Report

DUNGENESS GROUNDWATE-R MODELING
EVALUATION OF FULL BUILDOUT
IN THE
DUNGENESS RIVER AREA

Prepared For

Department of Ecology
Shorelands and Environmental Assistance
and
Clallam County
Department of Community Development

Prepared By

TETRA TECH FW, INC.

12100 NE 195th St. Suite 200, Bothell, WA 98011

May 2004

CONTENTS

TABLES

FIGURES

DUNGENESS GROUNDWATER MODELING

EVALUATION OF FULL BUILDOUT IN THE DUNGENESS RIVER AREA

REPORT

1. INTRODUCTION

Clallam County is engaged in watershed planning for the Dungeness River, part of Watershed Resource Inventory Area 18 (WRIA 18) under the watershed planning mandate. The most important part of any watershed plan is the determination of the quantity of water present, currently used, and available for future use. As part of that analysis, Tetra Tech FW, Inc. (TtFWI) was asked to prepare and run a series of MODFLOW groundwater model applications examining the impact of full development of all available parcels in the study area on groundwater and surface water elements.

This report presents a hydrogeologic analysis through simulations of expanding well withdrawals to represent full land-use capacity (referred to hereafter as “buildout”) conducted through application of a groundwater flow model. The report does not describe the model itself, as that was presented in another report (TtFWI 2003), but does present the assumptions made for this set of model runs and summarizes the results. Results are shown for modeled impacts to groundwater and to surface water, and are followed by a brief discussion of model parameters and implications for groundwater management on the Dungeness area. Simulation results provide one tool in the process of evaluating future water demands in the Sequim-Dungeness area, both for people and for fish in the Dungeness River.

Population of the Sequim-Dungeness area has increased by approximately 250 percent in the last 20 years (USGS, 1999), and continued expansion will change the current distribution of residential and agricultural land use. This population growth has resulted in an increase in groundwater usage and an decrease in irrigation withdrawal from the Dungeness River (USGS 1999). Planning for future development requires an evaluation of potential impacts of changing land-use and water-use patterns on the groundwater flow system, the Dungeness River, its tributaries, and independent drainages in the area.

To evaluate the impact of future development on water quantity, the Washington State Department of Ecology (Ecology) and Clallam County seek an evaluation of aquifer levels, Dungeness River flow, and other stream flows. In particular, both agencies are interested in any differences shown in the model between establishing all new wells in the shallow aquifer (historic trend) and requiring the establishment of all new wells in the middle aquifer, also known as the upper confined aquifer.

2. GROUNDWATER MODEL

Tetra Tech FW, Inc. (TtFWI), formerly known as Foster Wheeler Environmental Corporation, developed a regional groundwater flow model of the Sequim-Dungeness area for use as a tool in analyzing the impacts of alternatives in the Dungeness River Water Users Association Comprehensive Water Conservation Plan (Conservation Plan; Montgomery Water Group 1999). Development of the groundwater model is presented in the *Groundwater Model Report* (TtFWI 2003). The calibrated groundwater model consists of both steady-state (time-averaged) and transient (monthly) versions, both of which are applied herein. The groundwater model was developed using the MODFLOW code and the Groundwater Vistas pre- and post-processing software. The groundwater model is referred to as the Ecology 2003 model to distinguish it from predecessors.

2.1 Assumptions for Buildout Simulations

The calibrated Ecology 2003 groundwater model represents conditions for December 1995 through September 1997. Model inputs apply aquifer stresses for that 22-month period. In order to represent the impacts to the area's hydrologic regime of increased construction, adjustments were made to the amount of impervious surfaces and therefore precipitation infiltration, to the number and location of wells, to the amount of septic recharge, and to the amount of irrigation recharge. Assumptions for modifying these aquifer stresses within the model are listed below by category.

2.2 Simulations

Two simulations were requested by the agencies to assess forecasted changes represented by the buildout: installation of all new wells in the shallow aquifer (model layer 1) and installation of all new wells in the middle aquifer (model layer 3). The following bullets list general assumptions used for implementing simulations:

- The base case assumed for these model runs is a previous model configurations (Cal24) for EIS Alternative 2, which represents fully piped or lined irrigation ditches and contains related reductions in irrigation recharge to groundwater. Additional buildout simulations applied changes to the EIS alternative 2 scenario.
- Simulations began with a steady-state run to establish time-averaged conditions.
- Separate simulations were conducted for adding all new wells to layer 1 and all new wells to layer 3 (except Sequim and Carlsborg water supply wells, as noted below).
- Results of the steady state run provided initial hydraulic heads for transient runs.
- Startup—that is, the runs needed to convert steady state heads to transient heads—for transient runs were conducted for 30 years to provide initial heads representative of transient conditions in November that lead into the transient start time of December.
- Transient runs were completed for 22 stress periods (months). Only the low-flow months of September 1996 (dry year) and September 1997 (wet year) results are presented in this report, but results for all other months are available upon request.

2.3 Buildout Wells

The Ecology 2003 model includes a total of 4,236 wells present within the model area, in all three aquifers through September 1997, which represent a total of 9,146 connections based on compiled records (wells range from 1 connection for single-family residences wells up to 638 connections for the largest public water supply well). The biggest challenge in representing the buildout is to identify the number and distribution of new wells that would be present at full development of existing zoning.

This process of well identification began with a land-use zoning map for the model area provided by Clallam County. The total number of dwellings or businesses allowed per lot was determined from the zoning map, each of which represents a “connection” to either a well or municipal water supply. Connections allowed by zoning total 31,278 within the model area. These results were overlaid in GIS with the model grid to assign the number of connections to each model cell, with connections designated as either residential or industrial for assignment of appropriate discharge rates. The total potential connections were exported to a spreadsheet with the designated model cell and the appropriate zoning designation (residential or industrial).

Establishing the number of new wells represented by buildout, when compared to existing wells in the model, was accomplished by prorating, as there is no easy mechanism to match up the existing wells with total potential wells. Subtracting the 9,146 connections represented by existing model wells from the maximum potential connections of 31,278 allowed by zoning yields a buildout increase of 22,132 connections. The increase compared to potential total yields a ratio of 0.708. Total potential connections for each model cell were multiplied by this factor to produce a prorated connection value. In so doing, buildout wells were located in the model based on the total buildout distribution.

Well discharge was assigned at either residential or industrial discharge rates. New wells from buildout were added to existing model wells and imported into the model. Elimination of wells in cells designated as No Flow (inactive) within the model grid revised to 19,020 the new connections and total model connections to 28,166. Values for new wells within the Sequim Urban Growth Area (UGA) and the Carlsborg UGA (outlines illustrated in Figure 1) were assigned to existing public water-supply wells for those areas rather than applying individual wells according to their geographical distribution. The following identifies principal assumptions for identifying buildout wells:

- Buildout assumes maximum subdivision of current zoning to calculate the greatest number of wells (or connections) likely to be required.
- The total number of new connections in the model area was determined by subtracting the existing model connections from the total potential connections. Accounting for inactive portions of the model area resulted in importing 19,020 connections along with the previous 9,146 to yield total connections at buildout of 28,166.

- New wells were assigned to model cells based on the parcel distribution and then prorated for the ratio of new wells to total potential wells (multiplier of 0.708) to account for wells already present in the model.
- Wells were identified as either residential or industrial based on zoning. "Residential" in this application also includes public water supply connections. Other categories applied previously in the model but not identified in buildout wells include: dairy, fish hatchery, crop irrigation, golf course, and stock. In other words, we assumed all new wells were either domestic or industrial.
- Industrial buildout potential was determined by flagging cells within the following zoning based on zoning summary information from the Clallam County website that described permitted or conditional potential uses to include 'limited industrial uses':
  CI - Carlsborg Industrial
  RC - Rural Commercial
  RLC - Rural Limited Commercial
  S(LM) – Sequim Light Manufacturing
  S(MU) – Sequim Mixed Use
- Rates for residential wells were assigned discharge rates of 350 gallons per day (gpd), while industrial wells were assigned 1,893 gpd (average of the two existing industrial wells in the model). Connections and total discharge rates are summarized in Table 1.
- Transient well discharge rates were varied for new residential and industrial wells in the same manner as existing model wells.
- New wells outside of the Sequim UGA and Carlsborg UGA were imported into the model at their parcel location and located in either layer 1 or layer 3, depending on the simulation. Wells that overlap with other model boundary conditions in layer 1 (drains and streams) were shifted to adjacent cells.
- New connections within the Sequim UGA were summed and assigned to the City of Sequim Port Williams wellfield in layer 5, regardless of simulation. The additional extraction of 1,123 gallons per minute (gpm) requires all of the identified sustained yield for City Wells #1 and #2, such that full development growth likely would require installation of a new well.
- New connections within the Carlsborg UGA were summed and assigned to the PUD's Carlsborg LUD#10 in layer 3, regardless of simulation. The additional extraction of 326 gpm requires all of the identified sustained yield for this well, such that full development growth likely would require installation of a new well.

Figure 1 illustrates the pumping rates by model cell for steady-state conditions. As noted, buildout connections within the Sequim and Carlsborg UGAs are consolidated into existing public water supply wells. Areas of greatest increase in well withdrawal are the Highway 101 corridor and the northern coast near Dungeness Bay, whereas mountainous areas show little increase. The additional well discharge from buildout totals 1,082,117 ft^3/day (or 5,612 gpm; 12.5 cfs), with rates within the UGAs indicated above.

2.4 Impervious Surfaces

Development of small lots or large structures will result in a greater density of impervious surfaces that will reduce recharge from infiltration of precipitation. It is assumed for buildout modeling that the entire area of each UGA will experience reduced infiltration. The Deep Percolation Model (DPM) applied by the USGS for calculating infiltration by precipitation (Thomas et al., 1999) used a 30 percent reduction for DPM cells in the Sequim area to account for decreased infiltration in the urbanized city. However, the specific model cells are not identified in the data set received, and so a reasonable approximation for the Sequim UGA was arrived at by subtracting the current city limits from the UGA boundary to identify all model cells in between these two limits. Precipitation infiltration for the entire Carlsborg UGA was reduced by 30 percent. The following assumptions were applied to represent reduced recharge from impervious surfaces:

- UGAs for Sequim and Carlsborg are selected to represent reduced recharge.
- The USGS DPM (Thomas et al., 1999) input a 30 percent reduction in recharge for the City of Sequim for 40 cells in their model. There is no indication of the location for these 40 cells.
- Reduction of 30 percent for precipitation recharge is input for the Sequim UGA for model cells in which more than 50 percent of the model cell lies within the area between the UGA boundary and the current city limit.
- Precipitation recharge reduction of 30 percent is input for the Carlsborg UGA for model cells in which more than 50 percent of cell lies within the UGA boundary.
- Precipitation infiltration for all other areas remains unaltered.

2.5 Septic Systems and Well Return

Wells within the model area associated with septic systems are modeled to generate recharge to the shallow aquifer at a rate that is 70 percent of well discharge. This has been applied in the model as “well return.” Wells associated with sewered areas are assumed to generate no recharge. It was assumed that Carlsborg would install sewers to achieve full buildout, although none currently exist. The following assumptions are applied to buildout wells for calculating well return:

- All new connections within the two UGAs are assumed to be treated by sewer systems that discharge to surface water. Therefore, these new connections have 0 percent return. Because Sequim currently irrigates land with treated sewage in vicinity of upper Bell Creek and Carlsborg might implement similar practice, this assumption underestimates well returns for UGAs. If successful at returning 50 percent of well discharge via land irrigation, the underestimation would be 108,131 ft^3/day for Sequim UGA and 31,387 ft^3/day for Carlsborg UGA for steady-state conditions.

- All new connections outside of the UGAs are assumed to have septic systems with the associated return rate to layer 1 of 70 percent. The resultant recharge from buildout septic returns is 666,888 ft^3/day for steady-state conditions.

2.6 Modifications to Irrigation

As development occurs, a reduction in farming is expected to some degree. No estimate is available for this reduction, so a reduction of 10 percent was selected for the simulations. The following assumptions are applied for irrigation reduction:

- Infiltration recharge due to irrigation will be reduced by 10 percent across the model to reflect reductions in farmed area. Under steady-state conditions, this represents a reduction of 742,604 ft^3/day. This reduces the daily irrigation infiltration rate of 7,426,041 ft^3/day under Alternative 2 to 6,663,437 ft^3/day.
- No changes were made to Dungeness River diversions within the numerical model. Reduction of irrigation diversions by 10 percent were accounted for in the reporting of river flows in the post-processing after the model runs.

3. IMPACTS TO GROUNDWATER

3.1 Pumping from the Shallow Aquifer

Impacts on the shallow aquifer (layer 1) from adding all exempt wells to layer 1 show similar patterns in the steady state and both September (low-flow) transient runs. The time-averaged (steady state) run shows maximum drawdown below the levels of Alternative 2 of 6 feet southeast of Sequim and about 4.5 feet west of Carlsborg just west of McDonald Creek (Figure 2a). The transient runs for September show the same pattern, but with maximum drawdowns of –7.5 feet in 1996 on both sides of the river and –6 feet west of Carlsborg, -7.5 feet southeast of Sequim, in 1997 (wetter year).

The impact of wet or dry precipitation year (1996 vs. 1997) is minimal compared to the impact of the expected proliferation of exempt wells. The differences between steady state and transient runs lies in the extent, not location, of drawdown. Finally, the influences of maximum pumping from both the Port Williams and the Carlsborg municipal wells from the deeper aquifers can be detected by location of drawdown even in the shallow aquifer on both steady state and transient runs.

Impacts on the middle aquifer (Figure 2b for steady state, Figure 4b for transient September 1996, and Figure 5b for transient September 1997) differ somewhat in pattern from the impacts modeled for the shallow aquifer, though the pattern is similar among steady state and the transient runs. Extent of impact shows a maximum of 9 feet drawdown below levels calculated for EIS Alternative 2 in steady state, with maximum drawdowns of 11 feet in a dry year (September 1996, Figure 4b) and 10.5 feet in a wet year (September 1997, Figure 5b).

All runs show an impact on the middle aquifer from increased pumping from the deep aquifer (layer 5) from the Port Williams and Carlsborg UGA well withdrawals, with the “bullseye” drawdown impacts more noticeable in the Carlsborg well area. The Carlsborg well is 177 feet deep (in the middle aquifer), while the Port Williams wells are 284 and 411 feet deep (in the deep aquifer).

The deep aquifer (layer 5) shows concentrated impacts from maximum pumping from the Carlsborg and Port Williams wells, with related impacts upgradient (south) of the well fields and relatively minor additional drawdowns north of the wells. Figure 2c, illustrating time-averaged (steady-state) conditions, shows a maximum drawdown of 9.5 feet in the vicinity of the Port Williams wells, with a secondary “bullseye” southeast of Sequim with a maximum 6-foot drawdown.

Drawdowns in the Carlsborg vicinity are less, showing only 3.5 feet west of Carlsborg and no large yearly influence of the Carlsborg well. However, the transient runs show that the deep aquifer in the vicinity of the Carlsborg well is sharply decreased, with a maximum withdrawal of 9 feet in both 1996 and 1997. The patterns of drawdown are nearly identical for runs modeling 1996 and 1997, with higher drawdowns being somewhat more widespread in the drier year but the maximum withdrawals the same as for a wetter year.

3.2 Pumping from the Middle aquifer

The impacts to the three aquifers from adding all new exempt wells to the middle aquifer are shown in Figures 3a, 3b, and 3c for the steady state model, in Figures 6a, 6b, and 6c for the transient model, September 1996, and in Figures 7a, 7b, and 7c for the transient model, September 1997. The pattern of impact of additional pumping from the middle aquifer on the shallow aquifer is very similar to the pattern seen in Figures 2a, 4a, and 5a and discussed in the previous section. This is understandable because there is no solid, continuous layer 2 aquitard but rather discontinuous impermeable lenses between layers 1 and 3. Impacts are more contained, less spread over the area, but show the same maxima of 4.5 feet drawdown west of Carlsborg and 6 feet drawdown southeast of Sequim, whether pumping occurs in the shallow or middle aquifer. (Compare figures 2a and 3a) The transient model runs also show very close similarities between pumping from the shallow and the middle aquifers. We see nearly identical drawdowns in Figures 4a and 6a, indicating that the modeled late-season aquifer response to pumping is indifferent to locating exempt wells in the intermediate or the shallow aquifer.

Impacts from additional pumping from the middle aquifer on the middle aquifer itself are shown in Figure 3b (steady state) and Figures 6b and 7b (transient, September 1996 and September 1997, respectively). The pattern of drawdown differs from that shown for the same layer when pumping from the shallow aquifer, though a strong “bullseye” is still apparent around the Carlsborg well. This pattern shows more concentrated drawdowns at the edge of the model (northwest corner and southeast corner), and more localized intense drawdowns where exempt wells are concentrated. Patterns differ between the steady state and transient model runs with the steady state showing maximum drawdown values of 18 feet near the mouth of Morse Creek to the west and 10 feet near the mouth of Johnson Creek to the east. Transient patterns are similar, with maximum drawdowns 2 or 3 feet deeper during the driest months in each modeled year. Both the steady state and the transient models show intense (localized) drawdowns in these areas and in several other areas along Highway 101, including the vicinity of the Carlsborg well, the Solmar development, and a localized concentration just west of Siebert Creek.

Impacts on the deep aquifer (layer 5) are concentrated also at the mouths of Morse and Johnson Creek and in a series of localized impacts along Highway 101 in addition to the 10 foot to 12 foot drawdown in the vicinity of the Port Williams wellfield. Across the northern part of the area (north of Sequim), drawdown is around a foot greater September of both 1996 and 1997 as compared to the steady state.

4. IMPACTS TO SURFACE WATER

4.1 Small Independent Streams and Tributaries

Modeled impacts of full buildout on the smaller streams of the area are summarized in Tables 3, 4, and 5 and in Figure 8. These data show that the creeks with the largest change in flow attributable to full buildout are in the lower watershed. Flow in Matriotti Creek, tributary to the Dungeness and draining only the lowlands, is reduced by 46 percent over the flow modeled for fully-lined ditches for shallow aquifer wells. Cassalary Creek, an independent creek emptying to the Strait of Juan de Fuca and also draining only lowlands, shows flow reductions of 23 percent for shallow aquifer buildout over those modeled for fully lined ditches. Another lowland creek, Gieren Creek, shows a flow reduction of 18 percent if buildout wells were all located in the shallow aquifer.

Model results for assigning all new wells to the middle aquifer are not substantially different, although there is consistently less loss of flow. For the lowland-draining creeks, the improvement in placing wells lower ranges from 3 percent for Gieren to 6 percent for Cassalary to 8 percent for Matriotti.

These buildout-related stream flow reductions are in addition to those modeled for EIS Alternative 2, fully lined ditches. If compared to the 1997 existing conditions (Table 3c), decreases in stream flow from all shallow aquifer well construction range from small (1 percent, Morse Creek) to substantial (40 percent, Gieren Creek, 27 percent attributable to lining ditches) to very large (68 percent, Matriotti Creek, 41 percent attributable to lining ditches).

In general, the streams whose headwaters are outside the modeled buildout area (i.e., Morse, Bagley, Siebert, McDonald, and Johnson) show much smaller flow decreases even though there may be substantial buildout modeled in the lower parts of their watersheds. The transient modeling shows similar impacts. Table 4 shows the same patterns of impact, though with larger magnitudes during critical low-flow periods. Matriotti Creek modeled flow is reduced by 63 percent over EIS Alternative 2 flows during dry year low-flow periods, while Morse Creek shows only a 1 percent reduction and Siebert a 2 percent reduction. The larger, higher-watershed creeks are not as responsive to wet or dry years, whereas the lower-watershed creeks show up to a 9 percent difference in flow response between drier (September 1996) and wetter (September 1997) years.

4.2 Dungeness River

Like the creeks with headwaters above the modeled buildout area, the Dungeness shows a relatively low percent of change from EIS Alternative 2 conditions. Unlike the smaller creeks, however, low-flow volumes in the Dungeness are critical to the survival of ESA-listed salmonids. The modeled loss of 3.9 cfs in the lowest reach of the river upon full buildout in the shallow aquifer is very important in terms of fish habitat. The Dungeness River is sensitive to wet and dry year differences in flow, showing up to a 1 cfs difference in buildout impact, but not very sensitive to differences between well placement in the shallow or middle aquifers, showing only 0 to 0.4 cfs maximum differences.

5. DISCUSSION

Full buildout, defined as fully subdividing and constructing a residence or a business on every parcel technically available under current zoning, has an important impact on the whole groundwater system as well as on streams and the Dungeness River. In these model runs, we assumed that buildout within the UGAs of Sequim and Carlsborg would be assigned to their existing wells, and that all other new construction would rely on one exempt well per unit. This implied an addition of 14,708 wells to the 4,236 wells assumed for the conditions existing in 1997.

Even though they seem extreme, these assumptions do not represent the legal maximum that could be withdrawn from all the exempt wells modeled. Domestic wells were modeled at 350 gallons per day withdrawal rather than the legal maximum of 5,000 gallons per day. The model does assume that 3.8 percent of the wells would pump at 1,893 gallons per day average ("industrial" wells) but even that rate is less than half of that allowed for an exempt well and is applied to a small percentage of all wells outside the UGAs.

The near- and medium-term future for new development is unlikely to approach such extremes. Population change in Clallam County recently has been about 0.5 percent per year (average over 2000 to 2003, census estimates). The growth rate is substantially higher in the unincorporated areas, reaching 0.8 percent per year. This maximum buildout scenario would add more than 28,000 new constructions or families to the water system; at the current rate of growth of around 300 people per year (75 families), many years would pass before this modeled water use is approximated. This estimate would change if growth resumed its rapid climb reminiscent of the 1980s.

However, this model allows us to examine the boundary conditions of growth in the Dungeness area and the consequences of continued groundwater withdrawals to support the development that growth implies. The Dungeness River is already below critical flows at times during very dry years, and all the factors, including groundwater use, need to be examined and considered if the Dungeness River is to be restored to functioning habitat. In addition, flows in small streams need to be examined and considered for maintenance where possible.

6. REFERENCES

Montgomery Water Group. 1999. Dungeness River Water Users Association Comprehensive Water Conservation Plan. Prepared for the Washington State Department of Ecology.

Tetra Tech FW, Inc. (TtFWI). 2003 Groundwater Model Report. Dungeness Water Users Association Comprehensive Water Conservation Plan. June.

Thomas, B.E., L.A. Goodman, and T.D. Olsen. 1999. Hydrogeologic Assessment of the Sequim-Dungeness Area, Clallam County, Washington. U.S. Geological Survey Water Resources Investigation Report 99-4048. Prepared in cooperation with Clallam County Department of Community Development and Washington State Department of Ecology. 162 p.

TABLES

DUNGENESS GROUNDWATER MODELING
EVALUATION OF FULL BUILDOUT
IN THE
DUNGENESS RIVER AREA

May 2004

Dungeness Groundwater Modeling

Table 1. Residential and Industrial Well Contribution to Modeled Buildout Discharge Rates

	Well Connections	**Discharge (ft^3/day)**	**Discharge (gpm)**	**Discharge (cfs)**
All Wells:				
Existing Model Wells	9,146.0	-676,693	-3,515.0	-7.8
New Buildout Wells	19,019.9	-1,082,117	-5,621.0	-12.5
Total Model Wells	28,165.9	-1,758,810	-9,136.0	-20.4
Residential Wells in Buildout (each 46.8 ft^3/day or 350 gallons/day):				
Other Areas	14,151.7	-662,297	-3,440.3	-7.7
Sequim UGA	3,467.9	-162,298	-843.0	-1.9
Carlsborg UGA	469.7	-21,981	-114.2	-0.3
Total New Residential	18,089.2	-846,576	-4,397.5	-9.8
Industrial Wells in Buildout (each 253 ft^3/day or 1893 gallons/day):				
Other Areas	556.2	-140,783	-731.3	-1.6
Sequim UGA	213.2	-53,965	-280.3	-0.6
Carlsborg UGA	161.2	-40,793	-211.9	-0.5
Total New Industrial	930.6	-235,541	-1,223.5	-2.7

Dungeness Groundwater Modeling

Table 2. Water Balances in Steady-State Simulations (cfs)

	Flow In	**Flow Out**	**Balance**	**Difference with Alt 2**	
	(cfs)	(cfs)	(cfs)	(cfs)	(percent)
EIS Alternative 2					
Wells	0.0	7.8	-7.8	--	--
Constant Heads	63.8	6.7	57.0	--	--
Drains--Offshore Discharge	0.0	161.7	-161.7	--	--
Drains--Streams	0.0	17.7	-17.7	--	--
Stream (Dungeness River)	38.8	18.1	20.7	--	--
Recharge--Precipitation	93.8	0.0	93.8	--	--
Recharge--Irrigation	9.8	0.0	9.8	--	--
Recharge--Well Return	5.9	0.0	5.9	--	--
Total	212.1	212.1	0.0	--	--
2514 Buildout: Shallow Aquifer Wells					
Wells	0.0	20.4	-20.4	-12.5	260%
Constant Heads	63.9	6.7	57.1	0.1	100%
Drains--Offshore Discharge	0.0	155.5	-155.5	6.2	96%
Drains--Streams	0.0	15.4	-15.4	2.3	87%
Stream (Dungeness River)	41.2	17.7	23.5	2.8	114%
Recharge--Precipitation	93.0	0.0	93.0	-0.7	99%
Recharge--Irrigation	8.8	0.0	8.8	-1.0	90%
Recharge--Well Return	8.8	0.0	8.8	2.8	147%
Total	215.6	215.6	0.0	0.0	
2514 Buildout: Intermediate Aquifer Wells					
Wells	0.0	20.4	-20.4	-12.5	260%
Constant Heads	63.9	6.7	57.1	0.1	100%
Drains--Offshore Discharge	0.0	154.7	-154.7	7.0	96%
Drains--Streams	0.0	15.9	-15.9	1.8	90%
Stream (Dungeness River)	41.0	17.8	23.2	2.5	112%
Recharge--Precipitation	93.0	0.0	93.0	-0.7	99%
Recharge--Irrigation	8.8	0.0	8.8	-1.0	90%
Recharge--Well Return	8.8	0.0	8.8	2.8	147%
Total	215.4	215.4	0.0	0.0	

Note: a positive balance indicates flow into the model, while a negative balance indicates flow out.

Table 3. Changes In Independent Streams and Tributaries from Full Buildout, Steady State Conditions

Table 3a. Drain Values for Stream Discharge, cfs

Creek	Model Drain Reach	1997 Existing Conditions	EIS Alternative 2	All New Wells in Shallow Aquifer	All New Wells in Intermediate Aquifer
Matriotti	2	3.28	1.93	1.04	1.20
Bagley	3	2.70	2.69	2.55	2.60
McDonald	4	2.30	2.23	2.18	2.18
Morse	5	1.60	1.60	1.59	1.59
Cassalery	6	3.55	2.82	2.17	2.34
Bell	7	2.35	2.03	1.67	1.73
Gierin	8	0.84	0.61	0.50	0.52
Johnson	9	0.60	0.60	0.59	0.59
Siebert	10	3.20	3.17	3.12	3.12
Total		20.41	17.67	15.40	15.87

Table 3b. Percent Change in Stream Flow Compared to EIS Alternative 2

		All New Wells in Shallow Aquifer	All New Wells in Intermediate Aquifer
Matriotti	2	-46%	-38%
Bagley	3	-5%	-3%
McDonald	4	-2%	-2%
Morse	5	-1%	-1%
Cassalery	6	-23%	-17%
Bell	7	-17%	-15%
Gierin	8	-18%	-15%
Johnson	9	-2%	-2%
Siebert	10	-1%	-1%

Table 3c. Percent Change in Stream Flow Compared to 1997 Existing Conditions

		EIS Alternative 2	All New Wells in Shallow Aquifer	All New Wells in Intermediate Aquifer
Matriotti	2	-41%	-68%	-63%
Bagley	3	0%	-6%	-4%
McDonald	4	-3%	-5%	-5%
Morse	5	0%	-1%	-1%
Cassalery	6	-21%	-39%	-34%
Bell	7	-14%	-29%	-26%
Gierin	8	-27%	-40%	-37%
Johnson	9	0%	-2%	-2%
Siebert	10	-1%	-2%	-2%

Table 4 Changes in Groundwater Discharge to Streams from Modeled Buildout, Transient Conditions

Table 4a: Change in Groundwater Discharge to Streams, Buildout in Shallow Aquifer

Creek	Reach	Sep-96		Sep-97	
		cfs	%	cfs	%
Matriotti	2	-1.53	63%	-1.18	54%
Bagley	3	-0.15	6%	-0.15	5%
McDonald	4	-0.10	4%	-0.08	4%
Morse	5	-0.01	1%	-0.01	1%
Cassalery	6	-0.97	33%	-0.75	27%
Bell	7	-0.47	22%	-0.44	21%
Gierin	8	-0.23	32%	-0.19	28%
Johnson	9	-0.01	2%	-0.01	2%
Siebert	10	-0.07	2%	-0.06	2%
Total		-3.54		-2.87	

Table 4b: Change in Groundwater Discharge to Streams, Buildout in Intermediate Aquifer

Creek	Reach	Sep-96		Sep-97	
		cfs	%	cfs	%
Matriotti	2	-1.37	57%	-1.03	47%
Bagley	3	-0.10	4%	-0.10	4%
McDonald	4	-0.09	4%	-0.08	3%
Morse	5	-0.01	1%	-0.01	1%
Cassalery	6	-0.80	27%	-0.56	20%
Bell	7	-0.41	19%	-0.37	18%
Gierin	8	-0.21	29%	-0.17	24%
Johnson	9	-0.01	2%	-0.01	2%
Siebert	10	-0.07	2%	-0.06	2%
Total		-3.07		-2.40	

Dungeness Groundwater Modeling

Table 5. Changes in Dungeness River Flow From Modeled Buildout, Transient Conditions

Reach	**EIS Alternative 2**		**Buildout in Shallow Aquifer**		**Buildout in Intermediate Aquifer**	
	Sep-96	**Sep-97**	**Sep-96**	**Sep-97**	**Sep-96**	**Sep-97**
River Flow (cfs)						
5	173.56	297.14	172.28	296.18	172.27	296.18
4	168.31	290.64	164.51	287.82	164.66	287.97
3	166.75	288.95	163.09	286.31	163.27	286.49
2	177.52	297.10	173.83	294.45	174.02	294.65
1	177.89	297.06	173.95	294.20	174.29	294.55
Decrease in River Flow (cfs)						
5			-1.3	-1.0	-1.3	-1.0
4			-3.8	-2.8	-3.7	-2.7
3			-3.7	-2.6	-3.5	-2.5
2			-3.7	-2.7	-3.5	-2.5
1			-3.9	-2.9	-3.6	-2.5
Decrease in River Flow (% of EIS Alt. 2 flows)						
5			-1%	0%	-1%	0%
4			-2%	-1%	-2%	-1%
3			-2%	-1%	-2%	-1%
2			-2%	-1%	-2%	-1%
1			-2%	-1%	-2%	-1%

Note: Reaches are defined for fisheries instream flow analysis:

1 - River Mile 0 to 1.8
2 - River Mile 1.8 to 2.5
3 - River Mile 2.5 to 3.3
4 - River Mile 3.3 to 6.4
5 - River Mile 6.4 to 11.2

FIGURES

DUNGENESS GROUNDWATER MODELING EVALUATION OF FULL BUILDOUT IN THE DUNGENESS RIVER AREA

May 2004

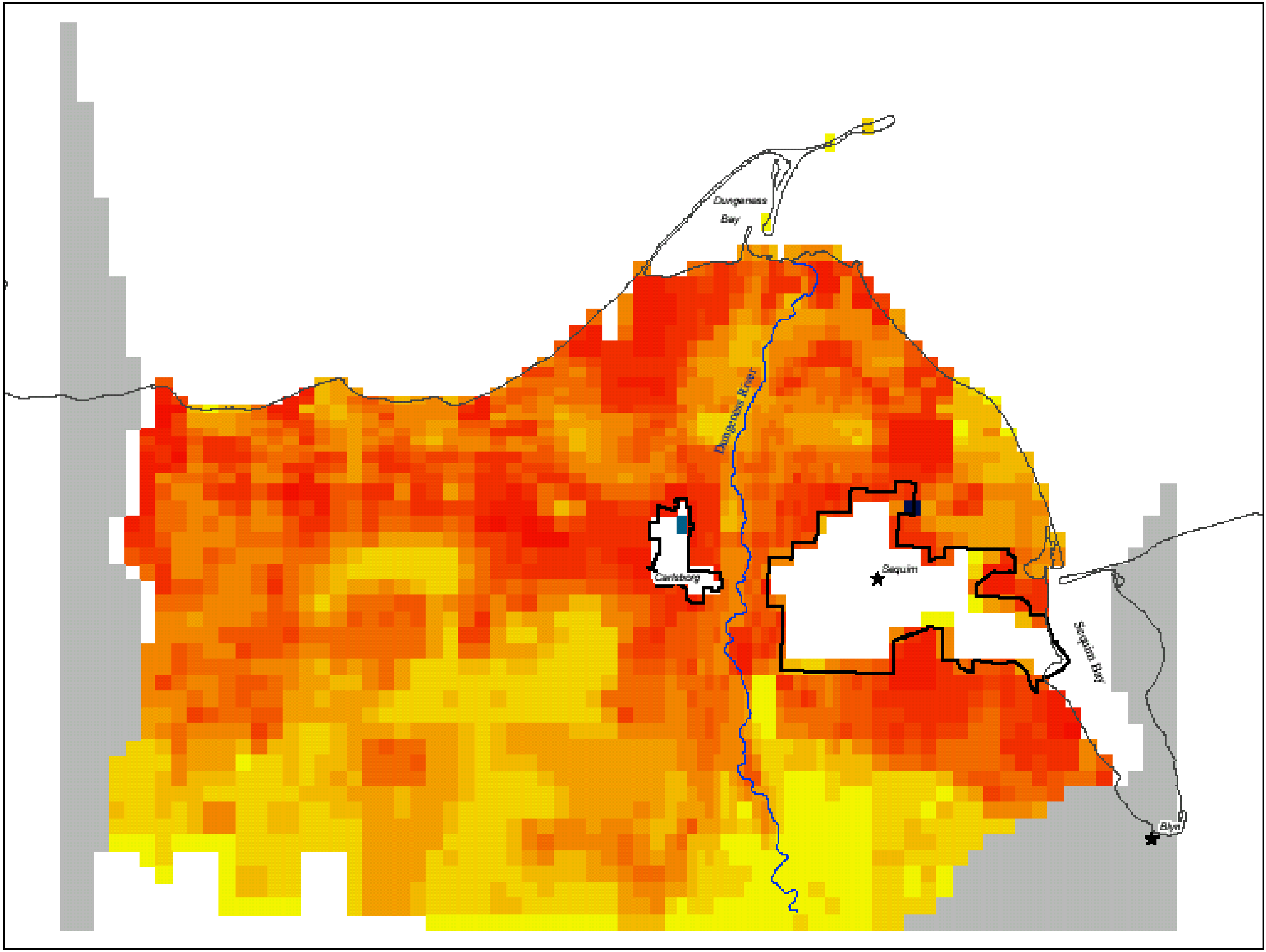


Figure 1
Modeled Steady-State Well Pumping Distribution for Maximum Buildout of Current Zoning

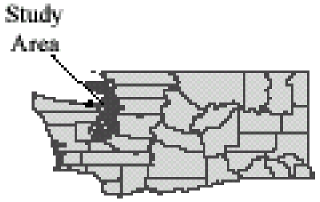
Legend

- ★ City
- ☐ Shore Line
- — Dungeness River
- ▭ Urban Growth Area
- ▨ No Flow Cells

Discharge Rate (ft^3/day)

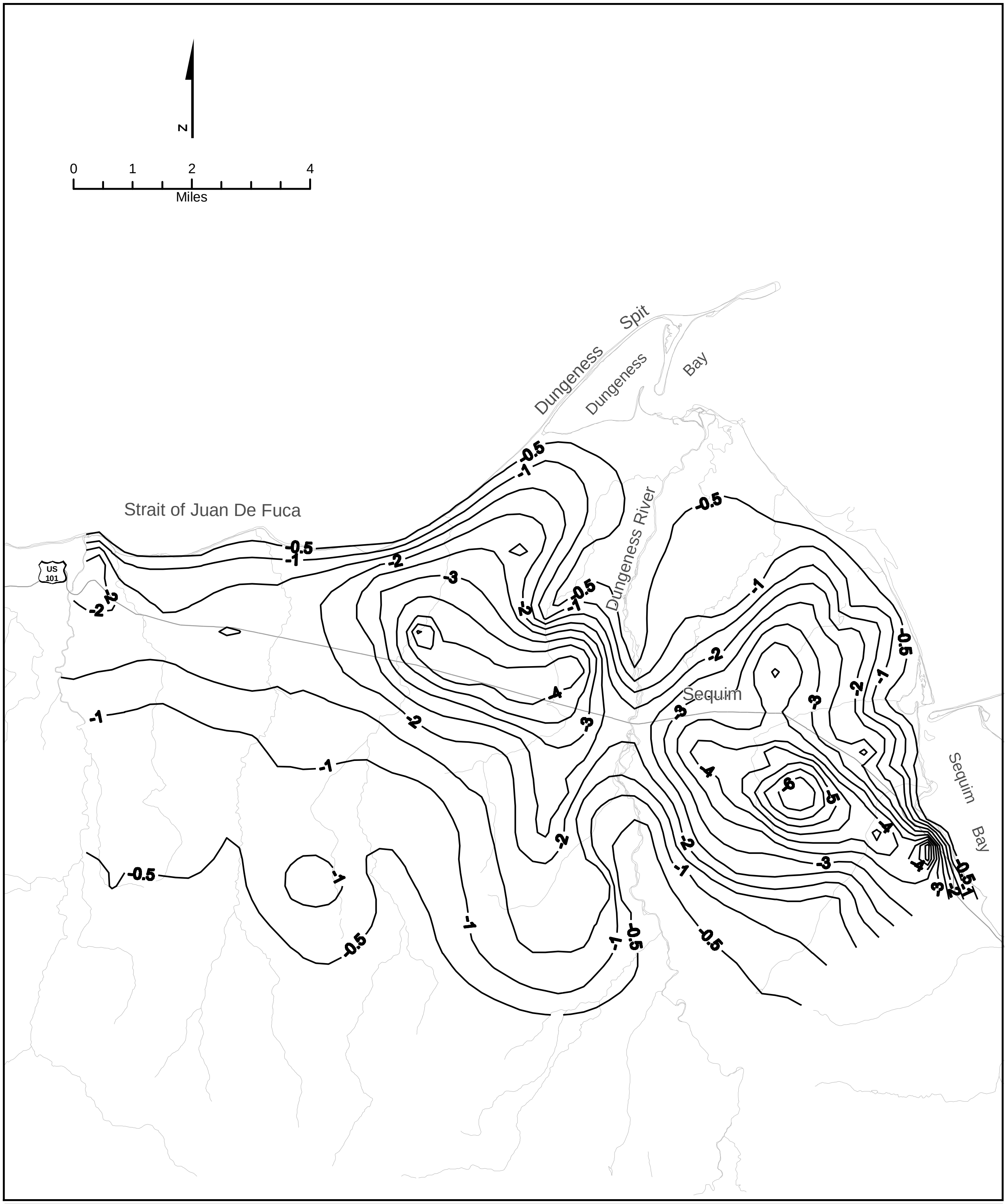
- 🟨 0 - 10
- 🟨 10 - 20
- 🟨 20 - 50
- 🟧 50 - 100
- 🟧 100 - 200
- 🟧 200 - 300
- 🟧 300 - 400
- 🟥 400 - 500
- 🟥 500 - 1000
- 🟥 1000 - 5000
- 🟥 5000 - 10500
- 🟦 62774
- 🟦 218488

Location Map



TETRA TECH FW, INC.

[illegible] Date: July 18, 2003



Map Features

Streams

Highway 101

Difference in head (ft)

Location Map

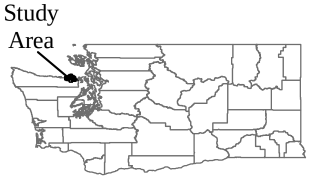
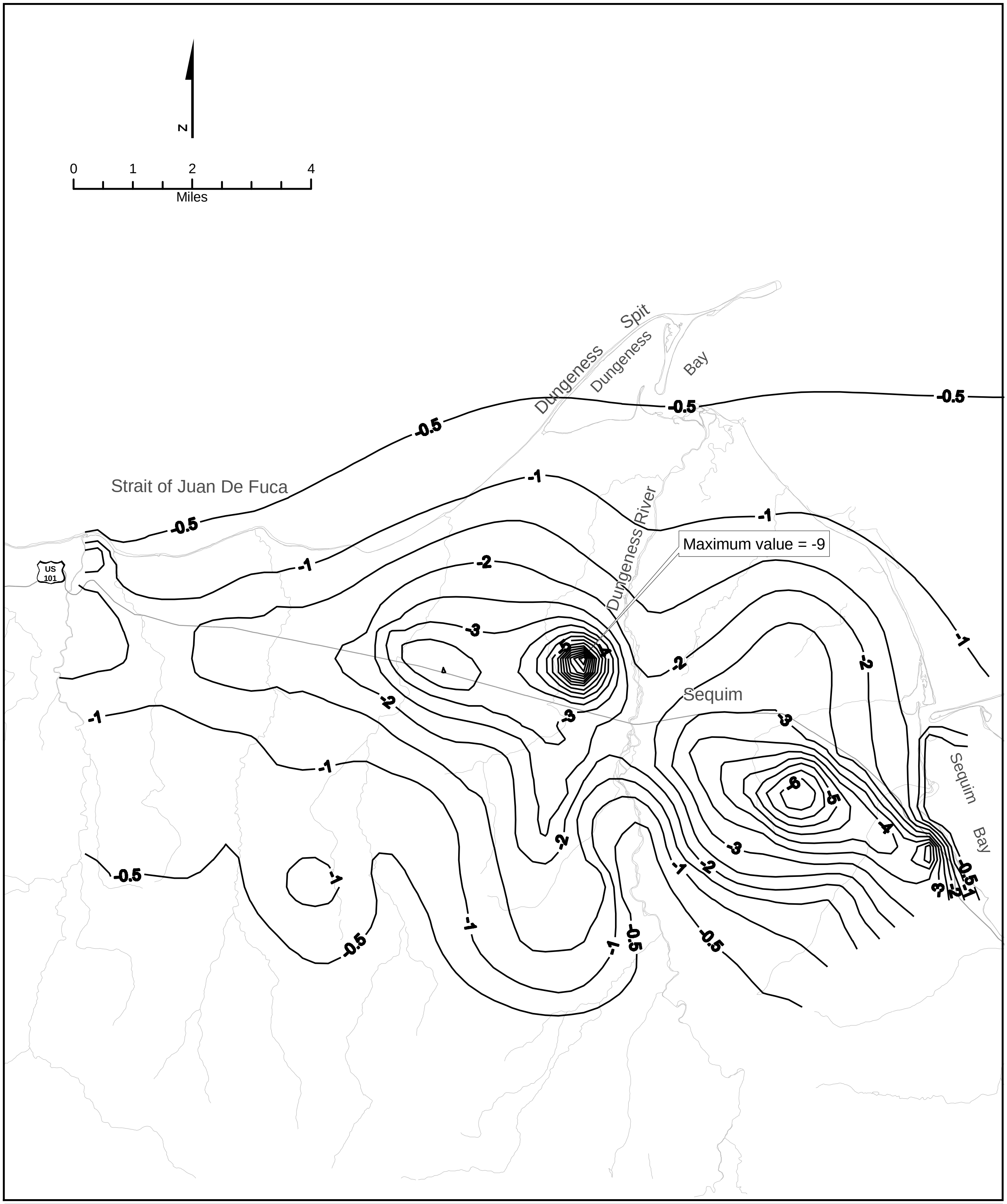


Figure 2a
2514 Buildout In Shallow Aquifer
Model Layer 1 Steady-State Differences
With EIS Alternative 2

TETRA TECH FW, INC.

Footnote: Negative values indicate that computed heads are lower in this simulation than for same layer in simulation of EIS Alternative 2.

Q:\projects_2002\dungeness\workdir\maps\tom_july_2003\fig2a_2514buildout_layer1_alt2.mxd Date: July 18, 2003



Map Features

Streams

Highway 101

Difference in head (ft)

Location Map

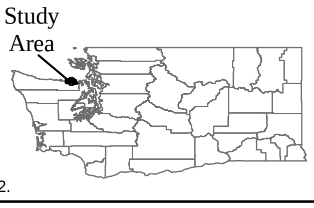
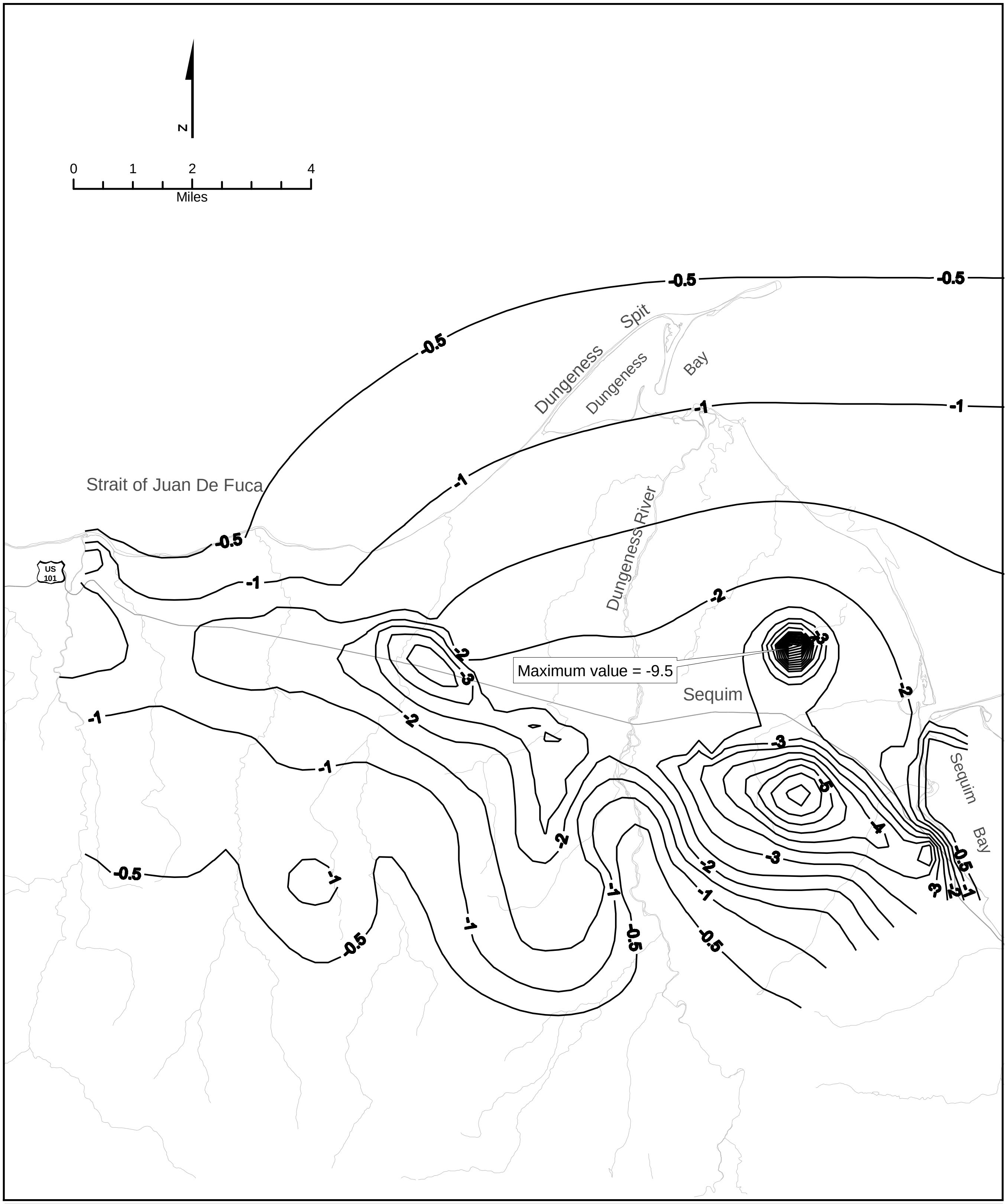


Figure 2b
2514 Buildout In Shallow Aquifer
Model Layer 3 Steady-State Differences
With EIS Alternative 2

TETRA TECH FW, INC.

Footnote: Negative values indicate that computed heads are lower in this simulation than for same layer in simulation of EIS Alternative 2.

Q:\projects_2002\dungeness\workdir\maps\tom_july_2003\fig2b_2514buildout_layer3_alt2.mxd Date: July 18, 2003



Map Features

Streams

Highway 101

Difference in head (ft)

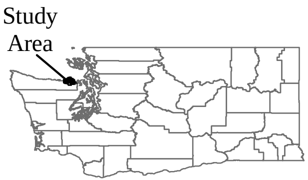
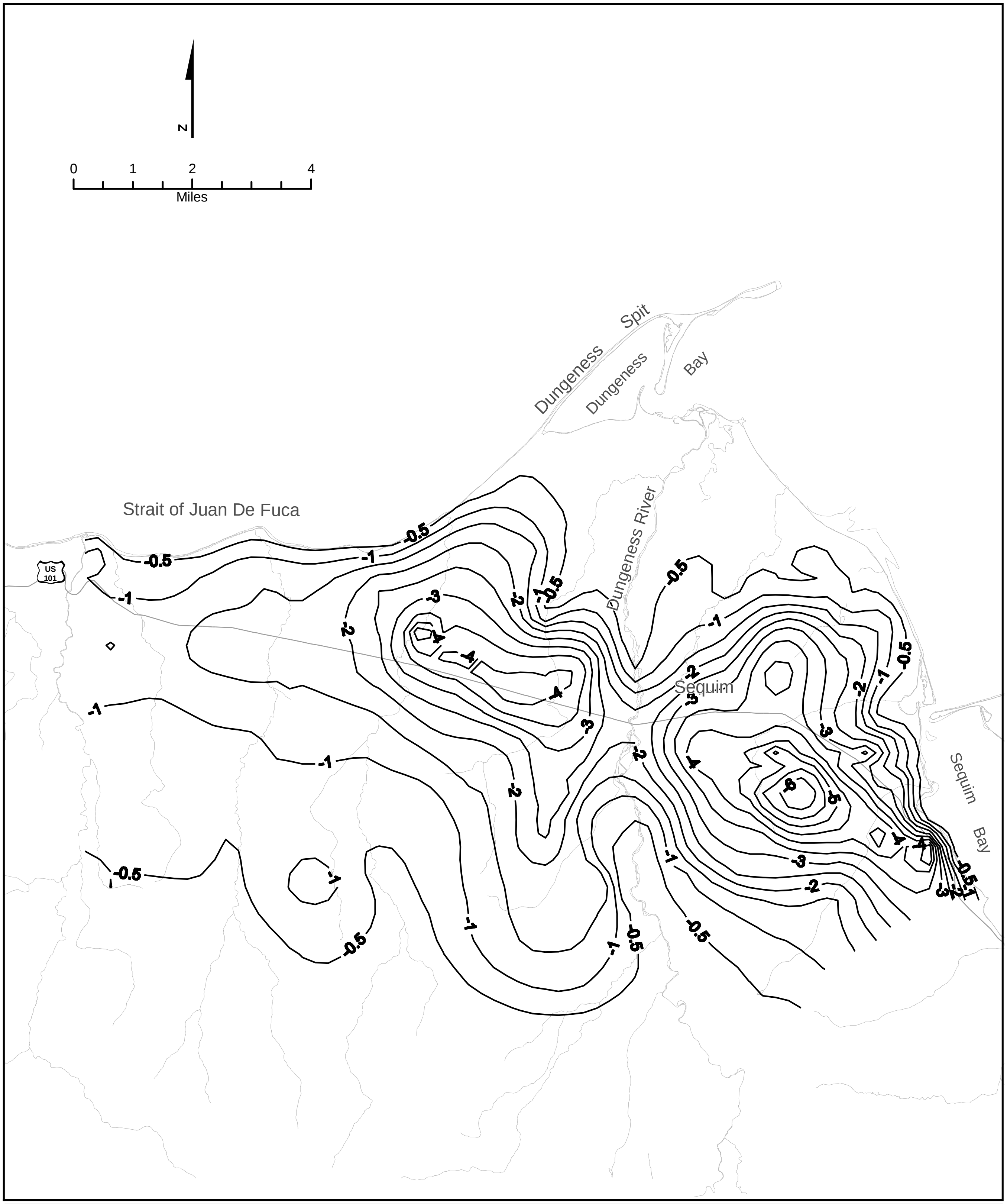


Figure 2c
2514 Buildout In Shallow Aquifer
Model Layer 5 Steady-State Differences
With EIS Alternative 2

TETRA TECH FW, INC.

Footnote: Negative values indicate that computed heads are lower in this simulation than for same layer in simulation of EIS Alternative 2.

Q:\projects_2002\dungeness\workdir\maps\tom_july_2003\fig2c_2514buildout_layer5_alt2.mxd Date: July 18, 2003



Map Features

Streams

Highway 101

Difference in head (ft)

Location Map

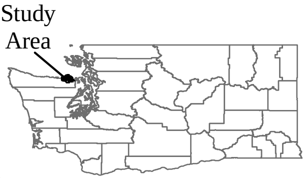
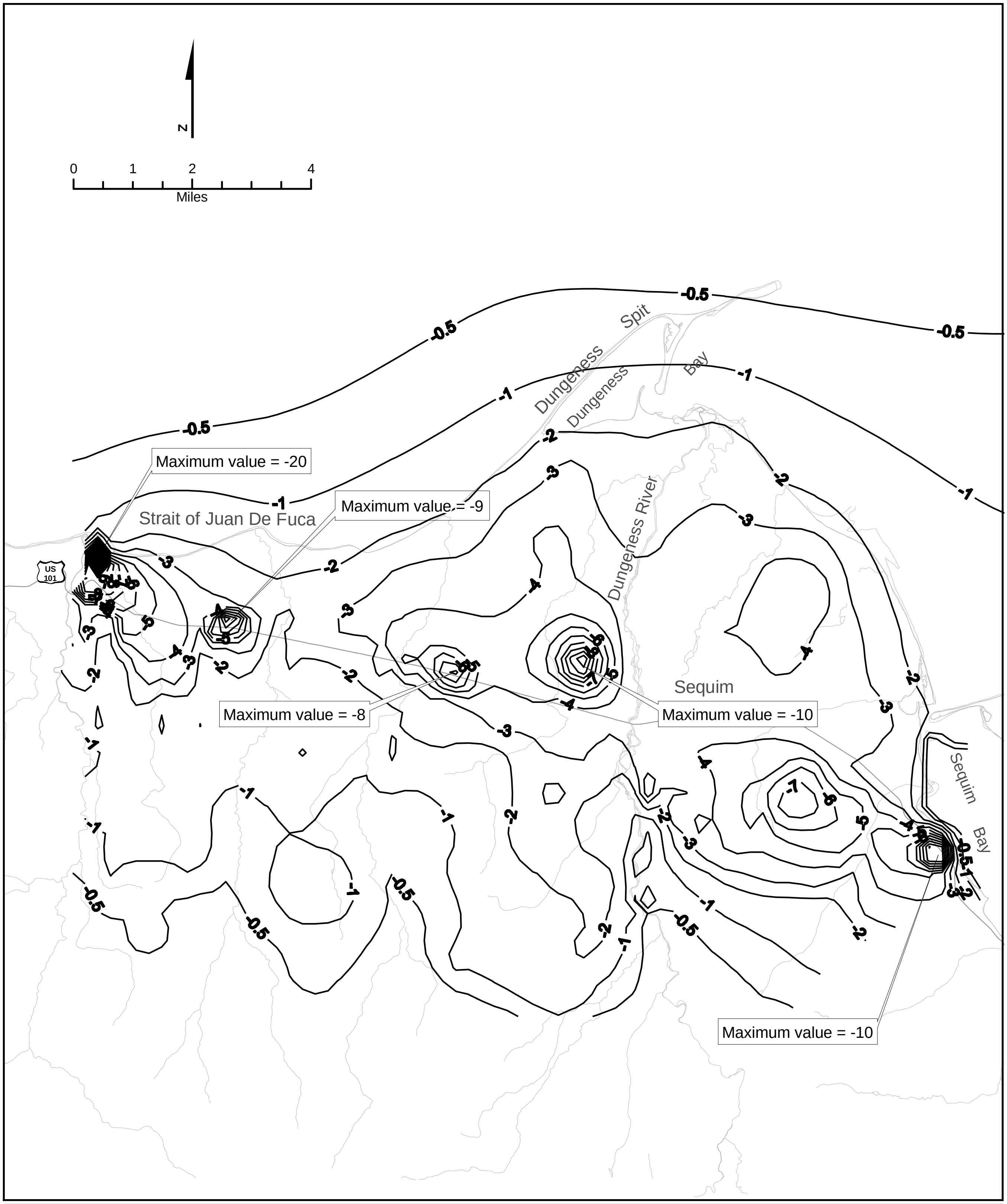


Figure 3a
2514 Buildout In Middle Aquifer
Model Layer 1 Steady-State Differences
With EIS Alternative 2

TETRA TECH FW, INC.

Footnote: Negative values indicate that computed heads are lower in this simulation than for same layer in simulation of EIS Alternative 2.

Q:\projects_2002\dungeness\workdir\maps\tom_july_2003\fig3a_2514buildout_intermed_layer1_alt2.mxd Date: July 18, 2003



Map Features

—	Streams
—	Highway 101
—	Difference in head (ft)

Location Map

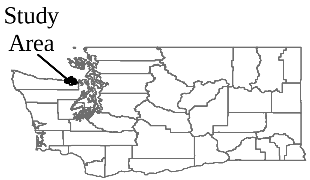
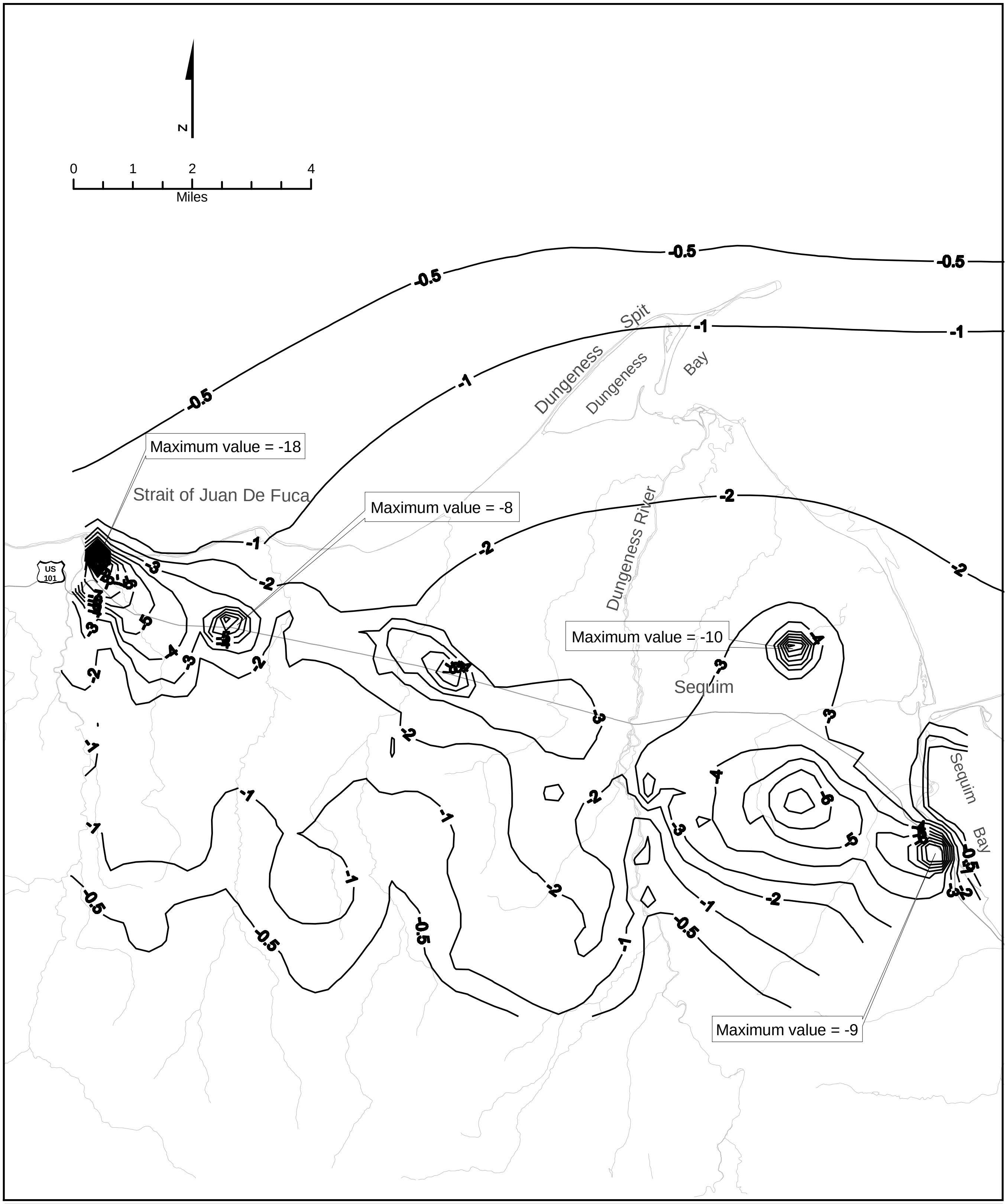


Figure 3b
2514 Buildout In Middle Aquifer
Model Layer 3 Steady-State Differences
With EIS Alternative 2

TETRA TECH FW, INC.

Footnote: Negative values indicate that computed heads are lower in this simulation than for same layer in simulation of EIS Alternative 2.

Q:\projects_2002\dungeness\workdir\maps\tom_july_2003\fig3b_2514buildout_intermed_layer3_alt2.mxd Date: July 18, 2003



Map Features

Streams

Highway 101

Difference in head (ft)

Footnote: Negative values indicate that computed heads are lower in this simulation than for same layer in simulation of EIS Alternative 2.

Location Map

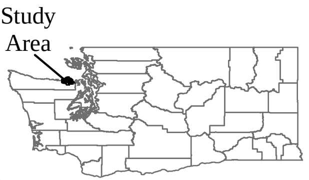
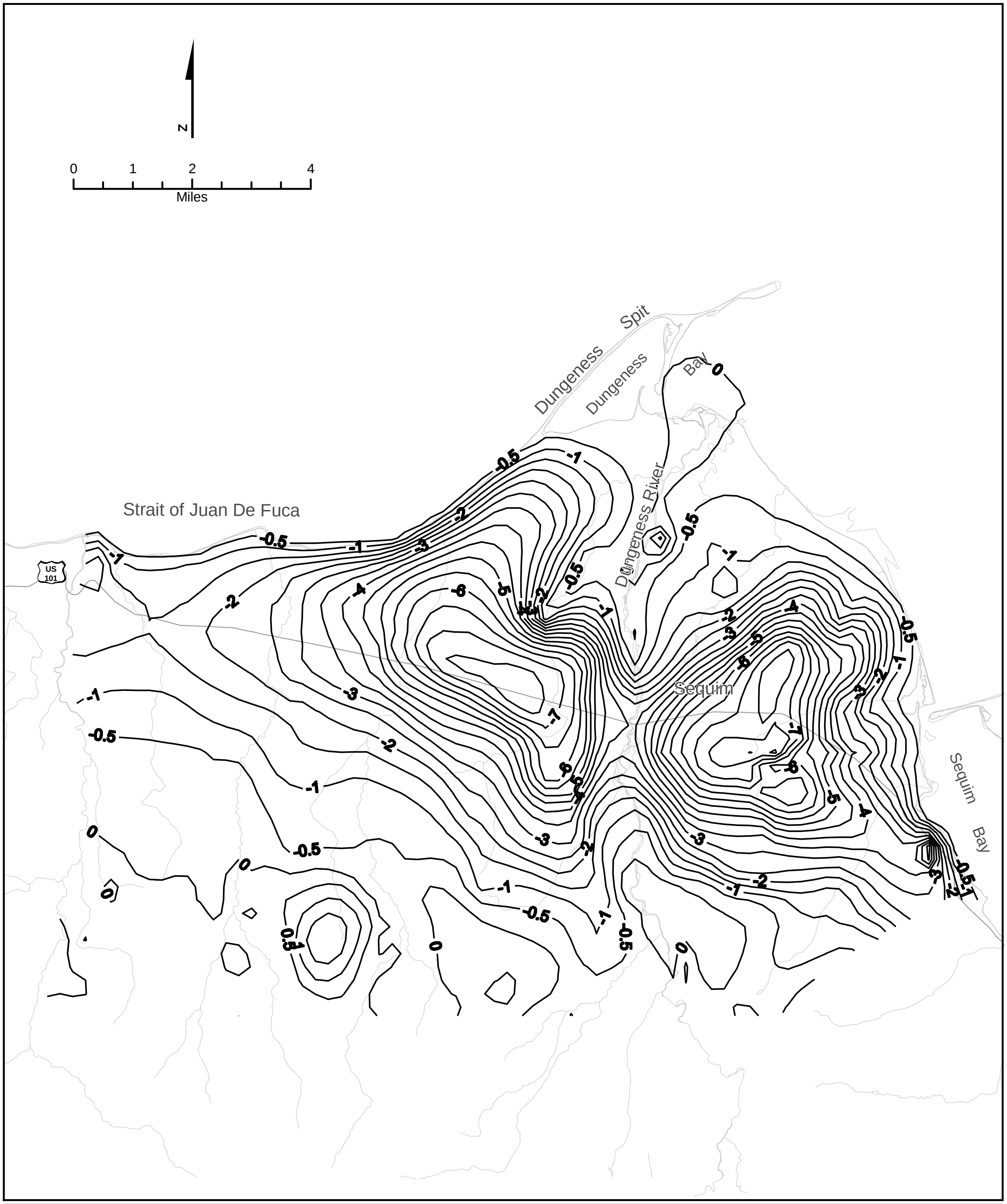


Figure 3c
2514 Buildout In Middle Aquifer
Model Layer 5 Steady-State Differences
With EIS Alternative 2

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\tom_july_2003\fig3c_2514buildout_intermed_layer5_alt2.mxd Date: July 18, 2003



Map Features

Streams

Highway 101

Difference in head (ft)

Location Map

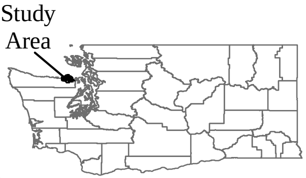
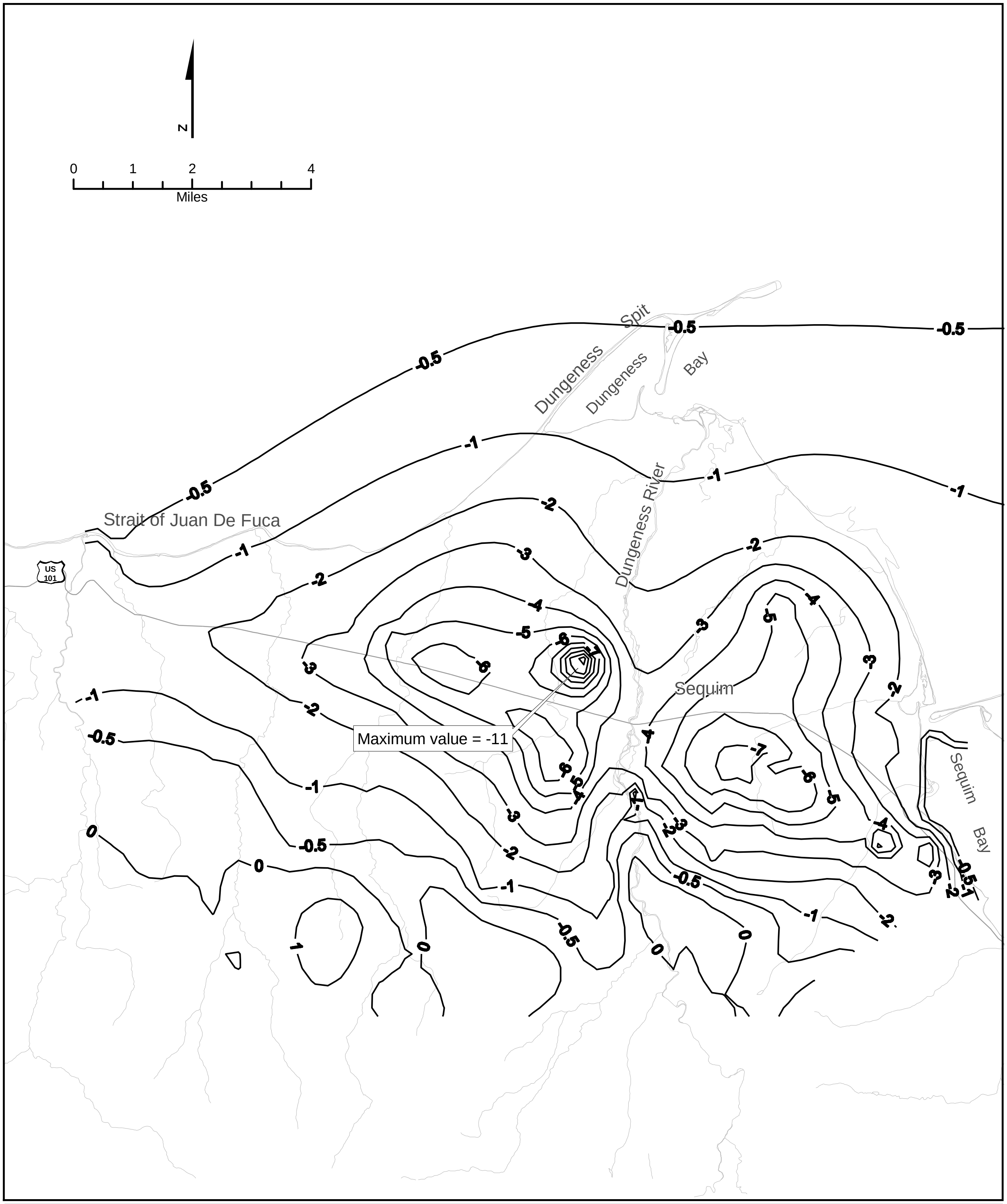


Figure 4a
2514 Buildout In Shallow Aquifer
Model Layer 1 Transient Differences
With EIS Alternative 2
for September 1996

TETRA TECH FW, INC.

Footnote: Negative values indicate that computed heads are lower in this simulation than for same layer in simulation of EIS Alternative 2.

Q:\projects_2002\dungeness\workdir\maps\tom_july_2003\fig4a_2514buildout_shallow_layer1_alt2.mxd Date: July 29, 2003



Map Features

Location Map

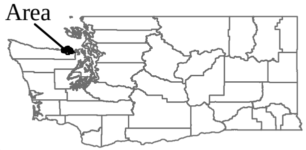
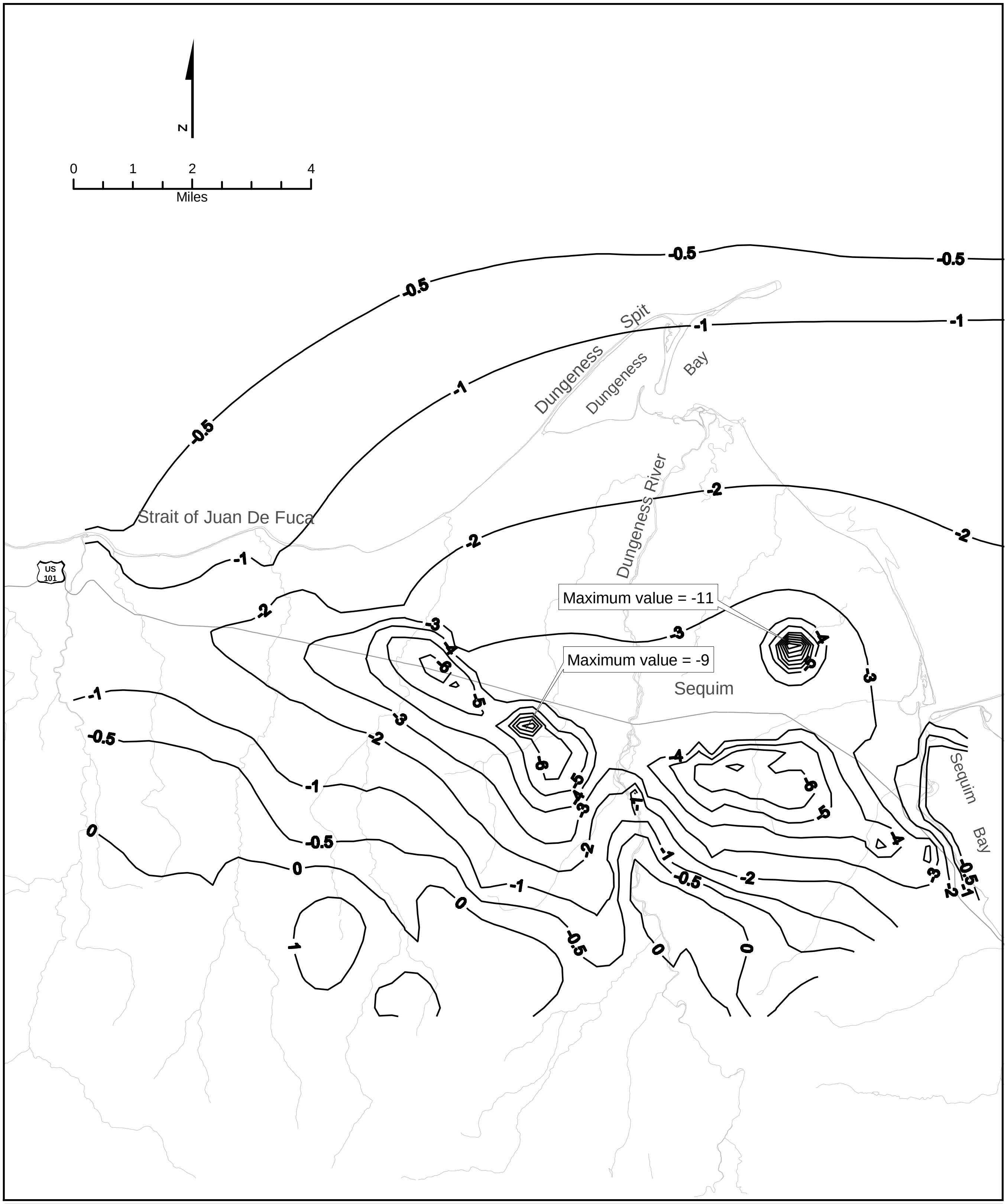


Figure 4b
2514 Buildout In Shallow Aquifer
Model Layer 3 Transient Differences
With EIS Alternative 2
for September 1996

TETRA TECH FW, INC.

Footnote: Negative values indicate that computed heads are lower in this simulation than for same layer in simulation of EIS Alternative 2.

Q:\projects_2002\dungeness\workdir\maps\tom_july_2003\fig4b_2514buildout_shallow_layer3_alt2.mxd Date: July 29, 2003



Map Features

—	Streams
—	Highway 101
—	Difference in head (ft)

Location Map

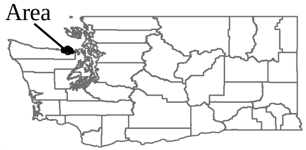
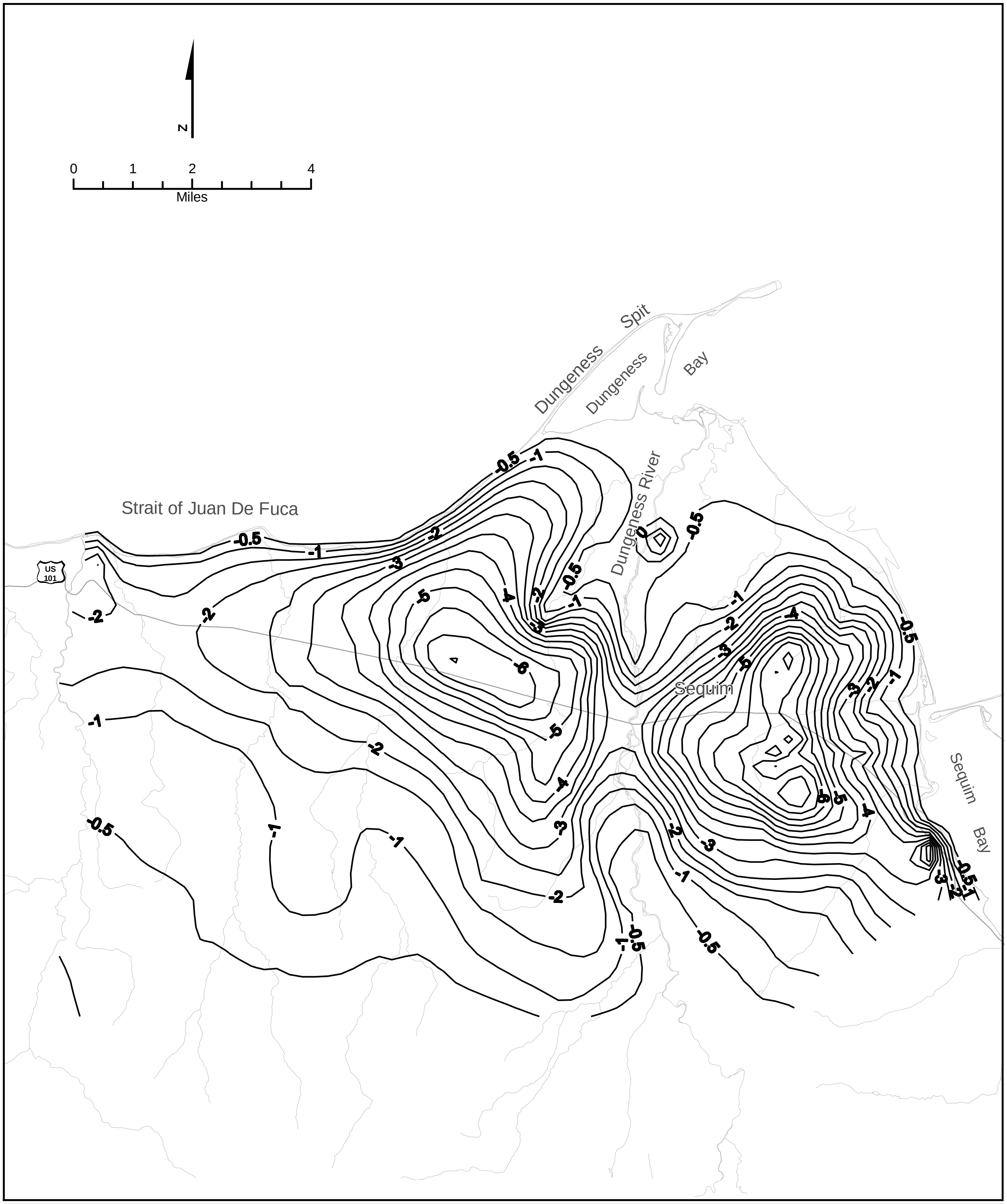


Figure 4c
2514 Buildout In Shallow Aquifer
Model Layer 5 Transient Differences
With EIS Alternative 2
for September 1996

TETRA TECH FW, INC.

Footnote: Negative values indicate that computed heads are lower in this simulation than for same layer in simulation of EIS Alternative 2.

Q:\projects_2002\dungeness\workdir\maps\tom_july_2003\fig4c_2514buildout_shallow_layer5_alt2.mxd Date: July 29, 2003



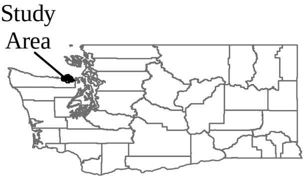
Map Features

Streams

Highway 101

Difference in head (ft)

Location Map

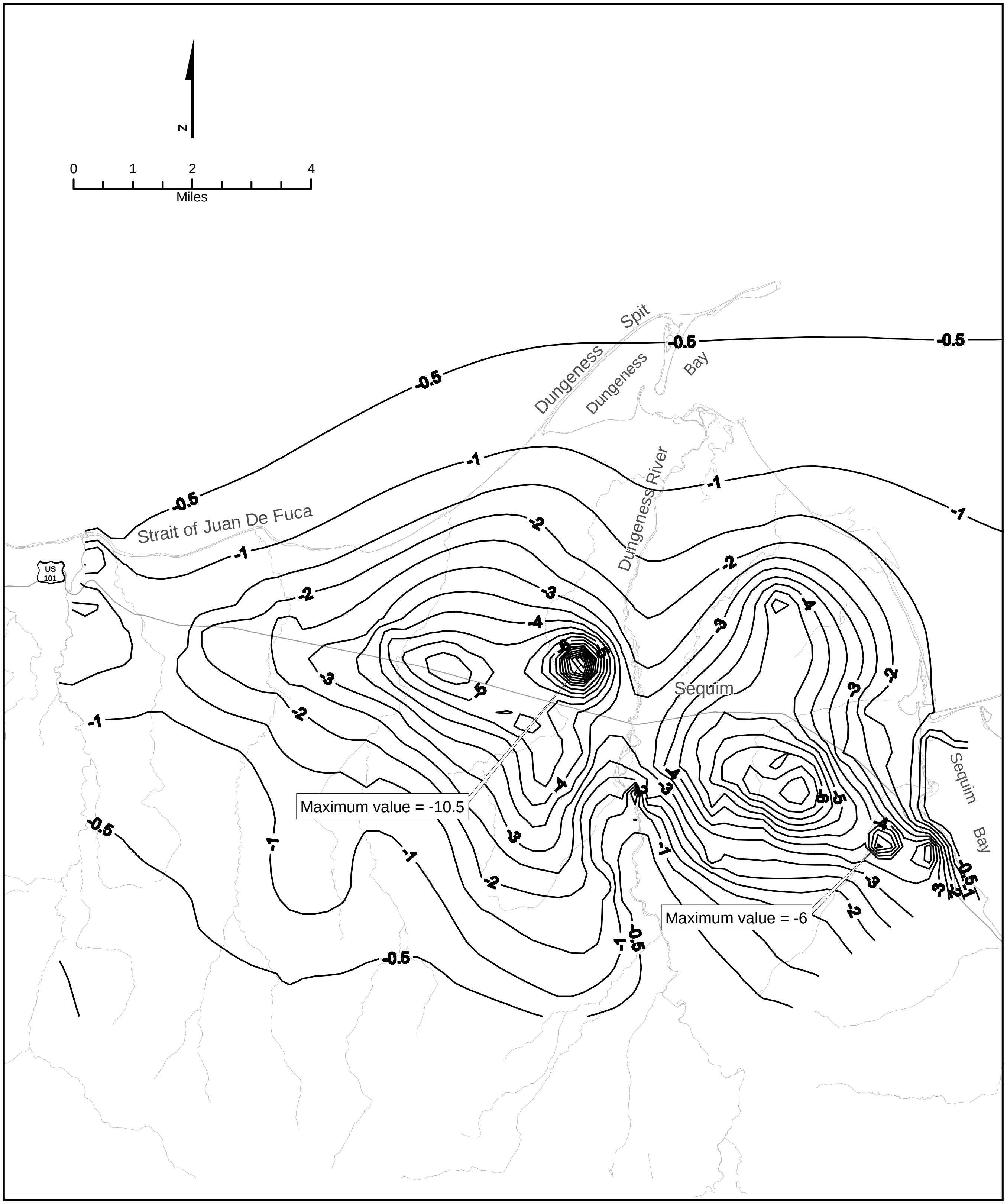


Footnote: Negative values indicate that computed heads are lower in this simulation than for same layer in simulation of EIS Alternative 2.

Figure 5a
2514 Buildout In Shallow Aquifer Model Layer 1 Transient Differences With EIS Alternative 2 for September 1997

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\tom_july_2003\fig5a_2514buildout_shallow_layer1_alt2.mxd Date: July 29, 2003



Maximum value = -10.5

Maximum value = -6

Map Features

─	Streams
─	Highway 101
━	Difference in head (ft)

Footnote: Negative values indicate that computed heads are lower in this simulation than for same layer in simulation of EIS Alternative 2.

Location Map

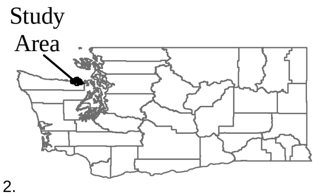
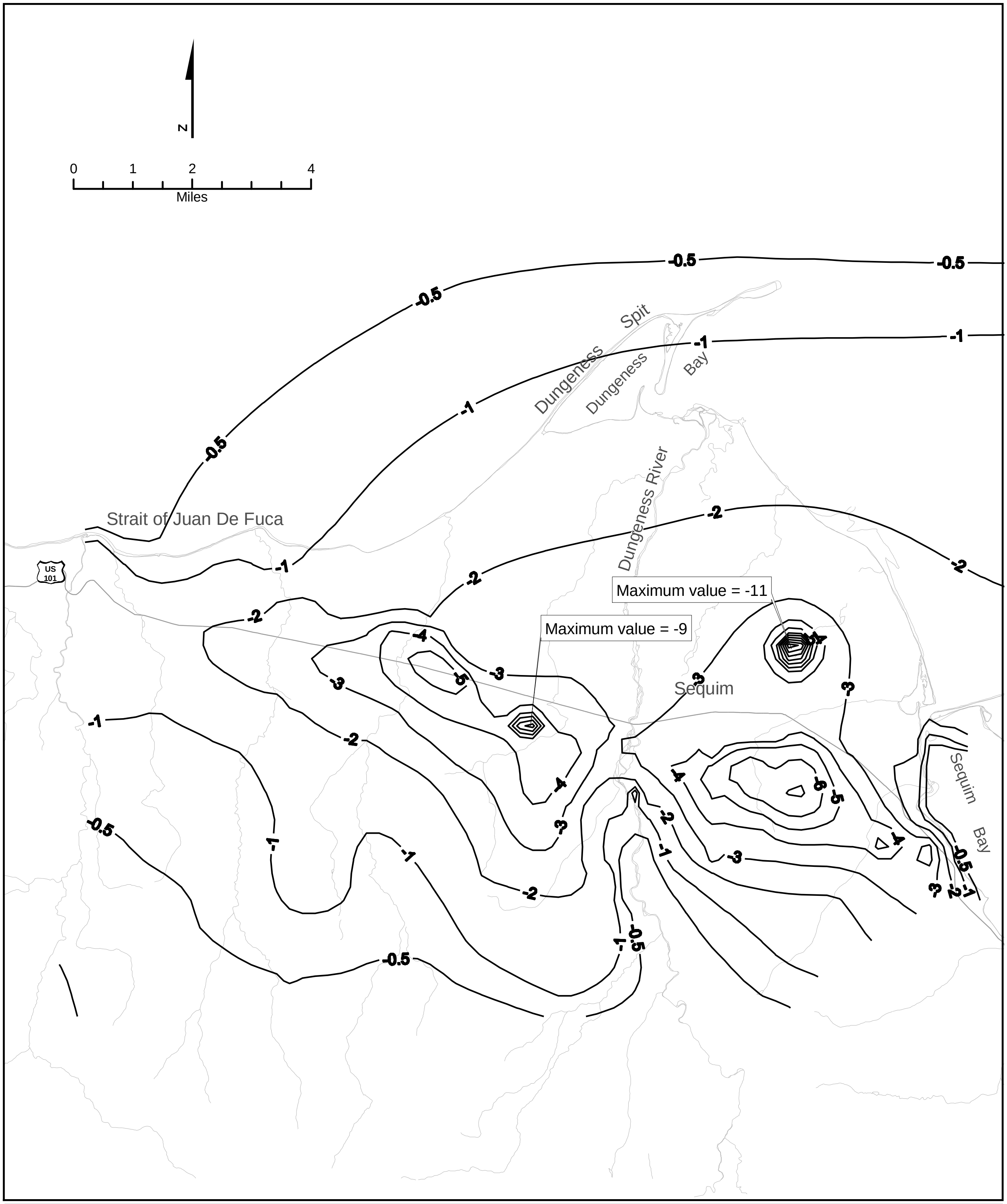


Figure 5b
2514 Buildout In Shallow Aquifer Model Layer 3 Transient Differences With EIS Alternative 2 for September 1997

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\tom_july_2003\fig5b_2514buildout_shallow_layer3_alt2.mxd Date: July 29, 2003



Maximum value = -11

Maximum value = -9

Map Features

- Streams
- Highway 101
- Difference in head (ft)

Footnote: Negative values indicate that computed heads are lower in this simulation than for same layer in simulation of EIS Alternative 2.

Location Map

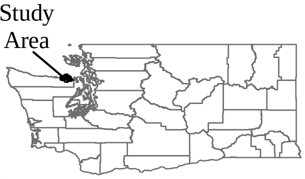
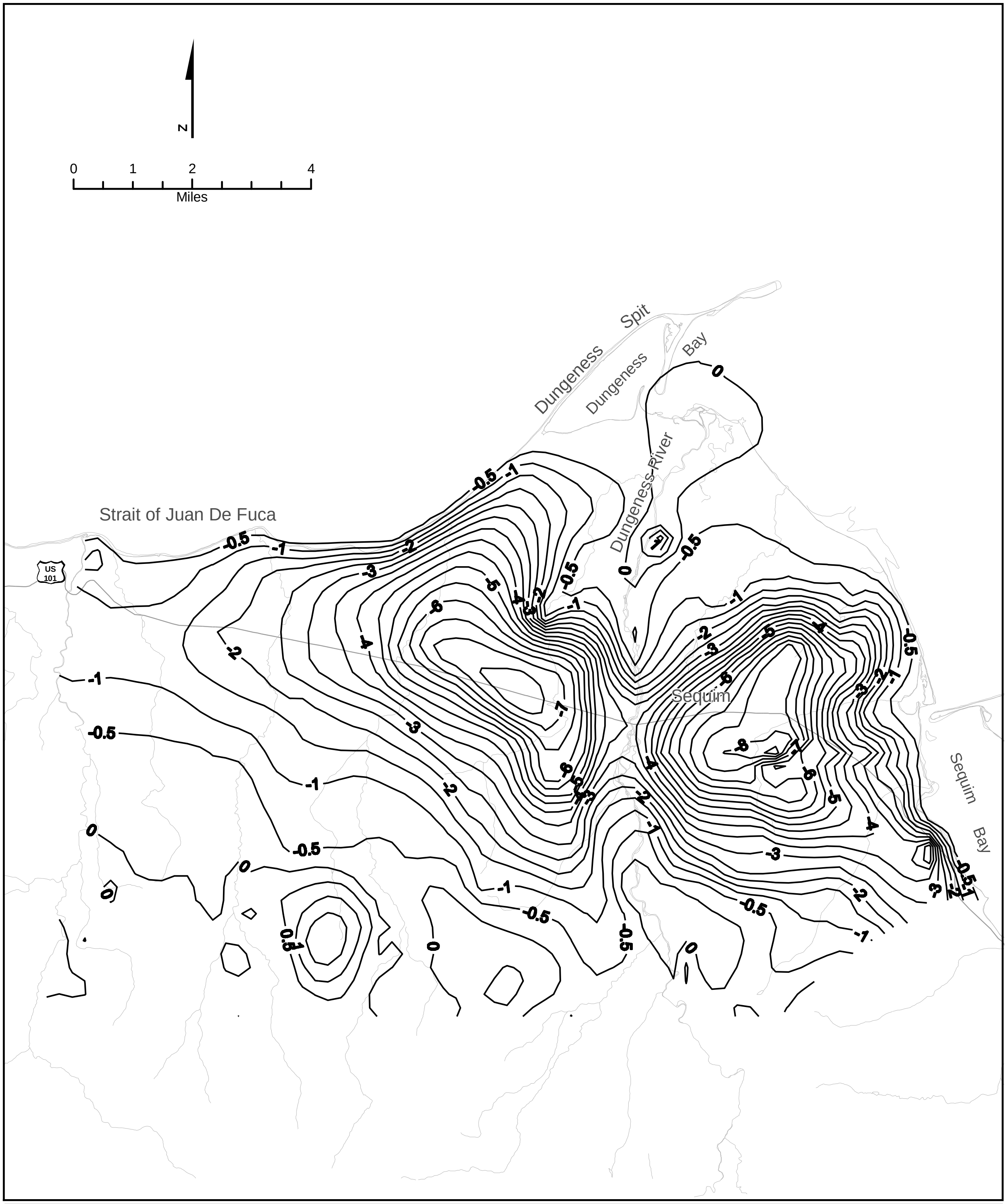


Figure 5c
2514 Buildout In Shallow Aquifer
Model Layer 5 Transient Differences
With EIS Alternative 2
for September 1997

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\tom_july_2003\fig5c_2514buildout_shallow_layer5_alt2.mxd Date: July 29, 2003



Map Features

───	Streams
───	Highway 101
───	Difference in head (ft)

Footnote: Negative values indicate that computed heads are lower in this simulation than for same layer in simulation of EIS Alternative 2.

Location Map

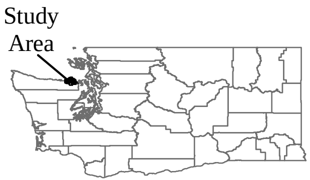
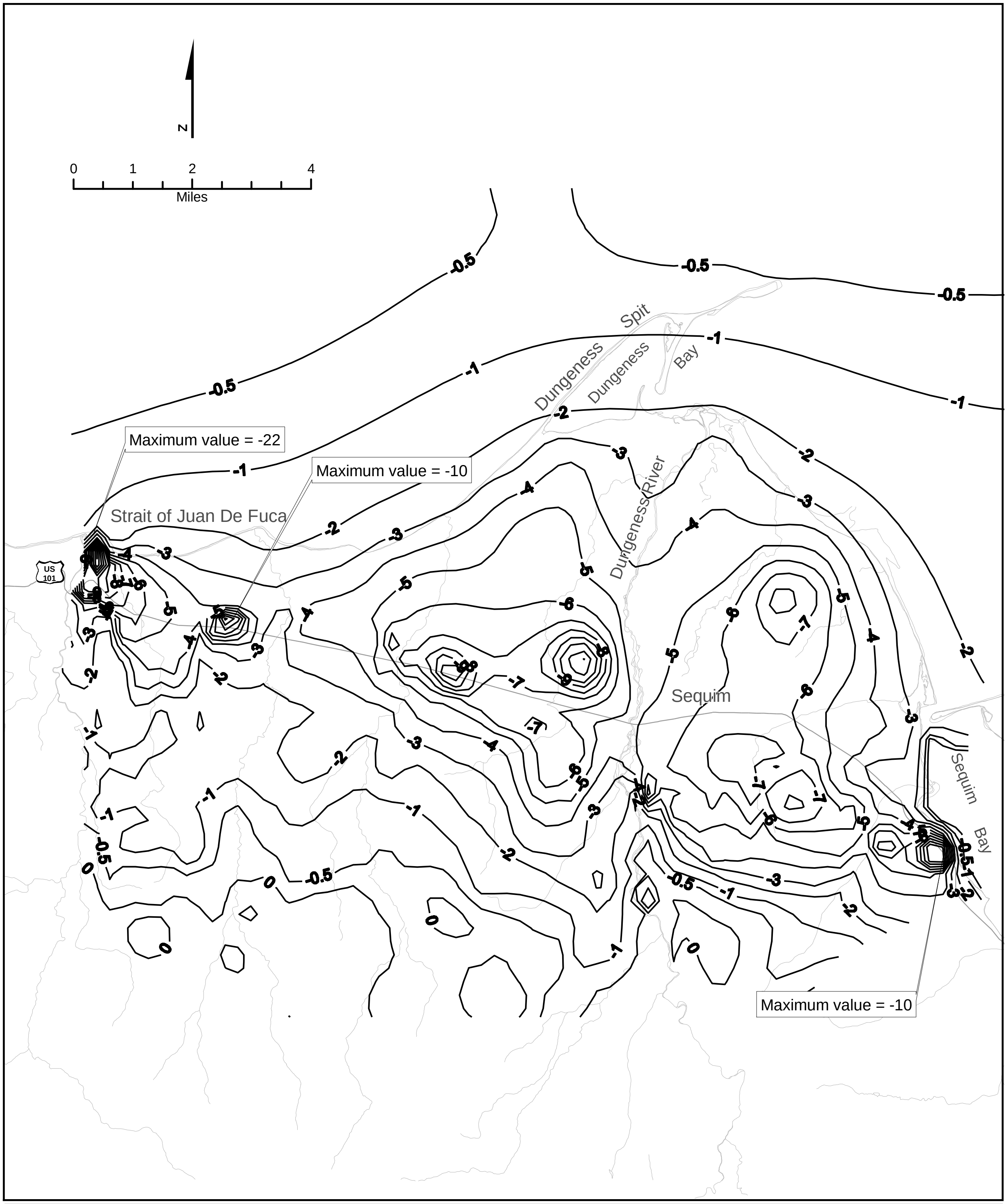


Figure 6a
2514 Buildout In Middle Aquifer
Model Layer 1 Transient Differences
With EIS Alternative 2
for September 1996

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\tom_july_2003\fig6a_2514buildout_intermed_layer1_alt2.mxd Date: July 29, 2003



Map Features

——	Streams
——	Highway 101
——	Difference in head (ft)

Footnote: Negative values indicate that computed heads are lower in this simulation than for same layer in simulation of EIS Alternative 2.

Location Map

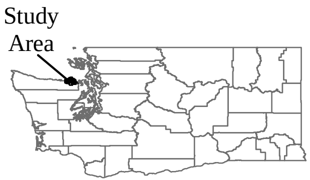
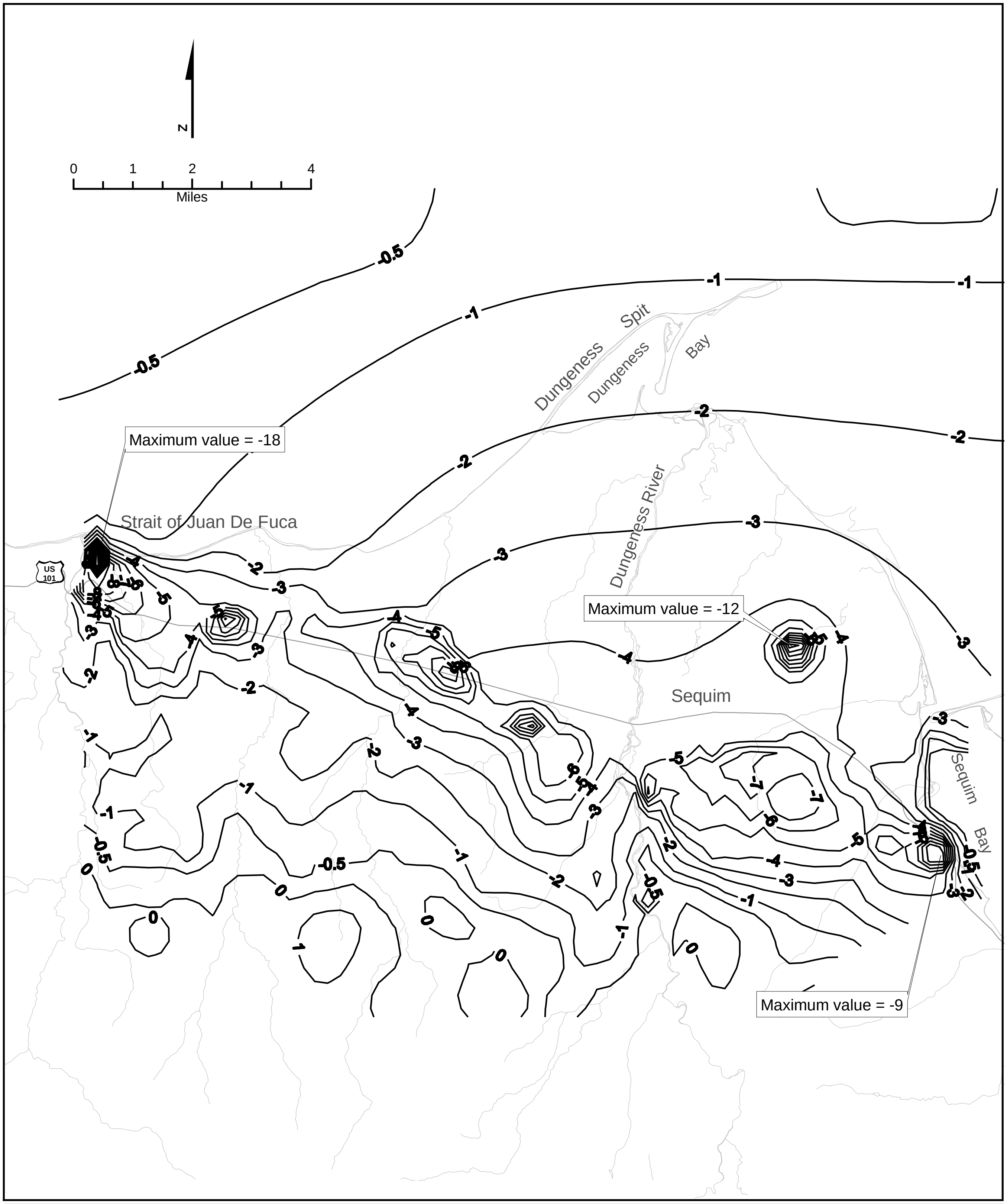


Figure 6b
2514 Buildout In Middle Aquifer Model Layer 3 Transient Differences With EIS Alternative 2 for September 1996

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\tom_july_2003\fig6b_2514buildout_intermed_layer3_alt2.mxd Date: July 29, 2003



Maximum value = -18

Maximum value = -12

Maximum value = -9

Map Features

─	Streams
─	Highway 101
━	Difference in head (ft)

Location Map

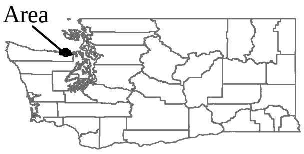
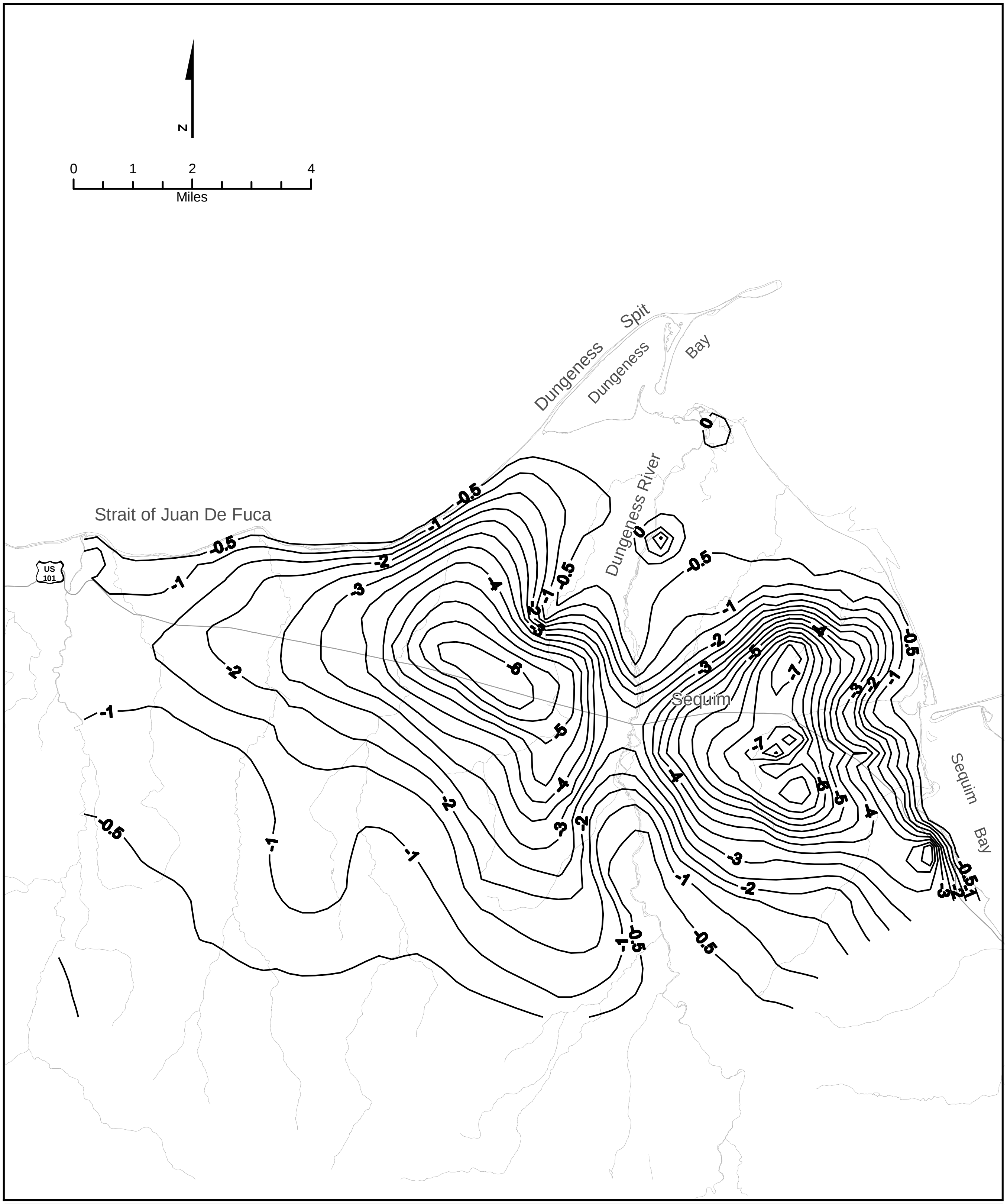


Figure 6c
2514 Buildout In Middle Aquifer
Model Layer 5 Transient Differences
With EIS Alternative 2
for September 1996

TETRA TECH FW, INC.

Footnote: Negative values indicate that computed heads are lower in this simulation than for same layer in simulation of EIS Alternative 2.

Q:\projects_2002\dungeness\workdir\maps\tom_july_2003\fig6c_2514buildout_intermed_layer5_alt2.mxd Date: July 29, 2003



Map Features

- Streams
- Highway 101
- Difference in head (ft)

Location Map

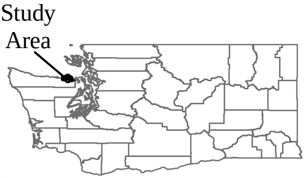
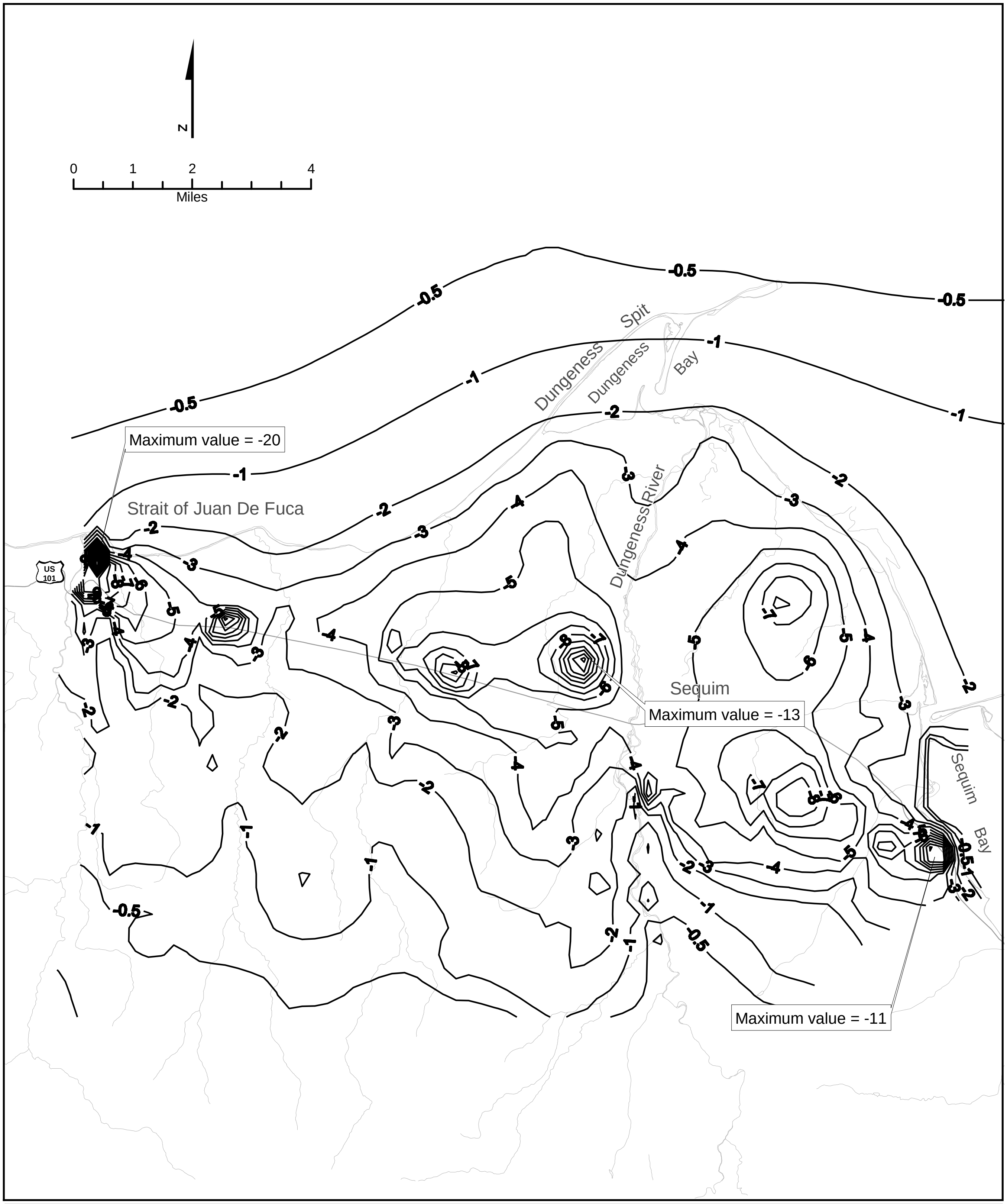


Figure 7a
2514 Buildout In Middle Aquifer Model Layer 1 Transient Differences With EIS Alternative 2 for September 1997

TETRA TECH FW, INC.

Footnote: Negative values indicate that computed heads are lower in this simulation than for same layer in simulation of EIS Alternative 2.

Q:\projects_2002\dungeness\workdir\maps\tom_july_2003\fig7a_2514buildout_intermed_layer1_alt2.mxd Date: July 29, 2003



Map Features

─	Streams
─	Highway 101
━	Difference in head (ft)

Location Map

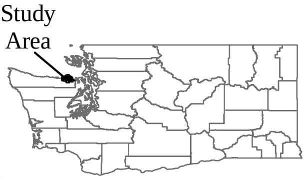
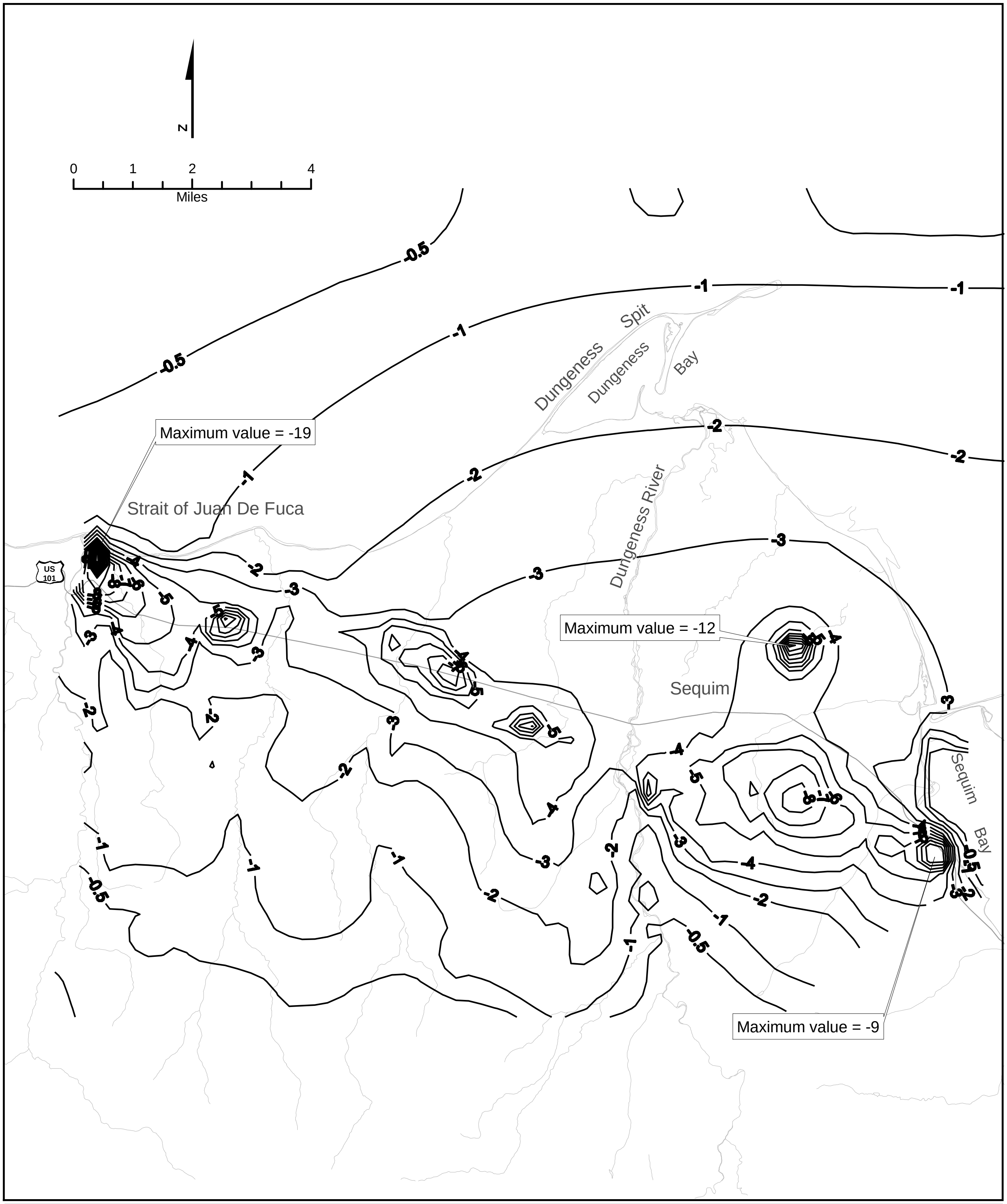


Figure 7b
2514 Buildout In Middle Aquifer Model Layer 3 Transient Differences With EIS Alternative 2 for September 1997

TETRA TECH FW, INC.

Footnote: Negative values indicate that computed heads are lower in this simulation than for same layer in simulation of EIS Alternative 2.

Q:\projects_2002\dungeness\workdir\maps\tom_july_2003\fig7b_2514buildout_intermed_layer3_alt2.mxd Date: July 29, 2003



Map Features

- Streams
- Highway 101
- Difference in head (ft)

Location Map

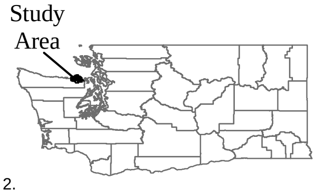


Figure 7c
2514 Buildout In Middle Aquifer Model Layer 5 Transient Differences With EIS Alternative 2 for September 1997

TETRA TECH FW, INC.

Footnote: Negative values indicate that computed heads are lower in this simulation than for same layer in simulation of EIS Alternative 2.

Q:\projects_2002\dungeness\workdir\maps\tom_july_2003\fig7c_2514buildout_intermed_layer5_alt2.mxd Date: July 29, 2003

Figure 8. Groundwater Discharges to Streams (cfs)

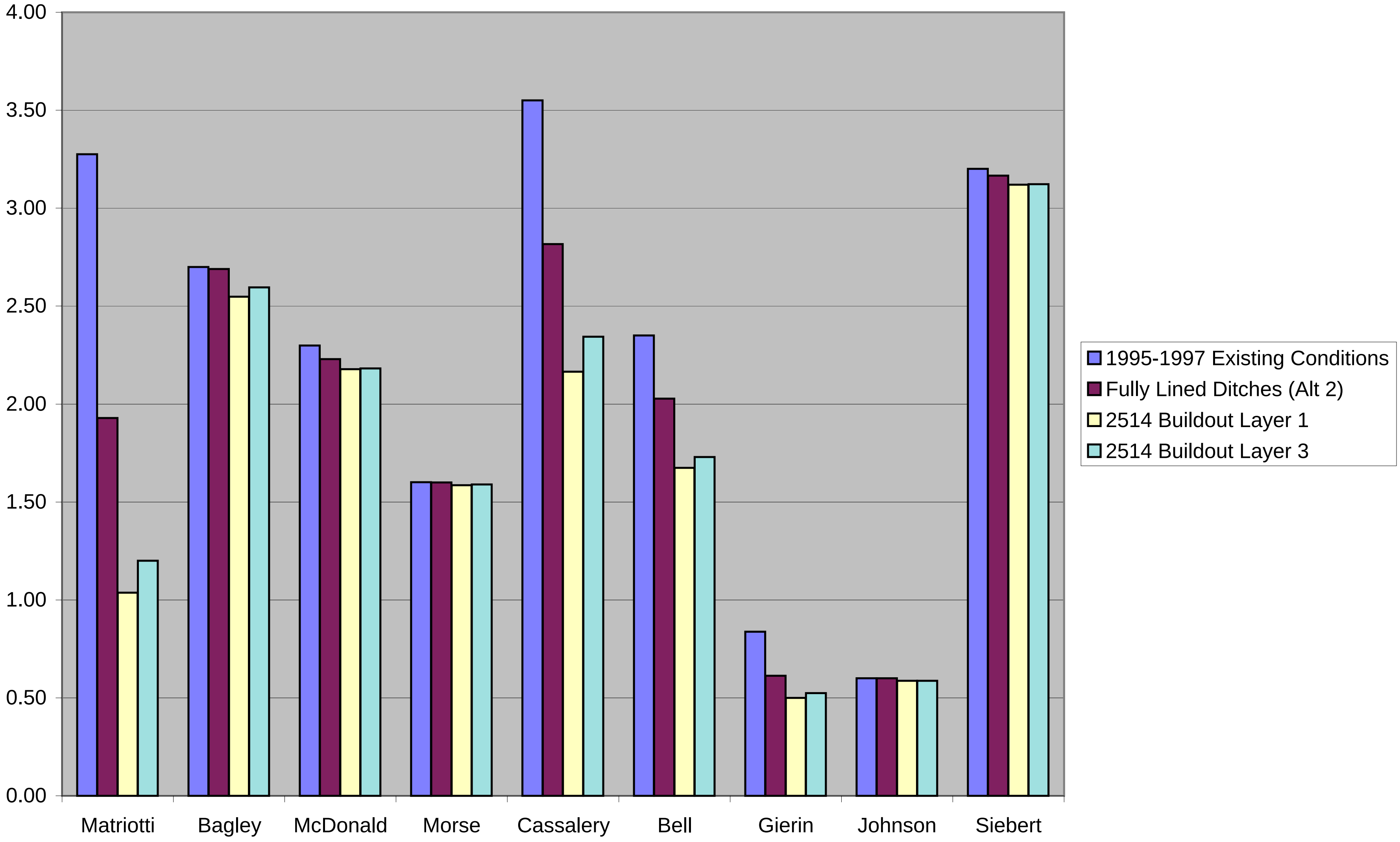


Figure 9. Buildout Impact on Dungeness River Flow (RM 3.3 to 6.4)