Yukon River Instream Flow Chinook Salmon Time Series Analysis

Prepared for Yukon Energy Corporation.

Normandeau Associates, Inc.

December 2012

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December 20, 2012

Travis Ritchie
Manager – Environment, Assessment and Licensing
Yukon Energy Corporation
2 Miles Canyon Road, Box 5920
Whitehorse, Yukon
Y1A 6S7

Dear Travis:

Project No: 60237818 – Task 2.2

Regarding: Marsh Lake Fall-Winter Storage Concept – Yukon River Instream Flow Chinook Salmon Time Series Analysis Report

Please find attached the above noted report prepared by Normandeau Associates Inc. on behalf of AECOM.

We trust this report meets your current needs. If you have any questions regarding this report, or if we can be of further assistance, please do not hesitate to contact the undersigned.

Sincerely,
AECOM Canada Ltd.

Forest Pearson

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cc:

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Table Acronyms

cms	Cubic meters per second
GWh	Gigawatt hour
HSC	Habitat Suitability Criteria
L	Liter
m	Meters
mg	Milligrams
MW	Megawatt
NTU	Nephelometric Turbidity Units
PHABSIM	Physical Habitat Simulation model developed by the U.S. Fish and Wildlife Service
s	Second
TRPA	Thomas R. Payne & Associates
WSEL	Water Surface Elevation
WUA	Weighted Usable Area, a Habitat Index
WY	Water Year
YEC	Yukon Energy Corporation

EXECUTIVE SUMMARY

Proposed operation changes at Lewes Dam for the purpose of increasing winter hydroelectric generating capacity will alter Yukon River flows downstream of the dam. Chinook salmon utilize the Yukon River for migration, spawning and rearing. PHABSIM was used to determine the relationship between flow and habitat index in the influenced reaches in a previous study (TRPA 2011). Further time-series analysis was completed for this report, combining the flow/habitat index relationship with hydrologic flow records for average, wet, and dry years. The index of spawning, incubation, and rearing habitat produced under the current operations was compared to habitat produced by the proposed operation changes.

The results of this analysis show the magnitude of the Chinook salmon habitat index available under Marsh Lake Fall Storage Concept flows varies depending on life stage and water year. Chinook spawning downstream of the Whitehorse Generating Station and upstream of the confluence with the Takhini River would be more affected than incubation or juvenile rearing. Concept flows increase (by an average daily change of 6%) the spawning habitat index in an average water year and decrease (by an average daily change of 5%) the index in a dry water year, with little change (average daily change of 1%) in a wet year. Concept flows increase the incubation habitat index between 3% and 4% for all water year types. Juvenile Chinook use sloughs and tributaries of the Yukon River as their primary rearing habitat and over-wintering habitat. Although juvenile Chinook utilize the mainstem Yukon River as a migration corridor to both non-natal rearing streams and the ocean, the extent and timing of rearing in the mainstem Yukon River between Lewes Dam and the confluence with the Takhini River is not well understood (von Finster 2009). As a result there is uncertainty regarding impacts to Chinook juvenile rearing habitat in the mainstem Yukon River relative to Southern Lakes Fall/Winter Storage Concept operations.

INTRODUCTION

YEC engaged AECOM to assist with the assessment of increasing water storage in Marsh, Tagish and Bennett Lakes (collectively referred to as “the Southern Lakes”) to increase winter electrical production from the Whitehorse Rapids Hydroelectric Generating station. Under the proposed Concept, the operating rules for the Lewes River Control Structure (also referred to as the “Marsh Lake Dam”, or “Lewes Dam”) would be modified to maintain a higher water level in Marsh Lake during the later summer and fall. Specifically, the current operating license would be modified to increase the Full Supply Level by 0.3 m from 656.234 m to 656.53 m, and lower the Low Supply Level by 0.1 m. The regulated period would generally remain unchanged from August 15th to May 15th. However, the goal of the proposed Concept is to save water from the high-flow periods for use during the low-flow periods of the year. This will result in reduced flows in the late summer and early fall, and higher winter stream flow, with volumes varying by water year type. In wet years, Marsh Lake would remain normally high through the summer and fall and the flow regulation gates would not close and begin winter storage until the fall (e.g. October). In dry years, when the lake level is low, the gates would close earlier than the historical practice and cause Marsh Lake levels to rise.

Aquatic habitat for Chinook salmon and other fish species downstream of Lewes Dam may be affected by the seasonal decreases and increases in flow by a new water management regime. Rearing habitat between Lewes Dam and the Whitehorse Rapids Hydrogeneration Station (identified as the Lewes Reach) and spawning and rearing habitat downstream of Whitehorse Rapids to the confluence with the Takhini River (identified as the Takhini Reach) may also be affected. This report describes a time series analysis of Chinook salmon spawning, incubation, and juvenile rearing relative to historical stream flow and potential altered flows under different water years (average, dry and wet water years) in the two reaches near Whitehorse. The analysis supplements a previous report for Yukon Energy Corporation (YEC) that described instream flow data collection and analysis of Chinook spawning and passage in the Yukon River downstream of Whitehorse Rapids which used the PHABSIM hydraulic and habitat modeling procedures (TRPA 2011). This analysis is based on updated potential Concept related flow regimes.

STUDY AREA

The study area extends from Lewes Dam on the upper Yukon River near the City of Whitehorse in southern Yukon, Canada, downstream to the Takhini River confluence. As mentioned in the 2011 Report (TRPA), data was collected on the Yukon River in two reaches, the 27.6 kilometre Lewes Reach (Upper Reach) and 18.1 kilometre Takhini Reach (Lower Reach). The Takhini Reach is the section of the Yukon River between the City of Whitehorse and the confluence of the Yukon River with the Takhini River (Figure 1). The Lewes Reach is the section of the Yukon River between Lewes Dam and Schwatka Lake upstream of the Whitehorse Rapids Hydrogeneration Station (Figure 2).

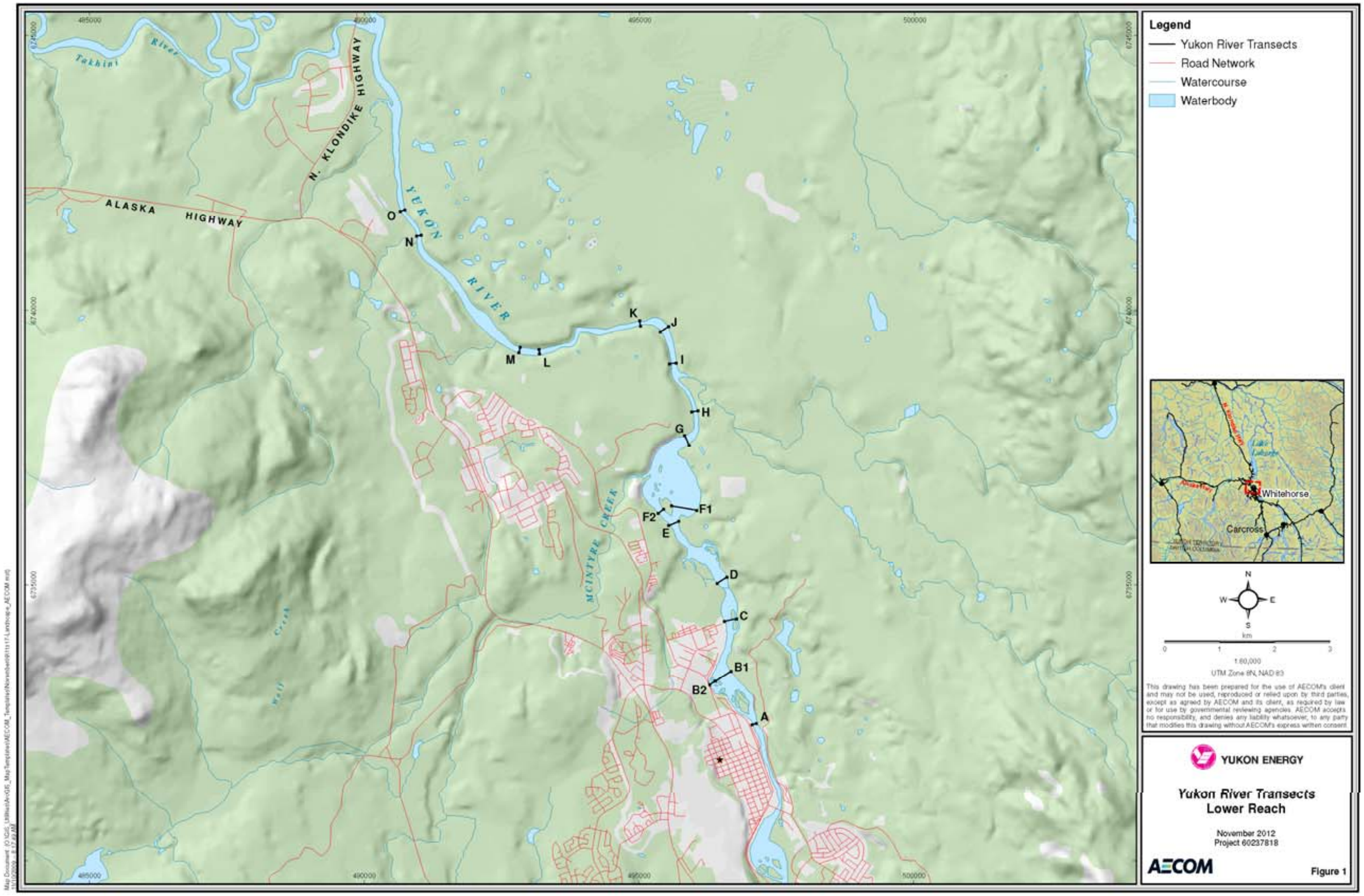

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Figure 1. Takhini Reach on the Yukon River showing locations of PHABSIM transects.

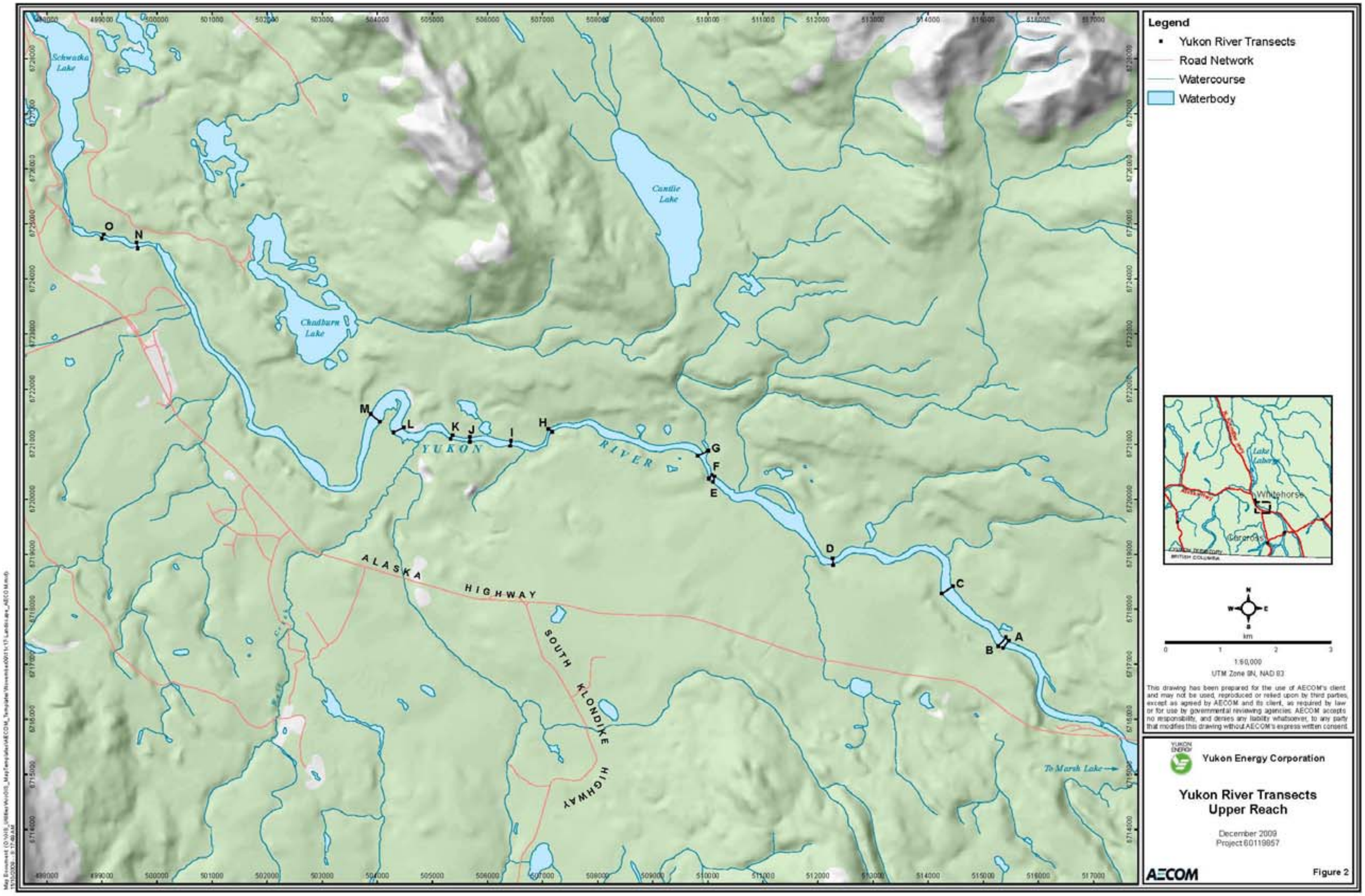


Figure 2. Lewes Reach on the Yukon River showing locations of PHABSIM transects.

METHODS

The AECOM study team previously built a Yukon River PHABSIM model based on cross-sections established in 2009 to simulate an index to Chinook spawning habitat (TRPA 2011). The output from the PHABSIM model (weighted useable area or WUA) was combined with past hydrology for wet, dry, and average water year types to create a time series habitat index baseline. The time series habitat baseline was compared to the time series habitat index produced in each of water year types under Concept flows. Refer to the Yukon River Instream Flow Chinook salmon passage and spawning report (TRPA 2011) for methods regarding transect selection, field data collection, and hydraulic and habitat modeling.

The current time-series analysis includes Chinook spawning and incubation (Takhini Reach), and juvenile rearing (Takhini and Lewes Reaches). This difference between the life-stages included in each reach was based on the lack of documented spawning in the Lewes Reach but known spawning in the Takhini Reach and in tributaries upstream of Lewes Dam. This spawning time-series differs from the previous report in that the current analysis utilizes an updated flow time-series which more accurately represents both the historical conditions as well as the simulated Concept flows. The incubation and juvenile rearing life-stages were not evaluated in the previous report.

HABITAT SUITABILITY CRITERIA

Habitat suitability criteria (HSC) are applied to the cross sectional PHABSIM hydraulic models to generate the WUA index of habitat availability. HSC for depth, velocity, substrate and/or cover are based on probable suitability values that run from zero (no suitability) to 1.0 (maximum suitability).

SUBSTRATE CODES

Substrate was characterized and classified along each transect using the Bovee (1982) code for the TRPA (2011) Chinook spawning analysis (Table 1). Due to the turbid nature and the depth of the Yukon River, substrate could not be characterized for deep sections of transects, greater than approximately 1.5 m to 2 m deep. In such instances the last identified substrate code on each side of the river were continued out to the thalweg.

Table 1. Bovee code used for coding the Yukon River transects substrate.

Code	Description	Size (cm)
1	Organic/veg	------
2	Mud/clay	------
3	Silt	<0.005
4	Sand	0.005 – 0.25
5	Gravel	0.25 – 6
6	Cobble	6 – 25
7	Boulder	>25
8	Bedrock	------

The code is recorded as x.y, where x is the smaller of the dominant two adjacent substrate sizes and y is the percentage of the larger (Bovee 1982).

CHINOOK SPAWNING AND INCUBATION CRITERIA

The process used for selection of Chinook spawning HSC was presented in TRPA (2011). Spawning depth and velocity curves (Figure 3) show that ideal conditions have velocities between 0.46 and 1.13 m/s and depths between 0.46 and 1.54 m. Substrate criteria (Table 2) indicate that the ideal particle size is between 0.25 and 6 m.

Sources for Chinook incubation and juvenile HSC include both “clear water” and “turbid water” criteria. There is not a definitive definition as to what constitutes clear or turbid. Turbidity is typically expressed in Nephelometric Turbidity Units (NTU) which is a measure of light penetration. Suchanek *et al*. (1984) refers to clear as <30 NTU and turbid >30 NTU, based on an apparent demarcation of cover use by juvenile Chinook. Bovee (1978) does not include a measure of turbidity for Chinook incubation criteria, only referring to clear or turbid.

Based on water quality standards for British Columbia, clear is defined as low concentrations of suspended sediment of <25mg/L which equates to <8 NTU (Caux *et al.* 1997). This standard was corroborated for the Yukon region by Birtwell *et al.* (2008). Samples taken at the Marsh Lake Water Control Dam between 1980 and 2006 include only nine instances out of 648 samples where NTU was >8. Based on this data, suitability criteria for clear water used in the analysis of Chinook incubation and juvenile rearing are appropriate.

Though similar to Chinook spawning HSC in terms of velocity, depth and substrate, incubation curves for low gradient rivers and clear water conditions (Bovee 1978) were selected for analyses in this report (Table 3, Figure 4). Ideal velocity and depth for rearing are slower and shallower than for spawning (0.27 to 0.64 m/s and 0.18 to 0.73 m), whereas the substrate remains the same.

CHINOOK JUVENILE REARING CRITERIA

The selection of Chinook juvenile rearing criteria was primarily based on river size and geographical locality relative to the Yukon River. HSC developed on the Susitna River in Alaska (Suchanek *et al.* 1984) were identified as the most appropriate (Table 4, Figure 5). The original depth criteria were limited to a suitability of 0.3 for depths greater than 0.6 meters. However the authors believed this to be an artifact of sampling due to the difficulty of acquiring data in deeper waters. As a result depth suitability was set at 1.0 for depths greater than 0.1 meters. Ideal velocity for juvenile Chinook is between 0.11 and 0.2 m/s. The Chinook juvenile HSC uses cover rather than substrate as a third variable (Table 5). Table 5 shows ideal cover for juvenile Chinook is debris and deadfall. All substrate codes were converted to the appropriate cover suitability based on Suchanek *et al*. (1984). Cover categories other than substrate were added to each transect based on field notes and photos.

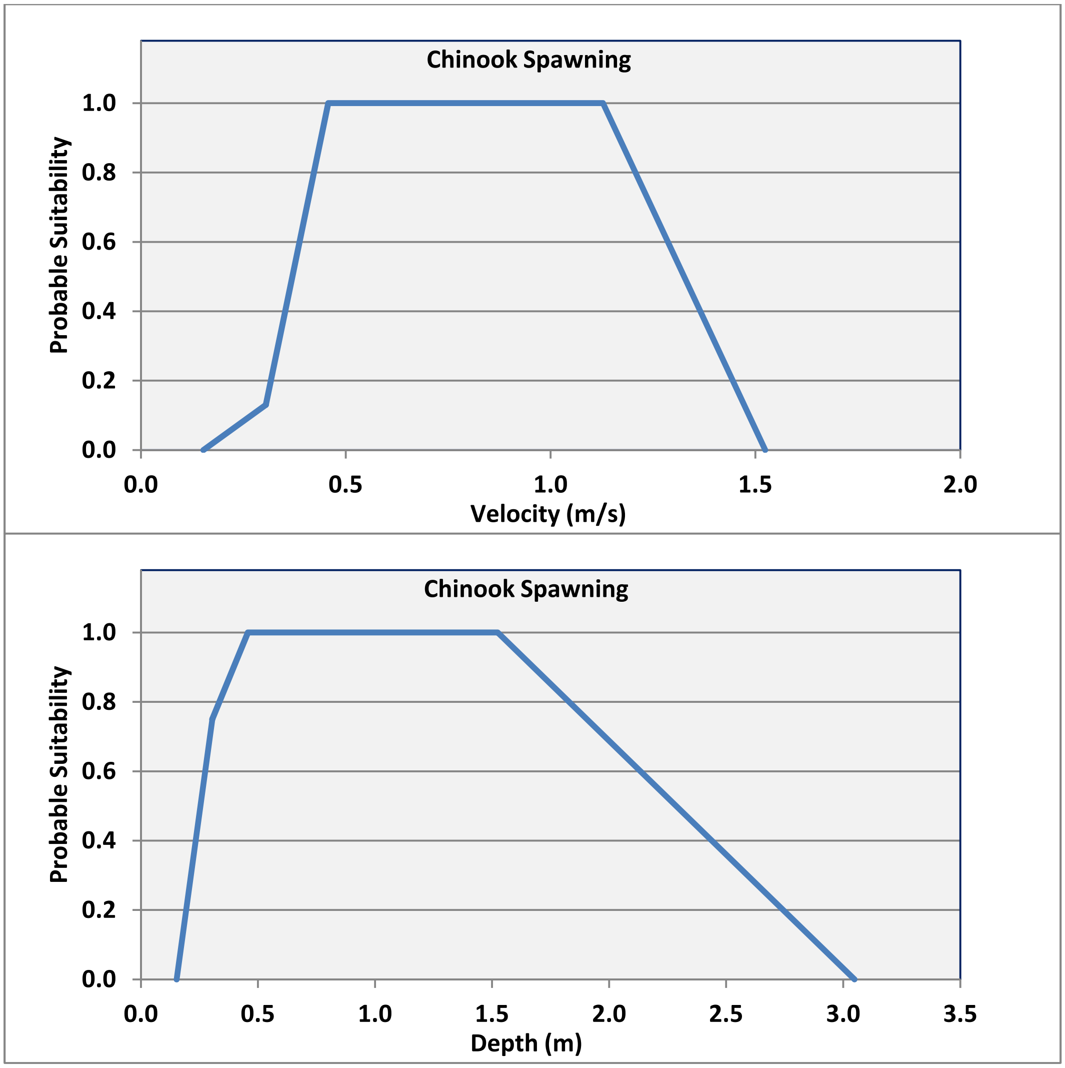


Figure 3. Chinook spawning velocity (top) and depth (bottom) HSC.

Table 2. Chinook spawning HSC for velocity, depth and substrate.

Velocity (m/s)	Suitability	Depth (m)	Suitability	Substrate	Suitability
0.15	0.00	0.15	0.00	1	0.00
0.30	0.13	0.30	0.75	2	0.00
0.46	1.00	0.46	1.00	3	0.00
1.13	1.00	1.52	1.00	4	0.00
1.52+	0.00	3.05+	0.00	5	1.00
				6	0.50
				7	0.00
				8	0.00

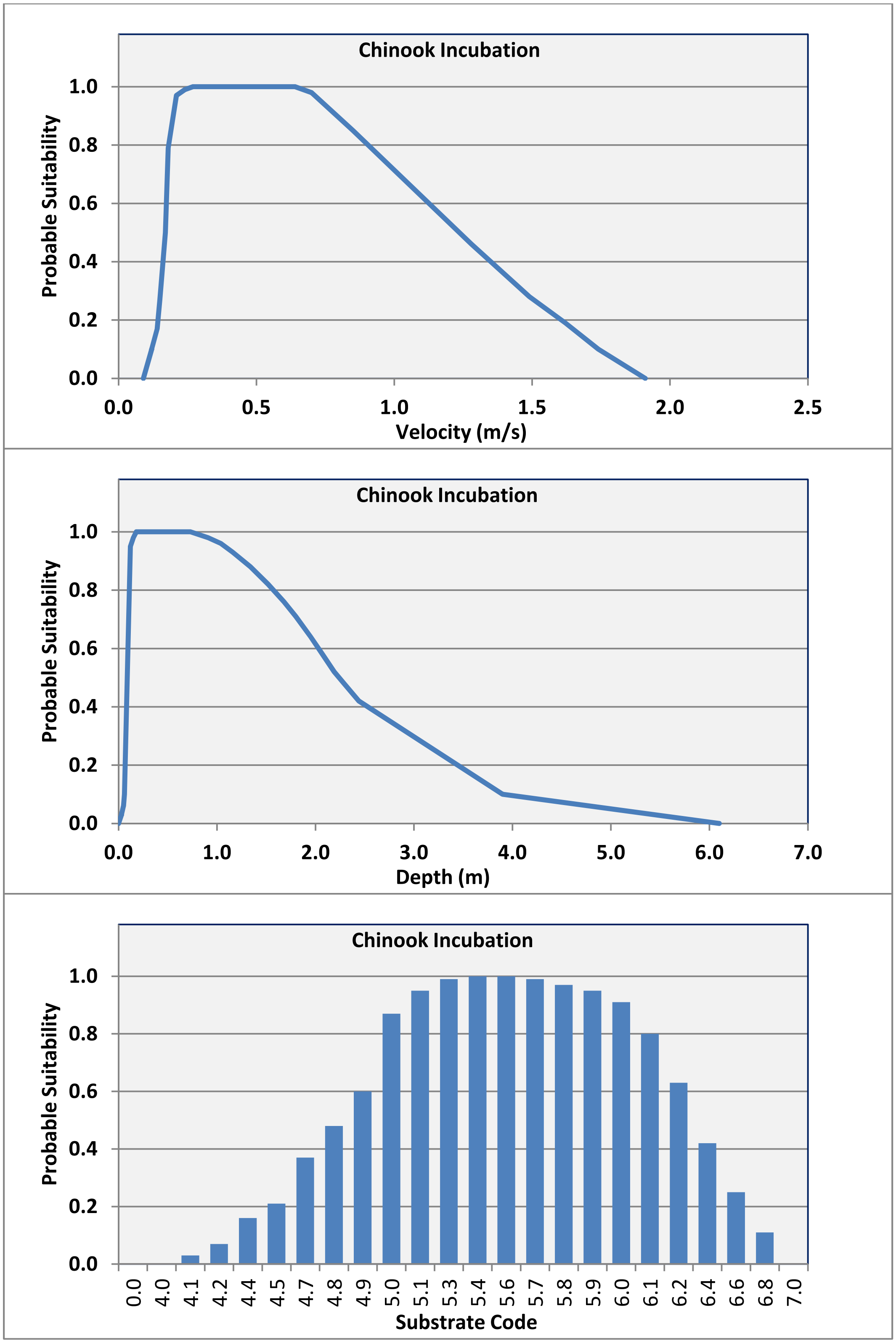


Figure 4. Chinook incubation HSC for velocity (top), depth (middle) and substrate (bottom).

Table 3. Chinook incubation HSC values for velocity, depth and substrate.

Velocity (m/s)	Suitability	Depth (m)	Suitability	Substrate	Suitability
0.00	0.00	0.00	0.00	0.00	0.00
0.09	0.00	0.03	0.03	4.00	0.00
0.12	0.10	0.06	0.10	4.40	0.16
0.15	0.27	0.12	0.95	4.50	0.21
0.17	0.50	0.18	1.00	4.70	0.37
0.18	0.79	0.73	1.00	4.80	0.48
0.21	0.97	0.82	0.99	4.90	0.60
0.24	0.99	1.04	0.96	5.00	0.87
0.27	1.00	1.34	0.88	5.30	0.99
0.64	1.00	1.52	0.82	5.40	1.00
0.70	0.98	1.68	0.76	5.60	1.00
0.85	0.85	1.80	0.71	5.70	0.99
1.28	0.46	2.07	0.58	6.00	0.91
1.49	0.28	2.29	0.48	6.10	0.80
1.62	0.19	2.44	0.42	6.40	0.42
1.74	0.10	3.90	0.10	6.60	0.25
1.91+	0.00	6.10+	0.00	7.00	0.00

Table 4. Chinook juvenile HSC values for velocity, depth, and cover.

Velocity (m/s)	Suitability	Depth (m)	Suitability	Cover	Suitability
0.00	0.18	0.00	0.00	0.00	0.00
0.06	0.57	0.14	0.00	1.00	0.01
0.11	1.00	0.15	1.00	2.00	0.12
0.20	1.00	3.00	1.00	3.00	0.68
0.24	0.68	10.00+	1.00	4.00	0.07
0.34	0.44			4.20	0.21
0.43	0.25			4.60	0.35
0.52	0.18			4.80	0.49
0.61	0.12			5.00	0.63
0.70	0.06			5.80	0.81
0.79	0.00			6.70	0.89
1.00+	0.00			7.00	1.00
				8.00	0.61
				9.00	0.97
				10.00	0.00

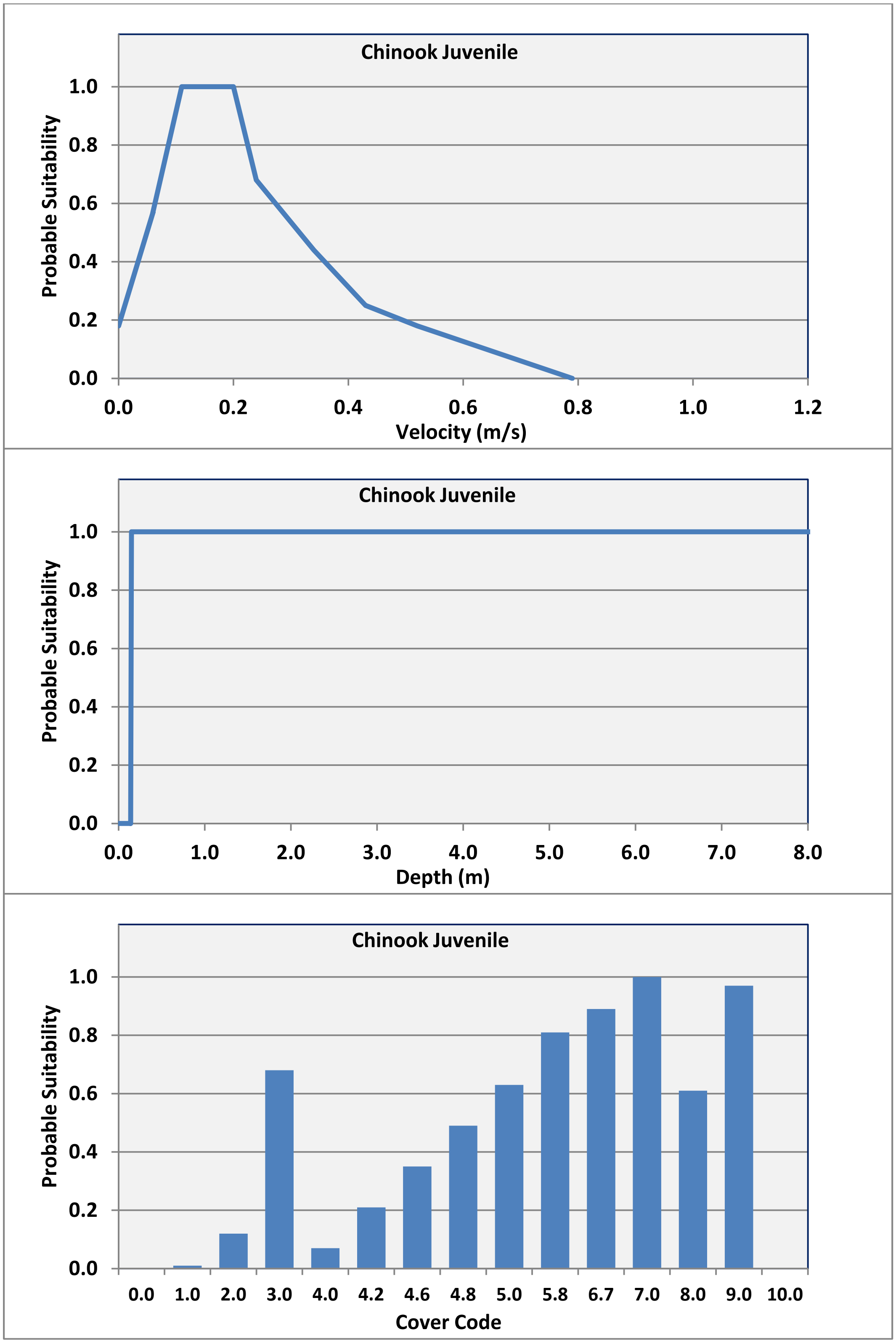


Figure 5. Chinook juvenile velocity (top), depth (middle) and cover (bottom) HSC.

Table 5. Chinook juvenile cover codes and suitability's. Suitability values based on Suchanek *et al.* (1984).

Cover Type Description	**Bovee Substrate Code**	**Cover Code**	**Suitability**
No cover	na	1	0.01
Emergent vegetation	na	2	0.12
Aquatic vegetation	na	3	0.68
Small gravel	4.1	4	0.07
Med. small gravel	4.2-4.5	4.2	0.21
Medium gravel	4.6-4.7	4.6	0.35
Med. Large gravel	4.8-4.9	4.8	0.49
Large gravel	5.0-5.7	5	0.63
Cobble/Rubble	5.8-6.7	5.8	0.81
Boulder	6.7-7.0	6.7	0.89
Debris/Deadfall	na	7	1.00
Overhead vegetation	na	8	0.61
Undercut banks	na	9	0.97

HABITAT SIMULATION

The hydraulic simulations of depth and velocity combined with the substrate and cover data were run with HSC for spawning, incubation and juvenile rearing for flows from 50 to 650 cms, the normal range of flow in the Yukon River. The resulting habitat models determine the relationship of the index of habitat suitability (commonly referred to as weighted usable area or WUA) and flow. For Transect F in the Takhini Reach dual velocity calibrations were required and is described in detail in 2011 Instream Flow Report (TRPA 2011), therefore the WUA was generated for two separate simulations and merged.

TIME SERIES ANALYSIS

Time series analysis incorporates river hydrology with the WUA/flow relationship to determine the change in habitat index over a period of time. Two scenarios, historical and Concept, using three water year types were modeled. The term “historical” in this context refers to the hydrology that actually happened in the years simulated with the Lewes Dam as it is currently operated. The term “Concept” refers to the hydrology that would occur if the proposed Marsh Lake Fall-Winter Storage Concept had been in place at that time.

RESULTS

HABITAT MODELING

TAKHINI REACH

The Chinook spawning habitat index in the Takhini Reach is maximized between 300 and 400 cms as shown in Figure 6. The incubation curve mirrors the spawning curve up to 250 cms before gradually declining. The divergence between the two curves can be explained by the difference in velocity suitability, with spawning having elevated suitability for slightly higher velocities.

The Juvenile Chinook habitat index in the Takhini Reach displays a relatively flat and unresponsive relationship to flow (Figure 6). This is a product of maximum suitability for low velocities which tend to occur close to shore and the concurrent location of primary high suitability cover elements. The small dip around 100 cms is most likely a result of low suitability in the side channels on Transects B and F as they begin to inundate with increased flow.

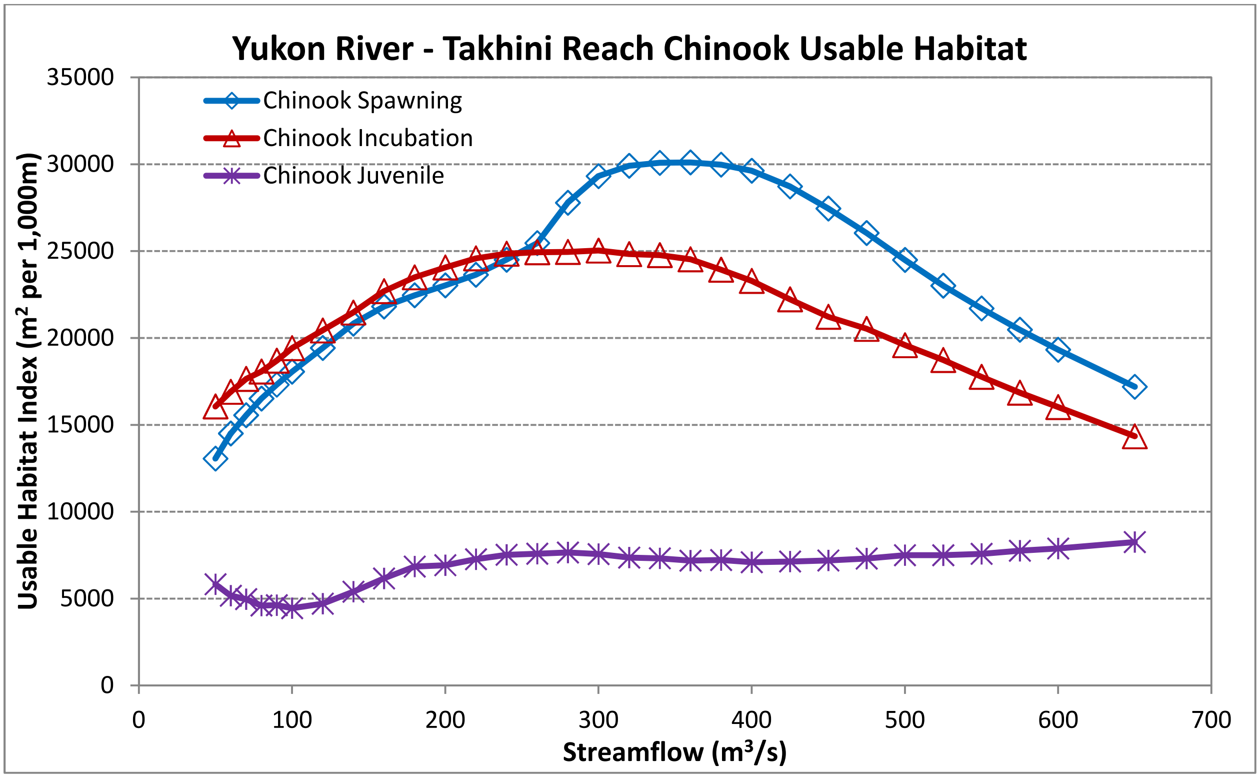


Figure 6. Usable habitat index by flow for Chinook life stages modeled in the Takhini Reach of the Yukon River.

LEWES REACH

The Chinook juvenile usable habitat index in the Lewes Reach as shown in Figure 7 is similar to that observed for the Takhini Reach in that the curve shows a relatively unresponsiveness to flow. Again this is a product of maximum suitability for low velocities and occurrence of primary high suitability cover elements, both which tend to occur close to shore. As flow increases this type of shoreline habitat remains stable or may increase as low lying areas become inundated.

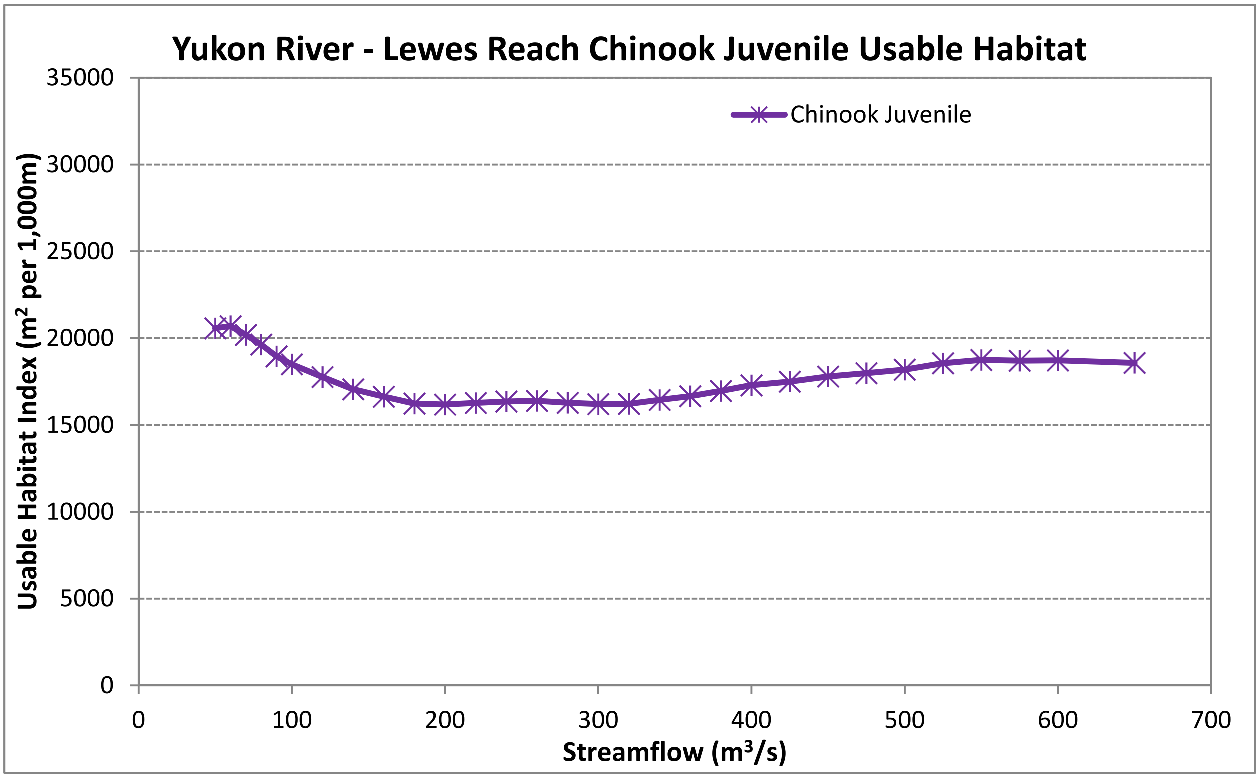


Figure 7. Usable habitat index by flow for Chinook juvenile in the Lewes Reach of the Yukon River.

TIME SERIES

HYDROLOGY

The flow time series graphs compare the Yukon River historical flow and the Concept flows for average, dry, and wet water years as shown in Figures 8, 9 and 10, respectively. An average water year is based on the daily flow records from 1984 to 2007, the dry water year example is from the 1996 flow record and the wet water year is based on 2007 flows. Concept flows are slightly higher than historical flows between January and March for all water year types. There is essentially no difference between historical or Concept flow levels from April to the end of July for all water year types. The Concept flows are lower than historical flows under average and dry water year types beginning in mid-August to late September, a function of control gate closure operations. Little difference between flow regimes is observed for wet water years (Figure 10).

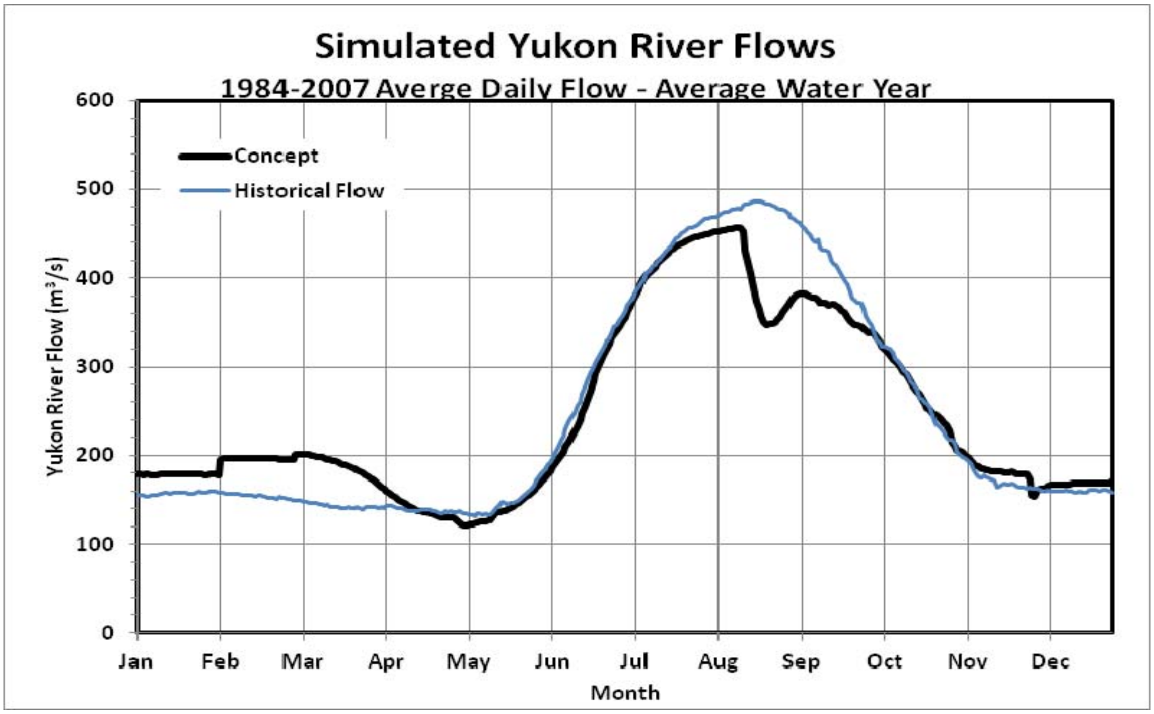


Figure 8. Daily average historic and projected Concept flow for an average water year.

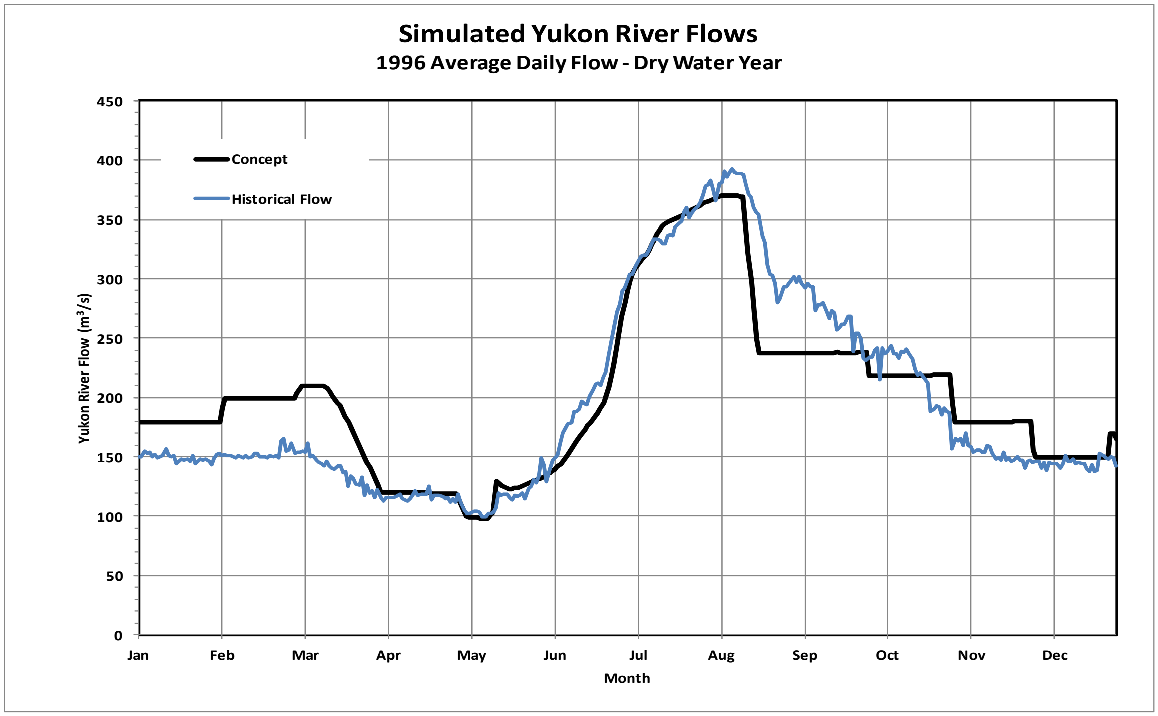


Figure 9. Daily average historic and projected Concept flow for a dry water year.

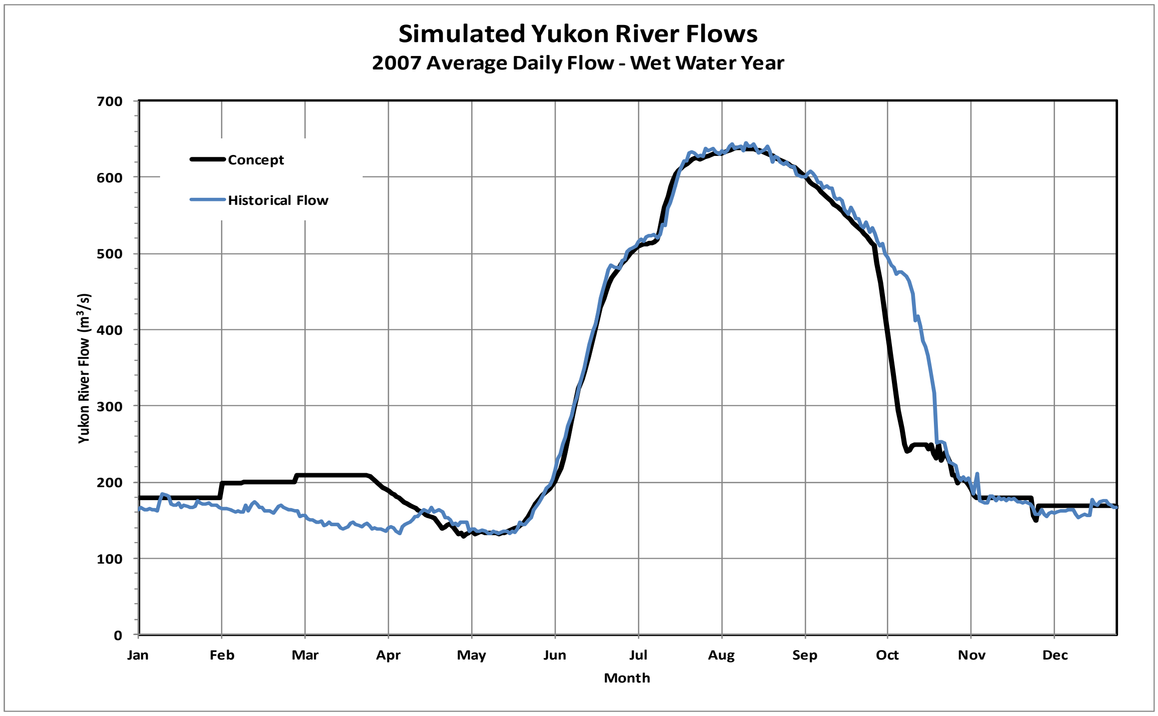


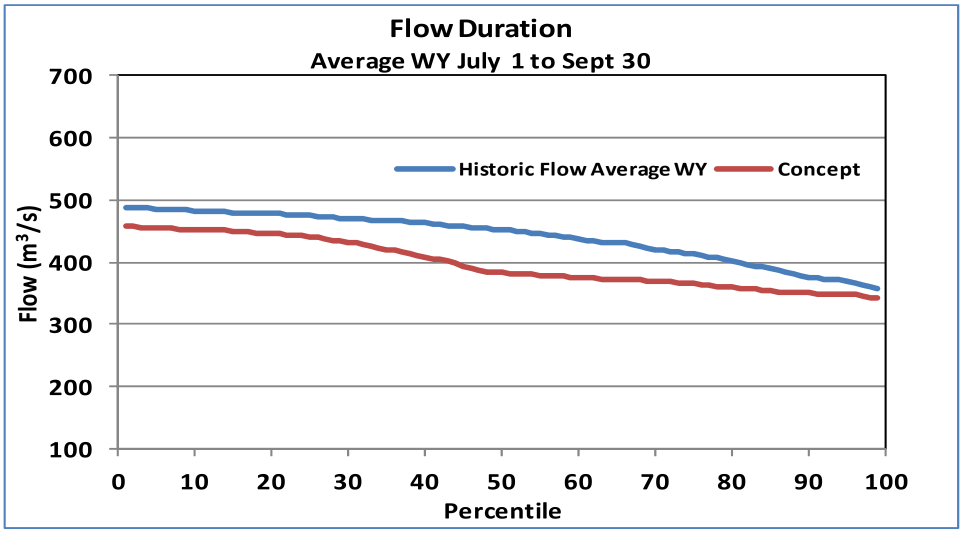
Figure 10. Daily average historic and projected Concept flow for a wet water year.

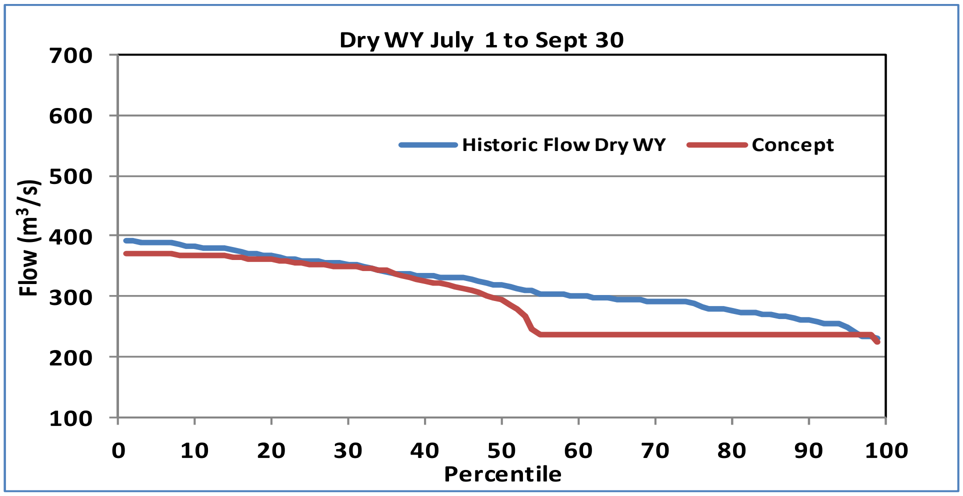
CHINOOK SPAWNING

Chinook spawning was evaluated for the July 1 to September 30 time period. Flow duration curves for the three water years are depicted in Figure 11. For an average water year flows are consistently higher under historical conditions. In a dry water year the percentage of higher flows are similar but flows are lower under Concept conditions approximately 50% of the time. There is essentially no difference between historical and Concept flows during a wet water year.

Habitat index duration curves which depict the occurrence of particular habitat index values are shown in Figure 12. There is a slightly higher spawning habitat index in an average water year under Concept flows and virtually no difference in a wet year. Under dry conditions the spawning habitat index is less for about 50% of the time under Concept flows, but nearly the same habitat index for the rest of the time.

In order to portray potential effects on Chinook spawning habitat over time, the percent change in habitat index was determined under the Concept flow regime as shown in Figure 13. For an average water year there is a positive effect for the entire spawning period averaging 6%. The opposite is true for a dry water year where the effect is primarily a negative change in the habitat index, averaging negative 5%. Wet water years show both positive and negative effects although they are minimal and never exceed a 4% difference, averaging a 1% increase in the habitat index.





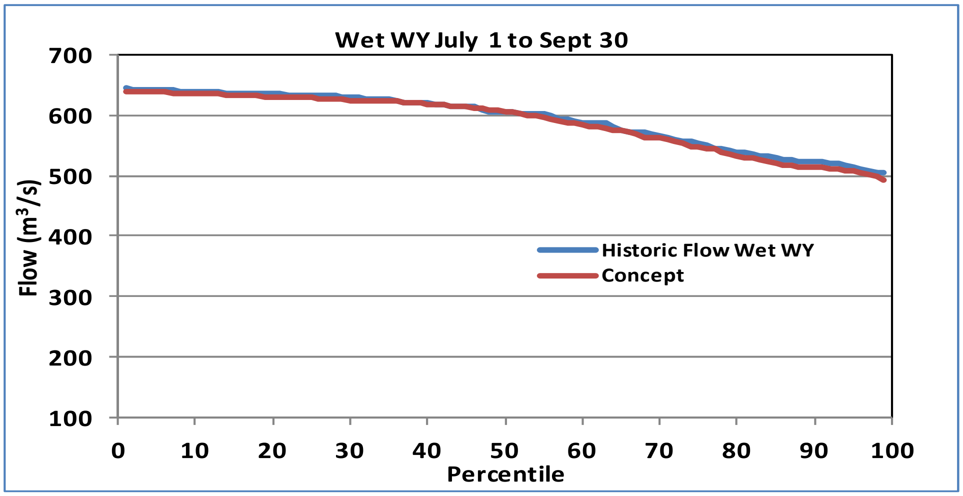


Figure 11. Average daily flow duration for the Chinook spawning period (July 1 to Sept 30) for average, dry and wet water years under historical and Concept conditions.

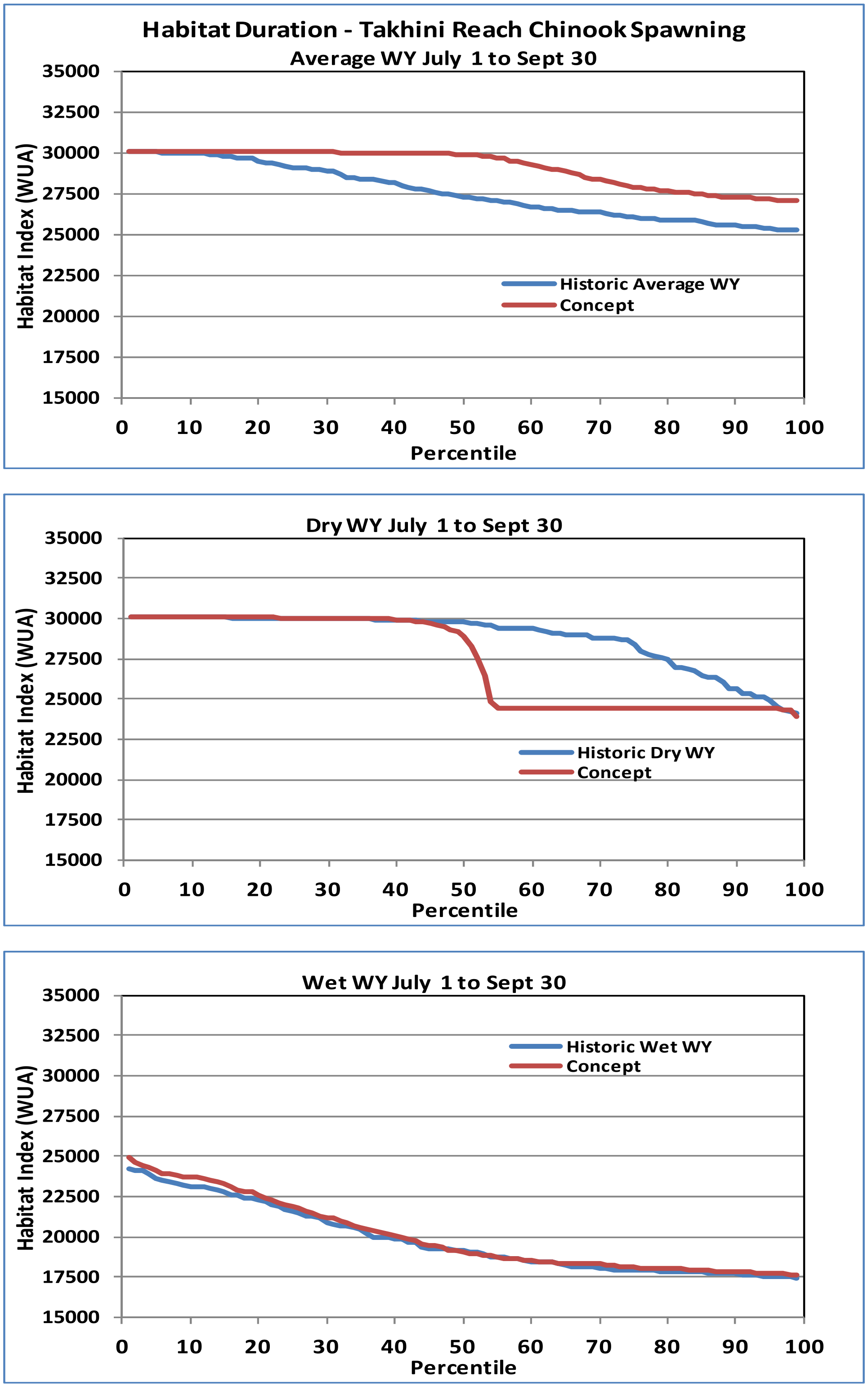


Figure 12. Habitat index duration for Chinook spawning under historical and Concept conditions for average, dry and wet water years.

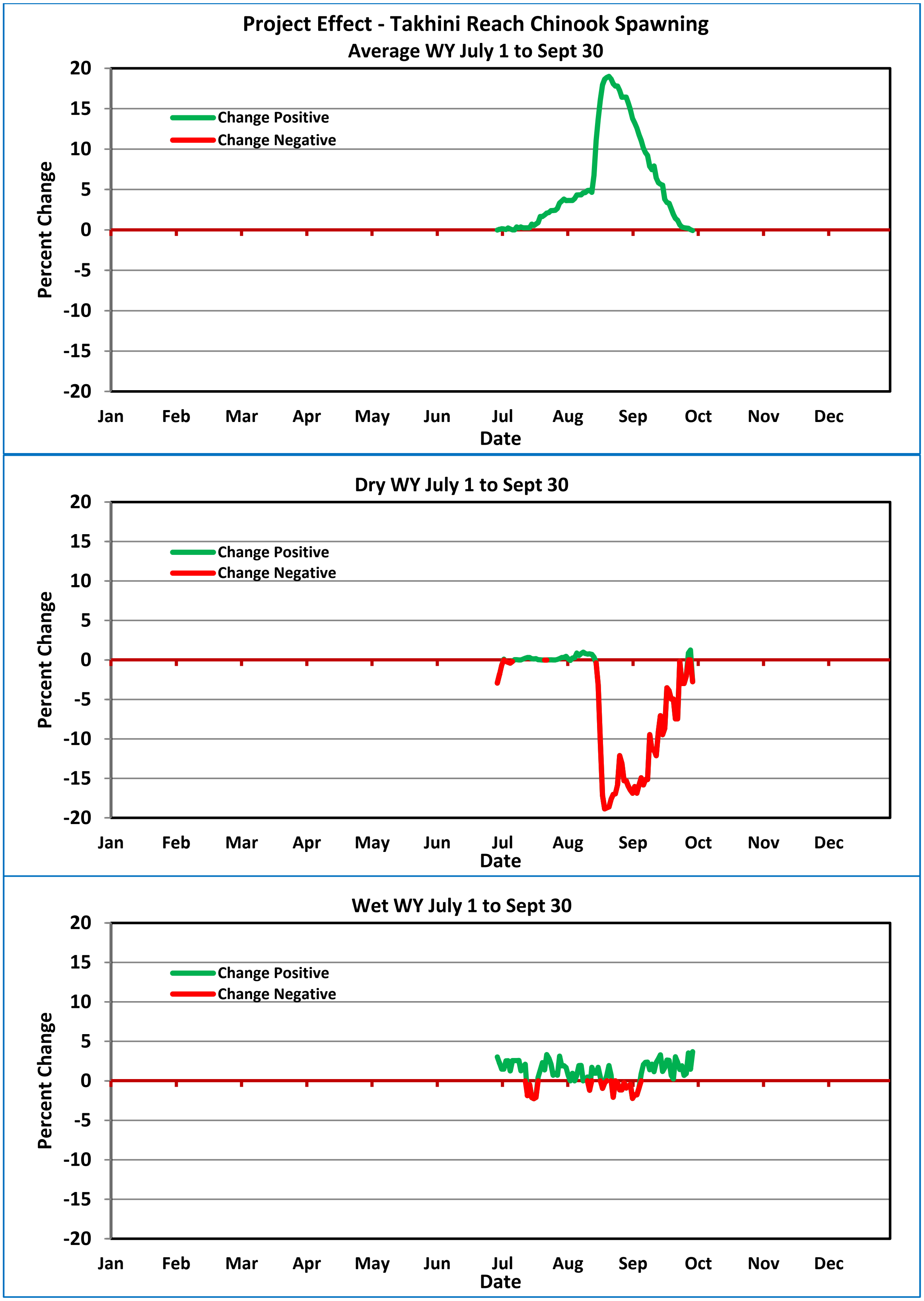


Figure 13. Percent change in the daily Chinook spawning habitat index under proposed Concept flow scenario.

CHINOOK INCUBATION

The period analyzed for Chinook incubation begins during September and ends in May immediately after ice break-up. Flow duration curves for three water year types during this time period are depicted in Figure 14. For all water years there is a slight reduction in higher flows and an overall trend of moderately higher flows under Concept flows.

Habitat index duration curves depict a progression towards an increase the incubation habitat index for all water year types under Concept flows as shown in Figure 15. The effects of the proposed Concept flows are mainly positive with the exception of mid-April to the end of May, where a negative change occurs (Figure 16). The average change in the incubation habitat index for all water year types is an increase between three and four percent.

CHINOOK JUVENILE

Juvenile Chinook were evaluated for summer and fall, May 1 to the end of November for both the Takhini and Lewes Reach. Flow duration during this period shows high flow events are reduced slightly for average and dry water years under the Concept flows as shown in Figure 17. During wet water years there is a moderate reduction in flows between 250 and 500 cms.

TAKHINI REACH

The rearing habitat index is maintained for a longer period of time during dry water years under Concept flows and this is shown in Figure 18. The same observation can be made for average and wet years although the difference is minor. Concept effects over time exhibit fluctuations between positive and negative depending on the time of year as shown in Figure 19. Negative effects tend to occur between May and June for average and wet water years. Both positive and negative changes are observed for the same time period based on dry water years. In all cases there is little change during summer months with percent differences generally less than 5%. Beginning in mid-October a noteworthy positive trend occurs which is attributed to the higher Concept flows during this time, regardless of water year.

LEWES REACH

The Chinook juvenile rearing habitat index in the Lewes reach favors historical flows under all water year types, but the difference is small relative to total habitat based on Concept versus historical flows (Figure 20). Concept effects over time are minimal (daily average of 1% or less for all water year types) except for mid-August to late September in average years and the month of October in wet years where a negative change in the habitat index is observed as shown in Figure 21. In both instances the effect is due to loss of high flow events under the Concept scenario.

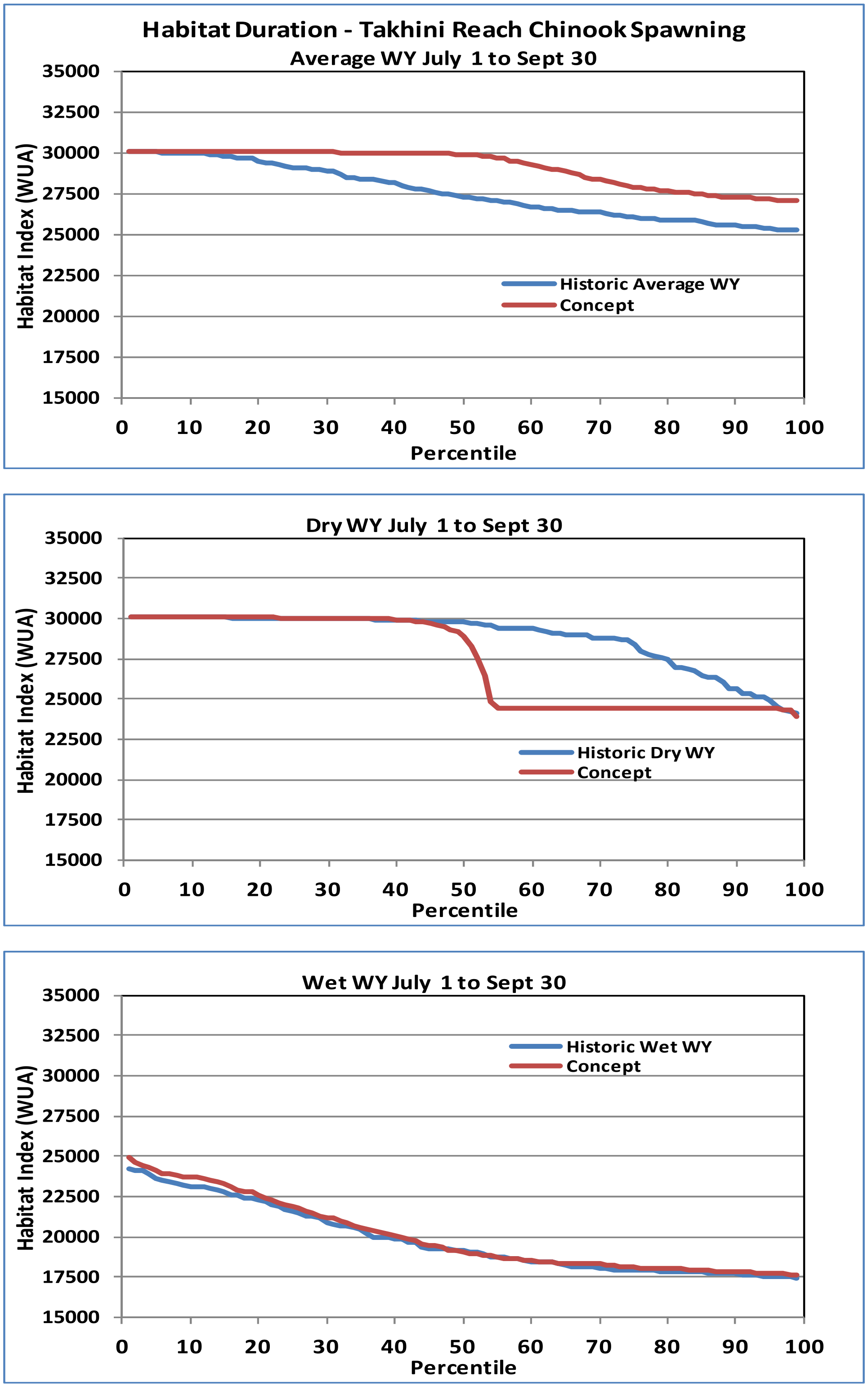


Figure 14. Average daily flow duration for the Chinook incubation period (Sept 1 to May 30) for average, dry and wet water years under historical and Concept conditions.

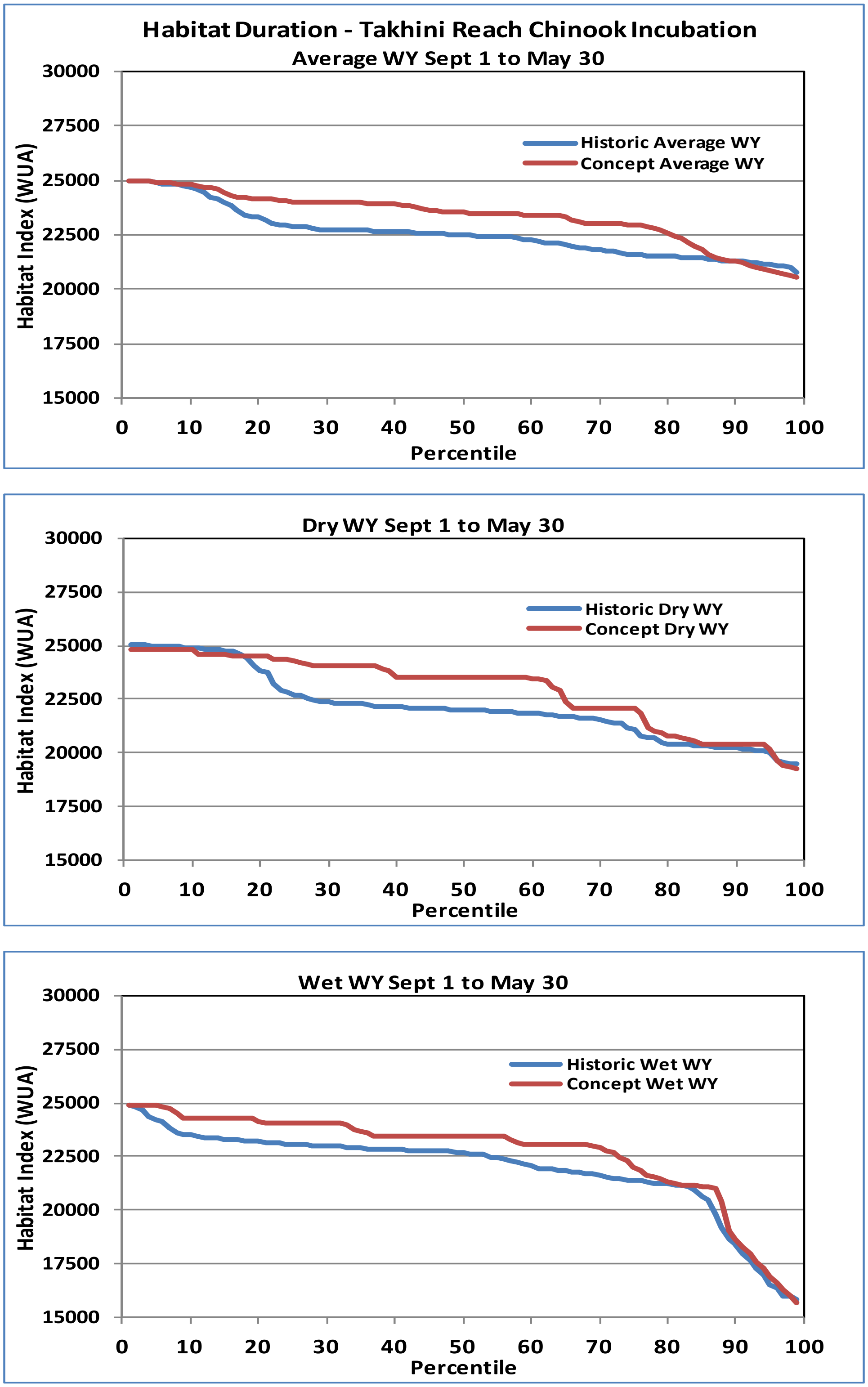


Figure 15. Habitat index duration for Chinook incubation under historical and Concept conditions for average, dry and wet water years.

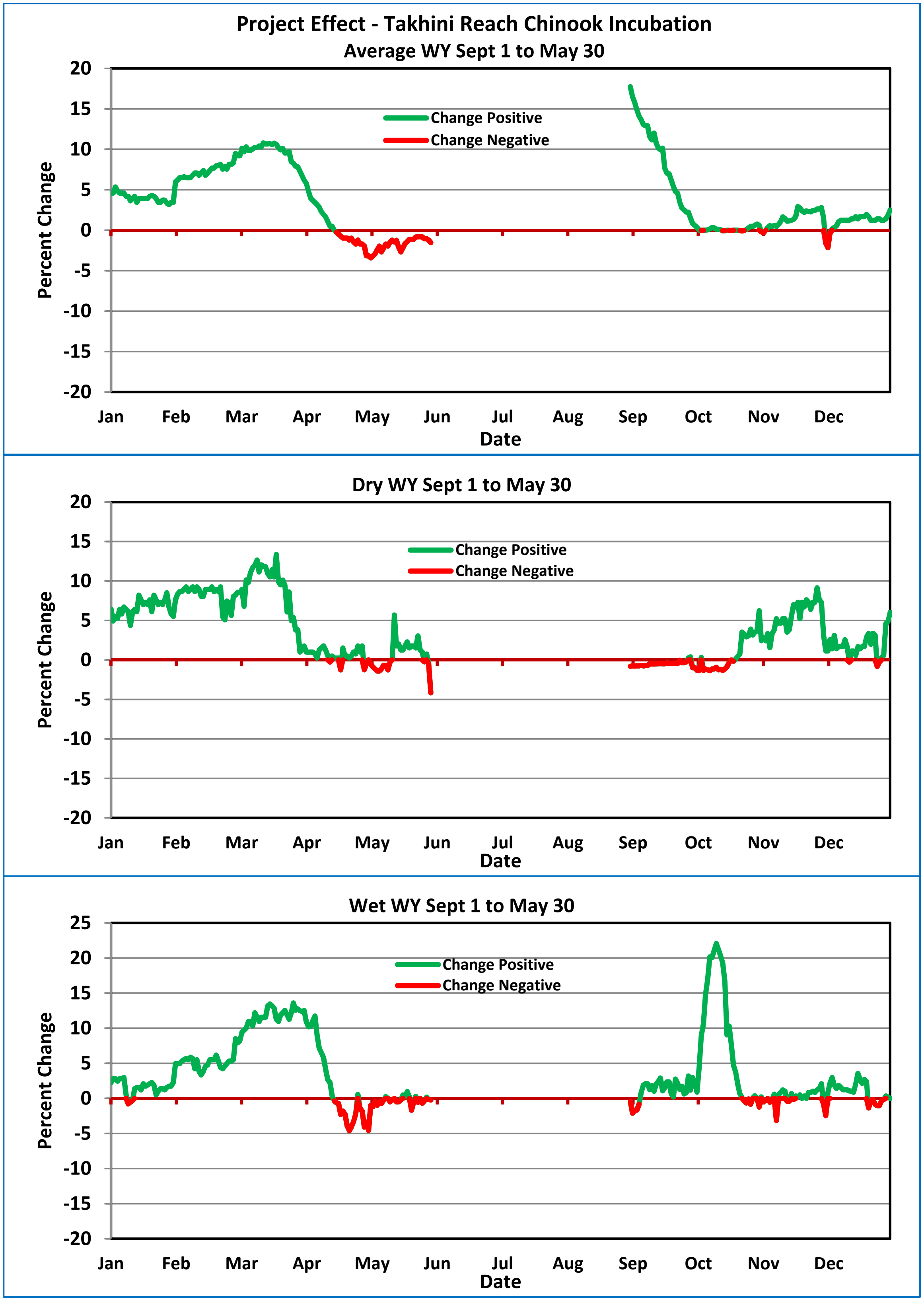


Figure 16. Percent change in daily Chinook incubation habitat index under proposed Concept flow scenario.

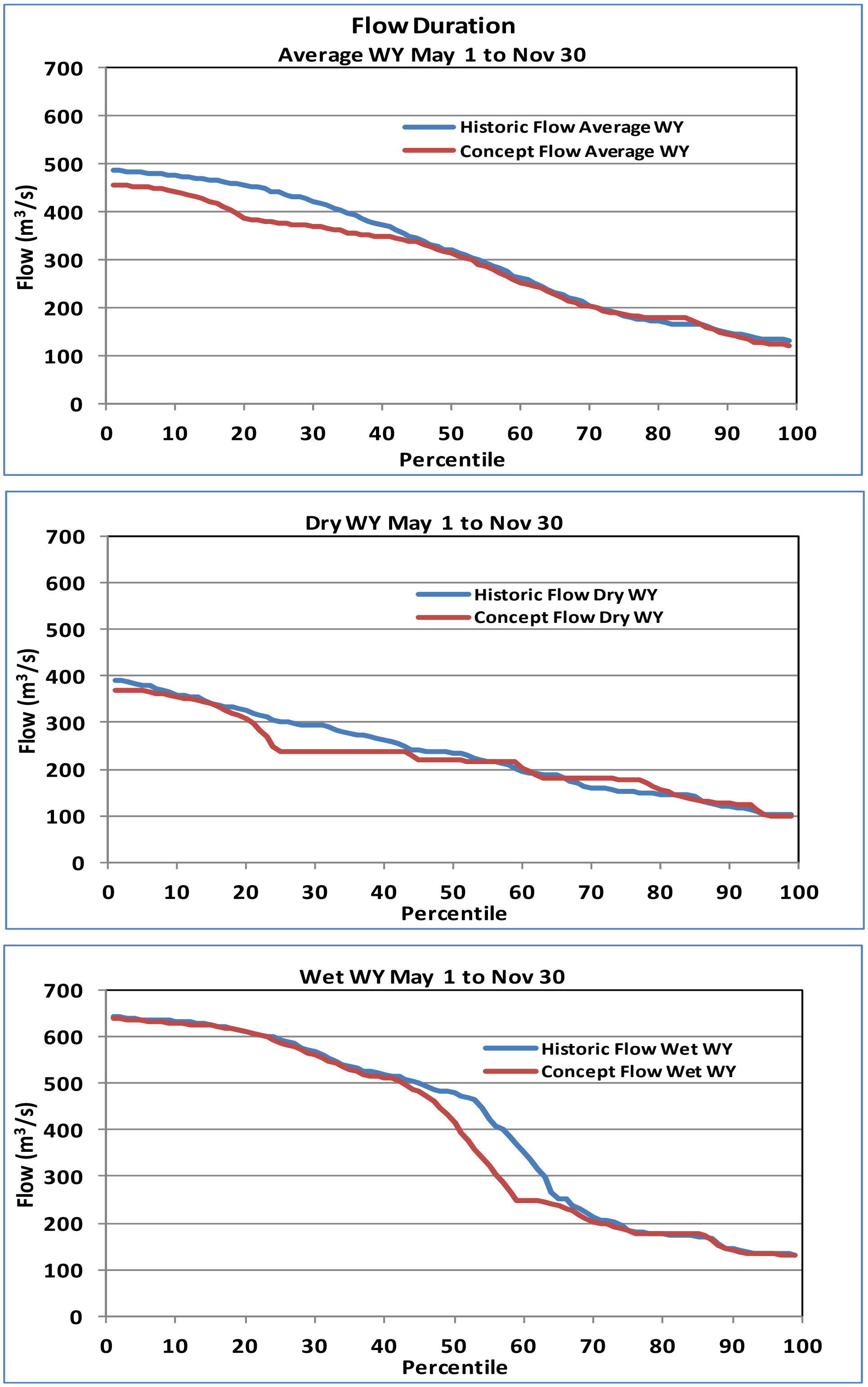
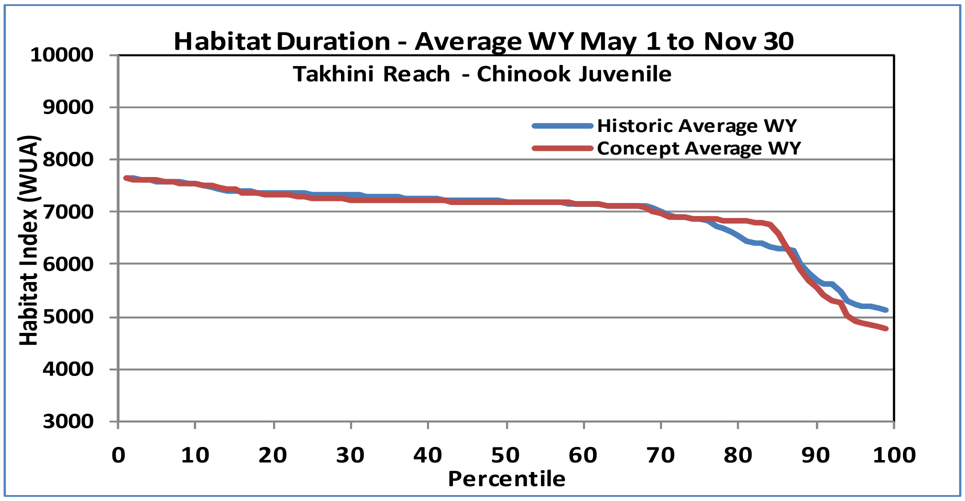
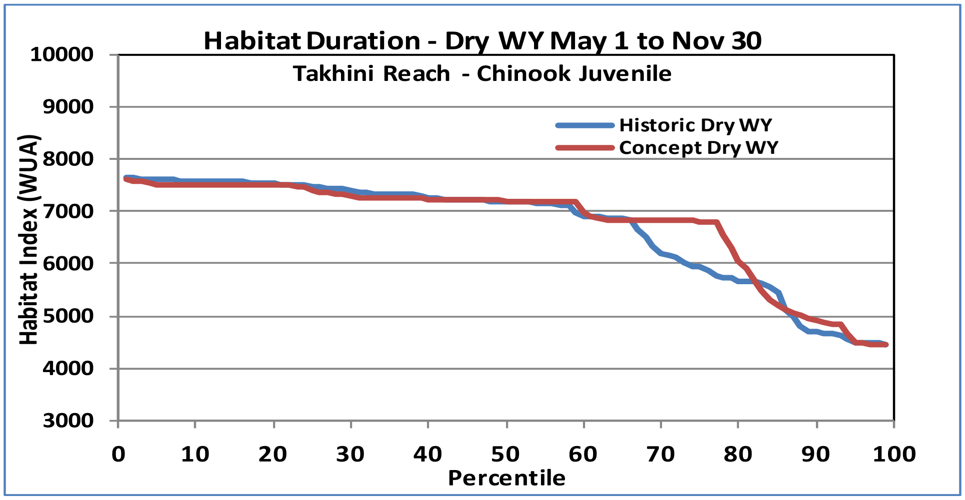


Figure 17. Average daily flow duration for the Chinook juvenile rearing period (May 1 to Nov 30) for average, dry and wet water years under historical and Concept conditions.





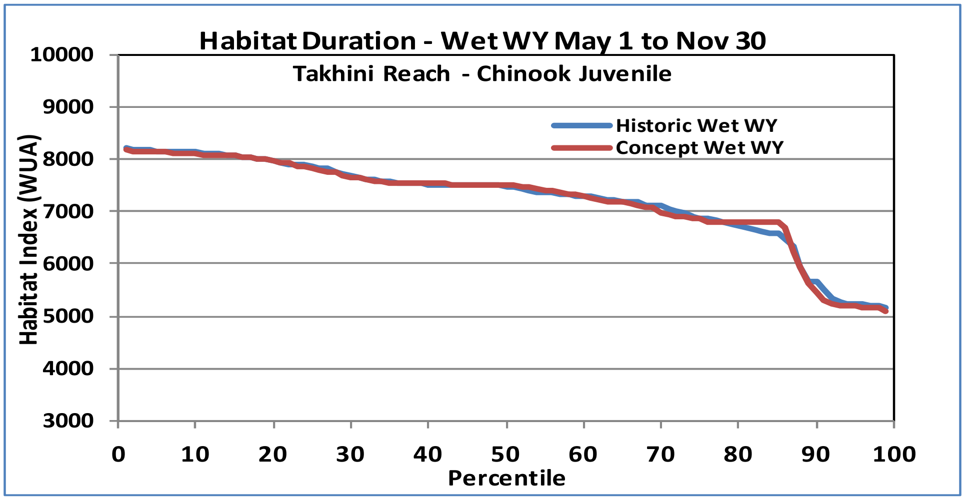


Figure 18. Habitat index duration for Chinook juvenile rearing in the Takhini Reach under historical and Concept conditions for average, dry and wet water years.

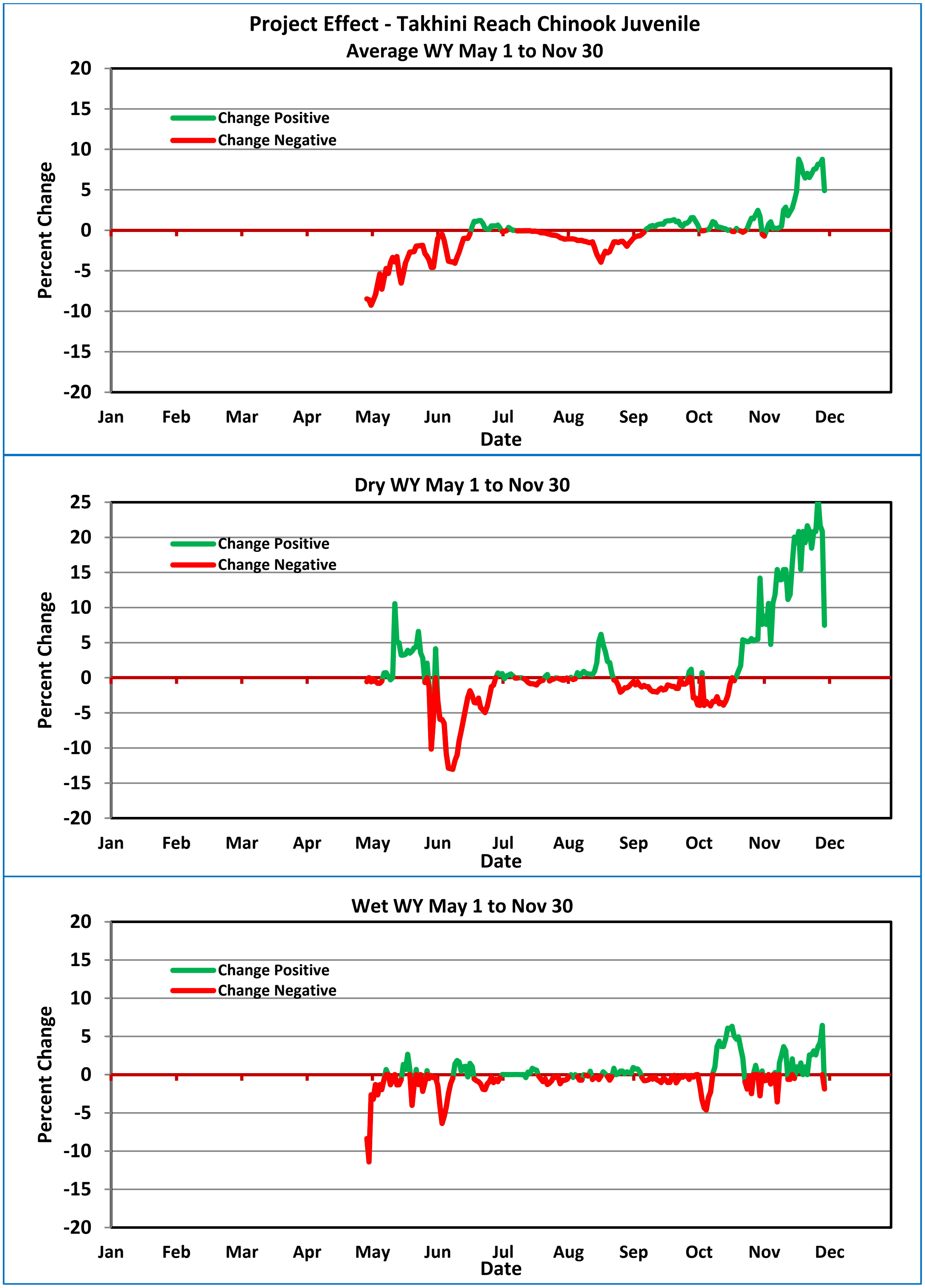


Figure 19. Percent change in daily Chinook juvenile rearing habitat index in the Takhini Reach under proposed Concept flow scenario.

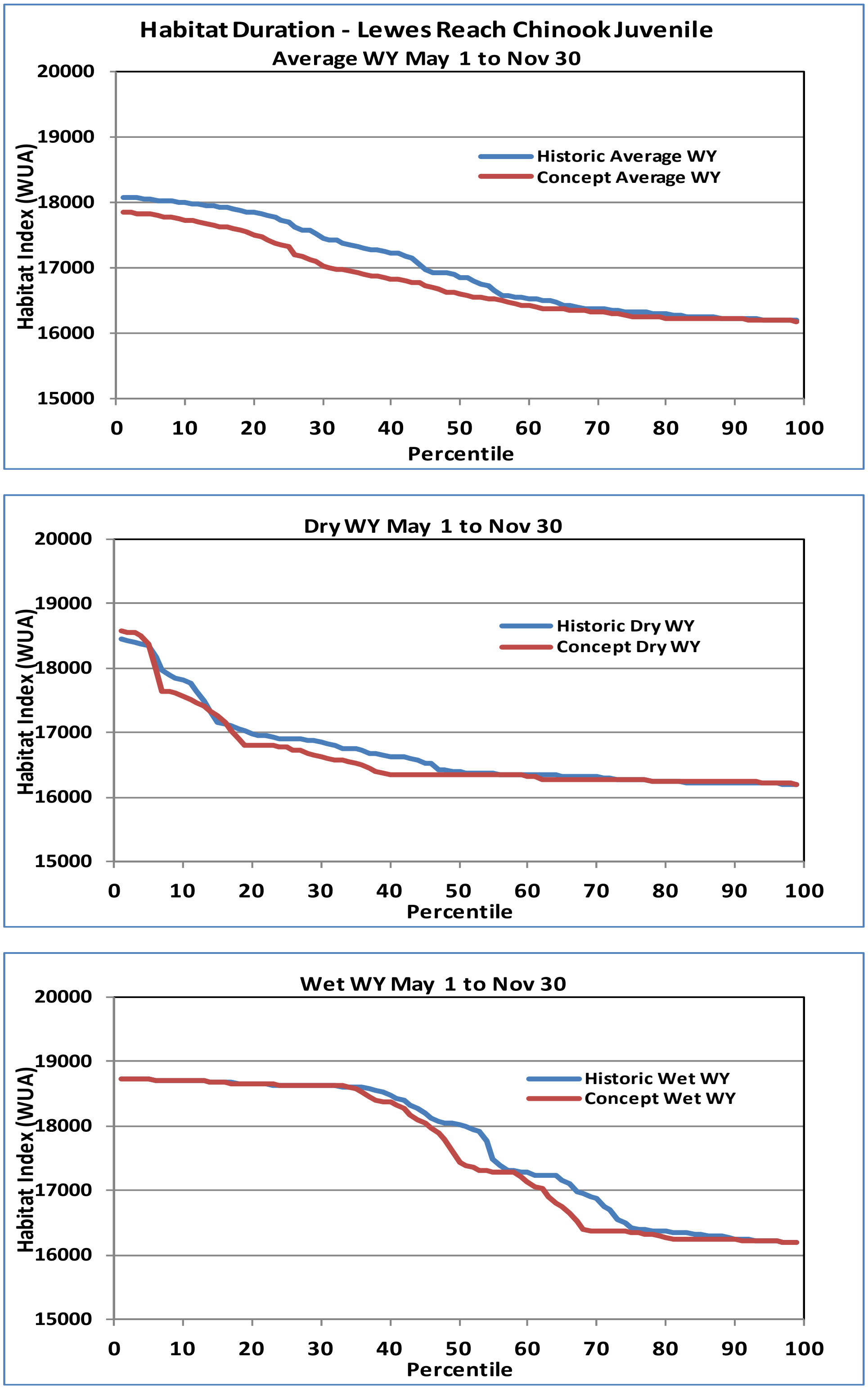


Figure 20. Habitat index duration for Chinook juvenile rearing in the Lewes Reach under historical and Concept conditions for average, dry and wet water years.

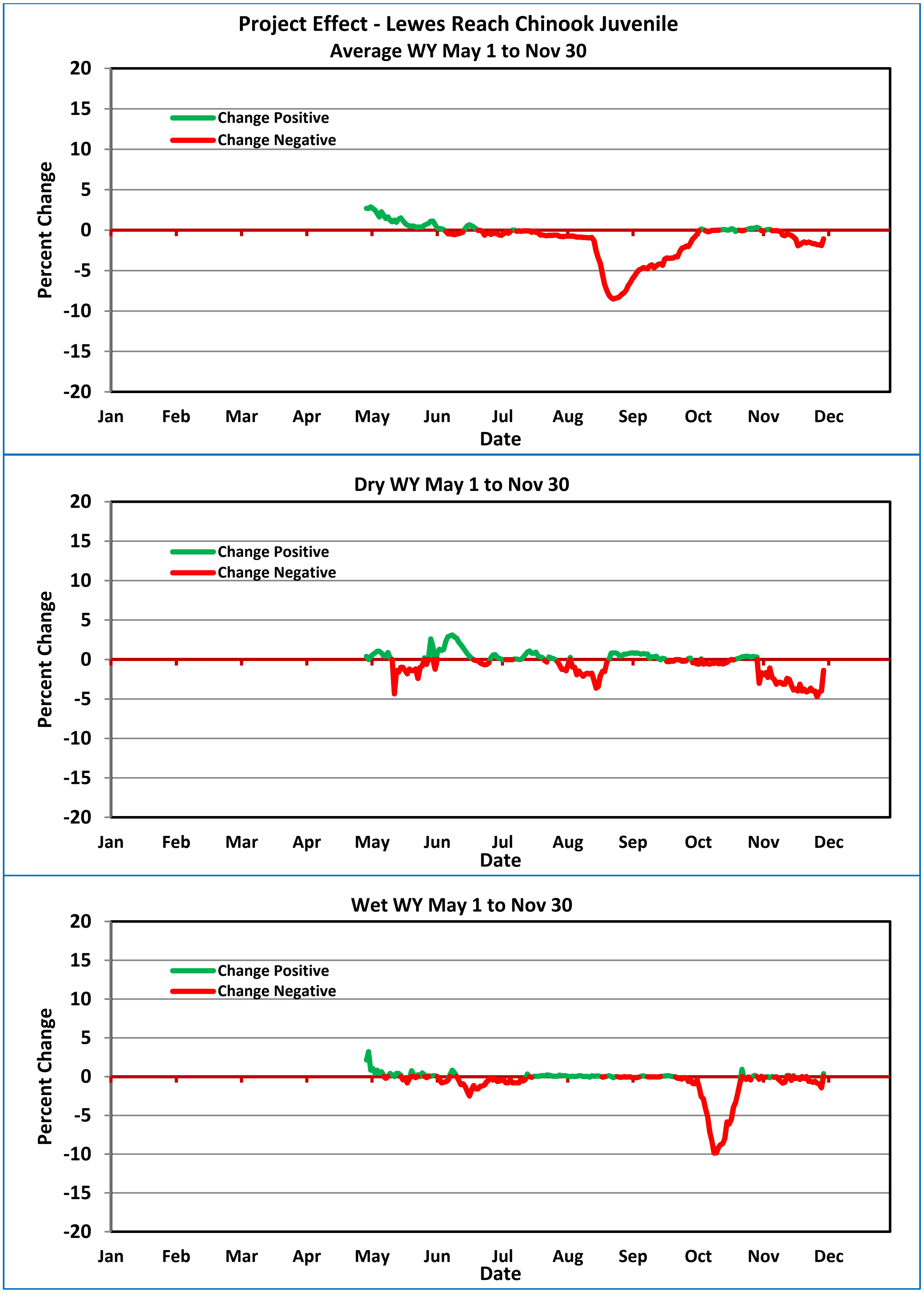


Figure 21. Percent change in daily Chinook juvenile rearing habitat index in the Lewes Reach under proposed Concept flow scenario.

DISCUSSION

The results of this analysis show the Chinook habitat index under Concept flows varies depending on life stage and water year. For Chinook spawning in the Takhini Reach from July to September the effect of the Concept flow regime is dependent on water year type. For average water years there is an increase in the spawning habitat index while in a dry year there is a decrease. In both instances the change in the habitat index is small and is attributed to dam operations that occur in mid-August. The potential for increased flow during winter would have a positive effect on Chinook incubation regardless of water year.

Chinook juvenile rearing analysis during the ice-free period from May to November shows that the habitat index varies depending on the reach and water year type. In the Takhini Reach there is a tendency toward a reduced habitat index in early summer and an increase in the habitat index during the fall under proposed Concept flow regimes. For the Lewes Reach effects are minimal except for brief periods in the fall for average and wet water years. In all cases the change is small.

The extent and timing of Chinook rearing in the mainstem Yukon River is not well understood. Indications in the literature suggest that juveniles use both natal and non-natal tributaries as primary rearing habitat, particularly 0+ individuals (Moodie et al. 2000, von Finster 2009, Daum and Flannery 2011). Timing of downstream migration of juvenile Chinook on the mainstem Yukon appears to consist of discrete age classes. Yearling (1+) juveniles leave non-natal streams early in the year and move down the mainstem earlier than 0+ (von Finster 1998, Moodie *et al*. 2000). 1+ migration generally peaks in June and 0+ in July though migration of both age classes tends to cease by the end of July. Based on length frequency data growth occurs throughout the migration period (Bradford *et al.* 2008).

There does not appear to be any relationship between flow and juvenile migration. Timing is dependent on time of year and to some degree temperature. Additionally, between May and the end of July, the primary migration period, historic and Concept flows are essentially the same.

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