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Technical Memorandum

To: Brandi Flyr, Nebraska Department of Natural Resources	
From: Larry Land, P.E. and Tricia Sebes, P.E.	Project:
CC: John Engel, P.E., Marc Groff	
Date: November 1, 2013	Job No:

RE: Review of Central Nebraska Groundwater Flow Model

1.0 Introduction

The Nebraska Department of Natural Resources (DNR) contracted with Brown and Caldwell (BC) to develop a groundwater flow model for the Lower Niobrara, Loup, and Upper Elkhorn River Basins in Nebraska and part of southern South Dakota (CENEB). The purpose of the model is to develop a tool that has the capability of simulating stream-aquifer interactions in support of DNR's annual evaluation of basin status with regard to water appropriation. The model is being developed by BC staff with technical support from The Flatwater Group (TFG) and in collaboration DNR staff. TFG applied the CROPSIM model to estimate historical pumping and recharge for the CENEB model. Before finalizing the model, DNR requested HDR Engineering, Inc. (HDR) to provide a technical review of the model and its documentation. This Technical Memorandum presents HDR's review comments.

2.0 Approach

HDR's approach to the review consisted of:

- Reviewing the model's design and spatial and temporal framework
- Obtaining a digital copy of the MODFLOW and Groundwater Vistas (GWV) files
- Creating a Groundwater Vistas model from these files and loading to HDR's computers
- Running the model and exporting various displays of model parameter values and results
- Reviewing the model parameters and results for reasonableness
- Reviewing the model's calibration and water budgets
- Reviewing the documentation,
- Documenting our review comments.

A copy of MODFLOW files and an executable program for a steady state and transient models was provided to HDR by DNR. These files included input files needed to reconstruct the model as well as output files, which provides model results and verification of HDR's model run. These results include groundwater levels, baseflow and water budgets). GWV's pre- and post-processing capability was used to facilitate the review.

3.0 Review Comments

HDR's review comments are divided into two categories. The first is a review of the documentation and the second is a review of the model parameter values and results.

As discussed extensively in the report, the CENEB model is largely based on the existing Elkhorn-Loup Model (ELM). This has the benefit of taking advantage of work that has already been done, but has the potential disadvantage of carrying over model deficiencies. If any significant model deficiencies did exist in the ELM, the detailed and rigorous calibration procedures in the CENEB model corrected these deficiencies.

3.1 Documentation

Overall: The document is very well written, concise, and includes excellent graphics and tables. The document provides an outstanding discussion and justification on all aspects of model, including approach, design, calibration, testing and sensitivity. It is an excellent report, which greatly aided the review.

3.1.1 Text: Editorial and Technical Comments

Sect 1: Excellent overview.

Sect 1.2.3, 2nd para, 4th bullet: A word choice, I suggest changing "smaller" to "lower" order tributaries.

Sect 2: Complete. Excellent.

Sect 2.2: Excellent summary of the ELM.

Sect 2.2, 6th para, 1st sent: A word choice. I suggest changing the term <u>simulation</u> in "steady-state simulation" and "transient simulation" to "steady-state period" and "transient period"

Sect 2.3, 3rd para, 1nd line: Suggest adding farm after "historical dryland".

Sect 3: Complete. Excellent overview.

Sect 4: Complete and with excellent explanations. Boundaries, aquifer parameter values and water budget seem reasonable.

Sect 4.6.2, 3rd para, last sent: The reference to Section 4.4 for the water balance approach appears to be incorrect.

Sect 5: Complete with minor exceptions, see comments below. Good balance between detail and brevity.

Table 5-1: The Evaporation ranges are inconsistent with the map (Figure 5-4).

Sect 5.3.1, 1st para: I suggest including a base of the aquifer map. This would provide documentation on the definition of the aquifer base outside the ELM.

Sect 5.3.2, 1st and 2nd para: Word choice. In this context, I prefer "lower" when referring to the vertical dimension instead of "decrease".

Sect 5.7, Fig 5-2: There are several substantial breaks in the hydraulic conductive ranges, i.e., where a transition from one zone to another jumps over one or more intermediate zones. The worst (or best example) is the 2.5-7.5 zone within a 25-30 zone (southwest area). On the surface this suggests an "Over Calibration" or not enough zones within the model. This is more cosmetic than a flaw. Bottom line, I do not suggest adding more zones within the model for the transition, which may require some recalibration. This is just a suggestion for future model development.

Sect 5.7, Fig 5-3: I did not notice any zone jumps in the specific yield, but there are several "bulls eyes" that suggest "Over Calibration". As with the hydraulic conductivity, I do not suggest a revision.

Sect 5.8: Suggest adding a discussion on the extinction depth.

Sect 5.8: The model data set shows a monthly distribution of ET rates, but this monthly signal is not discussed in the text.

Sect 5.8, Fig 5-4: Are the evapotranspiration rates potential or actual? What date or timeframe does this ET rate correspond to?

Sect 5.8, 3rd para: Error in last sentence. The cell size is 640 acres, so 7% is incorrect.

Sect 5.9, 1st para, 2nd sent: Suggest changing "…the increase in annual…" to "…long-term increasing trend…".

Sect 6: Very good.

Sect 6.2.2, 3rd para, 2nd sent: Word choice. In this context and as mentioned above, I prefer "lowering by" instead of "decrease".

Table 6-3: What does the "number of observations" refer to? Is it limited number of stress periods within the period of record? Maybe "Targets" is a better descriptor than "Observations".

Sect 6.6: Water budget looks reasonable.

Sect 6.7: Calibration looks good.

Sect 7: Very good.

Sect 7.2.1 1st para, 1st sent: A plus-minus 25% is not equivalent to an order of magnitude. Needs to be revised.

Sect 7.3, 2nd para, 2nd sent: Incorrectly worded. Decreased volume in aquifer is not attributed to deceased pumping and higher storage values. Consider changing the “volume” term to “groundwater levels”.

Sect 8: Okay.

Sect 9: Good wrap-up.

Sect 9.2, last para, 2nd sent: “Proportional” is not the correct term in that some of the responses are not linear to parameter values. The baseflow response has sensitive and insensitive ranges to several parameters.

3.1.2 Appendicies

Appendices A-D: Excellent. I really like the hydrograph displays.

Table C-1: Seems like it should be labeled A-1 to associate with Appendix A.

Pg 6, 1st para, 2nd line: Change “data is” to “data are”, that is, “datum is” and “data are”. An old USGS ism. There may other occurrences of this report.

3.2 Exports from Groundwater Model

The technical review also consisted of loading the CENEB model on to HDR’s computers, making a model run, preparing graphical and tabular summaries and compiling recharge and pumping results.

The following sets of model definition and results were exported from the model and reviewed. All looks reasonable, except as noted. Many of these maps, graphs and tables are attached at the end of this Tech Memo.

3.2.1 Aquifer Features and Property Maps

- Bottom and top of model layers
- Aquifer thickness
- Hydraulic conductivity
- Specific Yield
- Transmissivity

The only unusual distribution of parameters was Transmissivity where some relatively low T values were next to some relatively high T values.

3.2.2 Questions/Answers on Stream Package

- Do stages cascade downstream? Yes
- Are there discontinuity at junctions? No
- Are the stream stages and bottom elevations consistent? Yes

- Is Manning Equation used? Yes
- Is there a defined inflow hydrograph at points of inflow? No, except for Niobrara. This is consistent with the upstream point being the stream's headwaters.
  - Does the stream cells reasonably match the actual streams? Yes
  - Are stream segments, stream stage, and stream conductance values reasonable? Yes

3.2.3 Recharge Graphics and Maps

- Annual (1941-2011)
- Distribution by month (Jan-Dec)
- 1985
- Jan 1997
- April 1997
- July 1997
- October 1997

3.2.4 Pumping Graphics

- Annual (1941-2011)
- Distribution by month (Jan-Dec)

3.2.5 General Head Boundary Maps

- Conductance
- Stage

3.2.6 ET Maps

- Rate and Extinction Depth
- Stage

3.2.7 Calibration of Head Maps

- Steady State
- 1995
- 2011
- Dec 1985, January, April, July and October 1997

3.2.8 Mass Balance by Stress Period

- Steady State
- 1985
- January, April, July and October 1997

4.0 What's missing?

As mentioned earlier, the discussion on ET should be expanded to include extinction depth, monthly distribution of ET rates and distinction between potential and actual ET rates.

5.0 Conclusion

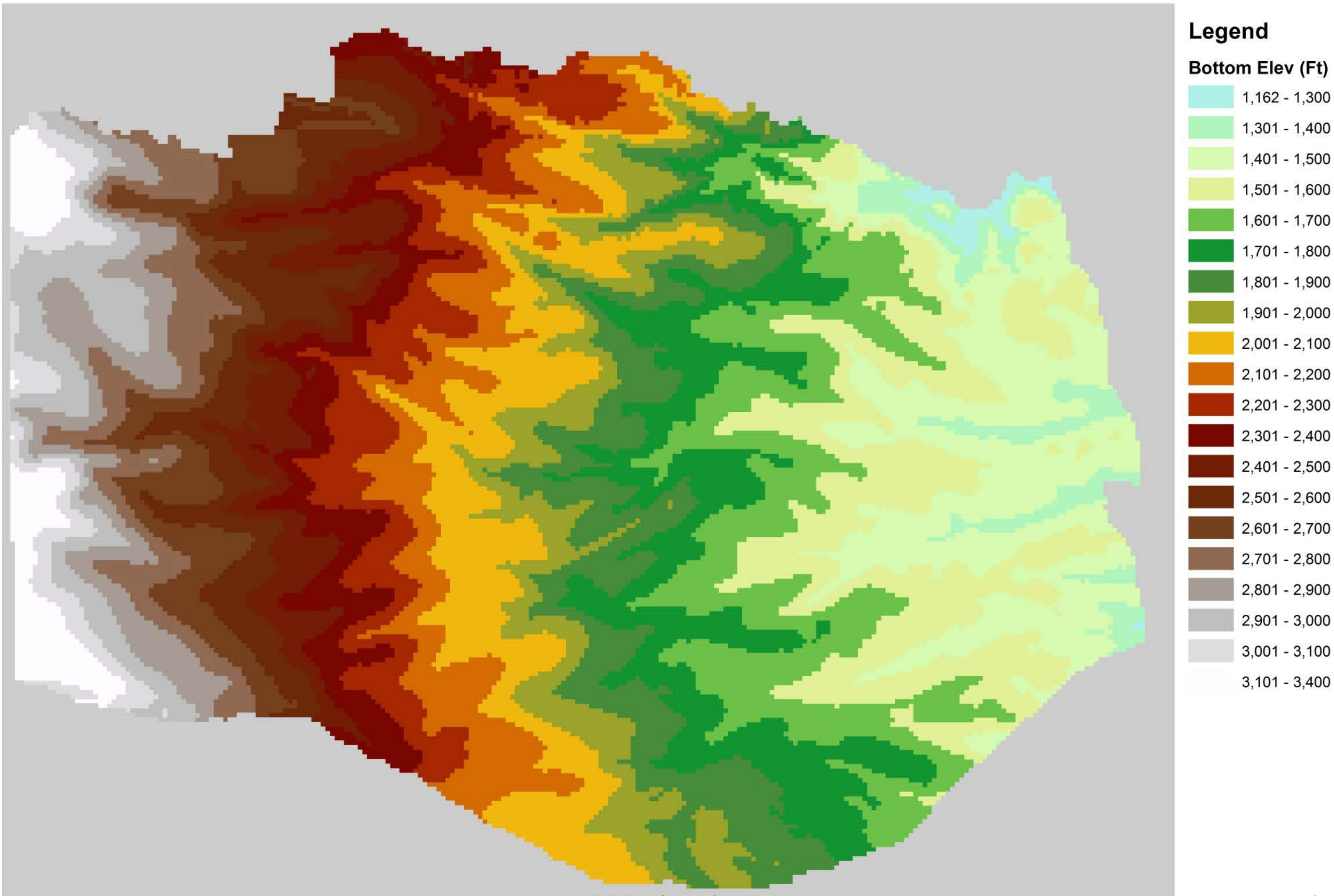
The model is suitable for its intended purpose.

Very good model and report.

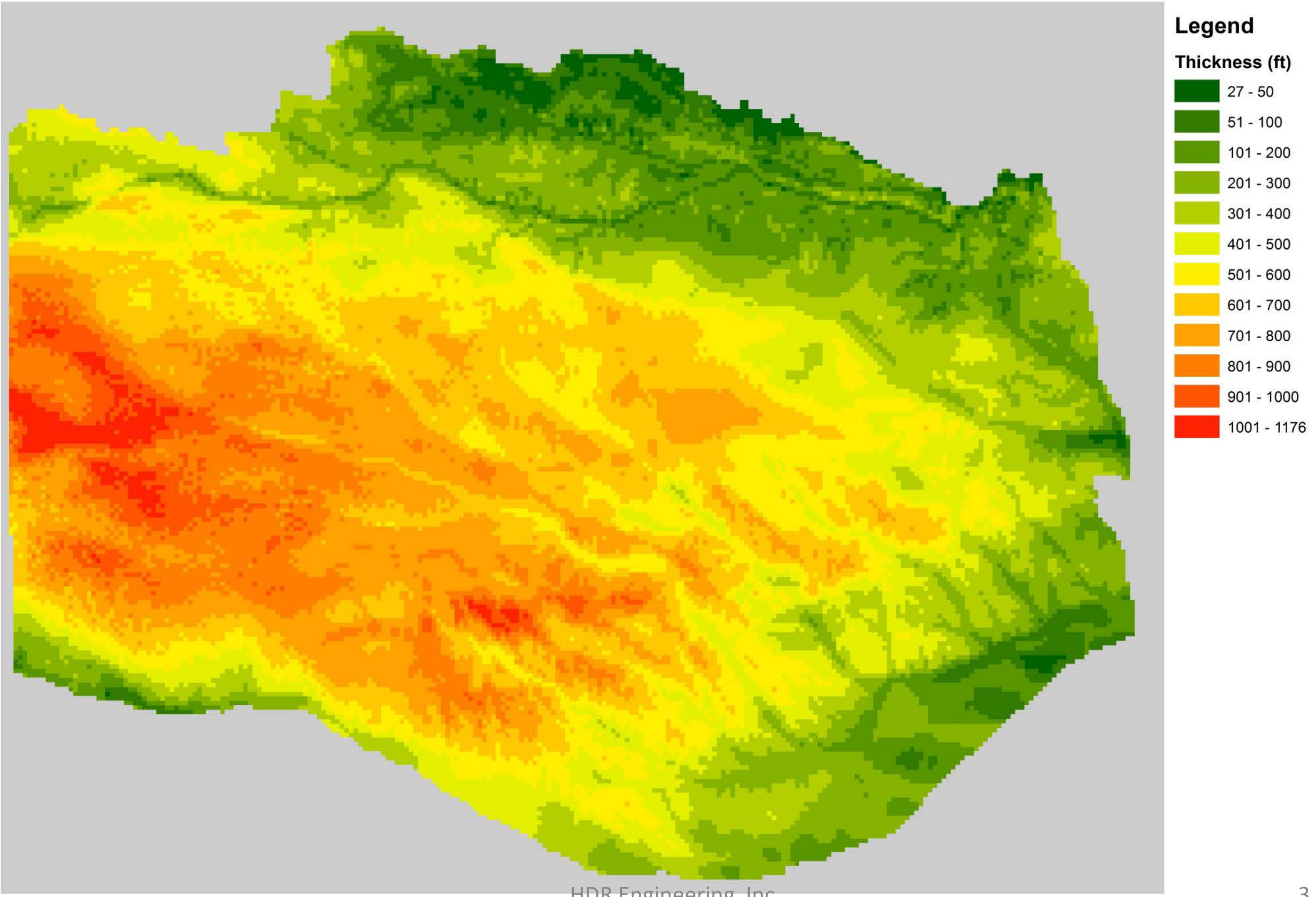
CENEB Model Review

Exports from CENEB Model

Layer 1 Bottom Elevation

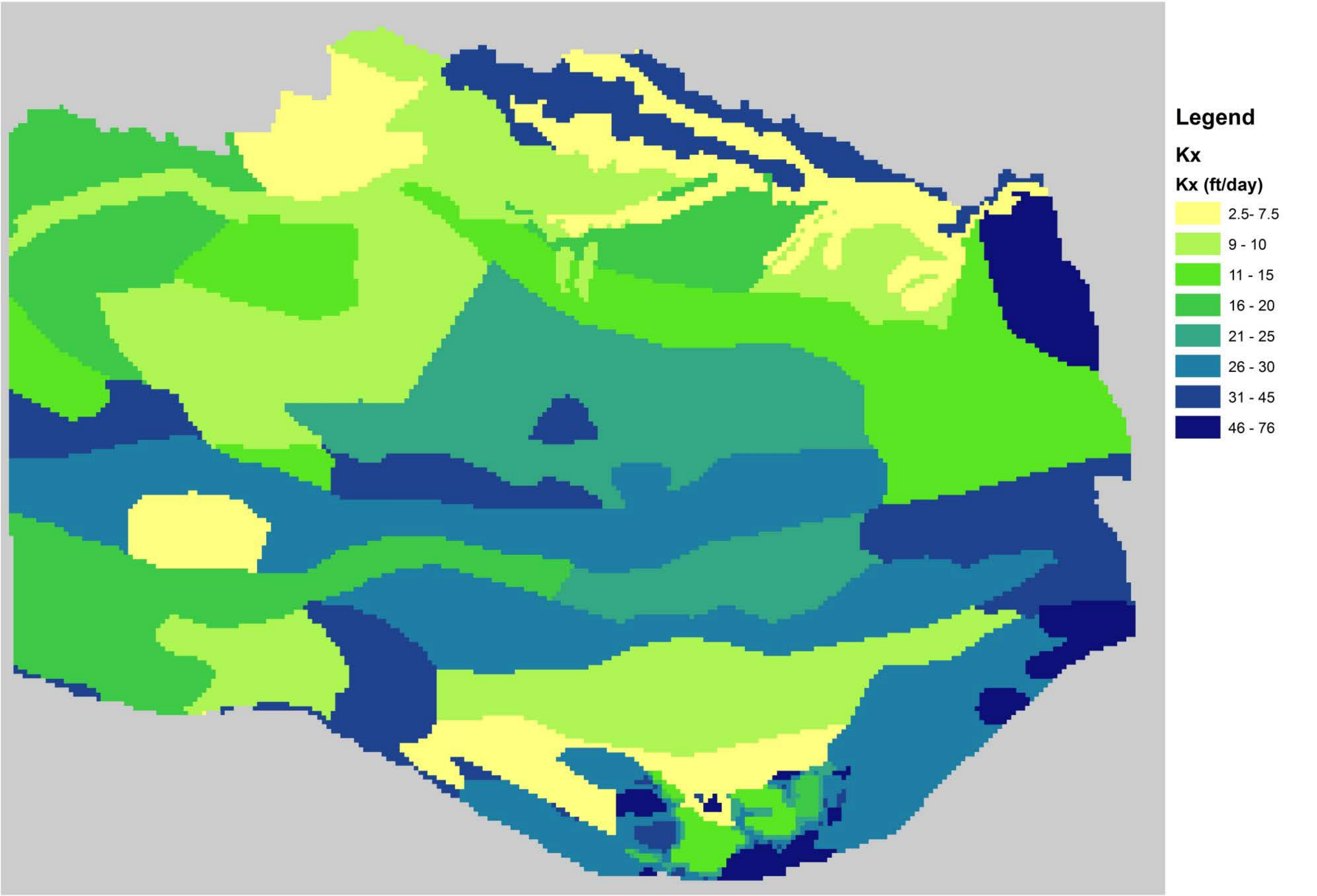


Thickness

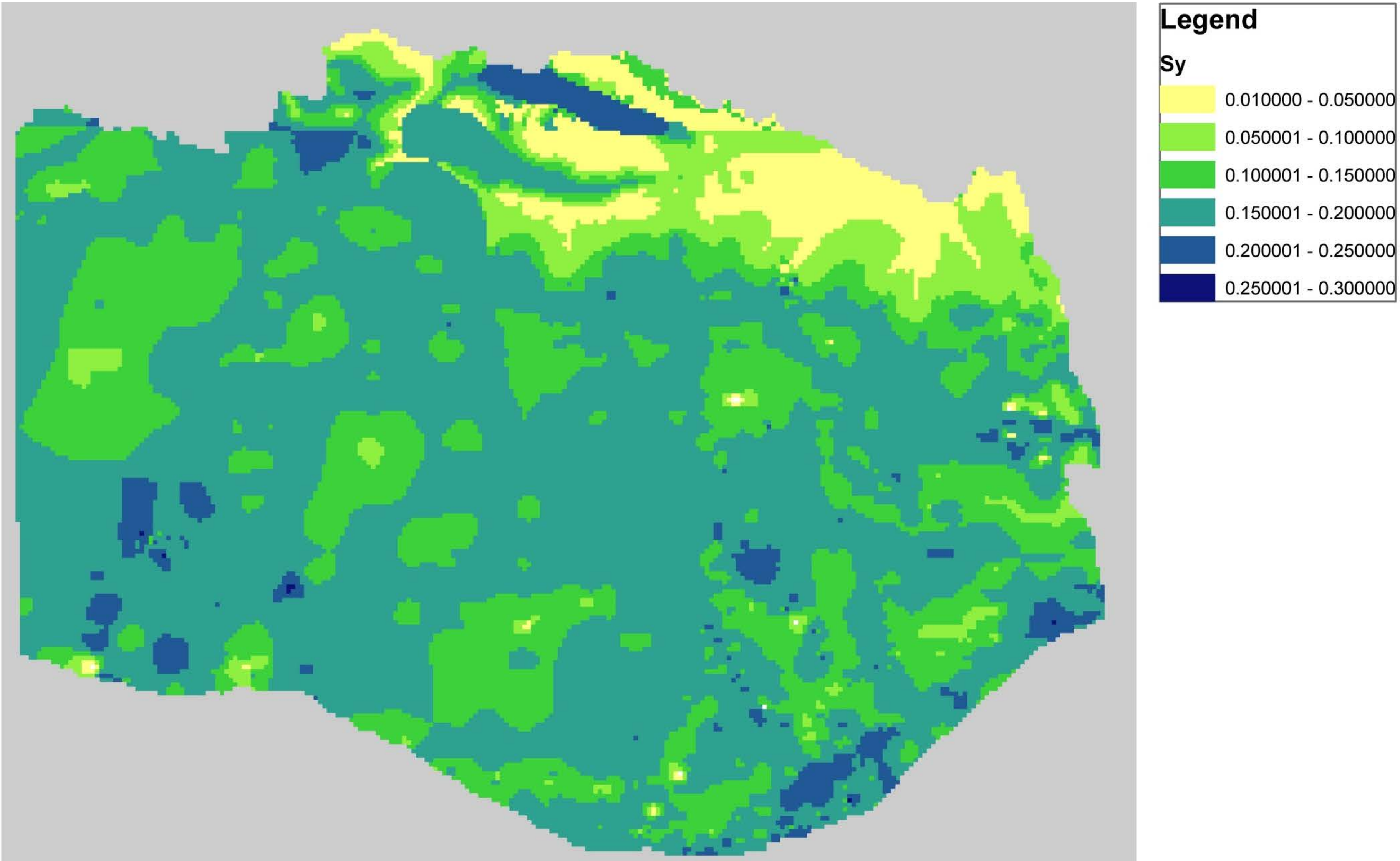


Legend
Thickness (ft)
27 - 50
51 - 100
101 - 200
201 - 300
301 - 400
401 - 500
501 - 600
601 - 700
701 - 800
801 - 900
901 - 1000
1001 - 1176

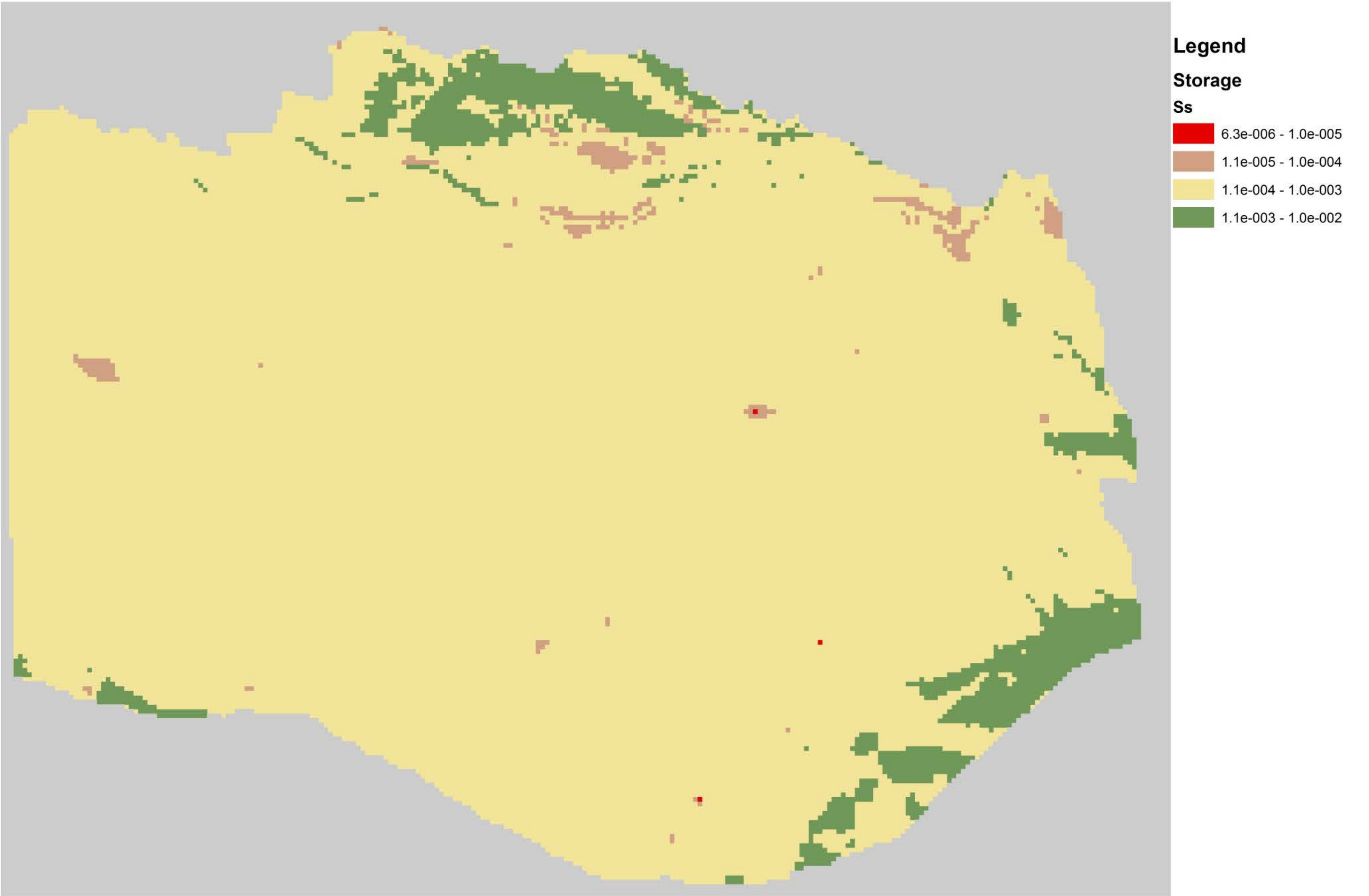
Hydraulic Conductivity



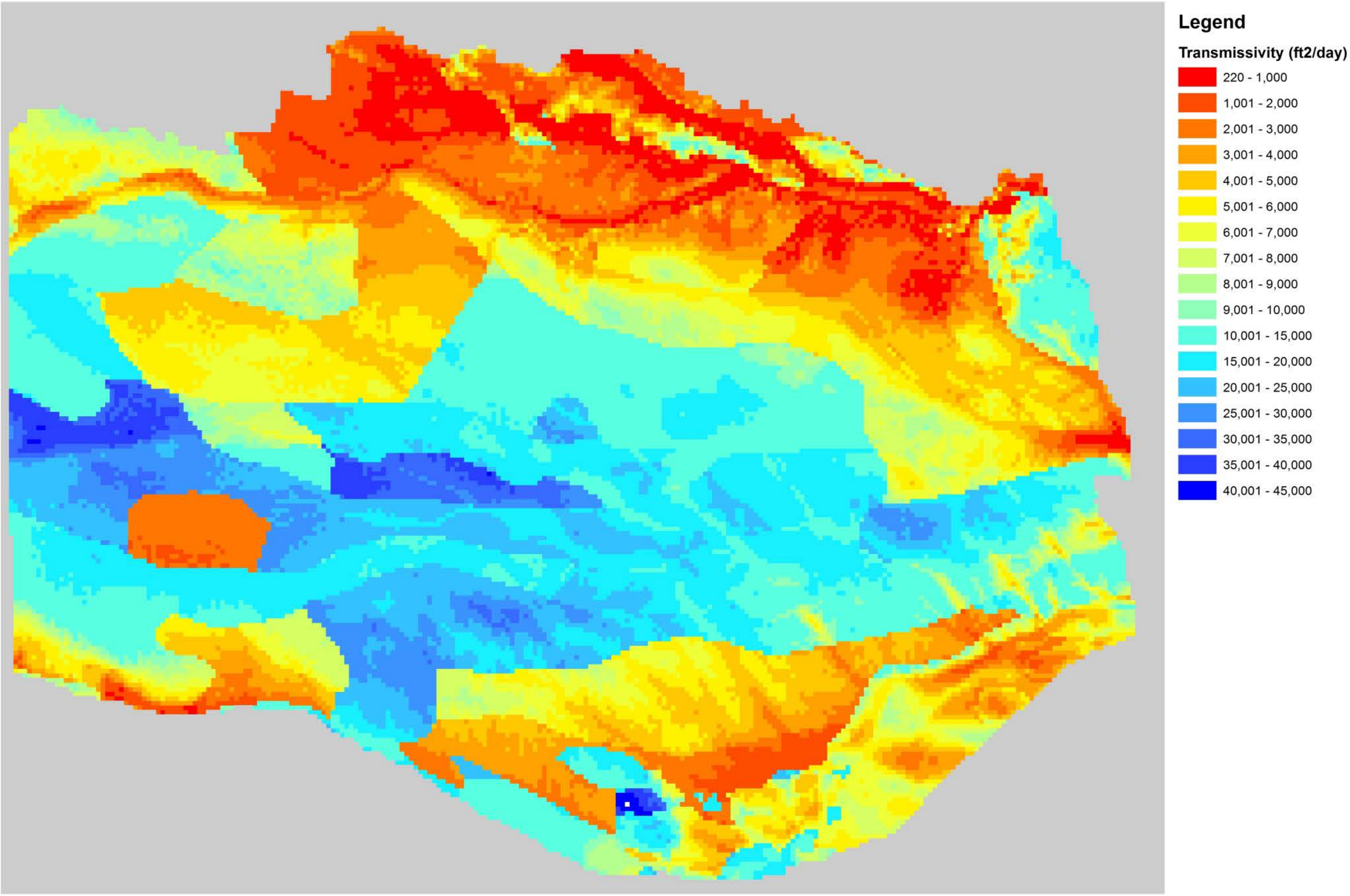
Specific Yield



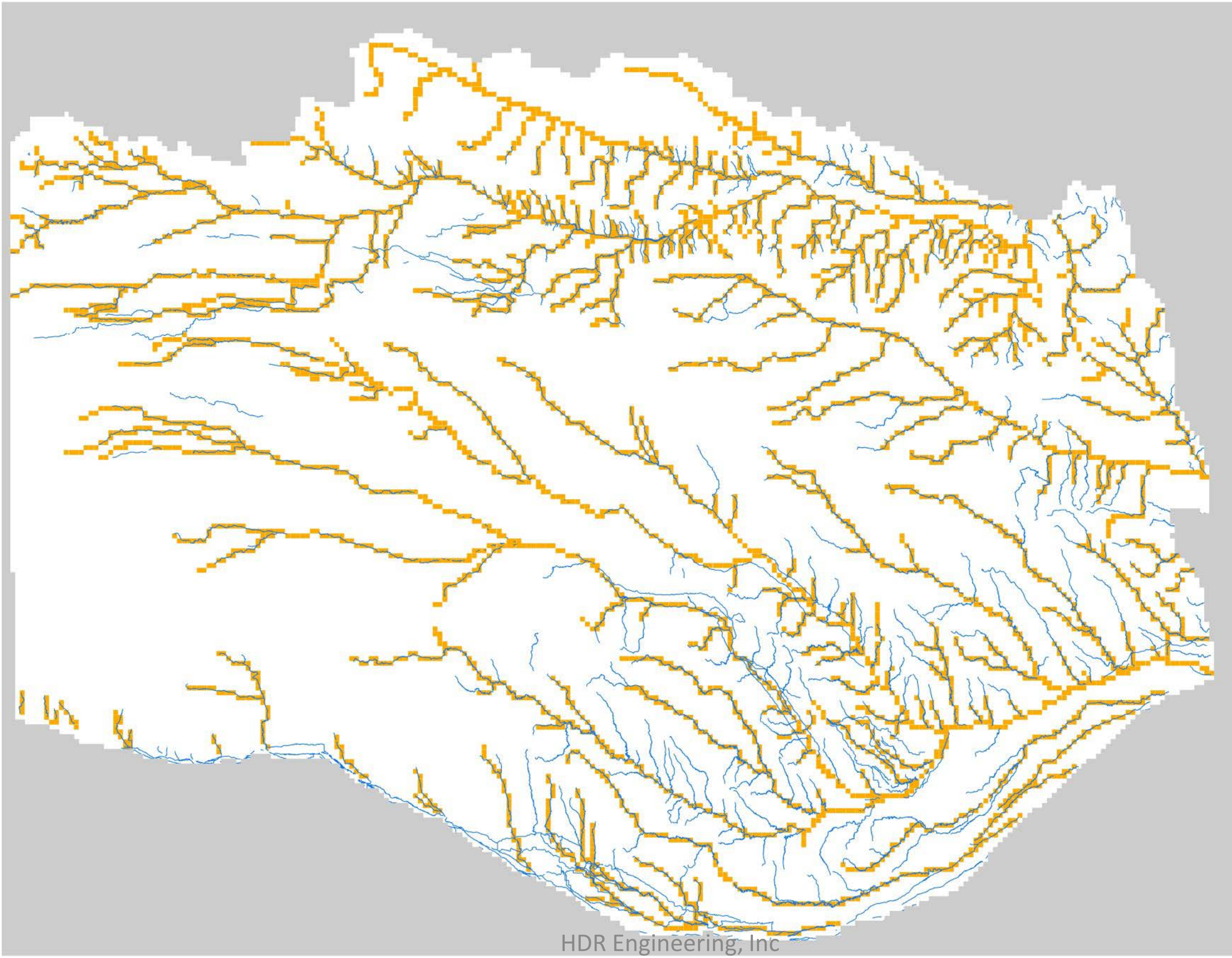
Storage


Legend
Storage
Ss
6.3e-006 - 1.0e-005
1.1e-005 - 1.0e-004
1.1e-004 - 1.0e-003
1.1e-003 - 1.0e-002

Transmissivity

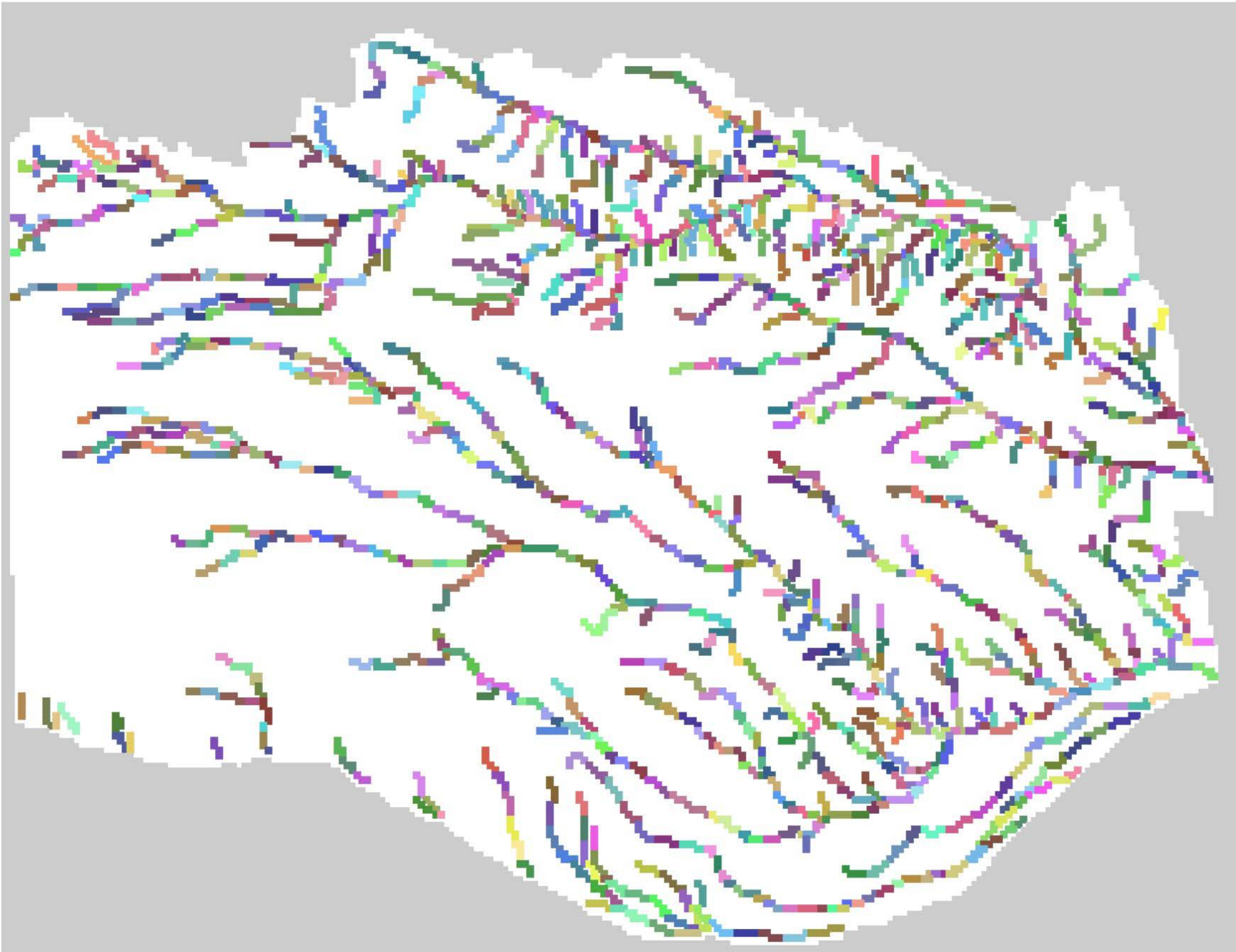


Model Stream Cells and Actual Streams



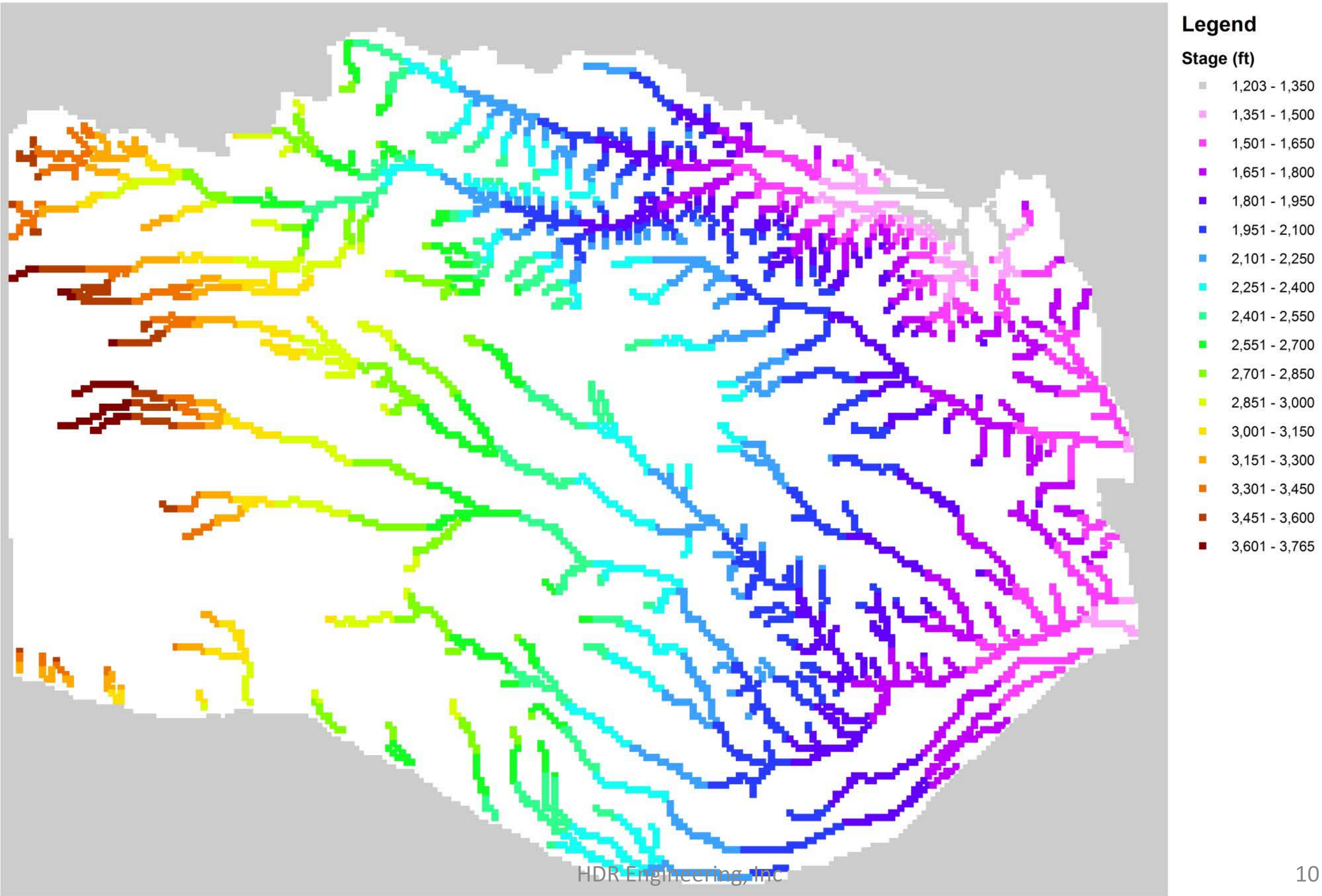
Stream Segments

There are 1,370 Segments. The max number of reaches is 22.

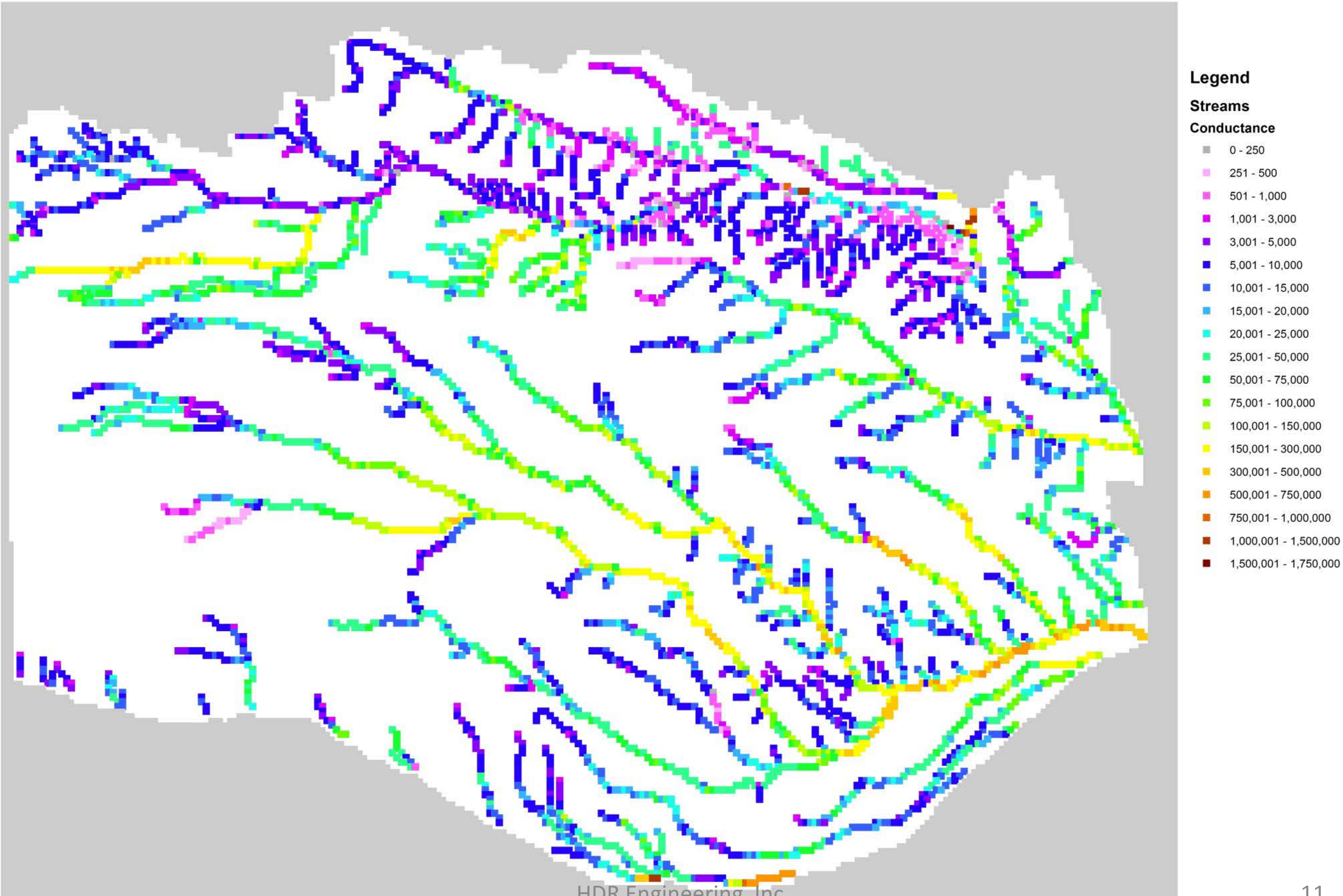


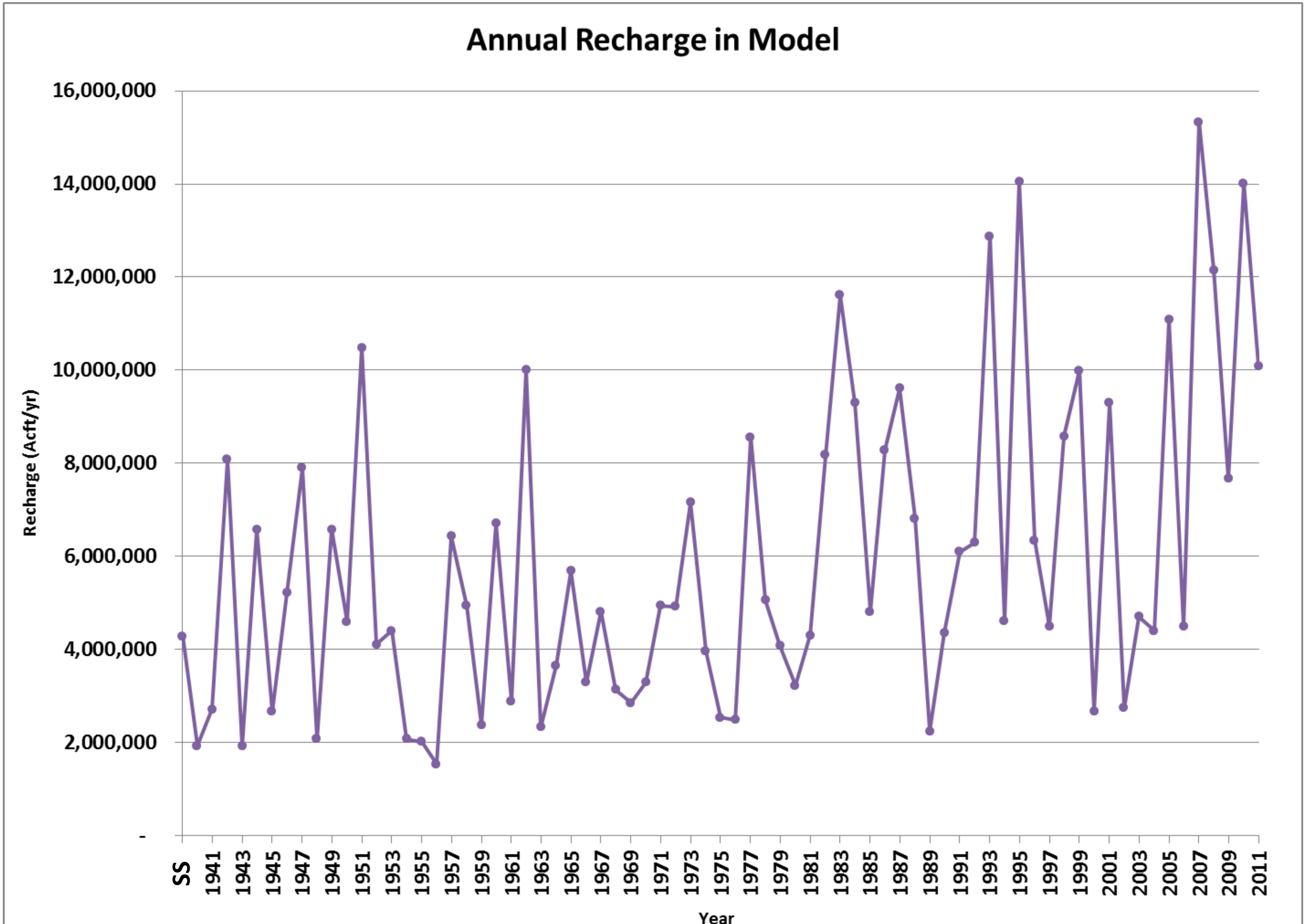
Stream Stage

Streambed thickness is 1'



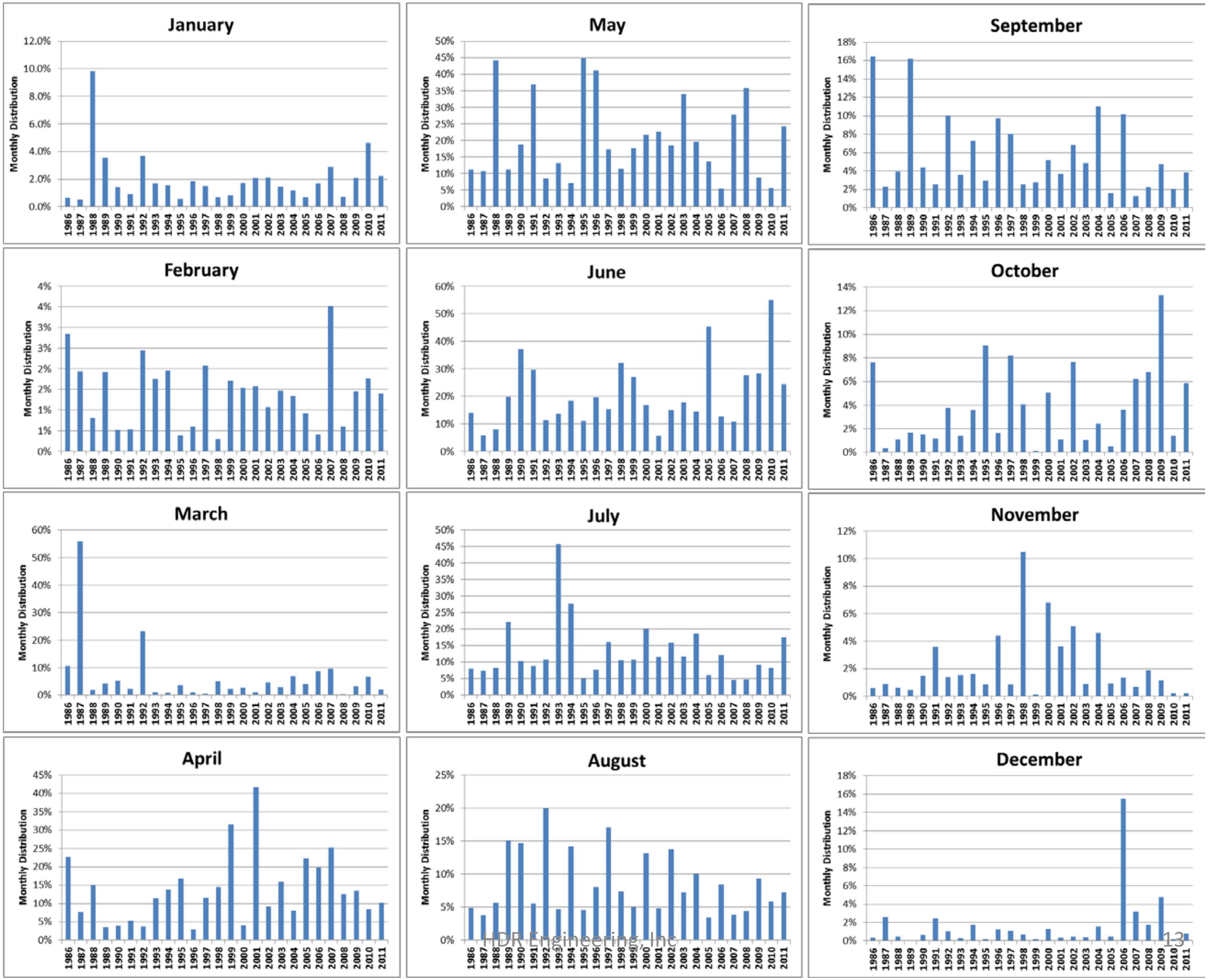
Stream Conductance



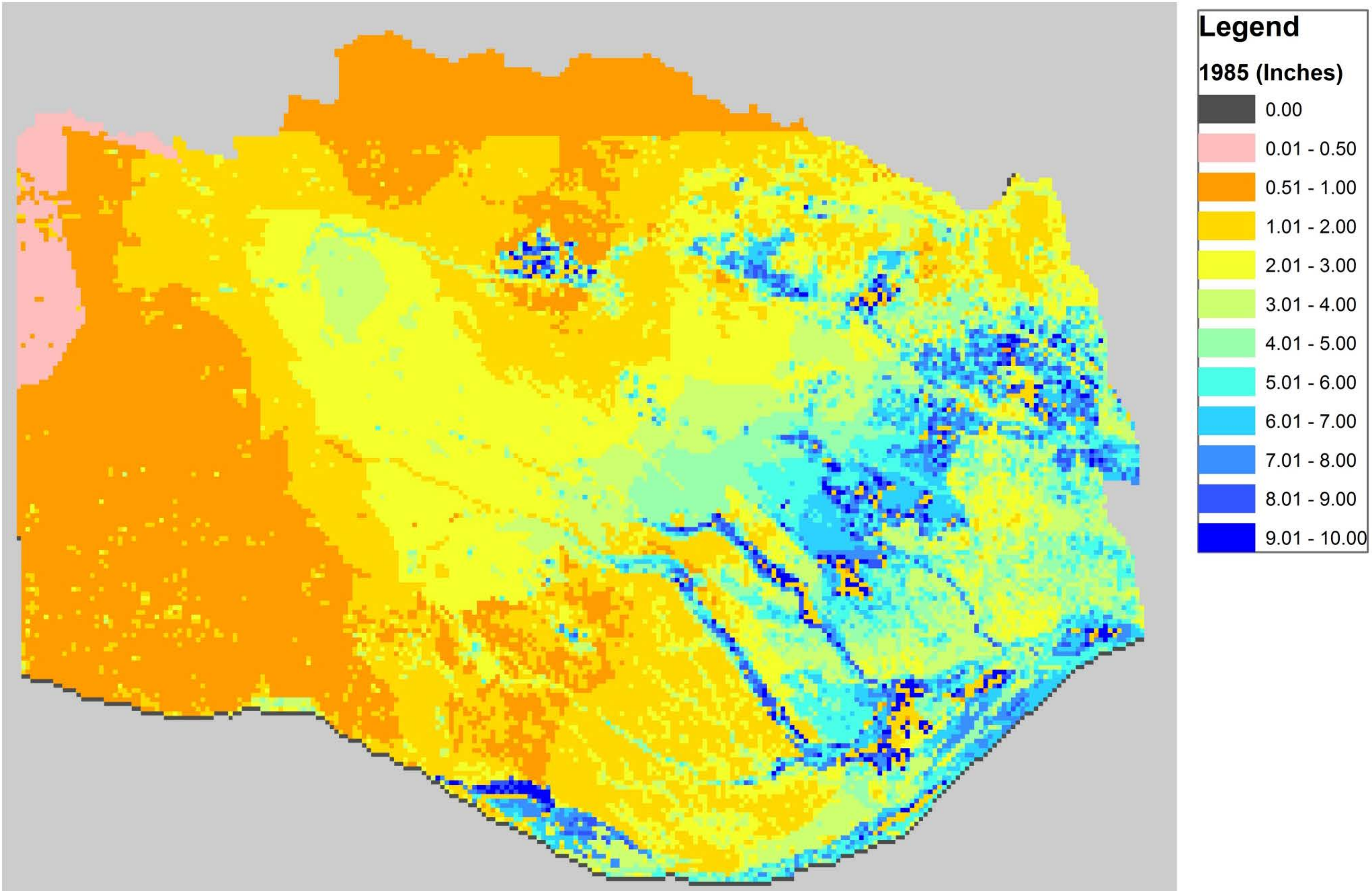


Annual Recharge in Model
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
-
Recharge (Acft/yr)
SS
1941
1943
1945
1947
1949
1951
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
Year

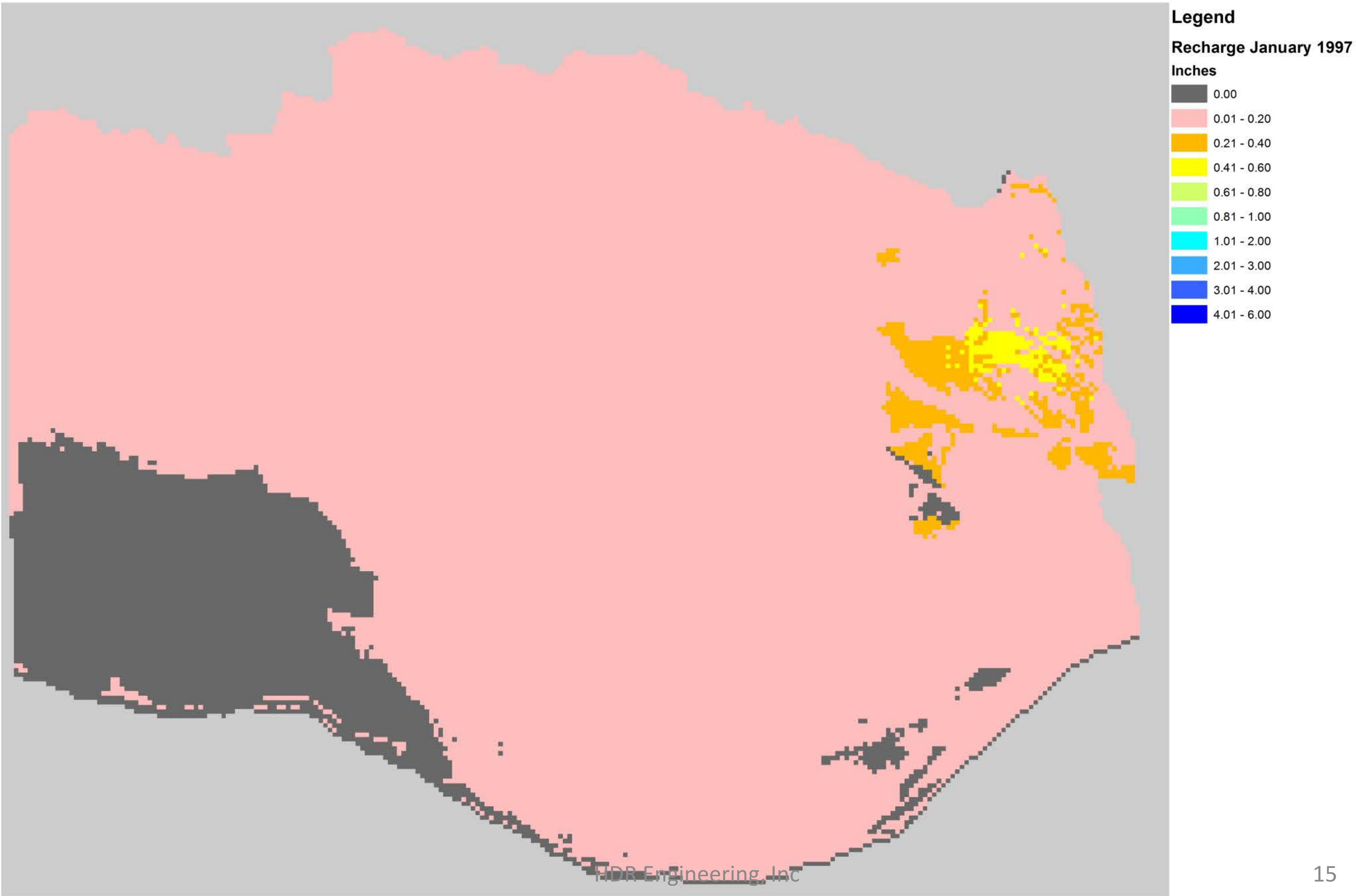
Recharge Distribution by Month



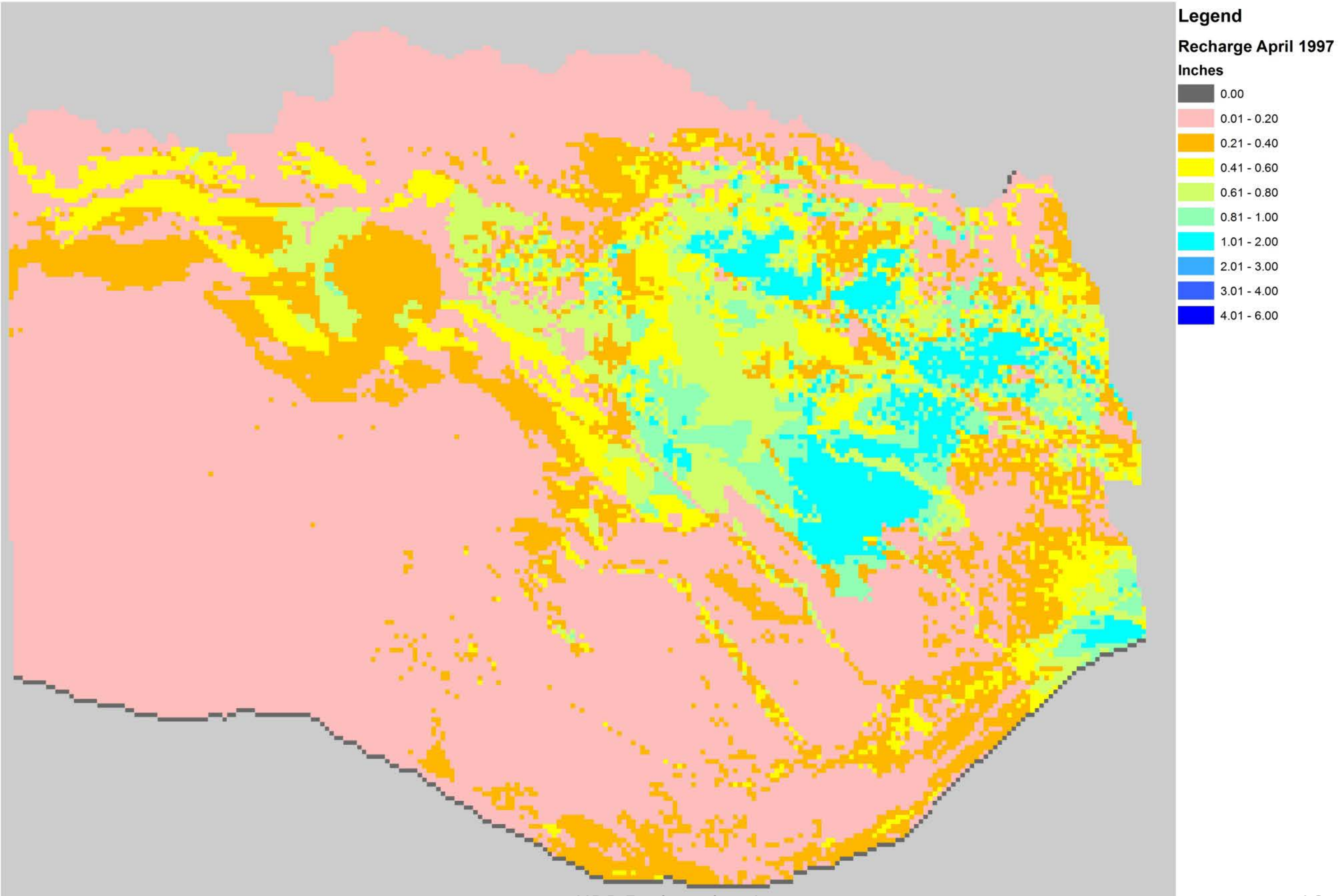
1985 Recharge (inches/month)



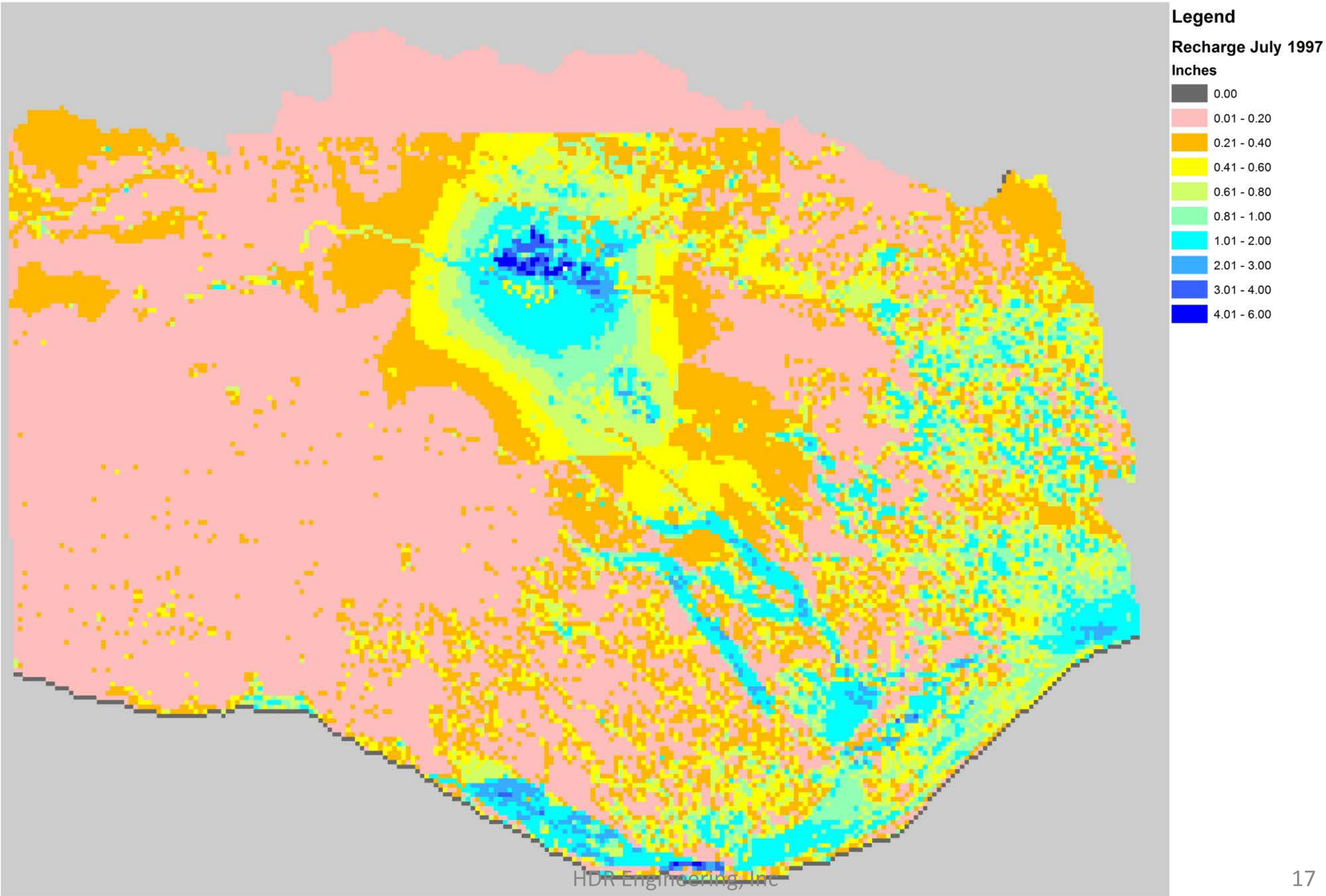
January 1997 Recharge (inches/month)



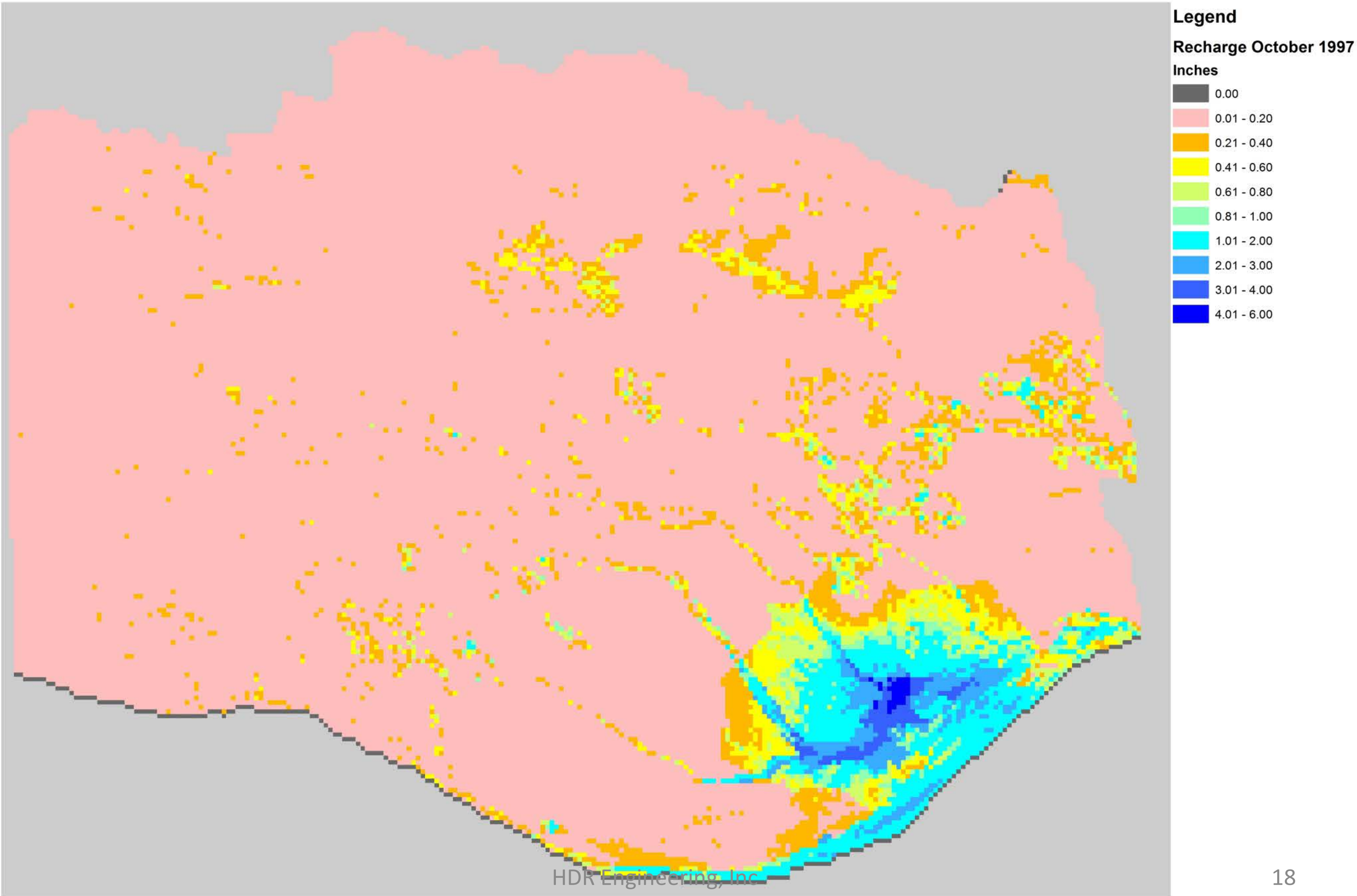
April 1997 Recharge (inches/month)

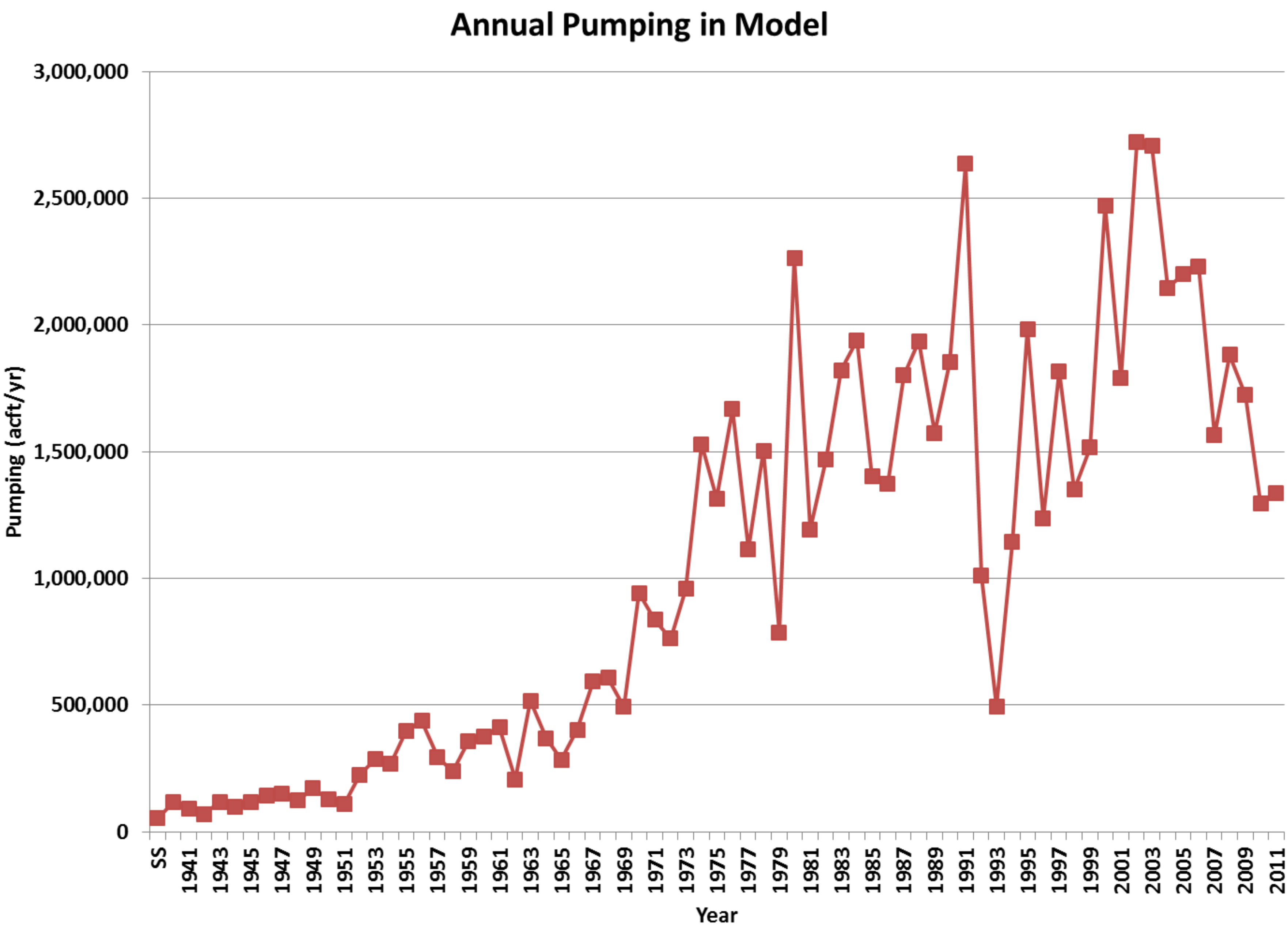


July 1997 Recharge (inches/month)

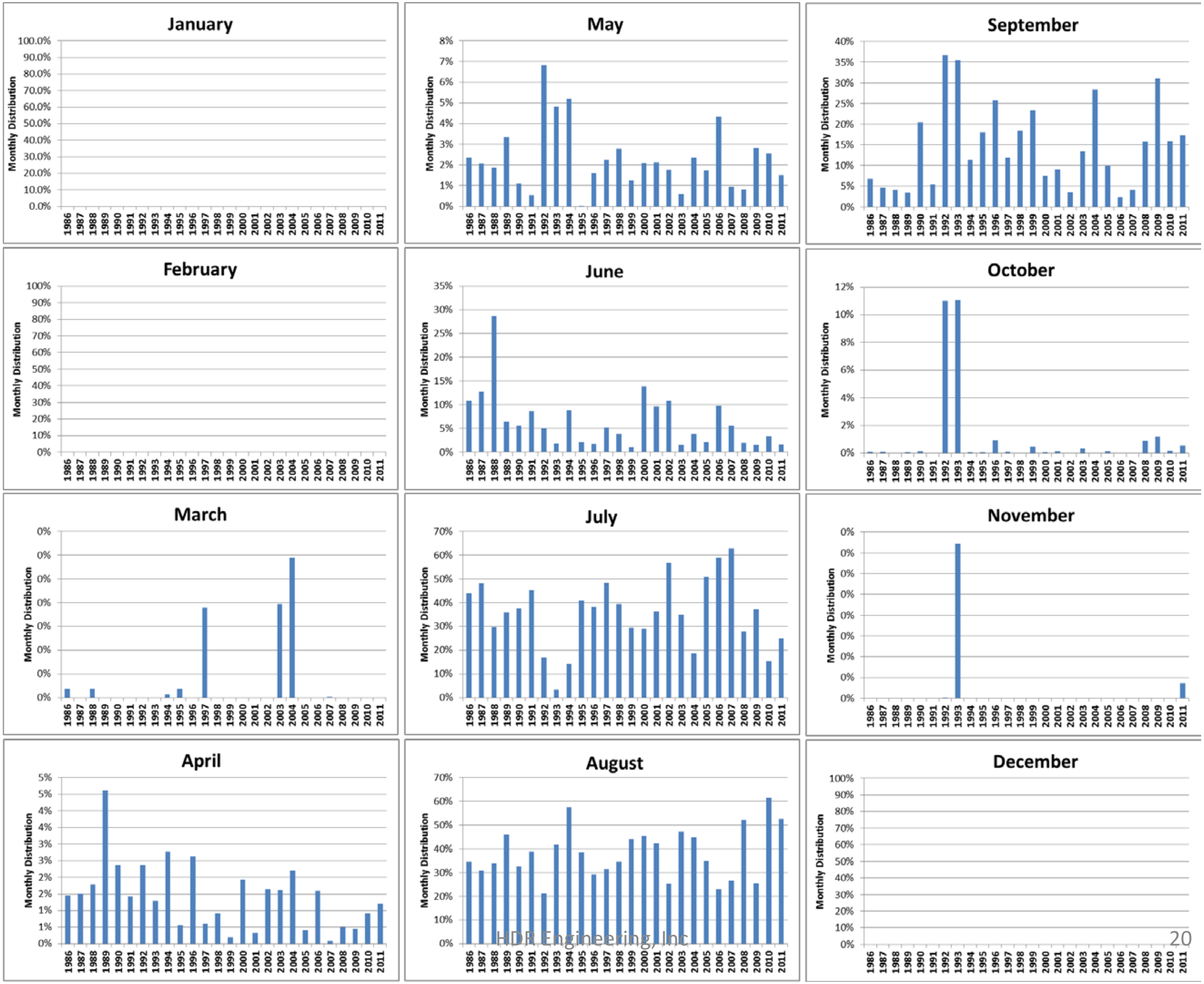


October 1997 Recharge (inches/month)

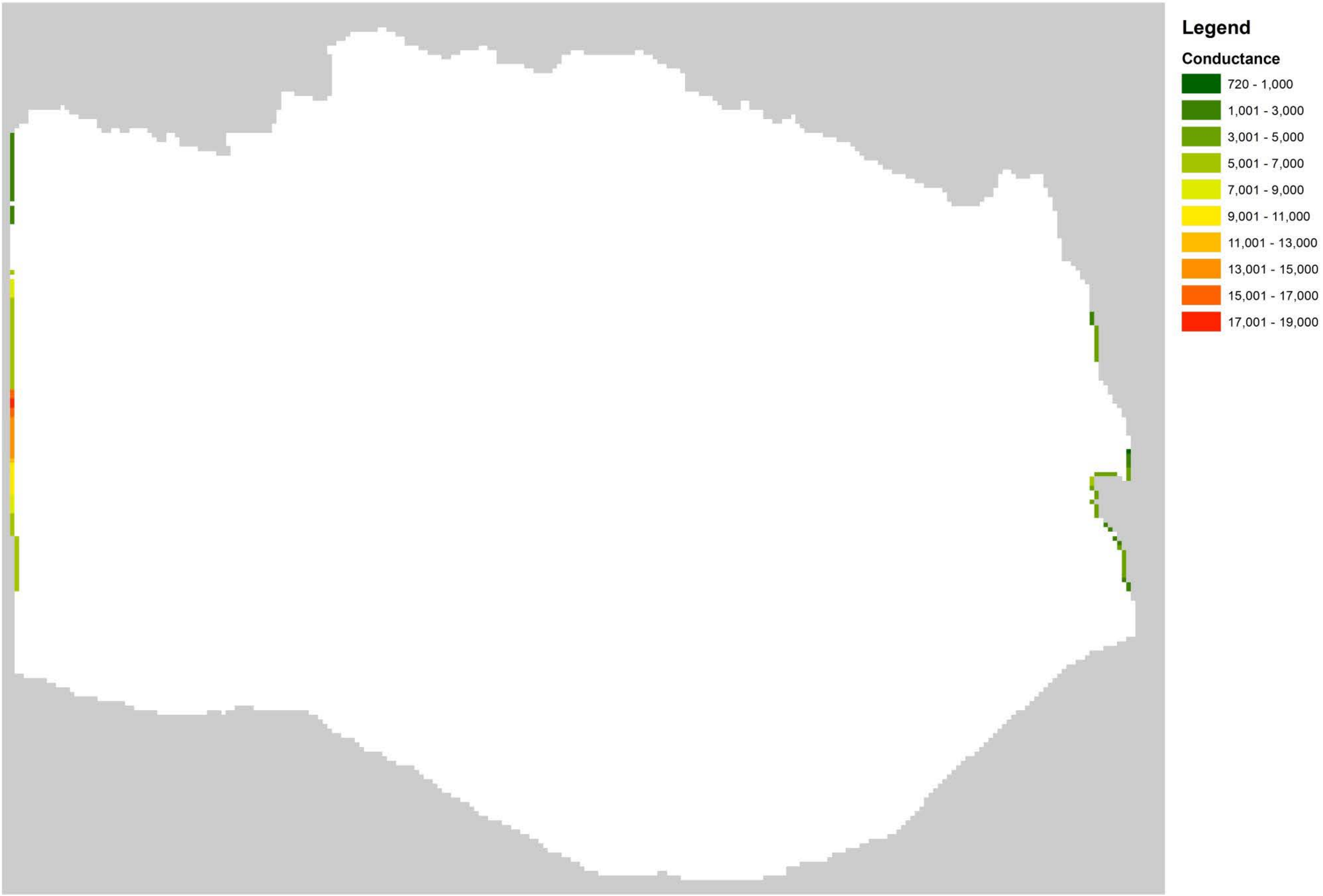



Annual Pumping in Model
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
Pumping (acft/yr)
SS
1941
1943
1945
1947
1949
1951
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
Year

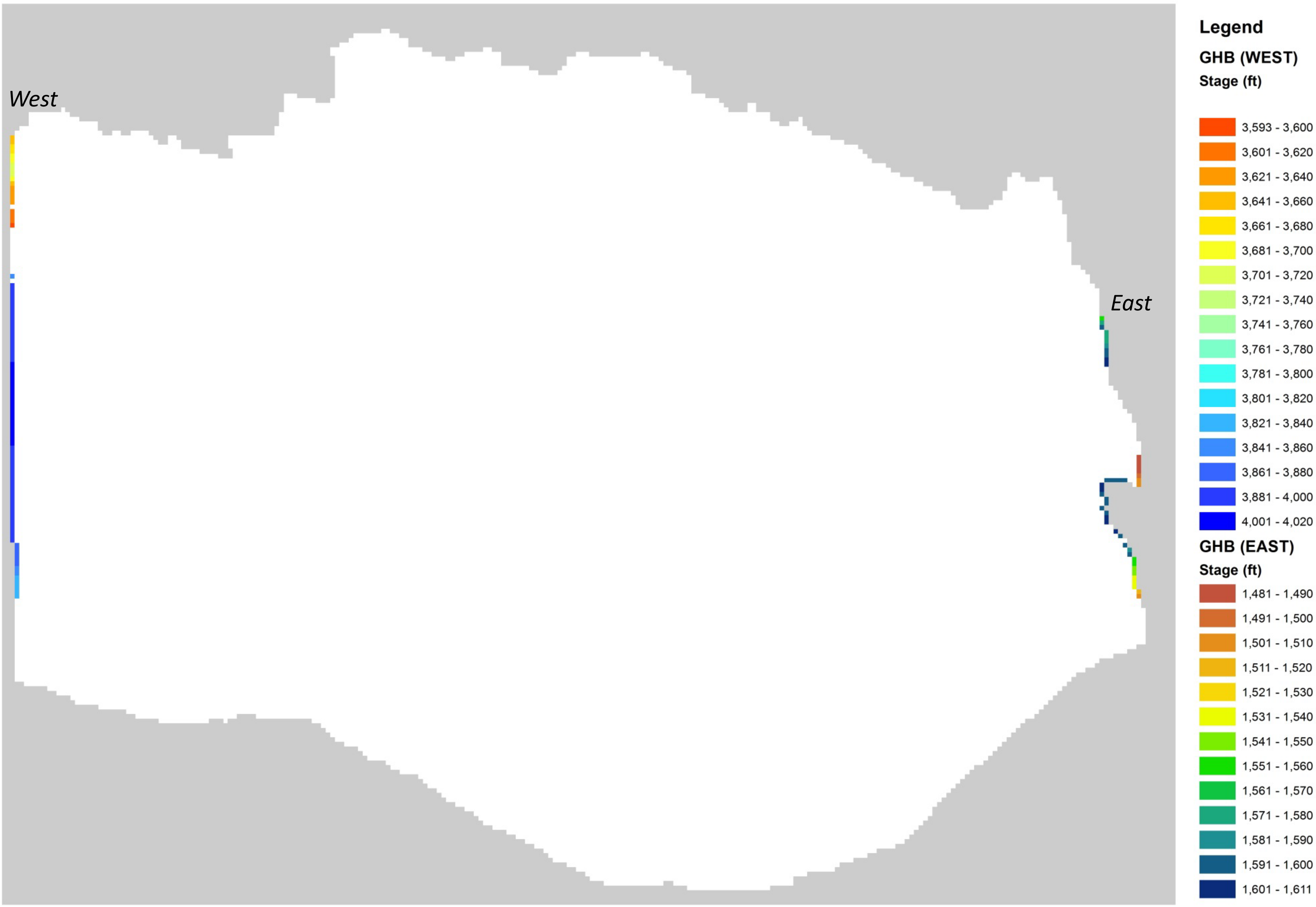
Pumping Distribution by Month



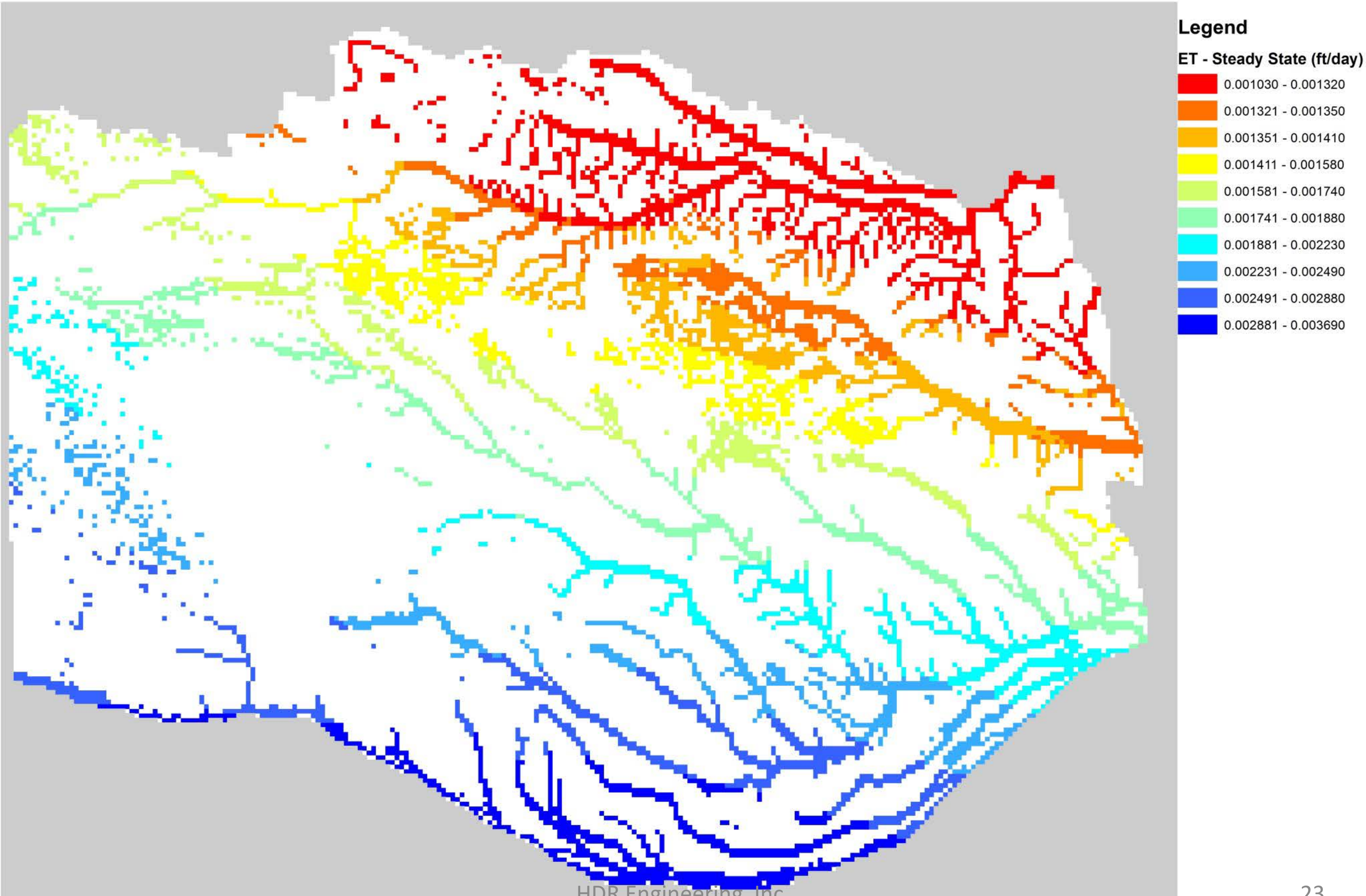
GHB Conductance



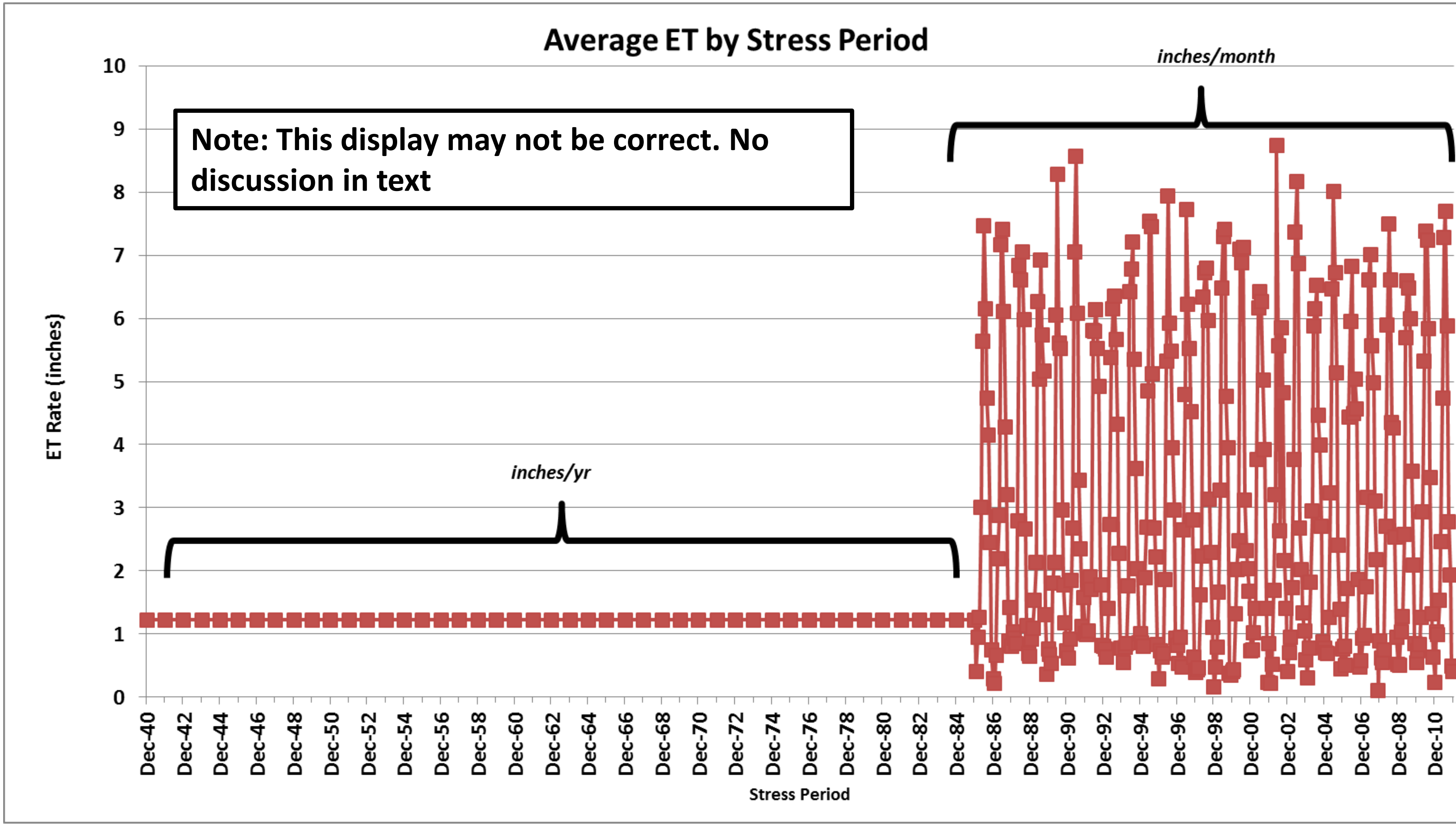
GHB Stage


West
East
Legend
GHB (WEST)
Stage (ft)
3,593 - 3,600
3,601 - 3,620
3,621 - 3,640
3,641 - 3,660
3,661 - 3,680
3,681 - 3,700
3,701 - 3,720
3,721 - 3,740
3,741 - 3,760
3,761 - 3,780
3,781 - 3,800
3,801 - 3,820
3,821 - 3,840
3,841 - 3,860
3,861 - 3,880
3,881 - 4,000
4,001 - 4,020
GHB (EAST)
Stage (ft)
1,481 - 1,490
1,491 - 1,500
1,501 - 1,510
1,511 - 1,520
1,521 - 1,530
1,531 - 1,540
1,541 - 1,550
1,551 - 1,560
1,561 - 1,570
1,571 - 1,580
1,581 - 1,590
1,591 - 1,600
1,601 - 1,611

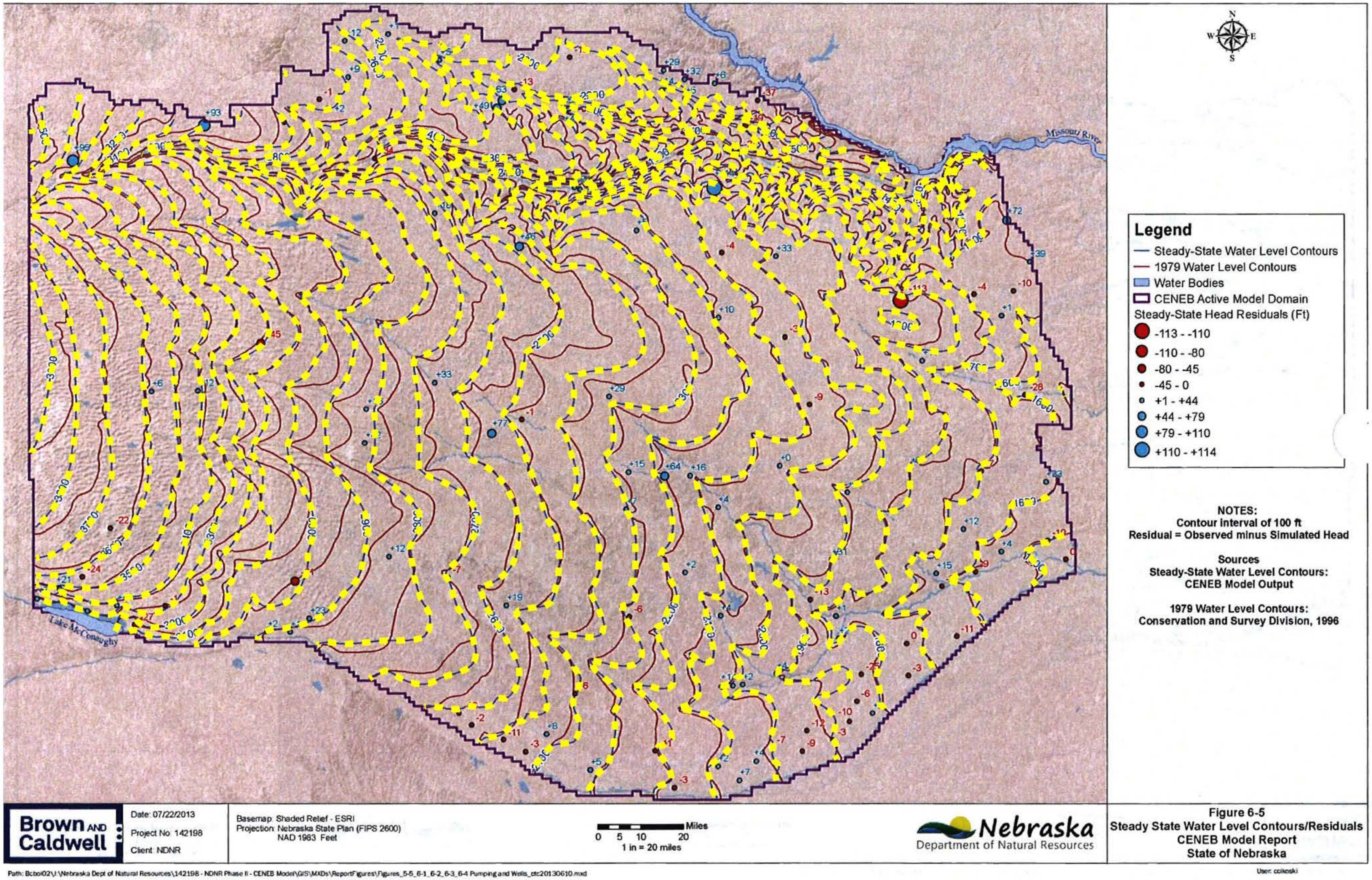
Steady State ET Cells and Rate
Extinction Depth = 5'



Evapotranspiration Rate



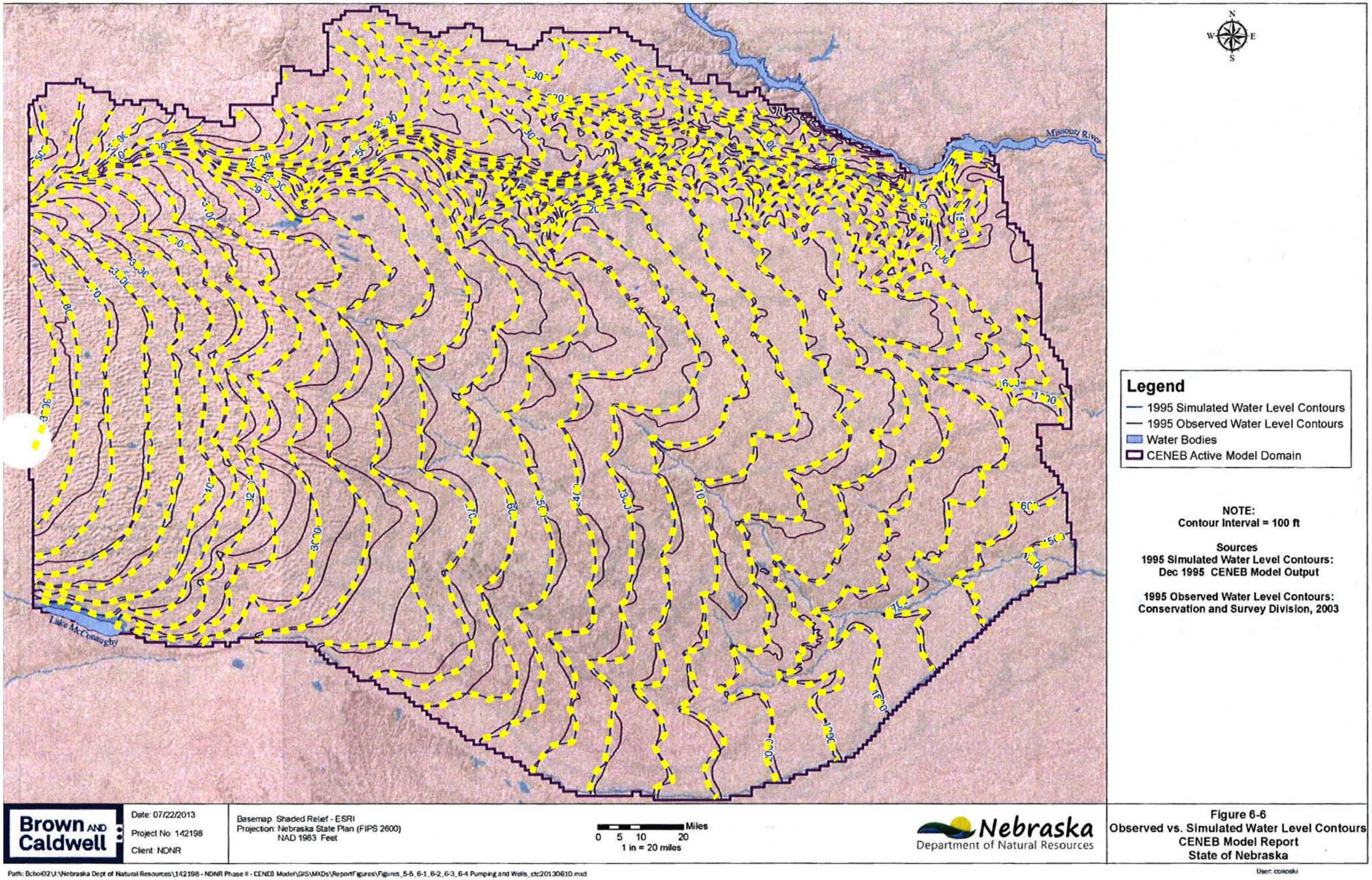
Steady State Heads (ft)



Legend

HDR-Calculated SS Model Heads

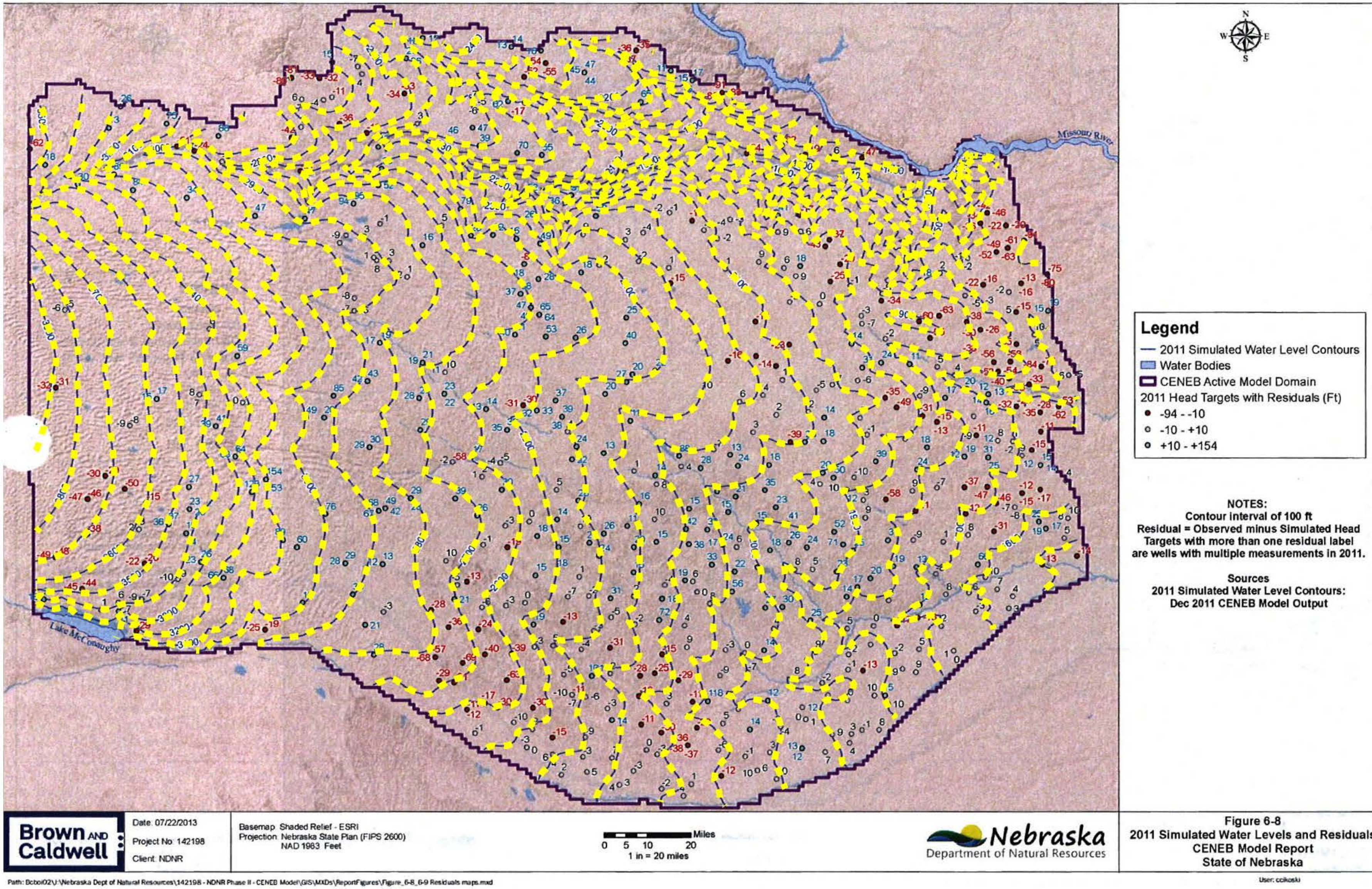
1995 Heads (ft)



Legend

HDR Calculated 1995 Model Heads

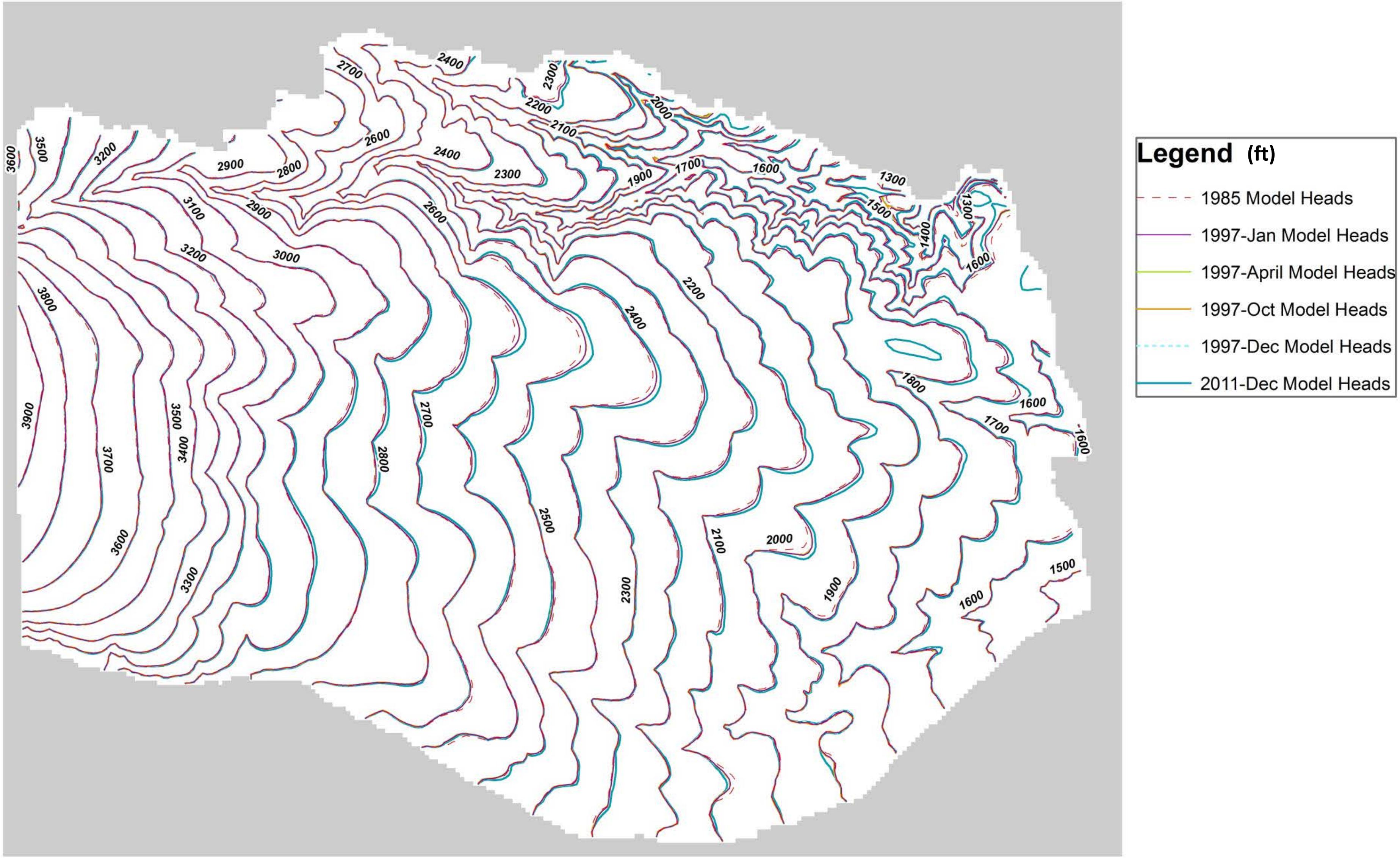
2011 Heads (ft)



Legend

HDR Calculated 2011 Model Heads

Heads from 1985 (December), 1997 (January, April, July, October) & 2011 (December)



Mass Balance by Stress Period

Acft/yr

Steady State

	Inflow	Outflow
Recharge	4,274,628	0
ET	0	1,937,493
Constant Hea	17,817	86,629
River	0	0
Lake	0	0
Drain	0	0
GHB	214,428	27,364
Well	0	51,000
Stream	166,490	2,570,876
Storage	0	0
TOTAL	4,673,362	4,673,362
ERROR	0.000000	

Acft/yr

1985

	Inflow	Outflow
Recharge	4,800,869	0
ET	0	1,906,181
Constant Head	20,962	83,589
River	0	0
Lake	0	0
Drain	0	0
GHB	212,765	34,349
Well	0	1,378,302
Stream	115,867	3,011,871
Storage	1,642,832	378,885
TOTAL	6,793,295	6,793,178
ERROR	0.000001	

Acft/month

January-97

	Inflow	Outflow
Recharge	66,929	0
ET	0	28,263
Constant Head	1,568	7,490
River	0	0
Lake	0	0
Drain	0	0
GHB	17,101	3,200
Well	0	0
Stream	9,406	277,964
Storage	285,881	63,955
TOTAL	380,885	380,872
ERROR	0.000002	

Acft/month

April-97

	Inflow	Outflow
Recharge	524,007	0
ET	0	141,778
Constant Head	1,518	7,524
River	0	0
Lake	0	0
Drain	0	0
GHB	17,125	3,184
Well	0	10,509
Stream	9,568	277,441
Storage	110,818	223,270
TOTAL	663,035	663,705
ERROR	-0.000071	

Acft/month

July-97

	Inflow	Outflow
Recharge	723,663	0
ET	0	323,143
Constant Head	2,105	6,794
River	0	0
Lake	0	0
Drain	0	0
GHB	17,198	3,215
Well	0	865,350
Stream	12,584	250,524
Storage	830,534	137,138
TOTAL	1,586,085	1,586,164
ERROR	-0.000003	

Acft/month

October-97

	Inflow	Outflow
Recharge	367,548	0
ET	0	145,379
Constant Head	2,029	6,688
River	0	0
Lake	0	0
Drain	0	0
GHB	17,211	3,145
Well	0	1,873
Stream	10,974	254,669
Storage	229,212	215,263
TOTAL	626,974	627,018
ERROR	-0.000005	

Acft/month

December-11

	Inflow	Outflow
Recharge	82,338	0
ET	0	22,495
Constant Head	1,491	8,929
River	0	0
Lake	0	0
Drain	0	0
GHB	16,979	3,799
Well	0	0
Stream	8,787	338,973
Storage	347,657	83,132
TOTAL	457,251	457,329
ERROR	-0.000012	