AQUIFER STORAGE AND RECOVERY EVALUATION REPORT

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INTRODUCTION

Clallam County is evaluating the potential feasibility of augmented aquifer storage in the Sequim-Dungeness area as part of on-going planning requirements and current 2514 watershed planning efforts. Identification and evaluation of areas where artificial recharge (augmented aquifer storage) may be possible will help determine whether Aquifer Storage and Recovery (ASR) is a viable long-term water management strategy for this area. ASR involves the storage of water within an aquifer via injection or infiltration of water with the subsequent retrieval of the water from the aquifer when needed. Under ASR, the aquifer effectively functions as a water bank. Most ASR systems provide seasonal water storage with water injection and/or infiltration during the wet season and water recovery occurring during the subsequent dry season.

This report presents a hydrogeologic analysis through simulations of ASR conducted through application of groundwater flow model. Results of the simulations will support evaluation of the feasibility for augmented aquifer storage in the Sequim-Dungeness area.

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 more general ground water model report details the model structure, the assumptions made about the hydrogeology of the area, and explains the input parameter development. 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. This report builds upon that model and report, and details the specific assumptions and changes to input parameters made to simulate the change in ground water conditions if an aquifer storage program were instituted.

IDENTIFICATION OF POTENTIAL RECHARGE AREAS

TtFWI was tasked to evaluate the potential for aquifer storage and recharge via the irrigation system. It was determined that locations should be identified for infiltration ponds adjacent to irrigation ditches rather than calling upon leakage from the ditches themselves, as lining or piping of ditches may be completed in the future. Review of potential locations for infiltration ponds relied heavily upon hydrologic data presented in

Thomas et al. (1999), but also included review of surficial geological maps by Schasse and Logan (1998), Schasse, and Wegmann (2000), and Tabor and Cady (1978).

For ASR to be most effective, the recharge needs to occur in conductive portions of the upper basin so that sufficient room exists downgradient to allow for recovery of storage. Although the shallow aquifer (represented by layer 1 in the model) is tapped by most pumping wells, the underlying intermediate and deep aquifers (model layers 3 and 5, respectively) represent significant water resources and would benefit from augmented aquifer storage. Hydrogeologic review identified that suitable locations for recharge occur in the central part of the study area to the east and west of the Dungeness River. Assumptions for selecting simulation recharge locations are listed as follows:

- Recharge will be surficial to the shallow aquifer.
- Recharge will be accomplished via infiltration reservoirs or ponds served by existing ditches.
- Locations will be selected for high potential recharge and significant downward component to gradient so that the intermediate aquifer receives additional recharge.
- Separation from the Dungeness River of one mile or more is preferred for recharge locations so as not to diminish naturally occurring river losses that recharge the aquifer.

These criteria led to selection of two locations each more than a mile to the east and west of the river, as shown on Figure 1. Locations of these recharge ponds correspond to model cells Row 47, Column 39 (R47, C39) and R47, C56 in layer 1. Diversions required to deliver water to these recharge locations were identified as stream cells (representing Dungeness River) R58, C53 and R56, C51 in layer 1.

DIVERSION PERIOD AND RATE

Data for simulations of ASR were derived directly from records of river flow and precipitation to provide examples that represent actual conditions. Data from the USGS gage at River Mile (RM) 11.8 (Gage 12048000) were compiled for annual averages of daily rates over a period of 63 years, as shown on Table 1. The amount of Dungeness River flow potentially available for augmented storage was estimated for ASR simulations by comparing seasonal instream flow requirements against measured river flows during years of low, intermediate, and high flow. Conducting simulations for intermediate river flow conditions and then comparing results to simulations of low and high flow years provides an assessment of the aquifer storage potential at a range of recharge rates.

Assumptions for determining river diversions and recharge rates include the following:

- The optimum instream flow rate is projected at 580 cubic feet per second (cfs).

- Diversion for ASR is timed to occur for days when river flow exceeds the optimum instream flow; to allow for diverted flow, it is assumed that ASR diversion can occur for any day in which river flow exceeds 600 cfs.
- ASR diversions for river flow days above 600 cfs flow will be assumed to occur at 5 cfs total, which will be applied equally to both sides of the river (east and west).

The 22 months from December 1995 through September 1997 used in the calibration of the transient model (TtFWI, 2003) were selected as the intermediate river flow year. To select years representative of low river flow and high river flow, the two lowest and two highest years were discarded to avoid representing extreme conditions. As shown in Table 1, the year 1994 represents the third lowest river flow, and the year 1967 represents the third highest. Because subsequent years represent different conditions, the 22-month period for transient simulations of both low river flow conditions and high river flow conditions repeats their one-year record to accentuate the impacts of dry and wet years. In this fashion, the low and high year conditions applied over 22 months are assembled by using the previous December, then the 12 months of the subject year, followed by a repeat of the first nine months (e.g., the simulation for 1967 consists of records for December 1966, January through December 1967, and January through September 1967). This representation allows evaluation of the influence of a single low or high year, as well as the influence of the same conditions should they continue for a second straight year.

Figure 2 illustrates average monthly river flow rates and precipitation for the low, intermediate, and high years, wherein the last nine months of the low and high flow years are repeated to attain a simulation period of 22 months. Results from screening data as defined above are presented in Table 2. The total days reported above 600 cfs are listed by month (or stress period). For the first full year (January through December), the intermediate flow year shows 44 days above 600 cfs, whereas the low year shows 22 days and the high year 99 days. For the full 22-month period, the intermediate year totals 147 days above 600 cfs, whereas the low year totals 32 days and the high year 197 days. Although the river flow is greater for the high flow year than the intermediate flow year, precipitation in the latter is slightly greater than the former. Additionally, there is greater contrast in river flow the first year between high and intermediate flow than in the second year (Figure 2).

Comparison of recharge available from river diversions (Table 2) shows that the low flow year is 50 percent of the intermediate year for the first full year, and this decreases to 22 percent for the full 22 months. The same comparison for the high years shows 225 percent of recharge available compared to the intermediate for the first full year, with a decrease to 134 percent for the full 22 months. When annualized based on 670 days represented by the 22-month period, the intermediate flow year diversion and recharge total of 63,504,000 ft^3 equates to 34,595,463 ft^3/year, or 794 acre-ft/year. This annualized rate also converts to 94,782 ft^3/day, or 1.1 cfs.

STEADY STATE ASR SIMULATION

A time-averaged representation of ASR was run first to confirm the selection of diversion and recharge locations and rates and to provide a starting point for transient simulations. Annualized values of diversions and augmented recharge shown for intermediate flow on Table 2 were applied to the steady-state model represented in Cal24 (TtFWI, 2003). The following steps were completed to simulate time-averaged ASR:

- Diversions rates from the river were applied at an annualized rate of 94,782 ft^3/day total, or 47,391 ft^3/day for each diversion (split evenly).
- Concordantly, recharge rates for infiltration ponds were applied at an annualized rate of 94,782 ft^3/day total (794 acre-ft/year), or 47,391 ft^3/day for each diversion.
- The two ASR diversions were added to existing diversion rates at Dungeness River model stream cells R58, C53 and R56, C51 in layer 1.
- The two ASR infiltration ponds were input as “reverse wells” into model cells R47, C39 and R47, C56 in layer 1.

Ditch losses to the shallow aquifer, as represented in Thomas et al. (1999), provide a basis for comparison. These values were incorporated into the Ecology 2003 groundwater model (TtFWI, 2003), wherein the difference between Alternative 2 recharge (all lined or piped ditches) to Alternative 1 recharge (unlined ditches), shows recharge from ditches of 9,773 acre-ft/year. Therefore, ASR recharge in this simulation represents 8.1 percent of recharge attributed to ditch losses prior to lining/piping.

Resultant hydraulic heads from model layers 1, 3, and 5 were compared to heads from Cal24, which are presented on Figures 3a,b,c. Layer 1 (Figure 3a) exhibits a peak rise from the additional recharge of approximately 6.5 feet and a distribution of influence (water table mounding) greater than a radius of 1 mile in the upgradient direction (south) and greater than 2 miles in the downgradient direction (north). As seen in Figure 3a, the limits of the mounds (greater than 0.5 ft) coalesce beneath the river. Layer 3 shows a rise (Figure 3b) that is only slightly less than layer 1 in magnitude (maximum of over 5 ft) and spread (radius of approximately 1 mile), although the southern three-fifths of the mounding occurs within bedrock. Similarly, the layer 5 response is slightly diminished with a maximum height of 4 ft., although the area of mounding greater than 0.5 ft occurs almost entirely in bedrock.

TRANSIENT ASR SIMULATIONS

Transient simulations were conducted first for intermediate flow and then for low and high flow. Model setup and considerations for intermediate river flow include:

- Rate of river diversion was applied at 5 cfs total for actual days within a month with daily river flow recorded above 600 cfs.
- River flow and precipitation recharge representing December 1995 to September 1997 were maintained as before for the transient model calibration (TtFWI, 2003).
- The model was warmed up to transient ASR conditions by repeating the first 12 months for 30 years to generate initial heads representative of transient conditions.
- The intermediate flow ASR run of 22 months was then conducted using initial heads from the warm up runs.
- Results of the intermediate flow ASR transient

The transient model attempts to evaluate the groundwater system response to temporal stresses and, therefore, is sensitive to the initial heads specified for the model simulation. As identified in the bullet items above, the transient (monthly-varying) groundwater model was first run in a 1-year loop to produce a set of initial heads representative of December rather than time-averaged (steady state) conditions. First, the final hydraulic heads for the ASR steady state model were applied as the initial heads for transient model stress period 1 (December 1995). The model was run for 12 stress periods, or months, ending with November 1996. The resulting groundwater heads for November were in turn set as the initial heads for stress period 1, December 1995, and the model runs were repeated for 30 years. The resulting groundwater heads were used as the initial heads for the full 22-month transient intermediate flow ASR (December 1995 to September 1997).

Results of transient runs were evaluated for three months of the year: January to represent winter conditions, June to represent peak snow runoff, and September to represent lowest river flows and low precipitation. September values likely represent a time of greatest benefit for ASR when high water demand coincides with the potentiometric surface (water table in layer 1) at its annual low.

Resultant heads for layer 1 and layer 3 of the intermediate flow ASR are presented in Figures 4a,b through 9a,b for January, June, and September of both years. Overall, layer 3 results show similar responses by month as observed in layer 1 results, except the responses occur at slightly lower magnitude and distribution. The following summarizes observations for the 22-month simulation:

- January 1996 shows high mounding in vicinity of the infiltration ponds (Figure 4a) due to high river flows (Figure 2), along with a greater area of influence for the eastern infiltration pond than the western. The high mounding is consistent with 23 days in December and 16 days in January of river flow above 600 cfs (Table 2).

- June 1996 exhibits moderate mounding (Figure 5a) consistent with 7 days of river flow above 600 cfs (Table 2), but also broader influence that reflects the 51 days of ASR diversions in December through February.
- September 1996 (Figure 6a) shows that the broad influence of recharge from the first half of the year remains, although the peak mounding has subsided.
- January 1997 (Figure 7a) had 14 days of ASR diversion (compared to 16 days the previous year), but it follows 6 months with only 5 days of ASR diversion. Therefore, the peak mounding is lower in comparison to the previous January, although mounding still exhibits a broad distribution.
- June 1997 (Figure 8a) had 24 days of ASR diversion and follows a wet spring; therefore, mounding is high, although with a smaller distribution than the previous June through January.
- September 1997 (Figure 9a) again shows the broad influence of recharge from the first half of the year, with mounding still above 5 ft at its peak.

The influence of ASR on stream flows other than the Dungeness River was evaluated for the intermediate flow ASR. Table 3 provides a listing by stress period (month) for the transient calibration (TtFWI, 2003) and the intermediate flow simulation. In most cases, groundwater discharge to streams remains unchanged within 0.01 cfs (less than 0.5 percent), although very slight variations occurred for four drainages: Matriotti Creek, to the west of the Dungeness River and north-northwest of recharge areas, exhibits a reduction in flow of 0.03 cfs (change of 1 percent); Cassalery, Gierin, and Bell Creeks, to the east of the Dungeness River and northeast of recharge areas, exhibit increases in flow of 0.08 cfs (3 percent), 0.03 cfs (4 percent), and 0.15 cfs (7 percent), respectively.

LOW AND HIGH ASR SIMULATIONS

The low river flow and high river flow simulations were conducted using data from records of past years to evaluate the potential range of response of the aquifer to ASR. Model setup and considerations for low and high river flow include:

- ASR diversions and infiltration were varied by month to reflect actual days of river flow above 600 cfs, as indicated on Table 2.
- River flow entering the model area was varied by month, as illustrated on Figure 2.
- Precipitation also was varied by month based on records to reflect conditions of the model year, as indicated on Figure 2.
- Conditions for the low and high ASR runs were repeated for the second year (as described above under Diversion Period and Rate) to assess both the influence of a single low or high year, as well as the influence of the same conditions should they continue for a second straight year.
- Initial heads were developed in the same manner as the intermediate flow year.
- Results for both low and high flow years were compared against the intermediate flow year to assess the influence of variations in available water on ASR.

Low River Flow ASR Simulation

Results of the low river flow ASR simulation are shown on Figures 10 through 15 as a comparison to the intermediate flow ASR for the same stress period. Because this simulation includes changes to precipitation recharge, much of the difference illustrated by the contours reflects the lower or higher rates of precipitation infiltration. With this in mind, review of figures should focus on mounding of the water table in the lower center of the figures around the area of infiltration ponds, while ignoring changes indicated in the foothills (approximately bottom inch of figure area). The following summarizes observations for the 22-month simulation of low river flow conditions:

- January of the first year (SP2) shows the low flow ASR to have mound peaks about 6 ft lower than the intermediate flow ASR, but more distant areas of mounding are the same (Figure 10)
- June of the first year (SP7) show the low flow ASR about 4 ft lower, but over a broader area (Figure 11).
- September of the first year (SP10) compares to the intermediate flow ASR at 2 to 4 ft lower and over a broader area (Figure 12), which leaves only about 1 ft of mounding from artificial recharge.
- January of the second year (SP14) shows the low flow ASR to be about 2 ft lower, but only locally around the infiltration ponds (Figure 13).

- June of the second year (SP19) shows that peak mounding is much less than the high mounding present in the intermediate flow ASR (Figure 14), but that some broad mounding exists.
- September of the second year (SP22) follows a long period without artificial recharge and virtually no mounding is apparent (Figure 15) when compared against the intermediate ASR.

Overall, it would appear that only a small amount of beneficial mounding remains in September of the first year of a low flow ASR, and virtually no mounding remains in September following two consecutive low flow years.

High River Flow ASR Simulation

Results of the high river flow ASR simulation are shown on Figures 16 through 21 as a comparison to intermediate flow ASR for the same stress period. As in the low flow ASR simulation, these results also reflect changes due to variable precipitation recharge, which should be overlooked. The following summarizes observations for the 22-month simulation of high river flow conditions:

- January of the first year (SP2) for the high flow ASR has significantly less diversions than the intermediate flow ASR and, accordingly, are significantly lower (Figure 16)
- June of the first year (SP7) for the high flow ASR is in the middle of significant snow melt (Figure 2) and is higher at the mound peaks by 6 ft (Figure 17).
- September of the first year (SP10) is the second consecutive month with no ASR diversions, but follows numerous diversions in May through July from which the retained mounding (Figure 18) remains high compared to the intermediate flow ASR. As a result, mounds in September are 1 to 2 ft higher at their peak than in the intermediate year, but not significantly broader.
- January of the second year (SP14) for the high flow record shows little difference with the intermediate flow ASR, and mound peaks are virtually identical (Figure 19).
- June of the second year (SP19) again is in the midst of high snow melt, but a similar event occurred for the intermediate flow year and, thus, mounding for the high flow ASR is only about 1 ft higher (Figure 20).
- September of the second year (SP22) is virtually the same as the intermediate flow ASR (Figure 21).

Overall, the high flow ASR shows that additional water is available as aquifer storage in September, although in this example little difference was observed in the second year due to high numbers of diversions also occurring in the intermediate flow ASR.

CONCLUSIONS

Simulations of ASR show that artificial recharge can increase aquifer storage over a significant area. Principal conclusions drawn from the simulations under the assumptions represented include:

- Diversion of more than 700 acre-ft/year typically is available for ASR on days with river flow of 600 cfs if one assumes an infiltration rate of 5 cfs.
- Augmented aquifer storage through surface infiltration would primarily benefit the shallow aquifer, although increase to the intermediate aquifer will also occur.
- The intermediate flow ASR shows that mounding remaining in September can provide significant additional aquifer storage.
- The low flow ASR shows that only a small amount of beneficial mounding remains in September of the first year, and virtually no mounding remains in September following two consecutive low flow years.
- The high flow ASR shows that 1 to 2 ft of additional mounding remains in September following a spring river flow resulting in a high number of diversions.
- ASR affects groundwater discharge to surface streams in the vicinity only to a small degree.

Clearly, ASR can enhance aquifer storage and improve groundwater availability at times of higher need. Assumptions presented herein result in significant artificial recharge, but the annual rate of such recharge is just 8 percent of the recharge that may be displaced by piping all irrigation ditches. Therefore, it will be important for an ASR program to maximize the frequency and rate of diversions for recharge.

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TABLES

Table 1. Average Daily River Flow at RM 11.8 for 1938 Through 2000.

ABOVE MEDIAN FLOW YEARS			BELOW MEDIAN FLOW YEARS		
Rank	**Year**	**Average Daily Rate (cfs)**	**Rank**	**Year**	**Average Daily Rate (cfs)**
1	1999	718.4	33	1947	377.7
2	1950	567.7	34	1984	377.4
3	**1967**	**547.4**	35	1938	373.6
4	1983	538.4	36	1940	369.9
5	1954	537.1	37	1962	369.8
6	**1997**	**522.7**	38	1960	367.1
7	1995	510.5	39	1976	366.5
8	1972	499.8	40	1964	355.7
9	1956	494.5	41	1992	352.4
10	1982	473.6	42	1978	351.5
11	1953	465.7	43	1988	350.7
12	1980	456.3	44	1957	347.6
13	1974	453.8	45	1986	345.8
14	1958	451.5	46	1946	340.1
15	1975	449.1	47	1941	339.3
16	1961	439.6	48	1987	327.9
17	1955	427.9	49	1973	325.7
18	**1996**	**426.9**	50	1965	324.9
19	1949	426.3	51	1939	324.1
20	1968	424.3	52	1970	318.2
21	1998	422.0	53	1945	315.7
22	1971	422.0	54	1943	294.0
23	1981	421.9	55	1952	290.5
24	1990	417.0	56	1942	283.9
25	1963	416.3	57	1985	280.6
26	1966	415.5	58	1989	274.5
27	1991	409.5	59	1993	255.4
28	1948	403.7	60	1979	253.3
29	2000	402.4	**61**	**1994**	**247.8**
30	1969	400.4	62	1977	219.5
31	1951	387.6	63	1944	205.3
32	1959	384.5			

Bold values indicate flow years used in ASR simulations

Table 2. Daily Diversion and Recharge Rates for ASR Simulations.

		CALIBRATED TRANSIENT MODEL RUN		INTERMEDIATE ASR RUN (1995 - 1997) ADDITIONAL DIVERSION FOR RECHARGE			LOW ASR RUN (1994) ADDITIONAL DIVERSION FOR RECHARGE			HIGH ASR RUN (1967) ADDITIONAL DIVERSION FOR RECHARGE		
Month	Model Stress Period	Base Diversion Daily Flow at Model Cell R58, C53 (cfd)	Base Diversion Daily Flow at Model Cell R56, C51 (cfd)	Days per month Dungeness Gage Flow >600 cfs	Daily Diversion and Aquifer Recharge Prorated for Month (cfd)	Total Monthly Diversion and Aquifer Recharge (ft^3)	Days per month Dungeness Gage Flow >600 cfs	Daily Diversion and Aquifer Recharge Prorated for Month (cfd)	Total Monthly Diversion and Aquifer Recharge (cfd)	Days per month Dungeness Gage Flow >600 cfs	Daily Diversion and Aquifer Recharge Prorated for Month (cfd)	Total Monthly Diversion and Aquifer Recharge (cfd)
December	1	622,080	43,145	23	320,516	9,936,000	2	27,871	864,000	18	250,839	7,776,000
January	2	604,800	68,570	16	222,968	6,912,000	0	0	0	6	83,613	2,592,000
February	3	328,320	44,488	12	178,759	5,184,000	0	0	0	0	0	0
March	4	596,160	85,392	0	0	0	4	55,742	1,728,000	3	41,806	1,296,000
April	5	1,589,760	6,046	4	57,600	1,728,000	0	0	0	0	0	0
May	6	1,961,280	987	0	0	0	4	55,742	1,728,000	18	250,839	7,776,000
June	7	2,471,040	50,112	7	100,800	3,024,000	0	0	0	30	432,000	12,960,000
July	8	2,773,440	98,415	1	13,935	432,000	0	0	0	23	320,516	9,936,000
August	9	2,825,280	83,184	0	0	0	0	0	0	0	0	0
September	10	1,658,880	42,662	0	0	0	0	0	0	0	0	0
October	11	1,080,000	25,796	0	0	0	0	0	0	9	125,419	3,888,000
November	12	941,760	31,509	1	14,400	432,000	1	14,400	432,000	1	14,400	432,000
December	13	475,200	29,728	3	41,806	1,296,000	13	181,161	5,616,000	9	125,419	3,888,000
January	14	51,840	4,096	14	195,097	6,048,000	0	0	0	6	83,613	2,592,000
February	15	146,880	29,319	3	46,286	1,296,000	0	0	0	0	0	0
March	16	285,120	48,492	7	97,548	3,024,000	4	55,742	1,728,000	3	41,806	1,296,000
April	17	1,105,920	51,766	4	57,600	1,728,000	0	0	0	0	0	0
May	18	1,969,920	43,394	16	222,968	6,912,000	4	55,742	1,728,000	18	250,839	7,776,000
June	19	2,332,800	53,851	24	345,600	10,368,000	0	0	0	30	432,000	12,960,000
July	20	2,522,880	75,693	11	153,290	4,752,000	0	0	0	23	320,516	9,936,000
August	21	2,790,720	90,058	0	0	0	0	0	0	0	0	0
September	22	1,555,200	80,961	1	14,400	432,000	0	0	0	0	0	0
First Year Total	2 to 13	--	--	44	--	19,008,000	22	--	9,504,000	99	--	42,768,000
22 Month Total	1 to 22	--	--	147	--	63,504,000	32	--	13,824,000	197	--	85,104,000

* - Each day of river flow >600 cfs applied to the two diversions and recharge ponds at a rate of 5 cfs (14,400 cfd); each diversion/pond applied at half this rate.

cfs - cubic feet per second

cfd - cubic feet per day

-- - Not Applicable

Table 3. Comparison of groundwater discharge to streams for calibrated transient model and intermediate flow ASR run (cfs).

Transient Calibration by Stress Period

Stream	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Average
Morse	1.61	1.62	1.62	1.61	1.61	1.61	1.60	1.59	1.59	1.60	1.60	1.61	1.63	1.64	1.62	1.61	1.61	1.60	1.61	1.60	1.59	1.59	1.61
Bagley	2.72	2.76	2.78	2.74	2.74	2.74	2.71	2.68	2.69	2.69	2.70	2.73	2.80	2.83	2.80	2.79	2.77	2.76	2.76	2.73	2.70	2.70	2.74
Siebert	3.21	3.23	3.23	3.20	3.21	3.21	3.19	3.18	3.19	3.19	3.20	3.21	3.25	3.26	3.23	3.22	3.21	3.21	3.21	3.19	3.18	3.19	3.21
McDonald	2.30	2.31	2.31	2.30	2.30	2.30	2.29	2.29	2.29	2.29	2.29	2.29	2.31	2.32	2.31	2.30	2.30	2.30	2.30	2.29	2.28	2.28	2.30
Matriotti	3.23	3.25	3.21	2.86	2.79	2.99	3.06	3.02	3.07	3.10	3.03	3.17	3.50	3.32	2.96	2.79	2.81	3.04	3.22	3.11	3.11	3.05	3.08
Cassalery	3.65	3.77	3.82	3.57	3.54	3.51	3.38	3.24	3.28	3.29	3.32	3.43	3.73	3.81	3.59	3.50	3.39	3.32	3.33	3.19	3.11	3.13	3.45
Gierin	0.86	0.85	0.85	0.82	0.81	0.81	0.80	0.79	0.79	0.80	0.80	0.81	0.85	0.85	0.83	0.81	0.80	0.79	0.78	0.77	0.75	0.75	0.81
Bell	1.85	2.02	2.08	2.00	2.10	2.16	2.17	2.17	2.15	2.15	2.13	2.17	2.26	2.24	2.10	2.04	1.98	1.95	1.95	1.87	1.82	1.82	2.05
Johnson	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.61	0.61	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Total																							19.84

Intermediate Flow ASR Simulation by Stress Period

Stream	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Average
Morse	1.61	1.62	1.62	1.61	1.61	1.61	1.60	1.59	1.60	1.60	1.60	1.61	1.63	1.64	1.62	1.62	1.61	1.61	1.61	1.60	1.59	1.59	1.61
Bagley	2.73	2.77	2.79	2.75	2.75	2.75	2.72	2.69	2.70	2.70	2.71	2.74	2.81	2.84	2.81	2.80	2.78	2.77	2.77	2.74	2.71	2.71	2.75
Siebert	3.22	3.23	3.24	3.21	3.21	3.21	3.20	3.18	3.20	3.20	3.20	3.22	3.26	3.26	3.24	3.23	3.22	3.21	3.22	3.20	3.19	3.19	3.22
McDonald	2.30	2.31	2.31	2.30	2.30	2.30	2.30	2.29	2.29	2.29	2.29	2.30	2.31	2.32	2.31	2.31	2.30	2.30	2.30	2.29	2.29	2.29	2.30
Matriotti	3.06	3.10	3.09	2.76	2.71	2.91	3.00	2.98	3.04	3.08	3.02	3.17	3.50	3.33	2.97	2.81	2.83	3.07	3.25	3.15	3.15	3.09	3.05
Cassalery	3.68	3.80	3.86	3.61	3.59	3.57	3.45	3.32	3.36	3.37	3.40	3.52	3.83	3.91	3.69	3.59	3.49	3.42	3.43	3.29	3.20	3.22	3.53
Gierin	0.85	0.86	0.87	0.84	0.84	0.84	0.83	0.82	0.83	0.83	0.84	0.85	0.88	0.89	0.87	0.85	0.84	0.82	0.82	0.80	0.79	0.79	0.84
Bell	2.30	2.34	2.33	2.21	2.28	2.32	2.31	2.30	2.28	2.27	2.24	2.28	2.36	2.34	2.20	2.14	2.08	2.04	2.04	1.96	1.91	1.92	2.20
Johnson	0.60	0.60	0.61	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.61	0.61	0.61	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Total																							20.10

Note: Stress Period = 1 month; stress period 1 = December 1995

FIGURES

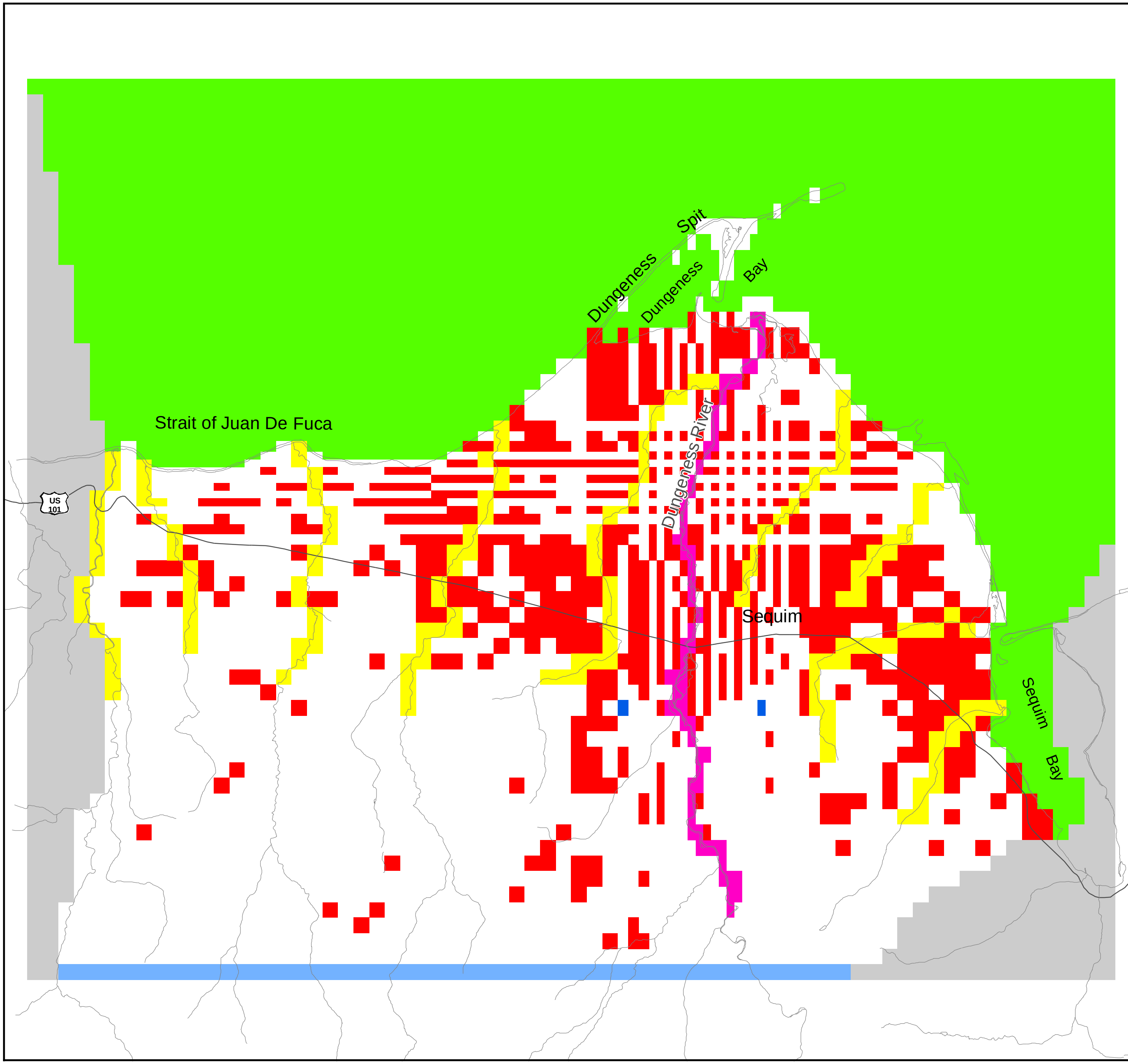


Figure 1
ASR Infiltration Ponds and Layer 1 Boundary Conditions

Map Features

Streams
Road
Infiltration Pond

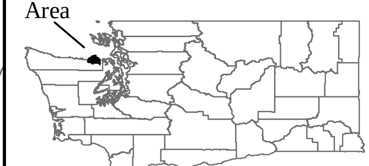
Grid Cell Boundary Conditions

No Flow Cells
Constant Heads
Offshore Drains
Dungeness River Stream Cells
Extraction Wells
Stream Drains

N

0 1 2 4
Miles

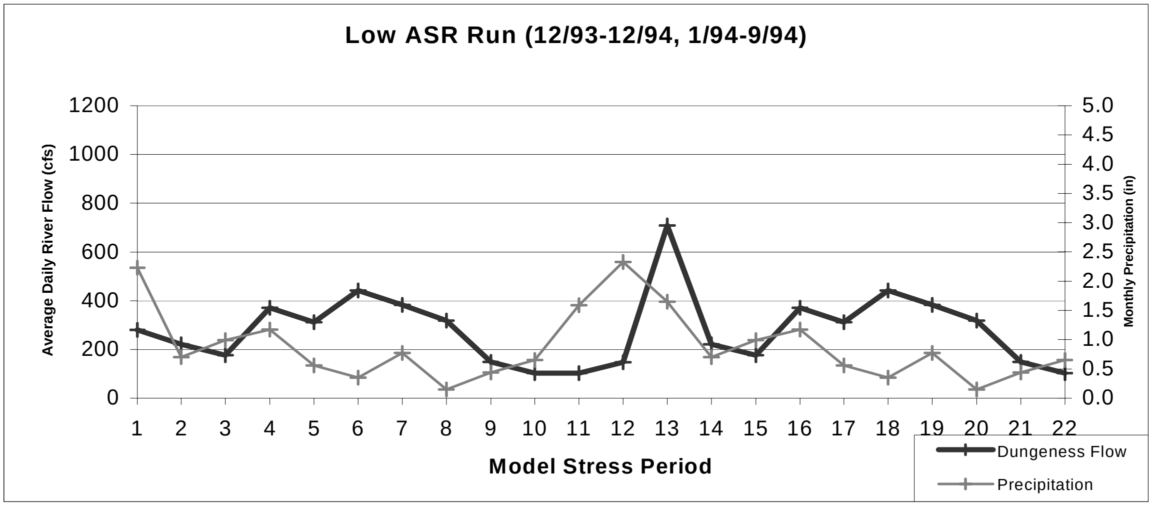
Location Map

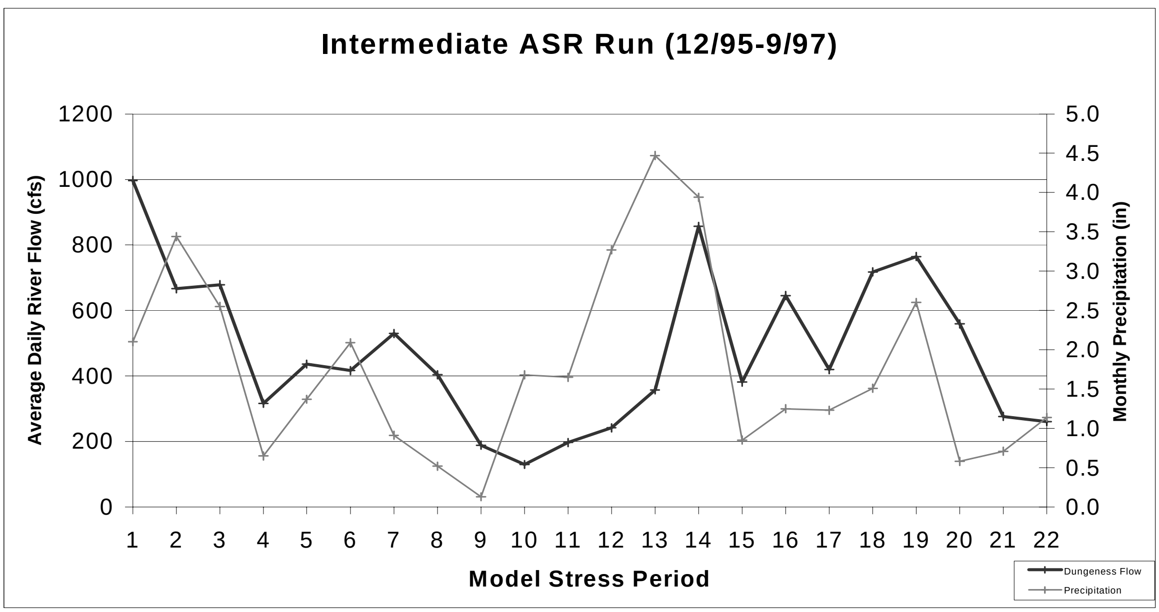


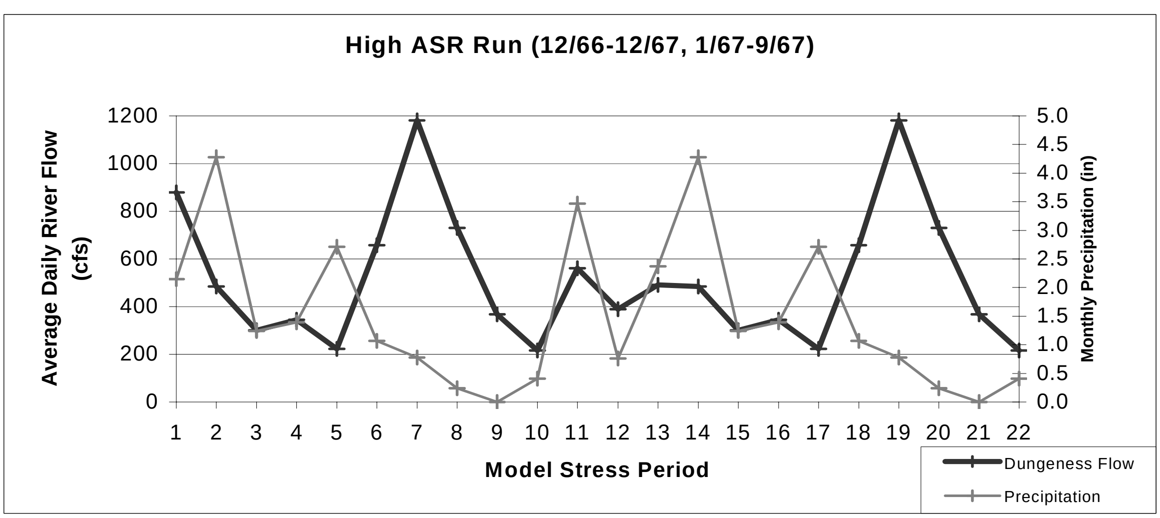
TETRA TECH FW, INC.

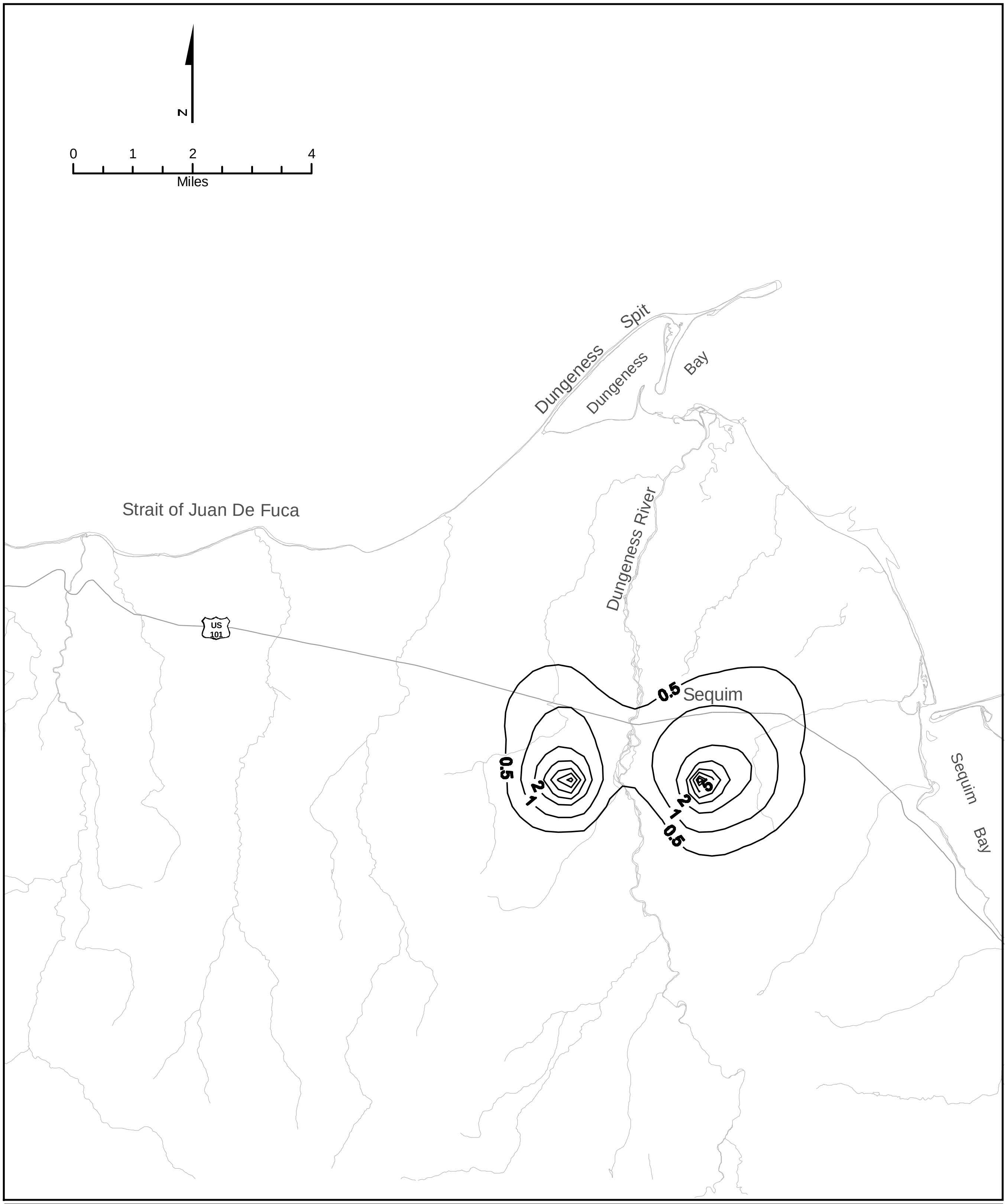
Q:\projects_2002\dungeness\workdir\maps\ASR_figures\infiltration_ponds.mxd 26 June 2003

Figure 2. Dungeness River Flows at RM 11.8 (USGS Gage 12048000) and Precipitation at Sequim (Stations 457538 and 457544) Low, Intermediate, and High ASR Runs









Map Features

Streams

Highway 101

Difference in head ASR and Cal24 (ft)

Location Map

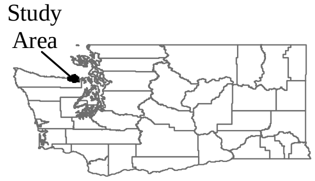
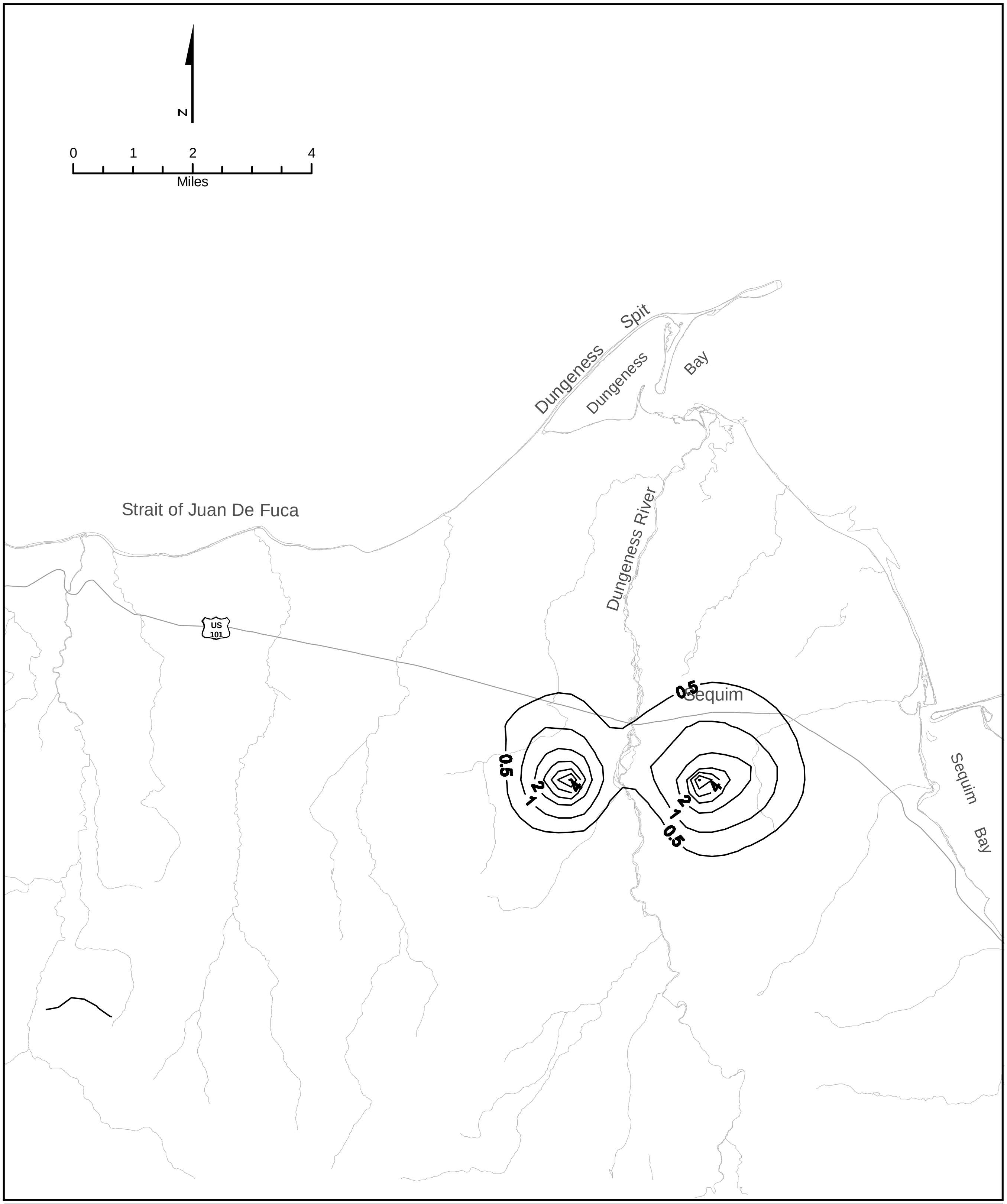


Figure 3a
Steady state head differences in Layer 1 head for ASR (compared to Cal24)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\steady_state_layer1.mxd 26 June 2003



Map Features

Streams

Highway 101

Difference in head ASR and Cal24 (ft)

Location Map

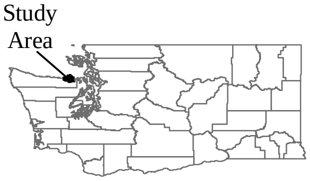
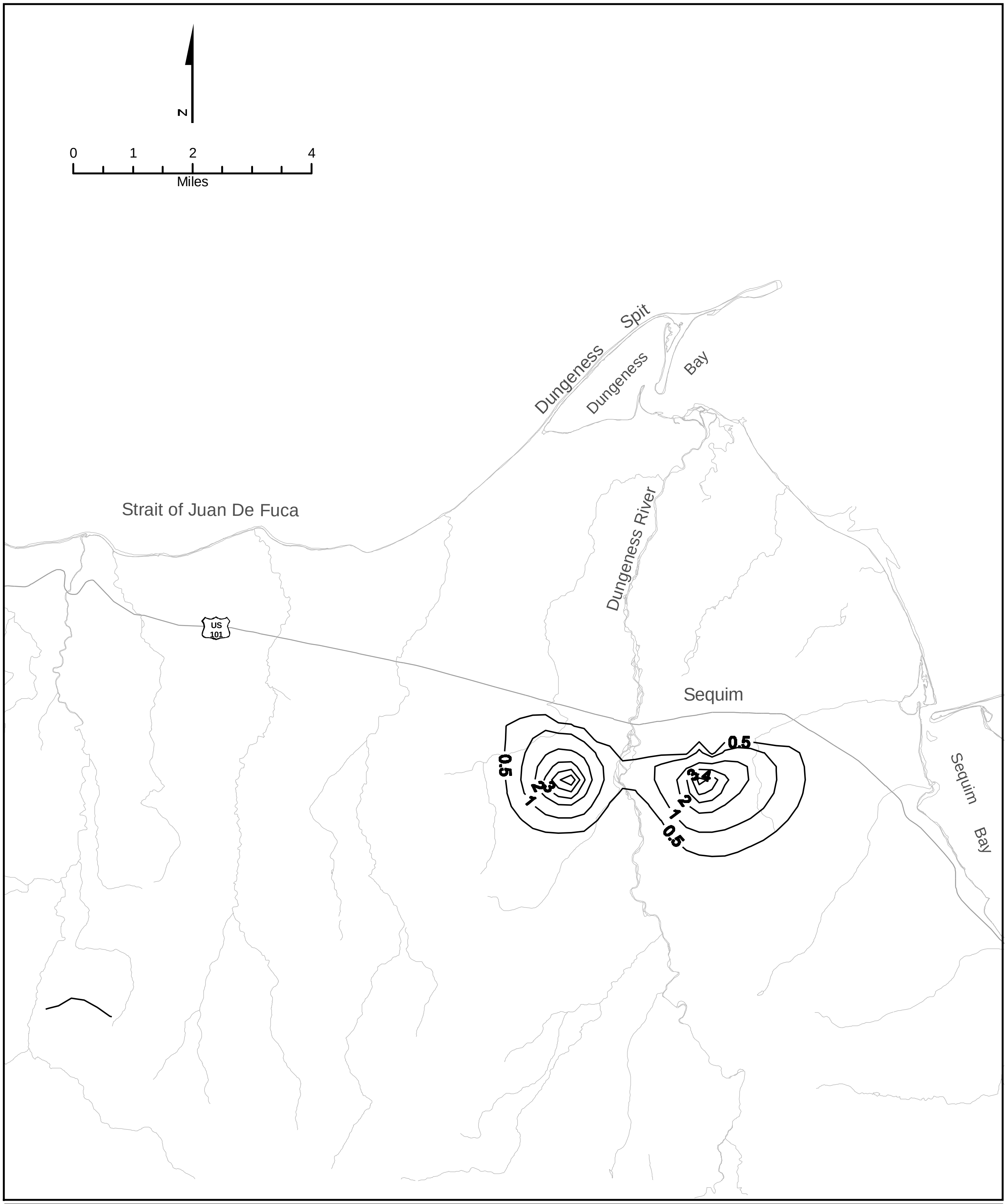


Figure 3b
Steady state head differences in Layer 3 head for ASR (compared to Cal24)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\steady_state_layer3.mxd 26 June 2003



Map Features

Streams

Highway 101

Difference in head ASR and Cal24 (ft)

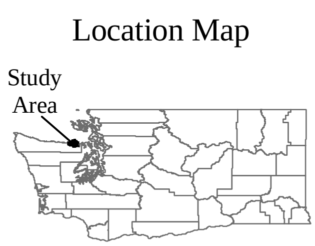
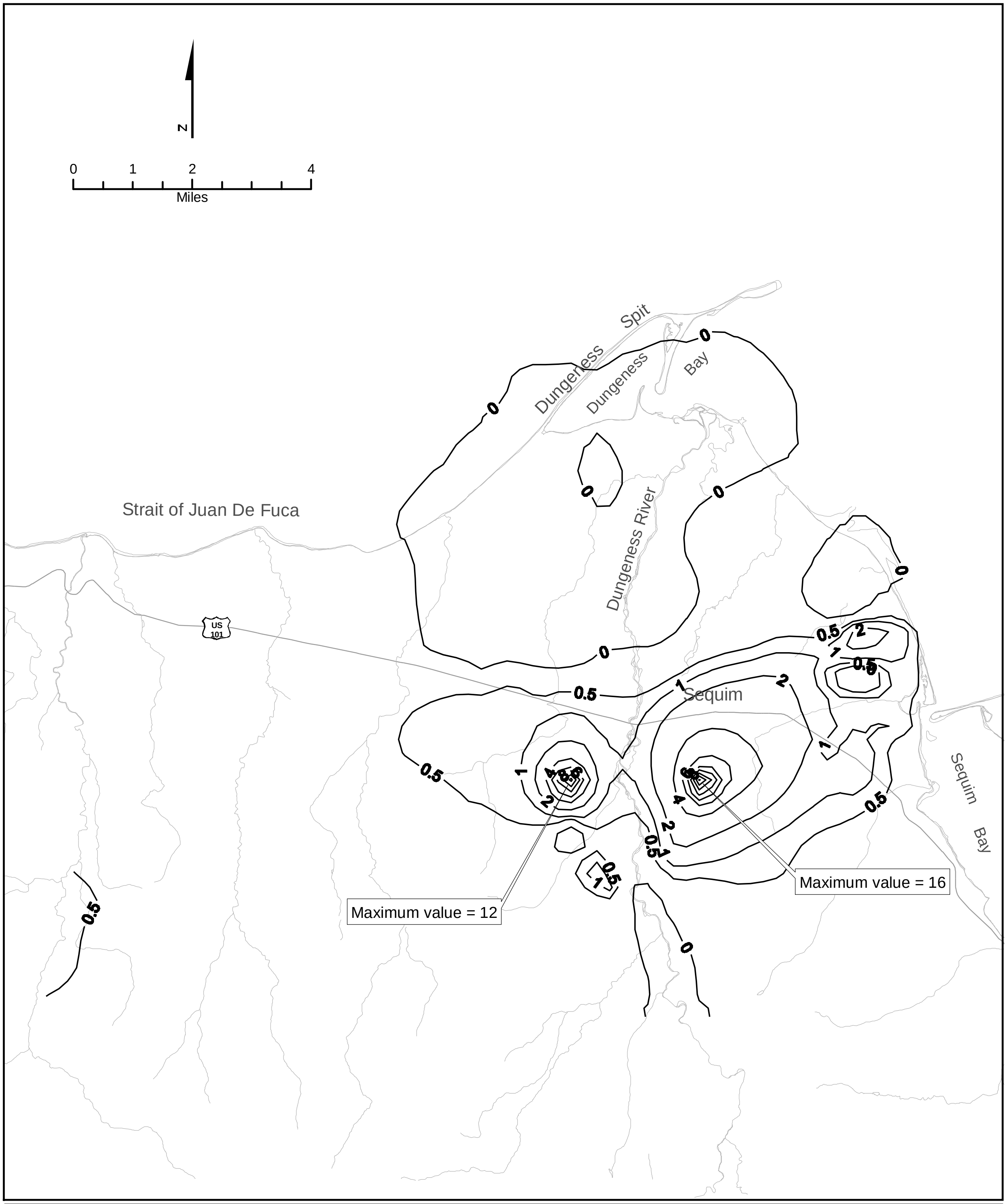


Figure 3c
Steady state head differences in Layer 5 head for ASR (compared to Cal24)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\steady_state_layer5.mxd 26 June 2003



Map Features

Streams

Highway 101

Difference in head between Intermediate ASR simulation and transient calibration (ft)

Location Map

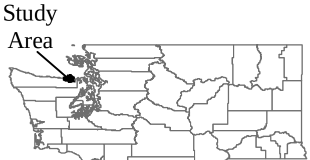
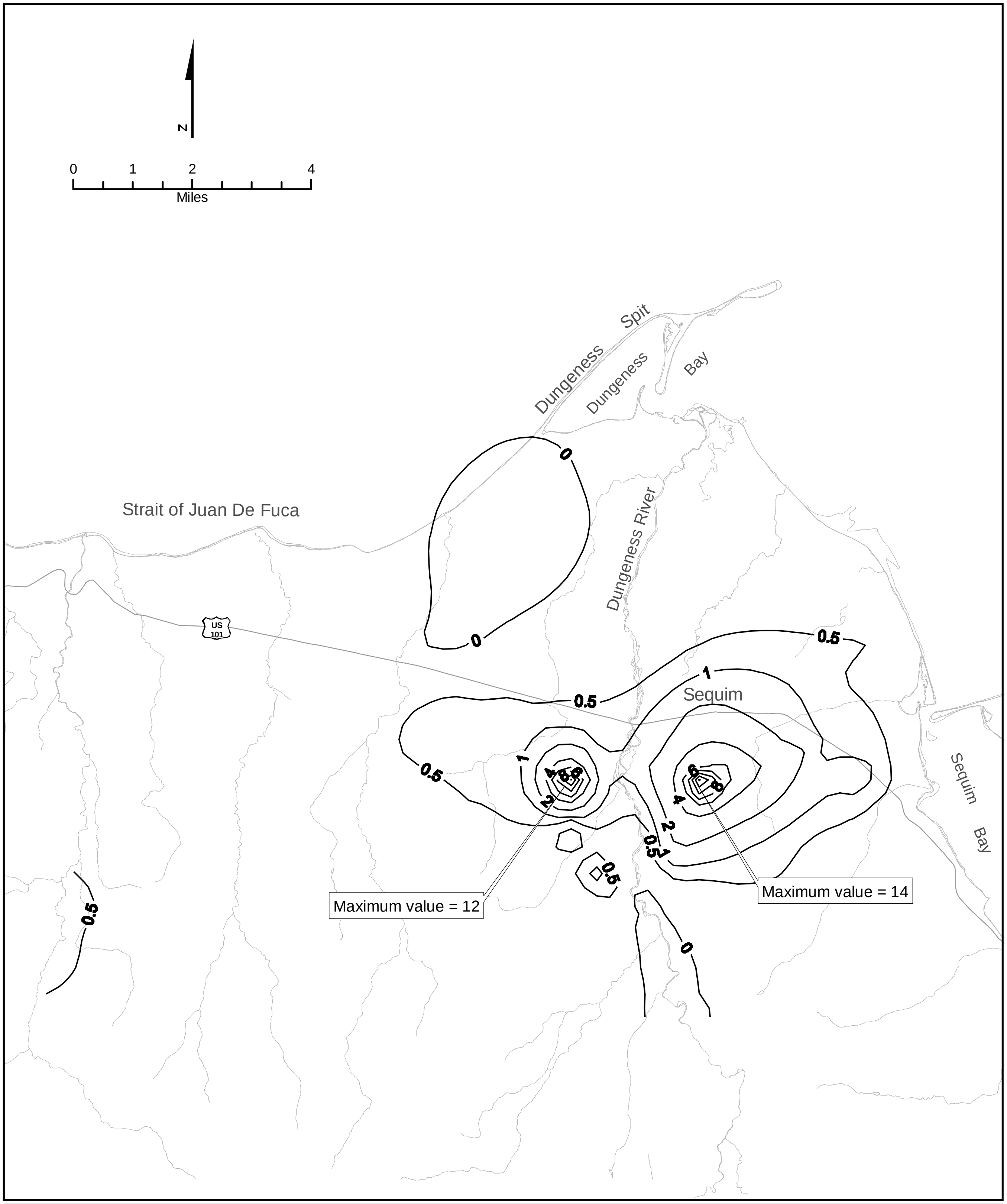


Figure 4a
ASR Layer 1 Difference in Head for Intermediate Flow - January 1996 (SP2)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\sp2_layer1.mxd 26 June 2003



Map Features

Streams

Highway 101

Difference in head between Intermediate ASR simulation and transient calibration (ft)

Location Map

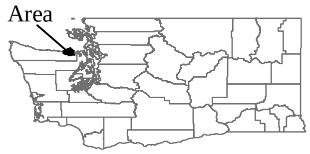
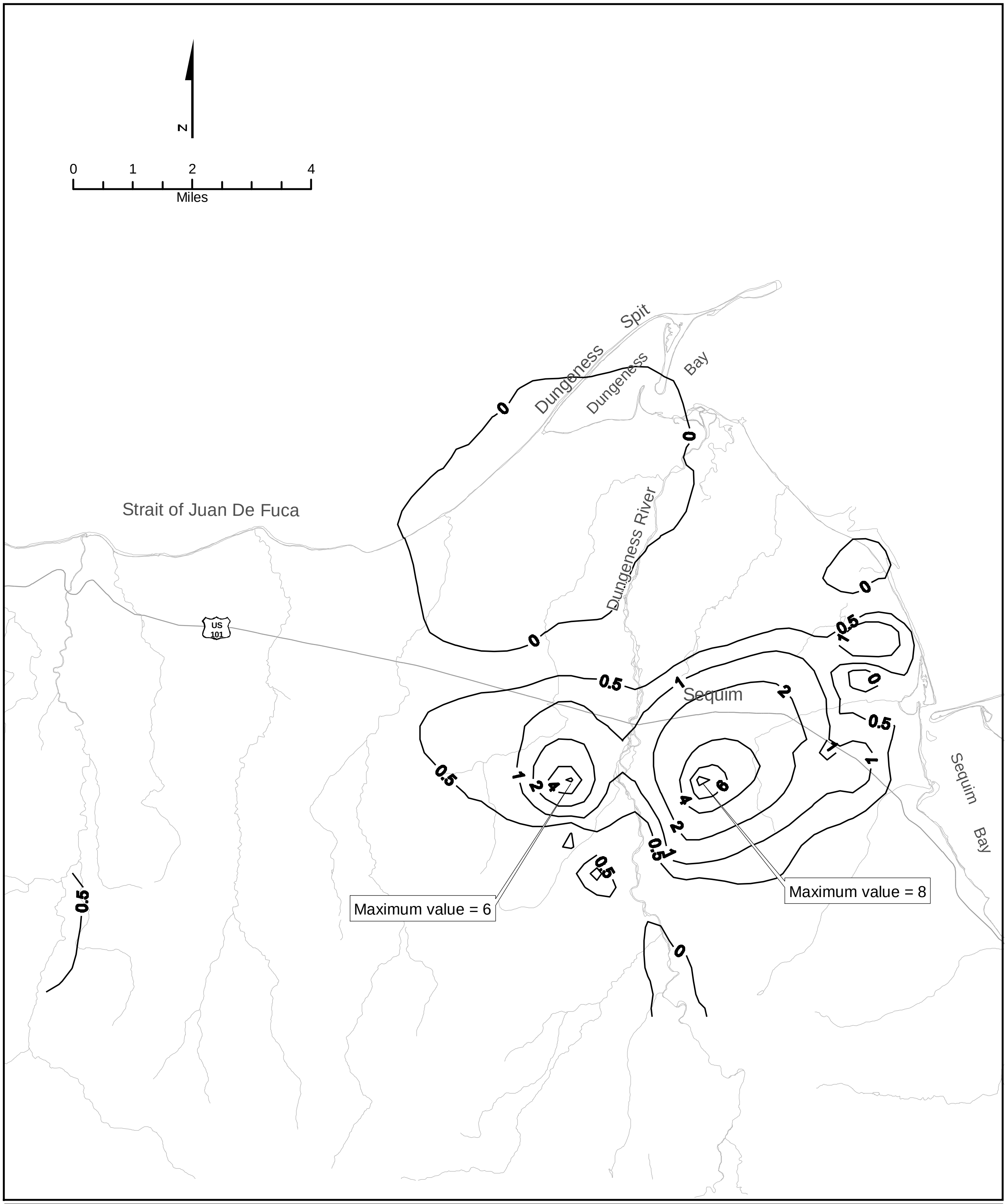


Figure 4b
ASR Layer 3 Difference in Head for Intermediate Flow - January 1996 (SP2)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\sp2_layer3.mxd 26 June 2003



Map Features

Streams

Highway 101

Difference in head between Intermediate ASR simulation and transient calibration (ft)

Location Map

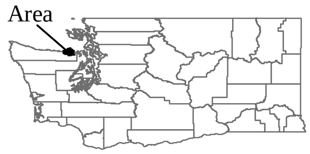
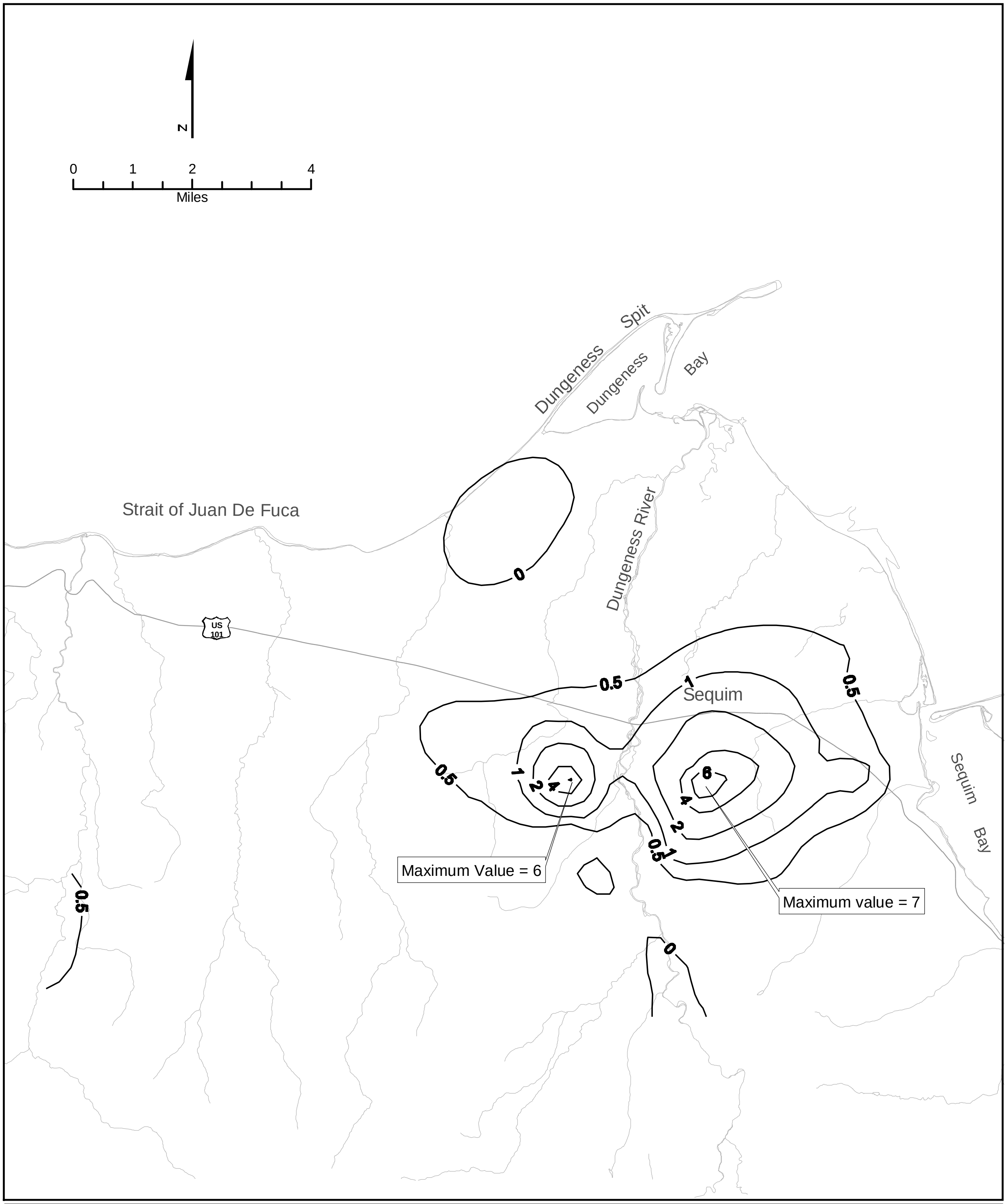


Figure 5a
ASR Layer 1 Difference in Head for Intermediate Flow - June 1996 (SP7)

TETRA TECH FW, INC.



Map Features

Streams

Highway 101

Difference in head between Intermediate ASR simulation and transient calibration (ft)

Location Map

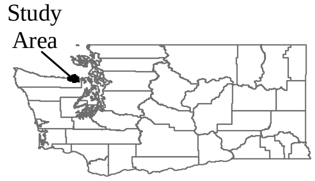
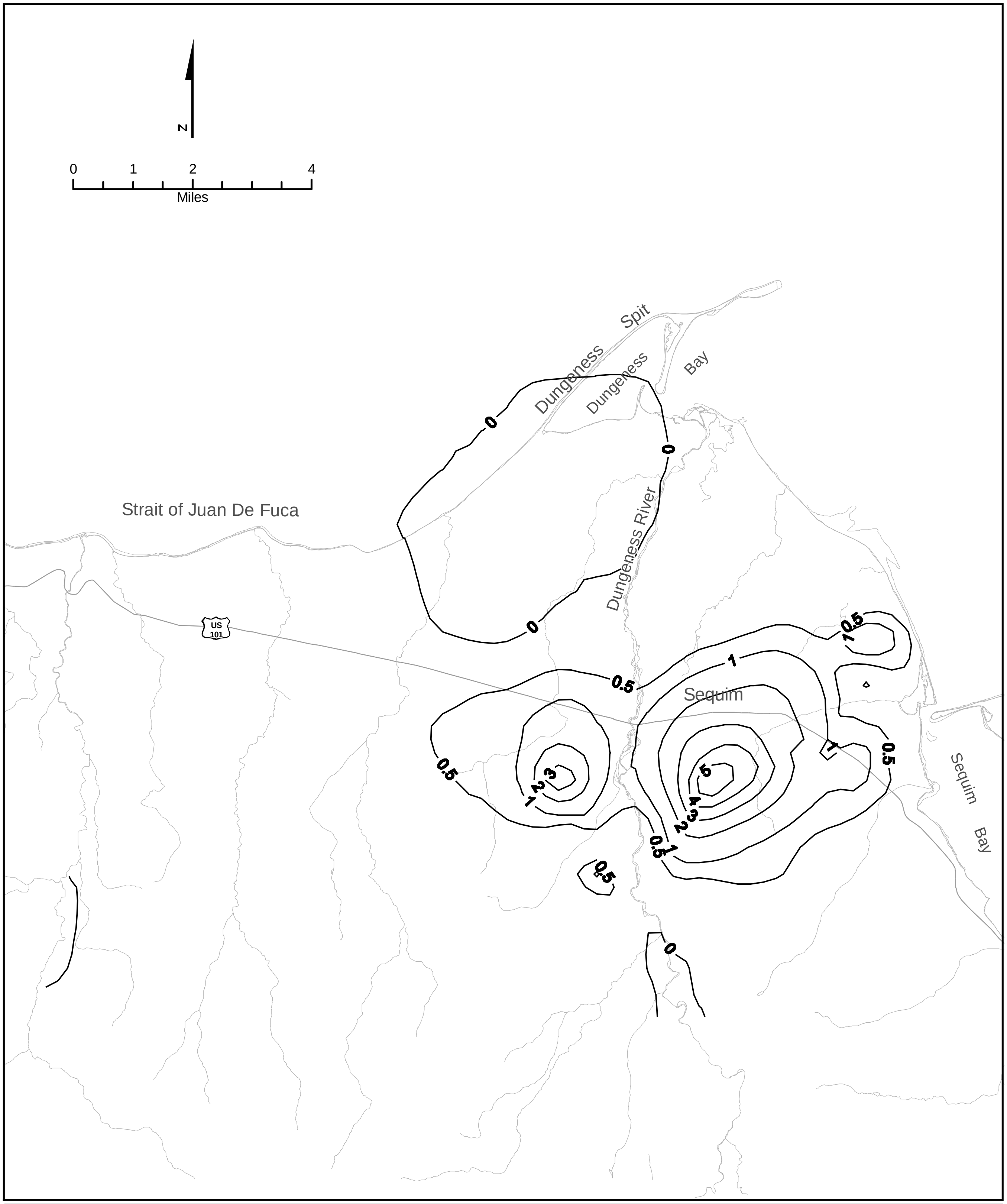


Figure 5b
ASR Layer 3 Difference in Head for Intermediate Flow - June 1996 (SP7)

TETRA TECH FW, INC.



Map Features

Streams

Highway 101

Difference in head between Intermediate ASR simulation and transient calibration (ft)

Location Map

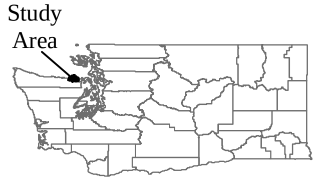
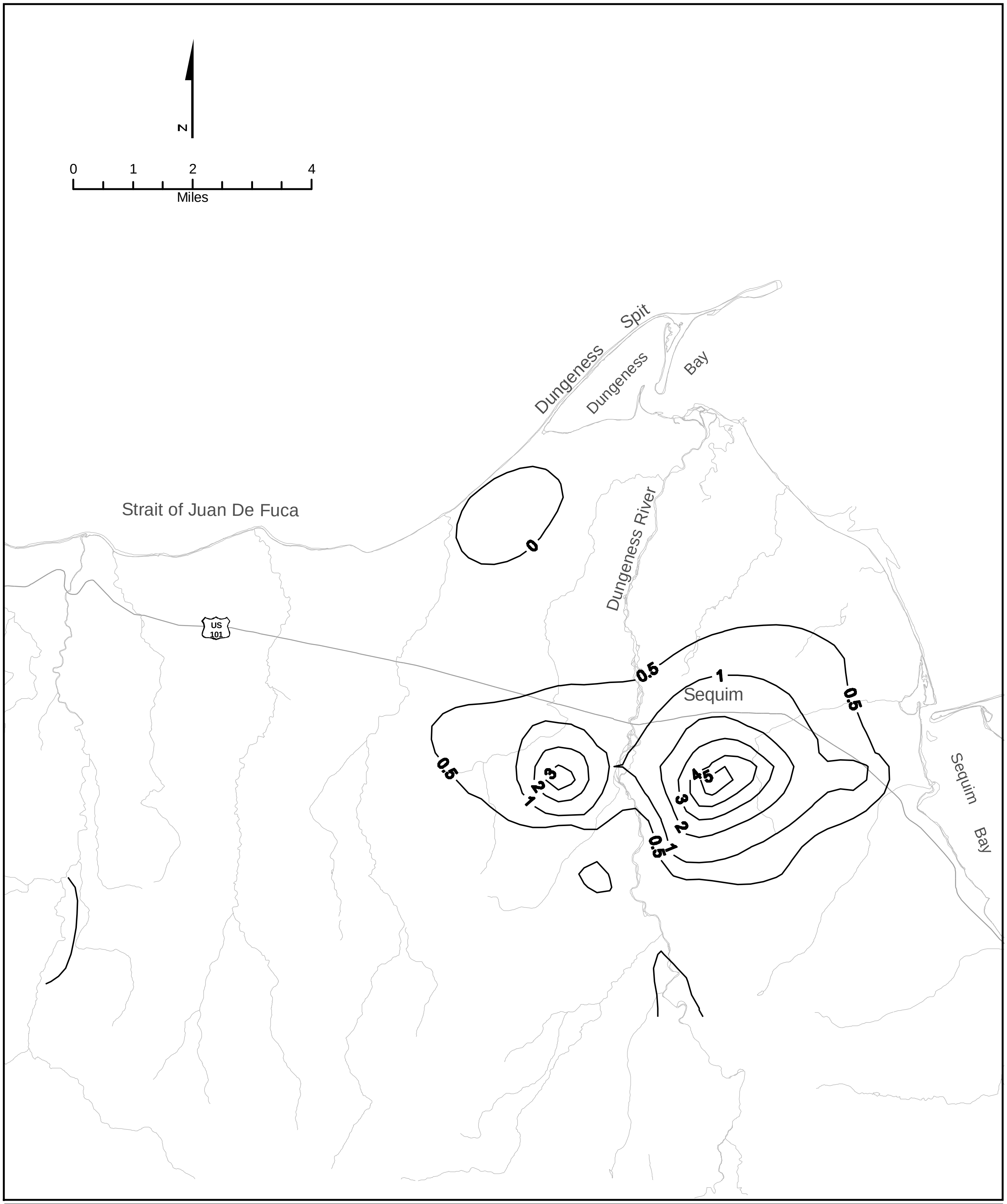


Figure 6a
ASR Layer 1 Difference in Head for Intermediate Flow - September 1996 (SP10)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\sp10_layer1.mxd 26 June 2003



Map Features

Streams

Highway 101

Difference in head between Intermediate ASR simulation and transient calibration (ft)

Location Map

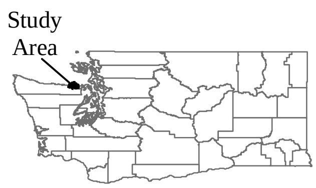
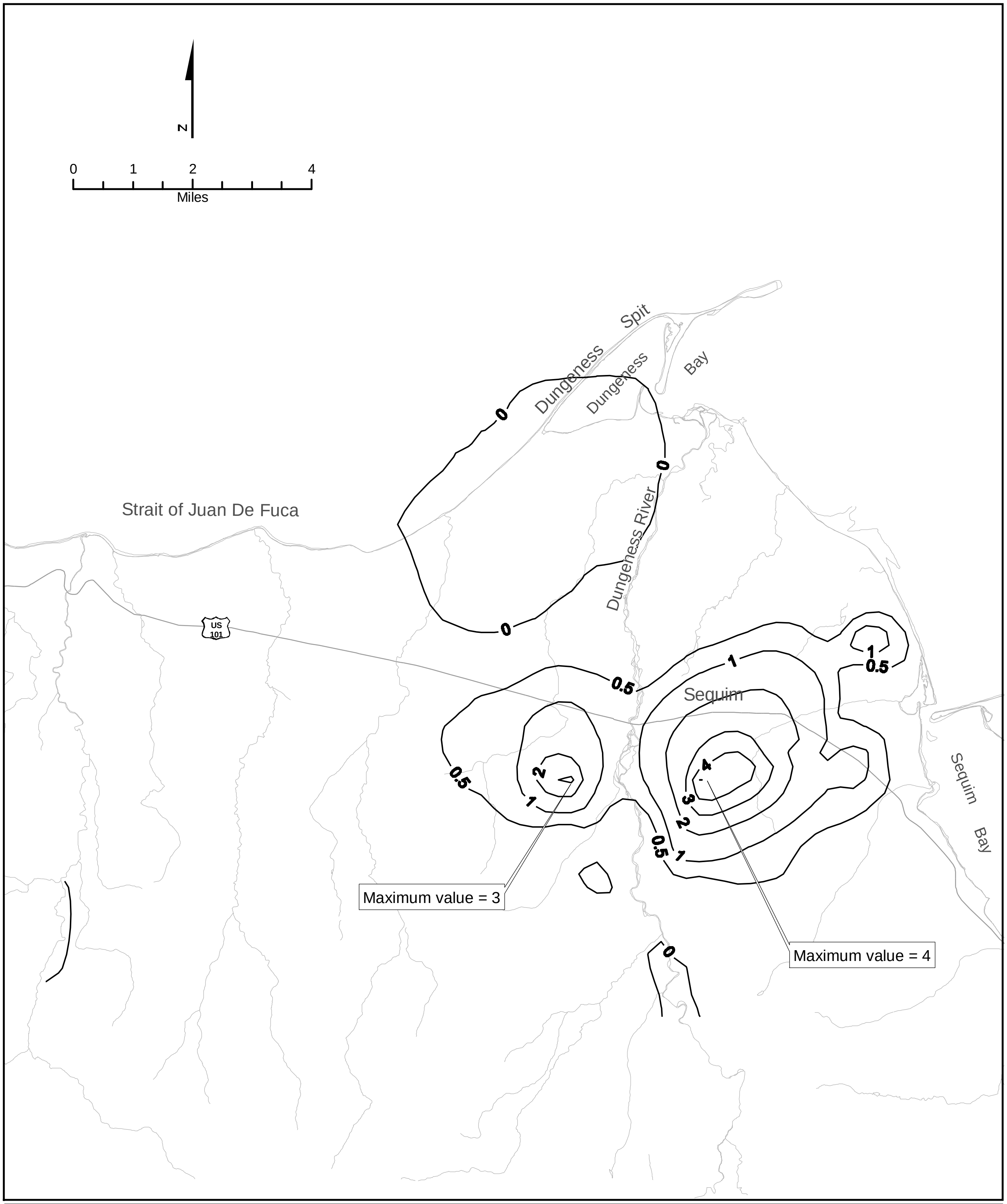


Figure 6b
ASR Layer 3 Difference in Head for Intermediate Flow - September 1996 (SP10)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\sp10_layer3.mxd 26 June 2003



Map Features

Streams

Highway 101

Difference in head between Intermediate ASR simulation and transient calibration (ft)

Location Map

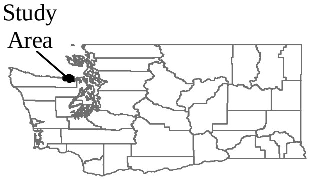
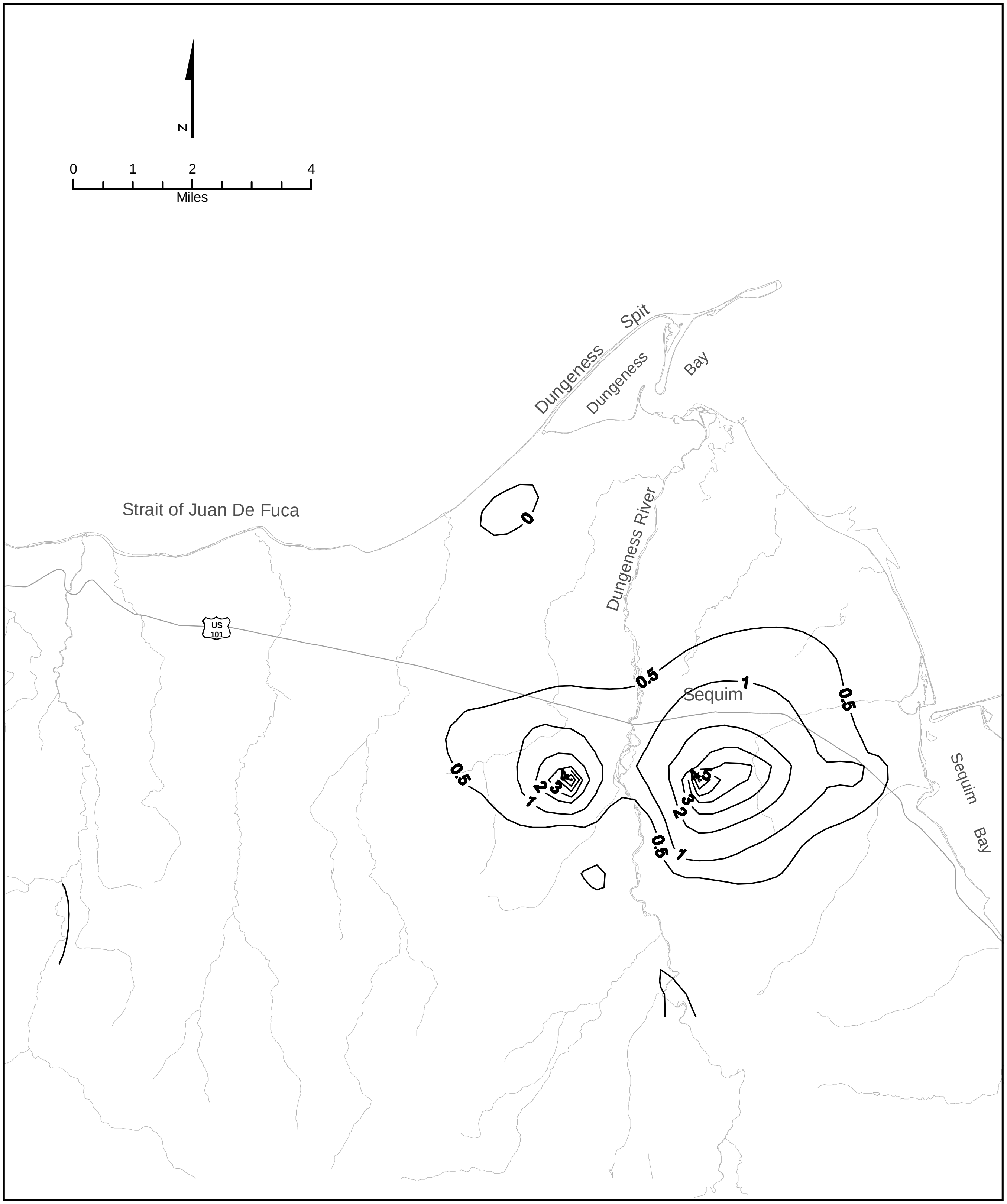


Figure 7a
ASR Layer 1 Difference in Head for Intermediate Flow - January 1997 (SP14)

TETRA TECH FW, INC.



Map Features

Streams

Highway 101

Difference in head between Intermediate ASR simulation and transient calibration (ft)

Location Map

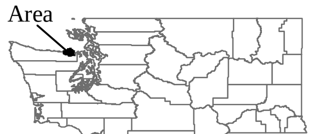
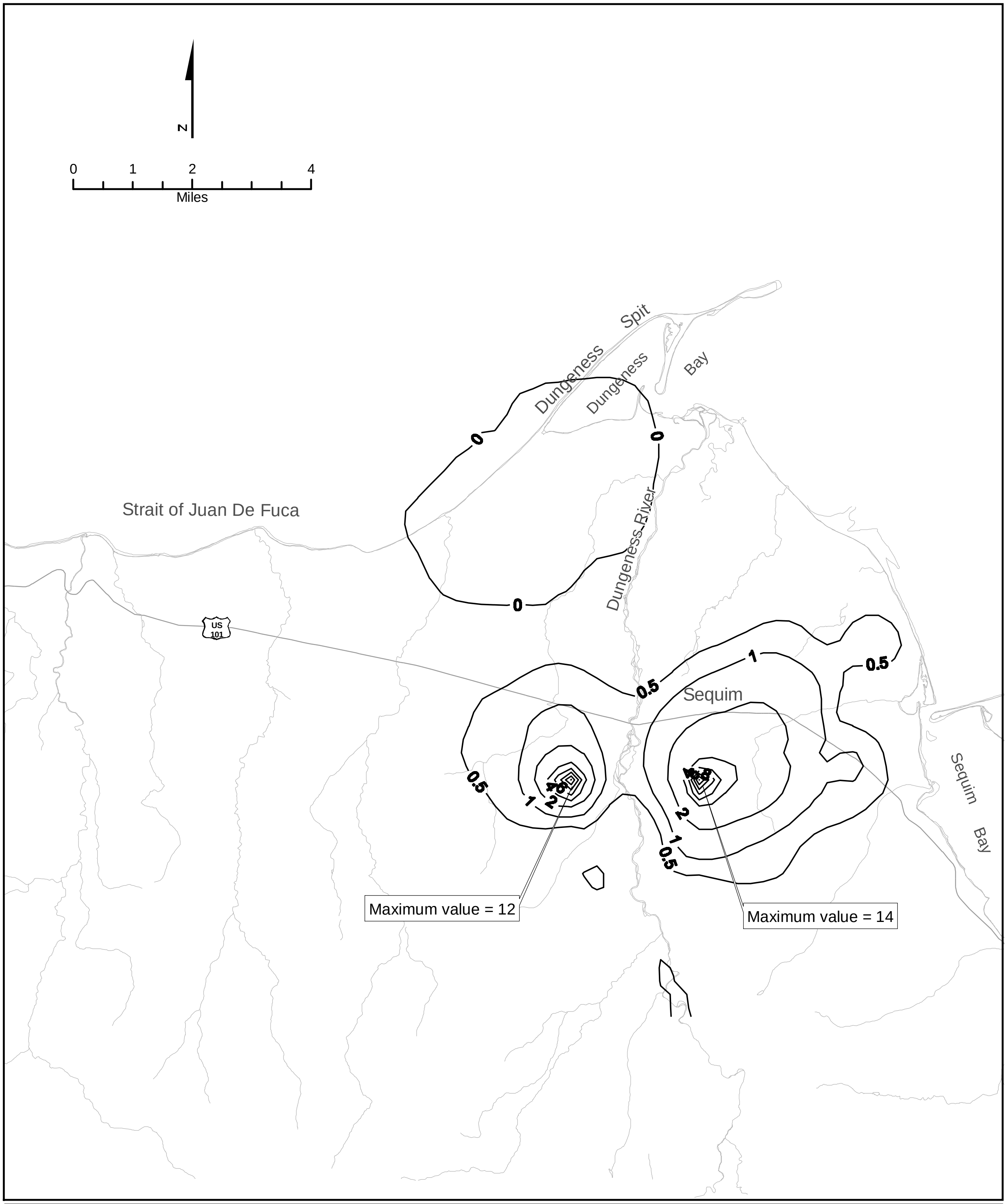


Figure 7b
ASR Layer 3 Difference in Head for Intermediate Flow - January 1997 (SP14)

TETRA TECH FW, INC.



Map Features

Streams

Highway 101

Difference in head between Intermediate ASR simulation and transient calibration (ft)

Location Map

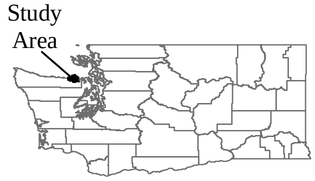
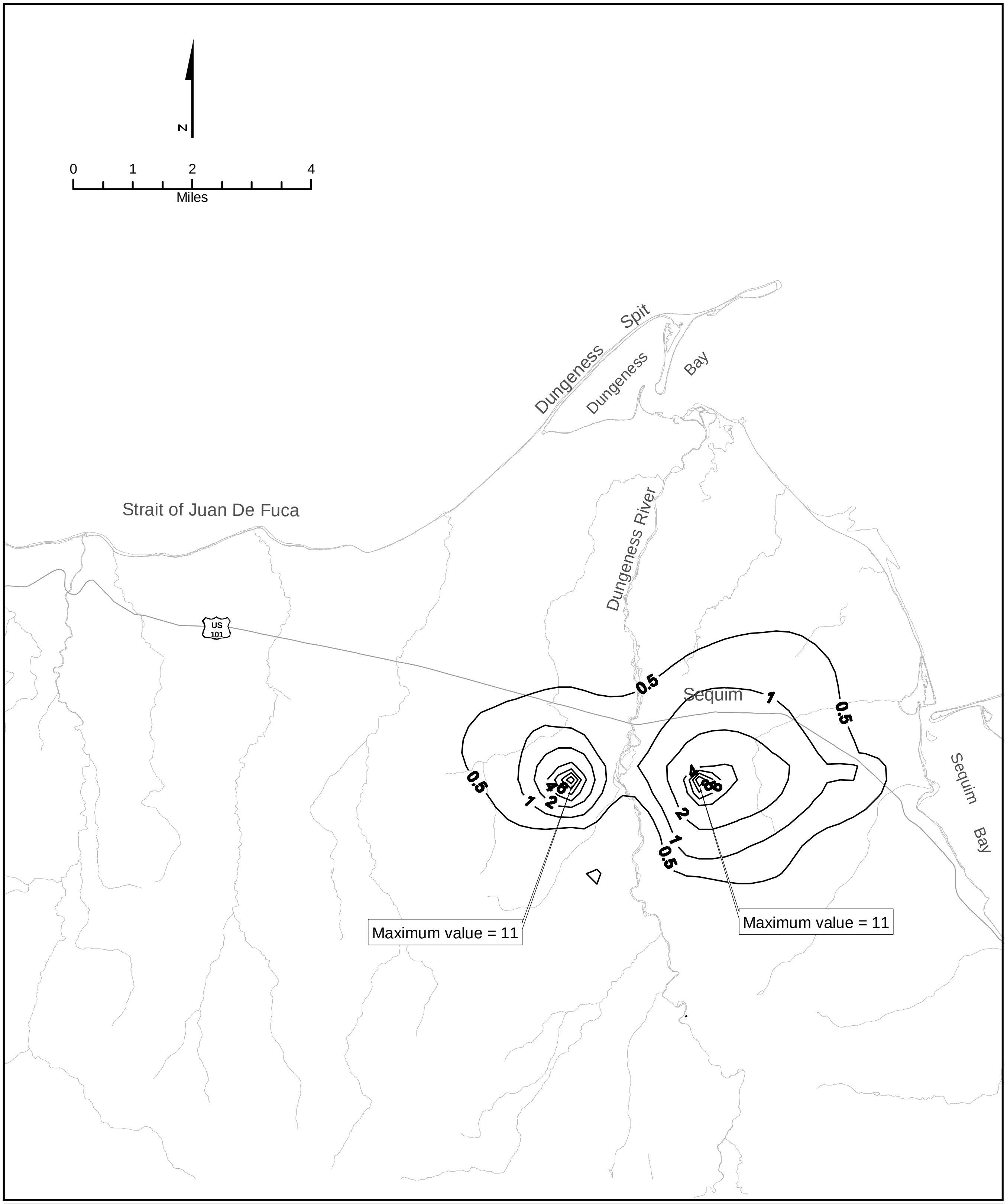


Figure 8a
ASR Layer 1 Difference in Head for Intermediate Flow - June 1997 (SP19)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\sp19_layer1.mxd 26 June 2003



Map Features

Streams
Highway 101
Difference in head between Intermediate ASR simulation and transient calibration (ft)

Location Map

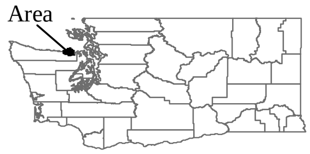
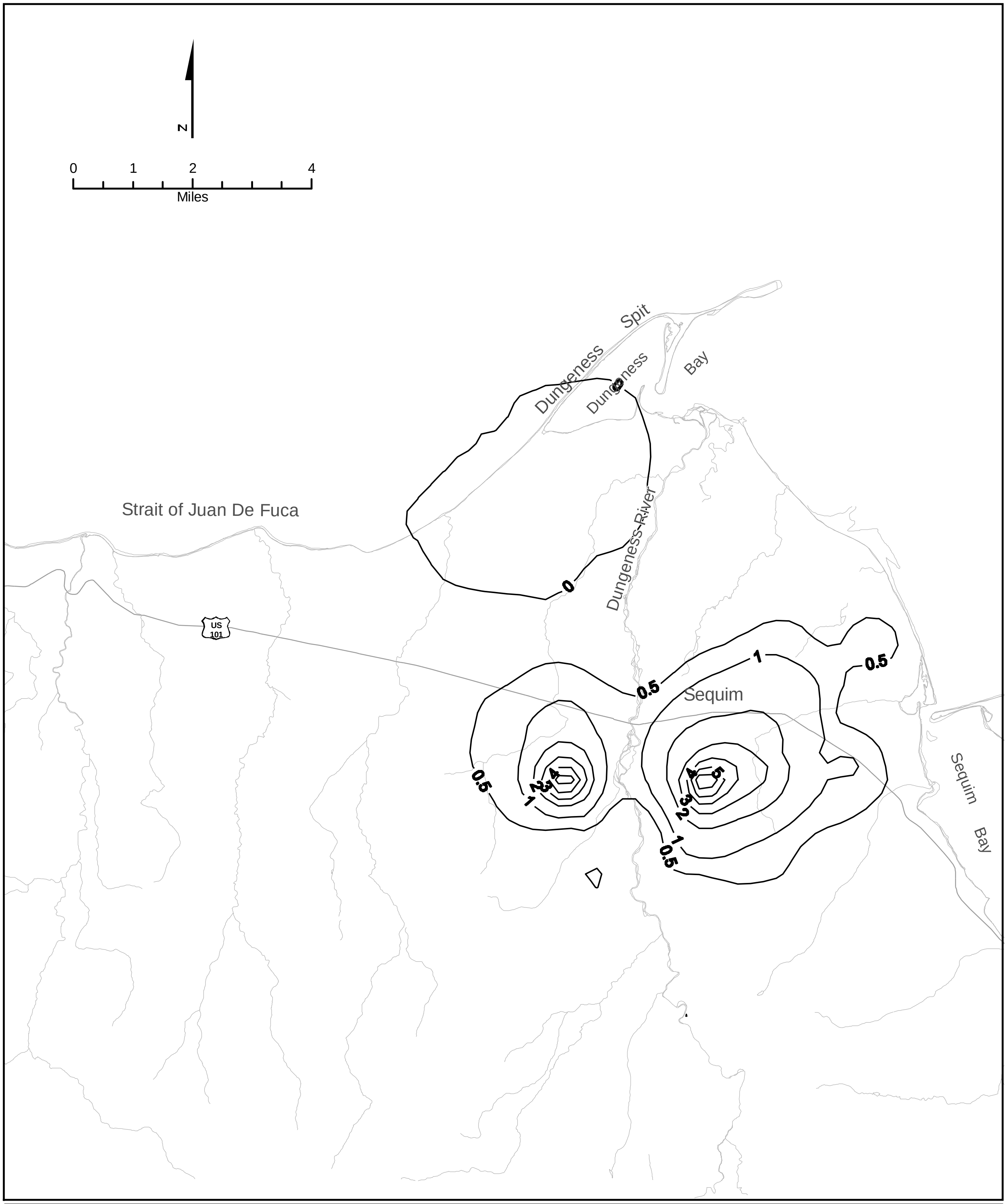


Figure 8b
ASR Layer 3 Difference in Head for Intermediate Flow - June 1997 (SP19)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\sp19_layer3.mxd 26 June 2003



Map Features

Streams

Highway 101

Difference in head between Intermediate ASR simulation and transient calibration (ft)

Location Map

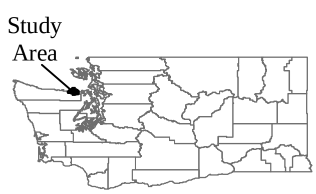
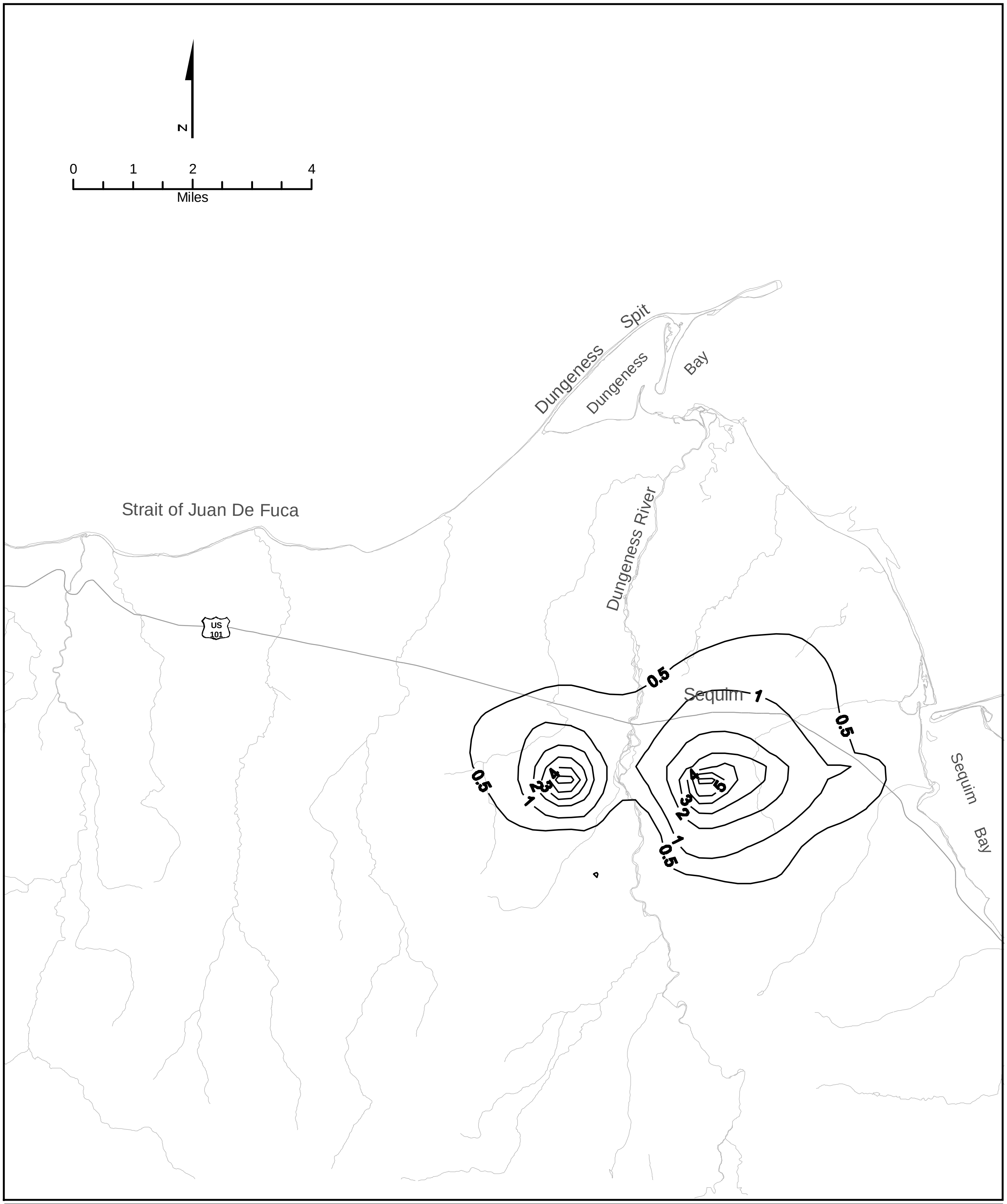


Figure 9a
ASR Layer 1 Difference in Head for Intermediate Flow - September 1997 (SP22)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\sp22_layer1.mxd 26 June 2003



Map Features

Streams

Highway 101

Difference in head between Intermediate ASR simulation and transient calibration (ft)

Location Map

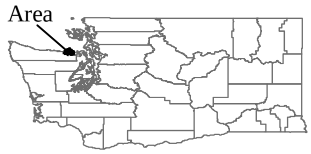
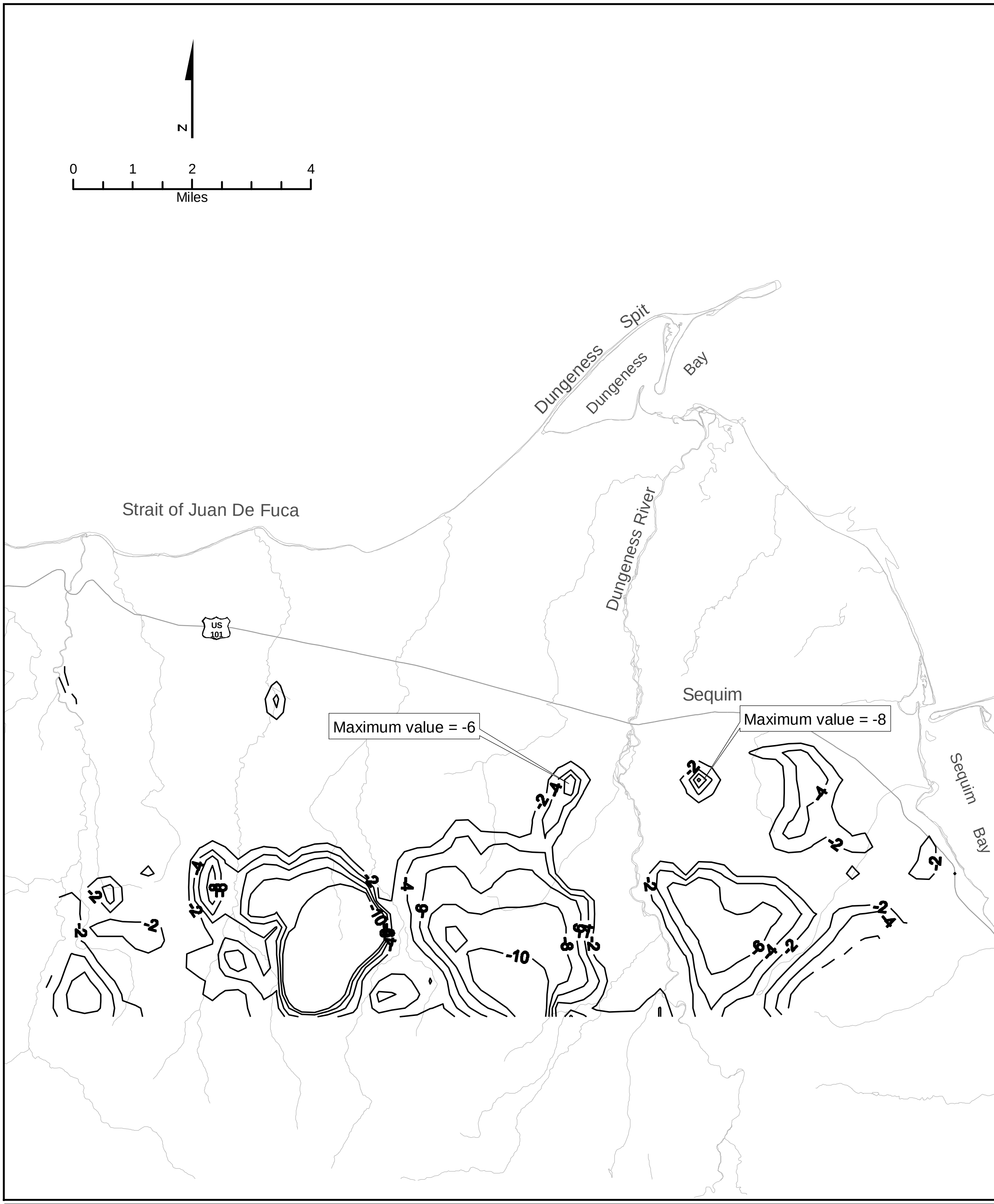


Figure 9b
ASR Layer 3 Difference in Head for Intermediate Flow - September 1997 (SP22)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\sp22_layer3.mxd 26 June 2003



Map Features

Streams

Highway 101

Difference in head between Low and Intermediate ASR simulations (ft)

Note: Negative contour values indicate head values are lower than those associated with Intermediate Flow. Contour values below -10 are not shown.

Location Map

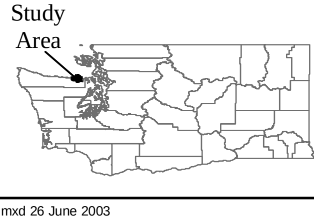
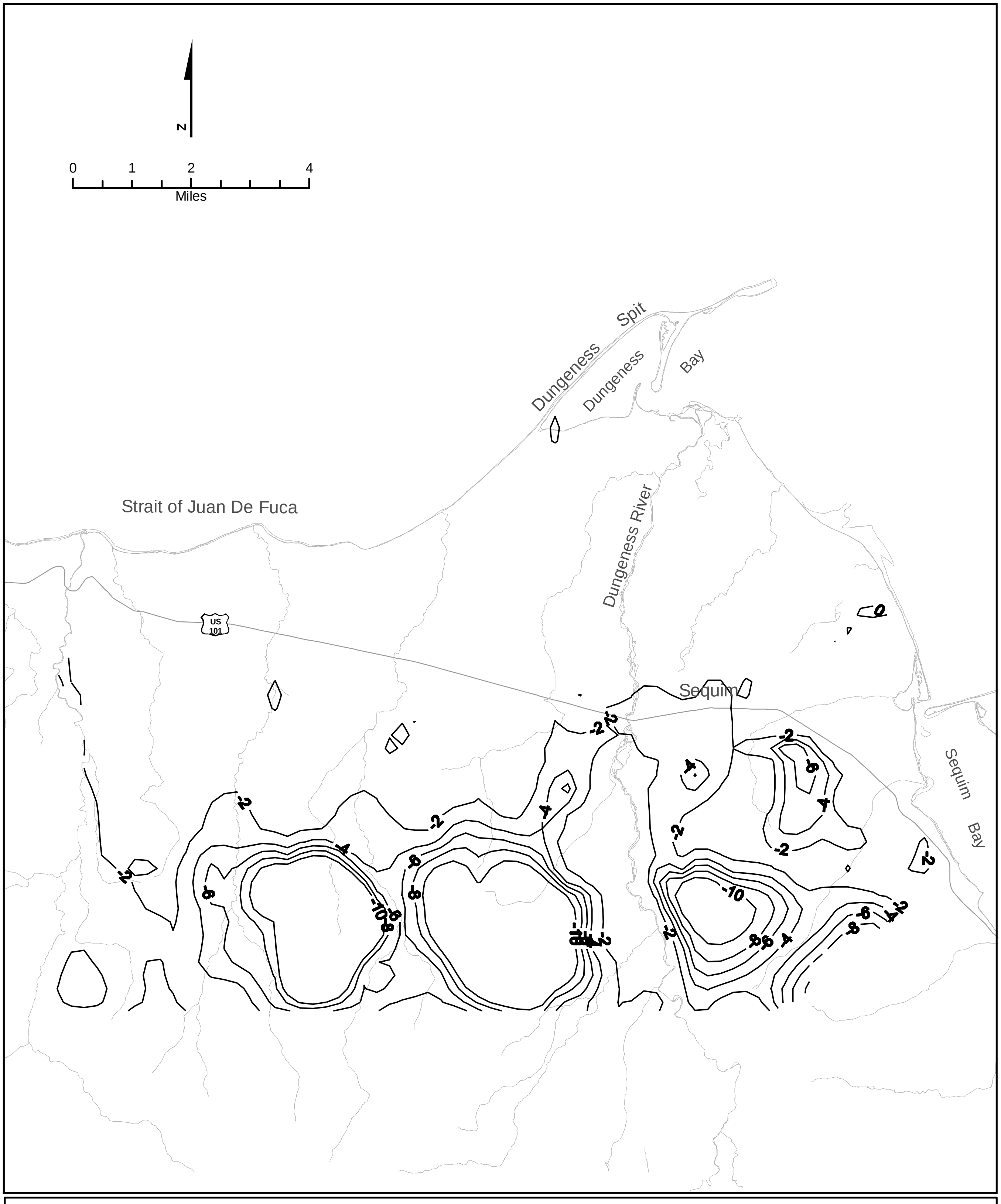


Figure 10
Low Flow ASR difference in Layer 1 head compared to Intermediate Flow - January first year (SP2)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\sp2_low_flow_layer1.mxd 26 June 2003



Map Features

Streams

Highway 101

Difference in head between Low and Intermediate ASR simulations (ft)

Note: Negative contour values indicate head values are lower than those associated with Intermediate Flow. Contour values below -10 are not shown.

Location Map

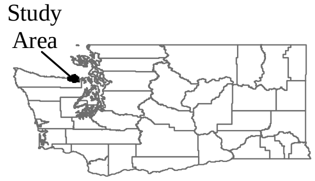
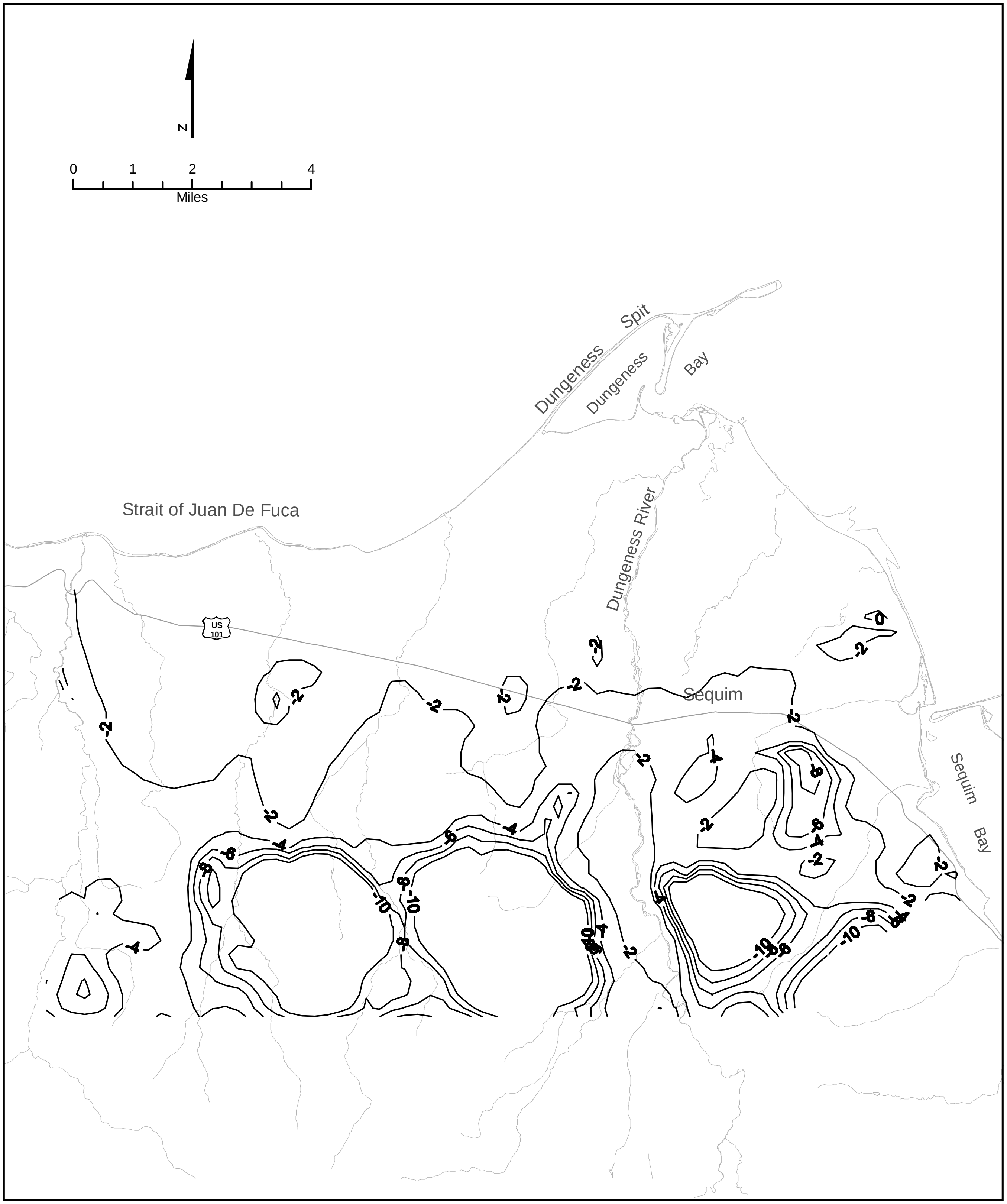


Figure 11
Low Flow ASR difference in Layer 1 head compared to Intermediate Flow - June first year (SP7)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\sp7_low_flow_layer1.mxd 26 June 2003



Map Features

Streams

Highway 101

Difference in head between Low and Intermediate ASR simulations (ft)

Note: Negative contour values indicate head values are lower than those associated with Intermediate Flow. Contour values below -10 are not shown.

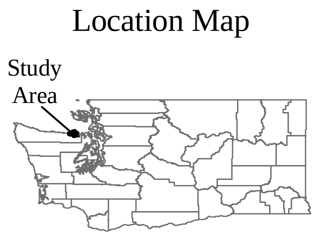
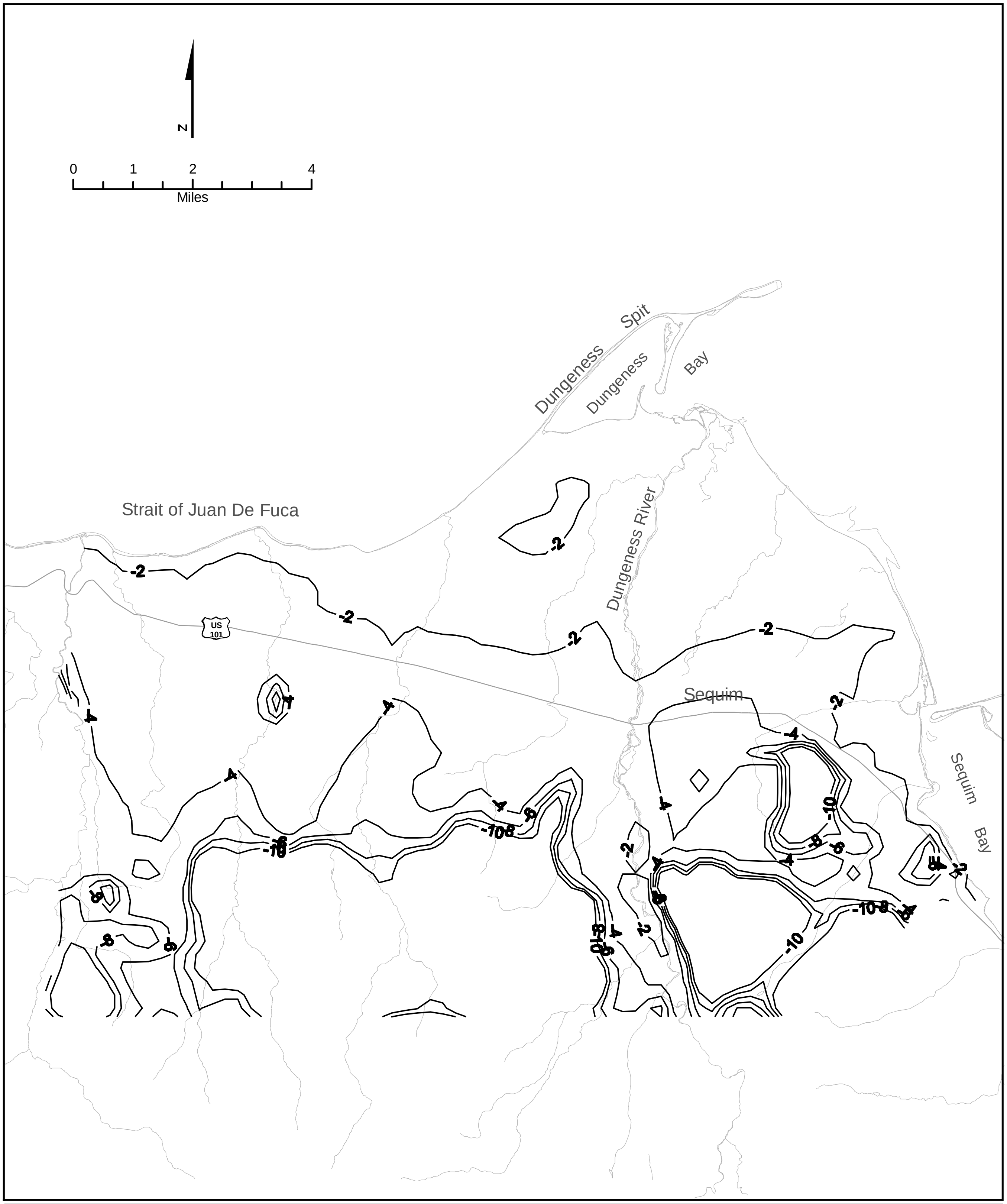


Figure 12
Low Flow ASR difference in Layer 1 head compared to Intermediate Flow - September first year (SP10)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\sp10_low_flow_layer1.mxd 26 June 2003



Map Features

Streams

Highway 101

Difference in head between Low and Intermediate ASR simulations (ft)

Note: Negative contour values indicate head values are lower than those associated with Intermediate Flow. Contour values below -10 are not shown.

Location Map

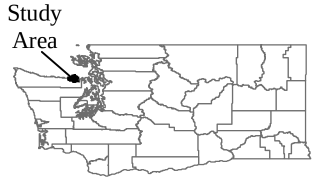
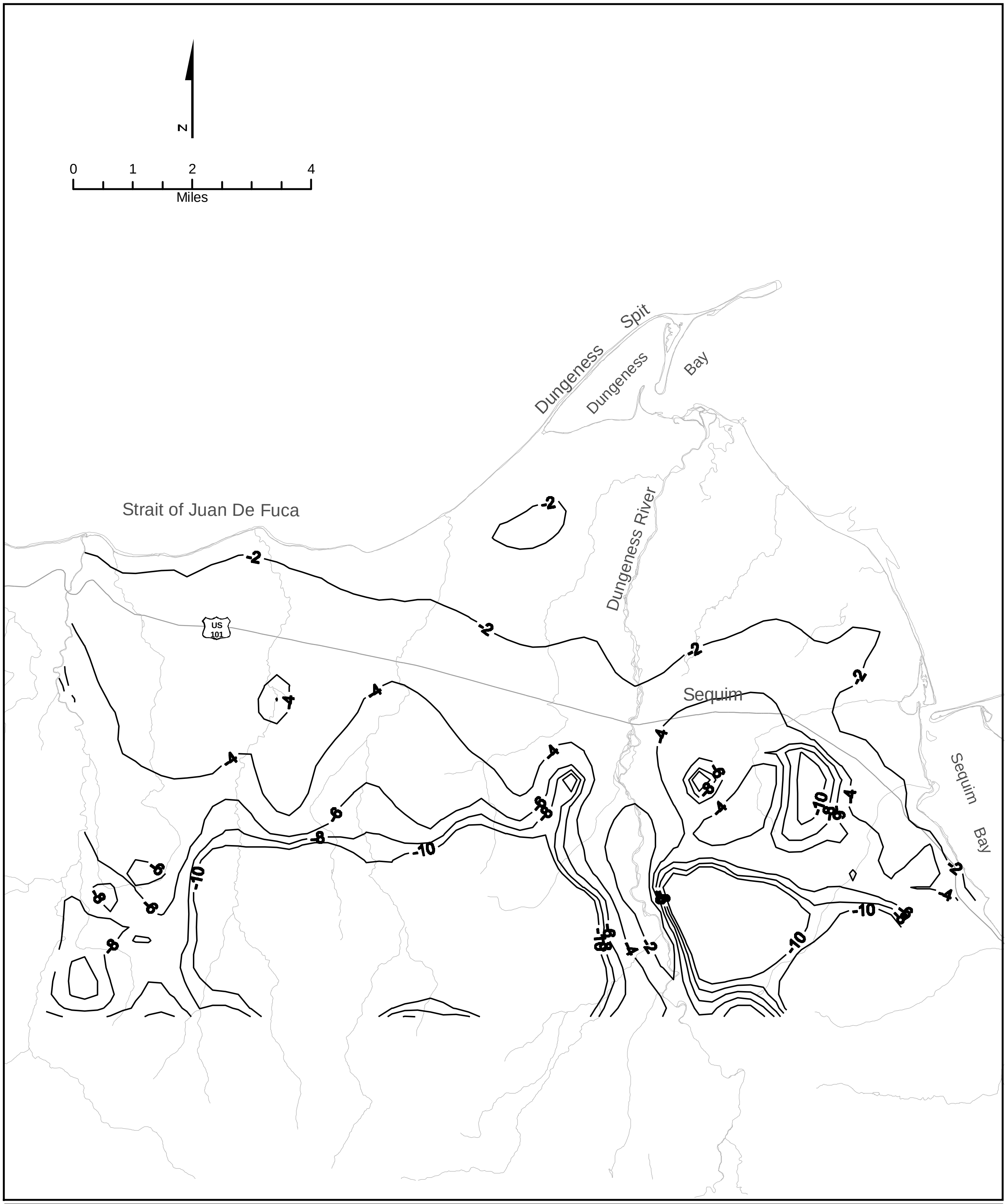


Figure 13
Low Flow ASR difference in Layer 1 head compared to Intermediate Flow - January second year (SP14)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\sp14_low_flow_layer1.mxd 26 June 2003



Map Features

Streams

Highway 101

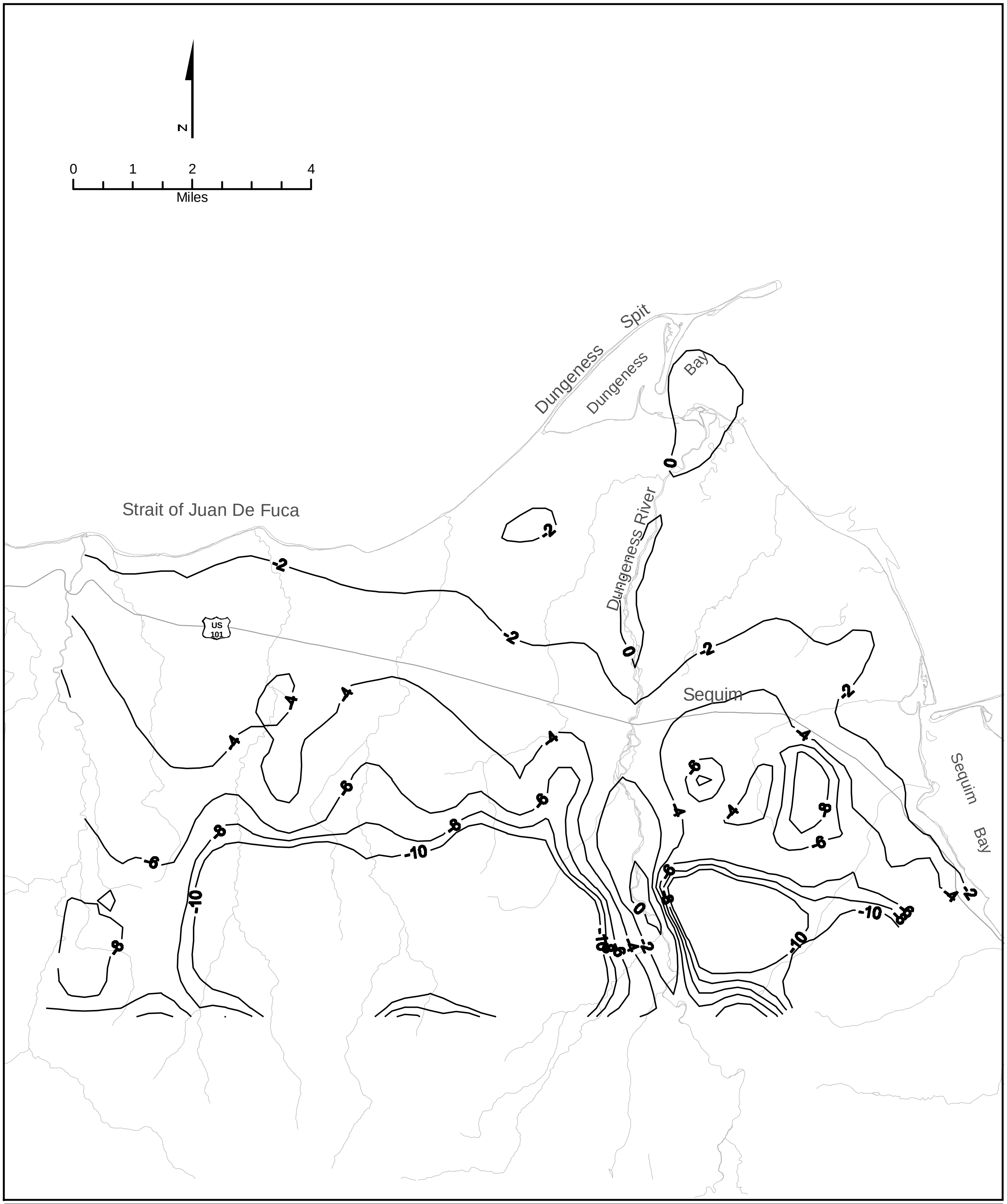
Difference in head between Low and Intermediate ASR simulations (ft)

Note: Negative contour values indicate head values are lower than those associated with Intermediate Flow. Contour values below -10 are not shown.

Figure 14
Low Flow ASR difference in Layer 1 head compared to Intermediate Flow - June second year (SP19)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\sp19_low_flow_layer1.mxd 26 June 2003



Map Features

Streams

Highway 101

Difference in head between Low and Intermediate ASR simulations (ft)

Note: Negative contour values indicate head values are lower than those associated with Intermediate Flow. Contour values below -10 are not shown.

Location Map

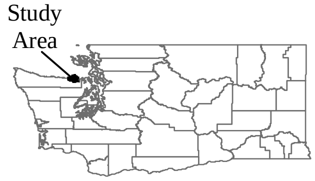
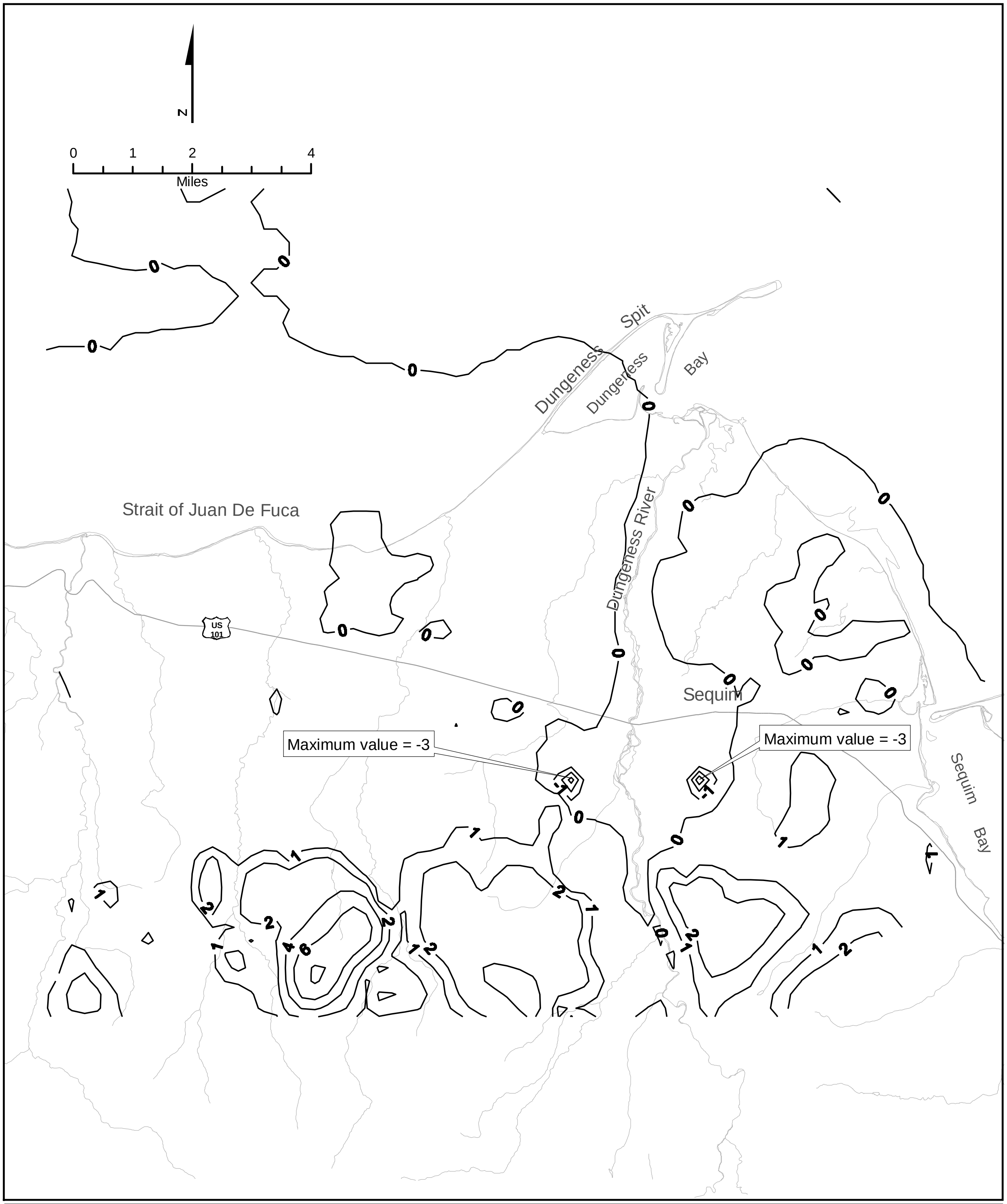


Figure 15
Low Flow ASR difference in Layer 1 head compared to Intermediate Flow - September second year (SP22)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\sp22_low_flow_layer1.mxd 26 June 2003



Map Features

Streams

Highway 101

Difference in head between High and Intermediate ASR simulations (ft)

Note: Negative contour values indicate head values are lower than those associated with Intermediate Flow. Contour values below -10 are not shown.

Location Map

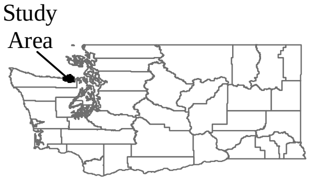
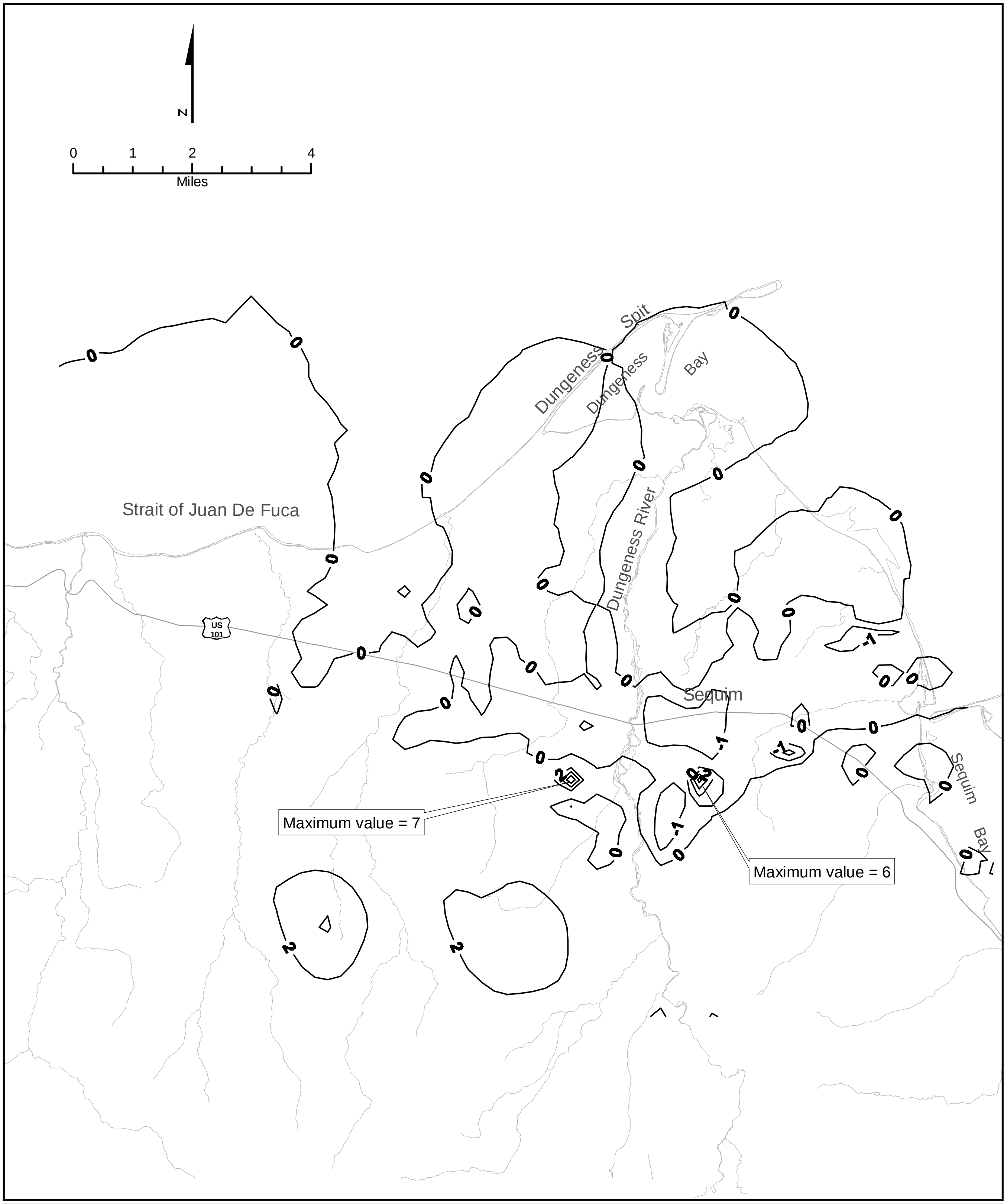


Figure 16
High Flow ASR difference in Layer 1 head compared to Intermediate Flow - January first year (SP2)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\sp2_high_flow_layer1.mxd 26 June 2003



Map Features

Streams

Highway 101

Difference in head between High and Intermediate ASR simulations (ft)

Note: Negative contour values indicate head values are lower than those associated with Intermediate Flow. Contour values below -10 are not shown.

Location Map

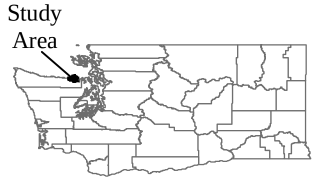
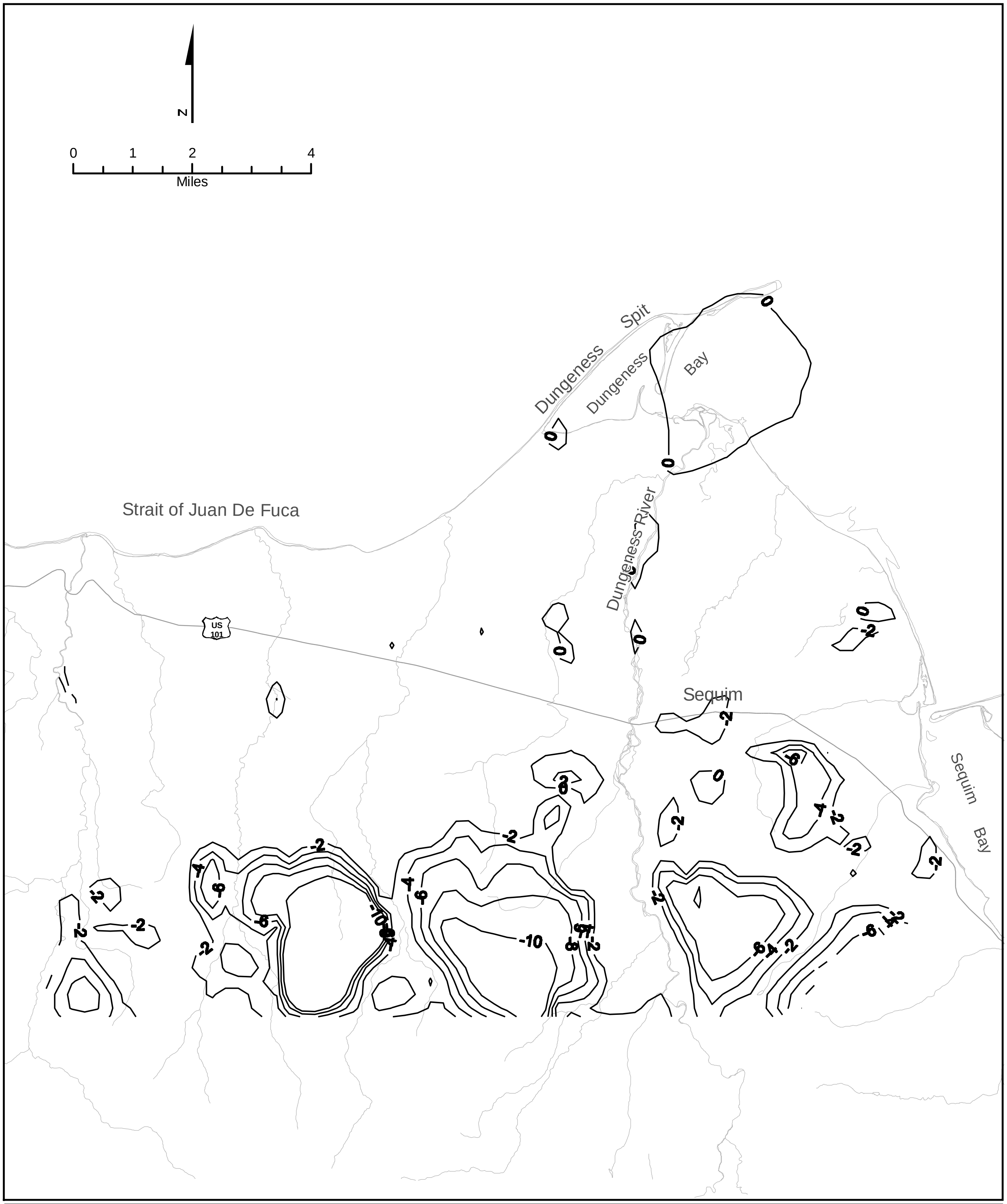


Figure 17
High Flow ASR difference in Layer 1 head compared to Intermediate Flow - June first year (SP7)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\sp7_high_flow_layer1.mxd 26 June 2003



Map Features

Streams

Highway 101

Difference in head between High and Intermediate ASR simulations (ft)

Note: Negative contour values indicate head values are lower than those associated with Intermediate Flow. Contour values below -10 are not shown.

Location Map

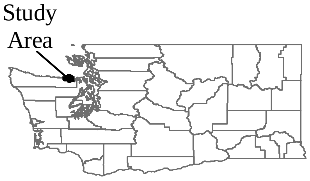
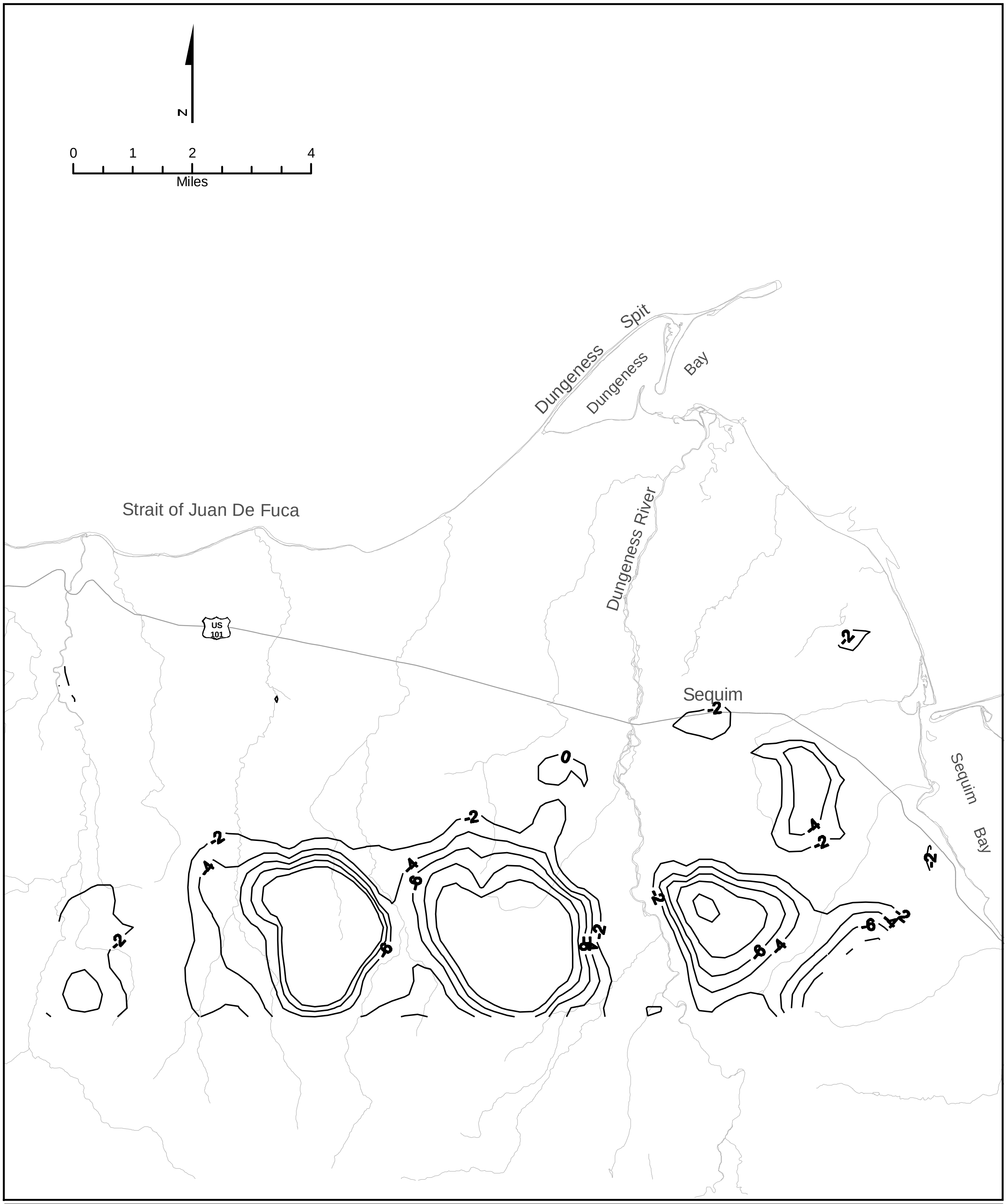


Figure 18
High Flow ASR difference in Layer 1 head compared to Intermediate Flow - September first year (SP10)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\sp10_high_flow_layer1.mxd 26 June 2003



Map Features

Streams

Highway 101

Difference in head between High and Intermediate ASR simulations (ft)

Note: Negative contour values indicate head values are lower than those associated with Intermediate Flow. Contour values below -10 are not shown.

Location Map

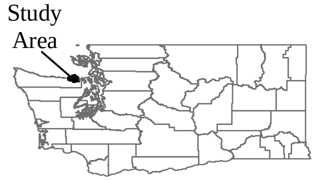
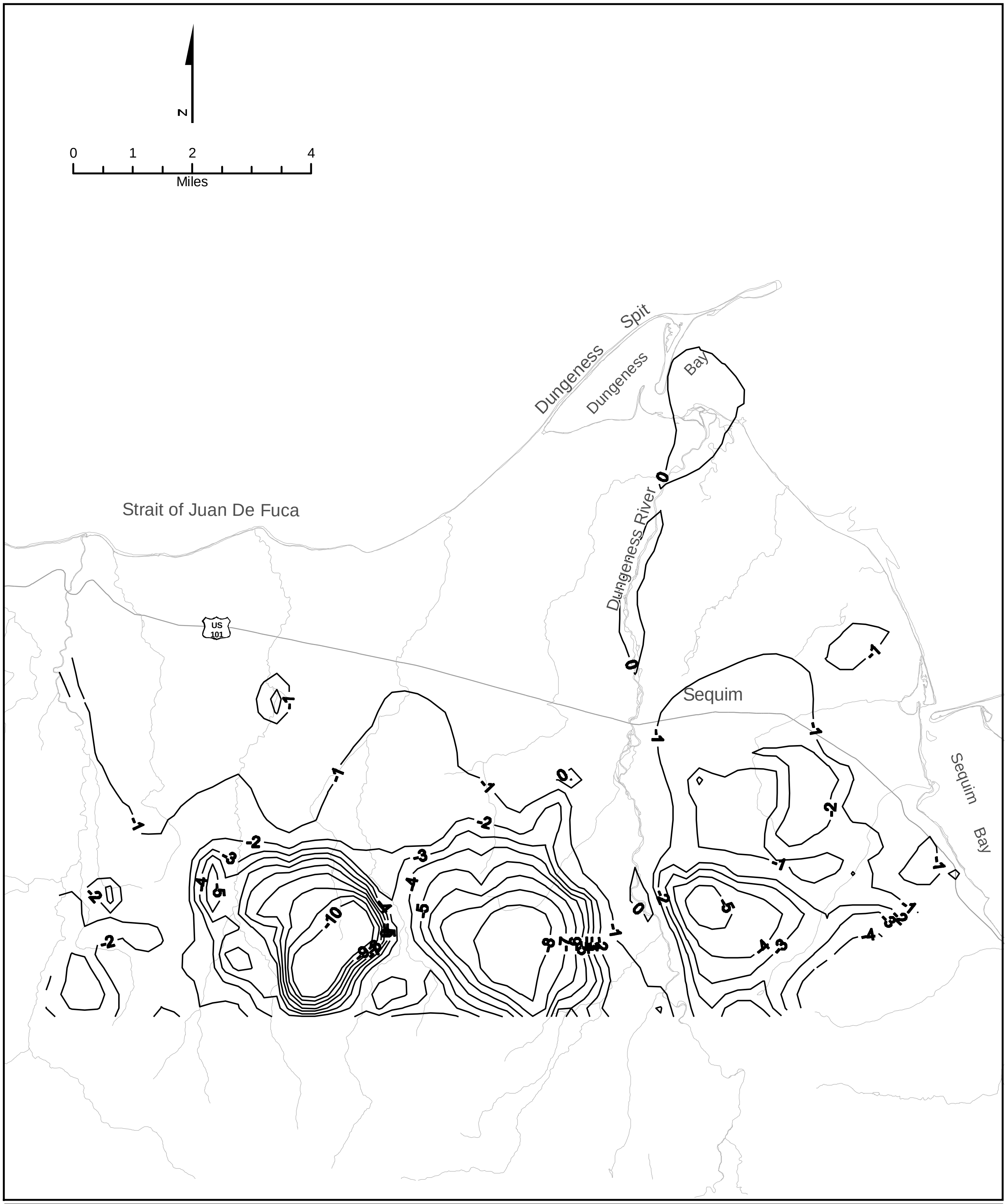


Figure 19
High Flow ASR difference in Layer 1 head compared to Intermediate Flow - January second year (SP14)

TETRA TECH FW, INC.



Map Features

Streams

Highway 101

Difference in head between High and Intermediate ASR simulations (ft)

Note: Negative contour values indicate head values are lower than those associated with Intermediate Flow. Contour values below -10 are not shown.

Location Map

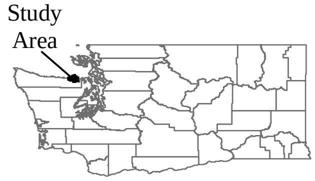
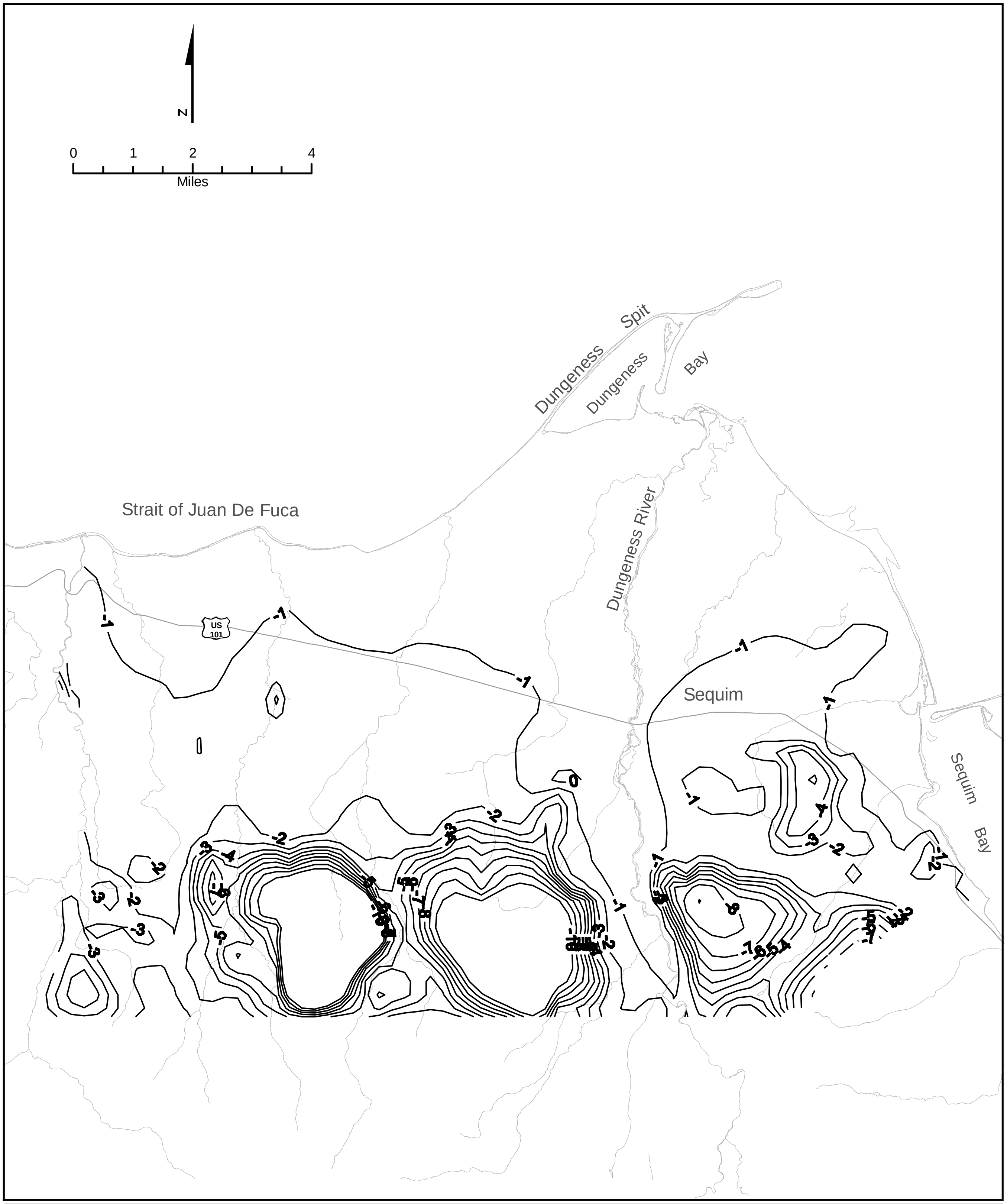


Figure 20
High Flow ASR difference in Layer 1 head compared to Intermediate Flow - June second year (SP19)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\sp19_high_flow_layer1.mxd 26 June 2003



Map Features

Streams

Highway 101

Difference in head between High and Intermediate ASR simulations (ft)

Note: Negative contour values indicate head values are lower than those associated with Intermediate Flow. Contour values below -10 are not shown.

Location Map

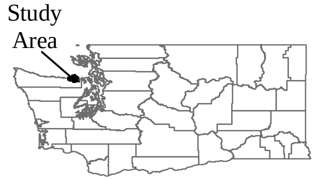


Figure 21
High Flow ASR difference in Layer 1 head compared to Intermediate Flow - September second year (SP22)

TETRA TECH FW, INC.

Q:\projects_2002\dungeness\workdir\maps\ASR_figures\sp22_high_flow_layer1.mxd 26 June 2003