Table Hydro-5
Summary Comparison of without HHD/TPU Projects and with Projects

IHA\RVA Groups	Index of Hydrologic Change	Results of median and RTV (Range of Typical Values) distribution analysis	Comments
Group 1: Monthly Means	5=High 1=Low		
January	**1**	**A 1% decrease in median, and a 133 cfs (6%) increase in magnitude of the RTV. As a result, there is a 20% increase in monthly means outside the Range of Typical Values as defined by the 16th and 84th percentiles relative to without-projects. This increase of unusually high and low monthly means is equally distributed above and below the RTV.**	**Given an index of change of 1, there are no significant changes overall with the exception that outliers are reduced. HHD Operations are reducing magnitude of storm events. Although a 20% increase in the number of monthly means outside the RTV has been identified, these excursions are only slightly greater than under without-projects conditions.**
February	**1**	**A 4% decrease in median, 2% increase in variance as represented in the increase in the magnitude of the RTV. Zero percent increases/decreases in all other statistics.**	**This is the month that is most like the without project conditions. HHD and TPU operations appear to be causing only the slightest of hydrologic changes. Hence, the Index Level of 1. If there was a zero index this month would be ranked as such.**
March	**2**	**A 4% decrease in median of the monthly means, 3% increase in magnitude of the RTV. Overall a 10% increase in the number of monthly means within the RTV.**	**No significance in median flow changes. However, the 10% increase in the RTV is a net result of 3 monthly means shifting from the upper range into the RTV range, and 2 monthly means from the RTV range shifting to the lower range below the 16th percentile. Hence, the net effect is minimal as the shifts in distributions are moderate, yet offsetting for the most part. Because of the distribution shifts, the index level of hydrologic change is listed as a 2.**
April	**2**	**A 10% decrease in the median, 6% increase in in the magnitude of the RTV. Again, only a slight increase in excursions outside the RTV. However, the excursions are a result of the shift in distribution with a 20% decrease in the upper range, and a 9% decrease from the RTV, resulting in a net 60% increase of monthly means in the lower range relative to the without-projects condition.**	**Not much in significance of change, only the shift in distribution to lower flow levels. It is difficult to distinguish the degree to which impacts are attributable to HHD vs. TPU operations. Howevera combination of the TPU diversion and HHD spring refill operations are likely the cause.**
May	**5**	**A 23% decrease in the median with a 24% increase in the**	**The distribution of excursions outside the RTV is 1/3**

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		magnitude of RTV. There is a 40% increase in excursions outside the RTV as a result of the number of means in the lower range (below the 16th percentile) doubling.	**above, 2/3 below RTV thresholds. Because of the doubling of the unusually low flows in conjunction with the overall reduction in the median, the index of change equates to a 5. Most like the result of HHD operations filling reservoir for low flow augmentation and TPU diversion.**
June	**5**	**A 28% decrease in the median flow. Almost all excursions are below the RTV. The overall variation in monthly means is reduced by 12%, based on the magnitude of the RTV.**	**50% of the flows are outside the RTV limits (60% increase over without projects). Over 88% of these are within the low flow distribution band. Most likely a result of inadequate flow augmentation for the TPU diversion.**
July	**5**	**A 30% decrease in median. Excursions of the RTV slightly more than double to 66%. Again almost all the excursions are a result of the 2.4 times increase in low monthly mean flows (ie. Below the 16th percentile). Monthly means in the RTV are reduced by half. And a modest 20% decrease in the higher monthly mean flows.**	**80% of excursions of the RTV are on the low flow side, more than doubling the frequency. Overall distribution remains similar to without project conditions. This is the second most severe month of extreme low flow events. Again this is likely a result of inadequate flow augmentation for the TPU diversion.**
August	**5**	**27% decrease in the median flow. Variability is only 14% above without project conditions. Similar to July means, August mean low flow excursions increase by a factor greater than 3.**	**Flows are at their lowest; as a result variability is low. 72% of the flows fall outside the RTV with most of them (95%) below low flow limits. Again this is likely a result of inadequate flow augmentation for the TPU diversion.**
September	**3**	**A 6% decrease in the median, with a slight increase (12%) in variability over without project conditions. RTV excursions remain at 40% above without project conditions. All exceedances are below the 16th percentile threshold.**	**Frequency of the monthly means above the 84th percentile remain the same. As a result, this suggests that the operations of HHD are unable to fully compensate for TPU's diversion. Interestingly, although September is commonly considered a critical month for the flow augmentation strategy (as the conservation pool is running out), this analysis suggests flow augmentation has been more**

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			successful here than in July and August.
October	**2**	**A 16% increase in the median flows. Variability has similar increase to September (13% increase). Values falling outside the RTV increase by 10%, all falling below the low flow threshold. Close to a 50/50 split on excursions above and below the RTV.**	**HHD operations are most likely increasing the flows by releasing excess stored water (in wet years) to prepare for the coming winter storms.**
November	**1**	**A 2% increase in the median flow. A 12% increase in variability. This distribution is the same as in October monthly means. RTV limits are exceeded 34% of the time (10% increase over without project conditions).**	**HHD operations are mitigating storm events by reducing peak flows and delaying timing, with no change in overall storm volume. Again close to 50/50 split on excursions. The only difference between October and November is the less significance of the shift in the median flow.**
December	**1**	**A 7% decrease in the median flow, with a 19% increase in variability over without project conditions. RTV limit exceedances are distributed 50/50 between low/high flow thresholds.**	**Not much significance, except that HHD flood management operations are in effect.**
Group 2: Magnitude of Mins/Maxs			
3-day Min	**4**	**Variability is significantly reduced. The 16th and 84th percentile range reduced from 99 cfs ~ 174 cfs to 99 cfs ~ 142 cfs. The median 3-day low flow was reduced 12% as well. All of the unusually higher low flows (upper range) are reduced to flows within the RTV. Overall, the range of 3-day minimum flows frequency in the RTV increased 60%.**	**While there were only 2 less instances of unusually low flows over without project conditions, the entire upper range of 3-day annual minimums has been reduced. Inter-annual variability is greatly reduced, resulting in an index of change of 4. The presumed cause of the decrease in variability is HHD operations augmenting low flows to offset TPU diversions**
7-day Min	**3**	**Distribution shifts down 12%. Variability decreases slightly. Relative to without project conditions, there are almost twice as many 7-day low flows below the RTV (or 16th percentile). Again all higher flows in the distribution are reduced to a value within the RTV.**	**While the overall number of excursions outside the RTV are minimal, there is a complete shift in distribution. Even with all these changes, the index of change is 3. This may be an example of how this technique of reducing all statistics to a single number loses descriptiveness and may need adjusting. The significance placed on the net**

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			percent change in RTV counteracts the obvious shifting of distribution. Most likely cause of this is the HHD operations attempting to augment flows, but inadequately compensating TPU's diversion.
30-day Min	**4**	**Moderate 19% decrease in the median, variability remains similar. Excursions outside the RTV almost double and all on the low end. There are over 3 times more flows below the defined RTV. The upper threshold of flows are reduced from a frequency of 5 to 2. Variability with and without projects is low.**	**Similar comments to the 3-day and 7-day minimums, except the 30-day low flow experiences the most dramatic shift of all defined durations. Here the index of change is 4. One percentage point more of a shift in the median, and the index level would be a 5. With the similarity of 30-day durations and the monthly means, they are similar effects in river dynamics for the low summer months. Again, most likely cause of this is the HHD operations attempting to augment flows, but inadequately compensating TPU's diversion.**
90-day Min	**4**	**A shift down of 15% in the median, overall distributions remains same, relative to the magnitude of the RTV. Because variability is very low regardless of with or without projects, any shift in the distribution results in significant changes in the defined ranges above and below the RTV. Distribution shifts are very similar to the 30-day minimum flows.**	**This duration of low flow statistics could be also labeled seasonal low flows. Since typical seasons are in 3-month intervals, +/-.**
3-day Max	**3**	**Only a slight shift down of 4% in the median. Variability is reduced 49%, with an obvious effect of reducing excursions outside the RTV. Overall excursions below the 16th or above 84th percentiles are reduced 80%, with all excursions in without- projects reduced to flow rates within the RTV. Similarly, 3 out of 5 (60%) excursions below the 16th are raised to levels within the RTV.**	**The concentration or reduction in distribution of the 3-day maxima strongly suggests HHD flood management operations are the cause. An Index of change for the shifts is calculated to be 3. This seems to be consistent with the fact that it is hard to say how much habitat is lost to lack of channel migration, organic debris loadings, etc.**
7-day Max	**2**	**With a 1% decrease in the median, a 8% decrease in the dispersion of the distribution-- the distribution shifts are**	**Only the higher events within the upper range are reduced. Most other hydrologic changes are**

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		moderate at best. With 40% of the high flow excursions reduced to RTV levels, and some shift of RTV flows to below the 16th percentile (20%), overall there is a 10% decrease in excursions outside the RTV.	**minimal. HHD flood management operations are becoming more like assumed natural conditions. There is no significant suggestion of influence by TPU's diversion. As a result, an Index level of 2 is given.**
30-day Max	**1**	**The median has increased 1%, and the spread in distribution has decreased by 50 cfs on each end of the RTV (4% in total). With the averaging of the 30-day statistic, distribution shifts in the maxima are minimal. 1 excursion from above and below the RTV are reduced to within RTV levels.**	**Of the N-Day duration statistics, the 30-day maxima shows the least significant change of all. HHD operations are reducing average flood flows, and augmenting any lower flows as a result of natural or TPU diversion. Index of Hydrologic change is 1.**
90-day Max	**2**	**The median of the 90-Maxima has shifted 4% down, dispersion of the distribution increases 12%. Overall excursions outside the bounds of the RTV increase 30% over without project conditions. A slight shift in the upper and slightly less than moderate shift in the middle distributions, results in almost doubling of the excursions in the lower distribution.**	**As with a majority of longer time period averages, the dispersion of distribution has increased but mostly in the lower end of the range. It is difficult to definitively state who is the cause of the shifts without identifying specific operations of both HHD and TPU. However, the shifts in distributions suggest TPU influence more than HHD operations. Index of hydrologic change is set to 2.**
Group 3: Timing of Annual Mins/Maxs			
Julian date of Annual Min	**3**	**There is a 20 day shift from mid September to late August in the median of annual minimums. Expansion of the distribution increases 19%, but in the lower range. Over 3 times more occurrences of annual minima occur earlier than August 28 and half of the upper range excursions were shifted within the RTV. Overall this constitutes a 73% increase of excursions.**	**Even though the generated without projects flow regime has been determined inadequate at this point and time for 1-day minima comparisons, the *timing* of the annual minima and maxima most likely would remain the same even using a 3-day average. Besides the shifting of the distribution, not much can be said about the impacts and their causes. A potential modification to this may be some type of overlay of timing of the annual minima with the timing of specific salmonid life stages.**

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Julian date of Annual Max	**2**	**Virtually no change in the average timing of the annual maxima or it's RTV magnitude. With January 7 as the median date for the annual maxima, there is only a slight increase in excursions outside the Range of Typical Values, or days in this case. The RTV based on without projects, is between December 1 and January 30.**	**Not much change. When a large event occurs, it still occurs, just less in magnitude. The only reason the Index of Hydrologic Change is greater than 1 is because a 40% increase in excursions later than January 30. Everything else tends to an Index of 1.**
Group 4: Number and duration of excursions < 75% (302 cfs) and > 25% exceedance (1292 cfs)			
Low Pulse Count	**2**	**A 11% decrease in the median of pulse counts, may be misleading. The pulse counts reduce from 4.5 to 4.0 per year. The magnitude in RTV increases by one pulse more per year on the upper threshold, and decreases by one pulse count per year on the lower threshold.**	**Not much value is added by this version of the statistic. The defined threshold of 302 cfs is either equal to or greater than the median summer month flows. Conclusions are therefore similar to those for the summer monthly means.**
High Pulse Count	**3**	**The median annual pulse count increase slightly from 10.5 to 11 per year, with the lower end of the RTV decreasing from 9 to 7 pulses per year. Excursions outside the RTV increase 50% with two-thirds of that increase in the lower range of unusually low values.**	**The 25% exceedance flow is less than the mean monthly flow for winter storm months. In order to make this statistic more unique with more description power, a reevaluation of the exceedance threshold should be conducted.**
Low Pulse Duration	**4**	**Low pulse durations and distribution increase for with-project conditions. With similar increases, the median duration and the magnitude of the distribution increase 49% and 41%. The shift in distribution masks the overall increase in excursions outside the RTV to a mere 10%. However, the distribution experiences severe shift. All unusually low events become typical events, and unusually high events (above the 84th percentile) slightly more than double in frequency.**	**The more interesting change here is the shift in distribution, and not just the excursions outside the RTV. As a result of the major shift, the cumulative distribution has shifted as well. The most likely cause of this shift is the TPU diversion not fully being compensated for by HHD operations. Based on the Index of Hydrologic Change, the median shift and the overall shift in distribution evaluate to a high level of change with an index of 4.**
High Pulse Duration	**2**	**The average duration of a high pulse decreases by 8%, while the upper threshold of the RTV decreases 23%. Shorter annual average pulse durations of less than 6-**	**Similar to low pulse durations, the overall number of excursions outside the RTV are nearly the same without- and with- projects. Because the High Pulse**

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		days double in frequency. The frequency of pulse durations greater than 11.4-days reduces to a single year with an average above 11.4-days.	**threshold is similar to monthly spring flows, the shifts in the pulse duration distribution resemble that of spring months as well. It is unclear as to the cause of this shift except for the general comments that it is most likely a result of the combination of HHD operations and TPU diversion. With only one significant change, the index of hydrologic change evaluates to 2.**
Group 5: Rates and Annual number of flow rises and falls			
Fall Rate, cfs/day	**2**	**While the difference of thresholds remains relatively the same, the median of fall rates increases 12%. 60% of the fall rates that were less than the typical rate increased to within the RTV (a 9% increase in frequency of years within the RTV). Overall excursions above and below the RTV, decreased 20%.**	**Fluctuations from day to day have increased on average for the 32 years of analysis. Years that average daily fluctuations less than 99 cfs decrease from 5 to 2, with the RTV defined as between 99 cfs and 223 cfs. This suggests that the HHD operations and TPU diversion may be in some discord with each other. In any case, with the small change in median fall rates, the small change in the RTV, the index of hydrologic change is assessed to be 2.**
Rise Rate cfs/day	**5**	**Rise rates decrease 22% and a decrease in the magnitude of change of 12%. Magnitudes of the Rise rates decreases such that the frequency of rates that are classified as unusually low (below the 16th percentile), more than double (2.4 times). With this distribution shift, the overall change in excursions outside the RTV increase, 40%.**	**As would be expected the average rise rate from day to day is reduced. Most likely a result of HHD operations. The ecological implications of such changes in the hydrologic regime are not clear; however, this suggests that on the whole the river may be less dynamic.**
Fall Count (1 cfs or larger)	**N/a**	**A 12% decrease in counts, 24% decrease in variability. A complete shift in distribution, such that the relative 84th \16th percentiles from without- , and with- projects almost have no overlap. The 16th percentile (203 cfs) in the without projects conditions practically equal the 84th**	**While there appear to be substantial changes with projects in place, the significance of evaluating 1-cfs changes from day to day is uncertain. This statistic as defined, can give an overview of the general dynamism but not much more than that.**

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		percentile (204 cfs) with project conditions. As a result, there are 2.7 times more excursions overall with-project conditions, all of which in the lower range.	
Rise Count (1 cfs or larger)	**N/a**	**A 6% decrease in the median, a 32% increase in range, and a 40% increase in overall excursions outside the RTV. Similar to but not as extensive as the Fall Counts, the Rise counts shift from higher frequency to a lower frequency per year.**	**Again not much can be gained from this statistic (*see Fall Count comments above*). The increase in distribution is primarily only in the lower end. The 16th percentile frequency decreases from 120 to 112 events per year. The 84th percentile remains relatively the same. What can be said is the general concept of HHD operations are moderating flow rate increases. TPU diversion compounds the decrease in rise rates. To balance out the impacts with projects in place, it would take a day-to-day operations link between HHD and TPU.**
Fall Count (10% Rule)	**2**	**As expected the average frequency of annual events decreased 10%, with a 25% decrease in variability. With the small shift in the median and the large decrease in variability, the overall change in excursions outside the RTV decrease with projects in place. This is accountable by a 60% decrease in frequency of counts greater than the 84th percentile and no change in the frequency of events below the 16th percentile.**	**Given the overall variability decrease in with- project conditions, this may suggest that HHD operations are augmenting TPU diversions and naturally occurring drops in flow rates for most years. In fact, for years that may be naturally experiencing a higher number drops in the flow regime the HHD operations may be over mitigating based on without projects conditions.** **While this "10% Rule" is designed to provide greater insight with respect to without- and with-projects, it may not be fully optimized for ecological relevance.**
Rise Count (10% Rule)	**3**	**The number of rise rates that exceed the 10% rule decrease on average 11%. The relative variability between without- and with- projects remains the same. 80% of the unusually more frequent years have been reduced in frequency to match more typical values (RTV).**	**In review of the changes and shifts in distribution compared to the Fall Count (10% Rule), one would expect the same level of hydrologic change. This illustrates the effect of weighting of particular factors of change. Since the median change is above**

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		In addition, the number of years that have been identified as an unusually low year have increased 40% (or from 5 years to 7 years). This shift in distribution nets an overall decrease of 19% in excursions outside the RTV.	**10%, the significance of change in the distribution is considered moderate or a "3" based on the algorithm as illustrated in Figure 1.**