Appendix A. Qualitative Assessment of Climate Change Vulnerability of National Fish Hatcheries in the Columbia-Pacific Northwest Region: Leavenworth National Fish Hatchery

I. INITIAL QUALITATIVE ASSESSMENTS, 2011

The U.S. Fish and Wildlife Service (USFWS) qualitatively assessed climate change vulnerabilities of all National Fish Hatcheries (NFHs) during calendar year 2011. These assessments were based on the professional judgment, experiences, and institutional knowledge of the respective hatchery managers and staffs and were recorded in a MS-Excel spreadsheet template developed in the Headquarters Office (HQ) of the USFWS. In the Columbia-Pacific Northwest Region, future climate and hydrology projection graphs from the Climate Impacts Group at the University of Washington (CIG-UW) were used as the foundation for the assessments. The appendix presented here summarizes the methods, results, and conclusions of those qualitative vulnerability assessments for Leavenworth NFH (Figure A1).

II. METHODS

The initial vulnerability assessment for Columbia-Pacific Northwest Region NFHs 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 Columbia-Pacific Northwest 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 USFWS's initial climate change evaluations for NFHs in the Columbia-Pacific Northwest 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 impacts of each climate change stressor identifed in *Spreadsheet 1* based on their relative risks. A template for this spreadsheet was not provided by HQ. Rather, *Spreadsheet 2* was developed specifically for Columbia-Pacific Northwest Region NFHs to facilitate the recording of the requested information.

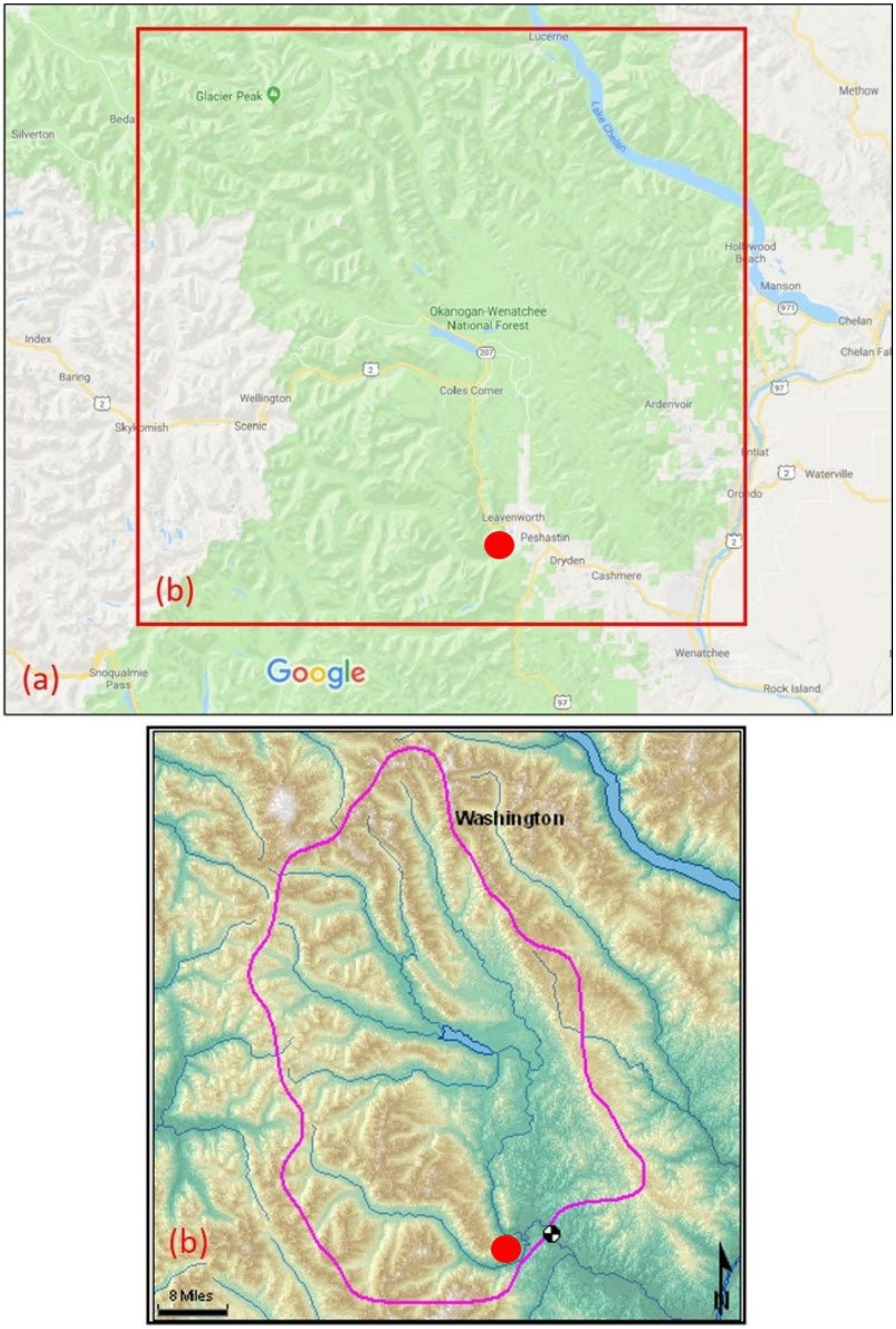

Figure A1. (a) Central Washington State. Leavenworth NFH (red circle) is immediately south of the town of Leavenworth at river mile 2.4 of Icicle Creek. **(b)** Downscaled, climate change projection graphs were obtained for the Wenatchee River watershed (lavender encirclement) from the Climate Impacts Group (CIG) at the University of Washington. The location of the USGS reference gaging station on the Wenatchee River is shown by the black and white quartered circle (at Dryden, Washington).

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 Leavenworth NFH

Hydrology projection graphs for the Icicle Creek watershed were not available in 2011. Consequently, climate projection graphs for the Wenatchee River watershed were used as surrogates to assess future temperature, precipitation, and hydrology conditions at Leavenworth NFH in the 2020s, 2040s, and 2080s relative to baseline conditions (Figure A2). Figure 5d from Mantua et al. (2010), reproduced here as Figure A3, was used to assess the potential future impacts to upstream-migrating salmon and Steelhead in the lower Columbia River during the summer months when water temperatures are projected to exceed 21 °C (Figure A3). Hatchery staff used all those projection graphs (Figures A2 and A3) 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. Figure A2: Temperature, precipitation, hydrology projections

Figure A2 on the following page shows the climate-hydrology projections for the Wenatchee River subbasin used by staff at Leavenworth NFH to complete *Spreadsheet 1*. Figure A2 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** is the average monthly streamflow at the gaging station (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 (Figure A1) 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 GCMs; and the orange circle shows the values for the composite delta downscale method.

3. **Graph (c): Monthly average air temperature (°F)** over the entire watershed upstream from the gaging station. Colored markings (dots, lines, shading) are the same as described for Graph (a).
4. **Graph (d): Monthly average total precipitation** (rain + snow) over the entire watershed upstream of the gaging station expressed as an average water depth (units = inches). Colored markings (dots, lines, shading) are the same as described for Graph (a).
5. **Graph (e): Simulated peak streamflow** at the gaging station 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. Colored markings (dots, lines, shading) are the same as described for Graph (b).
6. **Graph (f): Snow water equivalent (SWE) of projected snow pack** on first day of month averaged over the entire watershed upstream of the gaging station, expressed as an average water depth (units = inches). This variable is a primary component of the simulated water balance, and quantifies natural water storage of snowpack. Colored markings (dots, lines, shading) are the same as described for Graph (a).

Wenatchee River subbasin

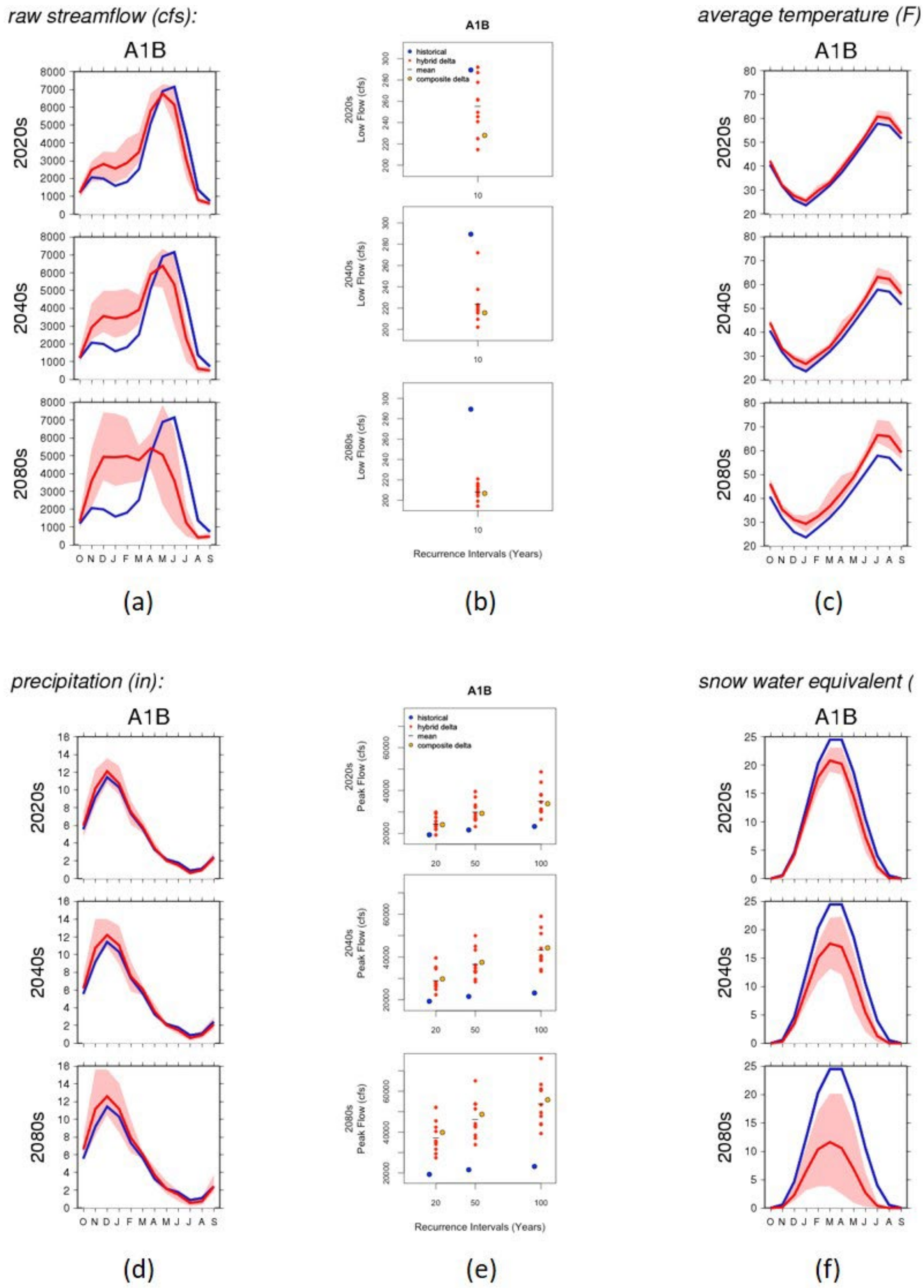

Figure A2. Climate and hydrology projections for the Wenatchee River subbasin, Washington (CIG 2011). The blue lines (a, c, d, and f) and dots (b, e) are the1971 – 1999 simulated historic means. The red line and red shading in (a), (c), (d), and (f) are the mean and range, respectively of outputs from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

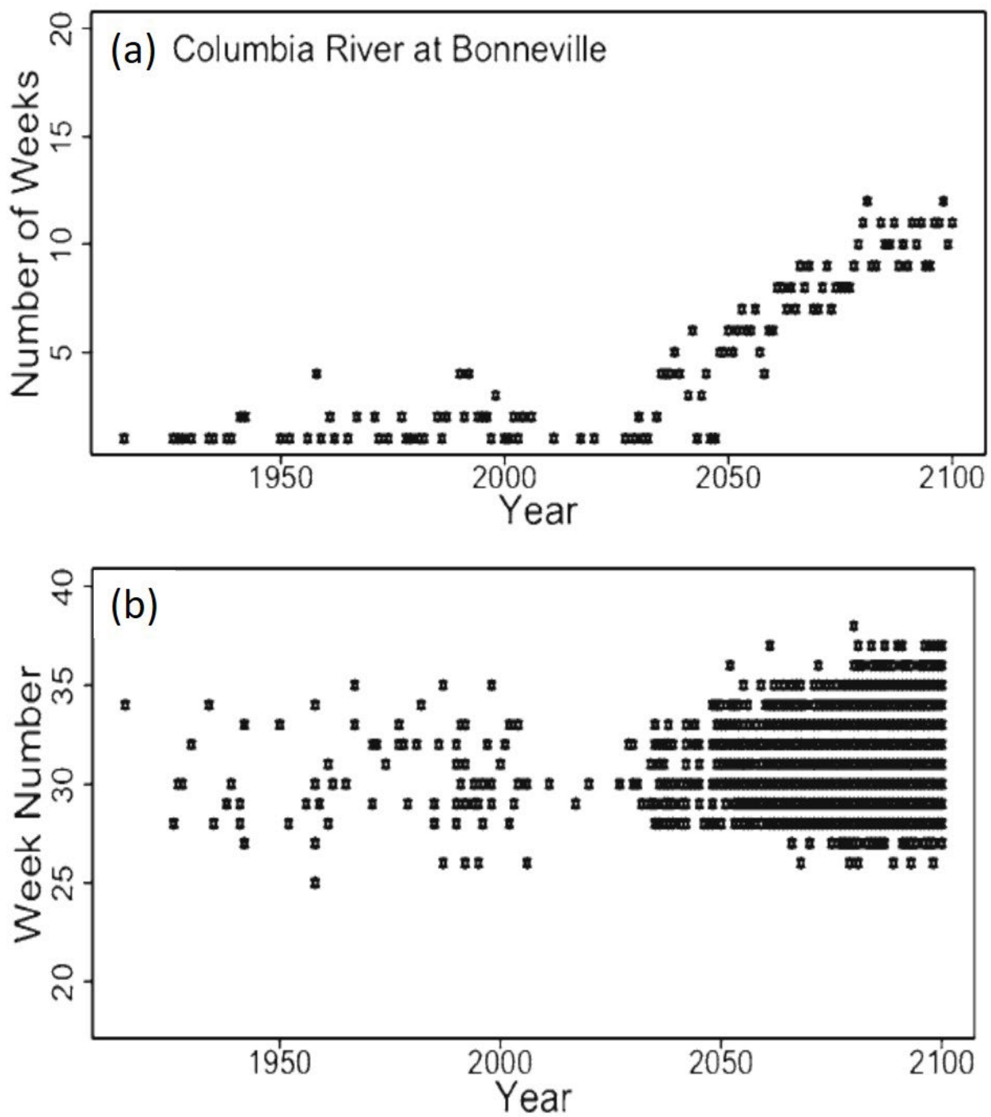

Figure A3. Number of weeks **(a)** and week numbers **(b)** when water temperatures in the lower Columbia River at Bonneville Dam are projected to exceed 21 °C (70 °F) based on the composite A1B emissions scenario and outputs of the same 10 GCMs used to produce the graphs in Figure A2. By the year 2050, mean water temperatures of the Columbia River at Bonneville Dam are projected to exceed 21 °C nearly continuously from week 28 through week 34, or approximately from July 15 to September 7. Graphs and data are from Figure 5d of Mantua et al. (2010).

III. RESULTS

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

1. **Stressors with the highest identified risks**[1]
   - Decreases in surface and ground water quality
   - Decrease in snow pack
   - Increases in the number and duration of annual droughts.
2. **Stressors with the next highest identified risks**[2]**:**
   - Decreases in surface and ground water quantity, particularly during the summer
   - Increases in surface and ground water temperature
   - Increases in ambient air temperature during the spring, summer and fall
   - Decreases in winter average precipitation, earlier snow-melt date, and higher elevation snow line
   - Increase in invasive species, pathogens, and disease, both at the hatchery and in the migration corridor
   - Biological and fish-health skill sets of hatchery staff to address increased fish health risks.

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

The manager and staff at Leavenworth NFH suggested the following management actions as first and second priorities (Priority Rank 1 or 2) for potentially adapting or mitigating for the projected effects of climate change based on time/effort, dollar cost, and feasibility of implementation (Table A2):

1. **Priority 1:**
   - Reduce rearing densities and number of fish reared at the hatchery;
   - Adjust feed rates and release timing of juvenile fish to coincide with optimum stream flows for outmigration;
   - Open fish ladder sooner for capturing adult fish for broodstock with cooler well water;
   - Expand water storage capacity of three alpine lakes [Upper and Lower Snow Lakes, and Nada Lake] that supplement the water supply to the hatchery;
   - Install UV treatment of surface water;
   - Modify water intake screen design and/or materials to inhibit growth of algae;
   - Increase labor to monitor water screens and pumps with greater frequency;
   - Increase number of fish health specialists for monitoring, diagnosis, and treatment of fish diseases.
2. **Priority 2:**
   - Install an oxygen injection and water recirculation system for fish culture.

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[1] Risk level = 5: *extreme risk, immediate action required* (Table A1).
[2] Risk level = 4: *high risk; high priority for action* (Table A1).

IV. DISCUSSION AND CONCLUSIONS

A primary concern at Leavenworth NFH, based on this initial qualitative assessment in 2011 of climate change vulnerabilities, was the projected decrease in surface and ground water quantity and quality, including projected increases in water temperatures and reduced water availability during the summer. Water flows and temperatures for Icicle Creek, the primary water source for the hatchery, have been supplemented and cooled, respectively, for decades by controlled releases from an alpine lake (Upper Snow Lake) which relies on melting snow pack for replenishment. Higher elevation snow levels in winter and reduced snowpack projected for the 2040s are expected to further constrain water availability and temperatures at Leavenworth NFH during the critical summer months.

A common concern at all NFHs in the Columbia-Pacific Northwest Region was the effects of climate change stressors on disease and increased prevalence of pathogenic organisms, both at the hatcheries and migration corridors. In general, disease risks for Pacific salmon and Steelhead increase with increases in water temperature, fish density indexes and water 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 (i.e., higher snow level elevations) during the winter.

Overall, the manager and staff at Leavenworth NFH used their expert opinions and professional experiences to conclude that both management and facility adaptations would most likely be necessary to adapt and/or mitigate for the projected effects of climate change.

Management adaptations include (a) reducing rearing densities and the number of fish reared on station, (b) adjusting feed rates and release timing of smolts to coincide with optimum stream flows, (c) opening the fish ladder earlier for capturing broodstock, (d) adding personnel for increased maintenance of facilities, and (e) increasing the number of fish health specialists for monitoring disease.

Facility adaptations include (a) expanding the water storage capacity of Nada and Snow lakes, (b) installing UV treatment of surface water, (c) modifying the water intake structure and screens, and (d) installing an oxygen injection system and water recirculation system for fish culture.

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.

Mantua, N., I Tohver, and A. Hamlet. 2010. Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. Climatic Change 102: 187–223.

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 Columbia-Pacific Northwest Region. The completed spreadsheet for Leavenworth NFH is presented as Table A1.

1. **<u>Step 1: Stressors</u>. Identify climate change stressors (columns 1 and 2).** The climate and hydrology projection graphs (Figure A2) was used to identify climate change stressors for Leavenworth NFH: 0 = not likely to be a stressor; 1= likely to be a stressor.

2. **<u>Step 2: Severity</u>. 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. **<u>Step 3: Likelihood</u>. 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. By definition, risk is the product of severity of impact (Step 2) and the probability of the stressor occurring (Step 3).

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 assessing the climate change vulnerability of Leavenworth 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.

Leavenworth 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**	**Step 4: Determine Risk Level**
Utilize Worksheet 2	Utilize Worksheet 2 (1= stressor, 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) (summer)	1	3	3	4
increase in water quantity (hatchery)	0			
SURFACE WATER QUANTITY (Migration Corridor)				
decrease in water quantity (migration corridor)	1	2	3	3
increase in water quantity (migration corridor)	0			
GROUND WATER QUANTITY (Hatchery and local watershed)				
decrease in water quantity (hatchery)	1	3	3	4
increase in water quantity (hatchery)	0			
SURFACE WATER QUALITY (Hatchery and local watershed)				
decrease in water quality (hatchery)	1	4	3	5
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)	1	4	3	5
improvement of water quality (hatchery)	0			
SURFACE WATER TEMPERATURE (Hatchery and local watershed)				
temperature increase (hatchery)	1	3	3	4
temperature decrease (hatchery)	0			
SURFACE WATER TEMPERATURE (Migration Corridor)				
temperature increase (migration corridor)	1	2	3	3
temperature decrease (migration corridor)	0			
GROUND WATER TEMPERATURE (Hatchery and local watershed)				
temperature increase (hatchery)	1	3	3	4
temperature decrease (hatchery)	0			

Table A1. Continued, page 2 of 6.

Leavenworth 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**	**Step 4: Determine Risk Level**
Utilize Worksheet 2	Utilize Worksheet 2 (1= stressor, 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	1	3	3	4
decrease in annual average temperature	0			
increase in number of warm days (aka heat waves1)	1	2	3	3
decrease in number of warm days	0			
increase in number of frost days2	0			
decrease in number of frost days	1	2	3	3
increase in spring average air temperatures	0			
increase in summer average air temperatures	1	3	4	4
increase in fall average air temperatures	1	3	4	4
increase in winter average air temperatures	1	2	4	4
decrease in spring average air temperatures	0			
decrease in summer average air temperatures	0			
decrease in fall average air temperatures	0			
decrease in winter average air temperatures	0			
PRECIPITATION CHANGES (Hatchery and local watershed)				
increase in annual average precipitation	0			
decrease in annual average precipitation	1	3	2	3
increase in spring average precipitation	0			
increase in summer average precipitation	0			
increase in fall average precipitation	0			
increase in winter average precipitation	0			
decrease in spring average precipitation	0			
decrease in summer average precipitation	1	1	2	2
decrease in fall average precipitation	0			
decrease in winter average precipitation	1	4	2	4
increase in frequency of extreme thunderstorms	0			
decrease in frequency of extreme thunderstorms	0			

Table A1. Continued, page 3 of 6.

Leavenworth 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**	**Step 4: Determine Risk Level**
Utilize Worksheet 2	Utilize Worksheet 2 (1= stressor, 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) Continued				
increase in annual average precipitation	0			
decrease in annual average precipitation	1	3	2	3
increase in spring average precipitation	0			
increase in summer average precipitation	0			
increase in fall average precipitation	0			
increase in winter average precipitation	0			
decrease in spring average precipitation	0			
decrease in summer average precipitation	1	1	2	2
decrease in fall average precipitation	0			
decrease in winter average precipitation	1	4	2	4
increase in frequency of extreme thunderstorms	0			
decrease in frequency of extreme thunderstorms	0			
increase in frequency of extreme snow storms	0			
decrease in frequency of extreme snow storms	1	2	3	3
increase in duration of extreme thunderstorms	0			
decrease in duration of extreme thunderstorms	0			
increase in duration of extreme snow storms	0			
decrease in duration of extreme snow storms	1	2	3	3
increase in amount of snow pack	0			
decrease in amount of snow pack	1	4	4	5
ealier snow melt date	1	3	4	4
later snow melt date	0			
lower snow line	0			
higher snow line	1	3	4	4

Table A1. Continued, page 4 of 6.

Leavenworth 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**	**Step 4: Determine Risk Level**
Utilize Worksheet 2	Utilize Worksheet 2 (1= stressor, 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)				
increased average wind speed annually	1	2	3	3
decreased average wind speed annually	0			
increased average wind duration annually	0			
decreased average wind duration annually	0			
change in wind patterns	0			
increased speed and duration of westerly wind flow	1	2	3	3
decreased speed and duration of westerly wind flow	0			
increased speed and duration of southernly wind flow	1	2	3	3
decreased speed and duration of southernly wind flow	0			
increase in number of flood events annually	1	2	3	3
decrease in number of flood events annually	1	2	3	3
increase in the average duration of flood events annually	0			
decrease in the average duration of flood events annually	1	2	3	3
increase in the severity of flood events annually	1	2	3	3
decrease in the severity of flood events annually	0			
increae in number of drought events annually	1	4	3	5
decrease in number of drought events annuaylly	0			
increase in the average duration of drought events annually	1	4	3	5
decrease in the average duration of drought events annually	0			
increase in the number of tornadoes	0			
decrease in the number of tornadoes	0			
increase in the severity of tornadoes	0			
decrease in the severity of tornadoes	0			
increase in the number of hurricanes	0			
decrease in the number of hurricanes	0			
increase in the severity of hurricanes	0			
decrease in the severity of hurricanes	0			

Table A1. Continued, page 5 of 6.

Leavenworth 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**	**Step 4: Determine Risk Level**
Utilize Worksheet 2	Utilize Worksheet 2 (1= stressor, 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) Continued				
increase in the number of ice storms	1	1	3	2
decrease in the number of ice storms	0			
increase in the severity of ice storms	1	1	3	2
decrease in the severity of ice storms	0			
increase in the number of monsoons	0			
decrease in the number of monsoons	0			
increase in the severity of monsoons	0			
decrease in the severity of monsoons	0			
increase in the number of hail storms	1	1	2	2
decrease in the number of hail storms	0			
increase in the severity of hail storms	1	1	2	2
decrease in the severity of hail storms	0			
OTHER (Hatchery and local watershed)				
increase in invasive species	1	3	4	4
decrease in invasive species	0			
increase in disease	1	3	4	4
decrese in disease	0			
increase in parasites	1	3	4	4
decrease in parasites	0			
increase in pathogens	1	3	4	4
decrease in pathogens	0			
increase in number of fire events	1	1	3	2
decrease in number of fire events	0			
increase in intensity of fire events	1	1	3	2
decrease in intensity of fire events	0			
extreme precipitation events-hurricane	0			
extreme precipitation events-troopical storm	0			
extreme precipitation events-cyclones	0			
extreme precipitation events	1	2	2	2

Table A1. Continued, page 6 of 6.

Leavenworth 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**	**Step 4: Determine Risk Level**
Utilize Worksheet 2	Utilize Worksheet 2 (1= stressor, 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 (Migration Corridor)				
increase in invasive species (migration corridor)	1	3	3	4
decrease in invasive species (migration corridor)	0			
increase in disease (migration corridor)	1	3	3	4
decrese in disease (migration corridor)	0			
increase in parasites (migration corridor)	1	3	3	4
decrease in parasites (migration corridor)	0			
increase in pathogens (migration corridor)	1	3	3	4
decrease in pathogens (migration corridor)	0			
COASTAL (Hatchery and local watershed)				
increase in wave size and intensity	0			
decrese in wave size and intensity	0			
increase in marine cloudines (decreasing temperature)	0			
decrease in marine cloudiness (increasing temperature)	0			
increase in sea level rise	0			
decrease in sea level rise	0			
change in ocean currents	0			
change in wave patterns	0			
Management				
skill set: additional biological and fish health training of hatchery staff	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 Columbia-Pacific Northwest 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 Leavenworth NFH is presented as Table A2.

1. **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.
2. **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.
3. **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

4. **<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

5. **<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 Leavenworth NFH, page 1 of 3.

Leavenworth 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 managemen t action (1, 2, 3, 4, or 5)	Step 10, part 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 (summer)	Increase in water temperature	Install industrial water chillers, develop ground water sources	4	5	5	3	Not realistically feasible; other options have higher priority
Decrease in surface water quality	Increase in fish health risks	Reduce rearing densities and number of fish	4	1	4	1	Could violate legal mitigation agreements and U.S. v. Oregon treaty with tribes.
	Reduced ability to meet legal mitigation goals	Expand facilities to location with additional water	5	5	5	5	Additional fish rearing facilities could be constructed at another location with water
	Reduced dissolved oxygen	Install oxygen injection, water recirculation system	3	3	4	2	Feasible, but may not mitigate completely for water loss
	Reduced carrying capacity of hatchery for rearing fish	Expand storage capacity of 3 alpine lakes that supplement water supply	3	4	4	4	Feasible, idea currently being considered by other agencies for other reasons.
Decrease in ground water quantity	Reduced dissolved oxygen	Install oxygen injection, water recirculation system	3	3	4	2	Feasible, but may not mitigate completely for water loss
Degradation in ground water quality	Increase fish health risks	Reduce rearing densities and number of fish	4	1	4	1	Could violate legal mitigation agreements and U.S. v. Oregon treaty with tribes.
	Reduced ability to meet legal mitigation goals	Expand facilities to location with additional water	5	5	5	5	Additional fish rearing facilities could be constructed at another location with water
	Higher prespawn mortality of adults held for broodstock	Install industrial chillers	3	5	5	4	Very expensive to build and operate for required volume of water.
		Expand storage capacity of 3 alpine lakes that supplement water supply	3	4	4	3	Currently under study by other agencies for other reasons
Increase in surface water temperature	Increased fish health risks	Install industrial water chillers	4	5	5	3	Not realistically feasible, other management options have higher priority
	Potential inability to rear current species (spring Chinook)	Rear alternative species	4	1	4	5	Could violate legal mitigation agreements and U.S. v. Oregon treaty with tribes.
	Reduced dissolved oxygen	Install oxygen injection, water recirculation system	3	3	4	4	Feasible, but may not mitigate completely for water loss
	Increased fouling of screens by algae/aquatic plants	Modify screen design or materials to inhibit growth of algae	3	2	3	1	Technology under investigation
		Expand storage capacity of 3 alpine lakes that supplement water supply	3	4	4	2	Feasible, idea currently being considered by other agencies for other reasons.
Increase in ground water temperature	Increased fish health risks	Install industrial water chillers	4	5	5	3	Not realistically feasible, other management options have higher priority
	Potential inability to rear current species	Rear alternative species	4	1	4	4	Could violate legal mitigation agreements and U.S. v. Oregon treaty with tribes.
	Reduced dissolved oxygen	Install oxygen injection, water recirculation system	3	3	4	2	Feasible, but may not mitigate completely for water loss
	Higher pre-spawn mortality of adults held for broodstock	Expand storage capacity of 3 alpine lakes that supplement water supply	3	4	4	1	Feasible, idea currently being considered by other agencies for other reasons.
WATER QUALITY AND QUANTITY CHANGES (Migration corridor)							
Decrease in surface water quantity	Reduced survival of smolts released at current times (April)	Adjust feed rates and release timing of fish to coincide with optimum stream flows for outmigration	2	1	2	1	May need greater flexability regarding release timimg of smolts with earlier snow melt and reduced snow pack
	Reduced number of adult fish available for broodstock	Open fish ladder sooner for capturing adult fish with cooler well water	1	2	2	2	May need to recharge aquifer more often
Decrease in surface water quality	Higher pre-spawn mortality of adults held for broodstock	Open fish ladder sooner for capturing adult fish with cooler well water	1	2	2	1	May need to recharge aquifer more often
Increase in surface water temperature	Creation of thermal barrier to upstream migration of adult salmon during summer	Adjust broodstock collection and spawn dates in response to life history adaptations to altered hydrologies and thermal regimes.	2	2	2	2	The dollar cost could increase if the length of time required to hold adult fish prior to spawning increases and/or increased fish health monitoring required..
	Reduced number of adult fish available for broodstock	Rear alternative species	4	1	4	3	Could violate legal mitigation agreements and U.S. v. Oregon treaty with tribes.
	Reduced ability to meet legal mitigation goals						
AMBIENT TEMPERATURE CHANGES (Hatchery)							
Increase in annual average temperature	Reduced dissolved oxygen	Install oxygen injection, water recirculation system	3	3	4	2	Feasible, but may not mitigate completely for water loss
Increase in number of warm days (aka heat waves1)	Increase fish health risks	Reduce rearing densities and number of fish	4	1	4	1	Could violate legal mitigation agreements and U.S. v. Oregon treaty with tribes.
	Reduced ability to meet legal mitigation goals	Expand facilities to location with additional water	5	5	5	5	Additional fish rearing facilities could be constructed at another location with water
	Increase in water temperature	Install industrial water chillers	4	5	5	3	Other management options have higher priority
		Expand storage capacity of 3 alpine lakes that supplement water supply	3	4	4	4	Feasible, idea currently being considered by other agencies for other reasons.
Decrease in number of frost days	Increased growth rates in species reared	Use chilled water to incubate eggs, adjust feeding	1	1	1	1	Very simple solution for most species reared
	Increase in water temperature	Install water chillers	4	5	5	4	Other management options have higher priority
	Increase fish health risks	Reduce rearing densities and number of fish	4	1	4	2	Could violate legal mitigation agreements and U.S. v. Oregon treaty with tribes.
		Expand storage capacity of 3 alpine lakes that supplement water supply	3	4	4	3	Feasible, idea currently being considered by other agencies for other reasons.

Table A2. Continued, page 2 of 3.

Leavenworth 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 managemen t action (1, 2, 3, 4, or 5)	Step 10, part 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) Continued.							
Increase in summer average air temperatures	Increased fish health risks	Install industrial water chillers	4	5	5	5	Other management options have higher priority
Increase in fall average air temperatures	Potential inability to rear current species	Rear alternative species	4	1	4	2	Could violate legal mitigation agreements and U.S. v. Oregon treaty with tribes.
	Reduced dissolved oxygen	Install oxygen injection, water recirculation system	3	3	4	3	Feasible, but may not mitigate completely for water loss
	Increased fouling of screens by alage/aquatic plants	Increase labor to monitor water screens and pumps	2	2	2	1	
		Expand storage capacity of 3 alpine lakes that supplement water supply	3	4	4	4	Feasible, idea currently being considered by other agencies for other reasons.
Increase in winter average air temperatures	Increase in water temperature	Install water chillers	4	5	5	4	Other management options have higher priority
	Increased growth rates in species reared	Use chilled incubation water	1	1	1	2	Very simple solution for most species reared
	Increase fish health risks	Reduce rearing densities and number of fish	4	1	4	3	Could violate legal mitigation agreements and U.S. v. Oregon treaty with tribes.
	Increased fouling of screens by alage/aquatic plants	Increase labor to monitor water screens and pumps	2	2	2	1	
PRECIPITATION CHANGES (Hatchery and local watershed)							
Decrease in annual average precipitation	Increase in water temperature	Install industrial water chillers, develop ground water sources	4	5	5	3	Other management options have higher priority
Decrease in summer average precipitation	Increase fish health risks	Reduce rearing densities and number of fish	4	1	4	1	Could violate legal mitigation agreements and U.S. v. Oregon treaty with tribes.
	Reduced ability to meet legal mitigation goals	Expand facilities to location with additional water	5	5	5	5	Additional fish rearing facilities could be constructed at another location with water
	Reduced dissolved oxygen	Install oxygen injection, water recirculation system	3	3	4	2	Feasible, but may not mitigate completely for water loss
		Expand storage capacity of 3 alpine lakes that supplement water supply	3	4	4	4	Feasible, idea currently being considered by other agencies for other reasons.
Decrease in winter average precipitation	Increase in water temperature	Install industrial water chillers, develop ground water sources	4	5	5	3	Other management options have higher priority
Decrease in frequency of extreme snow storms	Increase fish health risks	Reduce rearing densities and number of fish	4	1	4	1	Could violate legal mitigation agreements and U.S. v. Oregon treaty with tribes.
Decrease in duration of extreme snow storms	Reduced ability to meet legal mitigation goals	Expand facilities to location with additional water	5	5	5	5	Additional fish rearing facilities could be constructed at another location with water
Decrease in amount of snow pack	Reduced dissolved oxygen	Install oxygen injection, water recirculation system	3	3	4	2	Feasible, but may not mitigate completely for water loss
Higher snow line	Less snow pack: less water during critical summer period	Expand storage capacity of 3 alpine lakes that supplement water supply	3	4	4	4	Feasible, idea currently being considered by other agencies for other reasons.
Earlier snow melt							
EXTREME WEATHER EVENTS (Hatchery and local watershed)							
increased average wind speed annually	Increase in power outages	Use back up electrical generator	1	2	2	2	
increased speed and duration of westerly wind flow	Increase in fouling of screens	Increase labor to monitor water screens with greater frequency	1	1	1	1	
increased speed and duration of southernly wind flow							
increase in number of flood events annually	Reduced fish growth and health	Expand settling basin to remove sediment	4	3	5	3	Space available but cost would be high (>$500,000?)
	Fouling of water delivery system	Increase labor to monitor water screens with greater frequency	1	1	1	2	
	Damage to hatchery facilities	Increase labor to maintain and repair facility	1	1	1	1	
Decrease in number of flood events annually	Reduced ability to release fish at desired times	Hold fish longer prior to release	3	1	3	2	Could impact rearing densities for all species reared
Decrease in the average duration of flood events annually	Increased rearing densities	Adjust growth rates to avoid high densities	1	1	1	1	Very simple solution for most species reared
	Increase fish health risks	Reduce rearing densities and number of fish	4	1	4	3	Could violate legal mitigation agreements and U.S. v. Oregon treaty with tribes.
Increase in the severity of flood events annually	Debris blockages of surface water intakes	Modify intake design/log booms, etc. to divert debris	2	2	2	3	
	Increased sediment loads and physiological stress on fish	Emergency release of fish prior to smoltification	4	1	4	2	Could violate legal mitigation agreements and U.S. v. Oregon treaty with tribes.
	Increase risk of damage to hatchery facilities	Increase labor to maintain facilities and repair damage	1	1	1	1	
	Decreased fish growth due to poor water visibility	Expand settling basin to remove sediment	4	3	5	4	Space available but cost would be high (>$500,000?)

Table A2. Continued, page 3 of 3.

Leavenworth 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 managemen t action (1, 2, 3, 4, or 5)	Step 10, part 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.
EXTREME WEATHER EVENTS (Hatchery and local watershed) Continued.							
Increase in number of drought events annually	Reduced dissolved oxygen	Install oxygen injection, water recirculation system	3	3	4	2	Quite feasible, but may not entirely mitigate for water loss
Increase in the average duration of drought events annually	Increase fish health risks	Reduce rearing densities and number of fish	4	1	4	1	Could violate legal mitigation agreements and U.S. v. Oregon treaty with tribes.
	Reduced ability to meet legal mitigation goals	Expand facilities to location with additional water	5	5	5	5	Additional fish rearing facilities could be constructed at another location with water
	Increase in water temperature	Install industrial water chillers	4	5	5	3	Not realistically feasible, use other management options…reduce rearing, inject O2, etc.
	Decrease in surface and ground water quantity	Expand storage capacity of 3 alpine lakes that supplement water supply	3	4	4	4	Feasible, idea currently being considered by other agencies for other reasons.
Increase in the number of ice storms	Increased incidence of power outages	Use back up power generator	1	2	2	1	
	Increased incidence of icing of water screens	Modify screens with new technology to de-ice automatically.	3	3	4	2	
Increase in the severity of ice storms	Increase in freeze-up episodes and loss of surface water	Develop additional ground water sources	3	3	4	2	Ground water availability and aquifer recharge may be limited by reduced water flows in summer.
	Increased incidence of power outages	Use back up power generator	1	2	2	1	
Increase in the number of hail storms	Debris blockages of surface water intakes	Modify intake design/log booms, etc.	2	2	2	1	
Increase in the severity of hail storms	Damage to hatchery facility	Increased labor to maintain and repair facility	1	1	1	2	
OTHER (Hatchery and local watershed)							
Increase in invasive species	Increase fish health risks	Install UV treatment of surface water	4	5	5	1	Water volume (25 to 42 cfs) and turbidity may inhibit feasibility of UV treatment
	Potential inability to rear current species	Rear alternative species	4	1	4	2	Could violate legal mitigation agreements and U.S. v. Oregon treaty with tribes.
	Potential water system blockage (e.g., mussels)	Develop additional ground water sources	3	3	4	3	Ground water availability and aquifer recharge may be limited by reduced water flows in summer.
Increase in disease	Increase fish health risks	Construct intensive water recirculation system with water treatment	4	5	5	3	Expensive but doable. Increases feasibility of using water chillers.
Increase in parasites	Potential inability to rear current species	Rear alternative species	4	1	4	2	Could violate legal mitigation agreements and U.S. v. Oregon treaty with tribes.
Increase in pathogens	Increase disease virulence	Reduce rearing densities and number of fish	4	1	4	1	Could violate legal mitigation agreements and U.S. v. Oregon treaty with tribes.
Increase in number of fire events	Increase in surface water temperature	Construct intensive water recirculation system with water treatment	4	5	5	3	Expensive but doable. Increases feasibility of using water chillers.
Increase in intensity of fire events	Increased debris load and sediment from erosion	Expand settling basin to remove sediments	4	3	5	2	Space available but cost would be high (>$500,000?)
	Damage to hatchery facilities	Increased labor to maintain and repair facility	1	1	1	1	
Extreme precipitation events	Debris blockage of surface water intake	Modify intake design/log booms, etc.	2	2	2	3	
	Decrease fish growth due to poor water visibility	Emergency release of fish prior to smoltification	4	1	4	2	Could violate legal mitigation agreements and U.S. v. Oregon treaty with tribes.
	damage to hatchery facilities	Increased labor to maintain and repair facility	1	1	1	1	
		Expand settling basin to remove sediment	4	3	5	4	Space available but cost would be high (>$500,000?)
OTHER (Migration corridor)							
Increase in invasive species	Increase disease risk to smolts following release	Adjust feed rates and release timing of fish to coincide with optimum stream flows for outmigration	2	1	2	1	Pre-smolts spend little time in Icicle Creek and Wenatchee River following release
Increase in disease	Higher adult pre-spawn mortality of adults trapped for broodstock	Open fish ladder sooner using cooler well water	1	2	2	2	May need to recharge aquifer more often via Icicle Creek bypass canal.
Increase in parasites	Reduced smolt-to adult return rates (SARs)						
Increase in pathogens	Reduce numbers of adult fish available for broodstock						
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.