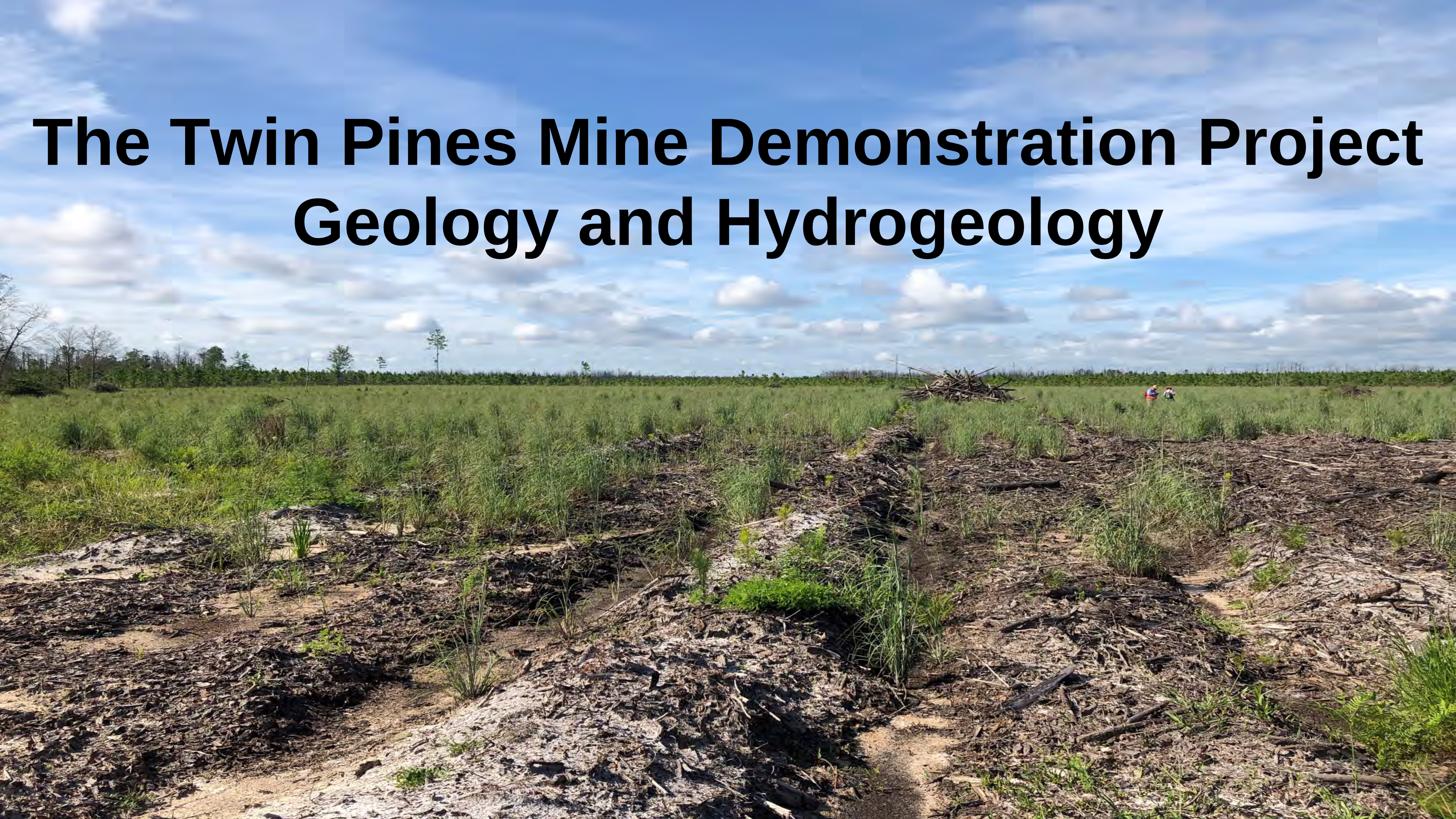
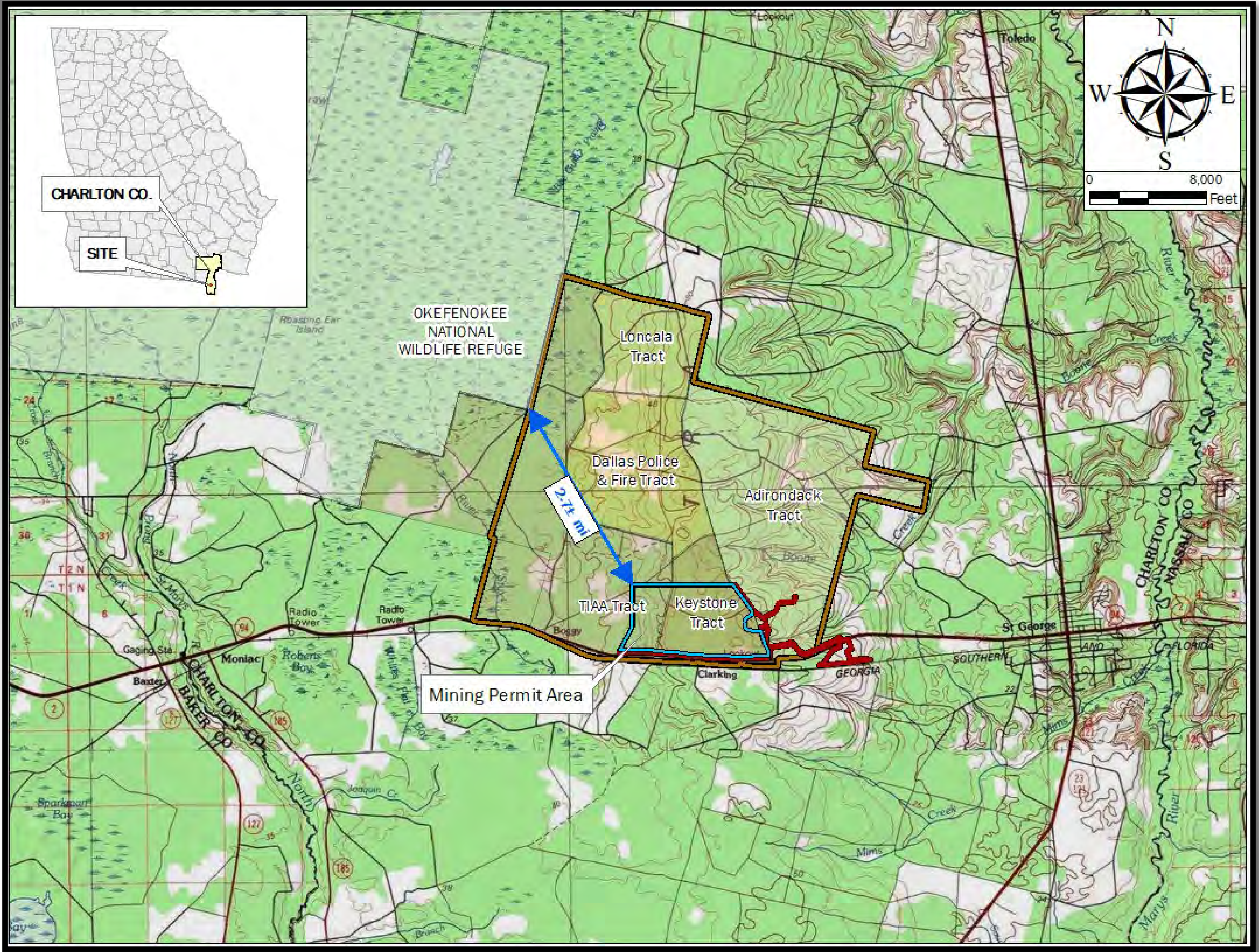
The Twin Pines Mine Demonstration Project
Geology and Hydrogeology



Brief Review



Project Location

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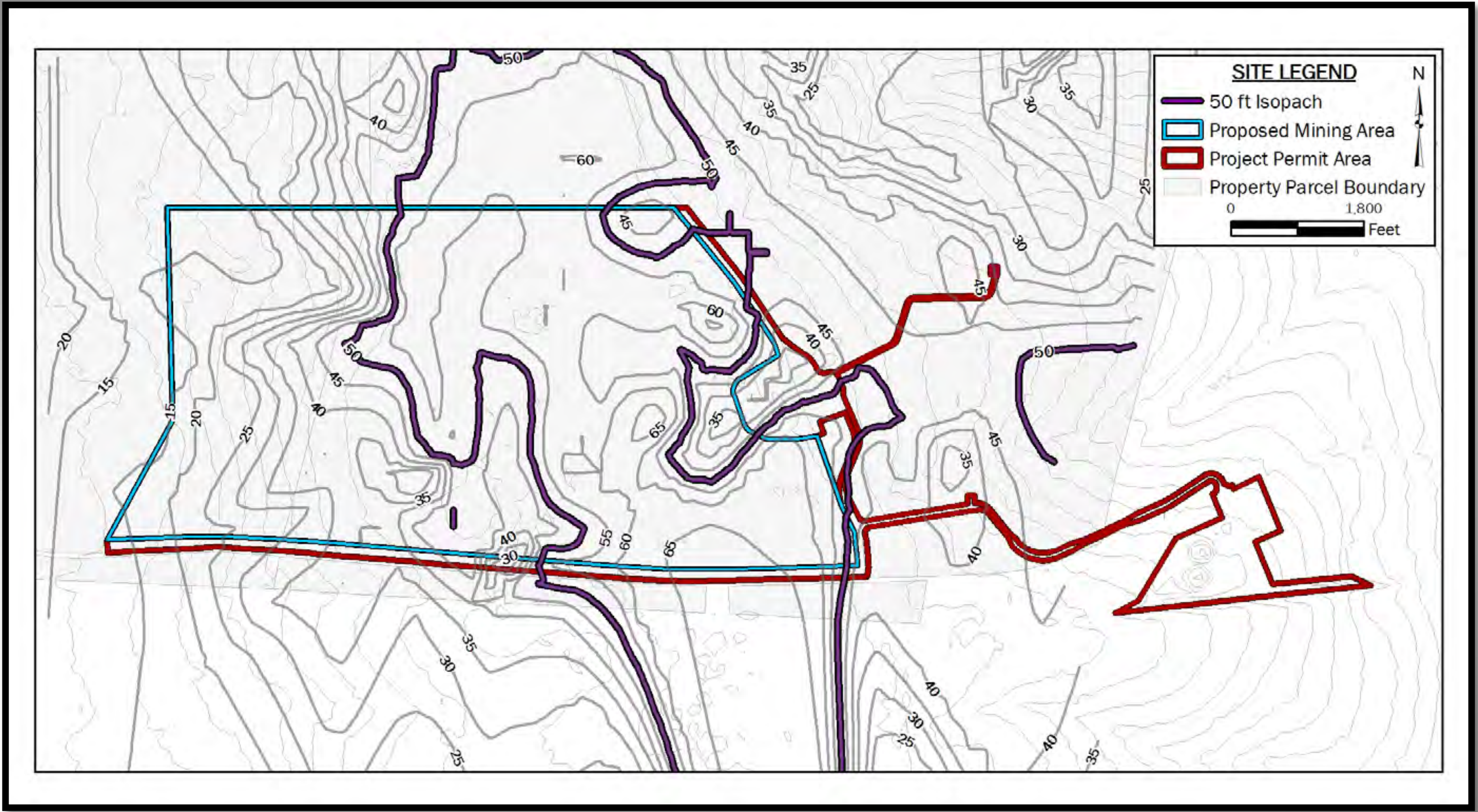
Mining Operations

- Sands will be excavated via dragline
- Pit will be 100 ft wide, 500 ft long, and maximum of 50 ft deep
- The pit will advance at ~ 115 ft/day
- Sands will be placed into a wet processing plant near the point of operations
  - ~98% of mined material moved back into the pit within 5 – 7 days
  - ~2% sent to dry processing plant to separate product from remaining sands

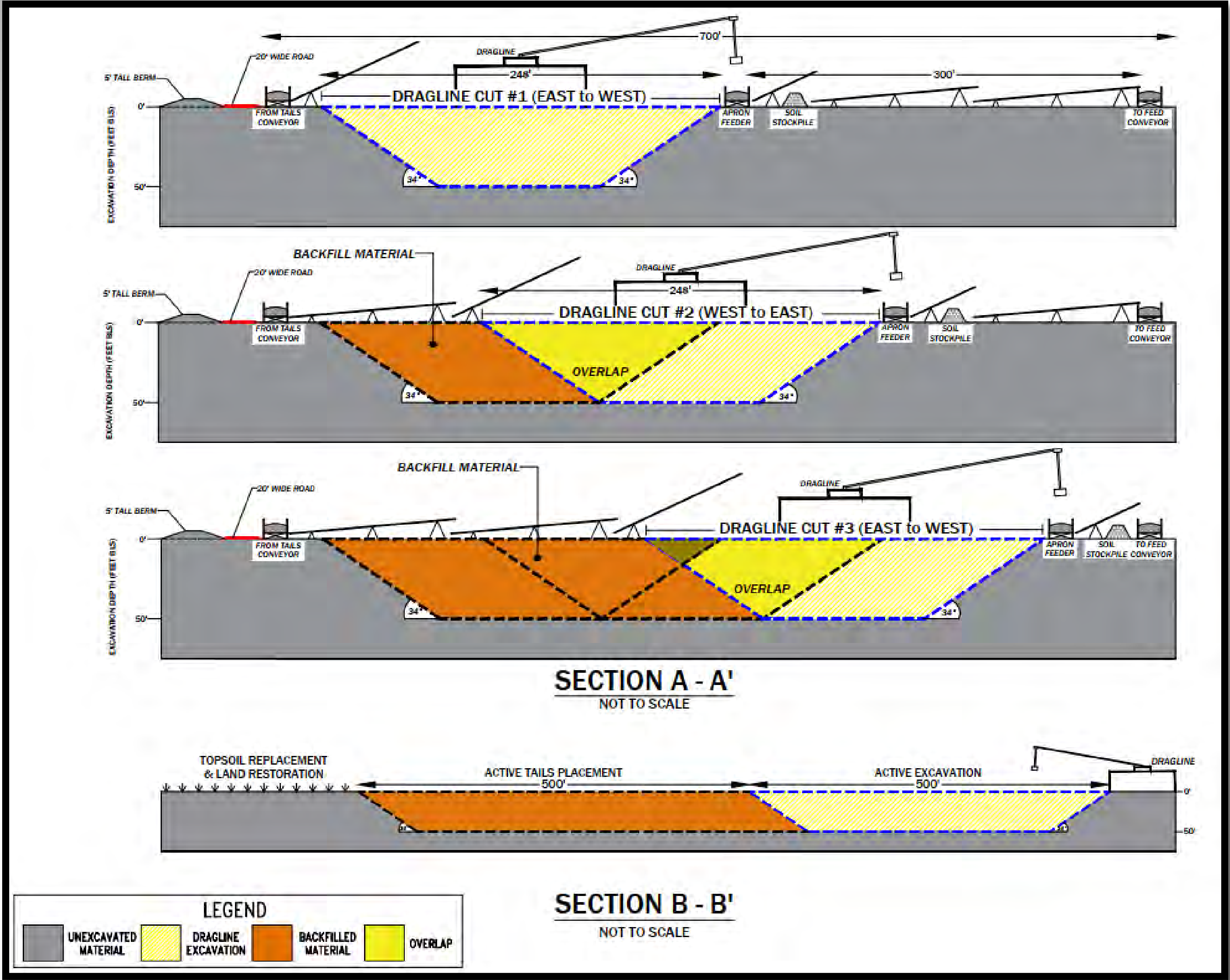
Depth to the Bottom of the Heavy Minerals



Maximum depth of mining: 50 ft

Depth of mining in the west part of the proposed mine: 20 – 50 ft

Moving Mine Pits will Overlap



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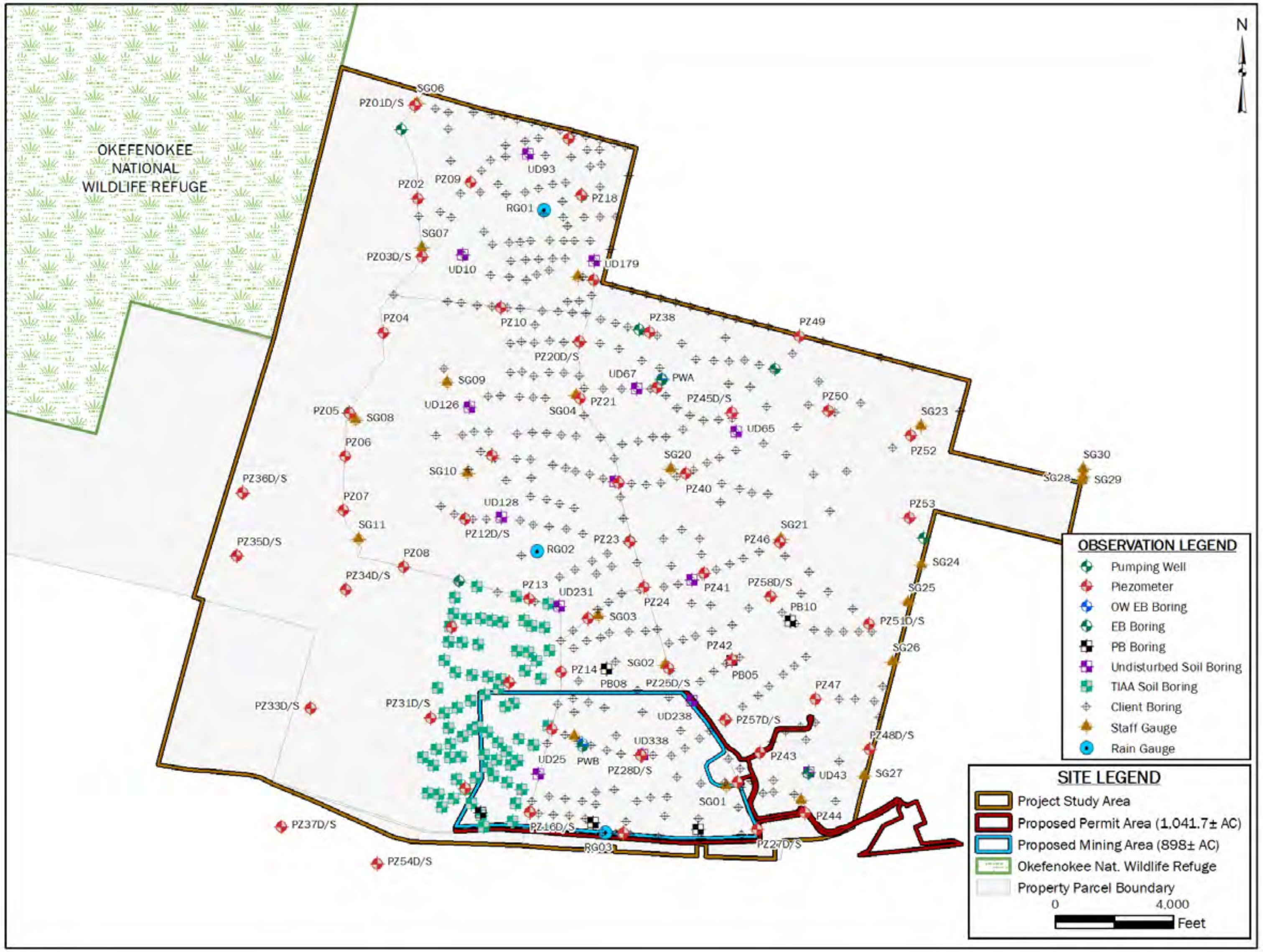
Hydrogeologic Characterization



Hydrogeologic Characterization

A total of 702 soil borings, wells, and piezometers drilled/installed in the site area

Field Data Collection

Number of soil borings, wells, and Piezometers:

- Piezometers = 86
- Pumping and observation wells = 24
- Exploratory borings = 492
- Piezometers in wetlands = 100

Stream Staff Gauges = 23

Pressure transducers installed to continuously monitor water levels = 215

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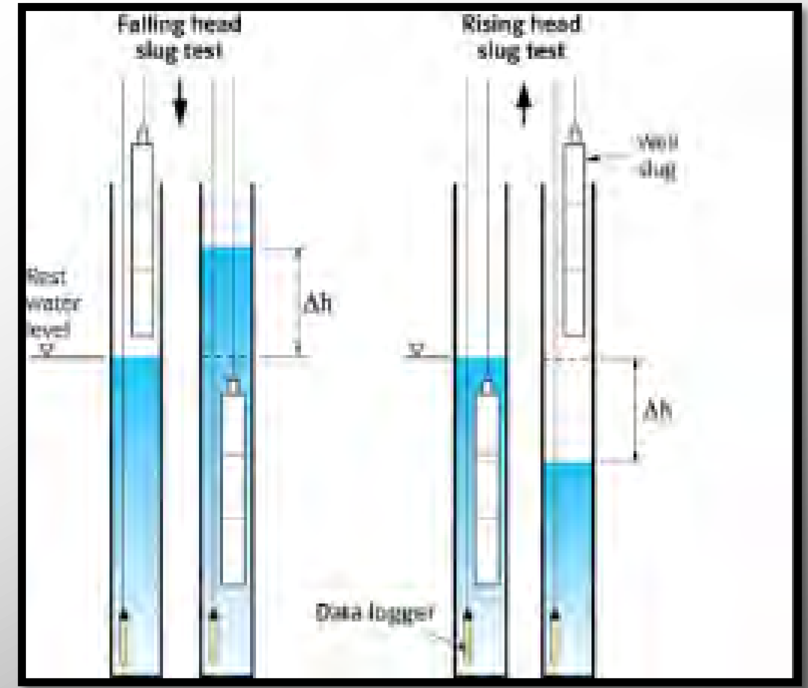
Slug Tests

- Slug Test Performed in 24 Piezometers
- Continuous Groundwater/Surface Water Monitoring Equipment Installed at 215 Locations



Average K = 12 ft/d, Minimum K = 0.2 ft/d, Maximum K = 75 ft/d

Soils Laboratory Data

- Grain-Size Analysis = 124
- Permeability Test = 46
- Soil Moisture Retention Curves = 3

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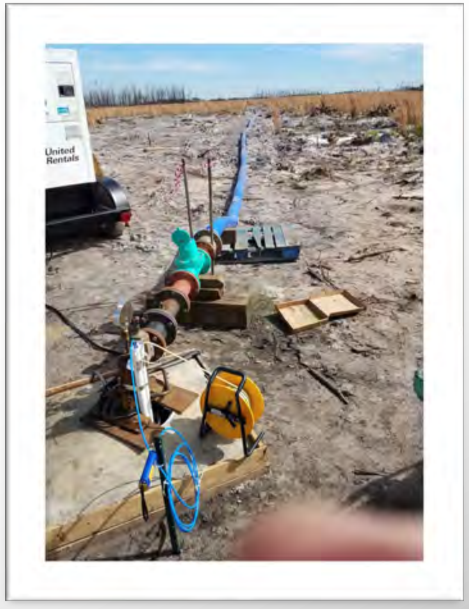
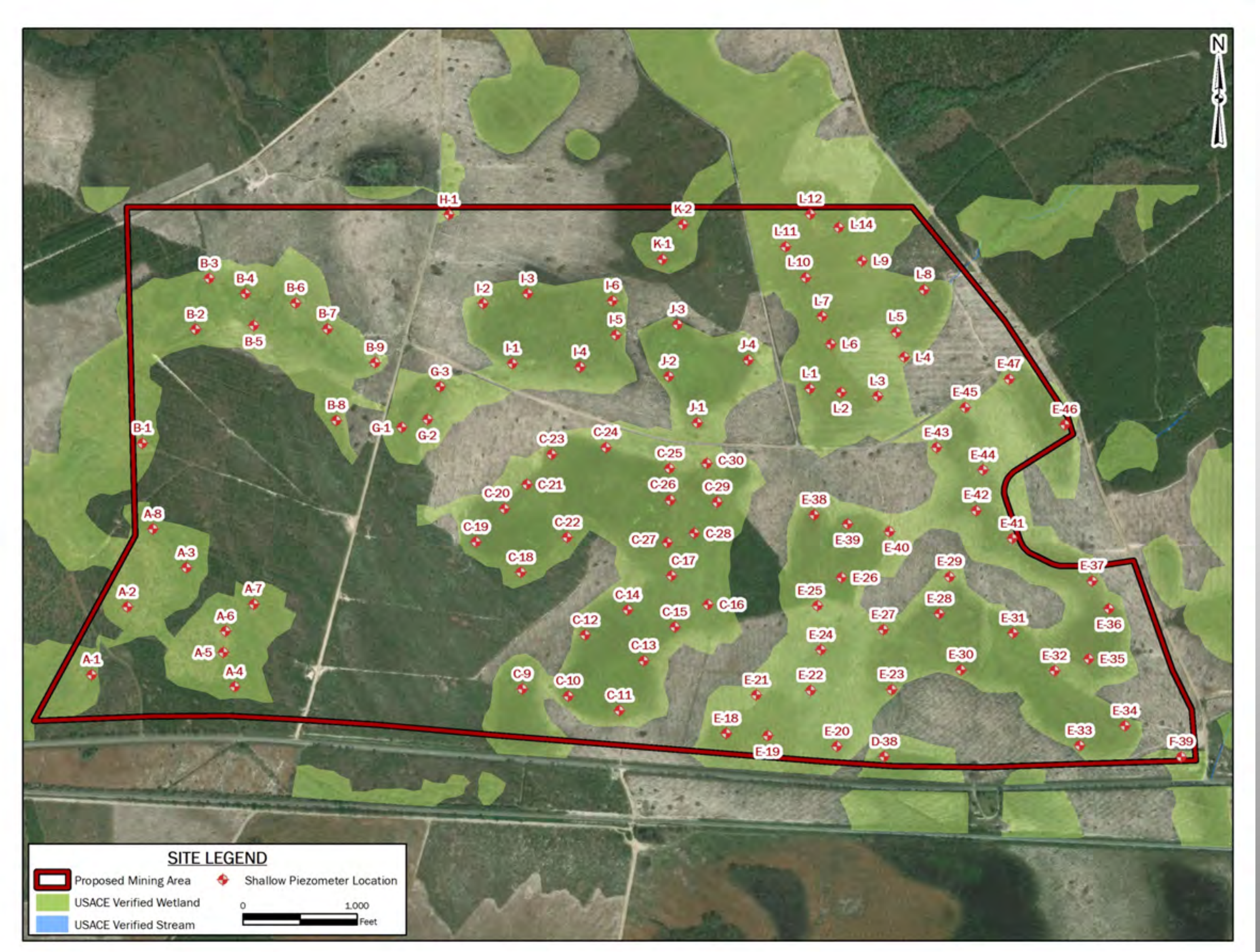
Aquifer Testing

- Two 24-Hour Pumping Test Conducted
  - Pump Area A (North): PWA T = 1,490 – 1,967 ft^2/d
  - Pump Area B (South): PWB T = 530 – 697 ft^2/d
  - Pumping Wells = 2
  - Observation Wells = 22: T = 1 – 2,288 ft^2/d

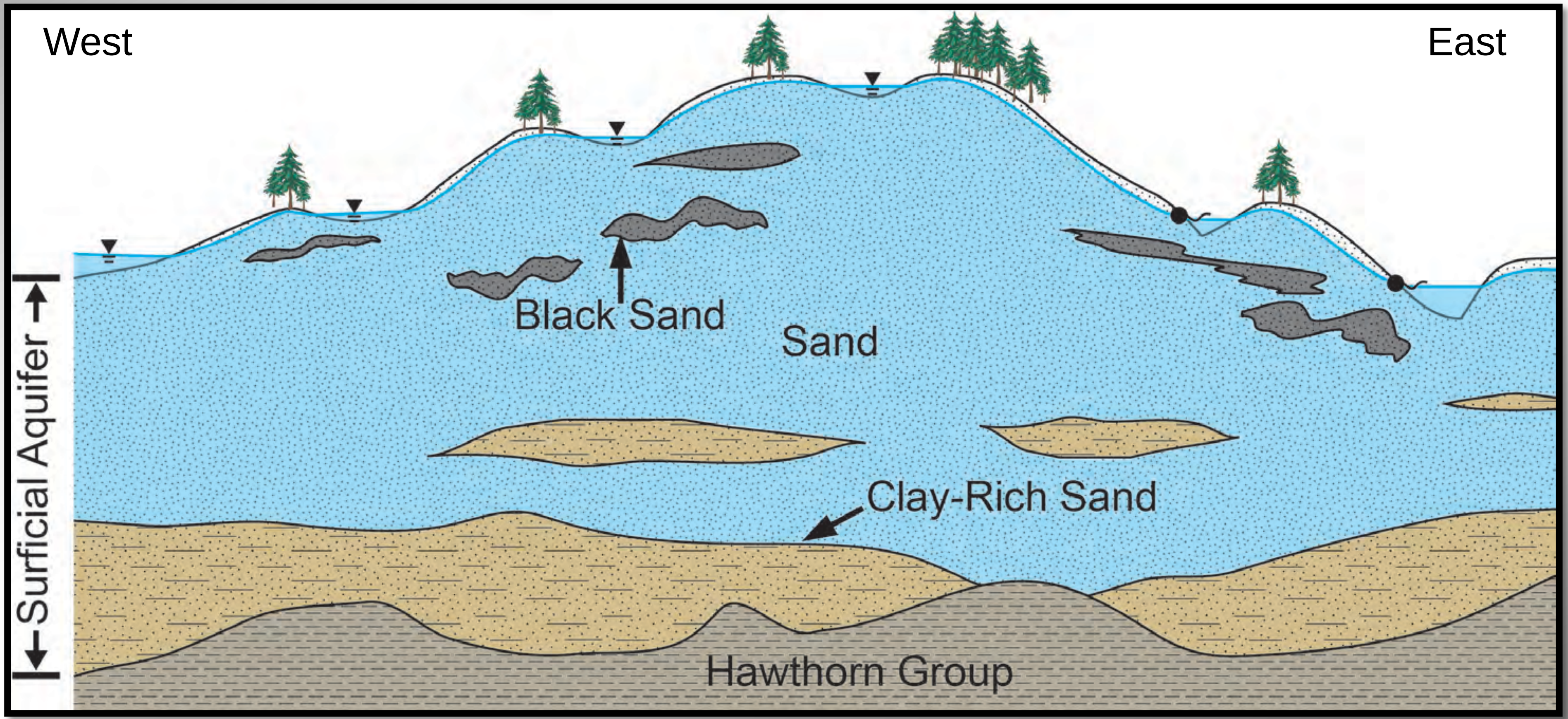


100 Shallow, 1.5-Foot Deep Piezometers were Installed in Wetlands



Geology of the Surficial Aquifer

General Lithology



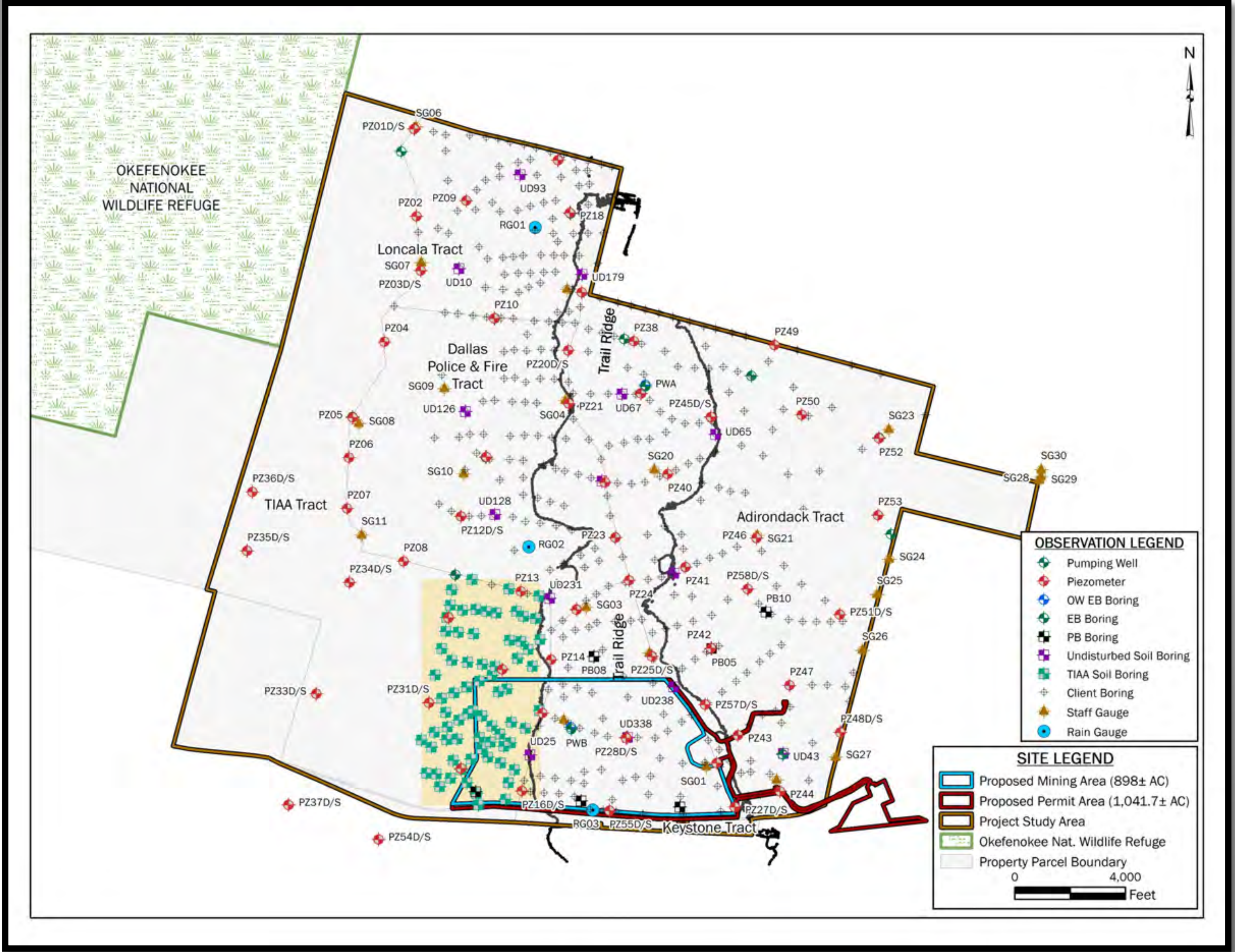
Subsurface Units

- Hawthorn Group (confining unit for the Floridan Aquifer)
- Surficial Aquifer
  1. Clay (3.82%)
  2. Clayey Sand (7.85%)
  3. Silty-Clayey Sand (8.52%)
  4. Unconsolidated Black Sands (1.34%)
  5. Semi-Consolidated Sands (10.27%)
  6. Consolidated Black Sands (5.54%)
  7. Unconsolidated Sand (58.33%)

Initial studies indicated that additional data would be required to characterize the spatial continuity of these units in the subsurface.

Note: 4.33% of the core collected from the surficial aquifer was unrecovered

A Series of Closely-Spaced Boreholes were Drilled to Evaluate the Subsurface Continuity of Surficial Aquifer Units



An additional 71 closely-spaced boreholes were drilled in the south-central part of the study area between March 2019 and July 2019

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Subsurface Continuity of Surficial Aquifer Units was Determined using Indicator Geostatistics

- Geostatistics is a branch of statistics that focuses on understanding the continuity of spatial data
- It is applied in many disciplines, including geology, hydrology, meteorology, forestry, soil science, agriculture, geography, and epidemiology
- Indicator kriging interpolates the probability that a geologic unit is present from observed locations (e.g., soil borings) to unobserved locations creating maps of probability that a geologic unit is present
- Indicator kriging uses the indicator variogram (a statistic that defines the dissimilarity between data points as a function of distance)
- A critical element of the indicator variogram is the “correlation length.”
- At distances beyond the “correlation length” points are no longer correlated, and we can no longer use knowledge that a unit is present at one location to predict the probability that the unit is present at another location

For each soil type, we present a description, horizontal and vertical indicator variograms, and probability maps generated using indicator kriging

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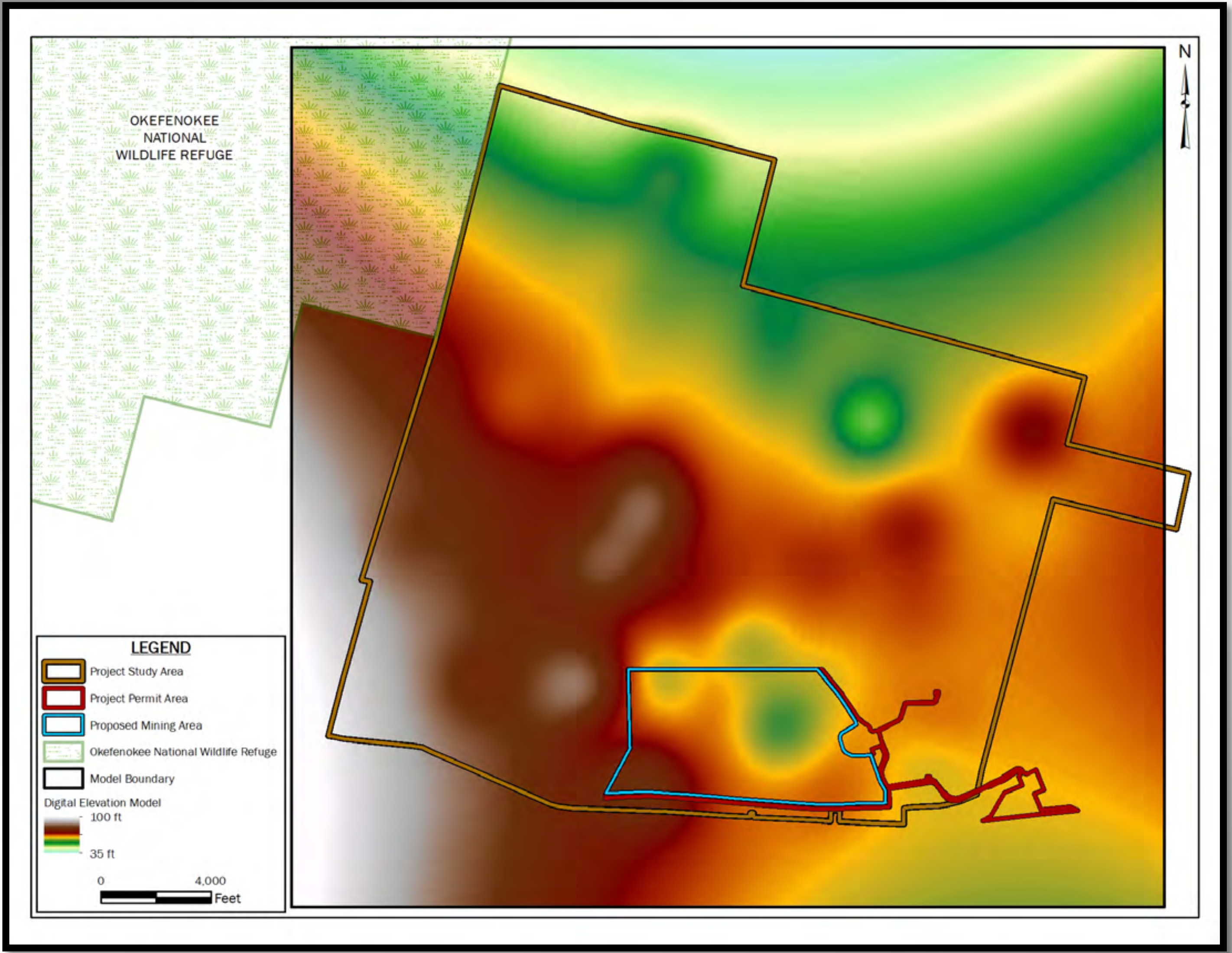
Hawthorn Group

- The top of Hawthorn Group consists of very low permeability calcareous sandy clays and lean to fat clays

The Top of Hawthorn is Erosional



Elevation varies from ~100 ft amsl in the southwest to ~36 ft amsl in the north

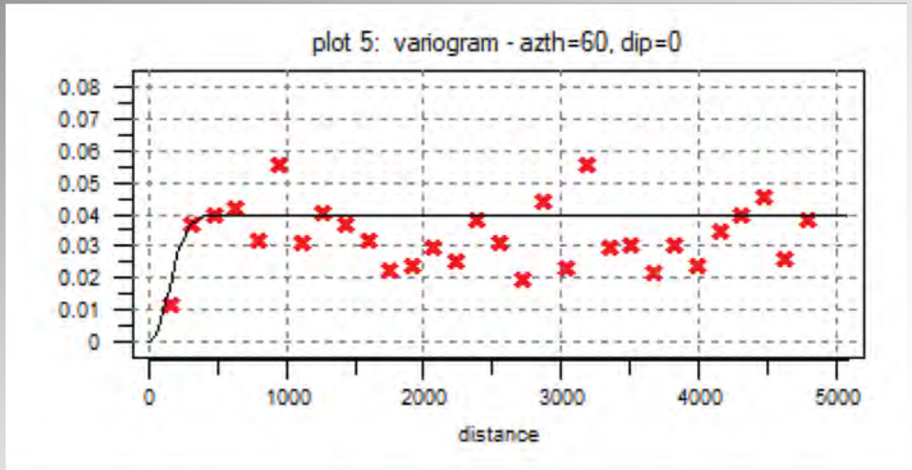
Hawthorn is likely the source of clays in the lower part of the surficial aquifer

Clay

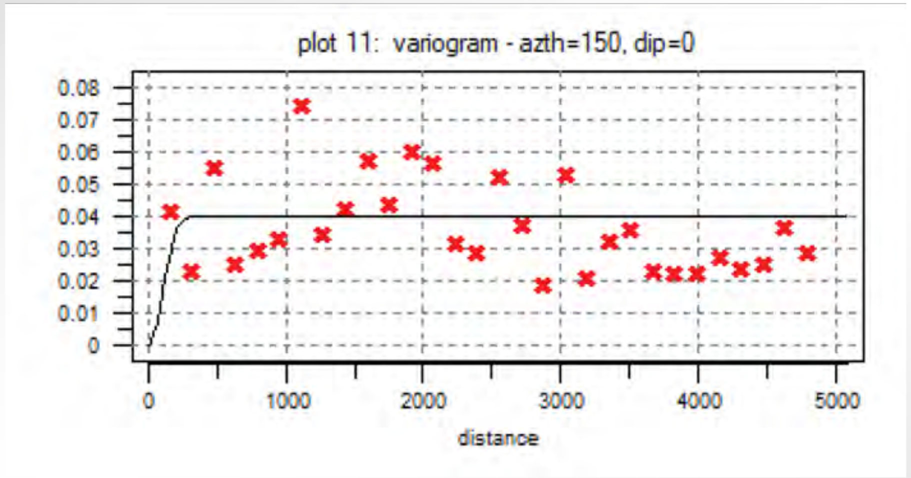
- Occupies 3.82% of the surficial aquifer (mainly below an elevation of 120 ft amsl)
- Consists of silty clays, sandy clays, and fat clays
- Likely reworked Hawthorn Group clays

Clay – Correlation Lengths

A)

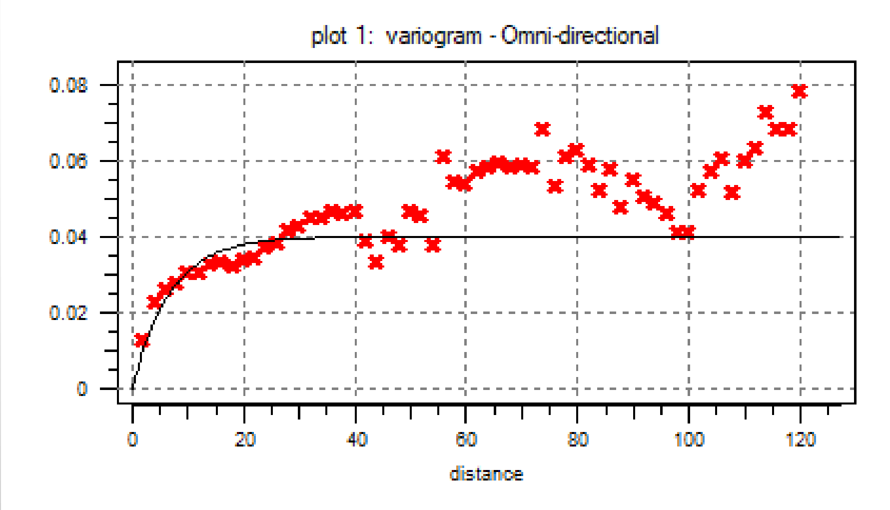


B)

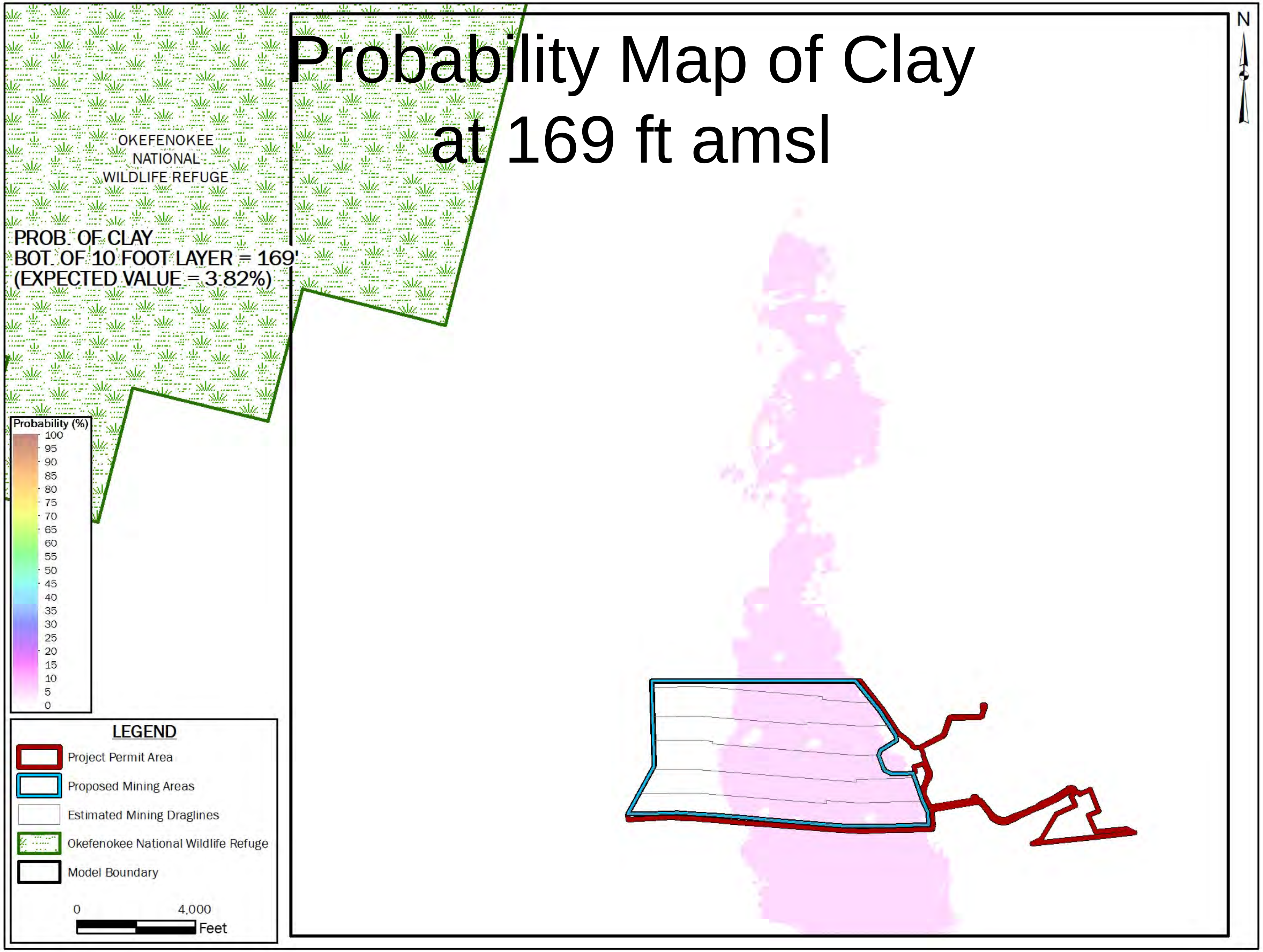


Horizontal correlation length = 336 ft max (az. = 60 degrees), 240 ft min (az. = 150 degrees)

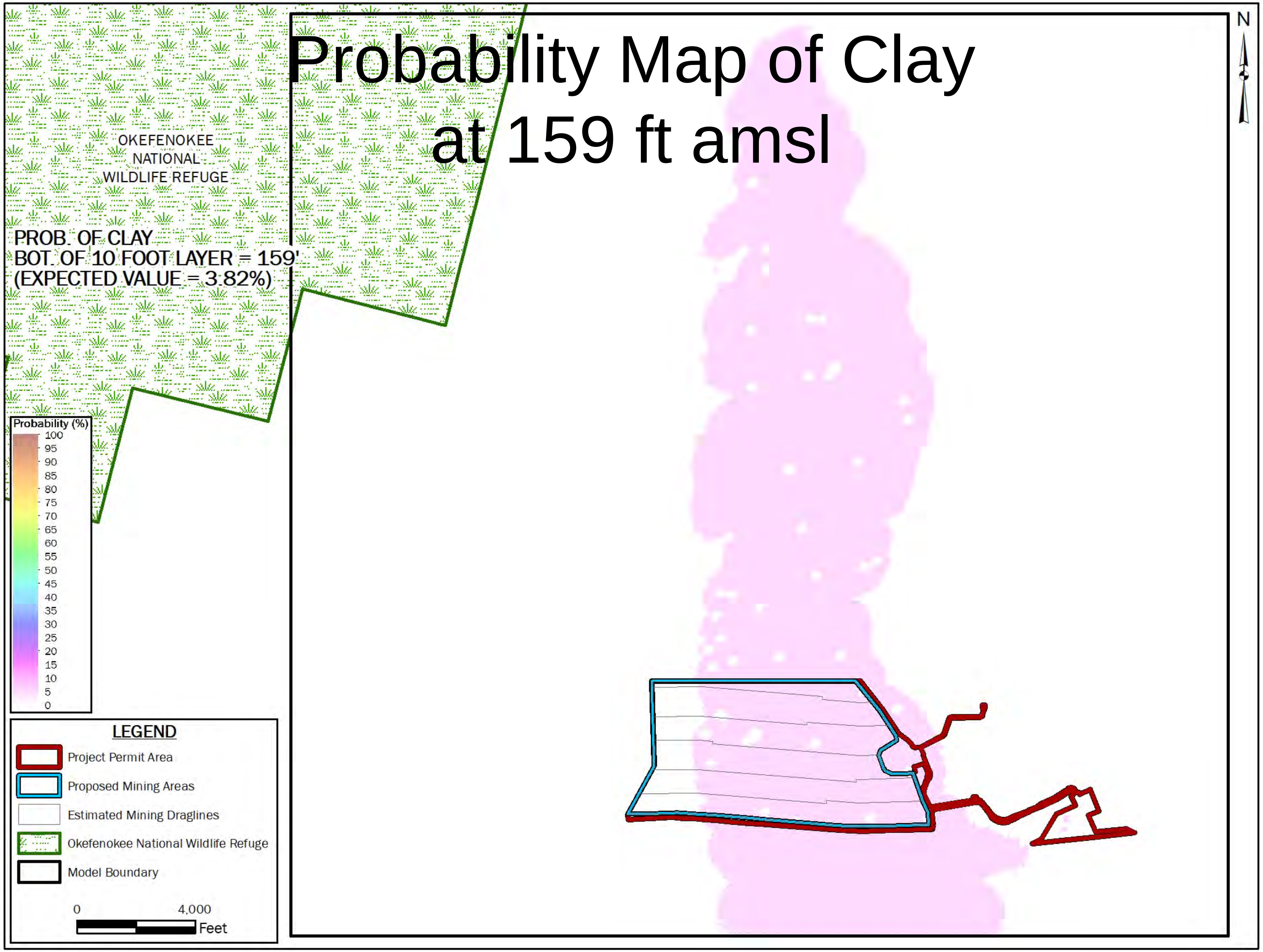
Vertical correlation length = 20.4 ft



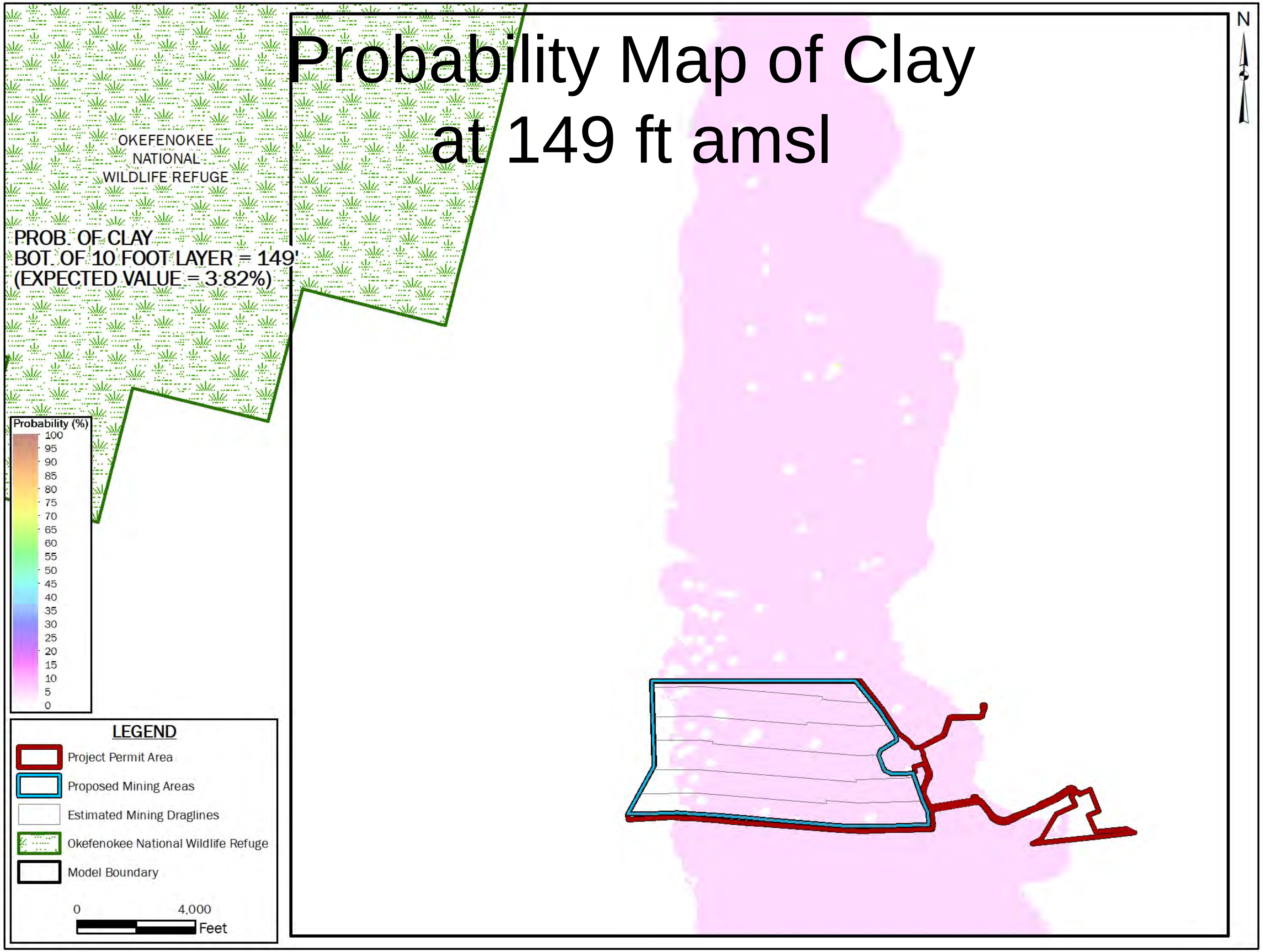
Probability Map of Clay at 169 ft amsl



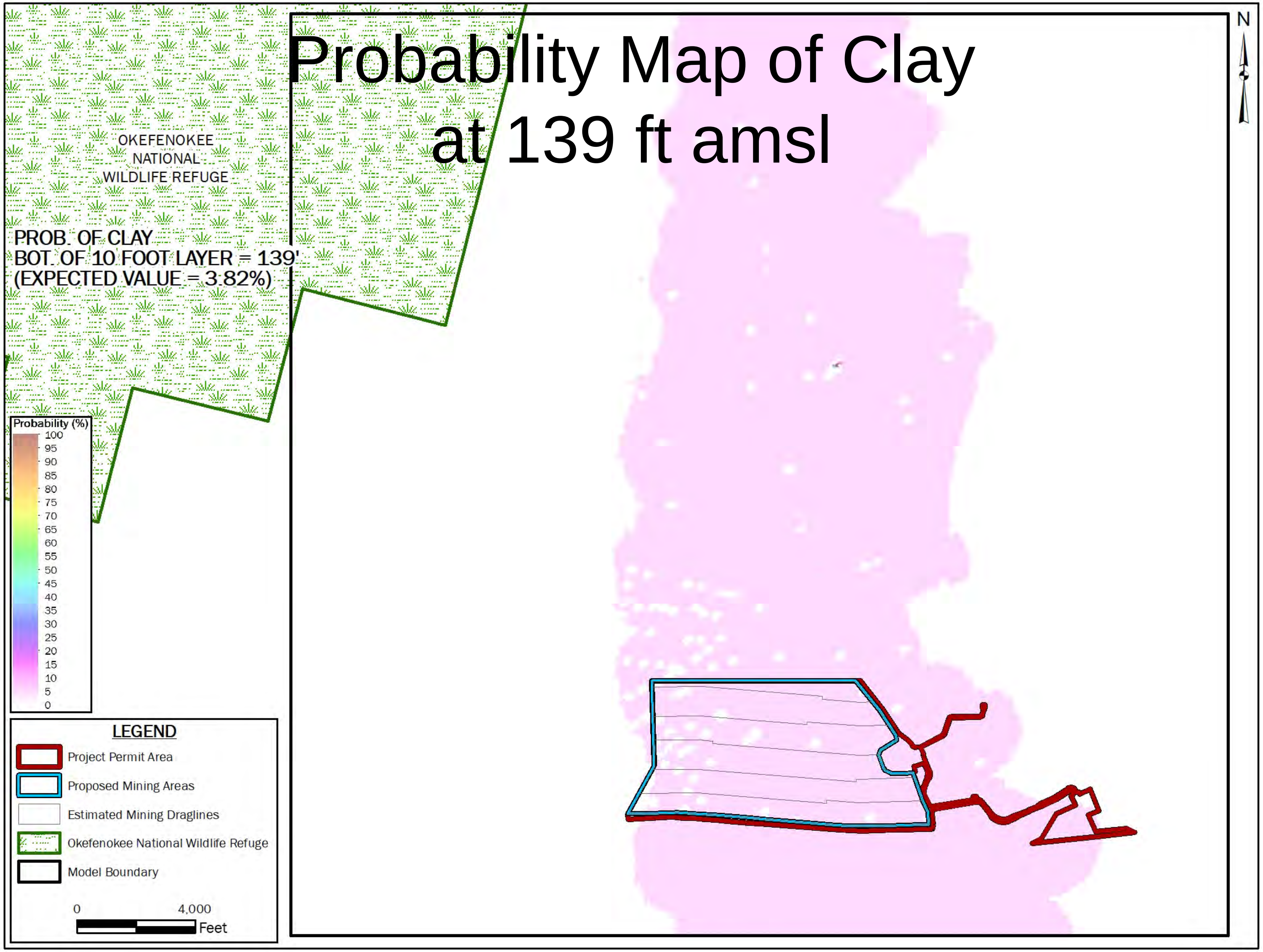
Probability Map of Clay at 159 ft amsl



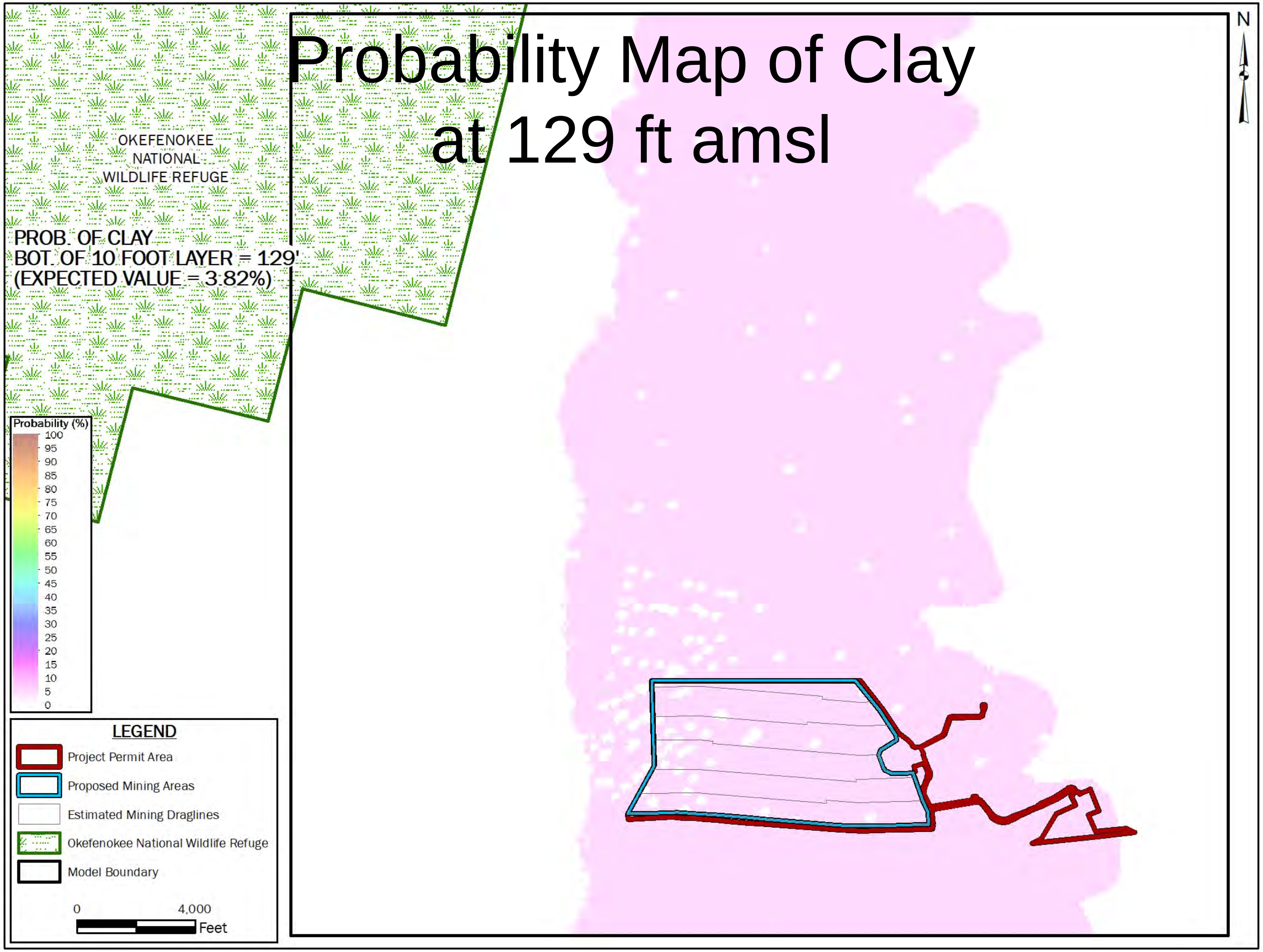
Probability Map of Clay at 149 ft amsl



Probability Map of Clay at 139 ft amsl



Probability Map of Clay at 129 ft amsl



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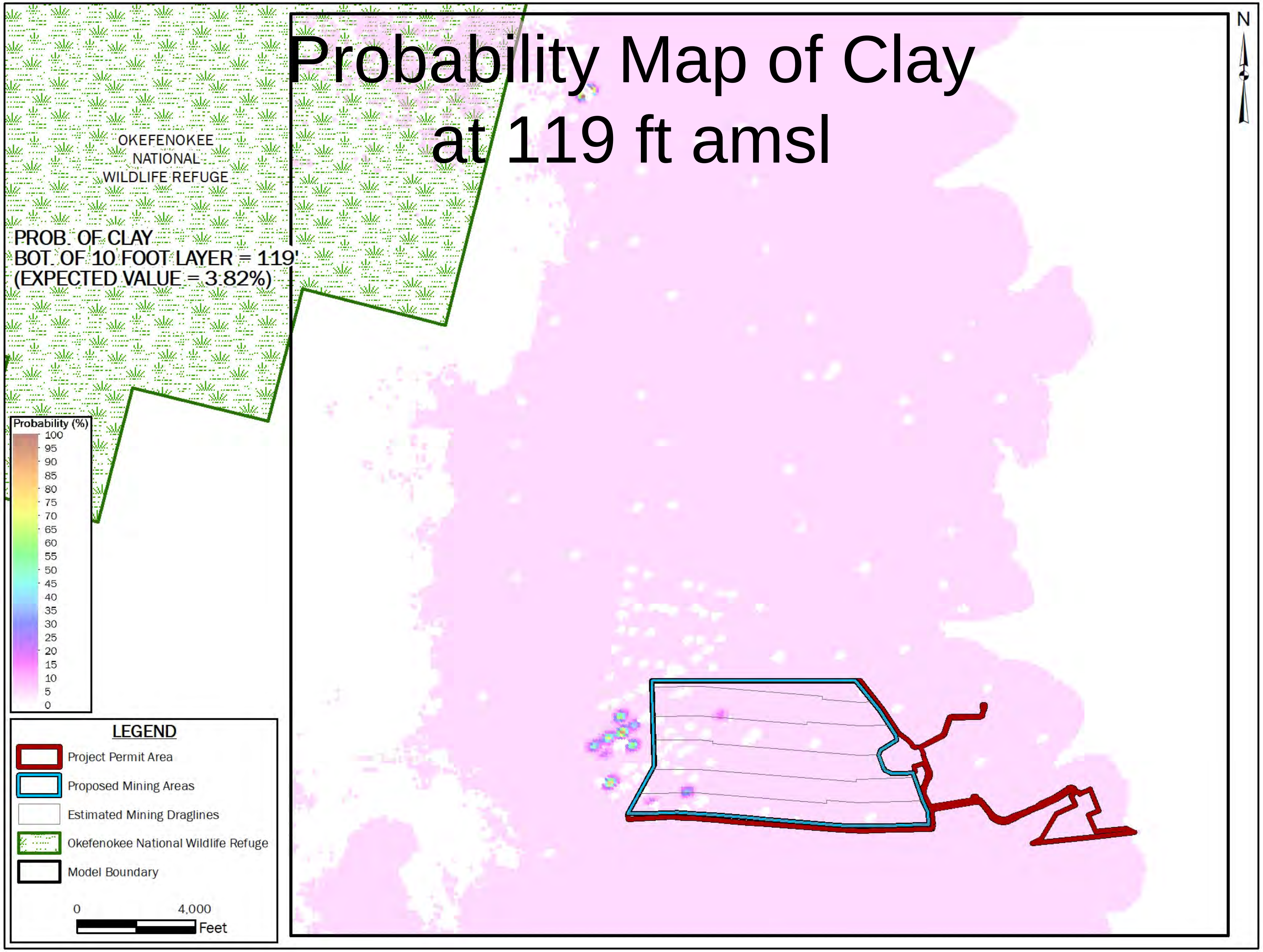
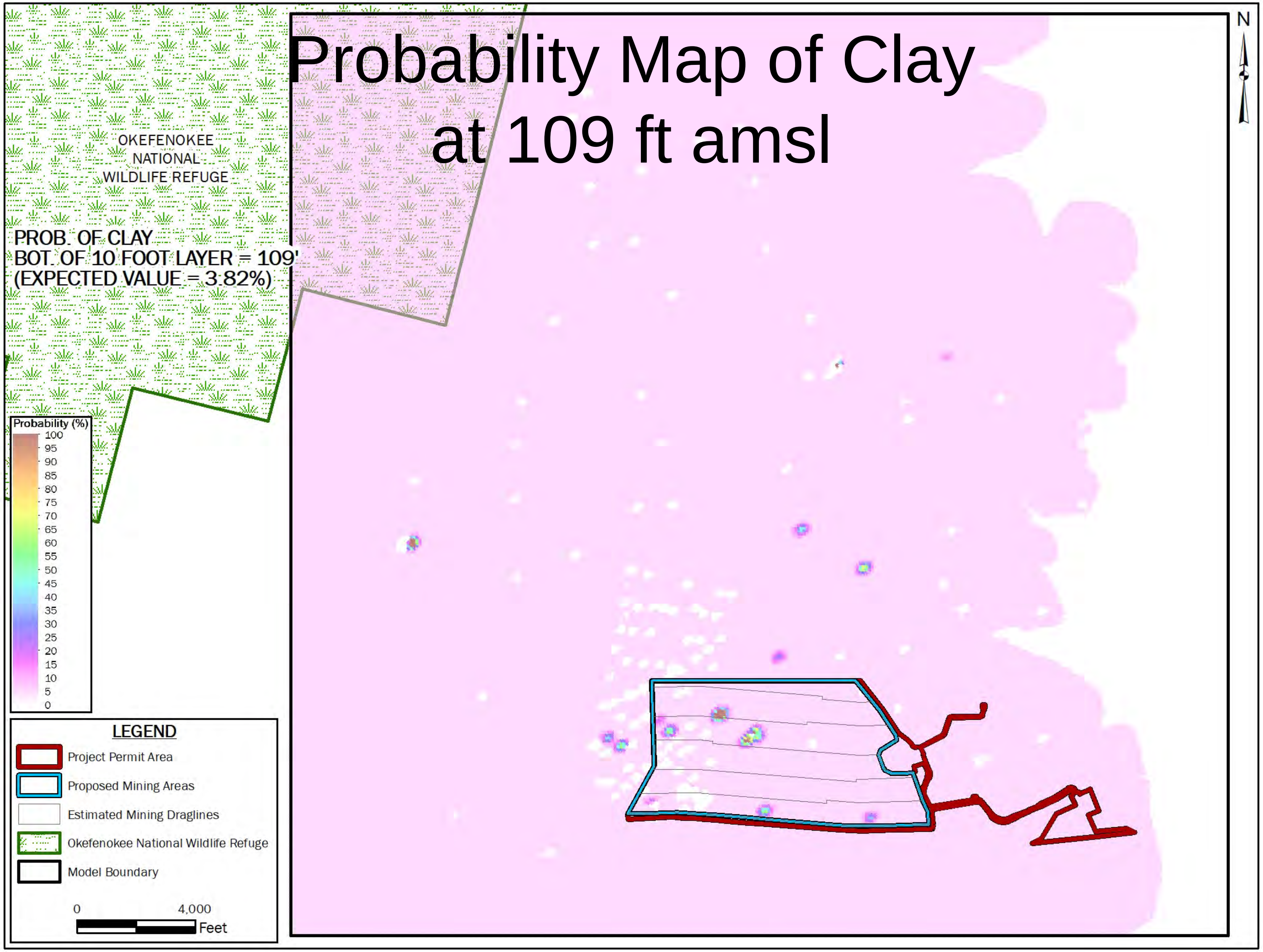
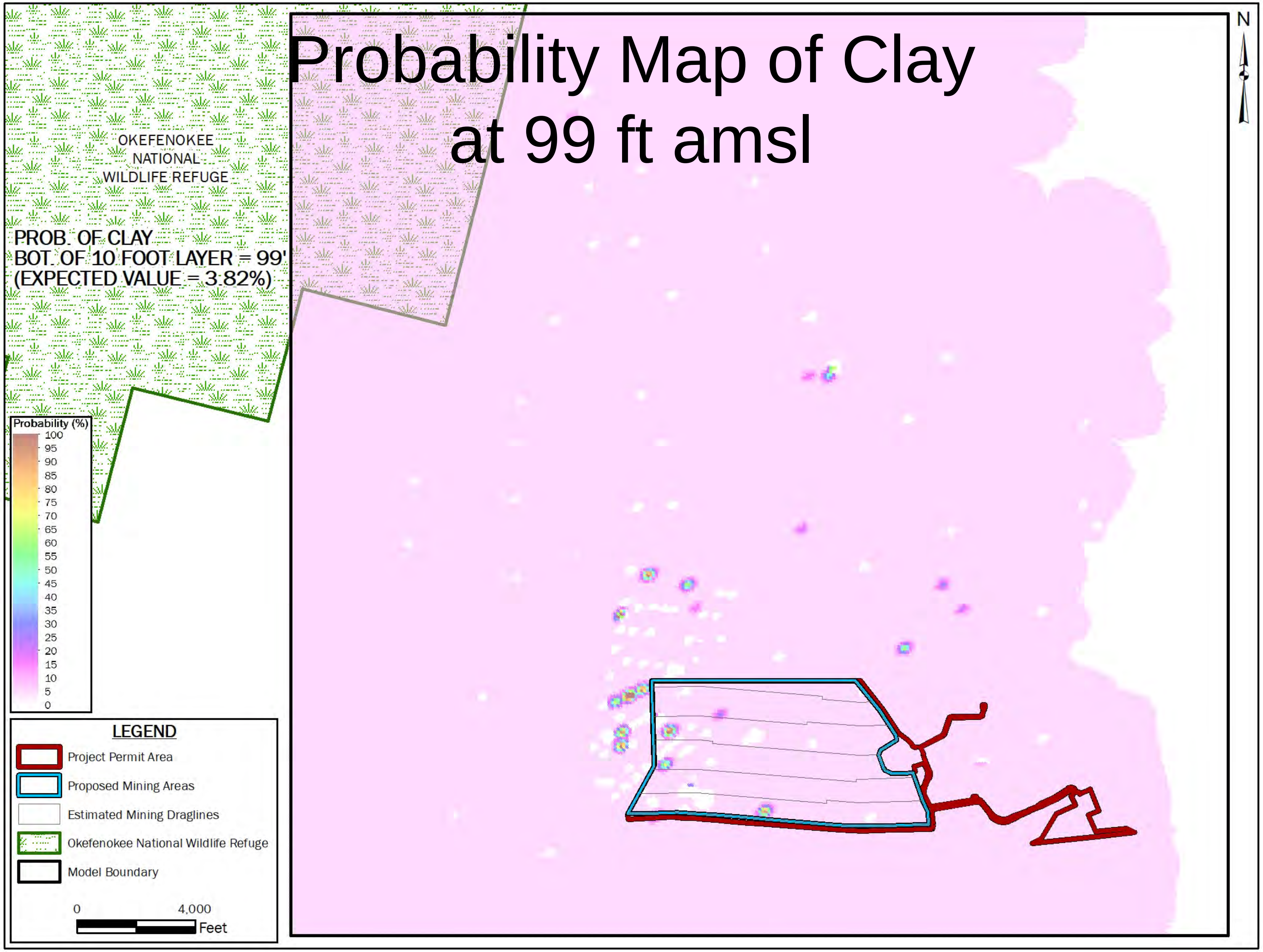


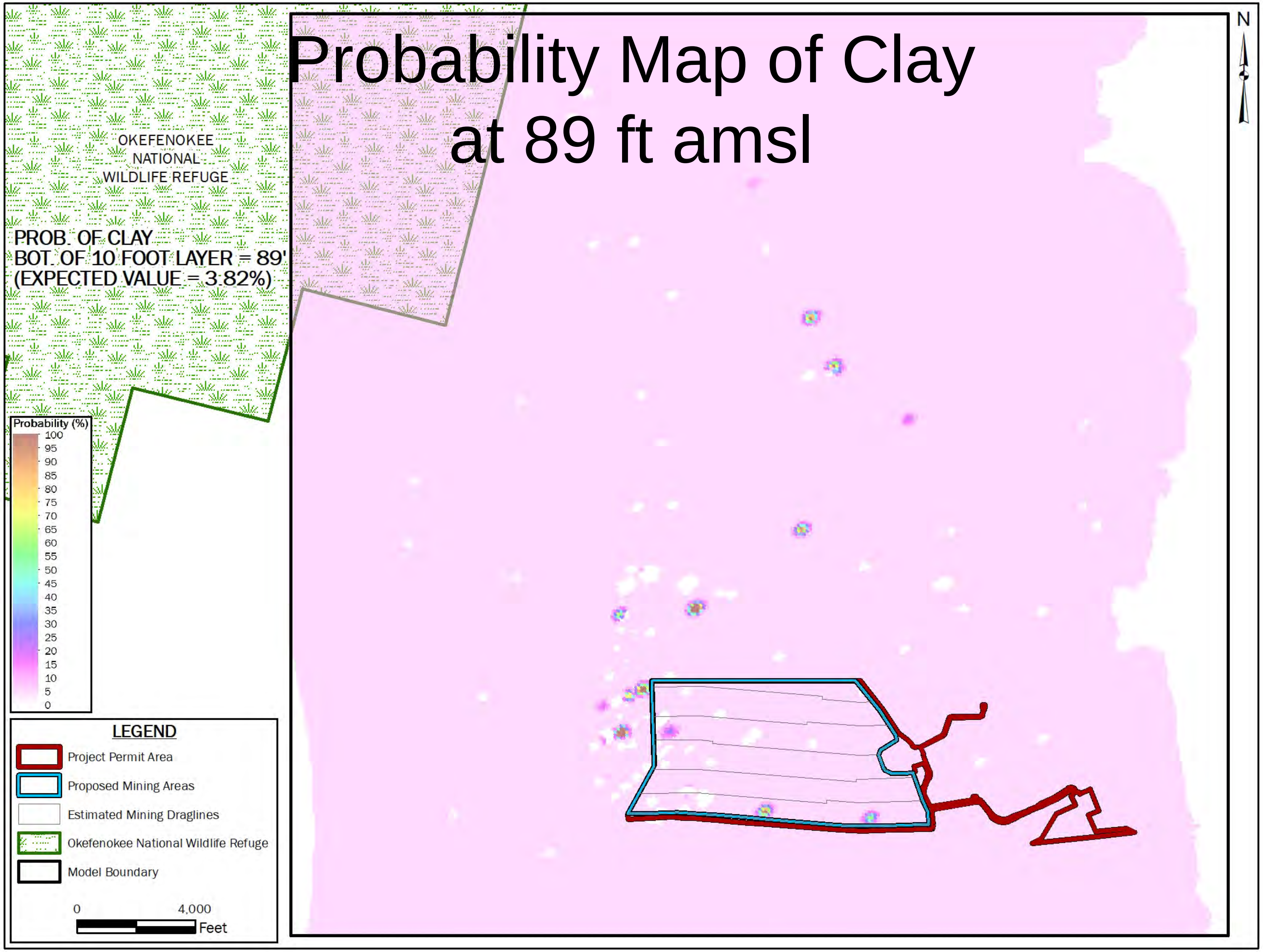
Probability Map of Clay at 109 ft amsl



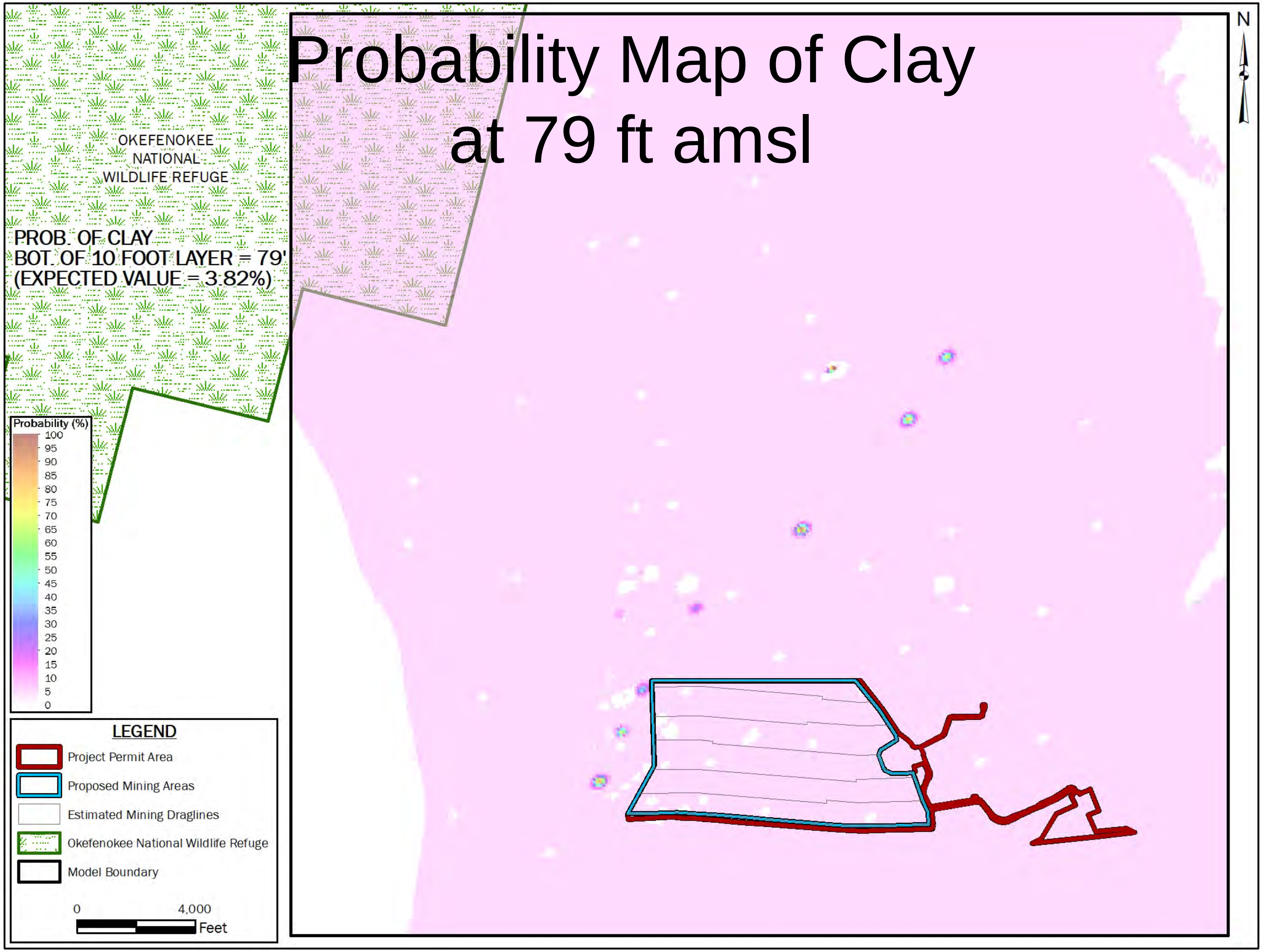
Probability Map of Clay at 99 ft amsl



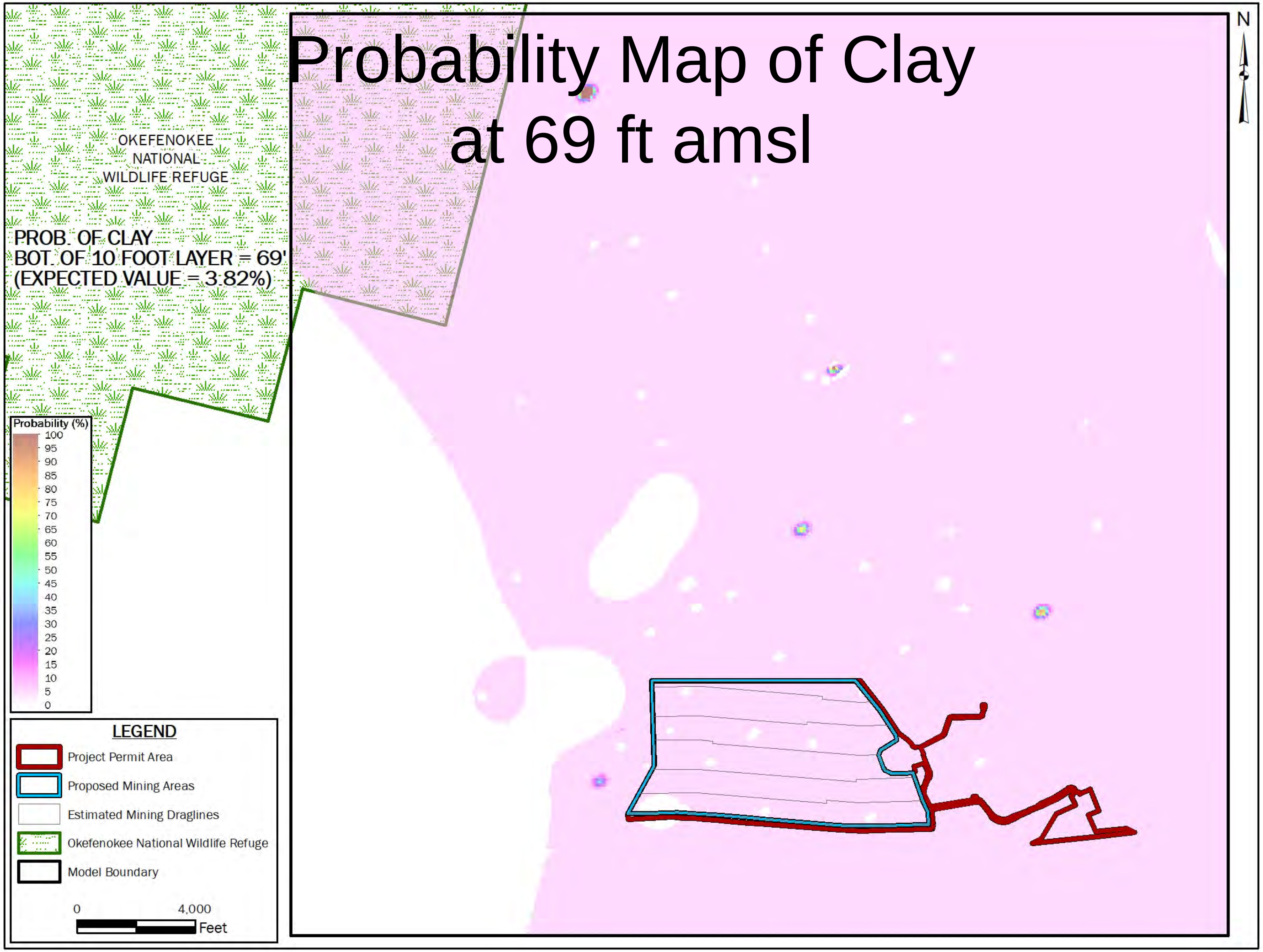
Probability Map of Clay at 89 ft amsl



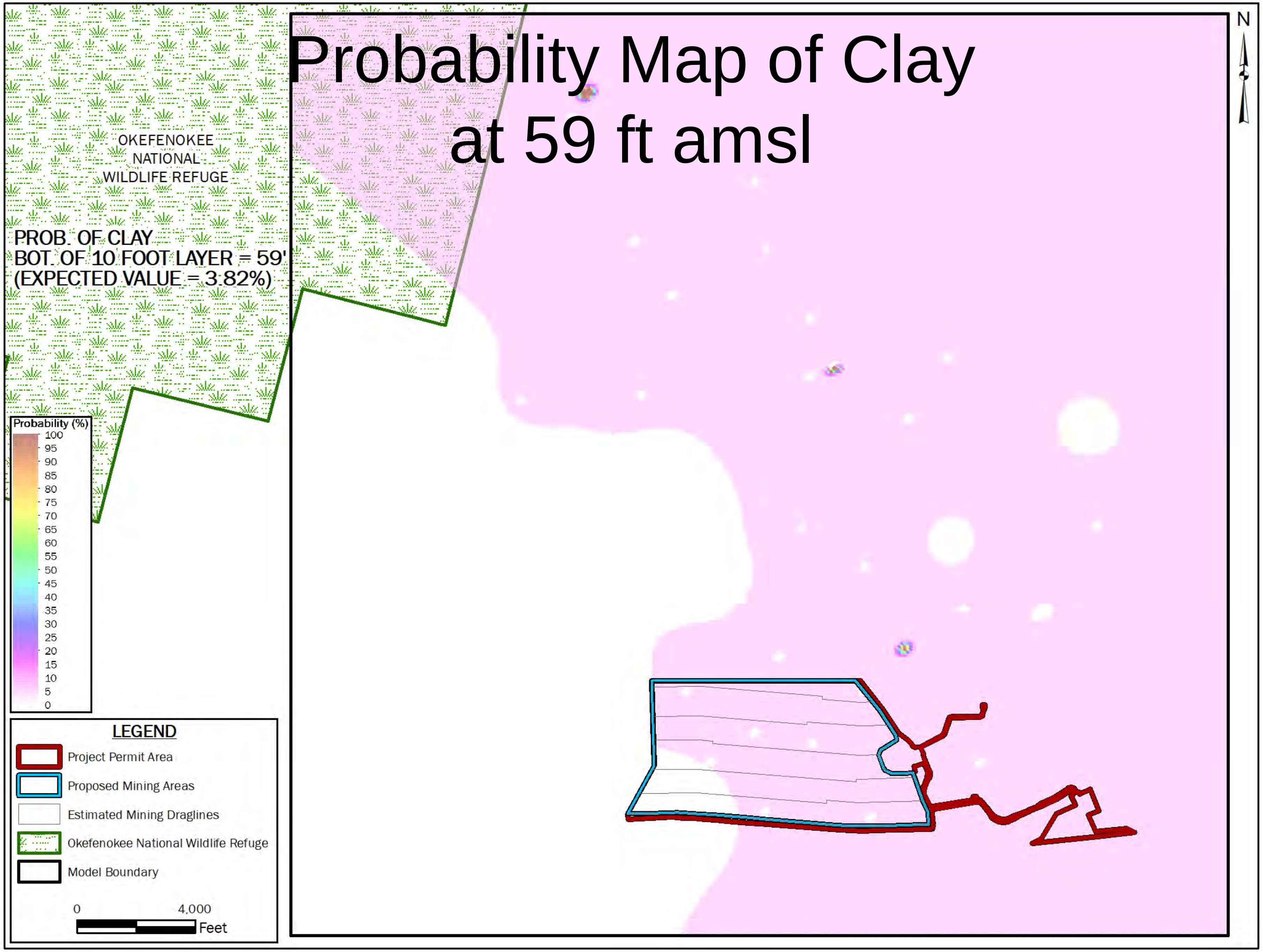
Probability Map of Clay at 79 ft amsl



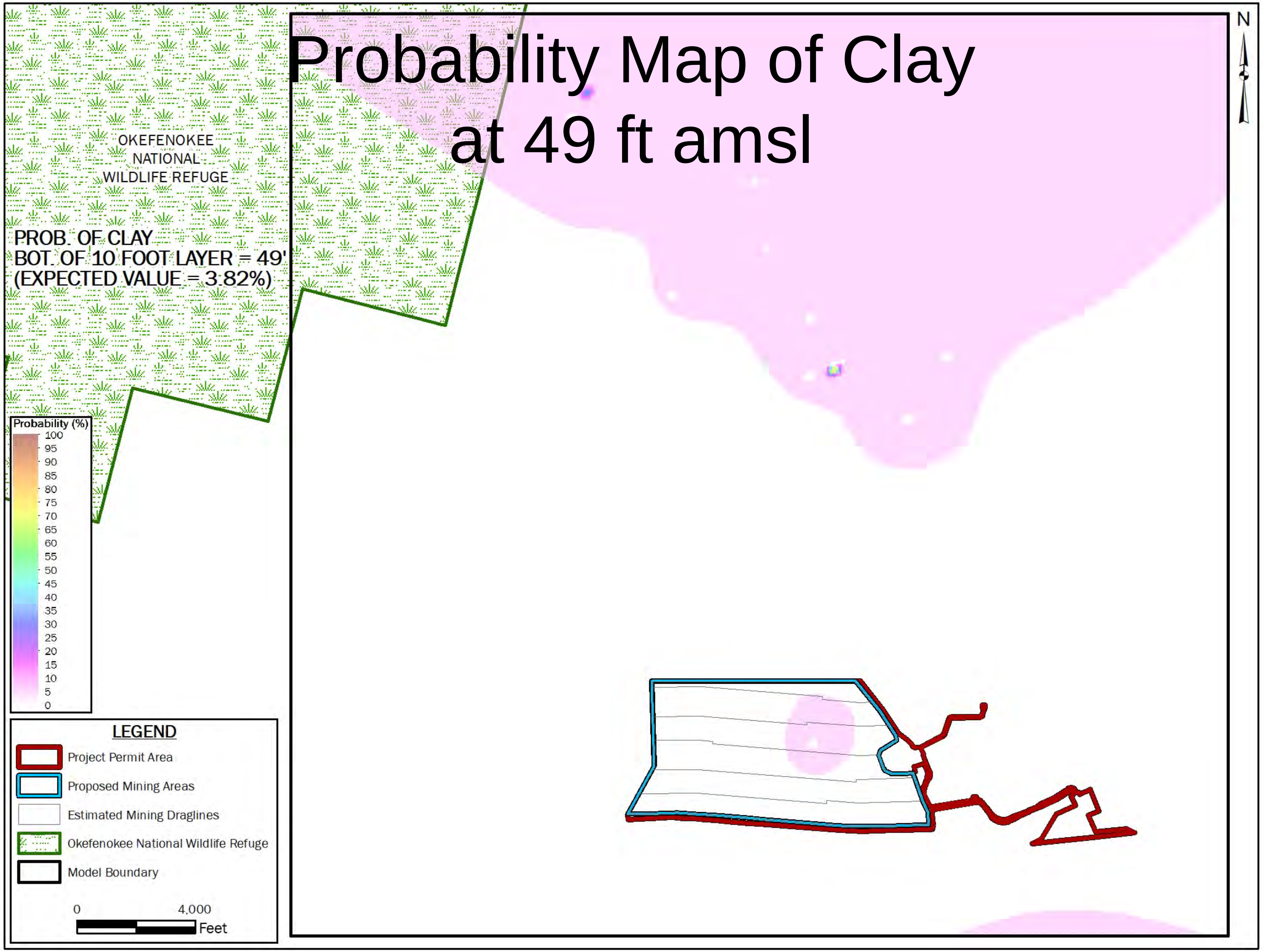
Probability Map of Clay at 69 ft amsl



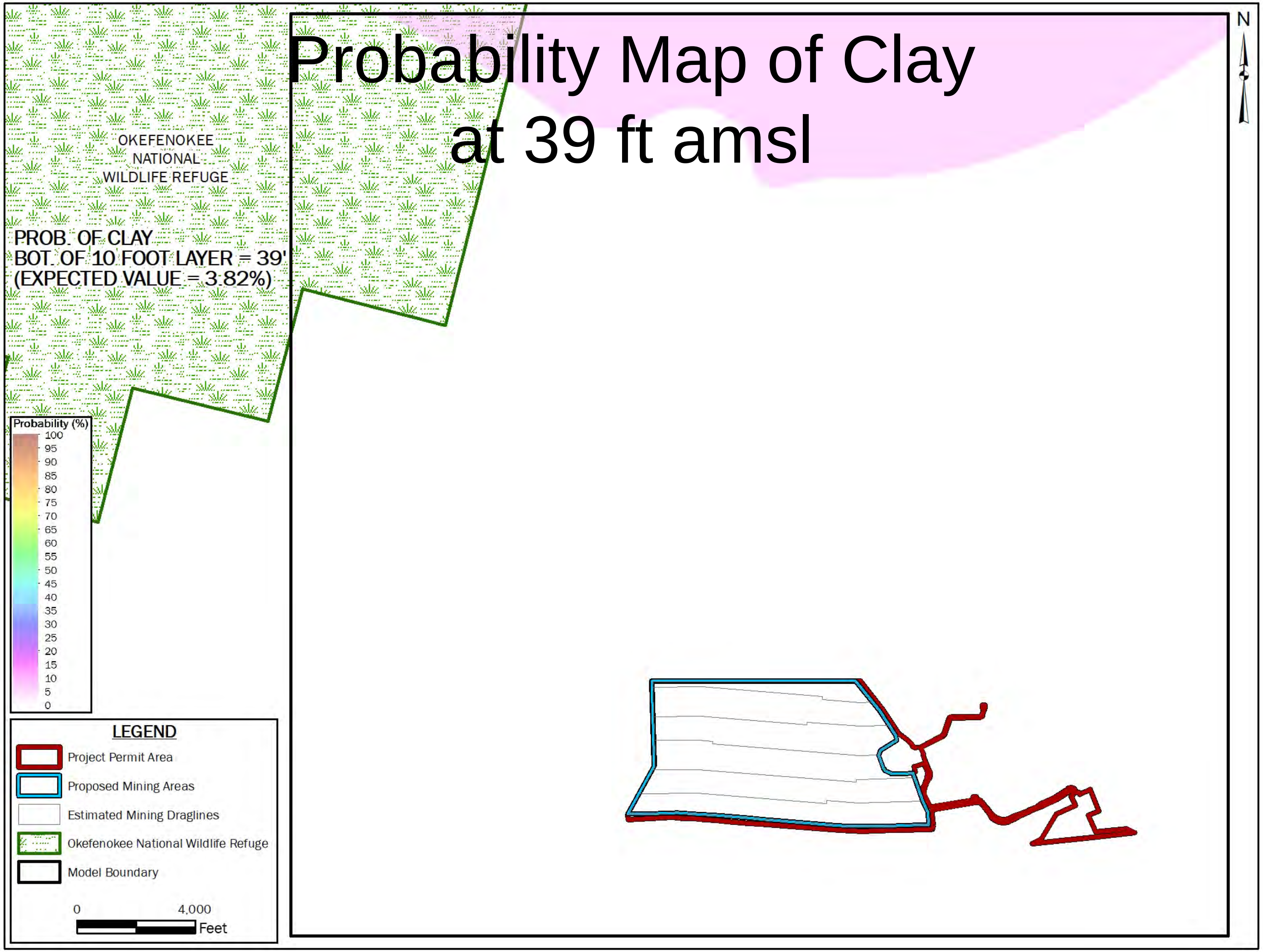
Probability Map of Clay at 59 ft amsl



Probability Map of Clay at 49 ft amsl



Probability Map of Clay at 39 ft amsl

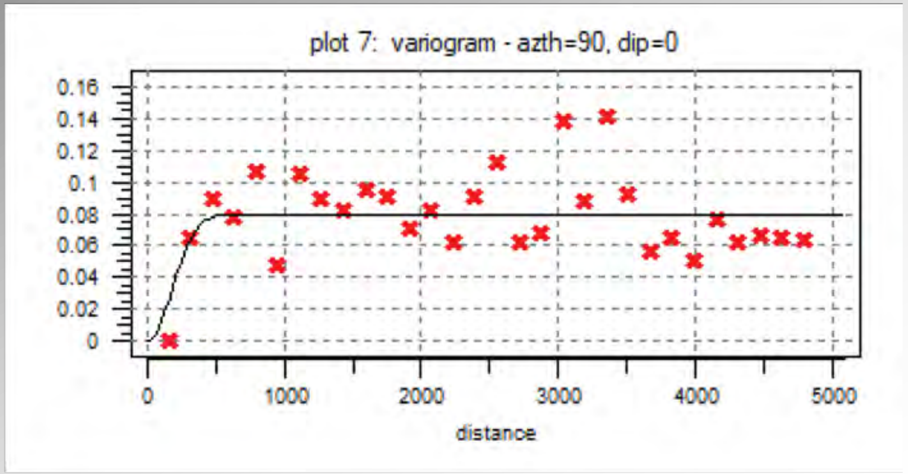


Clayey Sand

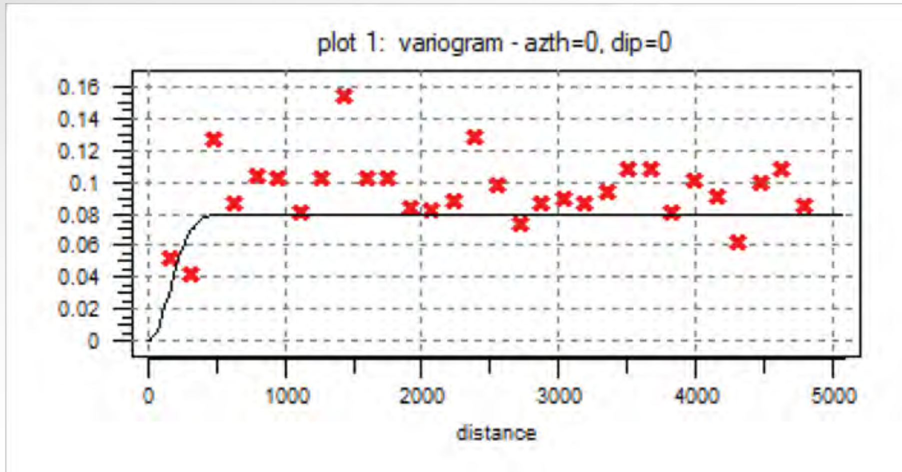
- Occupies 7.85% of the surficial aquifer (mainly below an elevation of 120 ft amsl)
- Consists of silty sands with clay content between 10% – 40%

Clayey Sand – Correlation Lengths

A)

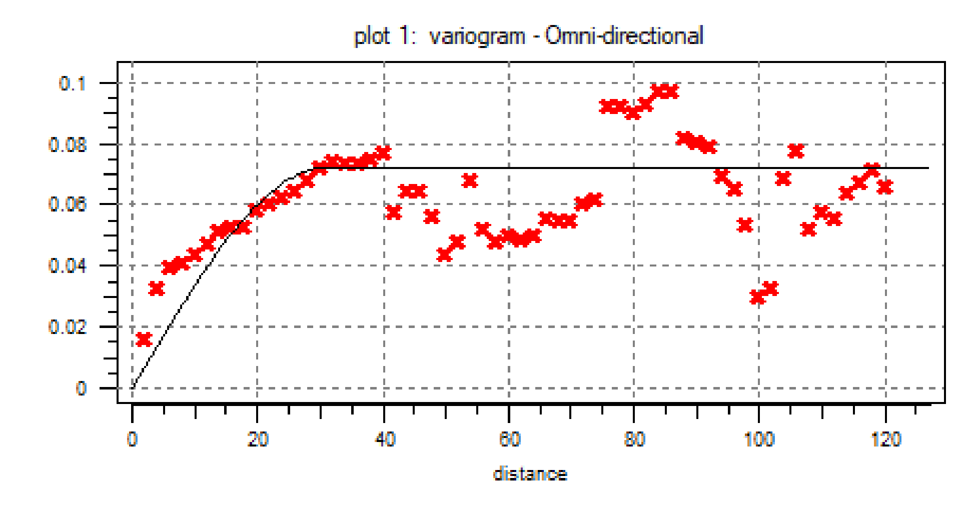


B)

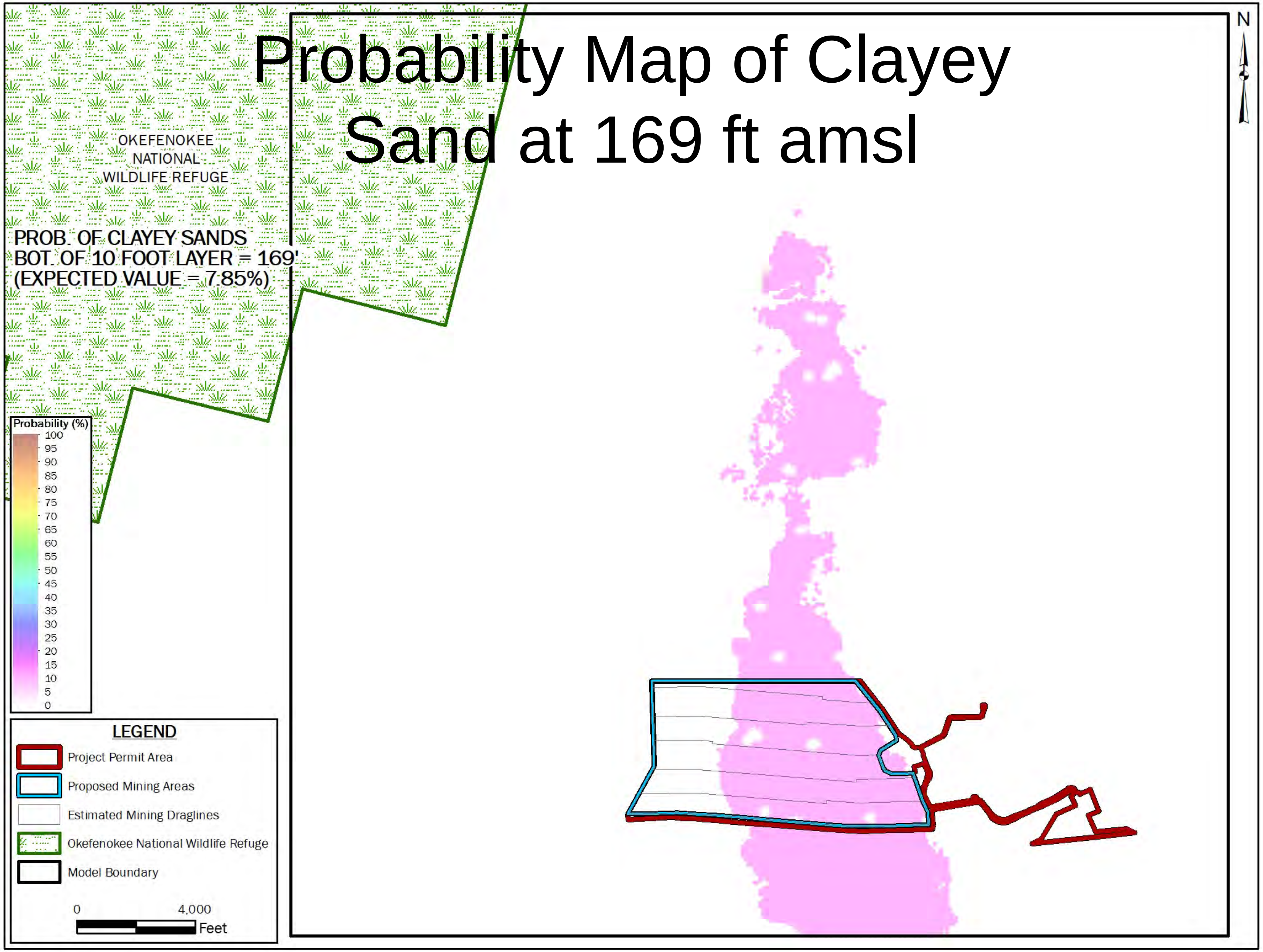


Horizontal correlation length = 432 ft max (az. = 90 degrees), 380 ft min (az. = 0 degrees)

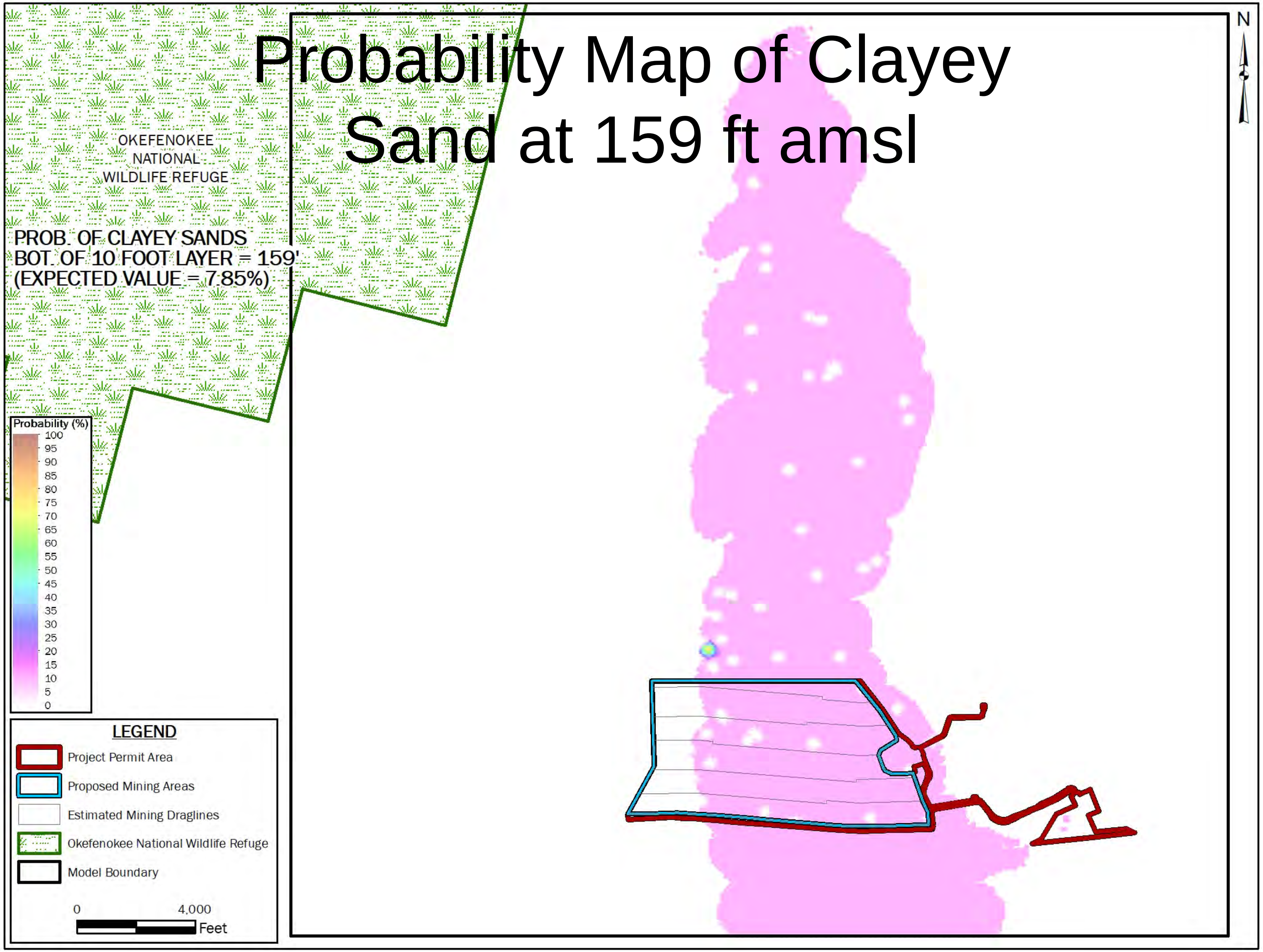
Vertical correlation length = 33.6 ft



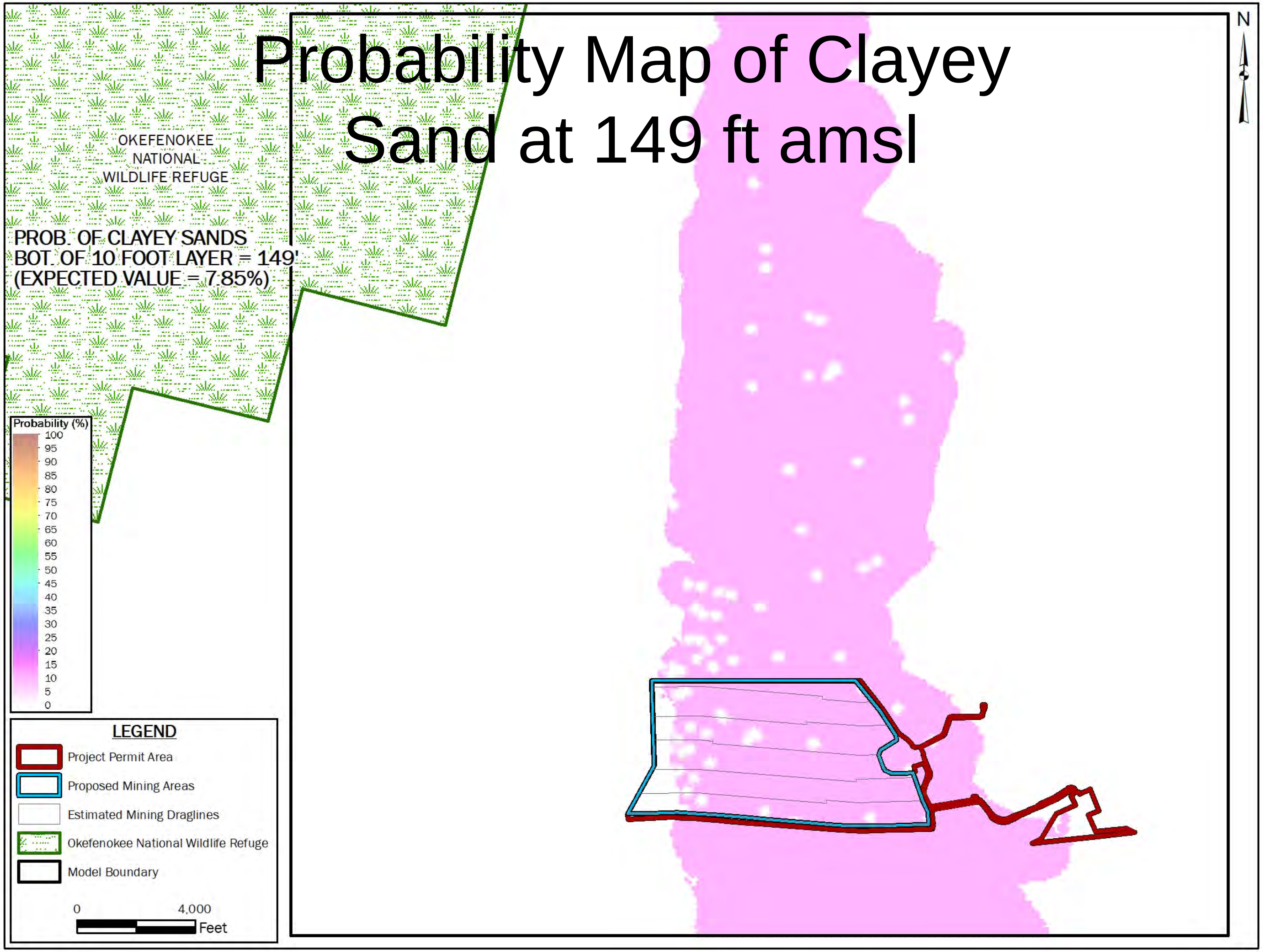
Probability Map of Clayey Sand at 169 ft amsl



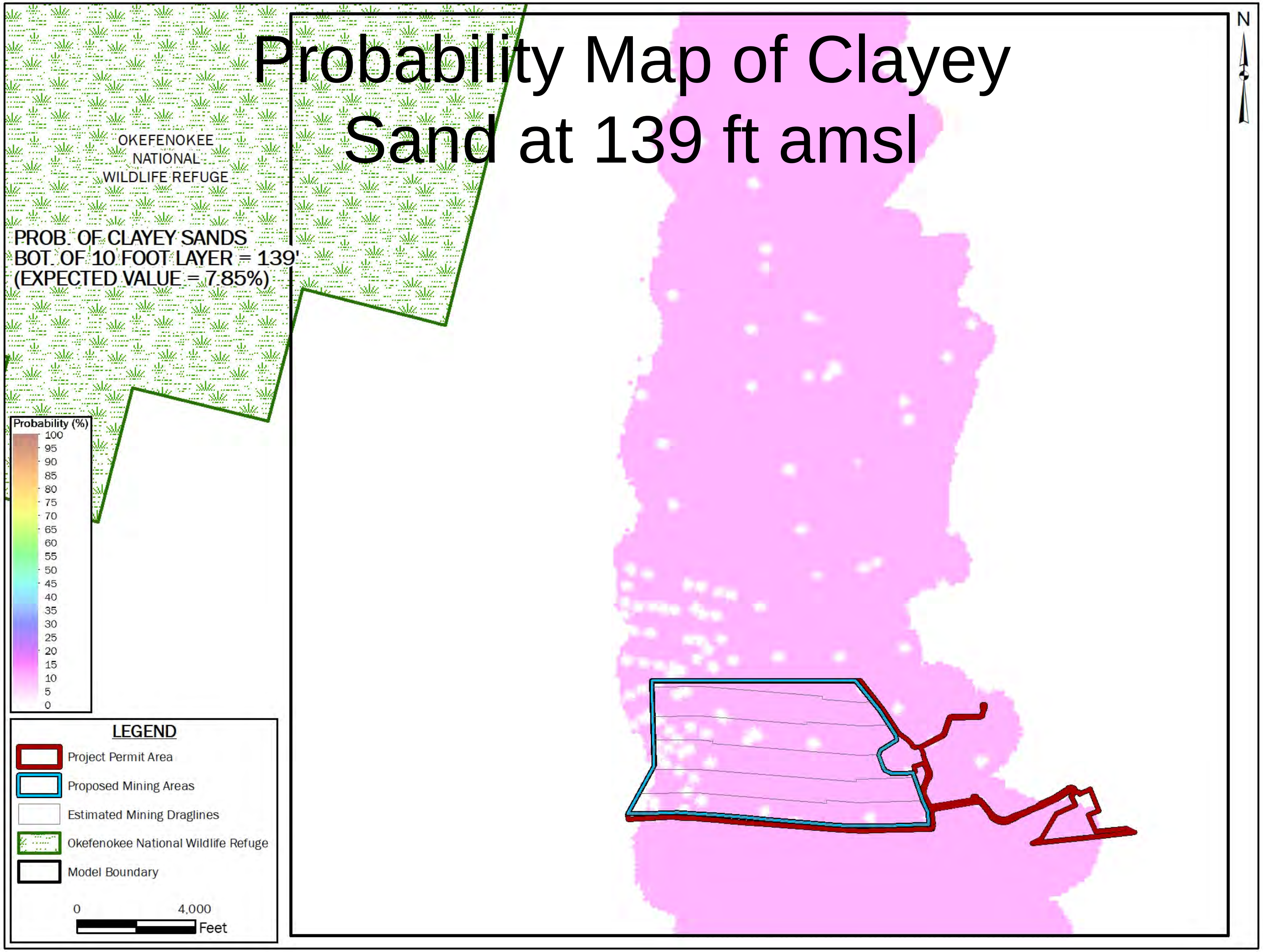
Probability Map of Clayey Sand at 159 ft amsl



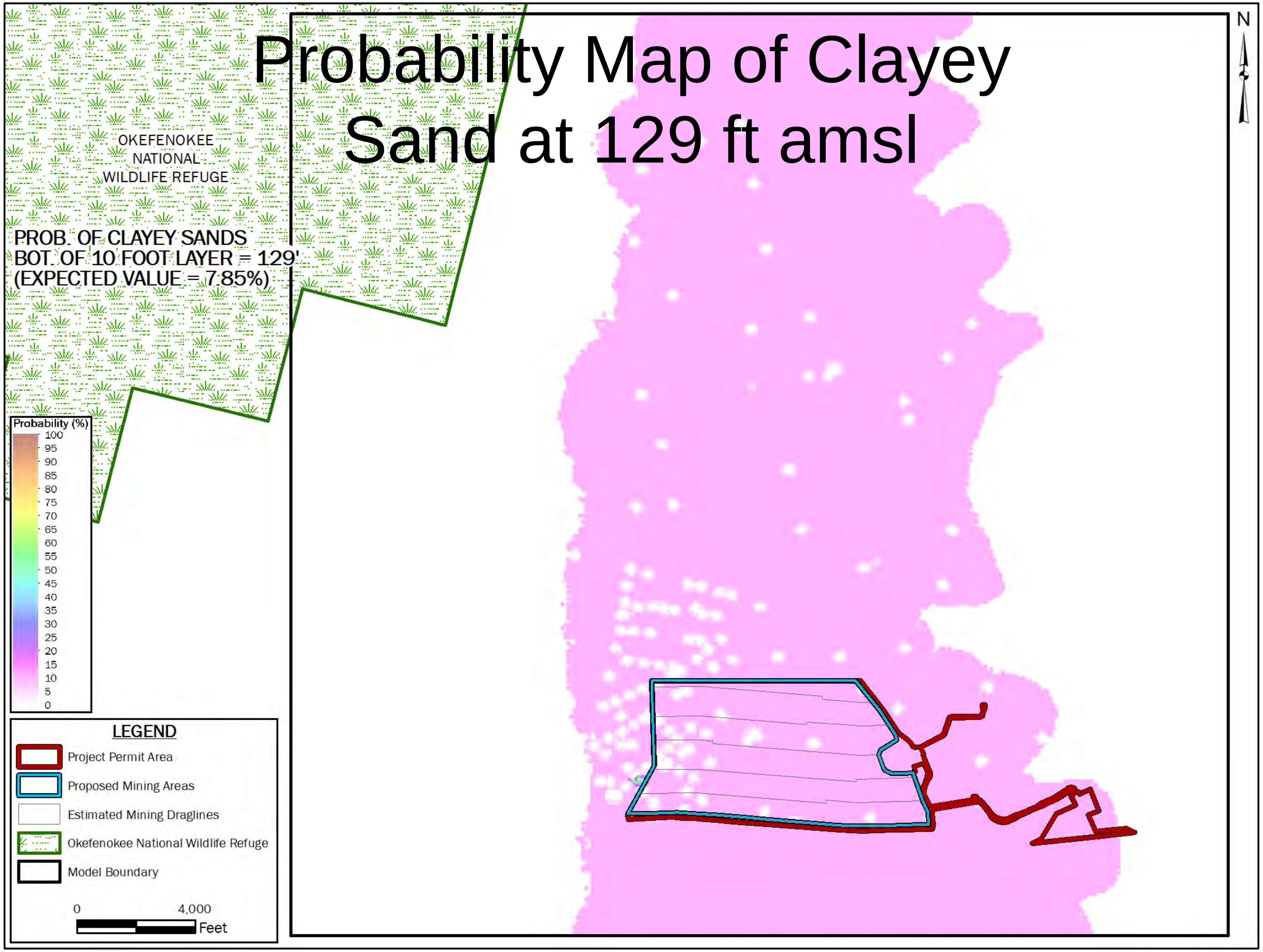
Probability Map of Clayey Sand at 149 ft amsl



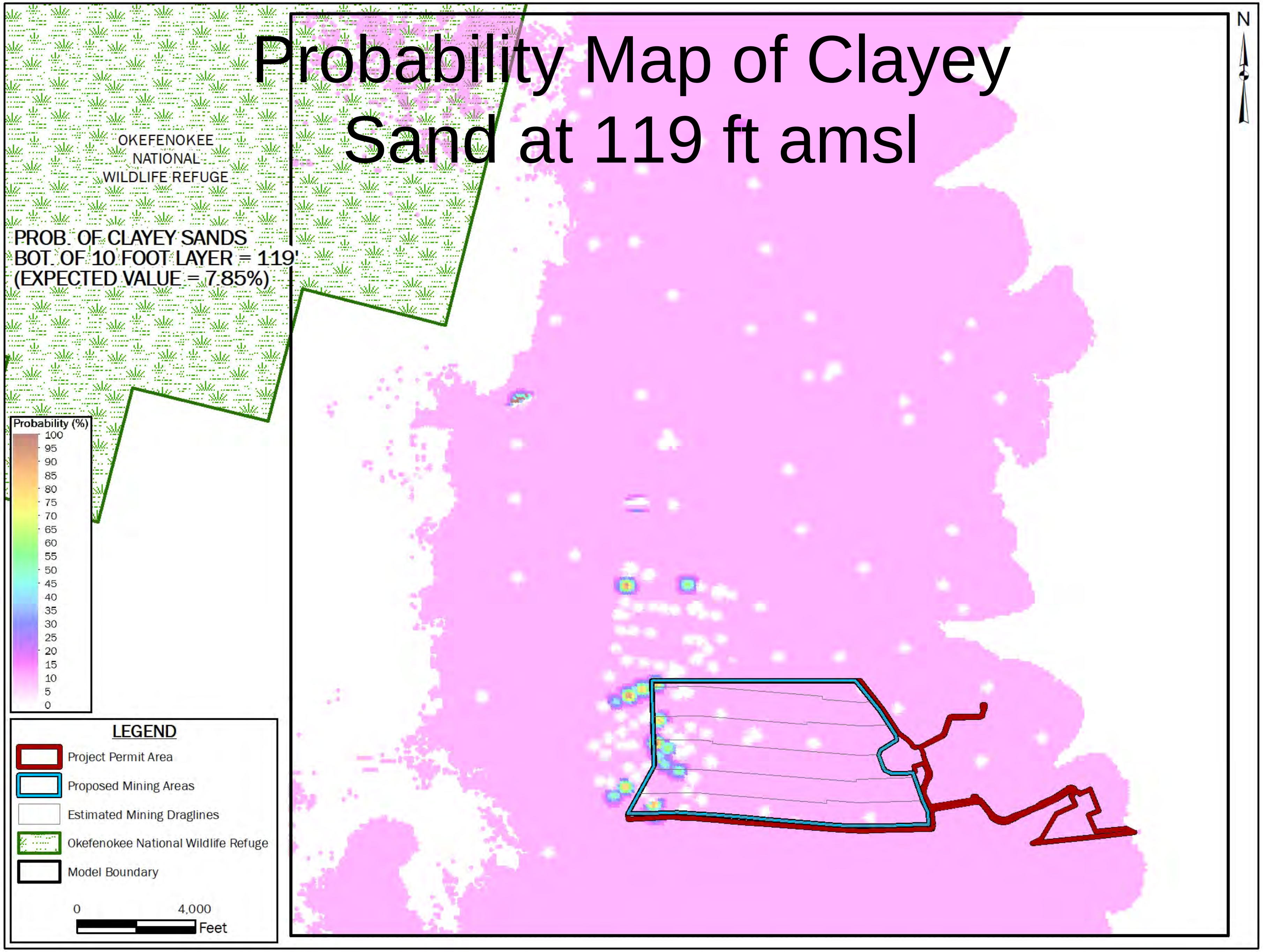
Probability Map of Clayey Sand at 139 ft amsl



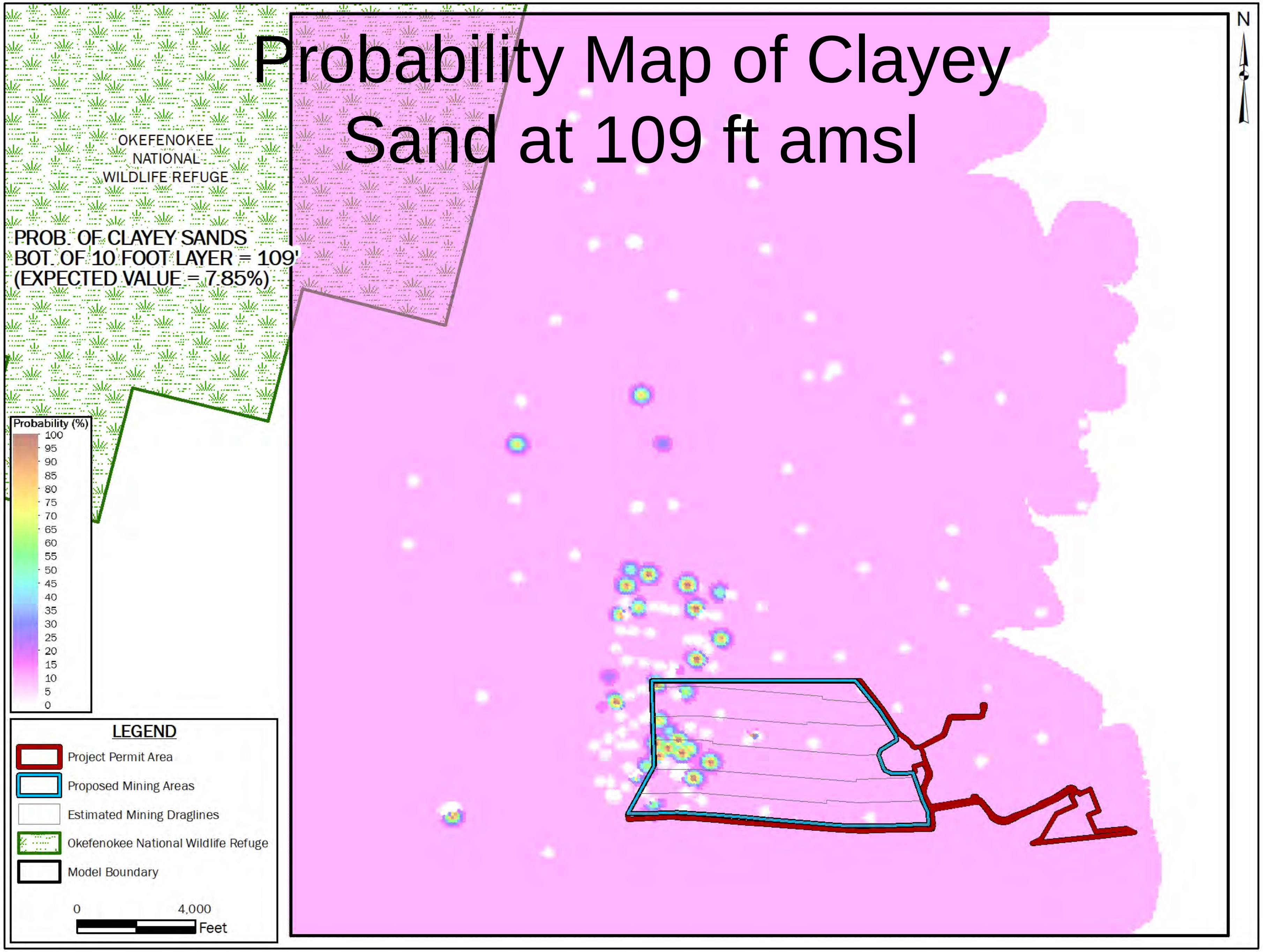
Probability Map of Clayey Sand at 129 ft amsl



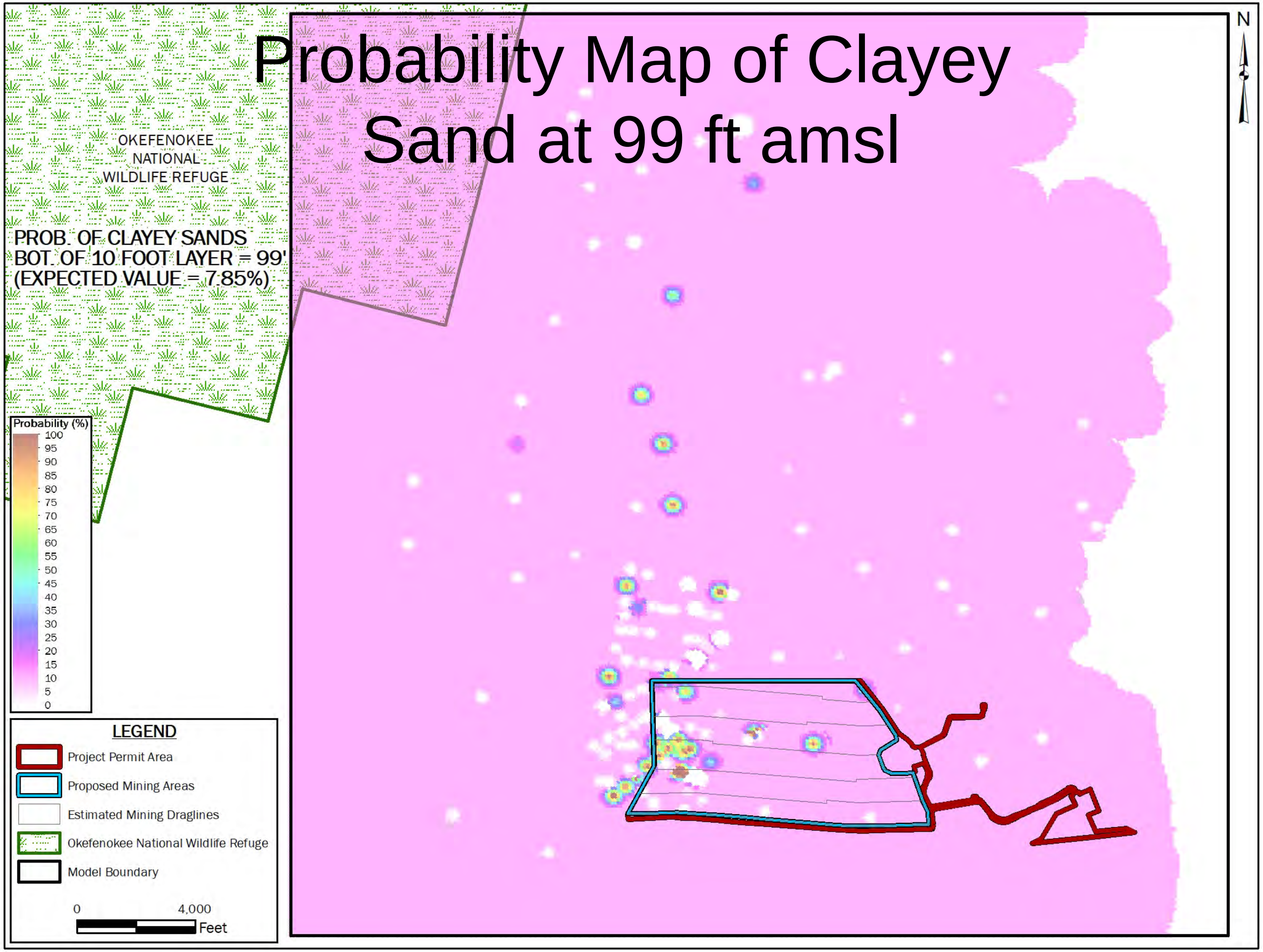
Probability Map of Clayey Sand at 119 ft amsl



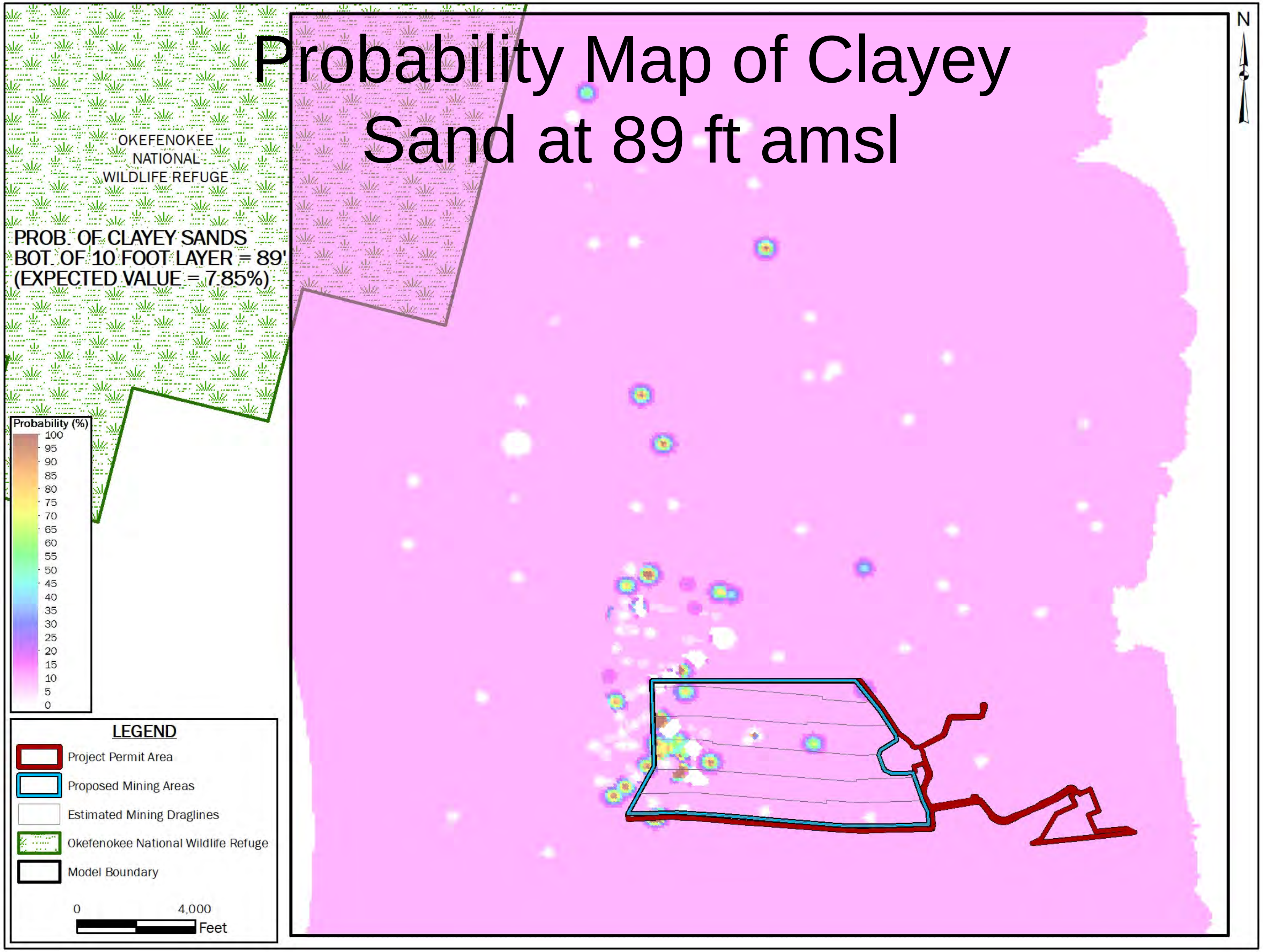
Probability Map of Clayey Sand at 109 ft amsl



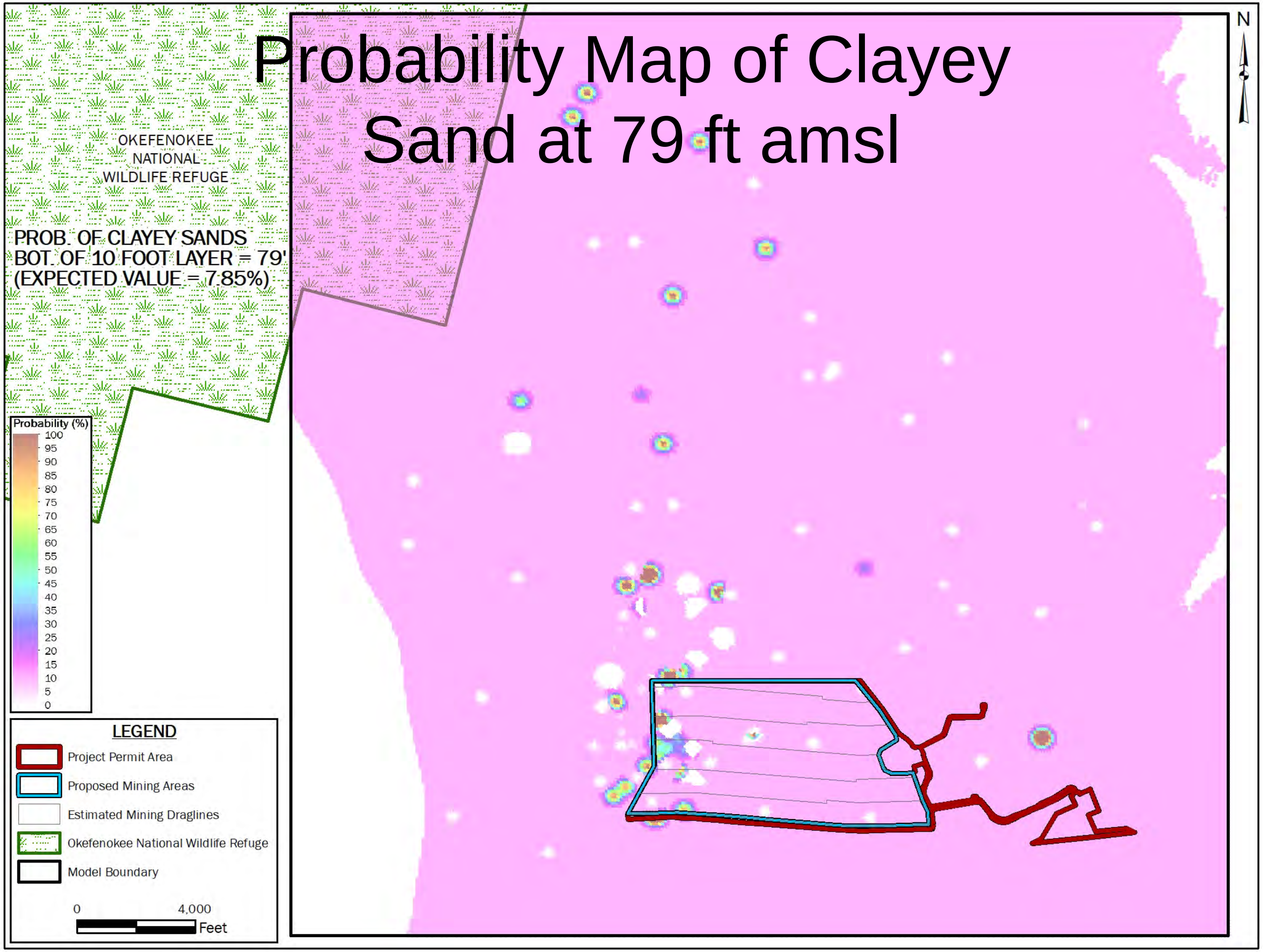
Probability Map of Clayey Sand at 99 ft amsl



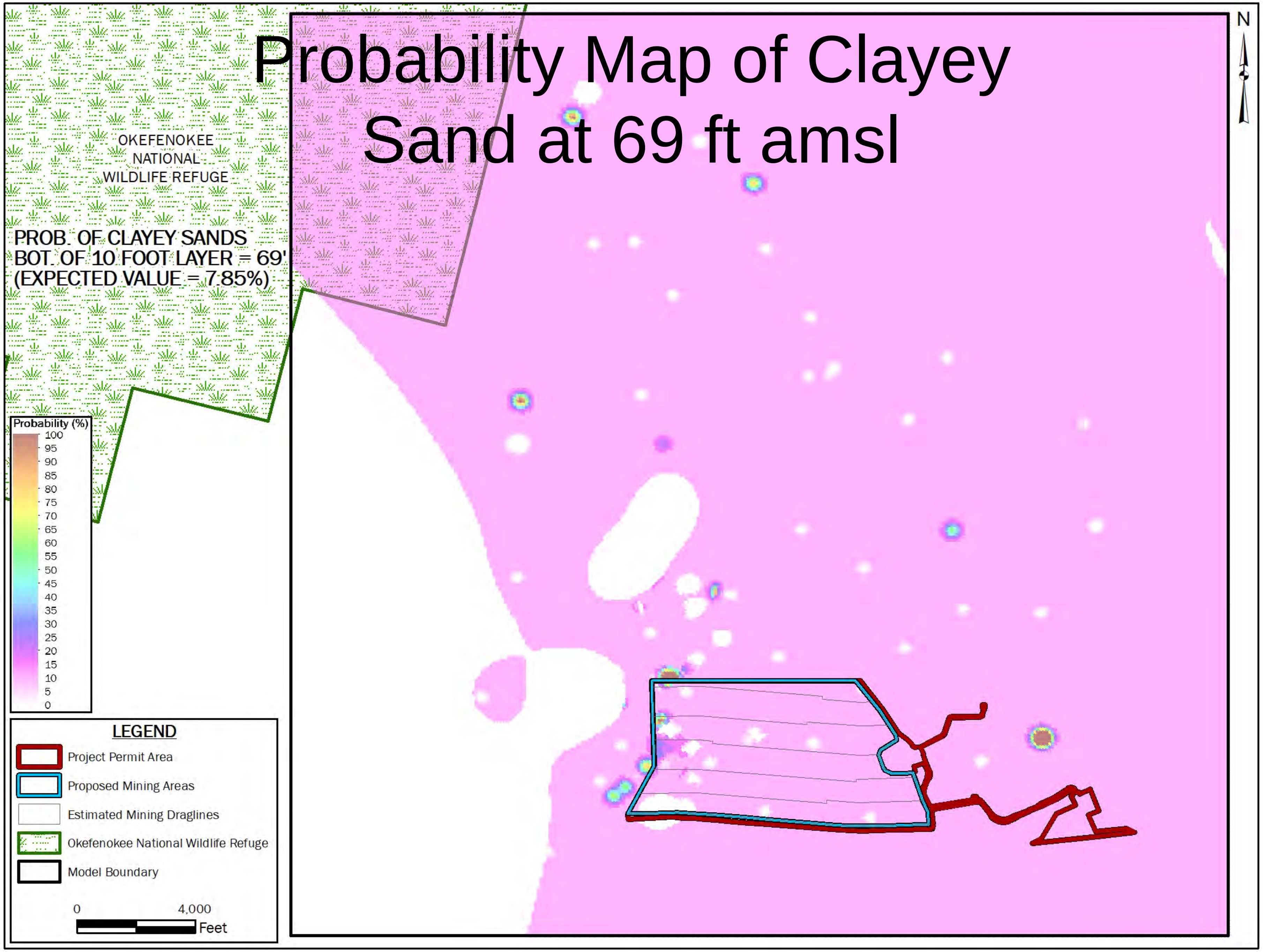
Probability Map of Clayey Sand at 89 ft amsl



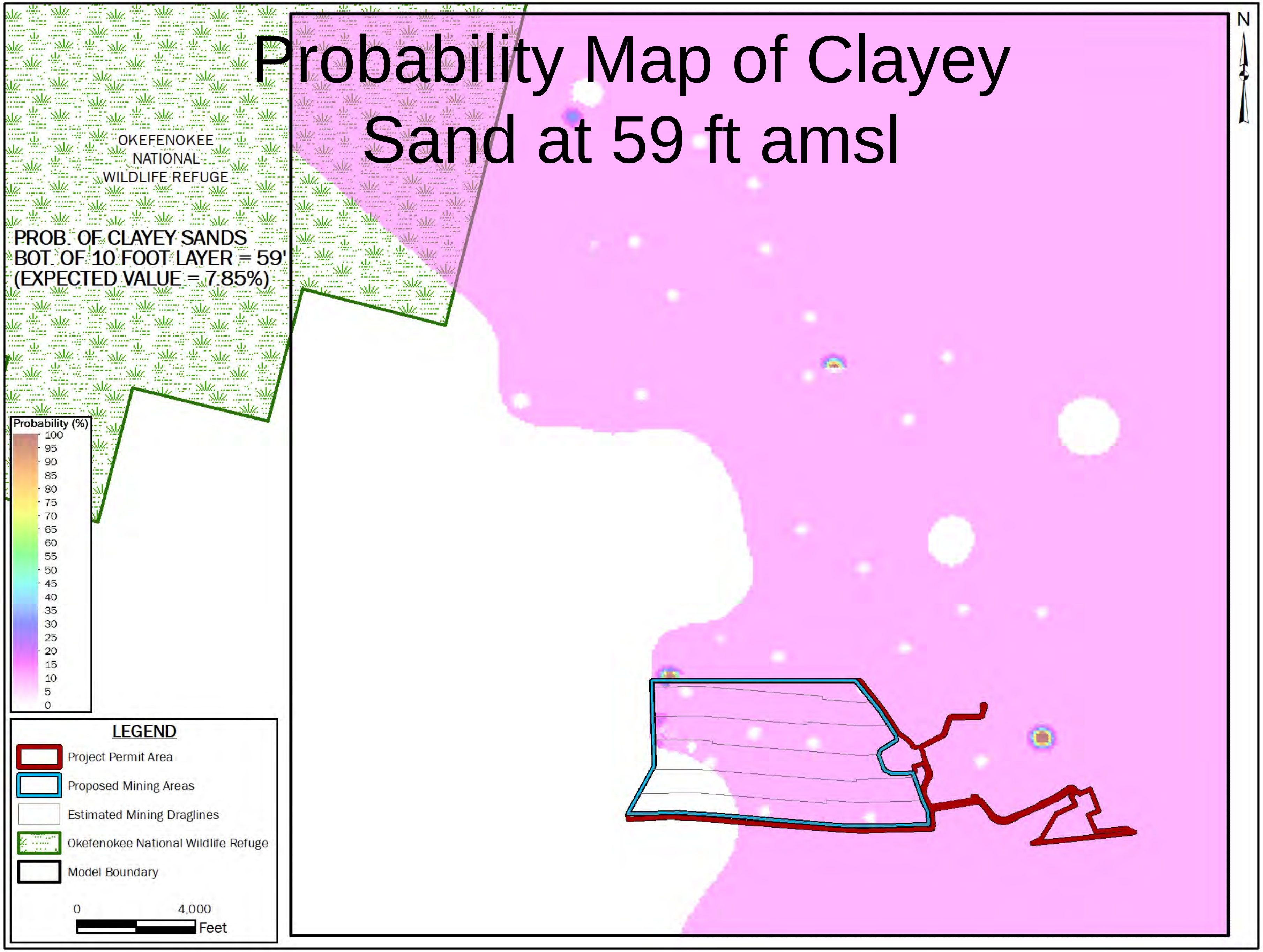
Probability Map of Clayey Sand at 79 ft amsl



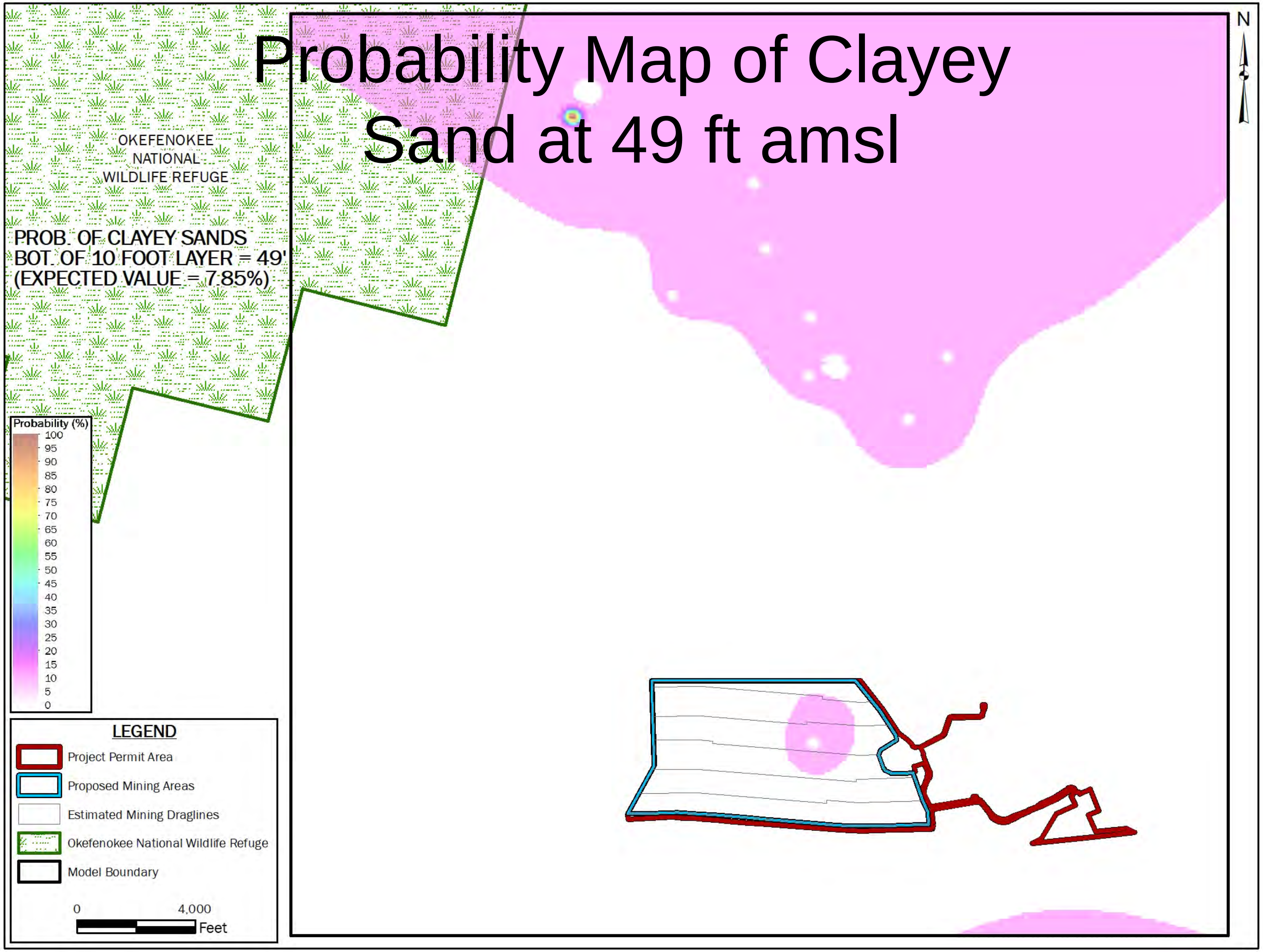
Probability Map of Clayey Sand at 69 ft amsl



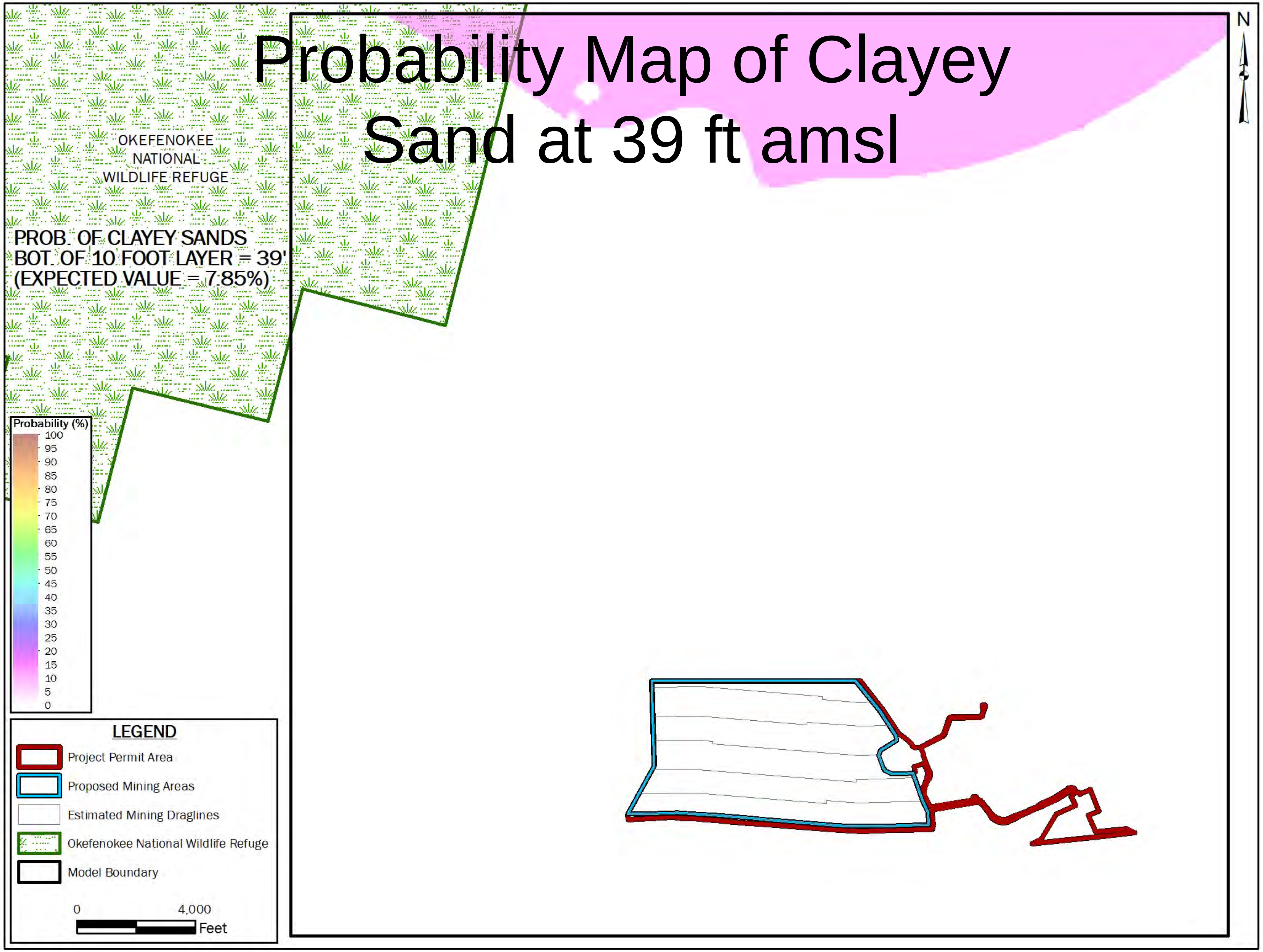
Probability Map of Clayey Sand at 59 ft amsl



Probability Map of Clayey Sand at 49 ft amsl



Probability Map of Clayey Sand at 39 ft amsl

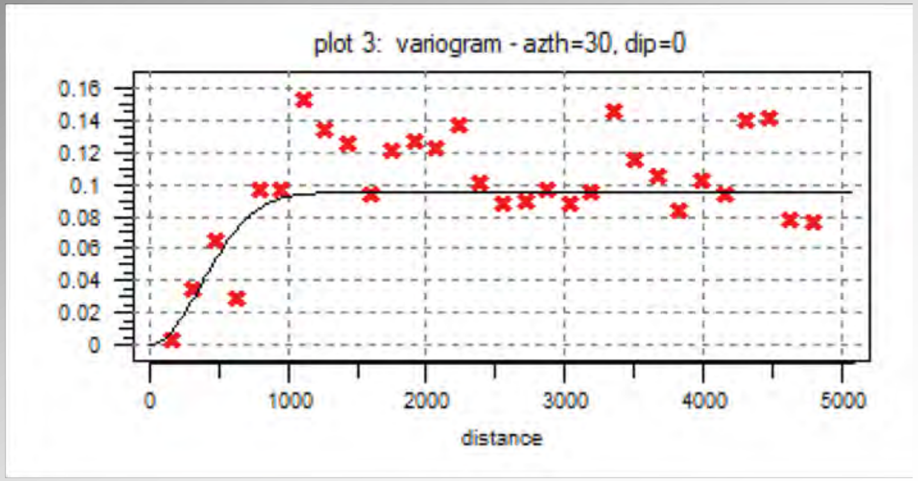


Silty-Clayey Sand

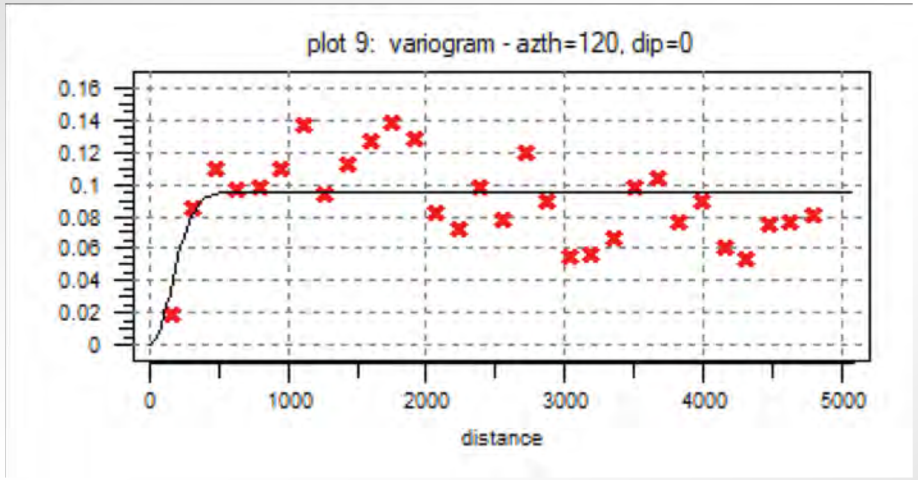
- Occupies 8.52% of the surficial aquifer (mainly below an elevation of 120 ft amsl)
- Consists of fine- to medium-grained sands with silt and < 5% clay

Silty-Clayey Sand – Correlation Lengths

A)

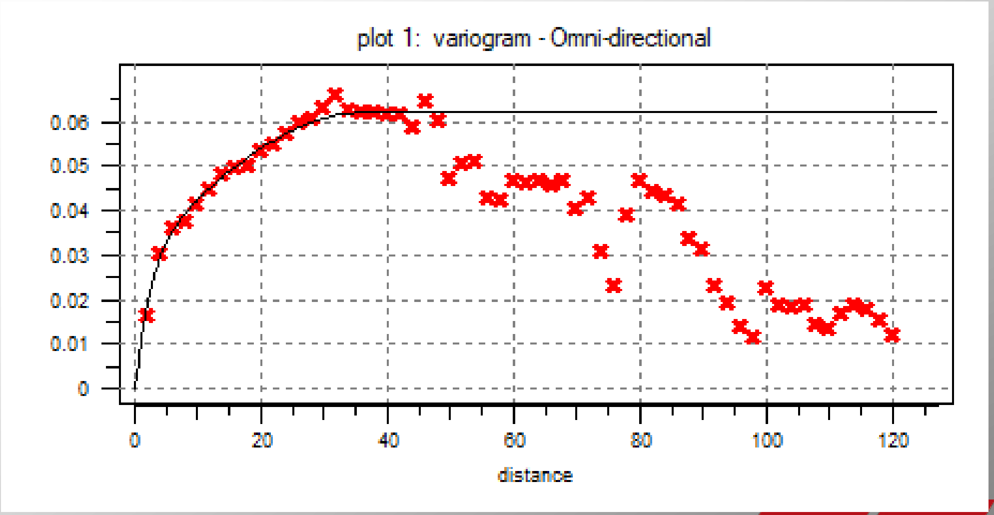


B)

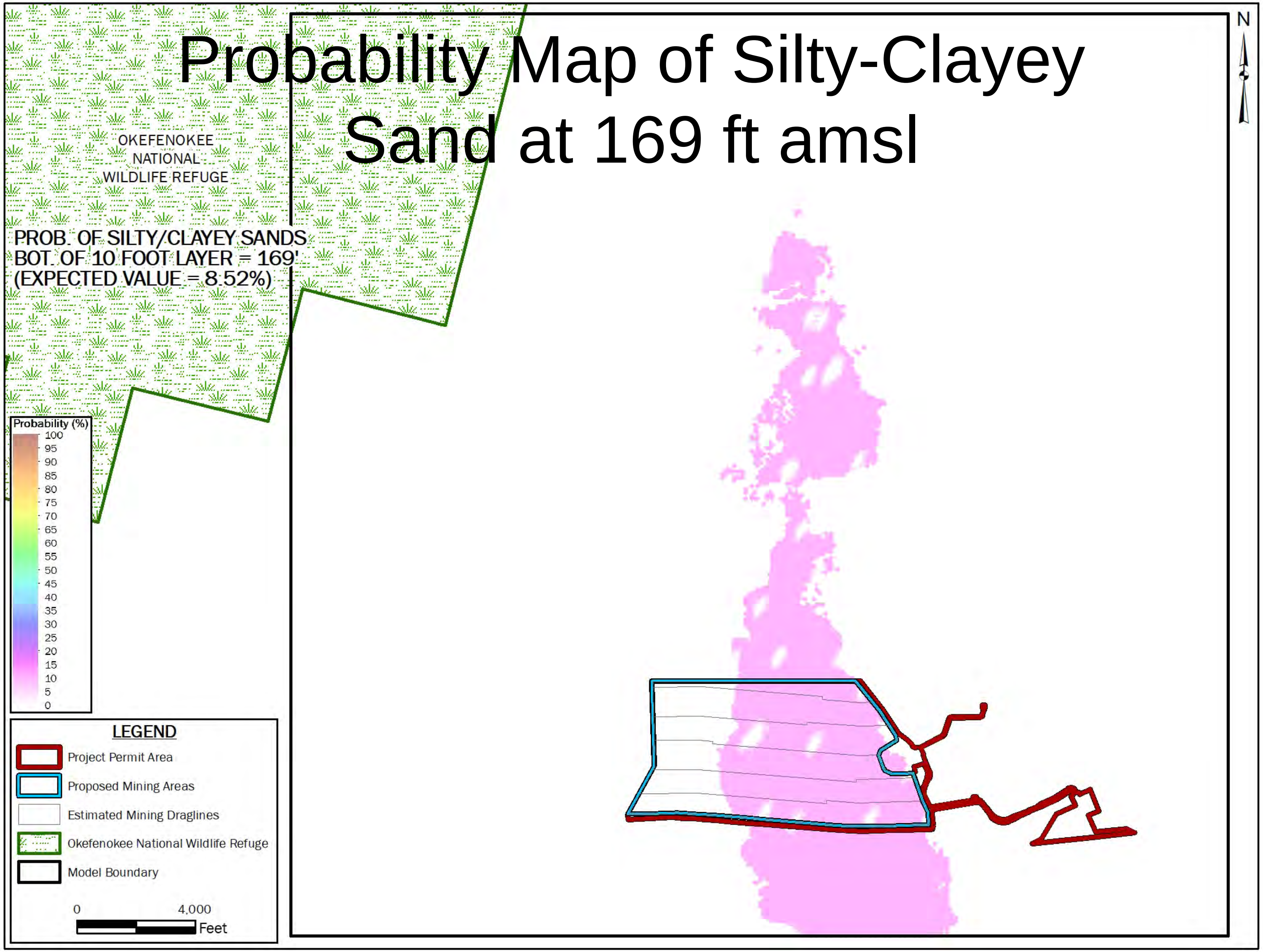


Horizontal correlation length = 912 ft max (az. = 30 degrees), 384 ft min (az. = 120 degrees)

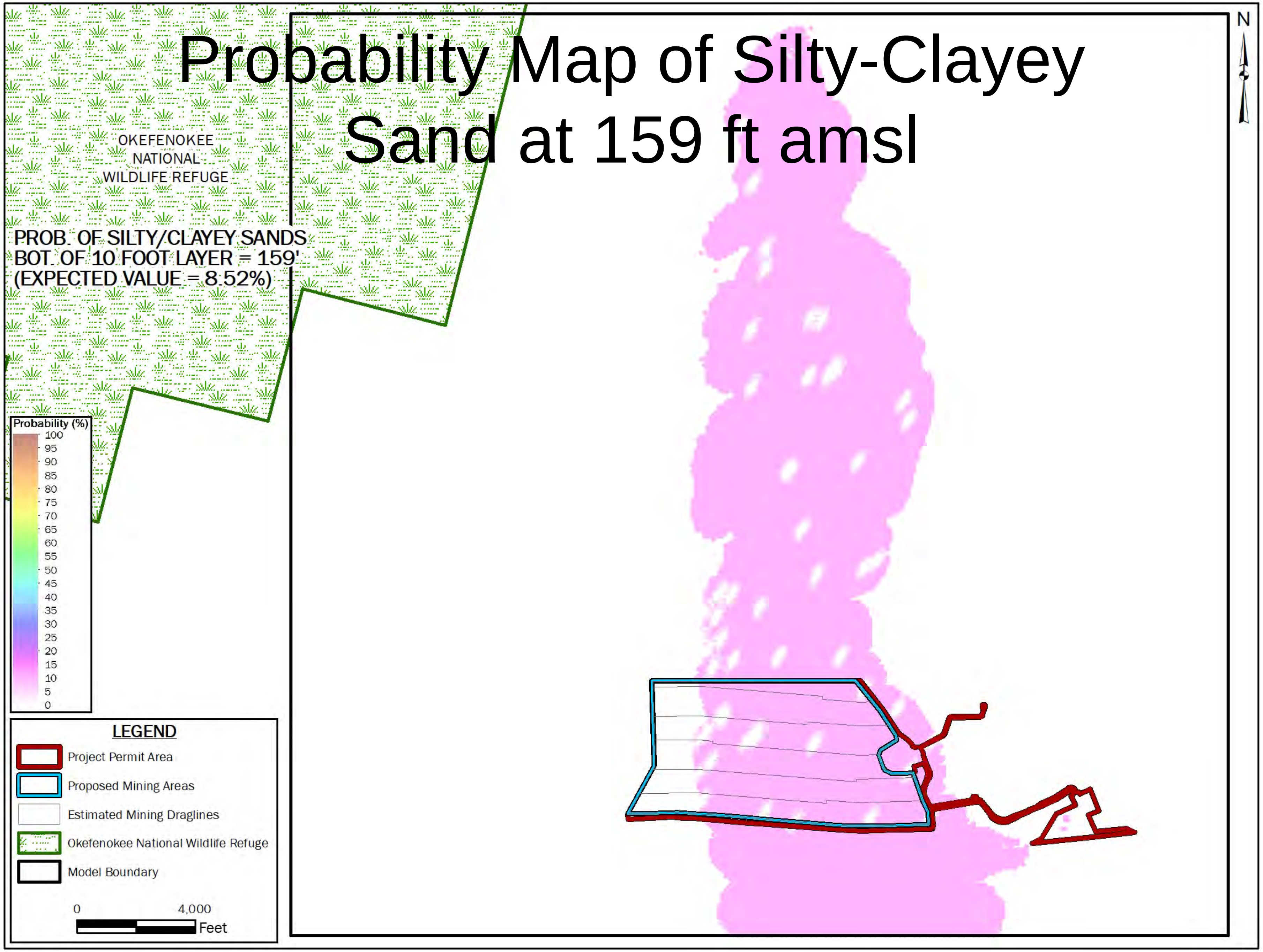
Vertical correlation length = 36.0 ft



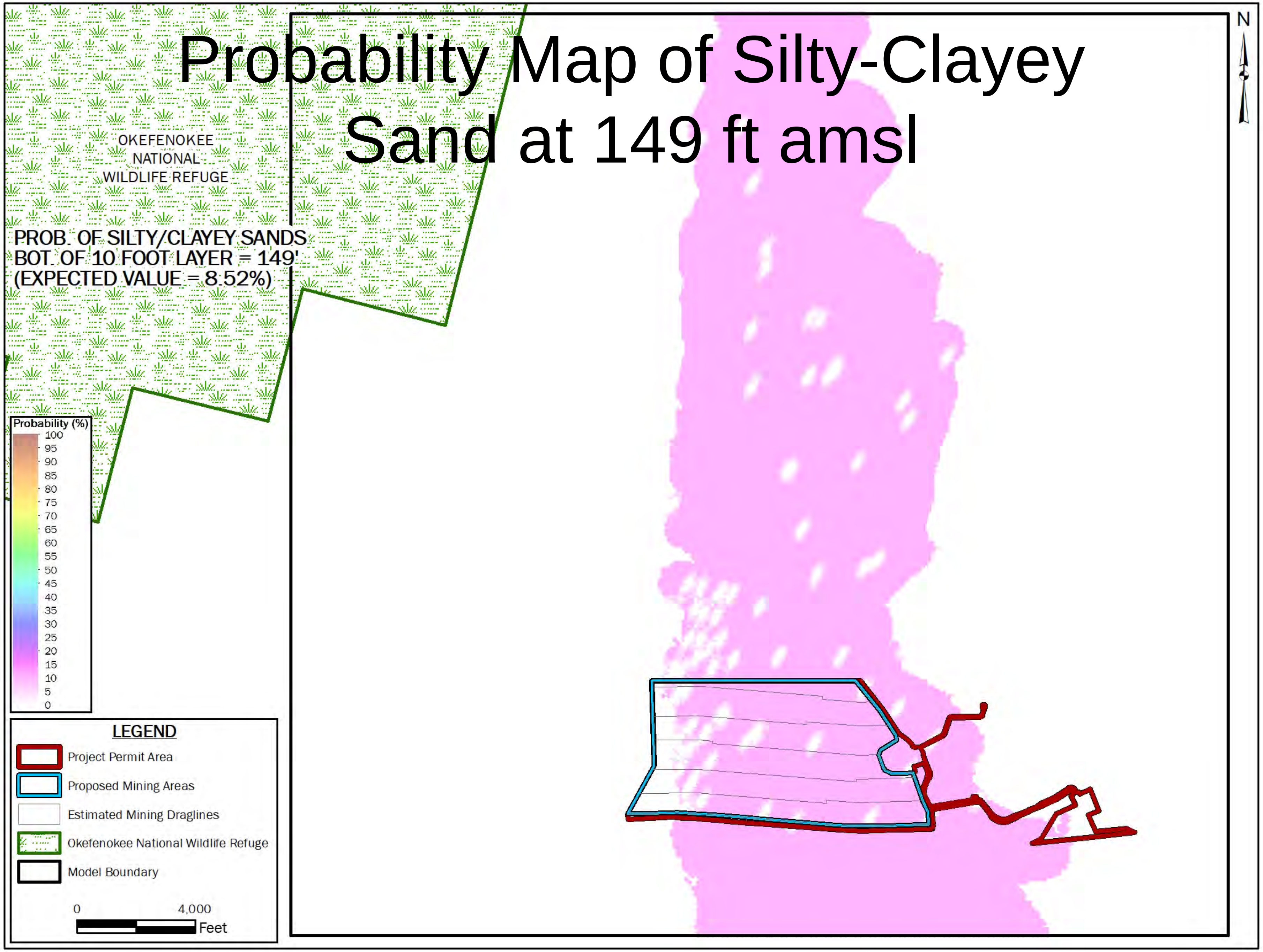
Probability Map of Silty-Clayey Sand at 169 ft amsl



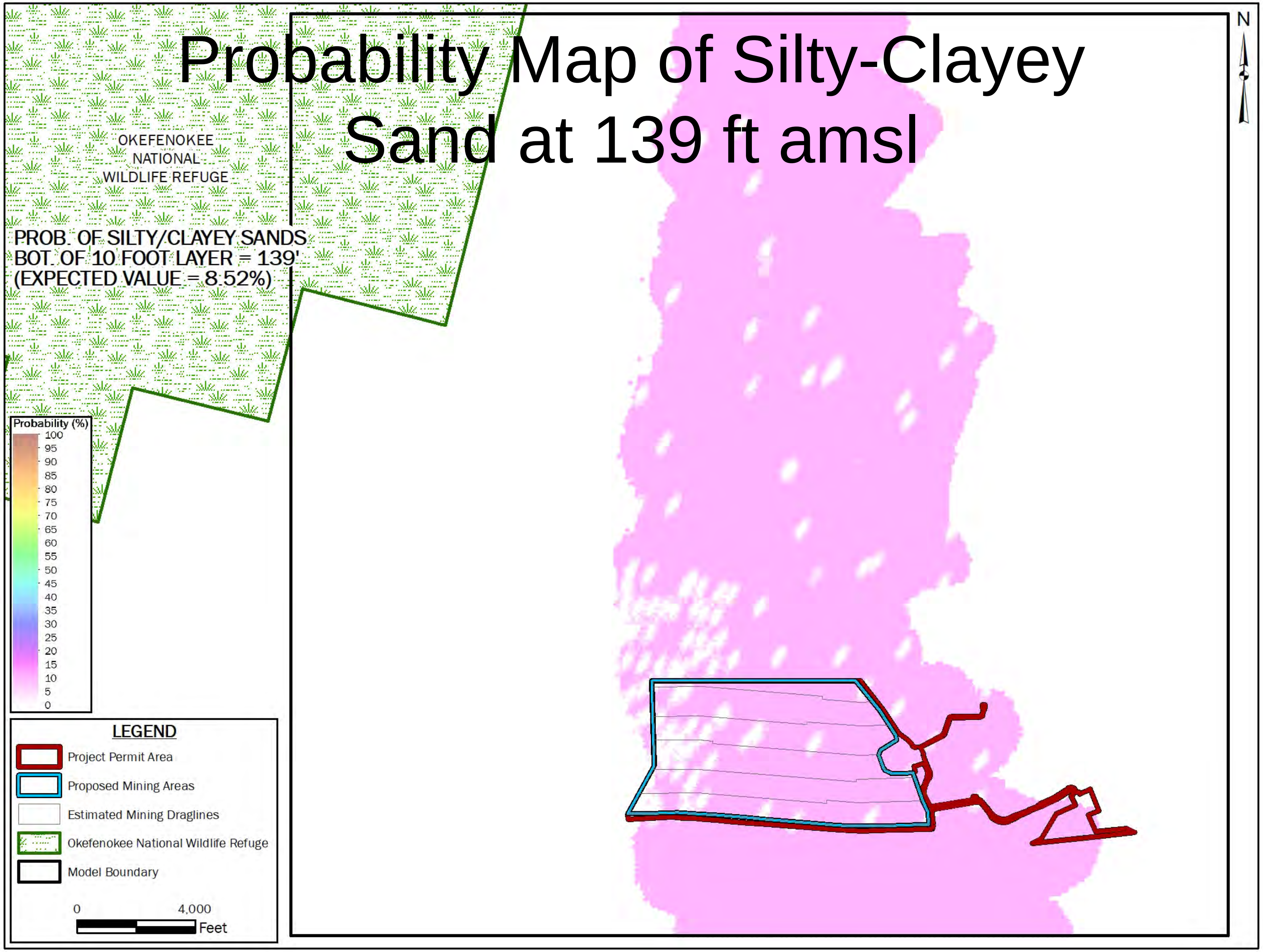
Probability Map of Silty-Clayey Sand at 159 ft amsl



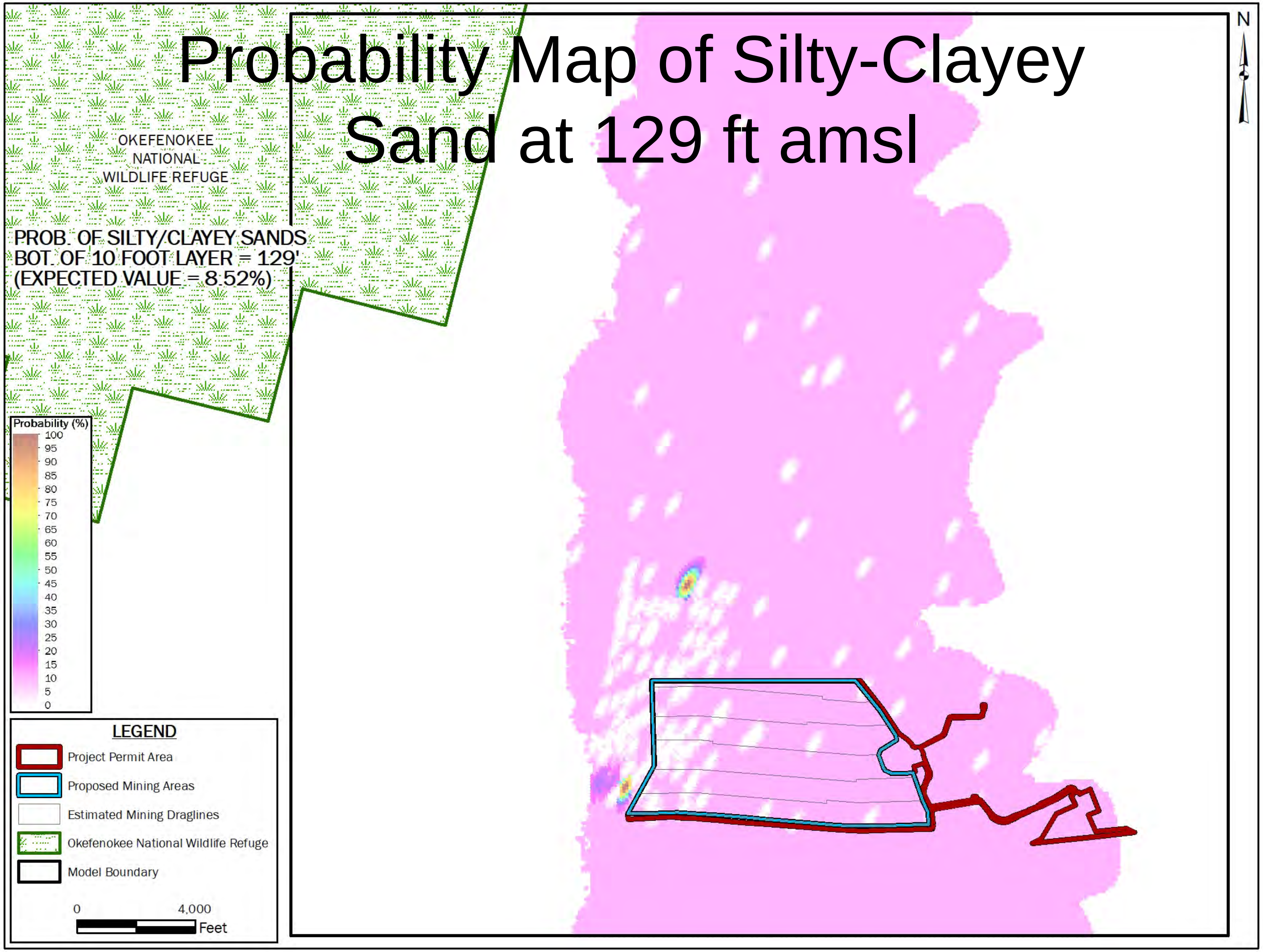
Probability Map of Silty-Clayey Sand at 149 ft amsl



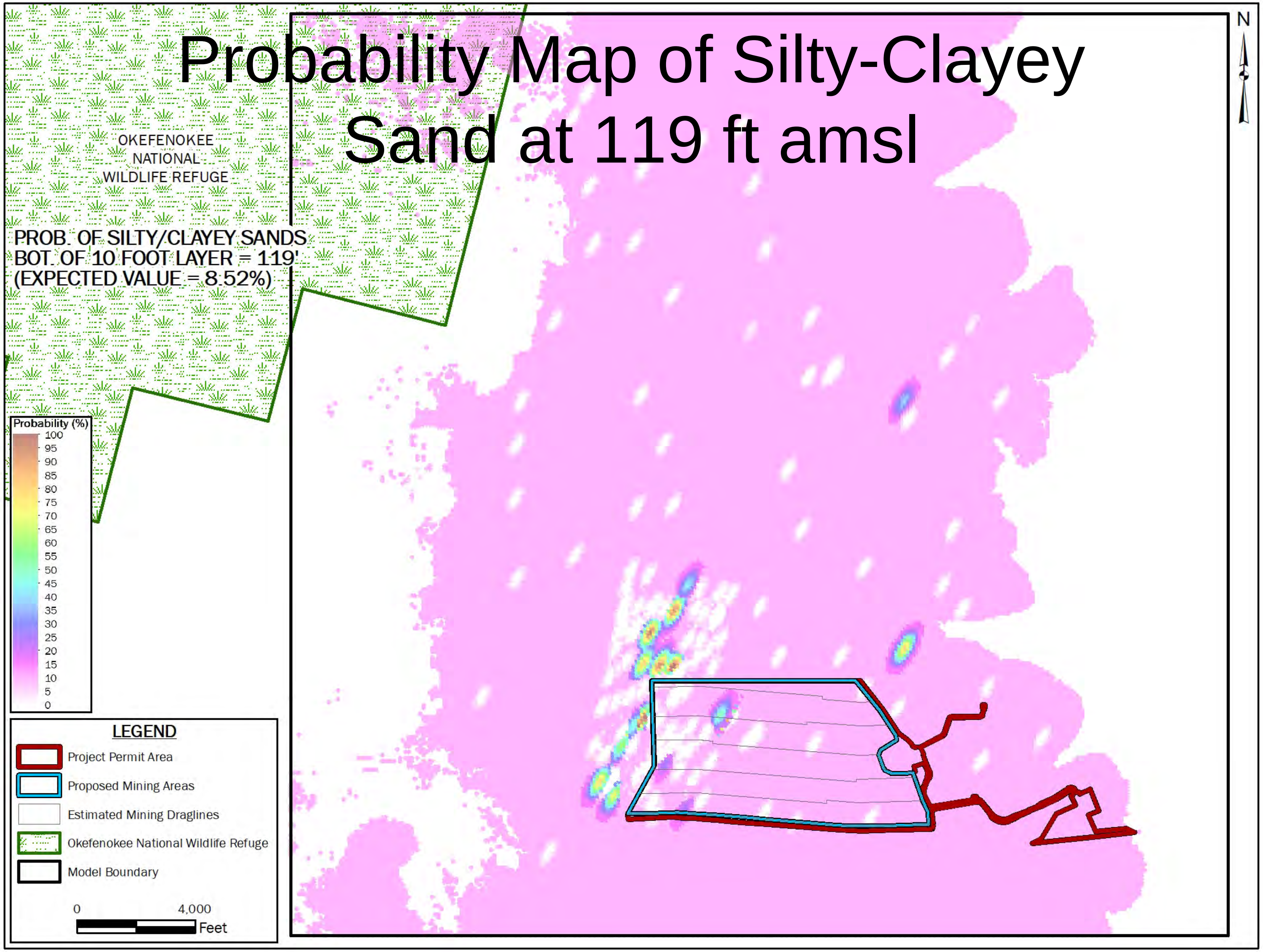
Probability Map of Silty-Clayey Sand at 139 ft amsl



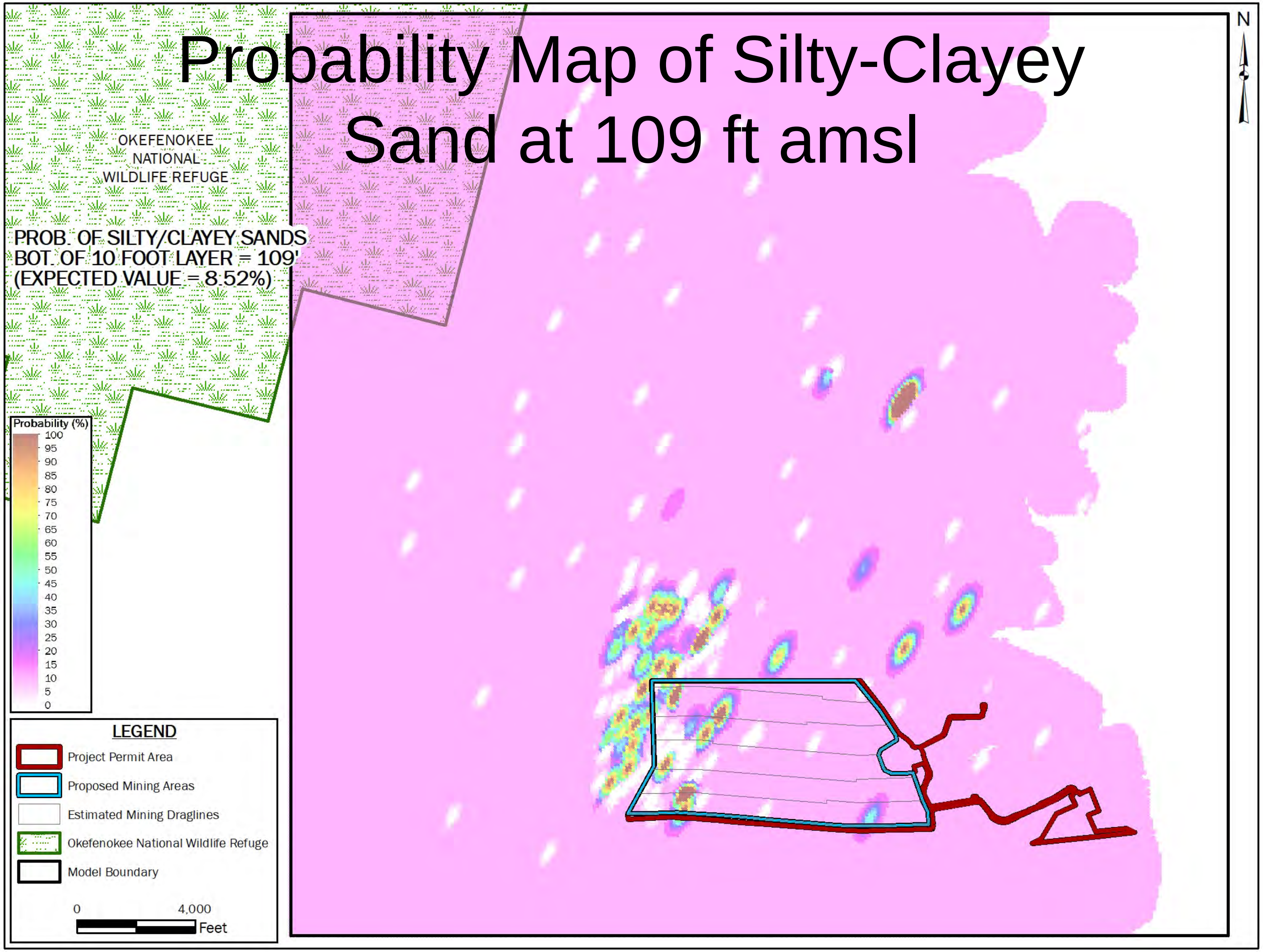
Probability Map of Silty-Clayey Sand at 129 ft amsl



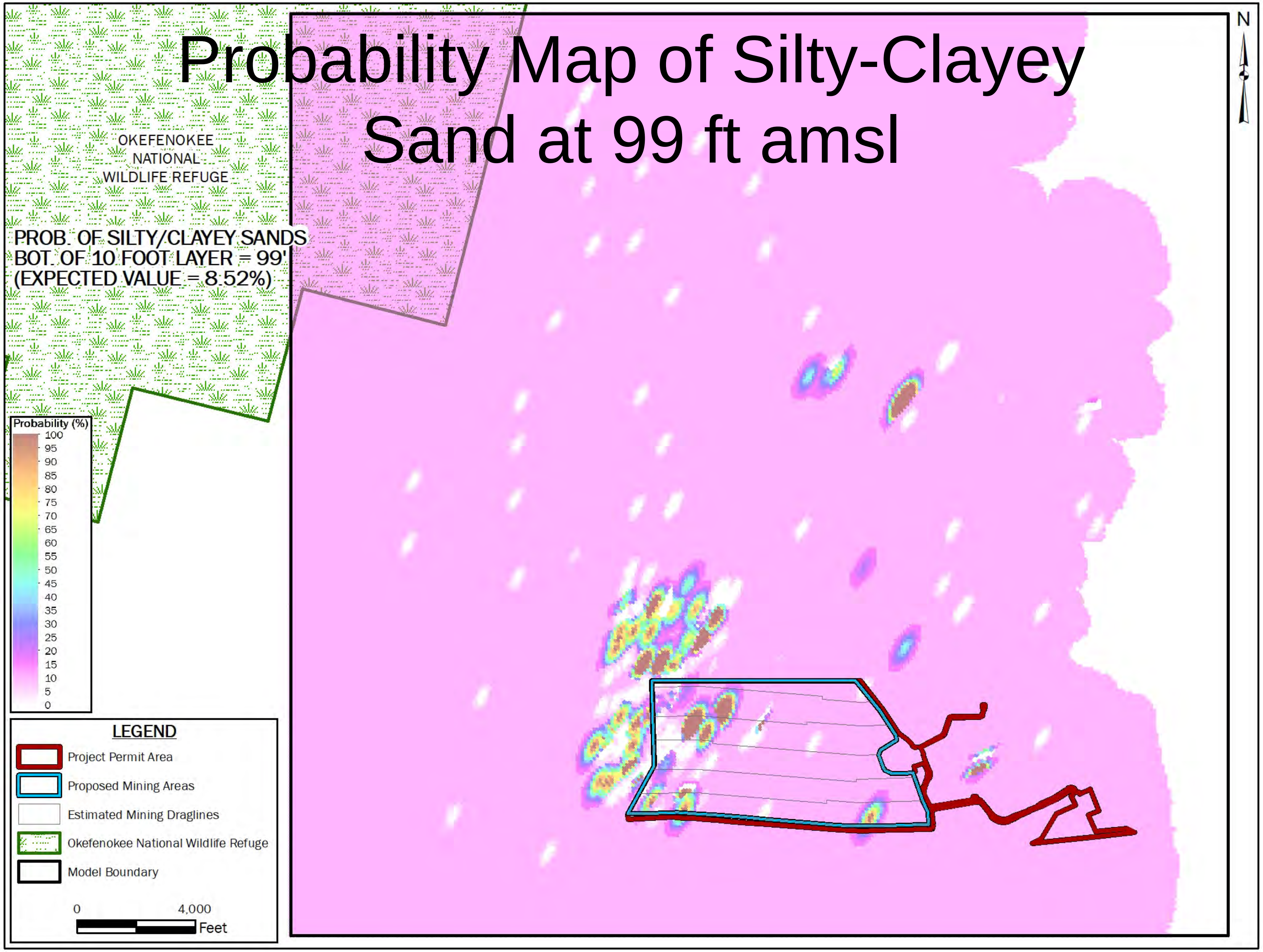
Probability Map of Silty-Clayey Sand at 119 ft amsl



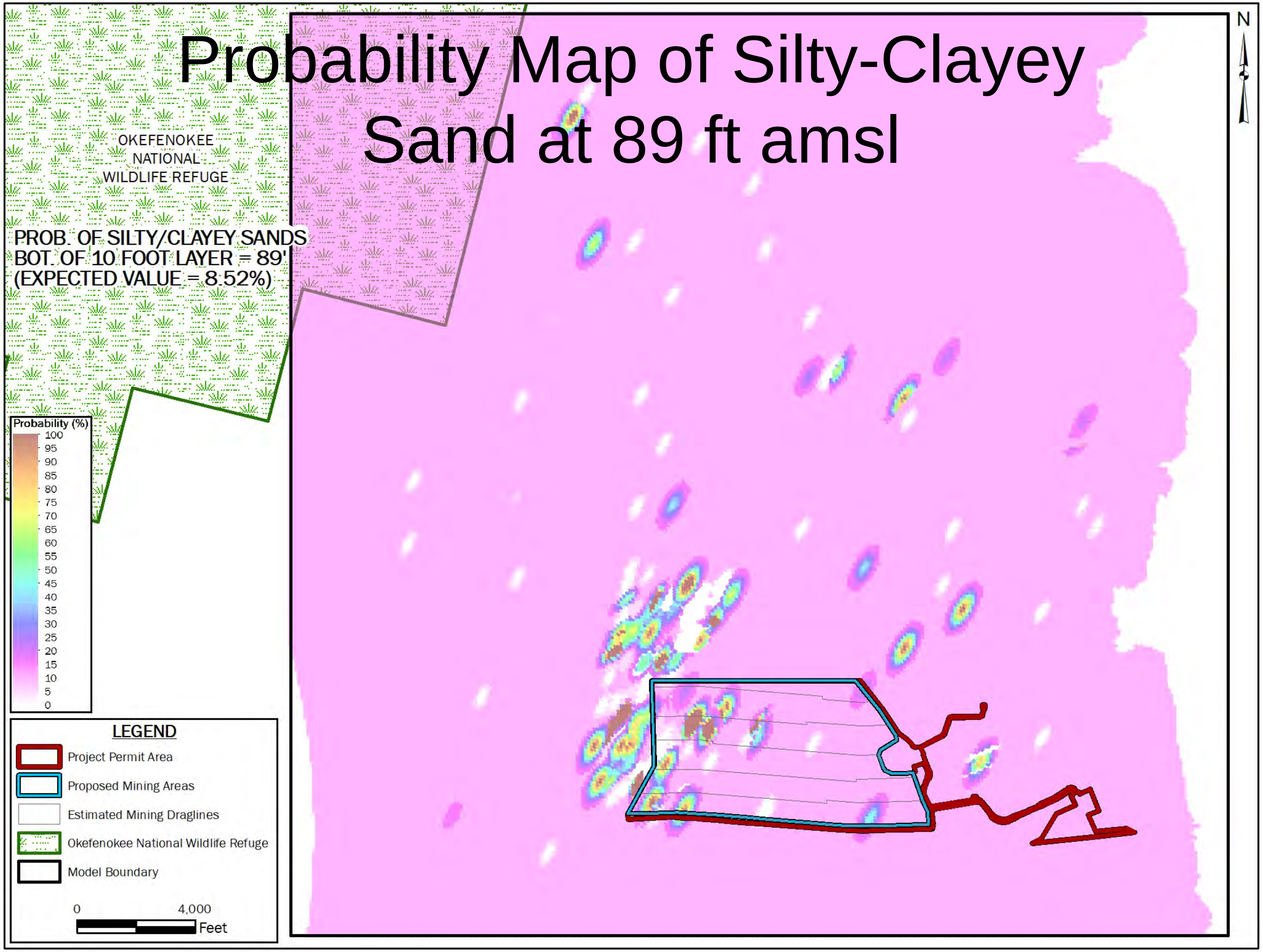
Probability Map of Silty-Clayey Sand at 109 ft amsl



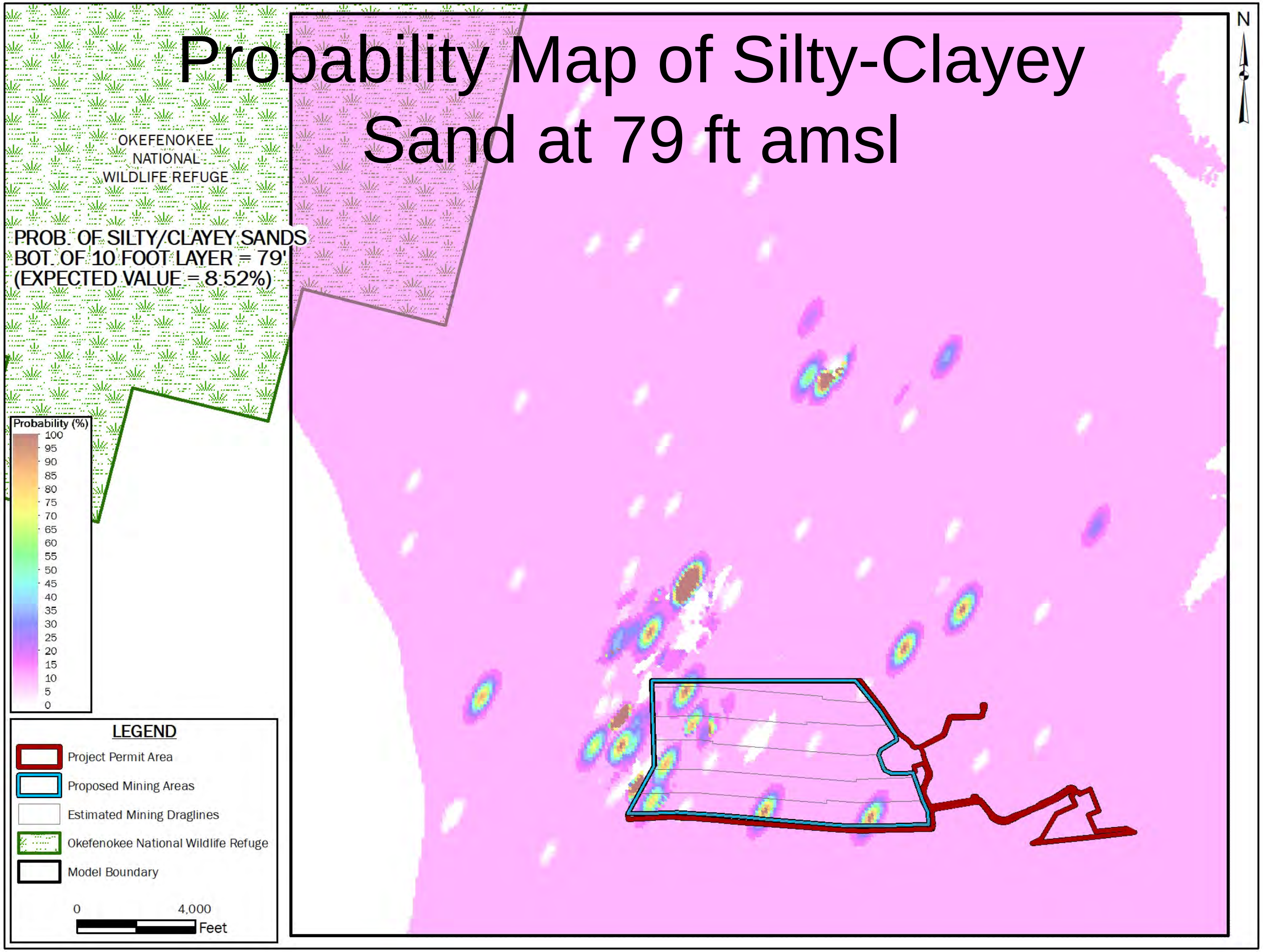
Probability Map of Silty-Clayey Sand at 99 ft amsl



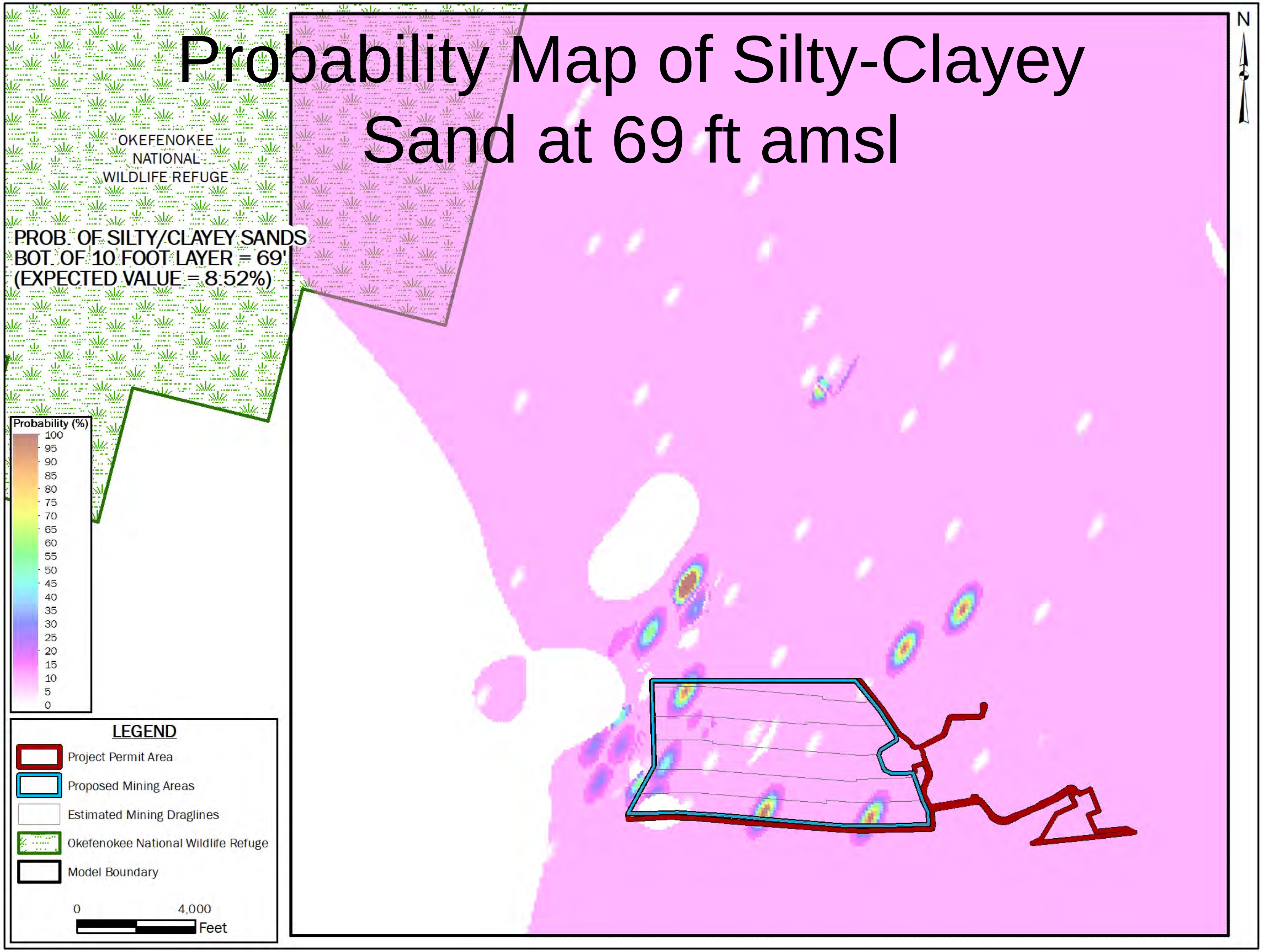
Probability Map of Silty-Clayey Sand at 89 ft amsl



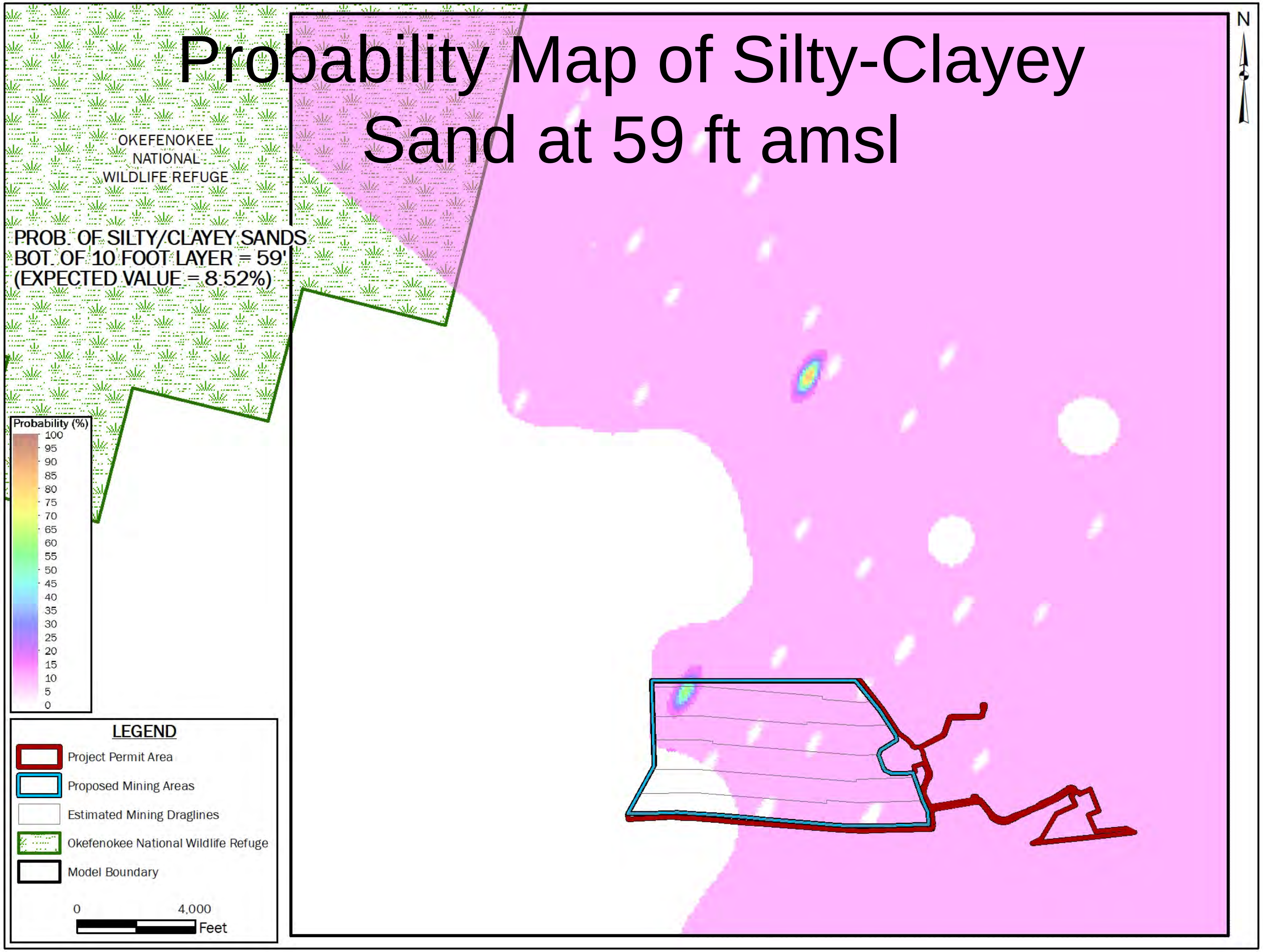
Probability Map of Silty-Clayey Sand at 79 ft amsl



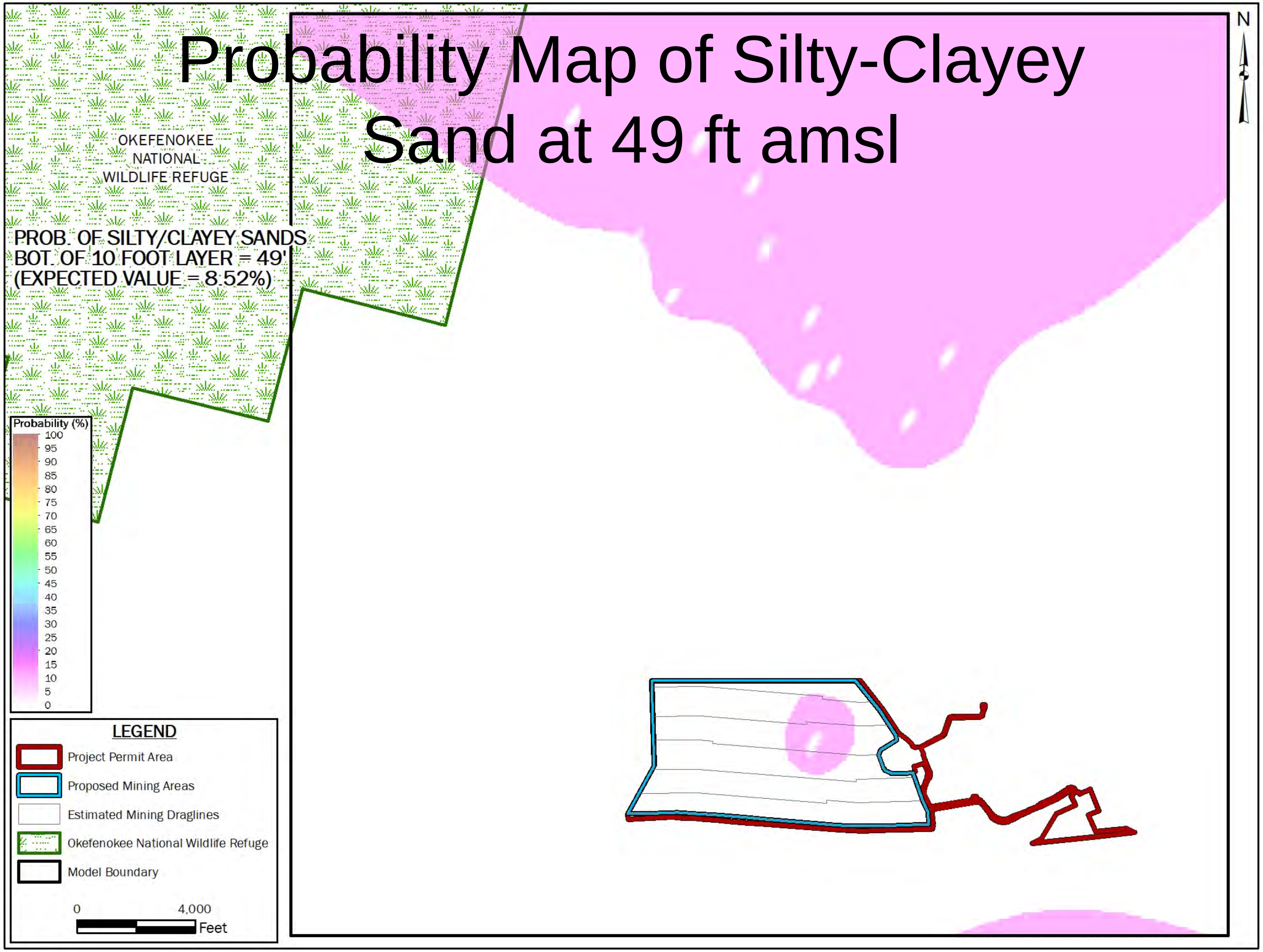
Probability Map of Silty-Clayey Sand at 69 ft amsl



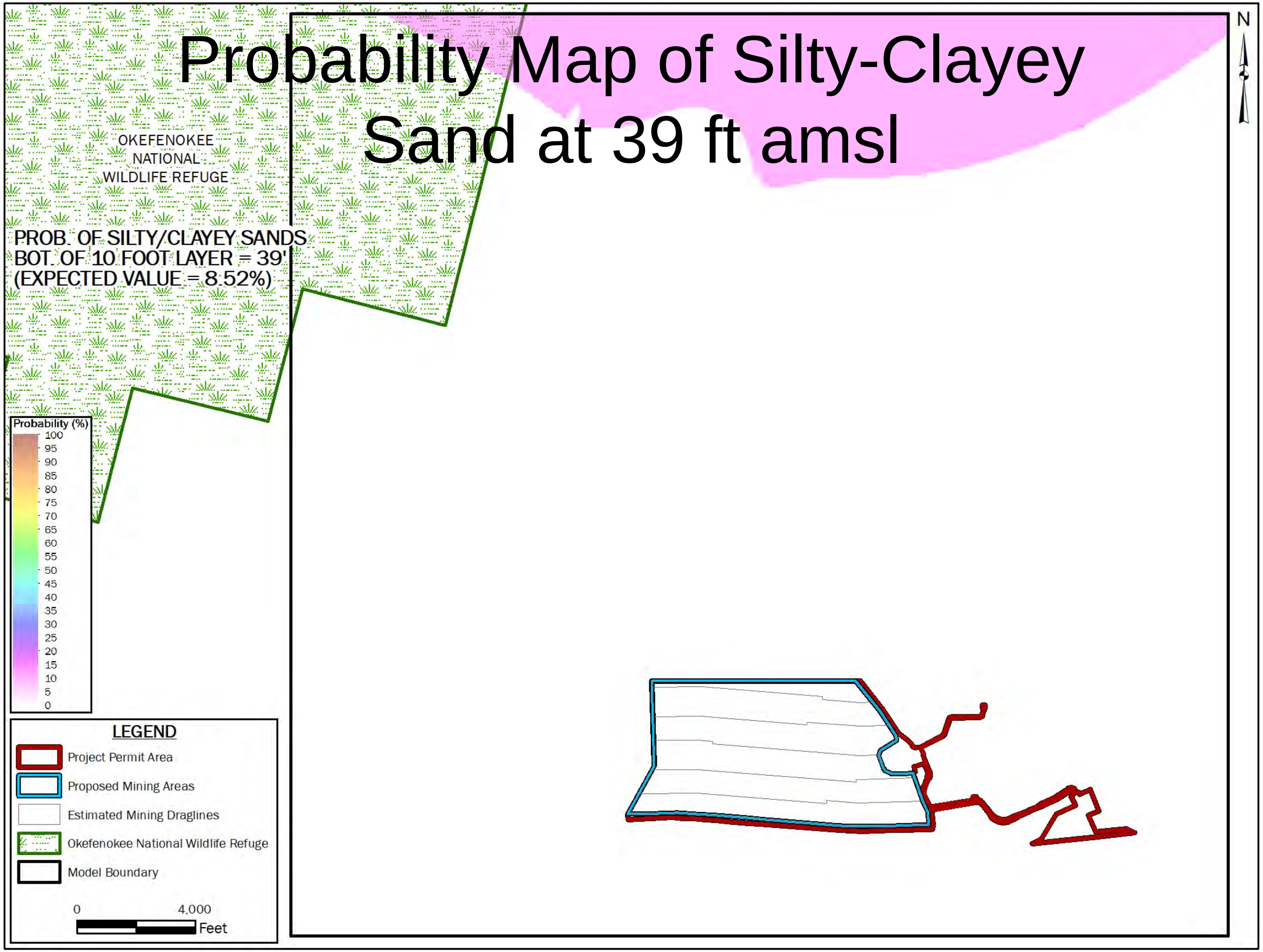
Probability Map of Silty-Clayey Sand at 59 ft amsl



Probability Map of Silty-Clayey Sand at 49 ft amsl



Probability Map of Silty-Clayey Sand at 39 ft amsl

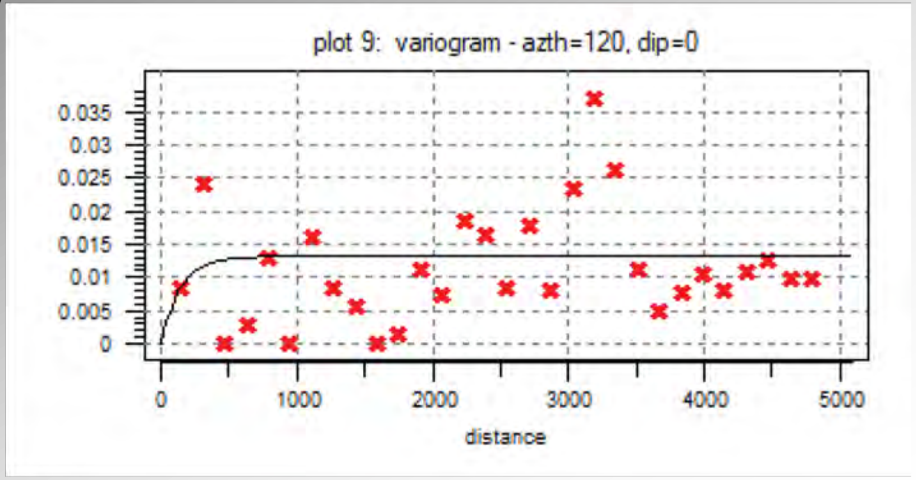


Unconsolidated Black Sand

- Least abundant unit. Occupies 1.34% of the surficial aquifer (mainly above 120 ft amsl)
- Consists of silty sands (SM) and well sorted sands (SP) stained with secondary humate

Unconsolidated Black Sand – Correlation Lengths

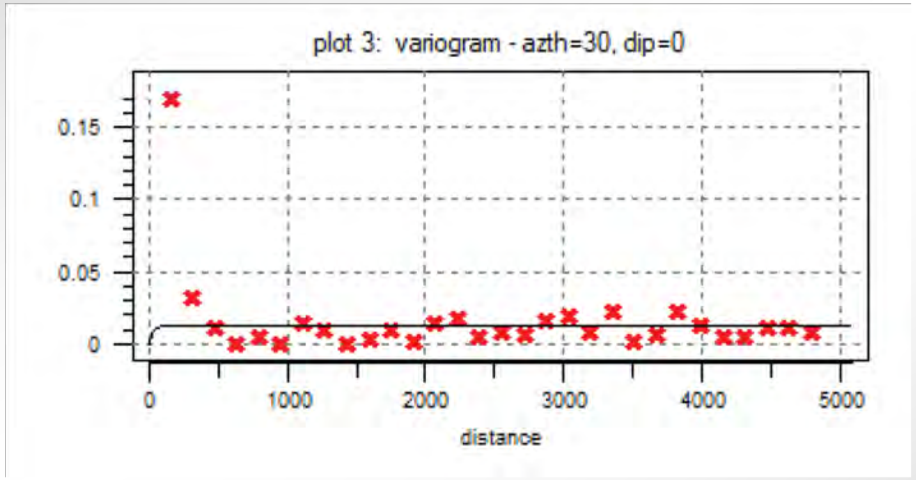
A)

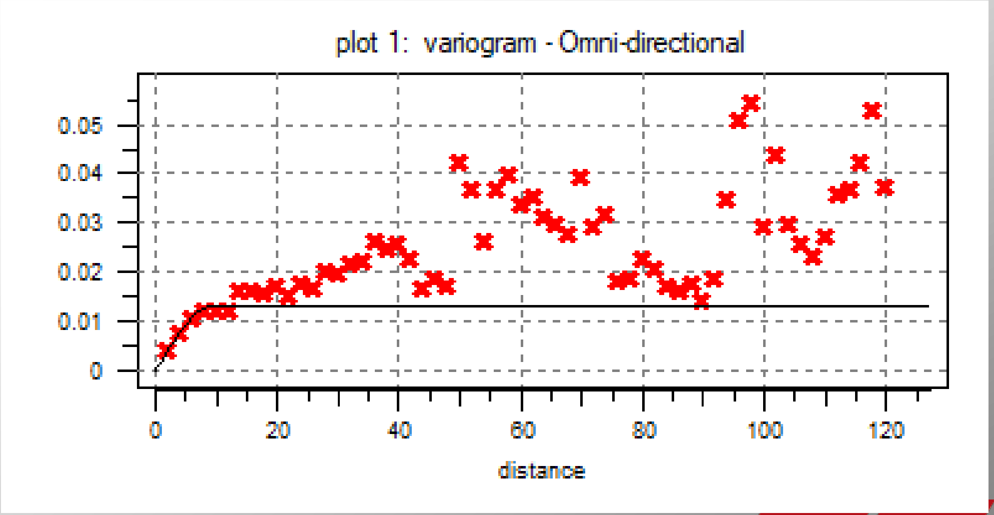


Horizontal correlation length = 432 ft max (az. = 120 degrees), 96 ft min (az. = 30 degrees)

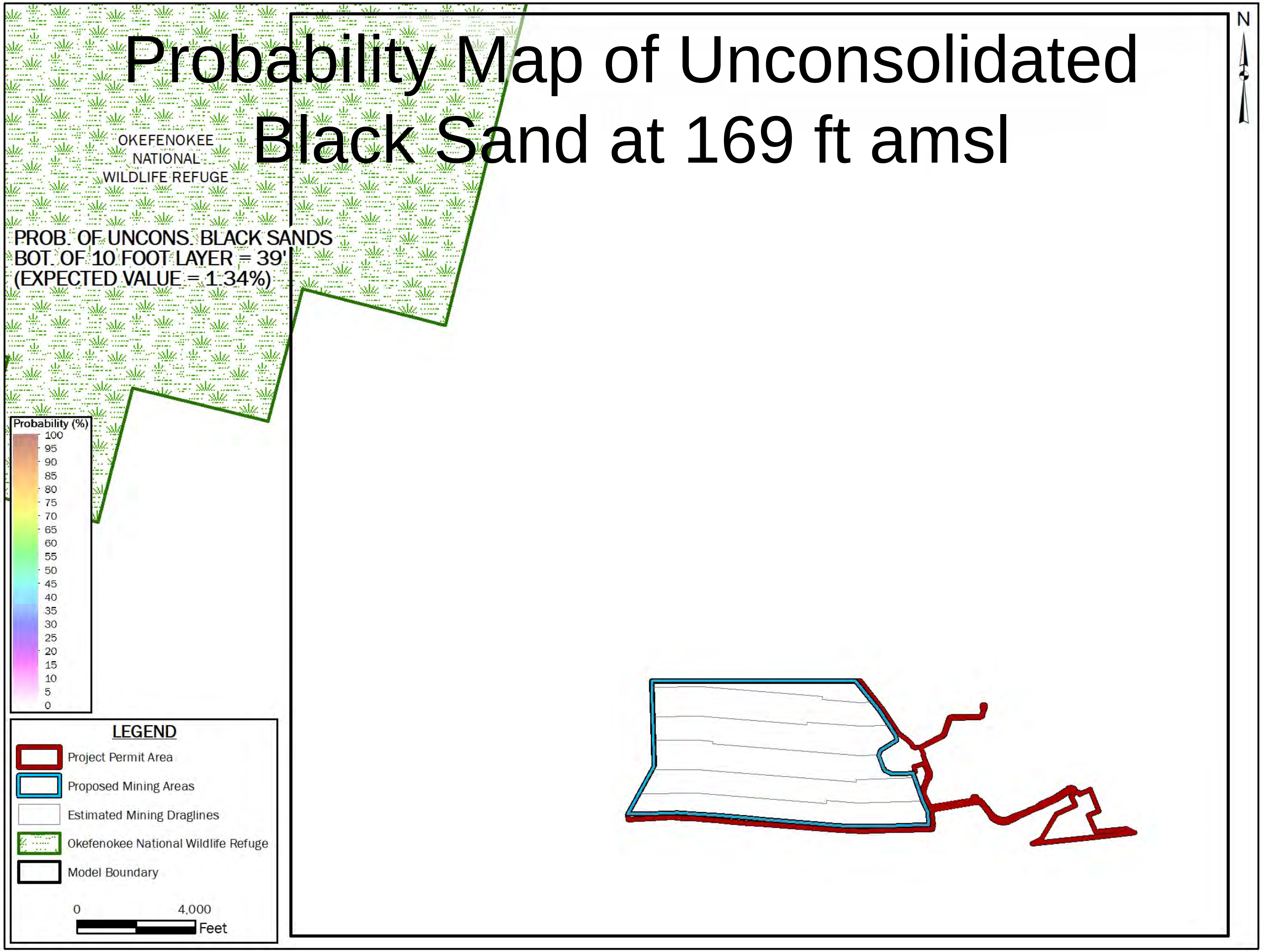
Vertical correlation length = 9.6 ft

B)

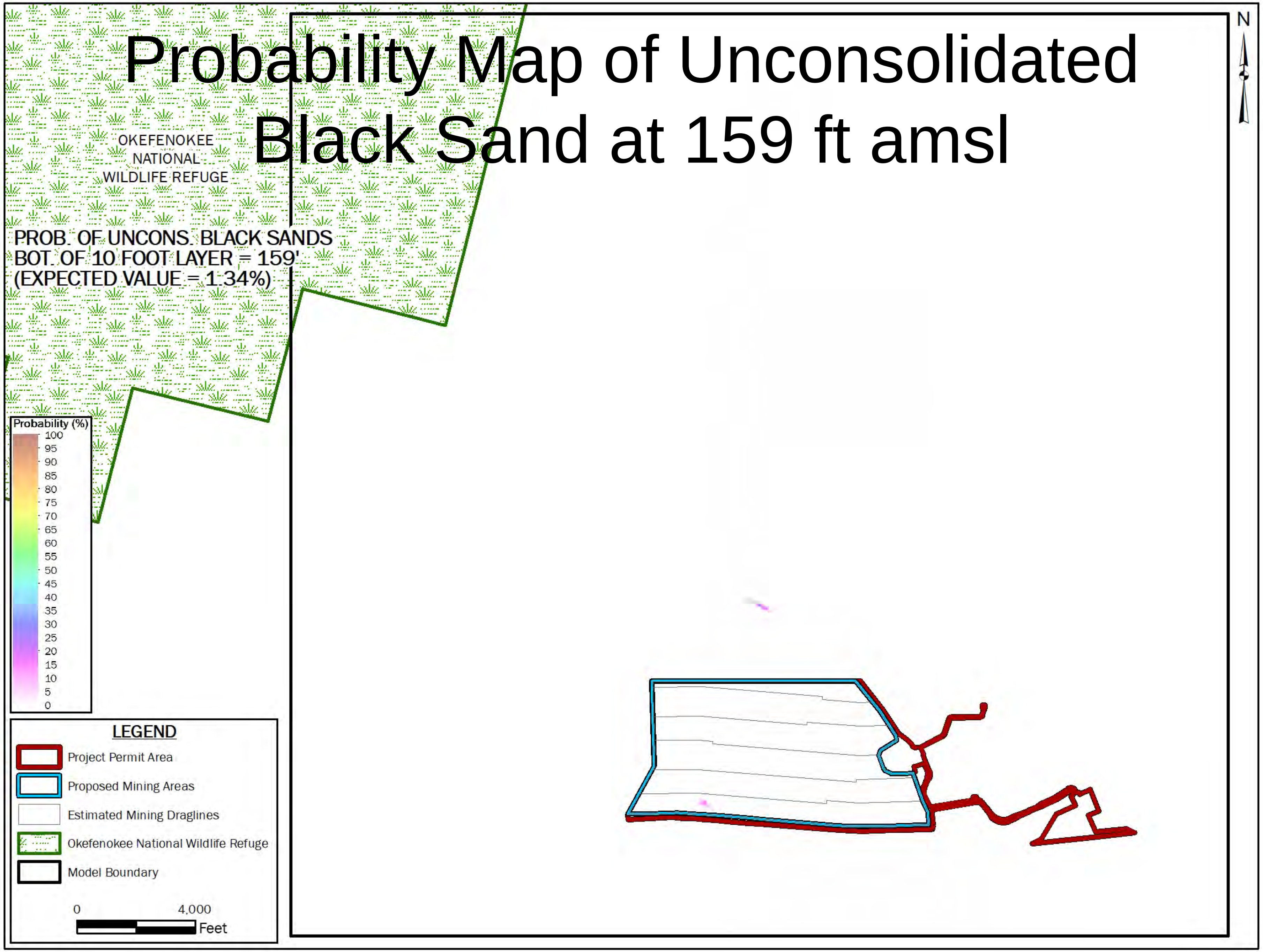




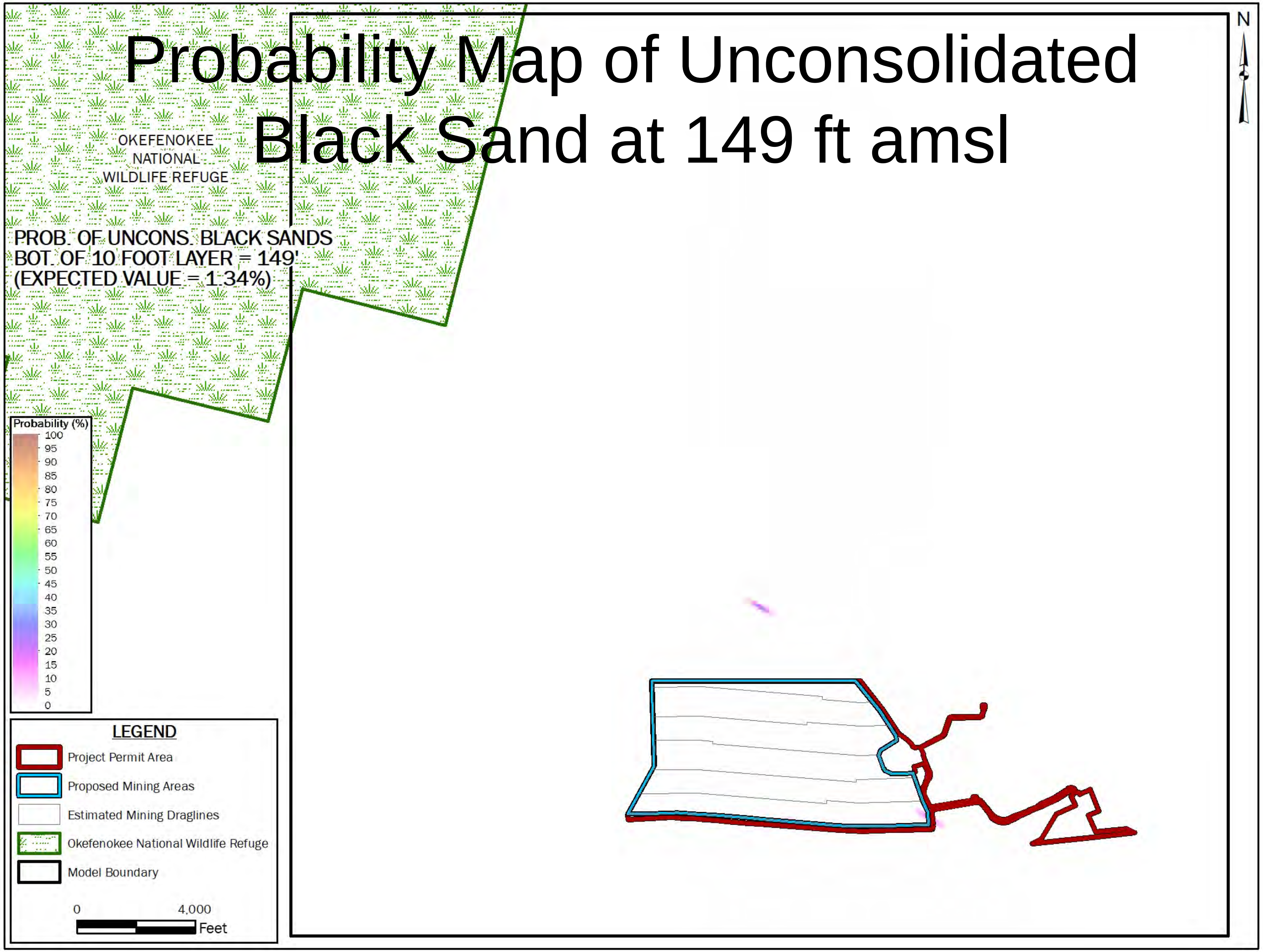
Probability Map of Unconsolidated Black Sand at 169 ft amsl



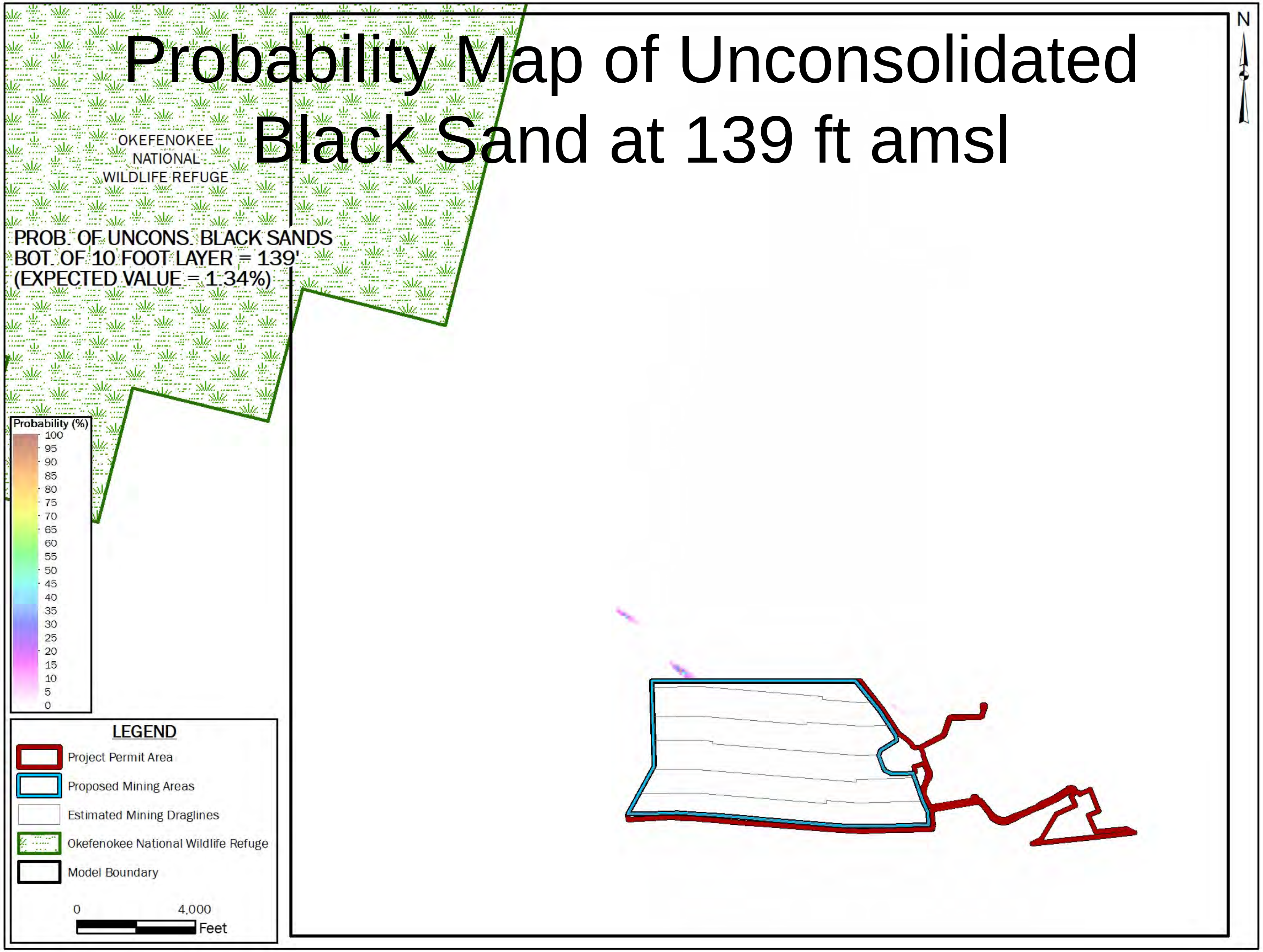
Probability Map of Unconsolidated Black Sand at 159 ft amsl



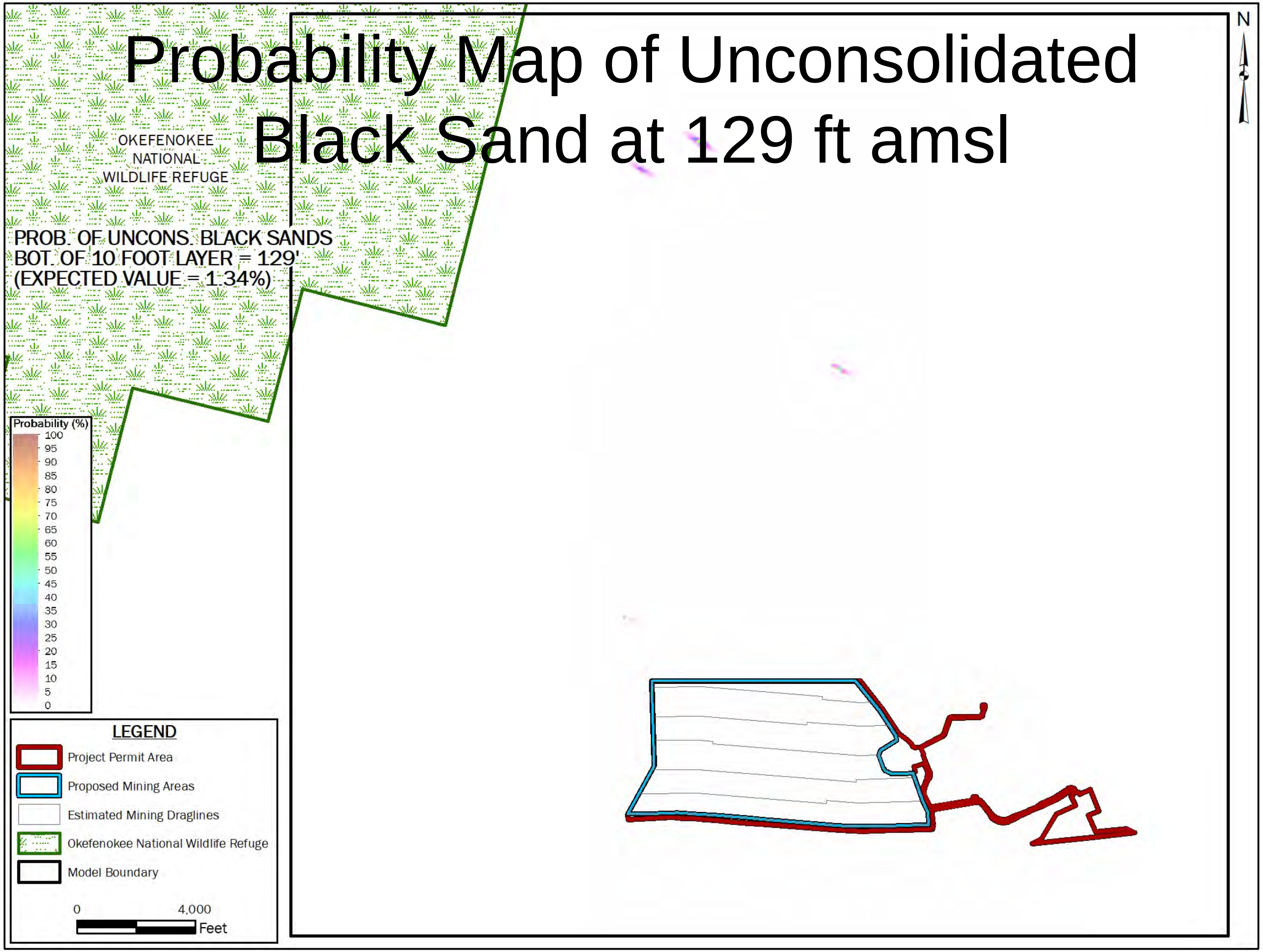
Probability Map of Unconsolidated Black Sand at 149 ft amsl



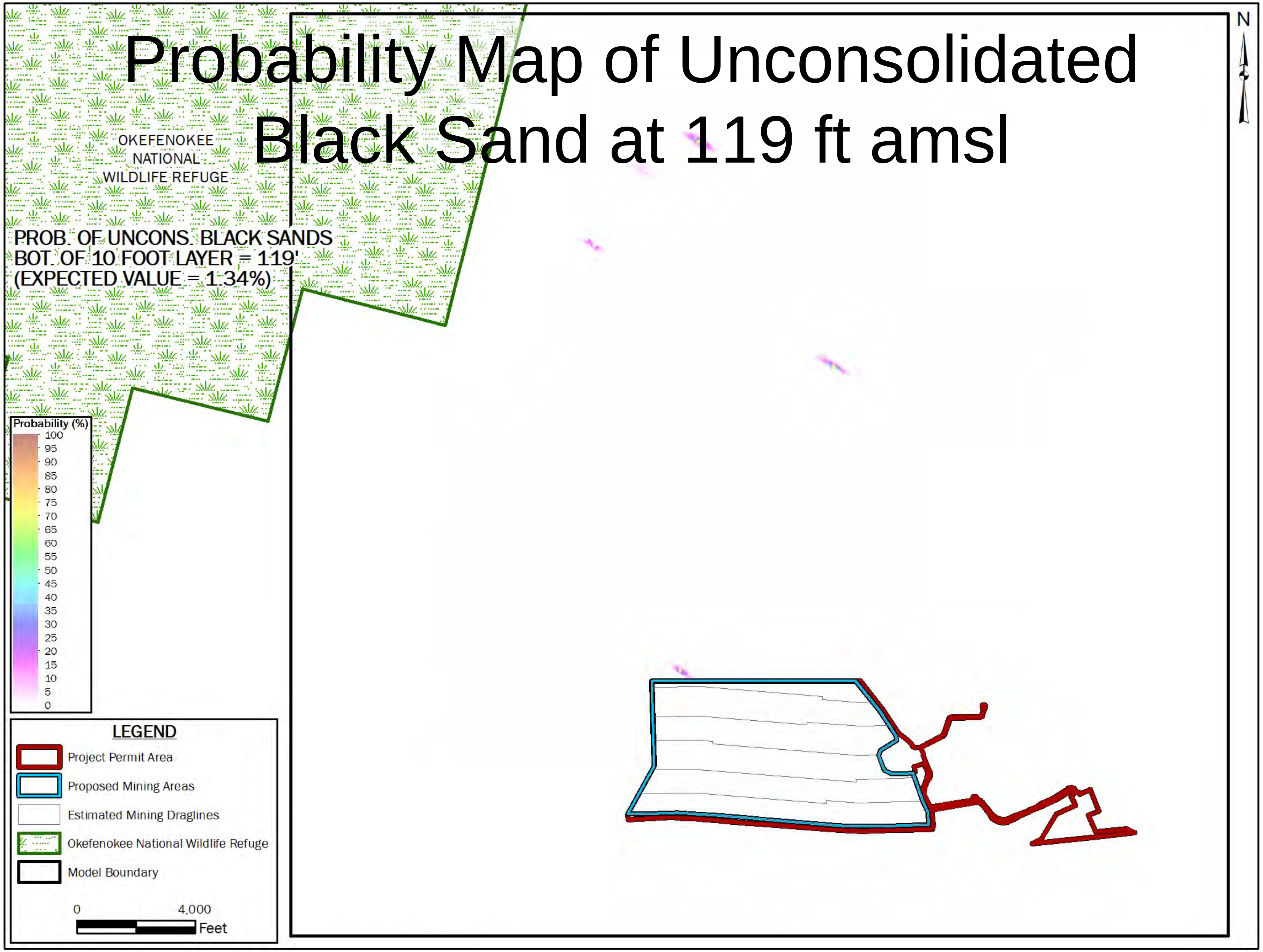
Probability Map of Unconsolidated Black Sand at 139 ft amsl



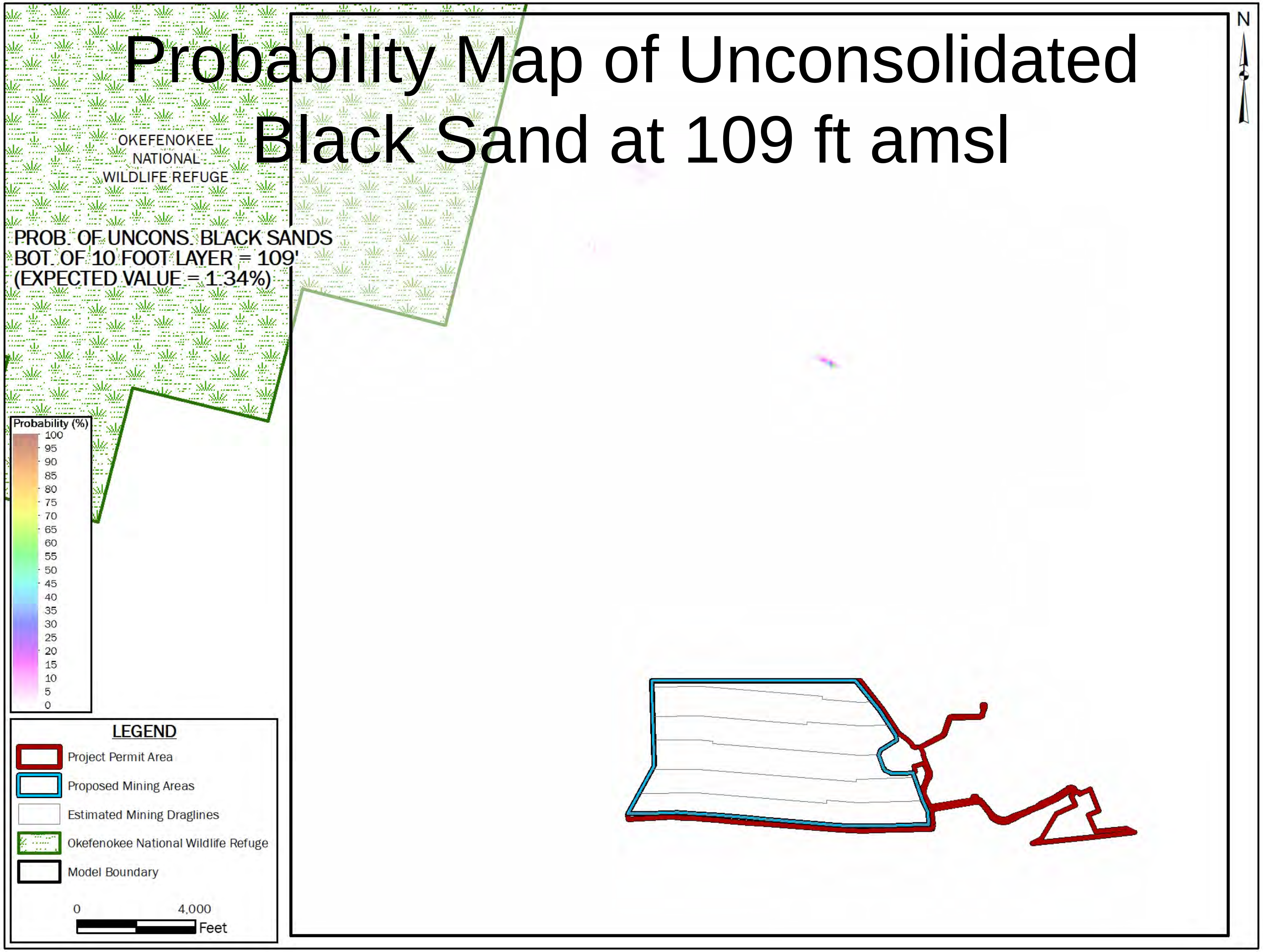
Probability Map of Unconsolidated Black Sand at 129 ft amsl



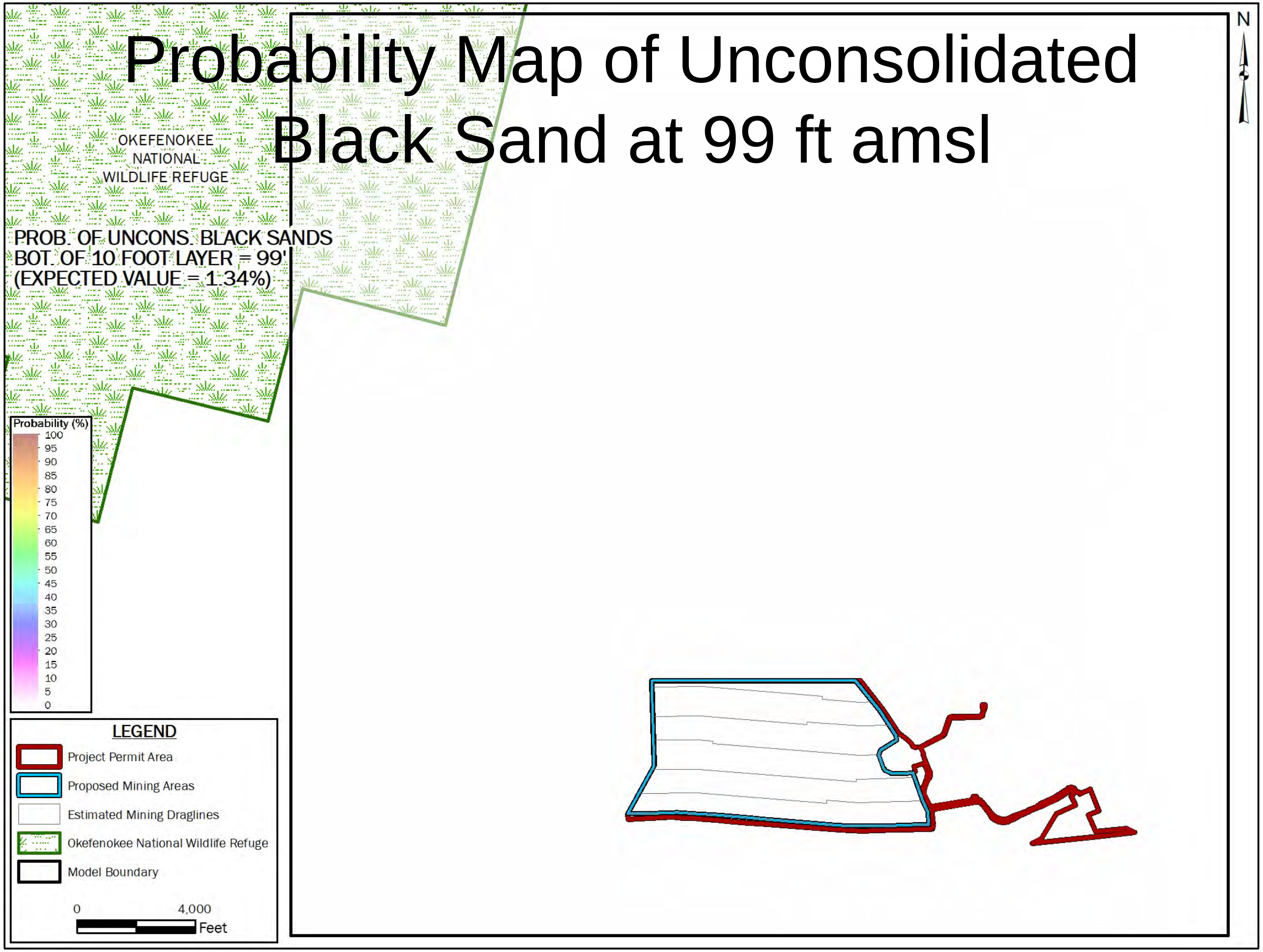
Probability Map of Unconsolidated Black Sand at 119 ft amsl



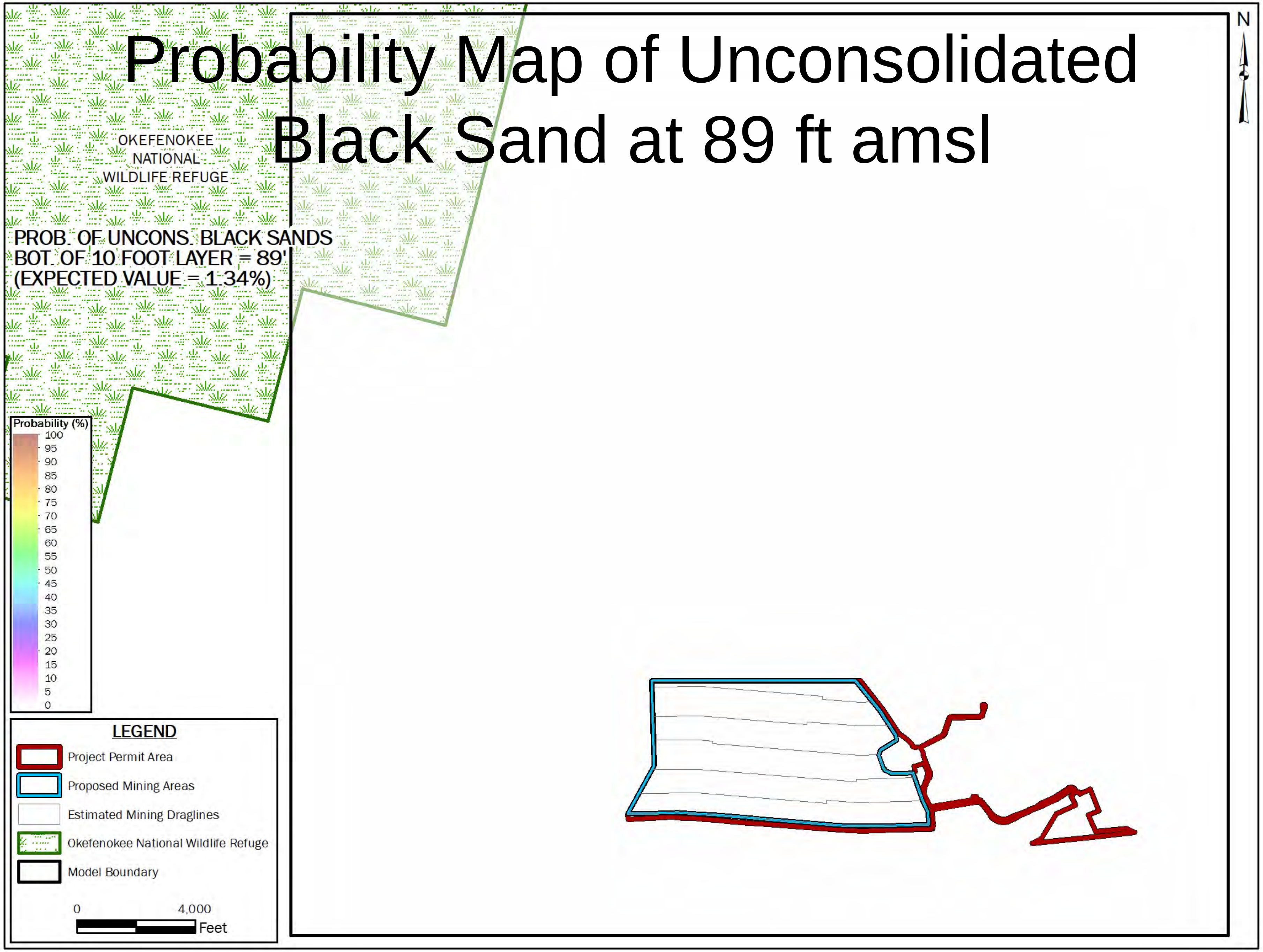
Probability Map of Unconsolidated Black Sand at 109 ft amsl



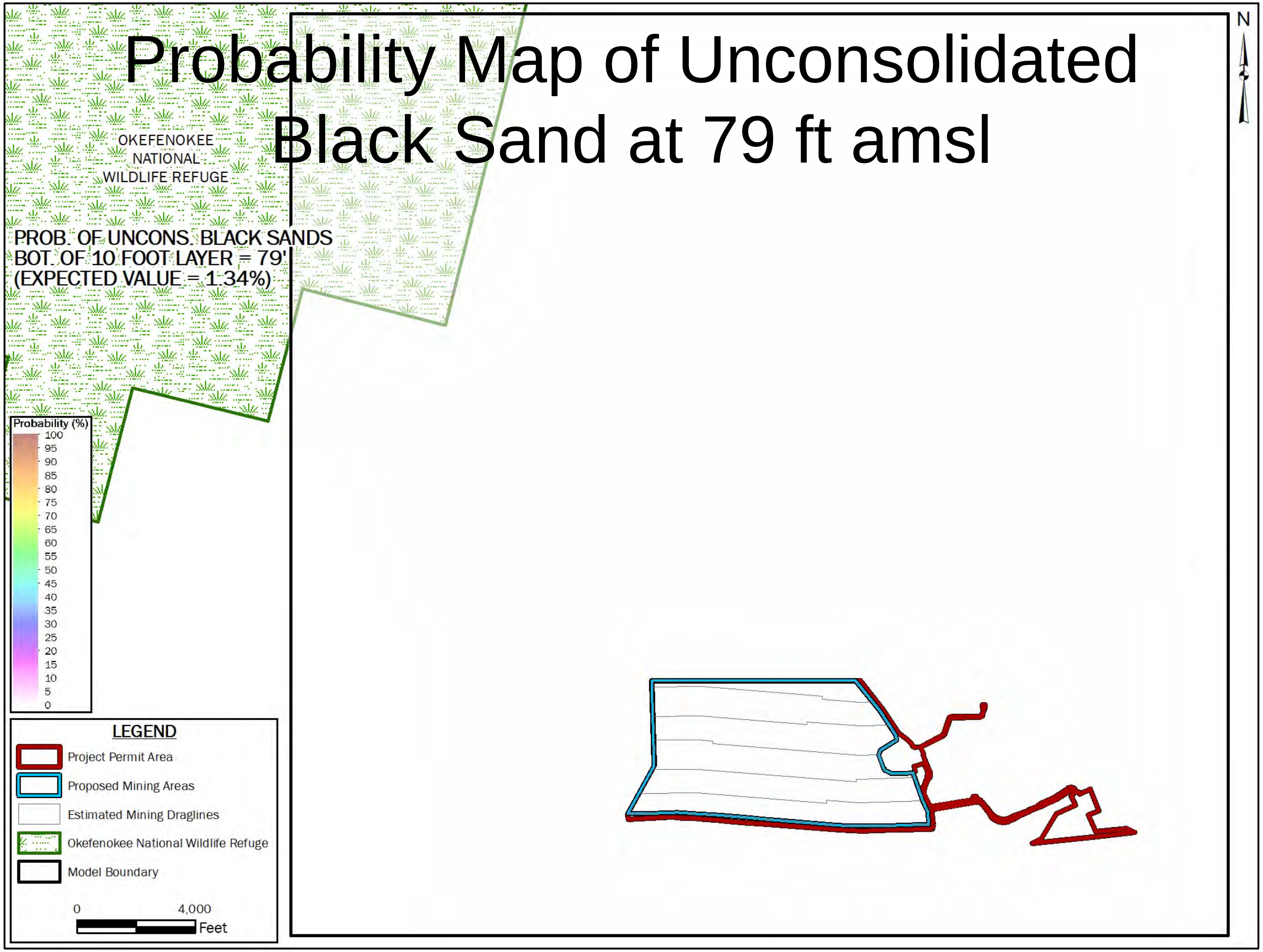
Probability Map of Unconsolidated Black Sand at 99 ft amsl



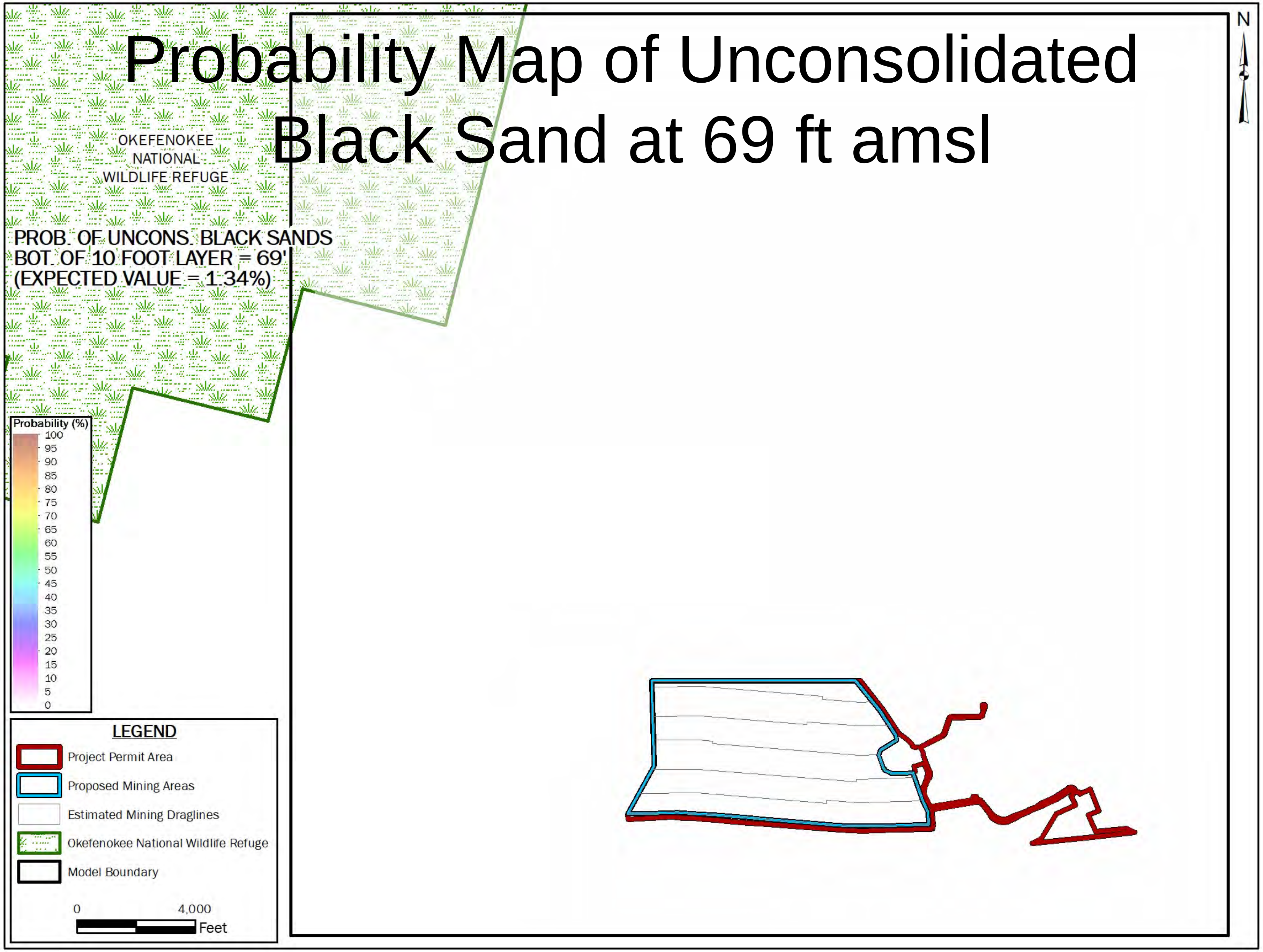
Probability Map of Unconsolidated Black Sand at 89 ft amsl



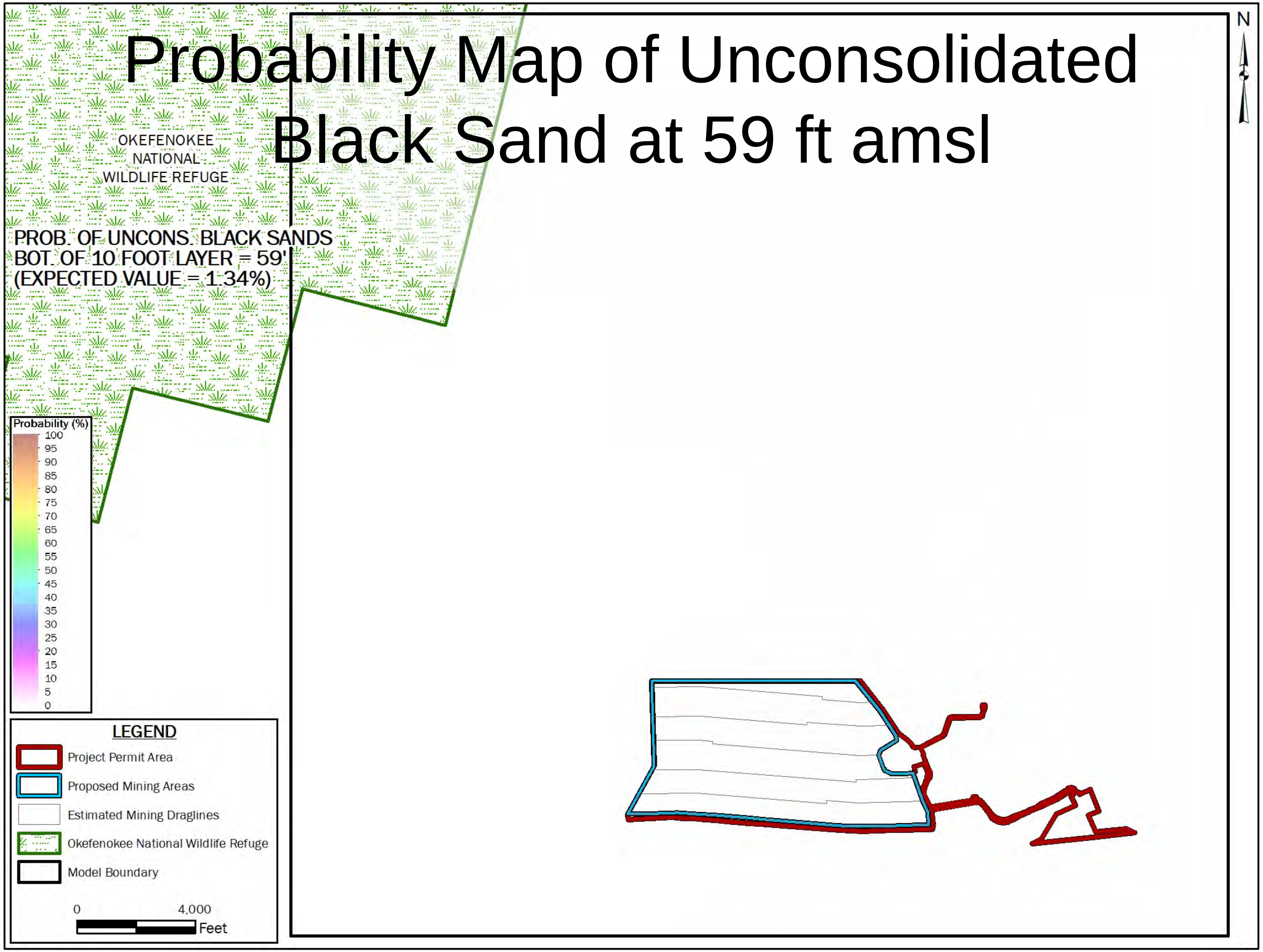
Probability Map of Unconsolidated Black Sand at 79 ft amsl



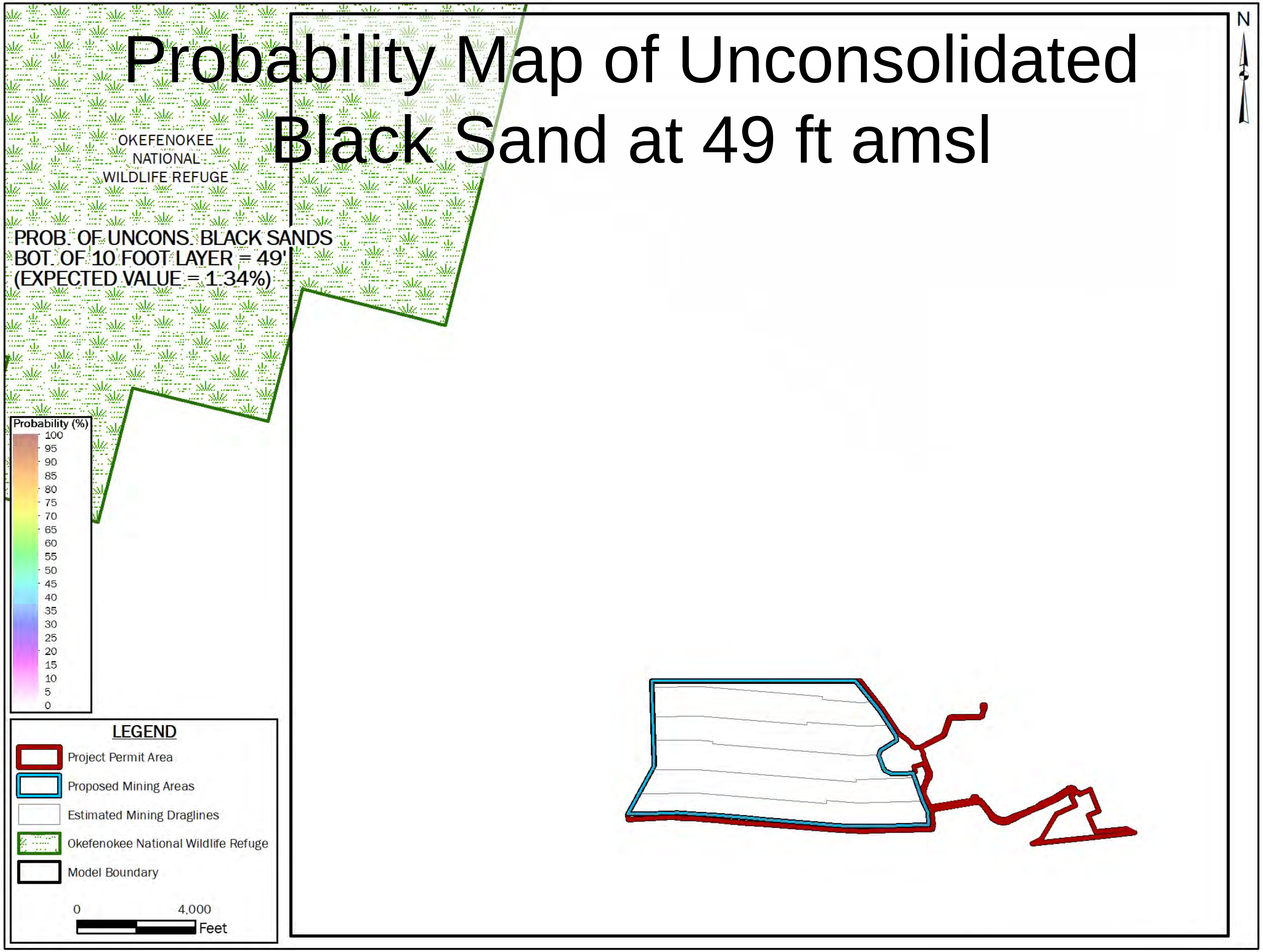
Probability Map of Unconsolidated Black Sand at 69 ft amsl



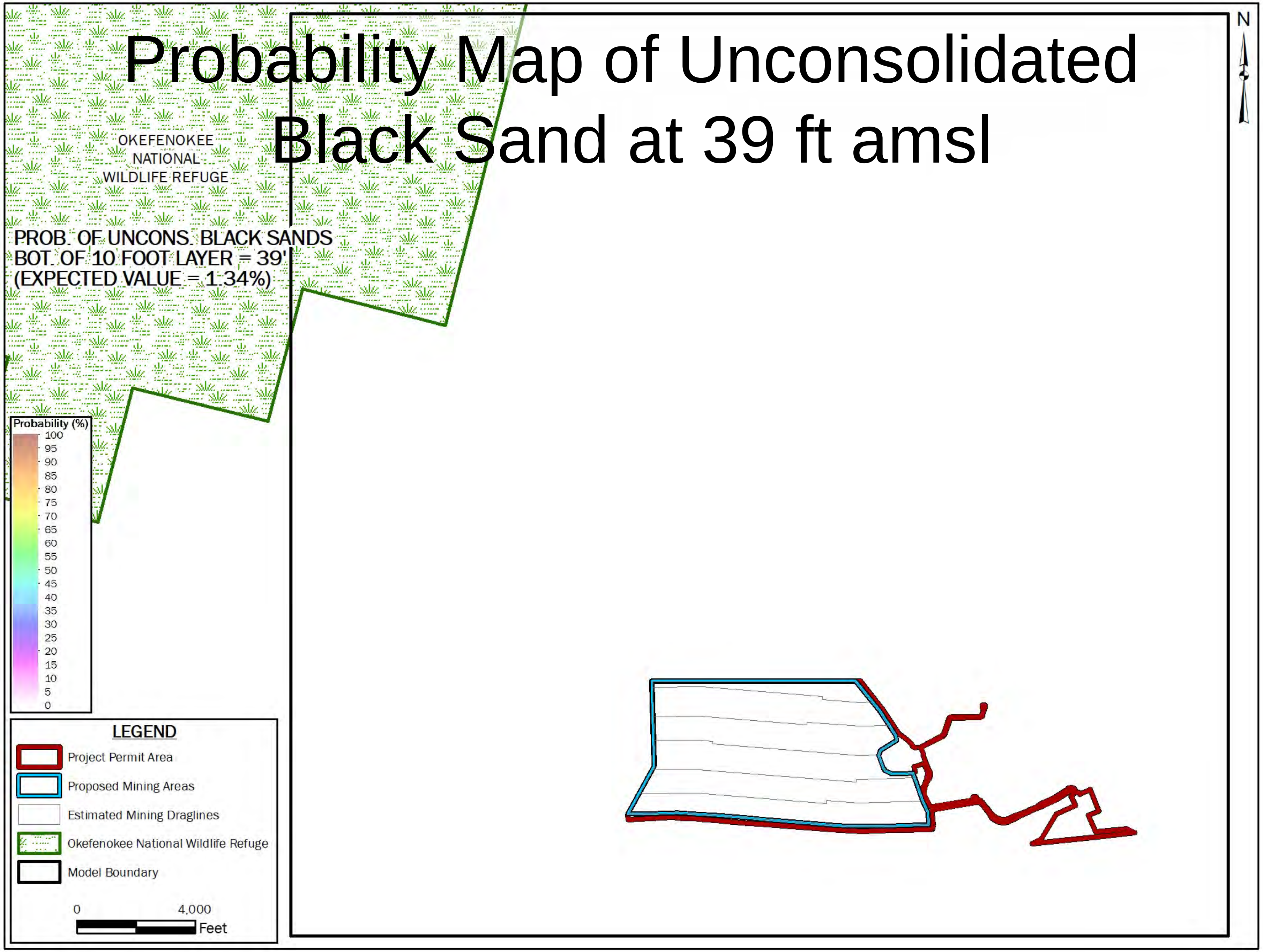
Probability Map of Unconsolidated Black Sand at 59 ft amsl



Probability Map of Unconsolidated Black Sand at 49 ft amsl



Probability Map of Unconsolidated Black Sand at 39 ft amsl

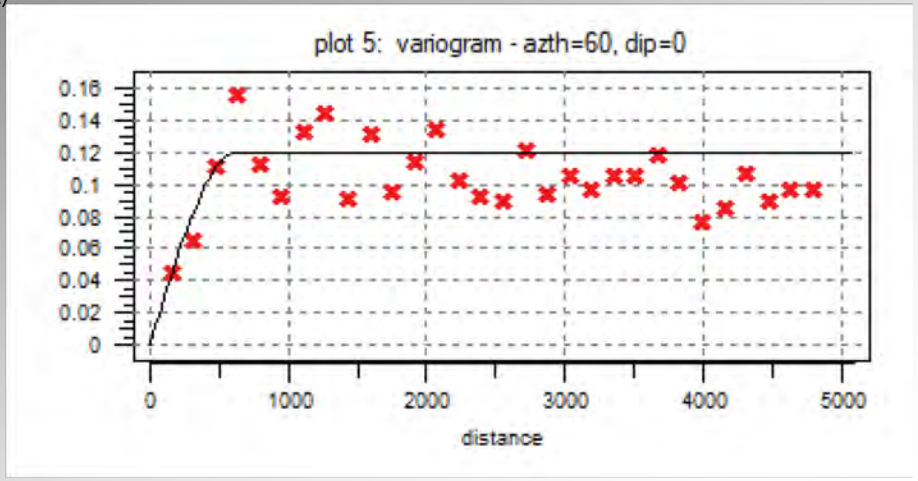


Semi-Consolidated Sand

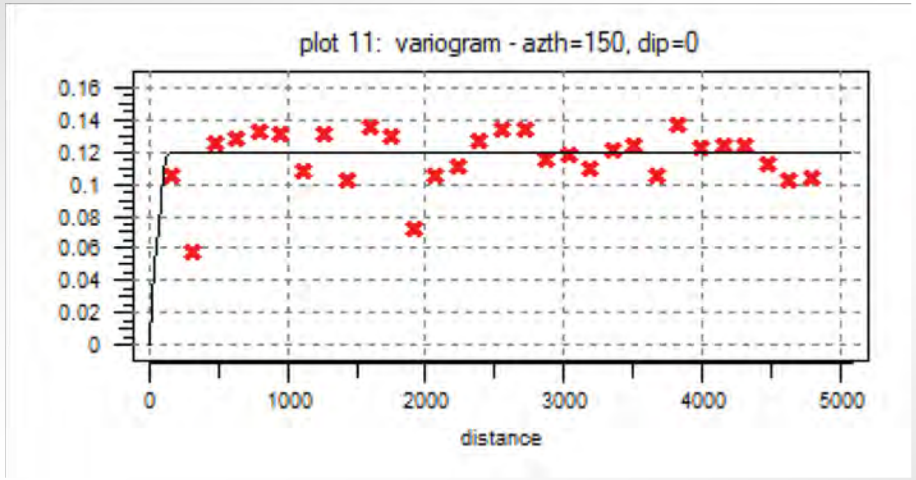
- Occupies 10.27% of the surficial aquifer (mainly above 120 ft amsl)
- Consists of silty sands (SM) and well sorted sands (SP) and silty-clayey sand (SC-SM) – Can contain secondary humate

Semi-Consolidated Sand – Correlation Lengths

A)

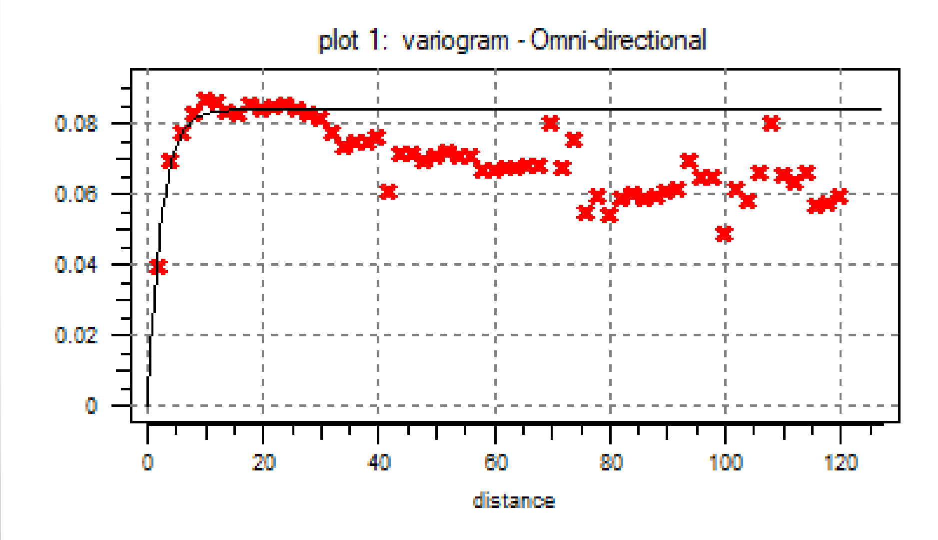


B)

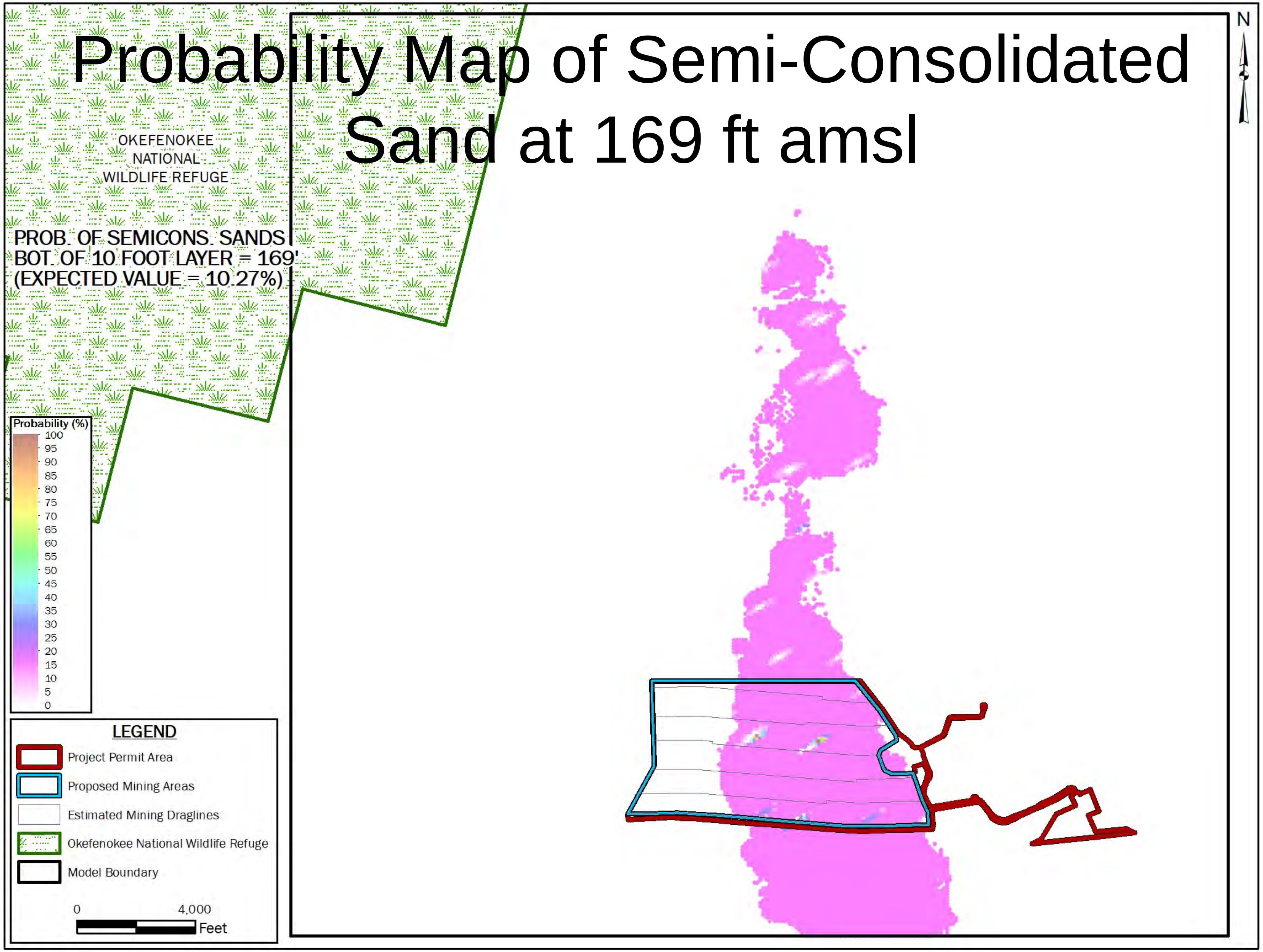


Horizontal correlation length = 624 ft max (az. = 60 degrees), 144 ft min (az. = 150 degrees)

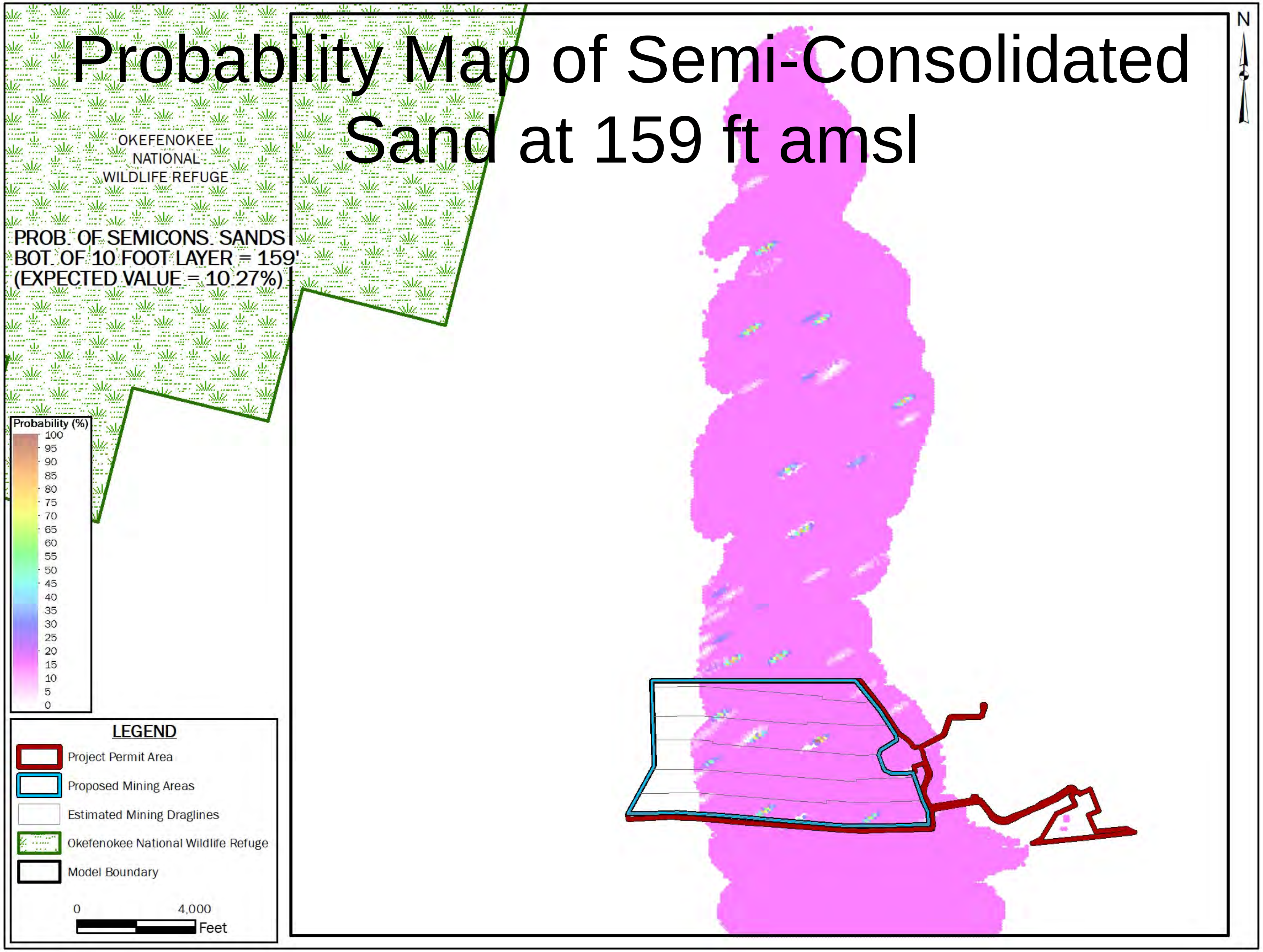
Vertical correlation length = 7.2 ft



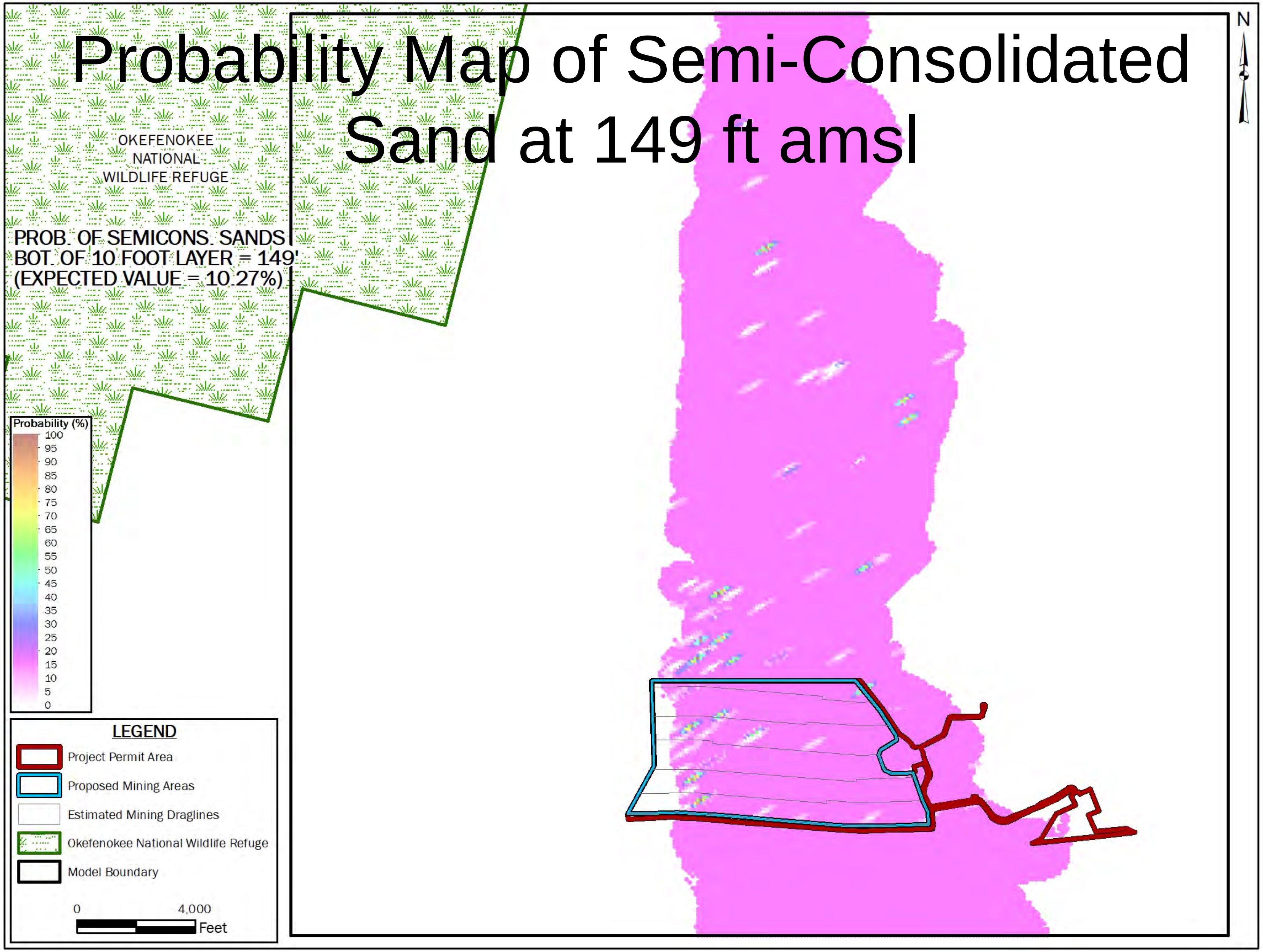
Probability Map of Semi-Consolidated Sand at 169 ft amsl



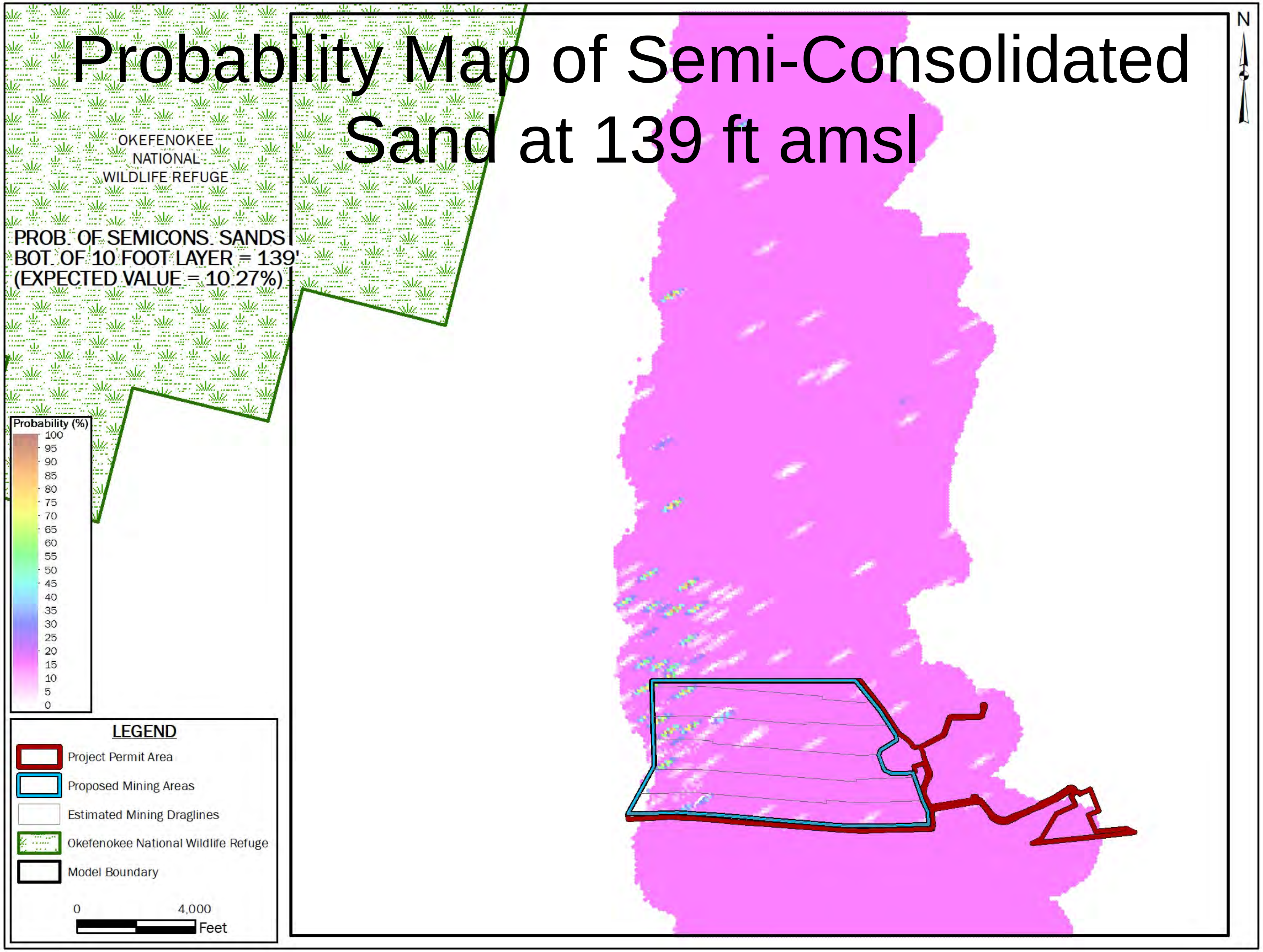
Probability Map of Semi-Consolidated Sand at 159 ft amsl



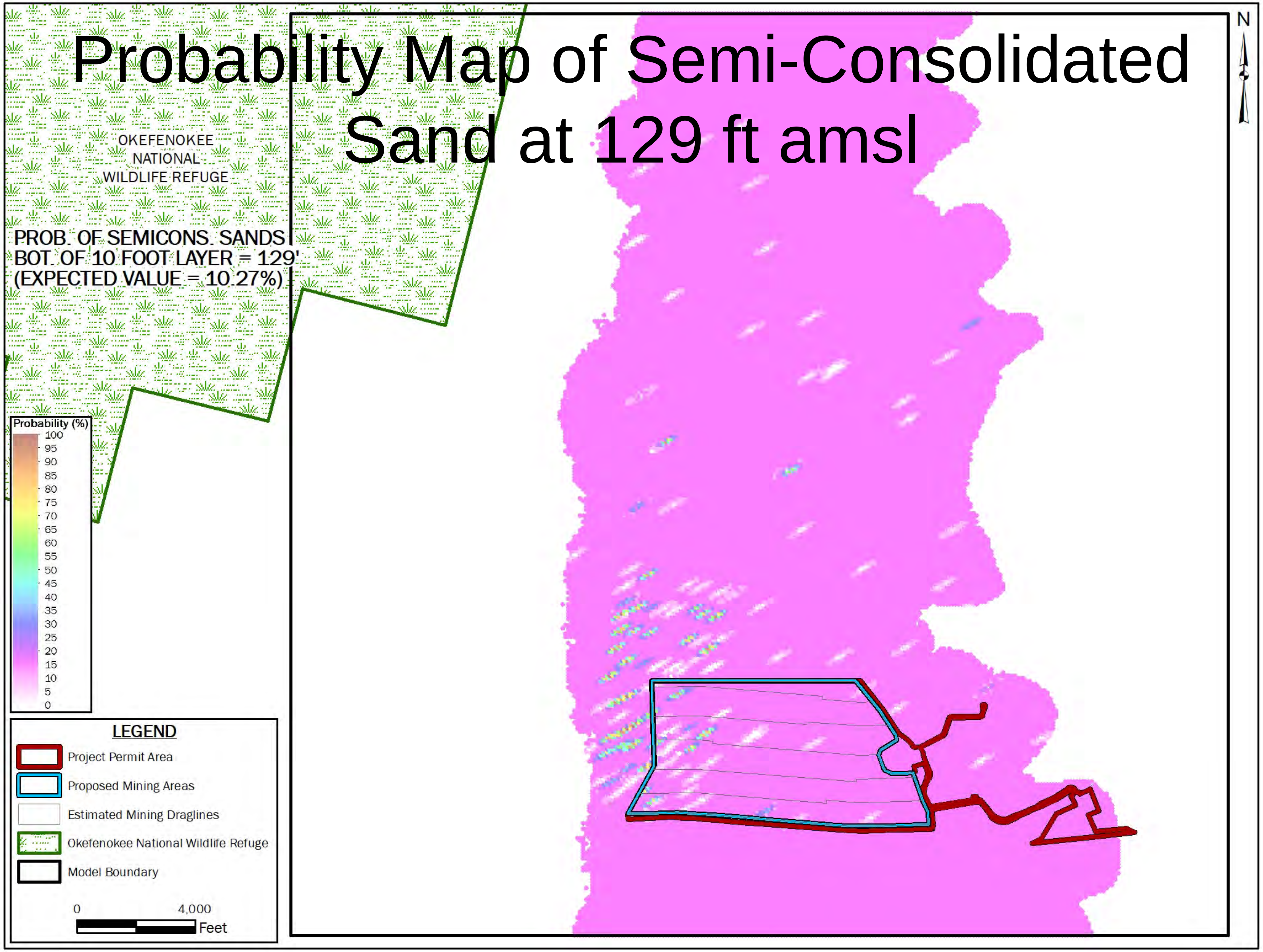
Probability Map of Semi-Consolidated Sand at 149 ft amsl



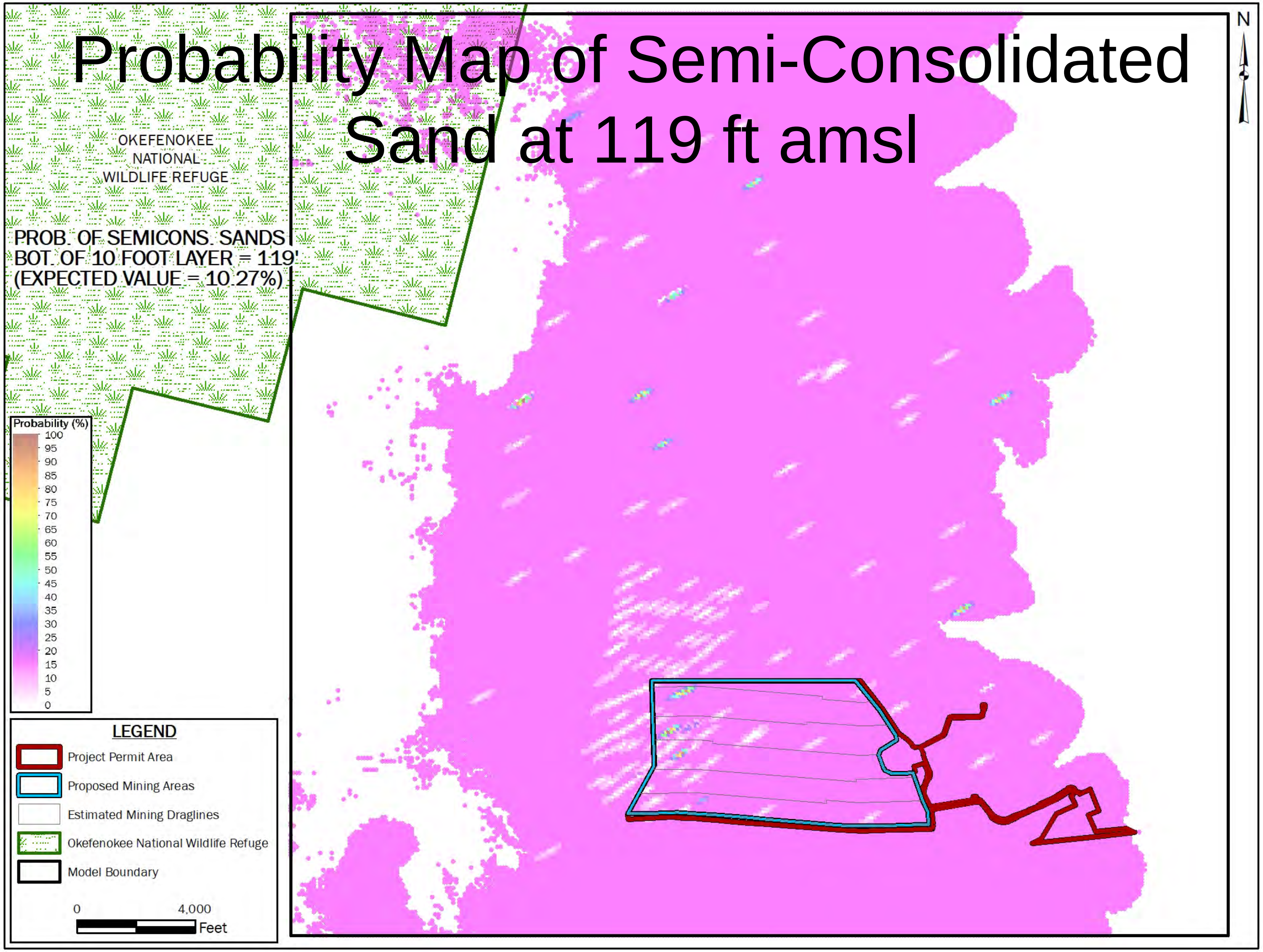
Probability Map of Semi-Consolidated Sand at 139 ft amsl



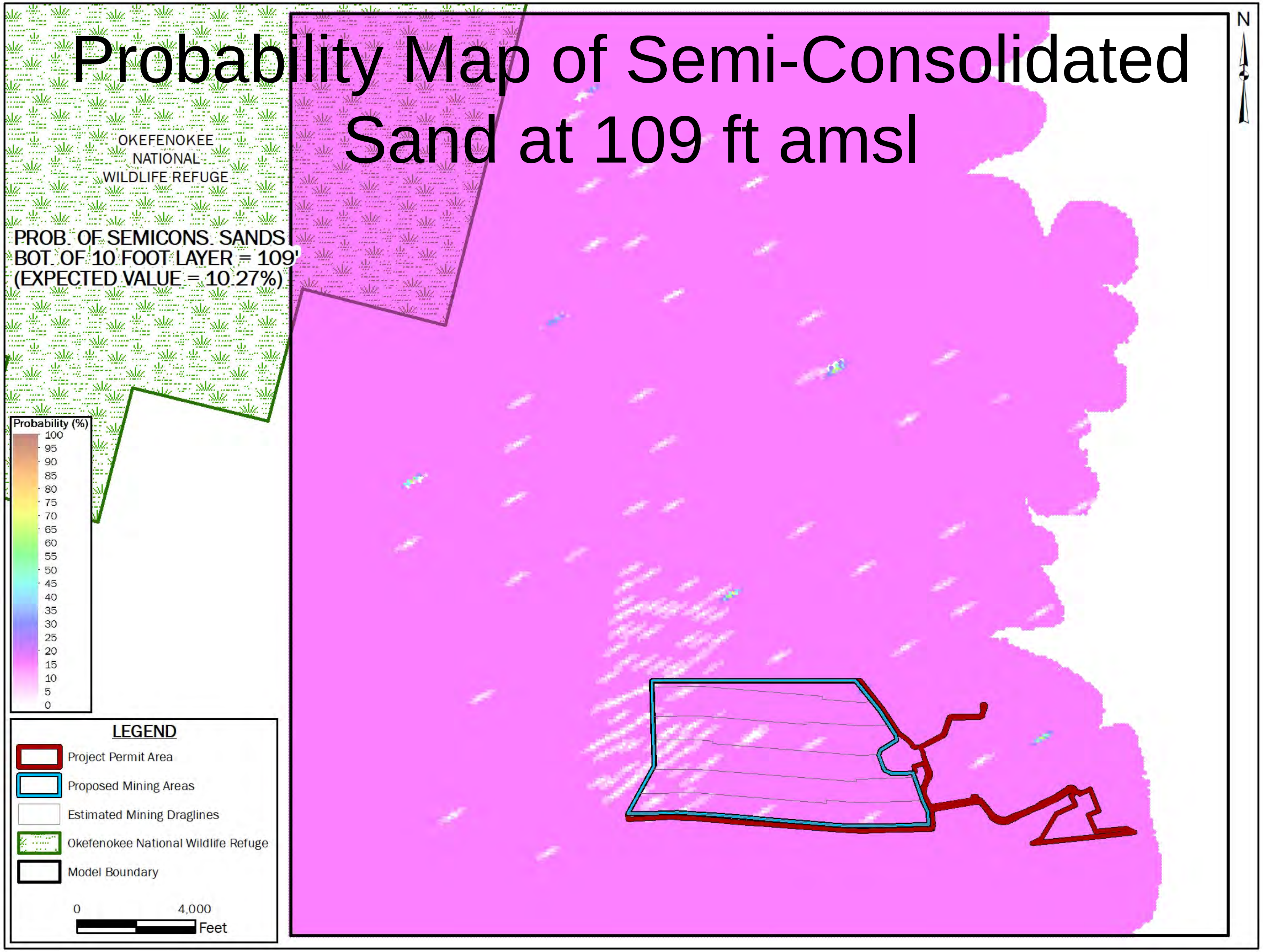
Probability Map of Semi-Consolidated Sand at 129 ft amsl



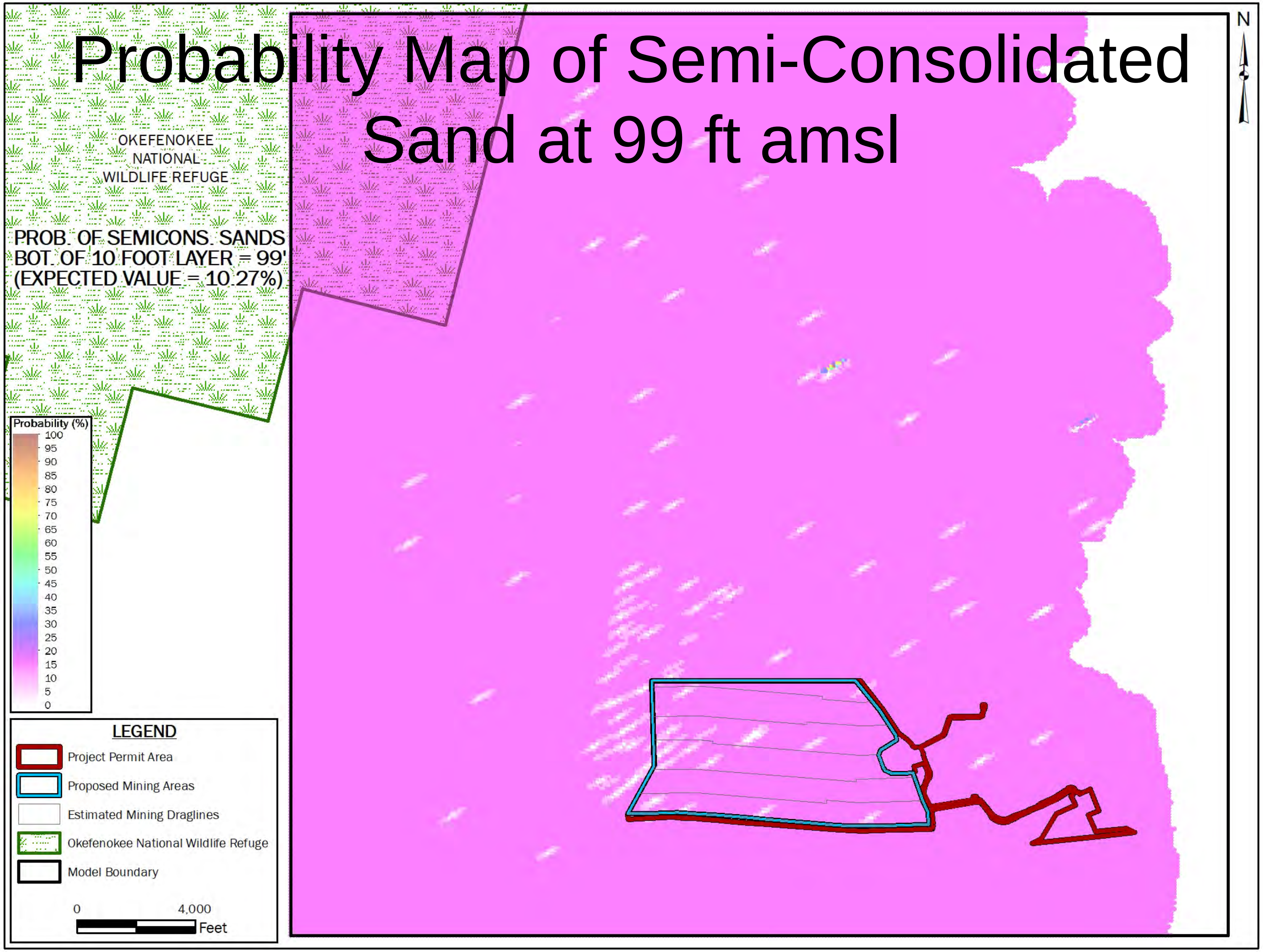
Probability Map of Semi-Consolidated Sand at 119 ft amsl



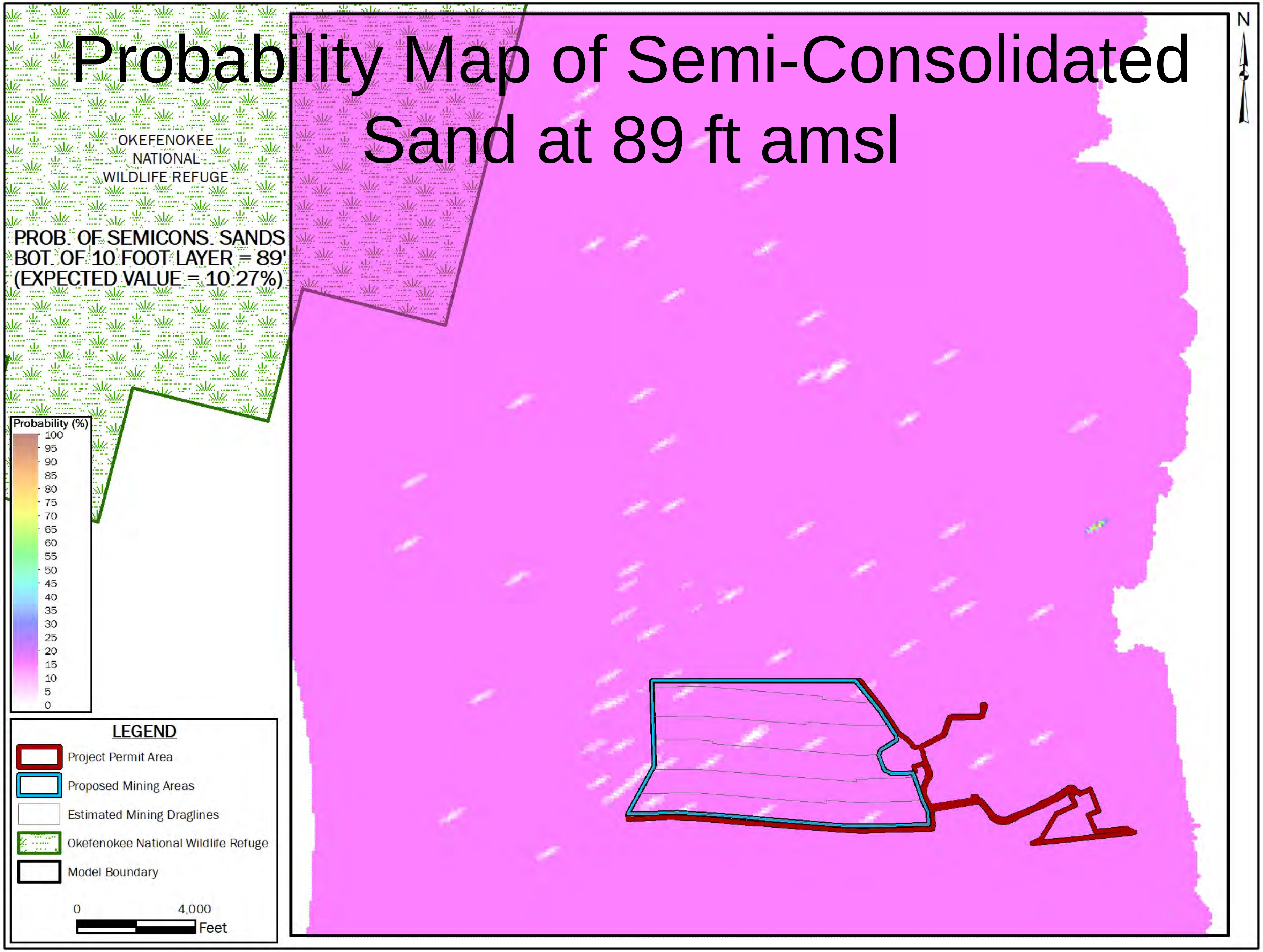
Probability Map of Semi-Consolidated Sand at 109 ft amsl



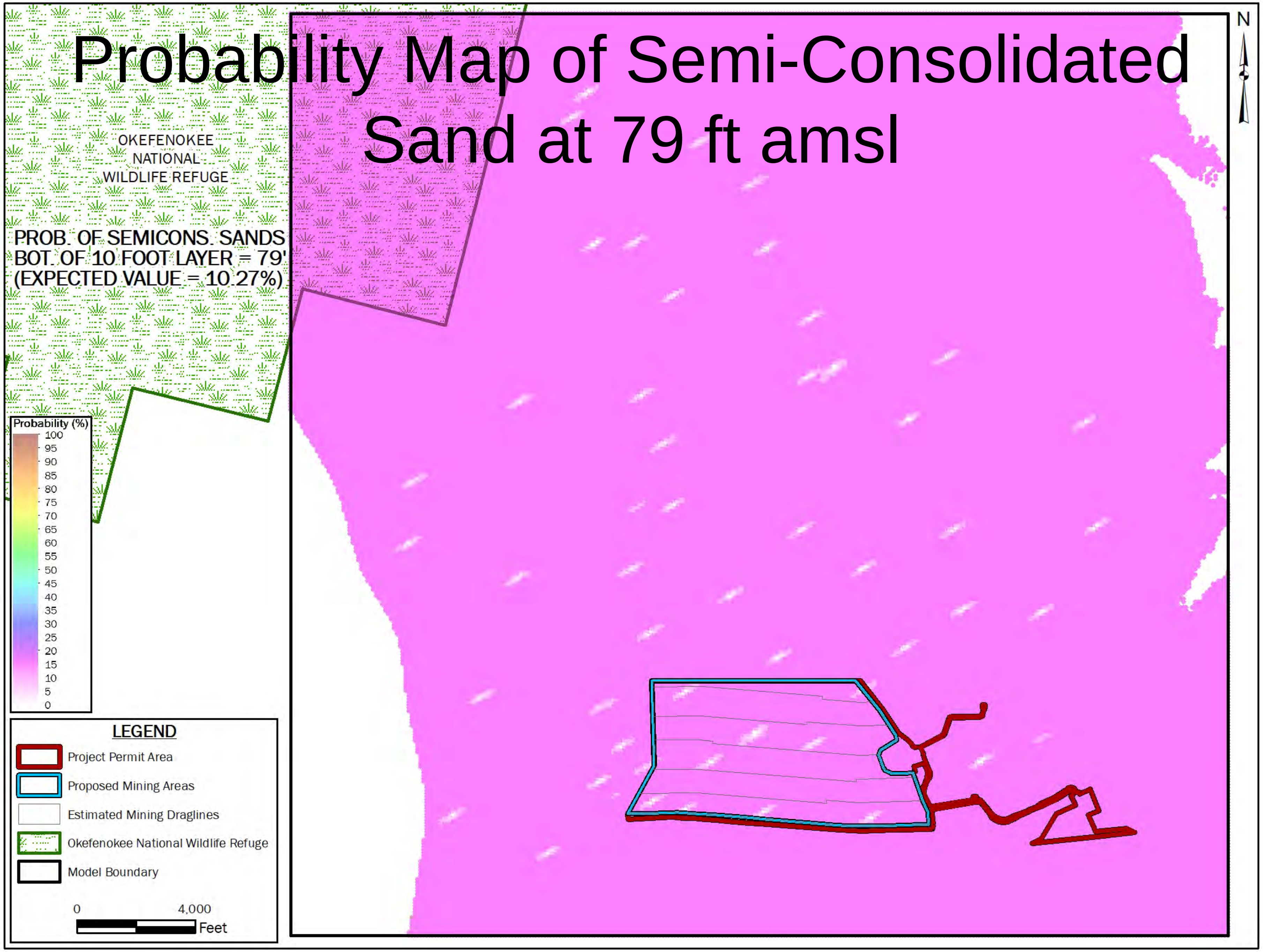
Probability Map of Semi-Consolidated Sand at 99 ft amsl



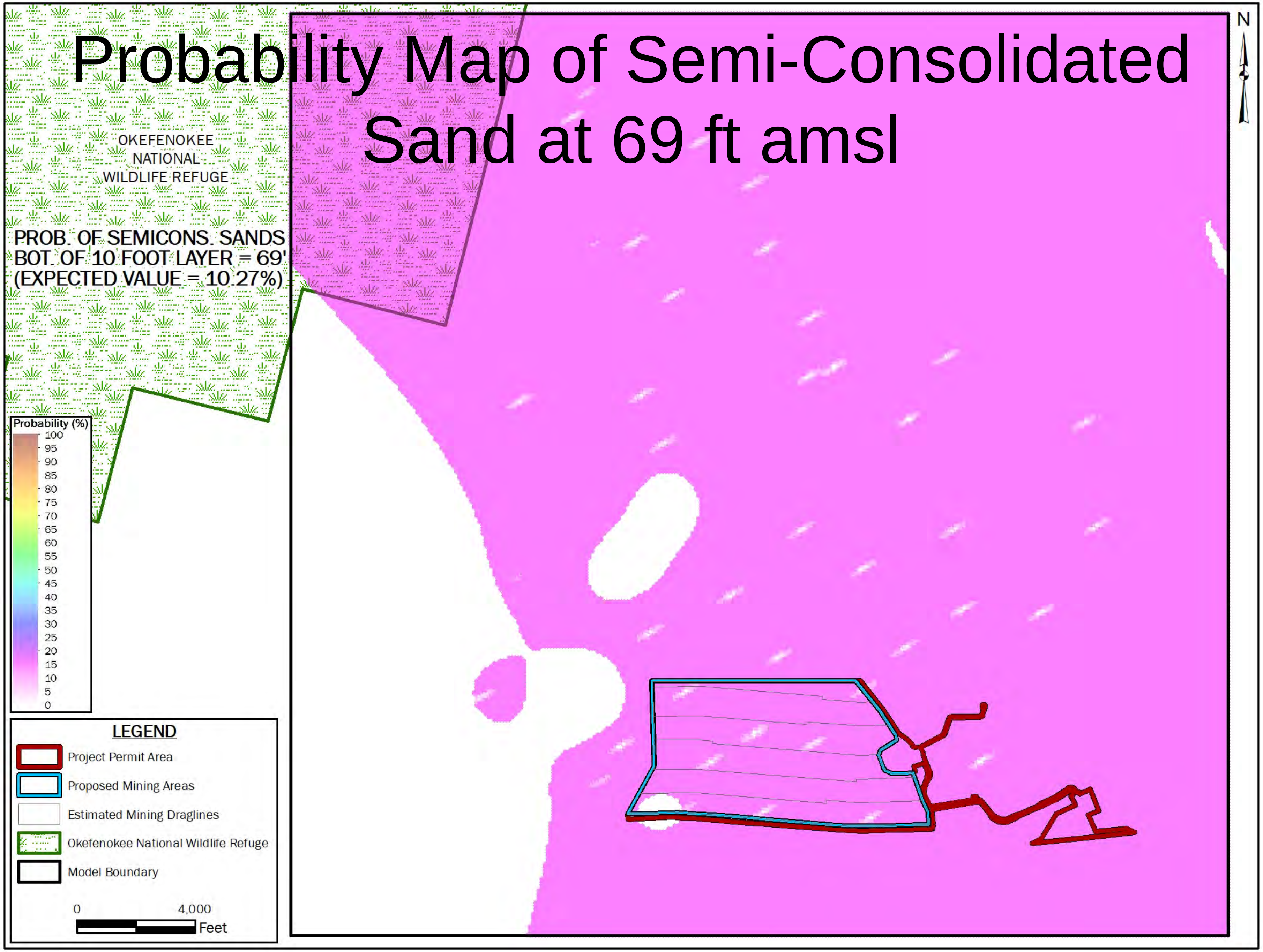
Probability Map of Semi-Consolidated Sand at 89 ft amsl



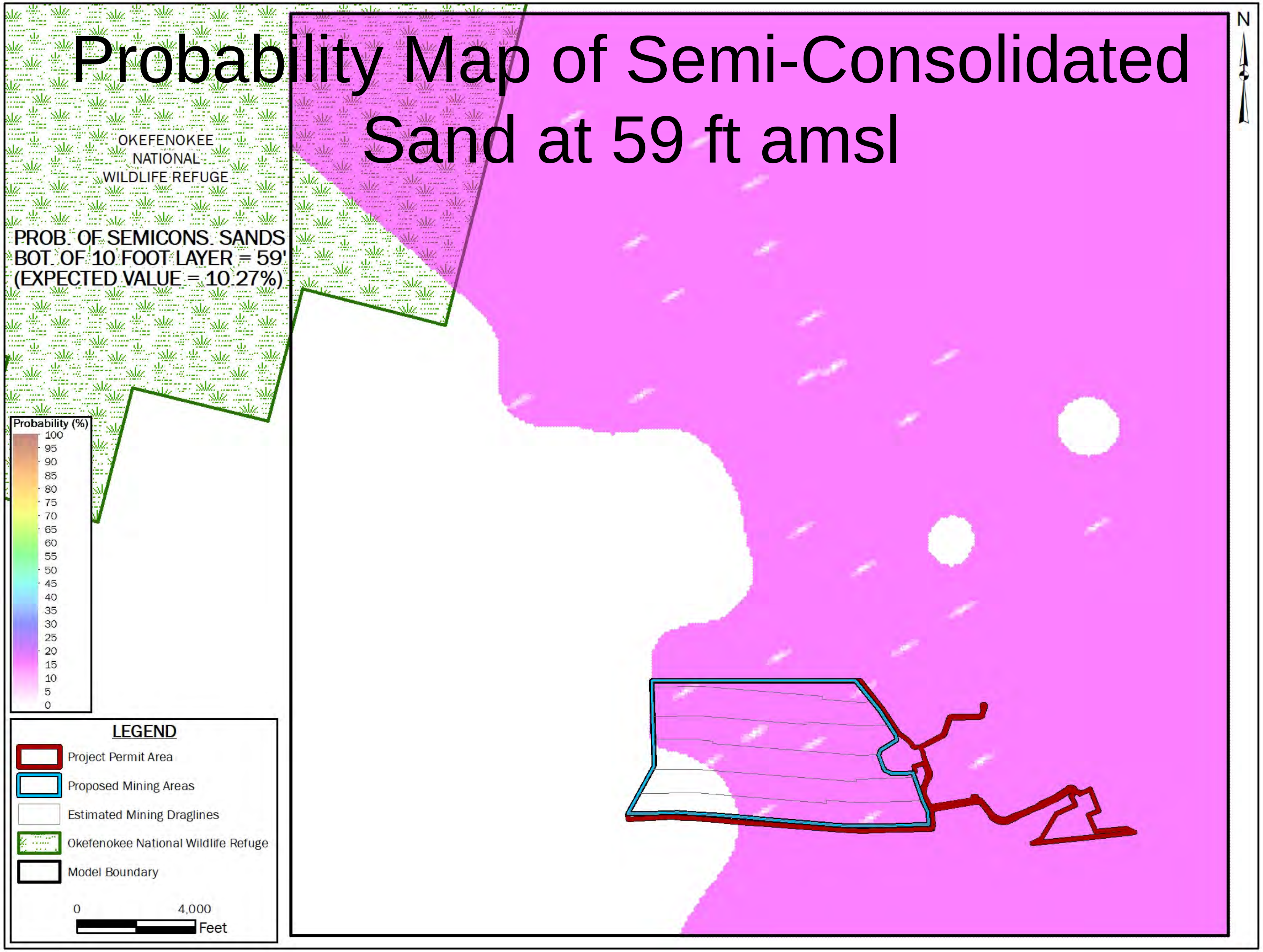
Probability Map of Semi-Consolidated Sand at 79 ft amsl



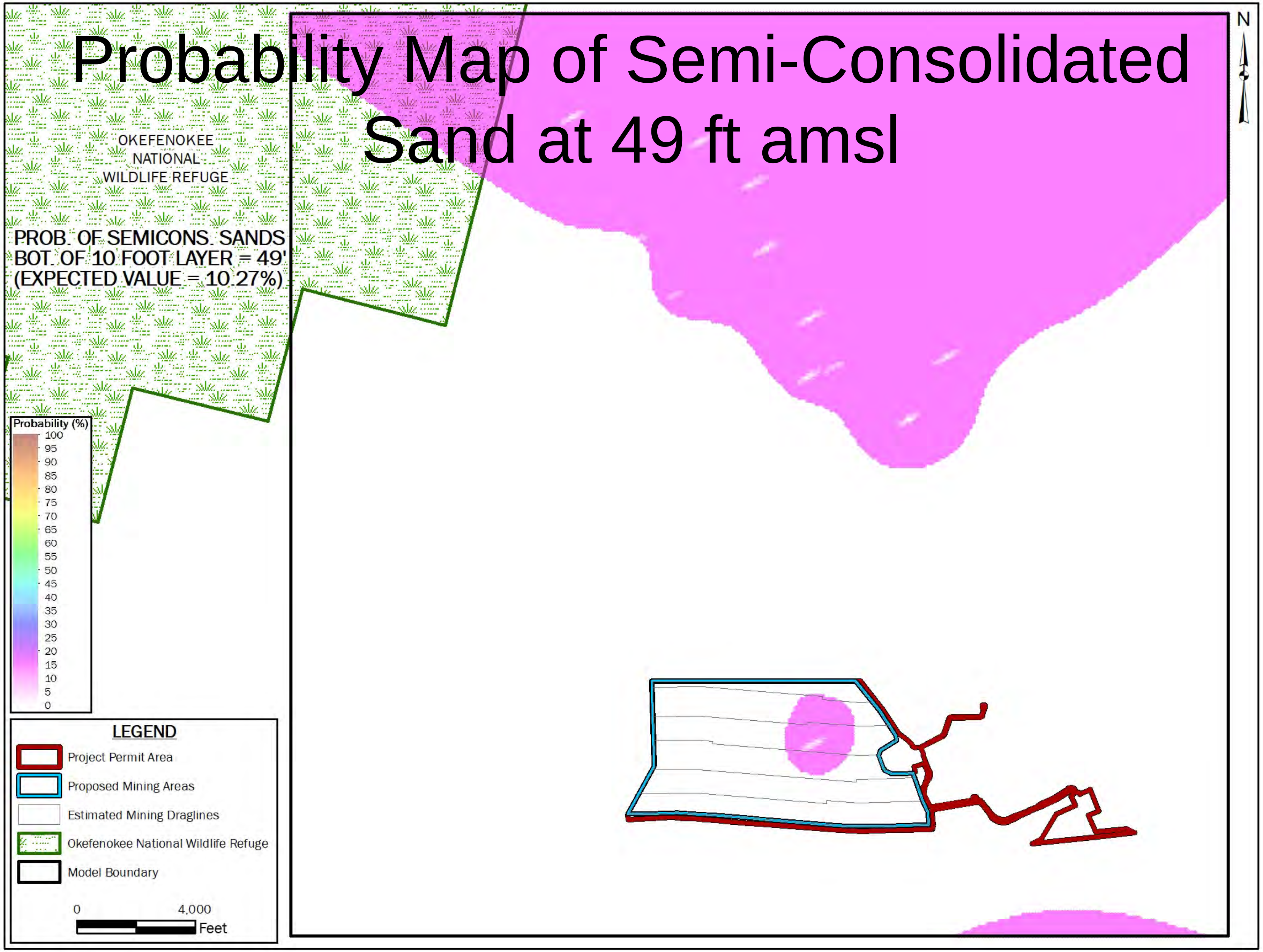
Probability Map of Semi-Consolidated Sand at 69 ft amsl



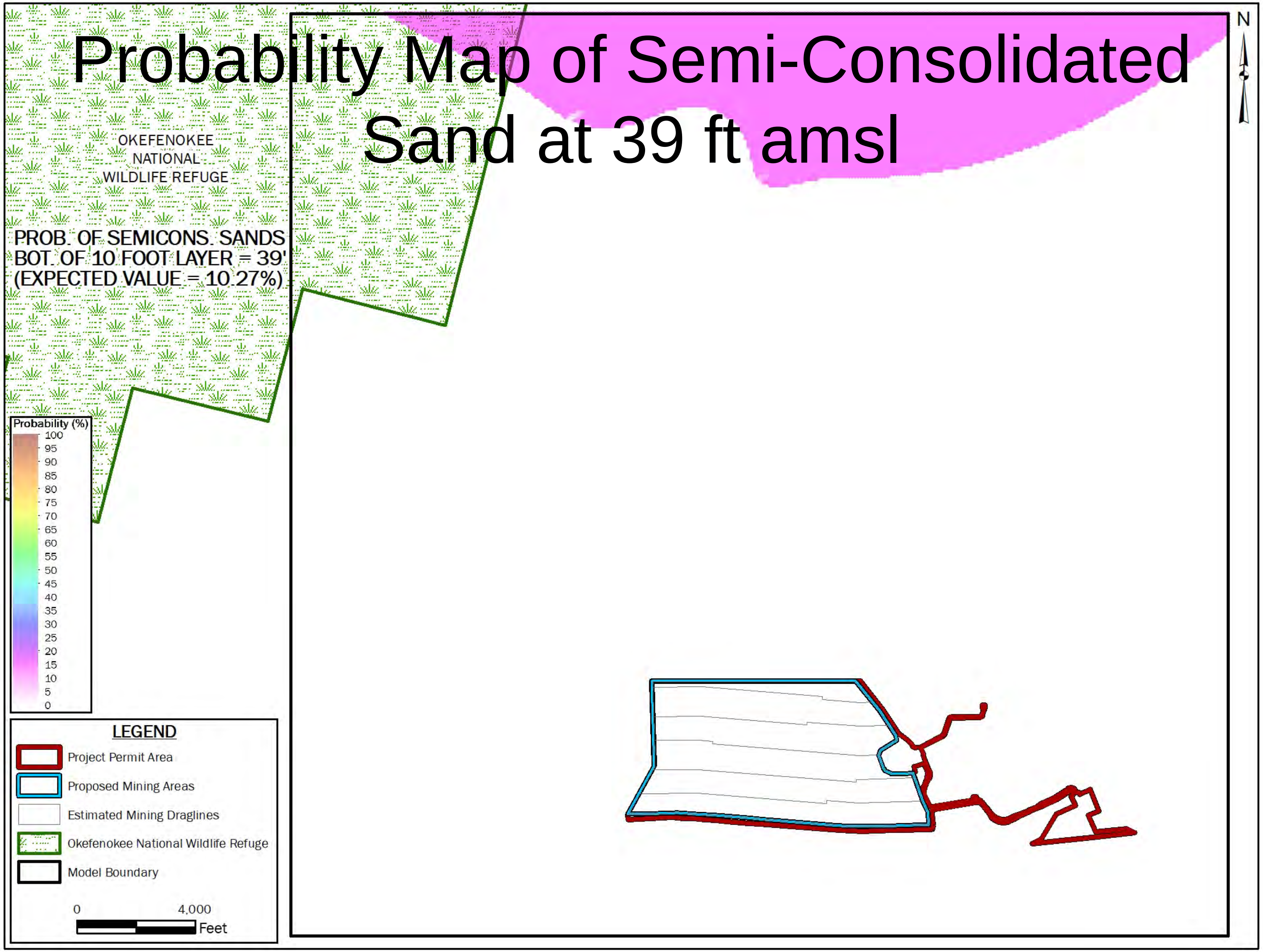
Probability Map of Semi-Consolidated Sand at 59 ft amsl



Probability Map of Semi-Consolidated Sand at 49 ft amsl



Probability Map of Semi-Consolidated Sand at 39 ft amsl

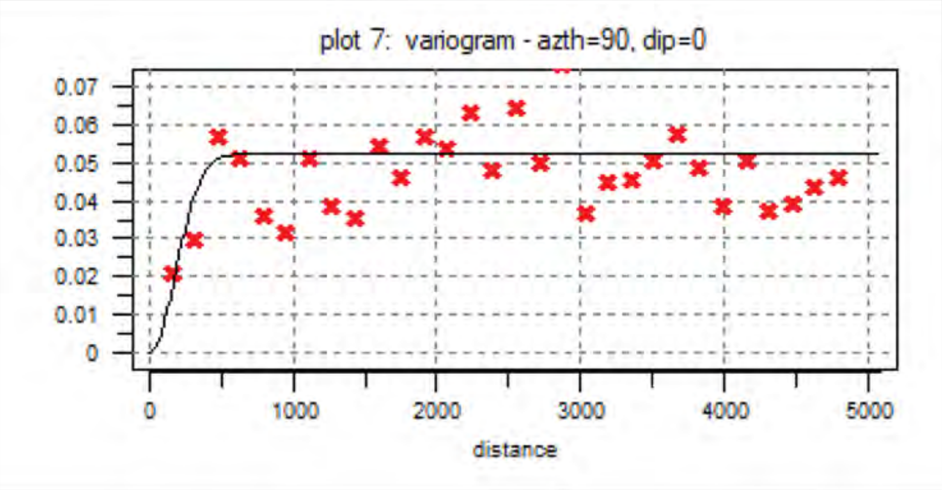


Consolidated (Humate-Cemented) Sand

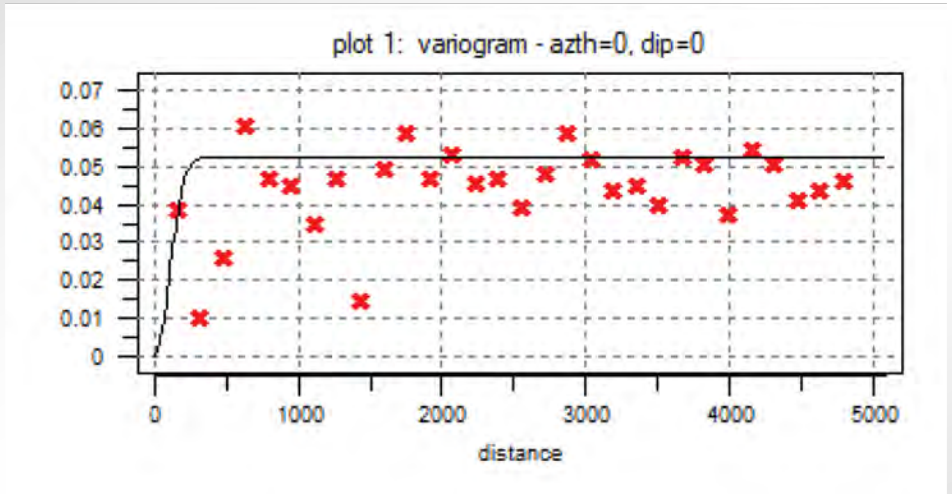
- Occupies 5.54% of the surficial aquifer (mainly above 120 ft amsl)
- Consisting of humate-cemented silty sands (SM) and well sorted sands (SP) - Humate cements formed after the deposition of the sand due to circulating groundwater

Consolidated Sand Correlation Lengths

A)

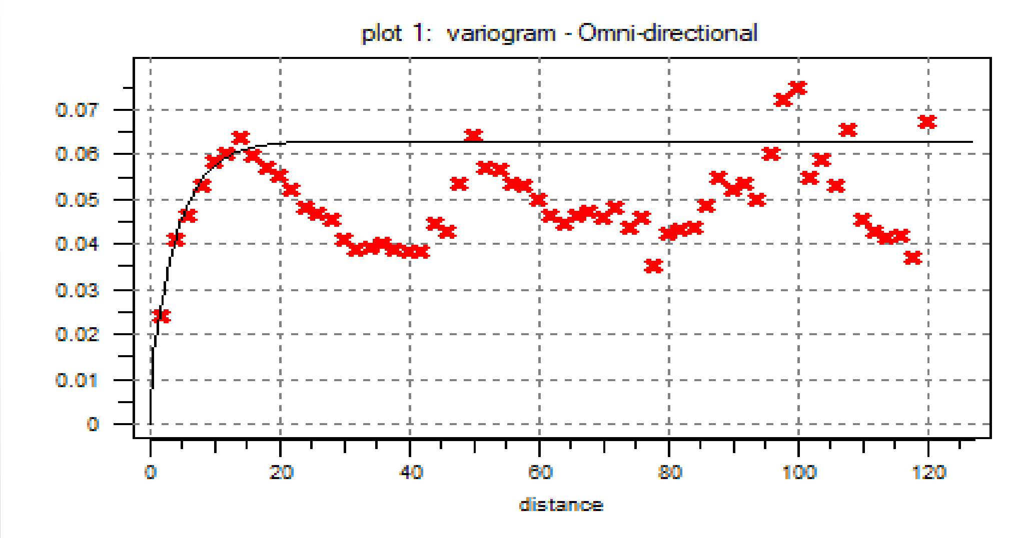


B)

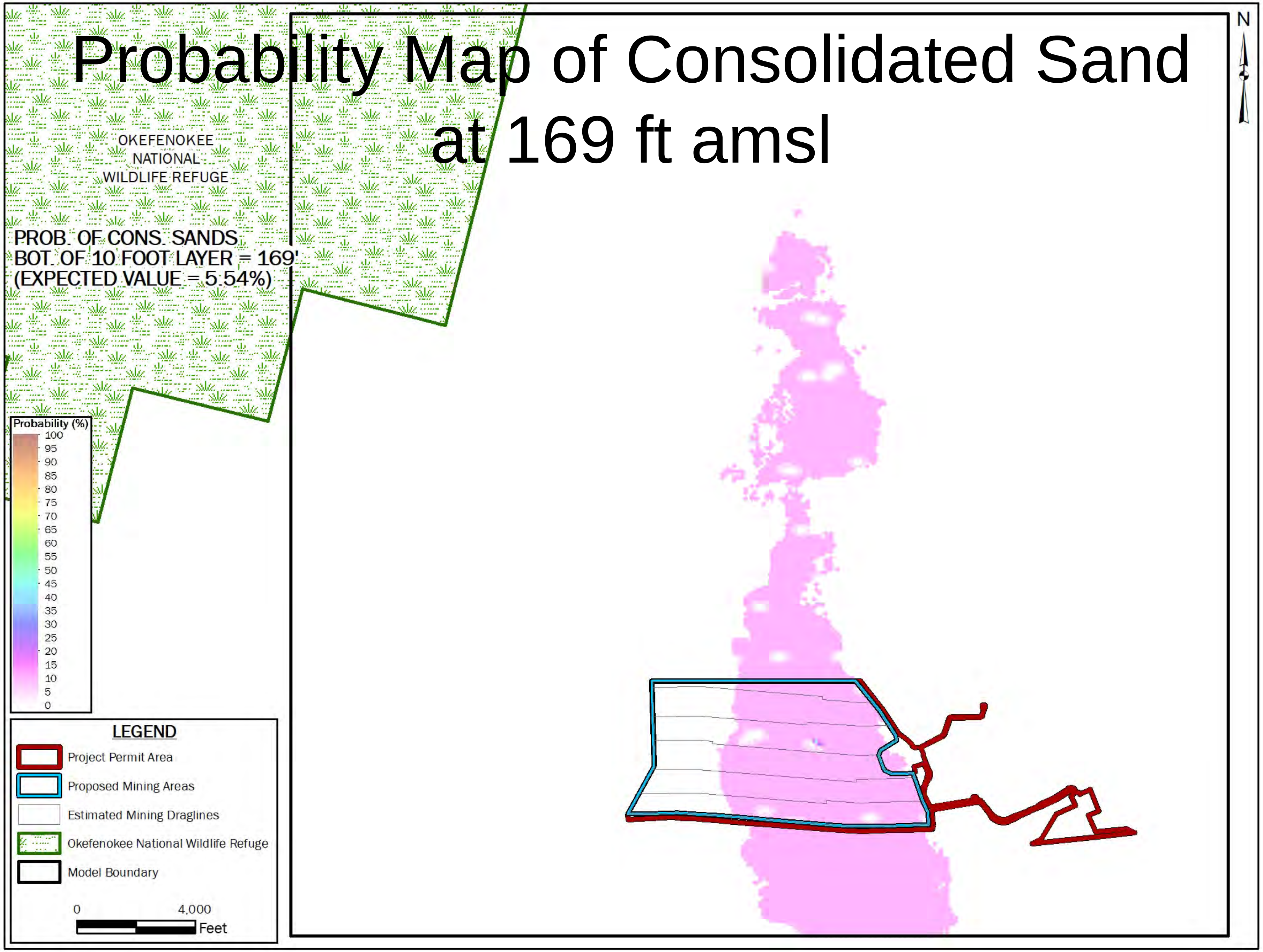


Horizontal correlation length for consolidated (humate-cemented) sand = 432 ft max (az. = 90 degrees), 240 ft min (az. = 0 degrees)

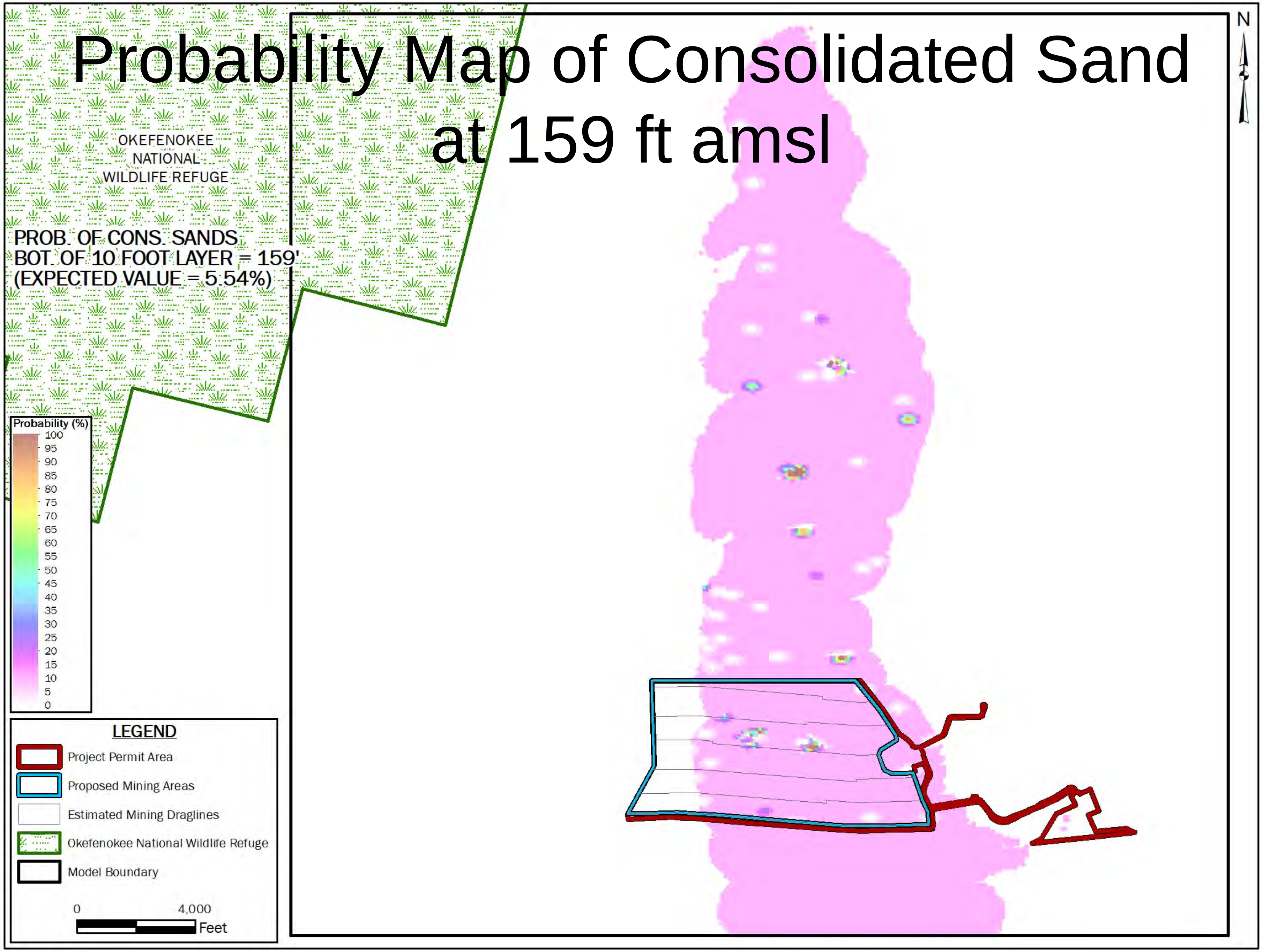
Vertical correlation length = 18 ft



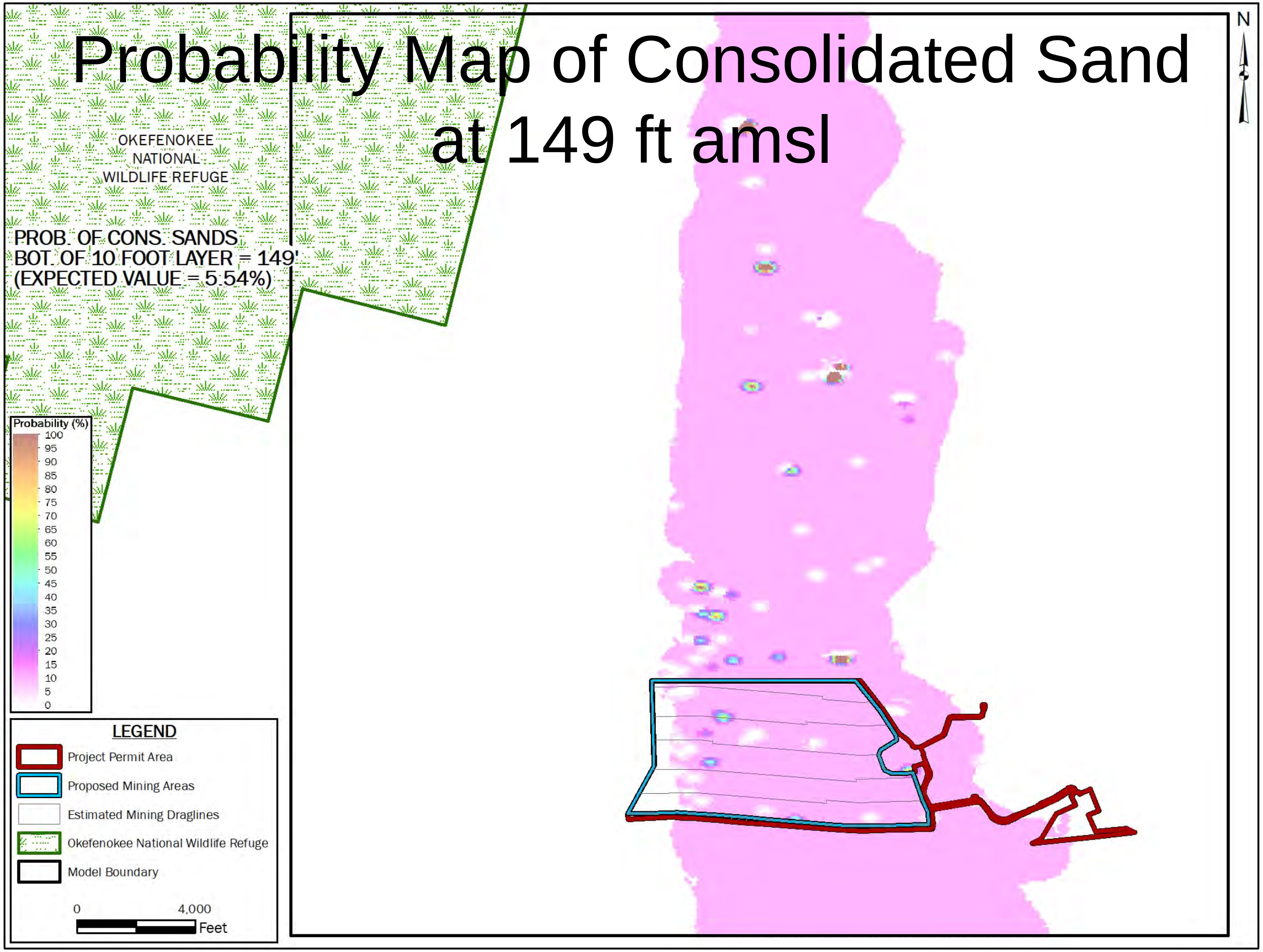
Probability Map of Consolidated Sand at 169 ft amsl



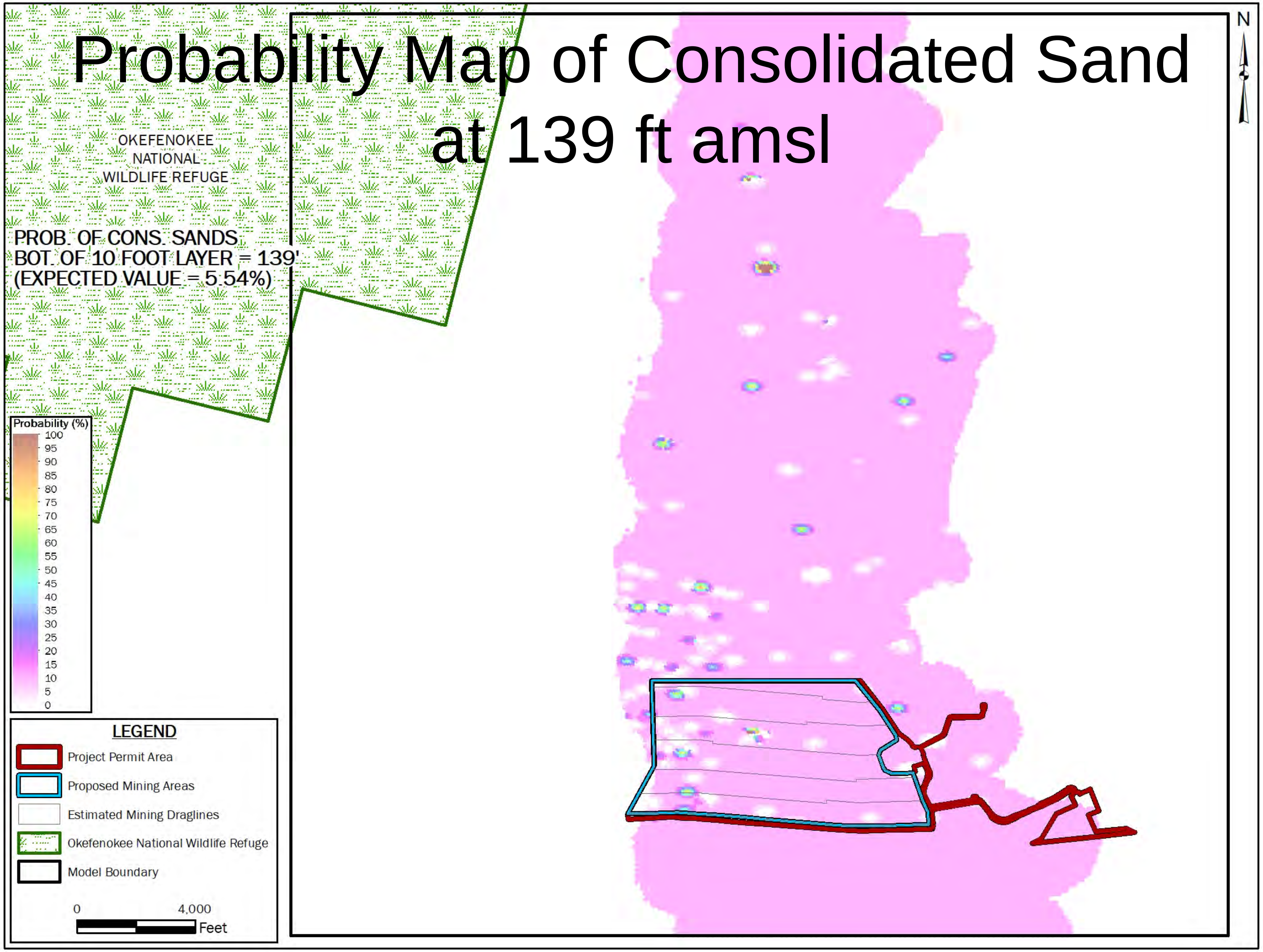
Probability Map of Consolidated Sand at 159 ft amsl



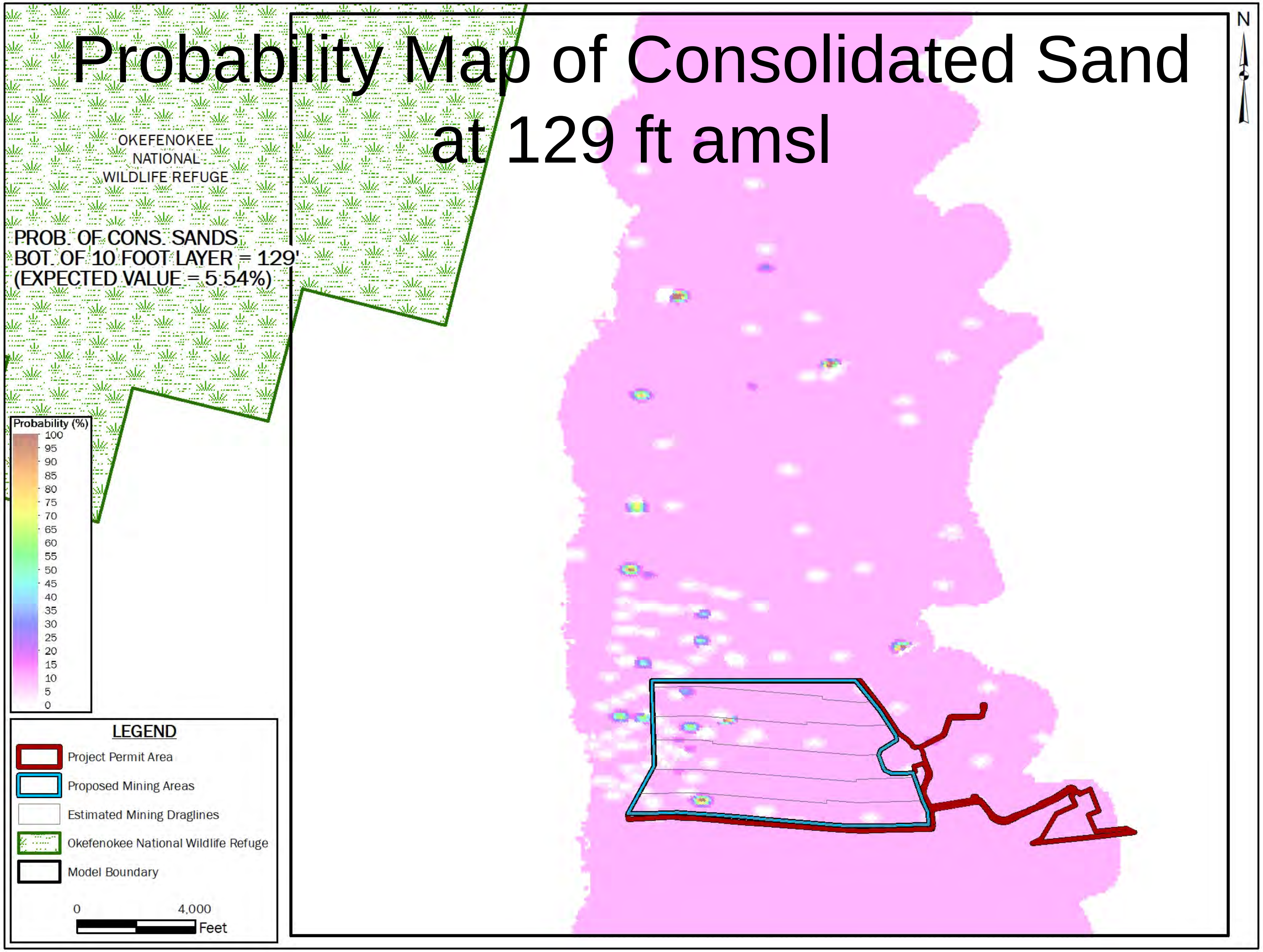
Probability Map of Consolidated Sand at 149 ft amsl



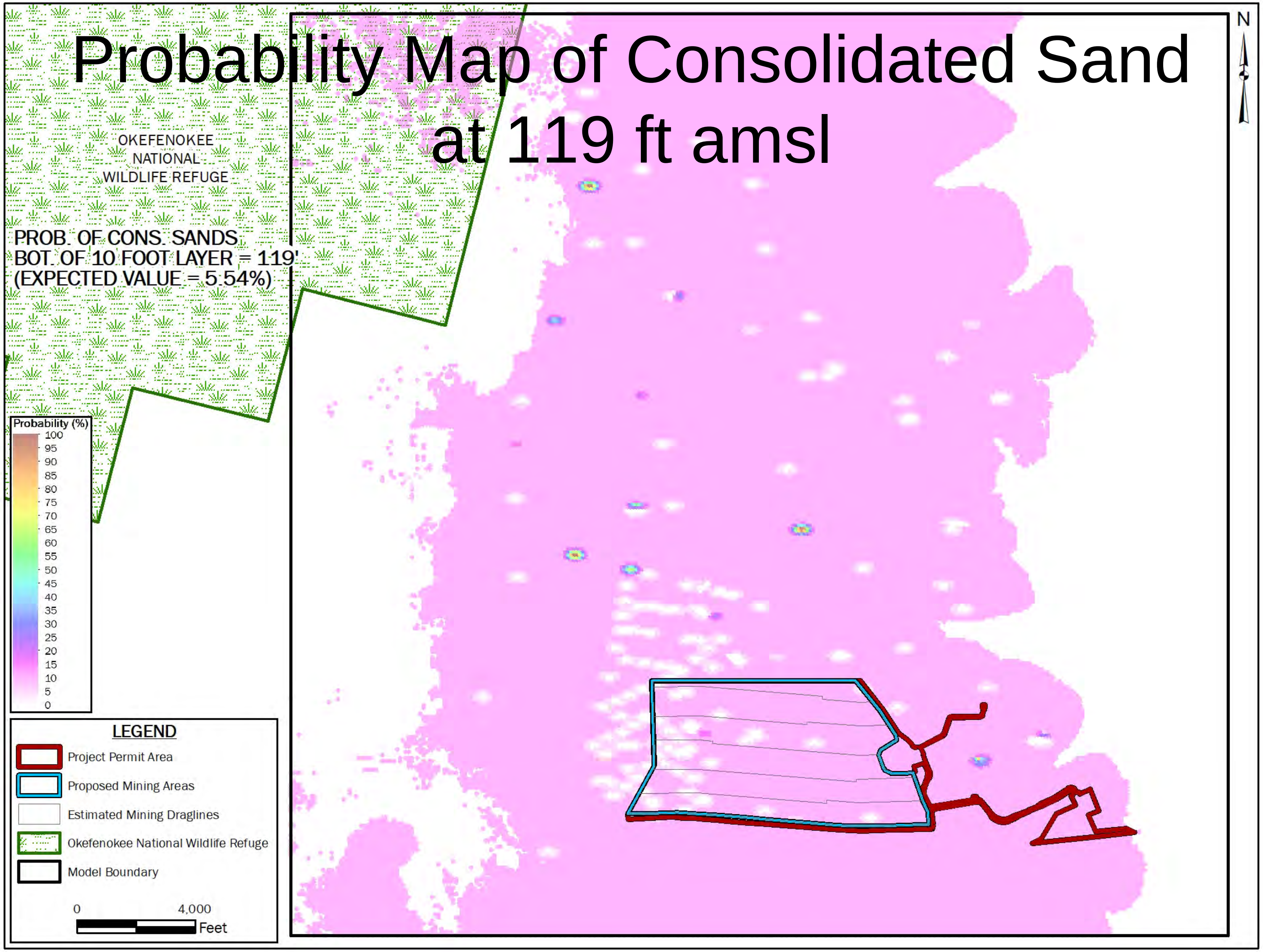
Probability Map of Consolidated Sand at 139 ft amsl



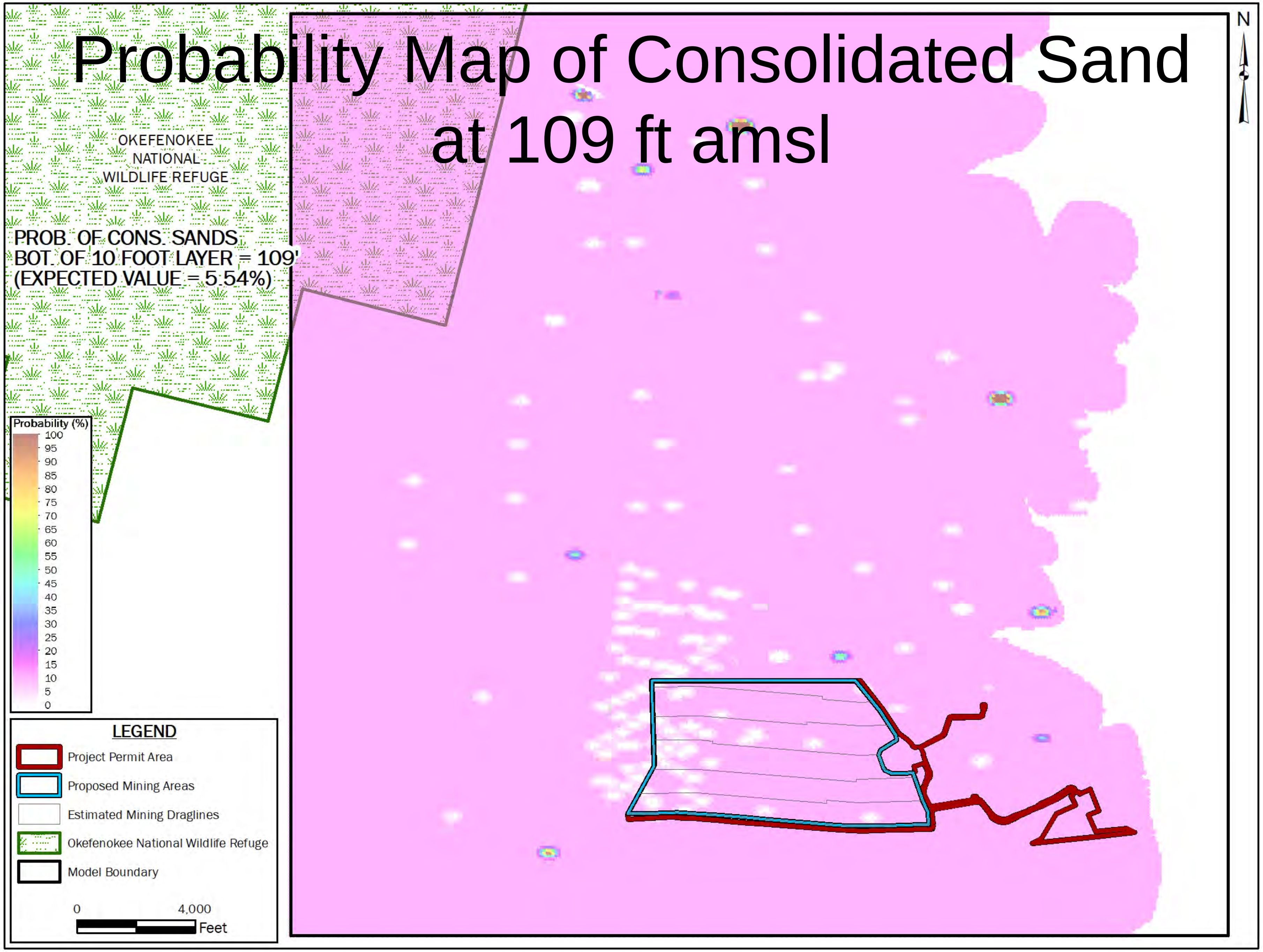
Probability Map of Consolidated Sand at 129 ft amsl



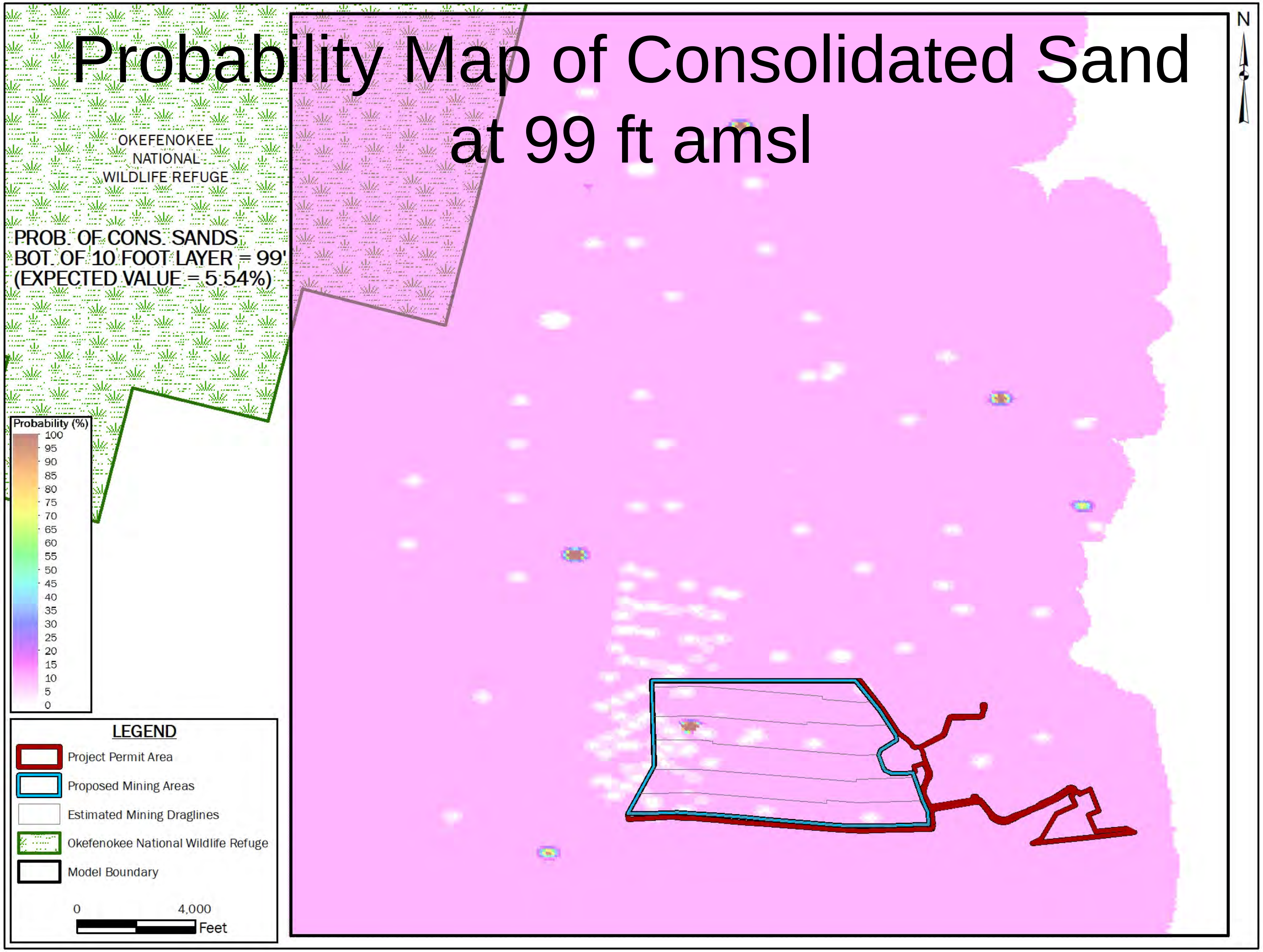
Probability Map of Consolidated Sand at 119 ft amsl



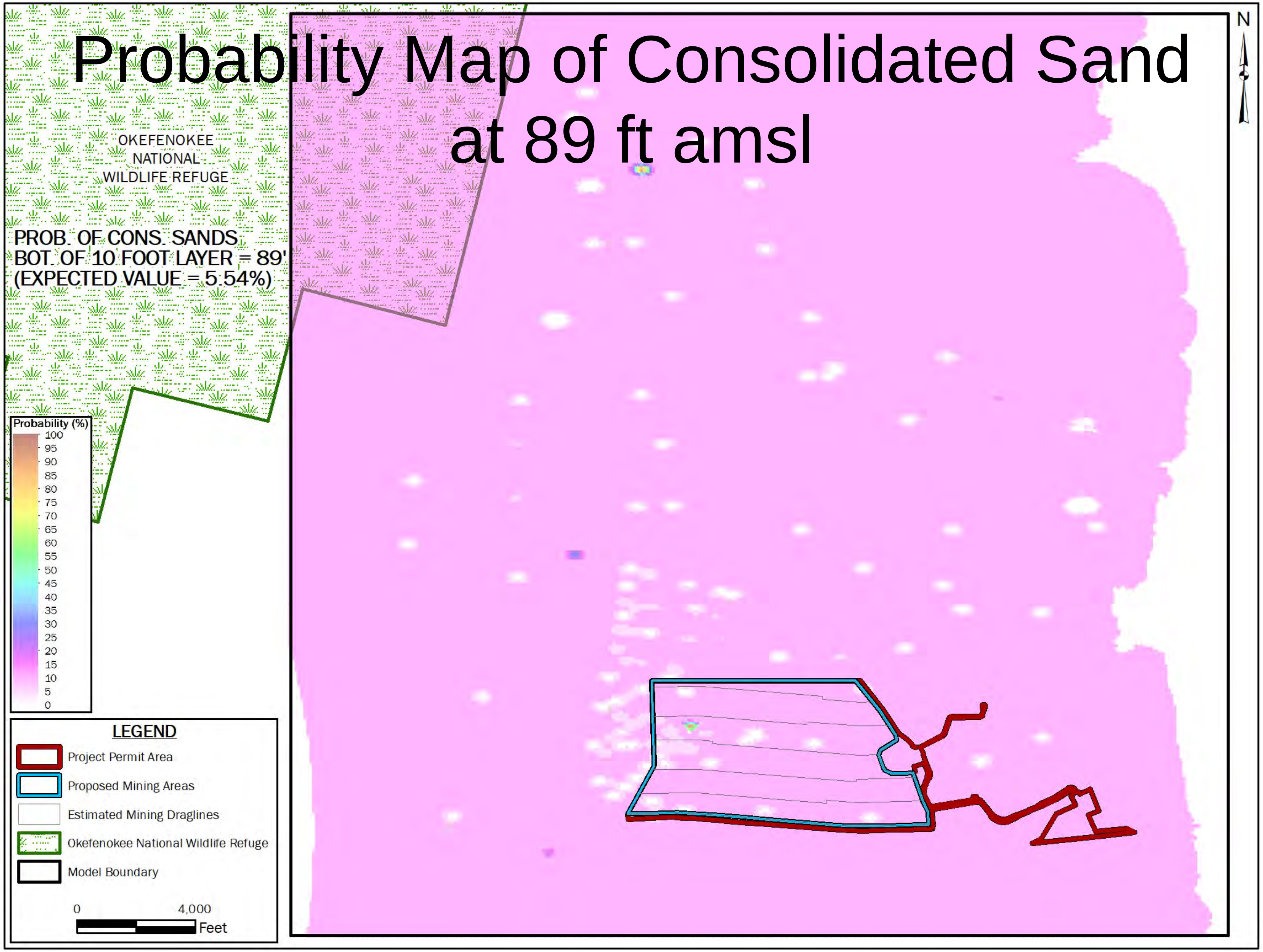
Probability Map of Consolidated Sand at 109 ft amsl



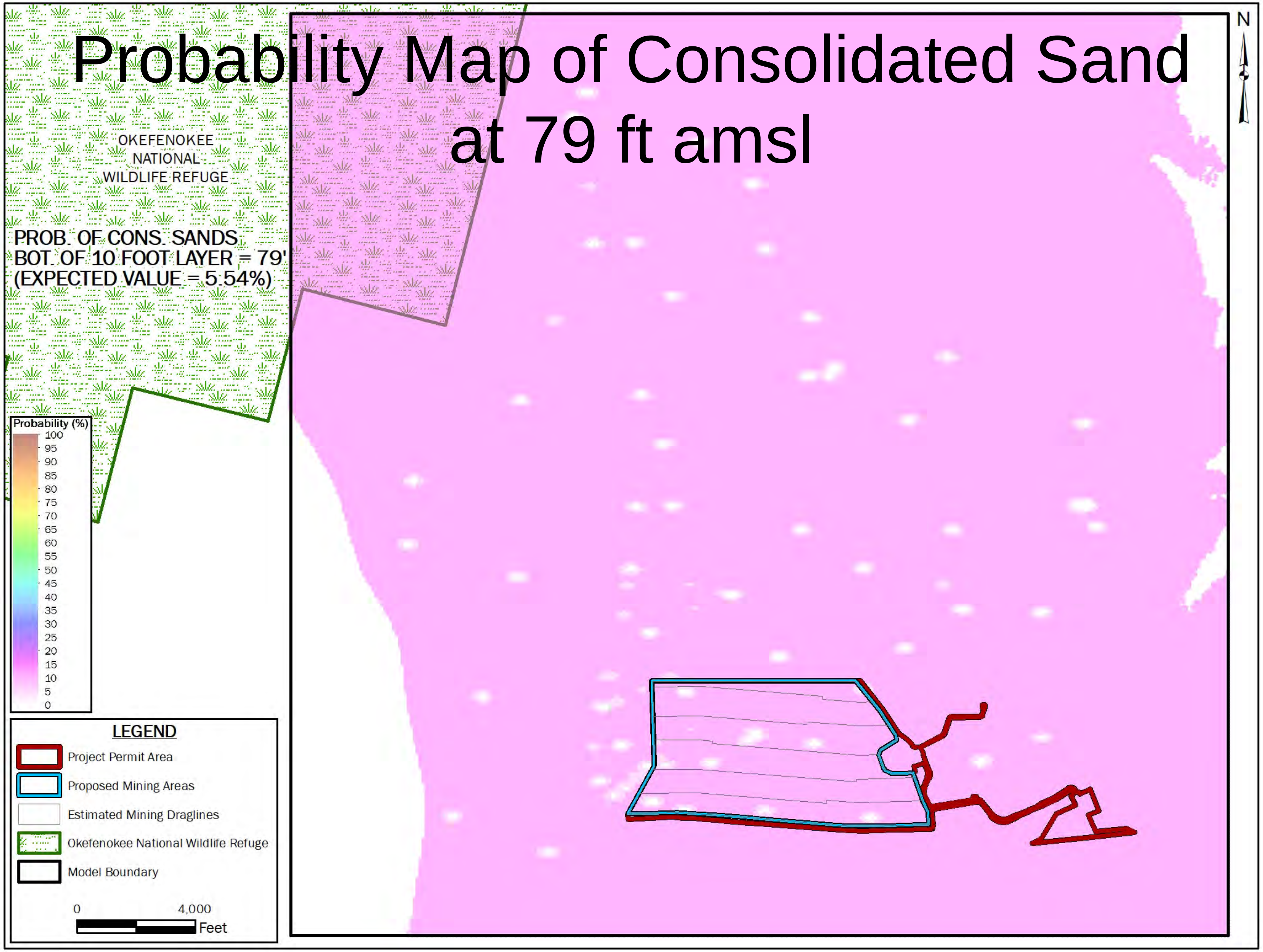
Probability Map of Consolidated Sand at 99 ft amsl



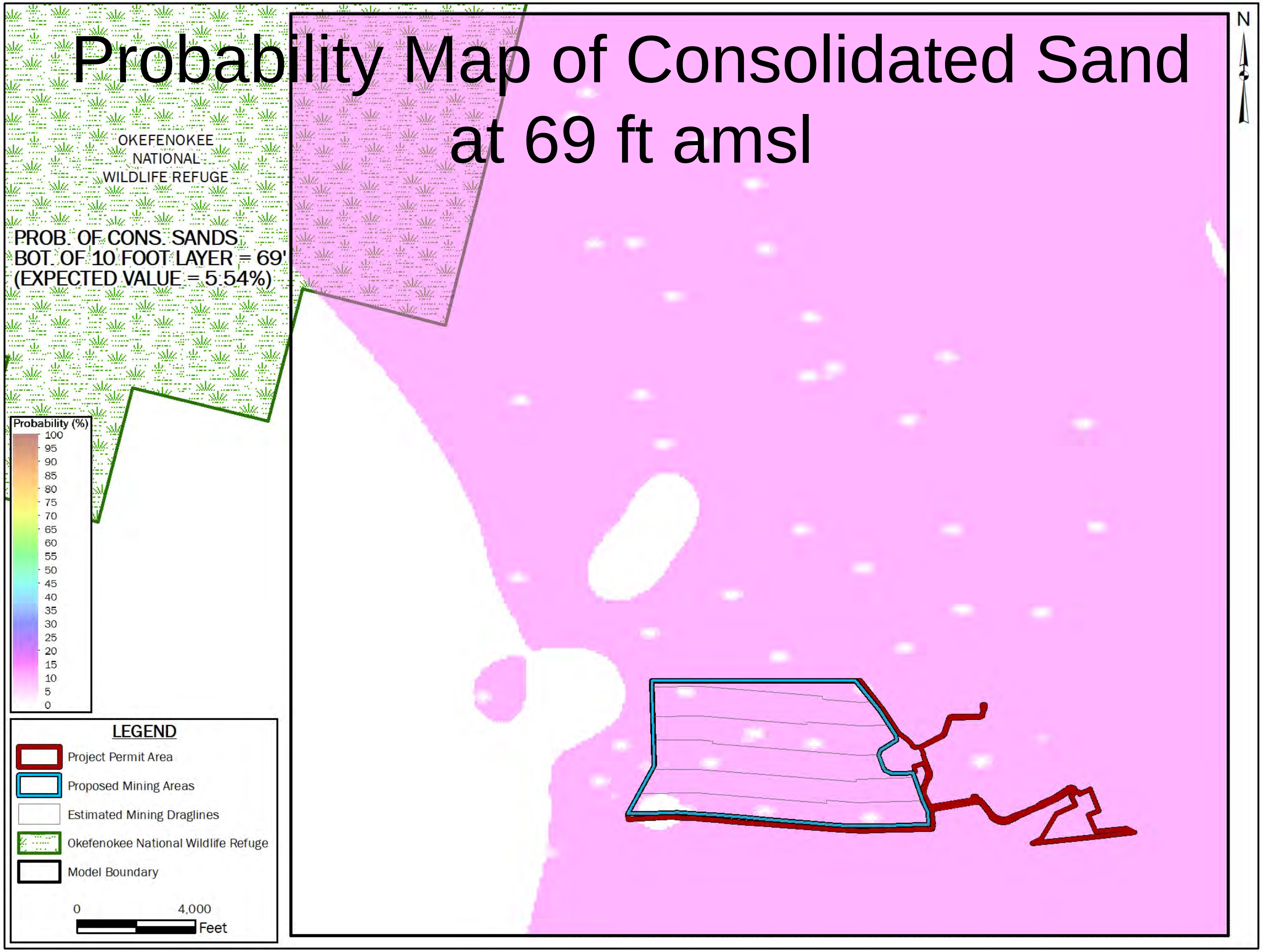
Probability Map of Consolidated Sand at 89 ft amsl



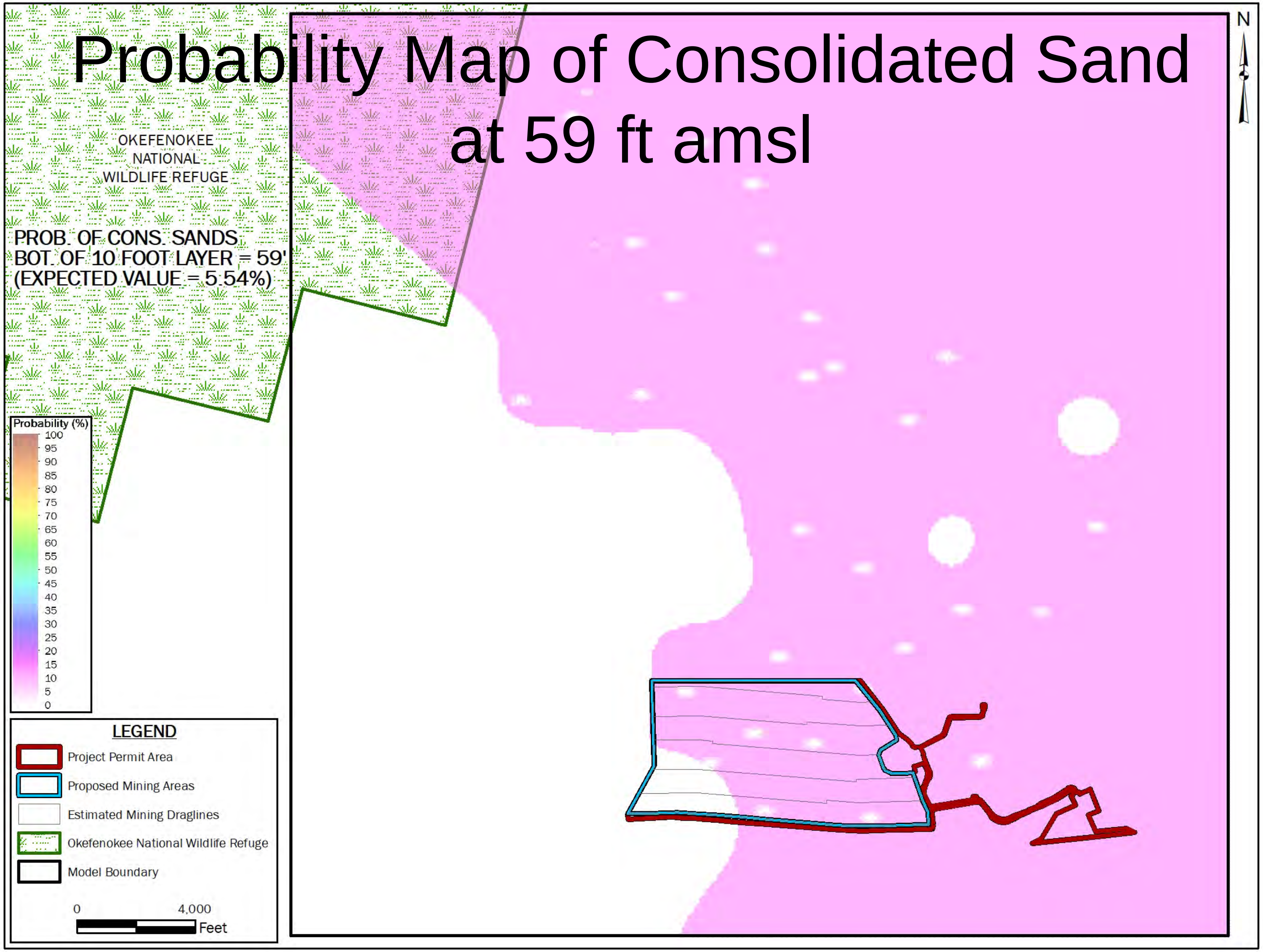
Probability Map of Consolidated Sand at 79 ft amsl



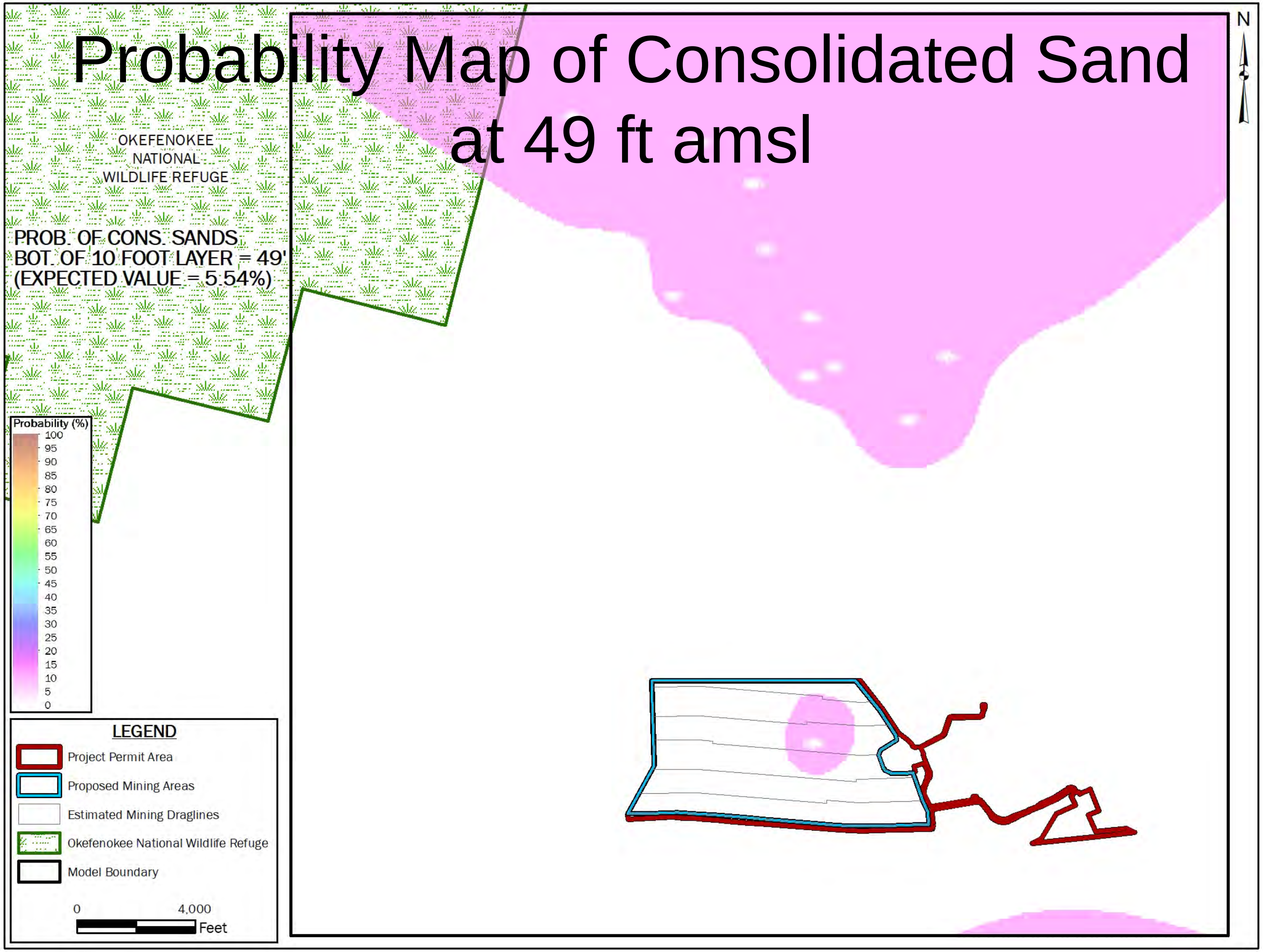
Probability Map of Consolidated Sand at 69 ft amsl



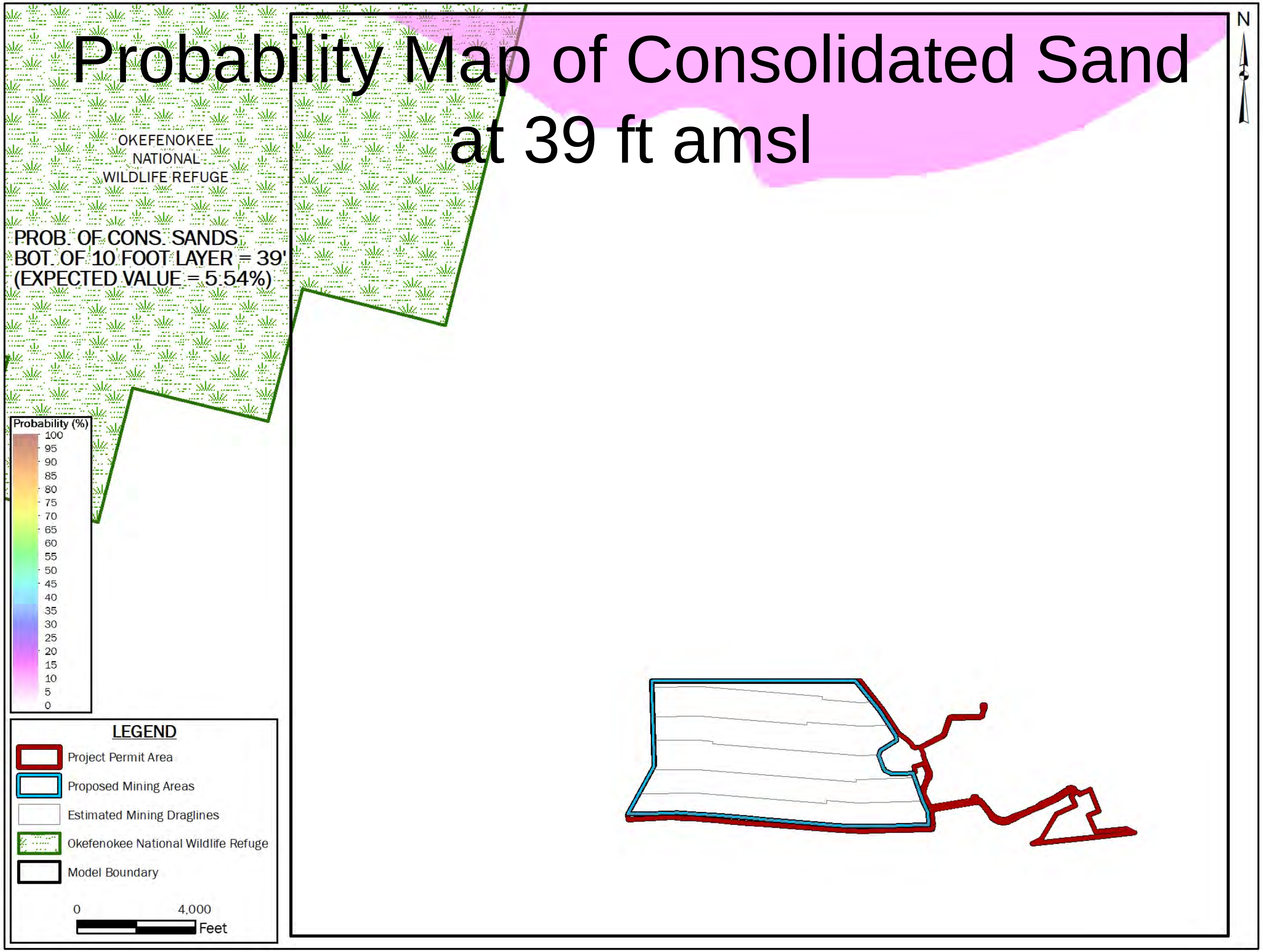
Probability Map of Consolidated Sand at 59 ft amsl



Probability Map of Consolidated Sand at 49 ft amsl



Probability Map of Consolidated Sand at 39 ft amsl

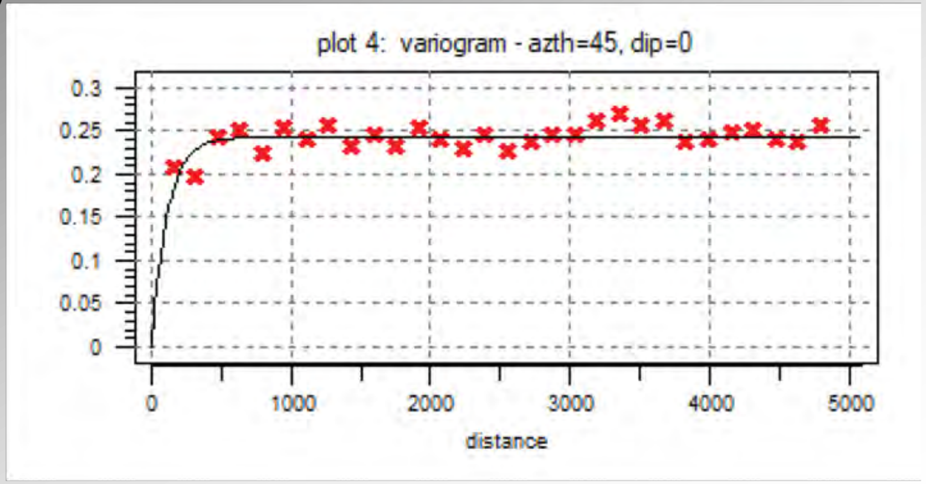


Unconsolidated Sand

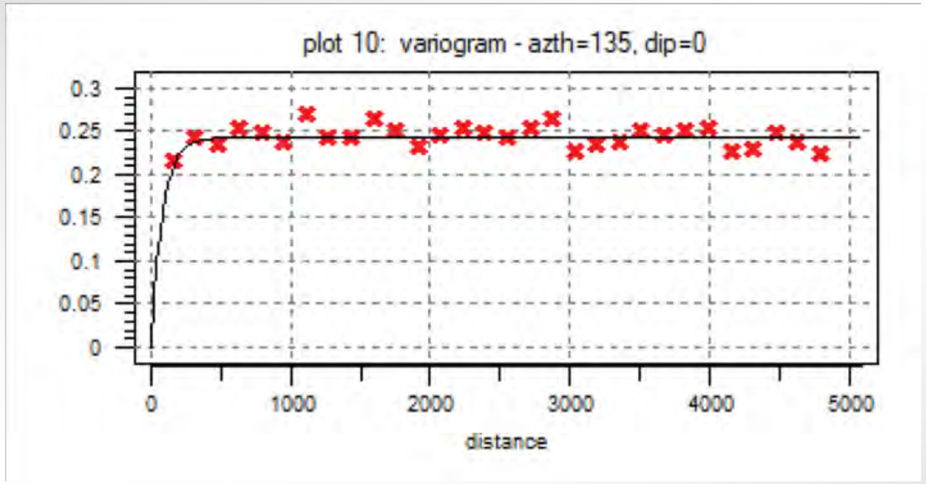
- Most abundant unit (58.33%)
- Consists of silty sands (SM) and well sorted sands (SP)

Unconsolidated Sand – Correlation Lengths

A)

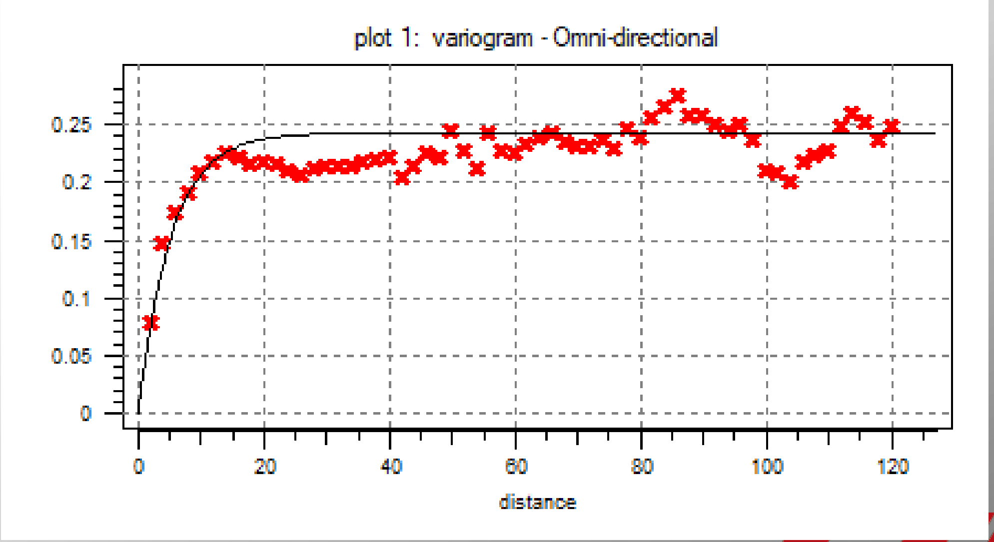


B)

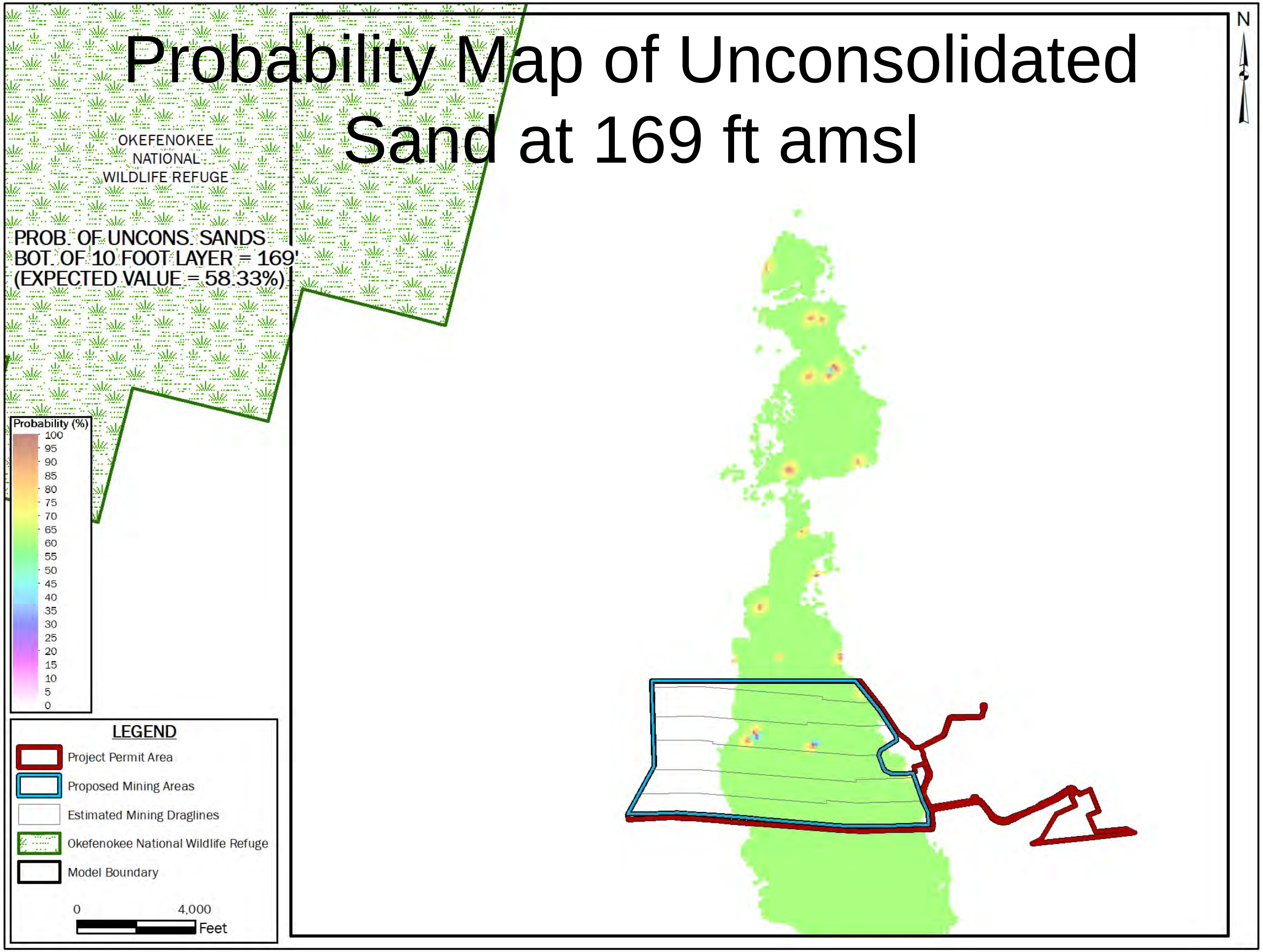


Horizontal correlation length = 336 ft max (az. = 45 degrees), 240 ft min (az. = 135 degrees)

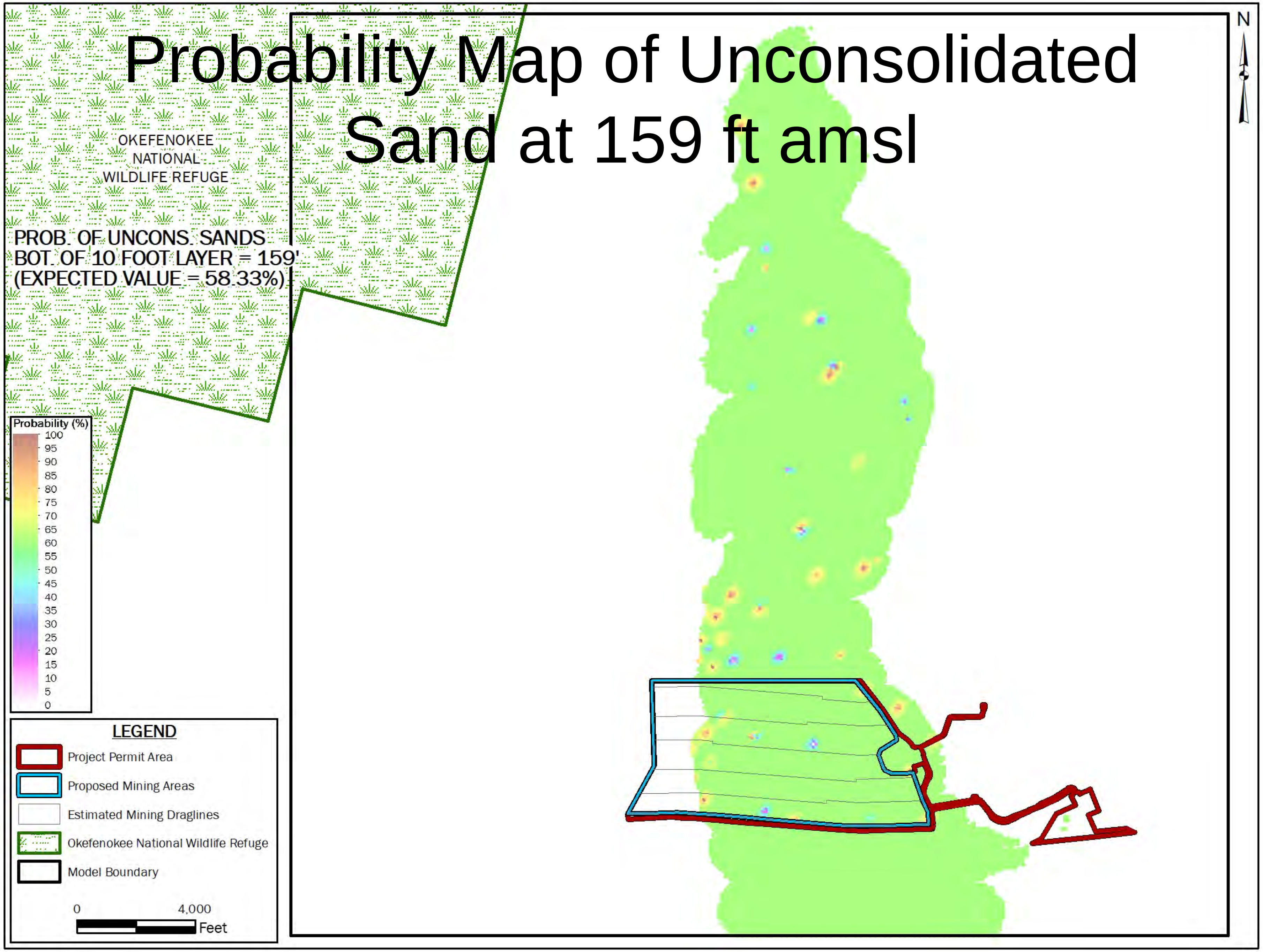
Vertical correlation length = 15.6 ft



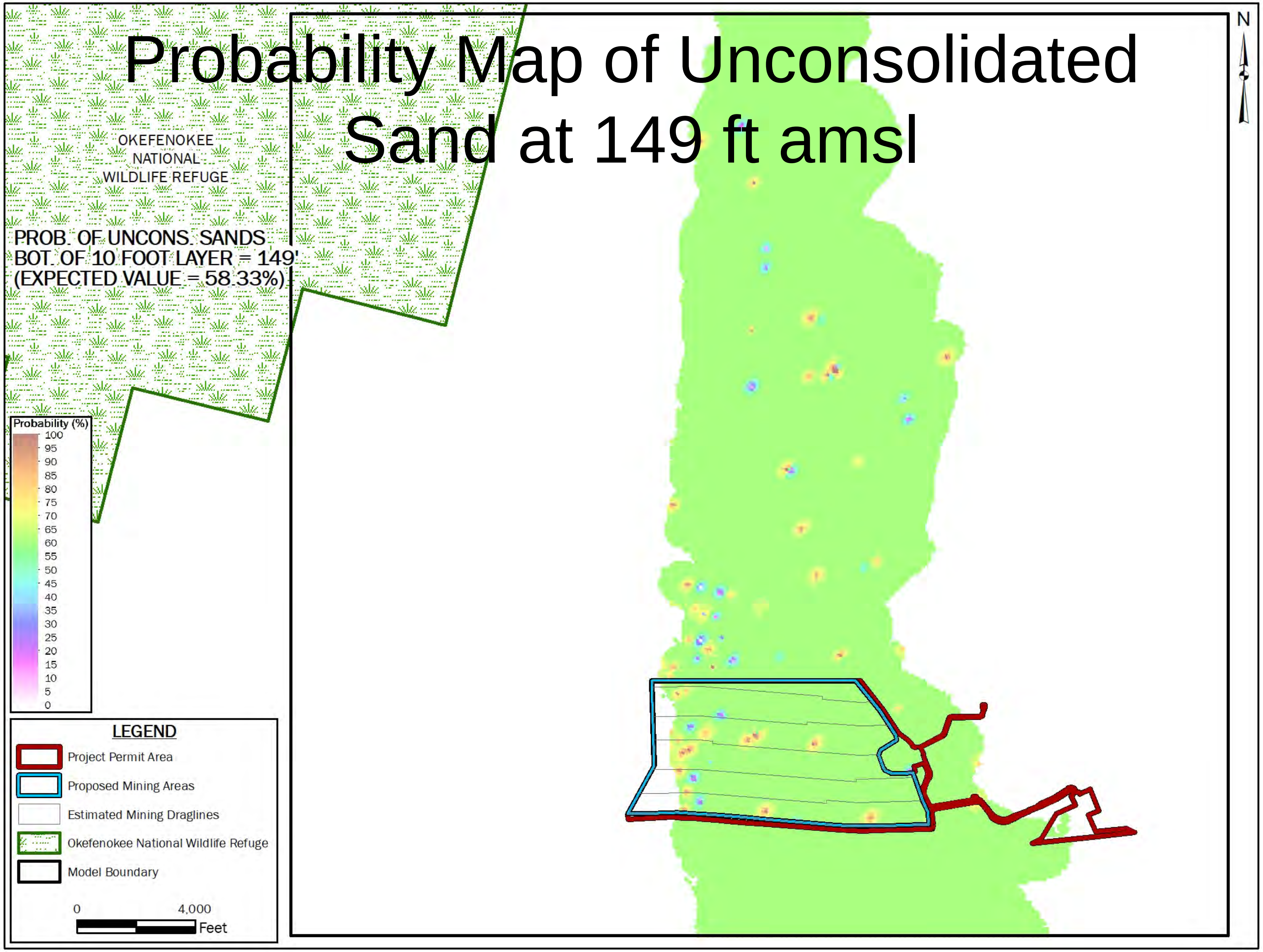
Probability Map of Unconsolidated Sand at 169 ft amsl



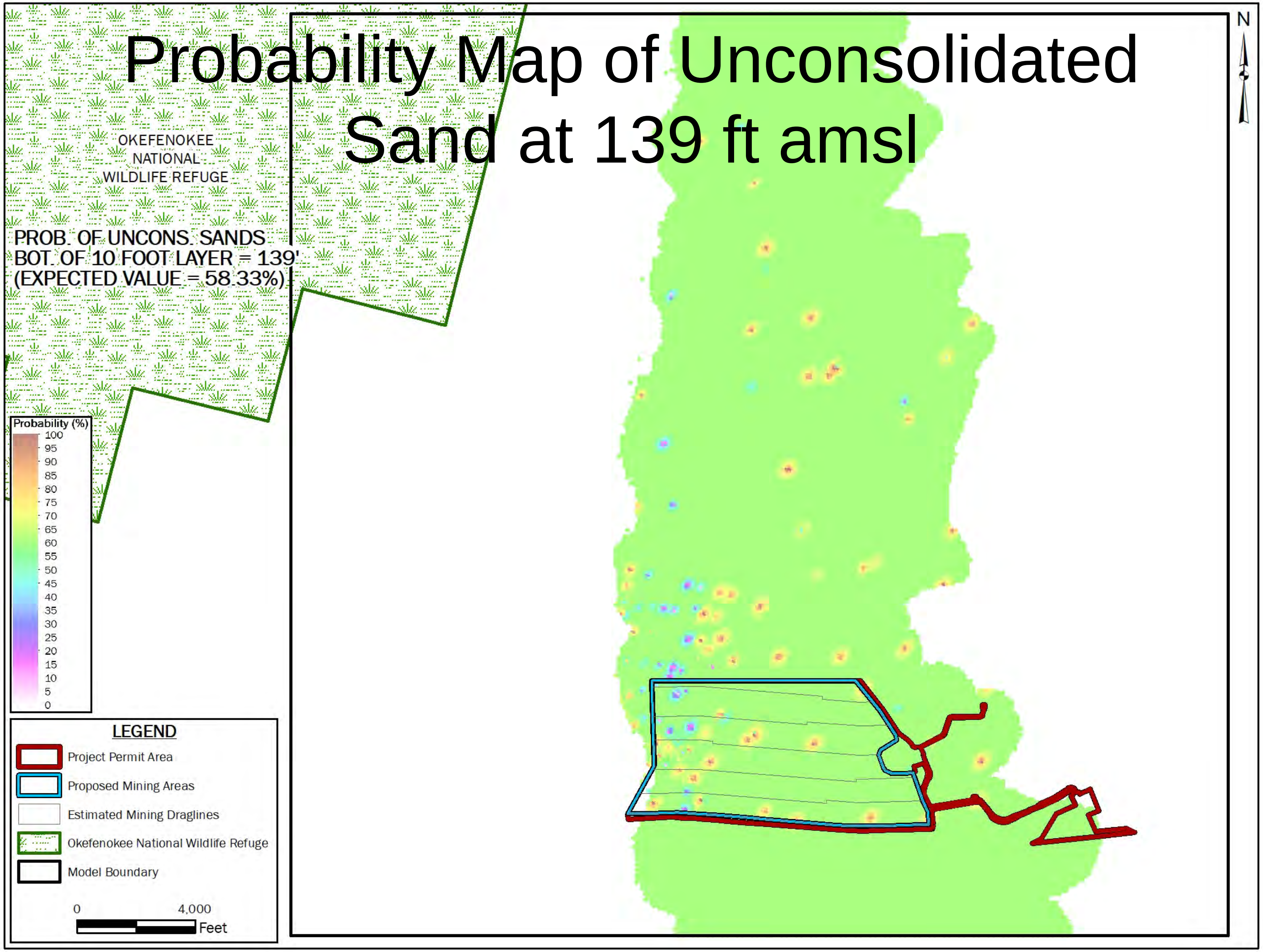
Probability Map of Unconsolidated Sand at 159 ft amsl



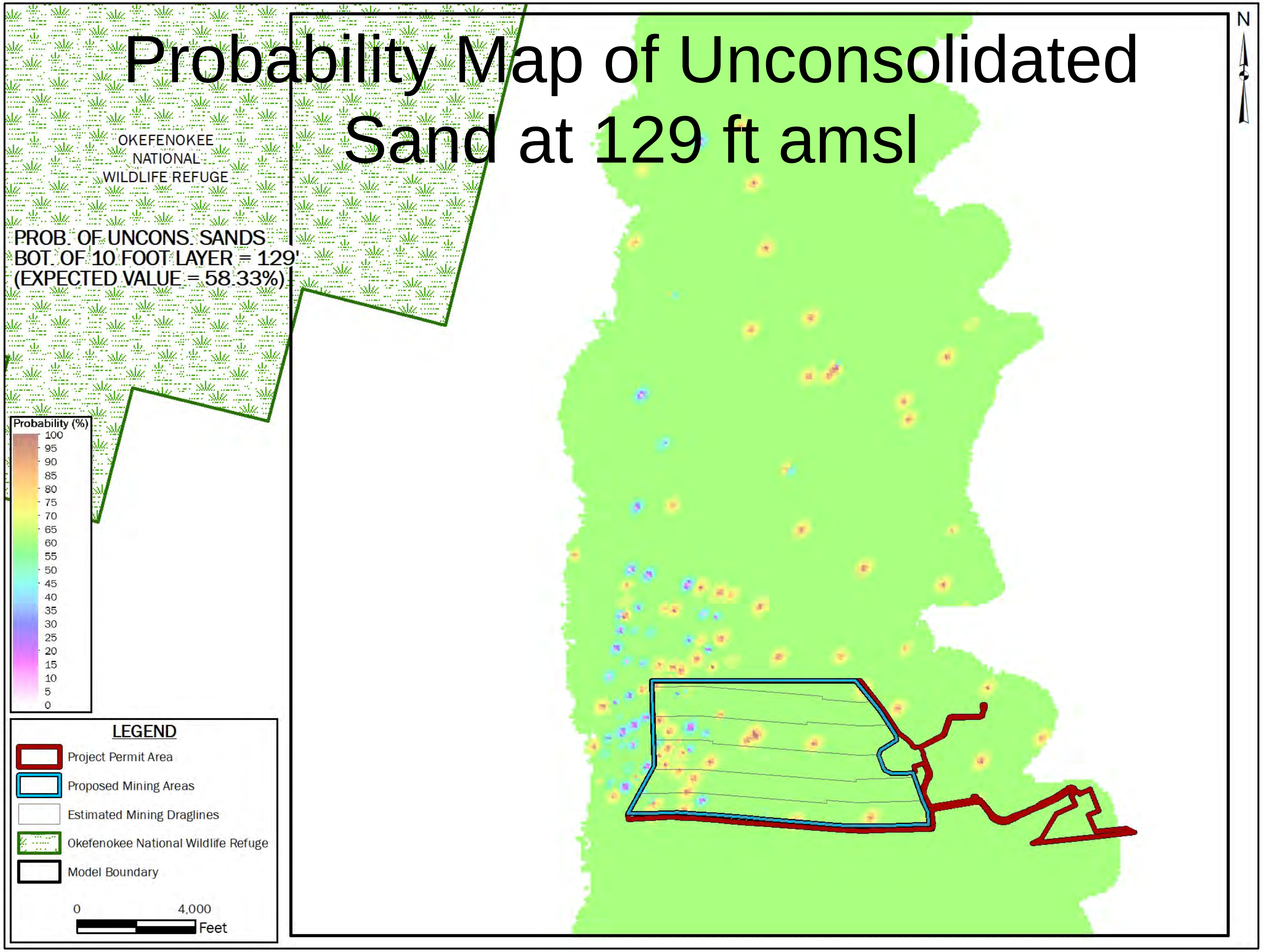
Probability Map of Unconsolidated Sand at 149 ft amsl



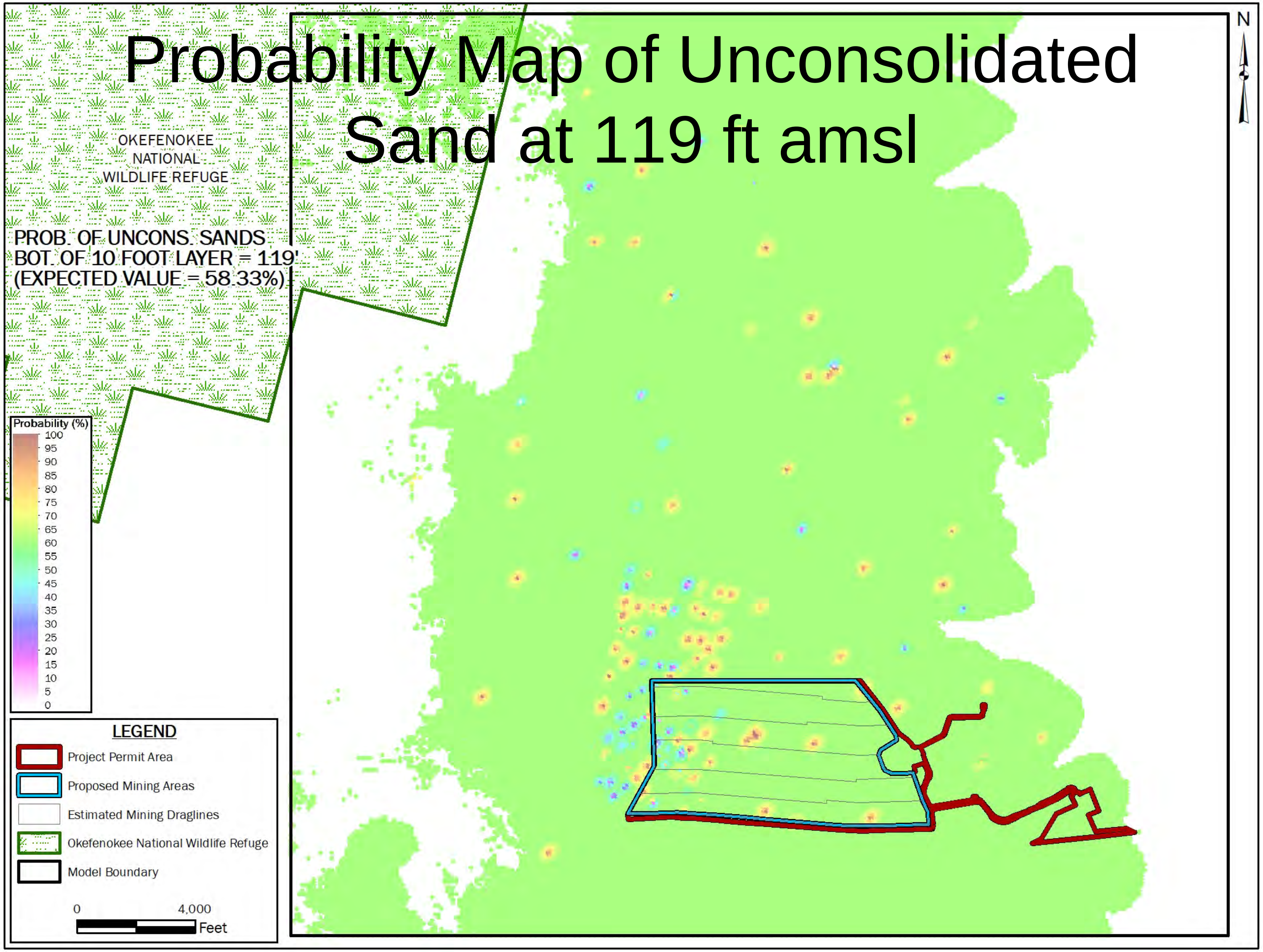
Probability Map of Unconsolidated Sand at 139 ft amsl



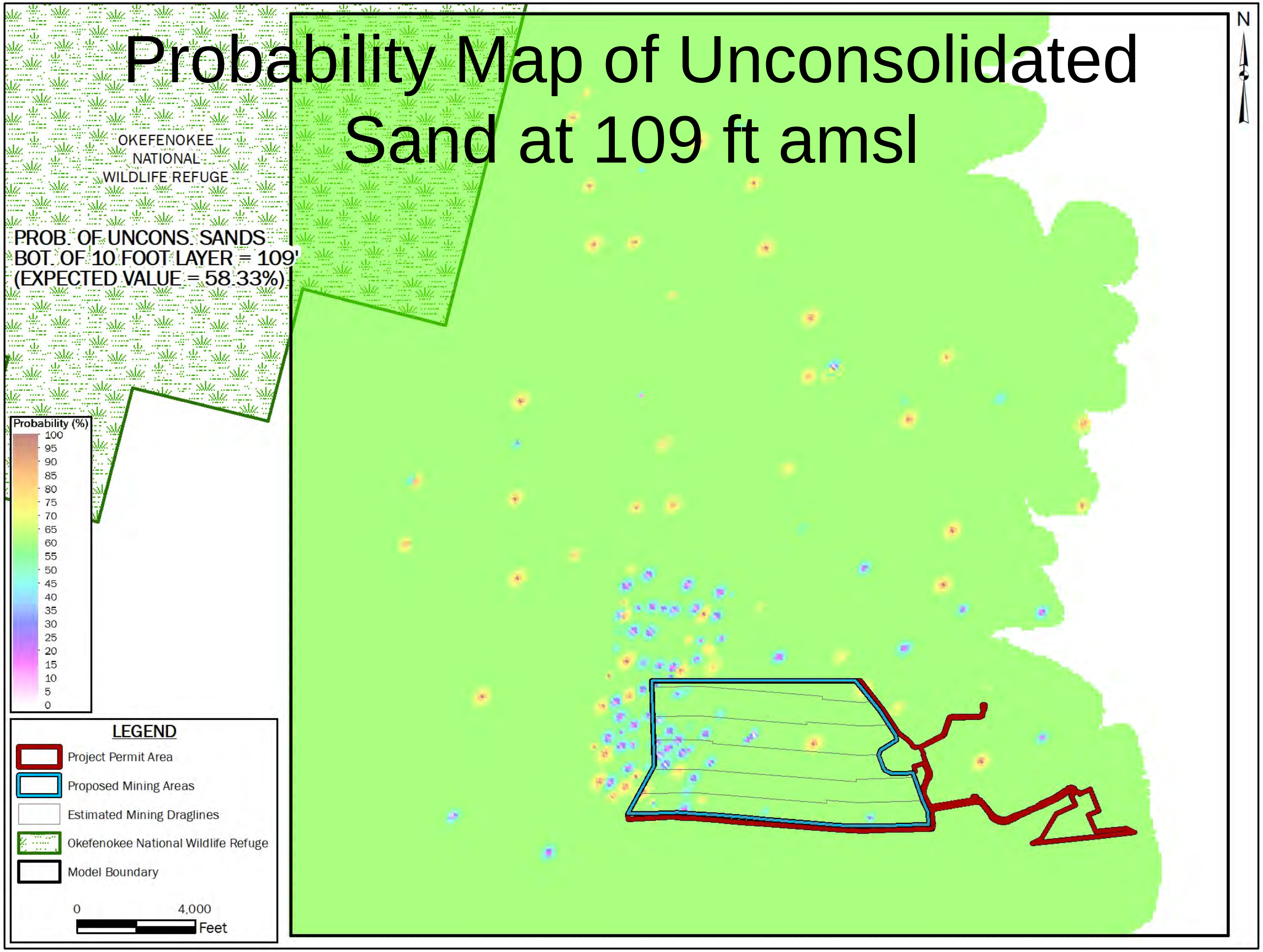
Probability Map of Unconsolidated Sand at 129 ft amsl



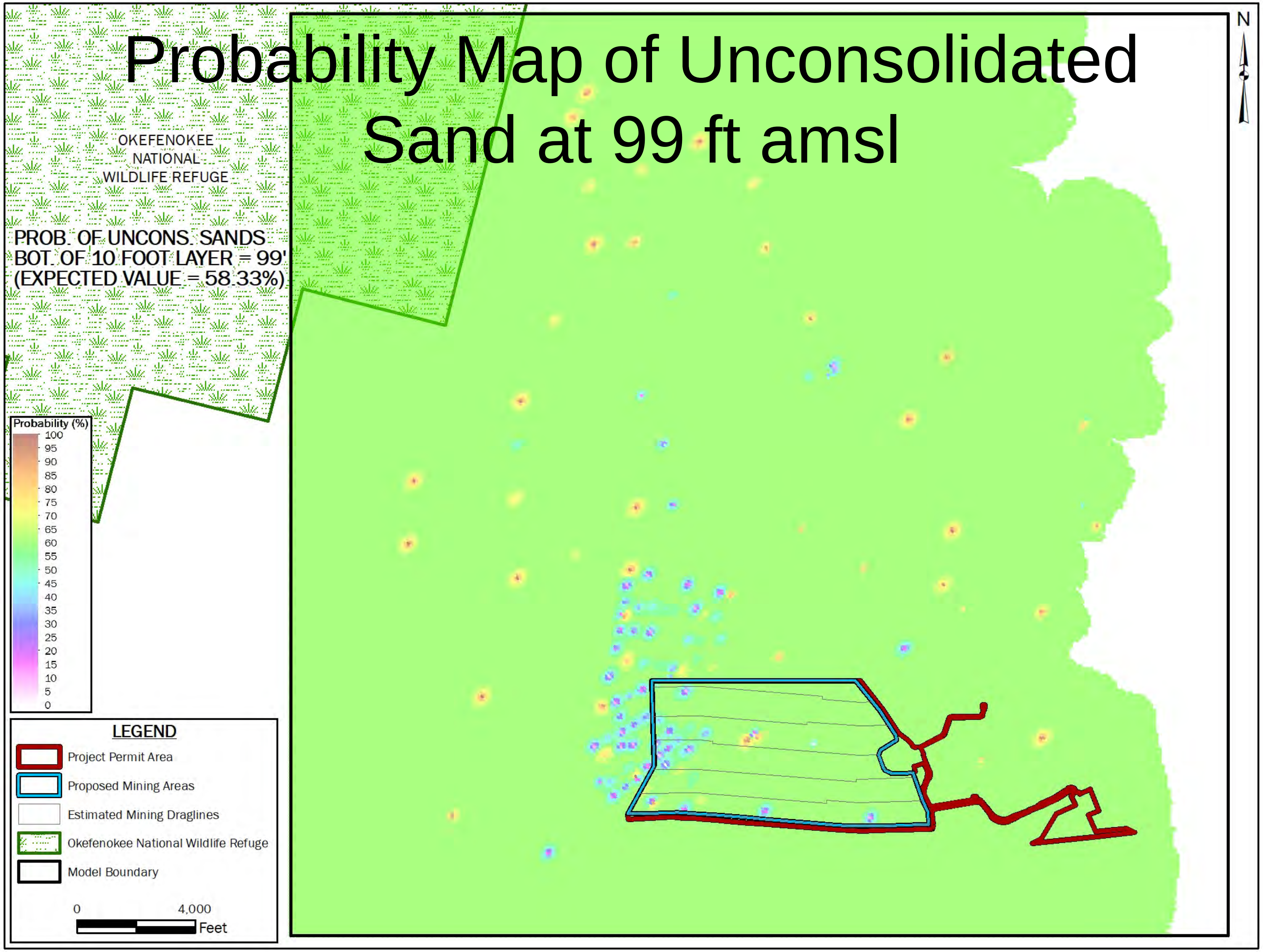
Probability Map of Unconsolidated Sand at 119 ft amsl



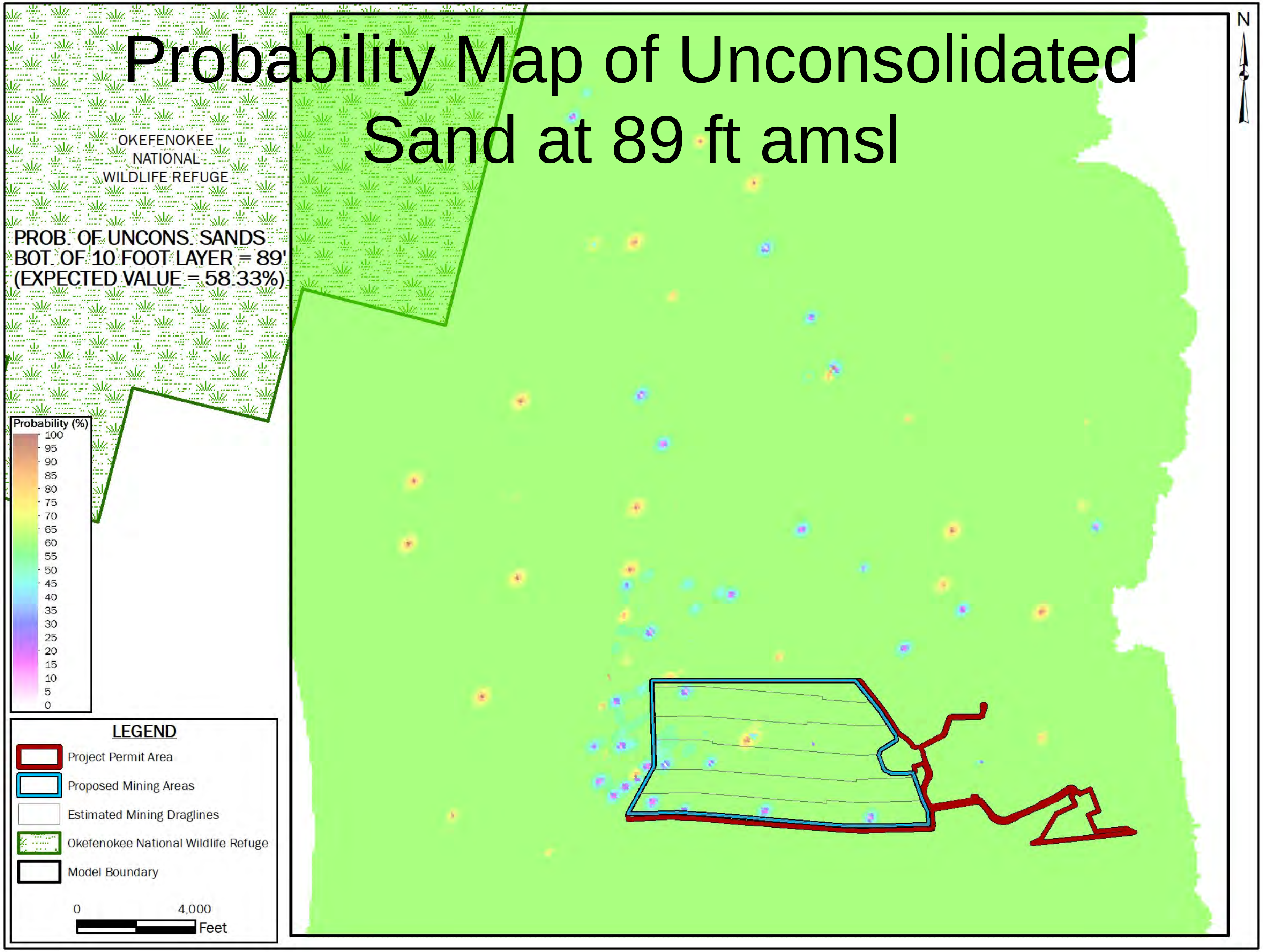
Probability Map of Unconsolidated Sand at 109 ft amsl



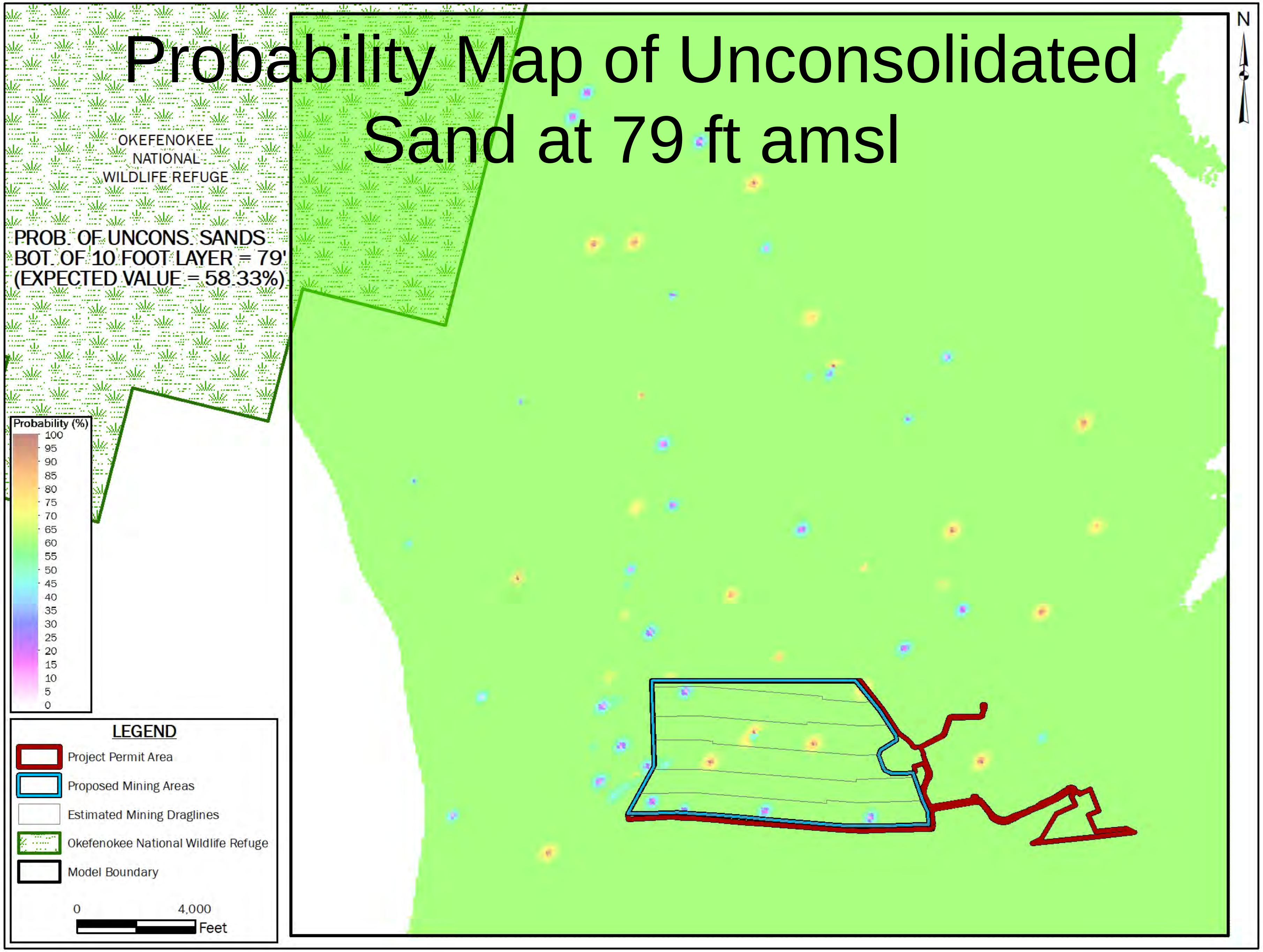
Probability Map of Unconsolidated Sand at 99 ft amsl



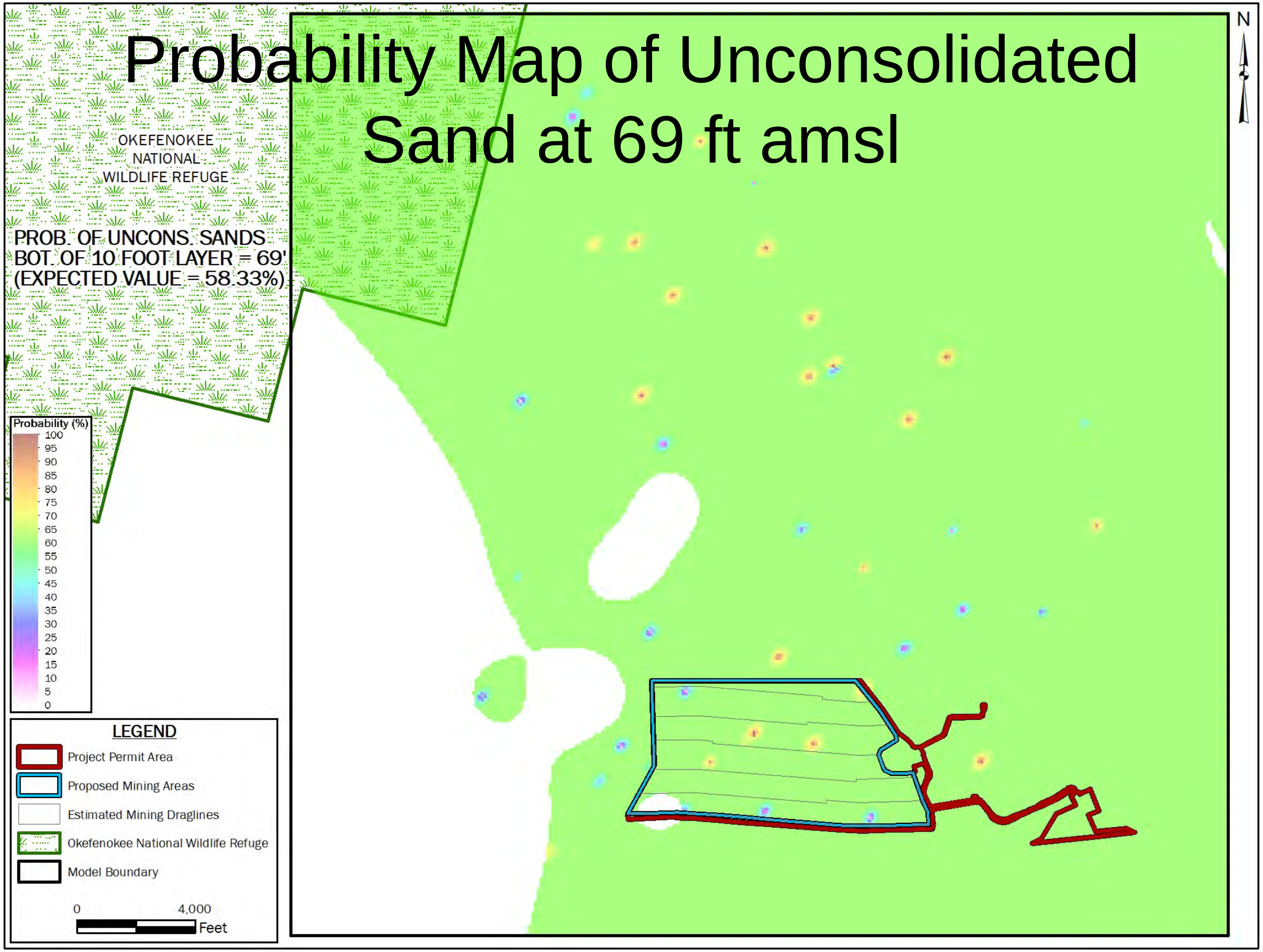
Probability Map of Unconsolidated Sand at 89 ft amsl



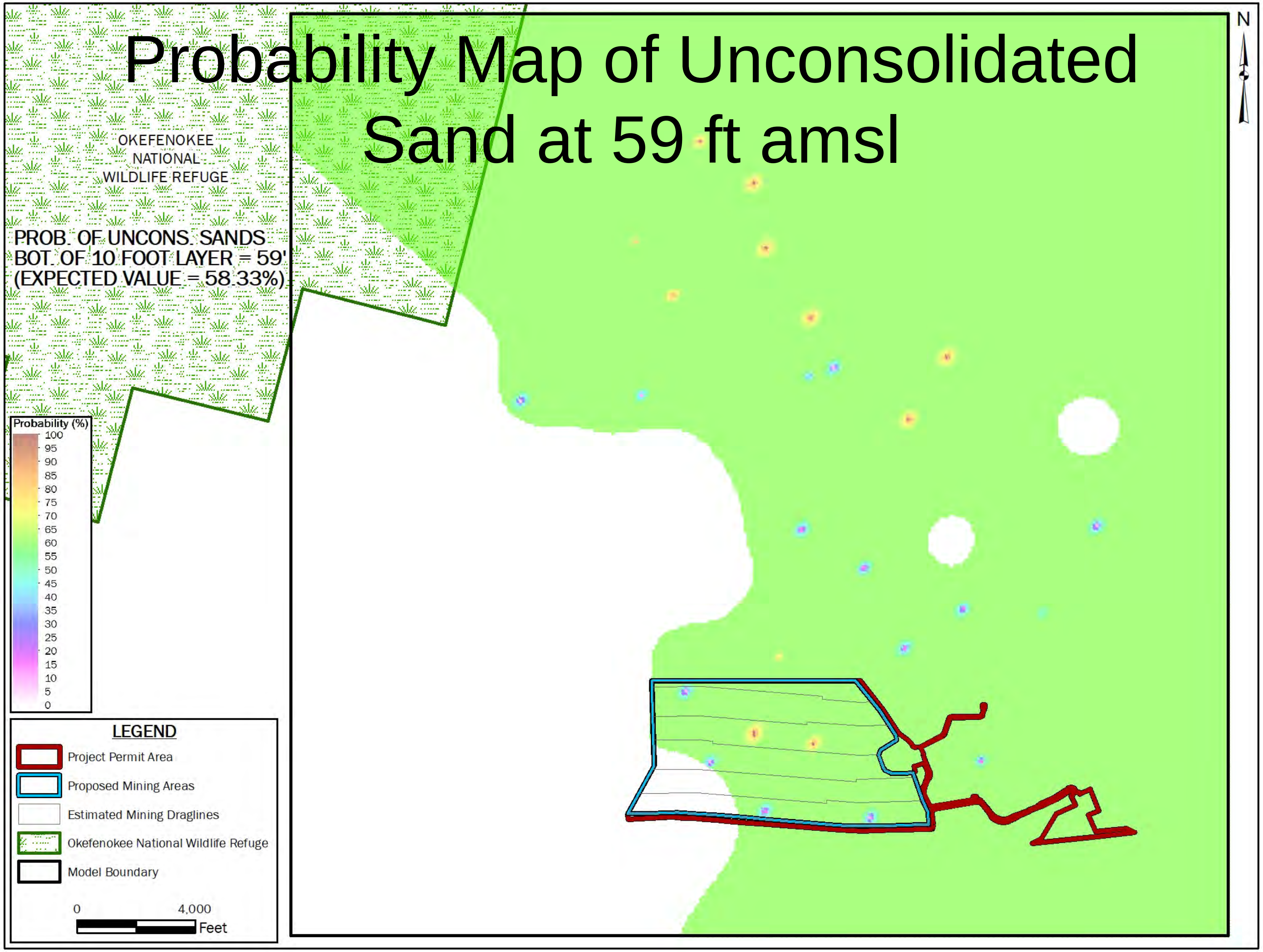
Probability Map of Unconsolidated Sand at 79 ft amsl



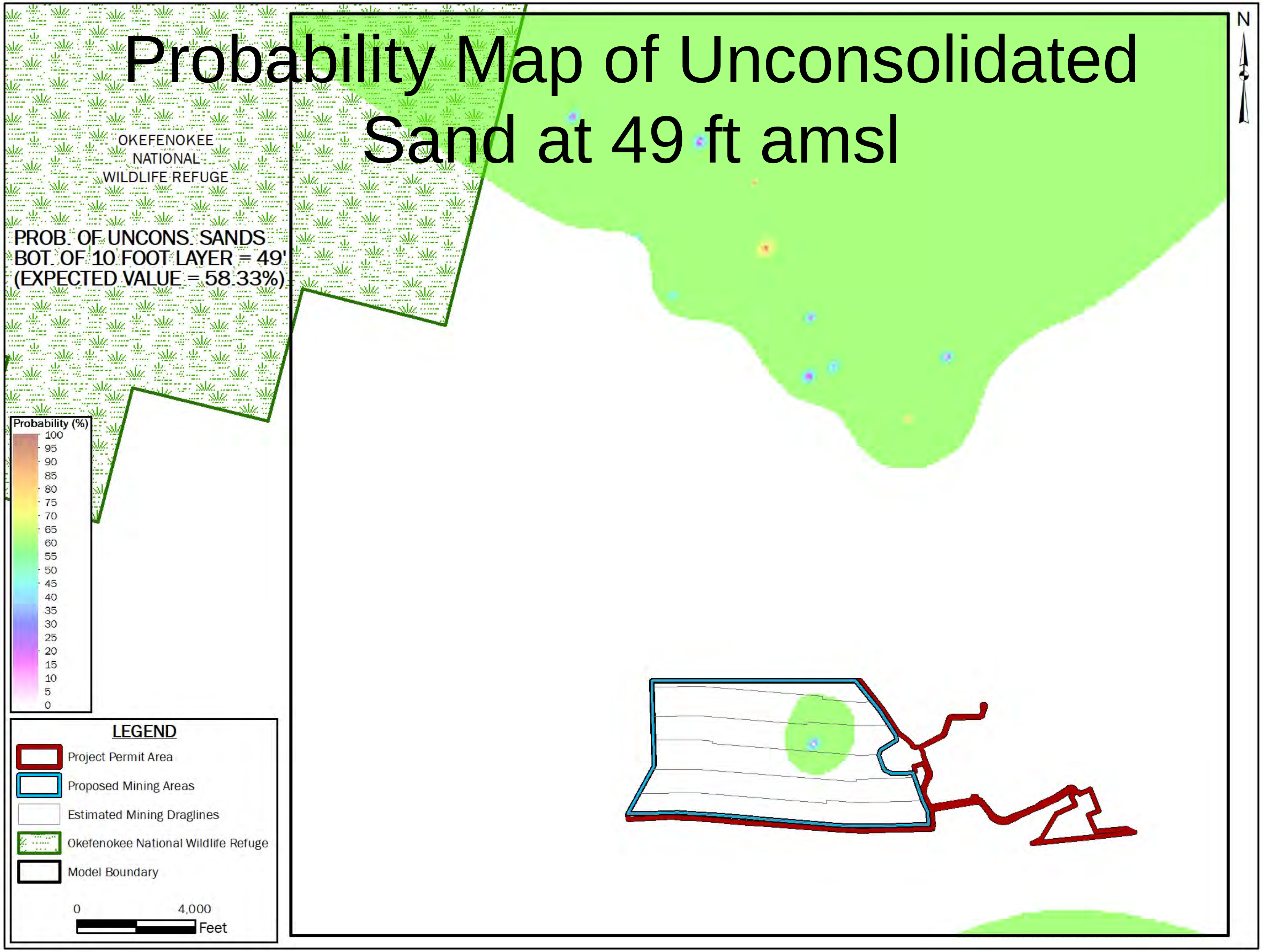
Probability Map of Unconsolidated Sand at 69 ft amsl



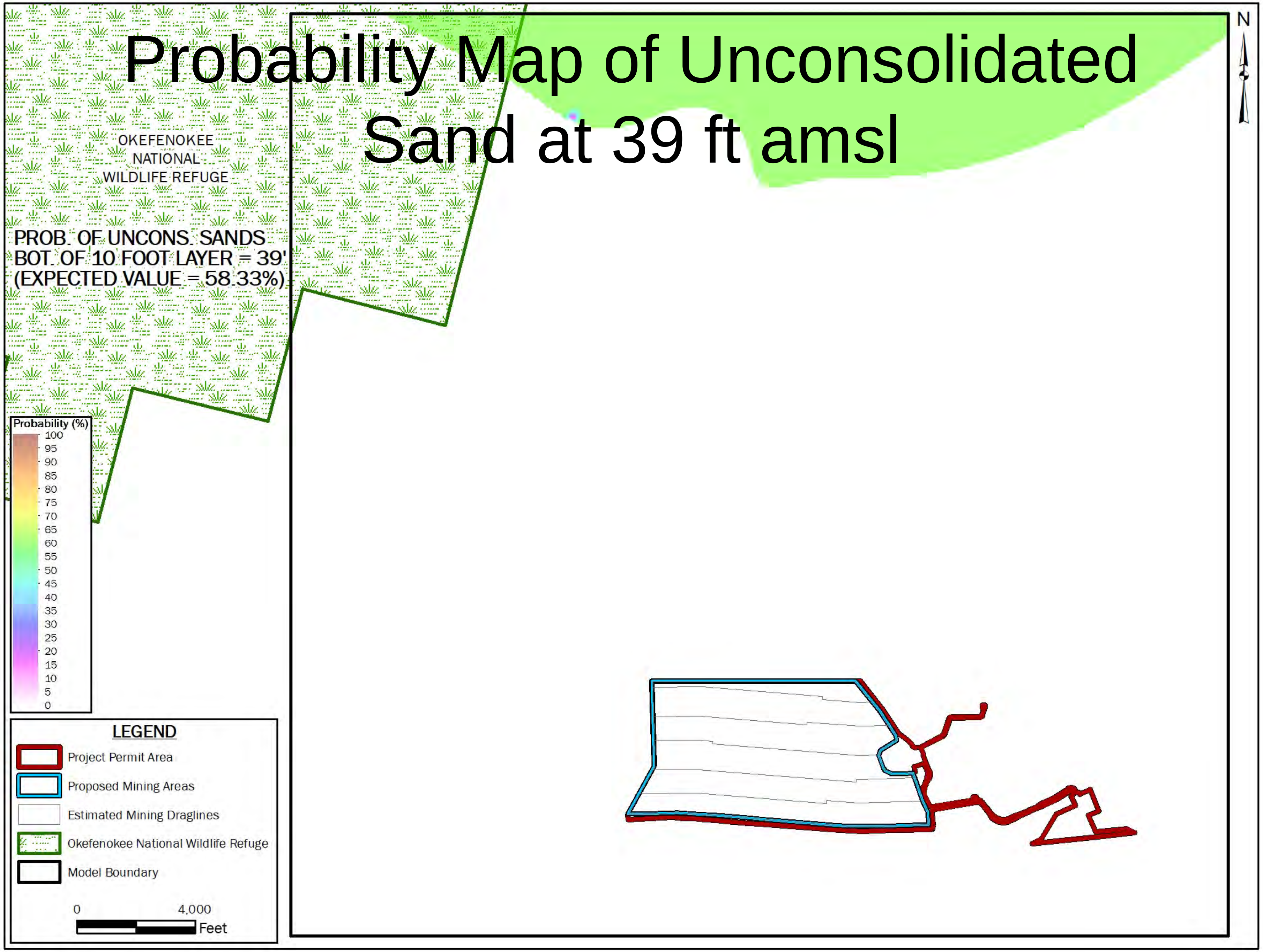
Probability Map of Unconsolidated Sand at 59 ft amsl



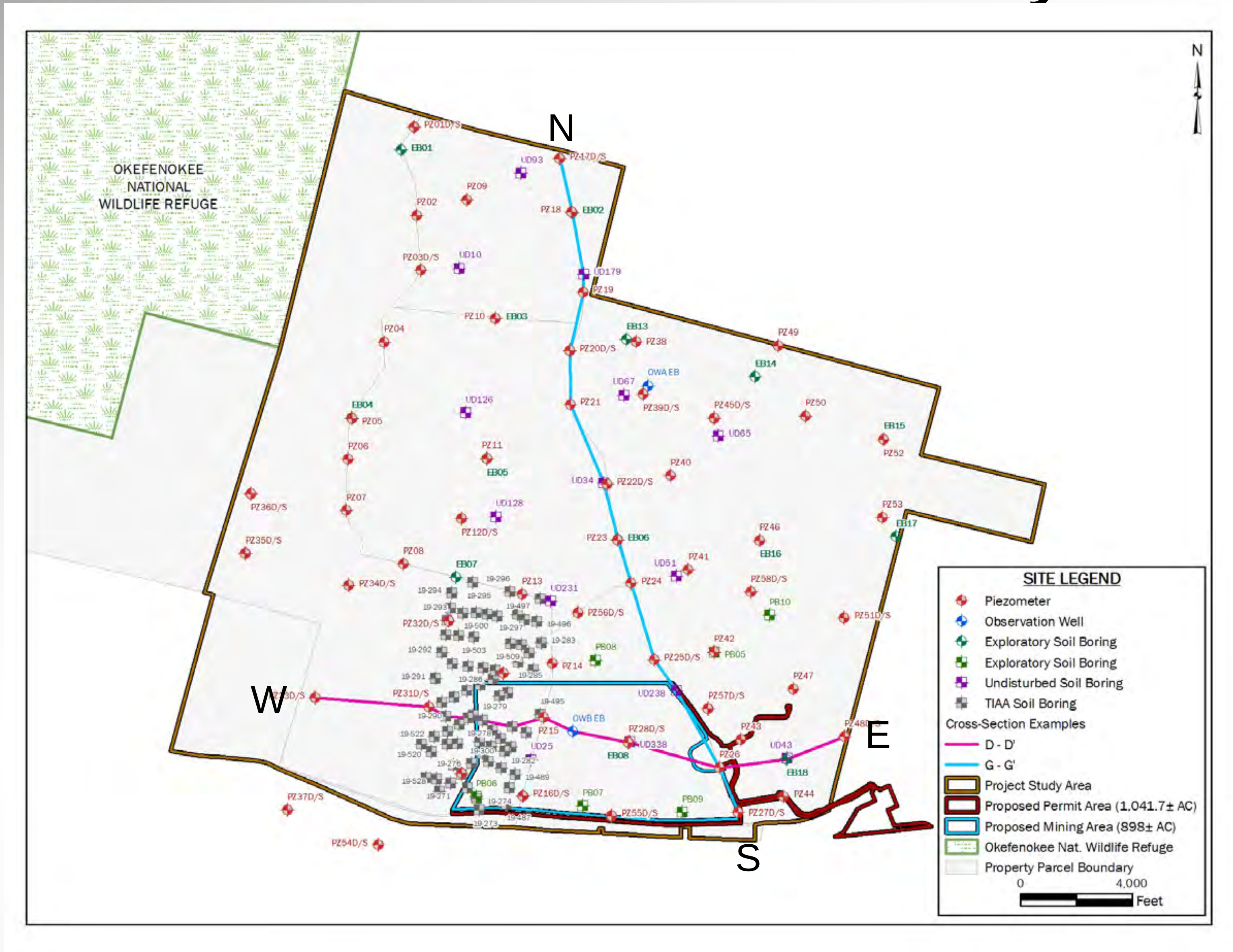
Probability Map of Unconsolidated Sand at 49 ft amsl



Probability Map of Unconsolidated Sand at 39 ft amsl

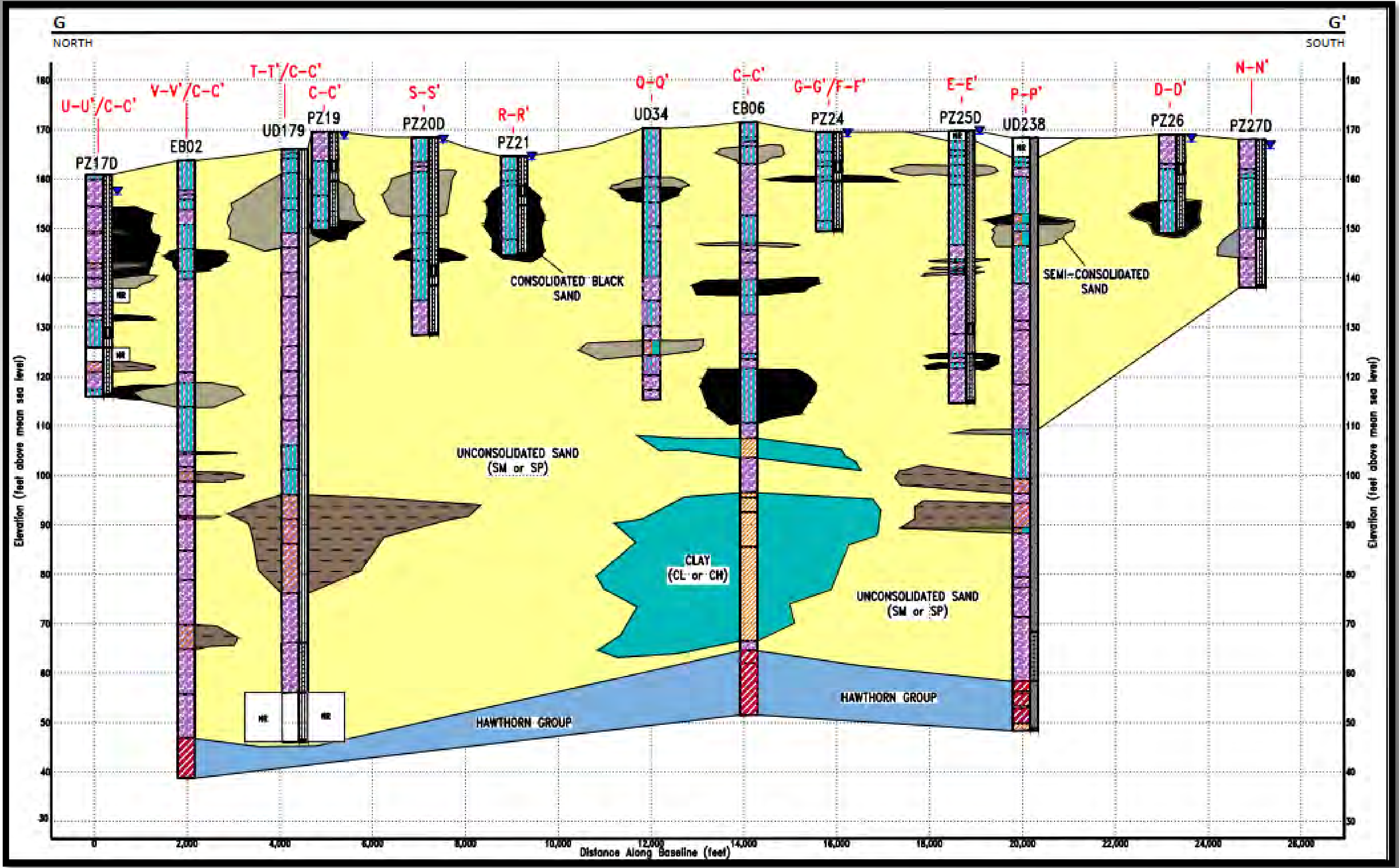


Geologic Cross-Sections Reflect the Results of the Geostatistical Study



NORTH-SOUTH GEOLOGIC CROSS SECTION

N S



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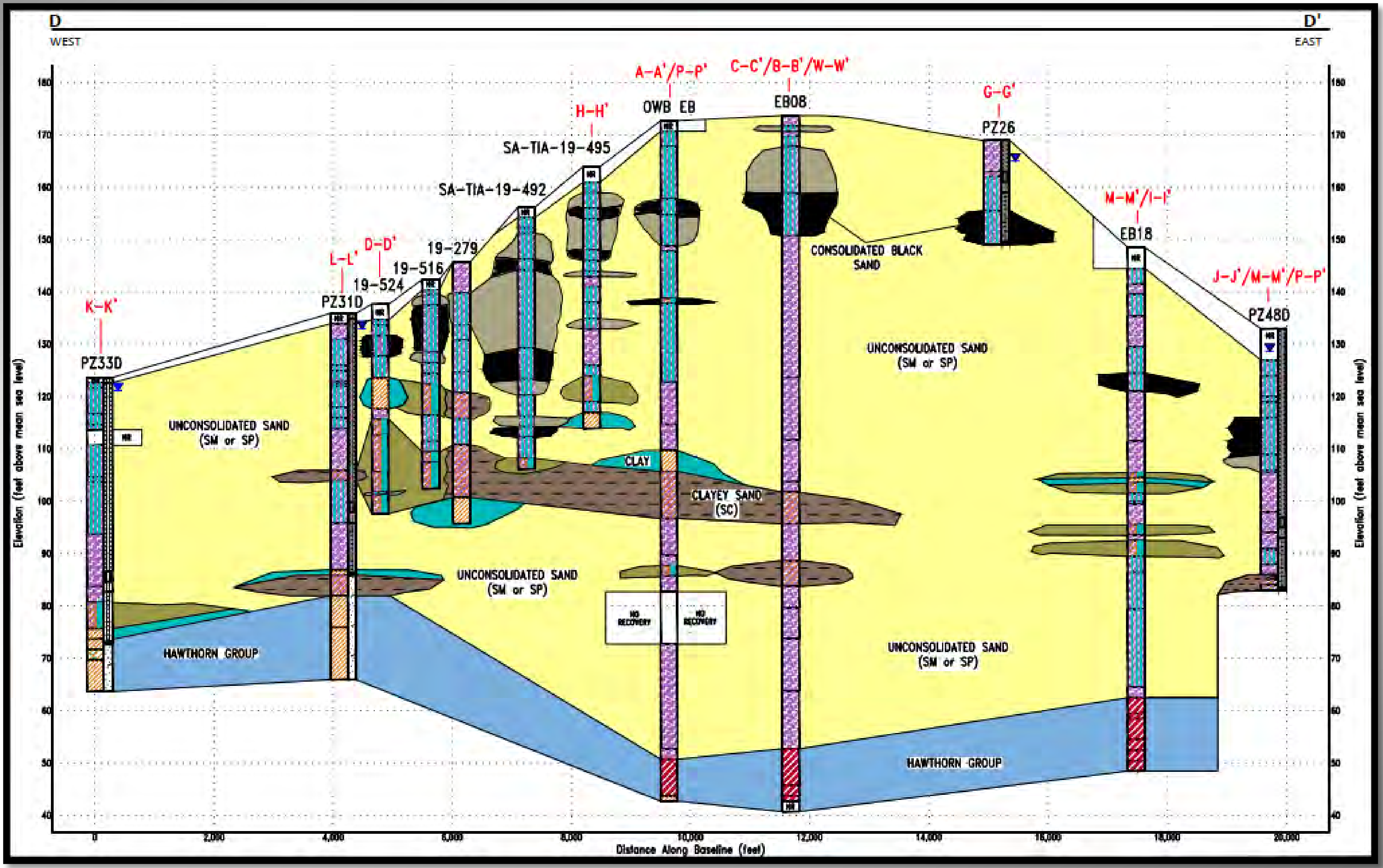
WEST-EAST GEOLOGIC CROSS SECTION

W E



Summary of the Geology

- 7 distinct geologic units are present in the subsurface
- Unconsolidated sand is the most abundant (58.33%)
- Consolidated sands are rare (5.54%)
- All units are very discontinuous with maximum horizontal correlation lengths ranging from 336 ft (unconsolidated sand and clay) to 912 ft (silty-clayey sand)
- Humate stains and cements are secondary, formed due to circulating groundwaters, and occur mainly above 120 ft amsl
- Clays are likely derived from the Hawthorn Group and mainly occur below 120 ft amsl

Groundwater Models of the Surficial Aquifer

Groundwater Modeling Background

- We applied two types of groundwater models to evaluate the impact of the proposed mine demonstration project:
  1. Steady-state numerical models (a numerical approximation that allows heterogeneous aquifers)– To simulate the average behavior of the aquifer. Two scenarios were considered:
     - A pre-mining condition – A calibrated model that can reproduce the observed water-levels in wells and piezometers
     - A post mining condition – A modification of the pre-mining model to assess the impact of homogenizing the mine pit
  2. An analytical model (exact mathematical solution for homogeneous aquifers) – To evaluate the impact of drawdown caused by the moving mine

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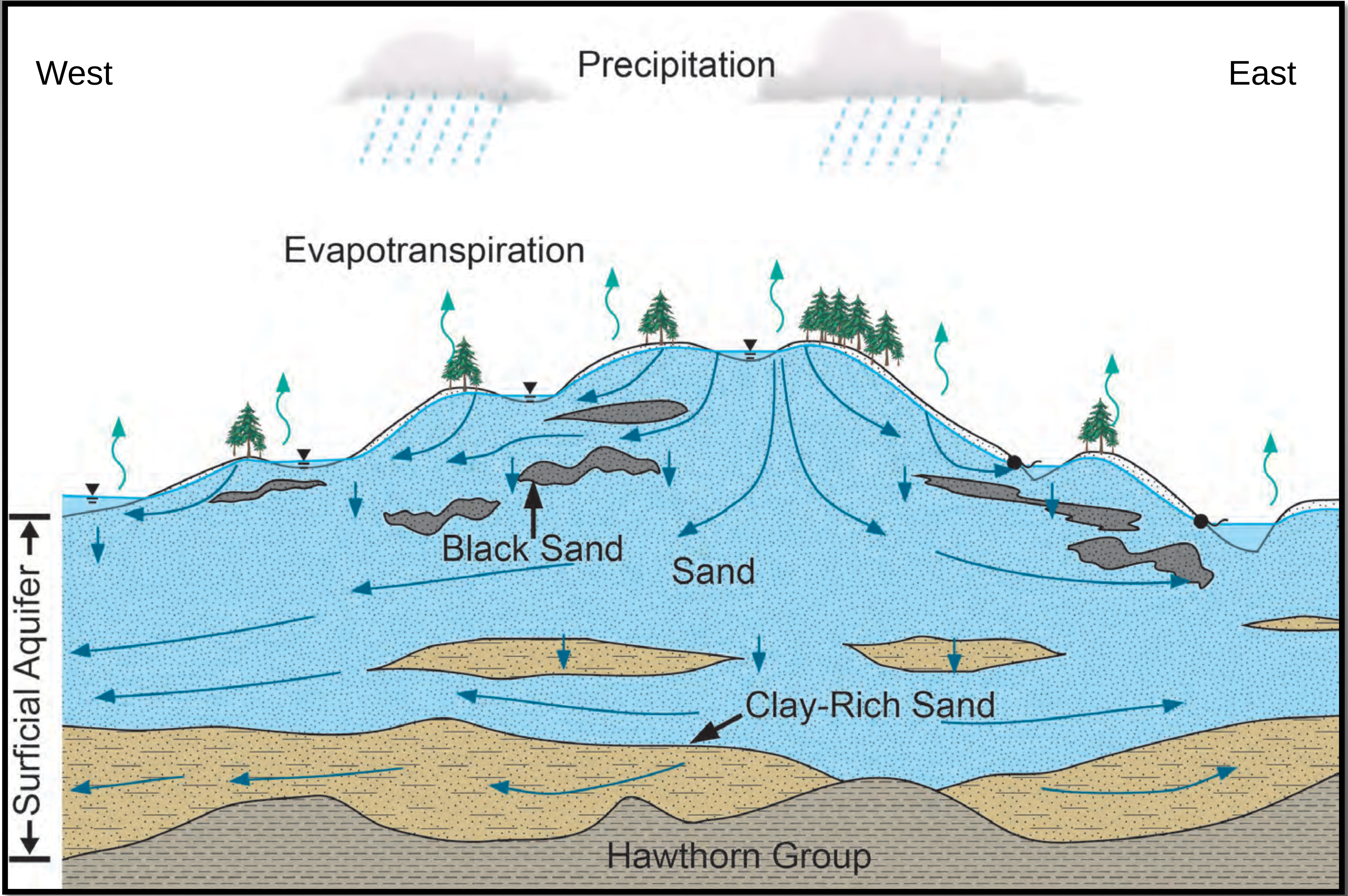
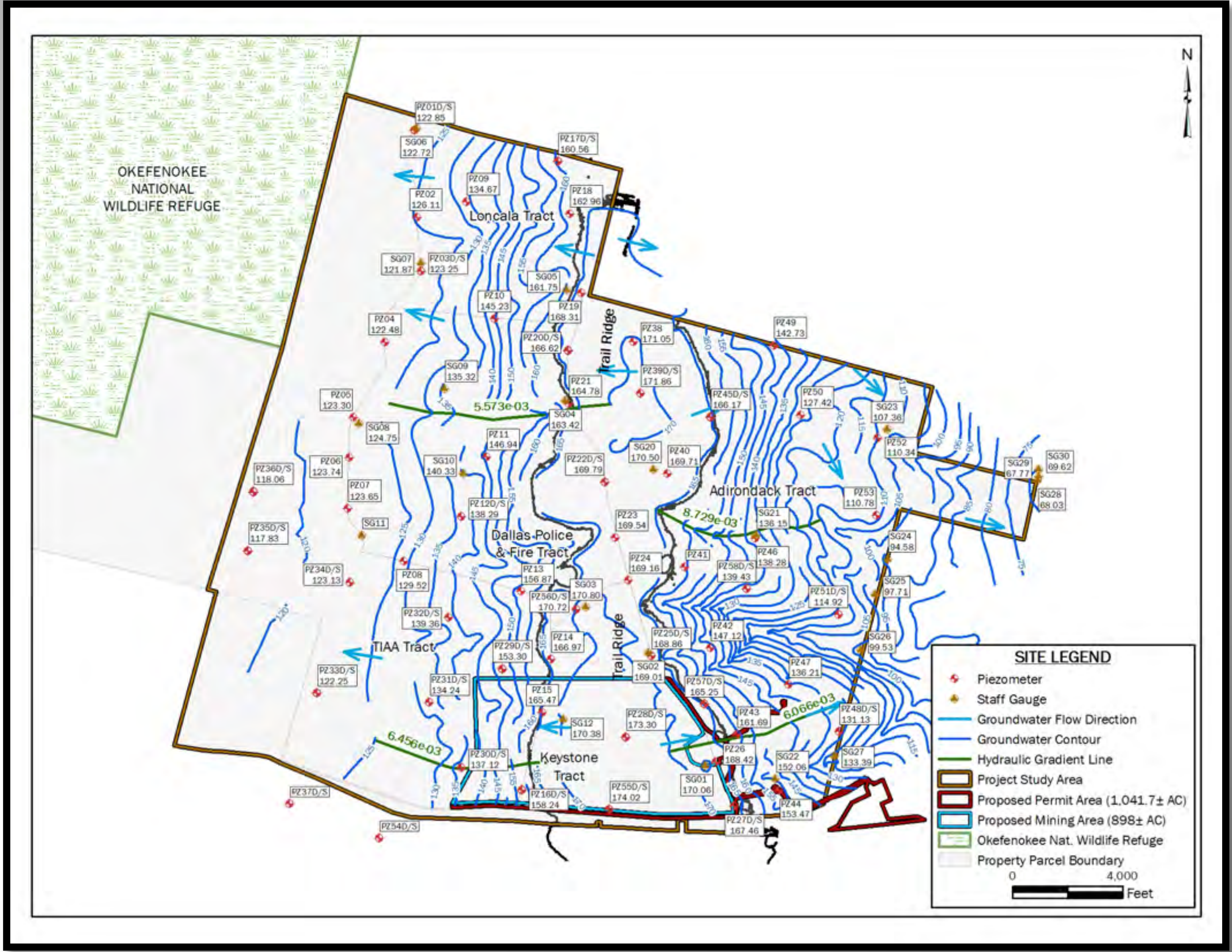
Steady-State Numerical Model

Conceptual Hydrogeologic Model

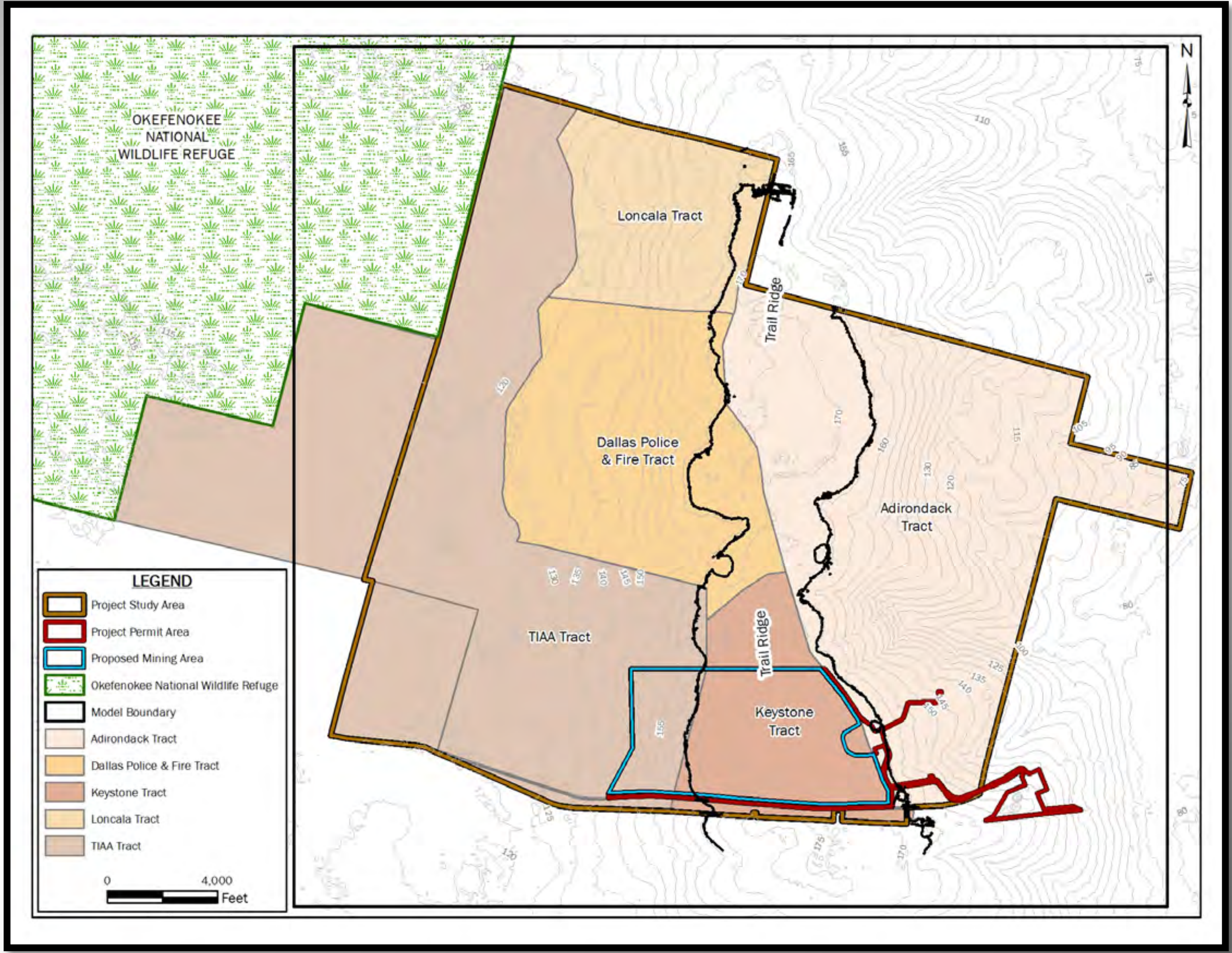


The Numerical Model was Calibrated to Match Groundwater Levels Observed on July 26, 2019

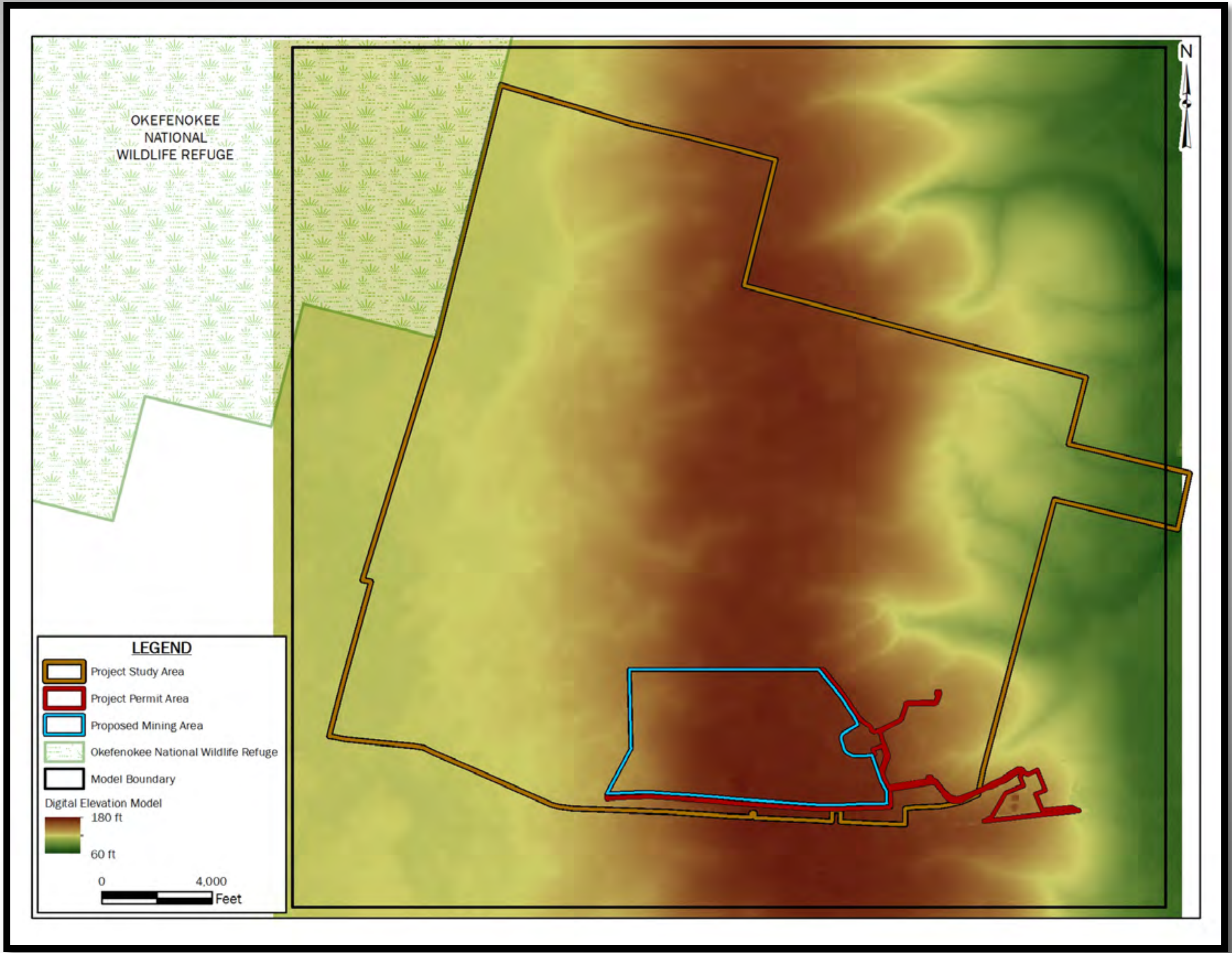


Model boundaries to the north and south east- and west-flowing streamlines

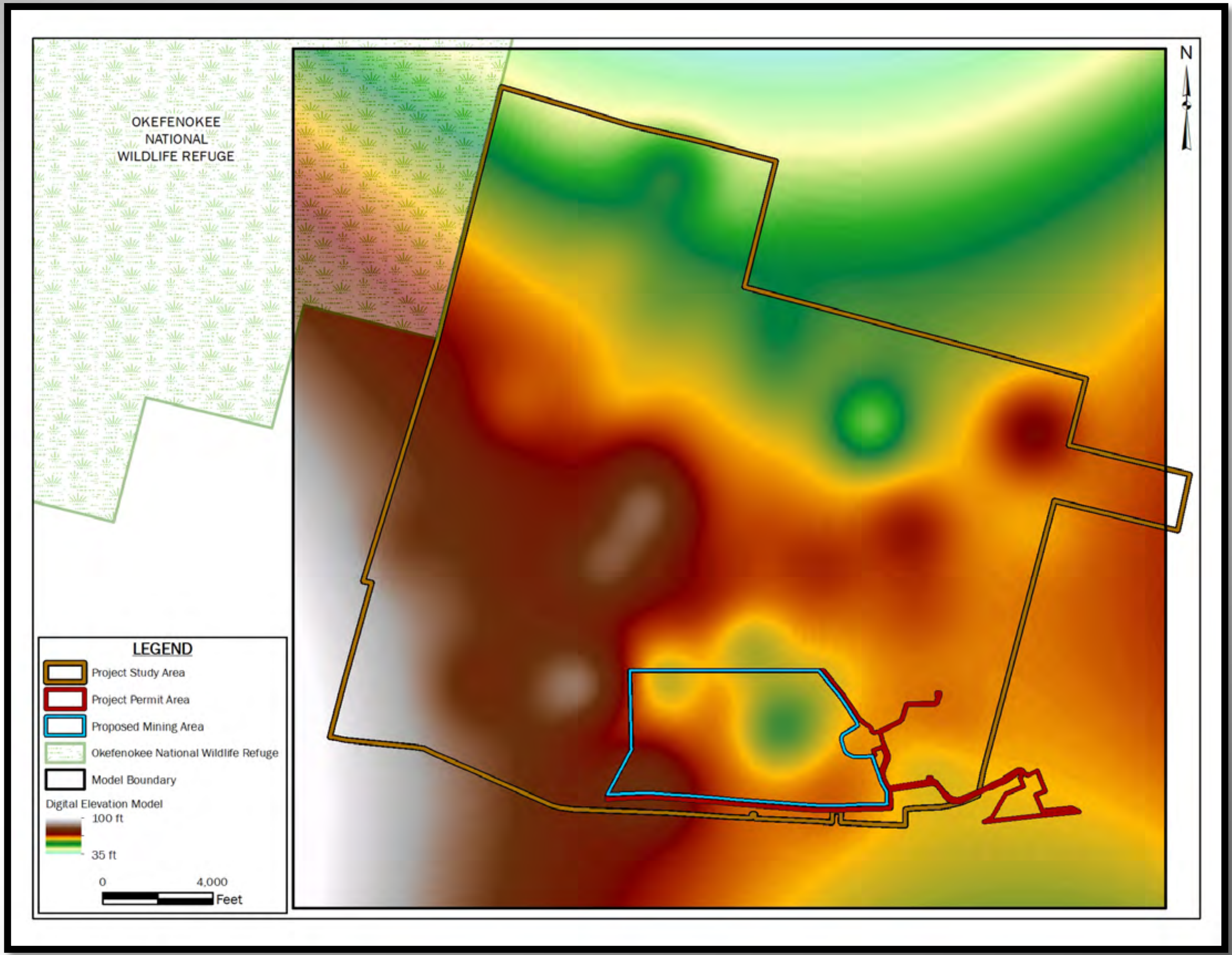
Model Boundary



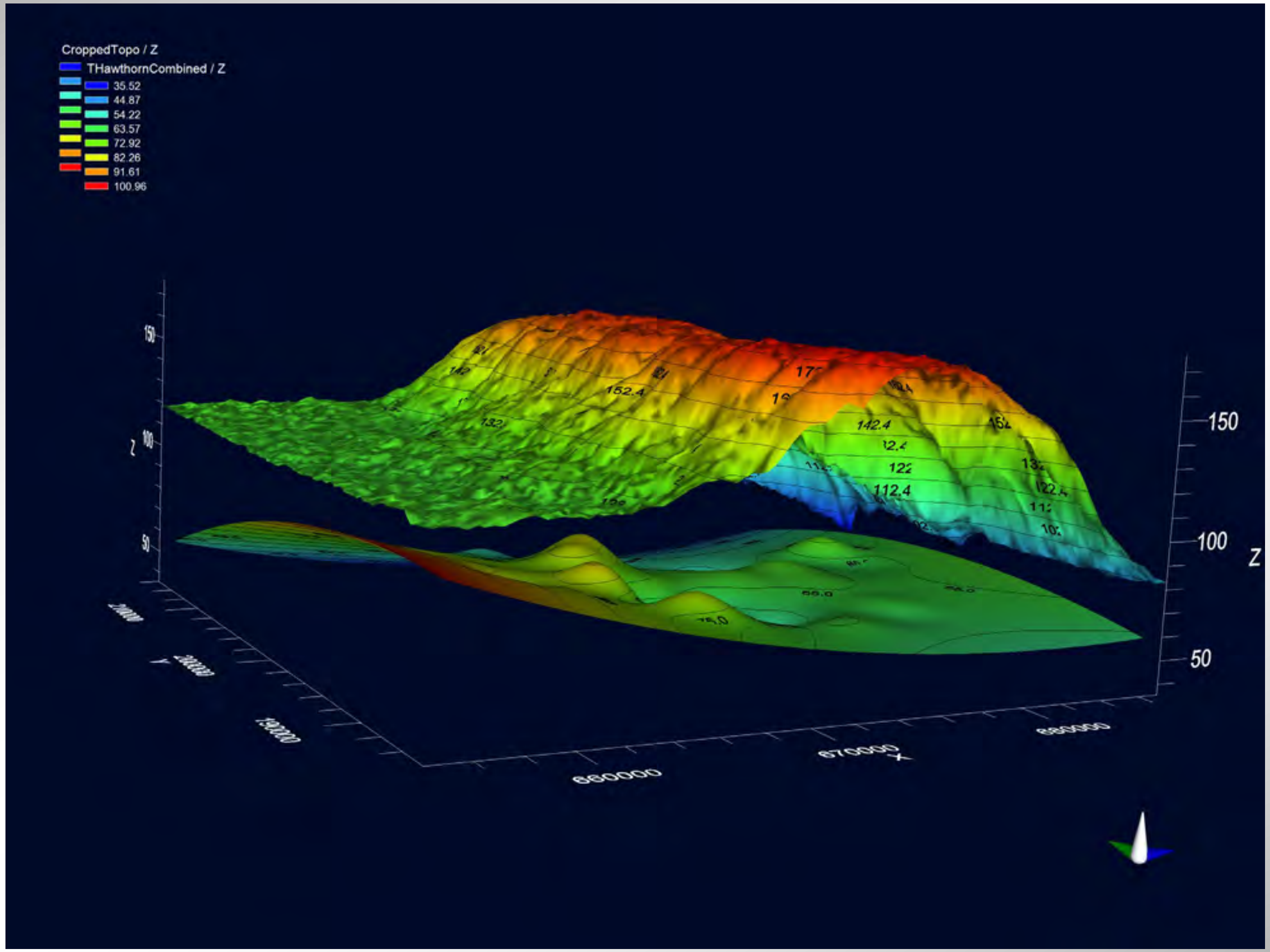
Land Surface – Top of Model



Top of Hawthorn – Base of Model

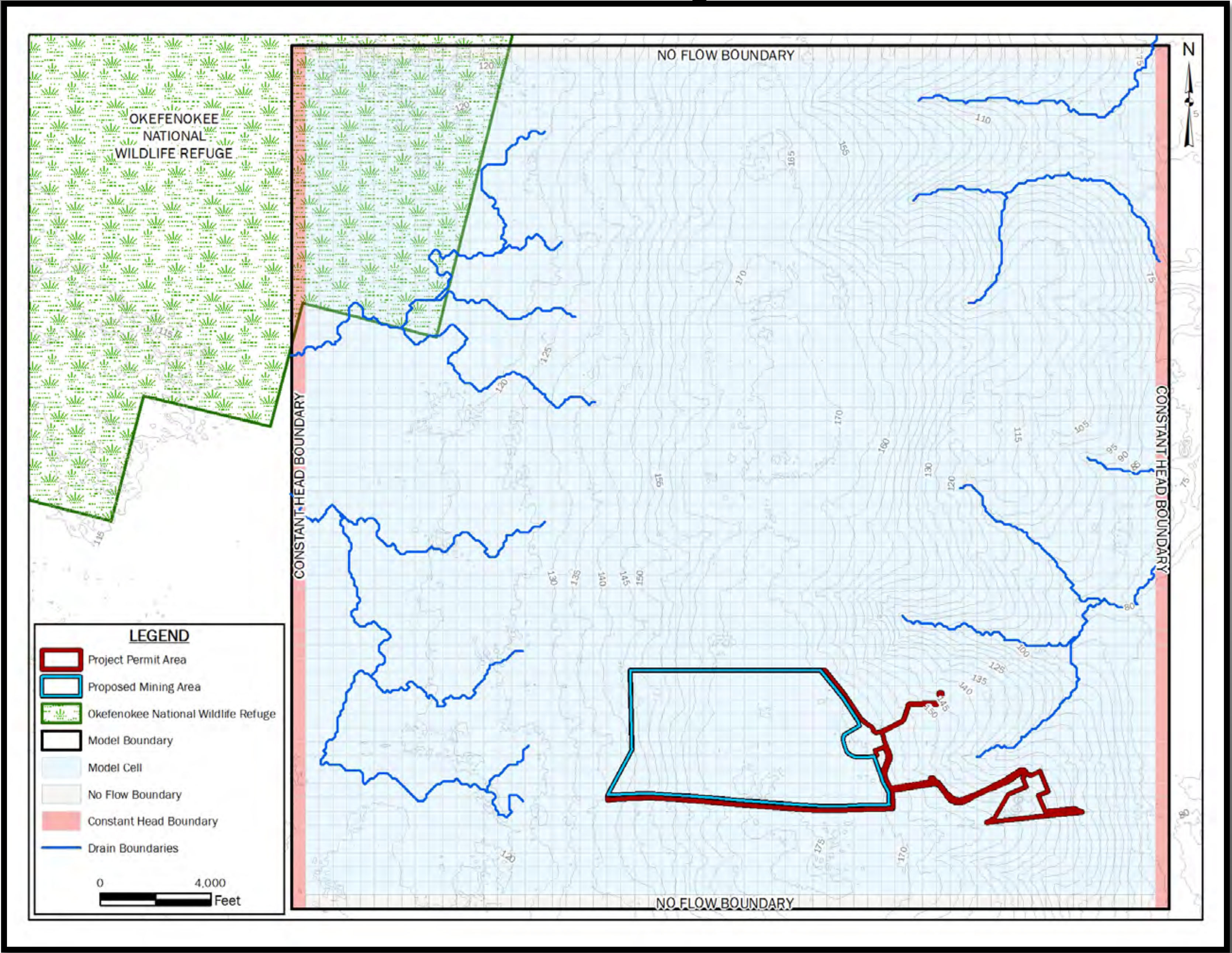


Model Domain is Subdivided into 15 Layers

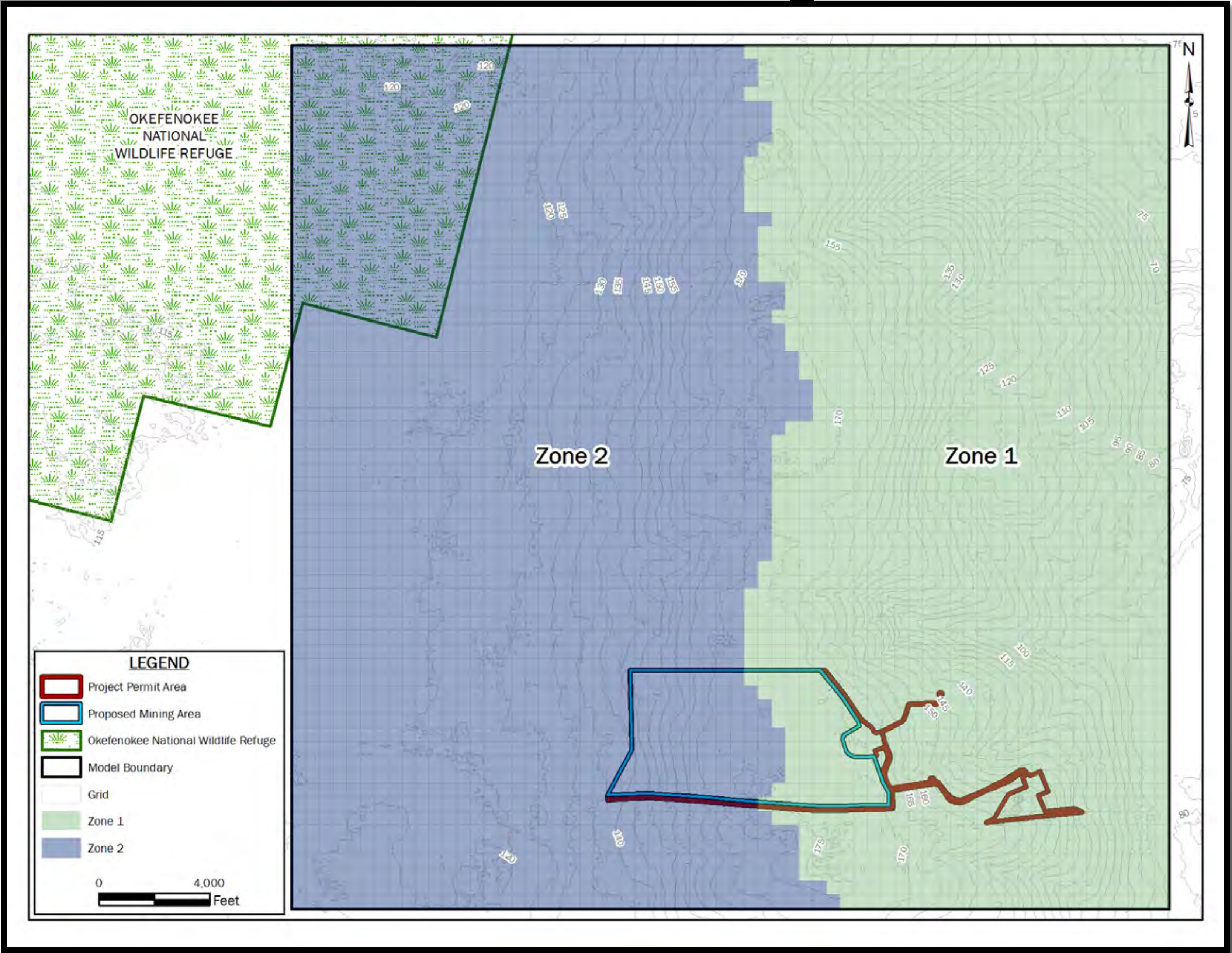


Layer thickness ranges from 0.1 ft to 10 ft

Model Boundary Conditions



Model Water-Budget Zones



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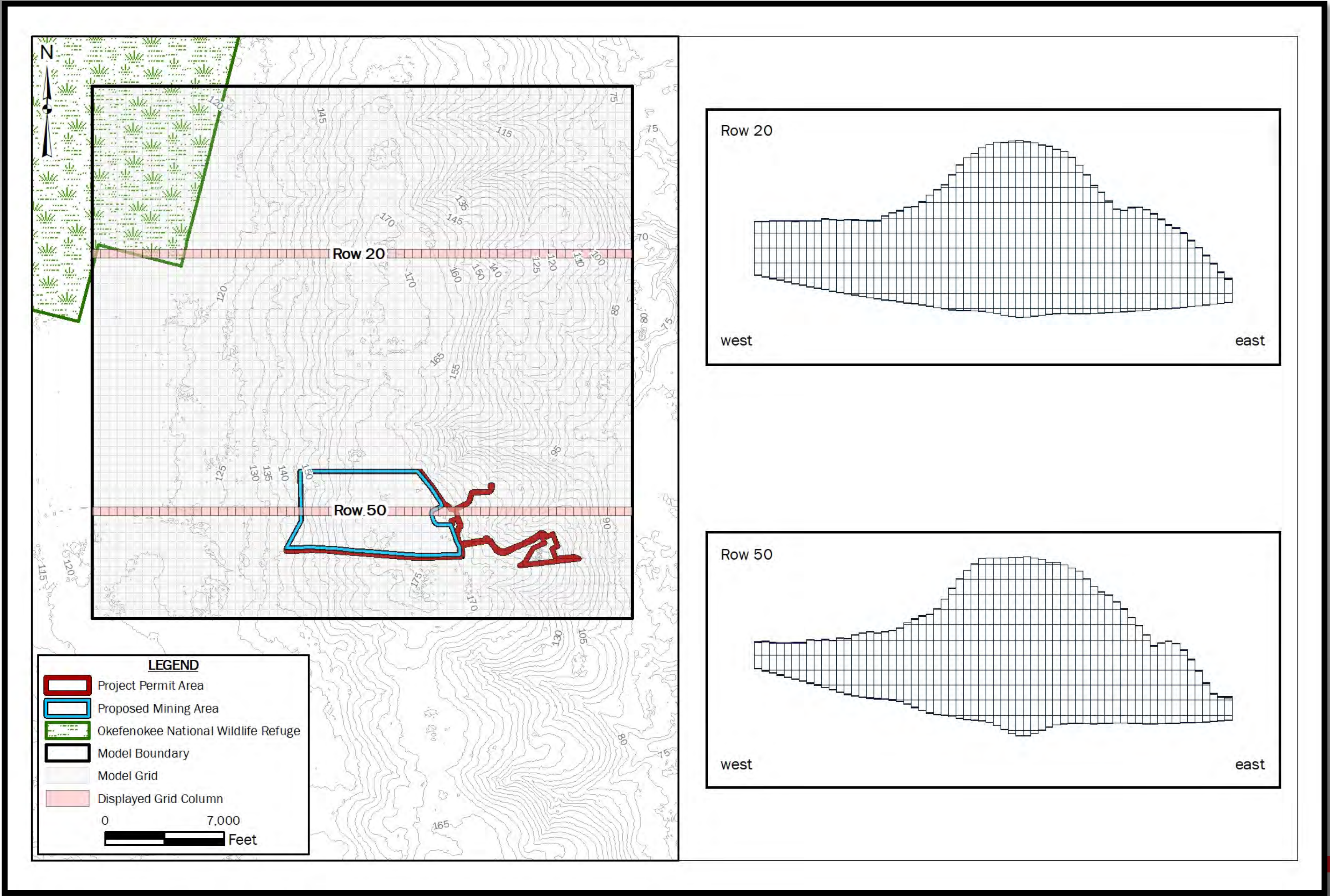
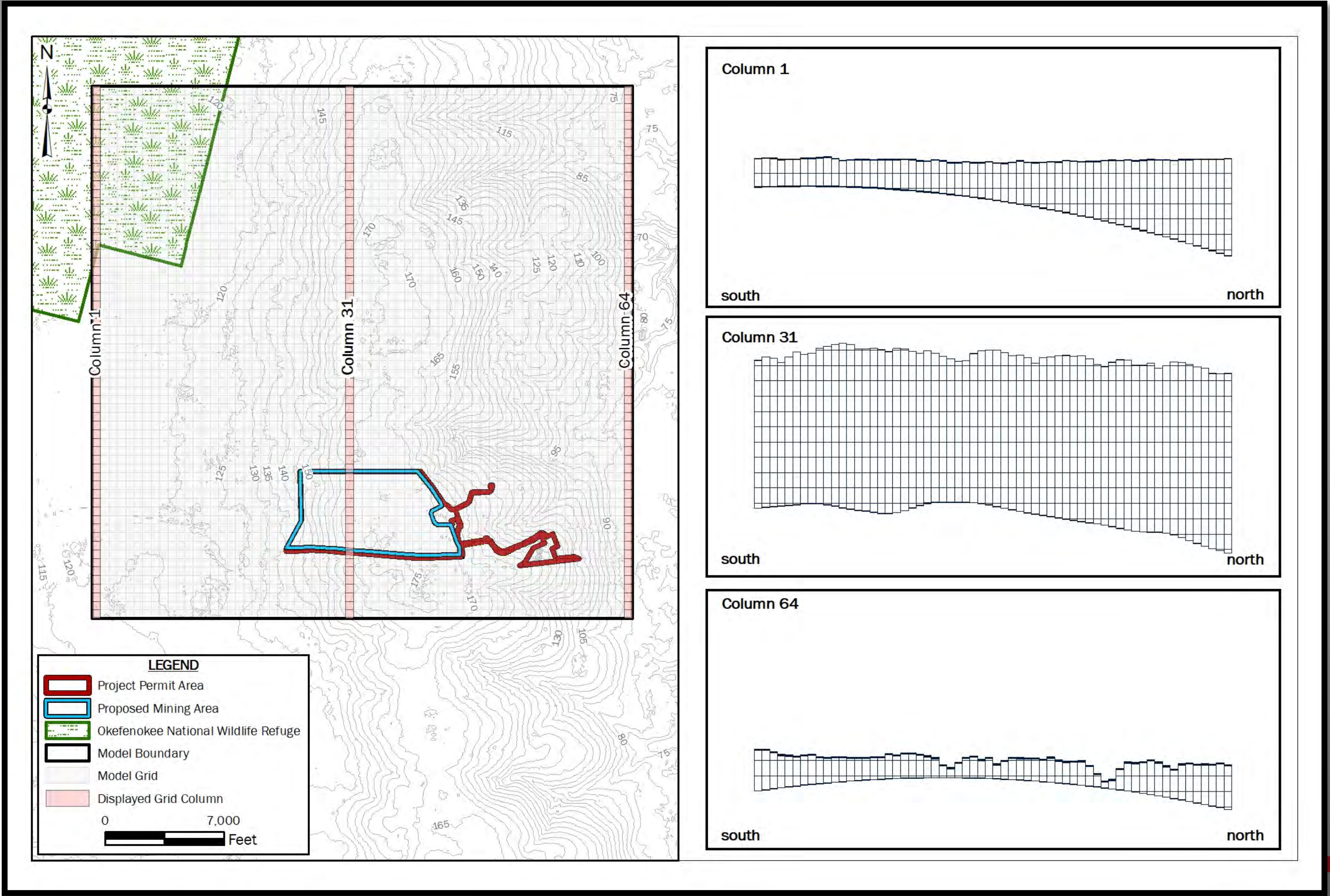
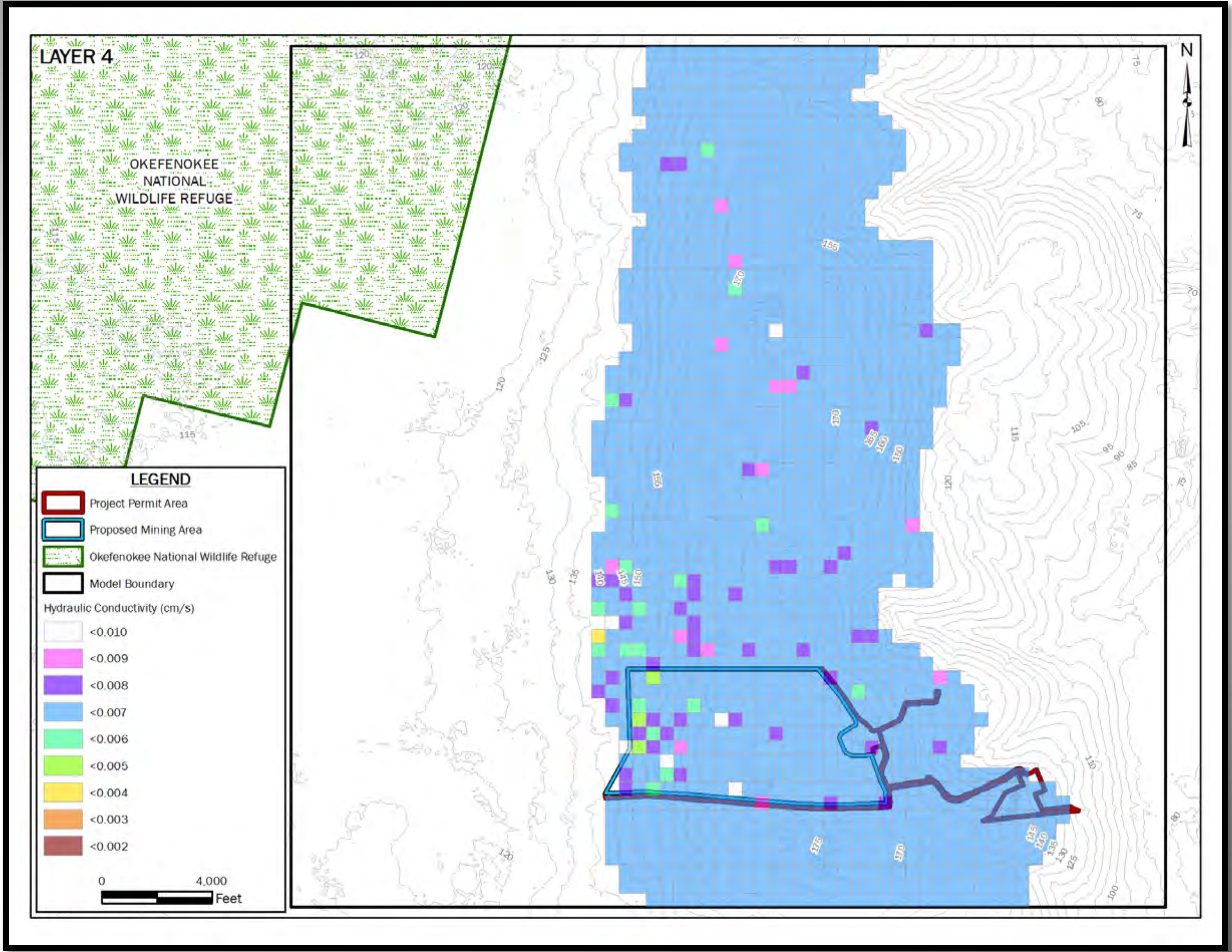
Model Grid Rows



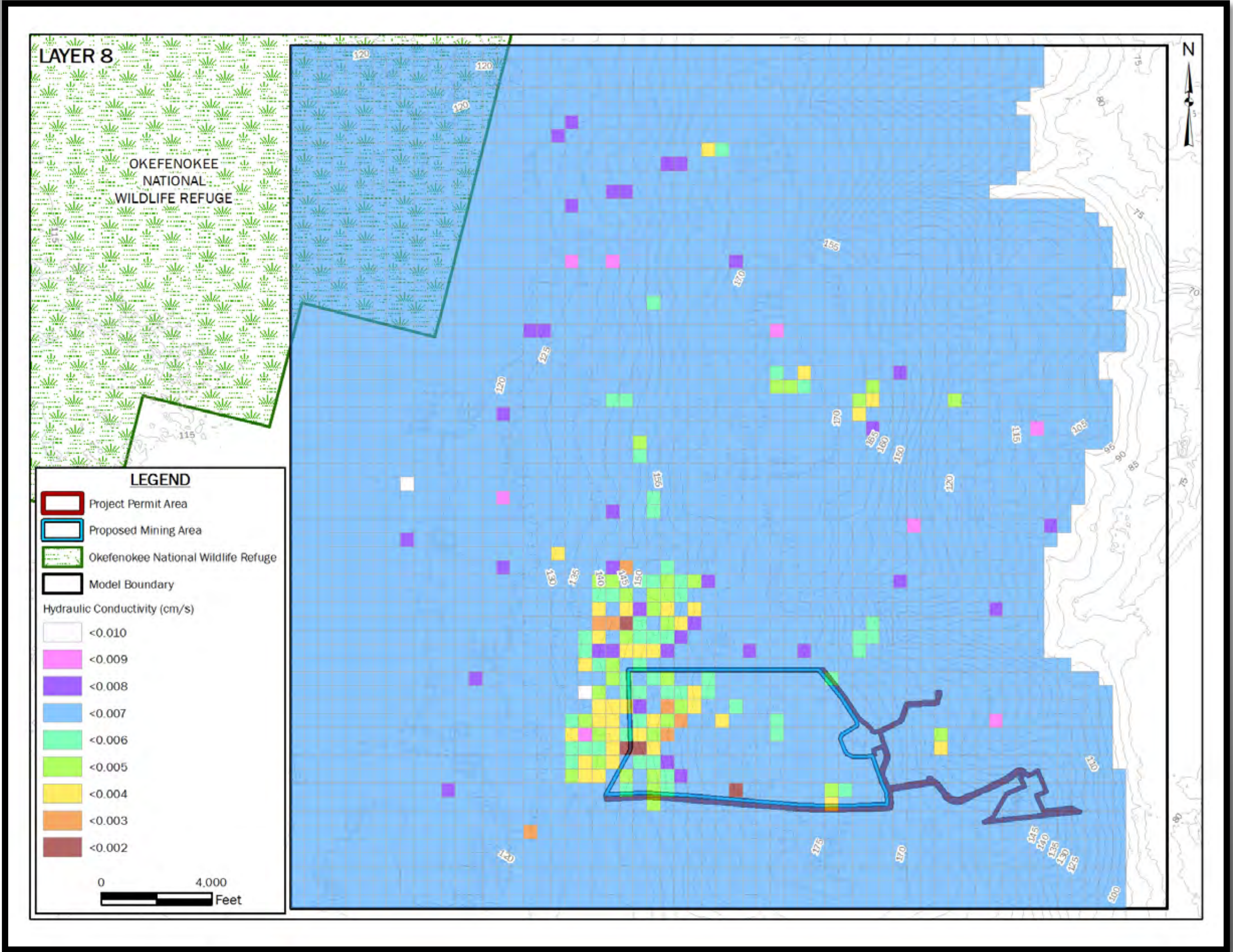
Model Grid Columns



Initial Model Horizontal K – 139 ft amsl, Layer 4



Initial Model Horizontal K – 99 ft amsl, Layer 8



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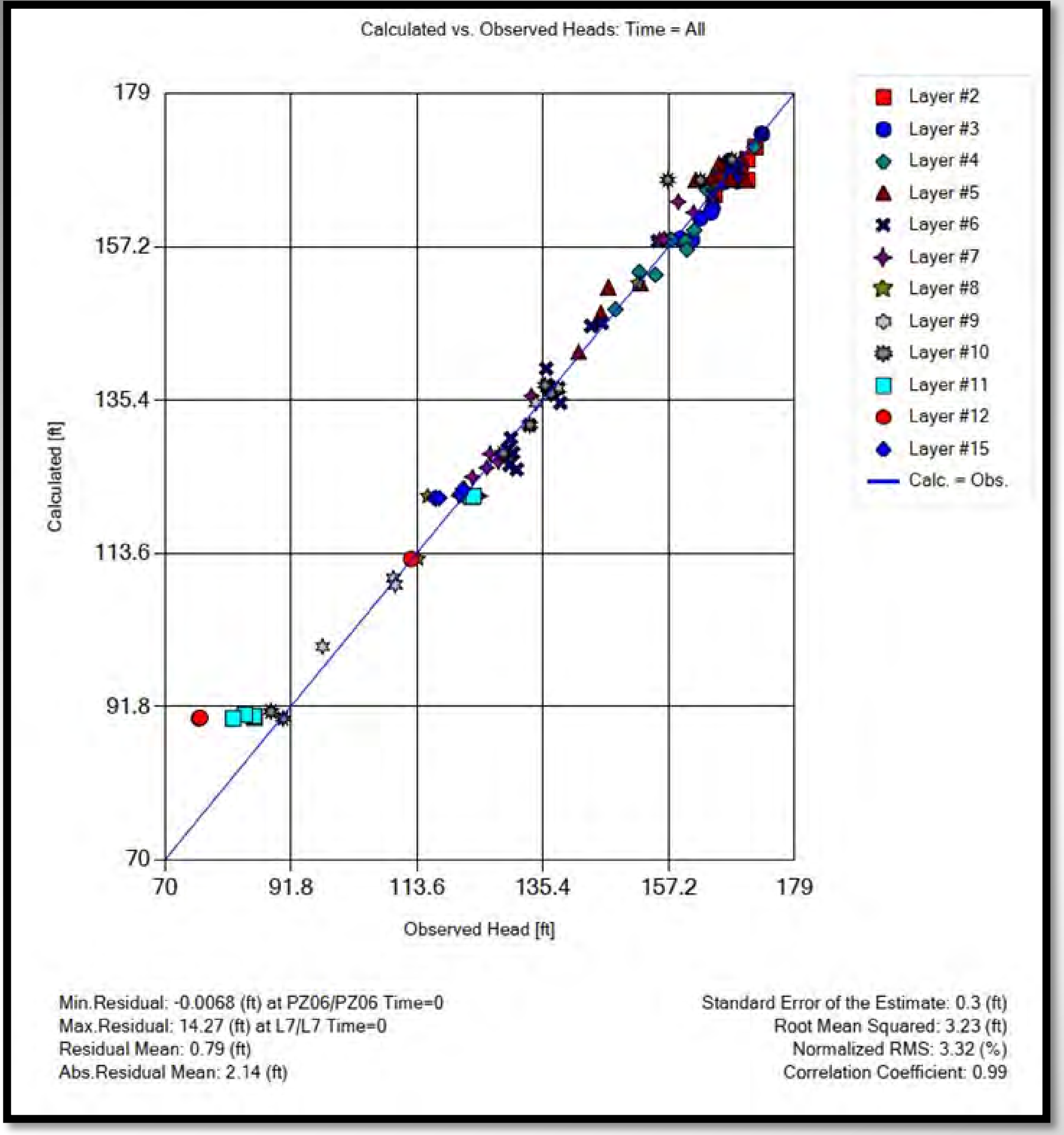
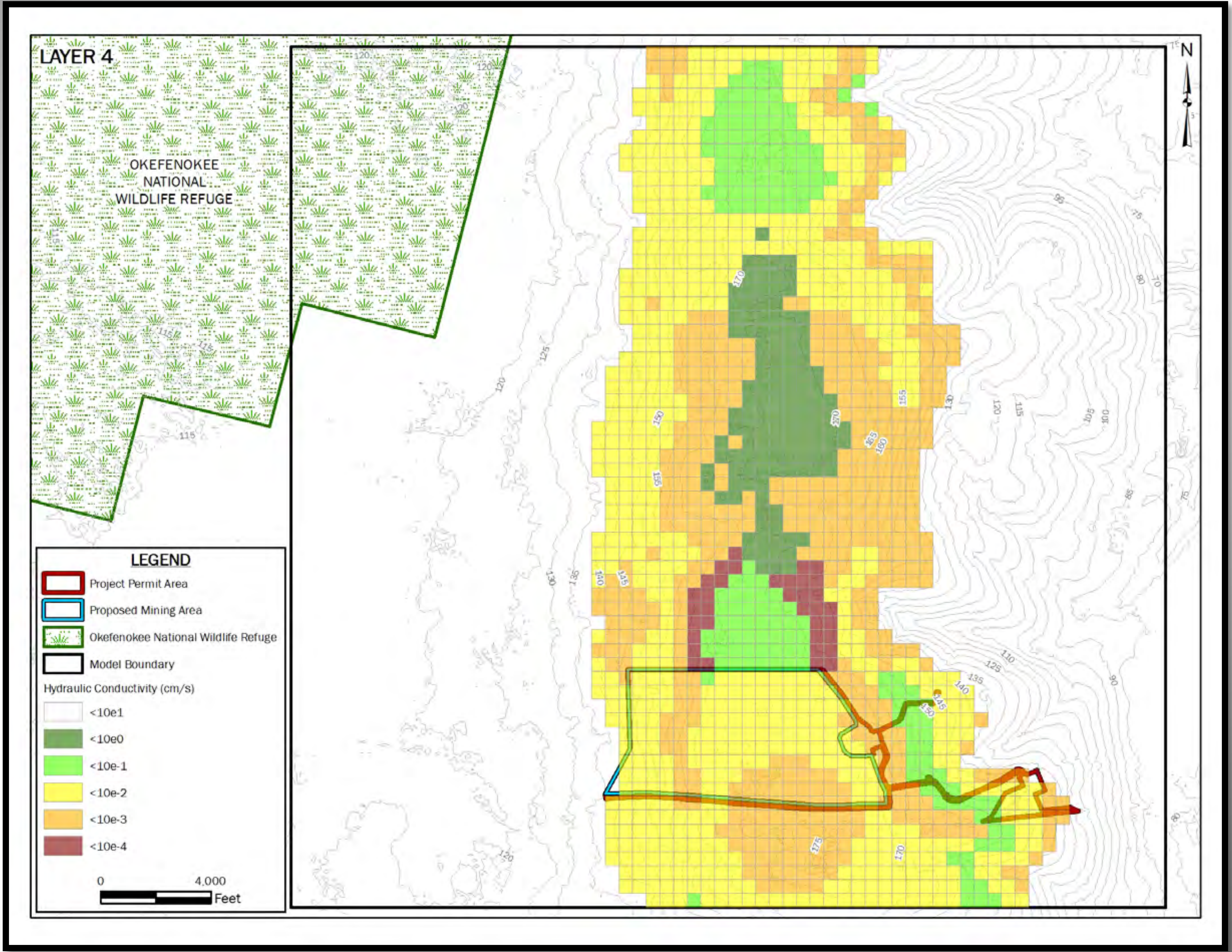
Model K Values were Adjusted During the Calibration Process



- *Non-linear optimization tools were used to calibrate the model*
- *During calibration, these tools adjust the hydraulic conductivity values until model-predicted water levels closely match water levels observed in wells*
- *This process requires that the model be run 1,000's of times*

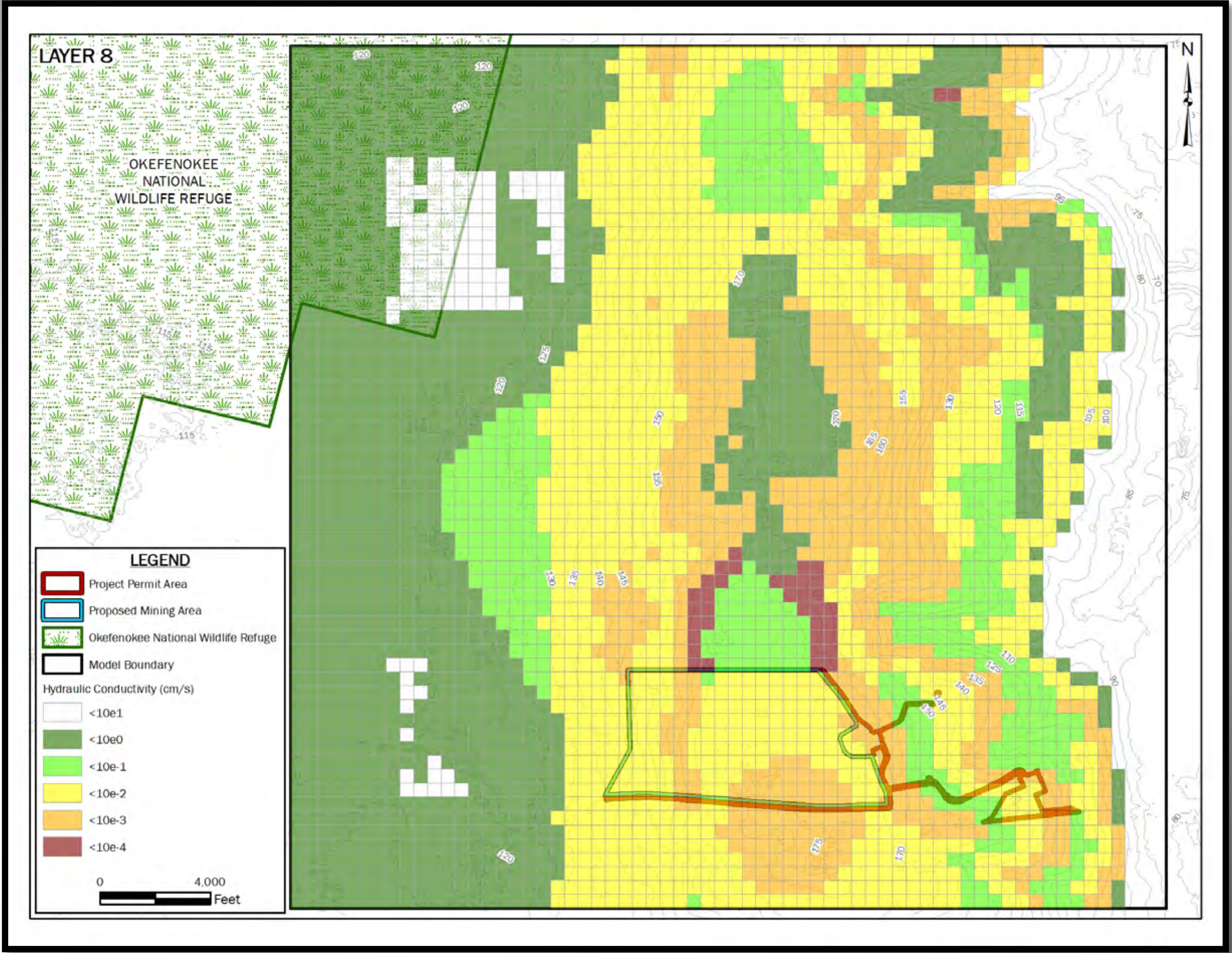
TTL

Calibrated Model Horizontal K – 139 ft amsl, Layer 4

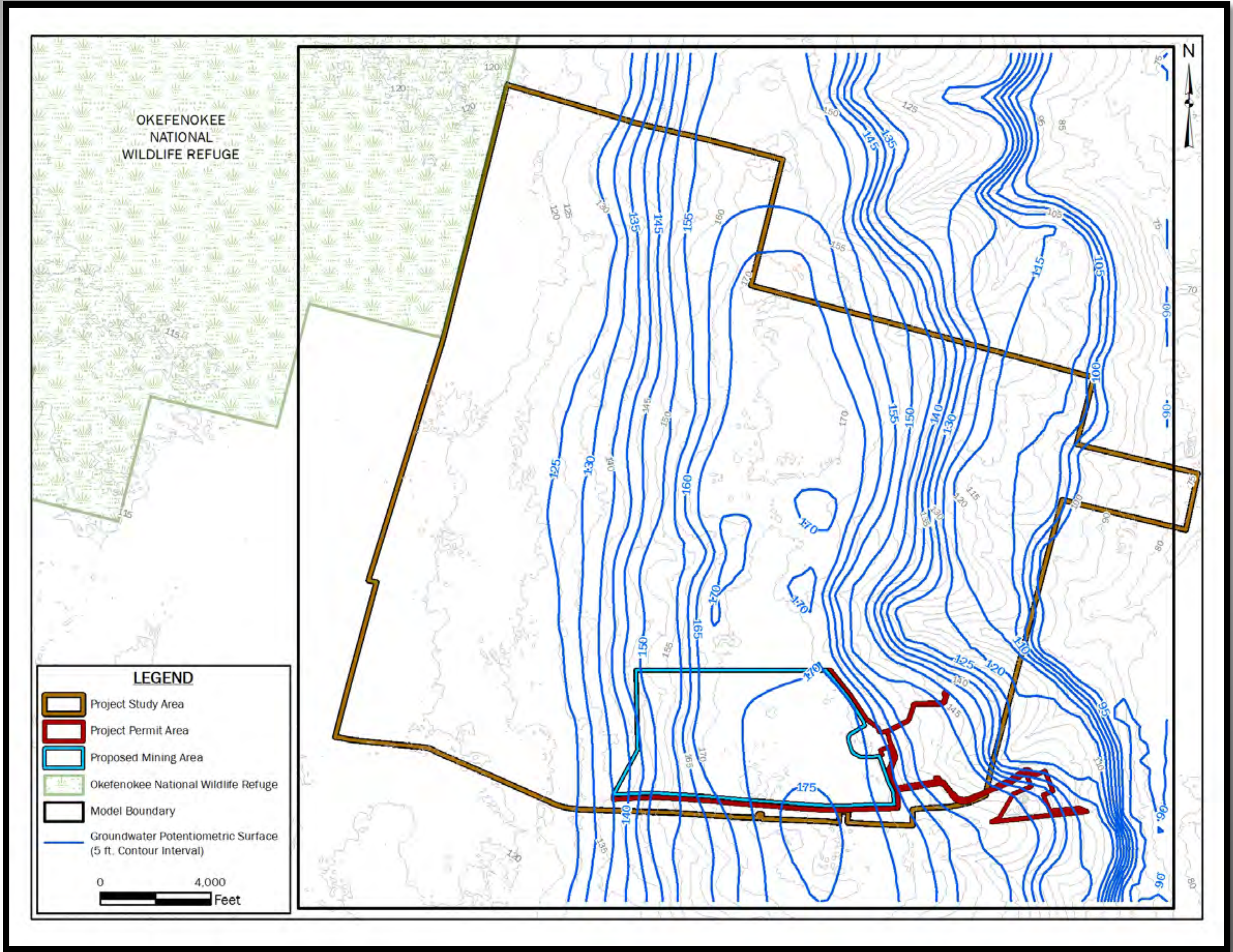


TTL

Calibrated Model Horizontal K – 99 ft amsl, Layer 8



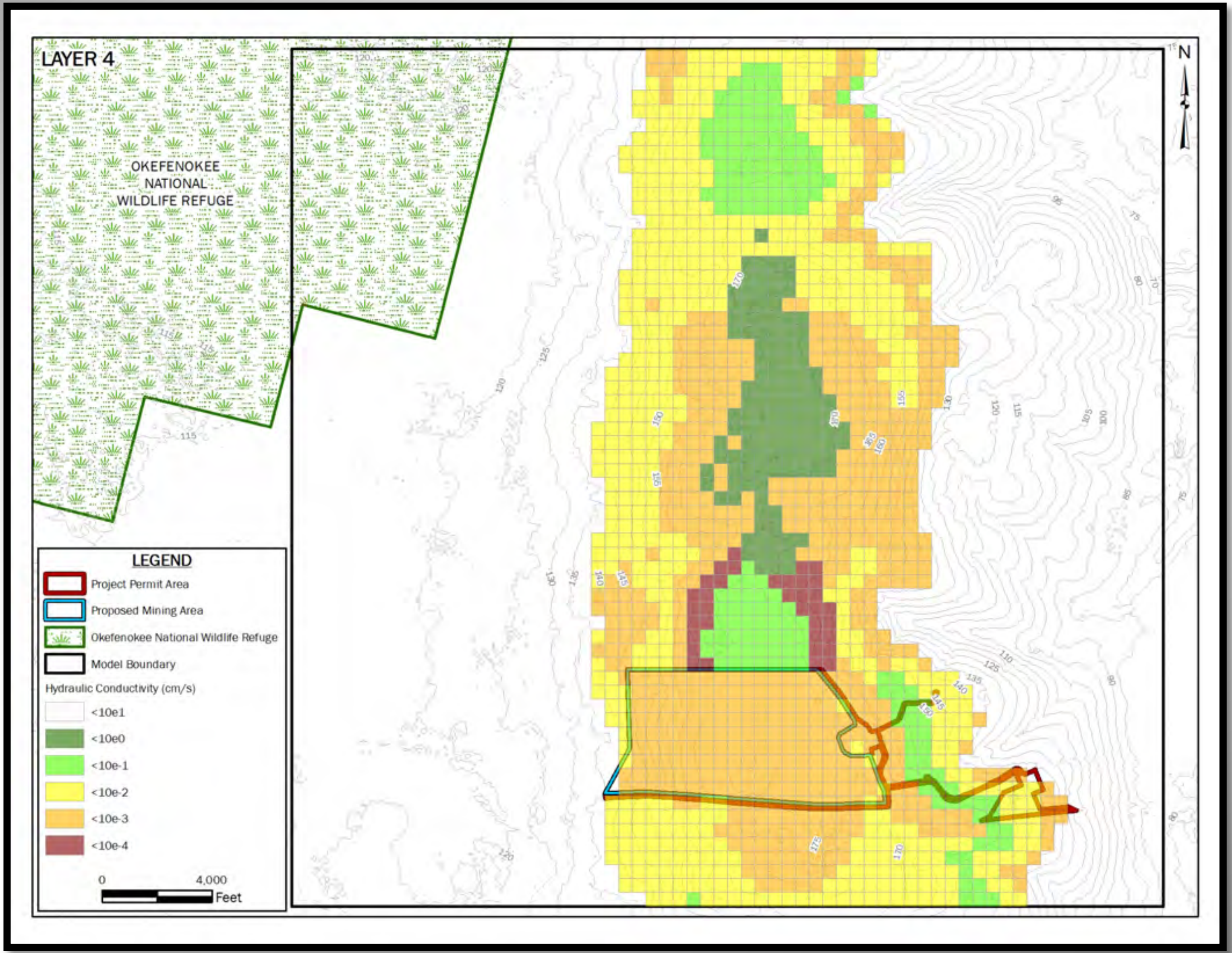
Modeled Pre-Mining Water Level Closely Matches the Observed Water Level



Post-Mining Scenario Model

- A number of soil cores were taken from the site and processed for heavy minerals
- The remaining sand (~98% of the original material) was sent to a TTL laboratory
- Samples of these sands were recompacted to represent burial in the pit
- The hydraulic conductivity (K) of these sands was then measured and found to be ~1E-03 cm/s
- In the post-mining model, we assumed that the entire mine area was homogenized (K=1E-03 cm/s) to an elevation of 119 feet
- The model was then run, and the resulting water levels were compared with the pre-mining model

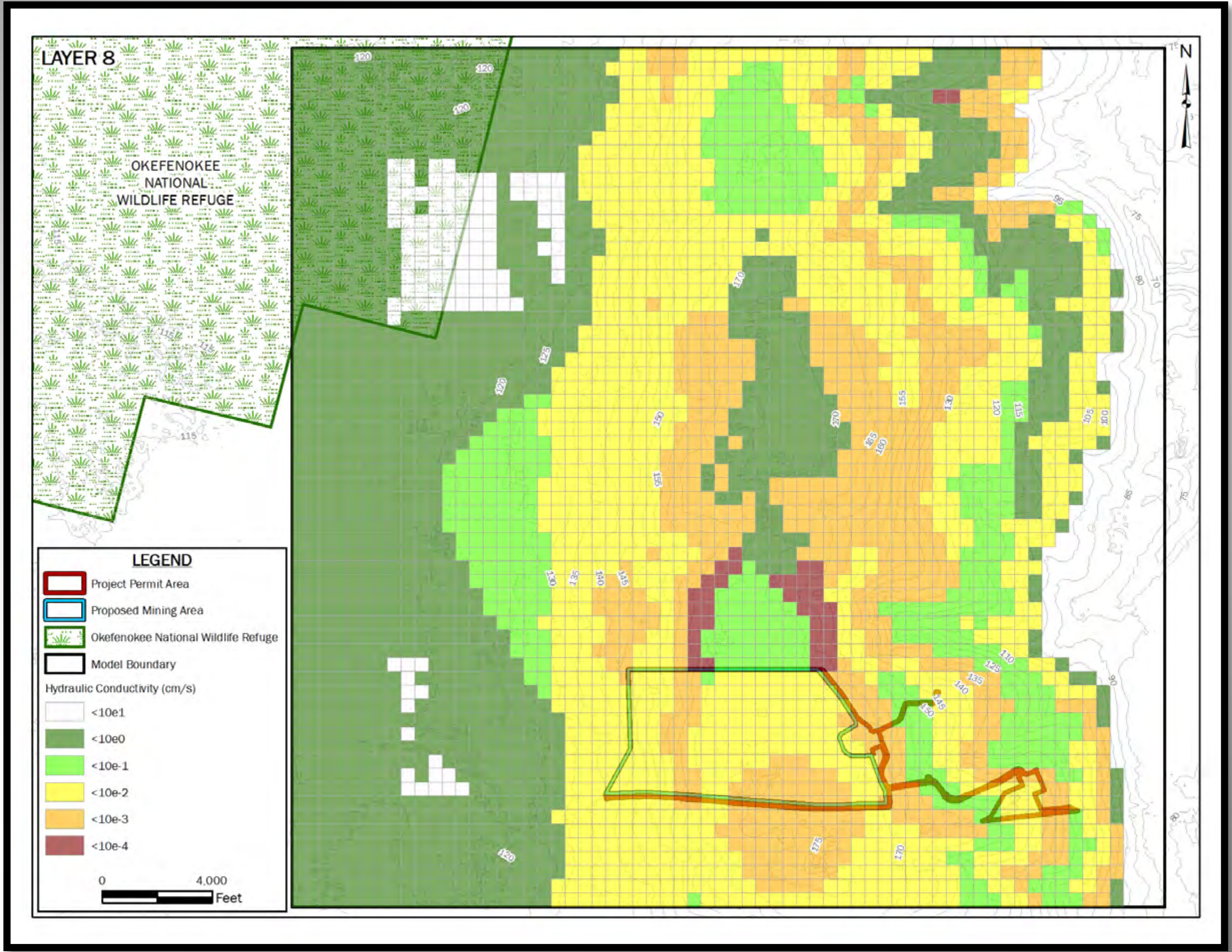
Post Mining Horizontal K – 139 ft amsl, Layer 4



K in the mine pit above 119 ft amsl altered to be 1E-03 cm/s

TTL

Post Mining Horizontal K – 99 ft amsl, Layer 8



K in the mine pit below 119 ft amsl unchanged

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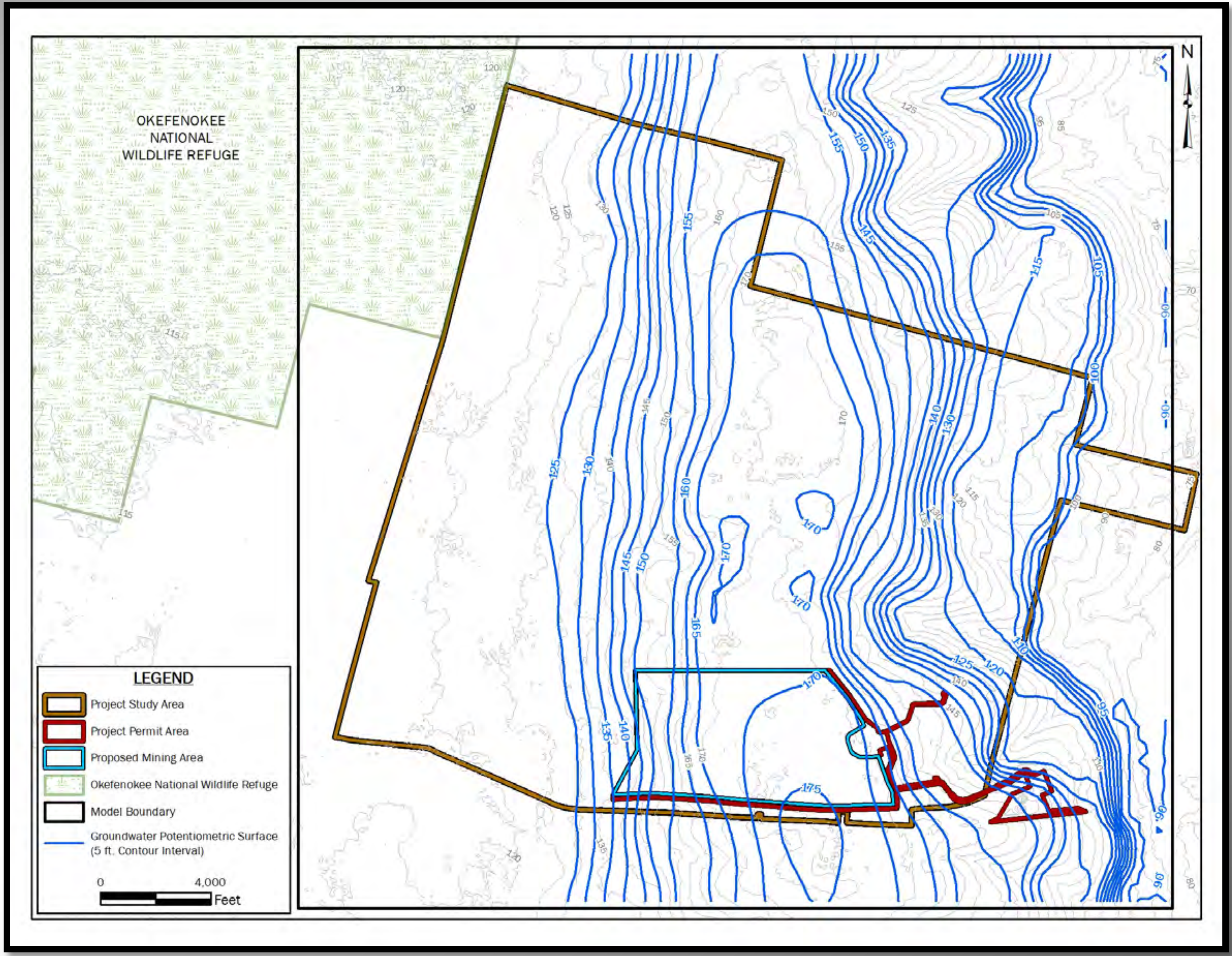
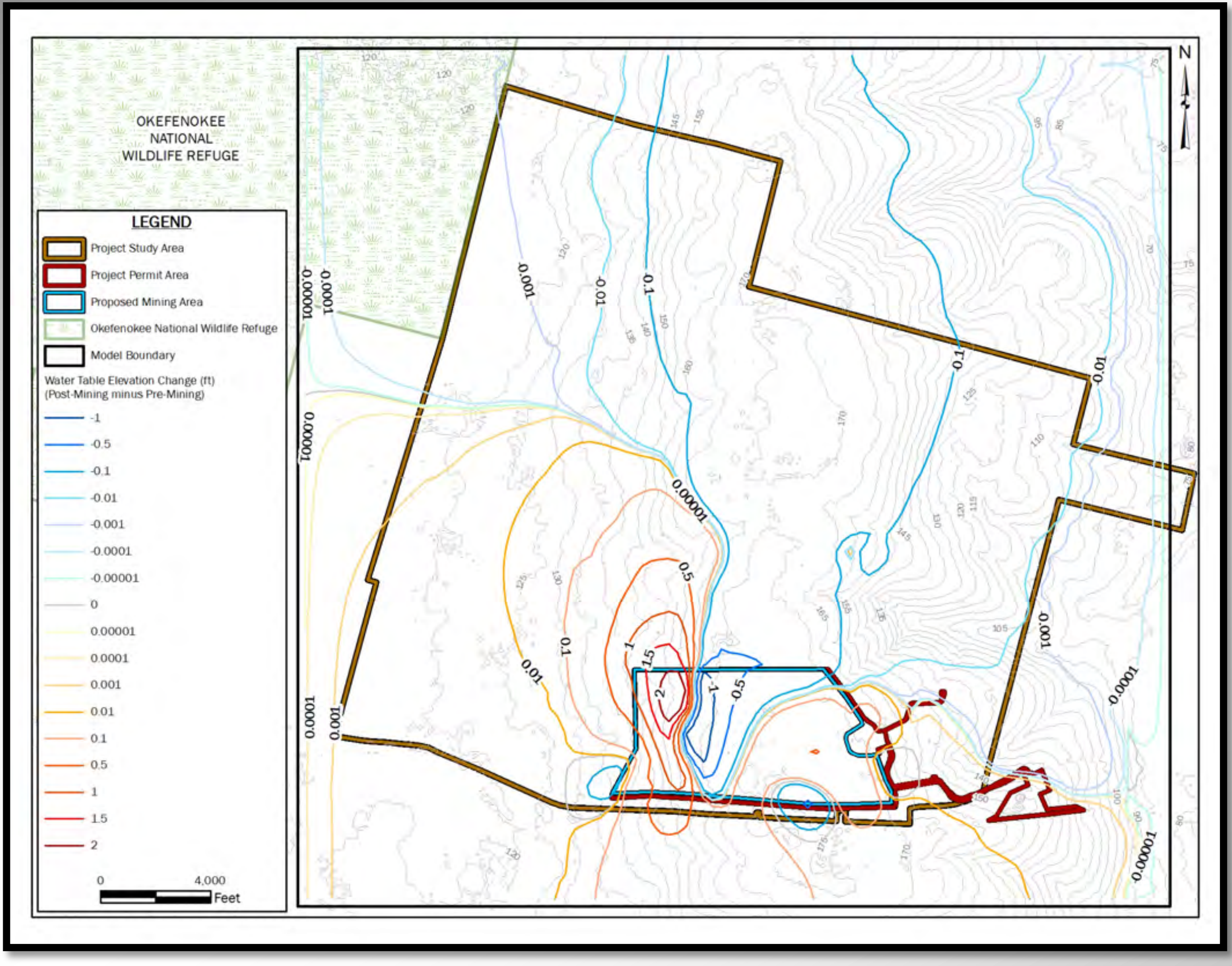
Modeled Post-Mining Water Level is Very Similar to the Pre-Mining Water Level



Post-Mining Water Table Change



- Water levels change the most within the mined area, with increase of up to 2 ft and decreases of down to 1ft
- Across most of Trail Ridge, the water levels decrease slightly
- Water levels at the closest edge of the Wildlife Refuge decrease by 0.0004 ft

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Differences Between Water Budgets is Insignificant

Model Water Budget Table (Cumulative Volume)						
Source	Pre-Mining		Post-Mining		Difference	
	In	Out	In	Out	In	Out
Storage*	0	0	0	0	0	0
Constant Head*	0	572079	0	572115	0	-35
Drains*	0	40802	0	40767	0	35
Recharge**	612882	0	612882	0	0	0
Total	612882	612882	612882	612882	0	0
* Cumulative Volume (ft^3)						
** Rates for time step (ft^3/day)						

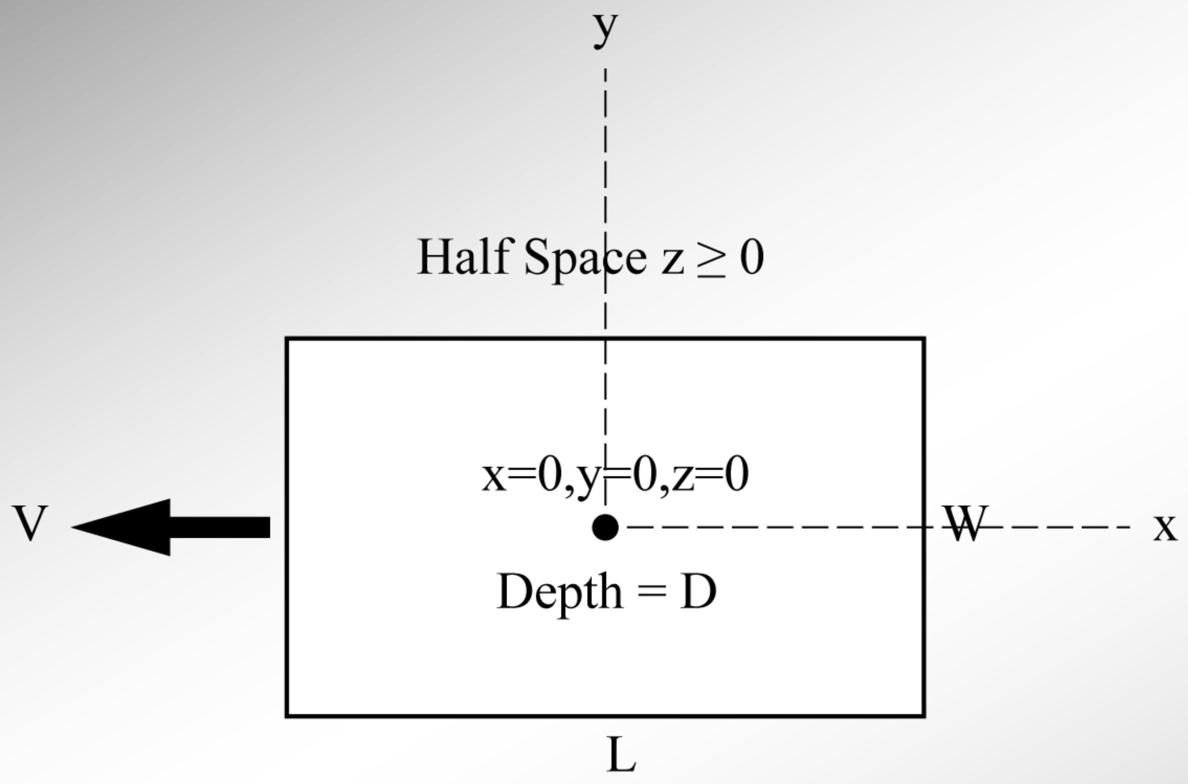
Net increase of stream flow:
35 cfd = 0.0004 cfs

Negligible increase in groundwater flow (0.1%) and stream flow (0.04%) to the west

Analytical Model of the Moving Mine Pit

Accounting for a Moving Mine Pit

- We can adapt an analytical solution for a moving rectangular source of heat (Ling, 1973)
- Here we have a pit with L=500 ft, W=100 ft, D=50 ft, and V=100 ft/d



Governing Equation

$$\nabla^2 h = \frac{S_s V}{K}\frac{\partial h}{\partial x}$$

Boundary Conditions

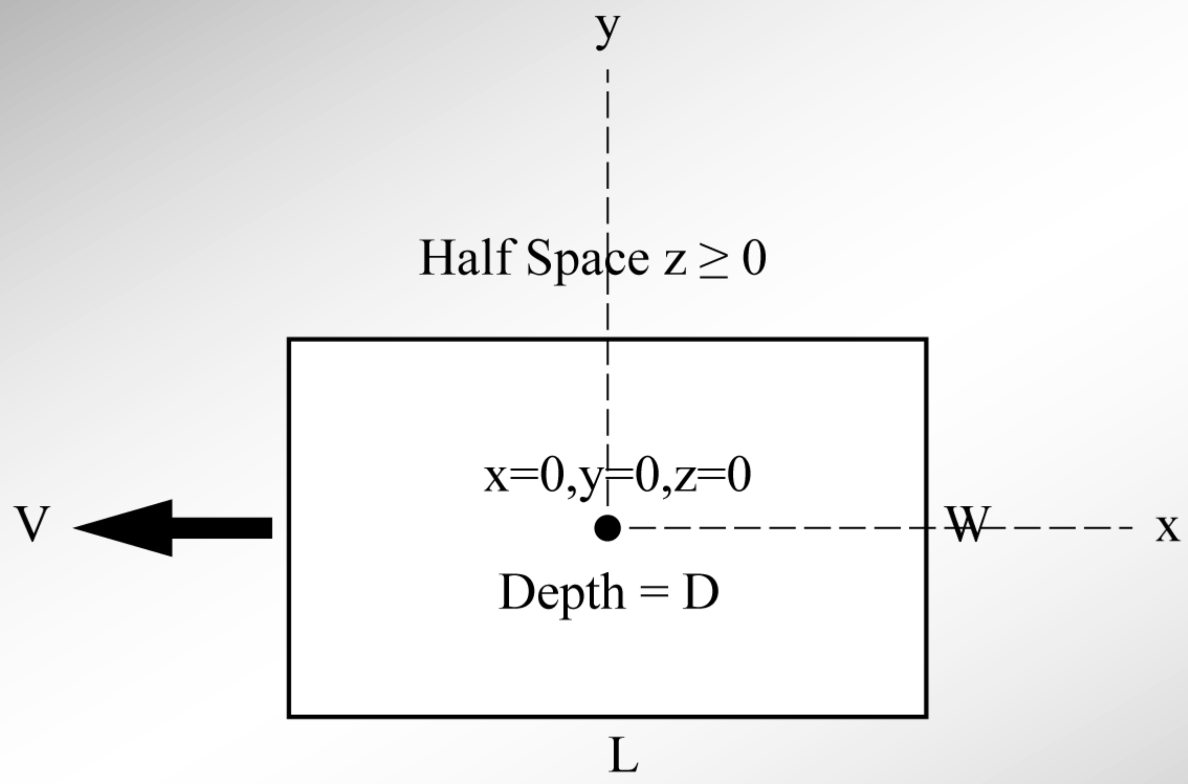
$$z = 0,\ |x| \le L,\ |y| \le W,\ q = -K\frac{\partial h}{\partial z}$$

$$z = 0,\ |x| > L,\ |y| > W,\ -K\frac{\partial h}{\partial z} = 0$$

$$z \ge 0,\ \sqrt{x^2 + y^2 + z^2} \to \infty,\ h \to 0$$

The Head Distribution Around the Sink Quickly Reaches Steady State as it Moves

- Assuming T=1,500 ft^2/d (K=13 ft/d), S=0.3
- The volumetric discharge is determined from the volume of water removed from the mine in a day Q=150,000 ft^3/d



Time Required to Reach Steady State (Hou and Komanduri, 2000)

$$t_{SS} = 20\frac{T}{SV^2} = 10 \text{ days}$$

The Dimensionless Analytical Solution is Numerically Integrated

- Using the following non-dimensional variables

$$x^* = \frac{x}{L},\ \mathrm{y}^* = \frac{y}{L},\ \mathrm{z}^* = \frac{z}{L},\ \mathrm{h}^* = \frac{hK}{qL}, Pe = \frac{S_s VL}{K}$$

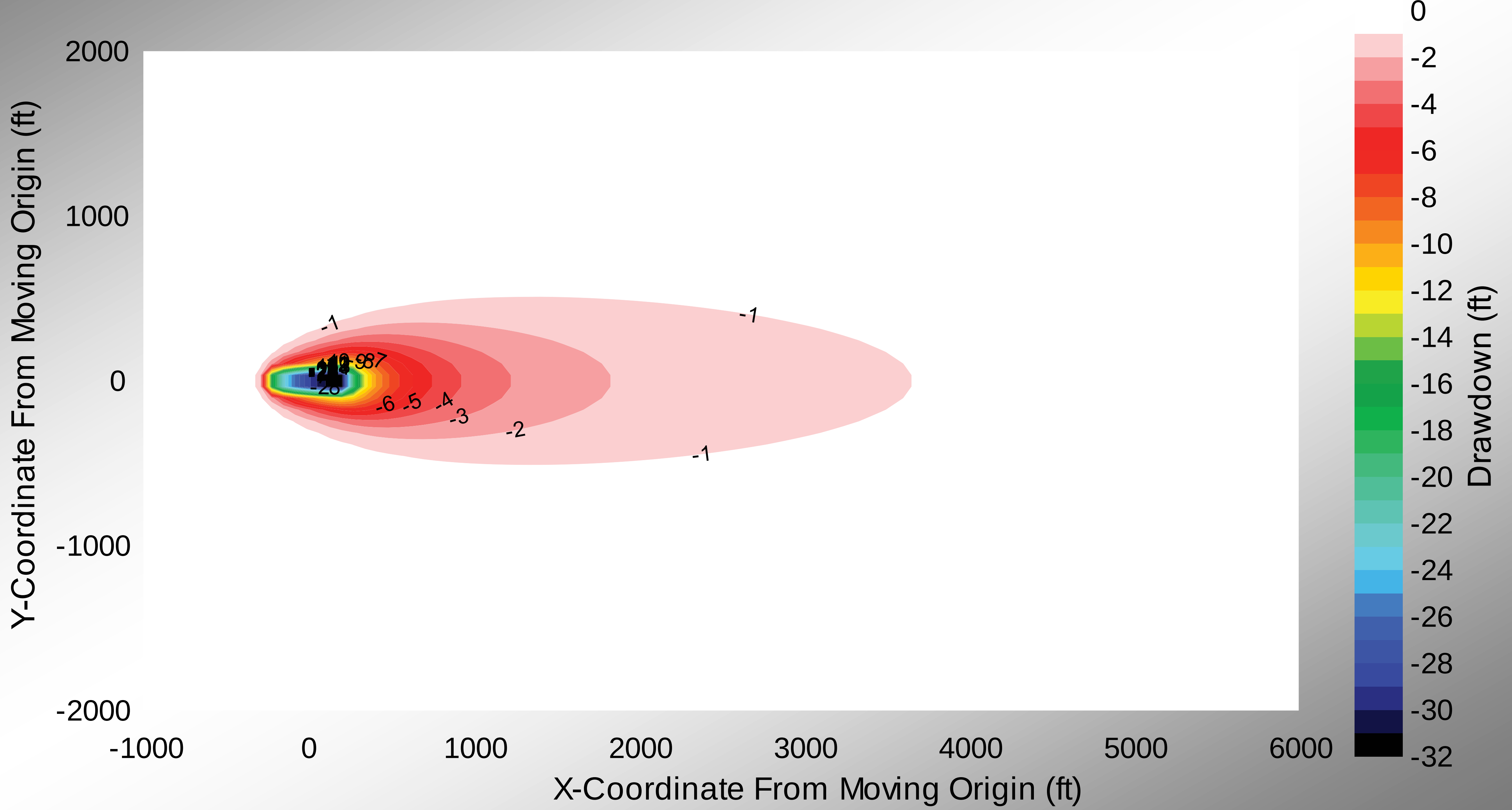
- The solution is

$$h^* = -\frac{1}{\pi}\int_{-1}^{+1}\int_{-W/L}^{W/L} \frac{\exp\left\{-Pe\left[r^* - (x^* - x^{*'})\right]/2\right\}}{r^*} dy^{*`} dx^{*`}$$

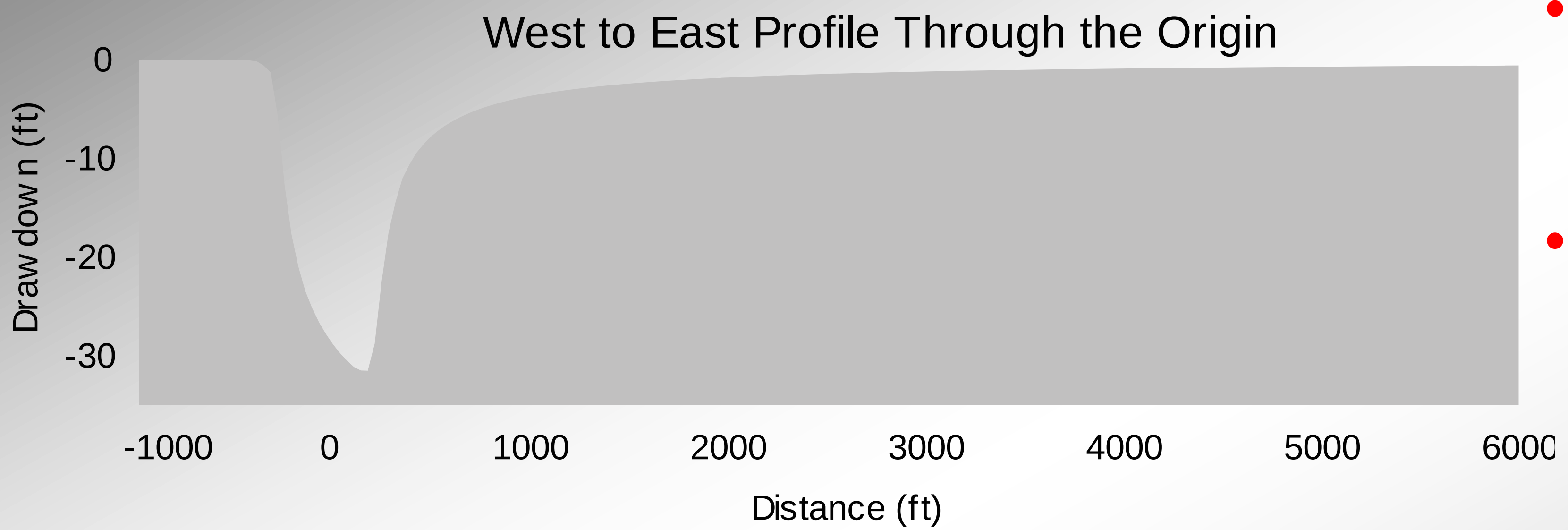
- With

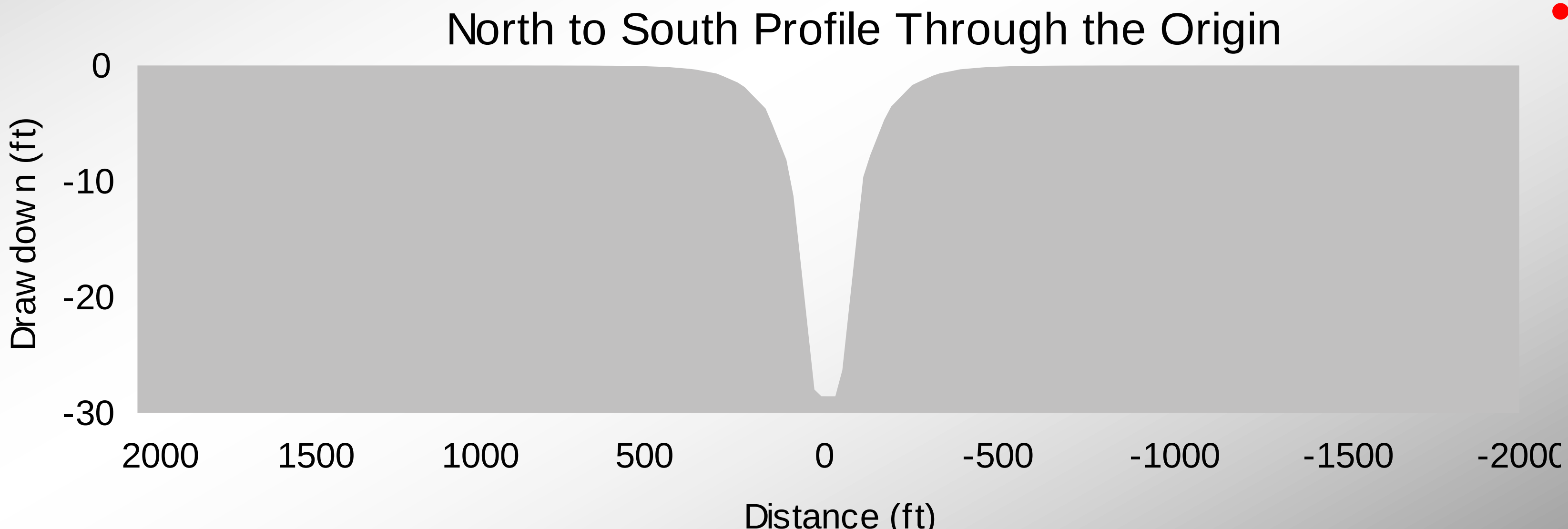
$$r^* = \sqrt{(x^* - x^{*'})^2 + (y^* - y^{*'})^2 + (z^*)^2}$$

Drawdown Due to a Moving Rectangular Pit



Drawdown Profiles Through the Origin





- *The zone of drawdown moves 100 ft/d in the x-direction*
- *Recovery is fast behind the pit, with drawdown decreasing to > -2 ft in less than 20 days*
- *When superimposed on the existing water table, groundwater divides will separate the moving pit from the Okefenokee to the west and the streams to the east*

Summary of Surficial Aquifer Modeling Results

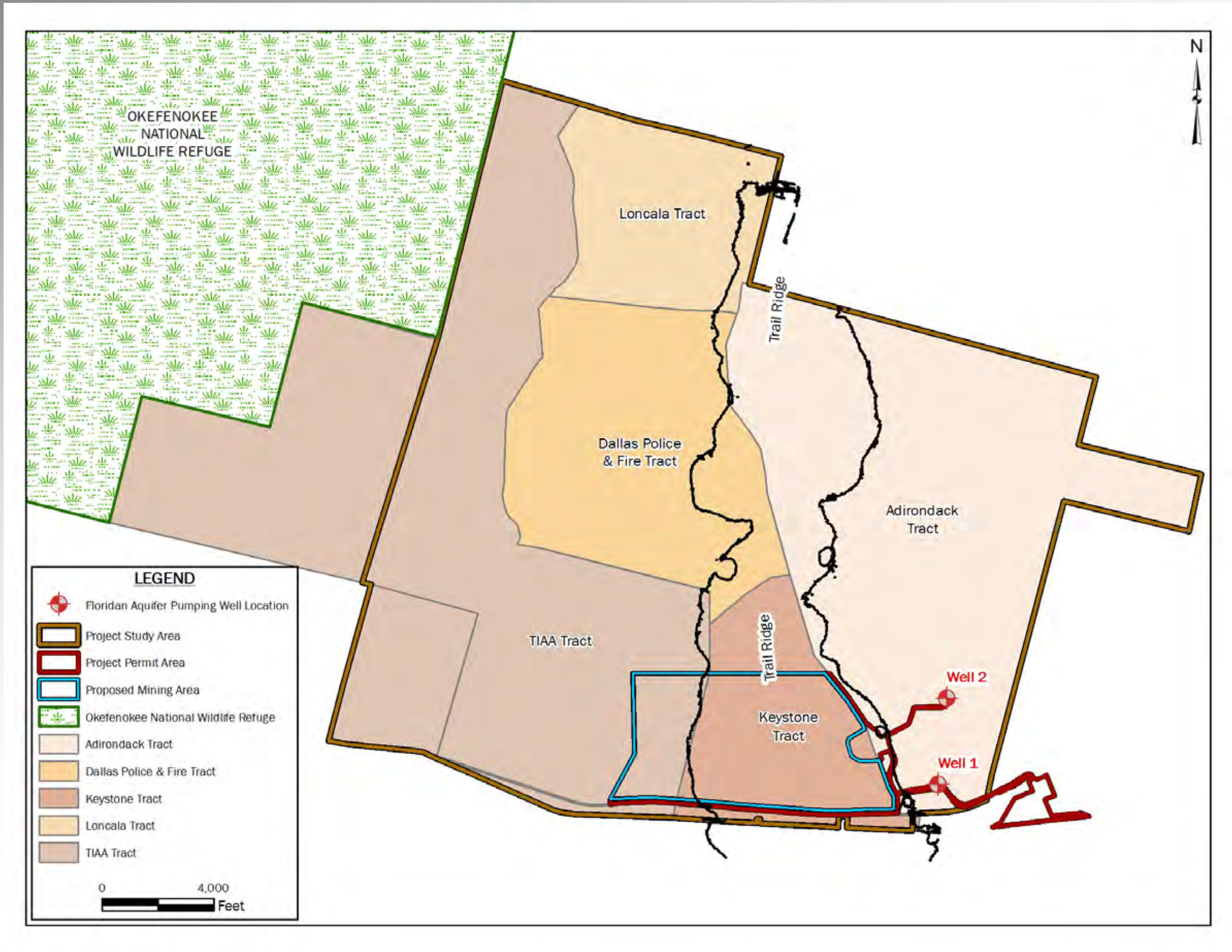
- Trail Ridge is a classic example of topographically-driven groundwater flow. **It acts as a hydrologic divide that separates the Okefenokee Swamp to the west from the Saint Mary's River to the east.**
- A comparison of groundwater models of the pre-mining conditions and post-mining conditions show that **proposed mining activities will have an insignificant impact on the groundwater and stream flow to the Okefenokee Swamp and the creeks and groundwater system to the east of Trail Ridge**.
- **Mining activities will cause insignificant changes in the water table across most of the study area**. Within the mine pit, the water table position will both increase and decrease due to the placement of homogenized sand spoil in the mine pit. **At the Okefenokee Wildlife Refuge, the models predict that the water table will decrease by 0.0004 ft due to mining**.
- **Mining activities will not dewater the Okefenokee Swamp**. The Okefenokee Swamp is > 2.7 miles away from the proposed mine footprint. The active mine pit will be filled within five days. Analytical groundwater models of the moving mine pit show that water levels will recover to within 2 ft of their original position within about 20 days. The perturbation of the water table caused by the moving mine pit will not affect the Okefenokee Swamp. **The Trail Ridge hydrologic divide separating the Okefenokee Swamp to west from the Saint Mary's River to the east will always be maintained.**

Analytical Model of the Pumping in the Floridan Aquifer

Analytical Model for Pumping in the Floridian Aquifer

- Analytical solutions (Theis, 1935) are superimposed to predict the time dependent drawdown in the Floridan Aquifer
- Hydraulic properties for the model are an average of those reported in Williams and Kuniansky (2016) for Floridan wells in north Florida (Transmissivity = 18,595 ft^2/day and Storage Coefficient 1.15E-03)
- Two pumping wells located on the eastern part of the project area will pump 500 gallons per minute for 5.5 years

Location of Floridan Aquifer Wells



Each well will pump 500 gpm

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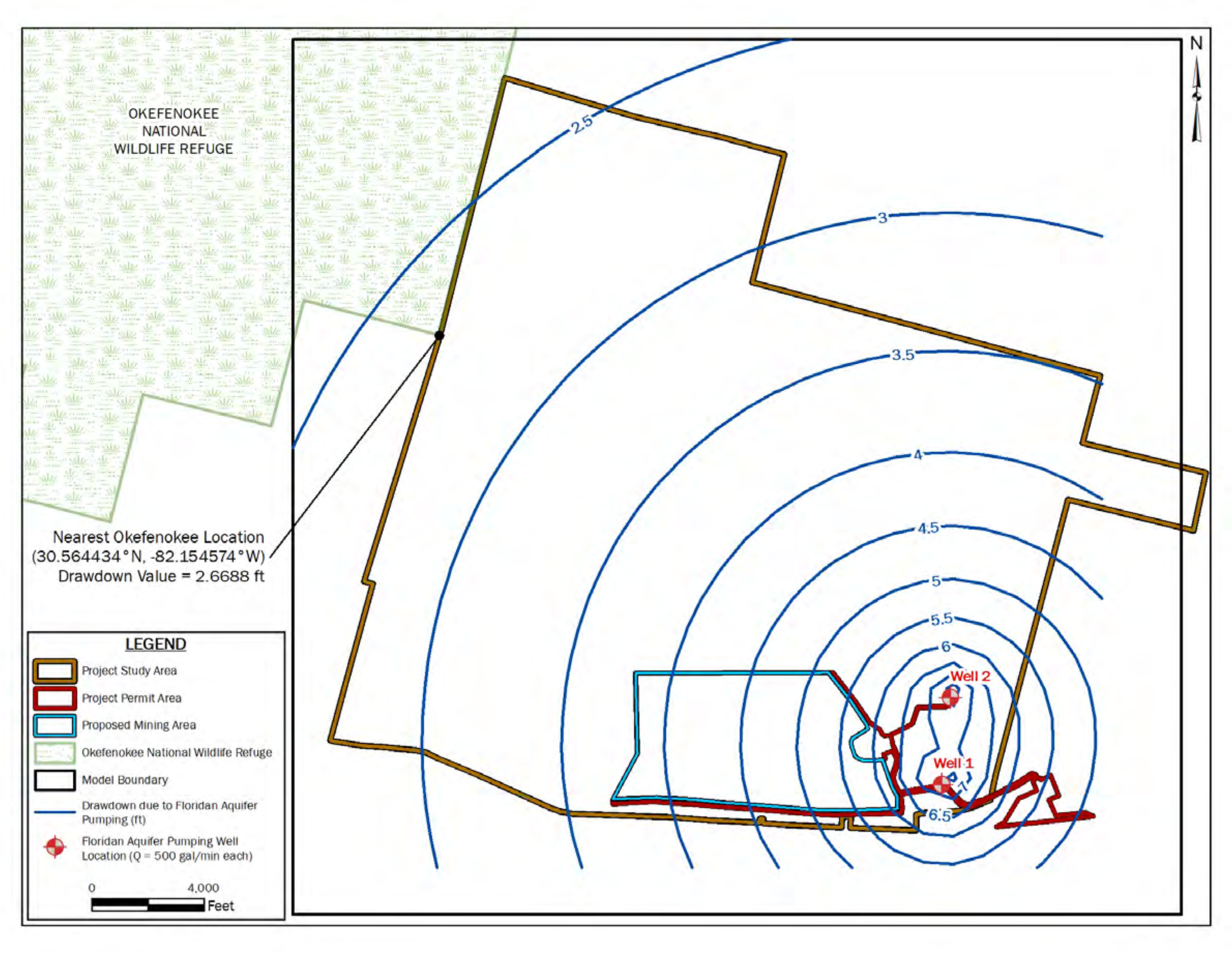
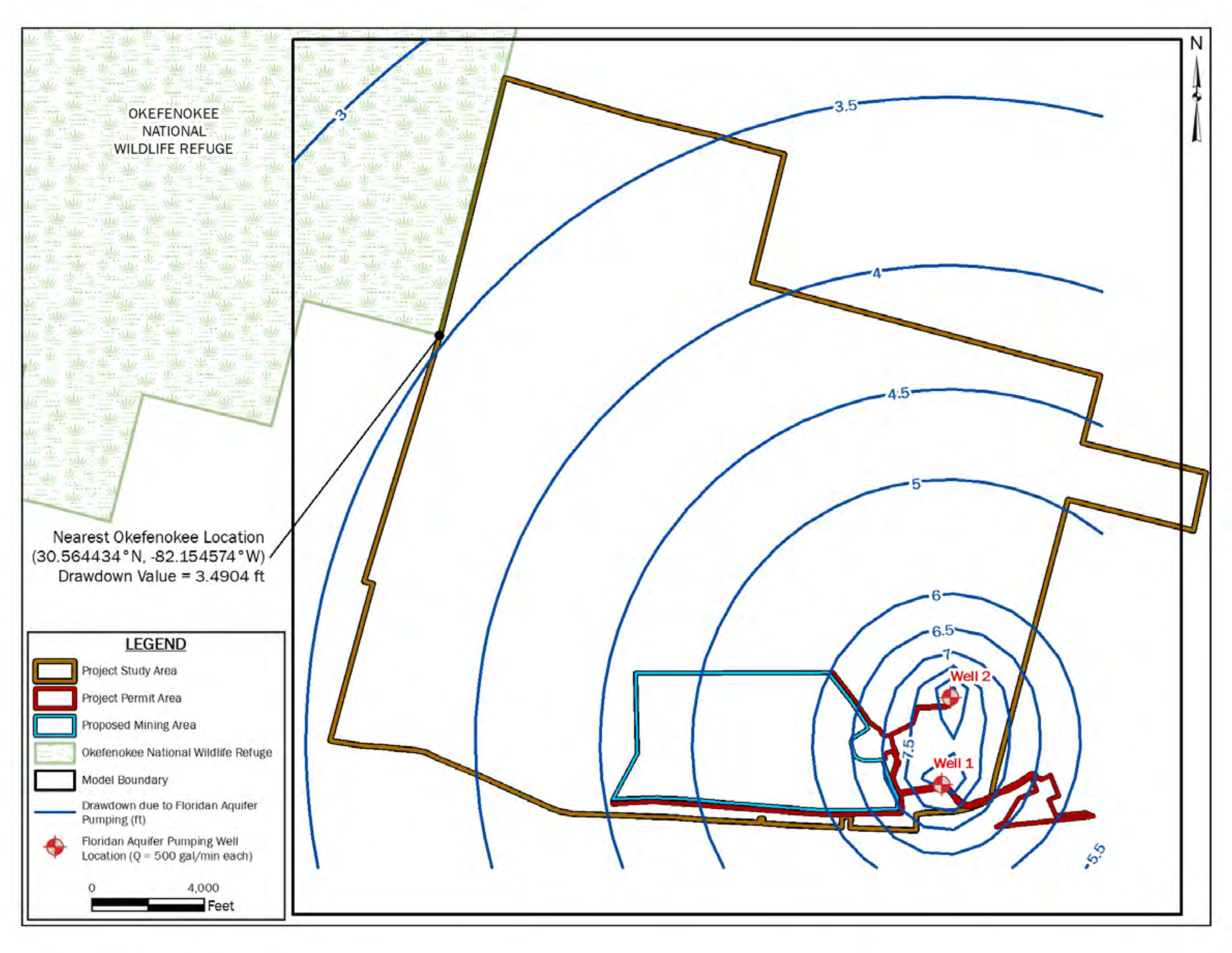
Floridan Aquifer Drawdown at 1 Year



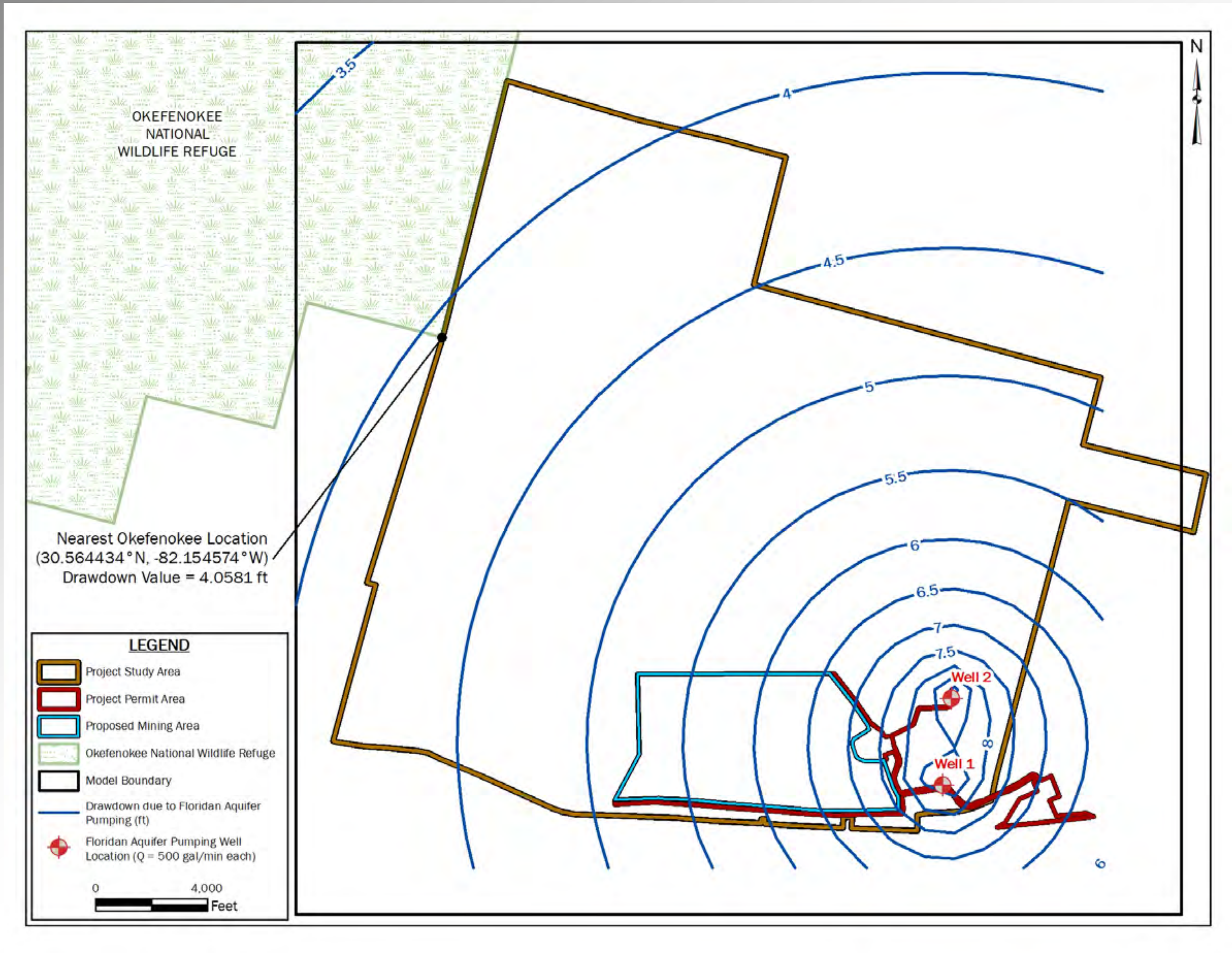
Drawdown at the boundary of the Wildlife Refuge = 2.7 ft

Floridan Aquifer Drawdown at 2.75 Years



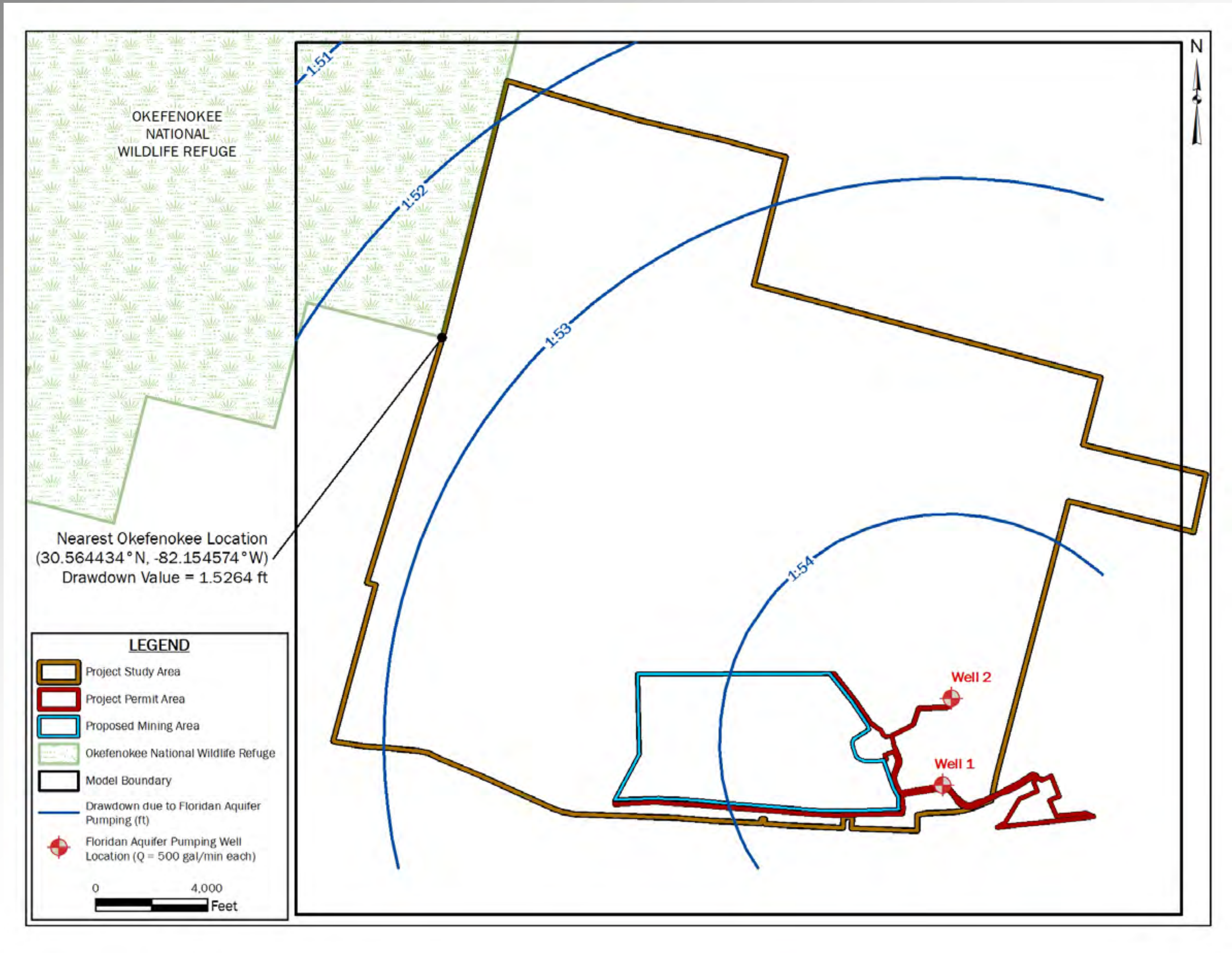
Drawdown at the boundary of the Wildlife Refuge = 3.5 ft

Floridan Aquifer Drawdown at 5.5 Years



Drawdown at the boundary of the Wildlife Refuge = 4.1 ft

Floridan Aquifer Recovery After 1 Year



Drawdown at the boundary of the Wildlife Refuge is reduced to 1.5 ft

Impact of Floridan Pumping on the Okefenokee Wildlife Refuge

Assuming that the Hawthorn Group thickness is 325 ft, hydraulic conductivity 1E-04 ft/d, and the specific storage coefficient is 1E-04 1/ft (Williams and Kuniansky, 2015):

- The aquifer time constant for the Hawthorn Group in the study area (a measure of the time required to move from one steady-state condition to another) is 289 years
- If the drawdown of 4.1 ft were present at the Wildlife Refuge boundary at the start of pumping, downward flow increase by 8.7E-08 in/year at year 5.5, which is insignificant compared to the difference between the average precipitation and evapotranspiration rate in the area, ~4.5 in/year

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Summary of Floridan Aquifer Modeling Results

- Pumping of 500 gpm from two wells on the eastern side of the project area will result in a maximum drawdown of 4.1 ft at the end of the project
- The Floridan Aquifer will quickly recover
- Pumping in the Floridan Aquifer will have a negligible and insignificant impact of the Okefenokee Wildlife Refuge

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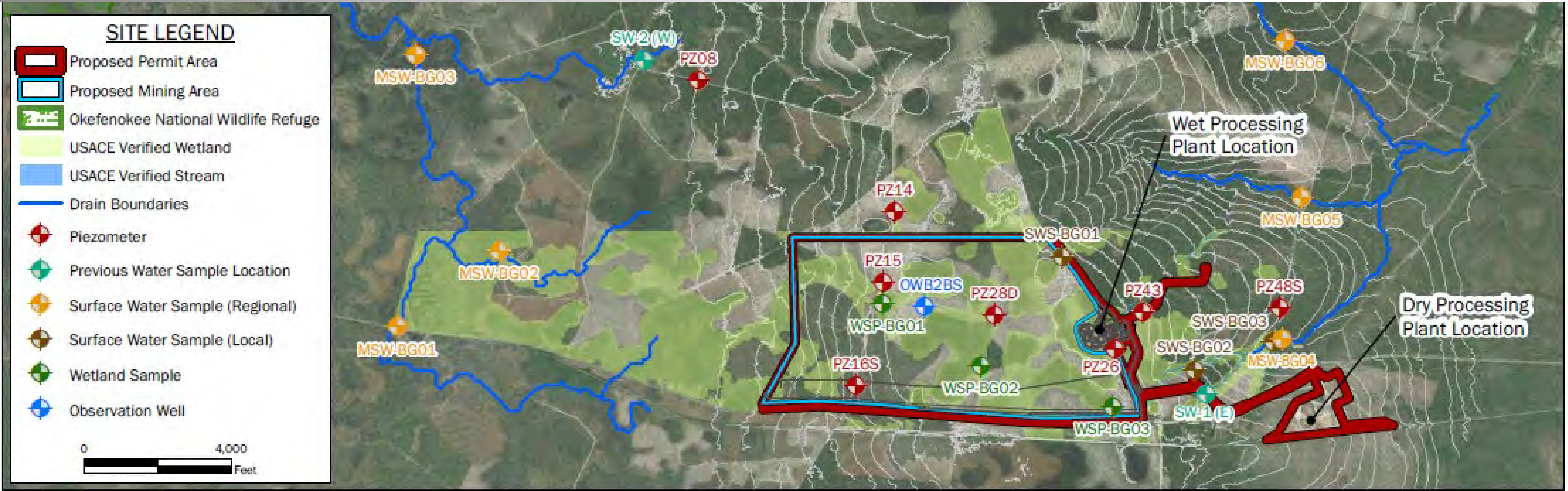
Groundwater and Surface Water Chemistry

Geochemistry of Water Samples

- Surface waters
  - dominated by sodium and chloride
  - low total dissolved solids (TDS), 25-50 mg/L
  - significant natural organic matter (total organic carbon 17-65 mg/L)
  - pH mainly in the 4-5 range, reflecting organic acid presence
- Groundwater
  - shallow groundwater varies in chemical signature
    - most similar to surface water
    - others have sodium/calcium-bicarbonate with higher pH (5-6) and TDS (60-120 mg/L)
    - dissolved organic matter present, though not as high as surface water
  - deep groundwater (Floridan) is calcium-bicarbonate, pH 7.4, TDS 480 mg/L



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BACKGROUND WATER-QUALITY SAMPLING POINTS

TWIN PINES MINERALS

ST. GEORGE, CHARLTON COUNTY, GEORGIA

BASEMAP: DigitalGlobe, 3/24/2018 (0.46 m Resolution).

DRAWN BY: DEK
CHECKED BY: JRS
DRAWING DATE: 2/28/2020
REVISION DATE: 5/6/2020
TTL JOB NO.: 000180200804.00
APPROX. SCALE: 1 in = 4,000 ft

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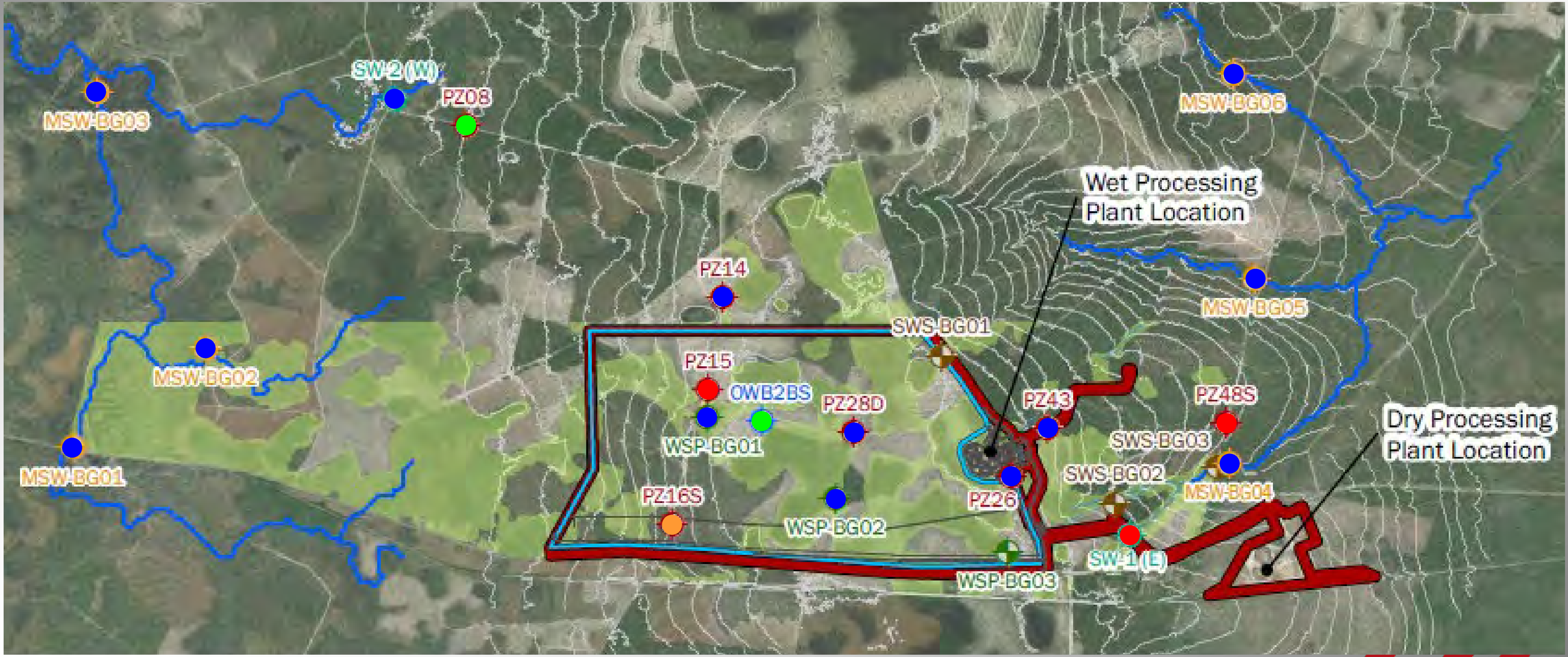
(Alkalinity) / (Chloride)

- 0 to 0.1
- 0.1 to 0.5
- 0.5 to 1
- 1 to 9.281



pH

● (red)	4 to 4.5
● (orange)	4.5 to 5
● (green)	5 to 6
● (blue)	6 to 6.6

Scope of Geochemical Analysis and Modeling

- Compile recent and current sampling chemical data for the water sources to be used for mine operations
- Use geochemical modeling tools to predict the chemical composition of the mine operations water
  - accounts for chemical reactions during mixing of the source waters
  - includes reactions that affect mobility of trace metals
- Use laboratory analytical tools to examine the properties of humate-slurry discharge and its potential effects on local shallow groundwater following burial

Groundwater and Surface-Water Monitoring Plan

Groundwater and Surface Water Monitoring Plan

- Designed to assess the impact or effect of proposed mining on hydrology along Trail Ridge and surrounding areas (including the Okefenokee Swamp)

- Verify the results of the groundwater models developed for the site

Purpose of Groundwater- and Surface Water-Level Monitoring

- Monitor changes in groundwater levels due to precipitation, recharge, and runoff
- Characterize the response of surface water levels to precipitation and groundwater levels
- Allow the development of models relating precipitation to groundwater levels and recharge
- Identify changes in levels induced by the moving mine pit
- Quantify changes in post-mining water levels
- Provide water-level data to assist in mine reclamation activities

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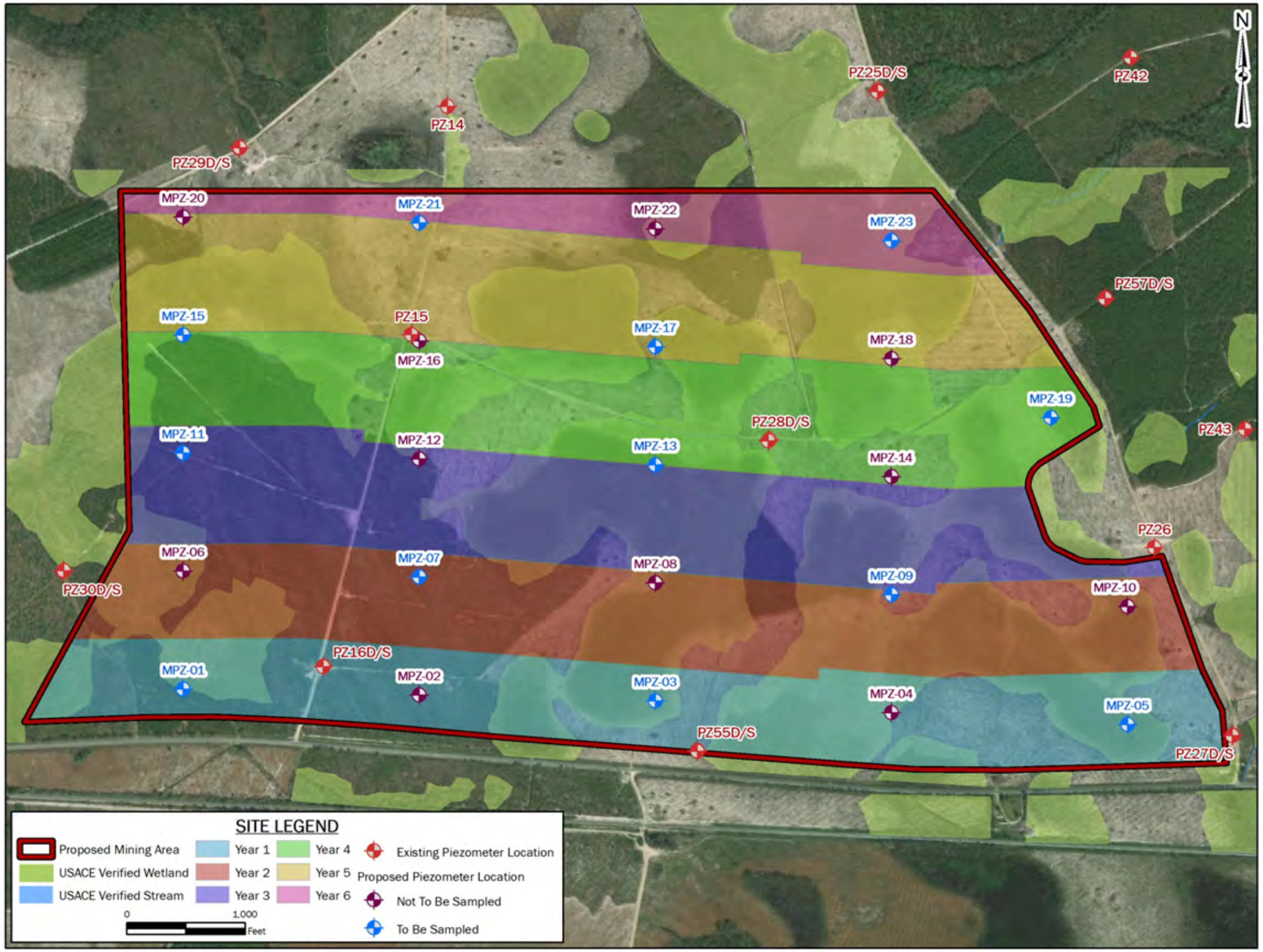
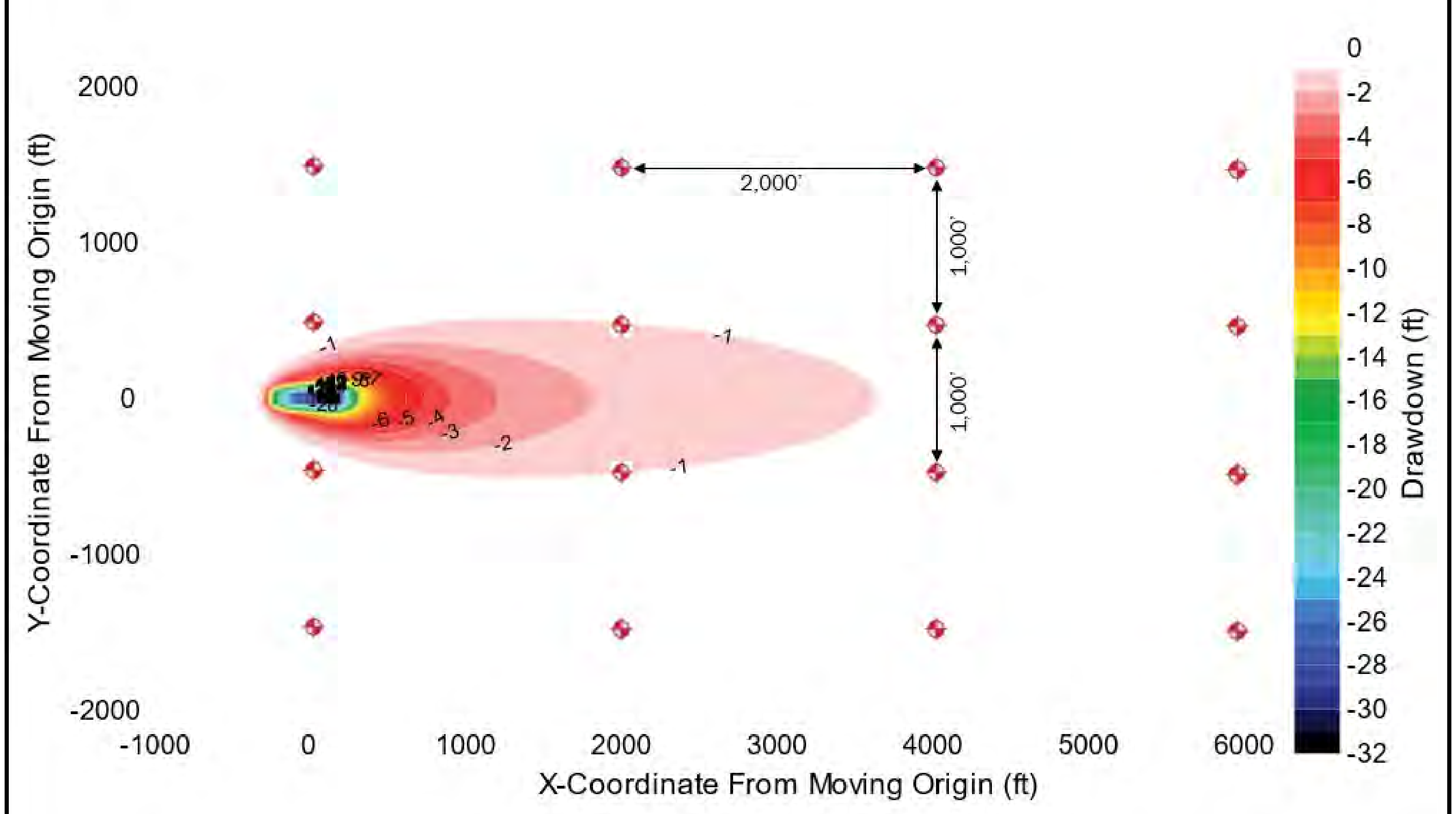
23 Piezometers will be Installed in the Mine Footprint



Piezometers will be spaced every 2000 ft in the east-west direction and 1000 ft in the north-south direction

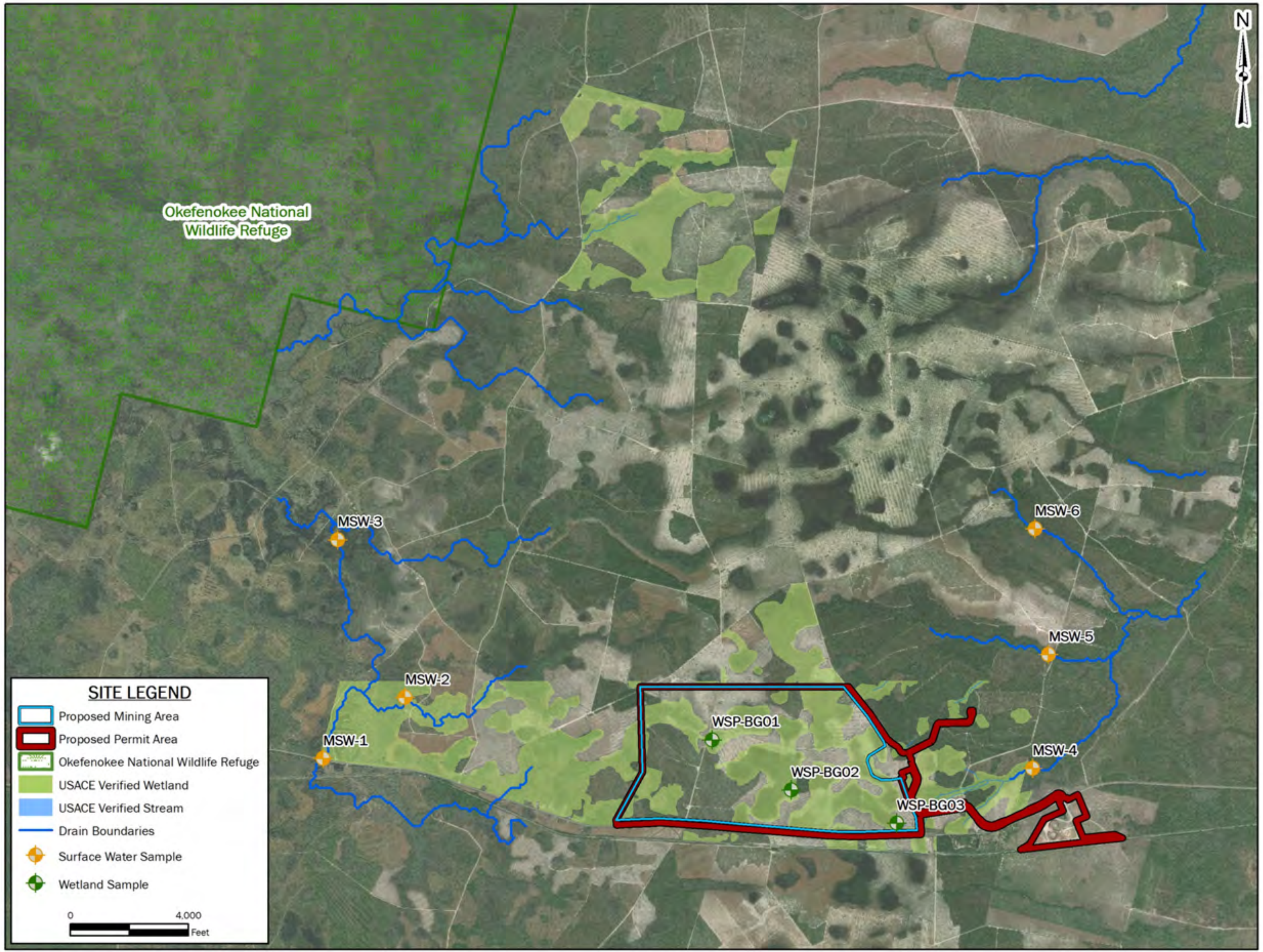
Piezometers will be replaced after they are mined out and monitored during pre-mining, mining and post-mining periods

The Configuration of the New Piezometers was Chosen to Verify Predicted Drawdown due to the Moving Mine Pit



TTL

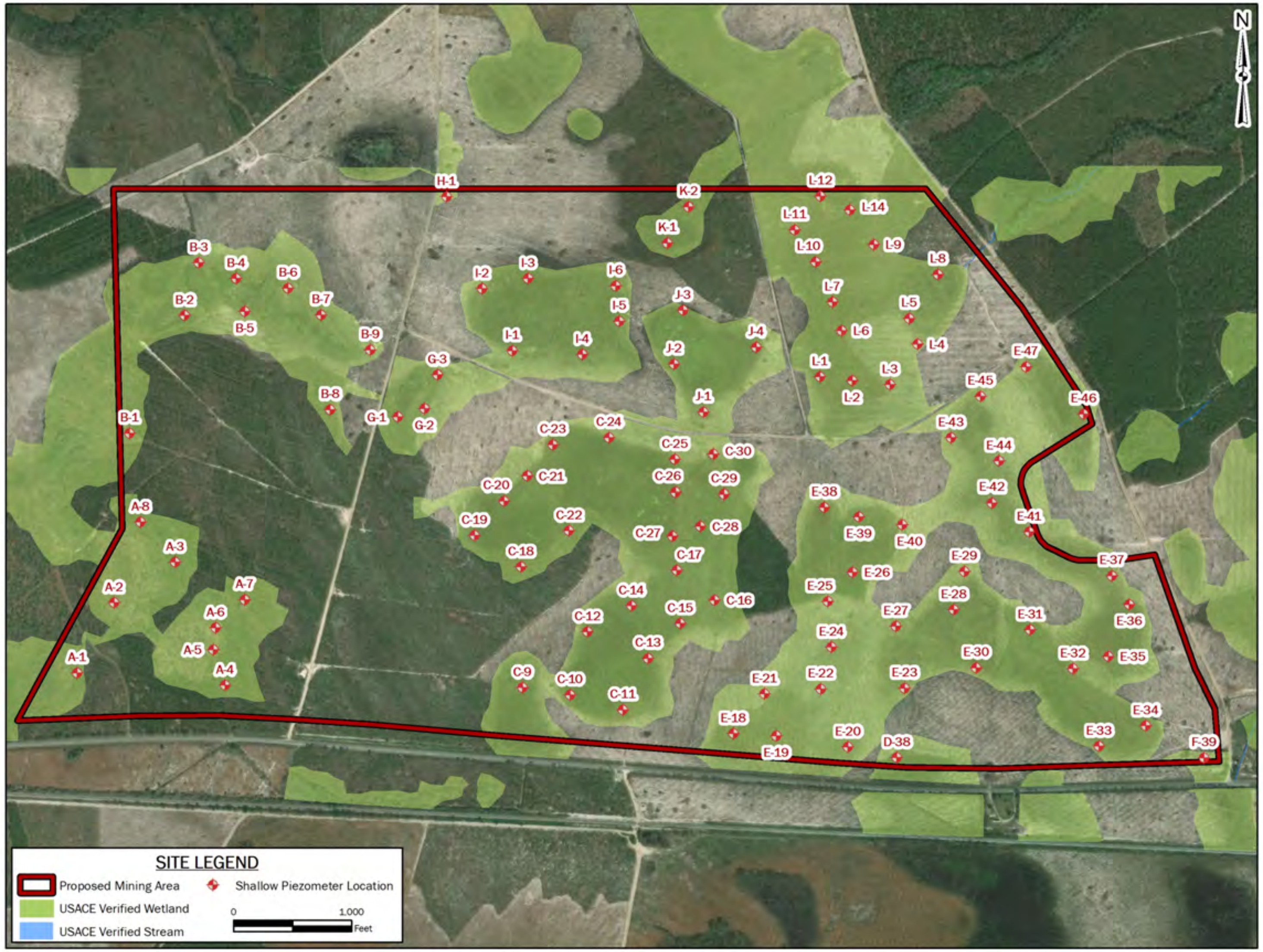
A Total of Nine Staff Gauges will be Monitored



These staff gauges will be continuously monitored during pre-mining, mining, and post-mining periods

TTL

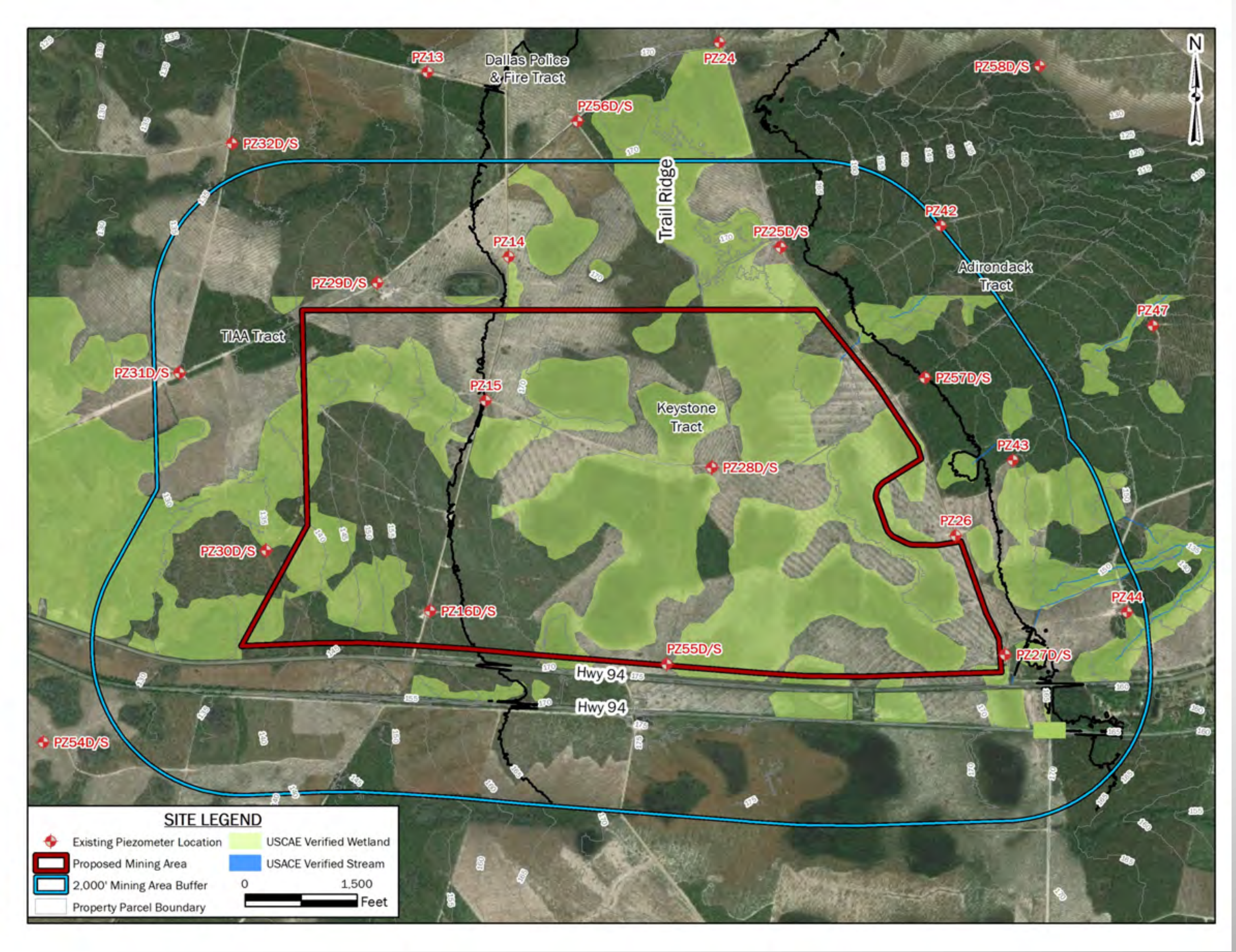
100 Shallow, 1.5-Foot Deep Piezometers were Installed in Wetlands



These piezometers will be continuously monitored during pre-mining, mining, and post-mining periods

TTL

24 Piezometers within in Mine Footprint and within 2000 ft of the Mine



Water levels in all existing piezometers outside the mine footprint will be continuously monitored during pre-mining, mining, and post-mining periods

TTL

Purpose of Water-Quality Sampling

- Establish baseline groundwater and surface water chemistry
- Monitor spatial and temporal changes in water chemistry due to mining activities
- Provide groundwater chemistry data for mine reclamation activities

Water-Quality Sampling Locations (36)

- 23 newly installed piezometers (MPZ-01 through MPZ-23)
- Piezometers PZ30D, PZ14, PZ57D, and PZ44
- Wetland Monitoring Points WSP-01 through WSP-03
- Stream monitoring points MSW-01 though MSW-06

All monitoring points will have pressure transducers installed

TTL

Water-Quality Sampling Frequency

- One sampling event performed prior to initiation of mining.
- Four quarterly monitoring events beginning three months after mining is initiated
- Semi-annual sampling thereafter until the end of mining unless a notable change in water quality occurs
- Semi-annual monitoring of post mining conditions for an estimated period of six to seven years (estimated duration of mining)

TTL

Post-Mining Monitoring

- Post-mining monitoring will be performed for a period equal to the period of mining, and will consist of the monitoring of water levels in the piezometers on a continuous basis

Reporting

- Prepared on a quarterly basis for the first year and on an annual basis thereafter
- Will include groundwater contour maps, water-quality analysis, and trend graphs
- Monitoring data will be evaluated to determine the success of initial mining operations and methods.
- Groundwater-level data will be compared with groundwater models
- Water-chemistry data will be evaluated against current groundwater and surface water quality standards

Questions?