TETRA TECH

MEMO

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Cc:	Tony Countryman and Kathleen Coates, NWFWMD
From:	Greg Council, Lisa Grogin, Pete Andersen, and Scott Simpson
Date:	January 24, 2020 (Revision 1)
Subject:	Construction of a Coastal Region II SEAWAT Model

1.0 INTRODUCTION

This technical memorandum summarizes the construction of a SEAWAT version 4 (Langevin and others, 2007) variable-density groundwater flow and transport model for the coastal portion of Northwest Florida Water Management District (NWFWMD) Planning Region II (Santa Rosa, Okaloosa, and Walton Counties) using two existing DSTRAM (Huyakorn, Panday, and Lingam, 1994; Hydrogeologic, Inc. [HGL], 2008) models covering portions of this area (**Figure 1**). This work was completed to fulfill Task Order 4 of NWFWMD Contract 18-078 with Tetra Tech. NWFWMD is updating its existing groundwater flow and transport models to assess the need to develop and establish minimum aquifer levels to manage saltwater intrusion in the Upper Floridan Aquifer (UFA) in the model area. This model construction task is one of several modeling tasks that will be used to complete the assessment. The variable-density SEAWAT model was not calibrated as part of this task. Instead, boundary-conditions, hydraulic property values, and transport property values used in the model were transferred from previously-calibrated DSTRAM models, which are documented in HGL (2005) and HGL (2007).

NWFWMD supplied documentation and model data sets for the Region II MODFLOW groundwater flow model (freshwater density assumed) and prior DSTRAM models of the "Western Domain" and "Eastern Domain" of the Region II coastal area (HGL, 2000; HGL, 2005; HGL, 2007). NWFWMD also provided geographic information system (GIS) data sets mapping various model parameters and boundary conditions of the Region II model and the DSTRAM models. The DSTRAM model data sets included input and output files for simulations of the "pre-development" period (no groundwater withdrawals) and the "post-development" period beginning in 1942. For the pre-development simulations, steady-state flow is assumed and transport is run in transient mode for a long period of time until salt-mass equilibrium (steady-state) is attained. The post-development simulations include groundwater withdrawals[1] at wells that vary on a yearly basis. The Western Domain model simulates groundwater withdrawals through 1998, while the Eastern Domain model simulates withdrawals through 2004. NWFWMD also provided proposed specifications for the new SEAWAT domain and grid.

Pre-development and post-development Groundwater Vistas files are being provided along with this memo to allow NWFWMD to easily view and review the model data for the new SEAWAT model. This is done in lieu of

[1] There is one location in the Western Domain model where groundwater is injected at an injection well. For convenience, this memo only discusses groundwater withdrawals, but the lone injection well is treated in a similar manner. In all the models discussed, withdrawals are defined by negative specified flows and injections are defined by positive specified flows.

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providing the myriad figures showing model properties, boundary conditions, and initial conditions that would be required to fully illustrate the model specifications for the 20-layer SEAWAT model.

2.0 MODEL CONSTRUCTION

2.1 GENERAL METHODOLOGY

DSTRAM uses finite elements to simulate flow and transport wherein aquifer properties are specified for rectangular-prism elements and the software calculates concentration and head at the nodes that comprise the corners of these elements. SEAWAT uses a block-centered finite-difference method wherein properties are specified for rectangular-prism cells and the computation points for head and concentration are at the centers of these cells.

The vertical layering scheme from the DSTRAM models is adopted for the SEAWAT model (see Section 2.2.2). However, since the variable DSTRAM mesh spacing in the two component models and the uniform SEAWAT grid spacing proposed for the new coastal-area model do not perfectly align, various steps were taken to translate DSTRAM model specifications into SEAWAT model specifications. The primary method of translation was bilinear interpolation, wherein data for SEAWAT cell-centers were based on either the data for the surrounding four DSTRAM nodes (boundary conditions and initial conditions) or the data for the surrounding four elements (aquifer properties) assigned to the center points of the elements. This operation applies to data defined for a single SEAWAT layer: in some instances, it was necessary to first vertically average data at adjacent DSTRAM nodal layers to generate two-dimensional DSTRAM grids of data that correspond to SEAWAT layers that have their computation points midway between DSTRAM nodes.

Note that the domains of the two DSTRAM models overlap (**Figure 2**). In the overlap area, model data are taken from the Eastern Domain model rather than the Western Domain model because the Eastern Domain model was calibrated more recently and presumably contains updated model specifications.

Also note that, while all models are aligned with the Universal Transverse Mercator (UTM) coordinate system, the SEAWAT model extends slightly beyond the total areal coverage of the Western Domain and Eastern Domain models. The westernmost column of the Western Domain model and the easternmost column of the Eastern Domain model were used (without interpolation) to define SEAWAT data at cells immediately east and west of these two DSTRAM models. Then, data from the northern rows of the Western Domain and Eastern Domain model were used (again without interpolation) to define SEAWAT data at cells north of the DSTRAM models. Similarly, the southernmost DSTRAM data were used to define SEAWAT data south of the DSTRAM model areas. The areas north and south of the DSTRAM meshes were made inactive in the new SEAWAT model; however, properties and initial conditions were defined in these areas for potential use in later modeling tasks.

2.2 SPATIAL DISCRETIZATION

2.2.1 Horizontal Domain and Grid

The Western Domain DSTRAM model consists of 72 nodal rows and 146 nodal columns with 21 nodal layers (which equates to 71 element rows, 145 element columns, and 20 element layers) (**Figure 3**). The Eastern Domain model has the same layers but consists of 83 nodal rows and 139 nodal columns (82 element rows, 138 element columns, and 20 element layers) (**Figure 3**). Both DSTRAM models have variable spacing in the horizontal plane. DSTRAM columns, rows, and layers are numbered from west to east, south to north, and bottom to top, respectively.

The new SEAWAT model was designed to cover the domains of both the Western and Eastern Domain models and fit within the variably spaced grid of the Region II model (**Figure 4**). The lower-left corner of the SEAWAT model is at 483,800 m east, 3,320,000 m north (UTM Zone 16), which is the lower-left corner of the Region II grid cell at row 114, column 15. The SEAWAT grid consists of 184 evenly spaced rows of 1292.71654 ft width aligned with the UTM Zone 16 east-west coordinate axis and 334 evenly spaced columns of 1292.68373 ft width aligned with the UTM Zone 16 north-south axis. While UTM coordinates are generally provided in meters, the model length unit is feet. SEAWAT columns, rows, and layers are numbered from west to east, north to south, and top to bottom, respectively.

The active area of the SEAWAT model encompasses the total area defined in the Western Domain and Eastern Domain models. Areas north and south of either model were defined to be inactive in the SEAWAT model (**Figure 2**).

2.2.2 Layering

HGL (2000) describes the hydrostratigraphic units of the Floridan Aquifer System. Within the DSTRAM and SEAWAT models, the Intermediate Aquifer System (IAS), UFA, Bucatunna Clay (BUC), Lower Floridan Aquifer (LFA) and Sub-Floridan (SUB) system (HGL, 2005 and 2007) are modeled. The overlying surficial aquifer system is not explicitly modeled. To match the layering in the DSTRAM models, the upper three layers (1-3) of the SEAWAT model represent the IAS, the next five layers (4-8) represent the UFA, the following three layers (9-11) represent the BUC (where present), the next six layers (12-17) represent the LFA, and the bottom three layers (18-20) represent the SUB. These correspond to the twenty element layers in the DSTRAM models, though DSTRAM numbers them in reverse order (**Figure 5**). Note that the BUC is not present throughout the SEAWAT model domain; portions of layers 9-11 are therefore assigned properties consistent with the LFA in portions of the model where the BUC is absent.

As with the DSTRAM models, layer elevations for several hydrostratigraphic-unit contacts are taken from the Region II model data, which were provided by NWFWMD in GIS files. The top of SEAWAT layer 1 (top of the model) was taken to be the top of the IAS in the Region II model: the top elevation at each SEAWAT layer 1 cell was defined to be the IAS-top elevation of the Region II model cell that contained the SEAWAT (horizontal) cell center (no interpolation). Similarly, the elevations of the bottoms of layers 3, 8, 11, and 17 were defined for the SEAWAT model based on the Region II model data for the bottoms of the IAS, UFA, BUC, and LFA, respectively. The bottoms of layers 1 and 2 were assigned to evenly divide the IAS into three layers (such that any set of cells in layers 1, 2, and 3 that have the same row and column values will have the same thickness). This same approach was used to vertically discretize the UFA, BUC, and LFA: the bottoms of layers 4-7 were assigned to evenly divide the UFA into five layers, the bottoms of layers 9 and 10 were assigned to evenly divide the BUC into three layers, and the bottoms of layers 12-16 were assigned to evenly divide the LFA into six layers

The SUB is not modeled in the Region II model. The bottom of the SUB (SEAWAT model layer 20) was therefore defined using the elevation of the bottom layer (nodal layer 1) in the two DSTRAM models. Bilinear interpolation was used for cell centers within the areas of the Western Domain and Eastern Domain models. The SUB bottom elevations at SEAWAT cell centers inside the DSTRAM-model footprints were then contoured using a contour interval of 50 ft. These contour lines were then extended to envelop the entire SEAWAT domain (including inactive areas), and a raster of smoothly varying elevations was created by interpolating between contours. The mean elevation of the raster surface within each cell outside the DSTRAM areas was then used to define the bottom of the SUB in these areas. The bottom of SEAWAT layer 19 was taken to be 30 feet above the bottom of the SUB consistent with the thickness of the bottom elemental layer in the DSTRAM models. The bottom of SEAWAT layer 18 was then calculated to be midway between the bottom of layer 17 and the bottom of layer 19. **Figure 6** shows an example south-to north cross section through the SEAWAT model (column 219) to show the model layering.

2.3 AQUIFER PARAMETERS

2.3.1 Flow Parameters

Horizontal hydraulic conductivity (*Kx* = *Ky*), vertical hydraulic conductivity (*Kz*), and specific storage (*Ss*) were extracted from the DSTRAM input files and, using the general bilinear interpolation methodology described in Section 2.1, translated from DSTRAM element centers to SEAWAT cell centers. **Table 1** lists the minimum, maximum, mean and median values for those parameters for each layer. Of note, HGL modified the SUB parameterization between the Western Domain and Eastern Domain model studies. The Western Domain model had variable conductivities in the bottom layer (element layer 1), a uniform value of 0.5 ft/d for the middle SUB layer (element layer 2), and a uniform value of 1.0 ft/d for the upper SUB layer (element layer 3). The Eastern Domain model had a uniform hydraulic conductivity value of 0.5 ft/d for the upper and middle SUB layers and a uniform value of 3.0×10^{-4} ft/d for the bottom SUB layer. Changes documented in the representation of the BUC are also evident in SEAWAT layers 9-11.

2.3.2 Transport Parameters

The effective porosity was set to a model-wide constant of 0.25 as documented by HGL (2005 and 2007). Dispersity and diffusion were also set as documented by HGL (2005 and 2007). Dispersivity values were spatially constant at values of 100 ft longitudinal, 20 ft horizontal transverse, and 1 ft vertical transverse. As in the DSTRAM models, the molecular diffusion coefficient was set to 0.001 ft^2/d for the bottom layer of the model and for the portions of model layers 9-11 where the BUC is presumed present (**Figure 7**). Elsewhere, the diffusion coefficient is assumed to be zero (diffusion is ignored).

2.4 BOUNDARY CONDITIONS

2.4.1 Specified Head and Concentration

Heads and concentrations are specified along the top, bottom, and lateral edges of the SEAWAT active domain. In DSTRAM, heads are specified as equivalent freshwater head, h_f (head of water at freshwater density) while in SEAWAT version 4, specified heads are input (by default) as point head, h (head of water at the water density for that location). In order to convert DSTRAM head specifications to SEAWAT input, the following formula is used:

$$h = \frac{h_f + 0.025cz}{1 + 0.025c} \qquad (1)$$

where c is the specified salt concentration relative to seawater (c = 1) and z is the elevation of the node (z = 0 at mean sea level).

2.4.1.1 Bottom Boundary

Heads and concentrations are specified for the bottom of each DSTRAM model (nodal layer 1) and do not vary in time. These specifications were translated to cells in the bottom layer in the SEAWAT model (layer 20) using bilinear interpolation after first calculating point head at DSTRAM nodes in layer 1 from freshwater head, concentration, and node elevation using equation (1). Bottom-layer heads are specified in the time-variant constant-head (CHD) package input file as point heads (h) in SEAWAT. Bottom-layer relative concentrations (c) are specified in the sink and source mixing (SSM) package input file in SEAWAT.

2.4.1.2 Top Boundary

Heads and concentrations are also specified for the top of each DSTRAM model (nodal layer 21) which corresponds to the interface between the surficial aquifer system and the IAS. The concentrations specified for the top of each DSTRAM model are constant in time whereas the specified heads vary by year in the post-development period. However, review of the specified heads at the top boundary indicated that there was no more than 0.5 ft of head variation at any top-boundary node in the post-development simulation for either DSTRAM model. Given the much larger head variations across the model domains and induced by post-development withdrawals, the top boundary of the SEAWAT model (layer 1) was treated as time-invariant at the values specified for the pre-development period.

The general-head-boundary (GHB) package is used in SEAWAT to specify point heads at the top of all active cells in SEAWAT model layer 1. The model-top relative concentrations are specified in the SSM package input file in SEAWAT. The specified concentrations and heads were defined using bilinear interpolation after first calculating point head at DSTRAM nodes in layer 21 from freshwater head, concentration, and node elevation using equation (1). The GHB conductance at each cell was calculated by multiplying the vertical conductivity assigned for that cell in layer 1 by the area of the top face of the cell and dividing by one half of the cell vertical thickness (i.e. the vertical distance between the top of the model and the center of the cell).

2.4.1.3 Lateral Boundary

At the lateral edges of the DSTRAM models, concentrations and heads are specified for the DSTRAM nodal layers bounding the UFA (nodal layers 13-18) and LFA (nodal layers 4-10). Concentrations along these lateral boundaries in the DSTRAM models are constant in time whereas heads vary by year in the post-development simulations. Unlike at the model top, heads vary significantly with time at some nodes along the lateral edges of the DSTRAM models. A multi-step procedure was used to define the specified concentrations and heads for the SEAWAT model lateral boundary cells:

1. For each DSTRAM model (Eastern Domain and Western Domain):
    a. Extracted node numbers and relative concentrations, c (constant), from input file
    b. Extracted node numbers and equivalent freshwater heads, h_f (variable by year in post-development period), from input file
    c. Matched specified heads and concentrations by node number
    d. Determined node column (i), row (j), and layer (k) from node number
    e. Subdivided the lateral boundary into boundary segments (**Figure 8**), and arranged data by segment, position within segment, and layer.
    f. Verified that data existed for all edge-boundary nodes in all UFA and LFA nodal layers (k = 4-10 and k = 13-18)
    g. Determined node x and y locations in UTM coordinates from mesh specifications
    h. Looked up node elevations z using elevations in input file
    i. Calculated point head h for each specified freshwater head (h_f) using equation (1)
    j. For each layer (k) in LFA nodal layers 4-9 and UFA nodal layers 13-17:
        i. For each node location (i,j) along boundary, calculated mid-layer average c (c_{avg}) between this node $c(i,j,k)$ and the corresponding node in the next layer $c(i,j,k+1)$
        ii. Similarly calculated mid-layer average point head h_{avg} for each period of simulation using nodal point heads from adjacent nodal layers
2. For each SEAWAT boundary cell:
    a. If the cell was along a southern or northern face of a DSTRAM model (boundary segments W-South, W-North, E-South, and E-North in **Figure 8**):
        i. Determined the cell-center UTM x coordinate (x_c) from grid specifications
        ii. Used x_c to determine which two DSTRAM boundary node positions the cell center was between: nodes at (i,j) and ($i+1,j$)
        iii. Calculated the relative horizontal x-direction distance (d) between the cell center and the two neighboring DSTRAM node positions: $d = [x_c - x(i,j)] / [x(i+1,j) - x(i,j)]$
    b. If the cell was along a western or eastern face of a DSTRAM model (W-West, W-East, E-West, and E-East in **Figure 8**):

i. Determined the cell-center UTM y coordinate (y_c) from grid specifications
ii. Used y_c to determine which two DSTRAM boundary node positions the cell center was between: nodes at (i,j) and ($i,j+1$)
iii. Calculated the relative horizontal y-direction distance (d) between the cell-center and the two neighboring DSTRAM node positions: $d = [y_c - y(i,j)] / [y(i,j+1) - y(i,j)]$

c. Used horizontal one-dimensional linear interpolation to determine the cell-center concentration c_c in each UFA and LFA SEAWAT layer m (m = 4-8 and m = 12-17 for the UFA and LFA, respectively): $c_c = c_{avg1}(1-d) + c_{avg2}(d)$, where c_{avg1} and c_{avg2} are the vertically averaged DSTRAM mid-layer boundary concentrations at the DSTRAM nodes on either side of the cell center for the corresponding DSTRAM layer k (where $k = 21 - m$)
d. Similarly used one-dimensional linear interpolation to determine cell-center point head for each SEAWAT layer and each year of simulation (including pre-development): $h_c = h_{avg1}(1-d) + h_{avg2}(d)$, where h_{avg1} and h_{avg2} are the vertically averaged DSTRAM mid-layer boundary head values at the DSTRAM nodes on either side of the cell center for the corresponding DSTRAM elemental layer k (where $k = 21 - m$)

2.4.2 River Boundary

The methodology outlined in the Eastern Domain model documentation (HGL, 2007) to transfer the river boundaries from the Region II MODFLOW model to the DSTRAM model was applied to the new SEAWAT grid. The rivers were defined using the ArcGIS River and Spring Tool Parent Database (Parent River Database, Version 1) (Tetra Tech, 2017). The Parent River Database was developed from the National Hydrography Dataset Plus, Version 2 (McKay et al., 2012) to be a grid-independent data source to use in the development of drain and river packages for MODFLOW-based models. The Parent River Database contains stage elevations, average flow depths, stream widths, and stream order rankings. Reaches in the SEAWAT model domain with stream order greater than 4 (i.e. Holmes Creek and Choctawhatchee River) were selected from the GIS database. The river bottom elevations at the upstream and downstream ends of each reach were computed from the stage elevations and average flow depths at the upstream and downstream ends of the reach. A Groundwater Vistas GIS import tool was then used to automatically define the SEAWAT cells that intersected the reaches (**Figure 9**) and to define stage and river bottom based on the positions along the stream reaches. Each SEAWAT cell was then graphically matched to a particular river-boundary cell in the Region II model (**Figure 9**), and the conductance specified for the Region II model cell was divided by the number of corresponding SEAWAT cells to define the conductances for the SEAWAT river cells. In this manner, the total river conductance matched the Region II model specification for the river cells within the SEAWAT domain. All river cells were applied to the top layer of the UFA (SEAWAT layer 4).

2.4.3 Wells

To accurately replicate well extractions in the DSTRAM post-development models while locating the wells in their actual locations, DSTRAM-specified withdrawal rates were joined to GIS based well locations (**Figure 10**). The withdrawal rates were taken directly from tables in the DSTRAM model documentation (HGL, 2005 and 2007). These rates extracted from the DSTRAM-model documents were totaled by year and were determined to match the yearly totals specified in the input files for the post-development DSTRAM simulations. These yearly withdrawal rates were used in the SEAWAT model. For wells that were in both the Western Domain and Eastern Domain models, rates found in the Eastern Domain model were used. The well locations in the NWFWMD well database were used to place wells in the correct SEAWAT rows and columns.

SEAWAT model layers for each well were defined from DSTRAM input data for the wells. In many cases multiple vertically-adjacent nodes were used to represent well extraction. To best match the DSTRAM model results, the top and bottom nodal layers assigned to each well in DSTRAM were mapped to top and bottom cell layers for each well in SEAWAT model layers using **Table 2**. For example, if DSTRAM nodes corresponding to a particular well are in node layers 17 (top) through 14 (bottom), then that well is assumed to be in SEAWAT layers 4 (top) through 8 (bottom) using the left and right halves of **Table 2**, respectively. In this way, pumping is generally assigned to aquifer layers and not aquitard layers when the top or bottom node for a well corresponds to an aquitard-aquifer interface. Once the SEAWAT layers were defined, the total withdrawal for each well, in each year of simulation, was divided evenly among the layers representing the well. The lone injection well in the model is assumed to inject freshwater (c = 0).

2.5 INITIAL HEADS AND CONCENTRATIONS

Initial heads and concentrations for the pre-development SEAWAT simulation were derived from initial heads and concentrations for the post-development DSTRAM simulations of the Western Domain and Eastern Domain models. These represent reasonable initial estimates of equilibrium pre-development heads and concentrations. After extracting the DSTRAM heads and concentrations at all nodes from the output files (the output files echo the initial conditions data that are read from unformatted files), equation (1) was used to calculate the initial point head at all DSTRAM nodes. Concentrations and point heads were then computed for the vertical midpoints between adjacent nodes by averaging the values of the nodes above and below each midpoint, yielding concentrations and heads corresponding to the elevations of cell centers in the SEAWAT model. Finally, bilinear interpolation was used for each layer to define initial concentrations and point heads in the SEAWAT model.

Initial conditions for the post-development SEAWAT simulation are taken to be the final (equilibrium) heads computed by the pre-development SEAWAT simulation.

2.6 OTHER SPECIFICATIONS

The SEAWAT model length and time units are feet and days. Salt concentration is modeled on a zero to one scale, with zero corresponding to freshwater and one (maximum) corresponding to seawater. Transport is coupled to flow via the concentration-dependent water density. The density of freshwater is specified as 62.44 lb/ft^3 and density is specified to increase linearly by 1.561 lb/ft^3 (2.5%) per unit change in relative concentration, consistent with equation (1). All SEAWAT layers are specified to be confined (type 0) which means that transmissivity and vertical leakance are calculated based on full layer thickness and are not functions of calculated head.

The pre-development period is set to an arbitrarily long duration of 10^6 days; steady-state flow and transient transport are assumed in this simulation. The post-development simulation is transient flow and transient transport and uses 57 time periods of 365 days each to simulate the period from 1942 through 1998, which is the same time period that is used for the Western Domain model. The Eastern Domain model extends to 2004, but boundary and well data are not included for the period from 1999-2004 for the portion of the SEAWAT model outside the Eastern Domain area.

Advection was simulated using the finite-difference method. Solution control parameters were set by trial and error to achieve reasonable convergence, mass balance, and simulation times. The geometric multigrid method was used to solve the groundwater flow equation and the generalized conjugate-gradient method was used to solve the groundwater transport equation (implicit in time). Other specifications for the solvers are provided in the Groundwater Vistas files transmitted with this memo.

3.0 MODEL RESULTS

The results from the pre- and post-development models were compared to DSTRAM results in the Western Domain (HGL, 2005) and Eastern Domain (HGL, 2007) documentation. For this purpose, true heads calculated by SEAWAT were converted to equivalent freshwater heads using the formula:

$$h_f = (1 + 0.025c)h - 0.025cz \qquad (2)$$

which is a rearrangement of equation (1). Also, relative concentrations were converted to chloride concentrations by multiplying the computed relative concentrations by 19,000 mg/L, the approximate chloride concentration of seawater. Note that there was no expectation of a perfect match between the SEAWAT and DSTRAM models due to the differences in certain specifications (notably treatment of the overlap area), differing discretization, and differing solution methods.

Figures 11 through 14 show SEAWAT vertical concentration profiles (chloride concentration vs. model layer at the end of pre-development [1942] and post-development [1998] simulations) at locations that correspond to Figures 4.62, 4.60, 4.57 of the Western Domain documentation (HGL, 2005) and Figure 4.25 of the Eastern Domain documentation (HGL, 2007). Overall, the match is reasonably accurate. The concentrations shown in layers 19 and 20 in **Figure 11 and 12** are lower than those in lowest nodes of the DSTRAM-model documentation (HGL, 2005). This was determined to be due to their location in the area where the Western Domain and Eastern Domain models overlap; the specified concentration of the bottom boundary was lower in the Eastern Domain model than in the Western Domain model. The SEAWAT model has the lower Eastern Domain model boundary concentration values assigned in the overlapping area. Also note that the 20 SEAWAT layer centers do not align with the 21 DSTRAM nodal layers (see **Figure 5**).

Figures 15 through 20 show SEAWAT simulated equivalent freshwater heads vs. time at select wells (Van Butler, Okaloosa School, DWU #1, EAFB FLD #5 Well #2, Navarre Cement, and Mary Esther #2). These correspond to Figures 4.45b, 4.45e, 4.45f, 4.45j, of the Western Domain model documentation (HGL, 2007) and Figures 4.39 and 4.41 of the Eastern Domain model documentation (HGL, 2005). Note that the SEAWAT post-development simulation only runs through 1998, while plots in the Eastern Domain model documentation show results through 2004. The SEAWAT-based equivalent freshwater heads follow the same general temporal patterns as the previous DSTRAM modeling results.

Figures 21 through 24 show SEAWAT simulated equivalent freshwater head contours in the UFA and LFA for year 1942 (pre-development) and 1998 (post-development). The UFA results were computed by averaging freshwater heads and concentrations in SEAWAT layers 5 and 6 (corresponding to DSTRAM nodal layer 16) and the LFA results were computed by averaging freshwater heads and concentrations in SEAWAT layers 14 and 15 (corresponding to DSTRAM nodal layer 7). These plots correspond to a combination of Figures 4.1, 4.2, 4.24, and 4.25 in the Western Domain model documentation (HGL, 2005) and Figures 4.3a, 4.3b, 4.31, and 4.32 in the Eastern Domain model documentation (HGL, 2007). Note that the post-development heads documented for the Eastern Domain are in 2004, not 1998. The patterns and head magnitudes compare reasonably well between SEAWAT and DSTRAM. There is evidence of the change in hydraulic conductivity between the Eastern and Western Domain models in **Figure 22** along the 50- and 60-ft contour lines where there is a bend at the transition. Also, there is a cone of depression on the eastern end of the SEAWAT model in 1998 that is not present in 2004 because significant pumping ceased along Panama City Beach at the end of 2001.

Figures 25 through 28 show SEAWAT chloride concentrations in the UFA and LFA for year 1942 (pre-development) and 1998 (post-development), respectively. These plots correspond to a combination of Figures 4.6, 4.7, 4.47, and 4.48 in the Western Domain model documentation (HGL, 2005) and Figures 4.7, 4.8, 4.46a, and 4.46b in the Eastern Domain model documentation (HGL, 2007). The SEAWAT concentrations are comparable to the documented DSTRAM concentrations. The transition zone from Western Domain to Eastern Domain is noticeable in all the concentration plots. This corresponds to the transition of the initial conditions used in the model.

4.0 RECOMENDATIONS

The SEAWAT model constructed for this task may be used as a starting point for development of a calibrated, variable-density flow and transport model of the Region II coastal area. In adapting this model for future use, the following factors should be considered:

- Extending the active model domain to the full SEAWAT (rectangular) domain area.
- Extending the post-development simulation period of the SEAWAT model to match the time frame of the current Region II flow model (1942-2015).
- Updating hydraulic properties and lateral head boundaries based on the Region II flow model after it has been recalibrated (the recalibration was in progress at the time this memo was written).
- Setting lateral east- and west-side constant concentration boundaries based on the revised initial concentrations and engineering judgment.
- Setting model top boundary conditions based on updated Region II model heads of the surficial aquifer system.
- Improving initial head and concentration specifications for the pre-development simulation. One possibility would be to use the "ELEV2CONC1" utility from the PEST suite (Doherty, 2019), which was developed specifically for this purpose and creates three-dimensional representations of initial concentrations and congruent initial heads.
- Investigating the salinity concentrations in the Sub-Floridan system to determine if the bottom boundary concentrations can be set to 1 across the entire domain.

These steps could be reasonable initial steps as part of a future calibration task for the new SEAWAT model.

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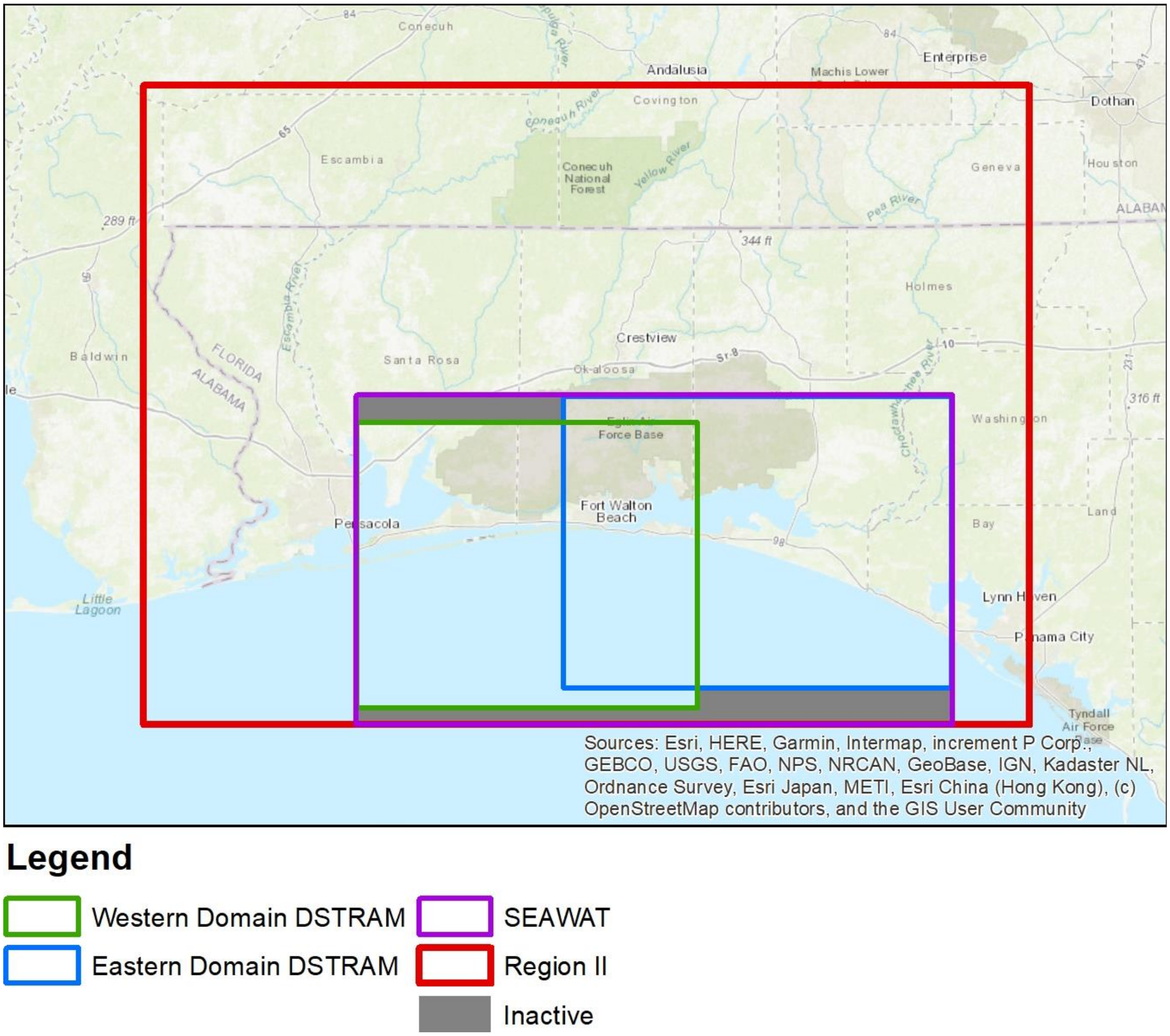
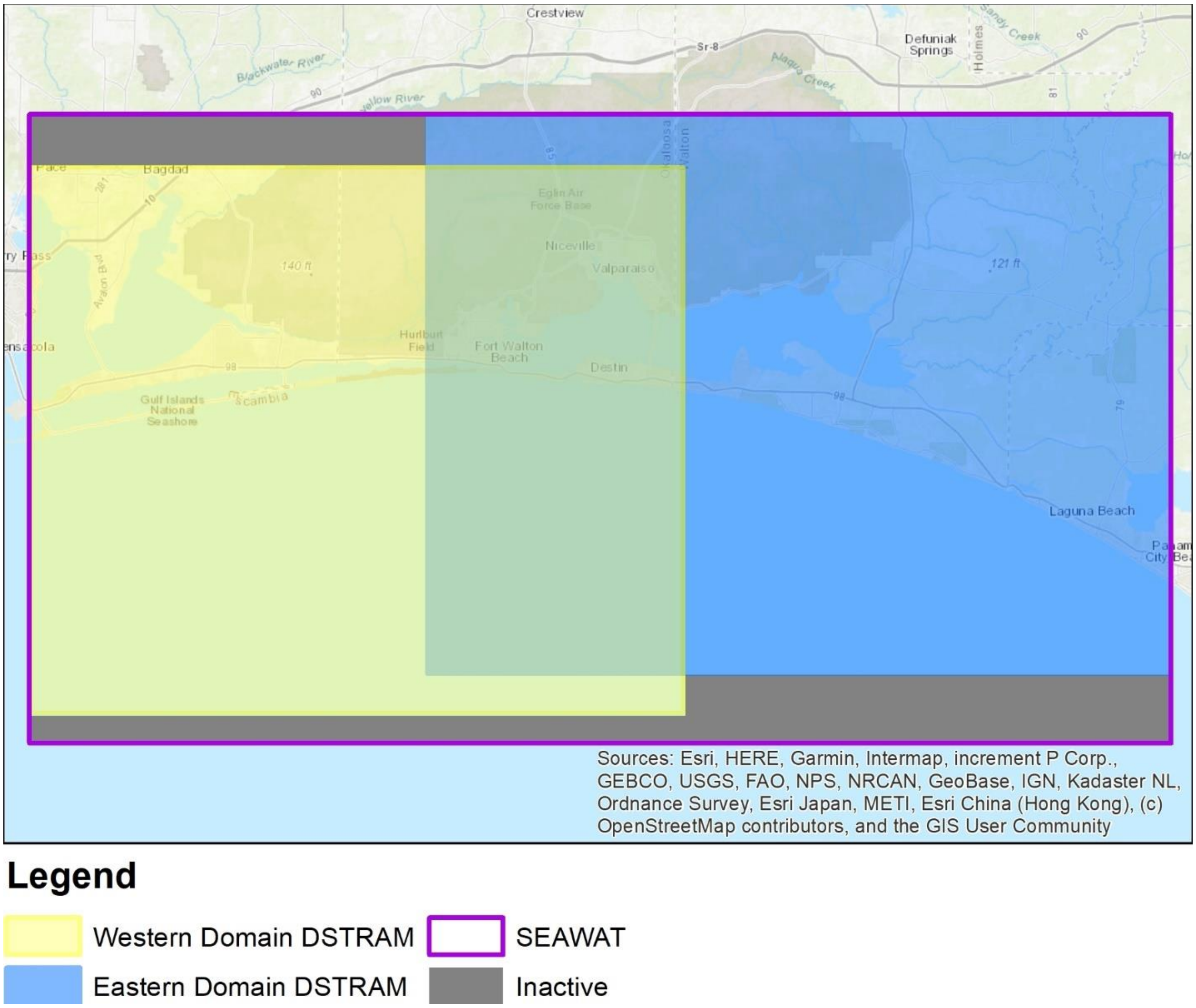


Figure 1 Location of Models



Note: In the green overlap area, data from the Eastern Domain model take priority

Figure 2 Model Data Priority

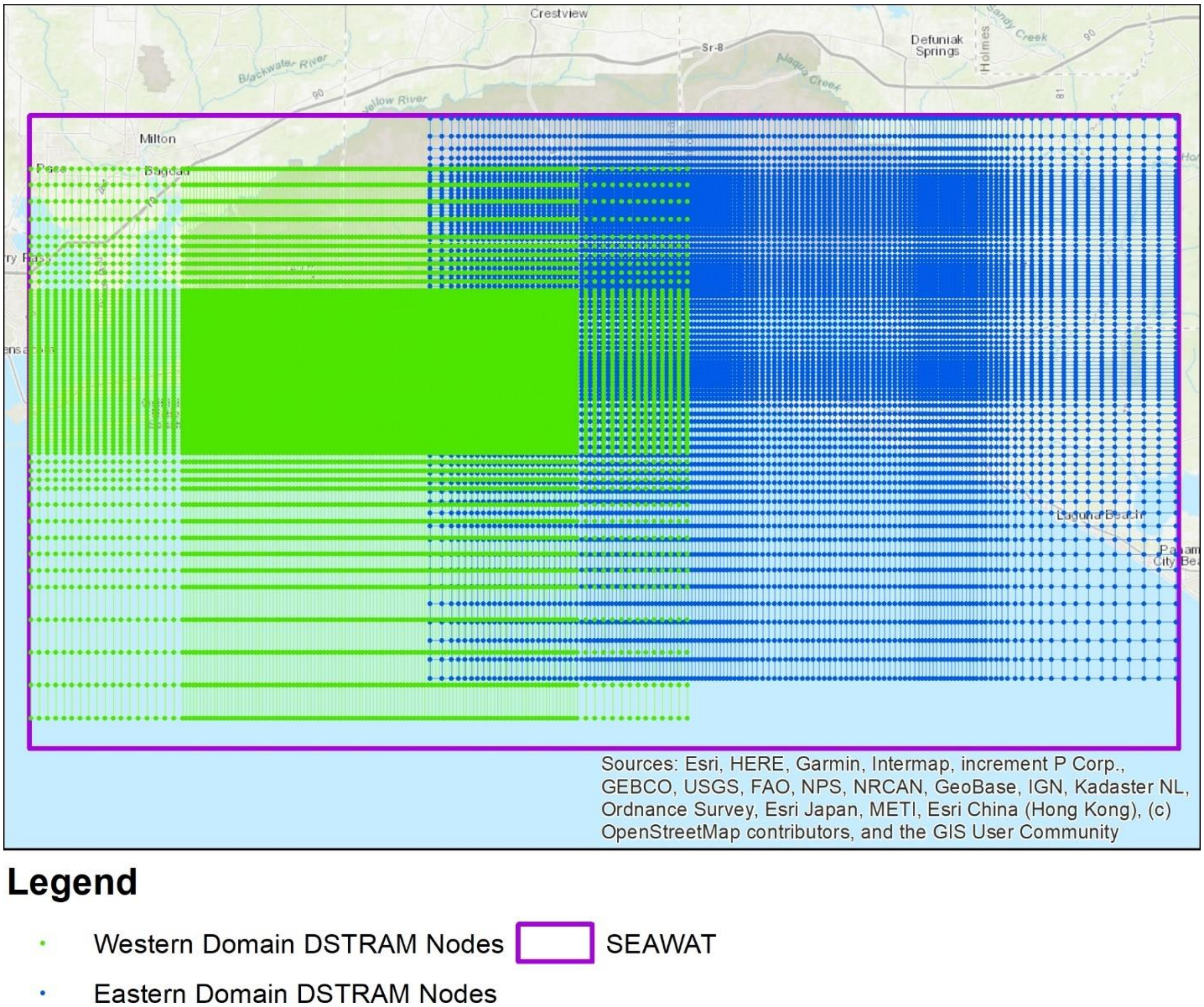


Figure 3 DSTRAM Model Node Locations

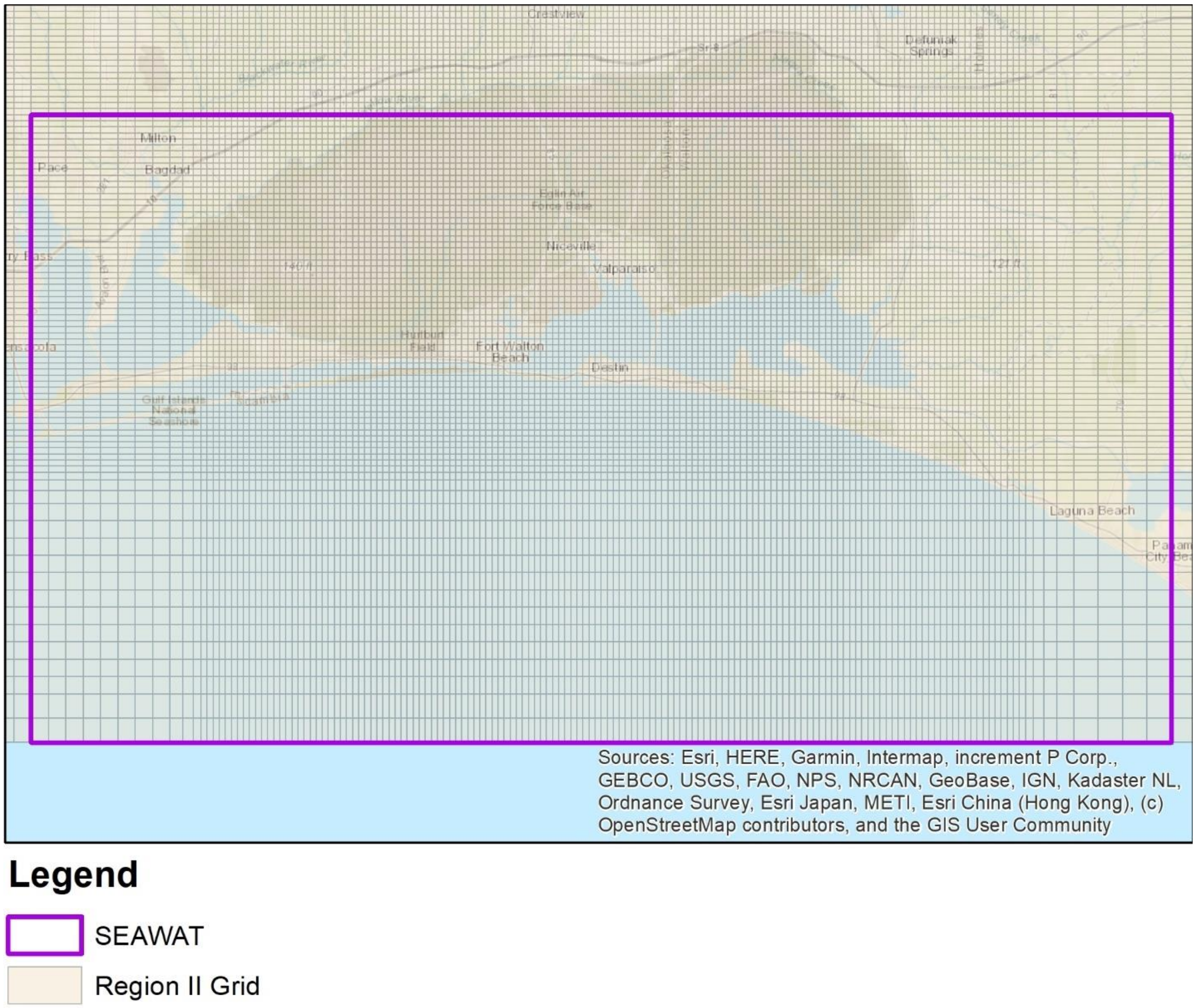


Figure 4 Location of SEAWAT Domain in Relation to Region II Grid Spacing

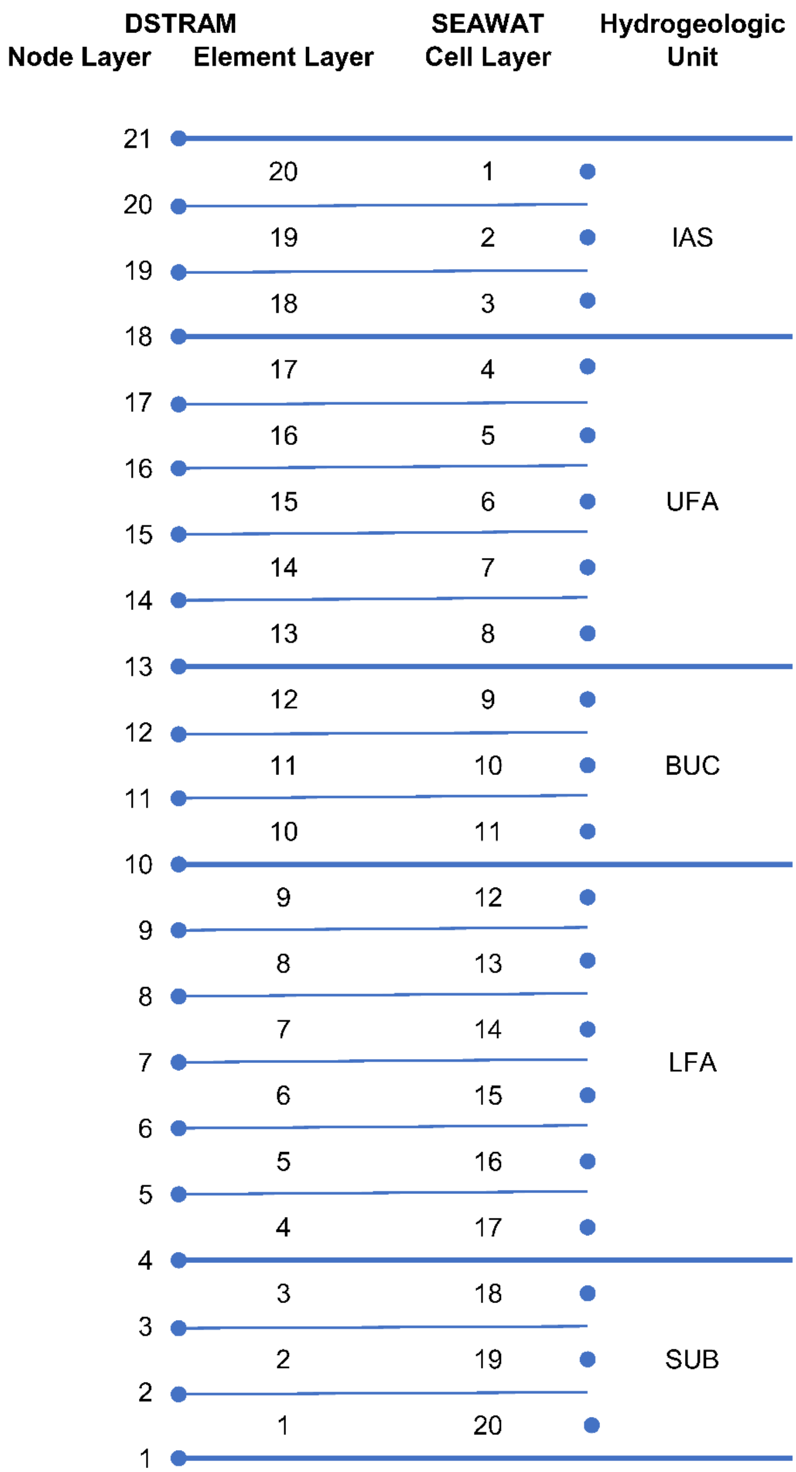
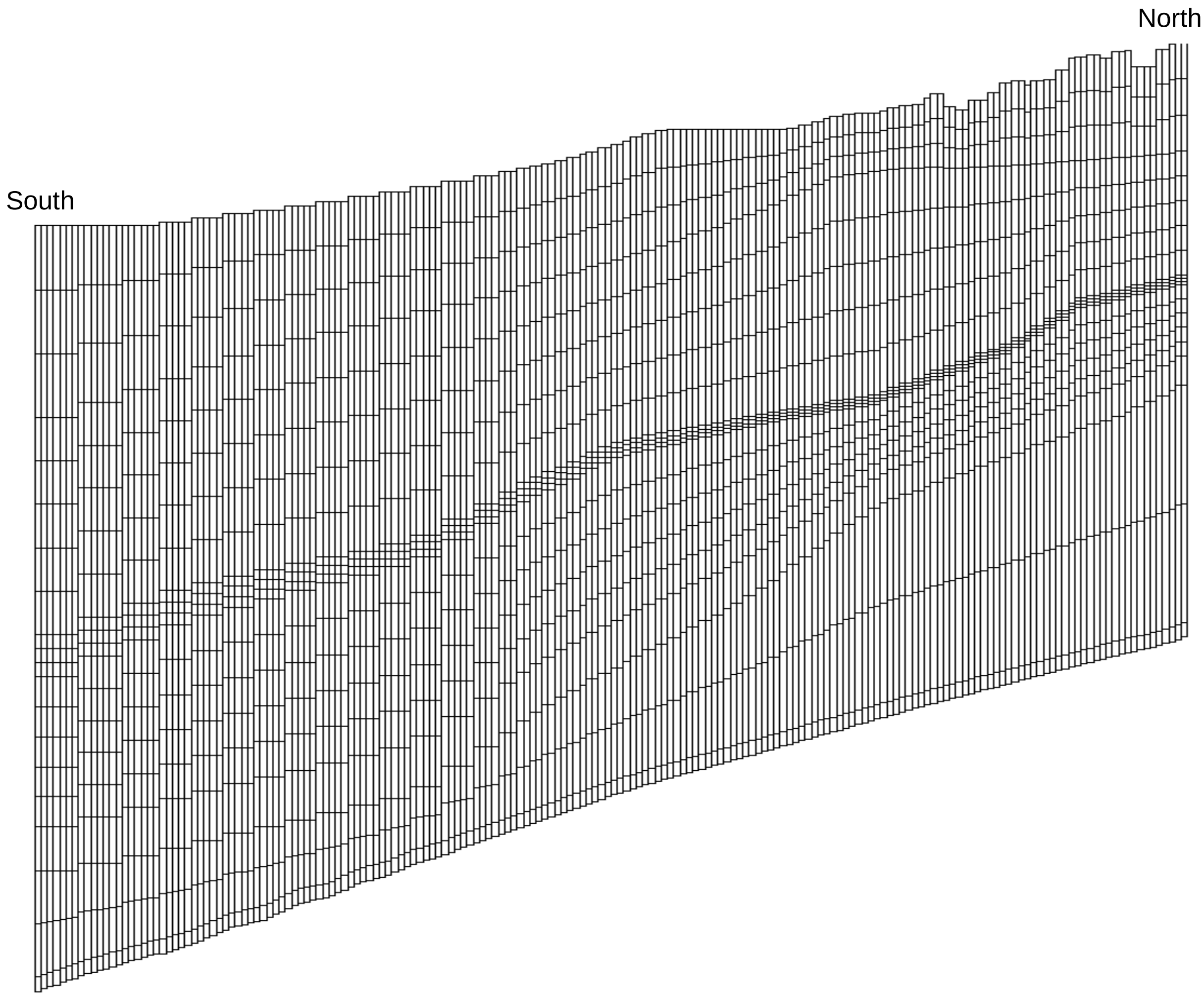


Figure 5 Comparison of Model Layers DSTRAM to SEAWAT



Note: Left and right edges of this section correspond to the southern and northern extents (respectively) of the SEAWAT grid.

Figure 6 SEAWAT Model Layering (Column 219)

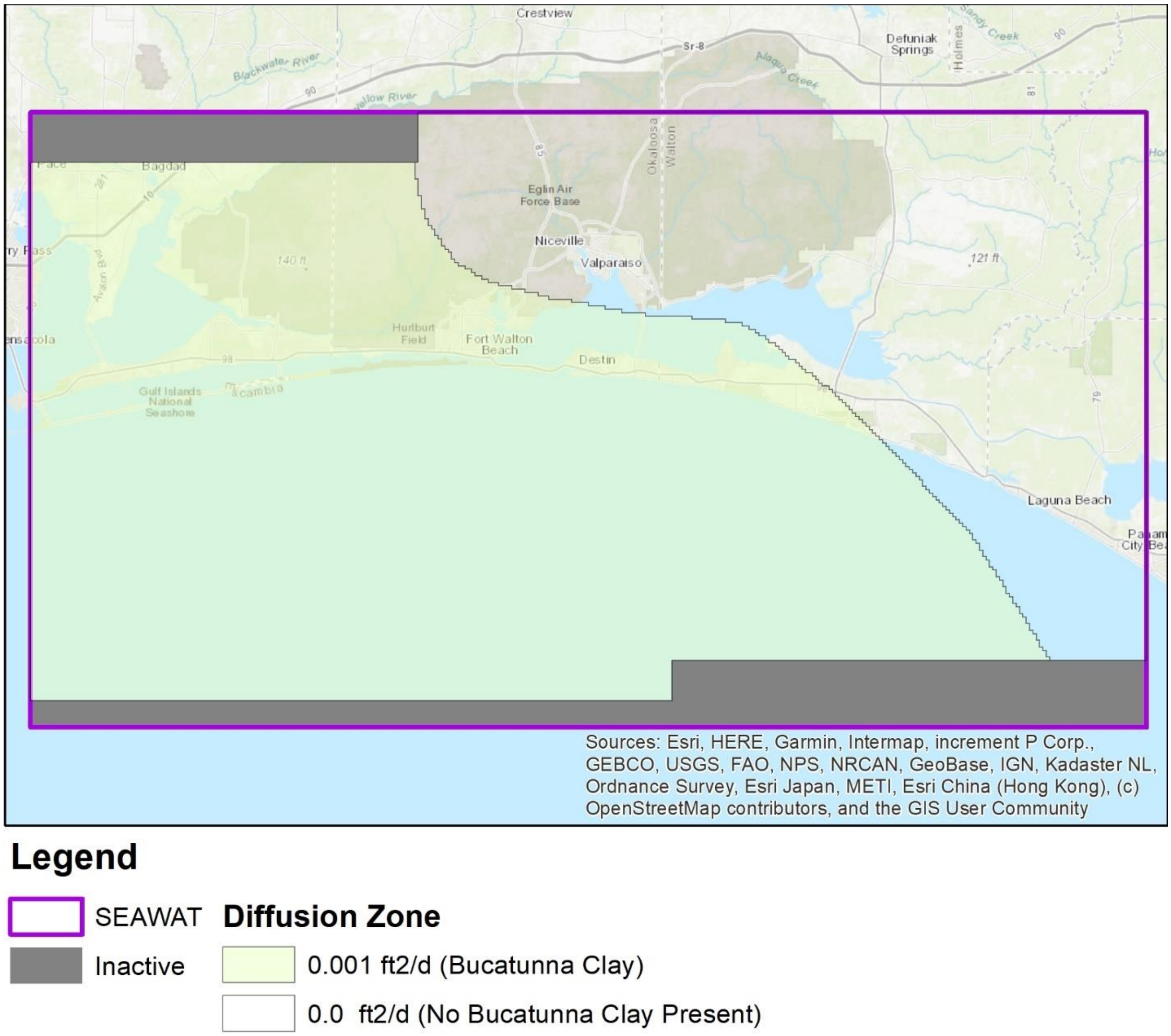


Figure 7 Location of Bucatunna Clay and Assigned Diffusion in SEAWAT Layers 9 through 11

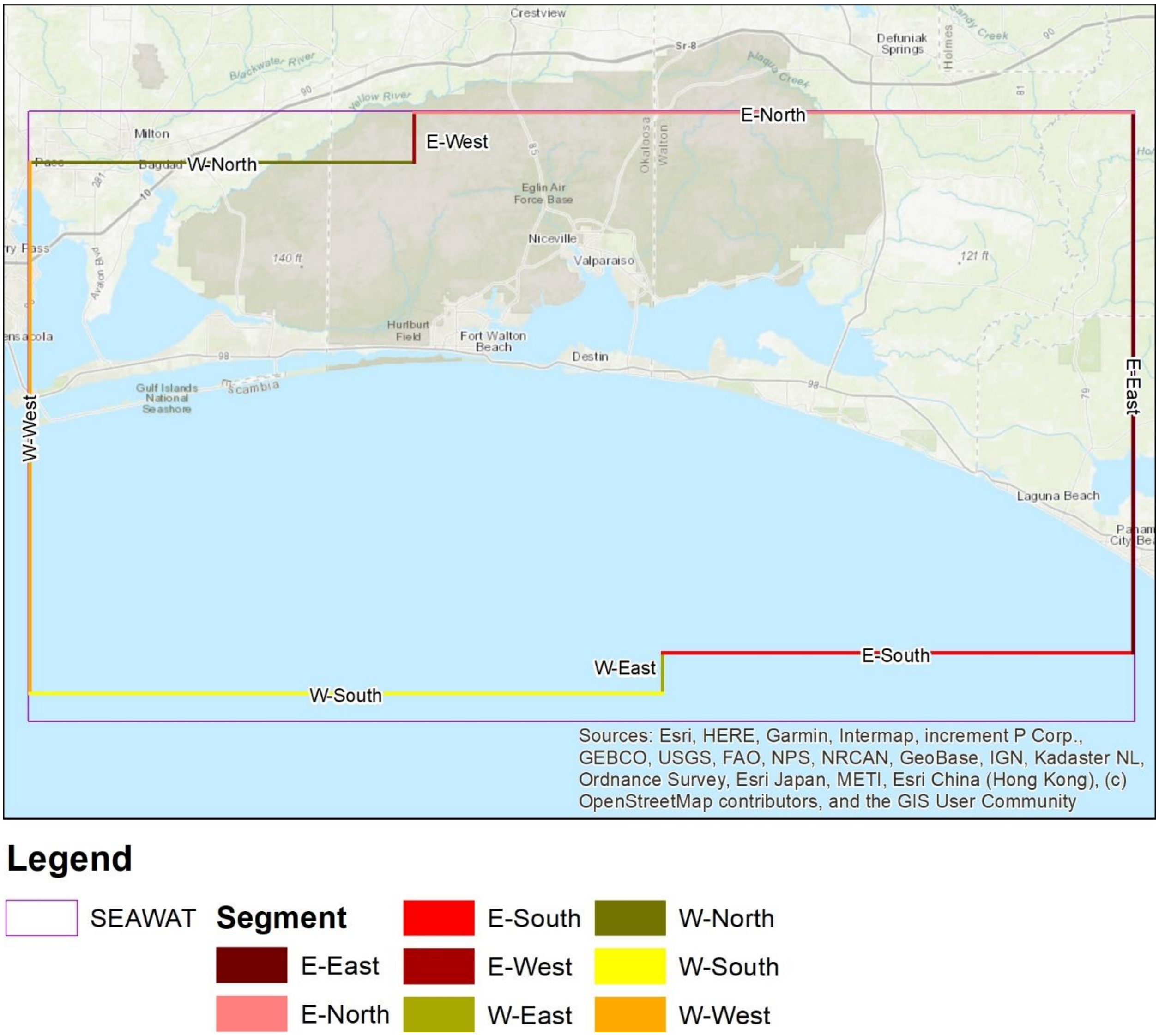


Figure 8 Location of SEAWAT Lateral Boundary, including Locations of Boundary Segments that Define Subdivisions of the Lateral Boundary

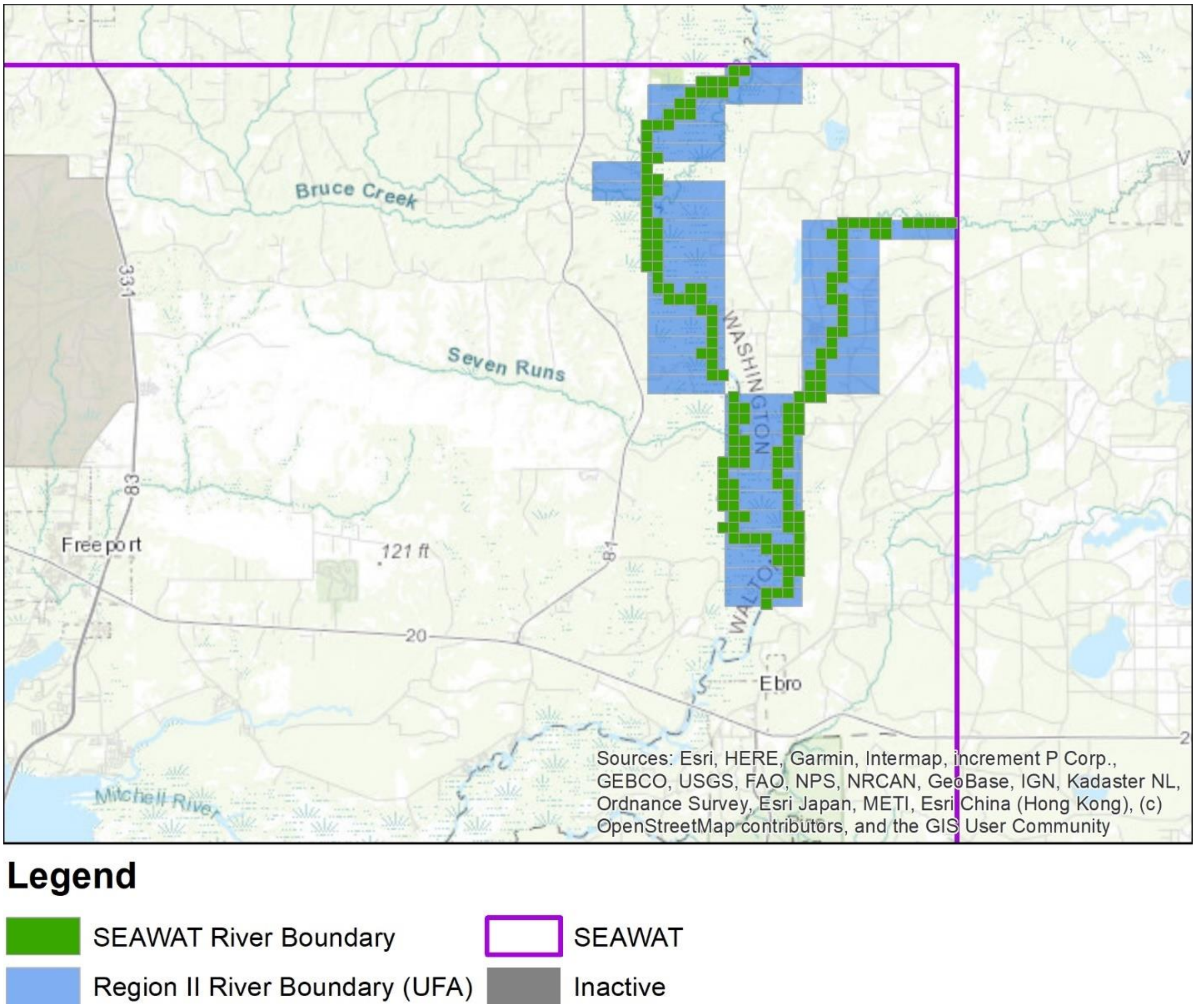


Figure 9 River Boundary Comparison between Region II and SEAWAT

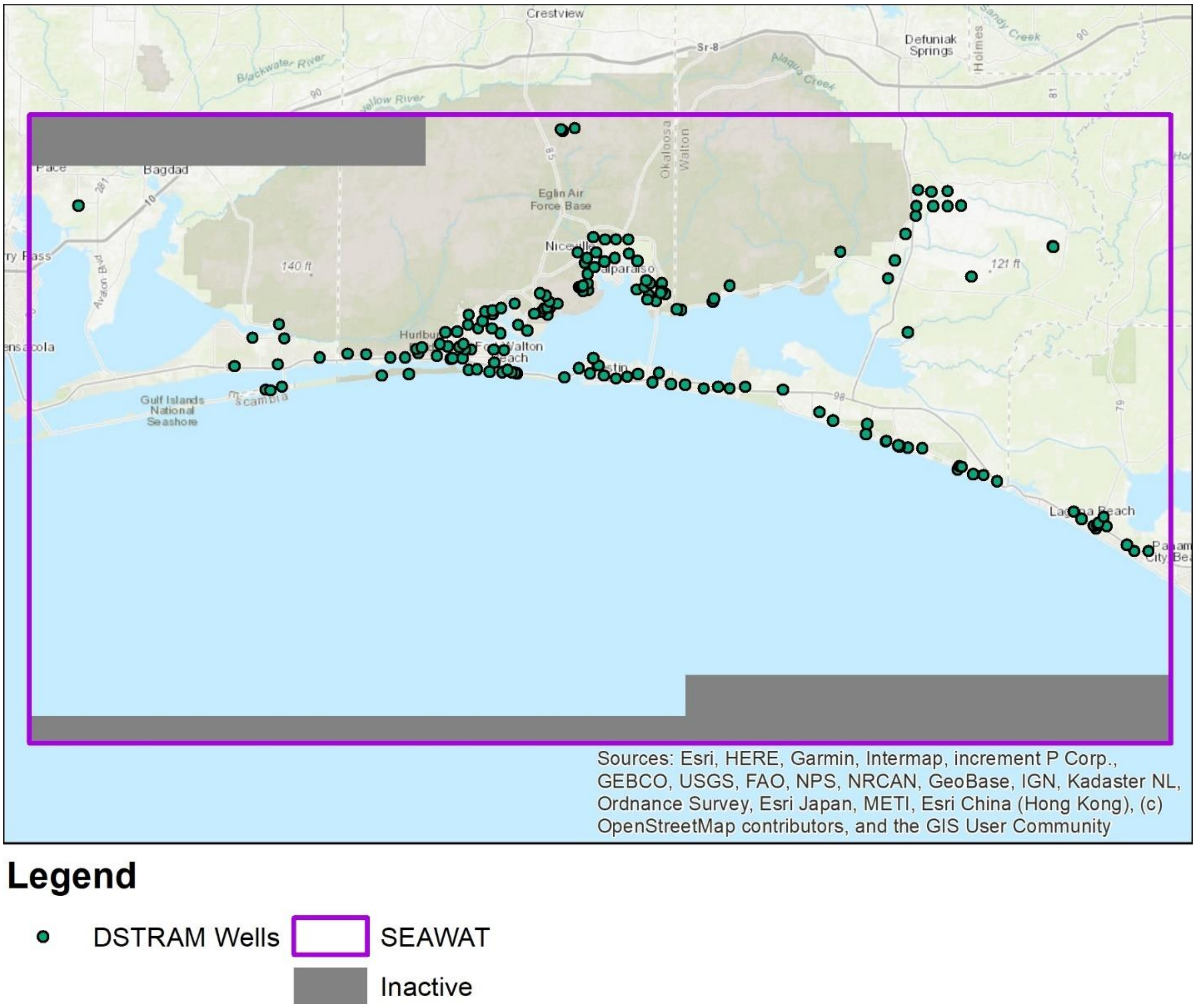
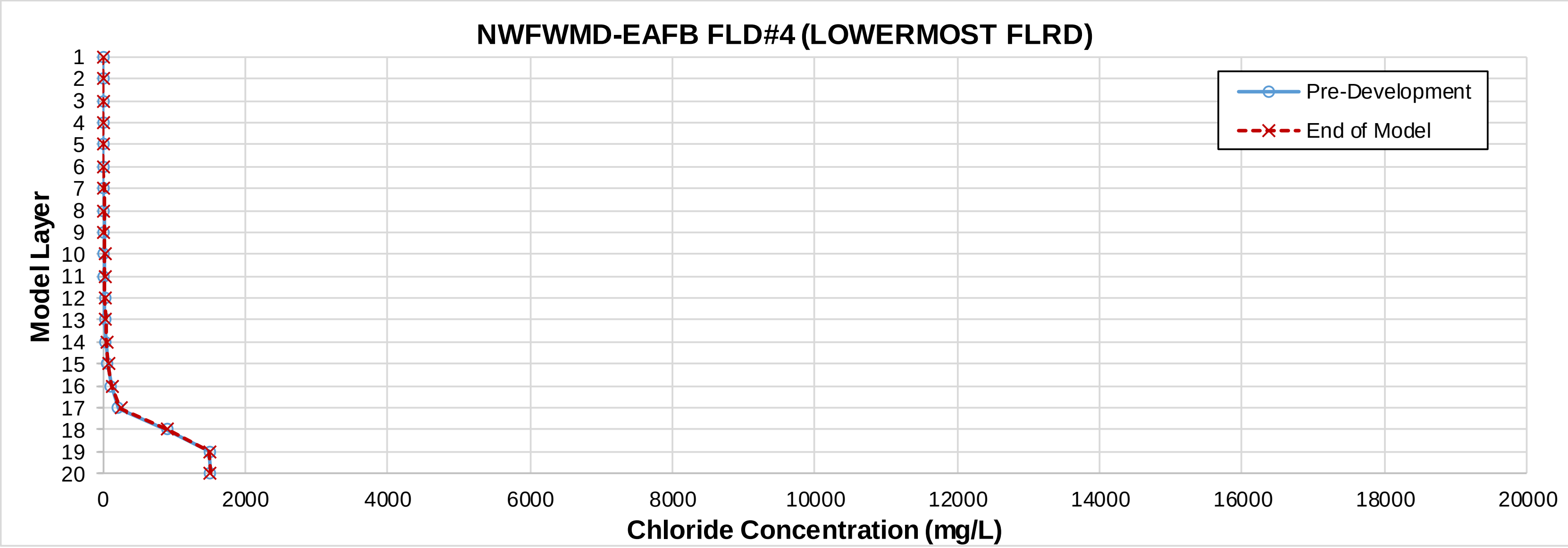
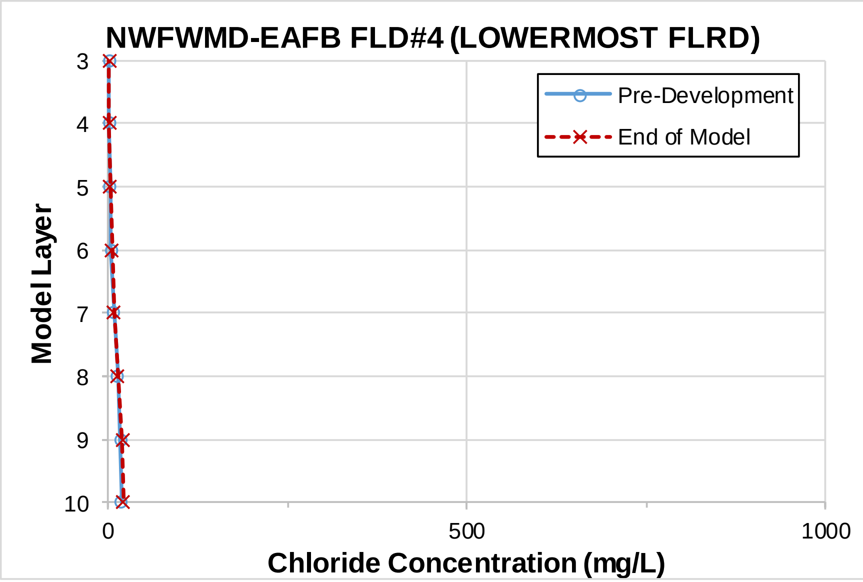


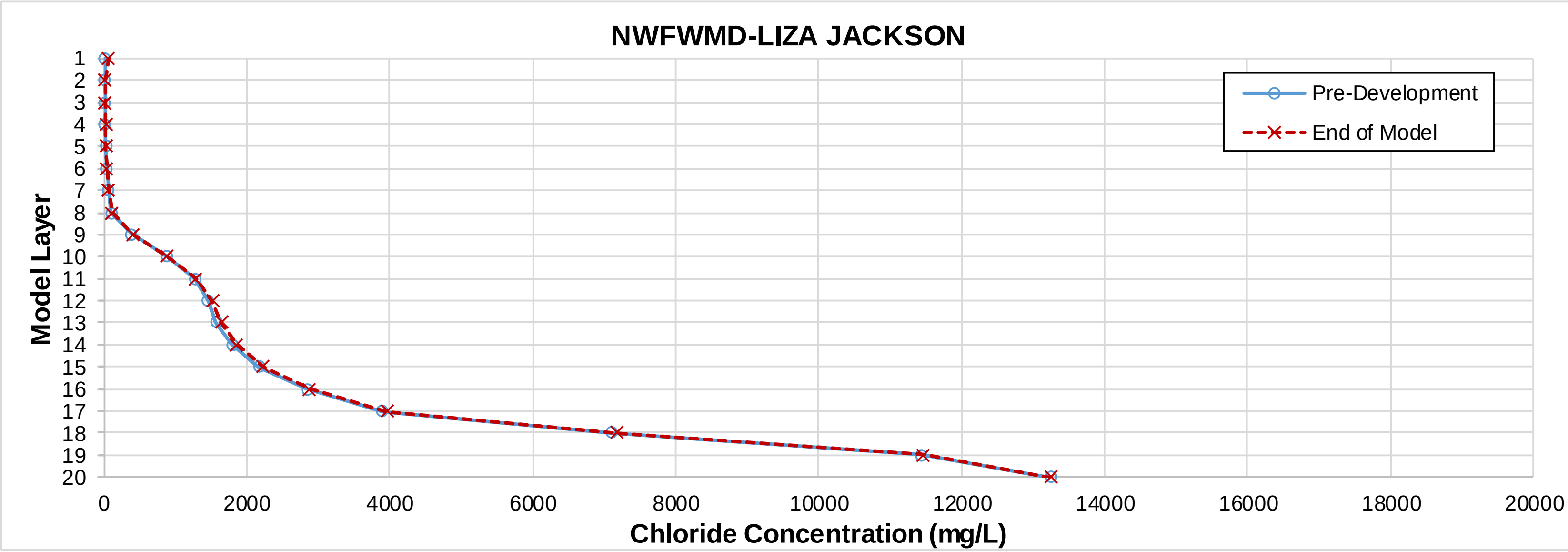
Figure 10 Pumping Wells from DSTRAM Models

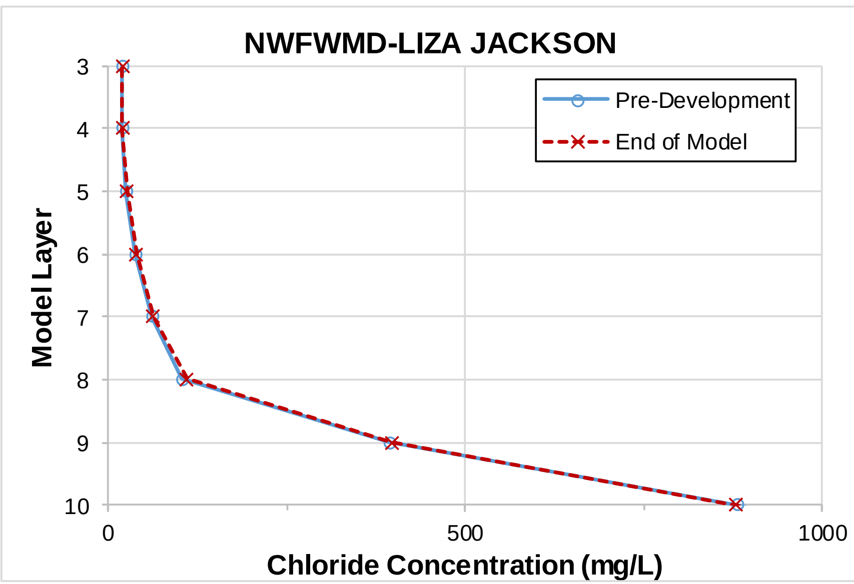




<u>Note:</u>
Model layers 1-3 represent the Intermediate System
Model layers 4-17 represent the undifferentiated Floridan Aquifer
Model layers 18-20 represent the Sub-Floridan System

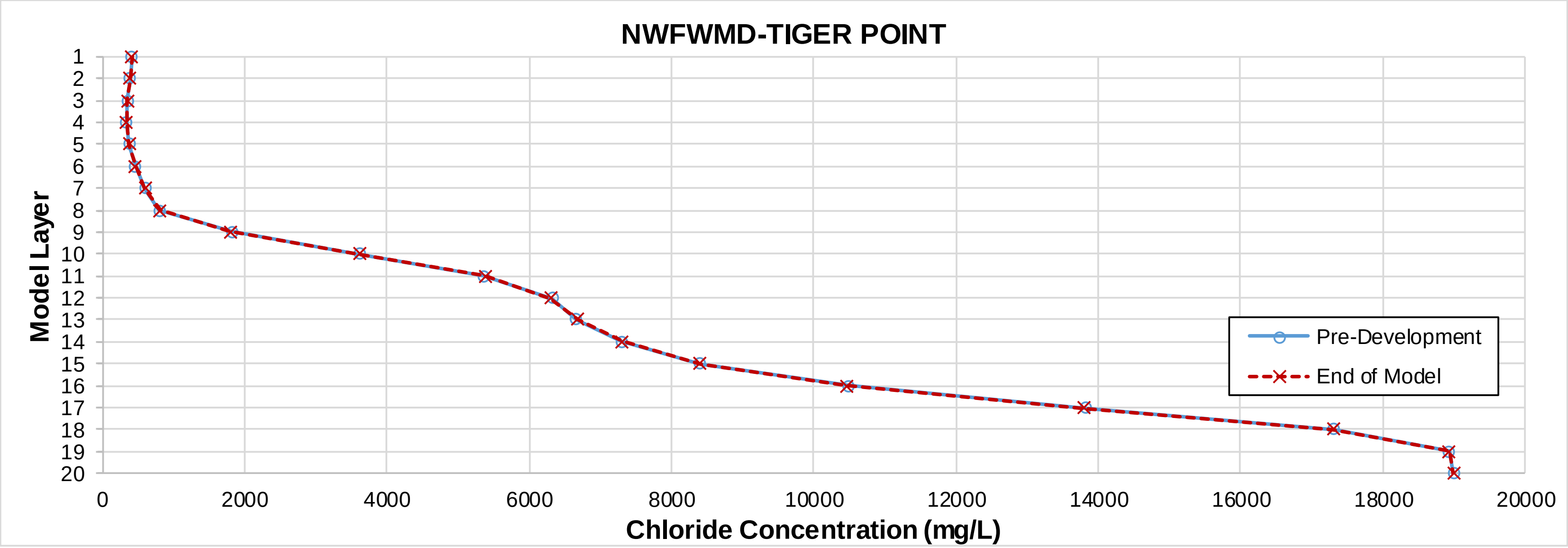
TITLE:	Simulated Chloride Concentrations at EAFB FIELD #4 (NWF3210)		
LOCATION:	Northwest Florida		
TETRA TECH	CHECKED: SCS	DRAFTED: SCS	FIGURE: 11
	PROJ 117-1305036	DATE: 12/16/19	

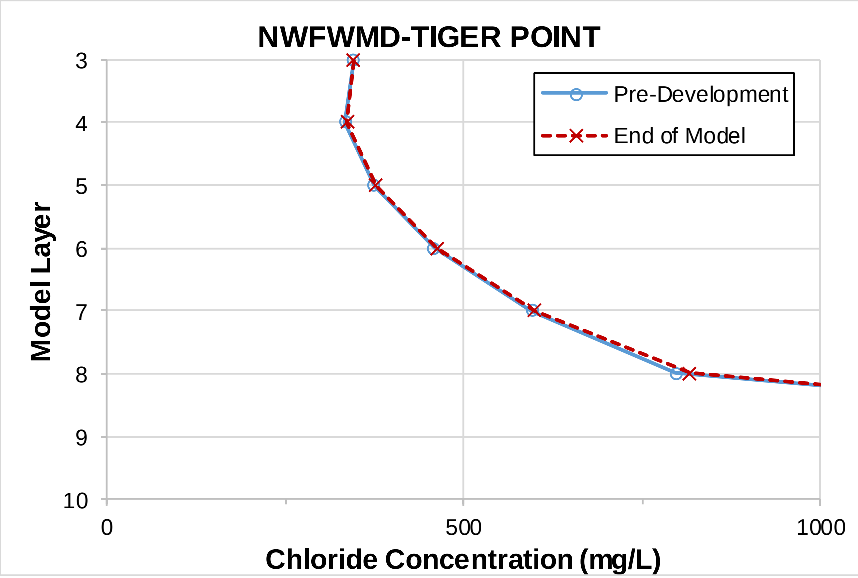




Note:
Model layers 1-3 represent the Intermediate System
Model layers 4-8 represent the Upper Floridan Aquifer
Model layers 9-11 represent the Bucatunna clay
Model layers 12-17 represent the Lower Floridan Aquifer
Model layers 18-20 represent the Sub-Floridan System

TITLE:	Simulated Chloride Concentrations at LIZA JACKSON PARK (NWF7523)		
LOCATION:	Northwest Florida		
TETRA TECH	CHECKED: SCS		FIGURE: 12
	DRAFTED: SCS		
	PROJ 117-1305036		
	DATE: 12/16/19		

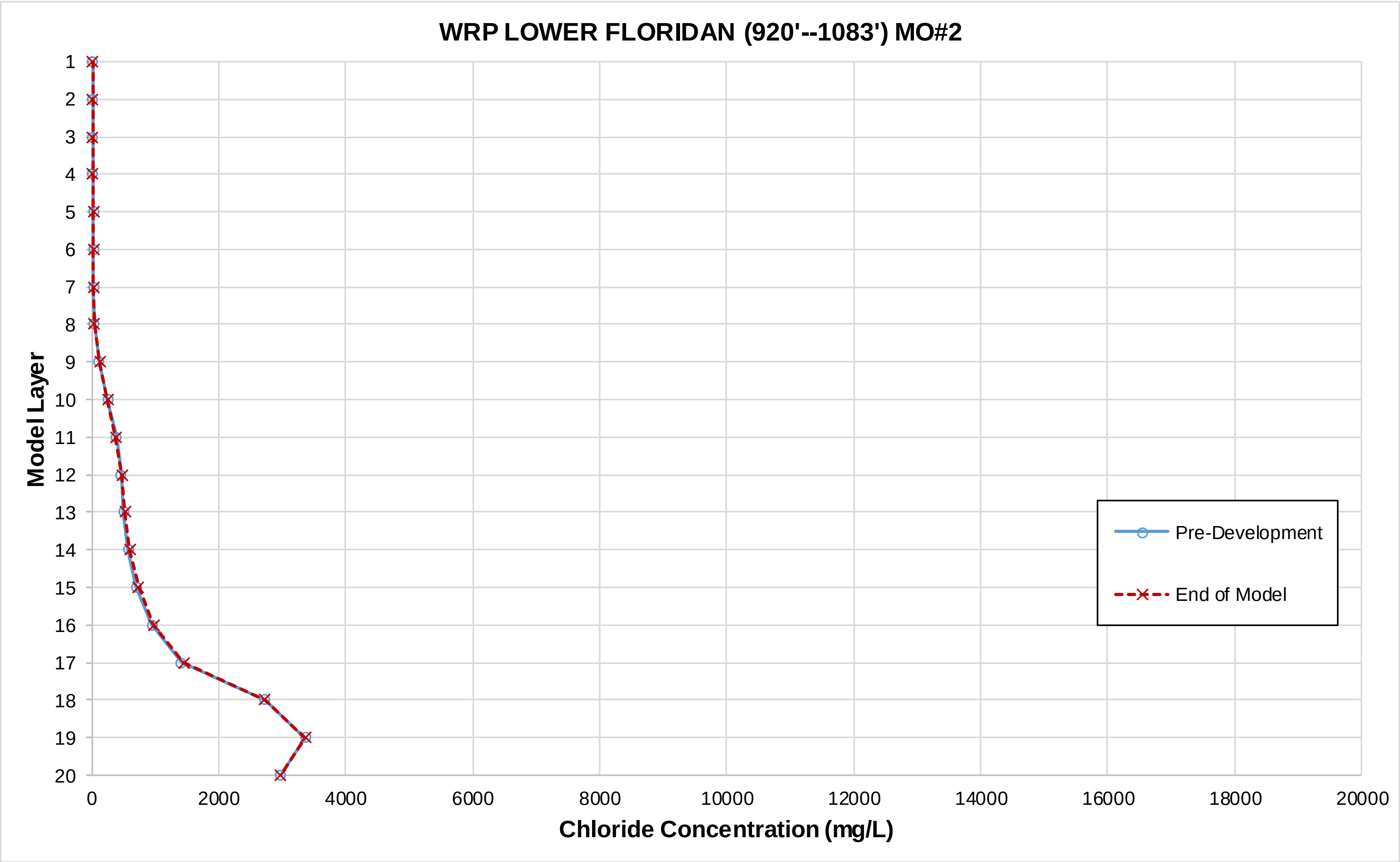




Note:

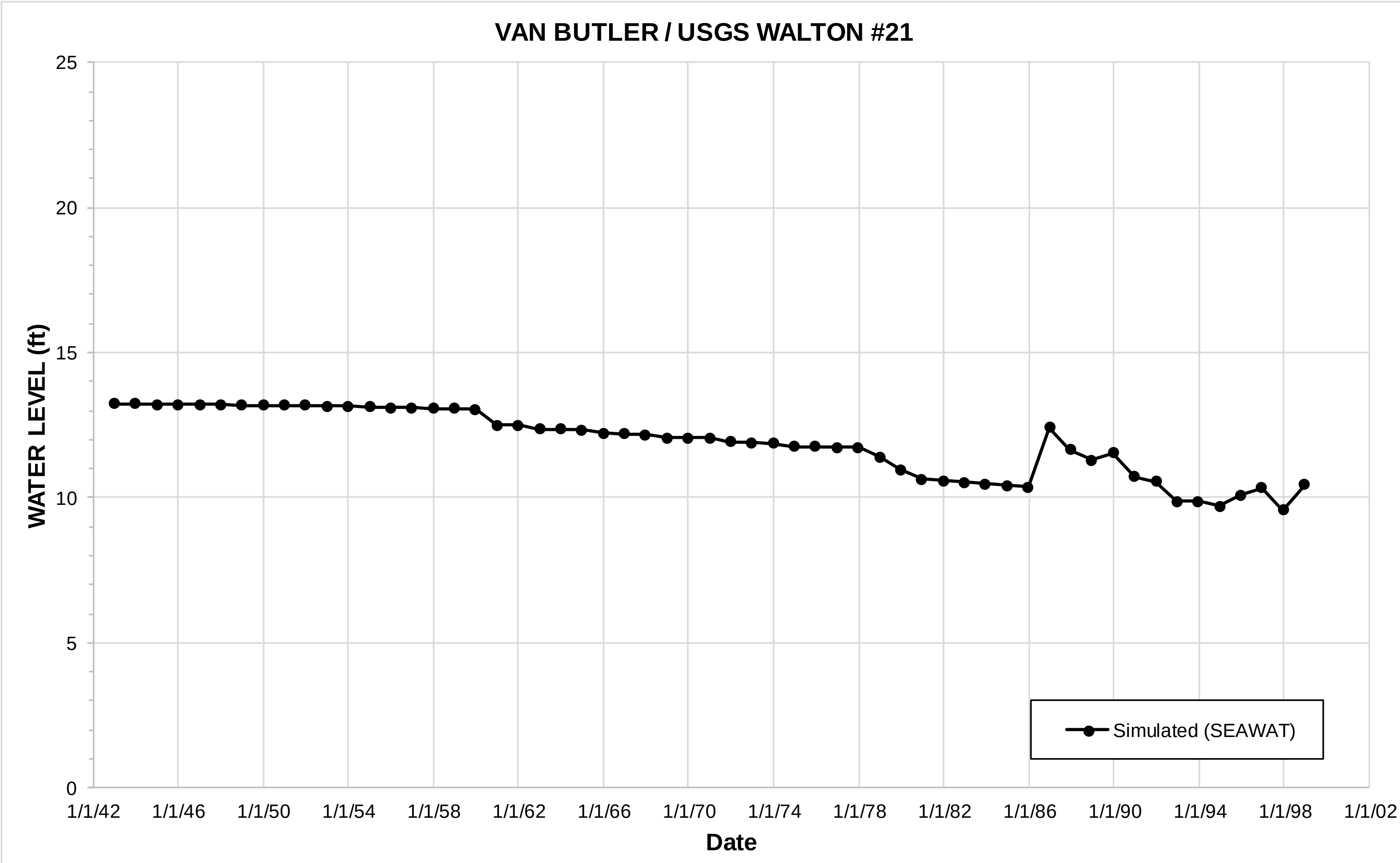
Model layers 1-3 represent the Intermediate System
Model layers 4-8 represent the Upper Floridan Aquifer
Model layers 9-11 represent the Bucatunna clay
Model layers 12-17 represent the Lower Floridan Aquifer
Model layers 18-20 represent the Sub-Floridan System

TITLE:	Simulated Chloride Concentrations at TIGER POINT PARK (NWF7686)			
LOCATION:	Northwest Florida			
TETRA TECH	CHECKED:	SCS	FIGURE:	13
	DRAFTED:	SCS		
	PROJ	117-1305036		
	DATE:	12/16/19		



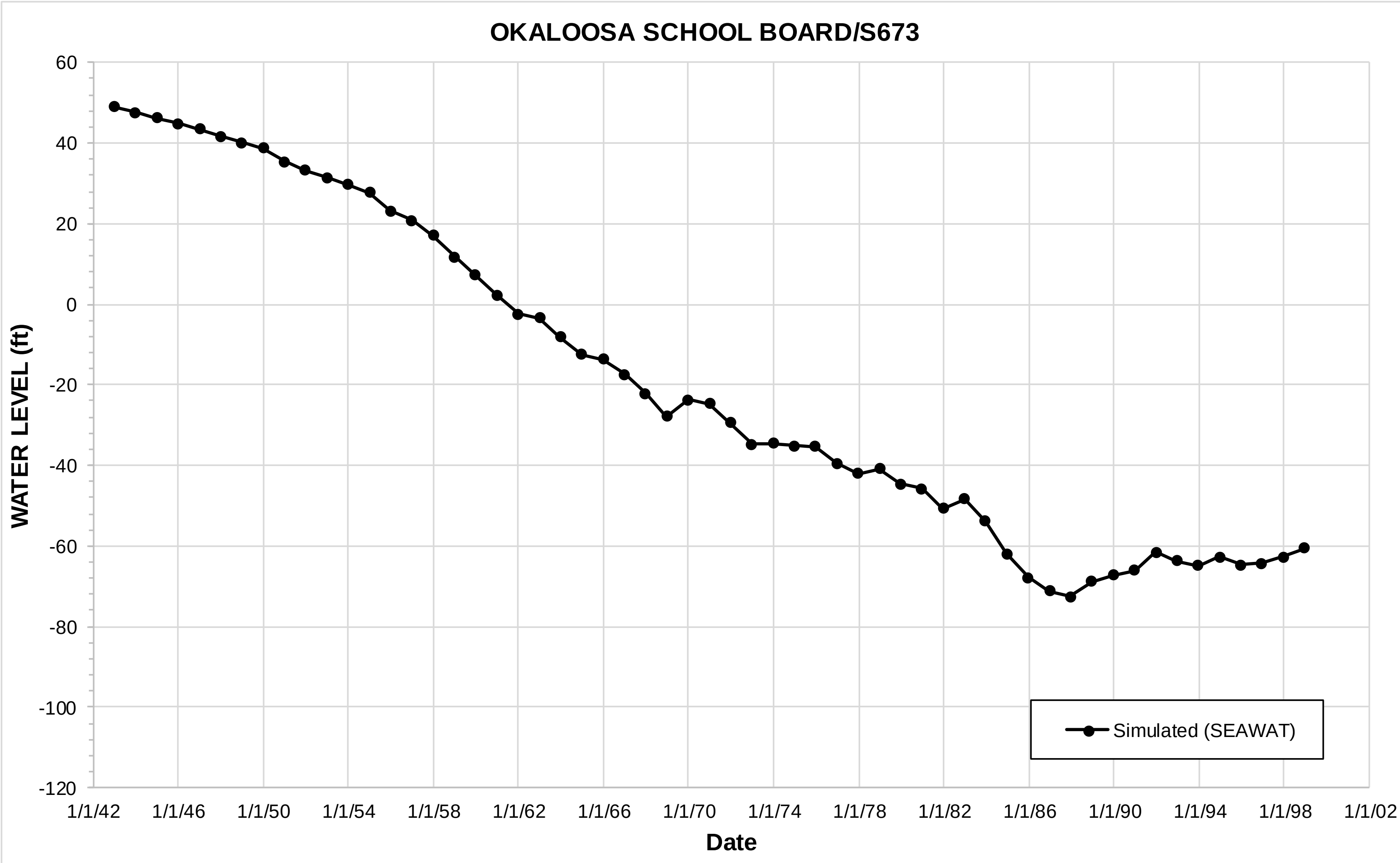
Note:
Model layers 1-3 represent the Intermediate System
Model layers 4-8 represent the Upper Floridan Aquifer
Model layers 9-11 represent the Bucatunna clay
Model layers 12-17 represent the Lower Floridan Aquifer
Model layers 18-20 represent the Sub-Floridan System

TITLE: Simulated Chloride Concentrations at DESTIN LOWER FLORIDAN (NWF7174)				
LOCATION: Northwest Florida				
TETRA TECH	CHECKED:	SCS	FIGURE:	14
	DRAFTED:	SCS		
	PROJ	117-1305036		
	DATE:	12/16/19		



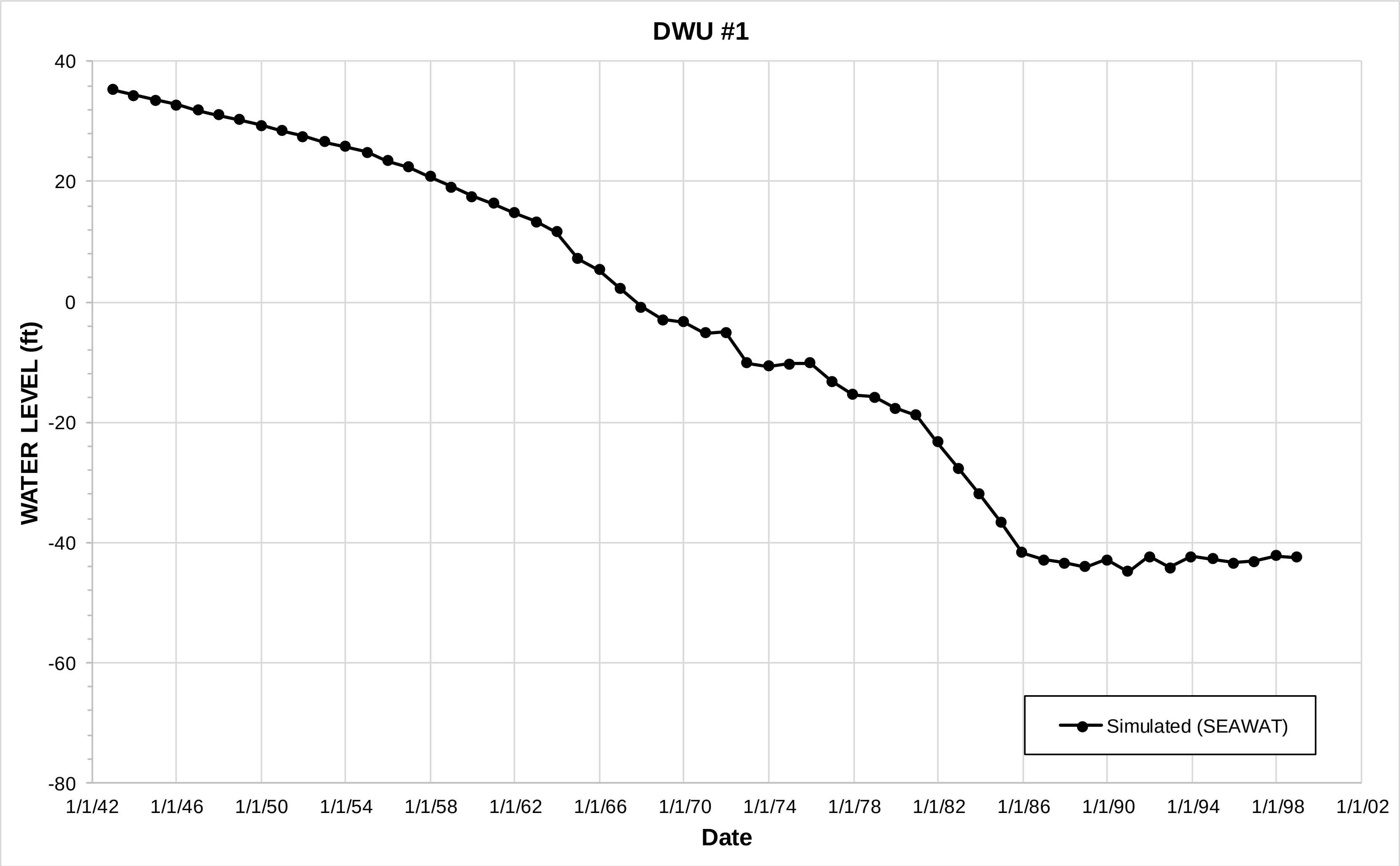
Note:
Results shown are from model layer 6 (middle of Upper Floridan Aquifer)

TITLE: Simulated Equivalent Freshwater Head at VAN BUTLER / USGS WALTON #21 (NWF1074)			
LOCATION: Northwest Florida			
TETRA TECH	CHECKED:	SCS	FIGURE: 15
	DRAFTED:	SCS	
	PROJ	117-1305036	
	DATE:	12/16/19	



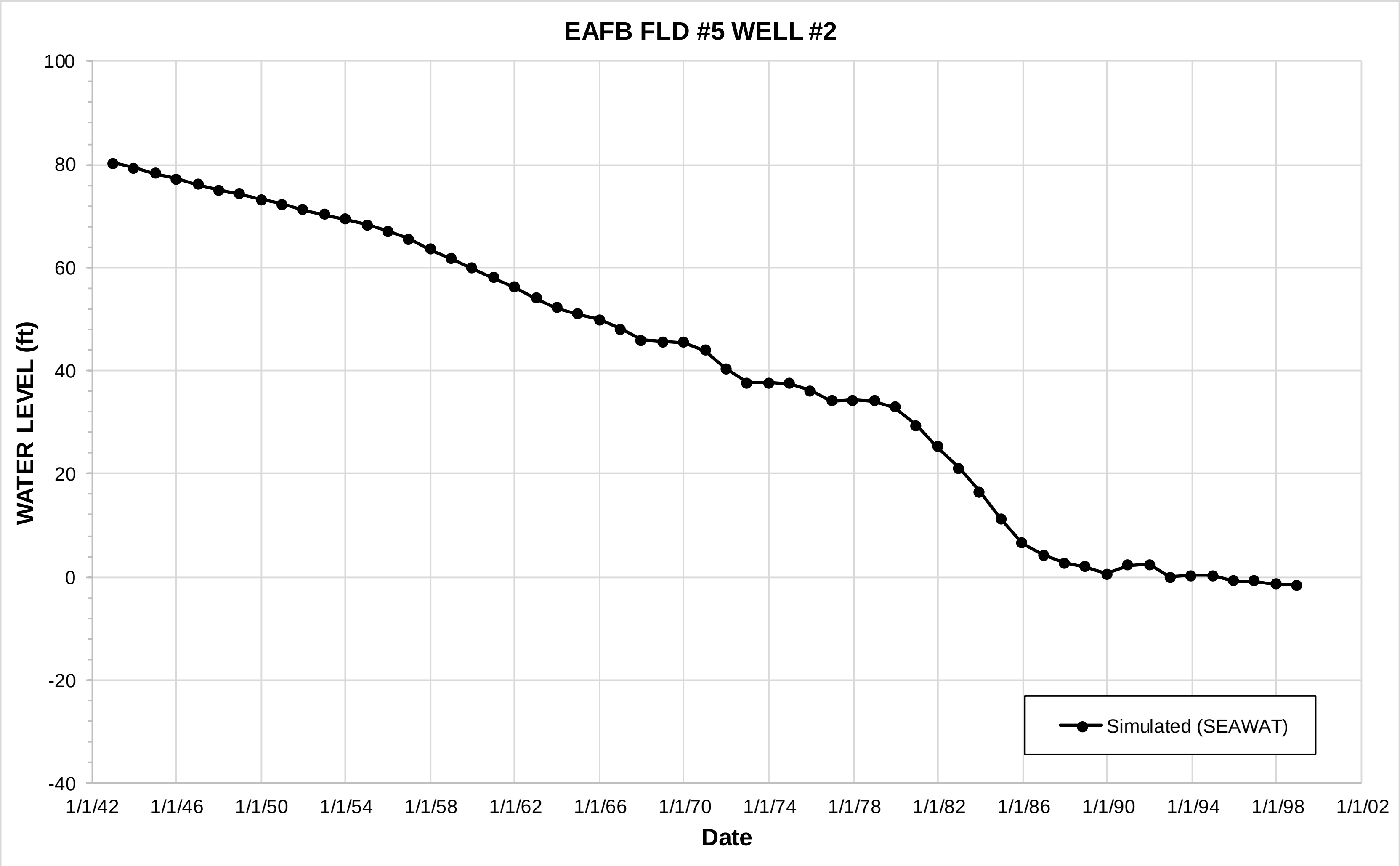
Note:
Results shown are from model layer 6 (middle of Upper Floridan Aquifer)

TITLE: Simulated Equivalent Freshwater Head at OKALOOSA SCHOOL BOARD/S673 (NWF1894)			
LOCATION: Northwest Florida			
TETRA TECH	CHECKED:	SCS	FIGURE:
	DRAFTED:	SCS	16
	PROJ	117-1305036	
	DATE:	12/16/19	



Note:
Results shown are from model layer 6 (middle of Upper Floridan Aquifer)

TITLE:	Simulated Equivalent Freshwater Head at DWU #1 (NWF1687)			
LOCATION:	Northwest Florida			
TETRA TECH	CHECKED:	SCS	FIGURE:	17
	DRAFTED:	SCS		
	PROJ	117-1305036		
	DATE:	12/16/19		

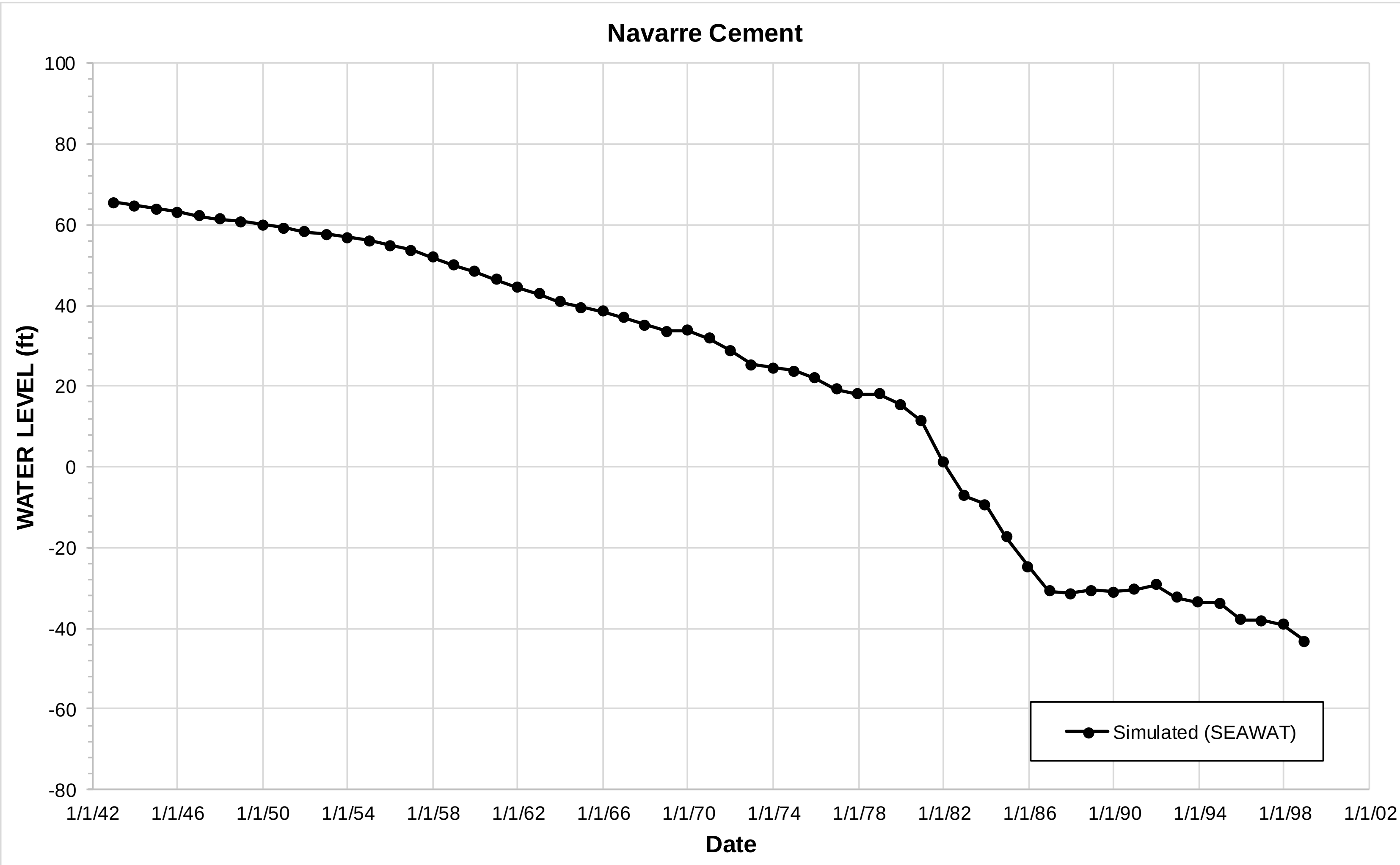


Note:
Results shown are from model layer 6 (middle of Upper Floridan Aquifer)

TITLE:	Simulated Equivalent Freshwater Head at EAFB FLD #5 WELL #2 (NWF3923)
LOCATION:	Northwest Florida

TETRA TECH

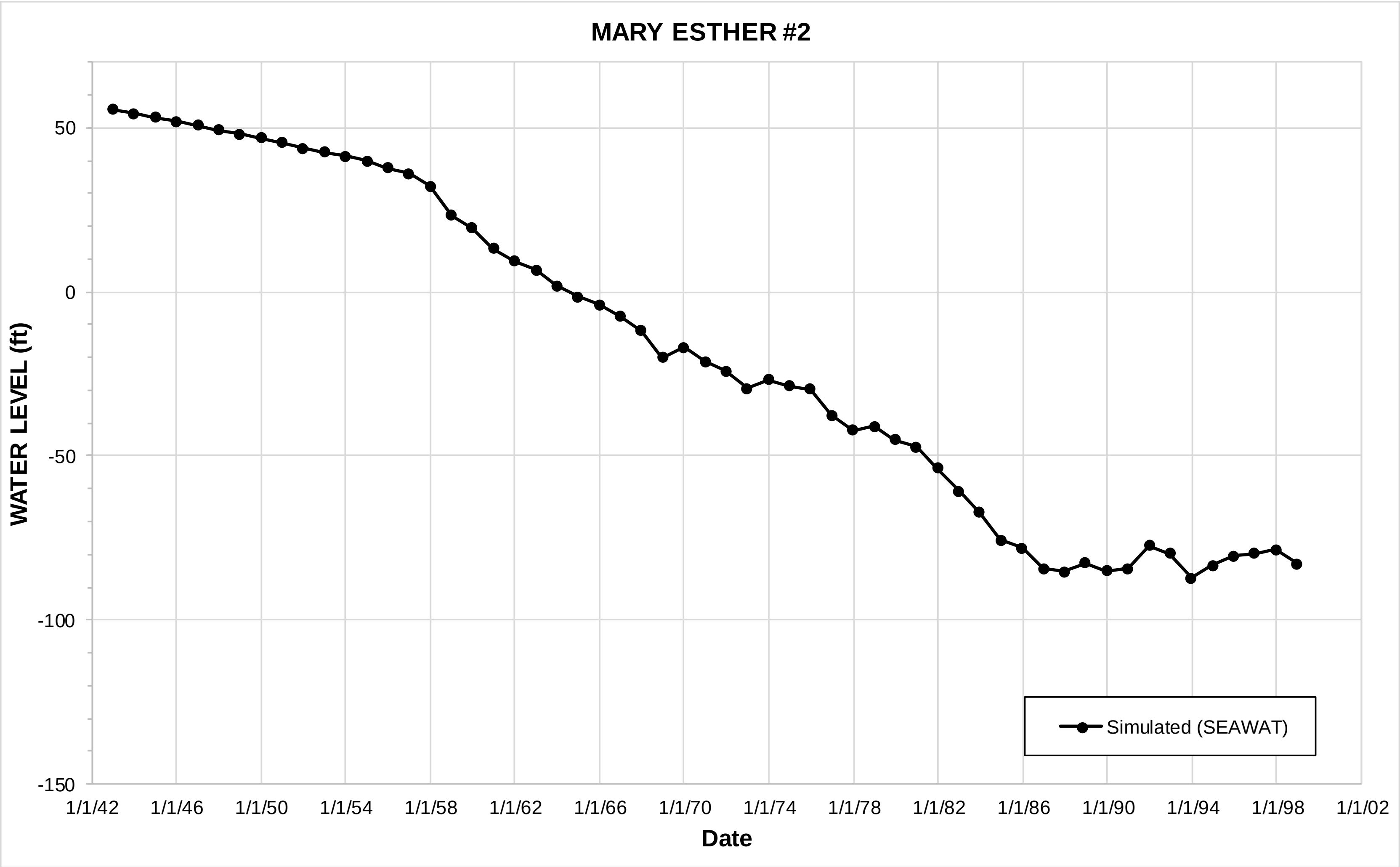
CHECKED:	SCS	FIGURE:
DRAFTED:	SCS	18
PROJ	117-1305036	
DATE:	12/16/19	



Note:
Results shown are from model layer 8 (deepest Upper Floridan Aquifer layer)

TITLE:	Simulated Equivalent Freshwater Head at Navarre Cement (NWF1839)
LOCATION:	Northwest Florida
CHECKED:	SCS
DRAFTED:	SCS
PROJ	117-1305036
DATE:	12/16/19
FIGURE:	19

TETRA TECH



Note:
Results shown are from model layer 6 (middle of Upper Floridan Aquifer)

TITLE:	Simulated Equivalent Freshwater Head at MARY ESTHER #2 (NWF2035)
LOCATION:	Northwest Florida
CHECKED:	SCS
DRAFTED:	SCS
PROJ	117-1305036
DATE:	12/16/19
FIGURE:	20

TETRA TECH

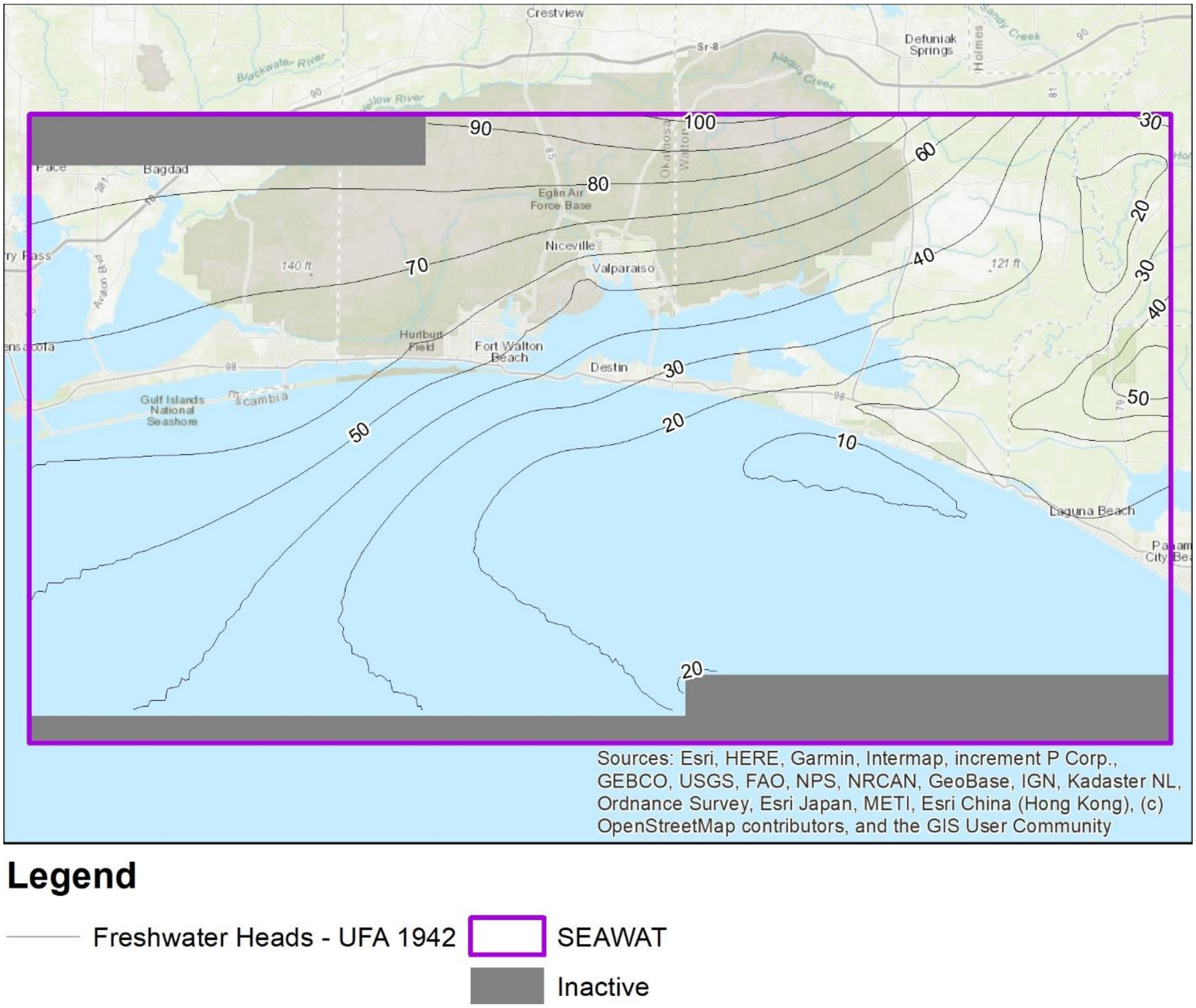


Figure 21 Freshwater Heads in UFA in 1942 (Computed as Average of SEAWAT Layers 5 and 6 which Compares to DSTRAM Nodal Layer 16)

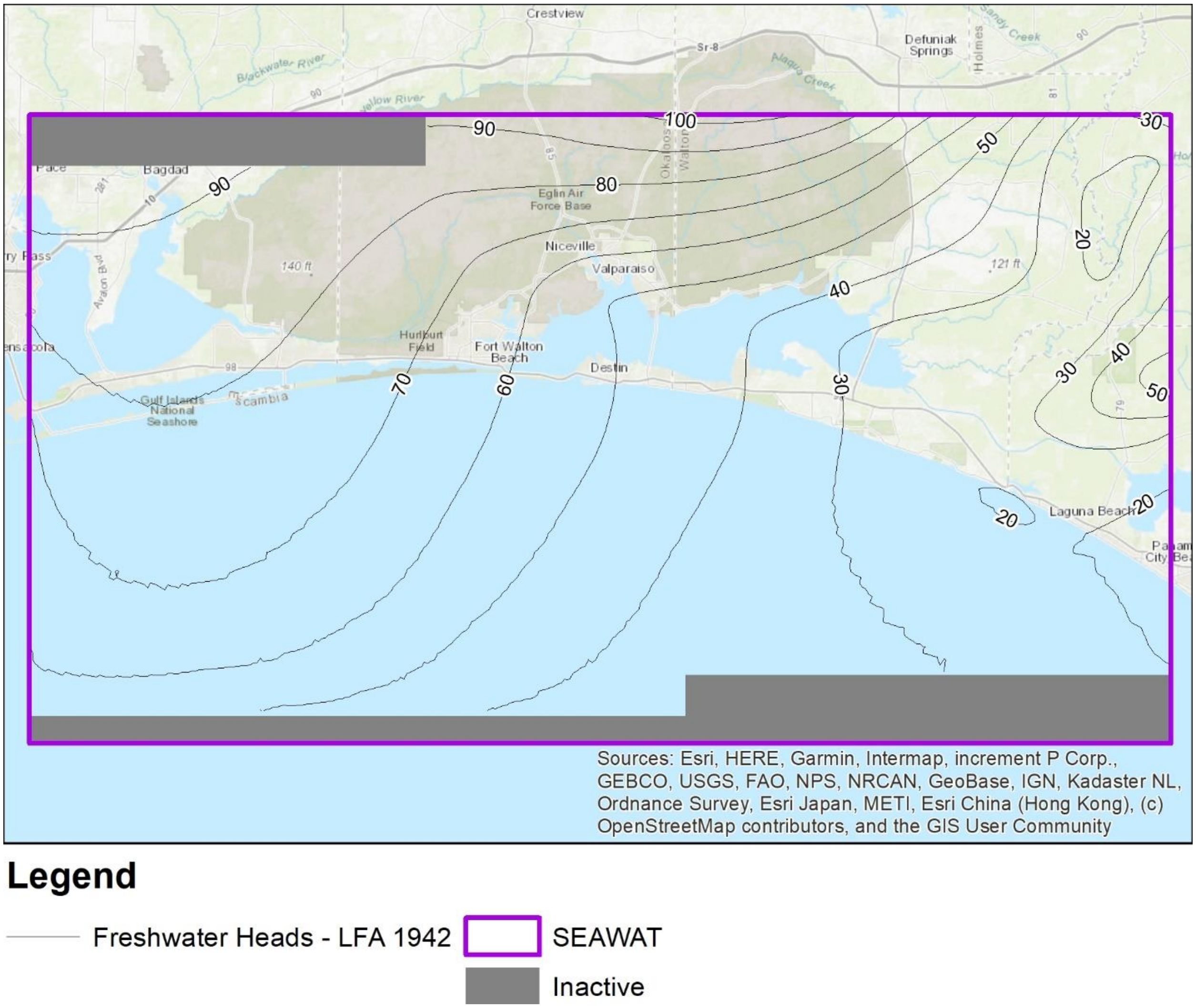


Figure 22 Freshwater Heads in the LFA in 1942 (Computed as Average of SEAWAT Layers 14 and 15 Which Corresponds to DSTRAM Nodal Layer 7)

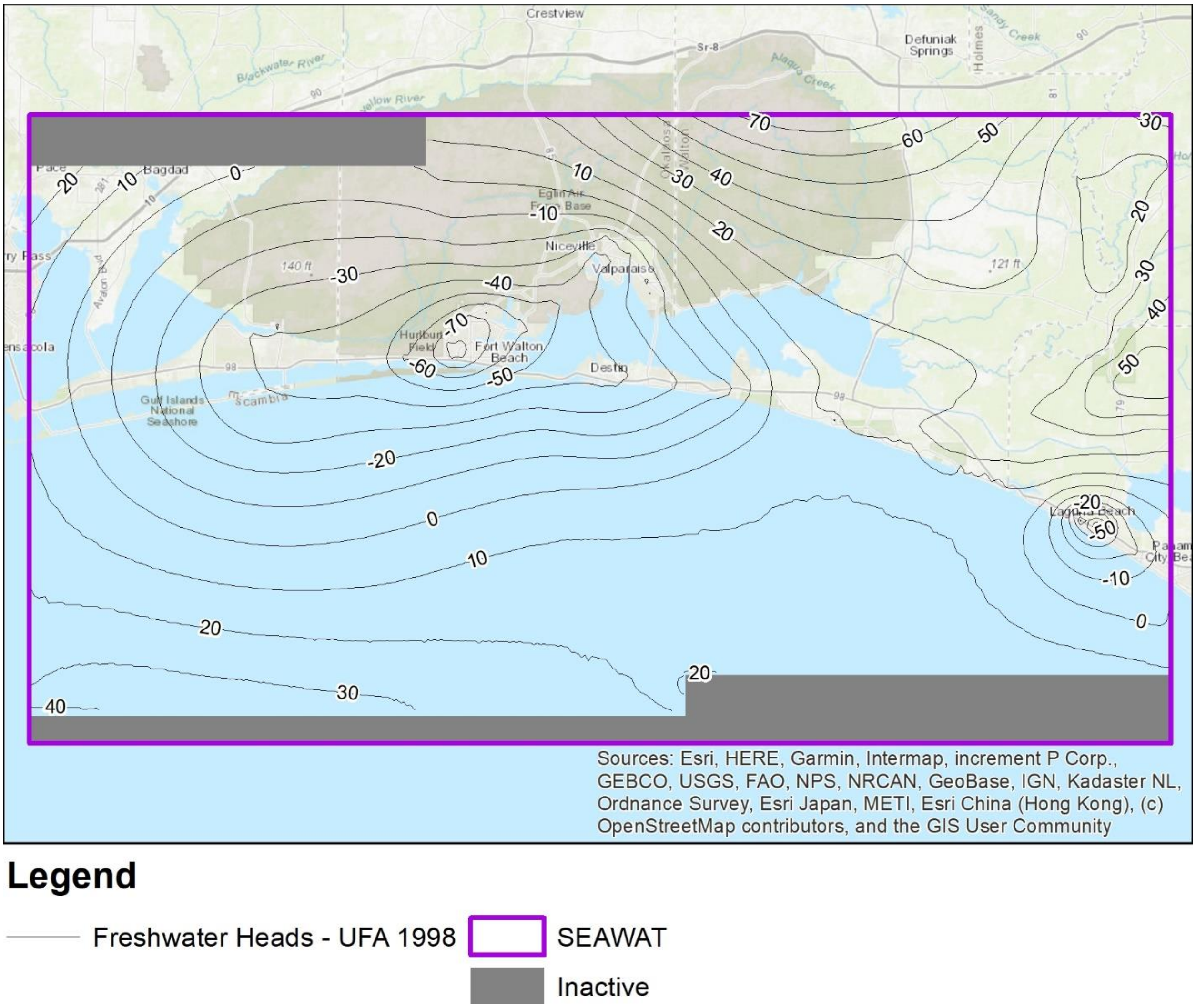


Figure 23 Freshwater Heads in the UFA in 1998 (Computed as Average of SEAWAT Layers 5 and 6 Which Corresponds to DSTRAM Nodal Layer 16)

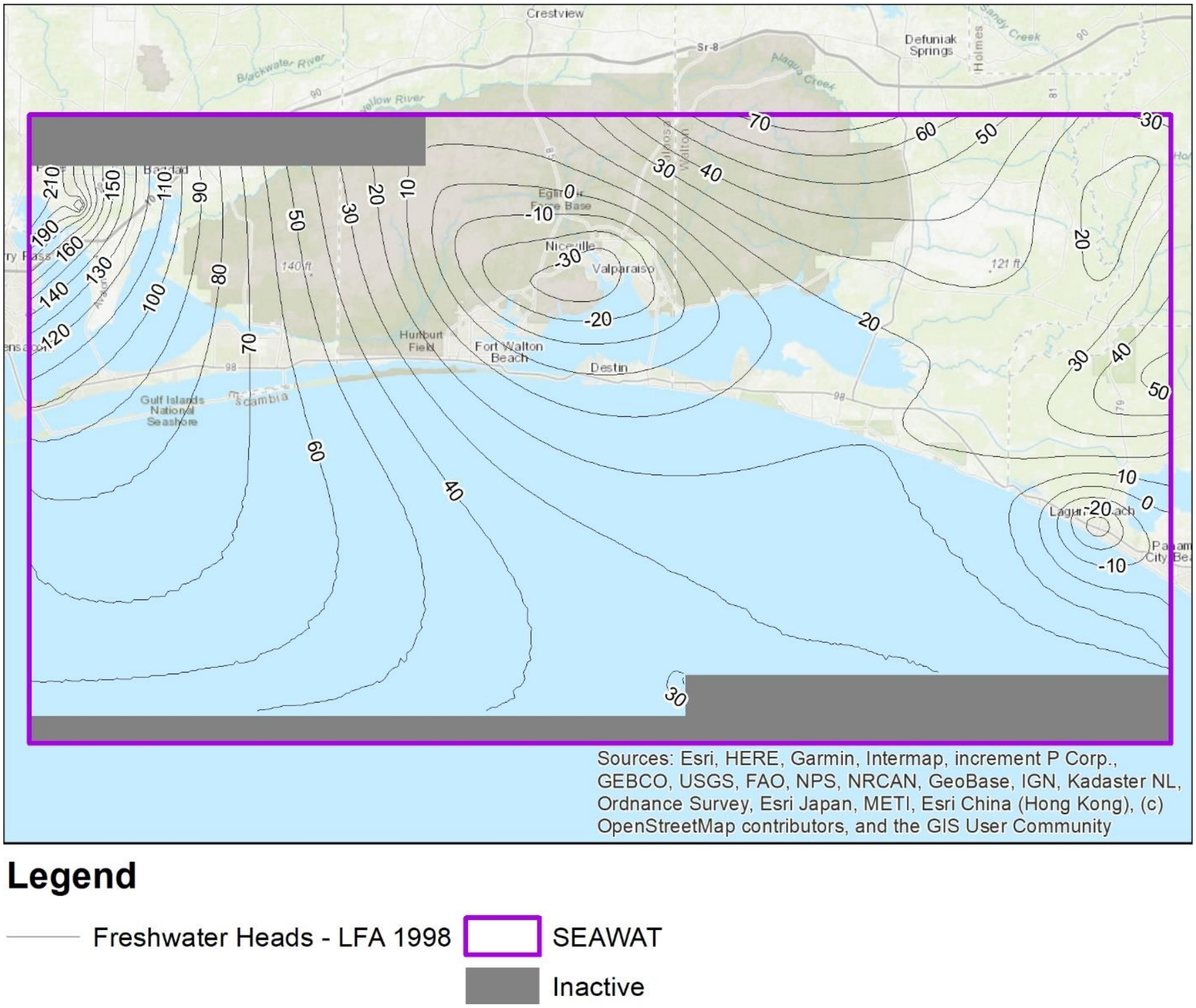


Figure 24 Freshwater Heads in the LFA in 1998 (Computed as Average of SEAWAT Layers 14 and 15 Which Corresponds to DSTRAM Nodal Layer 7)

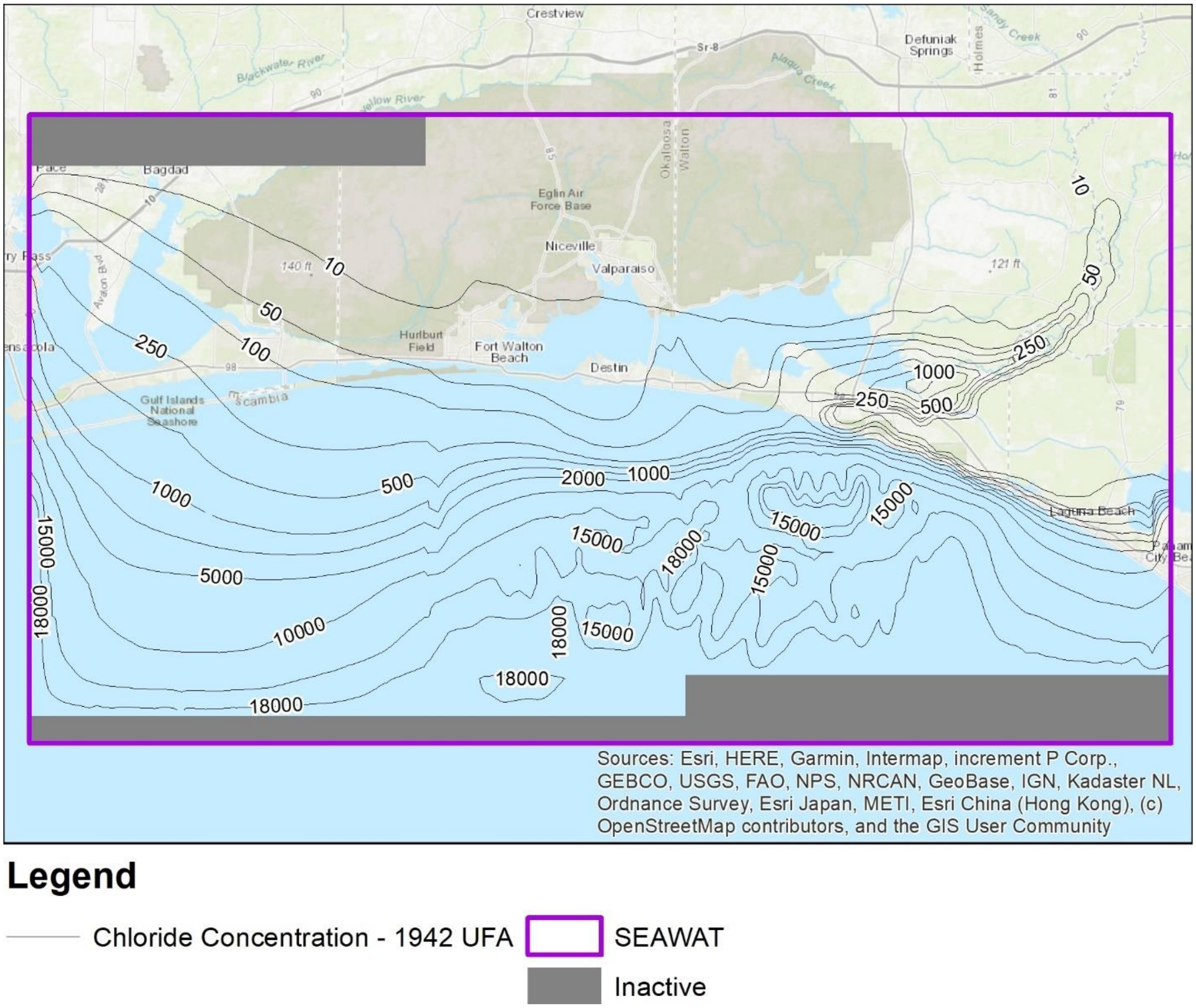


Figure 25 Chloride Concentrations in the UFA in 1942 (Computed as Average of SEAWAT Layers 5 and 6 Which Corresponds to DSTRAM Nodal Layer 16)

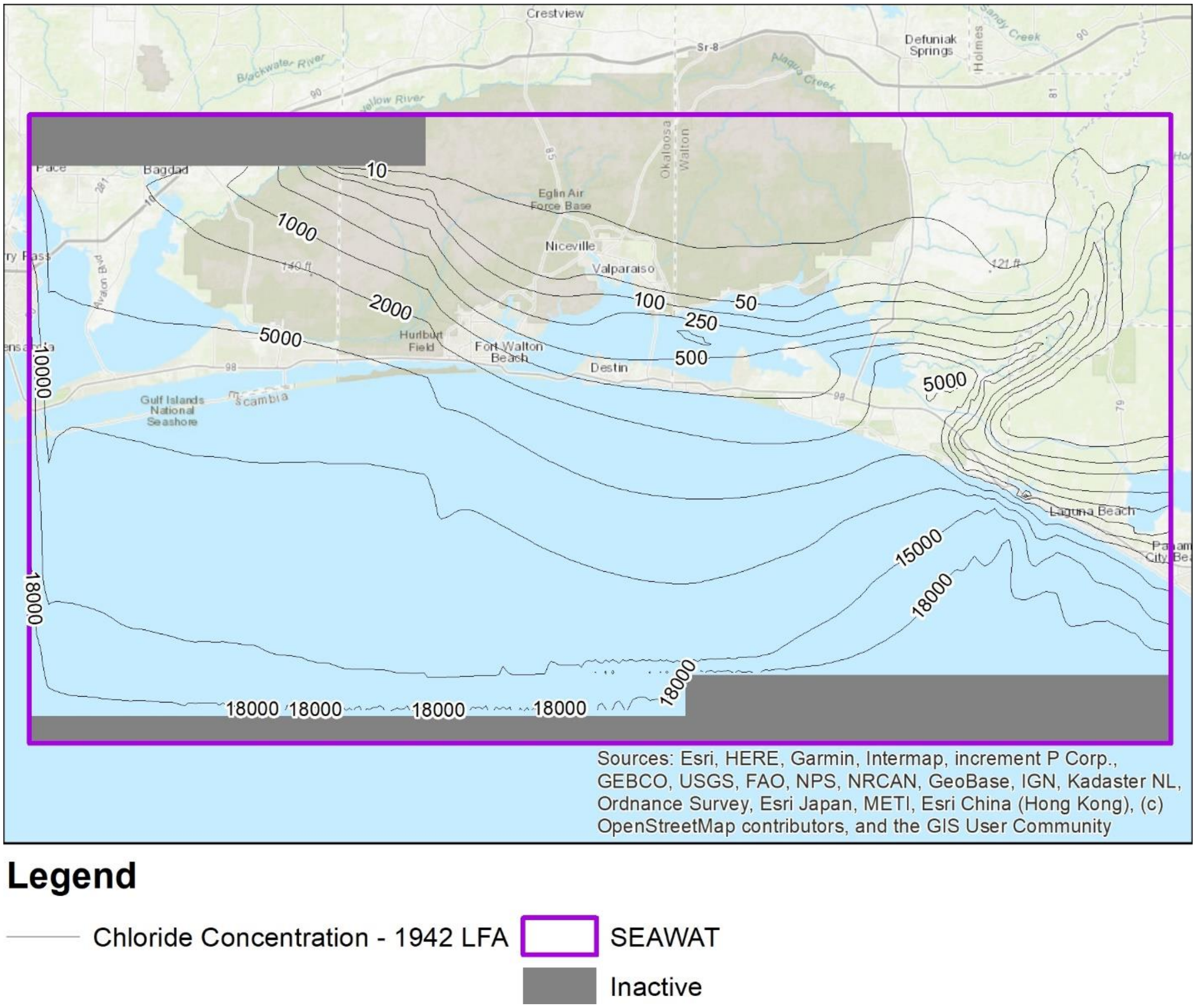


Figure 26 Chloride Concentrations in LFA in 1942 (Computed as Average of SEAWAT Layers 14 and 15 which Compares to DSTRAM Nodal Layer 7)

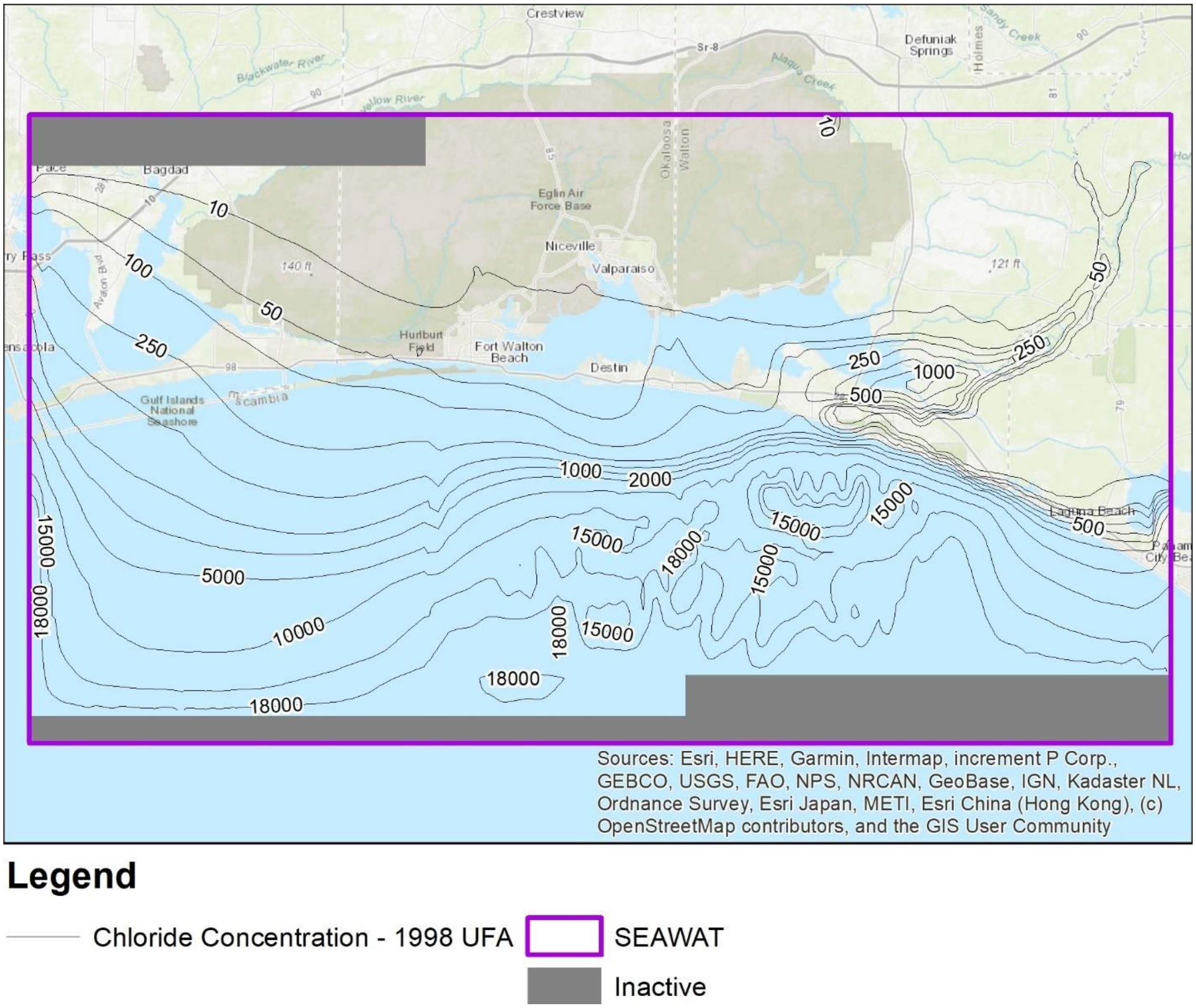


Figure 27 Chloride Concentrations in UFA in 1998 (Computed as Average of SEAWAT Layers 5 and 6 which Compares to DSTRAM Nodal Layer 16)

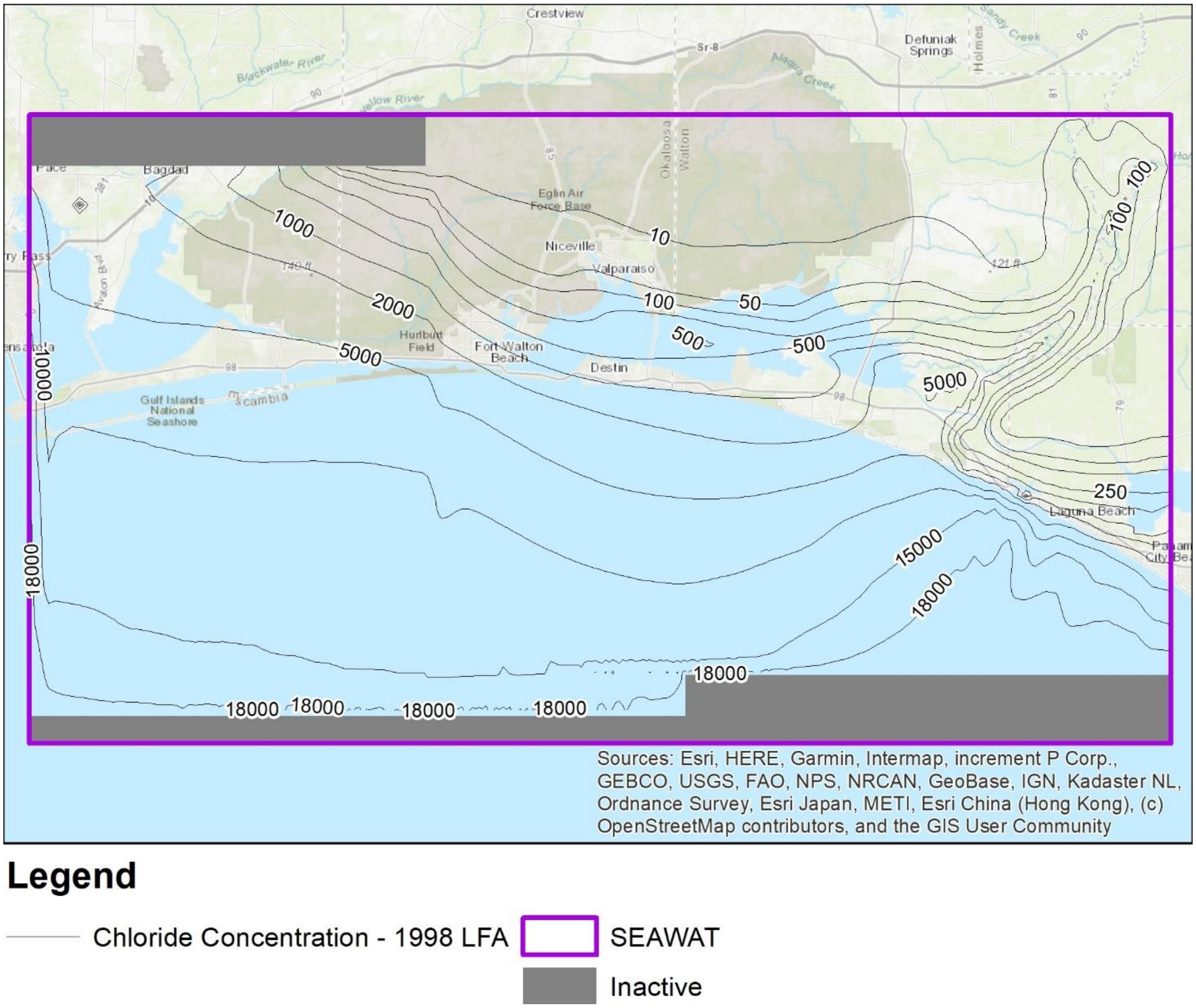


Figure 28 Chloride Concentrations in LFA in 1998 (Computed as Average of SEAWAT Layers 14 and 15 which Compares to DSTRAM Nodal Layer 7)

Table 1 Aquifer Property Summary by Layer

Lay	Horizontal Hydraulic Conductivity (ft/d)				Vertical Hydraulic Conductivity (ft/d)				Specific Storage (ft^{-1})			
	Min	Max	Median	Mean	Min	Max	Median	Mean	Min	Max	Median	Mean
1	7.00E-05	0.711	8.16E-03	0.0515	2.00E-06	0.02	2.33E-04	0.00147	7.32E-08	3.33E-06	3.21E-07	4.98E-07
2	7.00E-05	0.711	8.16E-03	0.0515	2.00E-06	0.02	2.33E-04	0.00147	7.32E-08	3.33E-06	3.21E-07	4.98E-07
3	7.00E-05	0.711	8.16E-03	0.0515	2.00E-06	0.02	2.33E-04	0.00147	7.32E-08	3.33E-06	3.21E-07	4.98E-07
4	1.72	880.20	6.66	21.13	0.0491	25.14	0.19	0.604	1.93E-07	5.85E-07	2.57E-07	2.78E-07
5	1.72	880.20	6.66	21.13	0.0491	25.14	0.19	0.604	1.93E-07	5.85E-07	2.57E-07	2.78E-07
6	1.72	880.20	6.66	21.13	0.0491	25.14	0.19	0.604	1.93E-07	5.85E-07	2.57E-07	2.78E-07
7	1.72	880.20	6.66	21.13	0.0491	25.14	0.19	0.604	1.93E-07	5.85E-07	2.57E-07	2.78E-07
8	1.72	880.20	6.66	21.13	0.0491	25.14	0.19	0.604	1.93E-07	5.85E-07	2.57E-07	2.78E-07
9	0.00	880.28	7.00E-04	15.19	0.00	25.14	2.00E-05	0.434	5.00E-07	5.00E-06	1.79E-06	2.57E-06
10	1.20E-05	880.28	7.00E-04	15.19	0.00	25.14	2.00E-05	0.434	5.00E-07	5.00E-06	1.79E-06	2.57E-06
11	1.20E-05	880.28	7.00E-04	15.19	3.42E-07	25.14	2.00E-05	0.434	5.00E-07	5.00E-06	1.79E-06	2.57E-06
12	4.17	1.58E+03	11.97	35.33	2.32E-03	0.88	6.65E-03	0.020	2.13E-07	1.20E-06	3.23E-07	3.76E-07
13	4.17	1.58E+03	11.97	35.33	2.32E-03	0.88	6.65E-03	0.020	2.13E-07	1.20E-06	3.23E-07	3.76E-07
14	4.17	1.58E+03	11.97	35.33	2.32E-03	0.88	6.65E-03	0.020	2.13E-07	1.20E-06	3.23E-07	3.76E-07
15	1.85	704.34	5.32	15.71	2.32E-03	0.88	6.65E-03	0.020	2.13E-07	1.20E-06	3.23E-07	3.76E-07
16	0.93	351.71	2.66	7.85	2.32E-03	0.88	6.65E-03	0.020	2.13E-07	1.20E-06	3.23E-07	3.76E-07
17	0.46	175.86	1.33	3.93	2.32E-03	0.88	6.65E-03	0.020	2.13E-07	1.20E-06	3.23E-07	3.76E-07
18	0.50	1.00	0.50	0.68	1.43E-02	0.03	1.43E-02	0.019	2.13E-07	1.20E-06	3.23E-07	3.76E-07
19	0.50	0.50	0.50	0.50	1.43E-02	0.01	1.43E-02	0.014	2.13E-07	1.20E-06	3.23E-07	3.76E-07
20	1.84E-04	6.74E-04	3.00E-04	3.61E-04	5.24E-06	1.93E-05	8.57E-06	1.03E-05	2.13E-07	1.20E-06	3.23E-07	3.76E-07

Table 2 Mapping of DSTRAM Nodal Layers to SEAWAT Pumping Layers

Top Pumping Layer			Bottom Pumping Layer		
DSTRAM Node Layer	SEAWAT Layer	Well Count	DSTRAM Node Layer	SEAWAT Layer	Well Count
21	1	0	21	1	0
20	1	0	20	2	0
19	2	0	19	3	0
18	4	1	18	4	0
17	4	128	17	5	16
16	5	5	16	6	51
15	6	8	15	7	34
14	7	2	14	8	39
13	8	0	13	8	1
12	9	0	12	10	0
11	10	0	11	11	1
10	12	0	10	11	5
9	12	0	9	13	13
8	13	1	8	14	4
7	14	0	7	15	0
6	15	0	6	16	0
5	16	0	5	17	1
4	17	0	4	17	0
3	18	0	3	18	0
2	19	0	2	19	0
1	20	0	1	20	0