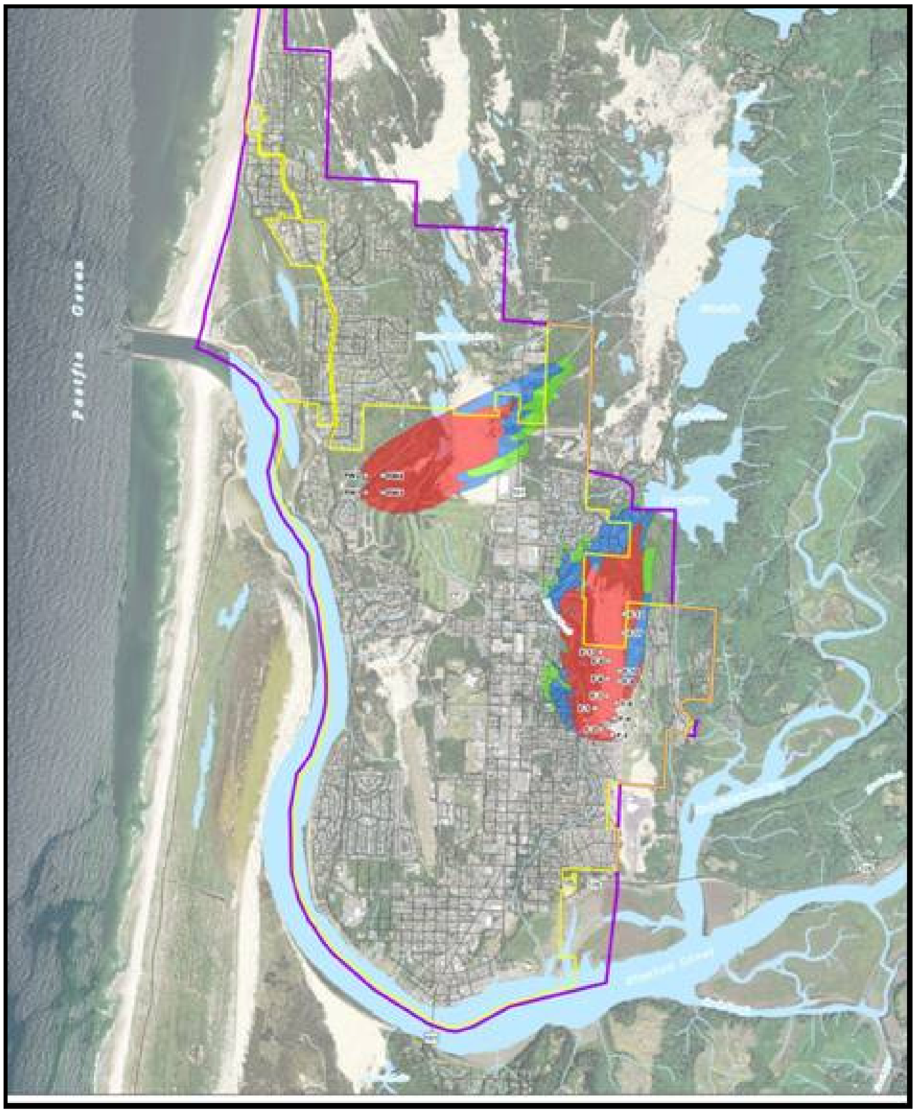
Appendix D

Delineation of Drinking Water Protection Areas

City of Florence, Oregon

February 15, 2012



Prepared by:

GSI Water Solutions, Inc.

OREGON PUBLIC HEALTH DIVISION
Drinking Water Program

John A. Kitzhaber, MD, Governor

Oregon Health Authority

444 A Street
Springfield, OR 97477
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FAX: 541-726-2596
www.healthoregon.org/dwp

March 16, 2012

Matthew Burdett
City of Florence
250 HWY 101
Florence, Oregon 97439

Re: OHA Drinking Water Program Delineation Certification # 0016

Dear Matthew:

Under the Administrative Rules that apply to Oregon's EPA-approved Drinking Water Protection Program, the Oregon Health Authority has the responsibility of certifying groundwater-derived drinking water protection areas in the State (see DEQ's OAR 340-40-180 (3)). This certification is granted after technical review assures that the submitted delineations meet minimum requirements for the system as outlined in OHA's OAR 333-61-0057, and that the delineation is a hydrogeologically reasonable representation of the capture zone of the well, wellfield or spring. The delineation of the capture zones for the current City of Florence wellfield meets the above requirements and is therefore certified collectively as Oregon Health Authority Drinking Water Program (OHA DWP) Delineation Certificate #0016. The delineation of capture zones for the proposed wellfield by OHA defintion is a provisional delineation and can not be included as part of this certification. Instead, OHA approves of the use of the provisional delineation for protection of possible future drinking water resources.

The City of Florence has more than 3000 service connections. As such, OHA DWP certification qualifies the existing wellfield delineation (i.e., Wells 1 through 13) as a significant groundwater resource for the purpose of State-Wide Planning Goal 5 (see LCDC's OAR 660-23-140). DLCD [(503) 373-0050] can answer questions regarding state-wide planning goals.

As you continue your efforts in implementing drinking water protection strategies, the Drinking Water Program can provide technical assistance. To complete this process please forward an ARCGIS compatible shapefile of the delineated capture zones for both wellfields to Steve Aalbers of DEQ (503-229-6798).

We appreciate the investment that the City of Florence is making on behalf of its drinking water resource. We also wish to thank you for your continued and constructive assistance in the development of Oregon's Drinking Water Protection Program.

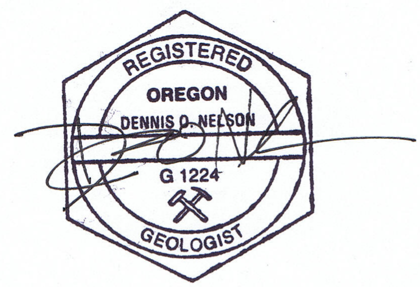
Sincerely,

Tom Pattee

Tom Pattee
Groundwater Coordinator
OHA Drinking Water Program

cc: Sheree Stewart, DEQ; Dennis Nelson, GSI Water Solutions

Water Solutions, Inc.



October 25, 2011

Tom Pattee, Groundwater Coordinator
Drinking Water Program
Oregon Health Authority
444 A Street
Springfield, Oregon

Re: Identification of the Drinking Water Protection Areas, Florence, Oregon

The City of Florence is part of the Siuslaw Estuary Partnership whose objectives include the protection of the Florence Dunal Aquifer water quality and quantity in the current and future well fields, of streams and wetlands, and of fish and wildlife habitat. The City also has the objective of developing an Aquifer Protection Plan which includes the development of a Drinking Water Protection Plan for current and future resources.

GSI was asked to participate in this project in three areas: surface and groundwater quality and quantity, the update of the delineation of the drinking water protection areas completed in 2003 by OHA, and assistance in developing drinking water protection strategies. This communication addresses the updating of the City of Florence's delineations. We are submitting this document as the first step in obtaining certification of these delineations.

The delineation project's goals are:

- Develop a local-scale numerical groundwater flow model that can simulate area groundwater conditions using groundwater and surface water data collected during the monitoring phase of the Partnership study.
- Use the model to refine the existing Drinking Water Protection Areas (DWPAs) delineation for the existing water supply wells and establish delineations for the proposed City wells. This effort will consist of defining the capture zones that provide groundwater to the City's wells during the 1-year, 2-year, 5-year,10-year, 20-year, and 30-year time periods.
- Submit documentation to DHS for certification of the City's new DWPA delineations.

The City of Florence has a population of approximately 8,400 and is supplied drinking water by a single wellfield comprising 12 wells, with one additional well to come on line in the near future. The City's current well field production capacity is 2.7 mgd during the dry summer months (Table 1, GSI, 2008). The City's existing ground water rights total 3.8 mgd. Expansion of the drinking water treatment plant from 3.0 mgd to 4.0 mgd is feasible.

Table 1. City of Florence Well Capacities (August 2007)		
Wells	**Combined Capacities (mgd)**	**Capacity Pump Rate/Well (gpm)**
Wells 1 through 7	1.2	120
Wells 8 through 12	1.6	222

The City anticipates an average annual population growth rate of 3.5 percent. Information provided by the City indicates that water production/demand has also grown, but at a slower rate than the projected 3.5 percent rate of population increase. GSI (2008) calculated the expected average rate of increase in water demand during the highest demand months at 2.9 percent, assuming no constraints to increased demand, such as well production capacity or drinking water treatment capacity limitations.

Given the projected water production growth of 2.9 percent, the capacity of the current wellfield may be reached by the end of 2011. The City has drilled an additional well (#13) in the field and will bring it on line in the near future, however, additional sources will be needed and the City is considering adding a second wellfield. The City wishes to include a future wellfield site in the delineation model. The purpose of delineating the proposed well field is to provide information that can be used to protect this future source of water.

Florence Groundwater Flow Model

Groundwater flow in the Florence area was modeled using the numerical finite element model MODFLOW 2000 (Harbaugh and others, 2000) packaged in the program Groundwater Vistas® 5.44 (Environmental Simulations, Inc., 2007). Numerical models allow the modeler to divide (discretize) the area of interest into discrete rectangular volumes (cells) in three dimensions that can be individually characterized in terms of aquifer properties, assigned head, boundary conditions, etc. The use of multiple layers and cell volumes/layer is permissible.

Numerical models use input data provided by the modeler to calculate the distribution of hydraulic head within the model area (domain). The input data is developed from a conceptual model of the area in which the modeler develops an understanding of the local geology, hydrogeologic units, their characteristics, including aquifer thickness, permeability and porosity, areal recharge, and boundary conditions, e.g., streams, geologic contacts, etc

As a means of constructing a representative model, the model is generally "calibrated" to one degree or another against data, generally hydraulic head, collected in the field as a check.

Conceptual Model

An important resource in developing the Florence area conceptual model was the U.S. Geological Survey Water Supply Paper, "Ground Water in the Coastal Dune Area Near Florence, Oregon" (Hampton, 1963). This publication provides descriptions of the major hydrogeologic units in the area and a map showing the distribution of hydraulic head in the area. A study by Brown and Caldwell (2001) provided a basis for estimating aquifer characteristics. The head map produced by Hampton (1963) and the model results of a three dimensional groundwater model developed by EGR & Associates (1997) for the purpose of evaluating the impact of increasing use of Clear Lake water, were used as first order calibration targets in this study.

Both of the studies above indicated that groundwater discharges to the Siuslaw River to the south and southwest, and to the Pacific Ocean to the west northwest. As a result, groundwater flow direction varies from north to south in the southern part of the City and to the west in the northern part of the area.

The local geology consists of younger (< 10,000 yrs) Holocene dunes overlying older (24-100,000 years) Late Pleistocene dunes. The ancestral Siuslaw River cut channels in the older dunes prior to the deposition of the younger dunes. This resulted in the Holocene dunes having variable thickness across the area. The variable thicknesses are shown in Figure 2 *(OSU Geophysics Group. 1980)* and vary from less than 20 feet to more than 200 feet. Thicker sections, e.g., along the eastern margin of the dune field apparently mark the locations of past channels of the ancestral Siuslaw River (Peterson, 2011, personal communication), while shallow sections represent topographic highs on the underlying sedimentary rock surface.

Model Development.

Model Grid. For characterization of model parameters, a rectangular grid was constructed as 3 layers with a grid spacing of 90 columns and 160 rows (Figure 3). Each cell has a dimension of 200 x 200 feet. This grid spacing was arbitrarily chosen to provide for a manageable number of cells given the size of the model area. For a larger scale head map of the active wellfield to qualitatively evaluate the modeled interference of the individual wells was refined to a 100 x 100 foot grid (see below).

The model grid was anchored to a specific location with UTM and Oregon State Plan coordinates. Specifically, the origin of the grid is at the UTM coordinates 409050E and 4868000N or x =3964455.55 and y = 857063.85, NAD83 Oregon State Plane, South Zone, International feet, respectively.

Model Layers. Three layers were established (Figure 1) initially to be able to account for subtle variations in the amount of clay associated with the sand. However, based on a seismic study (Figure 2), it became apparent that the properties chosen for the aquifer layers needed to be done in a manner to more accurately reflect the topographic high of the bedrock beneath the dunes in the central area and to establish the vertical and horizontal variation of the transmissivity (thickness) of the aquifer. No specific boundaries marking the layers are implied by the layer boundaries.

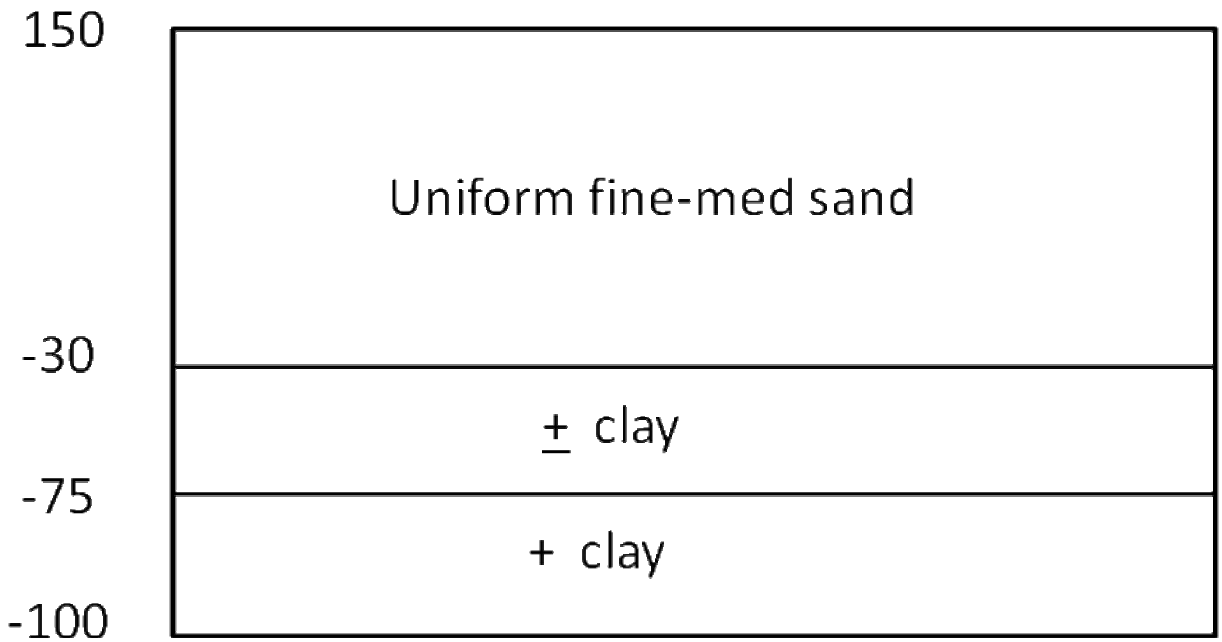


Figure 1. Schematic diagram of the layers originally established for the Florence Dunal Aquifer model (see text for discussion). Numbers on the y-axis reflect elevation (SMOW).

Model Boundaries. The eastern boundary of the dune deposits (Figure 3) is marked by a topographic slope break at the contact between the dune deposits and underlying Flournoy Formation of Middle Eocene. These rocks, exposed in outcrop just east of Florence on Highway 26, consist of fine grained sediments, chiefly siltstone. Based on exposures, the Flournoy contains some fracturing. For the purpose of this model, the sedimentary unit was considered impermeable and was considered to be a no flow boundary (Figure 4). Also considered to be a no flow boundary is the northernmost boundary arbitrarily drawn at 45^{o} 3.1' N. The Pacific Ocean forms the western boundary and is considered to be a constant head at a value of 0.0 feet.

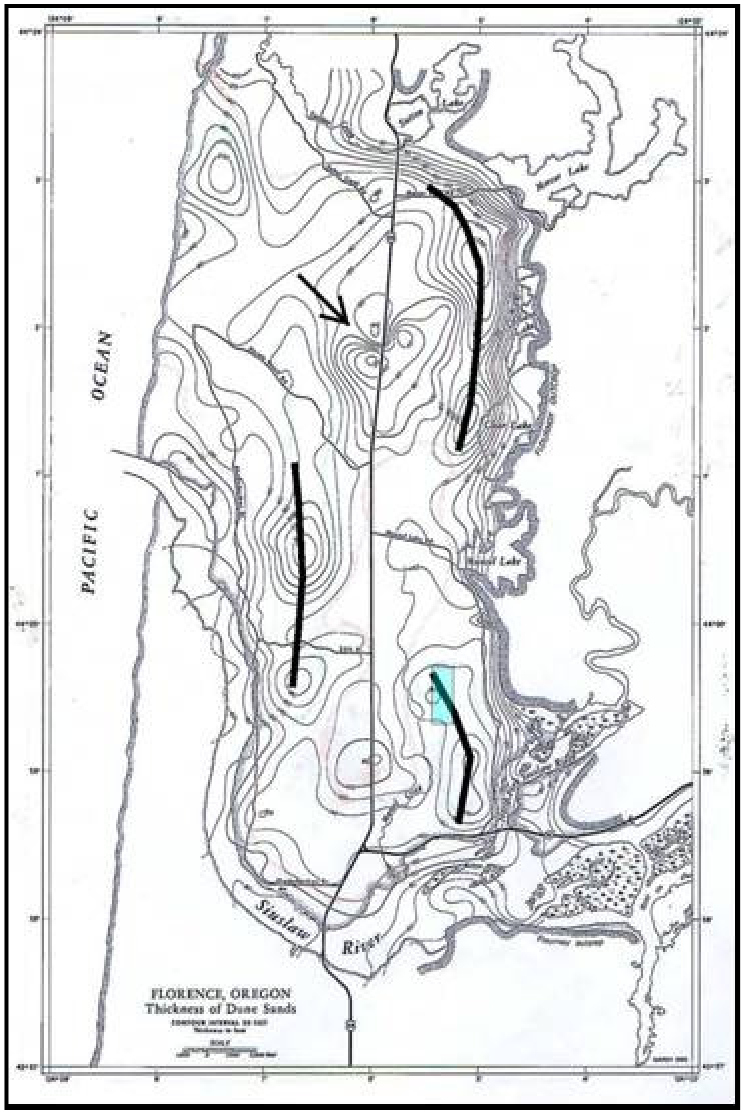


Figure 2. Seismic data indicating the variable thickness of the dune deposits in the Florence Area. Deep troughs (see dark lines) produce sand thicknesses of up to 200 ft. These troughs mark the locations of past channels of the ancestral Siuslaw River. Shallow (~20 feet) sand accumulations (see arrow) mark the location of topographic highs on the underlying sedimentary rock surface. Approximate location of the existing wellfield is shown in the lightly shaded rectangle. Map taken from (OSU Geophysics Group. 1980).

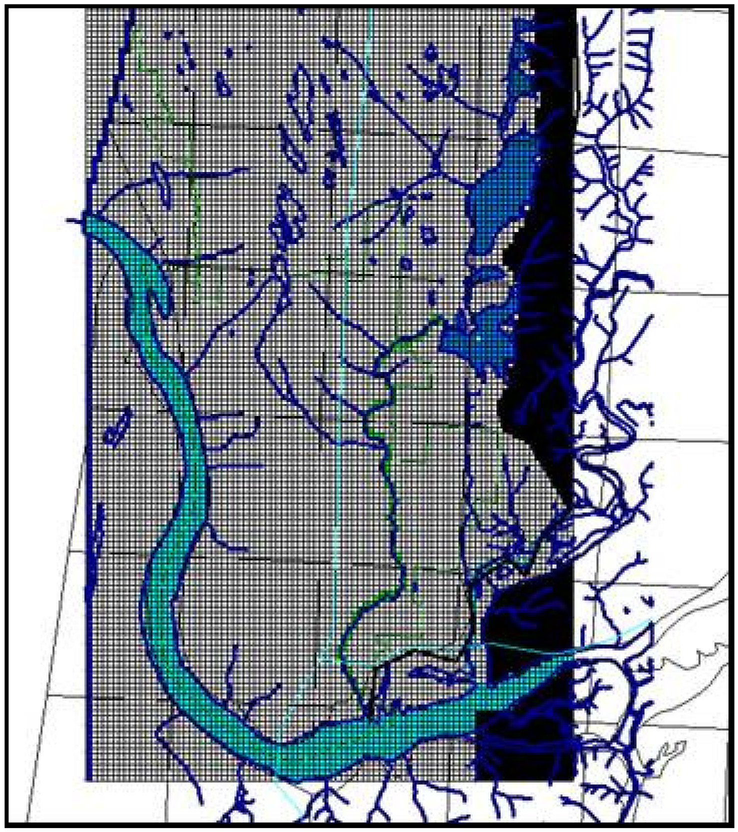


Figure 3. Model domain showing grid design, comprising 90 columns and 160 rows of cells with dimensions of 200 x 200 feet (14,400 individual cells).

<u>Surface Water.</u> The rivers, the lakes, and Munsel Creek were integrated into the flow model based on available data. The stage of the Siuslaw River and the North Fork of the Siuslaw were estimated based on digital elevations derived from the Florence 7.5 minute topographic map. Munsel Creek headwater stage was set at the average elevation of the outflow of Munsel Lake where the creek originates. Average lake elevations were determined from Portland State University's Center for Lakes and Reservoirs. Parameters used as input to the model are given in Table 2.

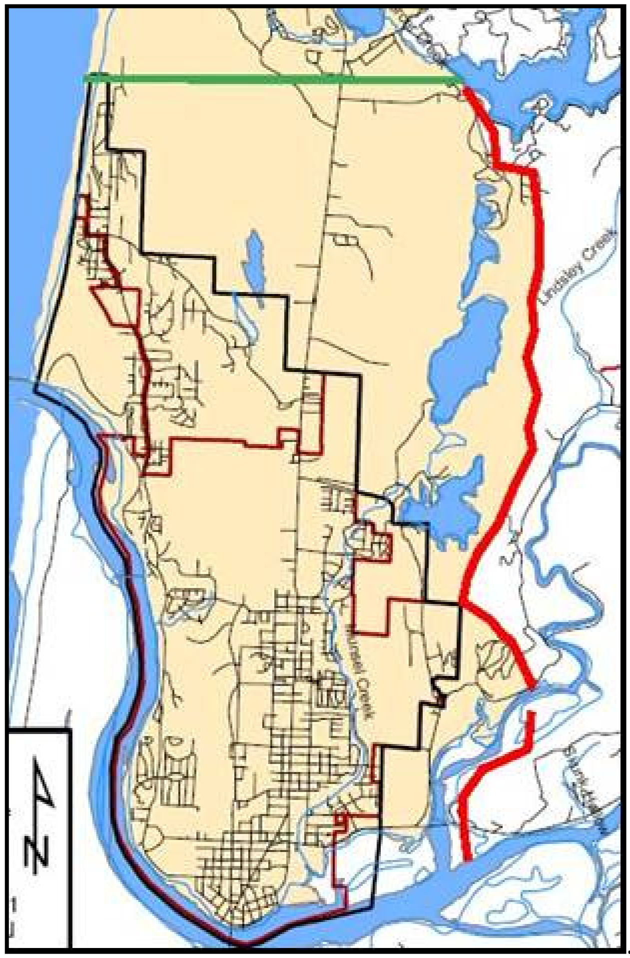


Figure 4. Map showing the approximate extent of the Florence Dunal Aquifer. Thin red line is the City limits of Florence while the thin black line represents the urban growth boundary (UGB). Thick red line represents the eastern no-flow boundary of the model. The Siuslaw River and the Pacific Ocean form the southern and western boundaries. The thick green line forming the northern boundary is a no-flow boundary arbitrarily drawn at 45^o 3.1' N.

Recharge. Virtually the entire recharge to the Dunal Aquifer is from direct infiltration of precipitation that falls on the dune surfaces. Total rainfall in Florence varies from 47 inches in a dry year to 122 inches in a wet year, with an average of 69 inches (Florence Stormwater Management Plan, 2000). Rainfall in the Florence area during the 2010-2011 rainfall year varied from 67.1 to 78.2 inches (from individual resident records).

Table 2. Model input for lakes, rivers and streams, Florence groundwater model.				
	Stage (ft msl)	Bed Thickness	K (ft/day)	W x L
Siuslaw River	0	5 – 10	2 – 0.1	200 x 200
N. Fork Siuslaw Riv	2 - 0	3	2 -1	100 x 200
Munsel Creek	89 – 0	2 – 1	1 – 0.5	50 x 200
Munsel Lake	89	3	0.5	NA
Ackerly Lake	93.5	3	0.5	NA
Clear Lake	98	3	0.5	NA
Collard Lake	115	3	0.5	NA

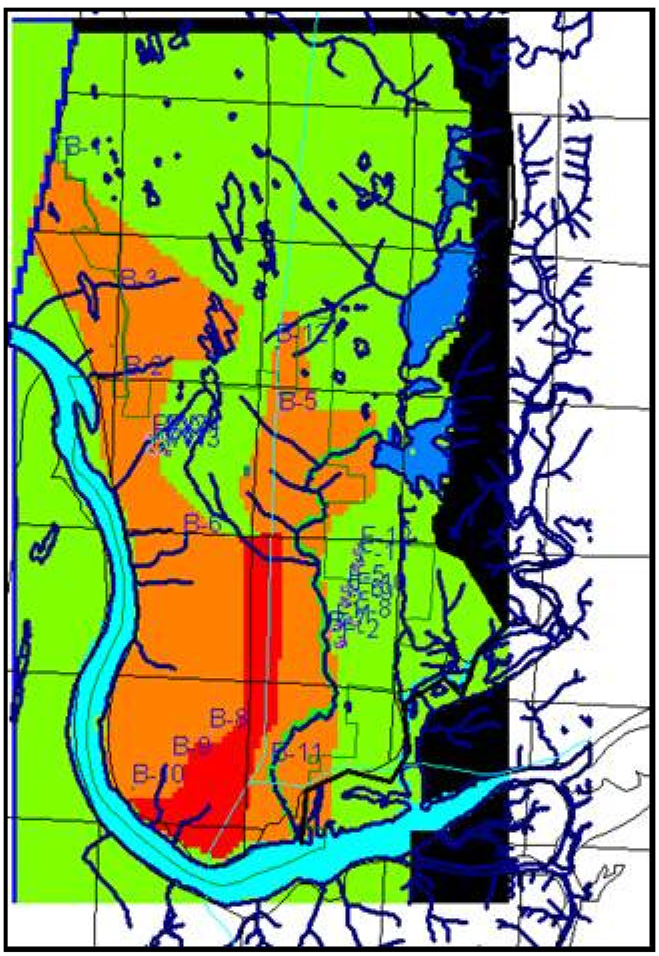


Figure 5. Distribution of recharge values as a function of specific land use activity. Open dunes (green) = 0.0133 ft/d, residential (orange) = 0.009 ft/d, and commercial/industrial (red) = 0.006 ft/d.

Accounting for evapotranspiration, Hampton (1963) estimated that recharge annually to the aquifer was 55 inches/year. Runoff coefficients were used to adjust the recharge rate as a function of land use (City of Florence, 2008)), e.g., open dunes = 0, residential areas = 0.4, and commercial/industrial = 0.6 (Dunne and Leopold, 1978). The final distribution of recharge rates used in the model are shown in Figure 5.

Porosity. The porosity, the volume fraction of the bulk material that consists of open pore space, is a function of particle size. Hampton (1963) demonstrated that the dunal sands in the Florence area are very uniform in size. Based on the data he provides, it would appear that ~80% if the sand is in the size range of 0.2 to 0.275 mm and therefore is considered to be fine to medium sand. The effective porosity of fine to medium sand varies from 0.23 to 0.28 (Moss and Moss, 1990). For modeling purposes here, a porosity value of 0.26 was chosen for the aquifer.

Hydraulic Conductivity. The hydraulic conductivity (K) of the aquifer was initially based on aquifer tests within the City's current wellfield. These tests indicated that the hydraulic conductivity of the sand deposits varied from 50 to 100 ft/day (Brown and Caldwell (2001). Aquifer thickness in the area of the wellfield suggested that the deposits were in excess of 200 feet thick (the SE trough in Figure 2). After a review of well reports and specific capacity data, DHS (2003) determined that the aquifer's permeability was higher in the eastern part of the area near the current wellfield than in the west. It was also noted that the variable thickness of the aquifer would significantly influence the movement of groundwater through aquifer in specific regions of the Dunal Aquifer.

The distribution of hydraulic conductivity in the Dunal Aquifer was weighted as a function of the thickness of the sand deposits (Figure 2). The final model values of K varied 5 to 55 ft/day. Figure 6 shows the final distribution of K values.

Wells. Individual well location was determined using gps latitude-longitude measurements converted in model coordinates. Well locations are independent of cell location. Casing diameters were used as well diameters.

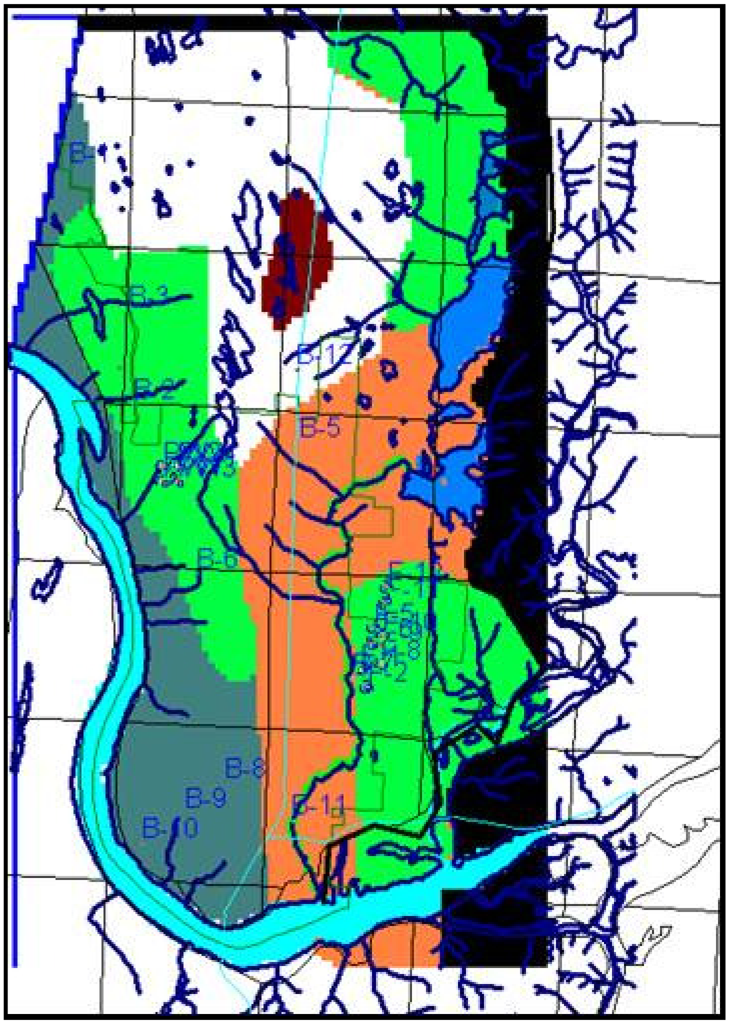


Figure 6. Variation of hydraulic conductivity within the sand aquifer. Colors represent the following K values (ft/day): green = 55, white = 35, orange = 18, gray = 15, brown = 5.

Running the Model

Model Description. MODFLOW 2000 was used in this effort, assuming steady state conditions (assumes no changes in any input parameters, including precipitation and pumping rates (City of Florence wells @125 gpm). The initial input data was used and the model was allowed to run. Criteria for convergence (reaching an acceptable solution) for the model were a head change = 0.01 and a residual criteria = 0.4. Convergence is achieved if the above criteria are met for 10 outer iterations. Input parameters were modified within reasonable ranges until the convergence criteria were met and convergence was achieved. Modifications continued until the model head predictions most closely approximated observed hydraulic head.

The City constructed a total of 15 shallow (<30 ft) monitoring wells within the Holocene dunes, 10 in September 2010 and an additional 5 in March 2011 (Figure 7). The depth to the water table has been measured monthly in each well since they were emplaced. Water levels in the wells varied up to 7 feet throughout the year, lowest in October 2010 and highest in April 2011, however the configuration of the water table remained relatively constant (Figure 8). The static water levels for the September, 2010 wells (white symbols in Figure 7) were converted to water table elevation and the 12-month average of the head at each well was used as a target to evaluate how representative the developing flow model was to reality.

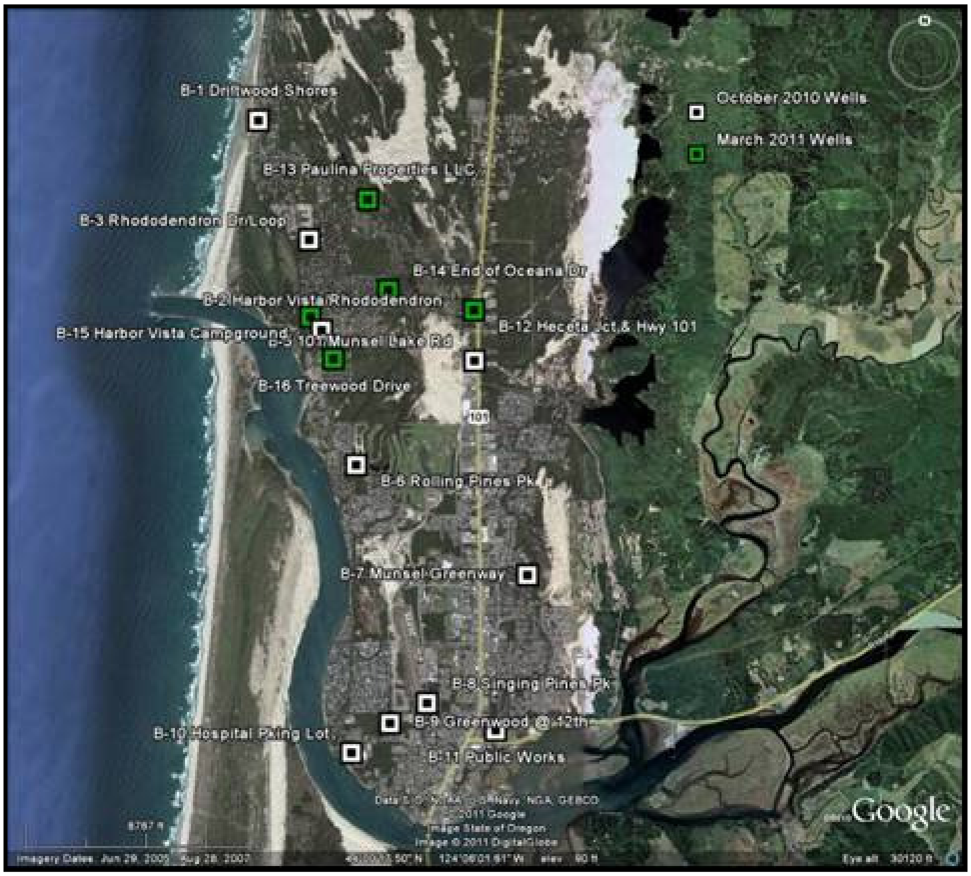
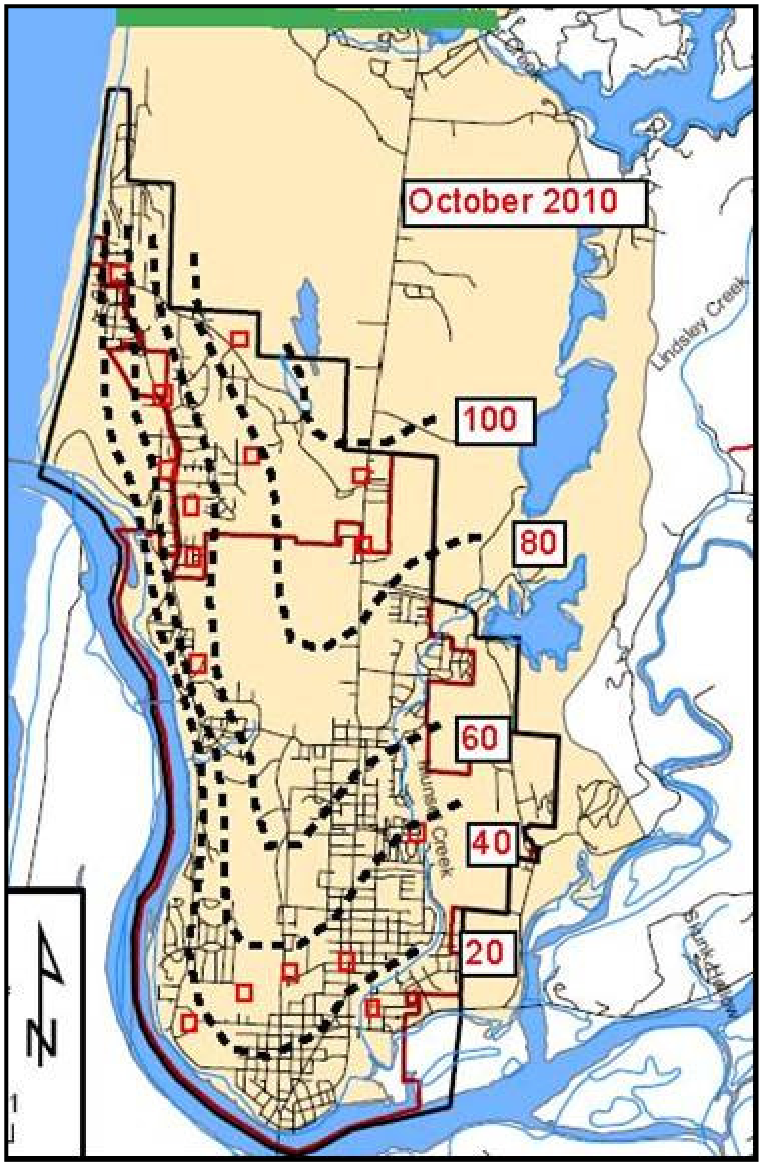
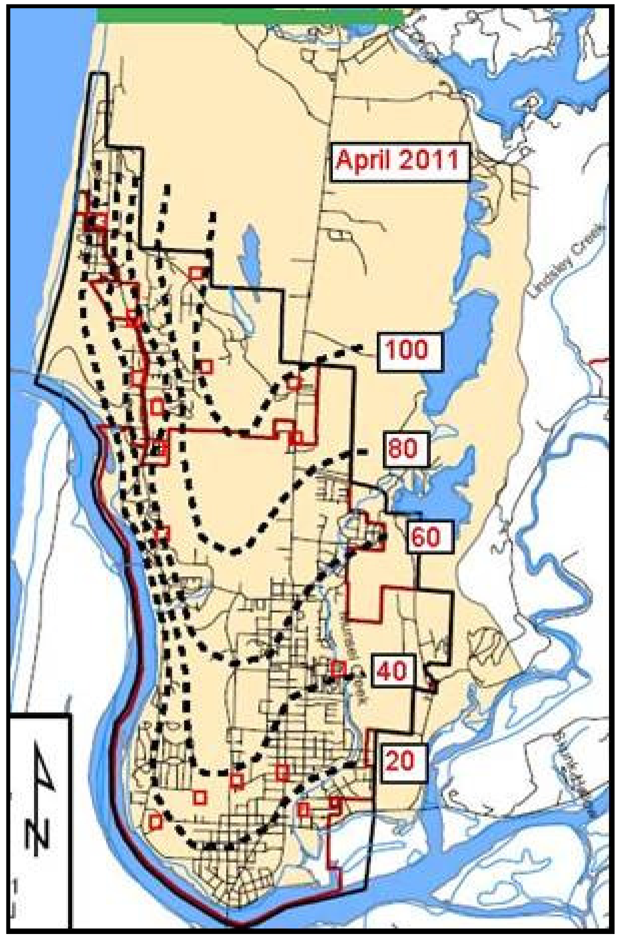


Figure 7. Location of monitoring wells in the Florence area. Wells with white symbols were installed in September 2010 while those with green symbols were installed in March 2011.



a.



b.

Figure 8. Comparison of the measured water table elevations from October 2010 (a) and April 2011 (b). Water table configuration remains similar throughout the year.

Model Calibration

Resources were not available to pursue the model calibration to a high degree of sophistication. The predicted water table elevations are in general agreement with the measured elevations (Figure 9). A more quantitative assessment of the model can be achieved by comparing predicted vs. observed heads at specific locations. Such an exercise was performed using monitoring wells B-1 through B-11 as shown in Figure 9 (B-4 was an unsuccessful well and is not listed).

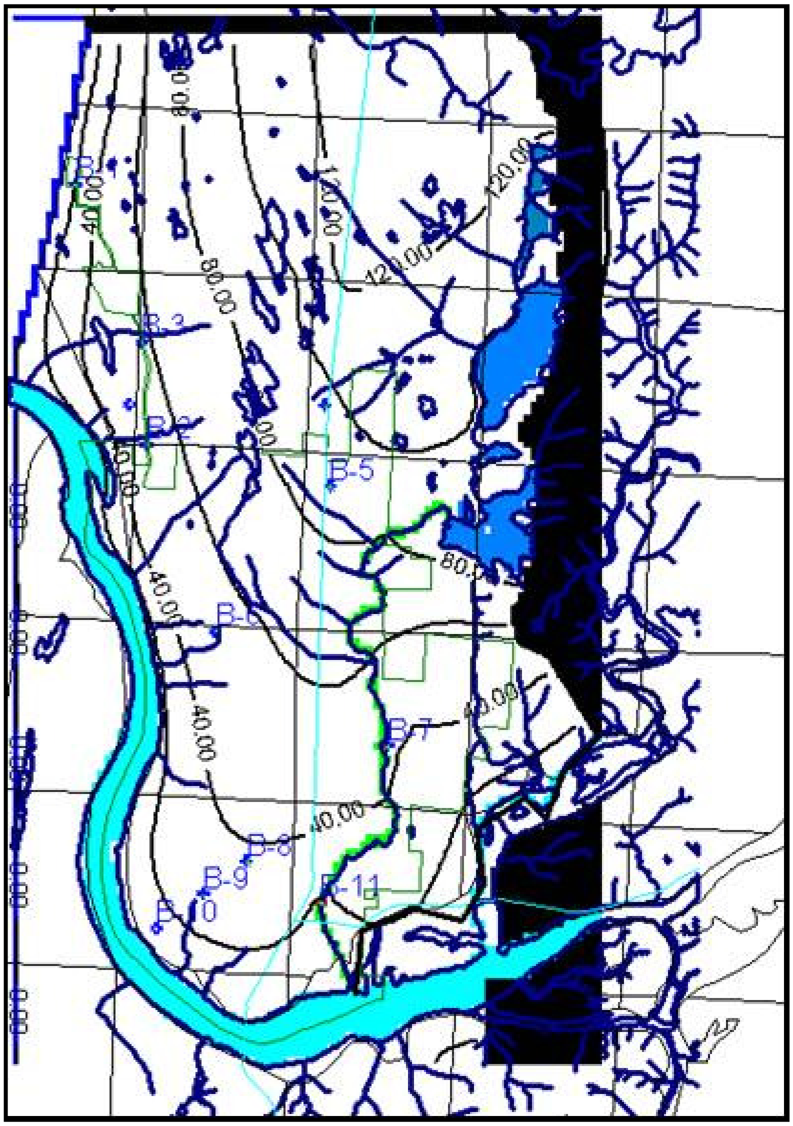


Figure 9. Model hydraulic head distribution. Contour interval is 20 ft. Monitoring wells used as calibration targets are labeled.

Differences between predicted and observed are referred to as residuals. In this model, the residuals varied from -7.29 feet to +10.4 feet with an absolute residual mean of 3.35 feet and a root mean squared error (RMS error) was 4.33. No geographic pattern of residuals is evident (Figure 10). The magnitude of the largest residual represents approximately 7.1% of the total head range in the area (~146 feet, based on GPR data provided by Sarah Doliber, 2012) while the residual mean value represents ~2.3% of the head range. Figure 11 is a plot of predicted vs. observed heads for the 10 monitoring wells used in the calibration.

Mass balance considerations indicate that the model is a reasonable representation of the groundwater flow system. The model wide mass balance error, comparing inflow to the model vs. outflow from the model, is 0.159%. Accurate stream flow data was available for Munsel Creek only. During the pumping season, July through September 2011, discharge from Munsel Creek to the Siuslaw River increased progressively varying from 1 to 10 cfs and averaging 3 to 5 cfs. The model predicts that inflow from groundwater to Munsel Creek is ~2.9 cfs, well within that range.

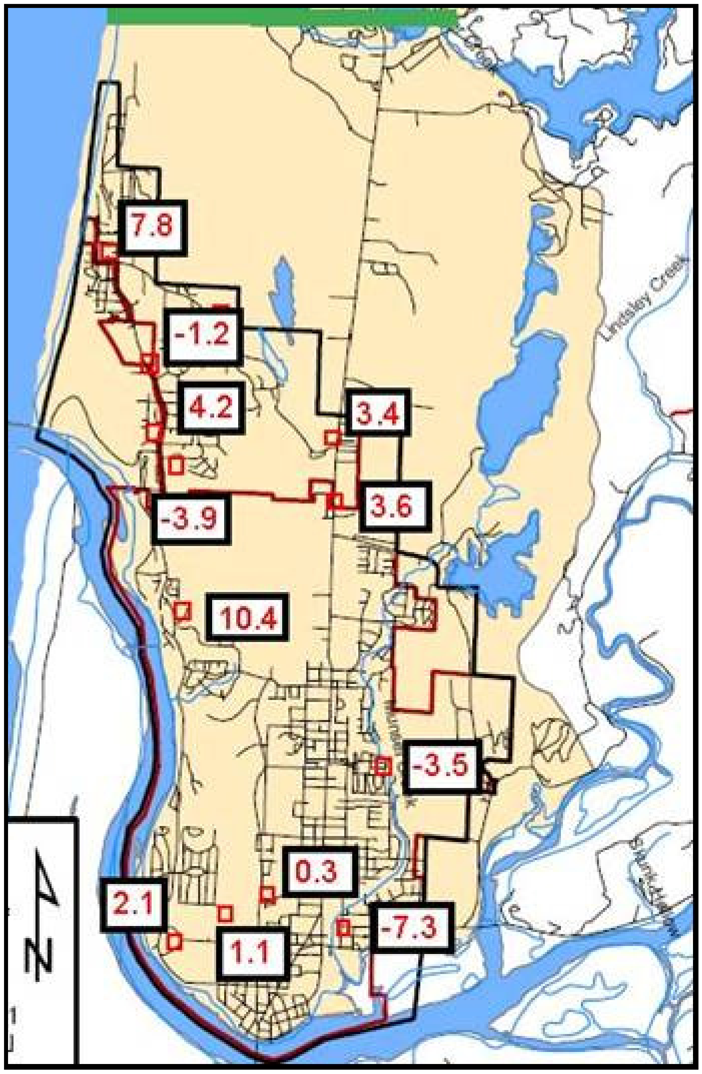


Figure 10. Map illustrating the residuals (= observed value - model value) at selected monitoring well sites. A negative number indicates that the model prediction is higher than the observed value, a positive value indicates that the model predicts a lower head than observed.

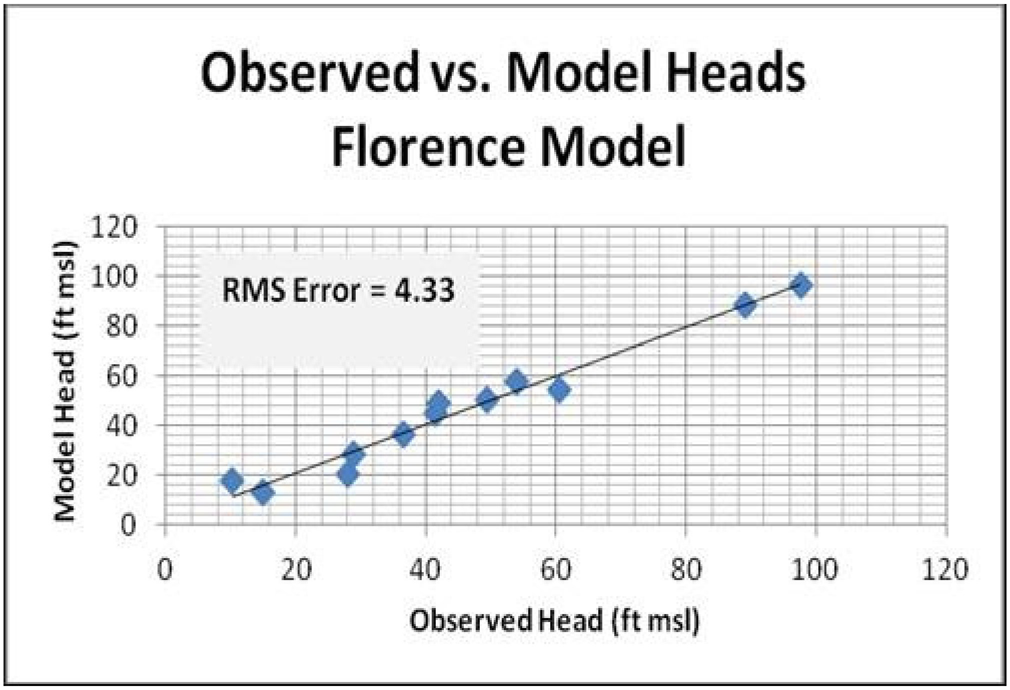


Figure 11. A plot of the observed vs. predicted heads as determined for the Florence area. The root mean of the squared residuals (RMS) is 4.33 feet.

Operation of the City's wellfield is recorded on a daily basis. Pumping schedules are variable as a function of demand, and mutual well interferences are complicated, however it is possible to estimate the combined impact of pumping wells on neighboring wells. Typical of an unconfined aquifer, the drawdown at the wellhead is considerable, e.g., 30 to 40 feet, rapidly becoming less as one moves away from the well. Reviewing the City's wellfield records suggests that the pumping of one well on a neighboring well produces a drawdown on the order of less than 1-2 feet. The flow model results in the vicinity of the wellfield are consistent with this small amount, reflecting the relatively high K value of the aquifer (Figure 12). To improve the local resolution in the wellfield, he model results represented in Figure 10 reflect a refinement of the grid in the wellfield to 100x100 foot cells (notice change in cell spacing in figure).

This refinement does not affect the overall results of the model described above. Figure 13 illustrates the positions of the groundwater contours over the model area. Aside from the shifting of the contours in the immediate vicinity of the existing and proposed wellfields, no significant changes in contour position are noted (compare with Figure 9).

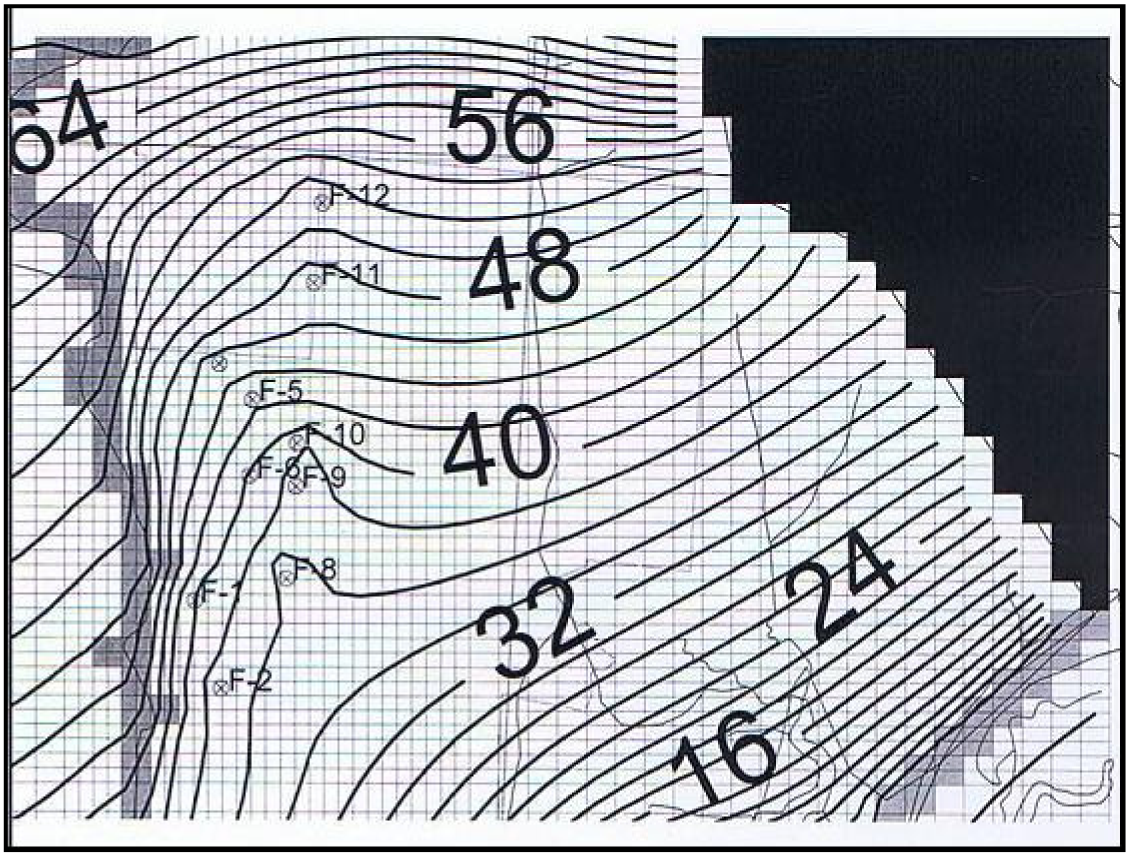


Figure 12. Head contours in the vicinity of the existing wellfield as predicted by the flow model (note grid has been refined to 100x100 ft for this model run). All wells are pumping at their respective capacities.Contour interval is 2 feet. Predicted impact of pumping on neighboring wells is minimal.

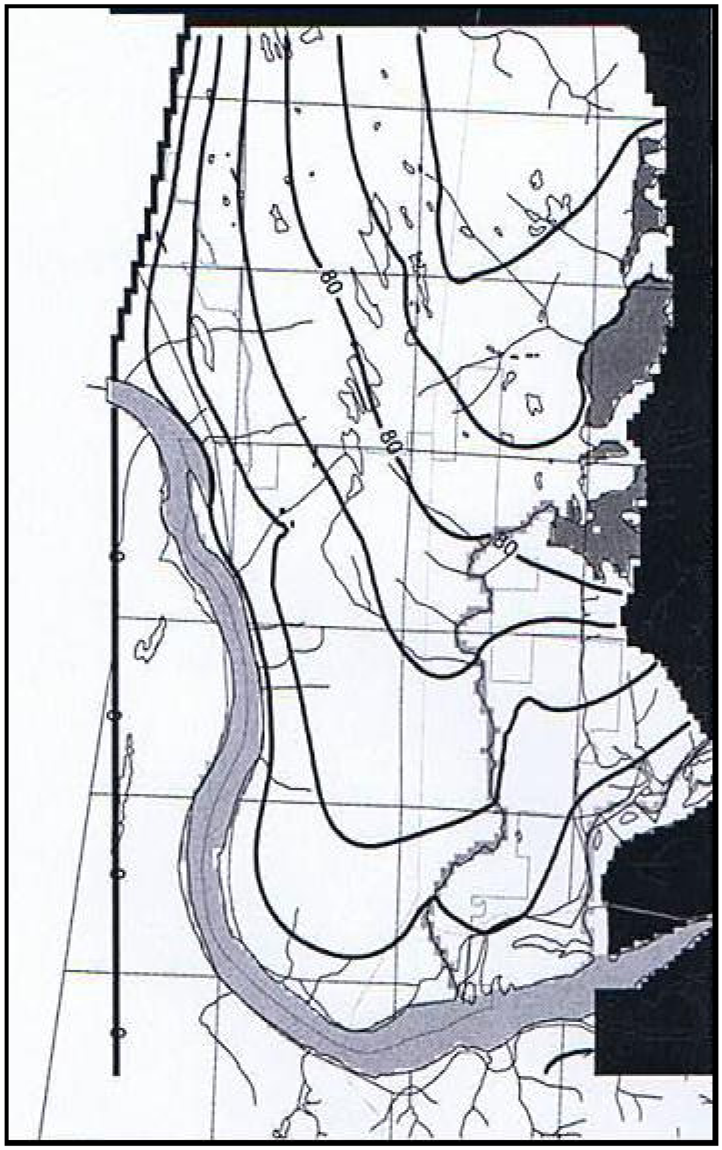


Figure 13. Contours of hydraulic head over the model area respresenting a refinement of the cell size within the wellfield to 100x100 feet (see Figure 12). No significant difference in contour placement is noted relative to the head distribution using the 200x200 cell dimension in the model used for capture zone analysis (compare Figure 9).

Capture Zone Analysis

The City of Florence has an existing Drinking Water Protection Plan (2003) and is in the process of updating it to make in consistent with the current conditions in the area. The updating process is as follows:

- Update the delineation of the current wellfield and proposed wellfield. The original delineation by OHA included a possible new wellfield site, however that site is no longer being considered and an alternate site has been located.

- Update the Potential Contaminant Source (PCS) inventory and aquifer susceptibility analysis.
- Develop strategies to minimize the risk of contamination within the newly defined delineations.

The update of the delineation exercise is the purpose of the current project and GSI has used where possible the requirements laid out by OHA in their administrative rules (OAR 333-061-0057). With respect to model pumping rates, OHA allows the option of using a rate of 90% of the safe yield of a given well. For the delineation of the Florence Drinking Water Protection Areas, we have chosen to use the more conservative full well capacities determined by GSI (2008) and shown in Table 1 of this report. Well 13 is not operational at the time of this report, however, for planning purposes, the well was added to the model using a pumping rate of 220 gpm. Proposed wells were "pumped" at a value of 250 gpm.

The model is steady-state, therefore, all wells were on in the model continuously, again, employing a conservative, i.e., producing a larger capture zone, estimate of groundwater usage. Running the model with the existing and proposed wells pumping at capacity produced a slightly larger error (Absolute Residual Mean = 3.99, RMS = 4.95) primarily because of the proximity of one of the calibration wells (B-6) to the proposed wells.

MODPATH (Pollock, 1994) allows for the tracking of "particles" during a model run. These "particles" are allowed to flow with the groundwater to either predict where the groundwater is going (forward tracking), or, predict where it came from (reverse tracking). The latter reverse particle tracking exercise is referred to as capture zone analysis. The capture zone outlines the land surface that overlies that part of the aquifer that supplies groundwater to the well over a given time period.

Using the Groundwater Vistas® interface, particles were placed in a circle with a radius of 100 feet centered on each well in the layer in which the well is screened. Particles were released at the bottom and at 50% of the height of the specific grid cell in which the well was located. Well locations are independent of cell positions, i.e., they are not arbitrarily located at cell centers or corners.

OHA asks for specific time-of-travel (TOT) zones be delineated within a given capture zone, specifically, the 1-, 2-, 5-, and 10-year TOTs. For planning purposes, the City of Florence desired to extend the delineations out to include the 20- and 30-year TOTs.

The results of the delineation modeling effort are shown in a regional view (30-yr) in Figure 14, a more focused view of the 10-yr TOTs for both wellfields in Figure 15, and a closeup view of the 10-year TOT zones for the existing wellfield in Figure 16.

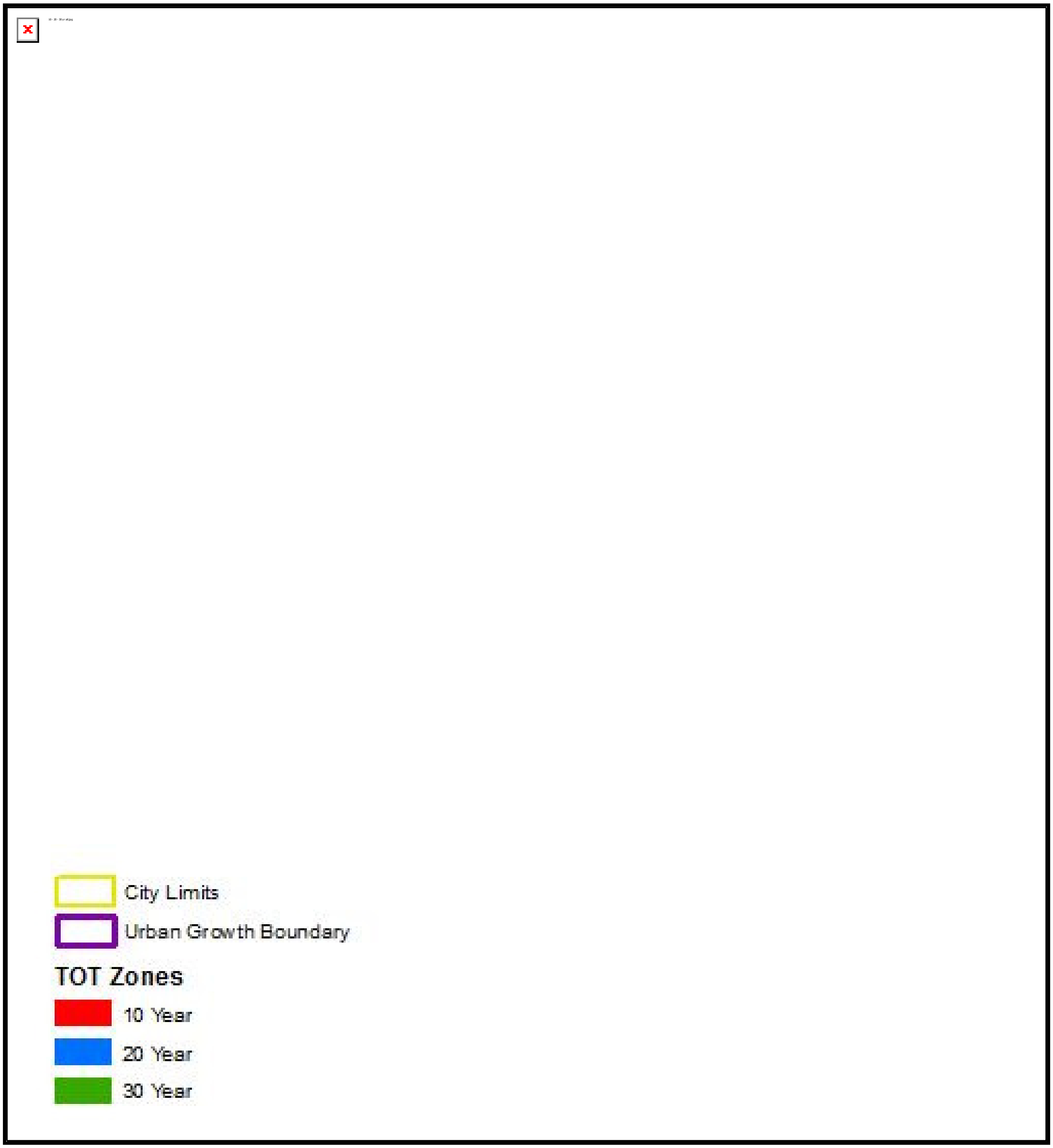


Figure 14. Regional view showing the 30-year capture zones of the existing wellfield (lower right) and the proposed wellfield (upper left) for the City of Florence.

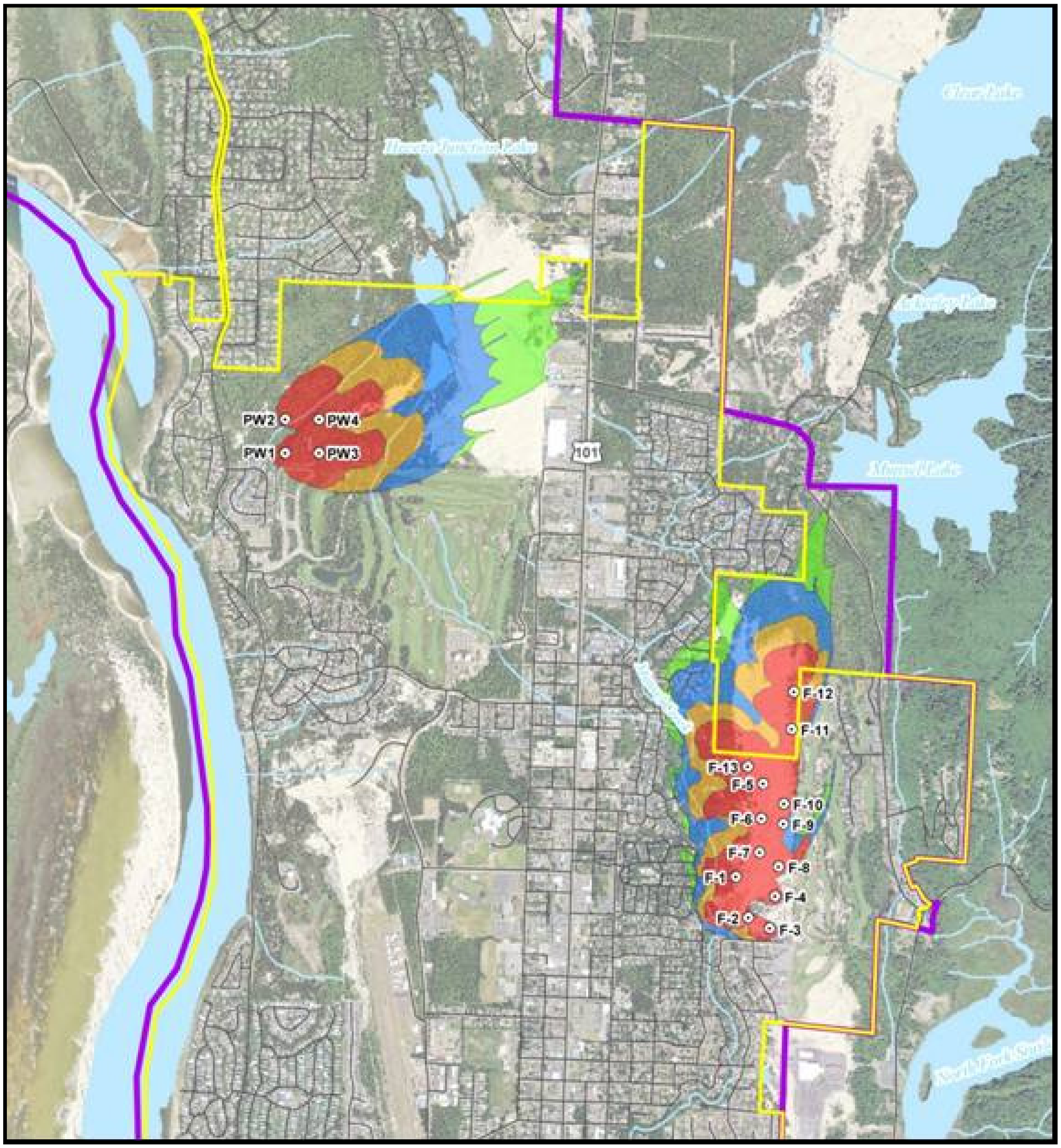


Figure 15. Ten-year capture zones for Florence's existing and proposed Wellfields. Different TOT zones indicated by shading: red = 1-yr TOT, orange = 2-yr TOT, blue = 5-yr TOT, and green = 10-yr TOT.

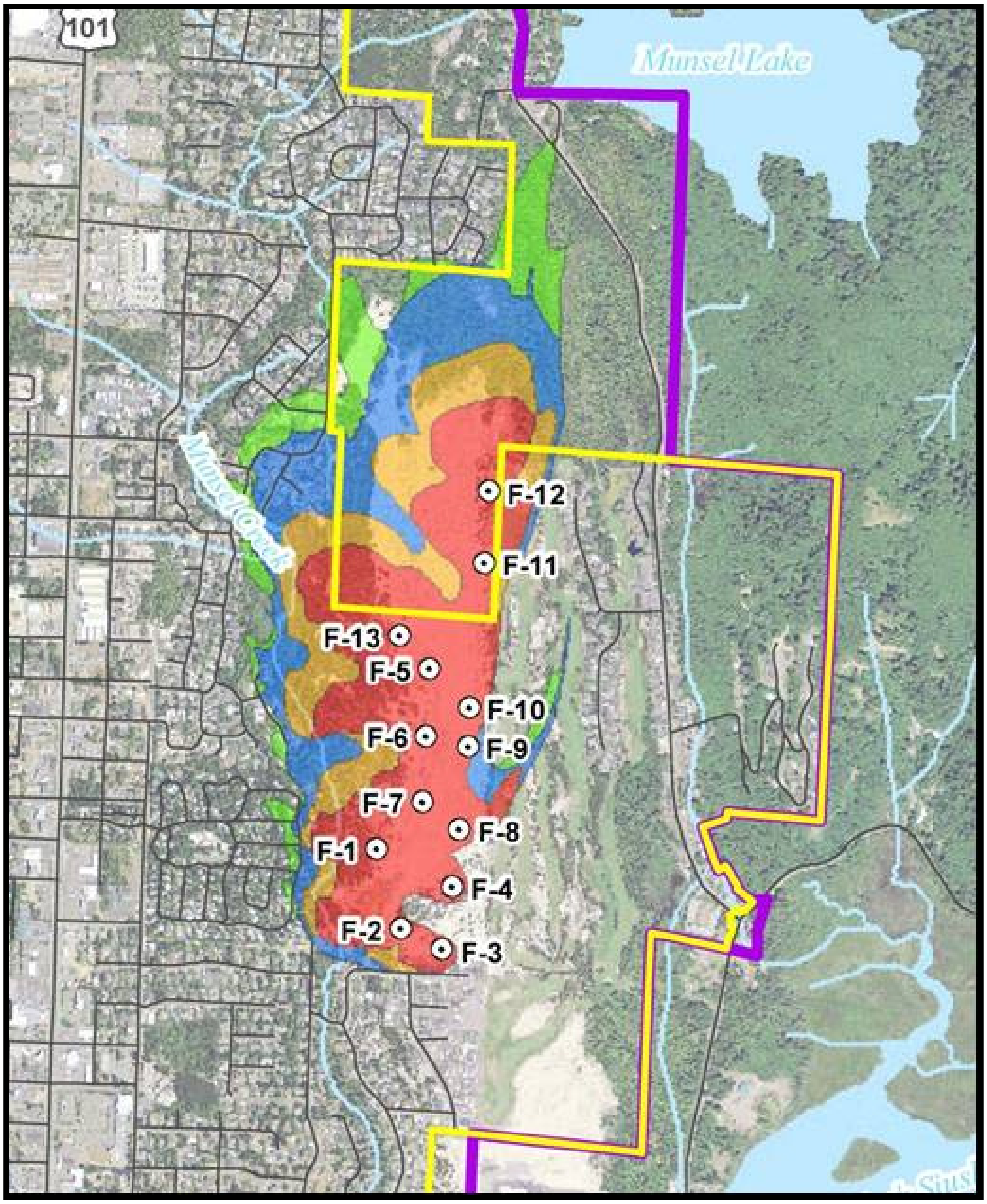


Figure 16. 10-year TOT capture zones for Florence's active wellfield. Florence wells 1 through 13 are shown. Different TOT zones indicated by shading: red = 1-yr TOT, orange = 2-yr TOT, blue = 5-yr TOT, and green = 10-yr TOT.

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