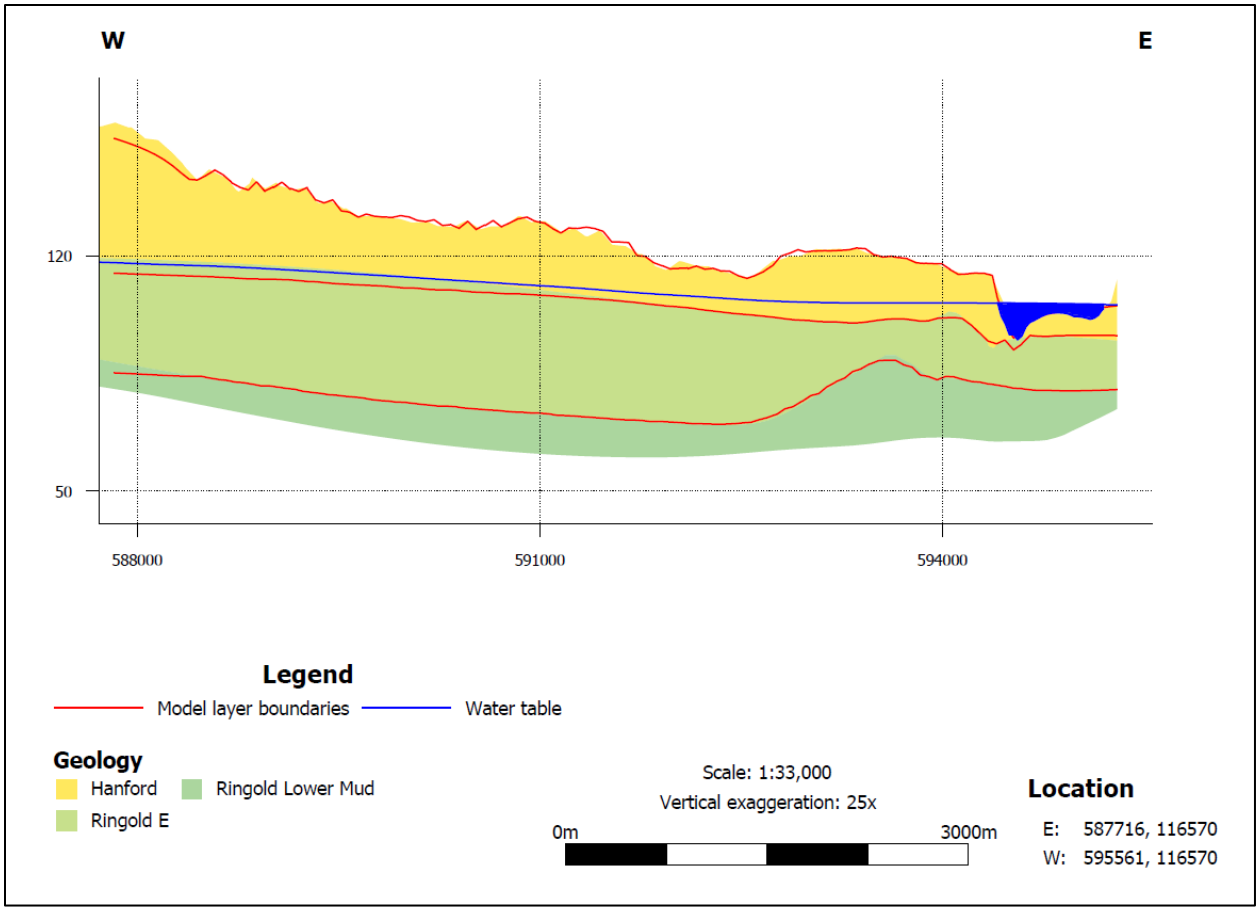


Figure 4-8. Hanford South GFM East-West Cross Section with Columbia River, and MODFLOW model layers at northing = 116570.3 m

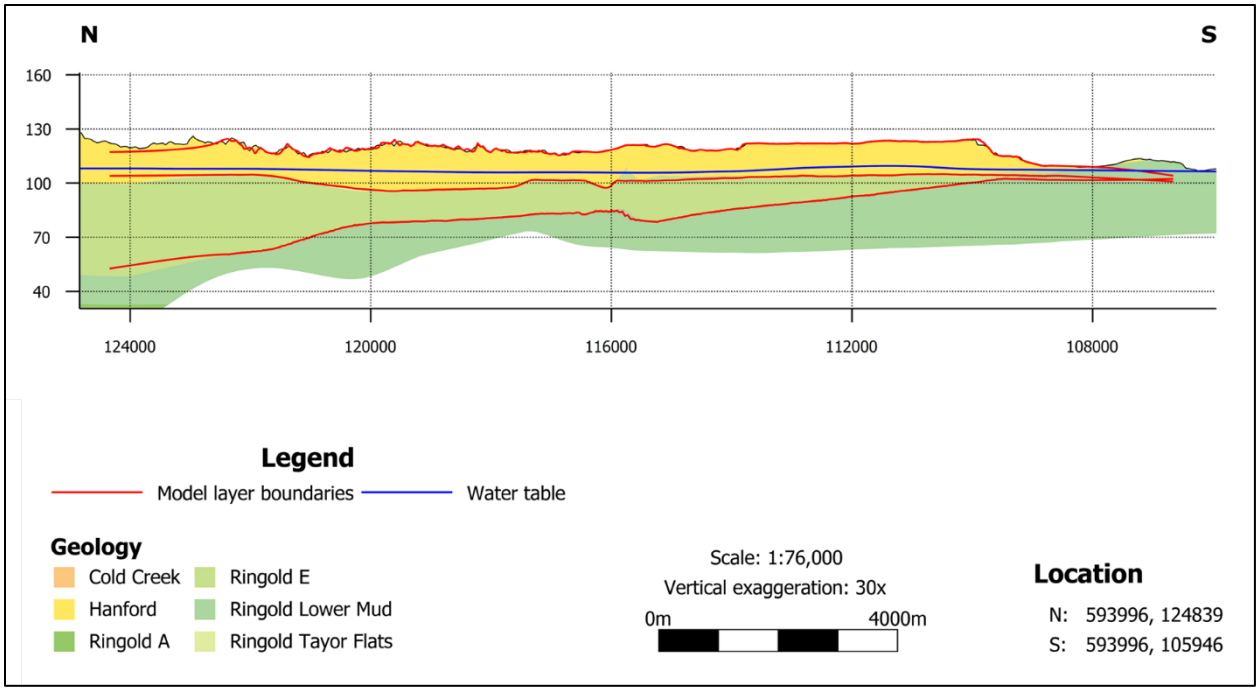


Figure 4-9. Hanford South GFM North-South Cross Section with MODFLOW model layers at easting = 593995.6 m

4.2.2 Parameterization

4.2.2.1 Recharge Boundary Condition

A Recharge Estimation tool (RET) was used to compute recharge rates both temporally and spatially. The RET was developed for ArcGIS®[2] using python scripts and to enable users to determine the spatio-temporal variation in recharge for their model domain and over their time period of interest. The site-specific information produced by the RET is used in the MODFLOW recharge package. The RET scripts use a dictionary which identifies all the years where a change in recharge rate occurs over the Hanford Site. This dictionary contains a list of all the waste sites in the Hanford Site, their associated remediation action and date from the disposition baseline report (CP-60254), and incorporates vegetation succession over time (ECF-HANFORD-15-0019, *Hanford Site-Wide Natural Recharge Boundary Condition for Groundwater Models*). The first RET script uses 13 spatial data sources and three tabular data sources to develop recharge estimates for the Hanford Site. This script produces a geodatabase of recharge rates over the Hanford Site for all years identified as having a change in recharge rate as listed in the dictionary. The second RET uses the user-provided model boundary (i.e., focus GWFM domain) to identify the waste sites within the model domain and references the dictionary to identify for which years over the time period of interest there are changes in recharge rate. This step is repeated for all the waste sites and the list is compiled to create a comprehensive list of years for the user-provided model domain and time period of interest. The RET then samples the relevant years in the geodatabase from the first RET script, clips them to the model domain, and compiles them into a new geodatabase or individual shapefiles as preferred by the user. Figure 4-10 shows the recharge rates that were applied to the calibration model for calendar year 2014 and 2015. An R script was used for evaluating the shapefiles onto the model grid and output to a MODFLOW readable array format. The RET tool did not include the City of Richland's infiltration gallery, which is about 43 m/yr. This adjustment was made using an R script.

[2] ArcGIS is a registered trademark of ESRI.

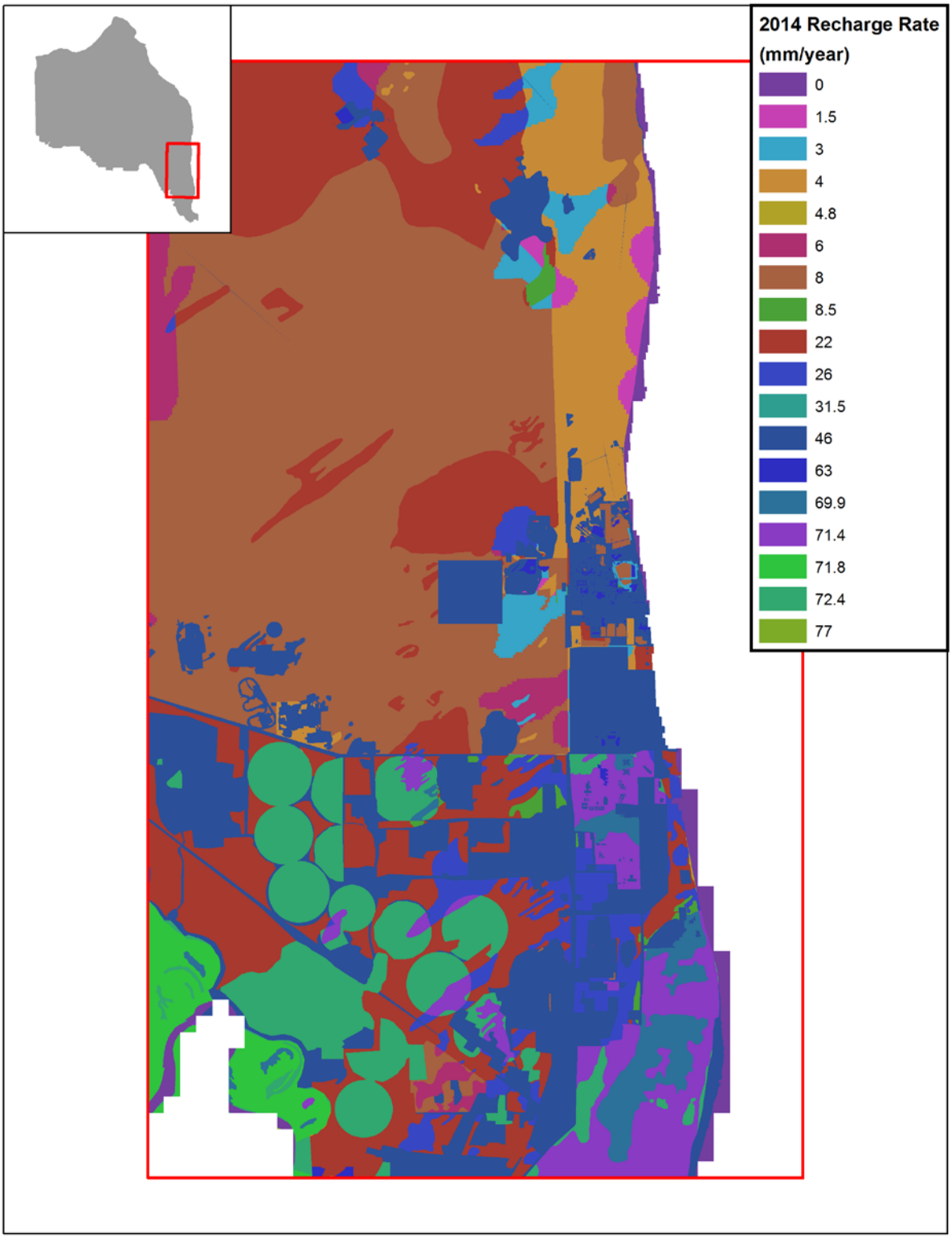


Figure 4-10. 2014 Recharge

4.2.2.2 South, West, and North Landward Boundary Conditions

General-head boundary conditions are used at northern, western and eastern boundaries of the focus GWFM to represent the influence of the unconfined aquifer not included in the model domain. Groundwater flows from west to east towards Columbia River which forms the eastern boundary of the model. Therefore, northern and southern boundaries may approximately be no-flow as defined by streamlines in Figure 2-2. However, it is more correct to allow for external influences to propagate through the boundaries (such as the inferred paleochannel entering 300 Area through north-west boundary). The fluctuations in the Columbia River stage are conceptualized to impact the head at these lateral boundaries with the impact of the river being largest near the river and lessening with increasing distance from the river. The observed water levels at several wells within the 300 Area were compared to the 300 Area River gauge stage data and a synthetic formula was developed to incorporate both the 300 Area River gauge stage and the prior groundwater level at those locations through the use of a damping parameter. The synthetic formula also allowed for a systematic increase in the groundwater levels at those locations to account for the regional groundwater gradient toward the river and a time lag to account for the time required for river fluctuations to propagate through the aquifer. The formula was fit to the observed water levels at several wells at varying distances from the Columbia River. The damping factor and lag time were adjusted for each well until a reasonable fit between the observed water levels and the calculated water levels was obtained. Results for all of the wells evaluated were then used to develop the synthetic formula. In this way, the effect of the Columbia River fluctuations as well as the aquifer between points along the boundaries was accounted for in generating the heads and conductance along the northern and southern boundaries. The western boundary is at least 5,850 m away from the Columbia River and it is expected that water-level fluctuations at these locations due to river stage fluctuations are strongly damped. Therefore, an average of 2013 and 2015 water-level surfaces was used as the GHB head for the western boundary.

A no-flow boundary was used to represent the south-west edge of the model where the basalt outcrops.

4.2.2.3 River Boundary Conditions

PNNL-14753 rev. 1 documents the steady-state water-surface of the Columbia River from the MASS1 surface-water model. This data is assumed to adequately represent the variation in the slope of the river over all times of interest. Practically, this assumption may be violated during sharp increases in stage as the flood wave propagates downstream. The MASS1 simulated stages were interpolated onto the focus GWFM river nodes; in turn, this data was interpolated and sampled at grid centers underlying the river. The relative stage at each location was then used with the 300 Area river gauge data to compute the river stage. The 300 Area river gauge transducer data was averaged over each stress period.

As stage changes over time the area of the riverbed that is submerged also changes – this phenomenon is noted as seeps along the river. To account for this, a river boundary is only assigned to a cell when the stress period average stage is above the cells bathymetry; only cells within the river are included in the computation. For grid cells where the stage is below the bathymetry, a drain boundary condition is substituted and the elevation set to the land (bathymetric) surface to emulate riverbank seeps that occur when the river drops.

The HSGFM shows that Columbia River contains mostly Hanford formation in its riverbed within the focus GWFM domain. Riverbed hydraulic conductivity (with an assumed riverbed thickness of 1 m) for Hanford formation was made PEST adjustable but not spatially variable.

4.2.2.4 Initial Conditions

The initial hydraulic head everywhere in the model was assigned from 2013 water-table conditions as published in the 2014 annual groundwater report (DOE/RL-2014-32, Rev. 0). This was done by importing the shape files into Groundwater Vistas and having it perform interpolation. Because this is a transient solution that uses an iterative solver the primary effect is to speed up the solution.

4.2.2.5 Aquifer Hydraulic Property Parameterization

Simulation of transient groundwater flow under unconfined conditions requires the following input data:

- Horizontal hydraulic conductivity in each model layer of the Hanford and/or Ringold
- The ratio of vertical to horizontal hydraulic conductivity (KvKh) used to compute vertical hydraulic conductivity
- Specific storage (S_s), and
- Specific yield (S_y).

These properties were specified using the MODFLOW LPF (Layer Property Flow) package. The first model layer is unconfined (type 1) where transmissivity is a function of saturated thickness, and the second is convertible (type 3) where transmissivity is computed from layer thickness when simulated head is above the layer or as saturated thickness when head is below the top of the layer.

Uniform values of KvKh for the Hanford and Ringold were specified, and used to multiply horizontal hydraulic conductivity to yield vertical hydraulic conductivity for model input, S_s and S_y were input as constant values for all layers and vary by formations. Upper and lower bounds on KvKh were set at 0.01 and 0.3, respectively. Specific storage upper and lower bounds were set at $1x10^{-4}$ and 1×10^{-6} 1/m, respectively.

Three hydrostratigraphic units (HSUs) are present in the model:

1. Hanford formation, only in Layer 1
2. Ringold E formation, mostly in Layer 2 and a portion in the western side of Layer 1
3. Ringold lower mud, a small portion in the southern end

Several pumping tests and slug tests data are available for 300 Area and documented in PNNL-17034. Hydraulic conductivity from pumping tests in the Ringold E formation varies from 42 m/d to 51 m/d and slug test results vary from 2 m/d to 39 m/d. Hydraulic conductivity from pumping tests in the Hanford formation varies from 980 m/d to over 5,000 m/d and slug test results vary from 100 m/d to 2300 m/d. The apparent channel scour in the top of the RUM suggests a cataclysmically deposited Hanford channel may exist in the northern side of 300 Area. However, the extent of the channel is not known. Figure 4-11 shows the pumping/slug test locations within the 300 Area.

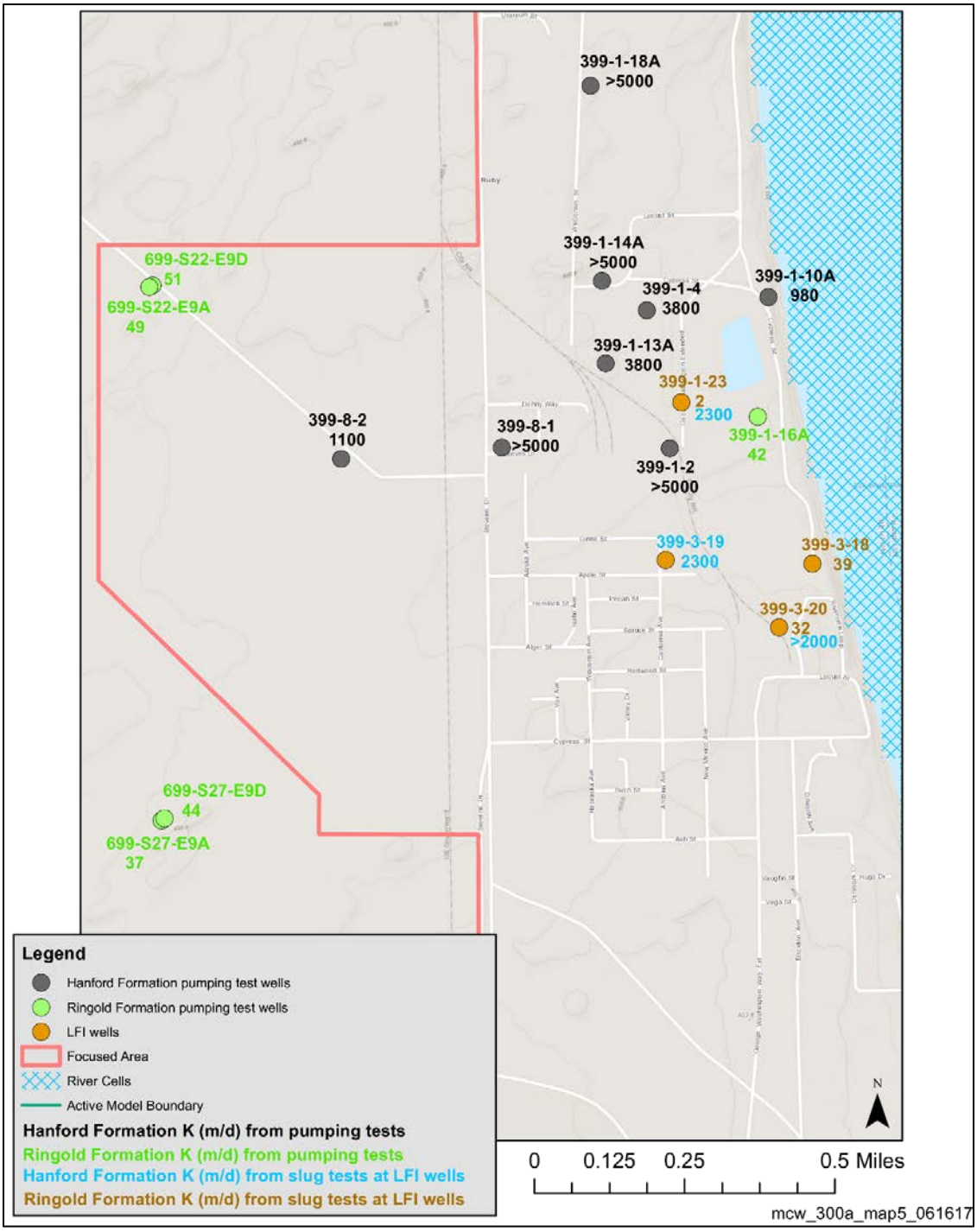


Figure 4-11. Slug/Pumping Test Results for Hanford and Ringold E Formation in 300 Area (PNNL-17034)

The hydrostratigraphic units (HSUs) are split into several zones for parameterization of the horizontal hydraulic conductivity. Hanford formation and Ringold E formation are subdivided into 5 zones and 2 zones, respectively. RUM formation, though negligible, was assigned as a separate zone. Below is the list of zones assigned for hydraulic conductivity:

1. Zone 1: Hanford formation

2. Zone 2: Ringold E formation
3. Zone 3: A combination of Hanford and Ringold E formation with more than 50 percent contribution from Hanford formation
4. Zone 4: A combination of Hanford and Ringold E formation with more than 50 percent contribution from Ringold E formation
5. Zone 5: Highly conductive Hanford formation according to three-dimensional groundwater model of the 300 Area developed by PNNL (PNNL-17708)
6. Zone 6: Hanford formation underneath the Columbia River
7. Zone 7: Hanford formation within the assumed Hanford channel
8. Zone 8: RUM formation in southern end of Layer 2

Figure 4-12 and Figure 4-13 show the lateral extent of each hydraulic conductivity zone used for model parameterization.

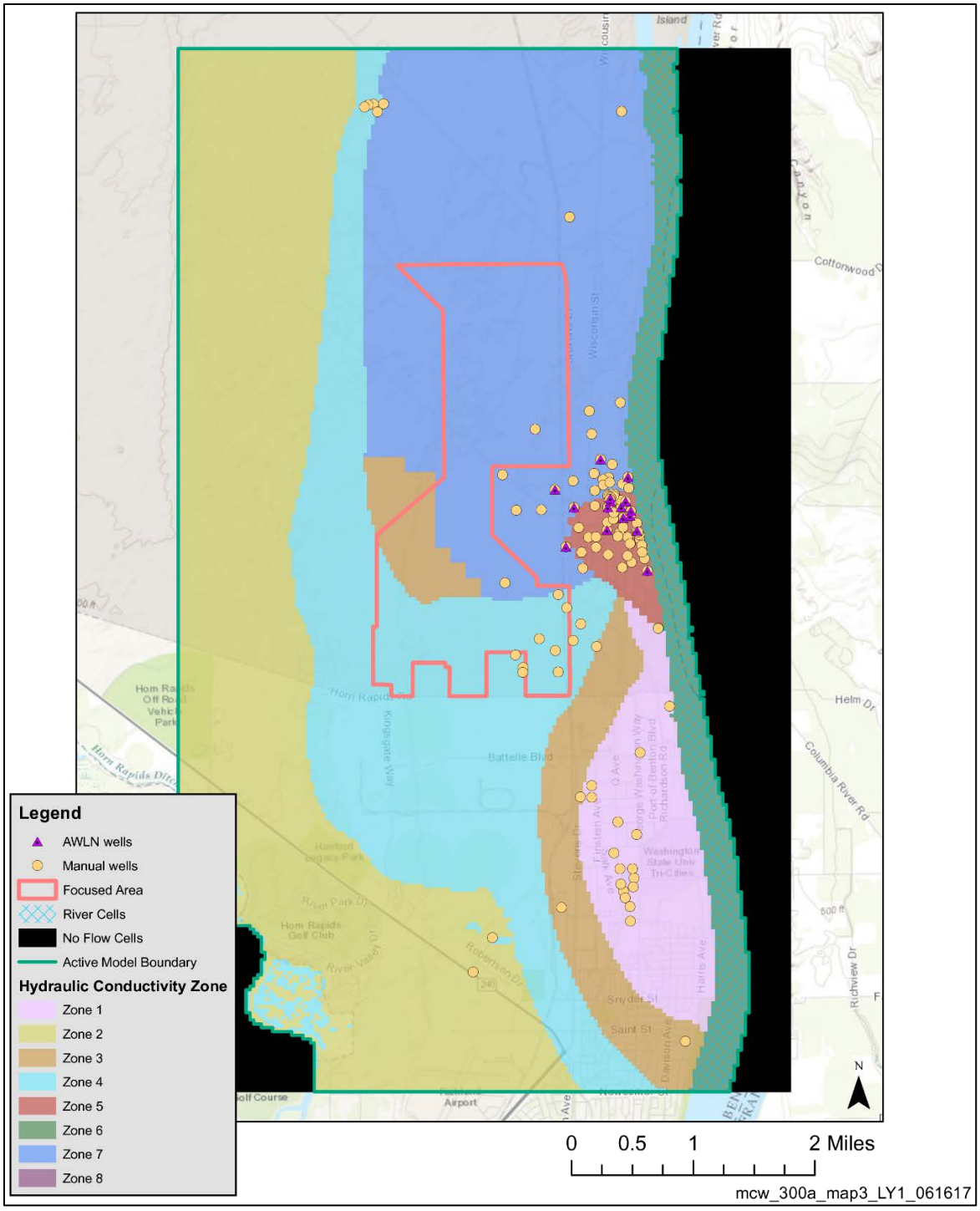


Figure 4-12. Hydraulic Conductivity Zones in Layer 1

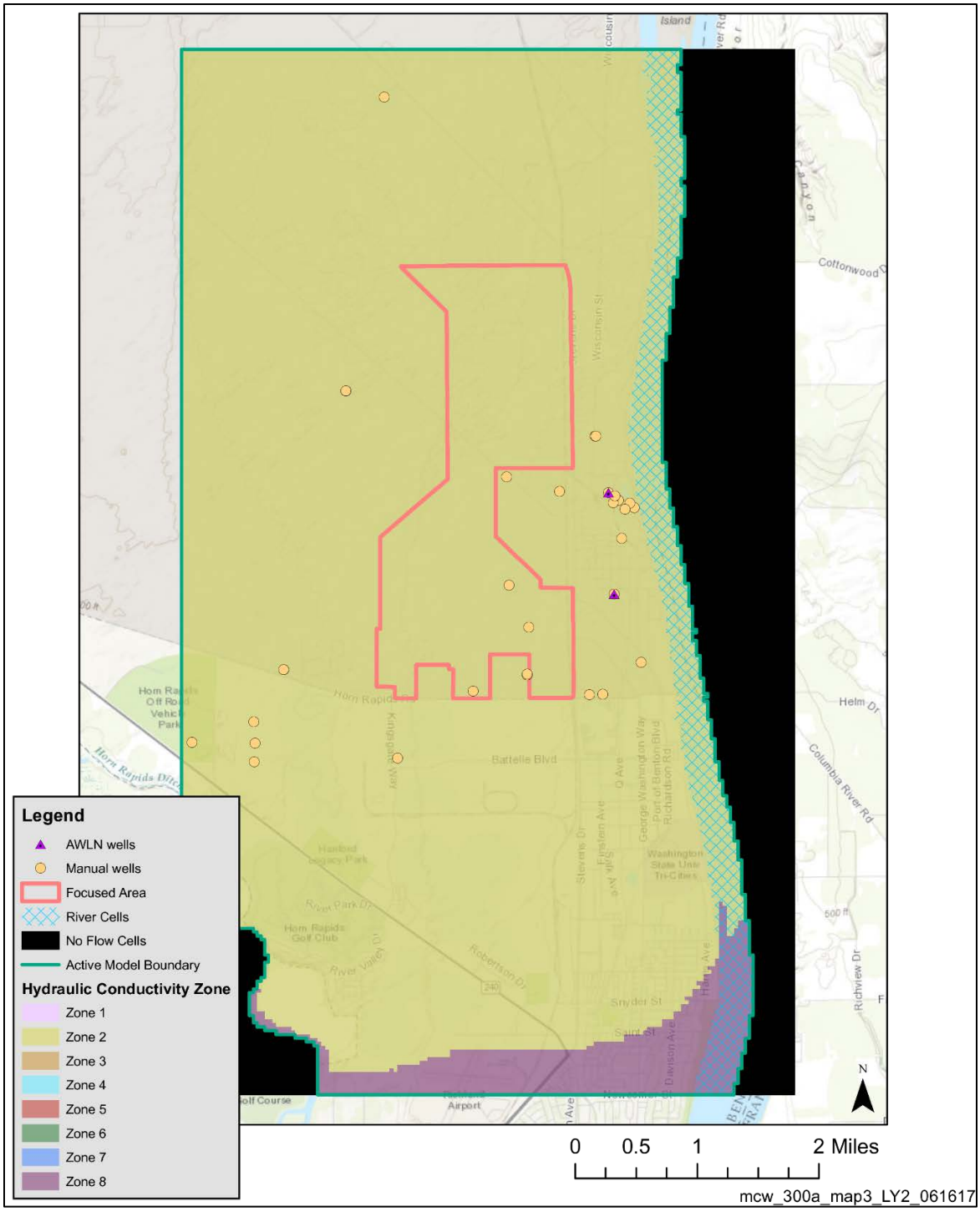


Figure 4-13. Hydraulic Conductivity Zones in Layer 2

4.2.2.6 Effective Porosity

The EIS groundwater model used an effective porosity of 0.25 for the particle tracking analysis. A uniform value of 0.25 was used to be consistent with the EIS model.

5 Software Applications

MODFLOW-2000, MODFLOW-2000-MST, MODPATH-MST, and Groundwater Vistas software programs were used for this environmental calculation. These are CH2M-HILL Plateau Remediation Company (CHPRC) approved software, managed and used in compliance with the requirements of PRC-PRO-IRM-309, *Controlled Software Management*. The following supporting information is provided.

5.1 Approved Software

For approved software used in this calculation, the required description is provided.

5.1.1 Description

MODFLOW-Richland

- Software Title: MODFLOW-2000-MST
- Software Version: CHPRC Build 0008 (mf2k-mst-chprc08dpl.x)
- Hanford Information System Inventory (HISI) Identification Number: 2517 (Safety Software, Level C)
- Workstation type and property number (from which software is run): MODFLOW was executed on the INTERA Richland OLIVE Linux®[3] Clusters that is owned and managed by INTERA, Inc., a subcontractor to CHPRC. The computer property tag for the front-end node is #469 at INTERA's office in Richland, Washington. This node is a Dell PowerEdge®[4] R510 with two six-core Intel Xeon®[5] X5660 processors @ 2.80GHz and 48 GB of RAM. As given by the command "uname –a", the operating system details are:
    - Linux olive 4.4.0-38-generic #57~14.04.1-Ubuntu SMP Tue Sep 6 17:20:43 UTC 2016 x86_64 x86_64 x86_64 GNU/Linux
- CHPRC Software Control Documents:
    - CHPRC-00257 Rev 1, *MODFLOW and Related Codes Functional Requirements Document*
    - CHPRC-00258 Rev. 2, *MODFLOW and Related Codes Software Management Plan*
    - CHPRC-00259 Rev. 2, *MODFLOW and Related Codes Software Test Plan*
    - CHPRC-00260 Rev. 5, *MODFLOW and Related Codes Requirements Traceability Matrix*
    - CHPRC-00261 Rev. 5, *MODFLOW and Related Codes Acceptance Test Report*
- Approved User: H. Rashid

MODFLOW-Austin

- Software Title: MODFLOW-2000
- Software Version: CHPRC Build 0008 (mf2k-chprc08spl.exe)
- HISI Identification Number: 2517 (Safety Software, Level C)
- Workstation type and ID (from which software is run): MODFLOW was executed on AUS-silicon.intera.com owned and managed by INTERA, Inc., a subcontractor to CHPRC and

[3] Linux is the registered trademark of Linus Torvalds in the U.S. and other countries.

[4] Dell and PowerEdge is a trademark of Dell Inc. in the U.S. and other countries.

[5] Intel and Xeon is a registered trademark of Intel Corporation or its subsidiaries in the U.S. and/or other countries.

WRPS. This PC is a Dell precision tower 5810 with an Intel® Xeon(R) CPU E5-1620 v3 @ 3.50GHz processor and 8 GB of RAM. The operating system is Windows 10 Pro.

- CHPRC Software Control Documents:
  - CHPRC-00257 Rev. 1, *MODFLOW and Related Codes Functional Requirements Document*
  - CHPRC-00258 Rev. 2, *MODFLOW and Related Codes Software Management Plan*
  - CHPRC-00259 Rev. 2, *MODFLOW and Related Codes Software Test Plan*
  - CHPRC-00260 Rev. 5, *MODFLOW and Related Codes Requirements Traceability Matrix*
  - CHPRC-00261 Rev. 5, *MODFLOW and Related Codes Acceptance Test Report*
- Approved User: D. Fryar

MODPATH

- Software Title: MODPATH-MST
- Software Version: CHPRC Build 0006 (modpath-mst-chprc06sp.x)
- HISI Identification Number: N/A (Support Software; see CHPRC-00258 Rev. 2)
- Authorized Workstation type and property number: N/A
- Authorized User: N/A
- CHPRC Software Control Documents:
  - CHPRC-00258 Rev. 2, *MODFLOW and Related Codes Software Management Plan*

Groundwater Vistas[6]

- Software Title: Groundwater Vistas™
- Software Version: 6.96 Build 19
- HISI Identification Number: N/A (Support Software; see CHPRC-00258 Rev. 2)
- Authorized Workstation type and property number: N/A
- Authorized User: N/A
- CHPRC Software Control Document:
  - CHPRC-00258 Rev. 2, *MODFLOW and Related Codes Software Management Plan*

5.1.2 Software Installation and Checkout

Approved Safety Software packages (MODFLOW) and the controlled version of the support software (MODPATH) were checked out in accordance with procedures specified in CHPRC-00258 Rev. 2. Executable files were obtained from the Software Owner who maintains the configuration-managed copies in MKS Integrity[7], installation tests identified in CHPRC-00259 Rev. 2 performed and successful installation confirmed, and Software Installation and Checkout Forms were completed and approved for installations used to perform model runs reported in this calculation. Copies of the Software Installation and Checkout Forms for approved users and installations used to perform this calculation are provided in Attachment A.

[6] Groundwater Vistas is a trademark of Environmental System Inc.

[7] MKS Integrity is a trademark of the Parametric Technology Corporation, Needham, Massachusetts.

5.1.3 Statement of Valid Software Application

The preparers of this calculation brief attest that the software identified above, and used for the calculations described in this calculation brief, is appropriate for the application and used within the range of intended uses for which it was tested and accepted by CHPRC.

Because MODFLOW is graded as Level C software, use of this software is required to be logged in the HISI. Accordingly, this environmental calculation has been logged by the software owner in the HISI under Identification Number 2517.

6 Calculation

6.1 EIS Sub-Model

6.1.1 Development of the EIS Sub-Model

The base case TC&WM EIS flow model (DOE/EIS-0391 Appendix L, 2012) was retrieved from EMMA and imported into Groundwater Vistas™ (Rumbaugh and Rumbaugh, 2015). The Groundwater Vistas™ TMR option was used to extract a section of the site-wide EIS model and subdivide it into a finer grid of 50 by 50 m. The EIS Sub-Model extends from easting 588,400 to 595,800 m and from northing 108,600 to 122,400 m. The constant head boundaries produced by the TMR were replaced by GHBs using time-varying heads extracted from the site-wide model results using Perl scripts (readHead.pl and hdsToGHB.pl). Figure 6-1 shows a comparison between groundwater head elevations for the site-wide EIS model and the EIS Sub-Model in layer 19 (water table layer at the focused study area) at the end of the simulation. Head contours show good agreement between the two models, especially in the focused study area. Some differences can be seen near the City of Richland's infiltration gallery in the southeast portion of the model, likely due to the very high infiltration rate and the different grid cell dimensions of the two models.

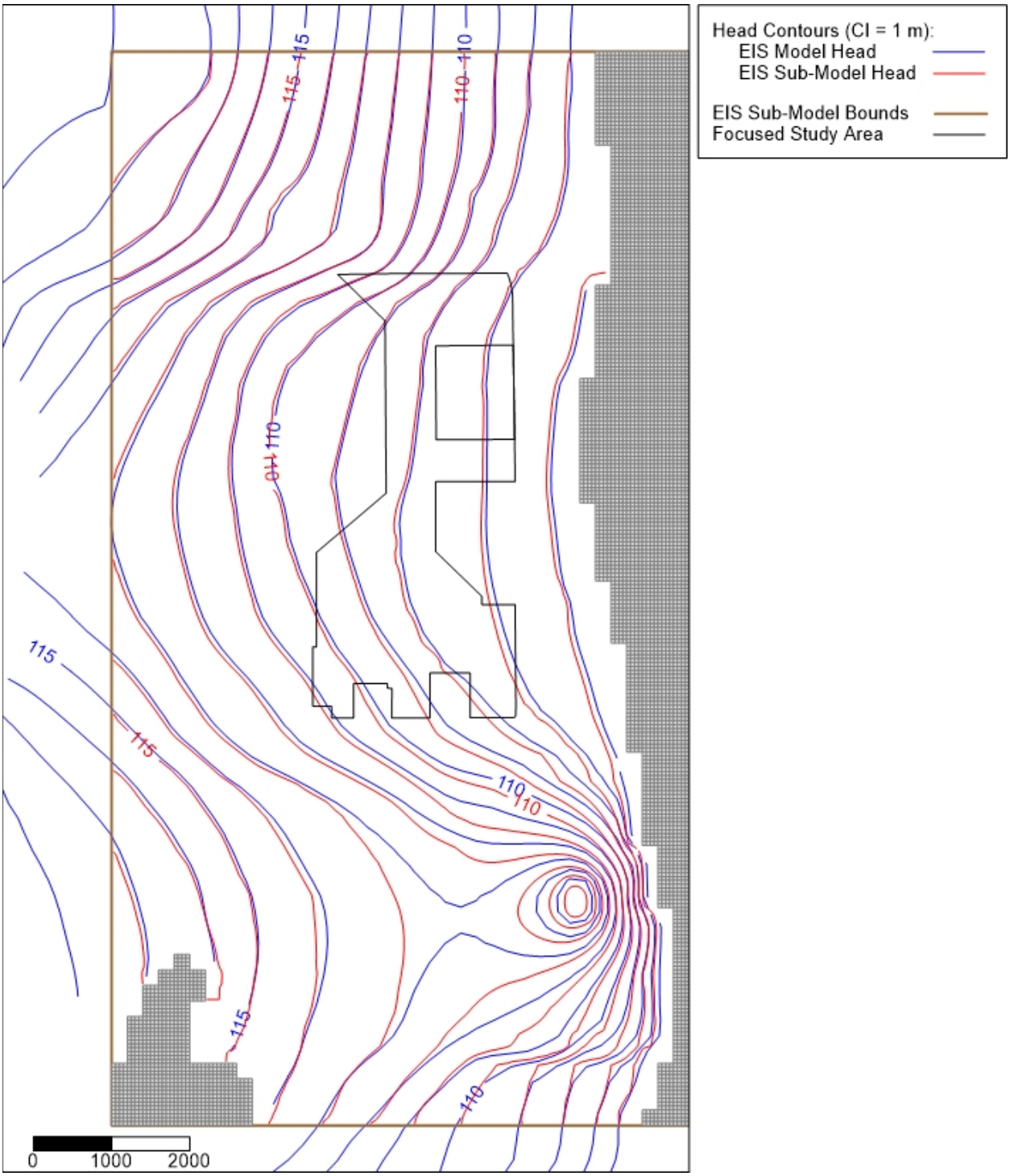


Figure 6-1. Comparison between Groundwater Head Elevations for the Site-Wide EIS model and the EIS Sub Model in Layer 19

6.1.2 Flow Simulations

Four development scenarios and a base case with no development were evaluated for a proposed light industrial park, including a solar farm, at the 300 Area Land Conveyance Site. These scenarios differ in the portion of the area assumed to be covered by impervious materials and the surface area of the

stormwater ponds developed to manage runoff from the impervious areas. Three different stormwater pond configurations (location and size), designated pond types i, ii, and iii, were used for the development scenarios. Figure 6-2 shows the grid cells included in each of these pond configurations. MODFLOW 2000 was used for all simulations.

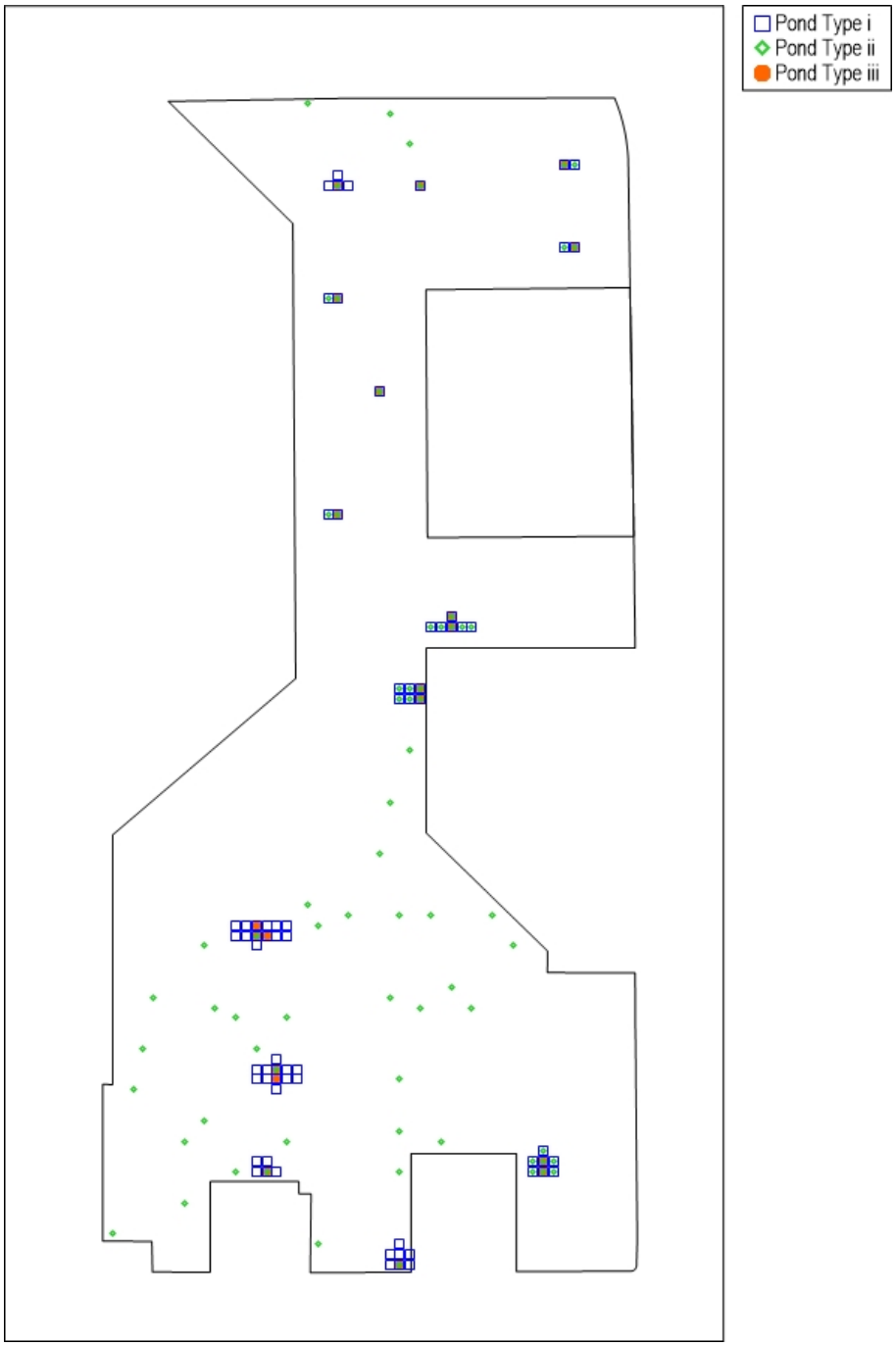


Figure 6-2. Grid Cells Included in Each of the Three Pond Configurations (Pond Types i, ii, and iii)

6.1.2.1 No Development

The no development scenario assumes that no development will occur in the focused study area over the 100-year evaluation period. Recharge remains the same as for the site-wide EIS model. Results from this

simulation are assumed to represent base case conditions and are used to evaluate the effects of the impervious cover and stormwater pond infiltration for each of the four development scenarios.

6.1.2.2 Development Scenario 1 – High Impact with Pond Type i

This scenario assumes an 85 percent impervious cover and large drainage basins to maximize the impervious area per pond, resulting in a conservative, high recharge simulation. Pond sizes and infiltration rate estimates for Pond Type i are presented in Tables 6-3 and 6-4 of ECF-300FF5-17-0065 for the fourteen drainage basins. Grid cells were selected to provide the best fit to the pond locations and dimensions presented in ECF-300FF5-17-0065. Recharge rates for each pond cell were developed based on the modeled area of the pond and infiltration rates in Table 6-4 of ECF-300FF5-17-0065. Recharge in the solar farm area remains unchanged from the site-wide EIS model at 3.5 mm/yr. Recharge in the remainder of the focused study area was reduced by 85 percent to account for the impervious area resulting from development. Figure 6-3 shows the pond locations and recharge rates for this scenario.

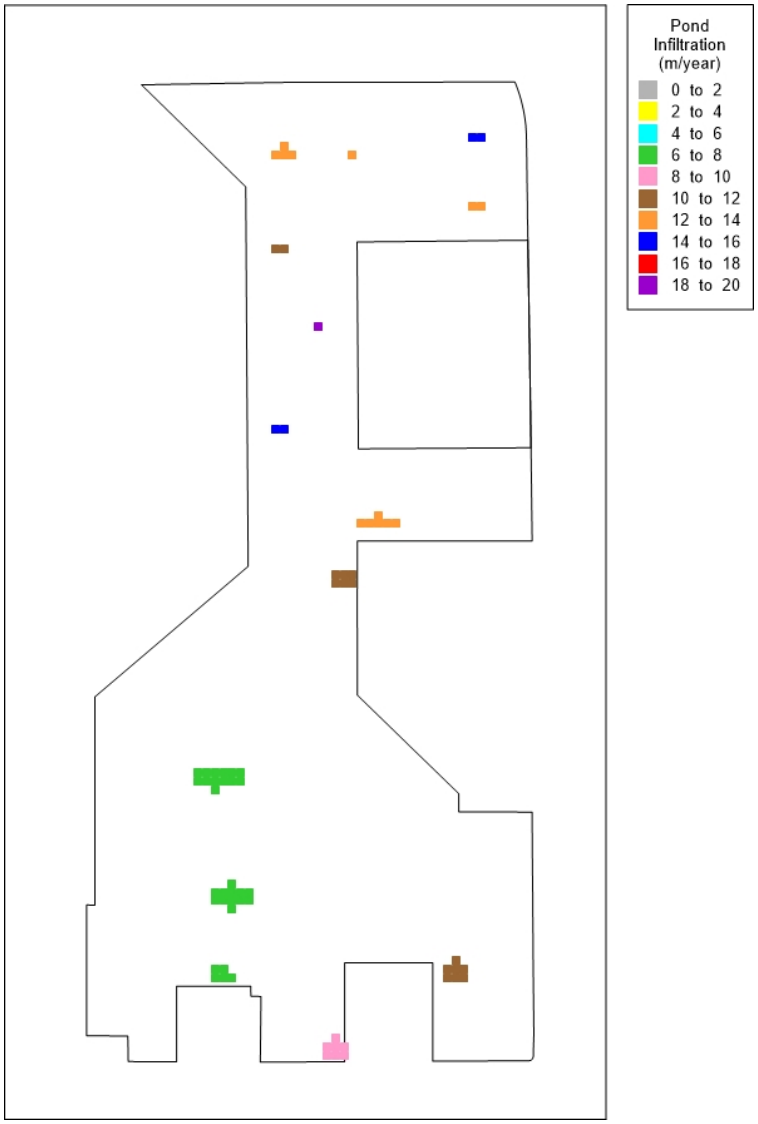


Figure 6-3. Pond Locations and Recharge Rates for Development Scenario 1

6.1.2.3 Development Scenario 2 – High Impact with Pond Type ii

This scenario assumes the same 85 percent impervious cover and total pond infiltration as Development Scenario 1, but splits five of the ponds into several smaller ponds (Pond Type ii) where groundwater mounding was the highest in the Development Scenario 1. Background and solar farm recharge are the same as for Development Scenario 1. Figure 6-4 shows the pond locations and recharge rates for this scenario.

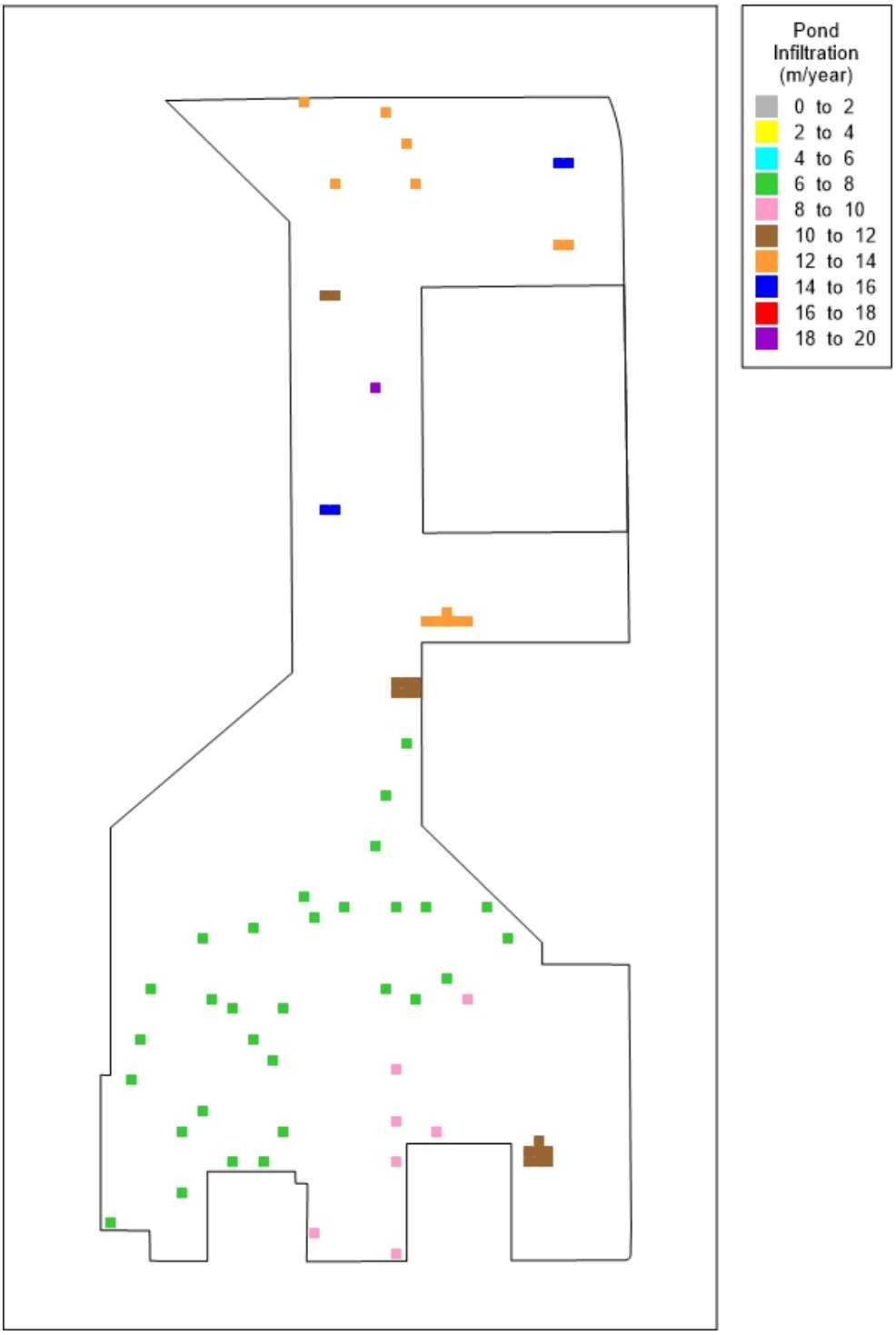


Figure 6-4. Pond Locations and Recharge Rates for Development Scenario 2

6.1.2.4 Development Scenario 3 – Low Impact with Pond Type iii

This scenario assumes 25 percent impervious cover. Pond sizes and infiltration estimates for Pond Type iii are presented in Tables 6-5 and 6-8 of ECF-300FF5-17-0065 (2017) for the fourteen drainage basins. Recharge in the solar farm (3.5 mm/yr) is the same as for Development Scenario 1. Recharge in the remainder of the focused study area was reduced by 25 percent to account for the impervious area resulting from development. Figure 6-5 shows the pond locations and recharge rates for this scenario.

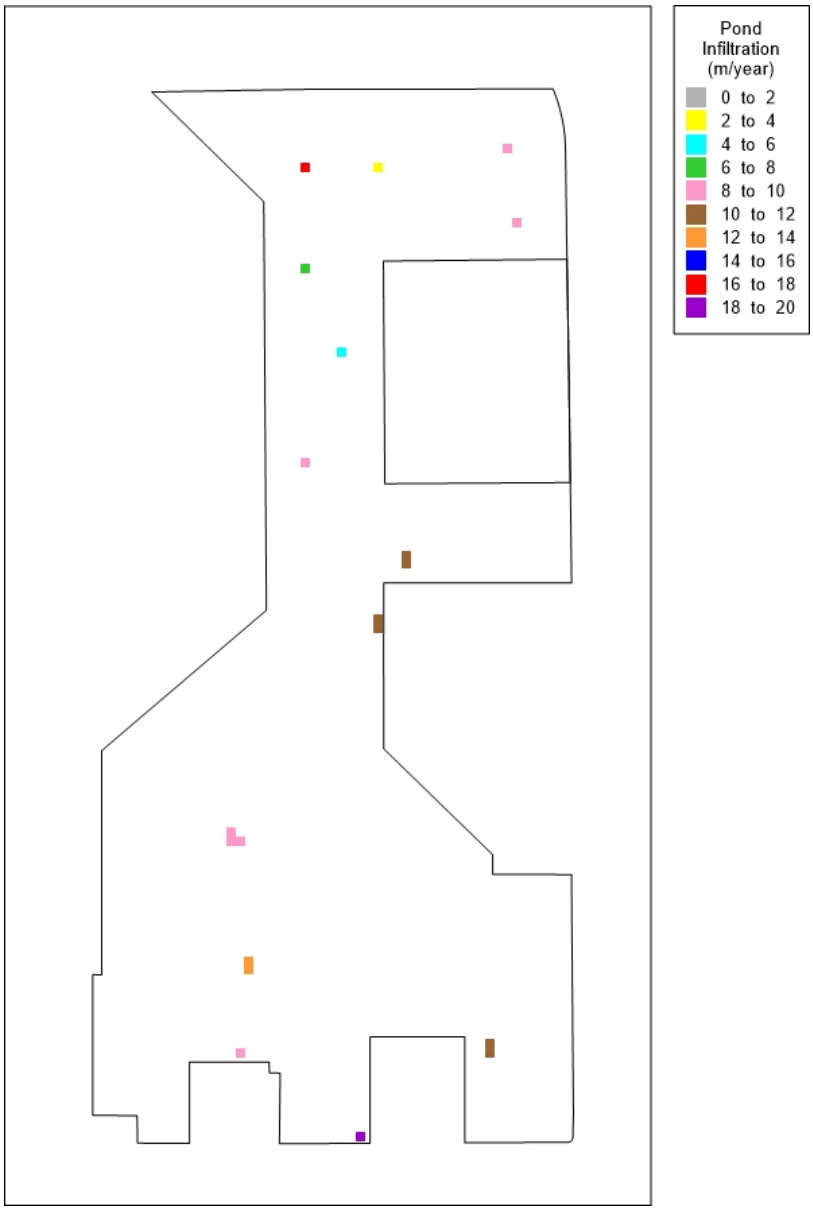


Figure 6-5. Pond Locations and Recharge Rates for Development Scenario 3

6.1.2.5 Development Scenario 4 – Low impact with Pond Type i

This scenario assumes the same 25 percent impervious cover and total pond infiltration as Development Scenario 3, but uses the pond sizes and locations of Development Scenario 1. Background and solar farm

recharge are the same as for Development Scenario 3. Figure 6-6 shows the pond locations and recharge rates for this scenario.

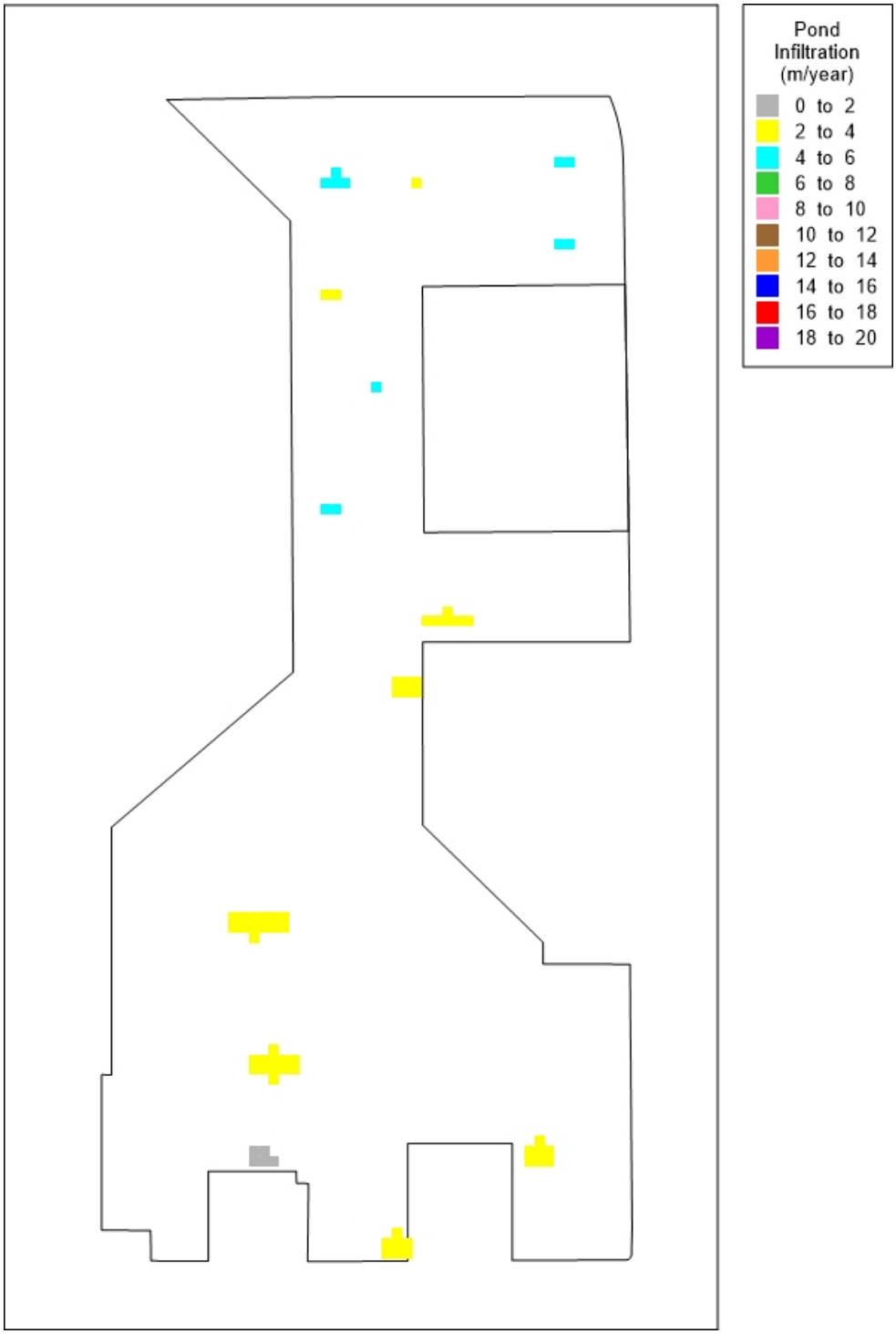


Figure 6-6. Pond Locations and Recharge Rates for Development Scenario 4

6.1.3 Particle Tracking

MODPATH particle tracking was performed for each of the flow simulations described in Section 6.1.2 to assess potential changes to groundwater flow paths and velocity. Particle tracks were evaluated for one set of particles that passed through the 2015 300 Area uranium plume area and another set that passed through the 2015 300 Area nitrate plume area. Particles were released at the midpoint of layer 19 at the beginning of the 100-year evaluation period and tracked for 100 years. Layer 19 is the water table layer over most of the focused study area. Figure 6-7 shows the particle starting locations and the uranium and nitrate plumes.

Figure 6-7. Particle Starting Locations and the Uranium and Nitrate Plumes

6.2 Focus Groundwater Flow Model

6.2.1 Flow Model Calibration

The focus GWFM was calibrated using PEST for the following hydraulic properties:

a. 8 hydraulic conductivity zones

b. 3 vertical to horizontal hydraulic conductivity ratio (1 each for Hanford, Ringold E, and RUM)

c. 3 specific storages (1 each for Hanford, Ringold E, and RUM)

d. 3 specific yields (1 each for Hanford, Ringold E, and RUM)

e. Conductance term in river, drain, and GHB packages

As mentioned in section 3.2.1, PEST tries to estimate the values for the above hydraulic properties by minimizing the objective function (difference between observed and simulated) for the calibration targets.

6.2.2 Predictive Model Simulation

The 100-year predictive flow model uses the calibrated parameters from the calibration model optimized by PEST. The predictive simulations were performed for four recharge scenarios described in section 6.1.2. In addition, each scenario is subdivided into two cases: a) non-irrigated native vegetation and b) irrigated urban vegetation. All other parameters and boundary conditions were same for all the simulations. Table 6-1 tabulates the recharge rates used in the predictive model simulation for the focus GWFM.

Table 6-1. Recharge Rates in the Focus Area for Different Recharge Rate Scenarios

Recharge Scenario[1]	Scenario Number	Non-Irrigated Native Vegetation[2] "Green Space" (mm/yr)	Scenario Number	Irrigated Urban Vegetation[3] "Green Space" (mm/yr)
High-Impact (85% impervious area) with Pond type i	1a	0.6 (4*0.15)	1b	10.72 (71.4*0.15)
High-Impact (85% impervious area) with pond type ii	2a	0.6 (4*0.15)	2b	10.72 (71.4*0.15)
Low-Impact (25% impervious area) with Pond type iii	3a	3 (4*0.75)	3b	53.55 (71.4*0.75)
Low-Impact (25% impervious area) with pond type i	4a	3 (4*0.75)	4b	53.55 (71.4*0.75)
1) Solar Farm recharge for all scenarios is assumed to be 8 mm/yr.				
2) Area weighted average recharge for mature native vegetation is 3.68 mm/yr. A value of 4 mm/yr, the most common value for mature native vegetation, was chosen as the low end value.				
3) Area weighted average recharge for urban irrigated is 71.48 mm/yr. A value of 71.4 mm/yr, one of the values for urban irrigated, was chosen as the high end value.				

6.2.3 Particle Tracking Analysis

Forward particle tracking was performed on the 100-year predictive model to evaluate the potential impacts of stormwater management on groundwater flow paths and velocity. Particle tracking analysis for the focus GWFM uses the same MODPATH setup described in section 6.1.3 except the model layer assignment for the particles. The water table lies in Layer 1 in 300 Area for the focus GWFM, which is where the particles were placed.

7 Results/Conclusions

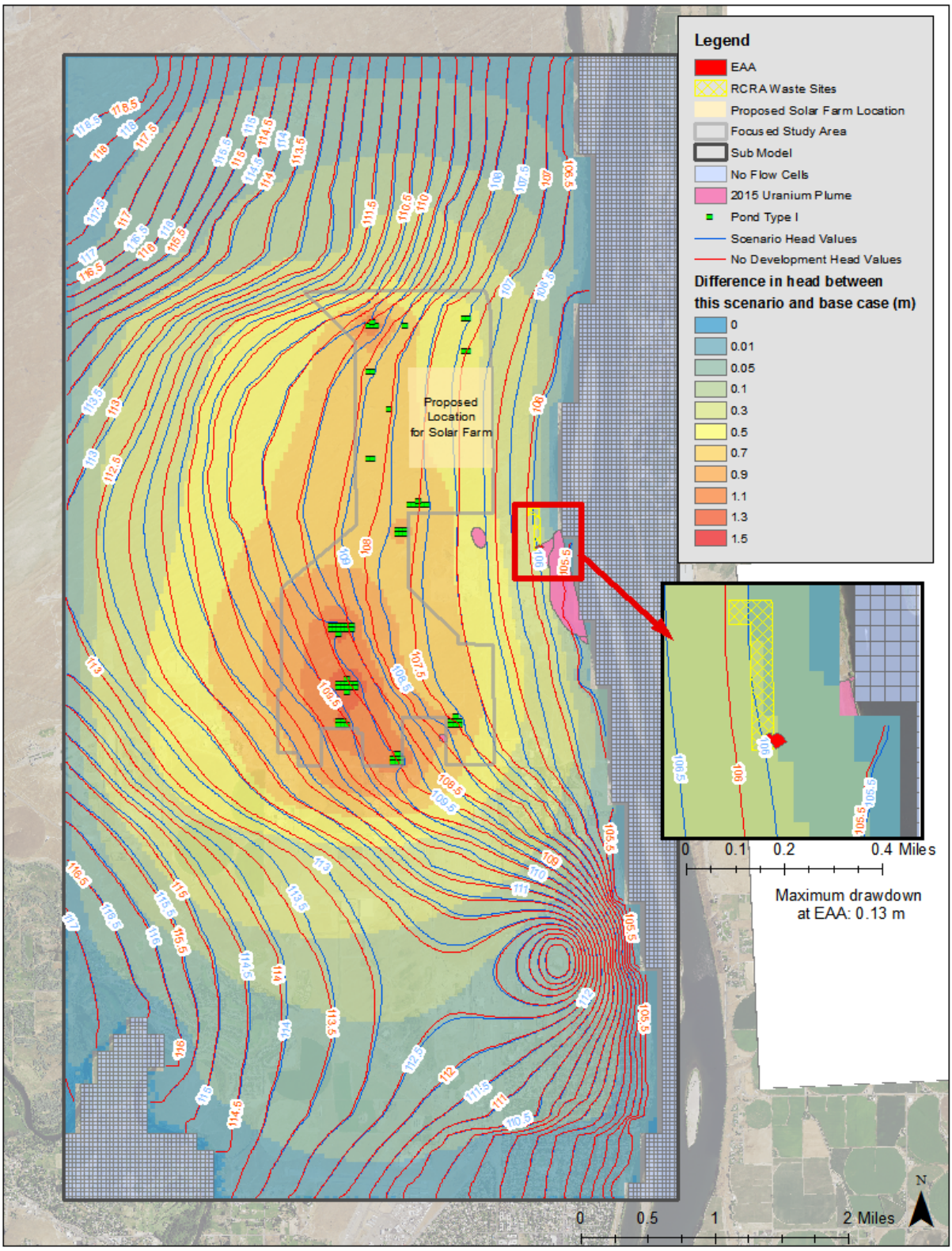
7.1 EIS Sub-Model

Simulation results for the EIS Sub-Model include both groundwater head elevation from the MODFLOW flow modeling and particle tracks from MODPATH. Section 7.1.1 presents flow model results and Section 7.1.2 presents particle tracking results.

7.1.1 Flow Model Results

Figure 7-1 through Figure 7-4 compare the groundwater head elevations for the base case (i.e., no development) to those for Development Scenarios 1, 2, 3 and 4, respectively. Groundwater heads are for layer 19, which is the water table layer over most of the focused study area. In addition to groundwater head contours, these figures show head differences (development scenario - base case) resulting from the altered recharge for the development scenarios. Maximum water level rise for the four scenarios ranged from 0.45 m for Scenario 4 (Low impact with Pond Type i) up to 1.41 m for Scenario 1 (High Impact with Pond Type i). Scenarios 2 (High Impact with Pond Type ii) and 3 (Low impact with Pond Type iii) produced intermediate water level rises of 1.36 m and 0.70 m, respectively.

Comparing Figure 7-1 and Figure 7-2 shows that scattering some of the ponds reduces the area that exceeds 1 m in water level rise from a large area in the south and a small area in the north to single small area around one pond cell at the north end of the site. Under low impact development conditions, water level rise exceeds 0.5 m in only a few cells for Pond Type iii (Figure 7-3) and does not exceed 0.5 m for Pond Type i (Figure 7-4). Near the EAA, the maximum water level rise for any of the development scenarios was 0.14 m, which occurred under Scenario 2. For Scenario 1, the maximum water level rise was only slightly less at 0.13 m. Maximum water level rise near the EAA for both low impact scenarios was only 0.04 m. Figures 7-1 through 7-4 show expanded views of the EAA area for easier comparison of water levels near the EAA. These minimal water level rises are not expected to significantly impact the 300 Area uranium plume.



mcw eis scen1 082017

Figure 7-1. Comparison of Groundwater Head Elevations for the Base Case and Development Scenario 1

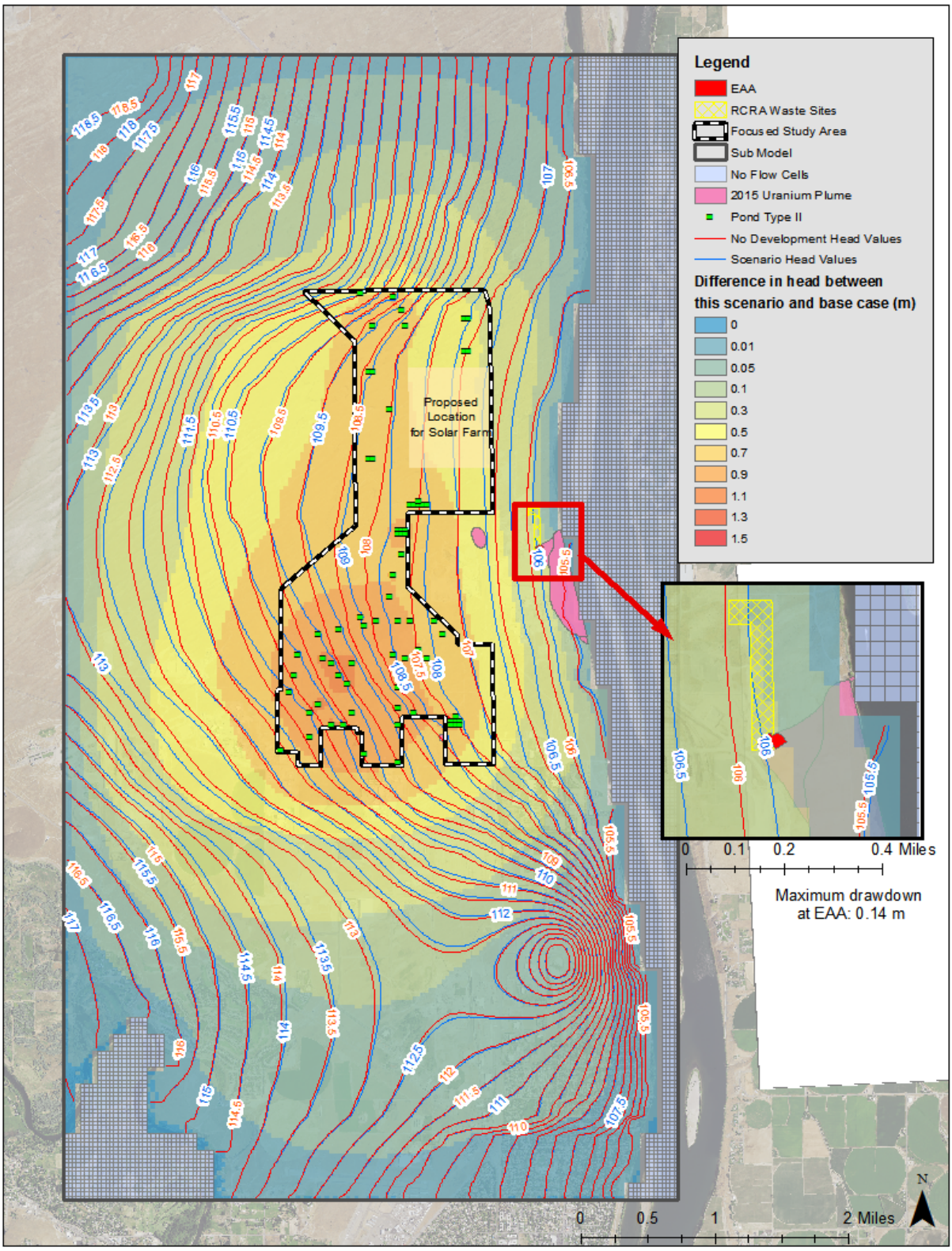


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Figure 7-2. Comparison of Groundwater Head Elevations for the Base Case and Development Scenario 2

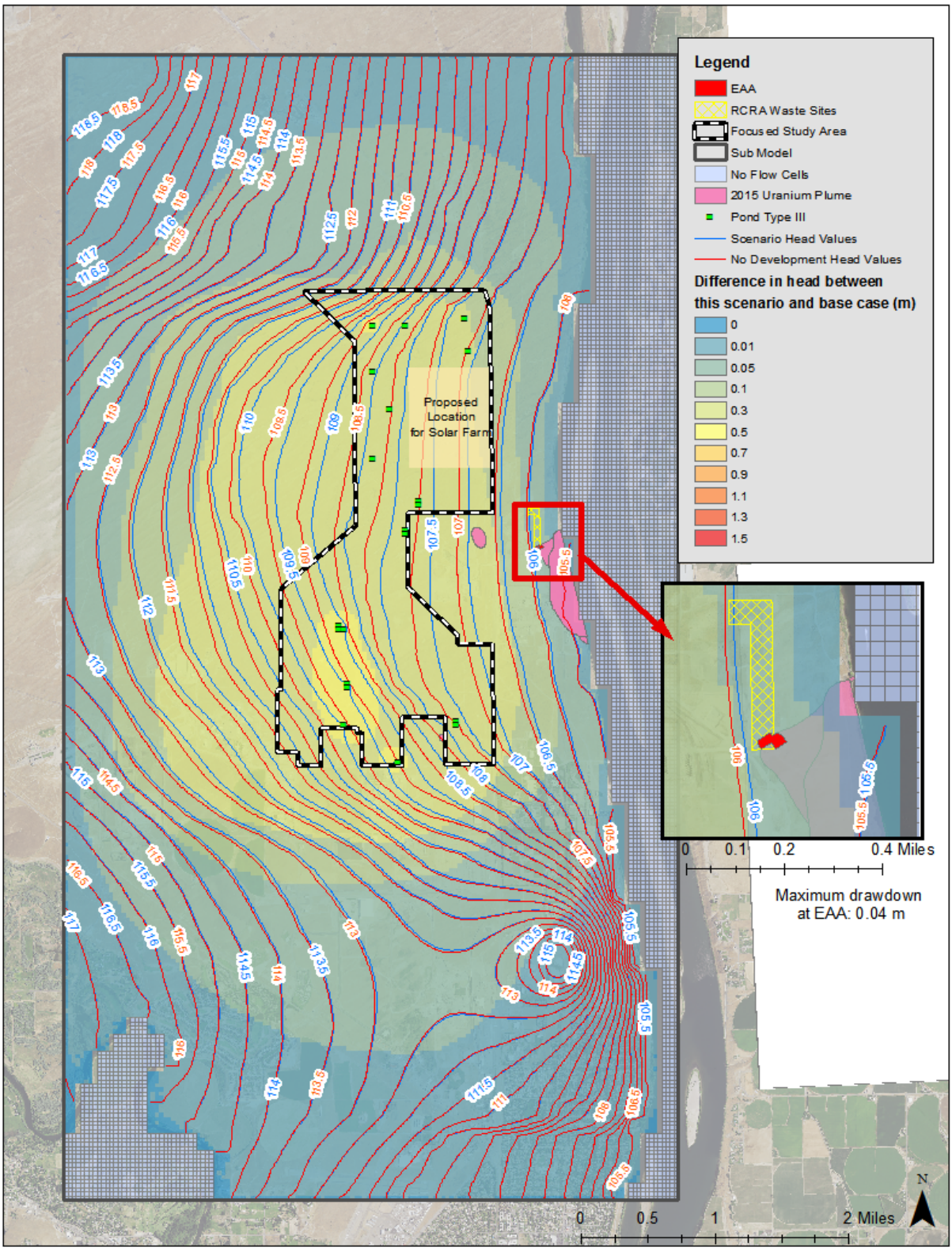

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Figure 7-3. Comparison of Groundwater Head Elevations for the Base Case and Development Scenario 3

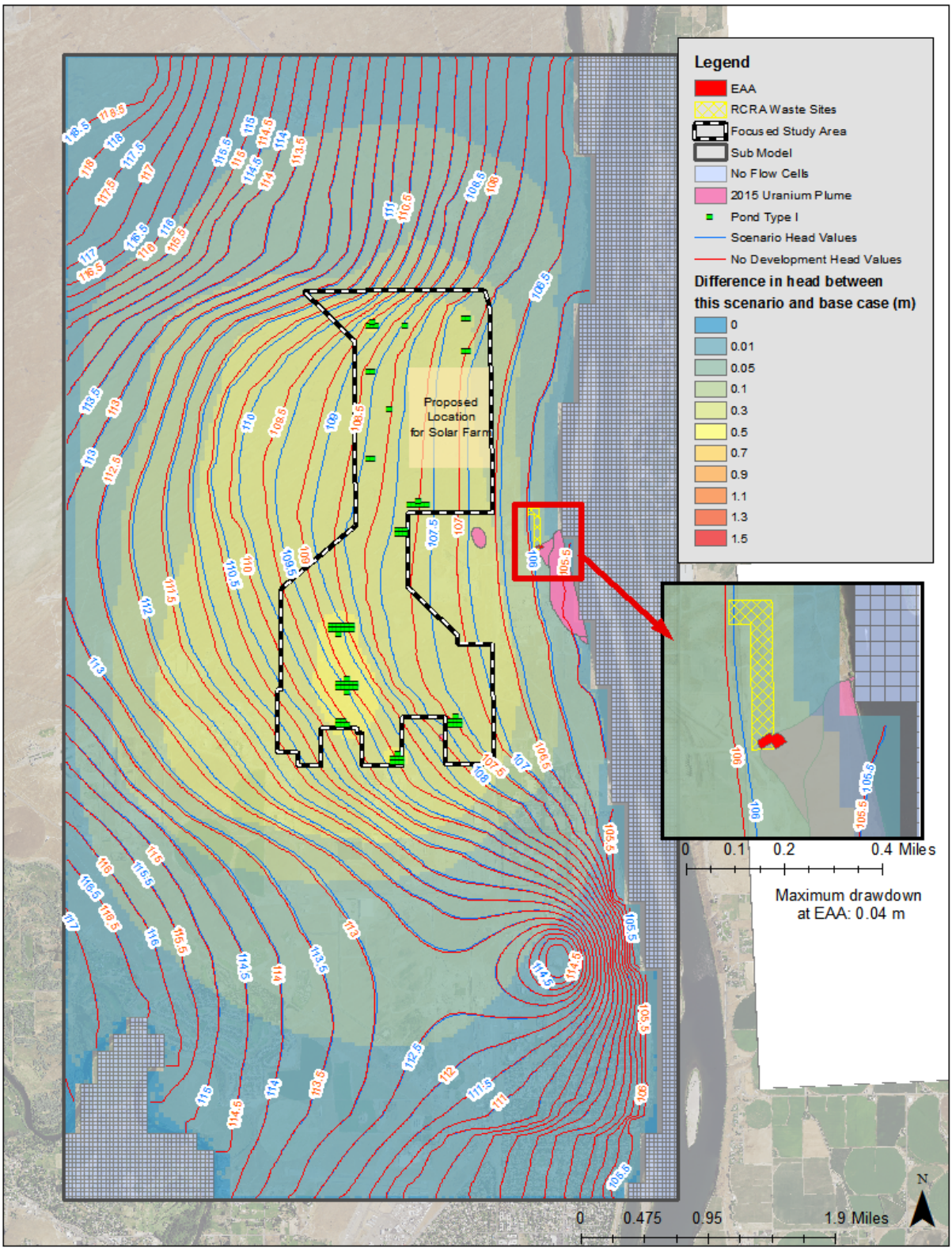

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Figure 7-4. Comparison of Groundwater Head Elevations for the Base Case and Development Scenario 4

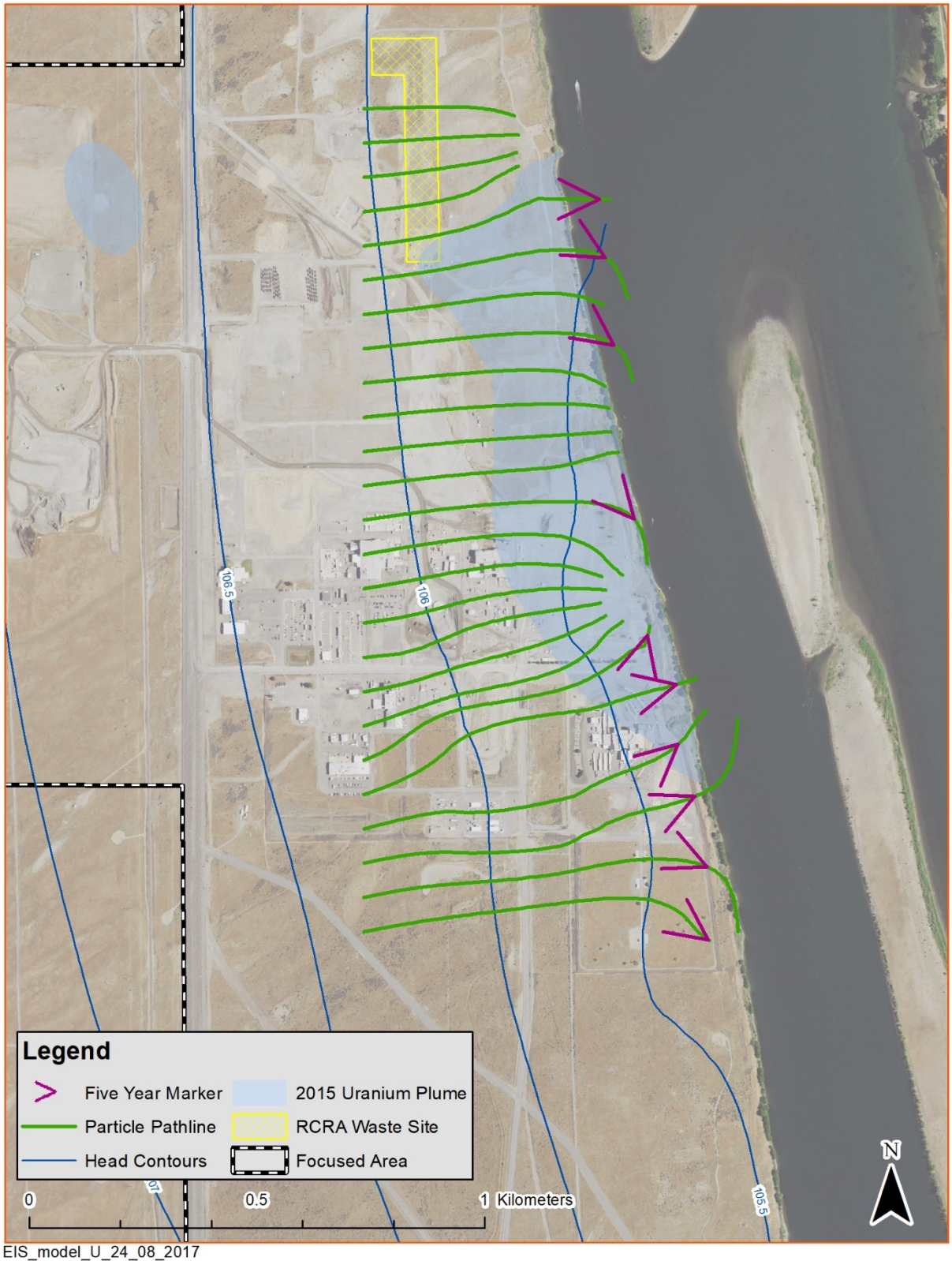
7.1.2 Particle Tracking Results

Figure 7-5 through Figure 7-9 show simulated flow paths through the 300 Area uranium plume area, as delineated in 2015, for the base case (no development) simulation and the four development scenarios. Figure 7-10 through Figure 7-14 show simulated flow paths through the 300 Area nitrate plume area, as defined in 2015, for the base case (no development) simulation and the four development scenarios. The particle tracks show some deflection near the infiltration ponds, but the overall direction of travel and discharge locations remain relatively unchanged. Table 7-1 lists average travel times, direction of travel and discharge locations for the simulated flow paths. Overall, simulated flow paths do not change substantially under any of the development scenarios and the discharge location remains the Columbia River.

Figure 7-5 and Figure 7-10 show results for the base case (no development) simulation and the remainder show results for the four development scenarios. When no arrow head is shown, the travel time is less than the marker interval.

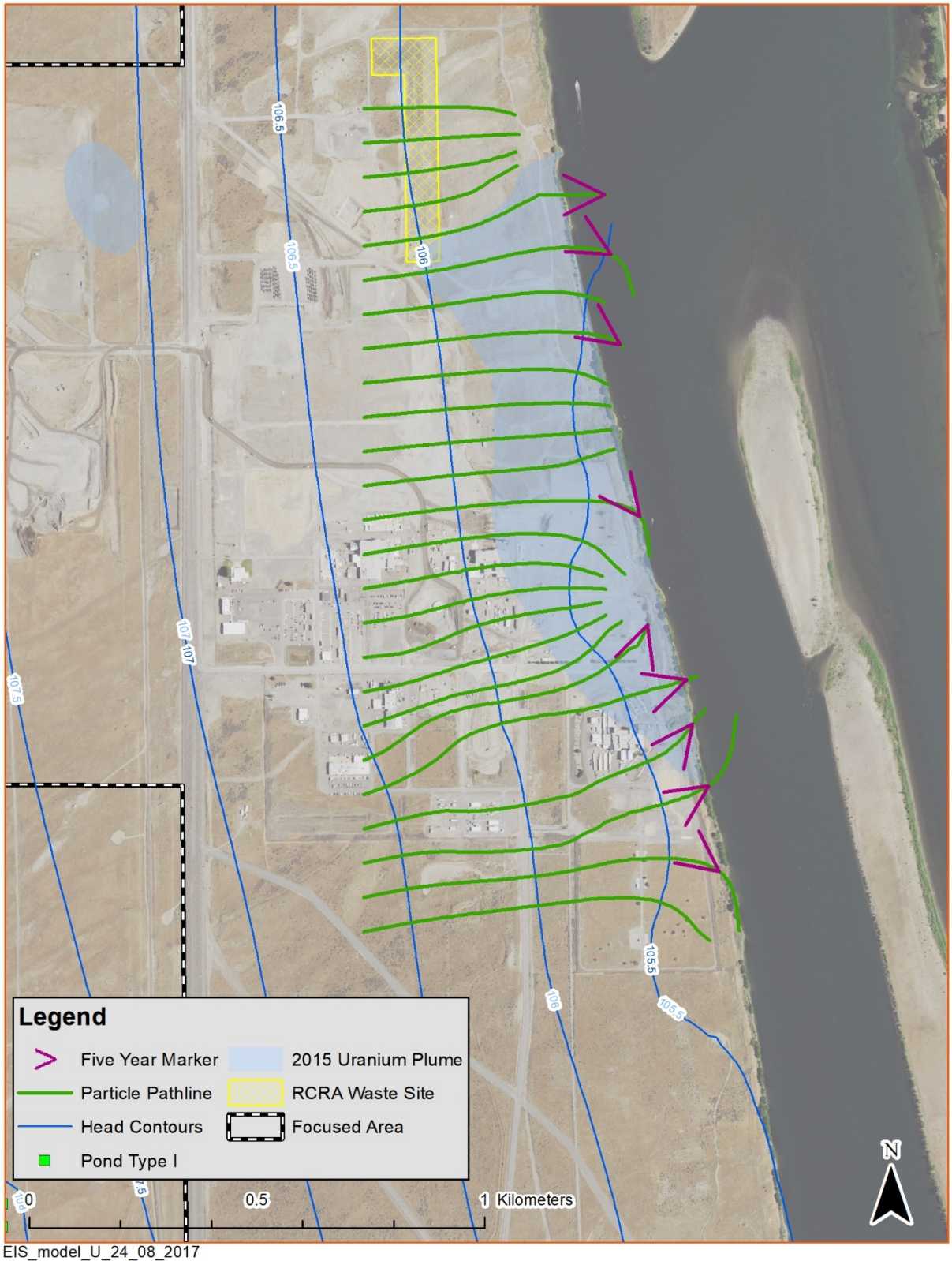
Table 7-1. Particle Tracking Results for the EIS Sub-Model

Plume Feature	No Development	Scenario 1 – High Impact with Pond Type i	Scenario 2 – High Impact with Pond Type ii	Scenario 3 – Low Impact with Pond Type iii	Scenario 4 – Low impact with Pond Type i
Uranium average travel time (yr)	3.0	2.7	2.7	3.0	3.0
Uranium trajectory	Due east to Columbia River	Unchanged, due east to Columbia River	Unchanged, due east to Columbia River	Unchanged, due east to Columbia River	Unchanged, due east to Columbia River
Uranium discharge point	Columbia River	Columbia River	Columbia River	Columbia River	Columbia River
Nitrate average travel time (yr)	48.8	48.3	53.1	52.5	52.6
Nitrate trajectory	East to Columbia River, away from Richland recharge mound	Slightly deflected near stormwater ponds	Slightly deflected near stormwater ponds	Slightly deflected near stormwater ponds	Slightly deflected near stormwater ponds
Nitrate discharge point	Columbia River	Columbia River	Columbia River	Columbia River	Columbia River



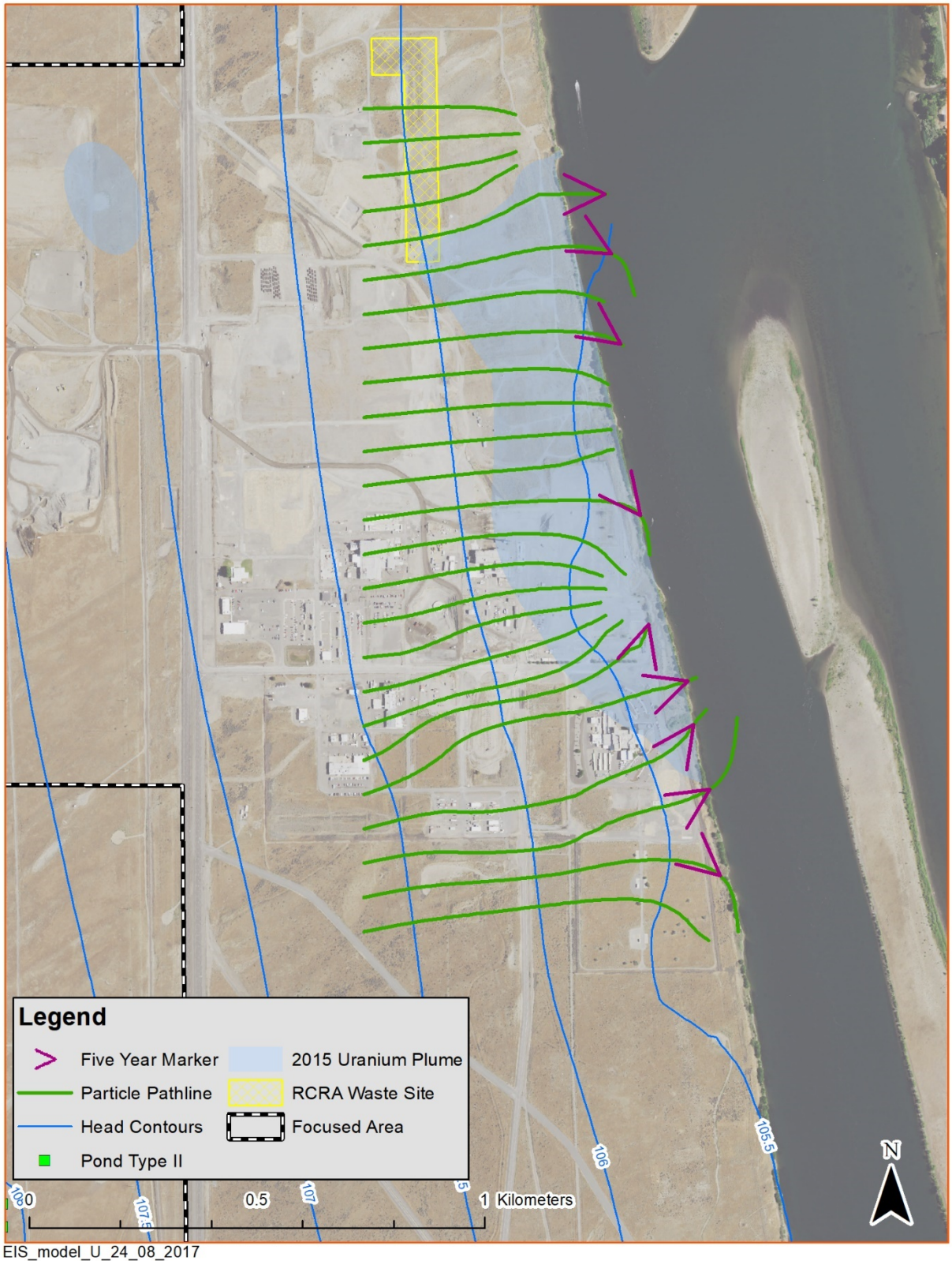
EIS_model_U_24_08_2017

Figure 7-5. Simulated Flow Paths through the 2015 Uranium Plume Area for the Base Case Simulation



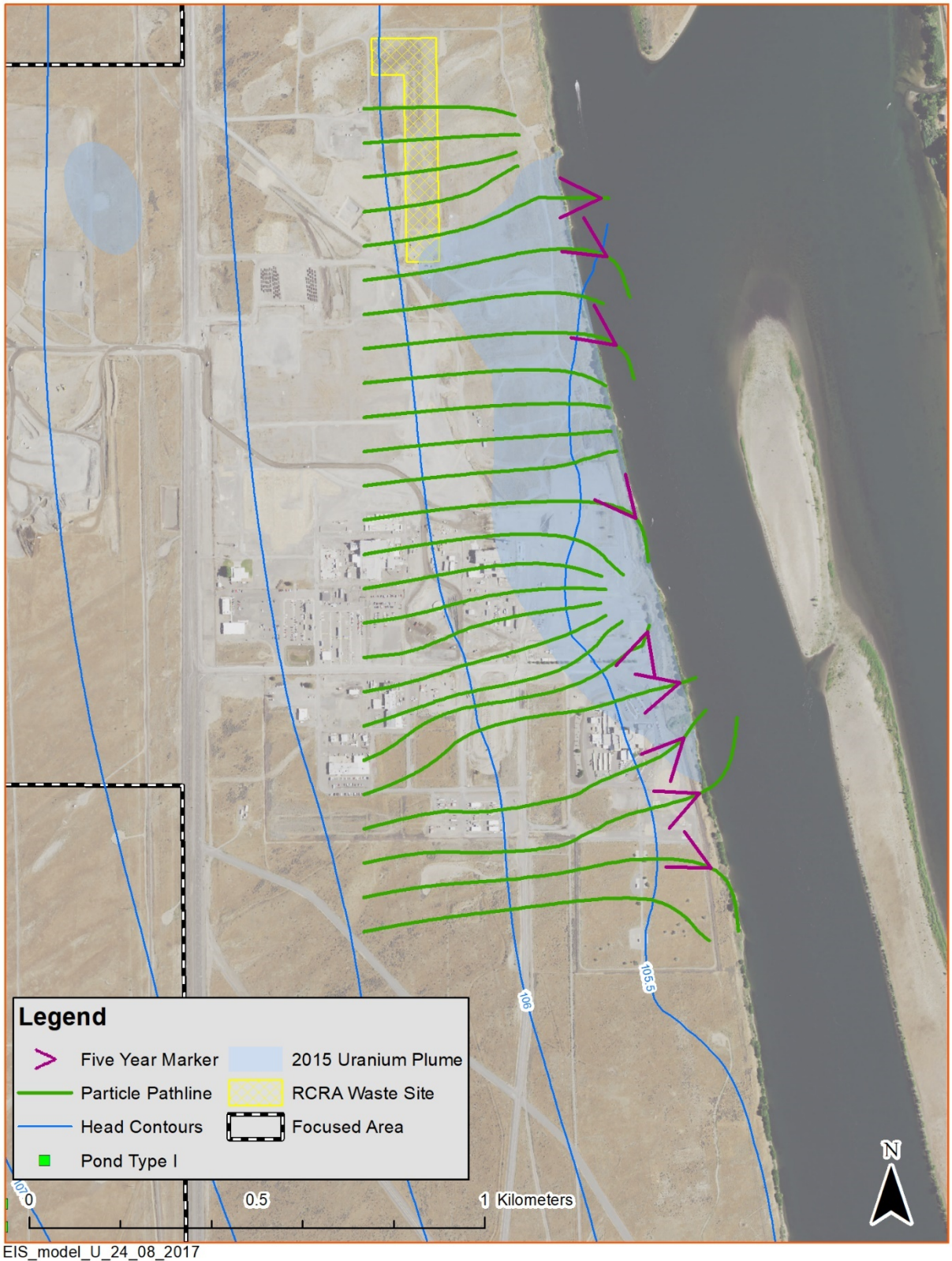
EIS_model_U_24_08_2017

Figure 7-6. Simulated Flow Paths through the 2015 Uranium Plume Area for Development Scenario 1



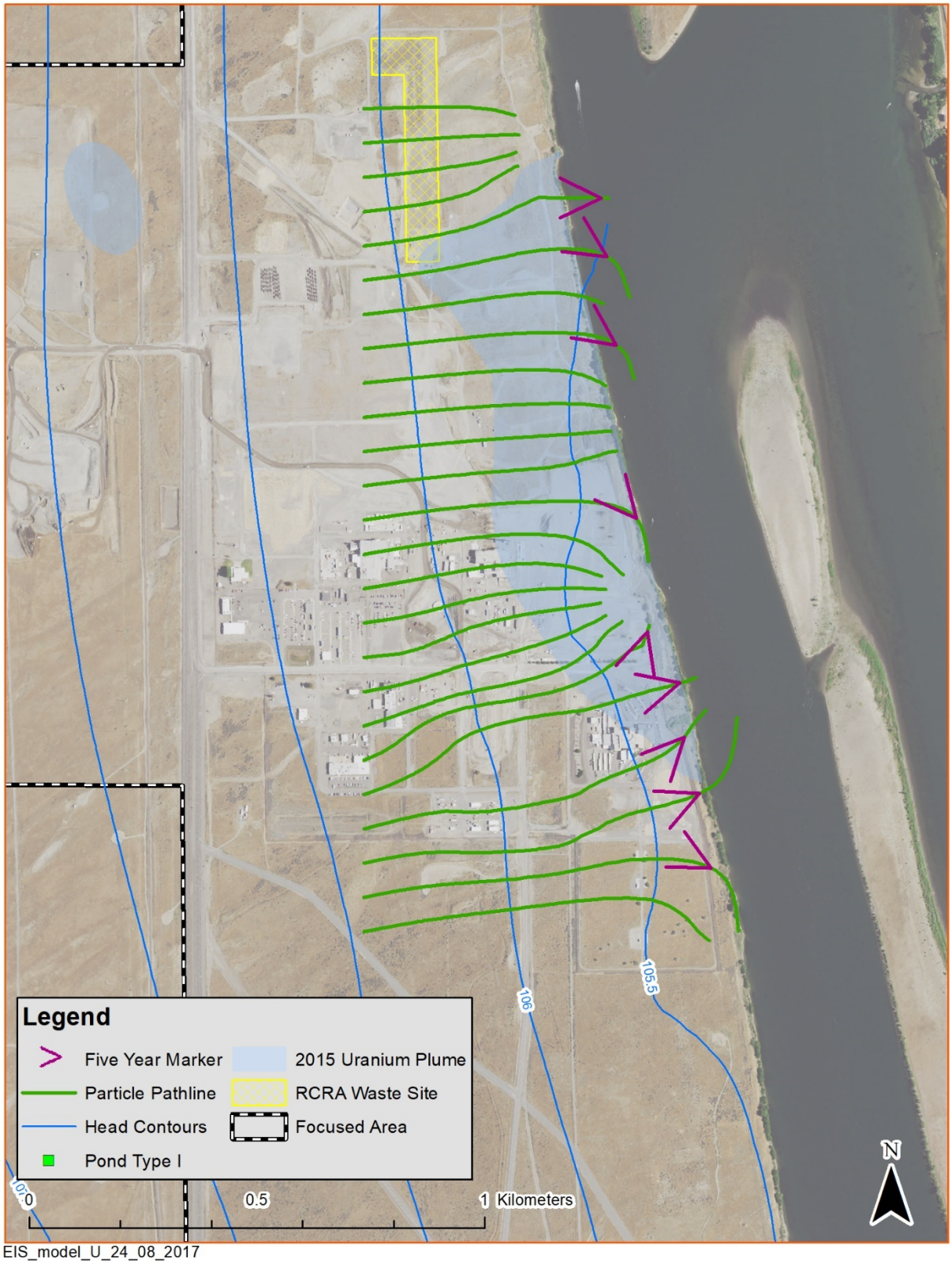
EIS_model_U_24_08_2017

Figure 7-7. Simulated Flow Paths through the 2015 Uranium Plume Area for Development Scenario 2



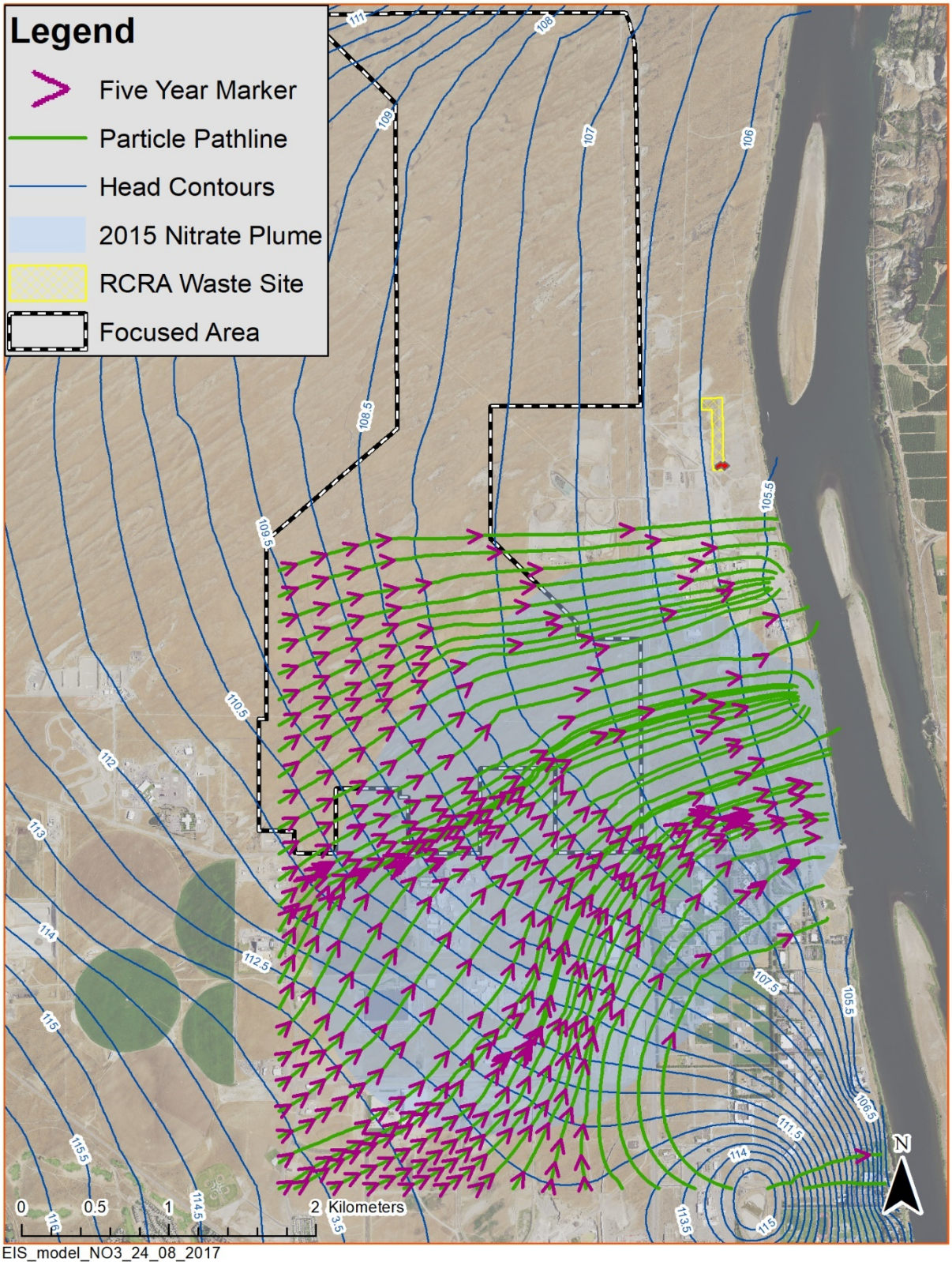
EIS_model_U_24_08_2017

Figure 7-8. Simulated Flow Paths through the 2015 Uranium Plume Area for Development Scenario 3



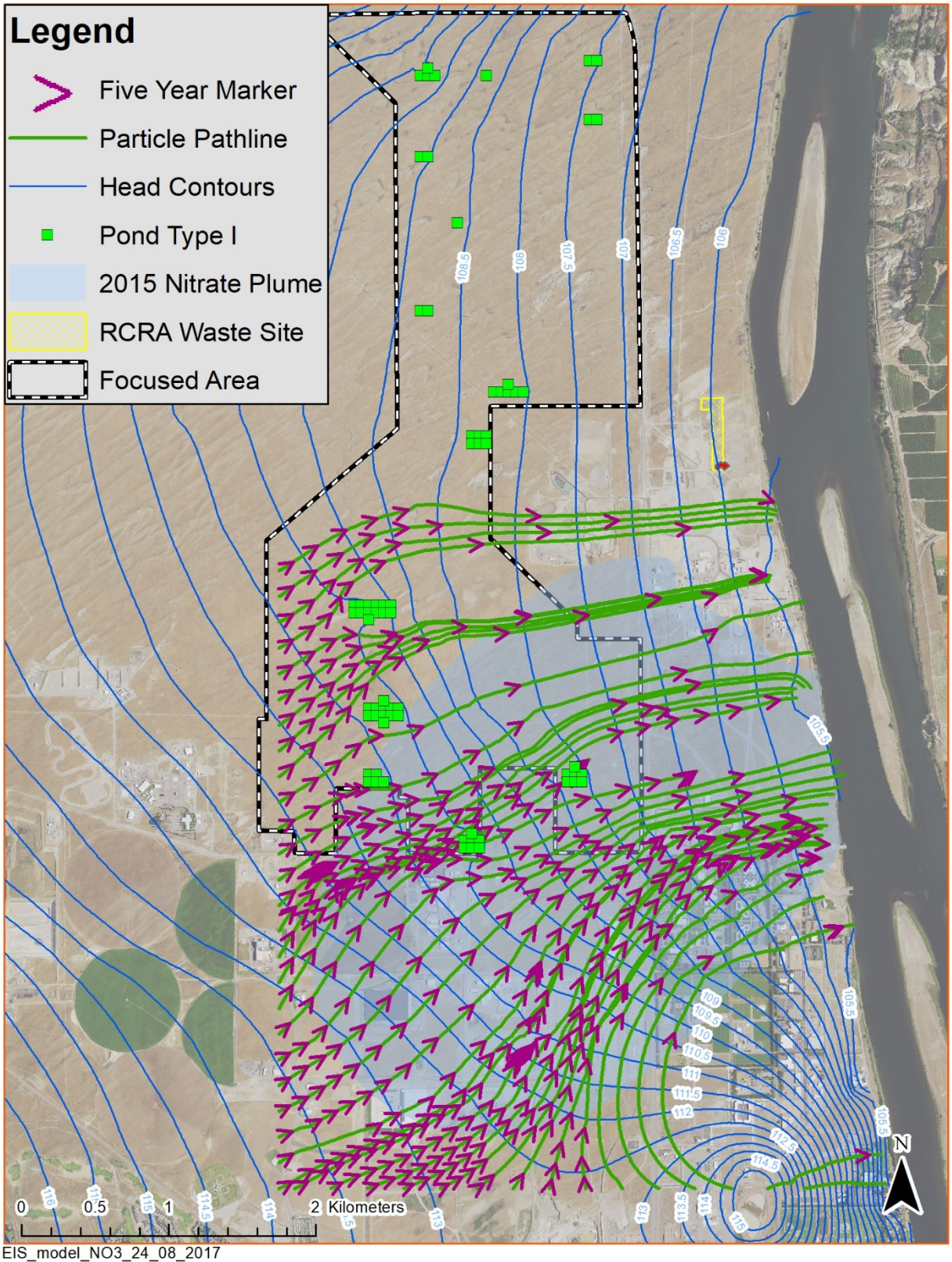
EIS_model_U_24_08_2017

Figure 7-9. Simulated Flow Paths through the 2015 Uranium Plume Area for Development Scenario 4



EIS_model_NO3_24_08_2017

Figure 7-10. Simulated Flow Paths through the 2015 Nitrate Plume Area for the Base Case Simulation



EIS_model_NO3_24_08_2017

Figure 7-11. Simulated Flow Paths through the 2015 Nitrate Plume Area for Development Scenario 1

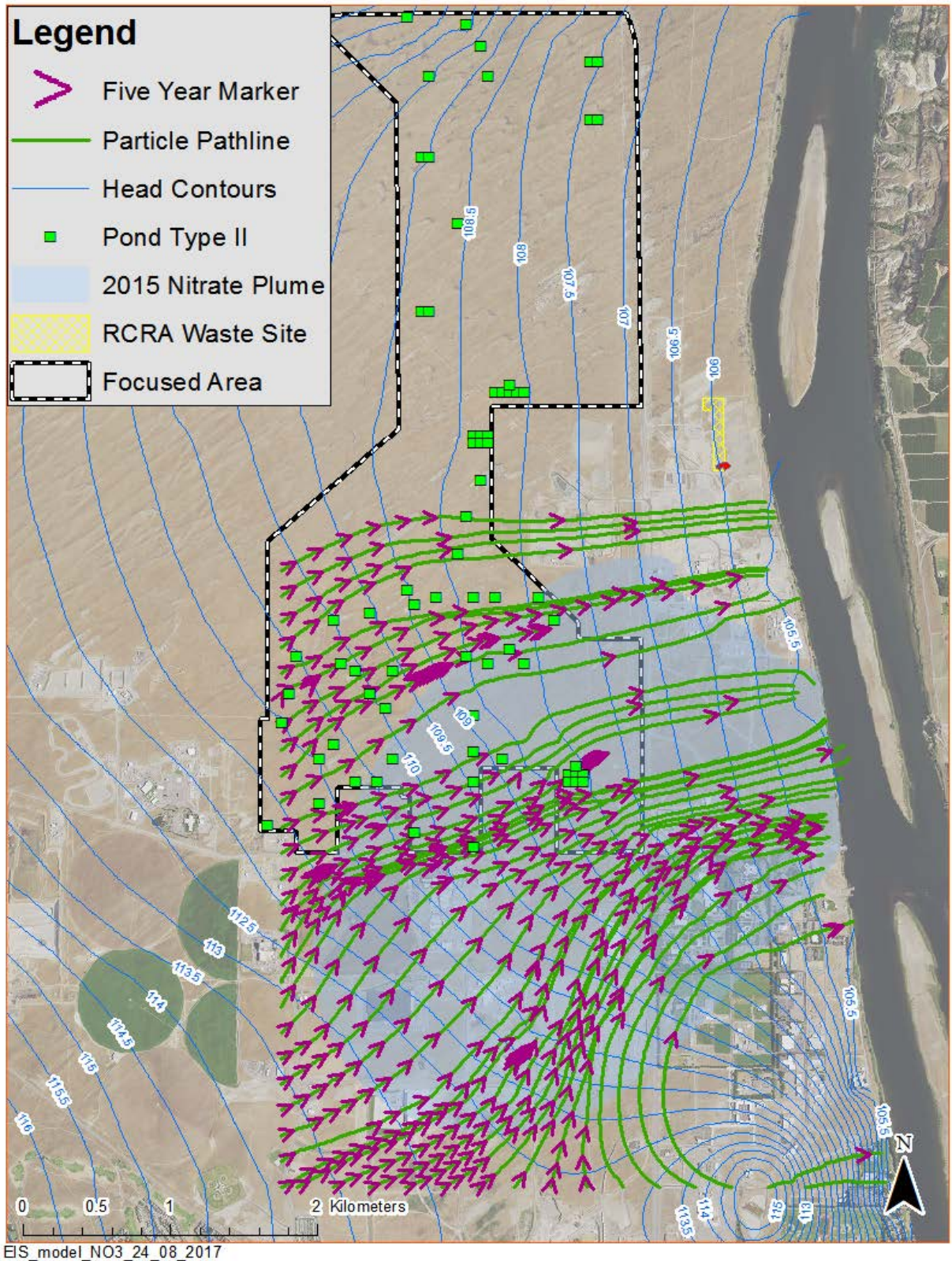
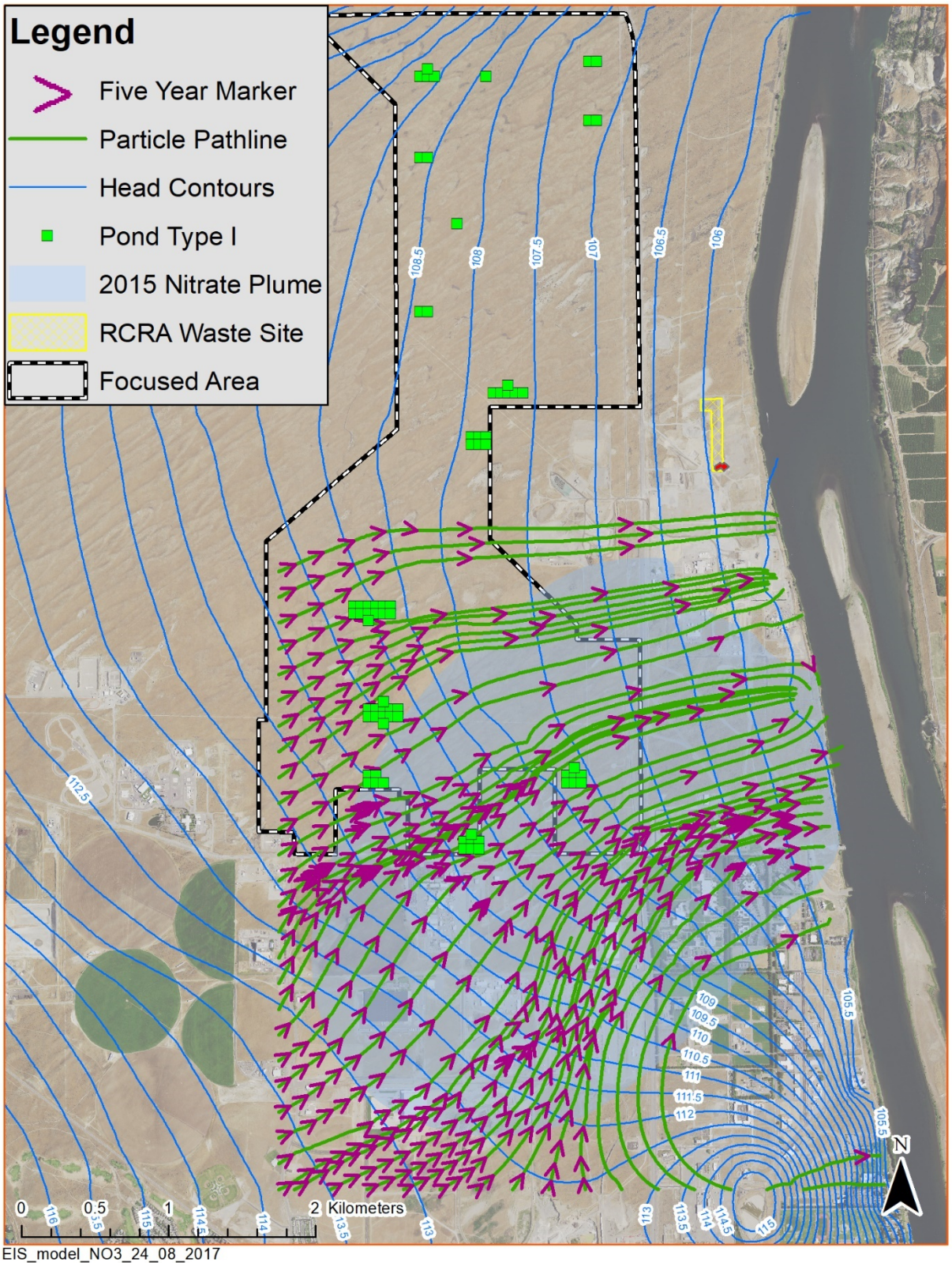


Figure 7-12. Simulated Flow Paths through the 2015 Nitrate Plume Area for Development Scenario 2



EIS_model_NO3_24_08_2017

Figure 7-13. Simulated Flow Paths through the 2015 Nitrate Plume Area for Development Scenario 3

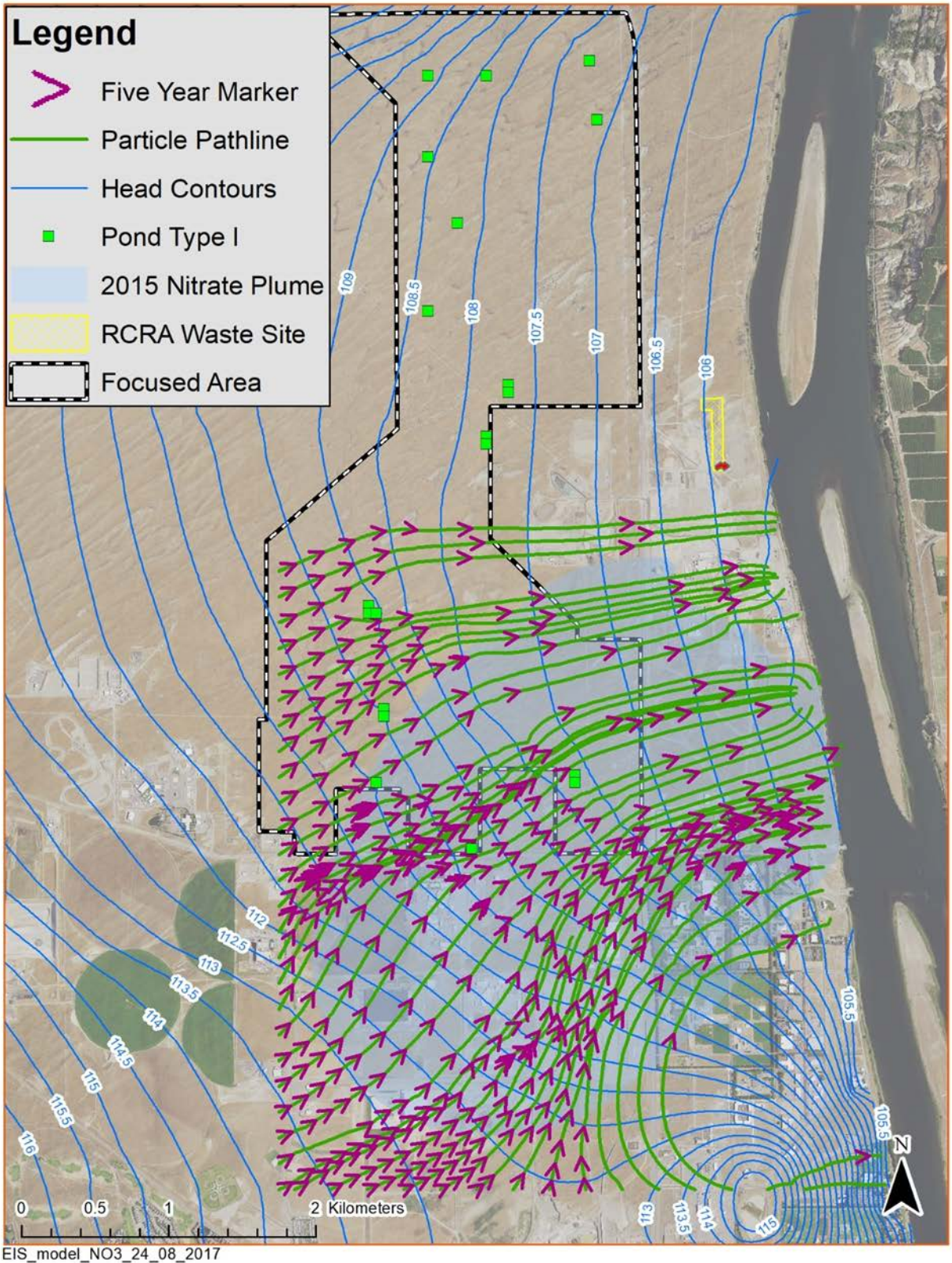


Figure 7-14. Simulated Flow Paths through the 2015 Nitrate Plume Area for Development Scenario 4

7.2 Focus Groundwater Flow Model

7.2.1 Flow Model Calibration Results

Simulated hydraulic head for the model run with the calibrated parameters show good fit with the observed hydraulic head in most of the wells. A plot of observed versus simulated hydraulic head from the AWLN wells is shown in Figure 7-15. All the AWLN wells could capture the seasonal variability in the water level due to the Columbia River stage fluctuation. However, simulated hydraulic head was consistently higher than the observed hydraulic head with an average difference of 0.15 m. Well 399-8-5A which is furthest away from the river shoreline shows maximum misfit with an average difference of 0.47 m. A plot of observed versus simulated hydraulic head from the manual measurement wells is shown in Figure 7-16. The simulated values at lower head show better agreement than the simulated values at higher head. In general, most of the lower hydraulic head measurements are from wells near the river where the simulated hydraulic head agrees well with the observed hydraulic head. An average difference of 0.29 m was found between simulated and observed hydraulic head at the manual measurement wells. Larger differences are due to measurement error at wells such as 399-4-10 (1 observed data does not match with others), contradictory hydraulic head measurements at multiple nearby wells (e.g., 699-S18-E2A, 699-S18-E2AP, and 699-S18-E2B), and model's inability to represent local scale heterogeneity in the aquifer.

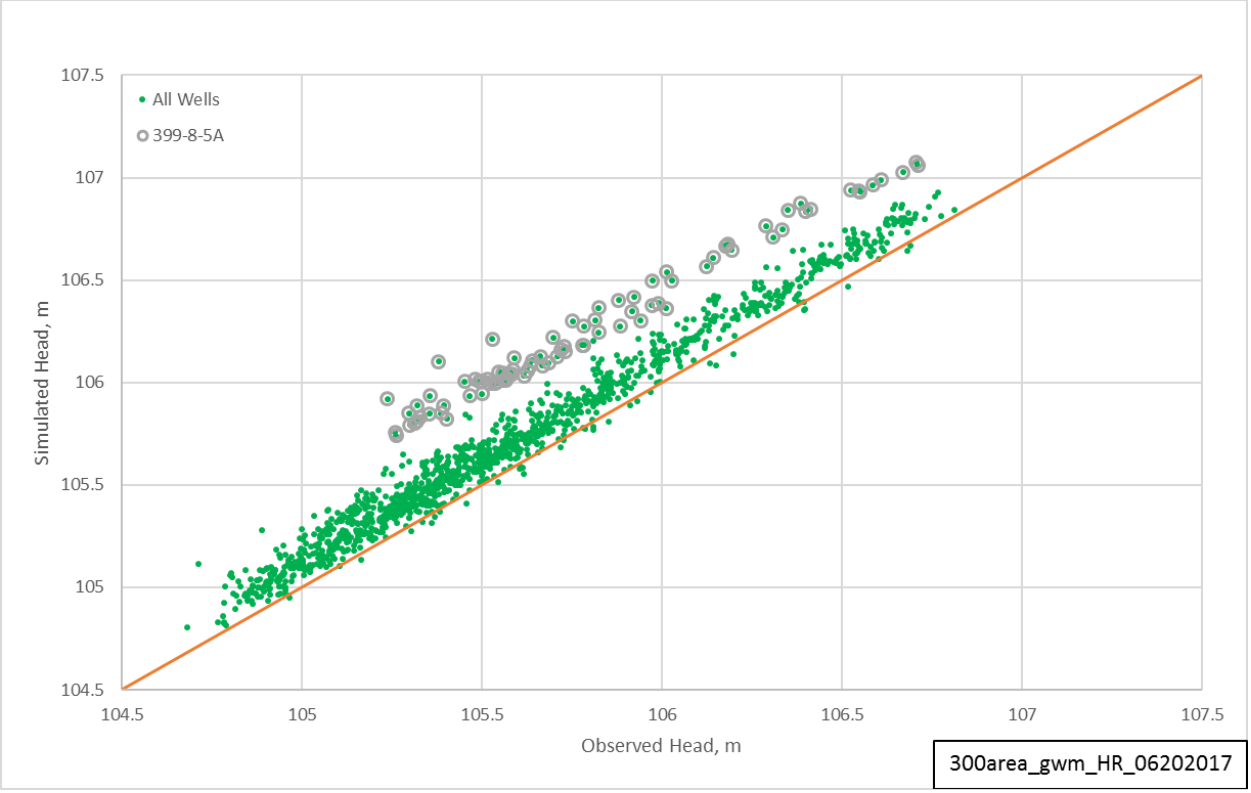


Figure 7-15. Observed vs Simulated Heads at AWLN Wells

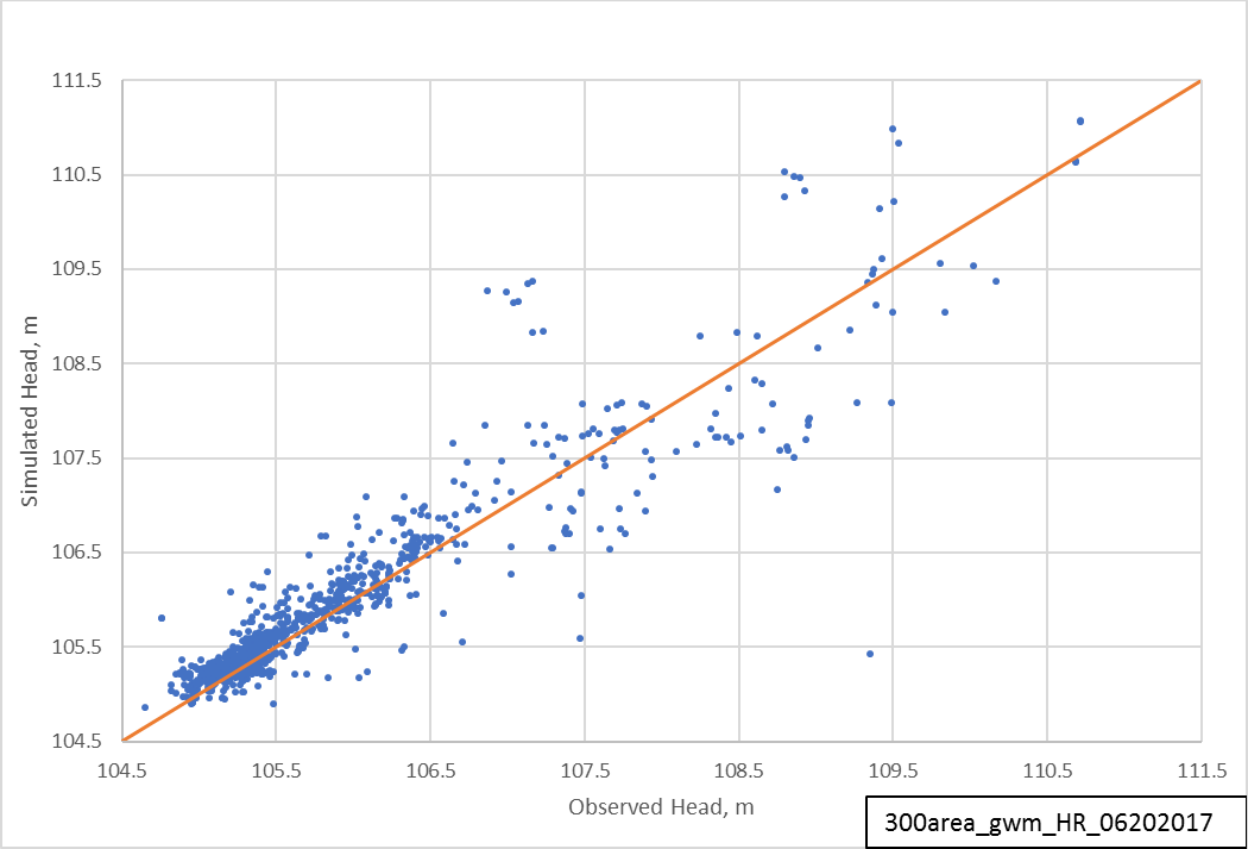


Figure 7-16. Observed vs Simulated Heads at Manual Measurement Wells

Appendix B shows comparison between observed and simulated hydraulic head at each well (both AWLN and manual measurement). Table 7-2 presents a synopsis of the calibrated input parameters used in the focus GWFM. Figure 7-17 and Figure 7-18 show model layer calibrated hydraulic conductivity along with the calibration target locations.

Table 7-2. Focus GWFM Calibrated Parameter Values

Parameter	Formation/Location	Value
Specific yield	Hanford	0.12
	Ringold E	0.12
	RUM	0.12
Specific storage (1/m)	Hanford	1.00×10^{-6}
	Ringold E	9.98×10^{-5}
	RUM	9.98×10^{-5}
Vertical to horizontal hydraulic conductivity ratio	Hanford	0.08
	Ringold E	0.11
	RUM	0.11
Riverbed hydraulic conductivity (m/d)	Hanford	23
GHB conductance (m^2/d)	North boundary (low)	30888
	North boundary (high)	50000
	South boundary	924
	West boundary	42838
Hydraulic conductivity (m/d)	Hanford (Zone 1)	535
	Ringold E (Zone 2)	31
	Combination of Hanford and Ringold E (Zone 3)	362
	Combination of Hanford and Ringold E (Zone 4)	55
	Hanford (Zone 5)	7939
	Hanford (Zone 6)	573
	Hanford (Zone 7)	1157
	RUM (Zone 8)	0.008

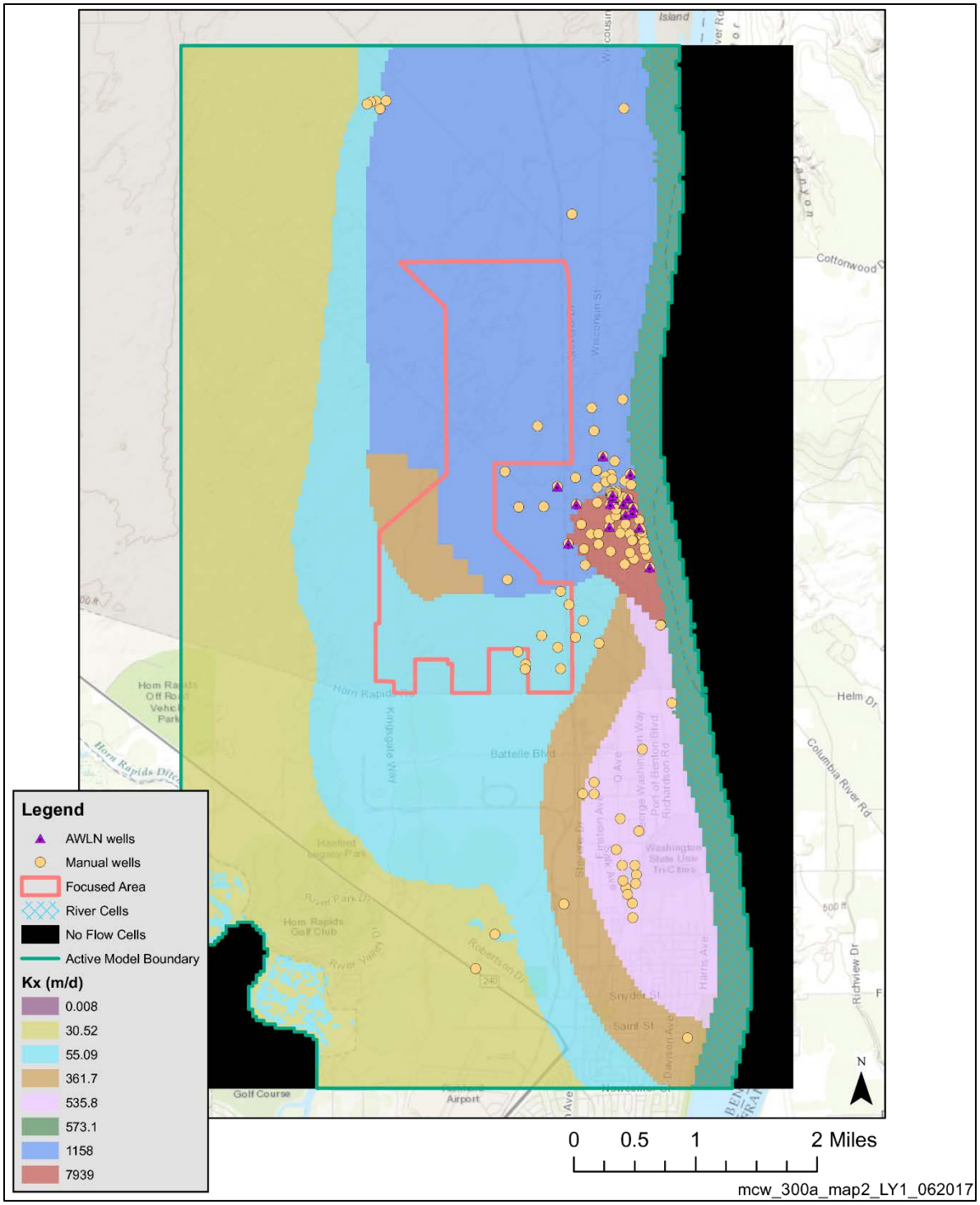


Figure 7-17. Layer 1 Hydraulic Conductivity

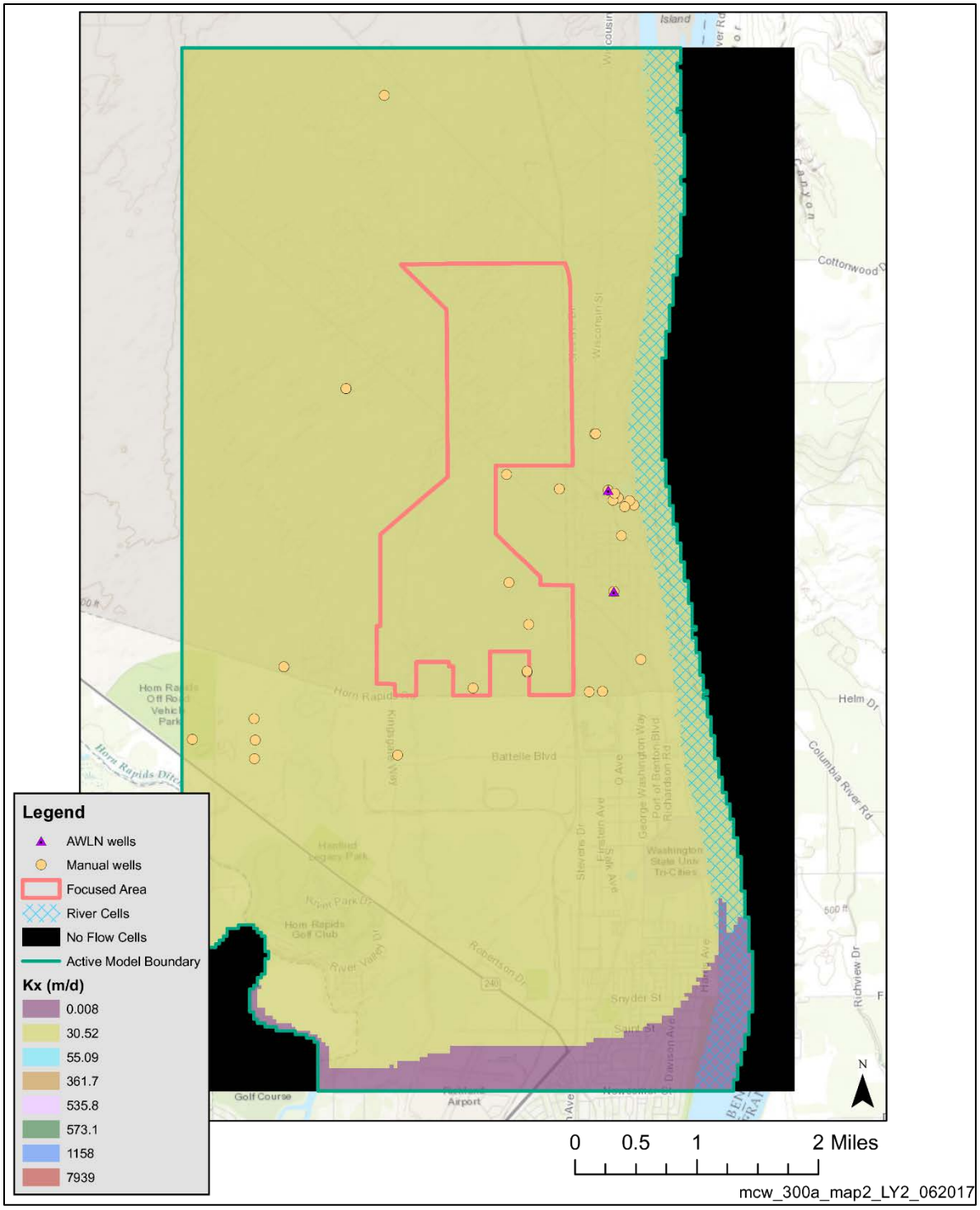


Figure 7-18. Layer 2 Hydraulic Conductivity

Most of the AWLN wells are very close to the Columbia River and lie within highly conductive Hanford formation (Zone 5 and Zone 7). A good agreement between observed and simulated hydraulic conductivity at the AWLN wells is consistent with the conceptual assumption of having a highly conductive zone in that area. Moreover, the model had good calibration on the seasonal fluctuation at the

AWLN wells due to the changes in the Columbia River stage which indicates that the river boundary condition is correctly represented in the model.

7.2.2 Predictive Flow Model Results

Figure 7-19 through Figure 7-26 compare the groundwater head elevations for the base case (i.e., no development) to eight predictive simulations (i.e., 4 Development Scenarios, each subdivided into 2 vegetation cases). Groundwater heads are for layer 1, which is the water table layer over the focused study area. In addition to groundwater head contours, these figures show head differences (development scenario - base case) resulting from the altered recharge for the development scenarios. Maximum water level rise for those eight predictive simulations ranged from 0.19 m for Scenario 4b (Low impact with Pond Type i with Non-Irrigated Native Vegetation) up to 0.63 m for Scenario 1b (High Impact with Pond Type i and Irrigated Urban Vegetation).

Comparing Figure 7-19 and Figure 7-21 shows that scattering some of the ponds reduces the area that exceeds 0.5 m in water level rise. Near the EAA, the maximum water level rise for any of the development scenarios was 0.02 m, which occurred under Scenario 1a, 1b, 2a, and 2b. Figure 7-19 through Figure 7-26 show expanded views of the EAA area for easier comparison of water levels near the EAA. These minimal water level rises are not expected to significantly impact the 300 Area uranium plume.

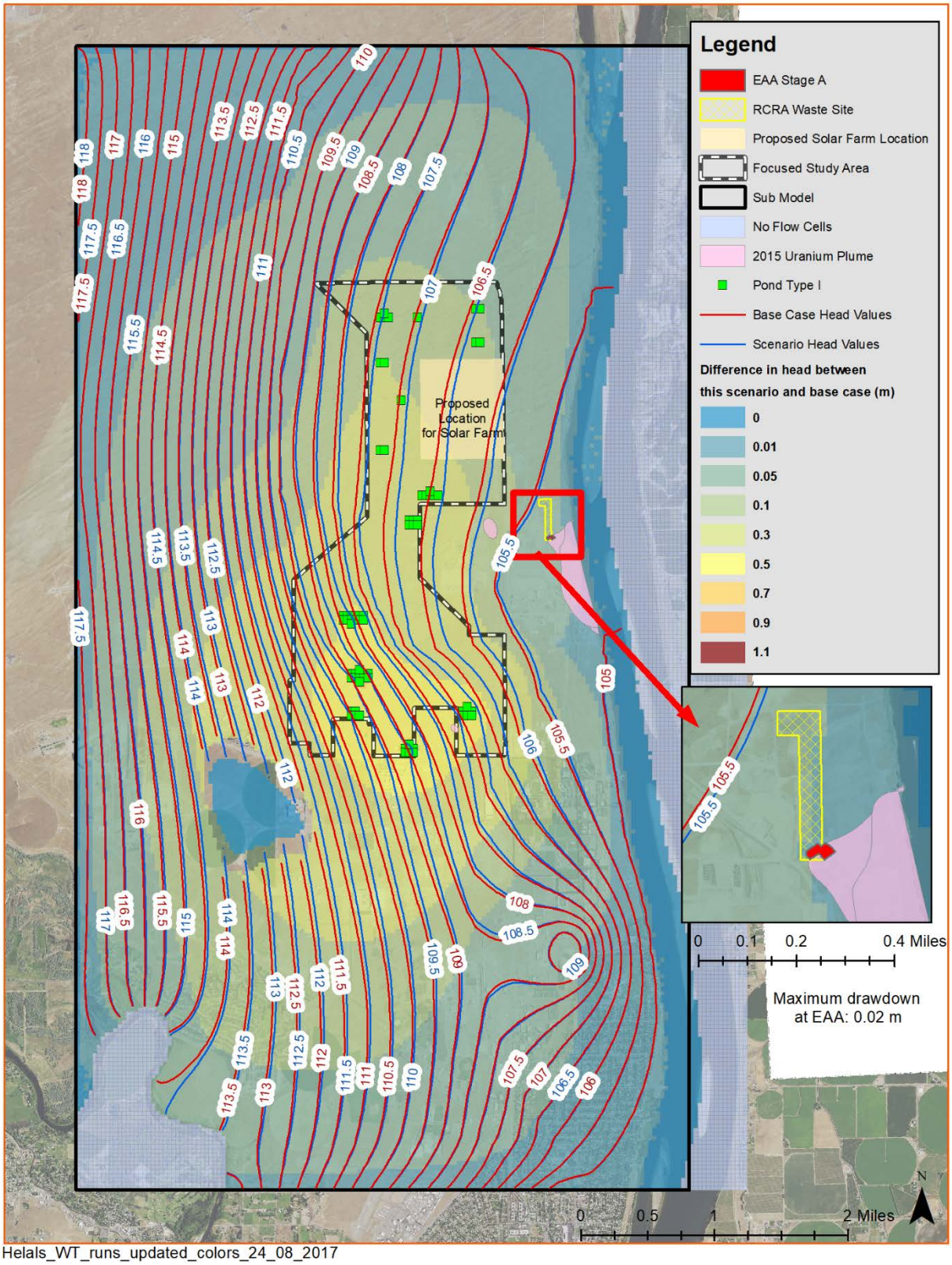


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Figure 7-19. Comparison of Groundwater Head Elevations for the Base Case and Development Scenario 1a

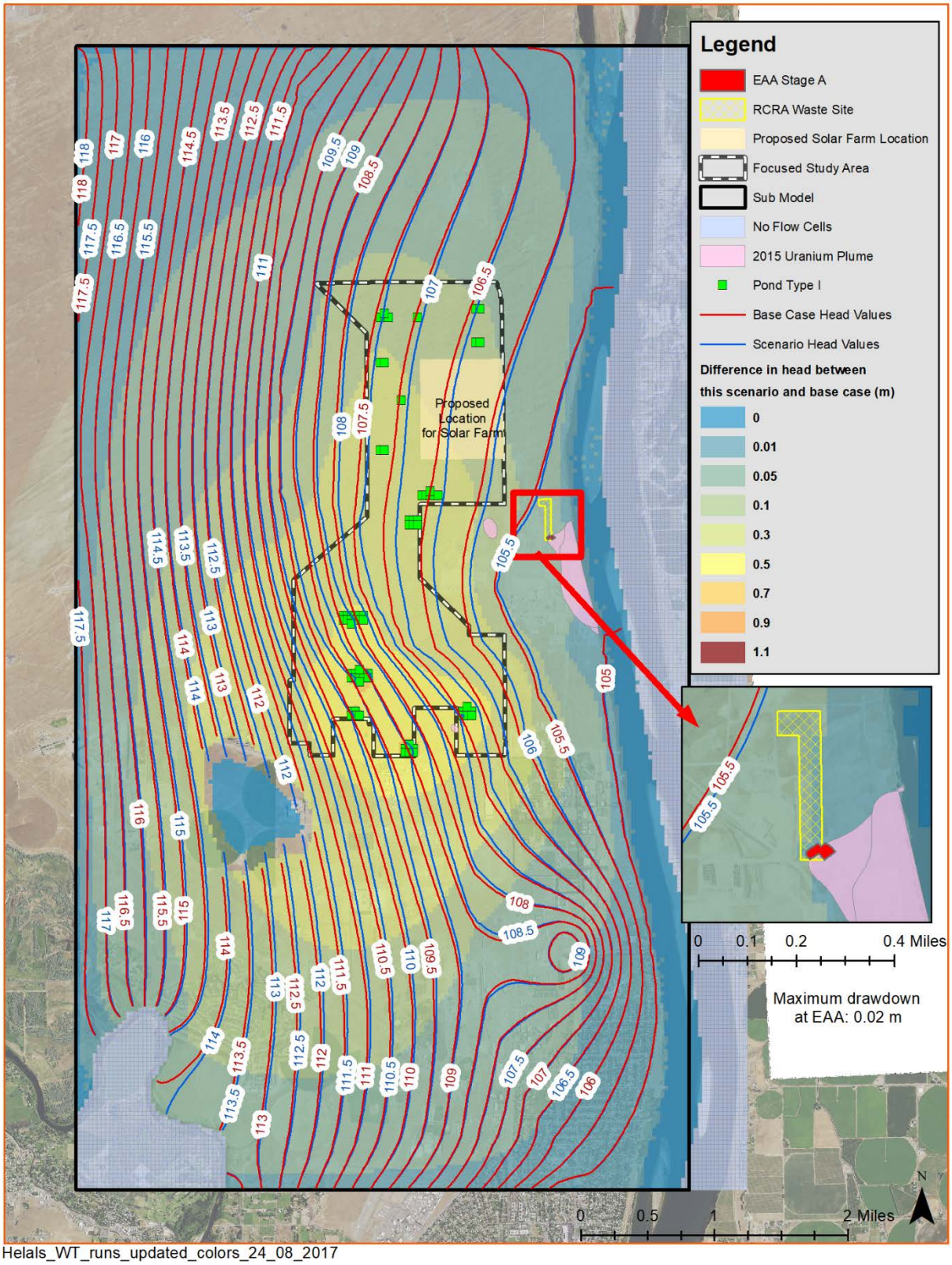

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Figure 7-20. Comparison of Groundwater Head Elevations for the Base Case and Development Scenario 1b

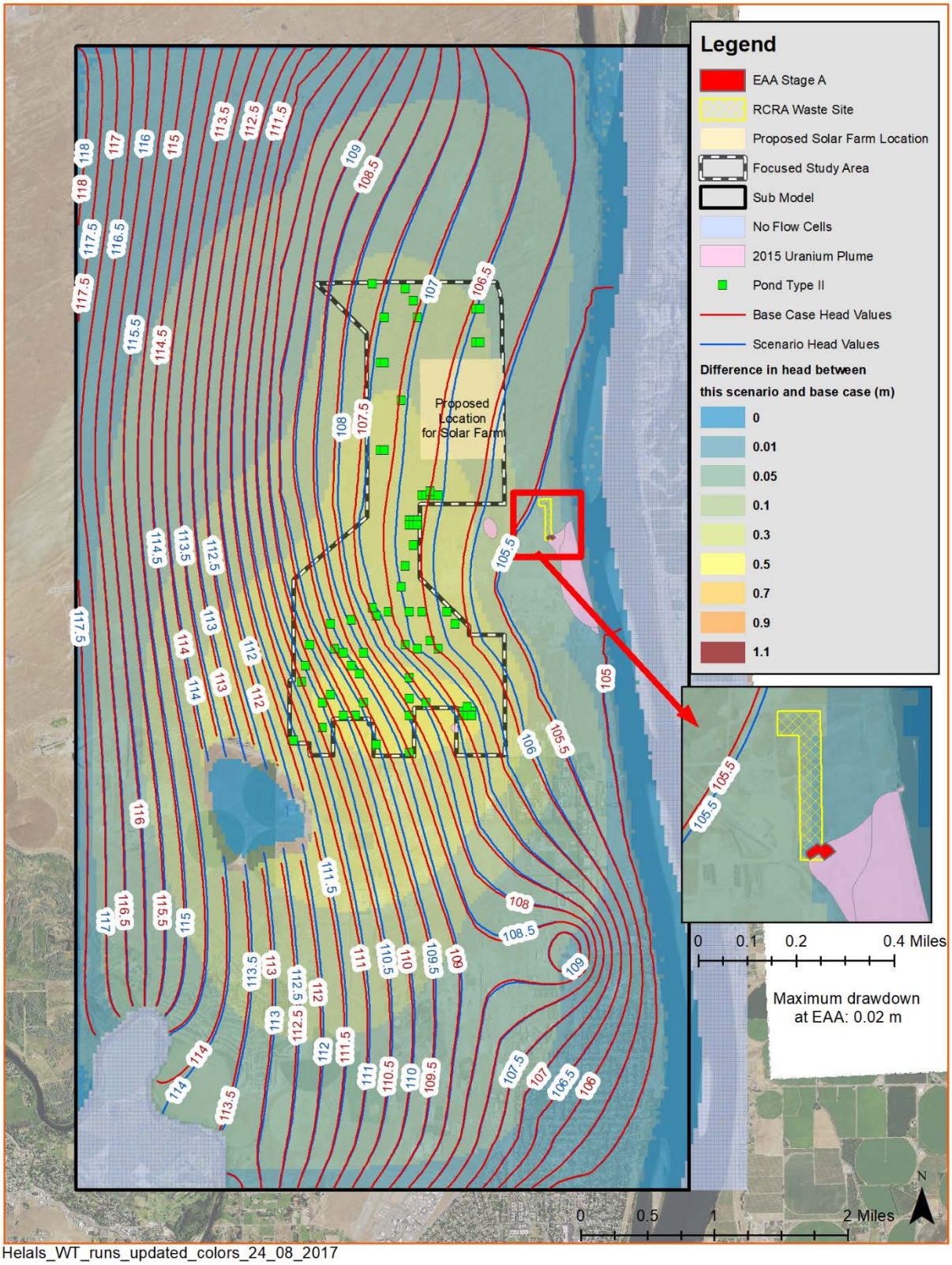

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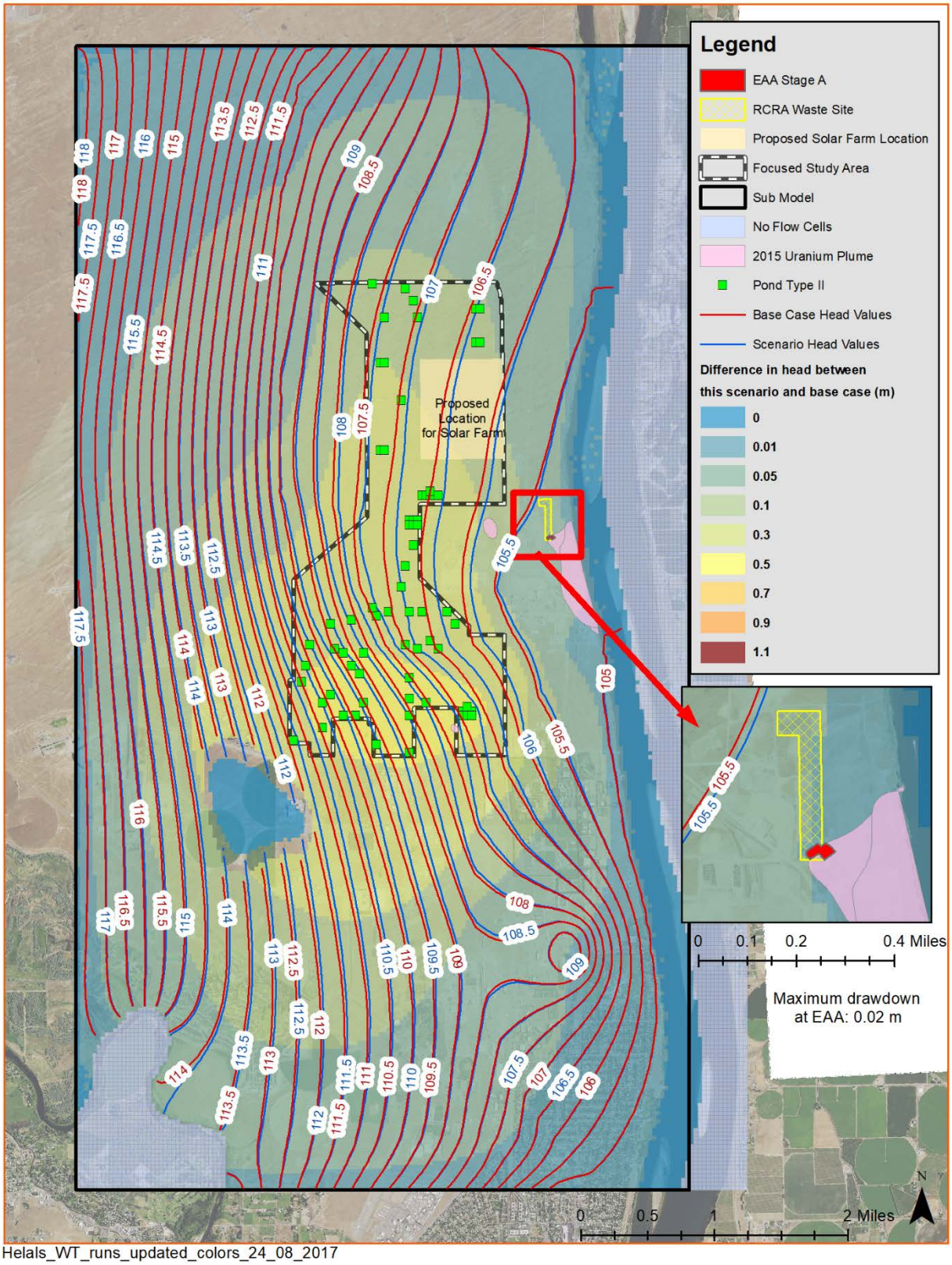
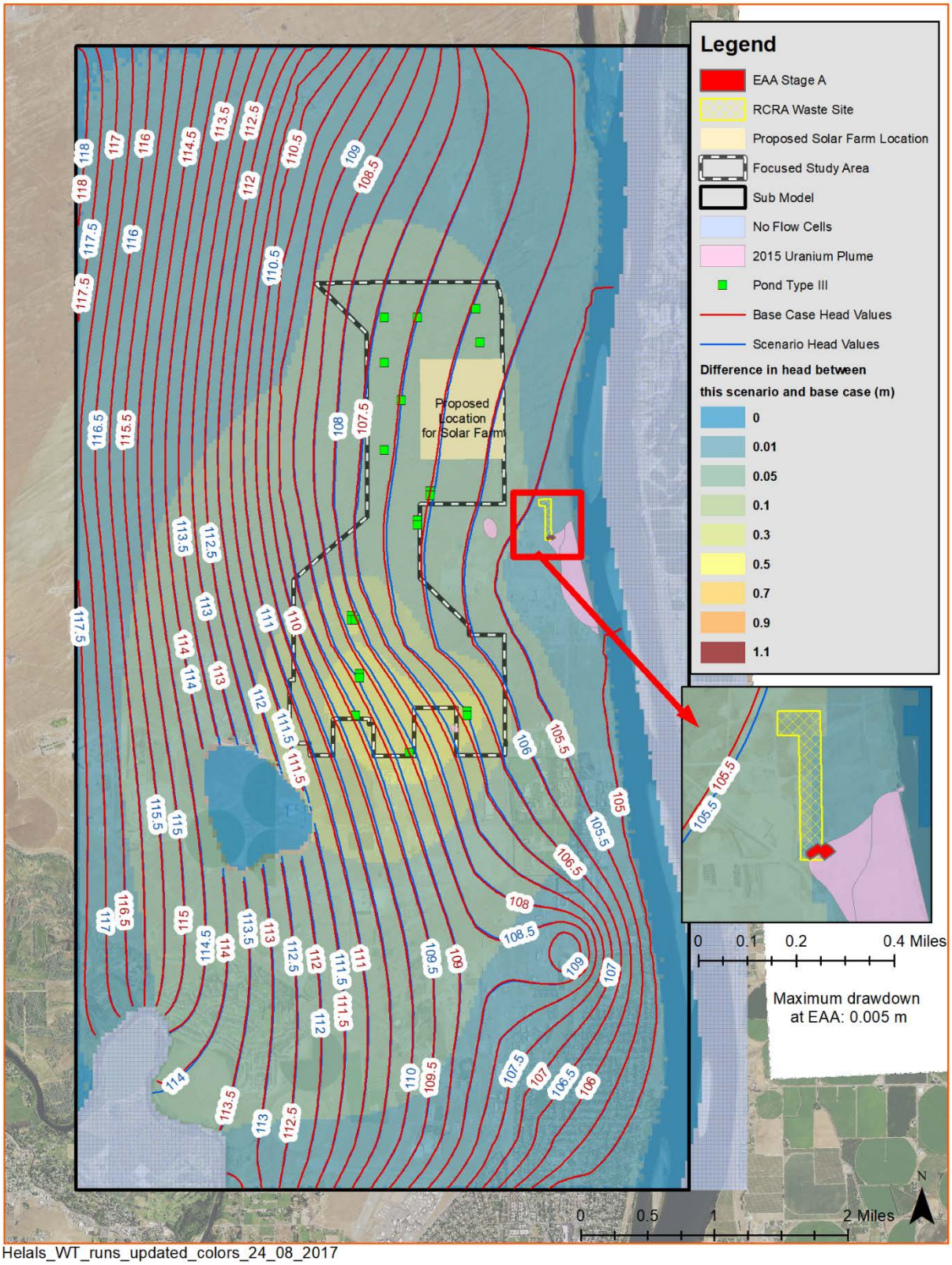
Figure 7-21. Comparison of Groundwater Head Elevations for the Base Case and Development Scenario 2a



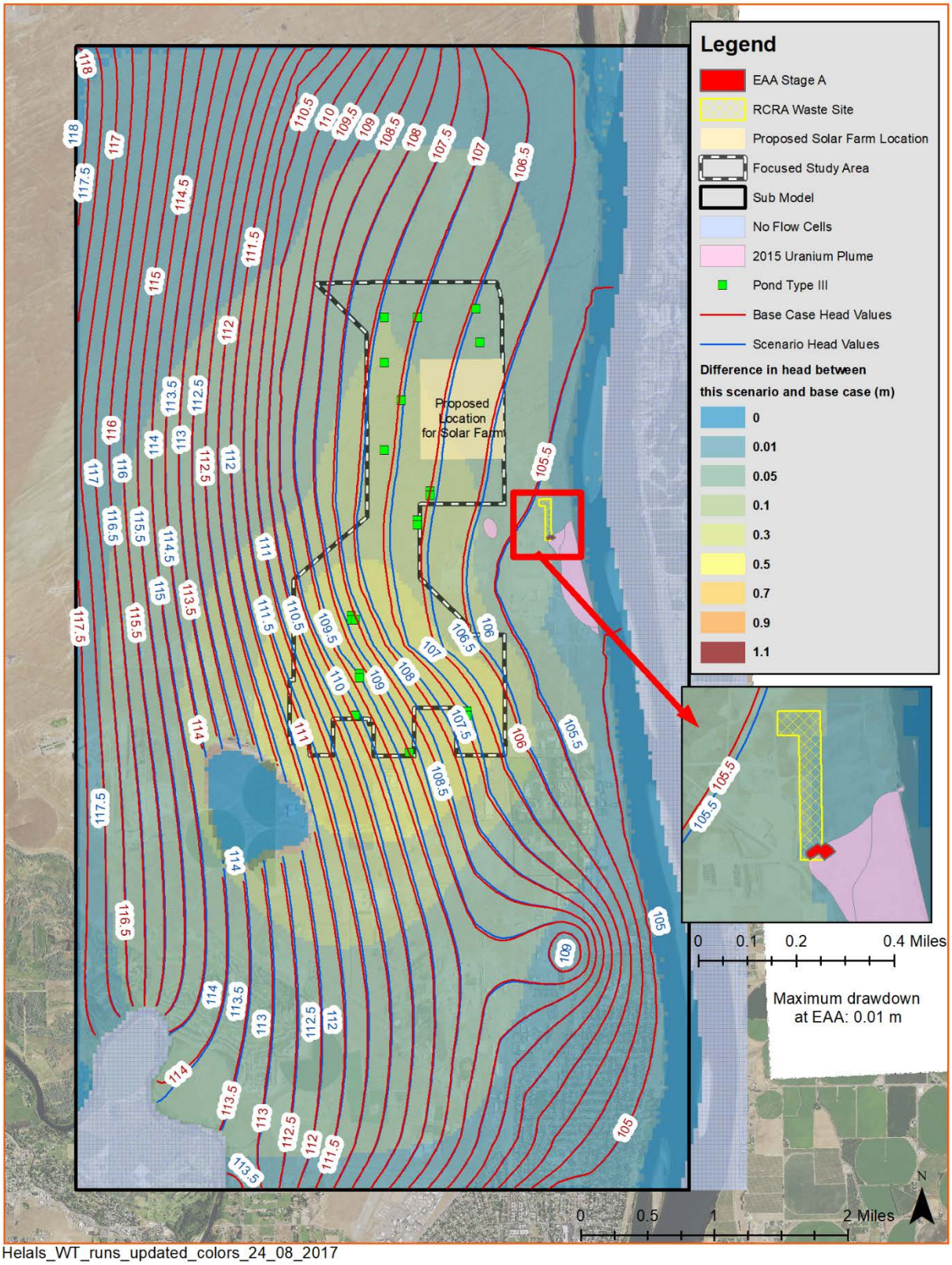
Helals_WT_runs_updated_colors_24_08_2017

Figure 7-22. Comparison of Groundwater Head Elevations for the Base Case and Development Scenario 2b



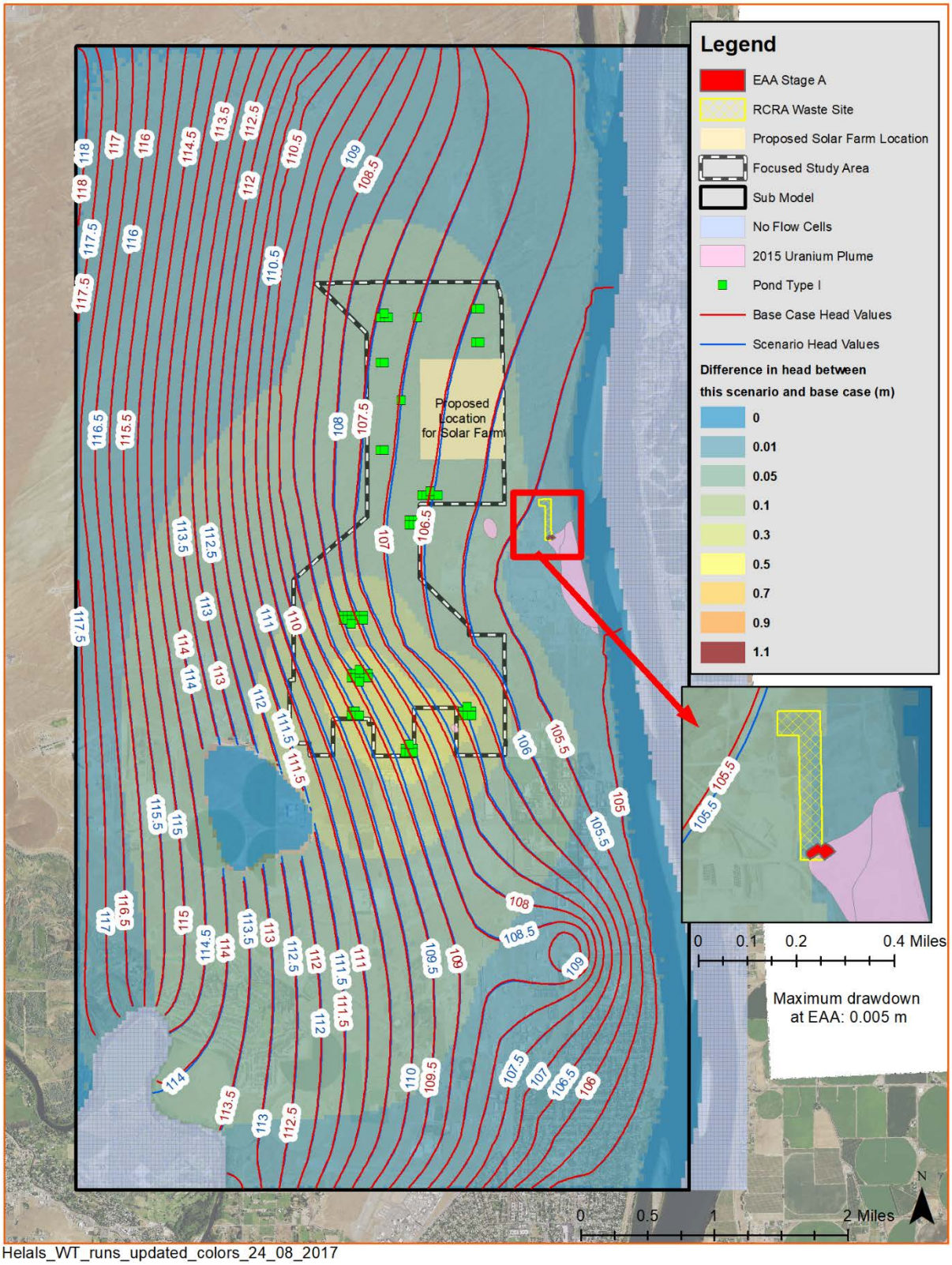
Helals_WT_runs_updated_colors_24_08_2017

Figure 7-23. Comparison of Groundwater Head Elevations for the Base Case and Development Scenario 3a



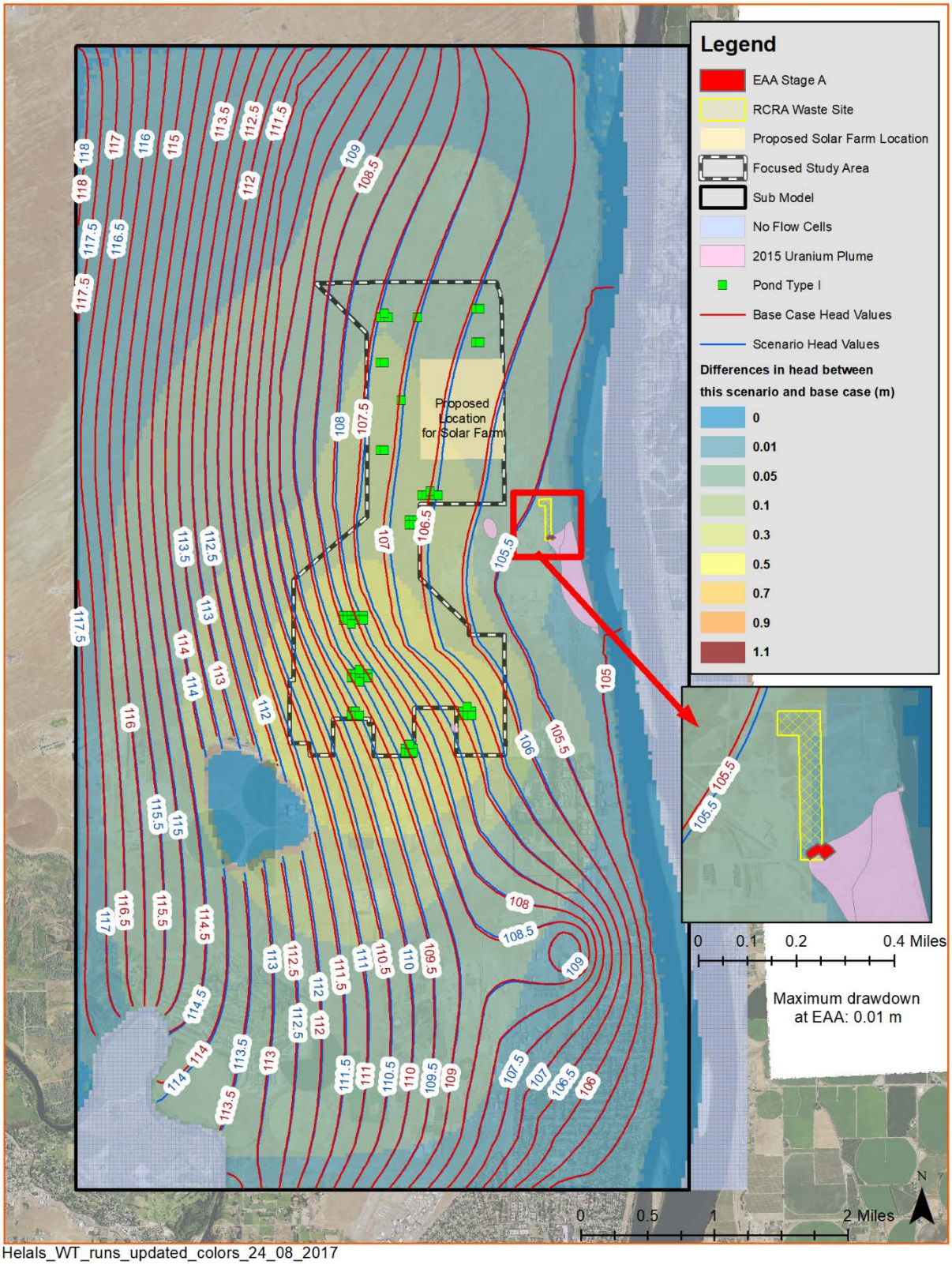
Helals_WT_runs_updated_colors_24_08_2017

Figure 7-24. Comparison of Groundwater Head Elevations for the Base Case and Development Scenario 3b



Helals_WT_runs_updated_colors_24_08_2017

Figure 7-25. Comparison of Groundwater Head Elevations for the Base Case and Development Scenario 4a



Helals_WT_runs_updated_colors_24_08_2017

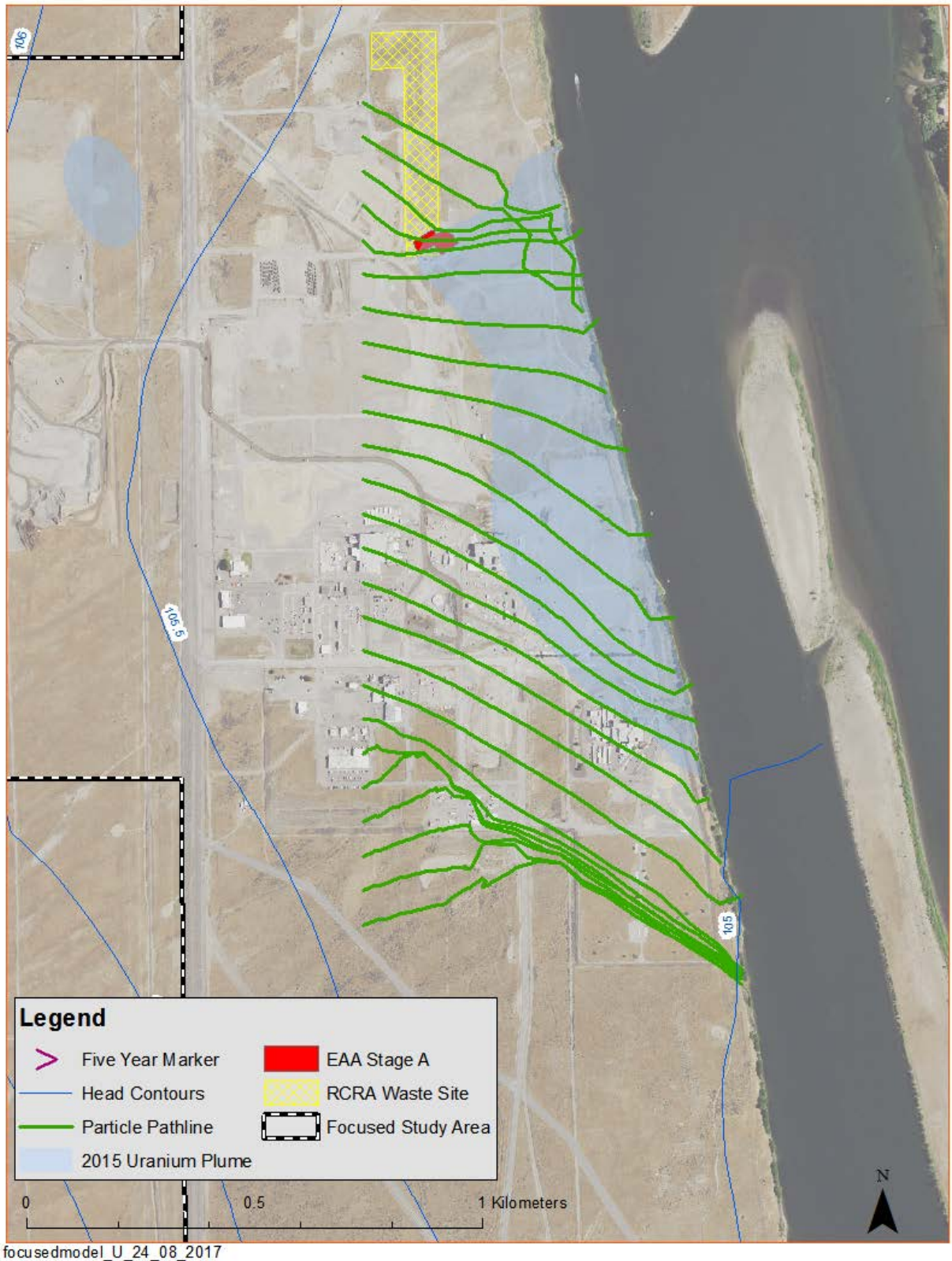
Figure 7-26. Comparison of Groundwater Head Elevations for the Base Case and Development Scenario 4b

7.2.3 Particle Tracking Analysis

Figure 7-27 through Figure 7-35 show simulated flow paths through the 300 Area uranium plume area, as delineated in 2015, for the base case and four development scenarios. Figure 7-36 through Figure 7-44 show simulated flow paths through the 300 Area nitrate plume area, as delineated in 2015, for the base case and four development scenarios. The flow paths are very similar to the EIS sub-model results. However, average travel time is significantly smaller than the EIS sub-model results. This is probably due the high conductivity zones within the nitrate/uranium plume footprint. Table 7-3 lists average travel times, direction of travel and discharge locations for the simulated flow paths. Overall, simulated flow paths do not change substantially under any of the development scenarios and the discharge location remains the Columbia River.

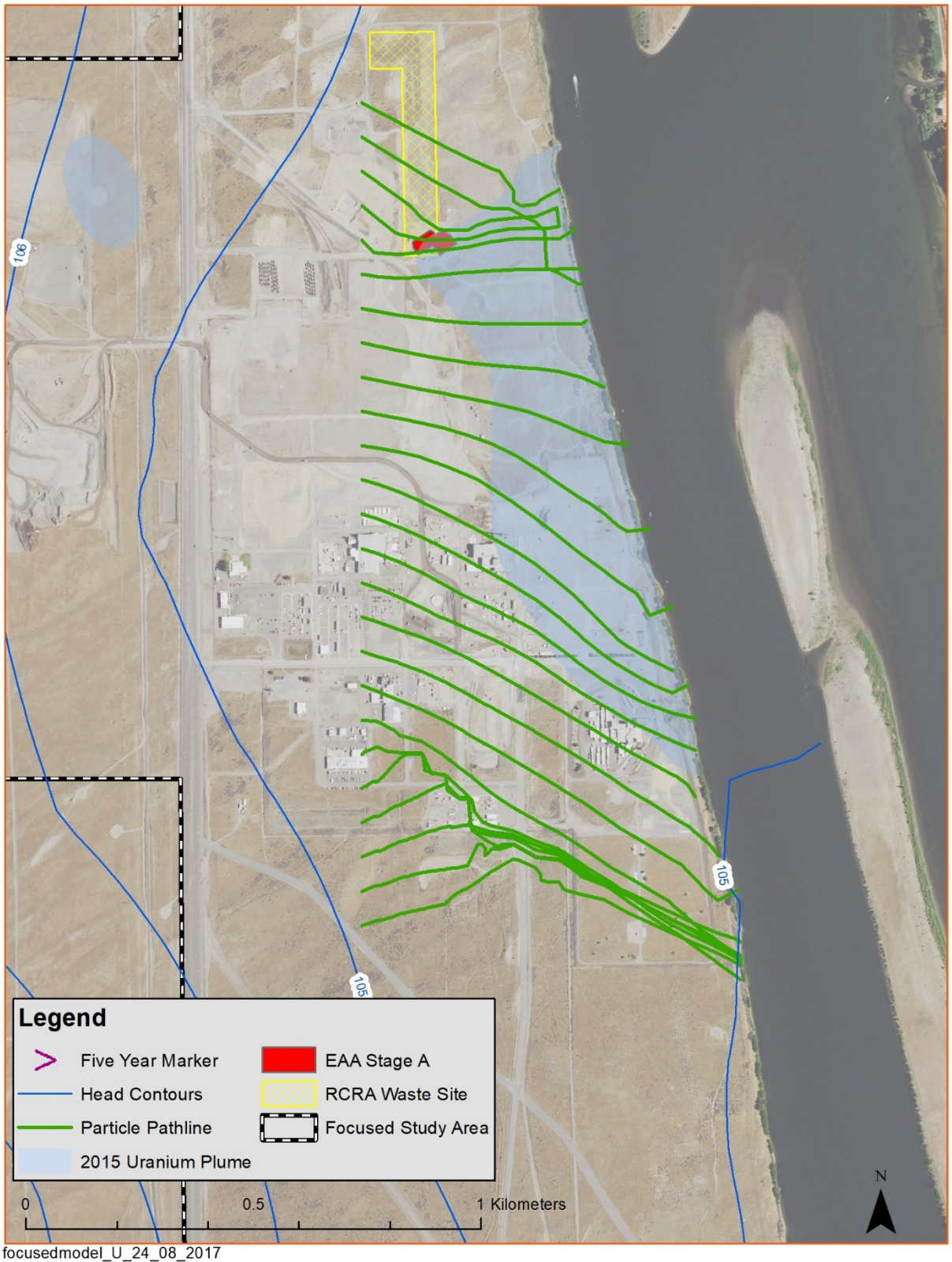
Table 7-3. Particle Tracking Results for the focus GWFM

Plume Feature	Base Case	Scenario 1a	Scenario 1b	Scenario 2a	Scenario 2b	Scenario 3a	Scenario 3b	Scenario 4a	Scenario 4b
Uranium average travel time (yr)	1.02	0.94	0.92	0.92	0.92	0.99	0.97	0.99	0.97
Uranium trajectory	Due east to Columbia River	Due east to Columbia River	Unchanged, due east to Columbia River	Unchanged, due east to Columbia River	Unchanged, due east to Columbia River	Unchanged, due east to Columbia River	Unchanged, due east to Columbia River	Unchanged, due east to Columbia River	Unchanged, due east to Columbia River
Uranium discharge point	Columbia River	Columbia River	Columbia River	Columbia River	Columbia River	Columbia River	Columbia River	Columbia River	Columbia River
Nitrate average travel time (yr)	10.6	10.9	10.9	10.8	10.9	10.7	10.5	10.7	10.7
Nitrate trajectory	East to Columbia River, away from Richland recharge mound	Slightly deflected near stormwat er ponds	Slightly deflected near stormwater ponds	Slightly deflected near stormwater ponds	Slightly deflected near stormwater ponds	Slightly deflected near stormwater ponds	Slightly deflected near stormwater ponds	Slightly deflected near stormwater ponds	Slightly deflected near stormwater ponds
Nitrate discharge point	Columbia River	Columbia River	Columbia River	Columbia River	Columbia River	Columbia River	Columbia River	Columbia River	Columbia River



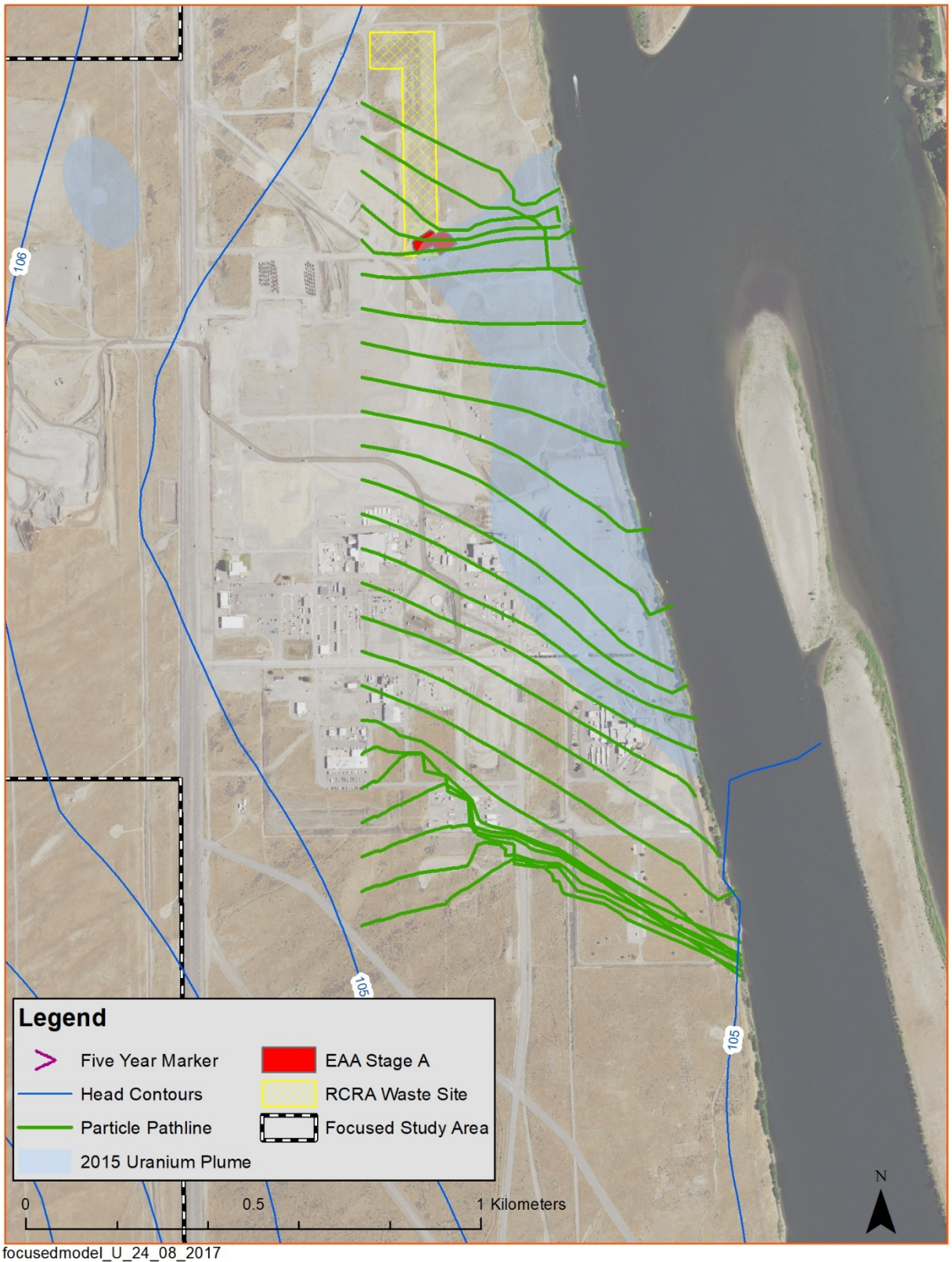
focusedmodel_U_24_08_2017

Figure 7-27. Forward Particle Tracking for the Base Case Simulation (Uranium)



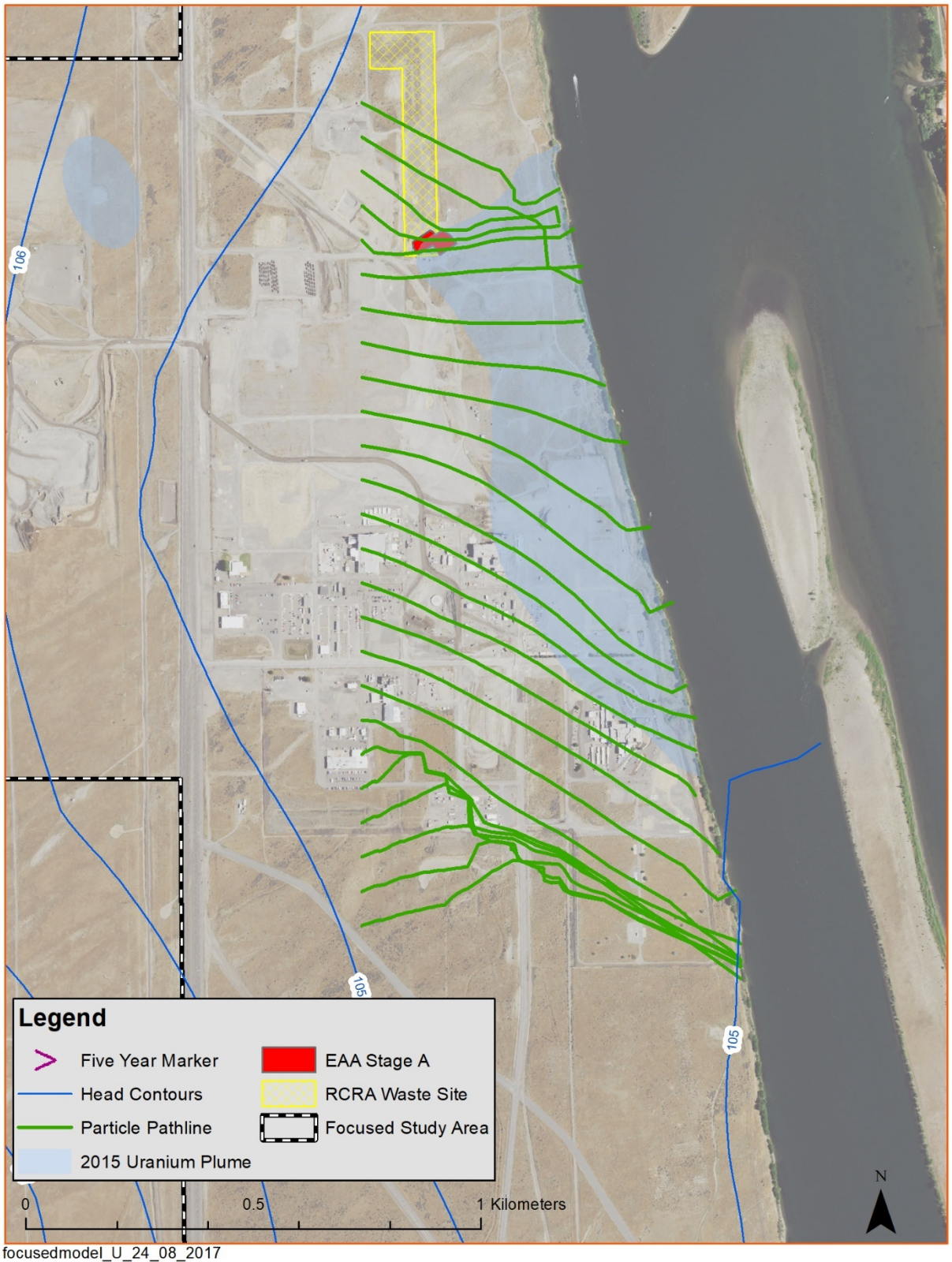
focusedmodel_U_24_08_2017

Figure 7-28. Forward Particle Tracking for High Impact Non-Irrigated Native Vegetation with Pond Type I (Uranium)



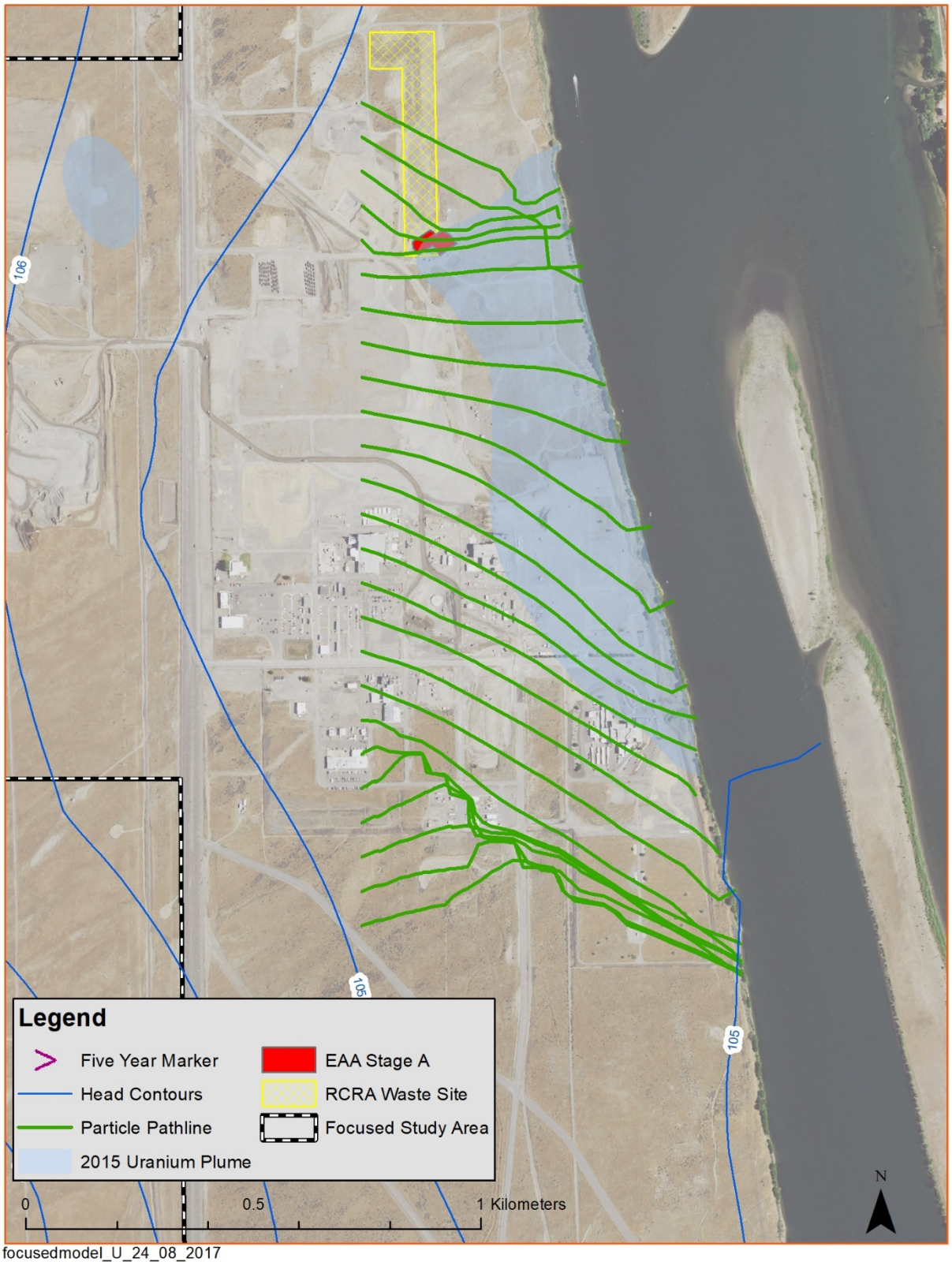
focusedmodel_U_24_08_2017

Figure 7-29. Forward Particle Tracking for High Impact Irrigated Urban Vegetation with Pond Type I (Uranium)



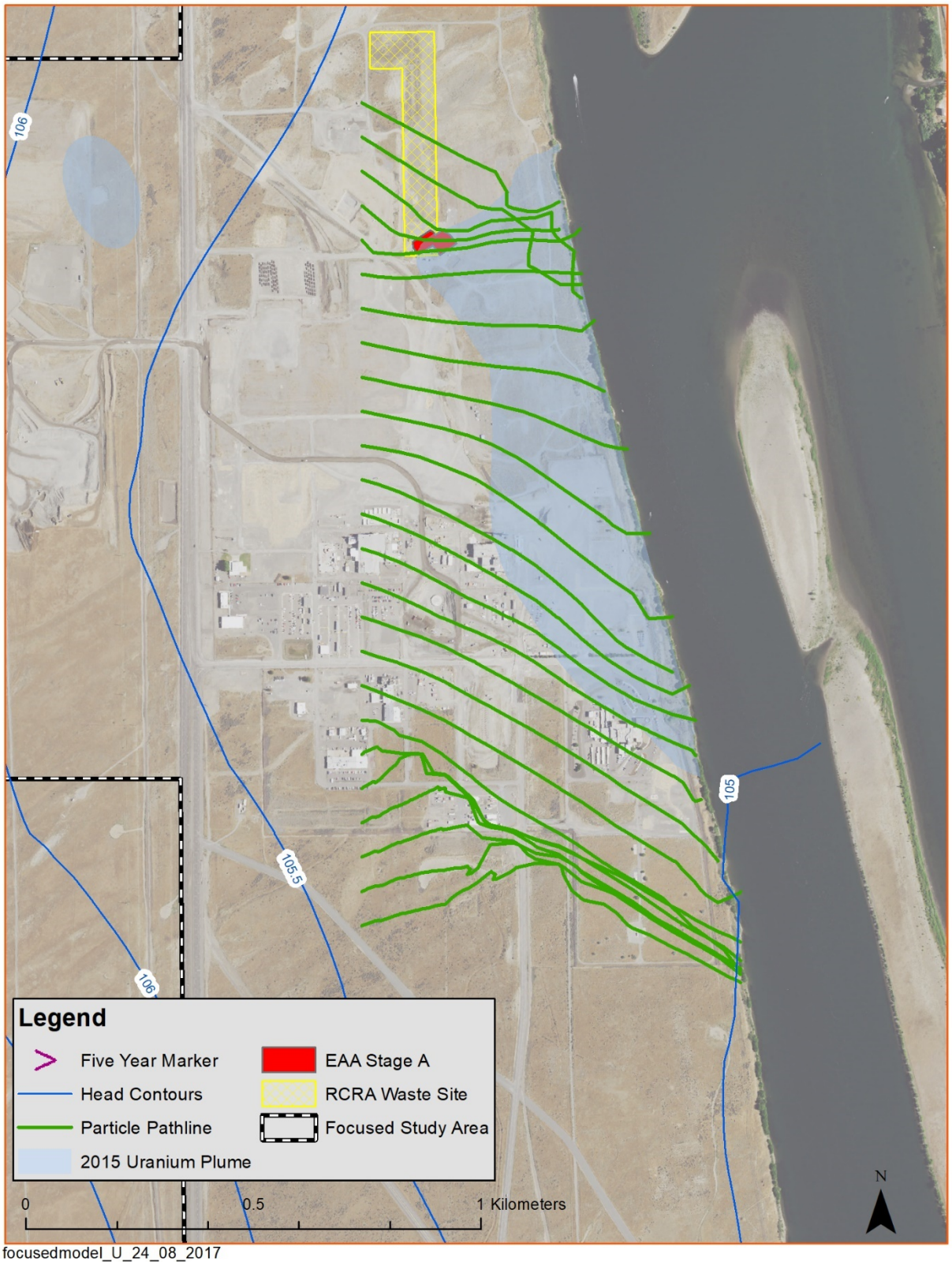
focusedmodel_U_24_08_2017

Figure 7-30. Forward Particle Tracking for High Impact Non-Irrigated Native Vegetation with Pond Type II (Uranium)



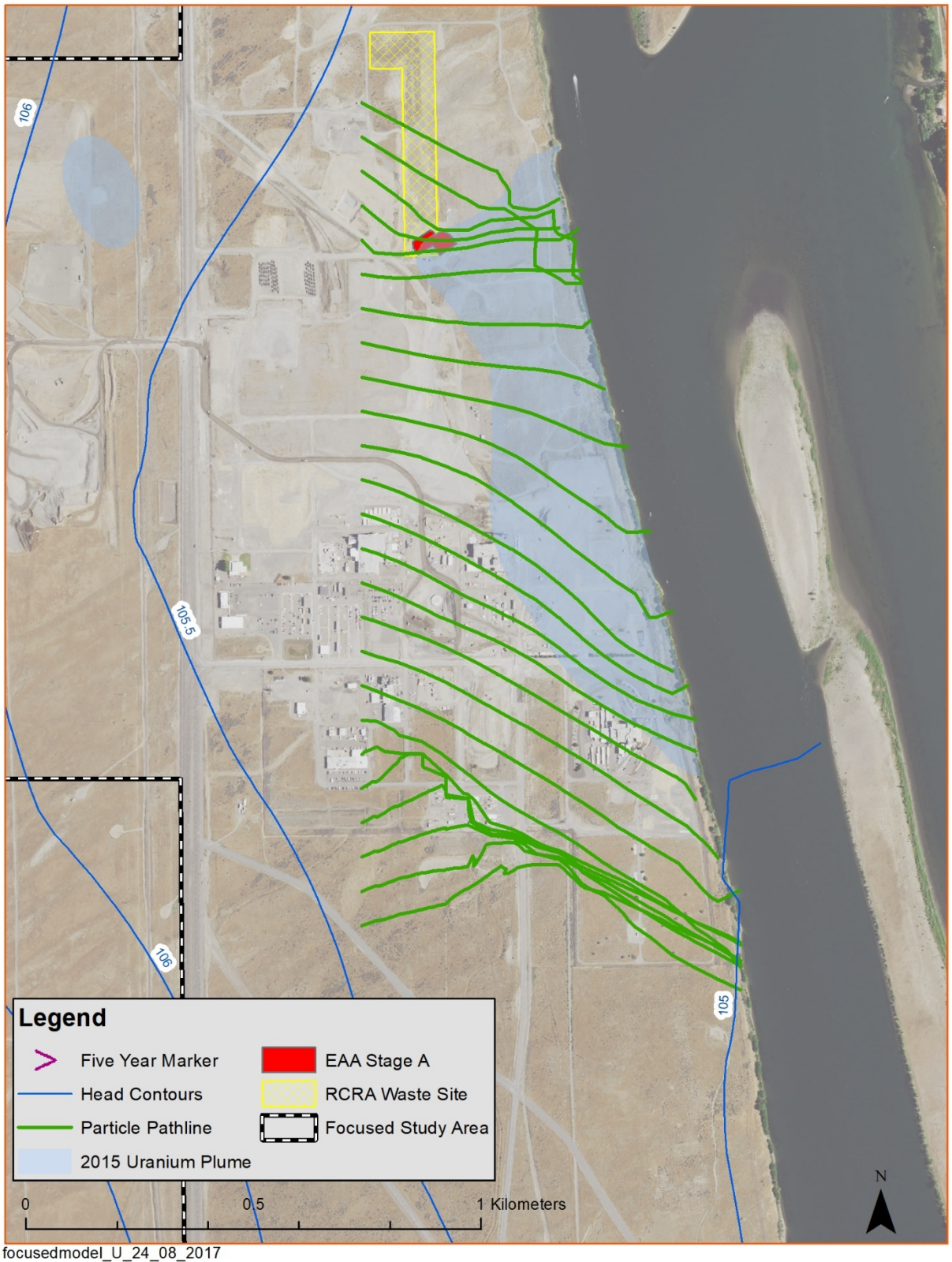
focusedmodel_U_24_08_2017

Figure 7-31. Forward Particle Tracking for High Impact Irrigated Urban Vegetation with Pond Type II (Uranium)



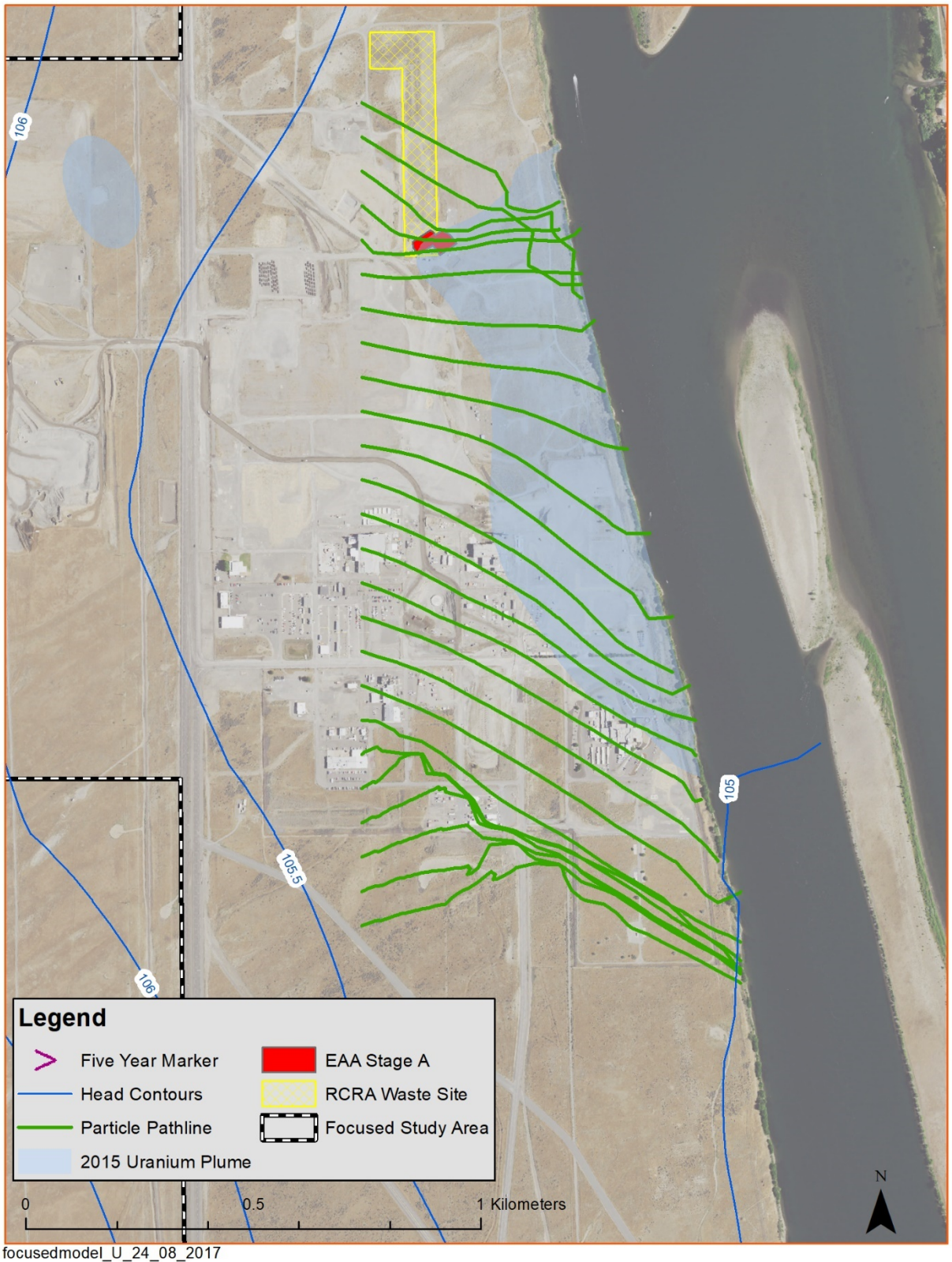
focusedmodel_U_24_08_2017

Figure 7-32. Forward Particle Tracking for Low Impact Non-Irrigated Native Vegetation with Pond Type III (Uranium)



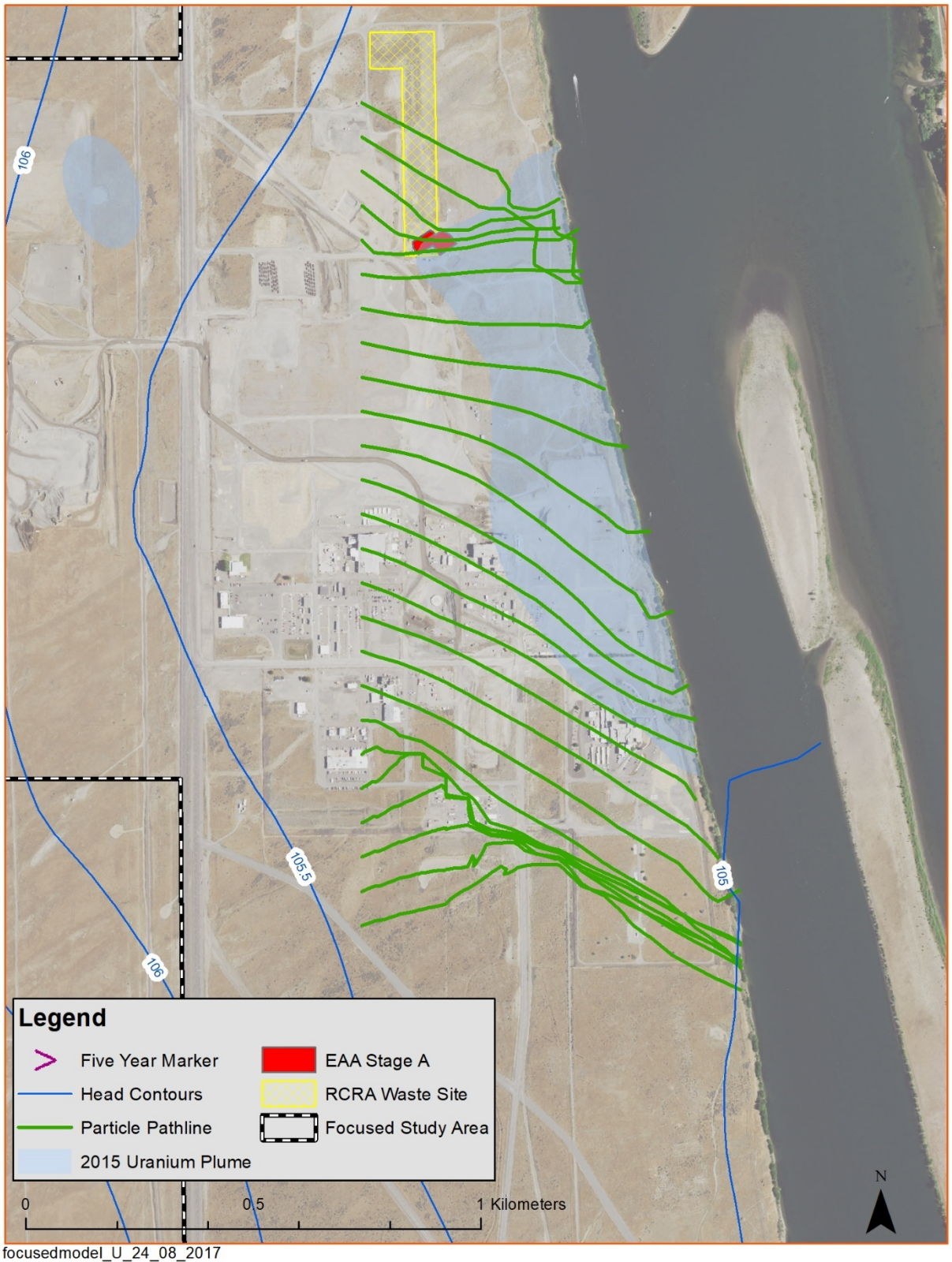
focusedmodel_U_24_08_2017

Figure 7-33. Forward Particle Tracking for Low Impact Irrigated Urban Vegetation with Pond Type III (Uranium)



focusedmodel_U_24_08_2017

Figure 7-34. Forward Particle Tracking for Low Impact Non-Irrigated Native Vegetation with Pond Type I (Uranium)



focusedmodel_U_24_08_2017

Figure 7-35. Forward Particle Tracking for Low Impact Irrigated Urban Vegetation with Pond Type I (Uranium)

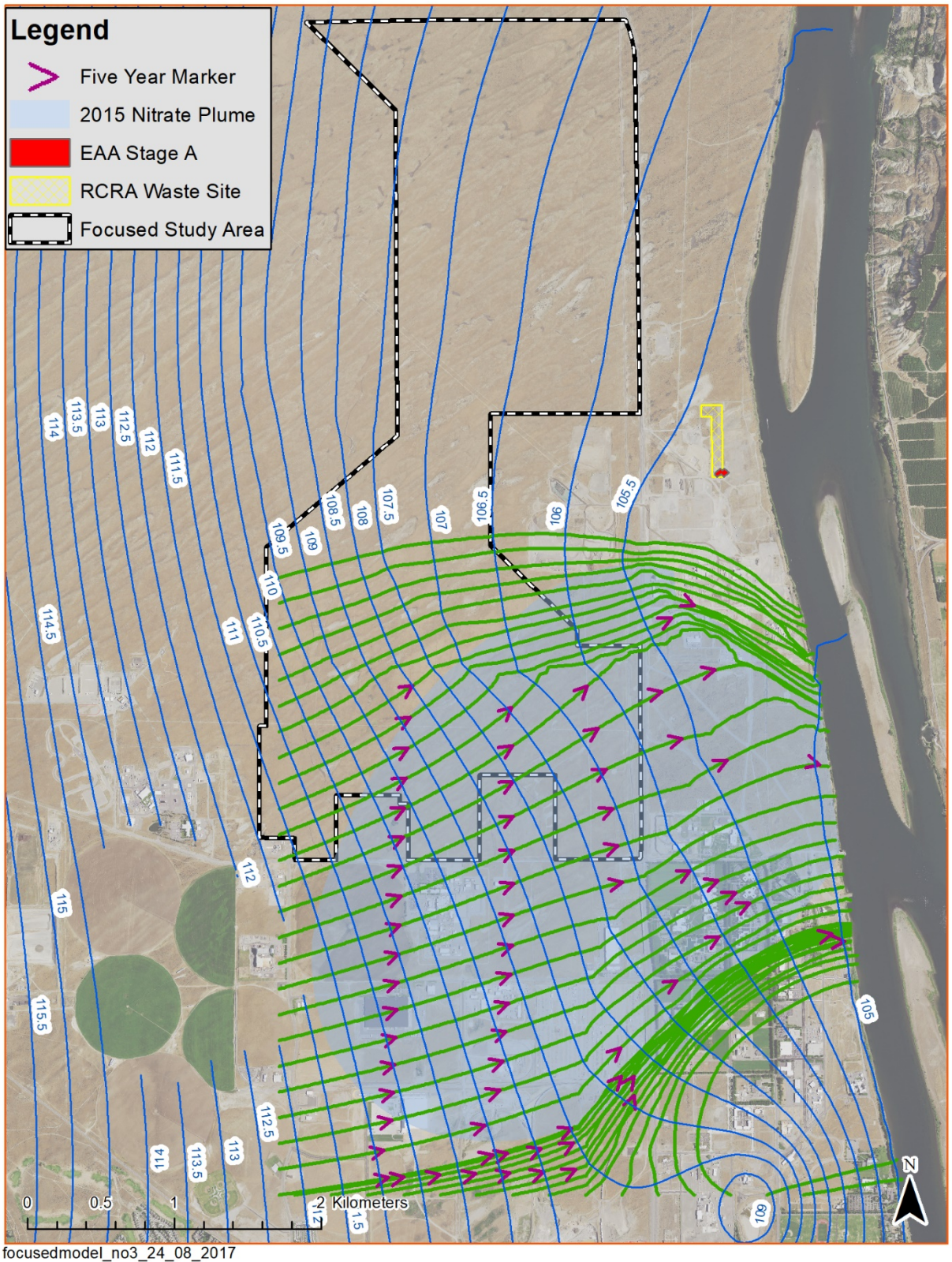
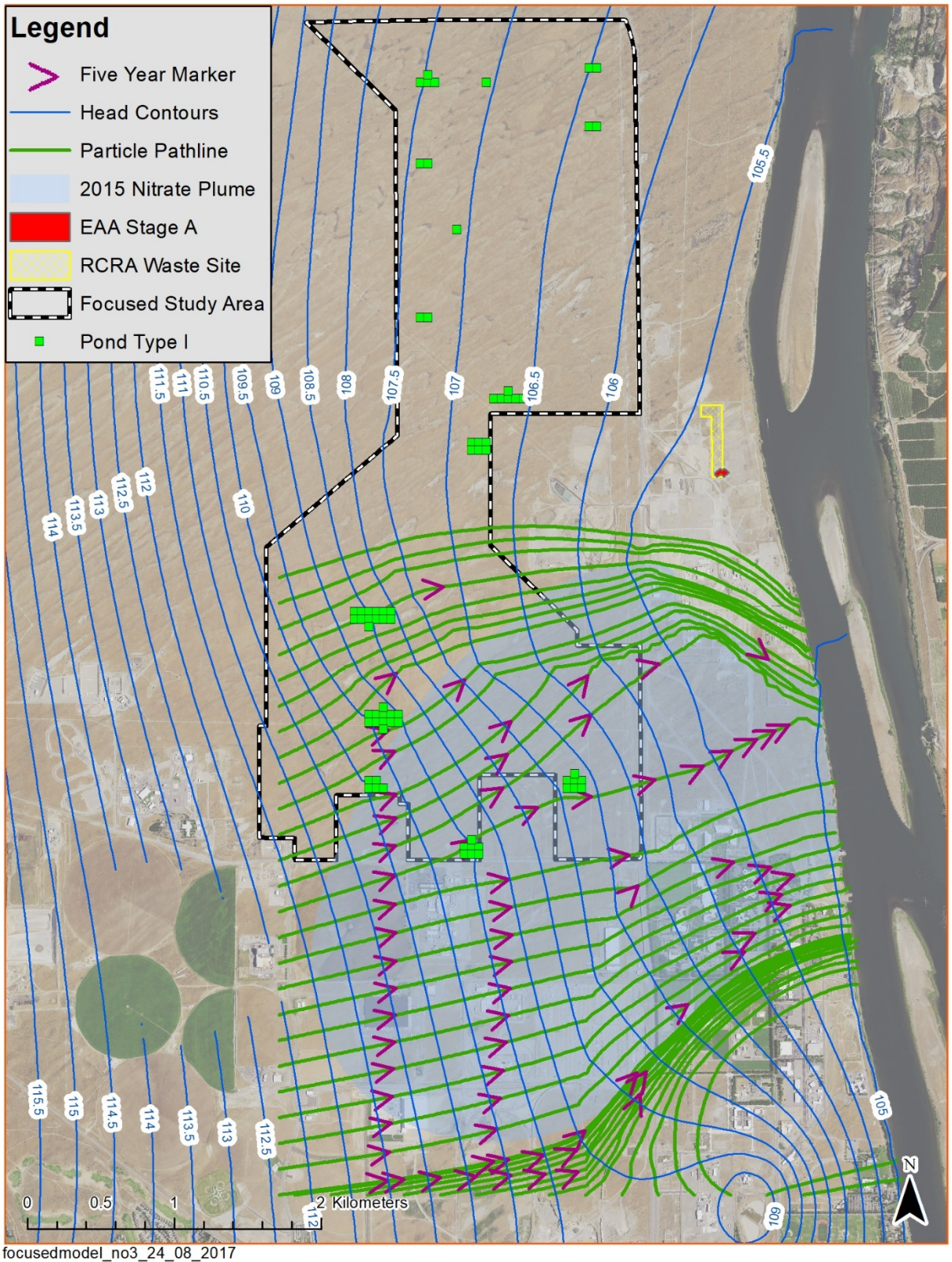
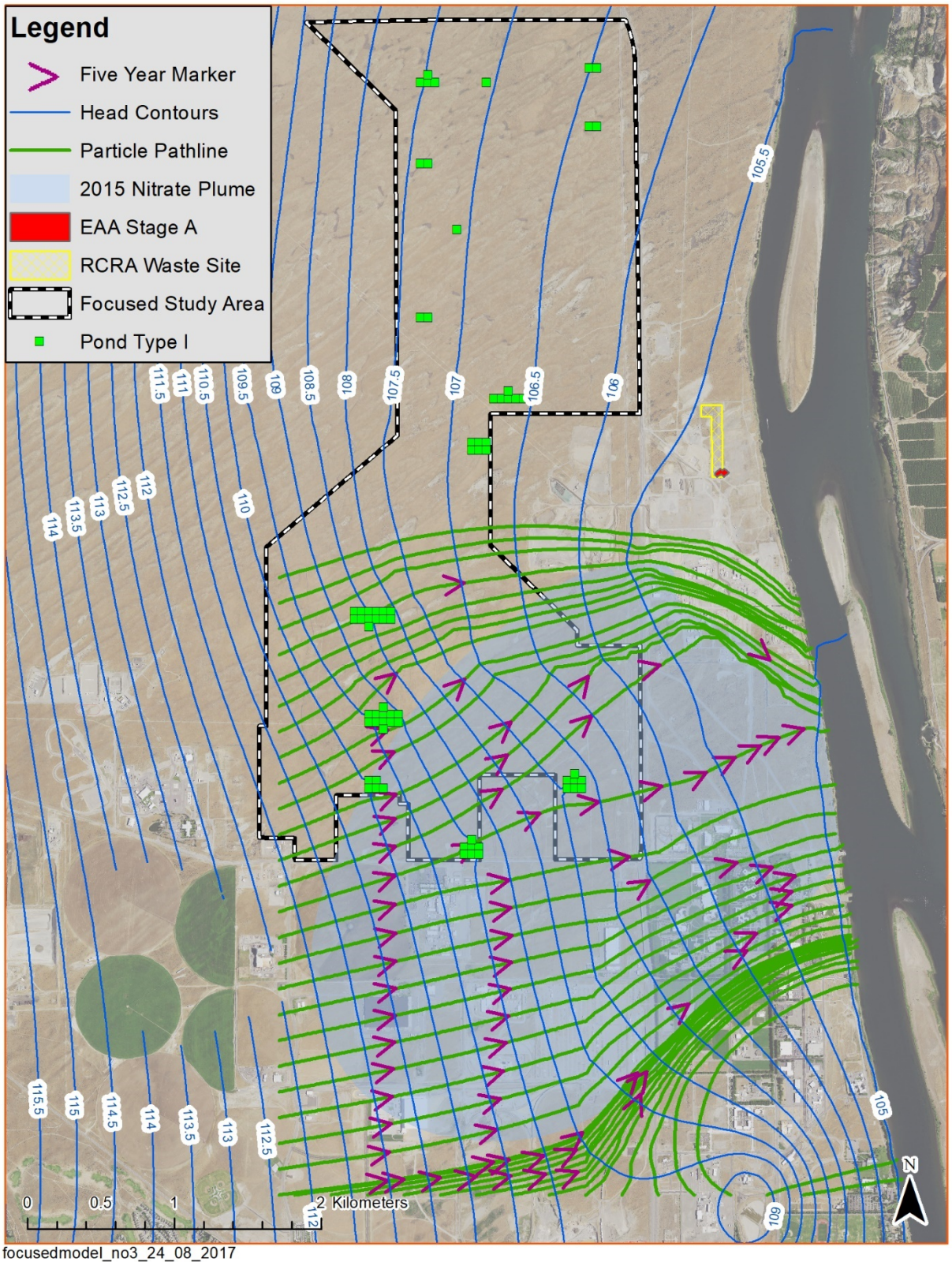


Figure 7-36. Forward Particle Tracking for the Base Case Simulation (Nitrate)



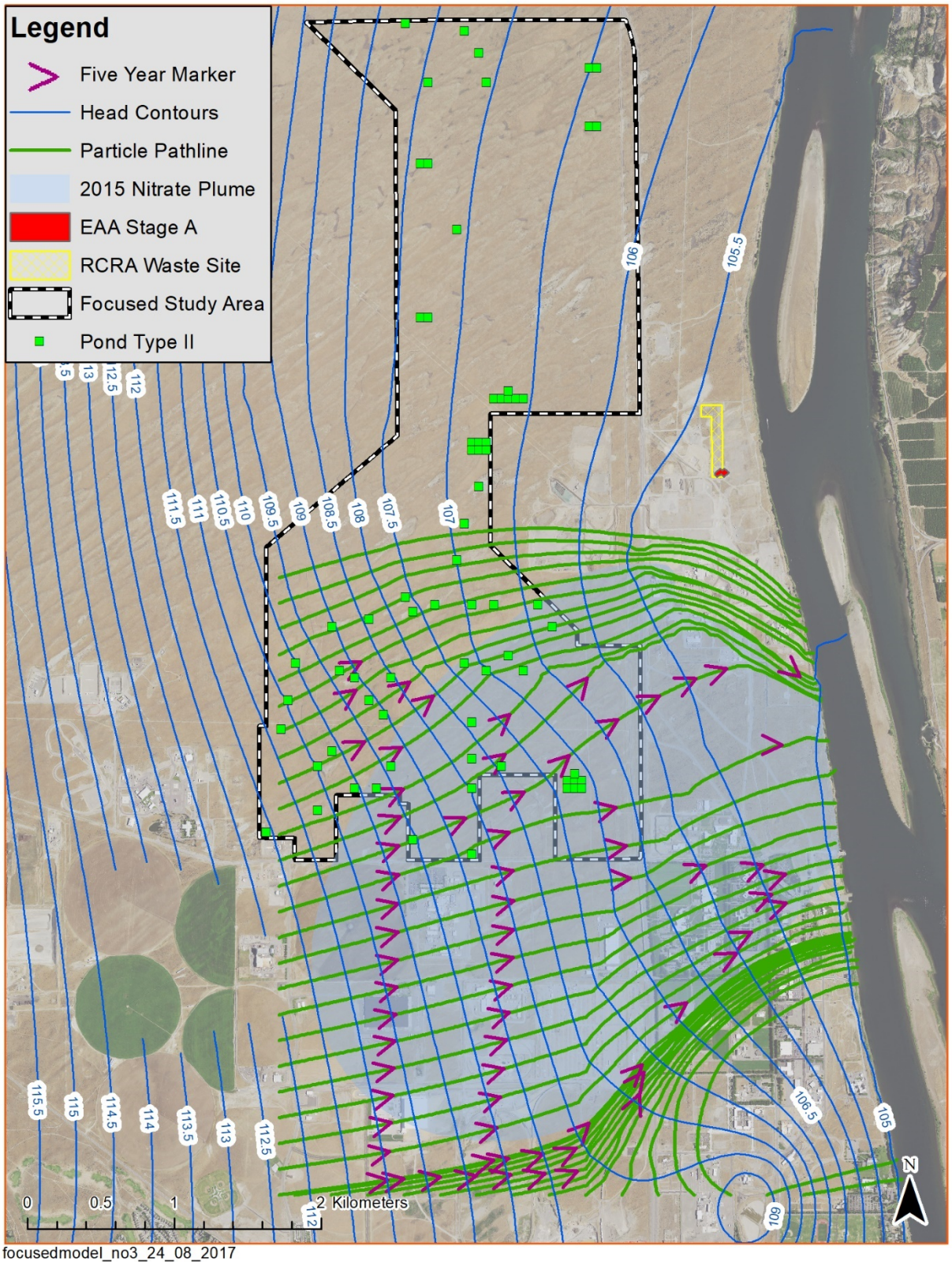
focusedmodel_no3_24_08_2017

Figure 7-37. Forward Particle Tracking for High Impact Non-Irrigated Native Vegetation with Pond Type I (Nitrate)



focusedmodel_no3_24_08_2017

Figure 7-38. Forward Particle Tracking for High Impact Irrigated Urban Vegetation with Pond Type I (Nitrate)



focusedmodel_no3_24_08_2017

Figure 7-39. Forward Particle Tracking for High Impact Non-Irrigated Native Vegetation with Pond Type II (Nitrate)

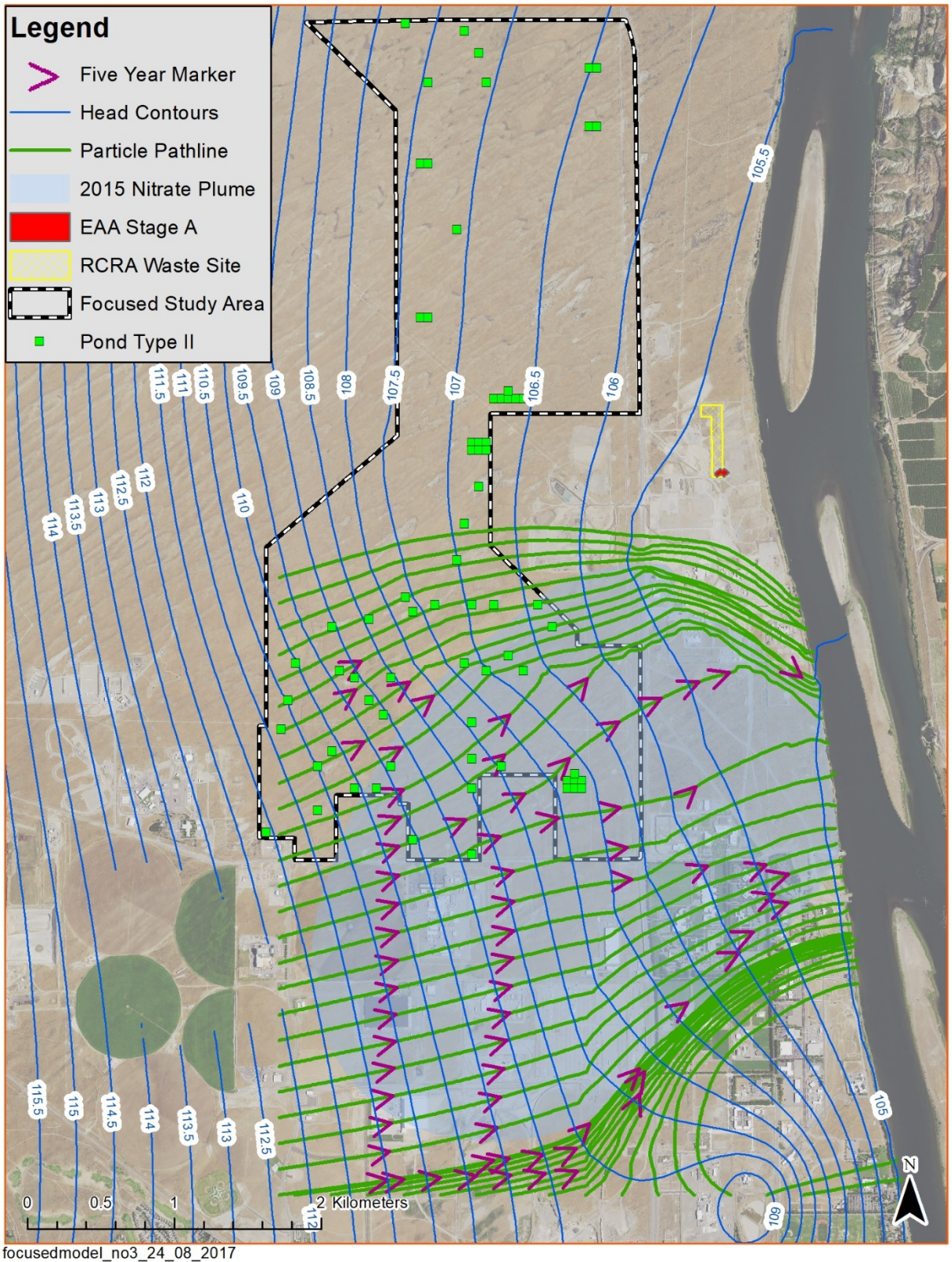


Figure 7-40. Forward Particle Tracking for High Impact Irrigated Urban Vegetation with Pond Type II (Nitrate)

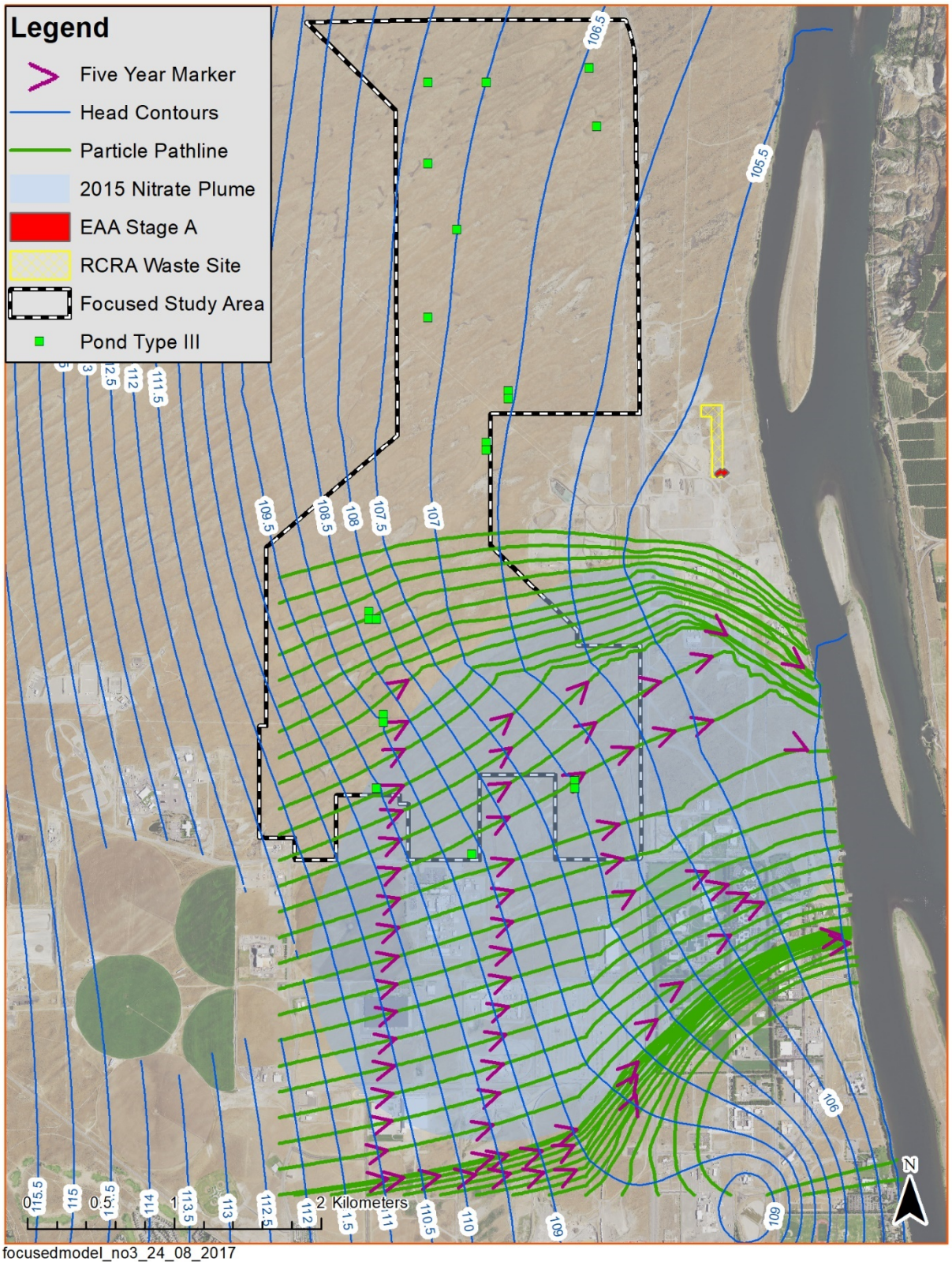


Figure 7-41. Forward Particle Tracking for Low Impact Non-Irrigated Native Vegetation with Pond Type III (Nitrate)

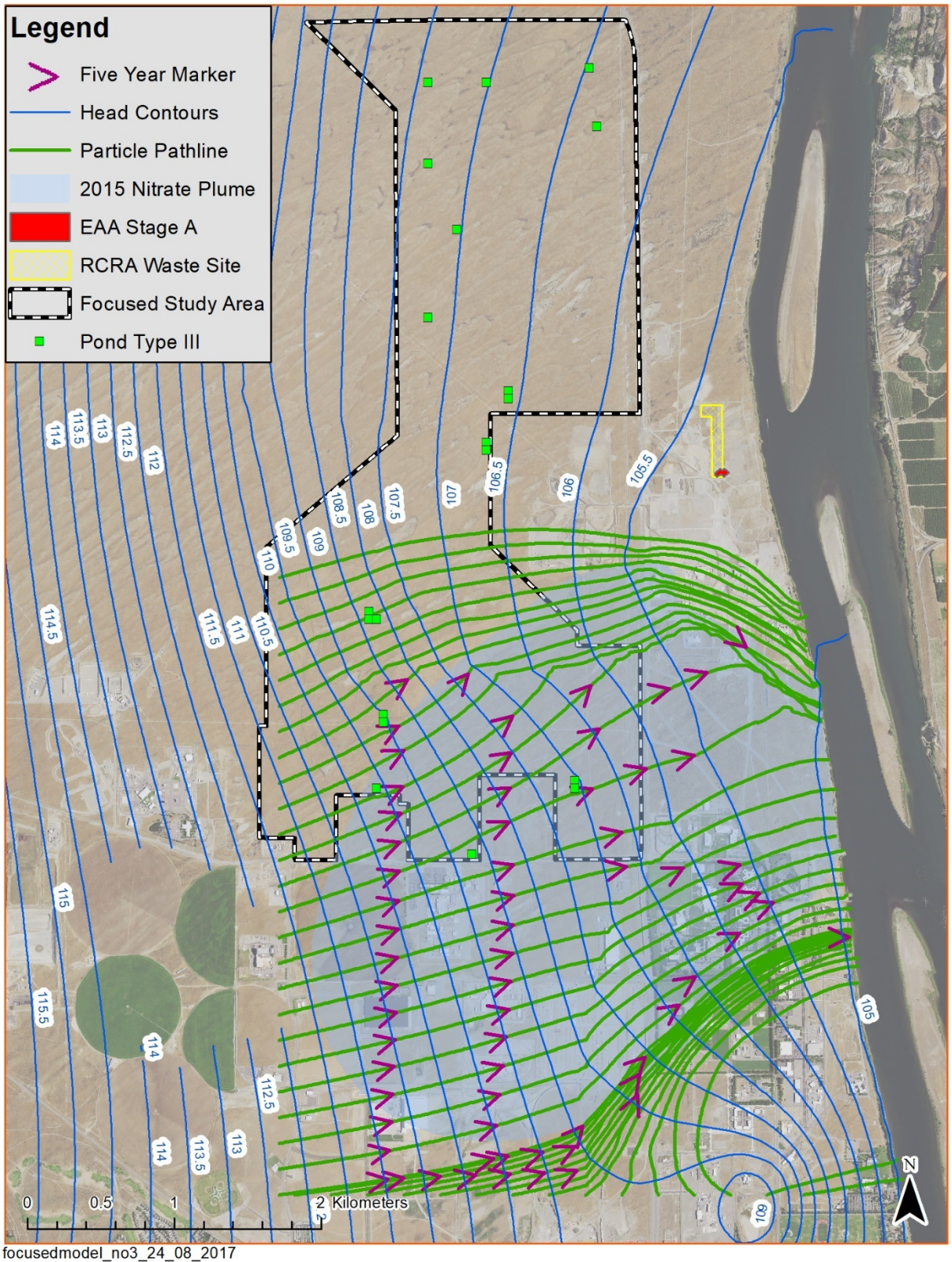
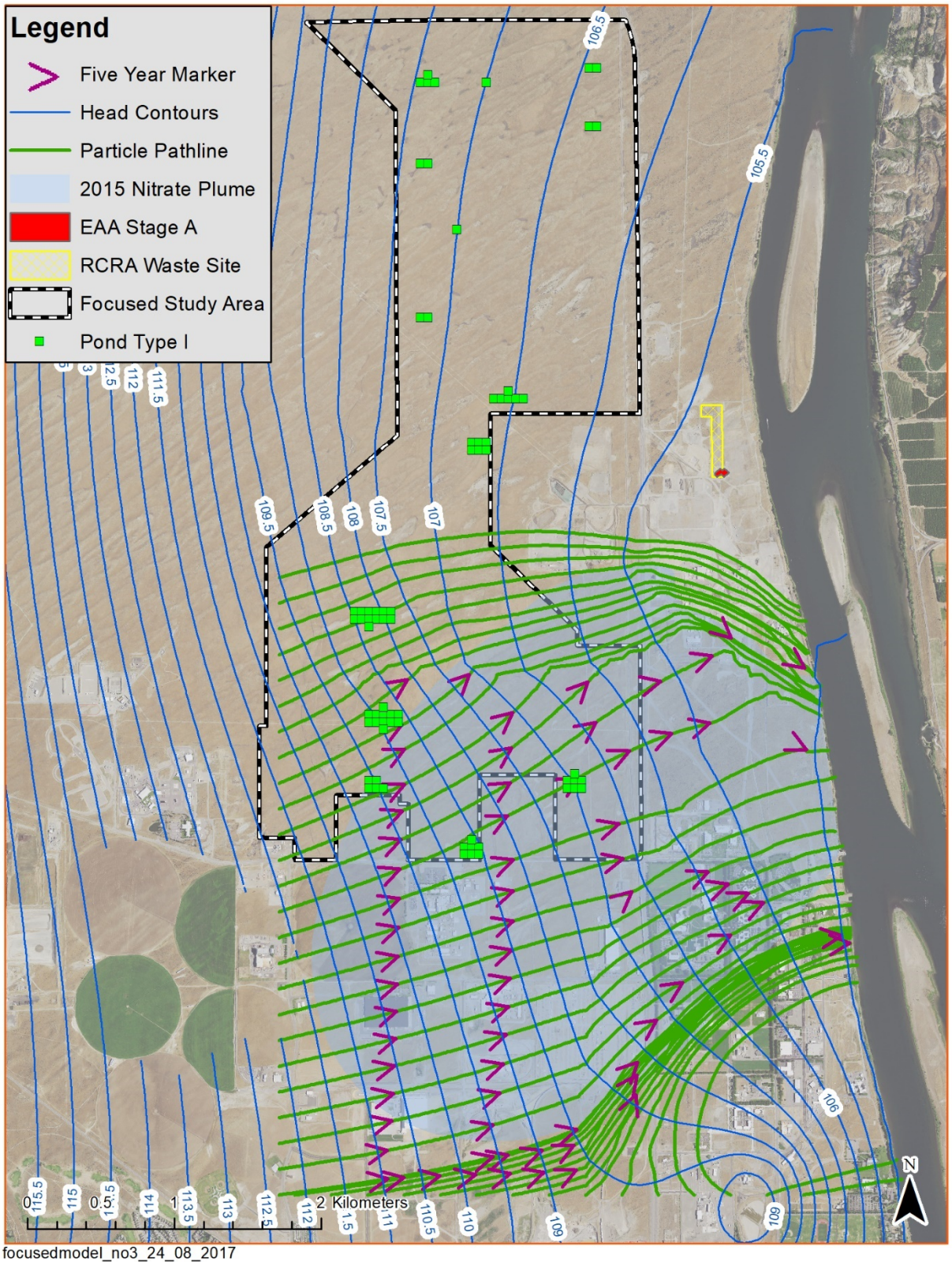


Figure 7-42. Forward Particle Tracking for Low Impact Irrigated Urban Vegetation with Pond Type III (Nitrate)



focusedmodel_no3_24_08_2017

Figure 7-43. Forward Particle Tracking for Low Impact Non-Irrigated Native Vegetation with Pond Type I (Nitrate)

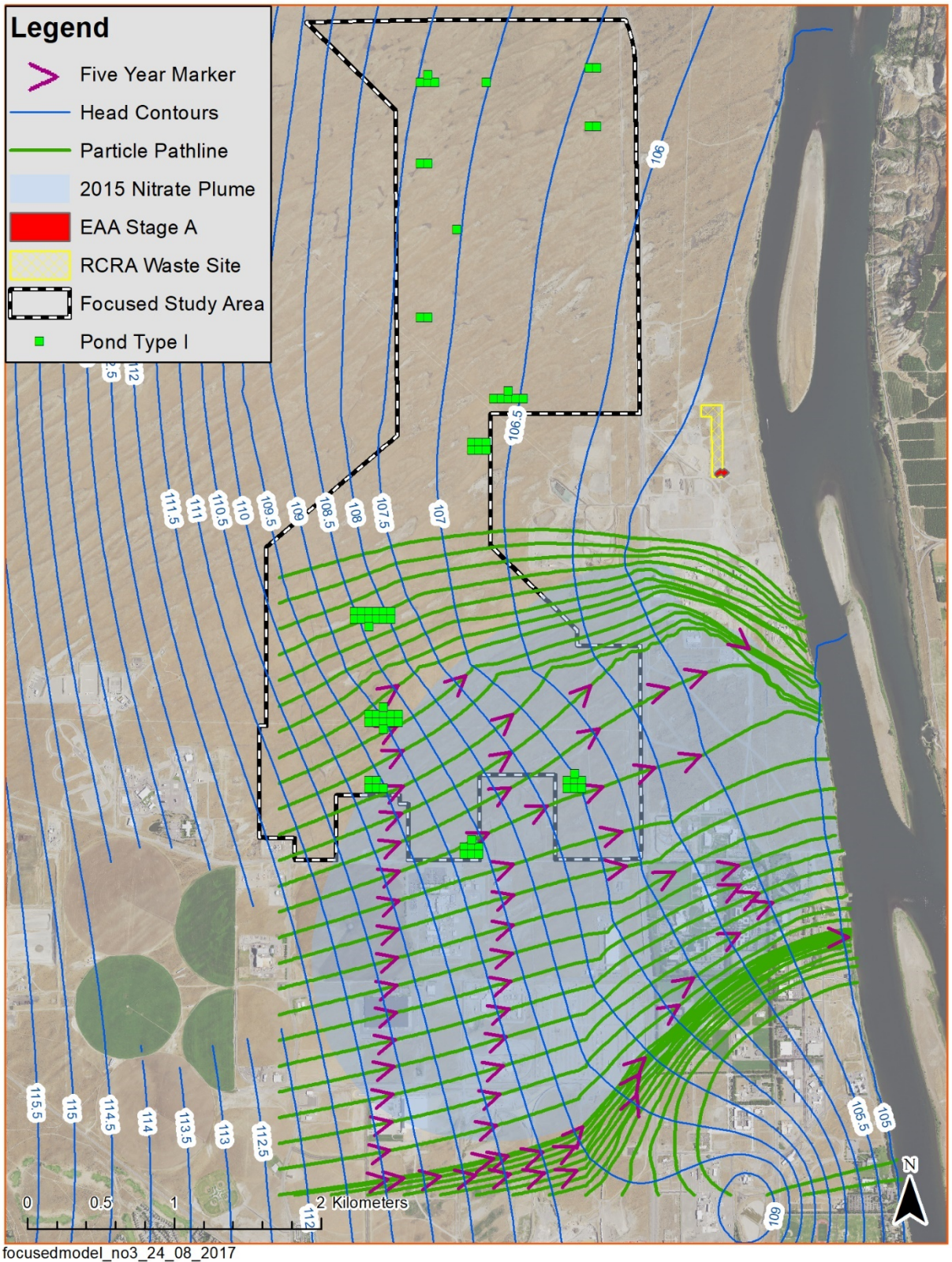


Figure 7-44. Forward Particle Tracking for Low Impact Irrigated Urban Vegetation with Pond Type I (Nitrate)

7.3 Conclusions

Two groundwater models, one a subdomain of the EIS groundwater model that did not include data within 600 m of the river in its calibration, and the other calibrated to Columbia River induced water-level changes in the aquifer were constructed and used to investigate the potential impact of stormwater management under several development scenarios. Comparison of mapped water-levels (Figure 2-2), the EIS submodel and focus model (Figure 6-1 and Figure 7-19) shows that the focus model better represents the effects of high hydraulic conductivity Hanford formation on the water table, which is a key conceptual feature of the 300 Area hydrogeology.

The conceptual implementation of non-pond recharge is not the same in the EIS sub-model and the focus model, however, approximate correspondence in the development scenarios is shown in Table 7-4 with simulated impact in descending order on the uranium plume in the EAA. The small head change in the focus model is attributable to the representation of the Hanford formation more consistent with characterization data and observed water level responses. This range of differences is much smaller than the annual fluctuation induced by the Columbia River and the natural uncertainty in the hydrologic cycle. The simulated changes in groundwater flow paths is minor, with flow remaining toward the Columbia River. This is due to the minimal change relative to the entire water balance of the area that is induced by stormwater management.

In all cases the highest impact implementation of stormwater management produces the most change in heads in the EAA, but with no change in plume migration direction and 10% or less increase in plume velocity. Pragmatically, it would be difficult to measure these magnitude changes.

Table 7-4 Summary Ranking of EIS Sub-Model and Focus Model Results in Descending Order of Uranium Plume Impact

EIS Sub-Model Case	Approximate Corresponding Focus Model Cases	Head Change m (EIS/Focus)	Maximum of EIS and Focus Model Uranium Plume Change
Scenario1 – High Impact	1a, 1b	0.13/0.02	Flow direction unchanged, 10% faster migration velocity
Scenario 2 – High Impact	2a, 2b	0.14/0.02	Flow direction unchanged, 10% faster migration velocity
Scenario 3 – Low Impact	3a, 3b	0.04/0.01	Flow direction unchanged, 5% faster migration velocity
Scenario 4 – Low Impact	4a, 4b	0.04/0.01	Flow direction unchanged, 5% faster migration velocity

8 References

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Appendix A

Software Installation and Checkout

CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM

Software Owner Instructions:

Complete Fields 1-13, then run test cases in Field 14. Compare test case results listed in Field 15 to corresponding Test Report outputs. If results are the same, sign and date Field 19. If not, resolve differences and repeat above steps.

Software Subject Matter Expert Instructions:

Assign test personnel. Approve the installation of the code by signing and dating Field 21, then maintain form as part of the software support documentation.

GENERAL INFORMATION:

1. Software Name: MODFLOW and Related Codes Software Version No.: Bld 8

EXECUTABLE INFORMATION:

2. Executable Name (include path):

Following executable files in directory: [redacted]

MD5 Signature (unique ID)	Executable File Name	
919F74196F5FB5BF0364FC373011B507	mf2k-chprc08dpl.exe	MODFLOW-2000 double precision
EAF037703ADD2C62CDD9CBC47468D2F6	mf2k-chprc08spl.exe	MODFLOW-2000 single precision
4E7F29DD5496D2CBA7144ADACB13DAAD	mf2k-mst-chprc08dpv.exe	MODFLOW-2000-MST single prec
CEB80288C616E0552E4CE5A2D4719387	mf2k-mst-chprc08spv.exe	MODFLOW-2000-MST double prec
ECA9828530B68D2D7C34078C019D5D0C	mt3d-chprc08dpl.exe	MT3DMS double precision
0920CC235862665D9400A3FC80F682DD	mt3d-chprc08spl.exe	MT3DMS single precision
5C61432D2CB98E83DDFE242C52A755AB	mt3d-mst-chprc08dpv.exe	MT3DMS-MST double precision
68F89DAF2E6913D2578DE53CBD34FBA0	mt3d-mst-chprc08spv.exe	MT3DMS-MST single precision

3. Executable Size (bytes): MD5 signatures listed above uniquely identify executable files

COMPILATION INFORMATION:

4. Hardware System (i.e., property number or ID):

Vendor Provided (SSP&A)

5. Operating System (include version number):

Vendor Provided (SSP&A)

INSTALLATION AND CHECKOUT INFORMATION:

6. Hardware System (i.e., property number or ID):

AUS-silicon.intera.com; Intel(R) Xeon(R) CPU E5-1620 v3 @ 3.50FHz

7. Operating System (include version number):

Windows 10 Pro

8. Open Problem Report? ◉ No ○ Yes PR/CR No.

TEST CASE INFORMATION:

9. Directory/Path:

[redacted]\test-windows

10. Procedure(s):

CHPRC-00259 Rev 3, MODFLOW and Related Codes Software Test Plan

11. Libraries:

N/A (static linking)

12. Input Files:

MF-ITC-1 and MT-ITC-1 inputs

13. Output Files:

MF-ITC-1 and MT-ITC-1 outputs

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CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM (continued)

1. Software Name: MODFLOW and Related Codes — Software Version No.: Bld 8

14. Test Cases:

MF-ITC-1 (both standard and MST versions of MODFLOW)- run for single & double precision
MT-ITC-1 - run for single and double precision

15. Test Case Results:

C:\MODFLOW-Build-8-distribution\test-windows (test.log attached)

16. Test Performed By: Dennis Fryar

17. Test Results: (●) Satisfactory, Accepted for Use ( ) Unsatisfactory

18. Disposition (include HISI update): Accepted; installation added to HISI entries. -WEN

Prepared By: WILLIAM NICHOLS (Affiliate) — Digitally signed by WILLIAM NICHOLS (Affiliate) DN: c=US, o=U.S. Government, ou=Department of Energy, 0.9.2342.19200300.100.1.1=S0326, cn=WILLIAM NICHOLS (Affiliate) Date: 2017.06.27 10:49:43 -07'00'

19. _____ Software Owner (Signature) — WE Nichols Print — Date

20. Test Personnel:

Sign	Print	Date
Dennis Fryar	Dennis Fryar	6-27-17

Approved By:

21. _____ Software SME (Signature) — N/R (CHPRC-00258 Rev 3) Print — Date

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CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM

Software Owner Instructions:

Complete Fields 1-13, then run test cases in Field 14. Compare test case results listed in Field 15 to corresponding Test Report outputs. If results are the same, sign and date Field 19. If not, resolve differences and repeat above steps.

Software Subject Matter Expert Instructions:

Assign test personnel. Approve the installation of the code by signing and dating Field 21, then maintain form as part of the software support documentation.

GENERAL INFORMATION:

1. Software Name: MODFLOW and Related Codes Software Version No.: Bld 8

EXECUTABLE INFORMATION:

2. Executable Name (include path):

Following executable files in directory: [redacted]

MD5 Signature (unique ID)	Executable File Name	Code
2fade33e27978063a9a70ff8605e4c0c	mf2k-chprc08dpl.x	MODFLOW-2000 double precision
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80d670658425653bf5bcbb97ad2a2730	mf2k-mst-chprc08dpl.x	MODFLOW-2000-MST double precis.
d879defafdc5ad25be51a484d73ea65d	mf2k-mst-chprc08spl.x	MODFLOW-2000-MST single precis.
682f0b1e9fcd6ac0b885f52a7ddfe821	mfusg-chprc08dpl.x	MODFLOW-USG double precision
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1be4b7d3fc81881ff0b97ff7e67bd3ff	mt3d-chprc08dpl.x	MT3DMS double precision
37ae3dcb3e56cd27e3e889a90d0ae7c1	mt3d-chprc08spl.x	MT3DMS single precision
1e468c4409ac913843ce783aabed819c	mt3d-mst-chprc08dpl.x	MT3DMS-MST double precision
2d0a8a4c480318763b6aaaa0f880348a	mt3d-mst-chprc08spl.x	MT3DMS-MST single precision

3. Executable Size (bytes): MD5 signatures above uniquely identify each executable file

COMPILATION INFORMATION:

4. Hardware System (i.e., property number or ID):

INTERA Austin Linux(R) Cluster

5. Operating System (include version number):

Linux head.cluster 2.6.32-358.11.1.el6.centos.plus.x86_64 #1 SMP Wed Jun 12 19:12:17 UTC 2013 x86 64 x86 64 x86 64 GNU/Linux

INSTALLATION AND CHECKOUT INFORMATION:

6. Hardware System (i.e., property number or ID):

INTERA "OLIVE" Linux Cluster

7. Operating System (include version number):

Linux olive 4.4.0-38-generic #57~14.04.1-Ubuntu SMP Tue Sep 6 17:20:43 UTC 2016 x86_64 x86 64 x86 64 GNU/Linux

8. Open Problem Report? ◉ No ○ Yes PR/CR No.

TEST CASE INFORMATION:

9. Directory/Path:

[redacted]/Build-8

10. Procedure(s):

CHPRC-00259 Rev. 3, MODFLOW and Related Codes Software Test Plan

11. Libraries:

N/A (static linking)

Page 1 of 2 A-6005-149 (REV 0)

CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM (continued)

1. Software Name: MODFLOW and Related Codes Software Version No.: Bld 8

12. Input Files:

Per CHPRC-00259 Rev. 3

13. Output Files:

Found in test subdirectories

14. Test Cases:

MF-ITC-1 (both standard and MST versions of MODFLOW); run both single & double precision
MT-ITC-1 run for single and double precision, multiple solvers

15. Test Case Results:

All pass.

16. Test Performed By: WE Nichols

17. Test Results: (●) Satisfactory, Accepted for Use ( ) Unsatisfactory

18. Disposition (include HISI update):

Approved; installation added to HISI entries for MODFLOW and MT3DMS.

Prepared By:

19. WILLIAM NICHOLS (Affiliate) Software Owner (Signature) | WE Nichols (Print) | Date

20. Test Personnel:

Sign	Print	Date
	WE Nichols	

Approved By:

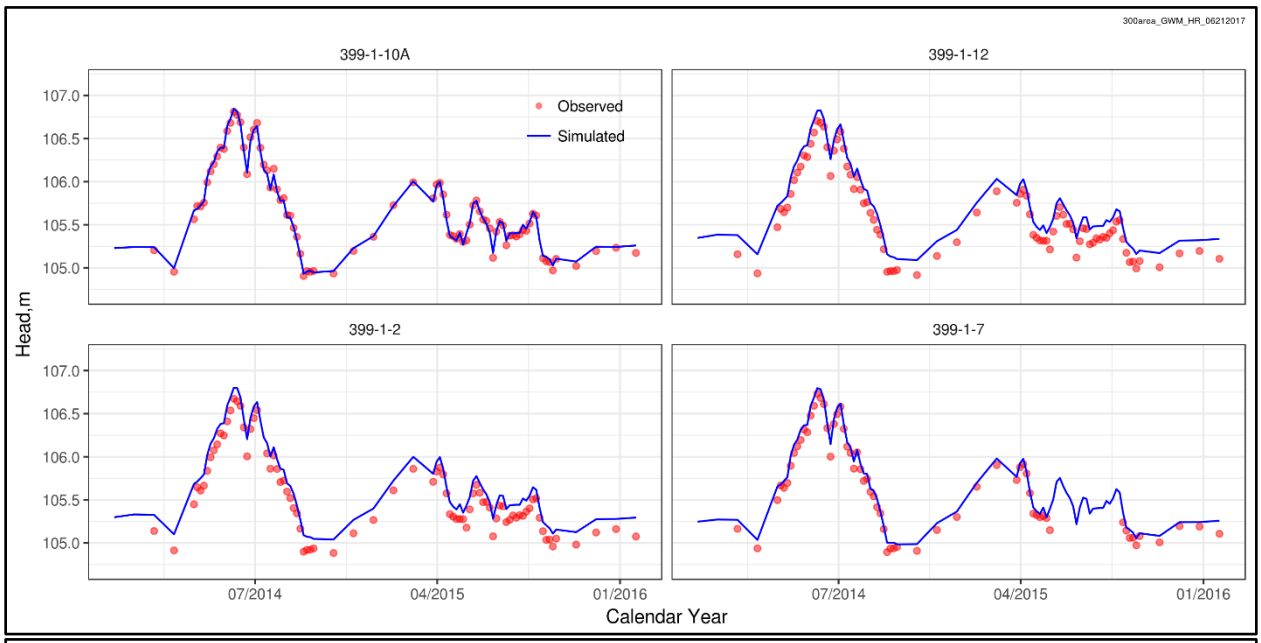
21. Software SME (Signature) | N/R (CHPRC-00258 Rev. 3) (Print) | Date

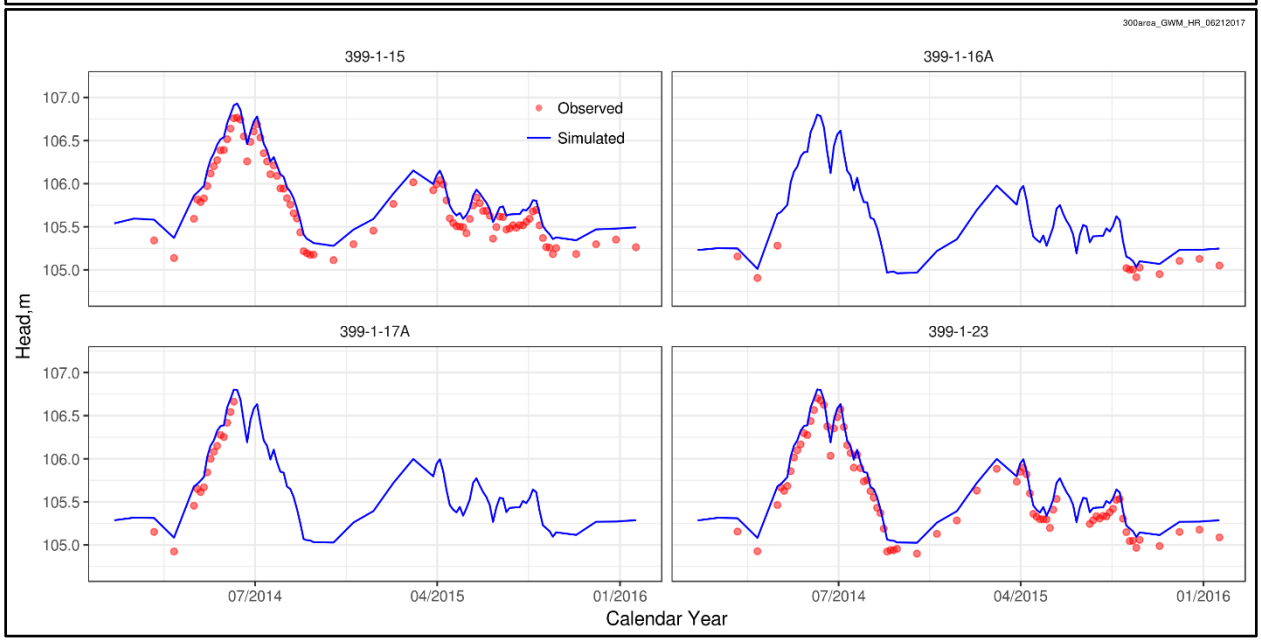
A-6005-149 (REV 0)

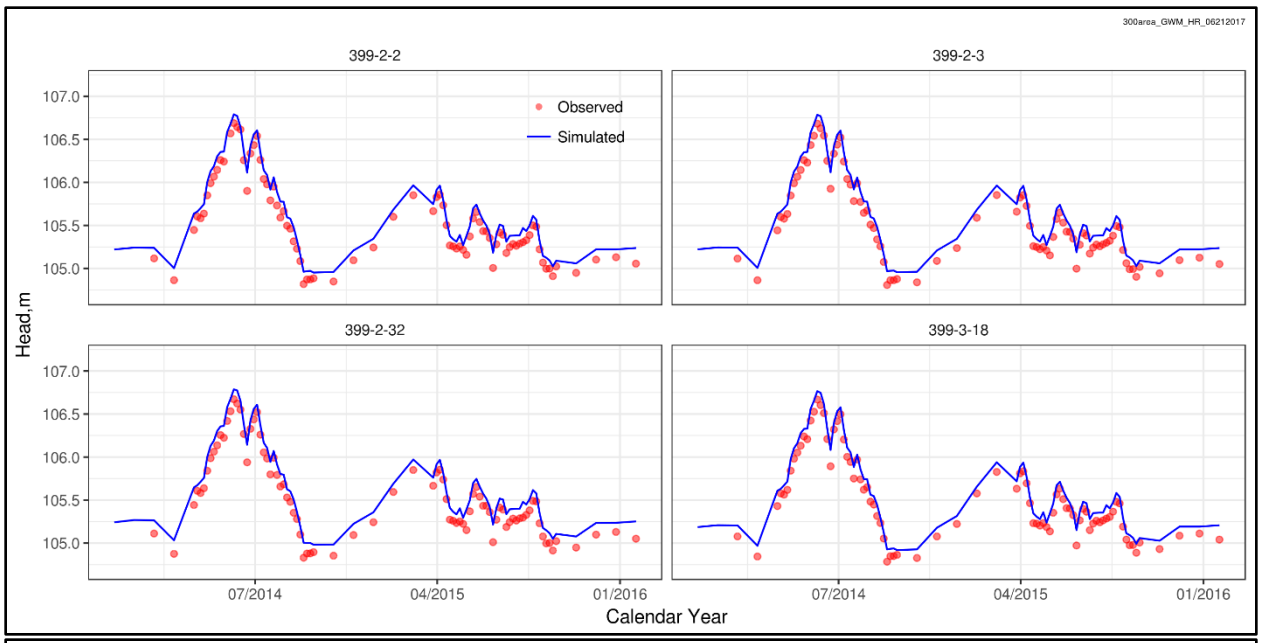
Appendix B

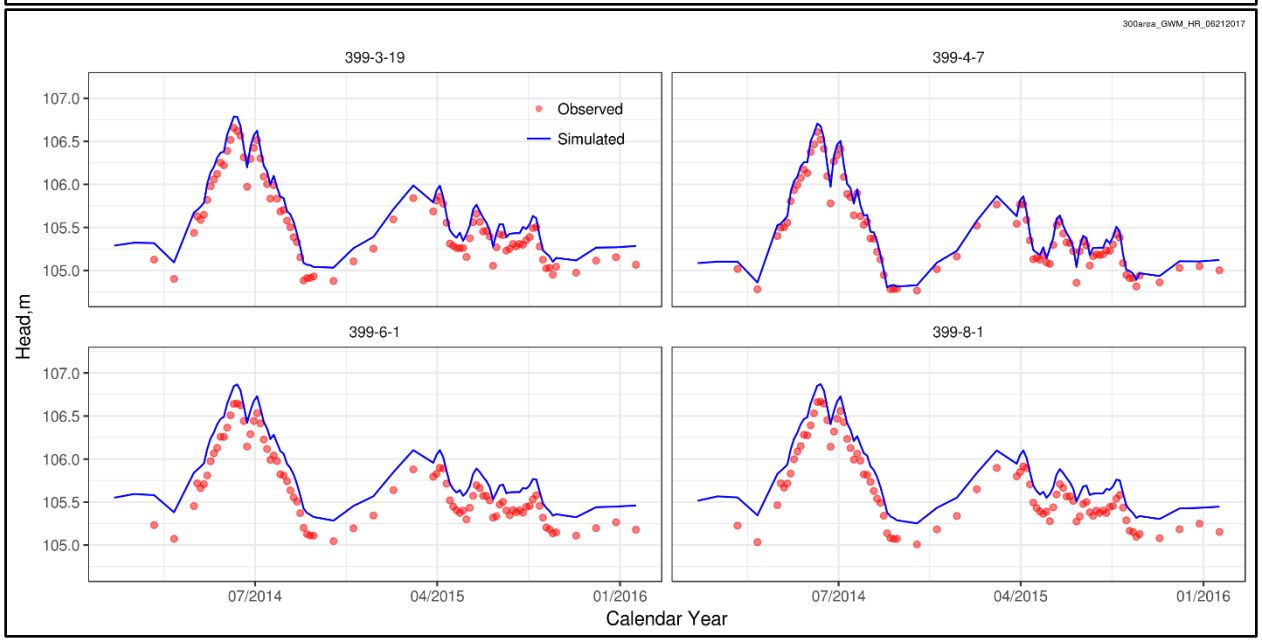
Observed Data and Simulated Hydrographs

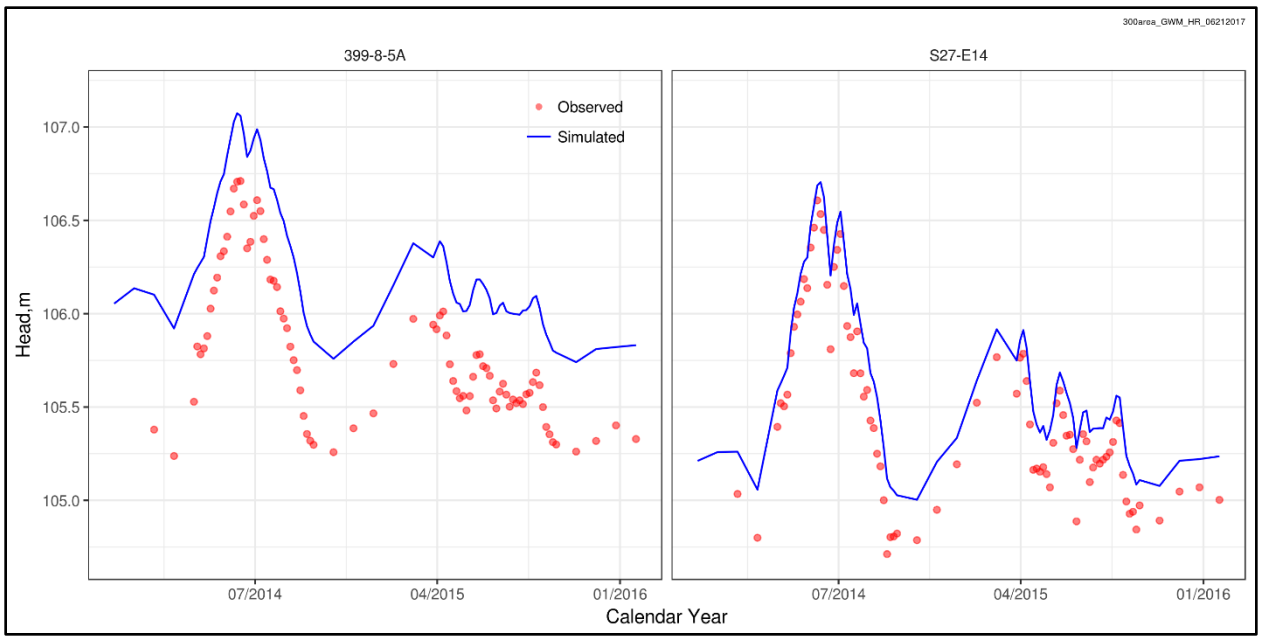
Observed vs simulated hydrographs for the AWLN wells:



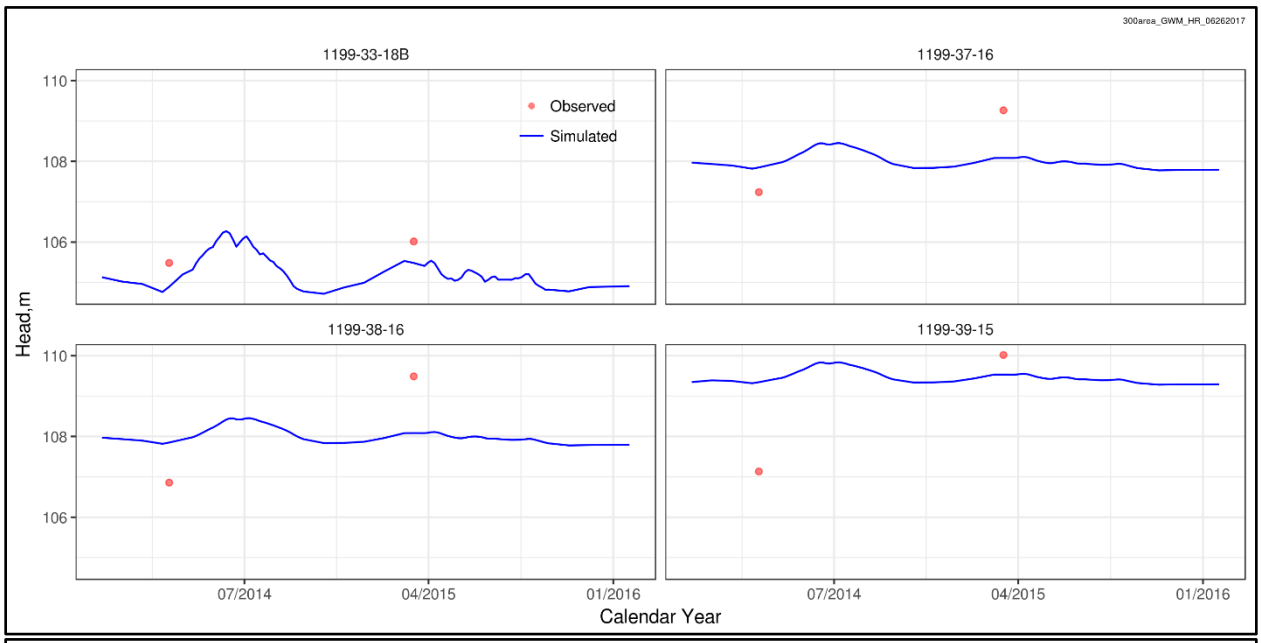


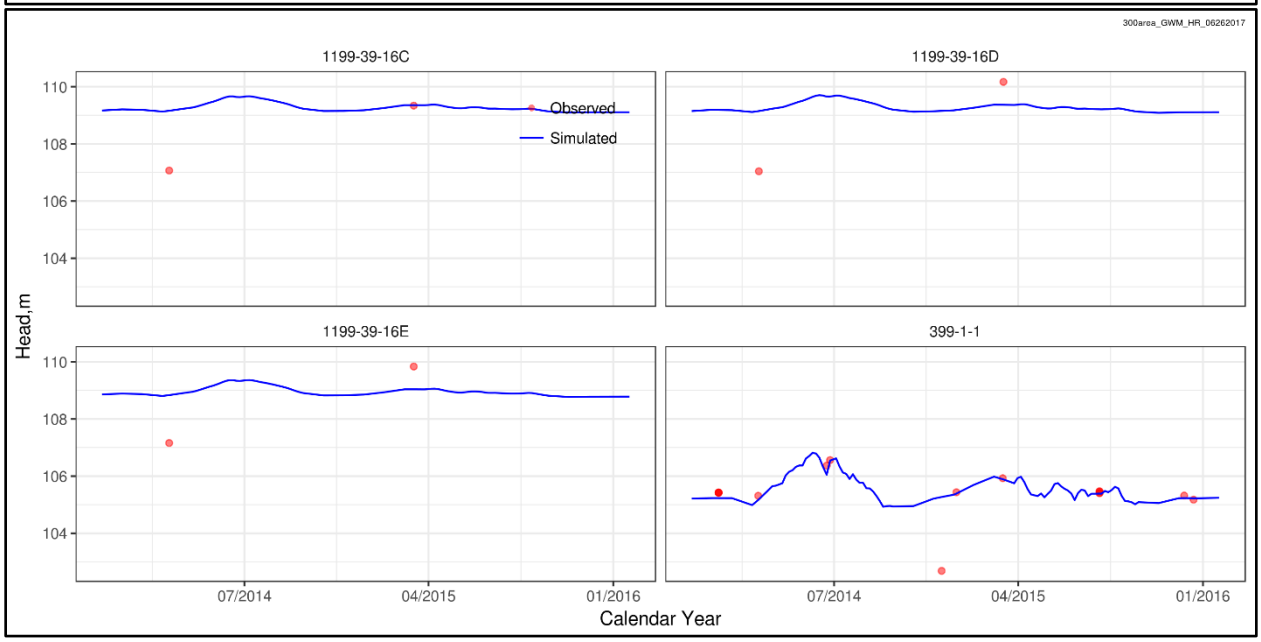

300area_GWM_HR_06212017
399-2-2
399-2-3
399-2-32
399-3-18
Observed
Simulated
Head,m
107.0
106.5
106.0
105.5
105.0
07/2014
04/2015
01/2016
Calendar Year

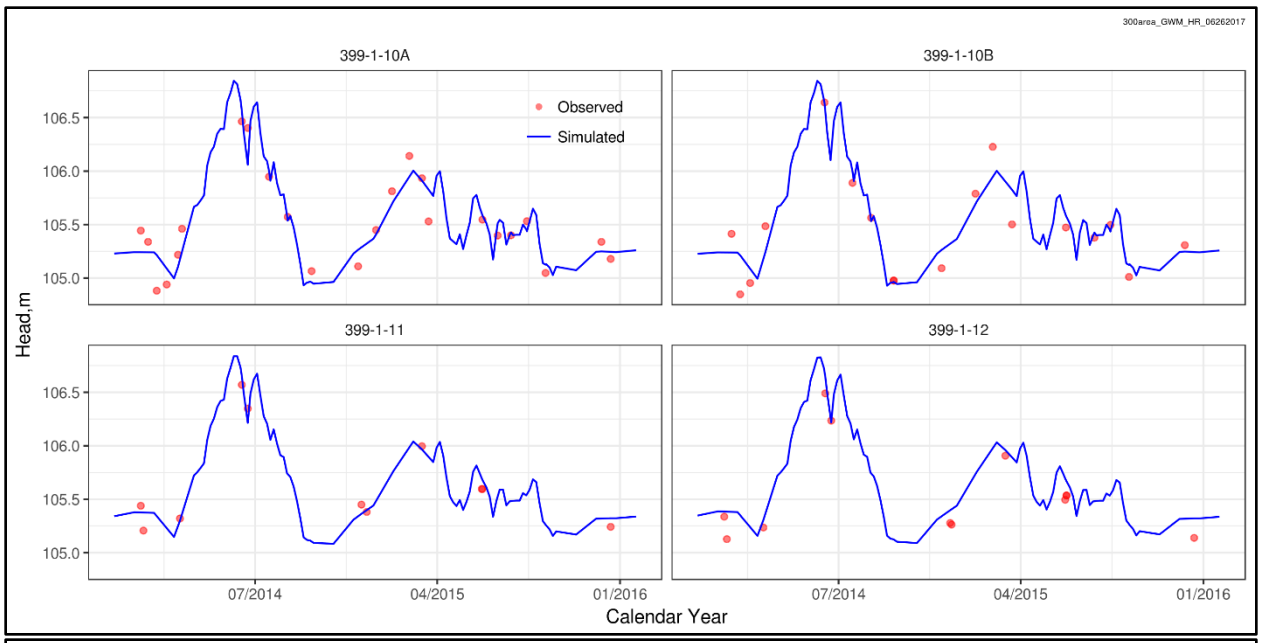

300area_GWM_HR_06212017
399-3-19
399-4-7
399-6-1
399-8-1
Observed
Simulated
Head,m
107.0
106.5
106.0
105.5
105.0
07/2014
04/2015
01/2016
Calendar Year

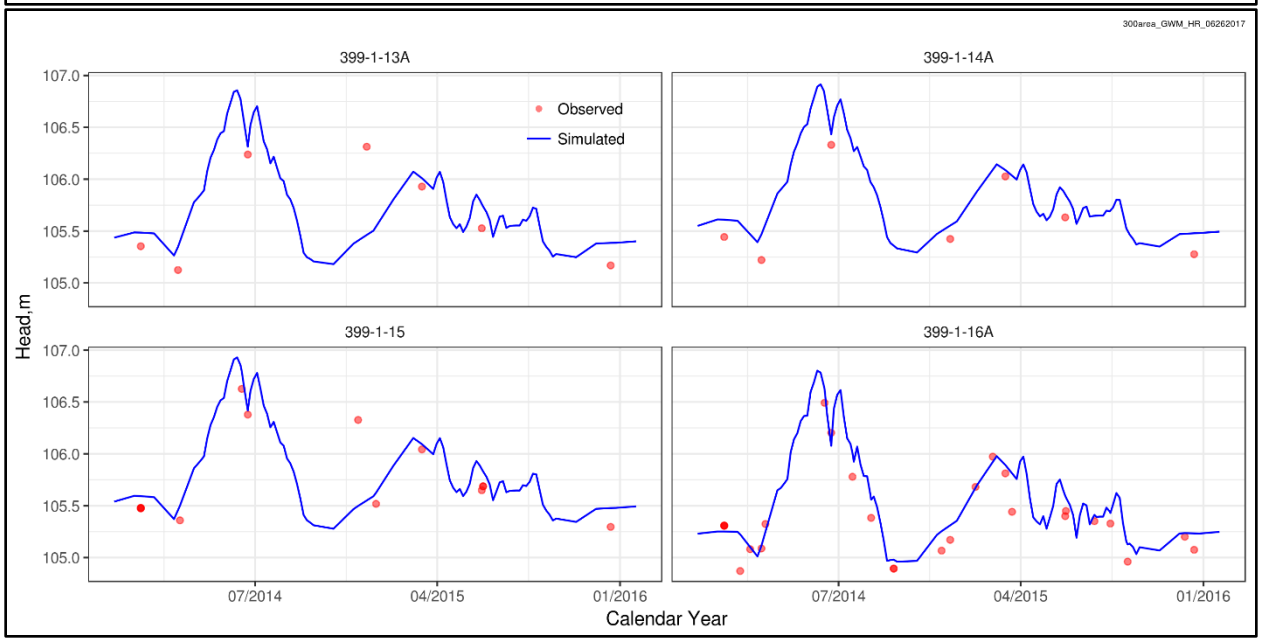

300area_GWM_HR_06212017
399-8-5A
S27-E14
Observed
Simulated
Head,m
107.0
106.5
106.0
105.5
105.0
07/2014
04/2015
01/2016
Calendar Year

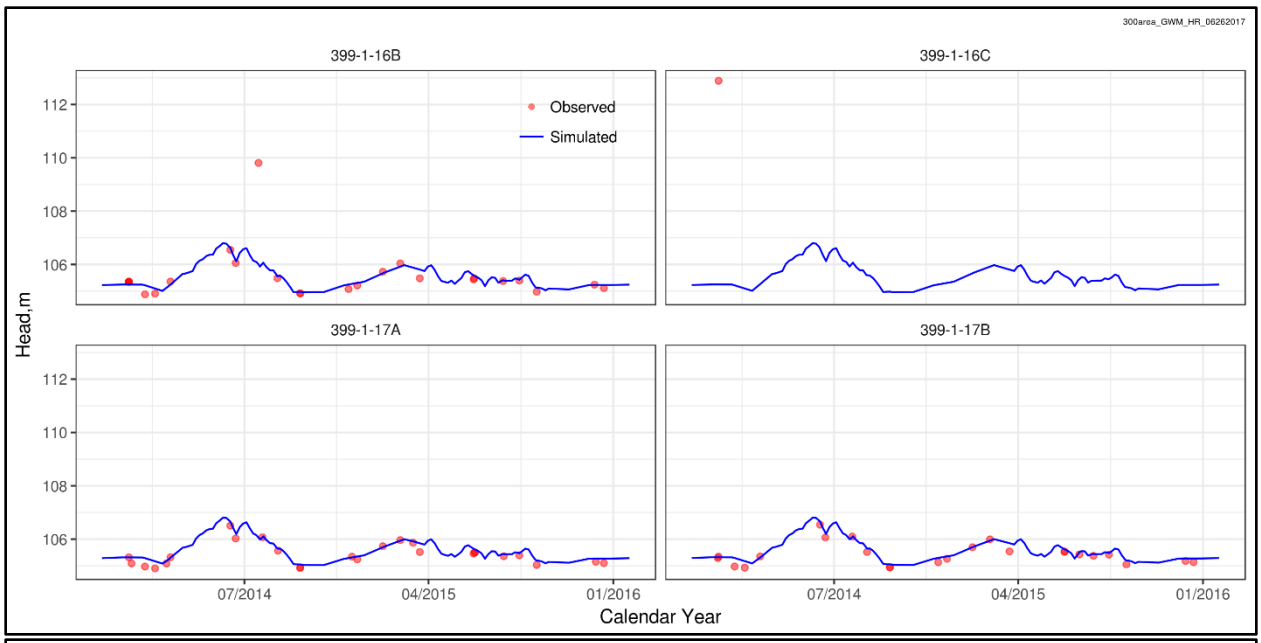
Observed vs simulated hydrographs for the manual measurement wells:

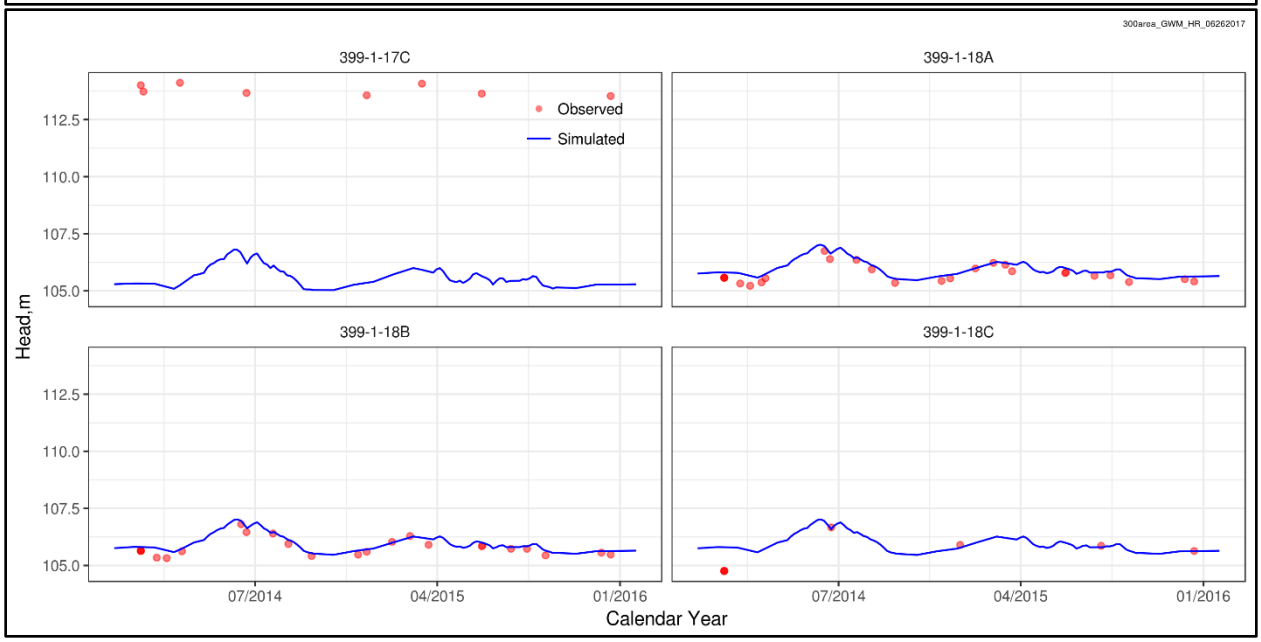


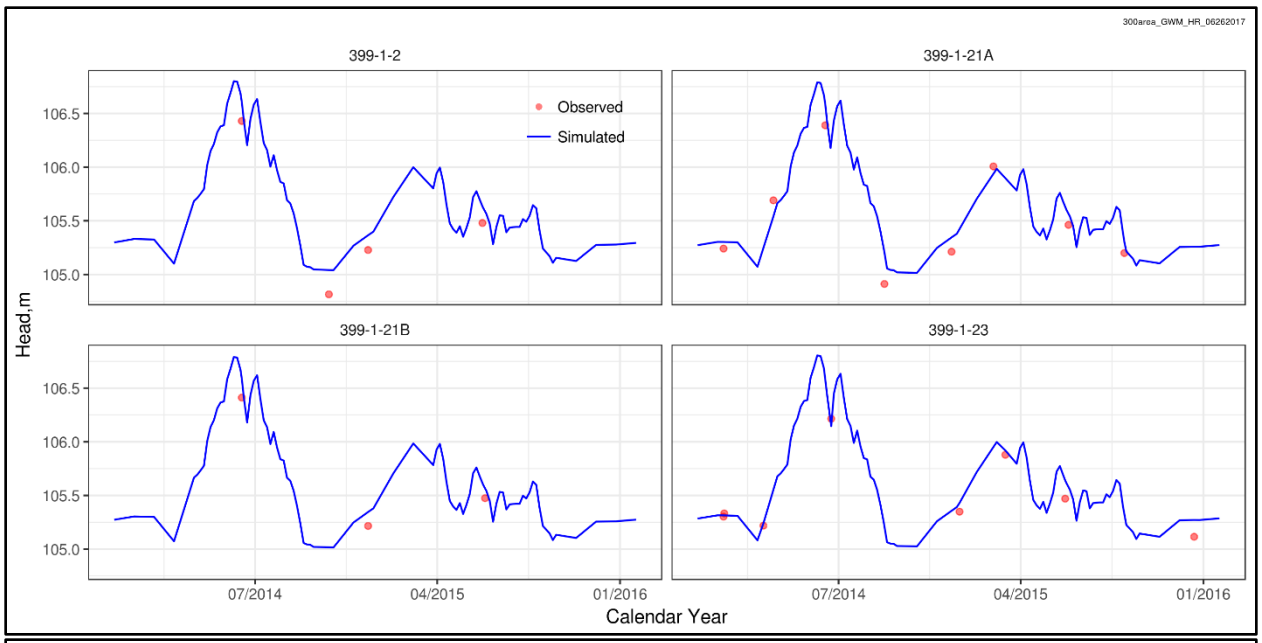


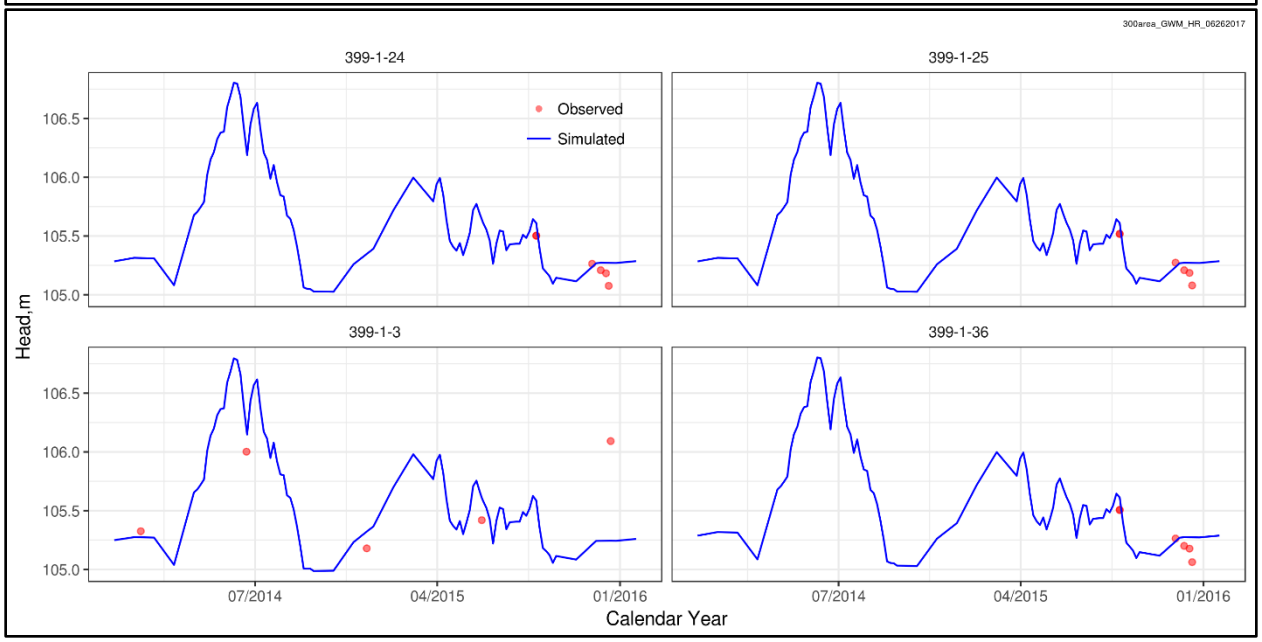

300area_GWM_HR_06262017
399-1-10A
399-1-10B
399-1-11
399-1-12
Observed
Simulated
Head,m
106.5
106.0
105.5
105.0
07/2014
04/2015
01/2016
Calendar Year

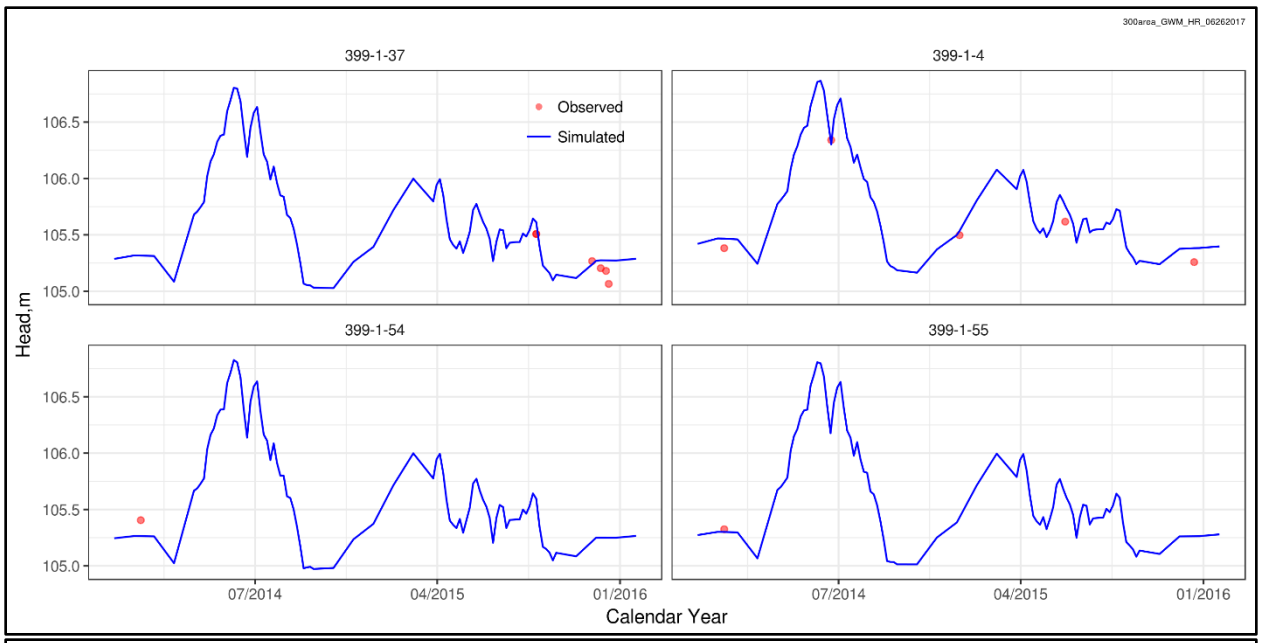

300area_GWM_HR_06262017
399-1-13A
399-1-14A
399-1-15
399-1-16A
Observed
Simulated
Head,m
107.0
106.5
106.0
105.5
105.0
07/2014
04/2015
01/2016
Calendar Year

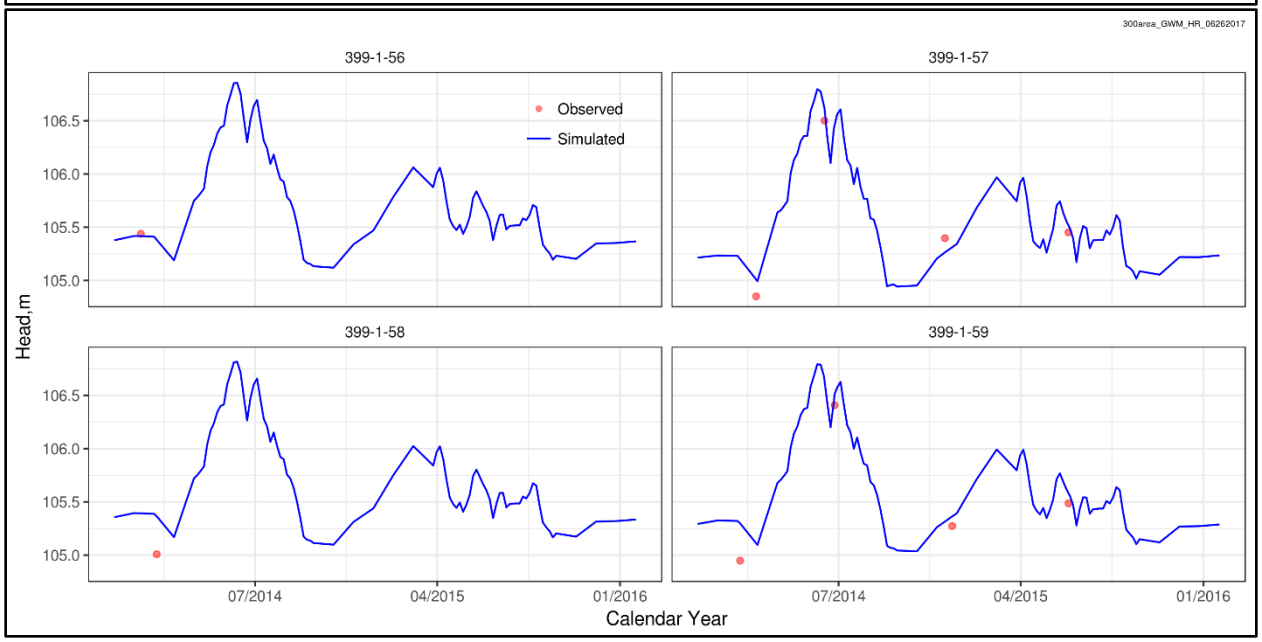

300area_GWM_HR_06262017
399-1-16B
399-1-16C
399-1-17A
399-1-17B
Observed
Simulated
Head,m
112
110
108
106
07/2014
04/2015
01/2016
Calendar Year

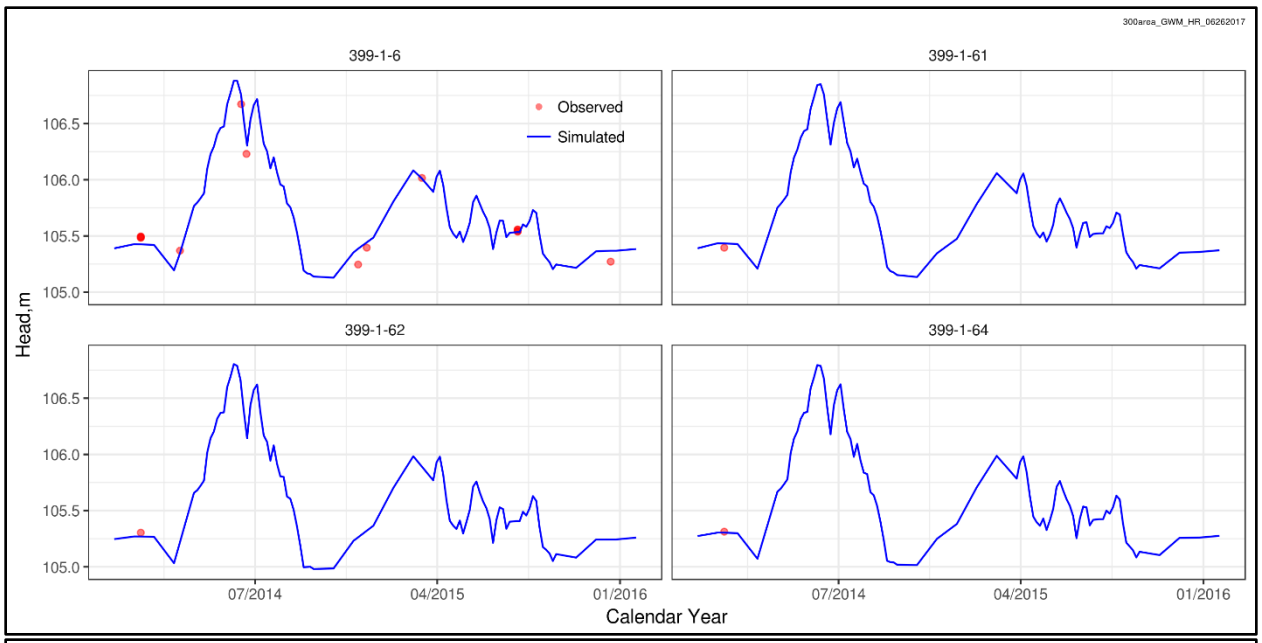

300area_GWM_HR_06262017
399-1-17C
399-1-18A
399-1-18B
399-1-18C
Observed
Simulated
Head,m
112.5
110.0
107.5
105.0
07/2014
04/2015
01/2016
Calendar Year


300area_GWM_HR_06262017
399-1-2
399-1-21A
399-1-21B
399-1-23
Observed
Simulated
Head,m
106.5
106.0
105.5
105.0
07/2014
04/2015
01/2016
Calendar Year


300area_GWM_HR_06262017
399-1-24
399-1-25
399-1-3
399-1-36
Observed
Simulated
Head,m
106.5
106.0
105.5
105.0
07/2014
04/2015
01/2016
Calendar Year


300area_GWM_HR_06262017
399-1-37
399-1-4
399-1-54
399-1-55
Observed
Simulated
Head,m
106.5
106.0
105.5
105.0
07/2014
04/2015
01/2016
Calendar Year


300area_GWM_HR_06262017
399-1-56
399-1-57
399-1-58
399-1-59
Observed
Simulated
Head,m
106.5
106.0
105.5
105.0
07/2014
04/2015
01/2016
Calendar Year


300area_GWM_HR_06262017
399-1-6
399-1-61
399-1-62
399-1-64
Observed
Simulated
Head,m
106.5
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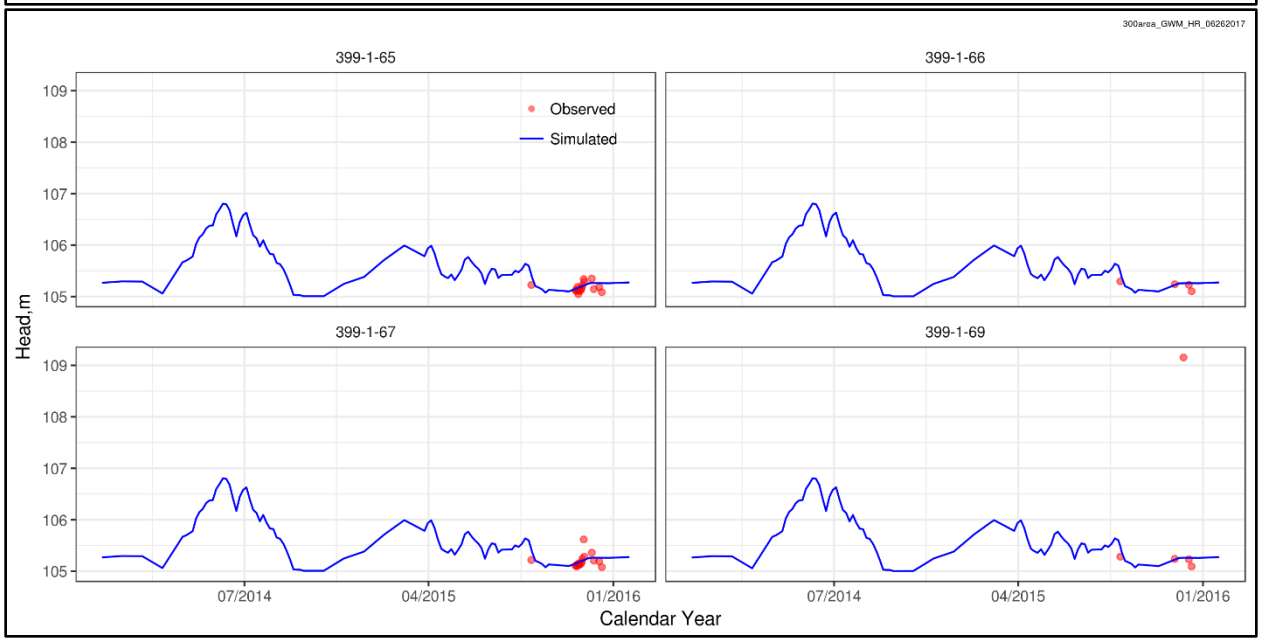
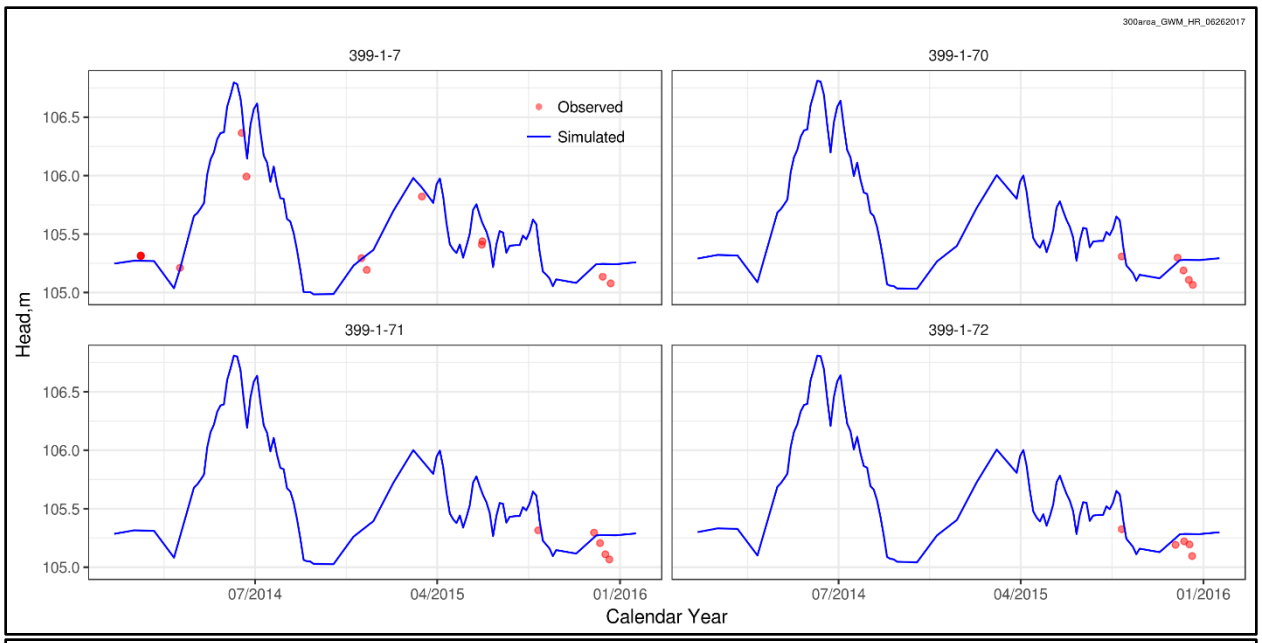
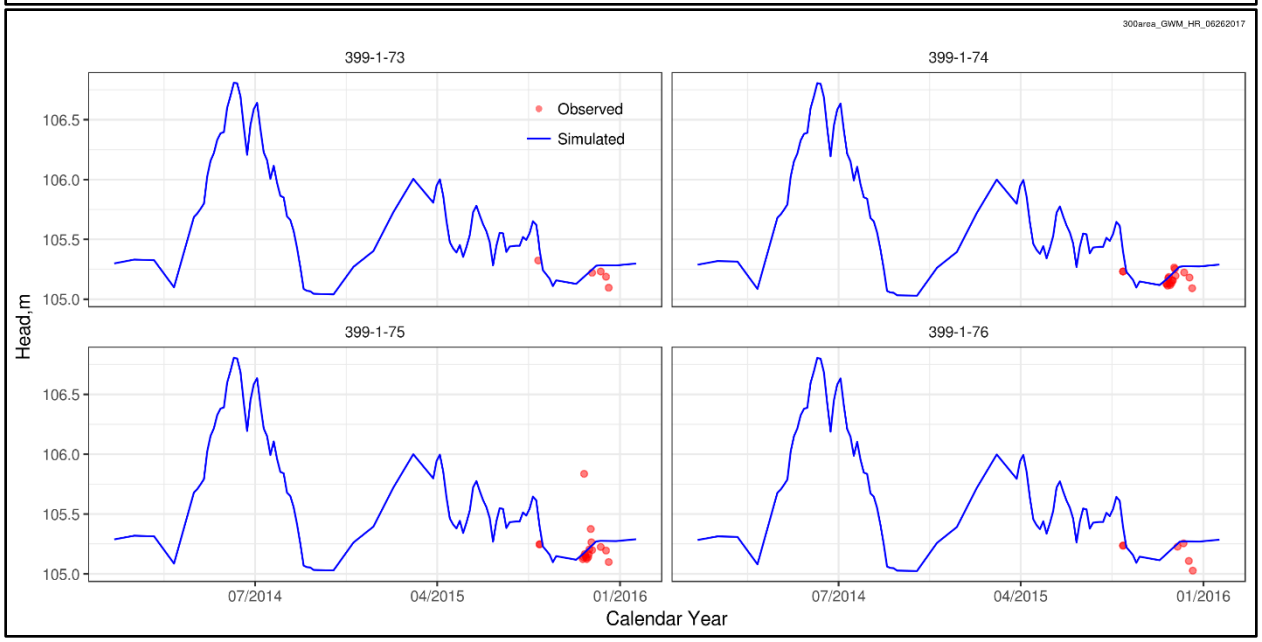
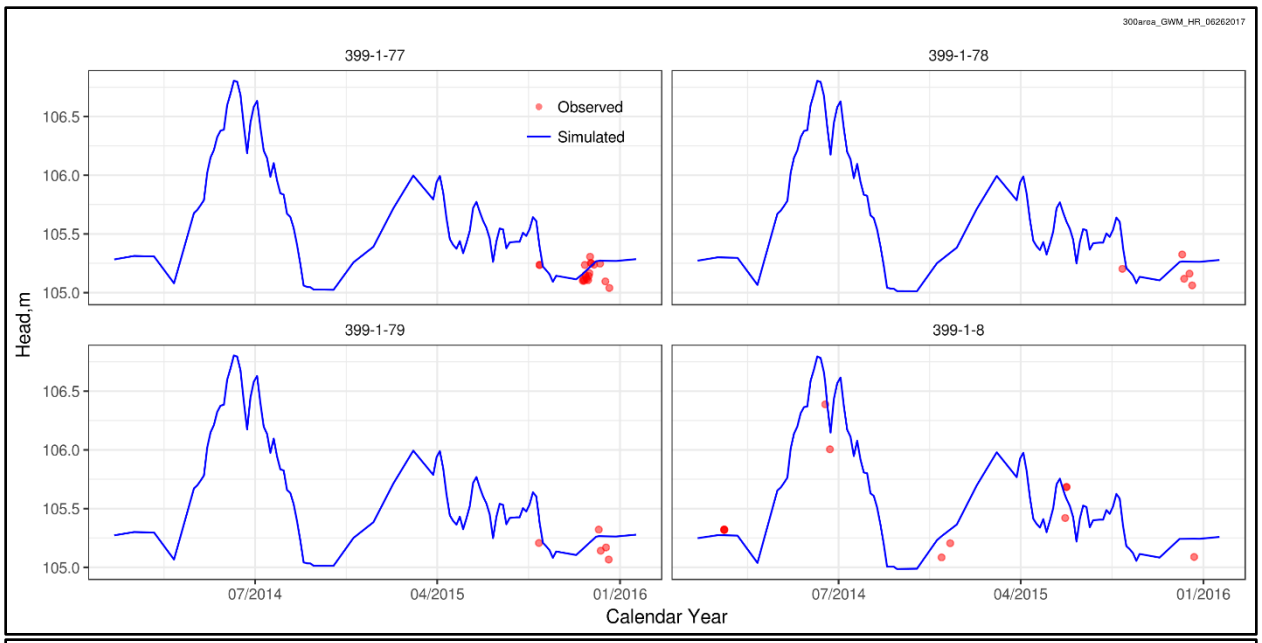
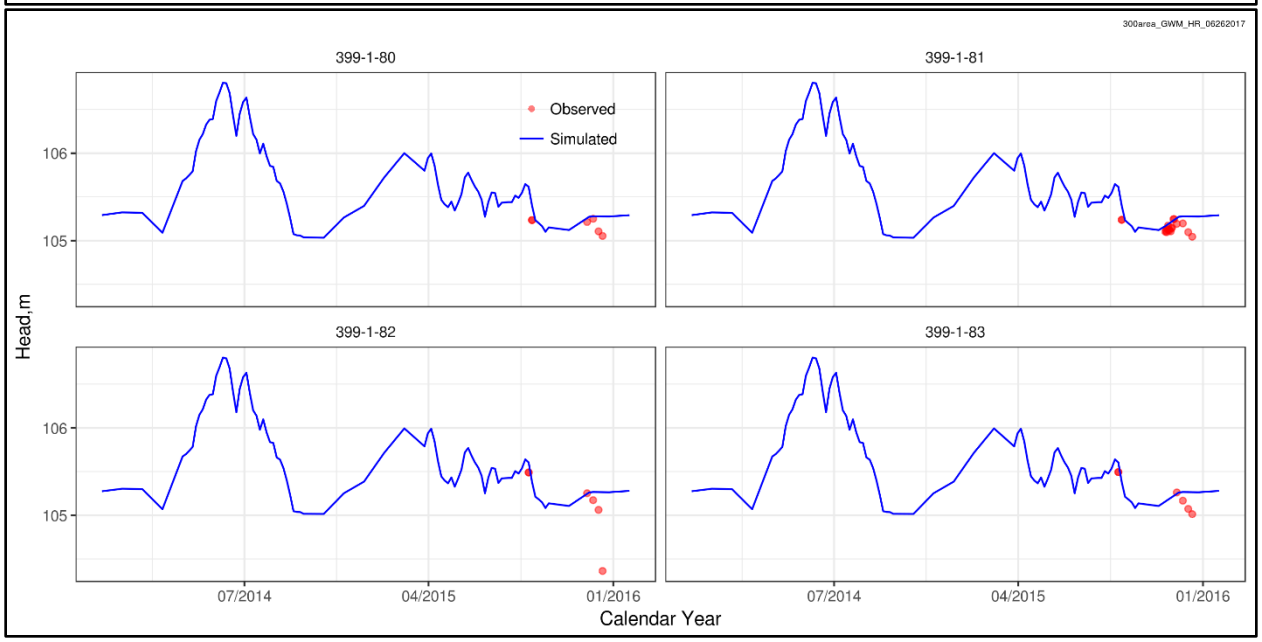
105.5
105.0
07/2014
04/2015
01/2016
Calendar Year

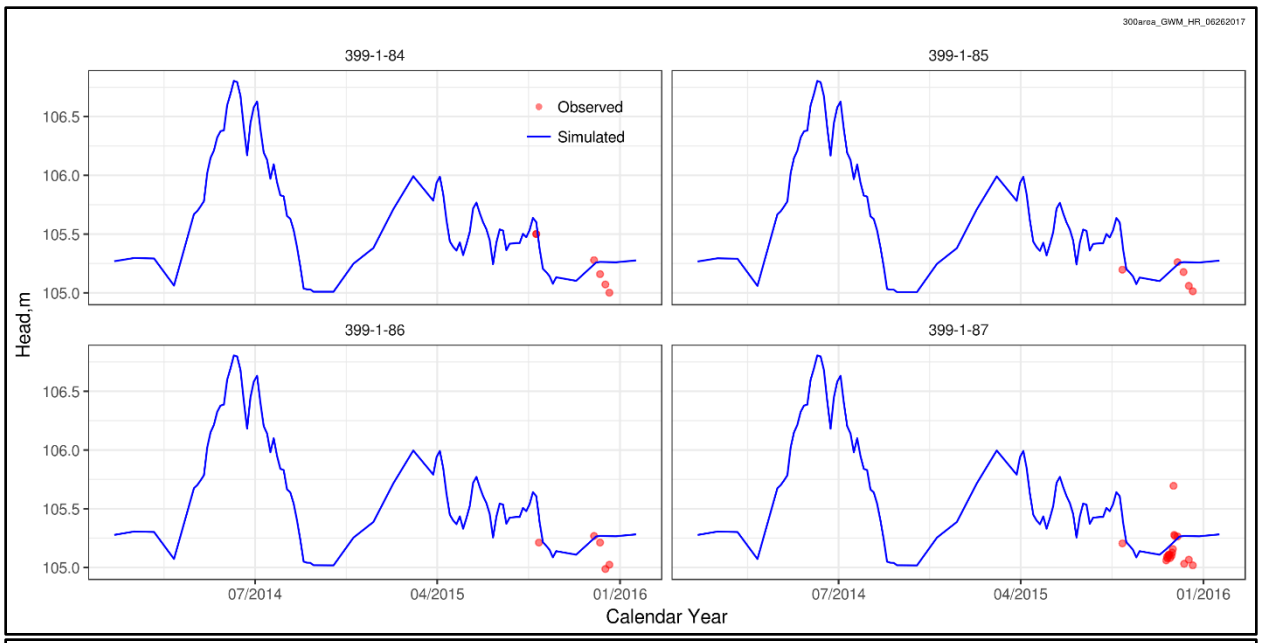

300area_GWM_HR_06262017
399-1-65
399-1-66
399-1-67
399-1-69
Observed
Simulated
Head,m
109
108
107
106
105
07/2014
04/2015
01/2016
Calendar Year

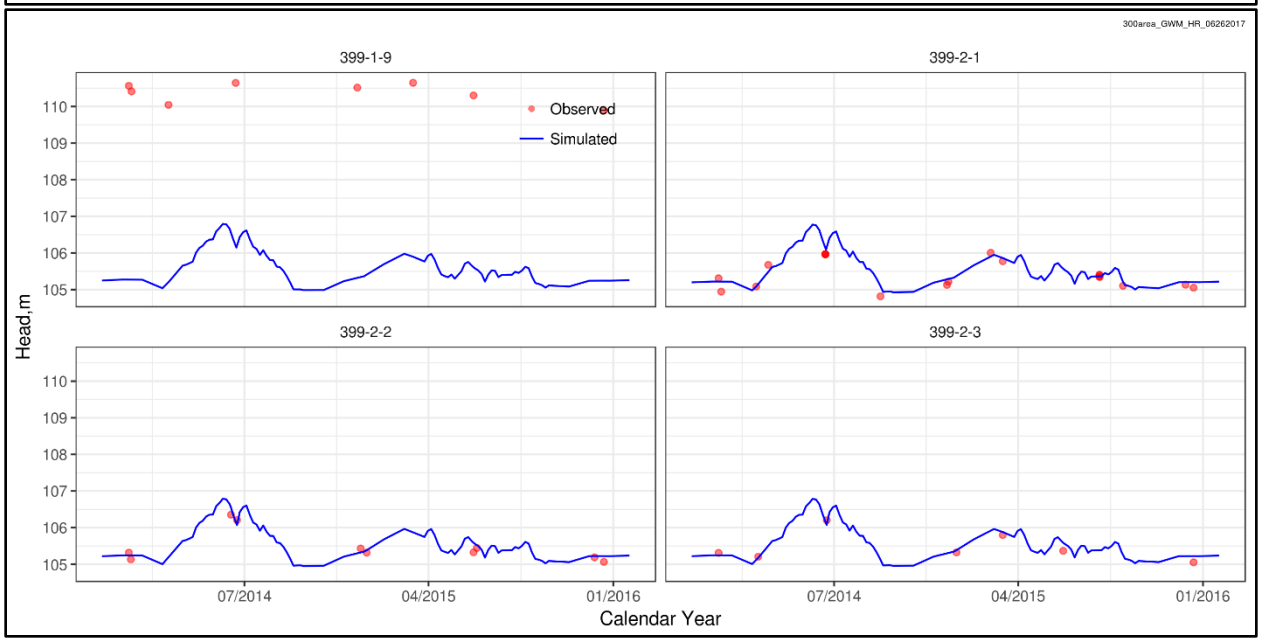

300area_GWM_HR_06262017
399-1-7
399-1-70
399-1-71
399-1-72
Observed
Simulated
Head,m
106.5
106.0
105.5
105.0
07/2014
04/2015
01/2016
Calendar Year

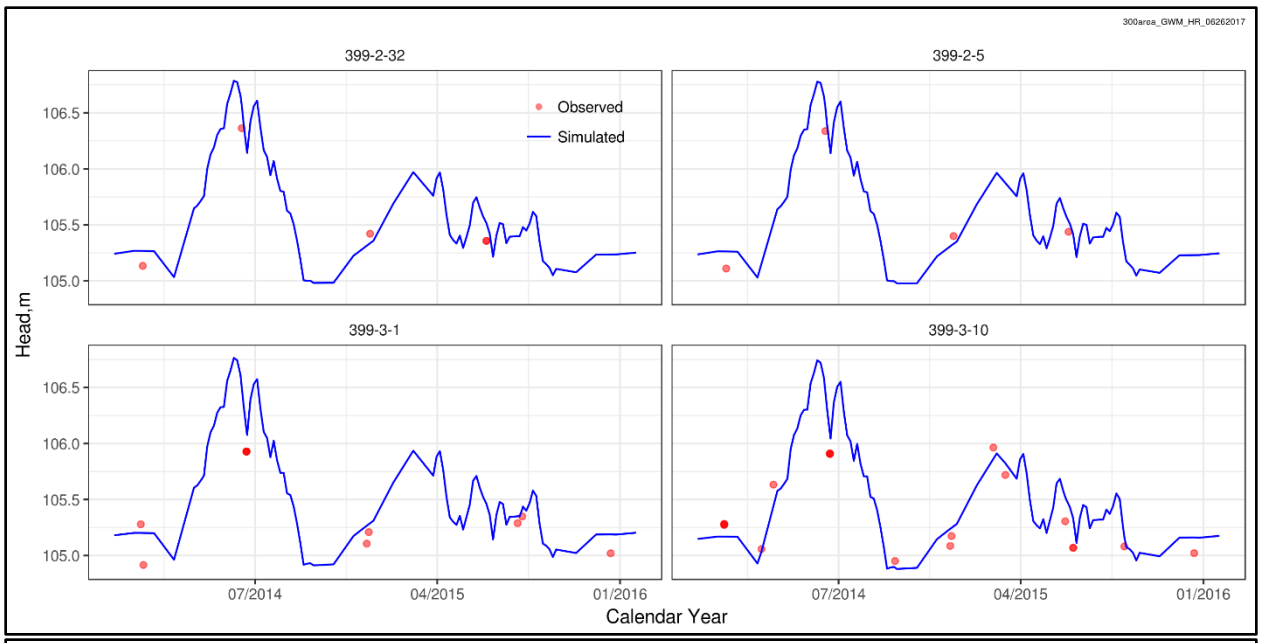

300area_GWM_HR_06262017
399-1-73
399-1-74
399-1-75
399-1-76
Observed
Simulated
Head,m
106.5
106.0
105.5
105.0
07/2014
04/2015
01/2016
Calendar Year

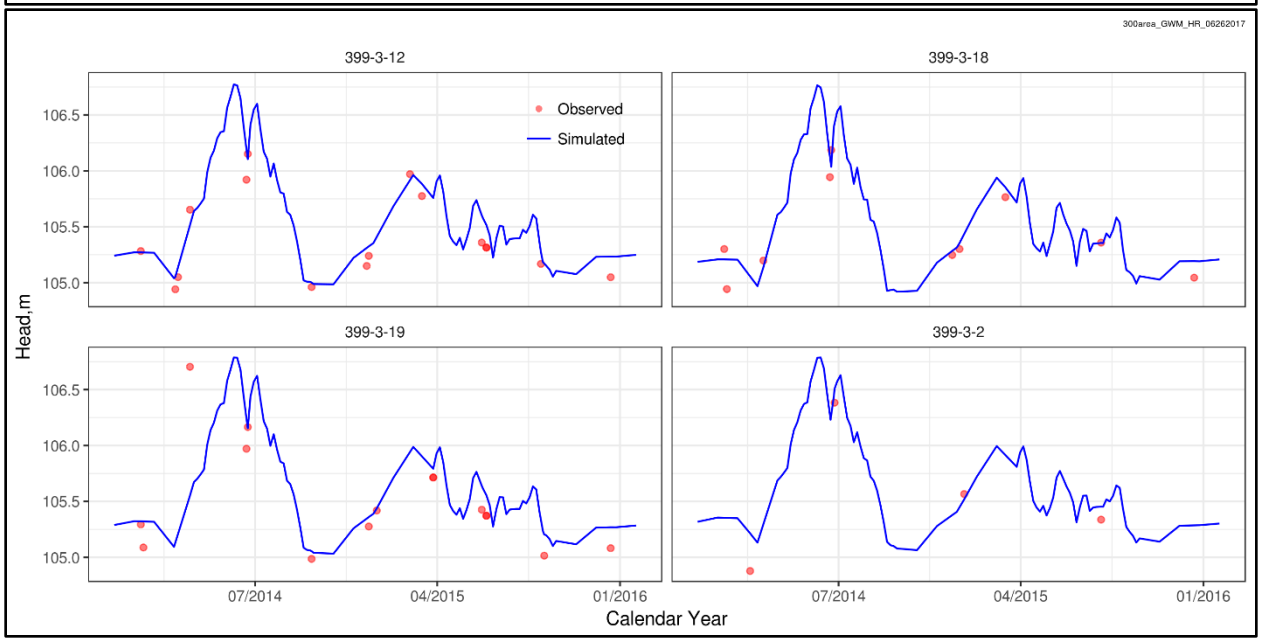

300area_GWM_HR_06262017
399-1-77
399-1-78
399-1-79
399-1-8
Observed
Simulated
Head,m
106.5
106.0
105.5
105.0
07/2014
04/2015
01/2016
Calendar Year


300area_GWM_HR_06262017
399-1-80
399-1-81
399-1-82
399-1-83
Observed
Simulated
Head,m
106
105
07/2014
04/2015
01/2016
Calendar Year


300area_GWM_HR_06262017
399-1-84
399-1-85
399-1-86
399-1-87
Observed
Simulated
Head,m
106.5
106.0
105.5
105.0
07/2014
04/2015
01/2016
Calendar Year


300area_GWM_HR_06262017
399-1-9
399-2-1
399-2-2
399-2-3
Observed
Simulated
Head,m
110
109
108
107
106
105
07/2014
04/2015
01/2016
Calendar Year


300area_GWM_HR_06262017
399-2-32
399-2-5
399-3-1
399-3-10
Observed
Simulated
Head,m
106.5
106.0
105.5
105.0
07/2014
04/2015
01/2016
Calendar Year


300area_GWM_HR_06262017
399-3-12
399-3-18
399-3-19
399-3-2
Observed
Simulated
Head,m
106.5
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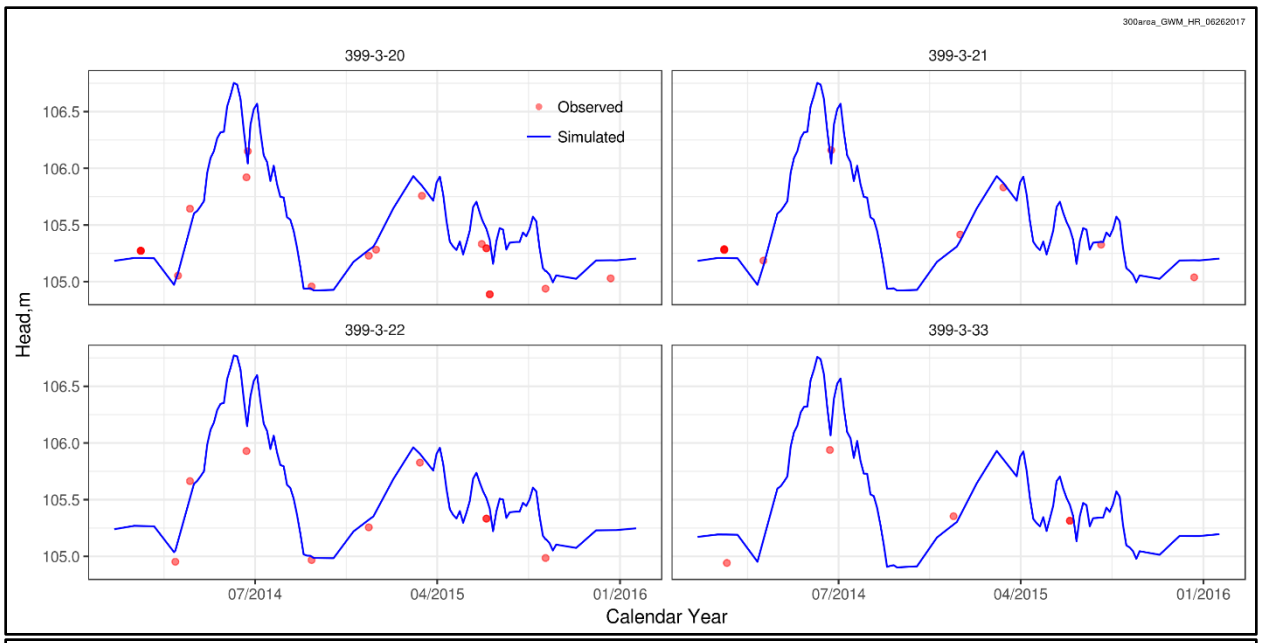
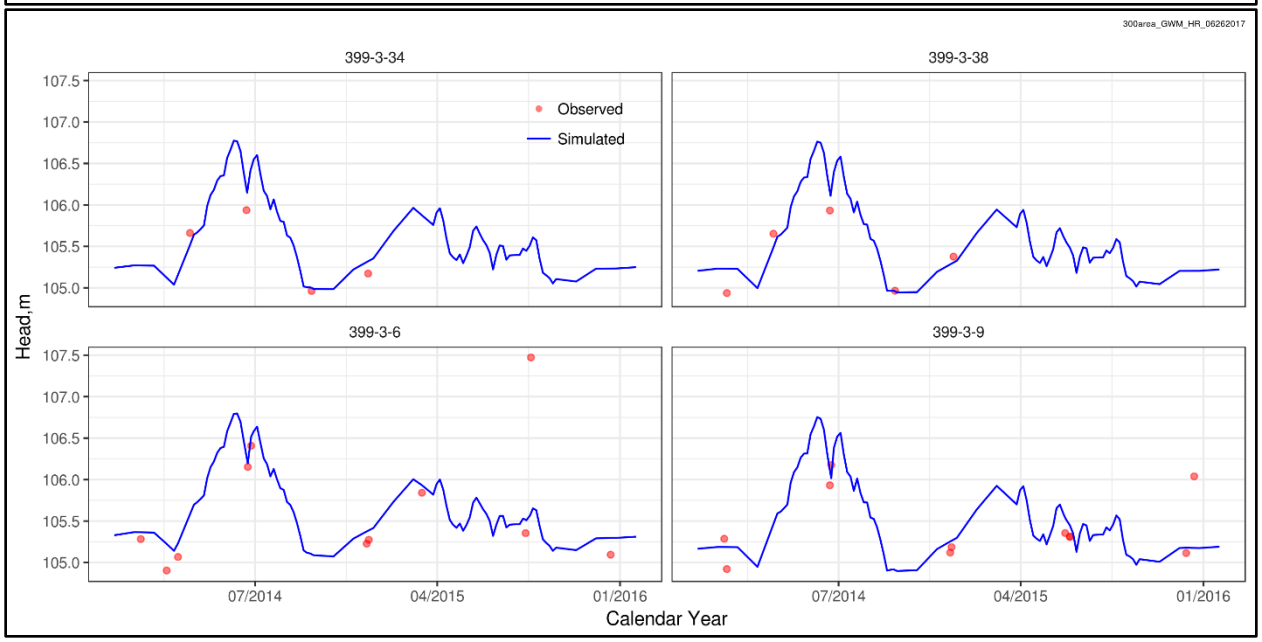
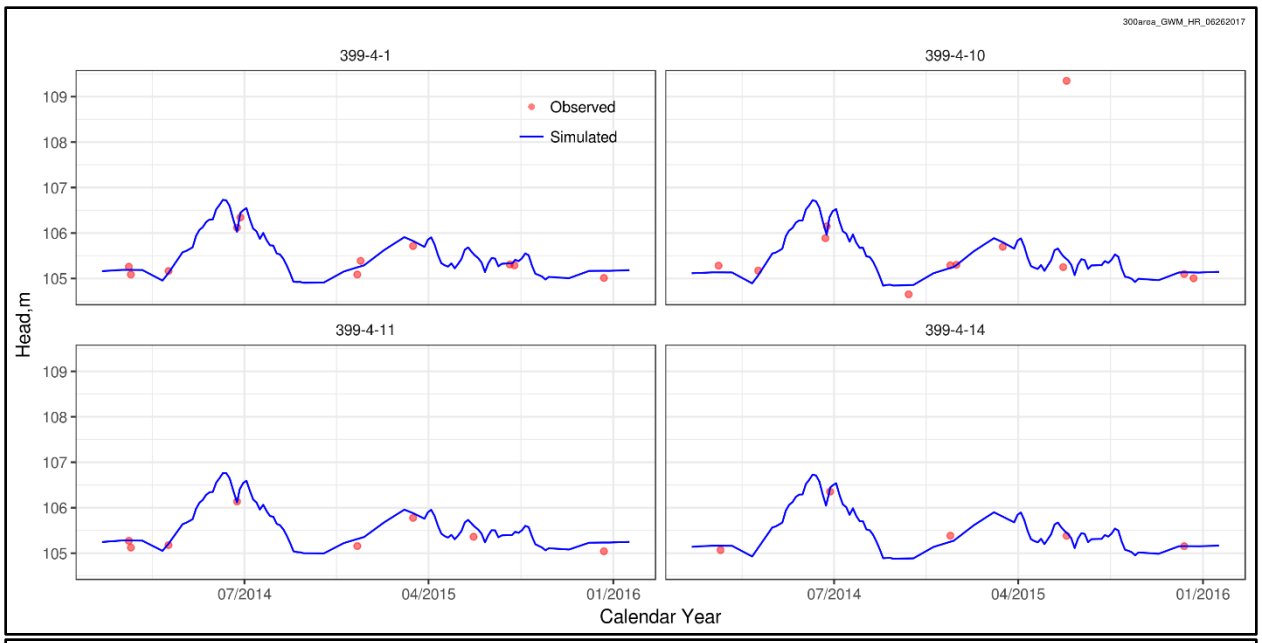
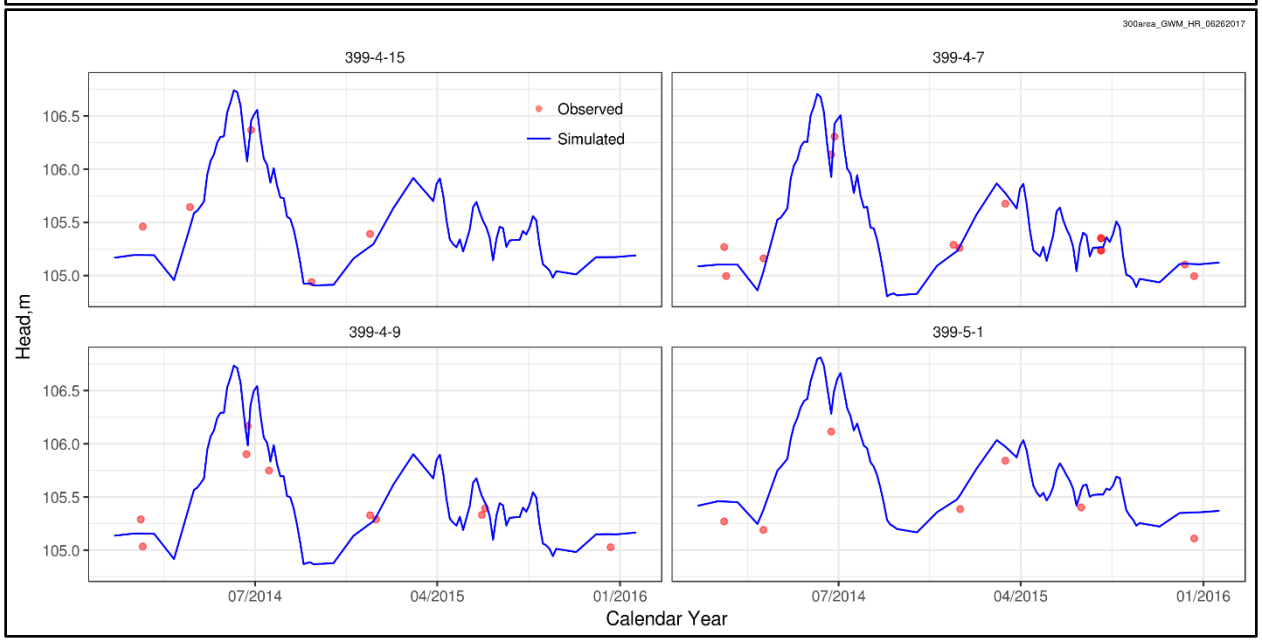
07/2014
04/2015
01/2016
Calendar Year


300area_GWM_HR_06262017
399-3-20
399-3-21
399-3-22
399-3-33
Observed
Simulated
Head,m
106.5
106.0
105.5
105.0
07/2014
04/2015
01/2016
Calendar Year


300area_GWM_HR_06262017
399-3-34
399-3-38
399-3-6
399-3-9
Observed
Simulated
Head,m
107.5
107.0
106.5
106.0
105.5
105.0
07/2014
04/2015
01/2016
Calendar Year


300area_GWM_HR_06262017
399-4-1
399-4-10
399-4-11
399-4-14
Observed
Simulated
Head,m
109
108
107
106
105
07/2014
04/2015
01/2016
Calendar Year


300area_GWM_HR_06262017
399-4-15
399-4-7
399-4-9
399-5-1
Observed
Simulated
Head,m
106.5
106.0
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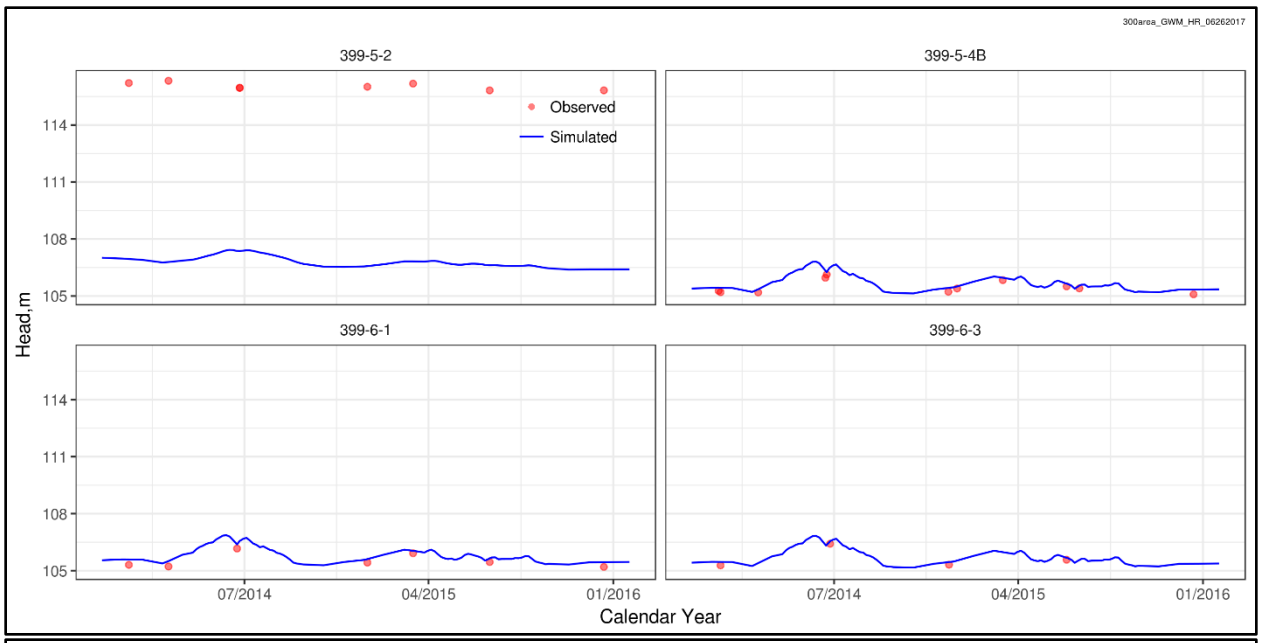
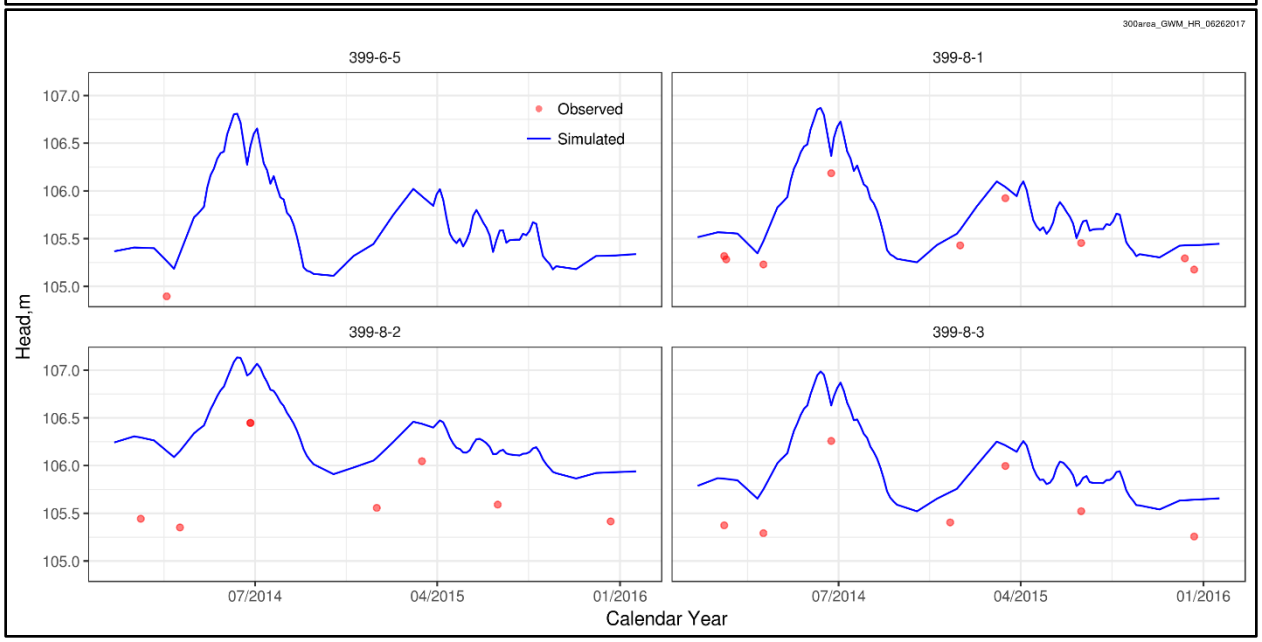
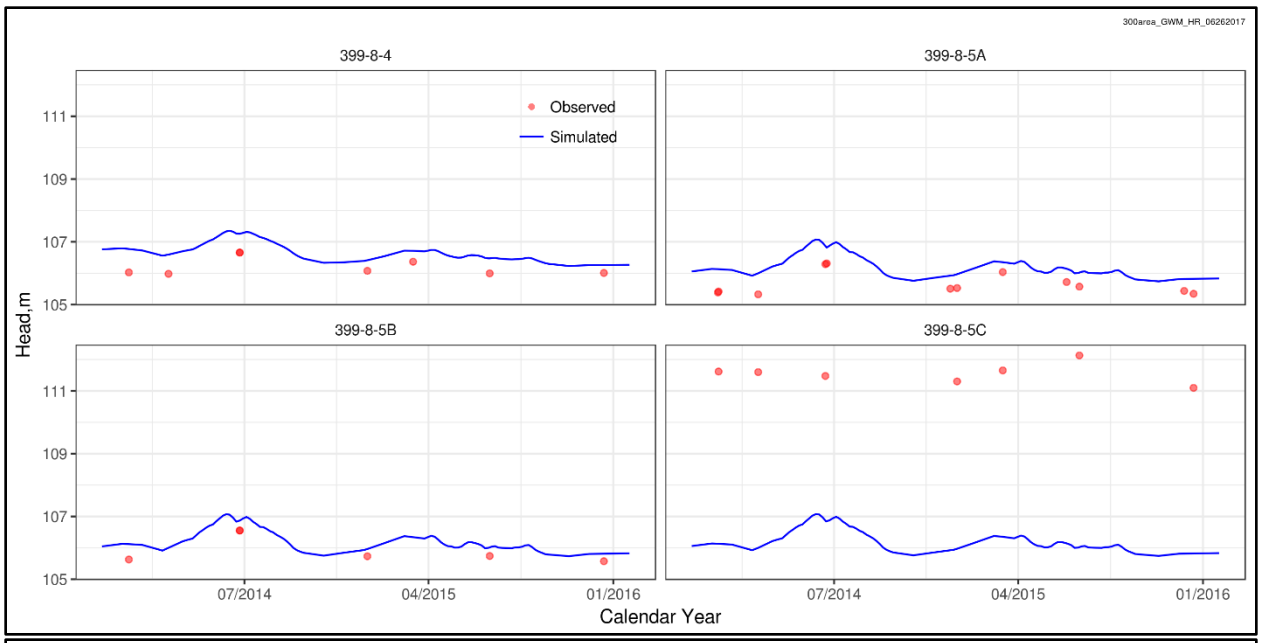
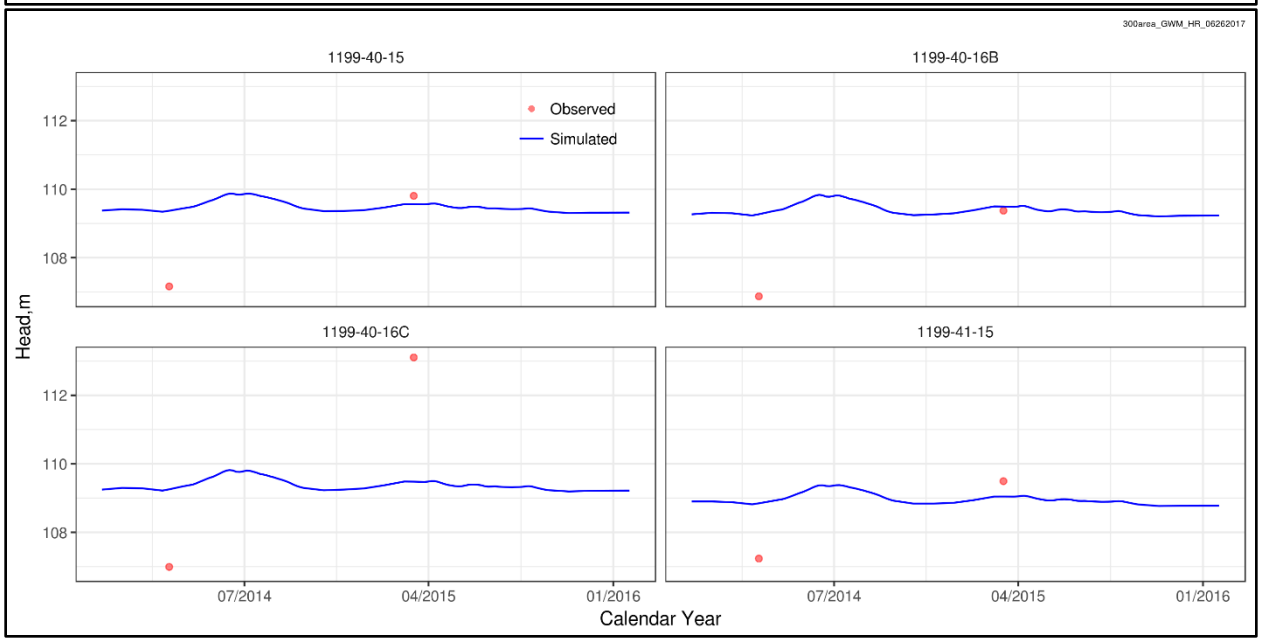
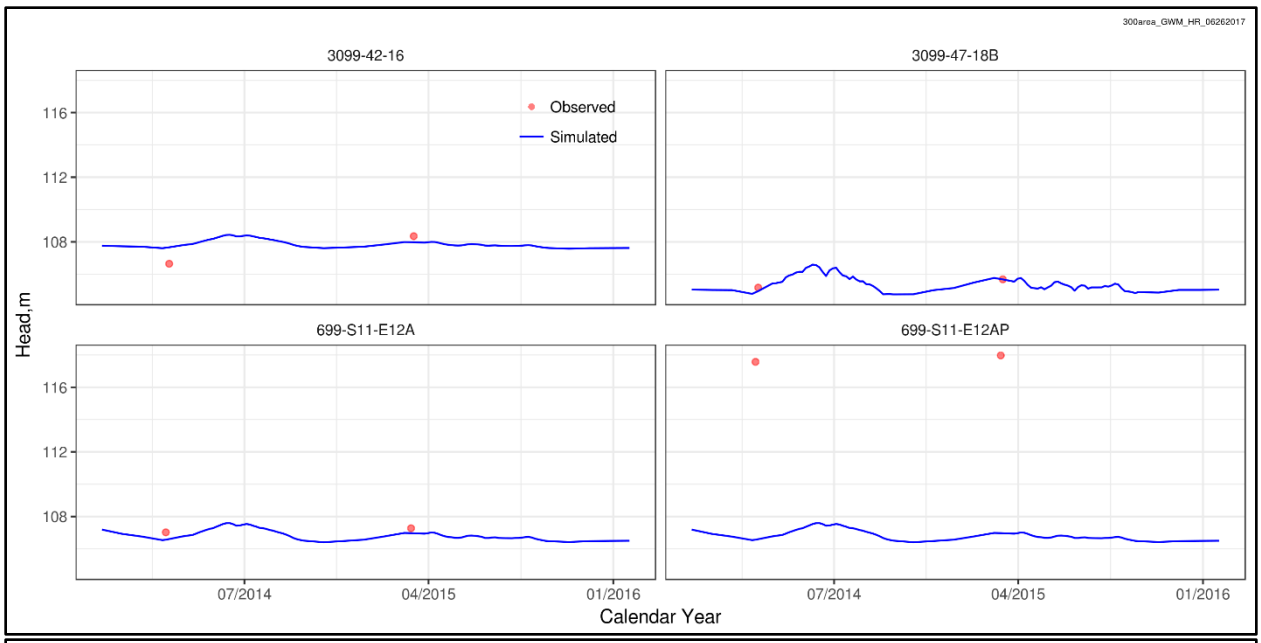
105.0
07/2014
04/2015
01/2016
Calendar Year

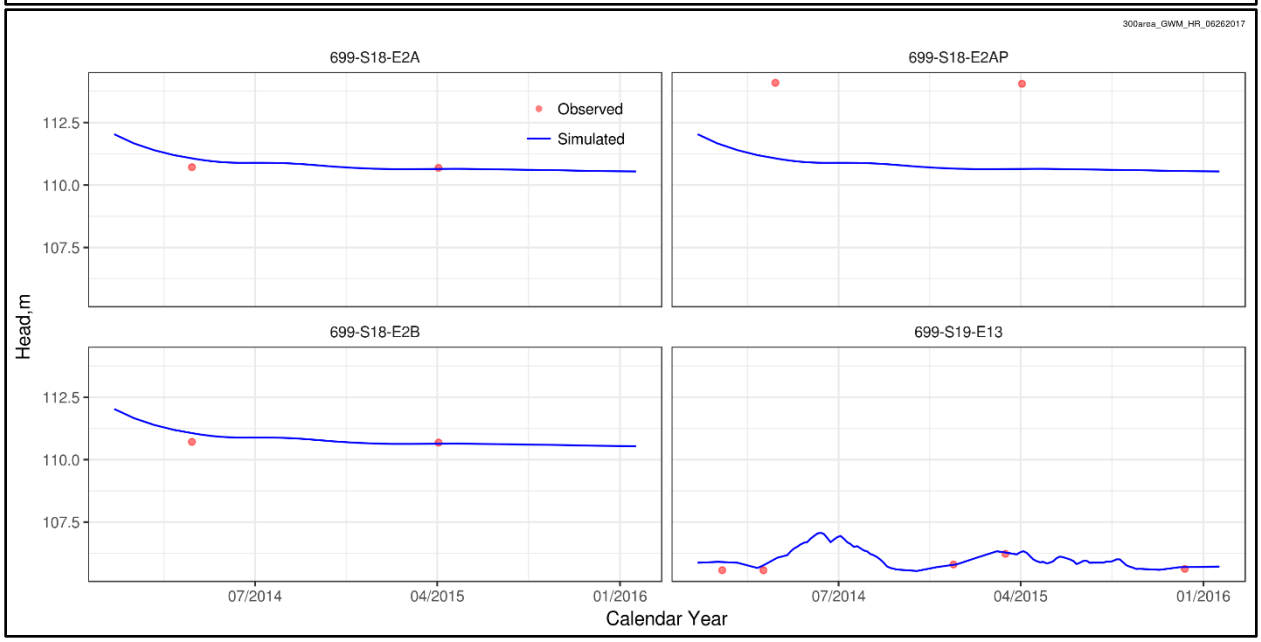

300area_GWM_HR_06262017
399-5-2
399-5-4B
399-6-1
399-6-3
Observed
Simulated
Head,m
114
111
108
105
07/2014
04/2015
01/2016
Calendar Year


300area_GWM_HR_06262017
399-6-5
399-8-1
399-8-2
399-8-3
Observed
Simulated
Head,m
107.0
106.5
106.0
105.5
105.0
07/2014
04/2015
01/2016
Calendar Year


300area_GWM_HR_06262017
399-8-4
399-8-5A
399-8-5B
399-8-5C
Observed
Simulated
Head,m
111
109
107
105
07/2014
04/2015
01/2016
Calendar Year


300area_GWM_HR_06262017
1199-40-15
1199-40-16B
1199-40-16C
1199-41-15
Observed
Simulated
Head,m
112
110
108
07/2014
04/2015
01/2016
Calendar Year


300area_GWM_HR_06262017
3099-42-16
3099-47-18B
699-S11-E12A
699-S11-E12AP
Observed
Simulated
Head,m
116
112
108
07/2014
04/2015
01/2016
Calendar Year


300area_GWM_HR_06262017
699-S18-E2A
699-S18-E2AP
699-S18-E2B
699-S19-E13
Observed
Simulated
Head,m
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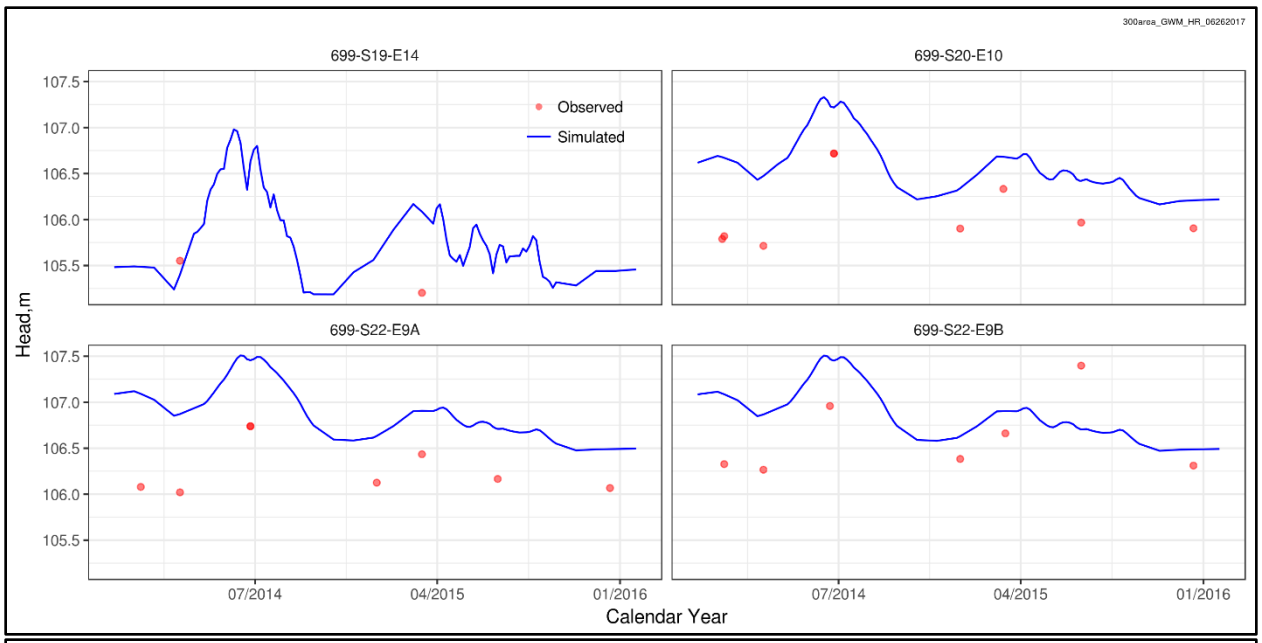
07/2014
04/2015
01/2016
Calendar Year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699-S22-E9A
699-S22-E9B
Observed
Simulated
Head,m
107.5
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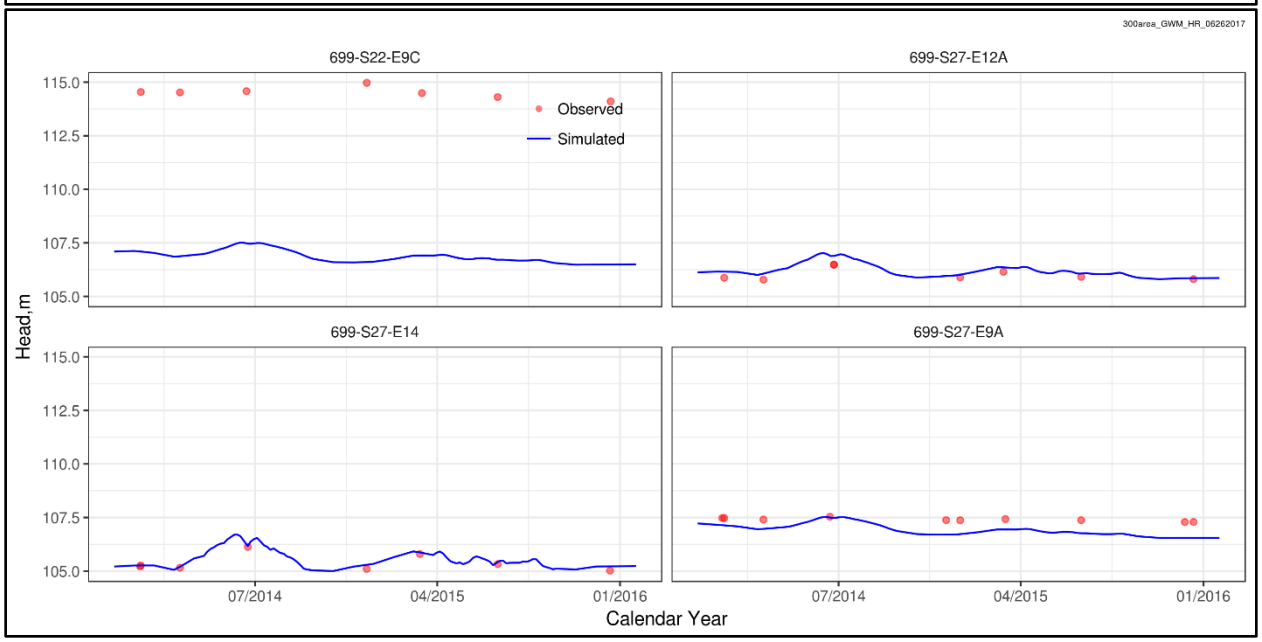
106.5
106.0
105.5
07/2014
04/2015
01/2016
Calendar Year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Head,m
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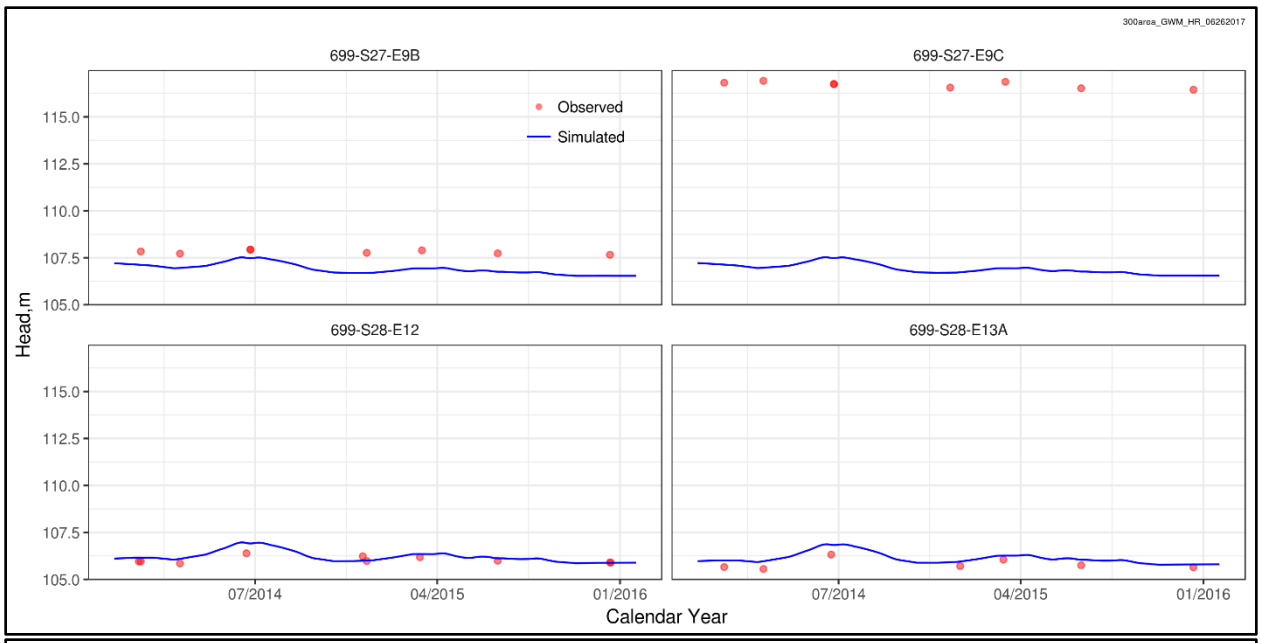
07/2014
04/2015
01/2016
Calendar Year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Head,m
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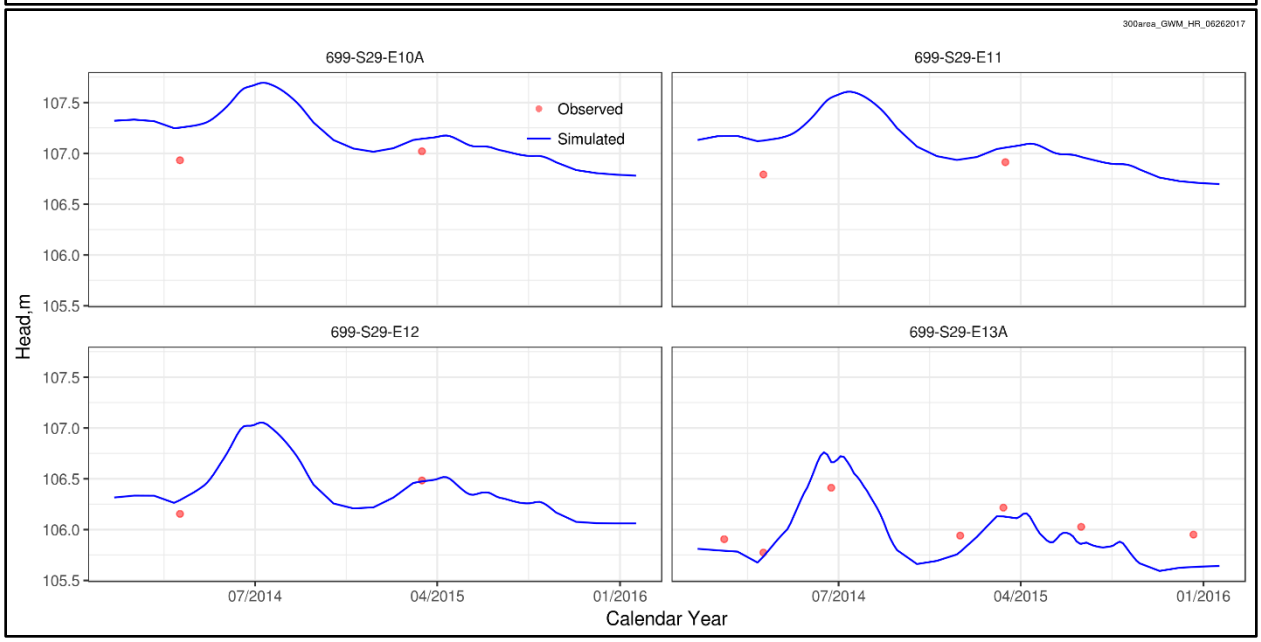
04/2015
01/2016
Calendar Year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Head,m
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106.5
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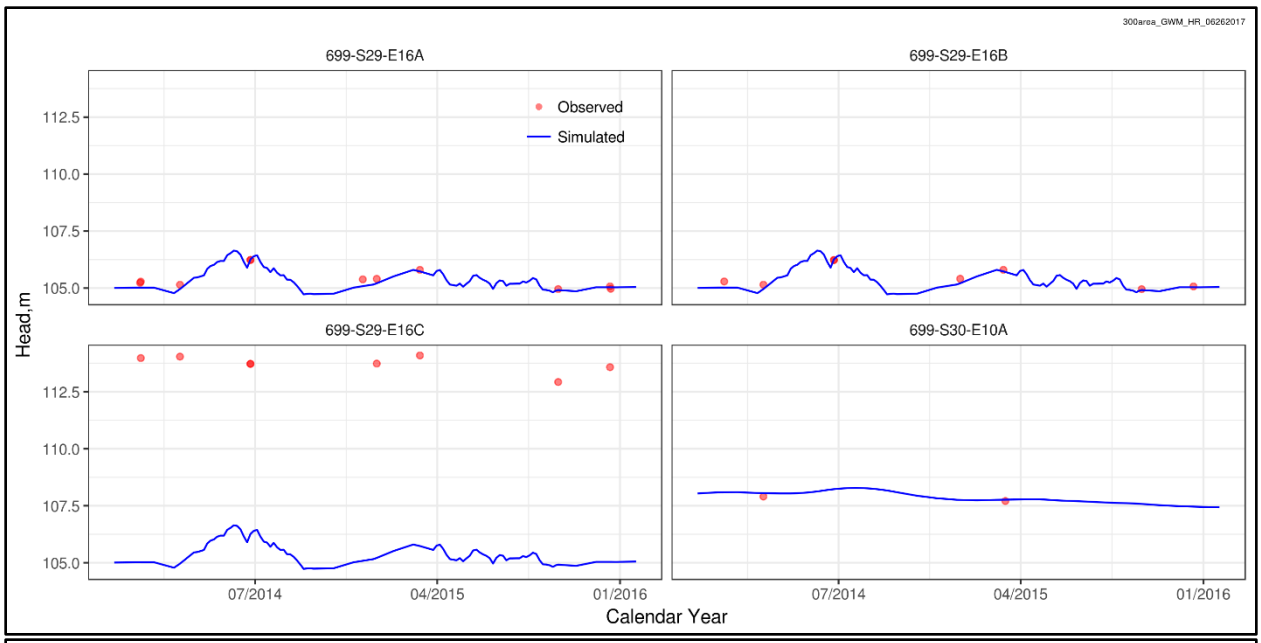
07/2014
04/2015
01/2016
Calendar Year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699-S29-E16C
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Head,m
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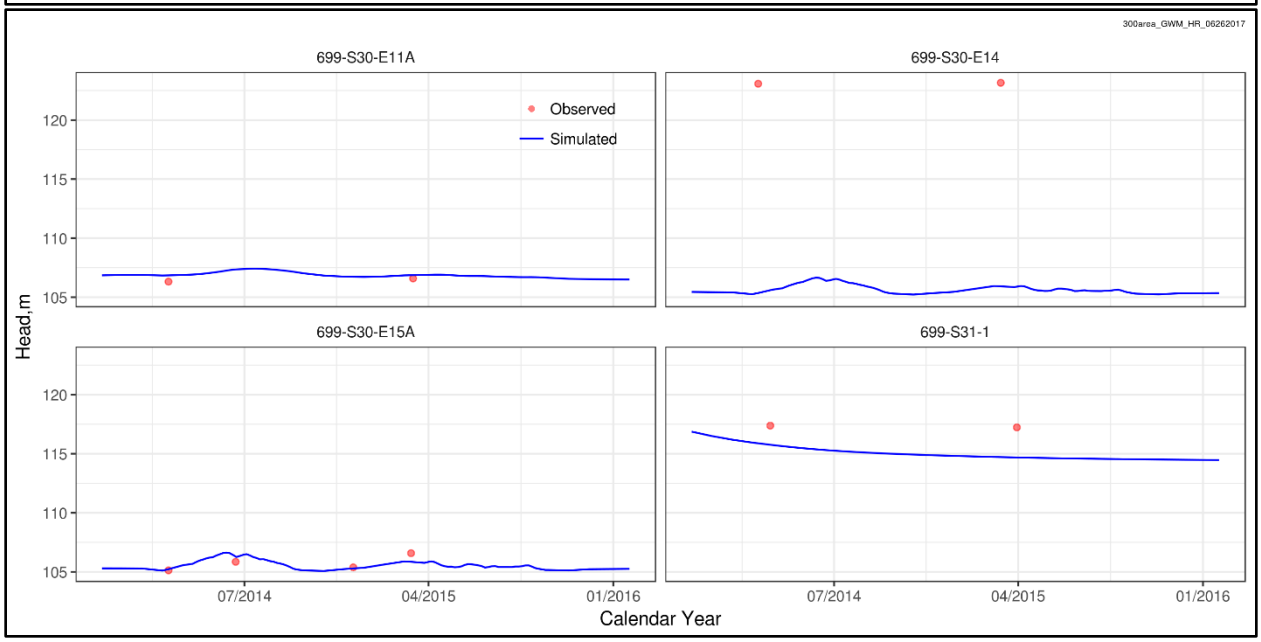
07/2014
04/2015
01/2016
Calendar Year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Simulated
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120
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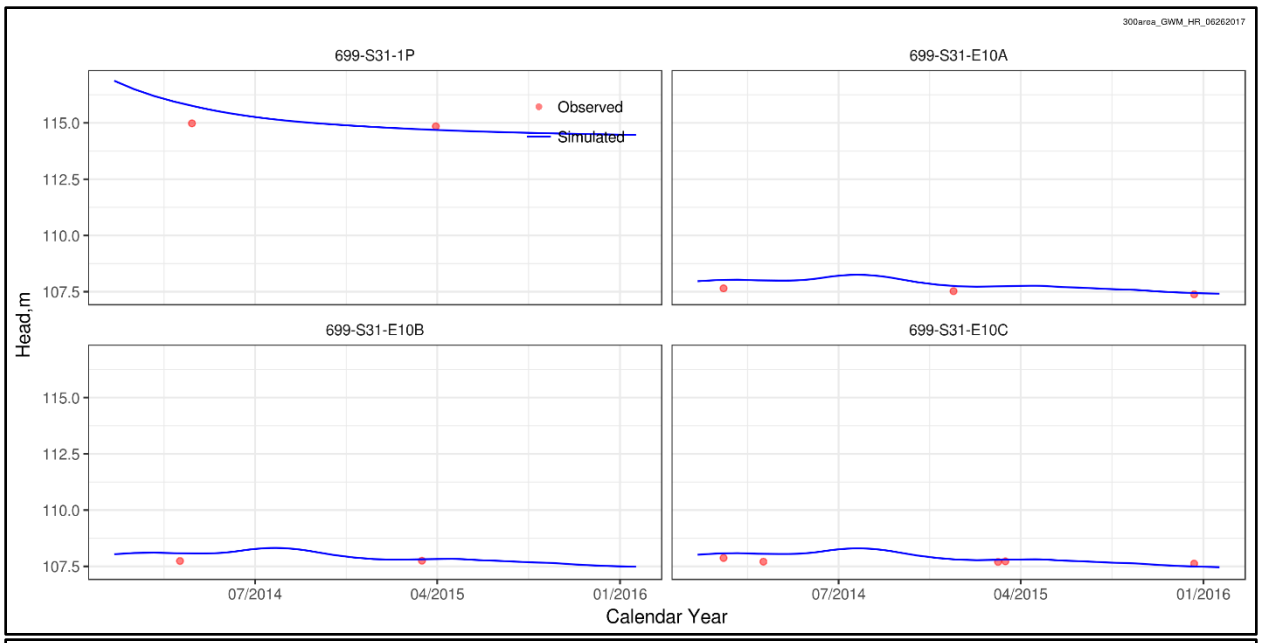
110
105
07/2014
04/2015
01/2016
Calendar Year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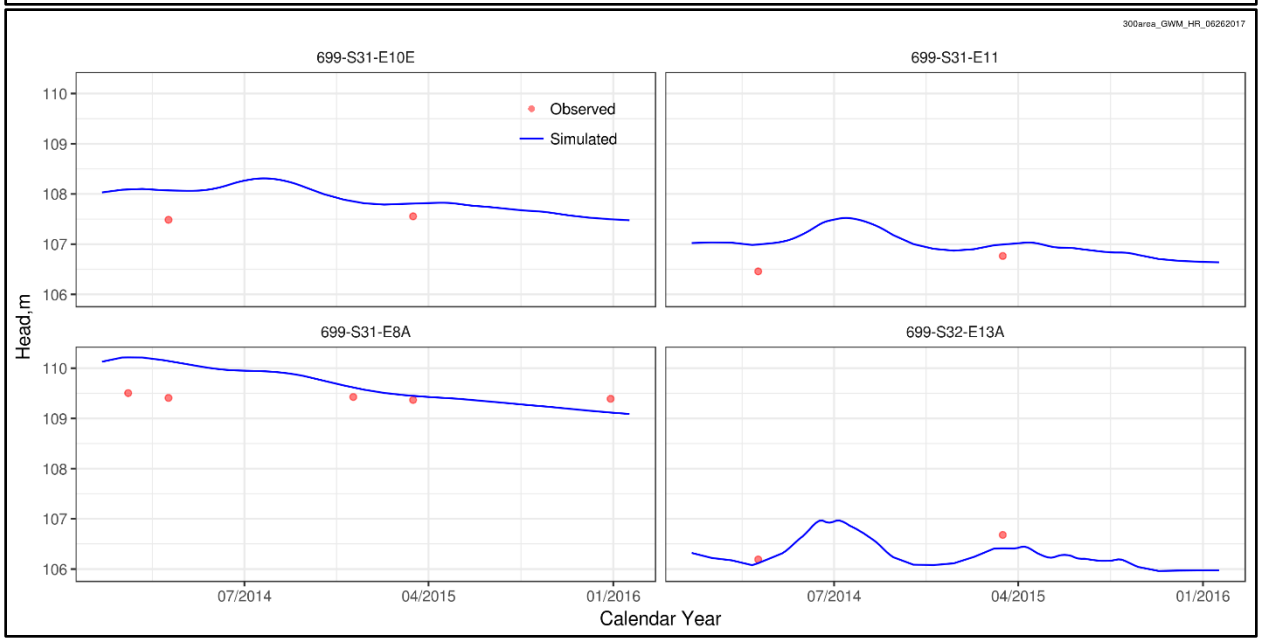
04/2015
01/2016
Calendar Year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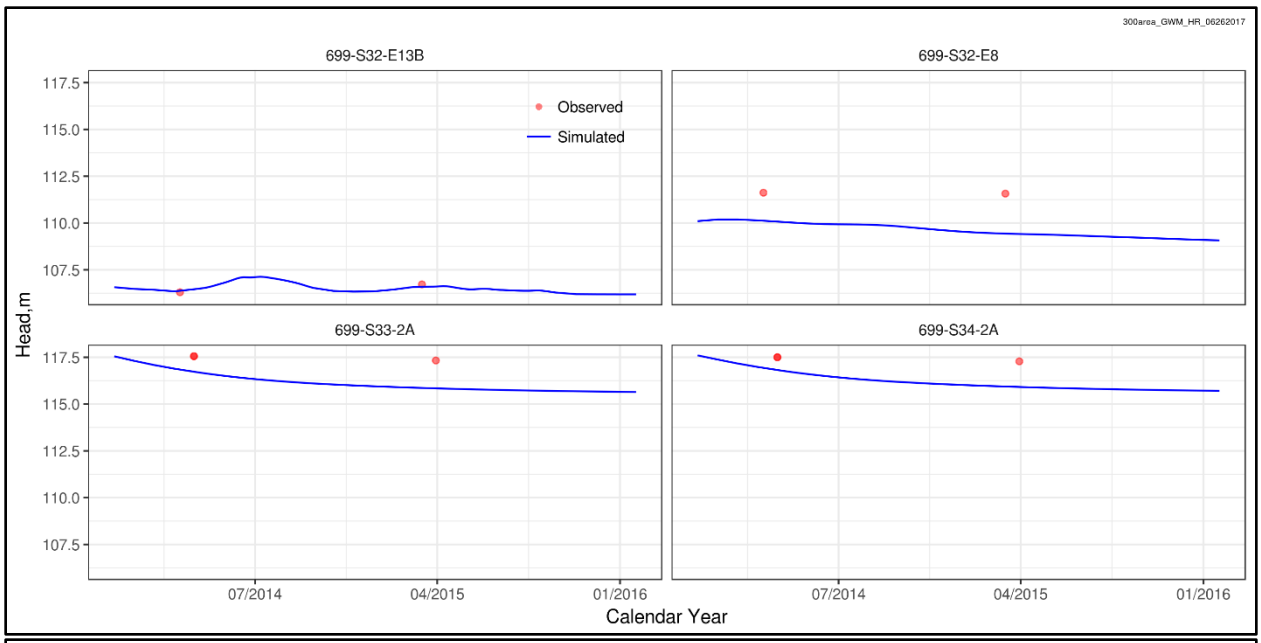
Observed
Simulated
Head,m
110
109
108
107
106
07/2014
04/2015
01/2016
Calendar Year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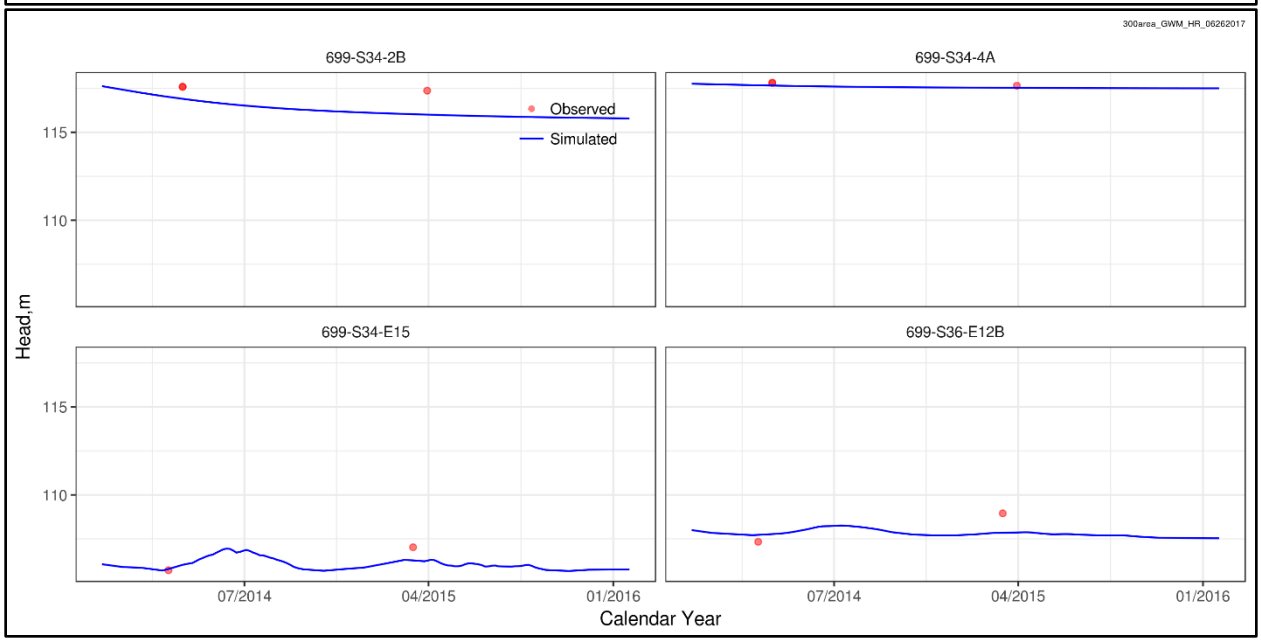
04/2015
01/2016
Calendar Year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Simulated
Head,m
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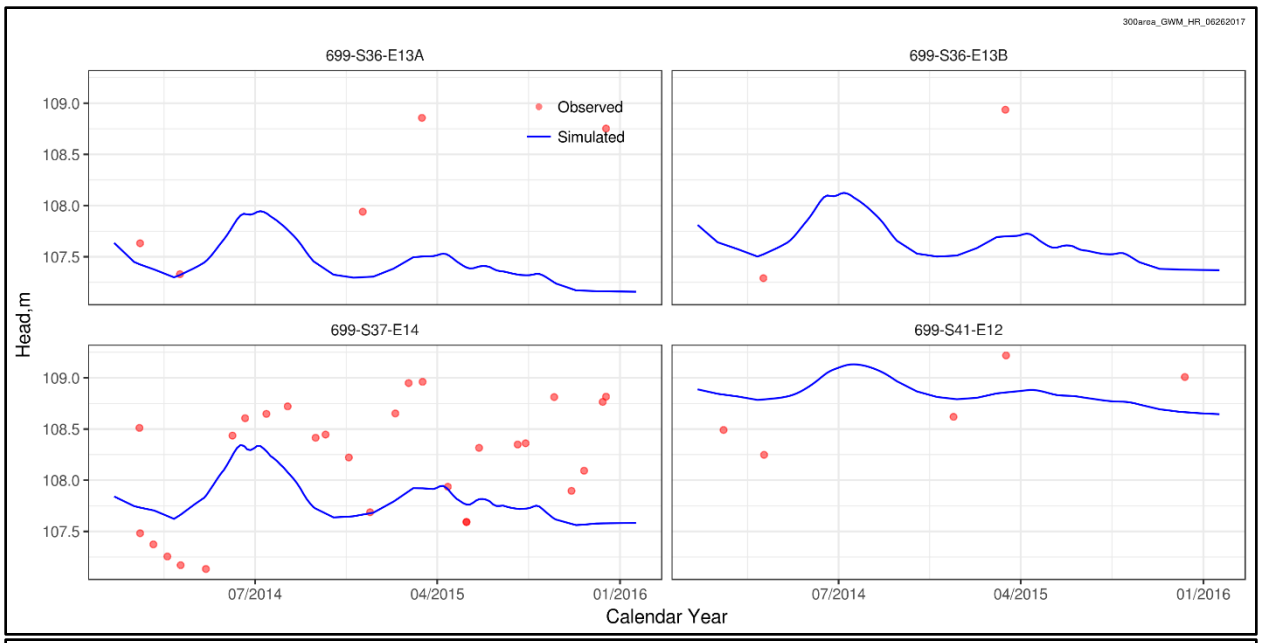
110
07/2014
04/2015
01/2016
Calendar Year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Simulated
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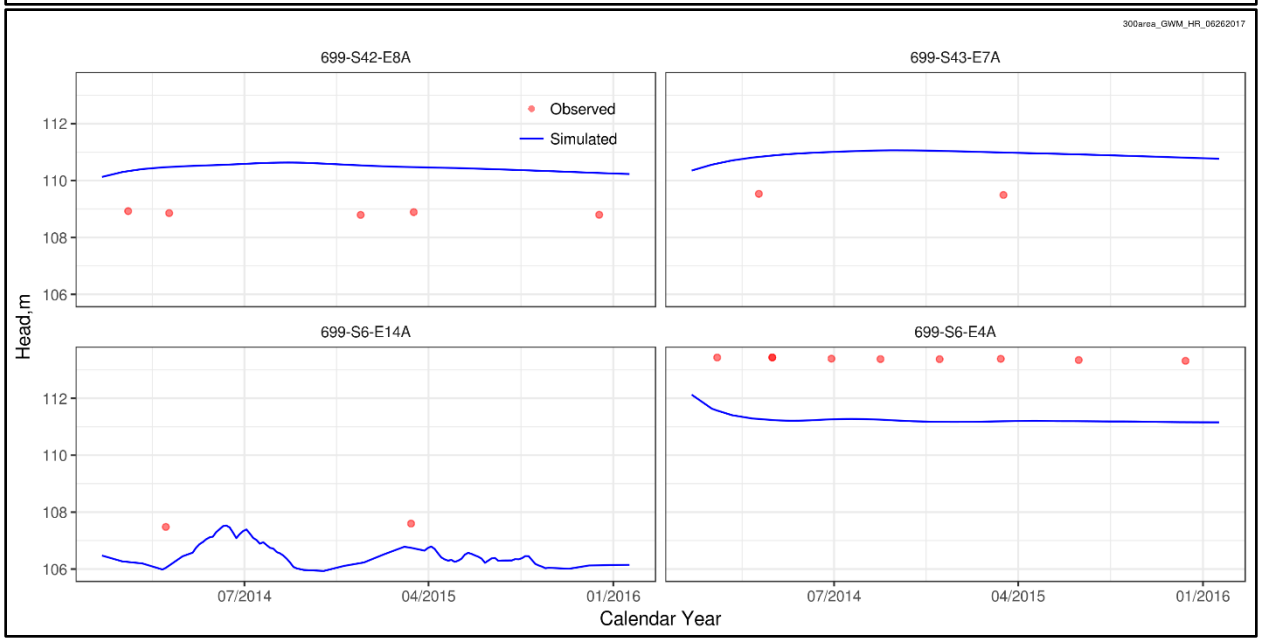
07/2014
04/2015
01/2016
Calendar Year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Head,m
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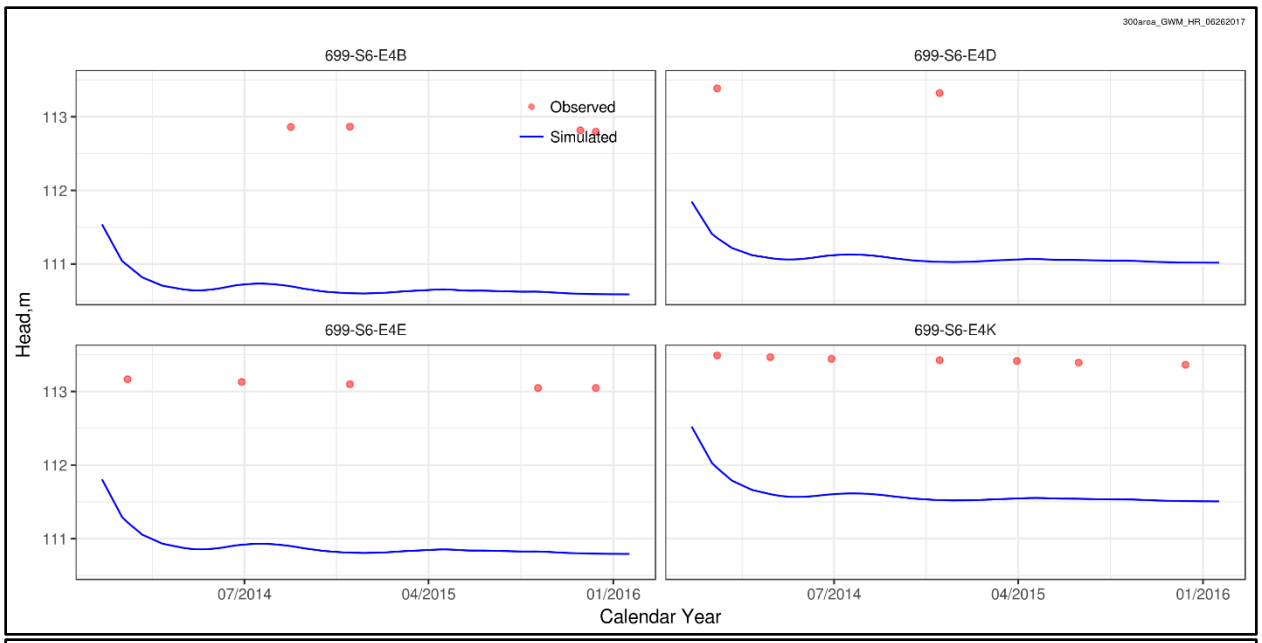
108
106
07/2014
04/2015
01/2016
Calendar Year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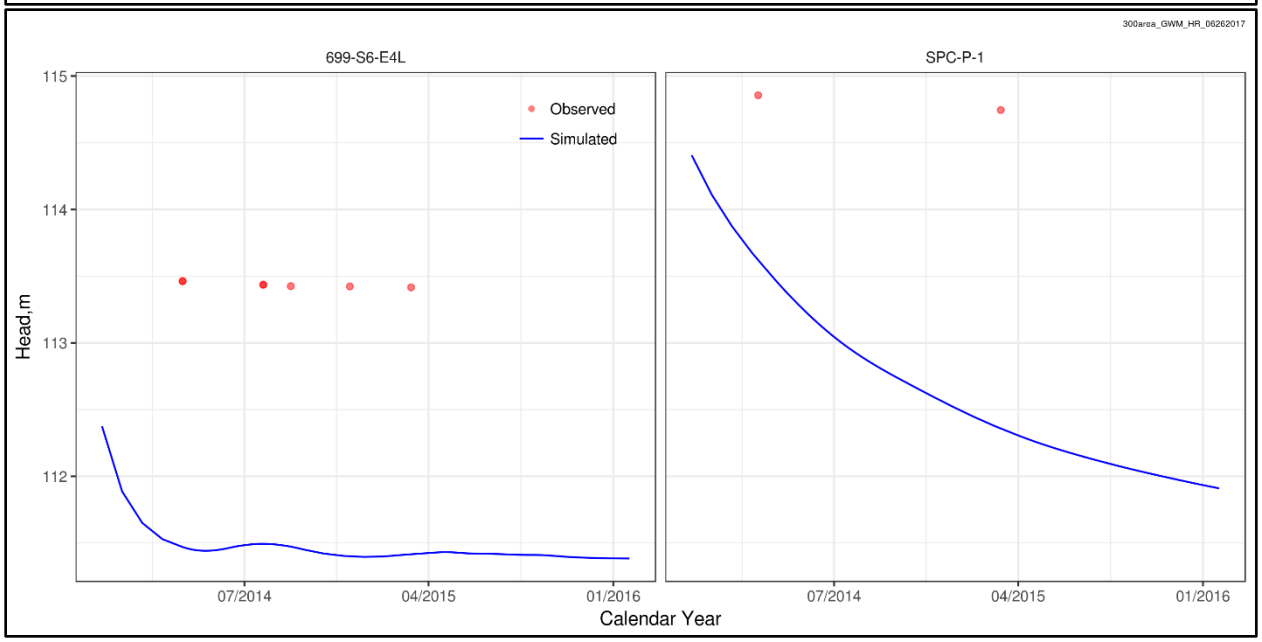
Head,m
113
112
111
07/2014
04/2015
01/2016
Calendar Year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113
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07/2014
04/2015
01/2016
Calendar Year