APPENDIX A. QUALITATIVE ASSESSMENT OF CLIMATE CHANGE VULNERABILITY OF NATIONAL FISH HATCHERIES IN THE PACIFIC REGION: MAKAH NATIONAL FISH HATCHERY

I. INITIAL QUALITATIVE ASSESSMENT, 2011

The U.S. Fish and Wildlife Service (Service) qualitatively assessed the climate change vulnerabilities of all National Fish Hatcheries (NFHs) during calendar year 2011. These assessments were based on a MS-Excel spreadsheet template that was developed in the Headquarters Office (HQ) of the Service and distributed to all NFHs. This appendix summarizes the methods, results, and conclusions of those initial vulnerability assessments for Makah NFH (Figure A1).

II. METHODS

The initial vulnerability assessment for Pacific Region hatcheries consisted of two Excel Spreadsheets, *Spreadsheet 1* and *Spreadsheet 2* (Tables A1 and A2, respectively).

A. Spreadsheet 1

The purpose of *Spreadsheet 1* was to identify climate change stressors that are likely to occur by the year 2050 ("40 years out") and then assign a risk level for each stressor. Possible risk levels ranged from 1 ("negligible risk") to 5 ("extreme risk") and were based on the projected severity and likelihood of the stressor (Table A1).

The original Excel template for *Spreadsheet 1* was focused on the NFH and local watershed and did not account for areas where fish are released or migrate. The ability of NFHs in the Pacific Region to meet their goals for Pacific salmon and steelhead requires that a portion of released fish successfully migrate to the ocean and return back to the NFH where they can be recaptured as adults for broodstock. Consequently, the Service's initial evaluations of climate change effects for NFHs in the Pacific Region were subdivided into two categories: (a) the "NFH and local watershed", and (b) the "migration corridor". This latter category included all stream and river areas between the NFH and the ocean (Table A1).

B. Spreadsheet 2

The purpose of *Spreadsheet 2* (Table A2) was to identify and prioritize – for each NFH - management actions that could potentially be implemented to adapt or mitigate for the effects of each climate change stressor identifed in *Spreadsheet 1*. A template for this Spreadsheet was not provided by HQ. Rather, *Spreadsheet 2* was developed specifically for Pacific Region NFHs to facilitate the recording of the requested information.

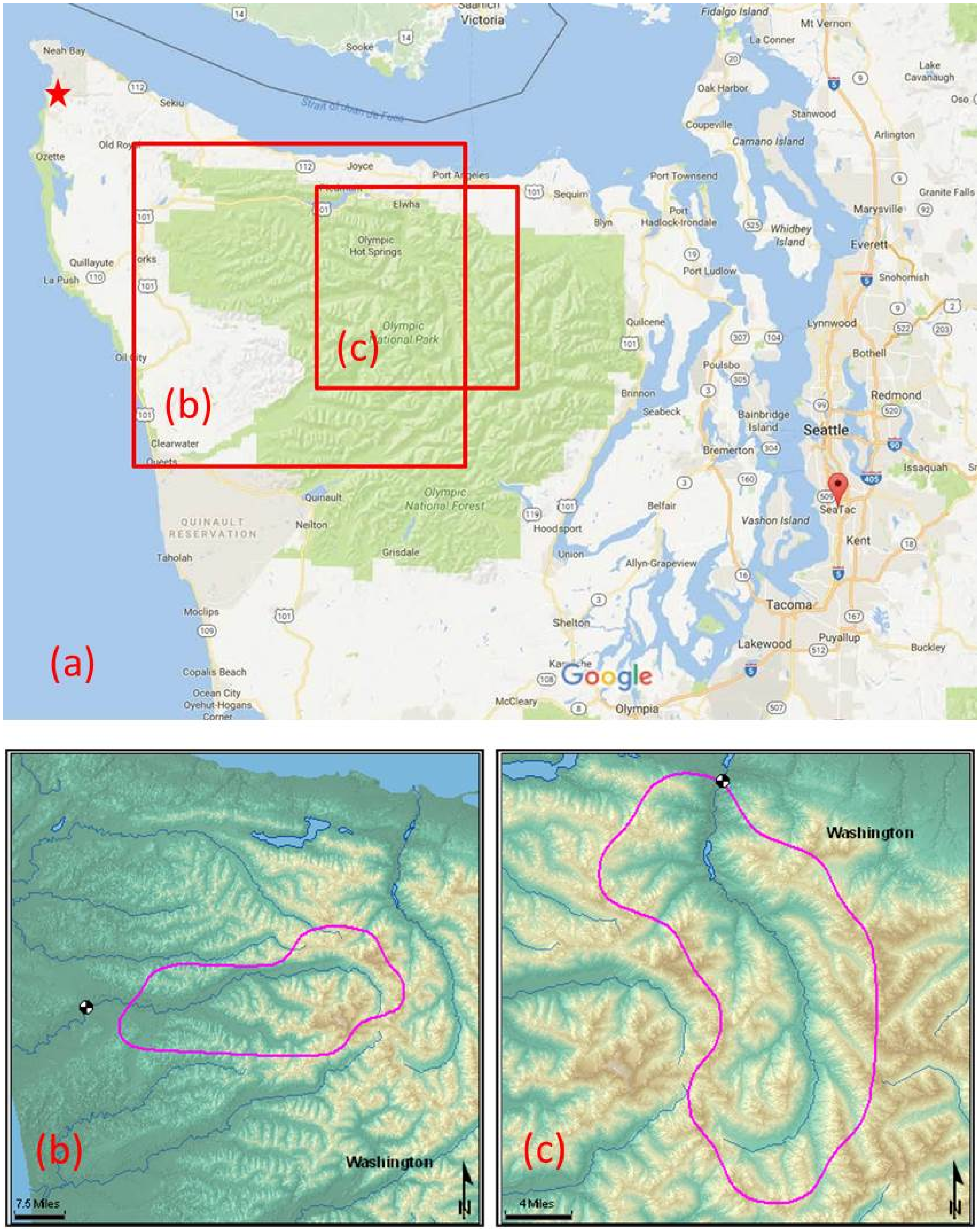

Figure A1. (a) Olympic Peninsula and Puget Sound of Washington State. Makah NFH is located in the far northwest corner of the Olympic Peninsula, indicated by the red star. Downscaled, climate change projection graphs were obtained for the Hoh and Elwha river basins: (b) Hoh River basin on the west slope of the Olympic Peninsula; (c) Elwha River basin on the north slope of the Olympic Peninsula. The locations of the U.S. Geological Survey reference gaging stations are shown by the black and white quartered circles.

C. Temperature, precipitation and hydrology projections, 2020s-2080s

Climate change projections for mean air temperature, precipitation, and several stream/hydrology parameters were obtained in the form of summary graphs from the Climate Impacts Group at the University of Washington (CIG-UW; http://warm.atmos.washington.edu/2860/). The summary graphs were generated for the 2020s, 2040s, and 2080s from the outputs of 10 general circulation models (GCMs) representing downscaled projections for monthly mean air temperature and precipitation at nearly 300 specific streamflow locations and representative watersheds throughout the Pacific Northwest. Those projections are based on the A1B greenhouse-gas emissions scenario from the Fourth IPCC Report (IPCC 2011). The A1B scenario assumes some future actions will be taken to reduce the emission of carbon dioxide and other greenhouse gases relative to historic and recent trends. CIG-UW has coupled those downscaled temperature and precipitation projections to historic and future streamflow patterns within watersheds via the *Variable Infiltration Capacity* (VIC) hydrologic model (Liang et al. 1994).

D. Temperature, precipitation and hydrology projections for Makah NFH

Hydrology projection graphs for the Tsoo-Yess River watershed were not available in 2011. Consequently, projection graphs for two nearby watersheds were used as surrogates for the Tsoo-Yess River: (1) the Hoh River basin on the west slope of the Olympic Peninsula, south of Forks, Washington, and (2) the Elwha River basin on the north slope of the Olympic Peninsula near Port Angeles, Washington (Figures A2 and A3). Hatchery staff used those projection graphs to complete *Spreadsheet 1* based on their best professional judgment, experiences, and institutional knowledge (Table A1). Hatchery staff then completed *Spreadsheet 2* to propose specific adaptation and mitigation actions for each of the climate stressors identified in *Spreadsheet 1* (Table A2).

E. Figures A2 and A3: Temperature, precipitation, hydrology projections

Figures A2 and A3 show the climate-hydrology projections for the Hoh and Elwha River basins, respectively, used by staff at Makah NFH to complete *Spreadsheet 1*. Each figure has six graphs labeled (a) through (f). Each graph shows climate and hydrology projections for three time periods: the 2020s, 2040s, and 2080s. Brief descriptions of those graphs follow.

1. **Graph (a): Raw streamflow.** This is the average monthly streamflow at the gaging station point of measurement (Figure A1) in cubic feet per second (cfs). The blue line shows the simulated historic mean value for the years 1971-1999; the red line shows the ensemble average of the outputs for 10 downscaled GCMs; and the red shaded area shows the range of outputs for the 10 GCMs for each of three future time periods.

2. **Graph (b): Simulated low streamflow** at the gaging-station measurement point in the watershed (Figure A1) measured in cubic feet per second (cfs), quantified by 7Q10 statistics. “7Q10 low flow” is the estimated minimum flow that occurs over seven consecutive days in 10% of the years (i.e., the estimated 7-day lowest flows that occur, on average, once every10 years). The blue circle shows the simulated historic mean value; red circles show the values for the 10 downscaled GCMs; the horizontal black line shows the ensemble average of the 10 downscaled models; and the orange circle shows the values for the composite delta downscale method (units = cfs).

3. **Graph (c): Monthly average air temperature** over the entire watershed upstream from

the point of measurement (units = degrees F). The blue line shows the simulated historic value, the red line shows the ensemble average of the outputs for 10 downscaled GCMs, and the red shaded area shows the range of outputs for the 10 GCMs for each of three future time periods.

4. **Graph (d): Monthly average total precipitation** (rain + snow) over the entire watershed upstream of the measurement point expressed as an average water depth (units = inches). The blue line shows the simulated historic value, the red line shows the ensemble average of the outputs for 10 downscaled GCMs, and the red shaded area shows the range of outputs for the 10 GCMs for each of three future time periods.

5. **Graph (e): Simulated peak streamflow** at the measurement point in the watershed for 20, 50 and 100-year peak flows (units = cfs). These graphs show simulated projected peak flows expected in 5%, 2% and 1% of the years, respectively over a 100-year period for each of three time periods. Blue circles show the simulated historical values; red circles show the values for 10 downscaled GCMs; the horizontal black line shows the ensemble average of the 10 downscaled models, and the orange circles show the values for the composite delta downscale method.

6. **Graph (f): Water volume equivalent of projected snow pack** on first day of month averaged over the entire watershed upstream of the point of measurement, expressed as an average water depth (units = inches). This variable is a primary component of the simulated water balance, and quantifies natural storage as snowpack. The blue line shows the simulated historical value, the red line shows the ensemble average of the outputs for 10 downscaled GCMs, and the red shaded area shows the range of outputs for the 10 GCMs for each of three future time periods.

Hoh River Basin

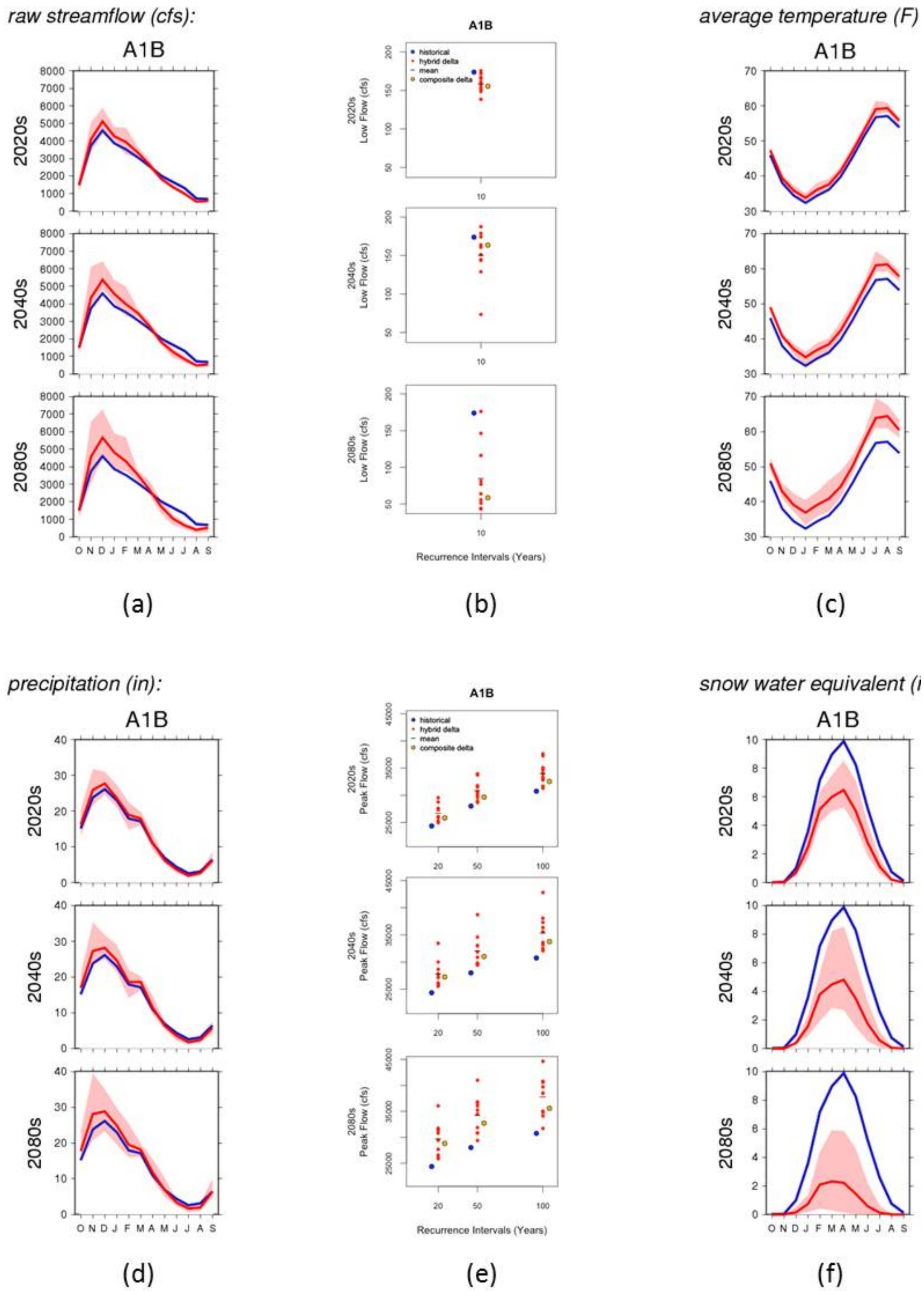

Figure A2. Climate and hydrology projections for the Hoh River Basin, Washington (CIG 2011). The blue lines (a, c, d, and f) and dots (b, e) are the1971-1999 simulated historic means. The red line and red shading in (a), (c), (d), and (f) are the mean and range, respectively of outputs from 10 GCM models. For low and peak flows (b and e), the red dots are the projections from the 10 models, the horizontal line is the average of the 10 projections, and the orange dot is the composite model output.

Elwha River Basin

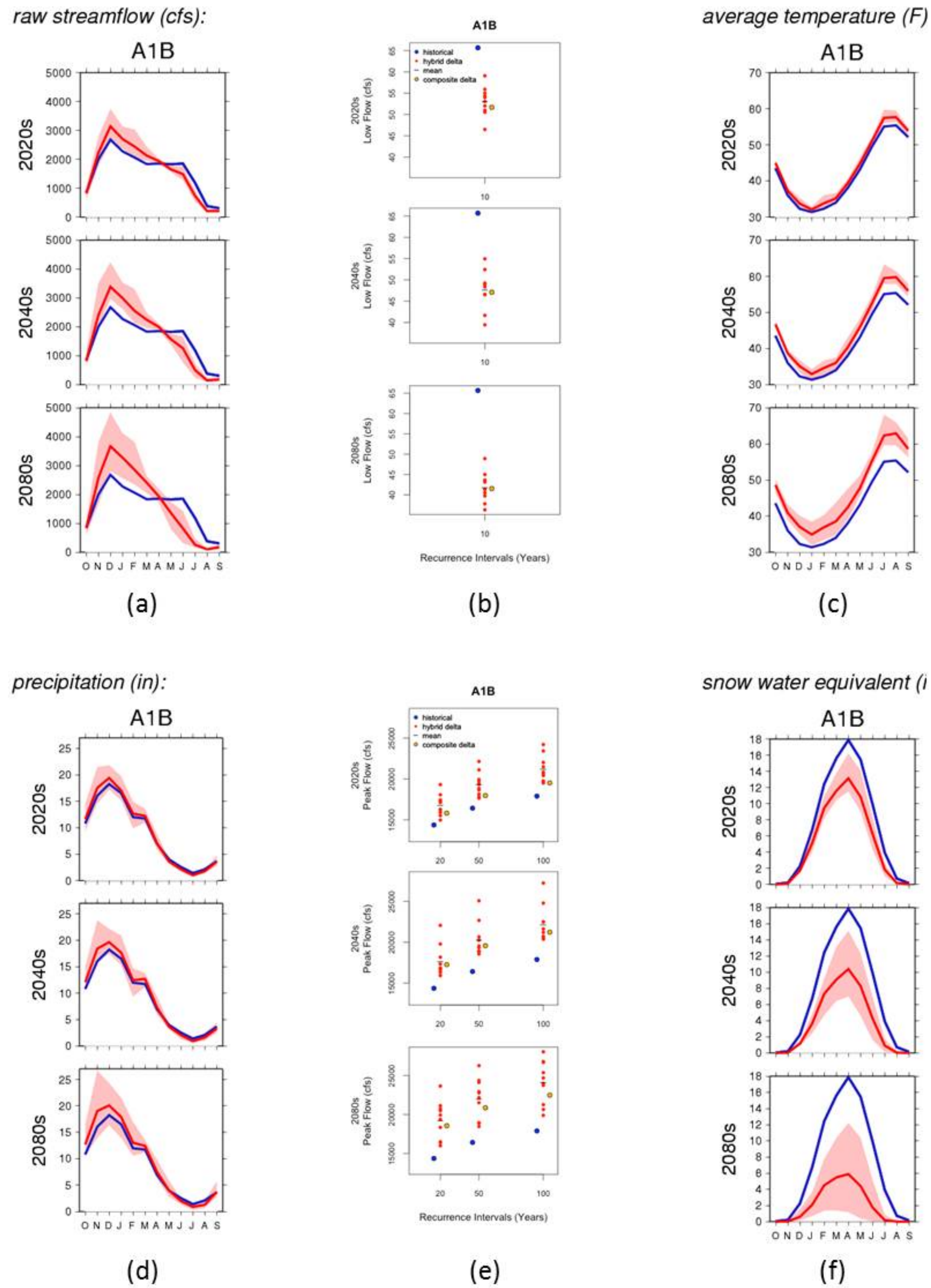

Figure A3. Climate and hydrology projections for the Elwha River Basin, Washington (CIG 2011). The blue lines (a, c, d, and f) and dots (b, e) are the1971-1999 simulated historic means. The red line and red shading in (a), (c), (d), and (f) are the mean and range, respectively of outputs from 10 GCM models. For low and peak flows (b and e), the red dots are the projections from the 10 models, the horizontal line is the average of the 10 projections, and the orange dot is the composite model output.

III. RESULTS

A. Climate change risks identified by hatchery staff at Makah NFH (see Table A1)

Future decreases in surface water quantity and increases in surface water temperature were considered the highest climate change risks at Makah NFH (risk level = 5: *extreme risk, immediate action required*; Table A1). Stressors with the next highest risks (risk level = 4: *high risk; high priority for action*) were (a) decreases in surface water quantity in the migration corridor, (b) decreases in surface water quality at the hatchery, (c) increases in surface water temperature in the migration corridor, (d) increases in ambient air temperature during the spring, summer and fall including the number of "heat waves", (e) decreases in average summer precipitation, (f) increases in the severity of flood events, (g) increases in the number and duration of drought events, and (h) increases in disease, parasite, and pathogen risks at the hatchery.

B. Management actions to adapt or mitigate for high-risk climate change stressors identified in Table A1 (see Table A2)

The manager and staff at Makah NFH suggested the following management actions as first priorities for potentially adapting or mitigating for the projected effects of climate change based on time/effort, dollar cost, and feasibility of implementation (Table A2): (a) increase fish health monitoring, diagnostics, and treatment; (b) install shade covers over outdoor raceways; (c) adjust brood stock collection and spawn dates at hatchery to be consistent with expected shifts in return timing and maturation of adult fish; (d) monitor egg quality and adjust treatments as needed; (e) adjust feed rates and schedules of juvenile fish to match life history stages and desired growth rates of fry and fingerlings; (f) develop a detailed flood preparation and management plan, including review and update of safety preparations and protocols at the hatchery. In summary, the manager and staff indicated that increased biological monitoring and evaluation of fish on station would need to be a top priority so that future staff would be able to adjust protocols in response to changing environmental conditions for maintaining fish health and productivity.

IV. DISCUSSION AND CONCLUSIONS

A primary concern at Makah NFH, based on this initial qualitative assessment of climate change vulnerability in 2011, was the projected decrease in surface water quantity and quality, including projected increases in water temperatures, at the NFH and migration corridor.

A common concern at all NFHs in the Pacific Region was the effects of climate change stressors on disease and increased prevalence of pathogenic organisms, both in the respective NFHs and migration corridors. In general, disease risks for Pacific salmon and steelhead increase with increases in water temperature, density indexes, and flow indexes. Climate models project increased air temperatures and decreased surface water quantities during the summer months throughout the Pacific Northwest, due in large part to more precipitation falling as rain and less as snow during the winter, although the total quantity of annual precipitation may remain relatively constant. This shift from snow-dominated watersheds to rain-dominated watersheds is particularly acute in the Olympic Mountains of northwest Washington State (Figure A3f).

Overall, the manager and staff at Makah NFH used their expert opinions and professional experiences to conclude that increased monitoring and evaluation would be necessary to adapt and mitigate for the projected effects of climate change, most likely reflecting uncertainties regarding the ability of the fish themselves to adapt to increasing water temperatures and decreasing water availability.

One other note: Makah NFH is in a tsunami evacuation zone and susceptible to sea level rise. However, the manager in 2011 noted that "the pump house is currently the only structure remotely at risk from sea level rise" and assigned a risk level = 3 for sea level rise in general (Table A1). Nevertheless, future storm surges during high tides would most likely need to be considered in future planning because of potential vulnerabilities to tsunamis. In this latter context, the staff also recommended that the Service "consider marine coastal effects in any new construction" at the hatchery.

V. LITERATURE CITED

Intergovernmental Panel on Climate Change (IPCC). 2007. Climate Change 2007, Fourth Assessment Report of the IPCC. Available at: https://www.ipcc.ch/report/ar4/syr/.

Liang, X., D. P. Lettenmaier, E. F. Wood, and S. J. Burges. 1994. A simple hydrologically based model of land-surface water and energy fluxes for general-circulation models. Journal of Geophysical Research 99(D7):14,415-14,428.

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VI. SPREADSHEET 1 INSTRUCTIONS (see Table A1)

The following steps were used to complete Spreadsheet 1 of the initial climate change vulnerability assessments of National Fish Hatcheries in the Pacific Region. The completed Spreadsheet for Makah NFH is presented as Table A1.

1. **Step 1: Stressors. Identify climate change stressors (columns 1 and 2).** The climate and hydrology projection graphs (Figures A2, A3) were used to identify climate change stressors for the evaluated hatchery: 0 = not likely to be a stressor; 1= likely to be a stressor.

2. **Step 2: Severity. Determine the severity of each stressor on NFH operations and programs (column 3).** The following table was used to classify the severity of each stressor on a scale of 1 to 5:

Designation	Impact	Examples
5	Catastrophic	Permanent loss of facility function, loss of all aquatic species, safety concerns
4	Major	Long term loss of function (> six months), loss of all or most of aquatic species
3	Moderate	Disruption and alteration of normal operations related to fish culture for up to six months, loss of aquatic species due to poor water quality or quantity
2	Minor	Disruption of normal operations for a week, no loss of organisms
1	Insignificant	Short-term inconvenience

3. **Step 3: Likelihood. Determine the likelihood that each stressor will occur (column 4).** The following table was used to classify the likelihood of each stressor on a scale of 1 to 5.

Designation	Percent (%) Likelihood	Description of Likelihood Level
5	>90%	Very likely, almost certain, is expected to happen
4	66 – 90%	Likely, will probably happen
3	33 – 66%	Possible, might occur, 50/50 chance of occurring
2	10 – 33%	Unlikely, but possible
1	<10%	Very or highly unlikely, but conceivable

4. **Step 4: Risk. Determine the risk level of each stressor to NFH operations and programs (column 5).** The following table was used to assign a risk level for each stressor as a function of its severity and likelihood.

Likelihood of Stressor	Impact = 5 Catastrophic	Impact = 4 Major	Impact = 3 Moderate	Impact = 2 Minor	Impact =1 Insignificant
5 (> 90%)	5	5	5	4	3
4 (66 – 90%)	5	5	4	4	3
3 (33 – 66%)	5	5	4	3	2
2 (10 – 33%)	5	4	3	2	2
1 (<10%)	4	4	3	2	1

Risk Level Score	Risk Level
5	Extreme risk; immediate action required
4	High risk; high priority for action, begin planning as soon as practicable
3	Moderate risk; include in response planning, but lower priority
2	Low risk; minimal action likely to be required
1	Negligible risk, no response required

Table A1. Spreadsheet 1 for qualitatively assessing the climate change vulnerability of Makah NFH. The goal of this Spreadsheet was to identify climate change stressors, and then assess their potential severity and likelihood to assign a "risk level" for that stressor.

Makah NFH **Potential Stressors from Climate Change**	**Step 1: Identify Hazards Likely to Occur on Hatchery**	**Step 2: Determine the Severity of the stressor**	**Step 3: Determine the Likelihood of Hazard Occurring**	**Step 4: Determine Risk Level**
Utilize Worksheet 2	Utilize Worksheet 2 (1= stressor for hatchery, 0 = not a stressor)	Utilize Worksheet 3 (1, 2, 3, 4, or 5)	Utilize Worksheet 4 (1, 2, 3, 4, or 5)	Utilize Worksheet 5 (1, 2 3, 4, or 5)
SURFACE WATER QUANTITY (Hatchery and local watershed)				
decrease in water quantity (hatchery)	1	3	5	5
increase in water quantity (hatchery)	0			
SURFACE WATER QUANTITY (Migration Corridor)				
decrease in water quantity (migration corridor)	1	2	4	4
increase in water quantity (migration corridor)	0			
GROUND WATER QUANTITY (Hatchery and local watershed)				
decrease in water quantity (hatchery)	1	1	2	2
increase in water quantity (hatchery)	0			
SURFACE WATER QUALITY (Hatchery and local watershed)				
decrease in water quality (hatchery)	1	3	3	4
increase in water quality (hatchery)	0			
SURFACE WATER QUALITY (Migration Corridor)				
decrease in water quality (migration corridor)	1	2	3	3
increase in water quality (migration corridor)	0			
GROUND WATER QUALITY (Hatchery and local watershed)				
degradation of water quality (hatchery)	0			
improvement of water quality (hatchery)	0			
SURFACE WATER TEMPERATURE (Hatchery and local watershed)				
temperature increase (hatchery)	1	3	5	5
temperature decrease (hatchery)	0			
SURFACE WATER TEMPERATURE (Migration Corridor)				
temperature increase (migration corridor)	1	2	4	4
temperature decrease (migration corridor)	0			
GROUND WATER TEMPERATURE (Hatchery and local watershed)				
temperature increase (hatchery)	1	1	1	1
temperature decrease (hatchery)	0			

Table A1. Continued, page 2 of 6.

Makah NFH **Potential Stressors from Climate Change**	**Step 1: Identify Hazards Likely to Occur on Hatchery**	**Step 2: Determine the Severity of the stressor**	**Step 3: Determine the Likelihood of Hazard Occurring**	**Step 4: Determine Risk Level**
Utilize Worksheet 2	Utilize Worksheet 2 (1= stressor for hatchery, 0 = not a stressor)	Utilize Worksheet 3 (1, 2, 3, 4, or 5)	Utilize Worksheet 4 (1, 2, 3, 4, or 5)	Utilize Worksheet 5 (1, 2 3, 4, or 5)
AMBIENT TEMPERATURE CHANGES (Hatchery and local watershed)				
increase in annual average temperature (hatchery)	1	2	4	4
decrease in annual average temperature (hatchery)	0			
increase in number of warm days (aka heat waves1) (hatchery)	1	3	4	4
decrease in number of warm days (hatchery)	0			
increase in number of frost days2 (hatchery)	0			
decrease in number of frost days (hatchery)	0			
increase in spring average air temperatures (hatchery)	1	2	4	4
increase in summer average air temperatures (hatchery)	1	3	4	4
increase in fall average air temperatures (hatchery)	1	2	4	4
increase in winter average air temperatures (hatchery)	1	1	4	3
decrease in spring average air temperatures (hatchery)	0			
decrease in summer average air temperatures (hatchery)	0			
decrease in fall average air temperatures (hatchery)	0			
decrease in winter average air temperatures (hatchery)	0			
PRECIPITATION CHANGES (Hatchery and local watershed)				
increase in annual average precipitation (hatchery)	1	1	3	2
decrease in annual average precipitation (hatchery)	1	2	1	2
increase in spring average precipitation (hatchery)	0			
increase in summer average precipitation (hatchery)	0			
increase in fall average precipitation (hatchery)	1	1	4	3
increase in winter average precipitation (hatchery)	1	1	4	3
decrease in spring average precipitation (hatchery)	1	1	2	2
decrease in summer average precipitation (hatchery)	1	3	3	4
decrease in fall average precipitation (hatchery)	1	2	1	2
decrease in winter average precipitation (hatchery)	0			
increase in frequency of extreme thunderstorms (hatchery)	0			
decrease in frequency of extreme thunderstorms (hatchery)	0			

Table A1. Continued, page 3 of 6.

Makah NFH **Potential Stressors from Climate Change**	**Step 1: Identify Hazards Likely to Occur on Hatchery**	**Step 2: Determine the Severity of the stressor**	**Step 3: Determine the Likelihood of Hazard Occurring**	**Step 4: Determine Risk Level**
Utilize Worksheet 2	Utilize Worksheet 2 (1= stressor for hatchery, 0 = not a stressor)	Utilize Worksheet 3 (1, 2, 3, 4, or 5)	Utilize Worksheet 4 (1, 2, 3, 4, or 5)	Utilize Worksheet 5 (1, 2 3, 4, or 5)
PRECIPITATION CHANGES (Hatchery and local watershed)				
increase in frequency of extreme snow storms (hatchery)	1	2	2	2
decrease in frequency of extreme snow storms (hatchery)	0			
increase in duration of extreme thunderstorms (hatchery)	0			
decrease in duration of extreme thunderstorms (hatchery)	0			
increase in duration of extreme snow storms (hatchery)	1	1	1	1
decrease in duration of extreme snow storms (hatchery)	0			
increase in amount of snow pack (hatchery)	0			
decrease in amount of snow pack (hatchery)	0			
ealier snow melt date (hatchery)	0			
later snow melt date (hatchery)	0			
lower snow line (hatchery)	0			
higher snow line (hatchery)	0			
EXTREME WEATHER EVENTS (Hatchery and local watershed)				
increased average wind speed annually (hatchery)	1	1	2	2
decreased average wind speed annually (hatchery)	0			
increased average wind duration annually (hatchery)	1	1	2	2
decreased average wind duration annually (hatchery)	0			
change in wind patterns (hatchery)	0			
increased speed and duration of westerly wind flow (hatchery)	1	1	2	2
decreased speed and duration of westerly wind flow (hatchery)	0			
increased speed and duration of southernly wind flow (hatchery)	1	1	2	2
decreased speed and duration of southernly wind flow (hatchery)	0			
increase in number of flood events annually (hatchery)	1	2	3	3
decrease in number of flood events annually (hatchery)	0			
increase in the average duration of flood events annually (hatchery)	1	2	3	3
decrease in the average duration of flood events annually (hatchery)	0			
increase in the severity of flood events annually (hatchery)	1	3	3	4
decrease in the severity of flood events annually (hatchery)	0			

Table A1. Continued, page 4 of 6.

Makah NFH **Potential Stressors from Climate Change**	**Step 1: Identify Hazards Likely to Occur on Hatchery**	**Step 2: Determine the Severity of the stressor**	**Step 3: Determine the Likelihood of Hazard Occurring**	**Step 4: Determine Risk Level**
Utilize Worksheet 2	Utilize Worksheet 2 (1= stressor for hatchery, 0 = not a stressor)	Utilize Worksheet 3 (1, 2, 3, 4, or 5)	Utilize Worksheet 4 (1, 2, 3, 4, or 5)	Utilize Worksheet 5 (1, 2 3, 4, or 5)
EXTREME WEATHER EVENTS (Hatchery and local watershed)				
increase in number of drought events annually (hatchery)	1	3	3	4
decrease in number of drought events annually (hatchery)	0			
increase in the average duration of drought events annually (hatchery)	1	3	3	4
decrease in the average duration of drought events annually (hatchery)	0			
increase in the number of tornadoes (hatchery)	0			
decrease in the number of tornadoes (hatchery)	0			
increase in the severity of tornadoes (hatchery)	0			
decrease in the severity of tornadoes (hatchery)	0			
increase in the number of hurricanes (hatchery)	0			
decrease in the number of hurricanes (hatchery)	0			
increase in the severity of hurricanes (hatchery)	0			
decrease in the severity of hurricanes (hatchery)	0			
increase in the number of ice storms (hatchery)	1	1	1	1
decrease in the number of ice storms (hatchery)	0			
increase in the severity of ice storms (hatchery)	1	1	1	1
decrease in the severity of ice storms (hatchery)	0			
increase in the number of monsoons (hatchery)	0			
decrease in the number of monsoons (hatchery)	0			
increase in the severity of monsoons (hatchery)	0			
decrease in the severity of monsoons (hatchery)	0			
increase in the number of hail storms (hatchery)	0			
decrease in the number of hail storms (hatchery)	0			
increase in the severity of hail storms (hatchery)	0			
decrease in the severity of hail storms (hatchery)	0			

Table A1. Continued, page 5 of 6.

Makah NFH **Potential Stressors from Climate Change**	**Step 1: Identify Hazards Likely to Occur on Hatchery**	**Step 2: Determine the Severity of the stressor**	**Step 3: Determine the Likelihood of Hazard Occurring**	**Step 4: Determine Risk Level**
Utilize Worksheet 2	Utilize Worksheet 2 (1= stressor for hatchery, 0 = not a stressor)	Utilize Worksheet 3 (1, 2, 3, 4, or 5)	Utilize Worksheet 4 (1, 2, 3, 4, or 5)	Utilize Worksheet 5 (1, 2 3, 4, or 5)
OTHER (Hatchery and local watershed)				
increase in invasive species (hatchery)	1	1	3	2
decrease in invasive species (hatchery)	0			
increase in disease (hatchery)	1	3	3	4
decrese in disease (hatchery)	0			
increase in parasites (hatchery)	1	3	3	4
decrease in parasites (hatchery)	0			
increase in pathogens (hatchery)	1	3	3	4
decrease in pathogens (hatchery)	0			
increase in number of fire events (hatchery)	1	1	1	1
decrease in number of fire events (hatchery)	0			
increase in intensity of fire events (hatchery)	0			
decrease in intensity of fire events (hatchery)	0			
extreme precipitation events-hurricane (hatchery)	0			
extreme precipitation events-tropical storm (hatchery)	0			
extreme precipitation events-cyclones (hatchery)	0			
extreme precipitation events (hatchery)	1	1	3	2
OTHER (Migration Corridor)				
increase in invasive species (migration corridor)	1	1	3	2
decrease in invasive species (migration corridor)	0			
increase in disease (migration corridor)	1	2	3	3
decrese in disease (migration corridor)	0			
increase in parasites (migration corridor)	1	2	3	3
decrease in parasites (migration corridor)	0			
increase in pathogens (migration corridor)	1	2	3	3
decrease in pathogens (migration corridor)	0			

Table A1. Continued, page 6 of 6.

Makah NFH **Potential Stressors from Climate Change**	**Step 1: Identify Hazards Likely to Occur on Hatchery**	**Step 2: Determine the Severity of the stressor**	**Step 3: Determine the Likelihood of Hazard Occurring**	**Step 4: Determine Risk Level**
Utilize Worksheet 2	Utilize Worksheet 2 (1= stressor for hatchery, 0 = not a stressor)	Utilize Worksheet 3 (1, 2, 3, 4, or 5)	Utilize Worksheet 4 (1, 2, 3, 4, or 5)	Utilize Worksheet 5 (1, 2 3, 4, or 5)
COASTAL (Hatchery and local watershed)				
increase in wave size and intensity (hatchery)	1	1	3	2
decrese in wave size and intensity (hatchery)	0			
increase in marine cloudines (decreasing temperature) (hatchery)	0			
decrease in marine cloudiness (increasing temperature) (hatchery)	1	2	3	3
increase in sea level (hatchery)	1	2	3	3
decrease in sea level (hatchery)	0			
change in ocean currents (hatchery)	0			
change in wave patterns (hatchery)	0			
Management				
Skill set: Additional fish health/disease monitoring training of hatchery staff will be needed	1	3	4	4

VII. SPREADSHEET 2 INSTRUCTIONS (see Table A2)

The following steps were used to complete Spreadsheet 2 of the initial climate change vulnerability assessments of National Fish Hatcheries in the Pacific Region. The climate change stressors identified in Spreadsheet 1 were listed in the first column of Spreadsheet 2. The following steps were then completed for each of those identified stressors. The completed Spreadsheet for Makah NFH is presented as Table A2.

5. Step 5: **Effects of stressor (Column 2).** For each stressor listed in column 1, list in column 2 one to five expected effects of that stressor to the hatchery facilities, programs, and/or fish propagated at the hatchery.
6. Step 6: **Proposed management actions (Column 3).** In column 3, list management actions that could be implemented to adapt or mitigate for each effect listed in column 2 for Step 5.
7. Step 7: **Time/effort to implement management actions (Column 4).** On a scale of 1 to 5, determine the time/effort to implement each management action identified in Step 6 based on the criteria in the following table, and enter that time/effort classification number in column 4 of Spreadsheet 2.

Time/Effort Classification	Difficulty	Duration	Description of Classification
5	extremely difficult	over 1 year	Intensive amount of effort and time is needed to implement
4	very difficult	6 months to 1 year	Large amount of effort and time is needed to implement
3	difficult	2 to 6 months	Moderate amount of effort and time is needed to implement
2	moderate	1 week to 2 months	Some effort and time is needed to implement
1	easy	less than 1 week	Little to no effort or time is needed to implement

8. **<u>Step 8</u>: Cost to implement management actions (Column 5).** On a scale of 1 to 5, determine the relative dollar cost ($$$) to implement each management action identified in Step 6 based on the criteria in the following table, and enter that dollar-cost classification number in column 5 of Spreadsheet 2.

Dollar-Cost Classification	Relative expense	Cost	Description of Classification
5	Extremely expensive	$$$$$	Not able to implement; cost prohibitive
4	Very expensive	$$$$	Intensive amount of funding is needed to implement
3	Expensive	$$$	Large amount of funding is needed to implement
2	Moderately expensive	$$	Moderate amount of funding is needed to implement
1	Not expensive	$	Little to no and funding is needed to implement

9. **<u>Step 9</u>: Feasibility to implement management actions (Column 6).** On a scale of 1 to 5, determine the feasibility to implement each management action identified in Step 6 based on the combination of time/effort (Step 7) and dollar-cost (Step 8) according to the following table, and enter that feasibility number in column 6 of spreadsheet 2.

Cost to implement	Time/effort. 5: Extremely Difficult	Time/effort. 4: Very Difficult	Time/effort. 3: Difficult	Time/effort. 2: Moderate	Time/effort. 1: Easy
5 = Extremely Expensive	5	5	5	4	3
4 = Very Expensive	5	5	4	4	3
3 = Expensive	5	5	4	3	2
2 = Moderately expensive	5	4	3	2	2
1 = Not Expensive	4	4	3	2	1

Feasibility Level Score	Feasibility
5	Very Low Feasibility
4	Low Feasibility
3	Moderate Feasibility
2	High Feasibility
1	Very High Feasibility

10. <u>Step 10, part 1</u>: **Priority of management actions (Column 7).** Prioritize or rank the management actions that could be implemented to adapt/mitigate for the identified effects of each climate change stressor and enter that rank priority in column 7. Each hatchery manager and his/her staff ranked the order, or priority, that they would implement each of the possible management actions based on (a) feasibility of implementation (time/effort + $$$) and (b) professional experience and institutional knowledge.

<u>Step 10, part 2</u>: **Comments (Column 8).** Provide comments regarding feasibility, constraints, priority, or any other information regarding the potential difficulty, benefits, risks, etc. of implementing each management action to adapt/mitigate for the effects of each climate change stressor.

Table A2. Spreadsheet 2. Qualitative assessment of climate change vulnerability of Makah NFH.

Makah NFH							
Potential Stressors from Climate Change (as identified as "1" in Worksheet 1)	**Step 5: Expected effects from stressor (list each effect in a new row; max.of 5)**	**Step 6: Management actions to adapt/mitigate for effects of stressor**	**Step 7: Time and effort to implement management action (1, 2, 3, 4, or 5)**	**Step 8: Dollar cost to implement management action (1, 2, 3, 4, or 5)**	**Step 9: Feasibility to implement management action (1, 2, 3, 4, or 5)**	**Step 10, pt 1: Priority/rank of management actions to adapt/mitigate for effects of stressor (enter 1, 2, 3, ...etc.)**	**Step 10, part 2: Comments on feasibility and priority to implement management action to adapt or mitigate for the effects of stressor.**
WATER QUALITY AND QUANTITY CHANGES (Hatchery)							
Decrease in surface water quantity (hatchery)	Decreased carrying capacity of hatchery for rearing fish	Reduce rearing densities and the number of fish reared	4	2	4	3	Requires agreement with comanagers, primarily the Makah Nation, but also includes state and federal comanagers
	Decreased flows in raceways	Adjust relative numbers of different species consistent with water supply (e.g., fewer steelhead, more Chinook)	4	2	4	4	Requires agreement with comanagers, primarily the Makah Nation, but also includes state and federal comanagers. Program is currently managed to maximize genetic diversity and potential for adaption of life history traits
	Increased fish health risks	Maintain water recirculation systems, investigate new water reuse technology	3	2	3	2	Increased use of water recirculation will increase fish health risks. Construction and installation costs have NOT been included with dollar cost of implementation.
	Shifts in mean and range of time of return of adult salmon and steelhead in response to flows	Increase fish health monitoring, diagnostics, and treatement	3	2	3	1	
Decrease in ground water quantity (hatchery)	Decrease in potable domestic water	Install new well	3	3	4	1	NFH
Decrease in surface water quality (hatchery)	Increased siltation of surface water supply	Expand silt and sediment removal capacity of hatchery to handle increased siltation	4	3	5	3	May require addition of additonal sand filters in area already confined by existing filters
	Increased fish health risks	Work with comanagers and landowners to restore habitat of watershed	5	3	5	2	Habitat resotration efforts are currently in progress
		Increase fish health monitoring, diagnostics, and treatment	3	2	3	1	
Degradation of ground water quality (hatchery)	Increased human health risks from domestic water supply	Install water treatment systems and/or new wells when needed	3	3	4	2	A new well or water treatment system for domestic water would be a low priority relative to other water needs at Makah NFH
		Increase use of chemicals/treatment to maintain potable domestic water supply for human consumption	3	2	3	1	
Increase in surface water temperature (hatchery)	Increased fish health risks	Install shade covers over raceways	3	3	4	1	Installation of shade covers over raceways is currently listed in the Deferred Maintenance 5-Year Plan (DMFP) for 2013.
	Faster growth rates of juvenile fish and earlier dates of smoltification	Adjust feed schedules, rearing densities, and release dates to optimize smolt-to-adult return rates and number of returning adult fish	3	2	3	2	
WATER QUALITY AND QUANTITY CHANGES (Migration corridor)							
Decrease in surface water quantity (migration corridor)	Temporal shifts in the return timing of adult salmon and steelhead	Adjust broodstock collection and spawn dates at hatchery to be consistent with shifts in return timing and maturation to miminize new risks to adult fish from climate change	2	1	2	1	Collaboration with Tribe is currently ongoing to minimize impacts to adult fish in river prior to collection for broodstock.
	Increased fish health risks and pre-spawning mortality of adult fish retained for broodstock	Increase fish health monitoring, diagnostics, and treatment	3	2	3	2	
	Increased vulnerability of adult fish to harvest and predation prior to being trapped for broodstock						
Decrease in surface water quality (migration corridor)	Temporal shifts in the return timing of adult salmon and steelhead	Work with comanagers and landowners to restore habitat of watershed	5	3	5	3	Habitat resotration efforts are currently in progress
Increase in surface water temperature (migration corridor)	Increased fish health risks and pre-spawning mortality of adult fish retained for broodstock	Increase fish health monitoring, diagnostics, and treatment	3	2	3	2	
	Change in quality of gametes and fertilization rates	Monitor egg quality and adjust treatments as needed	1	1	1	1	In progress currently

Table A2. Continued, page 2 of 3.

Makah NFH							
Potential Stressors from Climate Change (as identified as "1" in Worksheet 1)	**Step 5: Expected effects from stressor (list each effect in a new row; max.of 5)**	**Step 6: Management actions to adapt/mitigate for effects of stressor**	**Step 7: Time and effort to implement management action (1, 2, 3, 4, or 5)**	**Step 8: Dollar cost to implement management action (1, 2, 3, 4, or 5)**	**Step 9: Feasibility to implement management action (1, 2, 3, 4, or 5)**	**Step 10, pt 1: Priority/rank of management actions to adapt/mitigate for effects of stressor (enter 1, 2, 3, ...etc.)**	**Step 10, part 2: Comments on feasibility and priority to implement management action to adapt or mitigate for the effects of stressor.**
AMBIENT TEMPERATURE CHANGES (Hatchery)							
Increase in annual average temperature (hatchery)	Increase in surface water temperature	See: Increase in surface water temperature (hatchery)					
Increase in number of warm days (aka heat waves) (hatchery)							
Increase in spring average air temperatures (hatchery)							
Increase in summer average air temperatures (hatchery)							
Increase in fall average air temperatures (hatchery)	Increased developmental rates of incubating eggs and hatched fry	Adjust feed rates and schedules to match life history stages and desired growth rates of fry and fingerlings	2	1	2	1	In progress currently
Increase in winter average air temperatures (hatchery)							
PRECIPITATION CHANGES (Hatchery and local watershed)							
Increase in annual average precipitation (hatchery)	Increased risk of flooding	Include flood risks in design of new construction	3	3	4	2	Current water intake screens do not comply with NOAA-Fisheries requirements for streams with naturally spawning salmon (Makah NFH has 1/4" square mesh screens rather than 3/32" slotted screens). Estimated cost of rebuild was ≈$3.2M in 2009.
Increase in fall average precipitation (hatchery)		Develop a detailed flood preparation & management plan	2	1	2	1	
increase in winter average precipitation (hatchery)							
Decrease in annual average precipitation (hatchery)	Decrease in surface water quantity	Reduce rearing densities and the number of fish reared	4	2	4	3	Requires agreement with comanagers, primarily the Makah Nation, but also includes state and federal comanagers
Decrease in spring average precipitation (hatchery)	Decrease in carrying capacity of hatchery	Increased use of water recirculation and re-use	3	2	3	2	Makah NFH already has effective recirculation system. The preferred method currently is to shunt water back into the river from the tail end of the serpentine channel. Second possible method is to re-use water from four, first-pass raceways and pump through tower to supply two raceways with second-pass water. Physical equipment to do this exists, but has not been used in 10+ years and will require some maintenance on the pumps. Staff preference is not to use this system because of increased fish health problems. It is possible, however, to use both systems together in extreme need situations.
Decrease in summer average precipitation (hatchery)	Increased fish health risks	Increase fish health monitoring, diagnostics and treatment	3	2	3	1	
	Shifts in mean and range of time of return of adult fish	Investigate new water conservation treatments and technologies	5	2	5	4	
Increase in frequency of extreme snow storms (hatchery)	Increased physical challenge to crew and facility	Review and update safety preparations and protocols	2	1	2	1	
Increase in duration of extreme snow storms (hatchery)		Increased labor via overtime to deal with contingencies	1	2	2	2	
EXTREME WEATHER EVENTS (Hatchery and local watershed)							
Increased average wind speed annually (hatchery)	Increased physical challenge to crew and facility	Review and update safety preparations and protocols	2	1	2	1	
Increased average wind duration annually (hatchery)	Increased strucutural and safety risks to hatchery and crew, respectively.	Increased labor via overtime to deal with contingencies	1	2	2	2	
Increased speed and duration of westerly wind flow (hatchery)							
Increased speed and duration of southernly wind flow (hatchery)							
Increase in number of flood events annually (hatchery)	Increased mortality risk to fish on station (water quality, physical risk)	See increase in annual average precipitation and increase in average wind speed annually.					
Increase in the average duration of flood events annually (hatchery)	Increased physical challenge to crew and facility						
Increase in the severity of flood events annually (hatchery)	Increased strucutural and safety risks to hatchery and crew, respectively.						
Increase in number of drought events annually (hatchery)	See: Decrease in surface water quantity (hatchery)						
(hatchery)							
Increase in the number of ice storms (hatchery)	See: Increase in frequency of extreme snow storms (hatchery) and Increased average wind speed annually.						
Increase in the severity of ice storms (hatchery)							

Table A2. Continued, page 3 of 3.

Makah NFH							
Potential Stressors from Climate Change (as identified as "1" in Worksheet 1)	Step 5: Expected effects from stressor (list each effect in a new row; max.of 5)	Step 6: Management actions to adapt/mitigate for effects of stressor	Step 7: Time and effort to implement management action (1, 2, 3, 4, or 5)	Step 8: Dollar cost to implement management action (1, 2, 3, 4, or 5)	Step 9: Feasibility to implement management action (1, 2, 3, 4, or 5)	Step 10, pt 1: Priority/rank of management actions to adapt/mitigate for effects of stressor (enter 1, 2, 3, ...etc.)	Step 10, part 2: Comments on feasibility and priority to implement management action to adapt or mitigate for the effects of stressor.
OTHER (Hatchery and local watershed)							
Increase in invasive species (hatchery)	Impact to hatchery water operations (pumps and pipes)	Continue monitoring and education efforts	2	2	3	1	Makah NFH has initiated more detailed monitoring and evaluation work re the function and capacity of the watershed, in conjunction with the Makah Nation Fisheries office. Work on this will be on-going & diverse over a long period of time.
	Competition to native species						
	Degredation of habitat						
	New restrictions prohibiting transfer of fish from hatchery to other watersheds						
Increase in disease (hatchery)	Increased mortality risk to fish on station and reduced number of fish available for release	Rear alternative species less susceptible to increased disease risks associated with climate change	5	2	5	4	Requires agreement with comanagers, primarily the Makah Nation, but also includes state and federal comanagers
Increase in parasites (hatchery)	Increased environmental risks in watershed from increased use of chemicals and antibiotics at hatchery	Investigate new treatments/technologies for treating surface source water for fish culture and effluent water prior to discharge	5	4	5	3	
Increase in pathogens (hatchery)	Budget impacts from increased fish health treatments	Evaluate alternative fish culture methods that reduce disease risks	4	2	4	2	This management action will require a review of the scientific literature and evaluation of data collected at Makah NFH in past years to build a foundation of informaiton for assessing possible variations in culture strategies (e.g., variable growth rates) that could reduce disease risks and improve overall survival.
	Reduced smolt "quality" and post-release survival of smolts	Increased fish health monitoring, diagnostics, and treatment	3	2	3	1	IHN virus has been detected recently among steelhead at several coastal hatcheries in Washington state and appears to be spreading. No current vaccine or medication is currently available for treatment. The current action for inhibiting the spread of the virus is to euthanize all the fish in raceways which test positive for the virus, and/or disinfecting rearing water for steelhead. Technology (e.g., ozone, UV) exists also to treat water for viral pathogens. The relative costs, benefits, and effectiveness of alternative actions and treatments for controlling the virus and its disease need to be assessed.
	Increased disease risks to wild fish in Sooes River						The effluent water management system at Makah NFH is highly effective at limiting the amount of drugs/chemicals that are discharged into the Sooes River. The environmental risks of the current effluent and treatment system are considered low to negligible.
Increase in number of fire events (hatchery)	Increased physical risk to facility and safety risk to crew	Review and update contingency preparations and safety protocols	2	1	2	1	Fire events in the northwest corner of the Olympic Pennisula are infrequent currently. This situation could change with a decrease in summer precipitation and an increase in air temperature. At the very least, fire risks are expected to increase with climate change.
Extreme precipitation events (hatchery)	Increased mortality risk to fish on station						
OTHER (Migration Corridor)							
Increase in invasive species (migration corridor)	Competition to native species	Continue monitoring and education efforts	2	1	2	1	
	Degredation of habitat						
increase in disease (migration corridor)	Reduced smolt-to-adult return rates	Work with comanagers and landowners to restore habitat of watershed	5	3	5	1	Habitat resotration efforts are currently in progress
increase in parasites (migration corridor)	Increased disease risks of adult fish retained for broodstock						
increase in pathogens (migration corridor)	Increased pre-spawning mortality of adults trapped for broodstock						
COASTAL (Hatchery and local watershed)							
Increase in wave size and intensity (hatchery)	Loss of freshwater habitat in lower Sooes River	Monitor effects of storms and wave action on freshwater habitats in lower river.	2	1	2	1	Makah NFH is located in a tsunami evacuation zone on the northwest corner of Washington state
Decrease in marine cloudiness (increasing temperature) (hatchery)	Increase in mean water temperatures	Continue efforts to reduce carbon footprint	3	3	4	2	
Increase in sea level (hatchery)	Increased physical risk to facility and safety risk to crew	Consider marine coastal effects in any new construction	5	2	5	4	The pump house is currently the only structure remotely at risk from sea level rise.
		Work with comanagers and landowners to restore habitat of watershed	5	3	5	3	Habitat resotration efforts are currently in progress
Management							
Skill set	Reduced ability to adequately monitor, diagnose, and treat fish for disease because of increased work loads.	Increase number of fish health specialists for monitoring, diagnosis, and treatment of fish diseases.	2	3	3	1	
	Increased workload and challenges of hatchery culture staff because of increased physiological stress of fish prior to release.	Increase biological training requirements for fish culture staff.	5	2	5	2	May require reclassification of Position Descriptions.