Duncan Dam Project Water Use Plan

Lower Duncan River Hydraulic Model

Implementation Year 3

Reference: DDMMON-3

Lower Duncan River Hydraulic Model

Study Period: February 2012 – July 2013

Northwest Hydraulic Consultants Ltd.
30 Gostick Place
North Vancouver, BC
V7M 3G3

October 31, 2013

Duncan Dam Water Use Plan
DDMMON3 Lower Duncan River Hydraulic Model
Year 5 Report

BC Hydro
6911 Southpoint Drive
Burnaby, BC
V3N 4X8

Final Report
October 31, 2013

northwest hydraulic consultants

Citation

NHC. 2013. Duncan Dan Water Use Plan DDMMON3 Lower Duncan River Hydraulic Model Year 5 Report. Prepared for BC Hydro, October. October 31, 2013.

Acknowledgements

The authors would like to thank BC Hydro for initiating this study:

Margo Dennis	Project Manager
Alf Leake	Project Technical Advisor

The following NHC personnel participated in the study:

Barry Chilibeck	Principal Engineer
Matt Gellis	Project Engineer
Edwin Wang	Numerical Modelling
Sarah North	Senior GIS Specialist; GIS data analyses
Dawson Meier	Technician; hydrometrics
Will Skitmore	Senior Technician; surveys

The following Individuals and Companies provided sub-consultant services for this project:

Jeremy Baxter	Principal, Mountain Water Research Inc.

Certification

This document has been prepared by Northwest Hydraulic Consultants Ltd. in accordance with generally accepted engineering practices and is intended for the exclusive use and benefit of the BC Hydro and their authorized representatives for specific application to the Duncan Dam Water Use Plan. The contents of this document are not to be relied upon or used, in whole or in part, by or for the benefit of others without specific written authorization from Northwest Hydraulic Consultants Ltd. No other warranty, expressed or implied, is made.

Northwest Hydraulic Consultants Ltd. and its officers, directors, employees, and agents assume no responsibility for the reliance upon this document or any of its contents by any parties other than BC Hydro.

Report prepared by:

Matt Gellis, MEng, PEng

Report reviewed by:

Barry Chilibeck, MASc, PEng, APEGBC #17430

<u>Accepted final report to be sealed and retained on file.</u>

Executive Summary

As part of the Duncan Dam Water Use Plan (DDM WUP) 10-year review period, DDMMON3 *Lower Duncan River Hydraulic Model Development* aims to develop predictive tools for integrating habitat use with water flows at a range of operations to quantify operating impacts on habitat displacement. Along with a suite of other DDMMON programs, DDMMON3 is being implemented over the 10-year WUP review period to: (a) support the Adaptive Stranding Protocol Development Program (ASDP); and (b) improve Performance Measure accuracy.

BC Hydro's Program (ASDP) seeks to answer the management question:

> *What are the optimal operating strategies considering both benefits for fish populations and costs/forgone revenues at Duncan Dam to reduce fish stranding in the Lower Duncan River?*

As noted in the Terms of Reference (ToR) for DDMMON3, this management question cannot be answered by this study program alone. It must be addressed in conjunction with the other ASDP studies, and will be communicated through DDMMON15. Three areas of uncertainty regarding flow-habitat relationships were noted during the WUP process, leading to the following management questions for DDMMON3:

1. *Did the physical flow model developed prior to the DDM WUP accurately predict floodplain inundation levels and extent in Lower Duncan River mainstem and side channel areas?*
2. *Were the habitat-flow relationships for fish species of interest incorporated into DDM WUP performance measures accurate for the range of operations licensed for the Lower Duncan River?*
3. *Given the criteria for operating recommendations made during the DDM WUP, would a more extensive and validated modeling effort result in revised recommendations? Will future model revisions result in revised recommendations?*

To assist in answering these management questions, the following hypotheses were tested:

H_{01}:	The quantity and quality of fish habitat for the Lower Duncan River floodplain over the range of flows influenced by Duncan Dam operations predicted by the existing HEC-RAS model (2003) does not significantly differ from those predicted in a more comprehensive and updated 2-dimensional flow model.
Status:	H_{01} was rejected in the DDMMON Year 2 report (NHC, 2010). The original 1D model did not accurately represent the hydraulics of the river. This was attributed to limitations in the 1D model and available data at the time, as well as morphological changes, which occurred in the interim. H_{01} was not reviewed in in Year 5 as 2D modelling was utilized as in Year 2.

H_{02}:	Areas of habitat use predicted by the updated 2D flow model do not accurately reflect those observed in habitat use studies included in the DDM WUP monitoring program (i.e. DDMMON#2).
Status:	No conclusion can be drawn for H_{02} based on the biological information available at the time of reporting. Habitat use curves generated by DDMMON2 were incorporated into the hydraulic model for determining habitat suitability indices (HSI) and predicting weighted usable area (WUA) by reach. Fish population and microhabitat use data was not available at the time of reporting so no comparison can be drawn between observed and predicted habitat use. Coordination with DDMMON2 prior *to* and during the Year 10 monitoring program is required to address this question.
H_{03}:	The transient nature of the Lower Duncan River floodplain morphology does not significantly change the flow-habitat relationships that are predicted by the 2D flow model.
Status:	No conclusion can be drawn for H_{03} based on available information. Flow-habitat relationships differed from the Year 2 model, but the changes cannot be solely attributed to morphological change. Other contributing factors may include changes to the model downstream boundary condition, improved representation of channel bathymetry in key locations, and updated depth and velocity preference curves for rainbow trout fry rearing.
H_{04}:	Fish stranding risk predicted by the 2-D model of the Lower Duncan River floodplain for operating scenarios evaluated and/or considered in the Adaptive Stranding Protocol Development plan provides a reasonable surrogate for empirical observations made prior to and during the DDM WUP monitoring review period (i.e. the two approaches do not differ).
Status:	No conclusion can be drawn for H_{04} at this time. No quantitative data related to fish stranding distributions were available from DDMMON16 with which to compare the DDMMON3 model results. Further coordination with DDMMON16 *prior to* and during the Year 10 monitoring program is required to address this question.

Are estimates of suitable fish habitat and key metrics comparable between the original WUP 1D model and the project 2D flow-habitat model? Can we identify key differences in the performance measures and estimates of total suitable habitat?

Do fish habitat utilization observations (DDMMON2) compare favourably with estimates of highly suitable habitat made through the hydrodynamic habitat modelling?

Does the Duncan River exhibit dynamic stability, where habitats are lost and renewed through continuous geomorphic processes supported by the existing controlled flow regime?

How do potential stranding areas identified through modelling of dynamic flow ramping changes in the river compare to areas of known fish stranding during down-ramping events?

Year 5 of DDMMON3 did not attempt to answer all of the above management questions. The Year 5 study incorporated recent morphological changes in the lower river into the hydrodynamic model, updated the habitat modelling methodology to reflect improvements in analytical ability, and utilized data collected from other DDMMON programs over the past several years. The complete suite of performance measures and model outputs were also not modelled in the interim Year 5 reporting. In particular, the Year 5 update completed:

- Updating the digital elevation model (DEM);
- Upgrading the hydraulic model from a steady-state simulation using RIVER2D to and unsteady simulation using TELEMAC2D;
- Incorporating updated fish use preference curves;
- Implementing refined analytical tools for analyzing flow ramping effects; and
- Comparing the weighted usable area (WUA) derived from the updated TELEMAC2D model to the results obtained in the Year 2 RIVER2D model.

The Year 5 model update was an opportunity to capture changing conditions in the river, incorporate advancements in the hydraulic model; and reinforce the potential links between DDMMON programs. Recommendations for the Year 10 update include:

1. Greater and earlier integration with other DDMMONs, particularly DDMMON2, DDMMON4 and DDMMON16. Coordination should be facilitated by BC Hydro and should include an inter-team meeting prior to finalization of program scopes in order to identify the data requirements and capabilities of each monitoring program.
2. Selection of index sites for spawning, stranding and habitat suitability (fish-use), and development of down-scaled detailed models for comparison with quantitative data from DDMMON2, 4 and 16.
3. Renewed bathymetric and topographic survey and photogrammetry.
4. Incorporation of any further advancement in hydraulic and habitat modelling.
5. Update of the remaining fish preference curves.

Table of Contents

List of Tables

List of Figures

List of Appendices

1 Introduction

The DDMMON3 Year 5 update builds on the Year 1 and Year 2 work to incorporate advances in analytical methods, recent morphological changes on the river, and data collected from other DDMMON programs over the past few years. In particular the Year 5 update focused on:

1. Updating the digital elevation model (DEM);
2. Upgrading the hydraulic model from a steady-state simulation using RIVER2D to and unsteady simulation using TELEMAC2D;
3. Implementing refined analytical tools for analyzing flow ramping effects; and
4. Comparing the weighted usable area (WUA) derived from the updated TELEMAC2D model to the results obtained in the Year 2 RIVER2D model.

As per the DDMMON#3 terms of reference, final model development in Year 10 will provide a basis for establishing the impacts of morphologic change on habitat availability and provide decision support to manage flows for fish in a changing morphologic setting.

1.1 Background

The Duncan Dam Water Use Plan process (DDM WUP) recommended extensive monitoring programs over a 10-year period to address two key objectives: (1) support an Adaptive Stranding Protocol Development program; and (2) improve Performance Measure (PM) accuracy. These monitoring programs are identified in BC Hydro (2008).

As part of the original WUP decision process, flow-based fish habitat performance measures were developed using HEC-RAS modelling (Klohn Crippen, 2003) for the Lower Duncan River below BC Hydro's Duncan Dam (DDM). Seasonal flows were recommended during the WUP process to improve habitat condition, primarily by providing habitat stability via minimum flow targets and by ensuring stable flow during spawning and incubation periods. Goals were to reduce fish stranding and dewatering of redds, and to improve overall fisheries productivity of the Lower Duncan River.

The 1-dimensional (1D) HEC-RAS model yielded cross-sectionally averaged water levels and velocities. It was therefore limited in its ability to inform habitat-based criteria for the DDM seasonal flow changes. The 1D model was also limited in terms of:

- Ability to assess impacts of DDM flow changes throughout the season;
- Spatial distribution and resolution of modelling in the Lower Duncan River; and
- Use of species-specific habitat suitability indices by life stage.

To address these issues, the WUP process developed the following management questions for DDMMON3:

1. *Did the physical flow model developed prior to the DDM WUP accurately predict floodplain inundation levels and extent in Lower Duncan River mainstem and side channel areas?*
2. *Were the habitat-flow relationships for fish species of interest incorporated into DDM WUP performance measures accurate for the range of operations licensed for the Lower Duncan River?*

3. *Given the criteria for operating recommendations made during the DDM WUP, would a more extensive and validated modeling effort result in revised recommendations? Will future model revisions result in revised recommendations?*

DDMMON3 tested the following hypotheses to assist in answering the above management questions:

H_{01}: The quantity and quality of fish habitat for the Lower Duncan River floodplain over the range of flows influenced by Duncan Dam operations predicted by the existing HEC-RAS model (2003) does not significantly differ from those predicted in a more comprehensive and updated 2-dimensional flow model.

H_{02}: Areas of habitat use predicted by the updated 2-D flow model do not accurately reflect those observed in habitat use studies included in the DDM WUP monitoring program (i.e. DDMMON#2).

H_{03}: The transient nature of the Lower Duncan River floodplain morphology does not significantly change the flow-habitat relationships that are predicted by the 2-D flow model.

H_{04}: Fish stranding risk predicted by the 2-D model of the Lower Duncan River floodplain for operating scenarios evaluated and/or considered in the Adaptive Stranding Protocol Development plan provides a reasonable surrogate for empirical observations made prior to and during the DDM WUP monitoring review period (i.e. the two approaches do not differ).

1.1.1 Years 1 and 2

The DDMMON3 Year 1 and Year 2 reports (NHC 2009 and NHC 2010) addressed hypotheses 1, 2 and 4. The first two years of the study mitigated uncertainty in the original modeling by using a 2D numerical model, RIVER2D, calibrated with measured water levels at key habitats. This approach improved the resolution and quantification of modeled hydraulic habitats. The model identified variability in fish habitats resulting from changed DDM and Lardeau River flows, habitat change during critical life history phases, minimum flows to ensure suitable habitat, and flows required to ensure connectivity between refugia and critical habitats.

Using species-specific habitat suitability data the RIVER2D model provided:

1. Estimates of total suitable, percent of total wetted, stable and changed aquatic habitat through time relative to flow;
2. Flow-habitat relationships by fish species, habitat type and life stage;
3. Flow magnitudes that minimize habitat losses through critical periods (e.g. spawning and incubation); and
4. Estimates of areas dewatered, retained or lost, as flows changed in the Lower Duncan River.

H_{01} was rejected in the Year 2 report. Quantity and quality of fish habitat simulated by the 2D model were significantly different from the WUP 1D model results.

Preliminary assessment of H_{02} was accomplished by modelling weighted usable area (WUA) for species and lifestages in the LDR. Comparison of WUA with DDMMON2 monitoring results was deferred to Years 5 and 10.

NHC recommends evaluation of H_{03} in Year 10 when there are three assessments to compare and a more significant time for morphologic change (e.g. occurrence of large floods).

H_{04} was assessed in Years 1 and 2 by evaluating wetted areas relative to flows, and dynamic stage change related to short term flow variations at DDM. Results were inconclusive; wetted area alone appeared to be relatively insensitive as a direct measure of stranding risk for fish at the spatial scale used in the model. Collaboration with DDMMON16 was recommended to assess H_{04} more definitively.

Recommendations in the Year 2 report included:

1. Update the hydraulic model to incorporate morphological changes;
2. Develop river-specific fish preference curves and include them in the updated model; and
3. Improve modelled fish stranding and calibrate with index sites from DDMMON16.

1.2 Year 5

The Year 5 update of DDMMON3 incorporates recent morphological changes in the lower river into the hydrodynamic model, updates the habitat modelling methodology to reflect improvements in analytical ability, and utilizes data collected from other MON programs over the past few years. In particular the Year 5 update focused on:

1. Updating the digital elevation model (DEM);
2. Upgrading the hydraulic model from a steady-state simulation using RIVER2D to and unsteady simulation using TELEMAC2D;
3. Implementing refined analytical tools for analyzing flow ramping effects; and
4. Comparing the weighted usable area (WUA) derived from the updated TELEMAC2D model to the results obtained in the Year 2 RIVER2D model.

2 Data Collection

The Year 5 report had a limited scope of work for data collection. The program included a minor update of the Lower Duncan River bathymetry; installation of four new water level gauges; and review of BC Hydro October 2012 orthophotos.

2.1 Bathymetric Survey

Substantial morphological changes took place in the river, primarily during very high flows, which occurred in July 2012. The survey program made efforts to capture the most important changes that were identified through air photo analyses. A complete re-survey is envisioned for Year 10.

The bathymetric survey ranged in extent from downstream of the tailrace to Kootenay Lake, and was targeted toward key areas of hydraulic influence and fish habitat importance (**Error! Reference source not found.**). Areas in which detailed survey data was captured included:

- Downstream end of the Duncan Dam tailrace;
- Lardeau River confluence;
- Various locations along the Lower Duncan River mainstem; and
- Parts of side channels 3.5R, 4.1R, 6.9R, 8.2L and the Kootenay Lake delta.

BC Hydro's October 2012 orthophotos were reviewed to confirm banklines in the DEM were generally representative of conditions post 2012 flooding.

2.2 Hydrometric Data

Water level records were required to calibrate the hydraulic model. Hydrometric gauges from the Year 1 and Year 2 studies were no longer operational, so NHC installed four new hydrometric gauges and two barometric loggers, and re-activated two previously existing gauges (Figure 25). Hydrometric data were collected between May 2 and October 4, 2012 (**Error! Reference source not found.**). Rating curves for the two re-activated gauges and the four newly installed ones should be updated as part of the Year 10 DDMMON3 program.

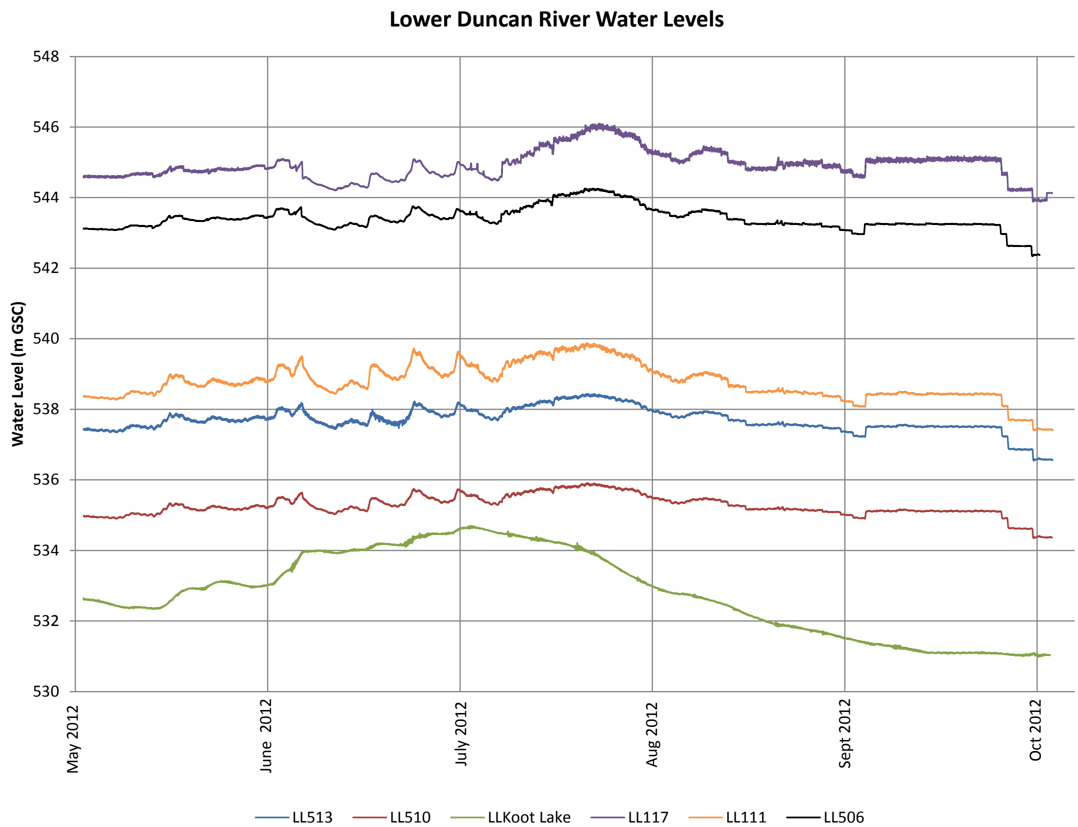


Figure 1. Recorded water levels on the Lower Duncan River and Kootenay Lake.

3 Hydraulic Modelling

The hydraulic model was updated in Year 5 to account for recent geomorphological changes and to improve the analysis of flow ramping effects on fish habitat and stranding. The update incorporated new survey data and moved the hydrodynamic model from RIVER2D to TELEMAC-2D.

TELEMAC-2D handles unsteady hydrodynamic analyses more efficiently and robustly than RIVER2D. An unsteady model is required to capture temporal aspect of the relationship between fish utilization, habitat types and water level changes during flow ramping events. While the built-in modules within RIVER2D allow for direct fish habitat analysis, the model computation algorithms are not efficient in unsteady modelling mode.

TELEMAC-2D solves the Saint-Venant equations using the finite-element or finite-volume method and a computation mesh of triangular elements. The model is part of the TELEMAC SYSTEM developed by the National Hydraulics and Environment Laboratory (Laboratoire National d'Hydrauliqueet Environnement - LNHE) of the Research and Development Directorate of the French Electricity Board (EDF-R&D), in collaboration with other research institutes.

3.1 Model Setup

The DDM TELEMAC-2D model mesh extends about 10 km North-South and 3 km East-West (Figure 25) and consists of over 184,000 nodes. The mesh size ranges from 1.5 m to 16 m. Regions representing side channels have been refined to better capture the drying process during flow ramping. The bed roughness is represented in the model by an effective roughness height coefficient, k_s, and a value of 0.2 was adopted from the Year 2 study and used in the model.

Hourly discharges from Duncan Dam, Lardeau River, Meadow Creek, Cooper Creek and Hamill Creek were prescribed as inputs at the upstream boundaries of the model. The downstream boundary was set by hourly Kootenay Lake water surface elevations.

3.1.1 Bathymetry and DEM Verification

Development of a digital elevation model (DEM) to support hydraulic modelling is described in detail in the DDMMON 3 Year 2 Final Report. HC's 2012 bathymetric and topographic survey data, along with BC Hydro's October 2012 orthophotos (revised January 2013), were used to update the DEM for the Year 5 hydraulic modelling.

NHC's 2012 survey comprises 25,872 bathymetric survey points and 520 topographic survey points along the river channel, banks and bars. A comparison of the survey data points to the original BC Hydro DEM confirmed that the survey matched well with the DEM, and that areas of significant difference matched areas of deposition and erosion reported by the field crew and observed in the October 2012 orthophotos.

In areas of erosion and deposition, points were removed from the original BC Hydro DEM and replaced with 2012 survey data. Breaklines were added to better define banks and other topographic features in these areas. Survey data and breaklines were also added at the gauge station sites, to ensure that the DEM accurately represents these key areas.

The final DEM was reviewed in comparison to the 2012 survey data and BC Hydro's October 2012 orthophotos. The DEM was then exported to a ten-metre resolution grid for import to the TELEMAC2D hydraulic model.

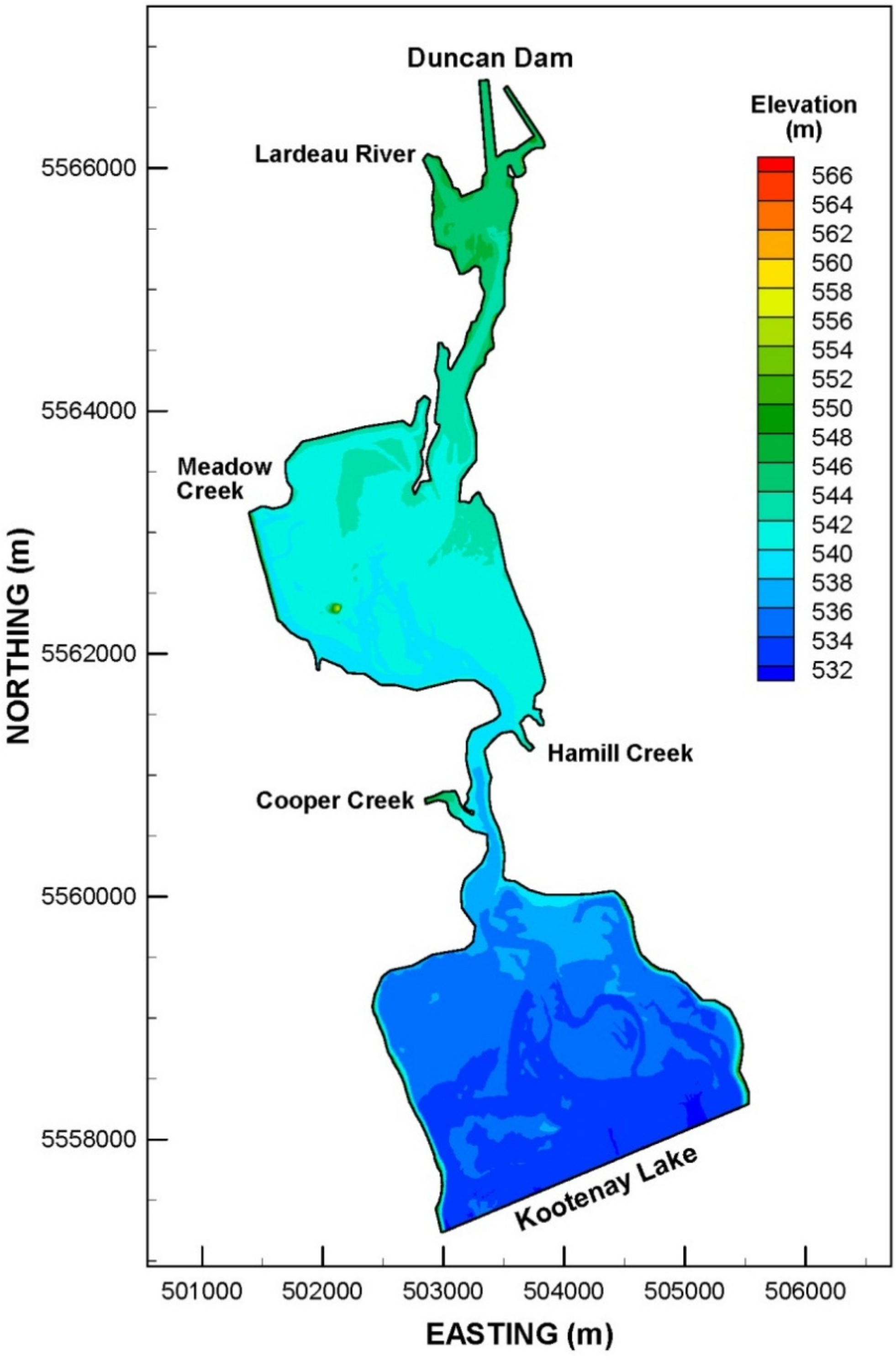


Figure 2. Extents of model mesh

3.2 Model Validation

3.2.1 2010 August ADCP Data

As a baseline the DDM TELEMAC-2D model was first validated against the Year 2 Acoustic Doppler Current Profiler (ADCP) data from August 2010. This test was conducted prior to the collection of 2012 survey and hydrometric data.

In August 2010 the water level at Environment Canada station Kootenay Lake at Queens Bay (08NH064) was at about 532.2 m and the flows from Duncan Dam and Lardeau River were relatively steady at 22 m^3/s and 55 m^3/s respectively. Details of the ADCP survey and data processing methodology are described in the 2010 report. The model topographic data were generated from the February 2010 DEM data.

The results at selected locations along the river are shown in the figures below. The solid line represents the modelled velocities and the squares represent measured velocities.

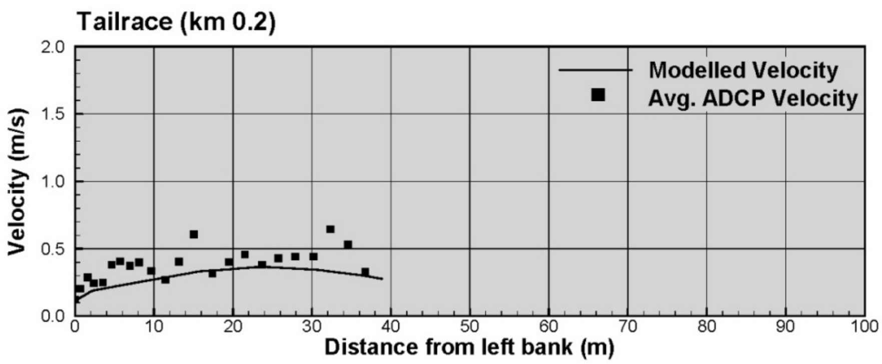


Figure 3. Modelled and ADCP velocities at DDM tailrace (km 0.2)

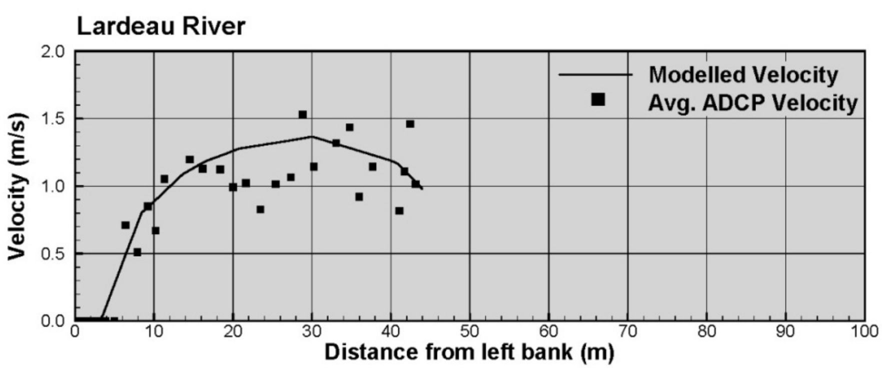


Figure 4. Modelled and ADCP velocities at Lardeau River.

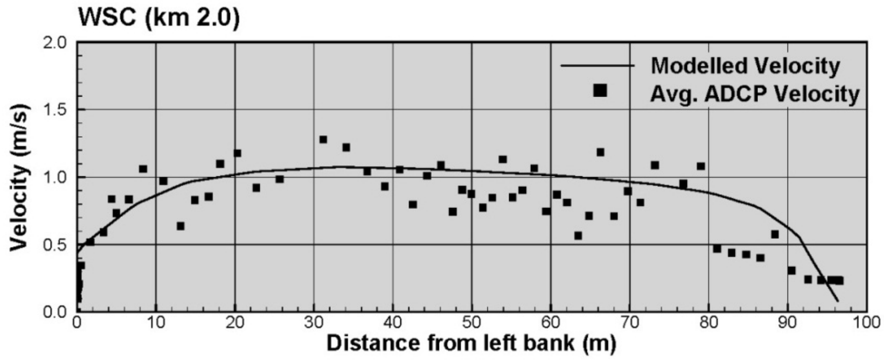


Figure 5. Modelled and ADCP velocities at Duncan River Below Lardeau (DRL) WSC gauge (km 2.0).

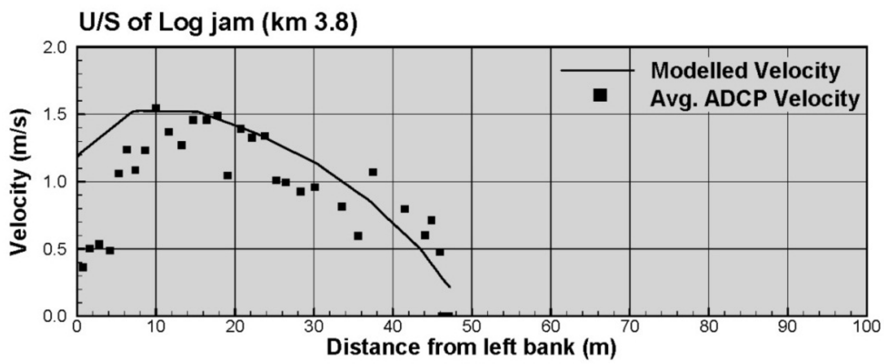


Figure 6. Modelled and ADCP velocities upstream of log jam (km 3.8).

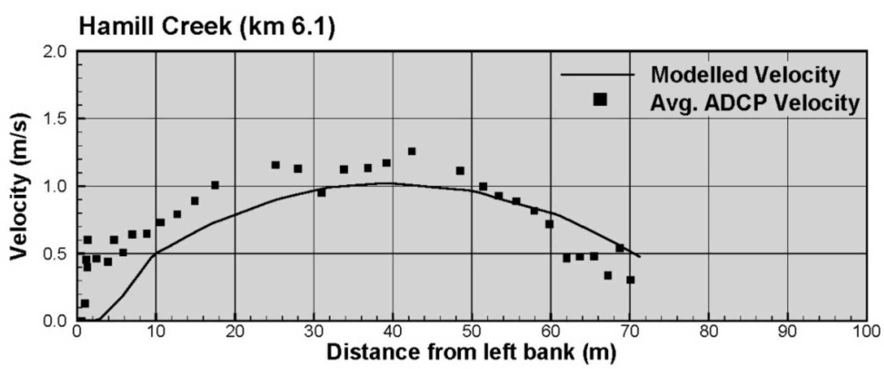


Figure 7. Modelled and ADCP velocities at Hamill Creek (km 6.1).

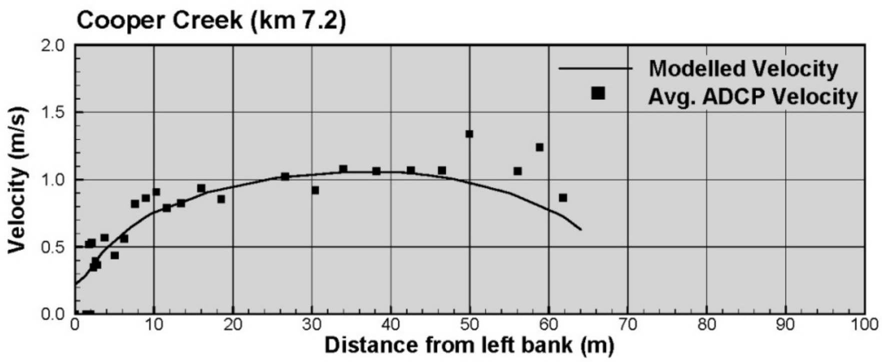


Figure 8. Modelled and ADCP velocities at Cooper Creek (km 7.2).

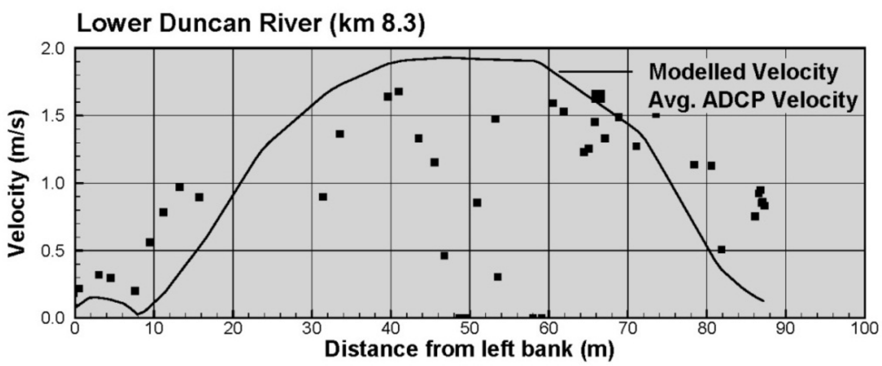


Figure 9. Modelled and ADCP velocities at Lower Duncan River (km 8.3).

The results indicate that The TELEMAC-2D model captured the general velocity profile at each station. The differences between the modelled and measured velocities may be due to localized backwater effect from the log jam and lake wind setup effect as the Environment Canada Kootenay Lake station is 55 km downstream of the model boundary.

3.2.2 2012 Fall Flow Ramping

The TELEMAC-2D model was then used to simulate the 2012 fall flow ramping event (September 25 to October 2). Model topographic data were generated from the 2012 DEM provided by BC Hydro and supplemented with the September 2012 NHC bathymetric survey.

To address the wind setup effect at the downstream model boundary, a water level gauge was installed during the Year 5 study in Kootenay Lake near Lardeau, about 2.3 km downstream of the Duncan River delta. The water level record from this gauge was used as the downstream boundary condition for the model, instead of the record from the Environment Canada station.

Model results at selected locations along the river are shown in **Error! Reference source not found.** through **Error! Reference source not found.** below. The red line represents the modelled water level and the blue line represents the measured water level.

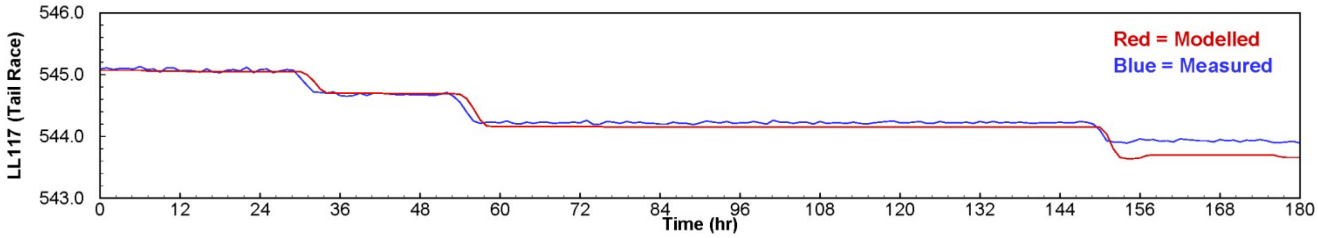


Figure 10. Modelled and measured water elevation at Station LL117 (Tailrace).

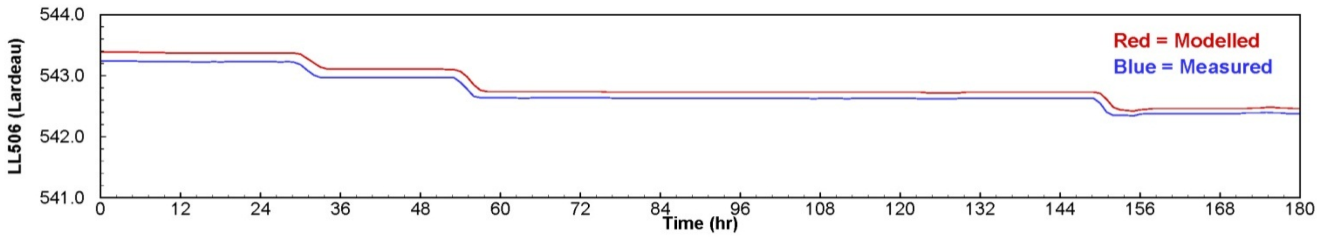


Figure 11. Modelled and measured water elevation at Station LL506 (Lardeau).

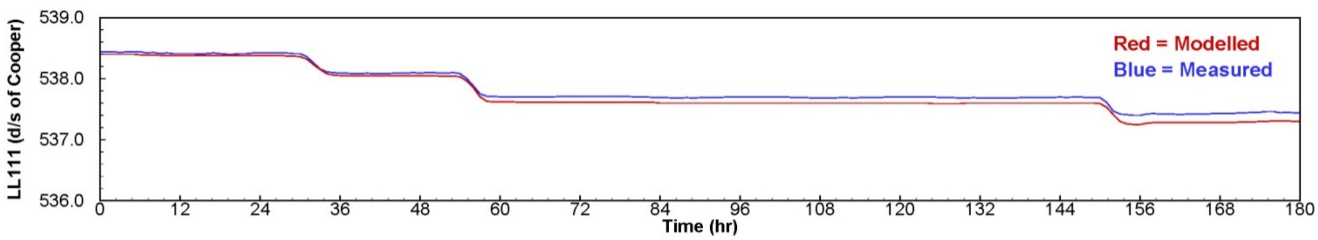


Figure 12. Modelled and measured water elevation at Station LL111 (downstream of Cooper).

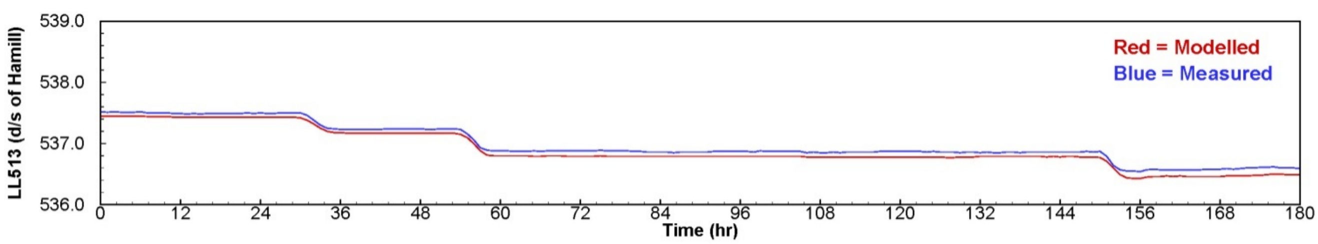


Figure 13. Modelled and measured water elevation at Station LL513 (downstream of Hamill).

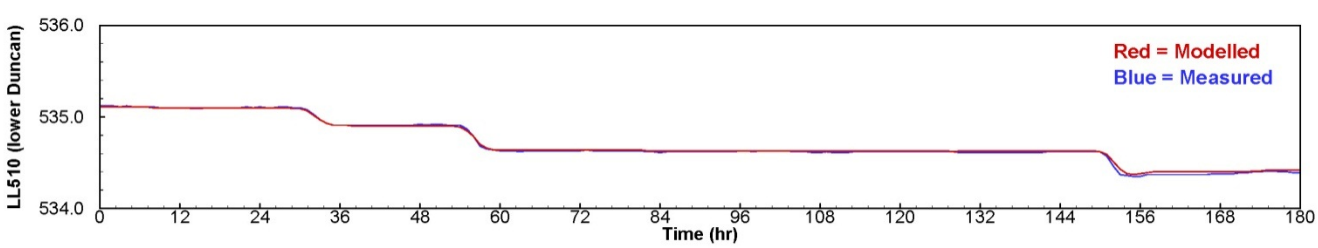


Figure 14. Modelled and measured water elevation at Station LL510 (lower Duncan).

The results show that there was a minor lag of approximately two hours between the modelled and the measured water level data at the LL117 - tailrace. Overall the model is able to predict the change in water level at each station during the ramping event. The average difference between the modelled and measured water data over the 2012 ramping event at LL117, LL506, LL111, LL513 and LL510 stations are +7 cm, -11 cm, +8 cm, +8 cm and -1 cm, respectively.

Hourly water level and velocity data at each node were archived and used to evaluate changes in habitat and fish utilization.

4 DDM WUP Flow Management Issues

Rather than assessing the complete suite of performance measures and model outputs, the scope of work for the Year 5 study focused on comparing updated model results to Year 2, incorporating the effects of improved model capability; morphologic changes in the river; and updated fish preference curves. Two species life stages were selected for analysis: rainbow trout rearing fry rearing and kokanee spawning.

4.1 Habitat Suitability Indices

Habitat suitability indices (HSI) for kokanee spawning and rainbow trout fry rearing were calculated at each model element based on fish use preference curves for depth, velocity and substrate.

4.1.1 Kokanee Spawning

The depth preference curve for kokanee spawning (Ecofish, 2009) used in Year 2 and Year 5 is shown in **Error! Reference source not found.**. The greatest suitability occurs around 0.2 m depth and drops off rapidly for depths greater than 0.4 m. By comparison, the WUP specified kokanee spawning habitat suitability based on depth only, where depths between 0.15 to 1.20 m were assumed to be suitable.

The velocity preference curve for kokanee spawning habitat (Ecofish, 2009) used in Year 2 and Year 5 is shown in **Error! Reference source not found.**. No velocity criteria were applied in the 1D WUP modelling.

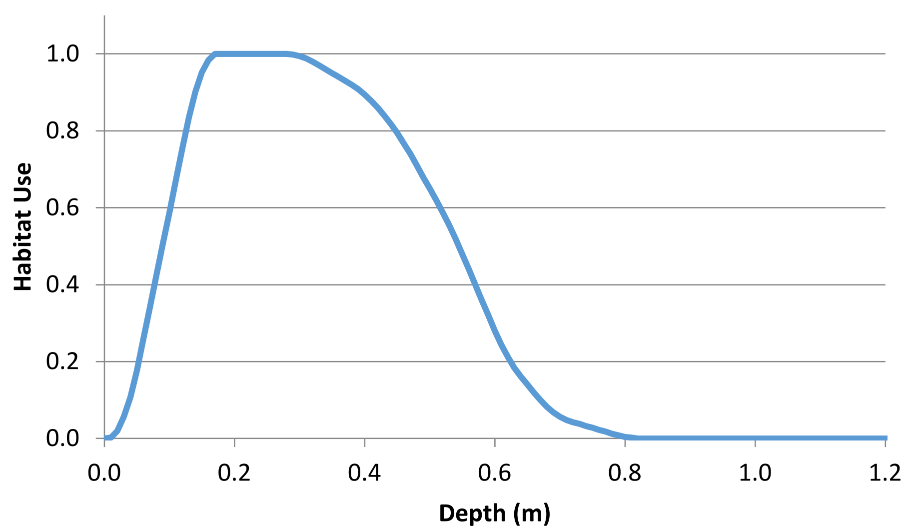


Figure 15. Depth preference curve for kokanee spawning.

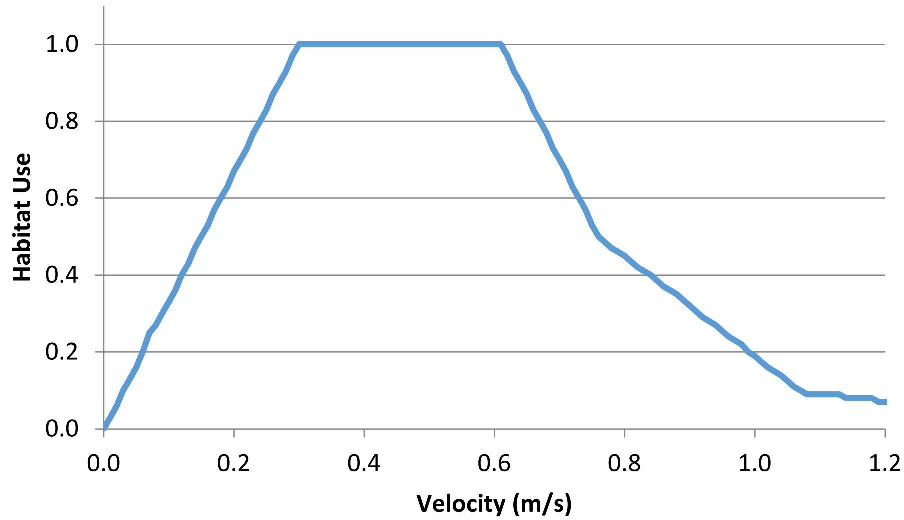


Figure 16. Velocity preference curve for kokanee spawning.

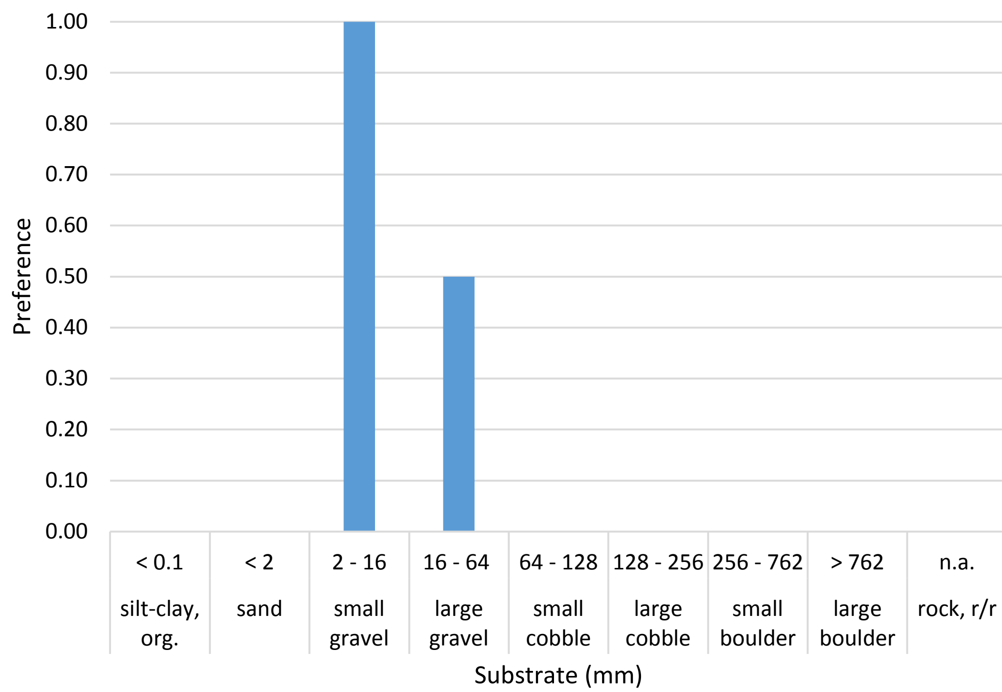


Figure 17. Substrate preference for kokanee spawning.

4.1.2 Rainbow Trout Fry Rearing

Velocity and depth preference curves for rainbow trout fry rearing were updated according to AMEC (2012) (Figure 18 and Figure 19). Substrate preference for rainbow trout fry rearing was unchanged from Year 2 (Figure 20).

The depth and velocity preference curves for rainbow trout fry rearing have changed substantially compared with Year 2. Most notably, the Year 5 depth curve has a preference value of 0.6 for zero depth. This suggests relatively high fish use in zero depth. The result is not viable, and the analyses should be reviewed in future in DDMMON2 iterations.

NHC applied a filter to the model data to remove any nodes with depth less than 0.02. The filter reduced the over-prediction of fish use in very low water depths. Another change is that the depth curve for Year 5 indicates a preference value of 0.1 for all depths greater than 0.65 m, whereas the Year 2 curve tended toward 0 for depths greater than about 0.7 m.

The Year 5 velocity curve has also changed substantially from Year 2. The updated velocity curve indicates that rainbow trout fry do not utilize habitats with velocities greater than 0.2 m/s, and that they overwhelmingly prefer waters less than 0.1 m/s. By comparison, the WUP specified only that “rearing side channels and cover” were suitable habitat for juvenile rainbow trout (Ecofish, 2009).

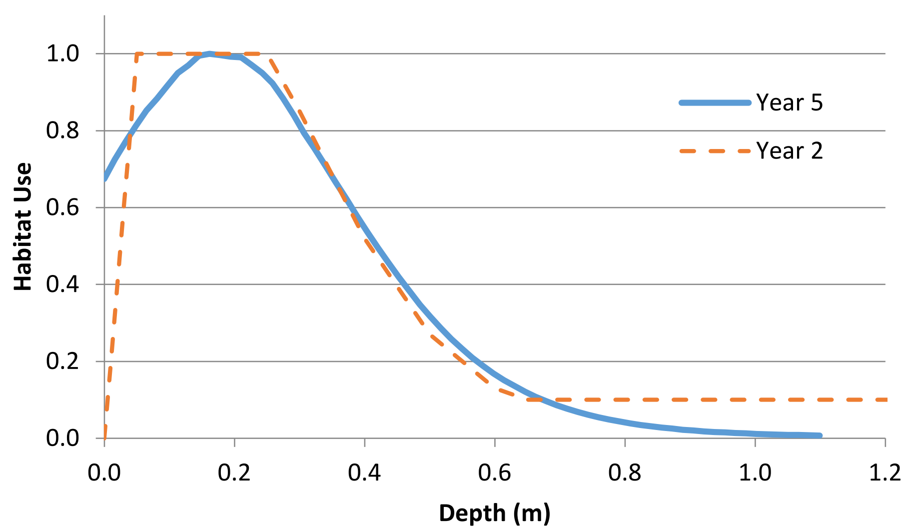


Figure 18. Depth preference curve for rainbow trout fry rearing.

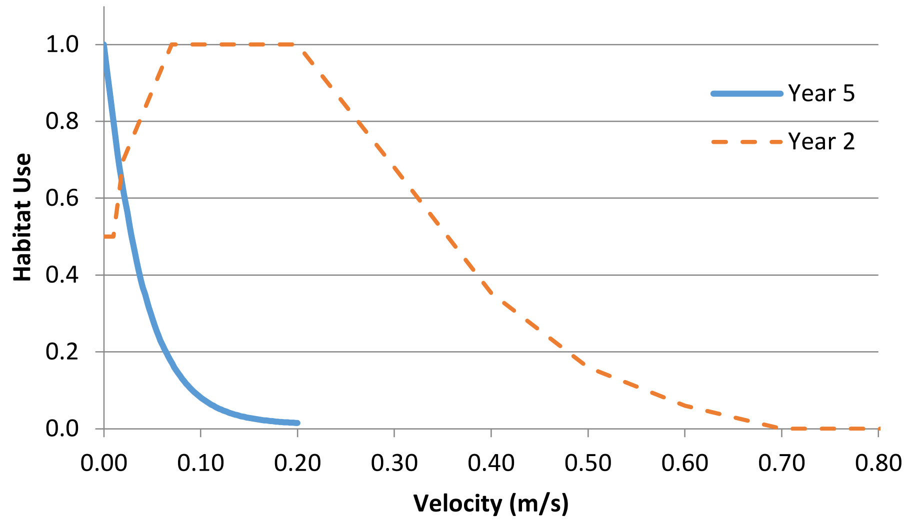


Figure 19. Velocity preference curve for rainbow trout fry rearing.

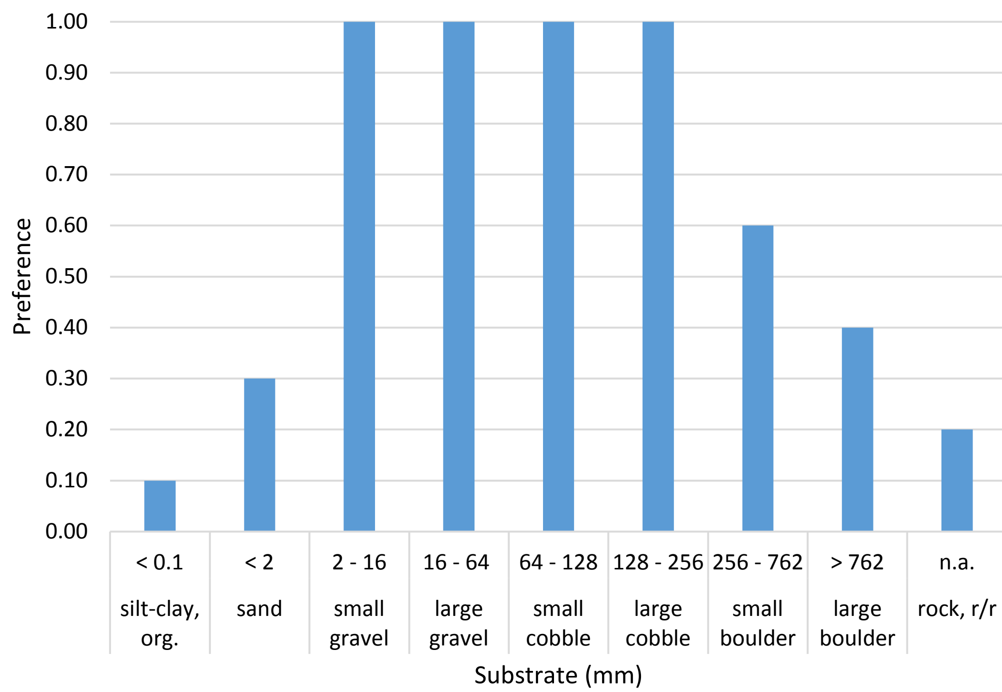


Figure 20. Substrate preference for rainbow trout fry rearing.

4.2 Weighted Usable Area

Weighted Usable Area (WUA) represents an index of total suitable habitat for a given species life stage and discharge. WUA is not a spatial measure (despite having units of m^2), but rather a comparative measure of the changes in overall quantity of suitable habitat at various flows. WUA is calculated as the sum of the Combined Suitability Index (CSI), which itself is the aggregate of HSI at a particular location. WUA was calculated using depth/velocity/substrate HSI, and also with only depth/velocity HSI. CSI is then calculated at each model node for a given species life stage and discharge, and the sum of CSI over the model domain is multiplied by the wetted area to determine WUA. For a more detailed discussion of WUA refer to NHC (2010).

In the Year 5 update WUA was modelled for kokanee spawning and rainbow trout fry rearing. Steady state model results were output for thirteen flows ranging from 25 to 325 m^3/s. For these steady state runs, the downstream model boundary was set by a Kootenay Lake level of 531.62 m, equivalent to the median level from BC Hydro's Kootenay Lake gauge for the months of September to December over the period of 1995 – 2009. The months of September through December were chosen to reflect downstream water levels during the fall downramping period.

Modelled WUA were broken down by reach, and were also analysed in terms of relative WUA (Reach WUA / Total WUA) and unit WUA (WUA / wetted area). Results are tabulated and plotted in Appendix A.

4.2.1 Kokanee Spawning WUA

When only depth and velocity HSI are considered, total WUA for kokanee spawning increased markedly for increasing flows, with maximum values at 275 m^3/s (Figure 21). At flows above 125 m^3/s Reach 5 had the greatest WUA, while at lower flows Reach 3 had the greatest WUA.

Total WUA calculated using depth, velocity and substrate HSI also increased for higher discharges, with maximum values between 200 to 250 m^3/s (Figure 22). With substrate included, total WUA drops off quite sharply above 250 m^3/s, probably as a result of inundation of gravel deposits.

Overall trends in kokanee spawning WUA were similar to the Year 2 model, however values were substantially higher in the Year 5 model. Since kokanee spawning preference curves remained unchanged, the difference in WUA is attributed to differences in the hydraulic model. The greatest proportion of the increase occurs in Reach 5. We hypothesize that better model representation of conditions in the delta due to improved downstream boundary condition is largely responsible for this change. Improved channel bathymetry in key locations may also be responsible for part of the change.

For complete tables and plots of kokanee spawning WUA, relative WUA and unit WUA refer to Appendix A.

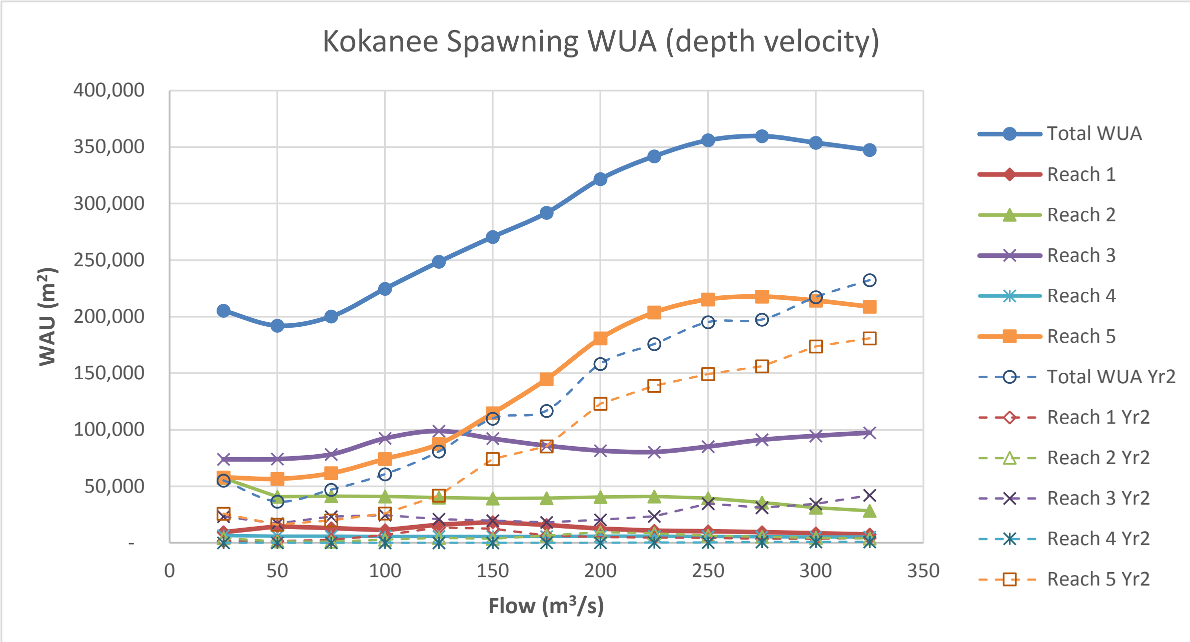


Figure 21. Kokanee spawning WUA using depth and velocity HSI.

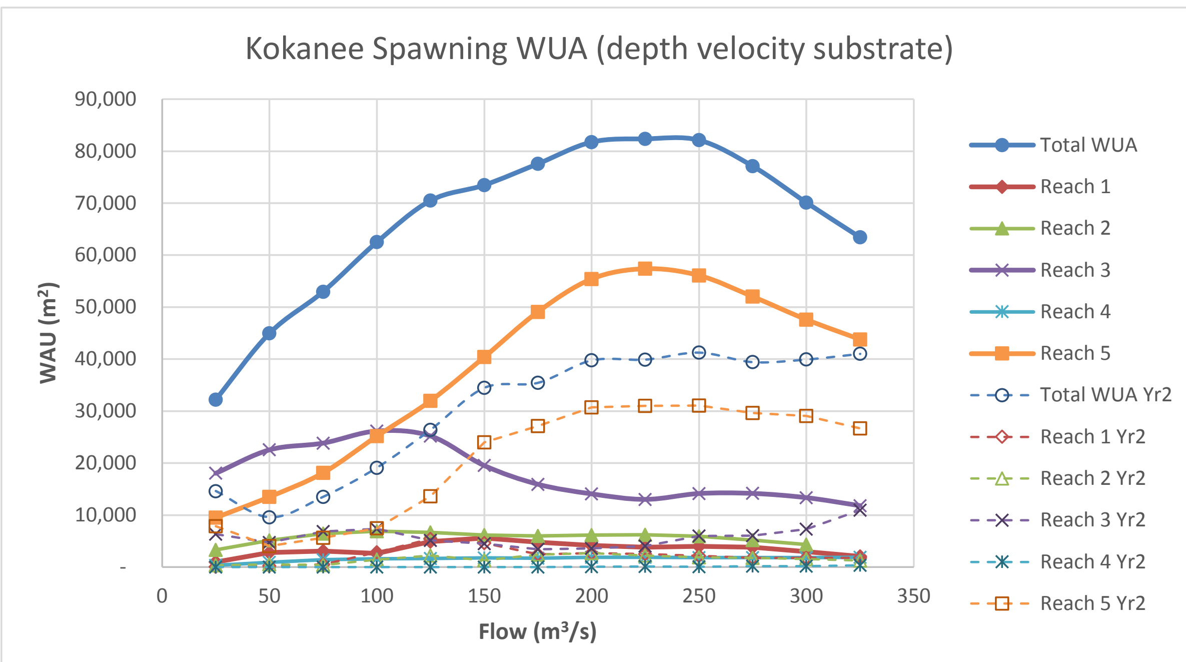


Figure 22. Kokanee spawning WUA using depth, velocity and substrate HSI.

4.2.2 Rainbow Trout Fry Rearing WUA

Rainbow trout fry rearing WUA varied inversely with discharge in Reaches 1, 3 and 5. WUA remained relatively constant in Reaches 2 and 4. These patterns held for WUA calculated using depth and velocity HSI, as well as WUA calculated with substrate HSI included (Figure 23 and Figure 24, respectively).

Overall, WUA values were somewhat lower than in Year 2, and trends were markedly different. Conversely with the Year 5 results, WUA in Year 2 tended to increase with discharge, especially for Reach 5. The change is a result of the updated depth and velocity preference curves (Section 4.1). The updated depth limits rainbow fry use to depths less than 1.0 m (Figure 18). Likewise, the updated velocity curve limits rainbow fry use to velocities below 0.20 m/s (Figure 19).

The updated velocity curve may also be the cause of increased WUA for lower discharges, as it yields very high HSI values for velocities less than 0.02 m/s.

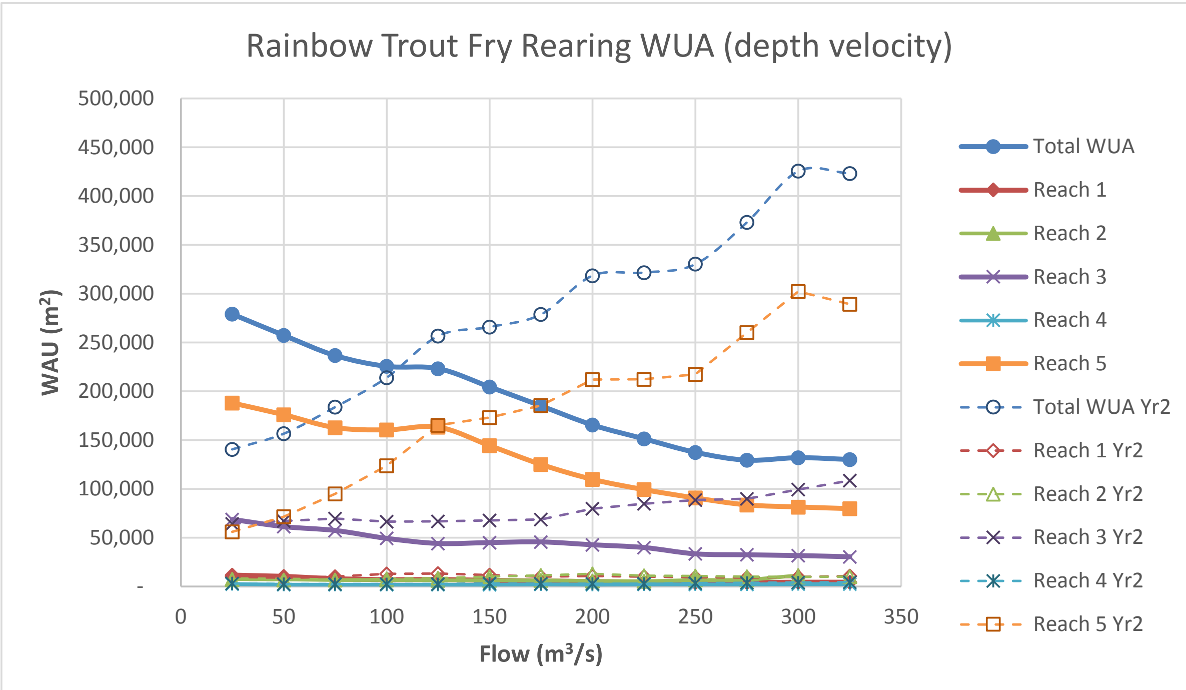


Figure 23. Rainbow trout fry rearing WUA using depth and velocity HSI.

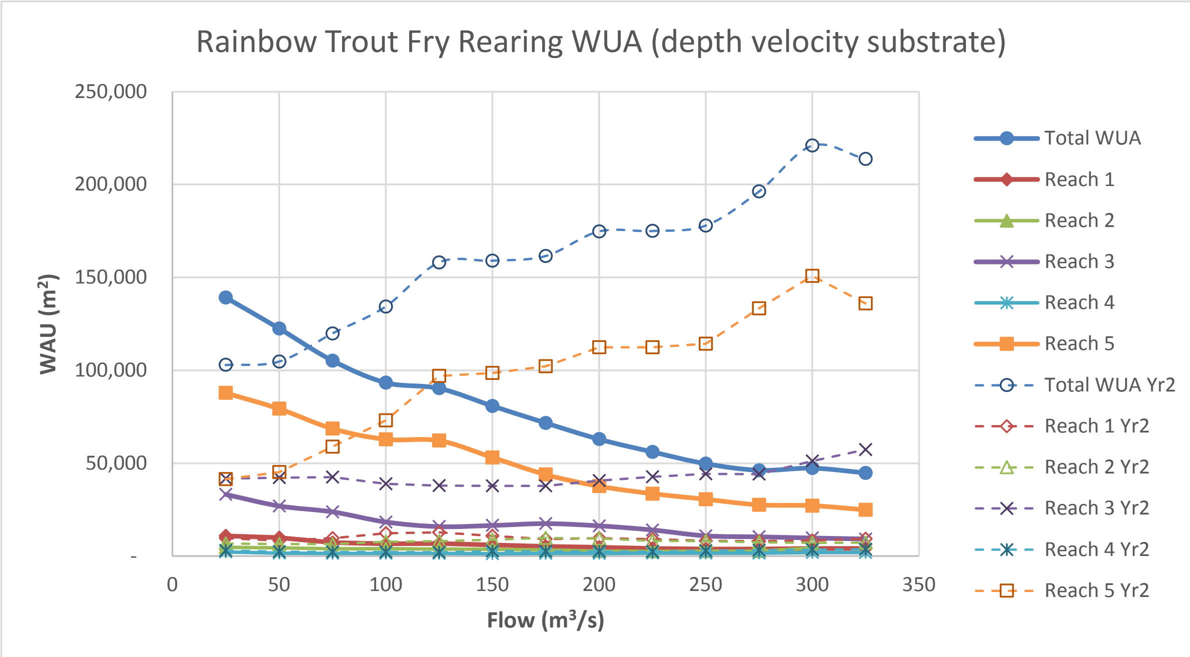


Figure 24. Rainbow trout fry rearing WUA using depth, velocity and substrate HSI.

4.2.3 Effective WUA Habitat

4.2.3.1 Effective Kokanee Spawning Habitat

The effective spawning performance measure (PM) assesses the effects of flow variations on the viability of spawning habitat. The model calculates areas containing viable spawning habitat (minimum depth 0.05 m and minimum velocity 0.05 m/s) and assesses their continued viability through time. The effective spawning habitat lost PM represents the cumulative value of spawning habitat WUA that is dewatered over the spawning and incubation period. For further detail on the calculation of these PMs refer to the Year 2 report (NHC, 2010).

Effective kokanee spawning habitat WUA and spawning habitat WUA lost were modelled for 10th, 50th and 90th percentile flows over the period of record (Table 1). Effective spawning area WUA ranged from 30,700 m^2 to 36,100 m^2 for the 10th and 90th percentiles respectively. Spawning habitat WUA lost ranged from 2,613,000 m^2 to 2,714,000 m^2 for the 10th and 90th percentiles respectively. Both effective spawning WUA and spawning WUA lost were higher in the Year 5 model than in Year 2. The result is consistent with the overall higher total kokanee spawning WUA in Year 5.

Table 1. Effective spawning area WUA and spawning habitat WUA lost.

Percentile	Effective Spawning Area WUA Estimates	Spawning Habitat WUA Lost (Spawning/Incubation Period)
10%	30,700	2,613,000
50%	31,800	2,707,000
90%	36,100	2,714,000

Effective kokanee spawning area WUA and percentage of effective spawning area WUA were also plotted as functions of spawning and incubations flows (Table 2).

Table 2. Effective spawning area WUA estimates, as a function of incubation and spawning flows.

Effective Flows:

Limiting Incubation Flow (m^3/s)

Spawning Flow (m3/s)

Flow	25	50	75	100	125	150	175	200	225	250	275	300	325
25	30,582	31,892	32,071	32,143	32,152	32,176	32,175	32,181	32,171	32,173	32,182	32,162	32,189
50	25,475	43,996	44,630	44,816	44,844	44,886	44,895	44,926	44,902	44,912	44,938	44,906	44,919
75	16,516	41,190	51,558	52,701	52,831	52,886	52,888	52,925	52,907	52,920	52,941	52,918	52,939
100	12,004	32,362	48,096	61,626	62,271	62,380	62,376	62,431	62,421	62,441	62,456	62,432	62,451
125	9,192	26,463	39,988	60,886	69,812	70,298	70,327	70,397	70,401	70,410	70,425	70,354	70,369
150	7,360	22,752	33,801	52,071	65,768	72,728	73,202	73,334	73,352	73,364	73,386	73,287	73,301
175	5,836	19,278	28,338	44,238	56,624	70,422	76,719	77,345	77,403	77,415	77,470	77,370	77,390
200	4,432	16,328	23,810	37,448	48,098	62,538	75,646	81,023	81,519	81,585	81,634	81,586	81,613
225	3,170	13,672	19,666	30,927	39,882	52,407	66,408	77,121	81,675	82,205	82,282	82,258	82,286
250	2,349	11,492	16,345	25,084	32,516	42,532	54,962	67,044	76,626	81,647	82,001	81,980	82,029
275	1,543	9,218	13,181	19,599	25,584	33,001	42,683	53,696	64,629	73,763	76,682	76,927	76,994
300	912	6,956	10,168	14,755	19,530	25,128	32,263	41,276	51,238	61,031	67,228	69,664	69,930
325	547	5,181	7,732	10,894	14,640	19,028	24,362	31,357	39,657	48,618	55,952	60,918	62,888

Percentage of Effective Spawning WUA:

Limiting Incubation Flow (m^3/s)

Spawning Flow (m3/s)

Flow	25	50	75	100	125	150	175	200	225	250	275	300	325
25	95	99	100	100	100	100	100	100	100	100	100	100	100
50	57	98	99	100	100	100	100	100	100	100	100	100	100
75	31	78	97	100	100	100	100	100	100	100	100	100	100
100	19	52	77	99	100	100	100	100	100	100	100	100	100
125	13	38	57	86	99	100	100	100	100	100	100	100	100
150	10	31	46	71	90	99	100	100	100	100	100	100	100
175	8	25	37	57	73	91	99	100	100	100	100	100	100
200	5	20	29	46	59	77	93	99	100	100	100	100	100
225	4	17	24	38	48	64	81	94	99	100	100	100	100
250	3	14	20	31	40	52	67	82	93	99	100	100	100
275	2	12	17	25	33	43	55	70	84	96	99	100	100
300	1	10	15	21	28	36	46	59	73	87	96	99	100
325	1	8	12	17	23	30	38	49	63	77	88	96	99

Note: Green = 98 - 100%, Yellow = 50 - 97%, Red < 50%

4.2.3.2 Effective Rainbow Trout Fry Rearing Habitat

The effective rearing habitat PM assesses the stability of rearing habitat associated with changing DDM outflows as a result of operational changes. A 10-day stability period is assumed to be required for fish to access and use suitable habitat. Minimum effective 10-day WUA values for rainbow trout fry rearing habitat were calculated for each flow year in the period of record. These values were calculated for each year in the record, and the 10th, 50th and 90th percentile values are reported. Net rearing habitat lost was also calculated, which is the effective habitat area subsequently dewatered.

Table 3 lists modelled effective rearing habitat WUA and rearing habitat WUA lost. Effective rearing WUA ranged from 58,900 m^2 to 72,300 m^2 for the 10th and 90th percentile flows respectively. Rearing habitat WUA lost ranged from 10,000 m^2 to 18,000 m^2 for the 10th and 90th percentile flows respectively.

Values were lower than in Year 2, which is consistent with the smaller total WUA estimates in Year 5. Effective rearing habitat in Year 2 ranged from 154,761 m^2 to 181,709 m^2 for the 10th and 90th percentile flows respectively. Rearing habitat lost in Year 2 ranged from 19,224 m^2 to 26,743 m^2 for the 10th and 90th percentile flows respectively.

Table 3. Effective rainbow trout fry rearing habitat WUA and WUA lost.

Percentile	Effective Rearing Habitat WUA	Rearing Habitat WUA Lost (10 Day Stability Period)
10%	58,900	10,000
50%	63,000	13,000
90%	72,300	18,000

4.3 Flow Ramping Effects

The unsteady TELEMAC-2D model enabled a more robust analysis of flow ramping effects in Year 5 than was possible in the Year 2 RIVER2D model. Water levels in the Lower Duncan River were modelled for the 2012 fall flow ramping event, to investigate potential fish stranding effects. The ramping event was separated into Phases 1, 2 and 3 corresponding to DDM outflow decreases of 196 to 140, 140 to 80 and 80 to 45 m^3/s respectively. Each downramping phase was analyzed separately for the two fish species-life stages under consideration.

Only model elements which met initial HSI criteria for their particular species / life stage were analyzed. Screening criteria were applied to remove model nodes if they were lacking data, had no habitat value, or had no potential for stranding fish. Screening criteria eliminated nodes which had no substrate data; had an initial depth less than 0.02 m; had combined suitability index (CSI) less than 0.1; or had total depth change less than 0.02 m over the ramping event.

For each of the remaining nodes, the model calculated:

- Change in depth during the downramping;
- Rate of change in depth; and
- Maximum rate of change in depth.

Results are provided in GIS format.

4.3.1 Spatial Distribution of Flow Ramping Effects

Modelled depth changes during the ramping events were overlaid on DDMMON16 stranding site S4.2R as an example of the possibilities for spatial analysis of stranding potential using the model. In general, large changes in modelled water levels were within the stranding site boundary. No quantitative data related to fish stranding severity were available from DDMMON16 with which to compare the DDMMON3 model results.

For kokanee spawning habitat, water level changes greater than -0.2 m occurred in all three phases of the downramping event, with the greatest decrease of -0.50 to -0.54 m occurring during Phase 2 (Figure 27). In Phase 1, notable drops in water level were concentrated in a sub-channel on the left bank. However it appears that the sub-channel was dewatered during Phase 1, and the dry nodes were then screened out of the Phase 2 and 3 analyses. Water level decreases in the latter two phases occurred on bars, near banks and at the entrance to the sub-channel.

Overall, water level changes in rainbow fry rearing habitat were smaller than for kokanee, with only a limited number model elements showing decreases greater than 0.30 m (Figure 28). Notable water level changes occurred primarily in edge habitats, except during Phase 2 when water level decreases between 0.20 and 0.39 m occur in downstream portion of the left sub-channel. Decreases of 0.10 to 0.19 m also occur in the inlet of the sub-channel during Phase 2.

Further coordination between DDMMON3 and DDMMON16 is recommended in the scoping stages of Year 10 so that field data collection can be coordinated for model verification.

4.3.2 Temporal Distribution of Flow Ramping Effects

Histograms of depth change, rate of change, and maximum rate of change were plotted for each species / life stage and downramping phase.

4.3.2.1 Depth Change

Depth change for kokanee spawning was primarily in the range of 0.00 to -0.39 m, with the greatest number of nodes having 0.10 to 0.19 m water level decrease for all three phases of downramping (Figure 29). Of the three downramping events, Phase 2 had the greatest number of nodes experiencing water level decrease greater than 0.20 m. This suggests the possibility that stranding occurrence may be most severe during this phase.

The distribution of depth change for rainbow trout rearing was more heavily weighted toward lower magnitudes (Figure 30). In all three phases, the majority of nodes experienced less than 0.09 m water level decrease. A potential reason for the contrast with kokanee spawning results is the preference for low velocity habitat amongst rainbow trout fry. Areas with very low velocities may tend to be pool habitat influenced by downstream sills, bars or woody debris. Water level fluctuations in such areas would tend to be dampened compared with faster flowing areas in the main channel. Similar to kokanee spawning habitat, Phase 2 resulted in the greatest proportion of larger magnitude depth changes for rainbow fry habitat.

4.3.2.2 Downramping Rate

The downramping rate for kokanee spawning habitat ranged from 0.02 to 0.14 m/h (Figure 31). Rates of water depth decrease were generally less severe during Phase 1 were generally between 0.02 and 0.05 m/h. Phases 2 and 3 resulted in more severe depth changes, with substantial areas experiencing rates between 0.06 and 0.011 m/h.

Downramping rates for rainbow trout fry rearing habitat ranged from 0.00 to 0.10 m/h (Figure 32). Distribution was similar to kokanee spawning habitat. The majority of nodes had downramping rates of 0.05 m/h or less. Phase 1 had the least severe downramping rates, while Phases 2 and 3 resulted in some areas with downramping rates between 0.06 and 0.10 m/h.

The increase in downramping rates during later phases may be a result of decreasing cross-sectional flow area as downramping progresses. As water levels in the river drop, the cross-sectional flow area decreases and therefore a unit decrease in discharge will result in a greater decrease in water level. The results suggest that stranding effects may be more severe in Phases 2 and 3 than in Phase 1.

4.3.2.3 Maximum Downramping Rate

Maximum downramping rates for kokanee spawning habitat ranged from 0.05 to 0.30 m/h (Figure 33). In general maximum rates were primarily less than 0.19 m/h. Phase 1 resulted in less severe maximum downramping rates, mostly between 0.05 and 0.14 m/h. Phases 2 and 3 had substantial numbers of nodes with maximum rates between 0.10 and 0.19 m/h.

Maximum downramping rates in rainbow trout fry rearing habitat ranged from 0.00 to 0.24 m/h, but were overwhelmingly distributed in the 0.05 to 0.09 m/h range (Figure 34). As discussed above, this may be a result of damping effects due to hydraulic controls in the low velocity areas favoured by rainbow trout fry. Again, Phases 2 and 3 resulted in some areas with greater maximum rates, in the range of 0.10 to 0.19 m/h.

The results suggest that fish stranding effects may be more severe in Phases 2 and 3 than in Phase 1. The greater maximum downramping rates for kokanee spawning habitat than for rainbow trout fry rearing habitat also suggest that the former species / life stage may be at greater risk of stranding than the latter.

5 Summary and Recommendations

The Year 5 update of the Lower Duncan River hydraulic model provided an opportunity to make improvements to the hydraulic model and performance measures. River bathymetry was updated to account for recent morphologic changes and to improve the digital elevation model in key areas. The hydraulic model was upgraded from a steady state simulation using RIVER2D to an unsteady simulation using TELEMAC2D. With the unsteady model, implementation of refined analytical tools for assessing flow ramping effects was possible. Weighted usable area (WUA) and performance measures derived from the updated model were compared with Year 2 model results.

The hydraulic model was improved over Year 2. Better representation of downstream boundary conditions yielded a more precise representation of conditions in Reach 5. More efficient computational techniques allowed for a single model to cover the entire river, as opposed to the split model used in Year 2.

Fish use preference curves for rainbow trout fry rearing were updated according to AMEC (2012). The updated curves resulted in very different WUA and effective rearing habitat areas. Continued efforts should be made to refine fish use preference curves, including development of kokanee spawning and other species / life stage curves specific to the Lower Duncan River. The updated depth curve for rainbow trout fry rearing should be revisited as it specifies unreasonably high preference values for depths below 0.02 m.

WUA and effective WUA habitat values generally increased over Year 2 results. For kokanee spawning the increase is attributed to improved representation of the downstream water level, and potentially to better representation of channel bathymetry in key locations. Increased WUA and effective WUA habitat for rainbow trout fry rearing are attributed to the updated depth and velocity preference curves.

Transferring the model from steady state to unsteady using TELEMAC2D enabled a greatly improved analysis of flow ramping effects. Proof of concept was achieved, showing that the unsteady hydraulic model could indicate potential stranding conditions in sufficient resolution to distinguish habitat types. However, quantitative data regarding the severity of fish stranding would be required to validate the model results.

Further coordination with DDMMON16 is recommended early in the Year 10 program. Scope of work for DDMMON16 in Year 10 should include data collection complementary to the requirements of DDMMON3. Similar efficiencies can be achieved by scoping DDMMON3 in Year 10 to complement DDMMON16 requirements.

6 References

AMEC, 2012. Lower Duncan Dam Habitat Use Monitoring (DDMMON-2), Year 3 Report. Report prepared by AMEC for BC Hydro.

Ecofish, 2009. DDMMON3 Curve Assumptions Technical Memo. Report prepared by Ecofish for BC Hydro and NHC.

NHC, 2010. Duncan Dam Water Use Plan, Lower Duncan River Hydraulic Model, DDMMON3 Year 2 Reporting. Report prepared by Northwest Hydraulic Consultants Ltd. for BC Hydro.

Figures

Scale 1:35,000

0 500 1,000 2,000 Metres

0 1,000 2,000 4,000 6,000 8,000 Feet

Coordinate System: UTM Zone 11 Metres, NAD 83

DSGN	JXD
IND CHKD	
DFTG	JXD
DFTG CHKD	MSG
INSPD	
REV	
ACPT	

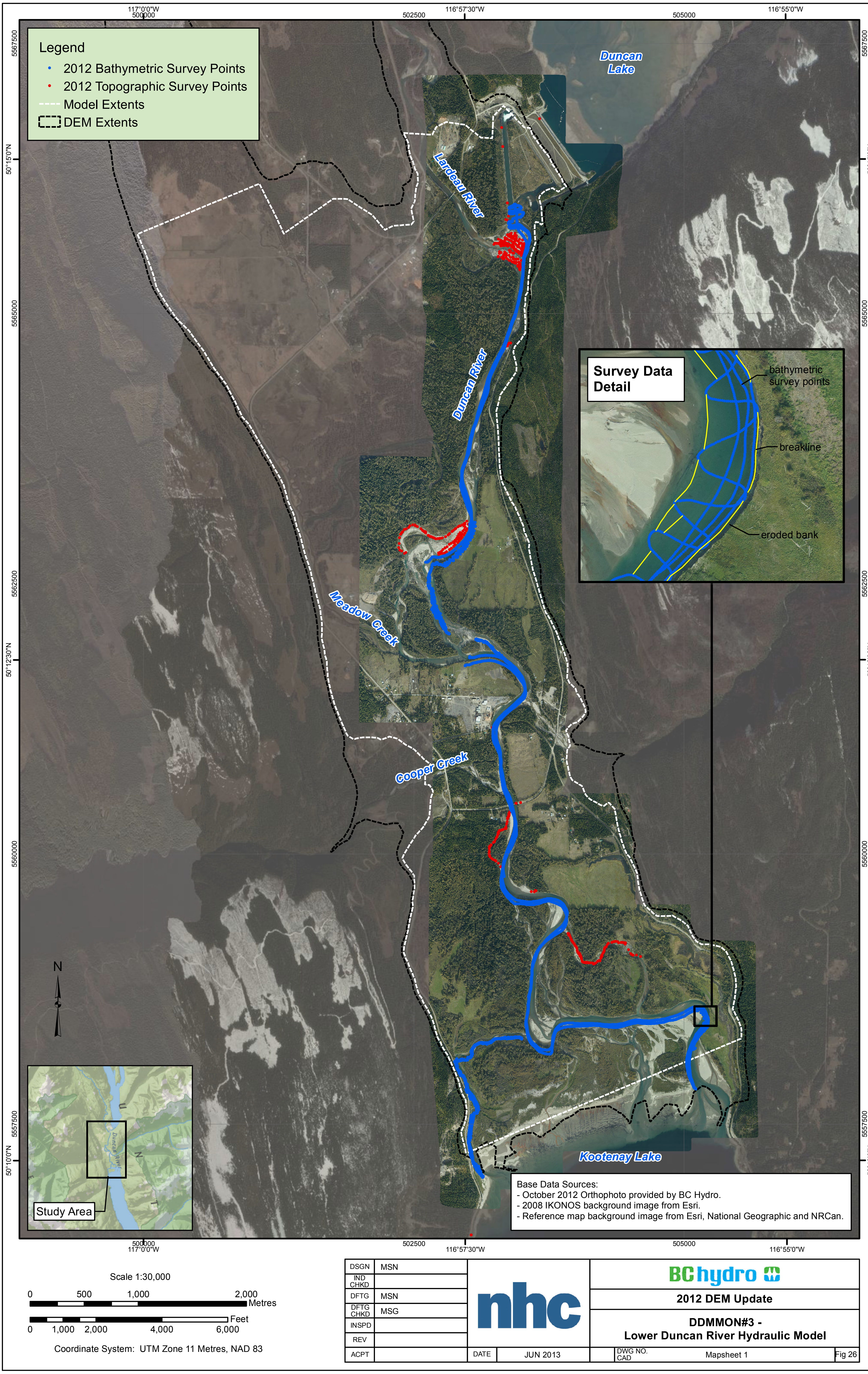
nhc

BC hydro

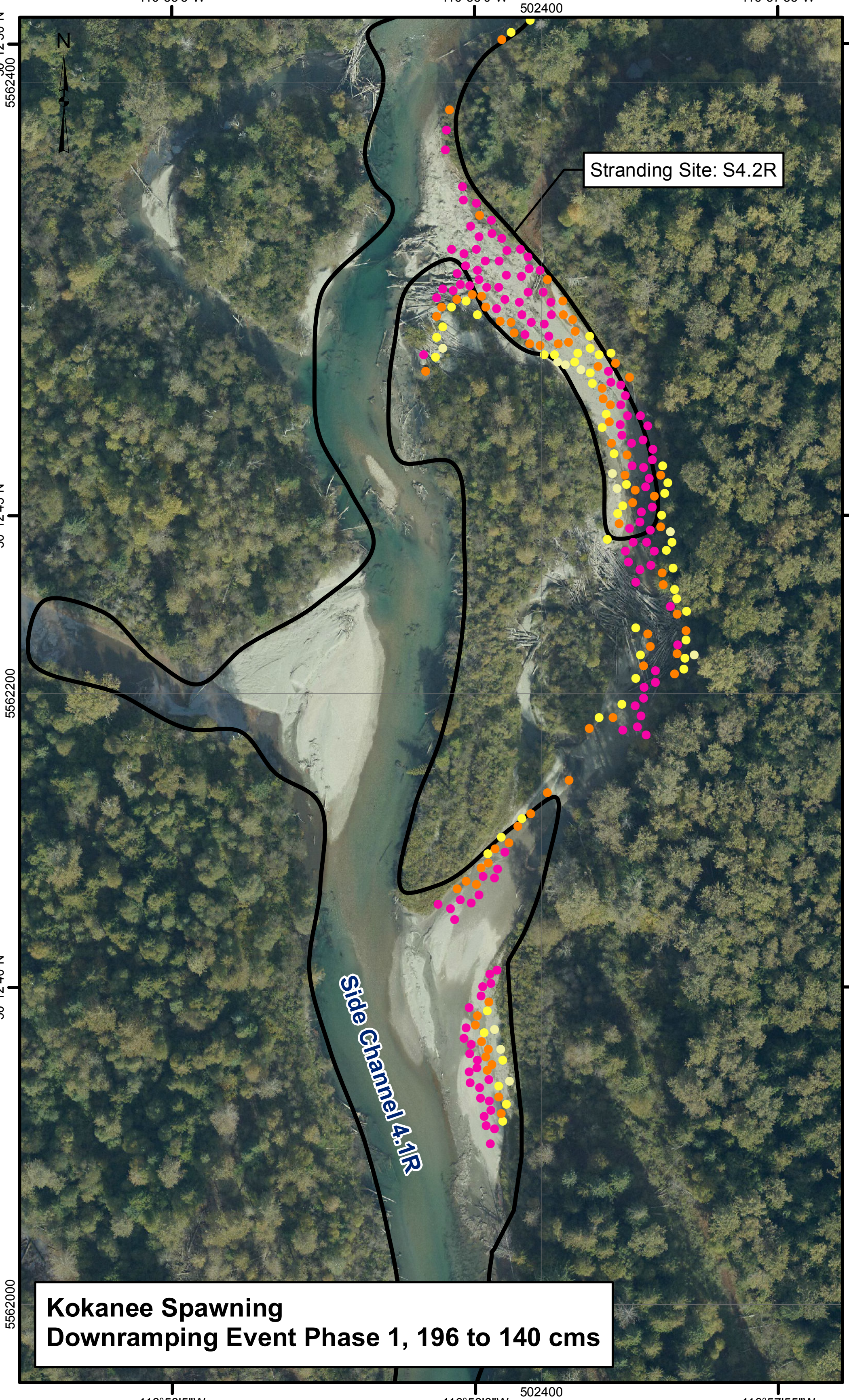
Logger Locations and Model Domain

DDMMON#3 - Lower Duncan River

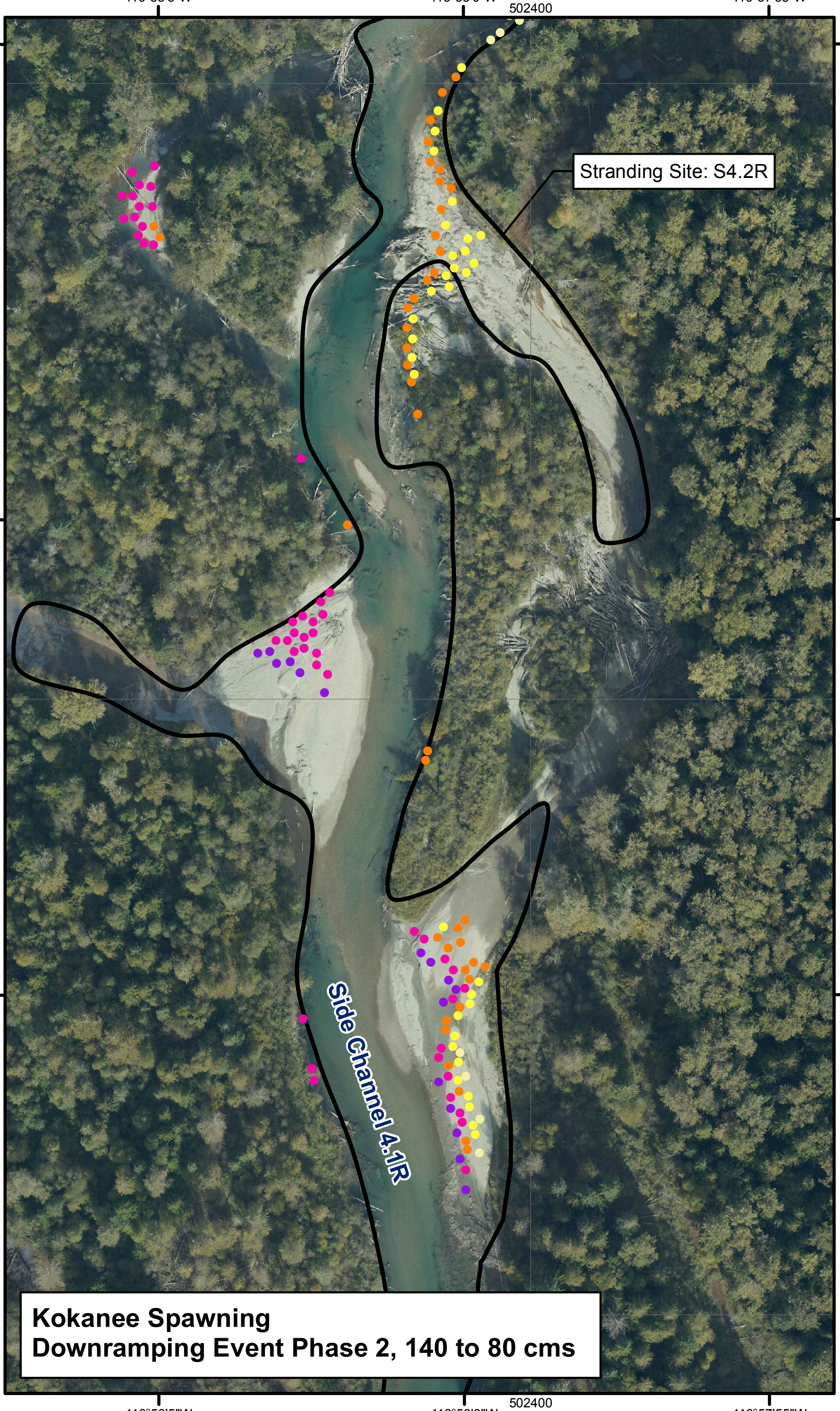
DATE	DWG NO. CAD		
JUN 2013		Mapsheet 1	Fig. 25



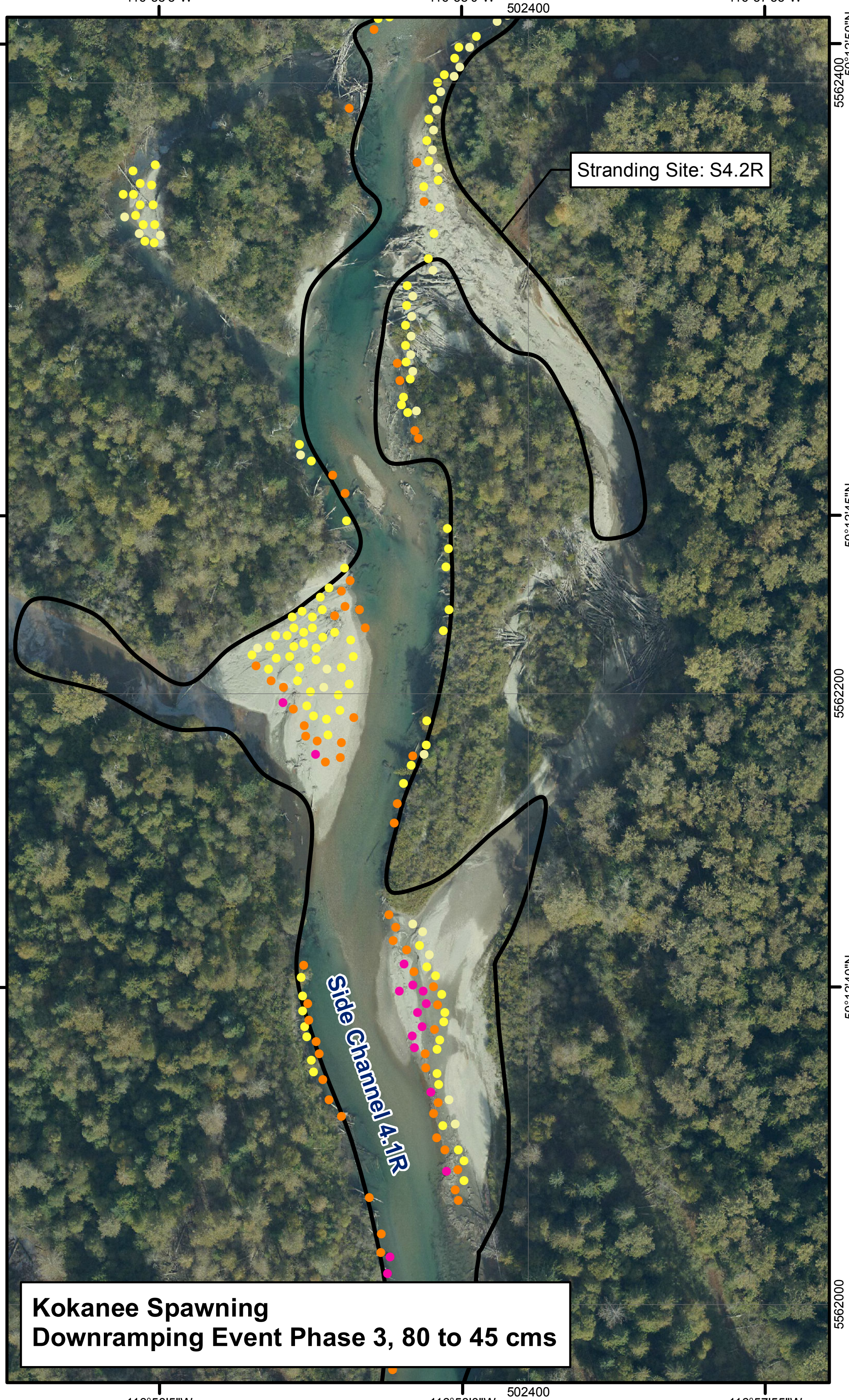
Legend
2012 Bathymetric Survey Points
2012 Topographic Survey Points
Model Extents
DEM Extents
117°0'0"W
116°57'30"W
116°55'0"W
500000
502500
505000
5567500
5565000
5562500
5560000
5557500
50°15'0"N
50°12'30"N
50°10'0"N
Duncan Lake
Lardeau River
Duncan River
Meadow Creek
Cooper Creek
Kootenay Lake
Survey Data Detail
bathymetric survey points
breakline
eroded bank
N
Study Area
Base Data Sources:
- October 2012 Orthophoto provided by BC Hydro.
- 2008 IKONOS background image from Esri.
- Reference map background image from Esri, National Geographic and NRCan.
Scale 1:30,000
0 500 1,000 2,000 Metres
0 1,000 2,000 4,000 6,000 Feet
Coordinate System: UTM Zone 11 Metres, NAD 83
DSGN MSN
IND CHKD
DFTG MSN
DFTG CHKD MSG
INSPD
REV
ACPT
DATE JUN 2013
nhc
BC hydro
2012 DEM Update
DDMMON#3 -
Lower Duncan River Hydraulic Model
DWG NO. CAD
Mapsheet 1
Fig 26



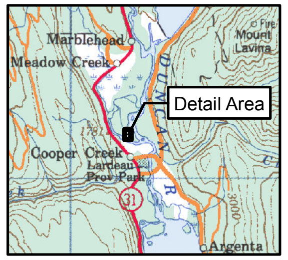
Kokanee Spawning
Downramping Event Phase 1, 196 to 140 cms



Kokanee Spawning
Downramping Event Phase 2, 140 to 80 cms



Kokanee Spawning
Downramping Event Phase 3, 80 to 45 cms



Legend

Change in Depth (m)

- -0.54 - -0.50
- -0.49 - -0.40
- -0.39 - -0.30
- -0.29 - -0.20
- -0.19 - -0.10
- -0.09 - 0.00

DDMMON16 Stranding Sites - Non-Index

Oct 2012 orthophotography supplied by BC Hydro.

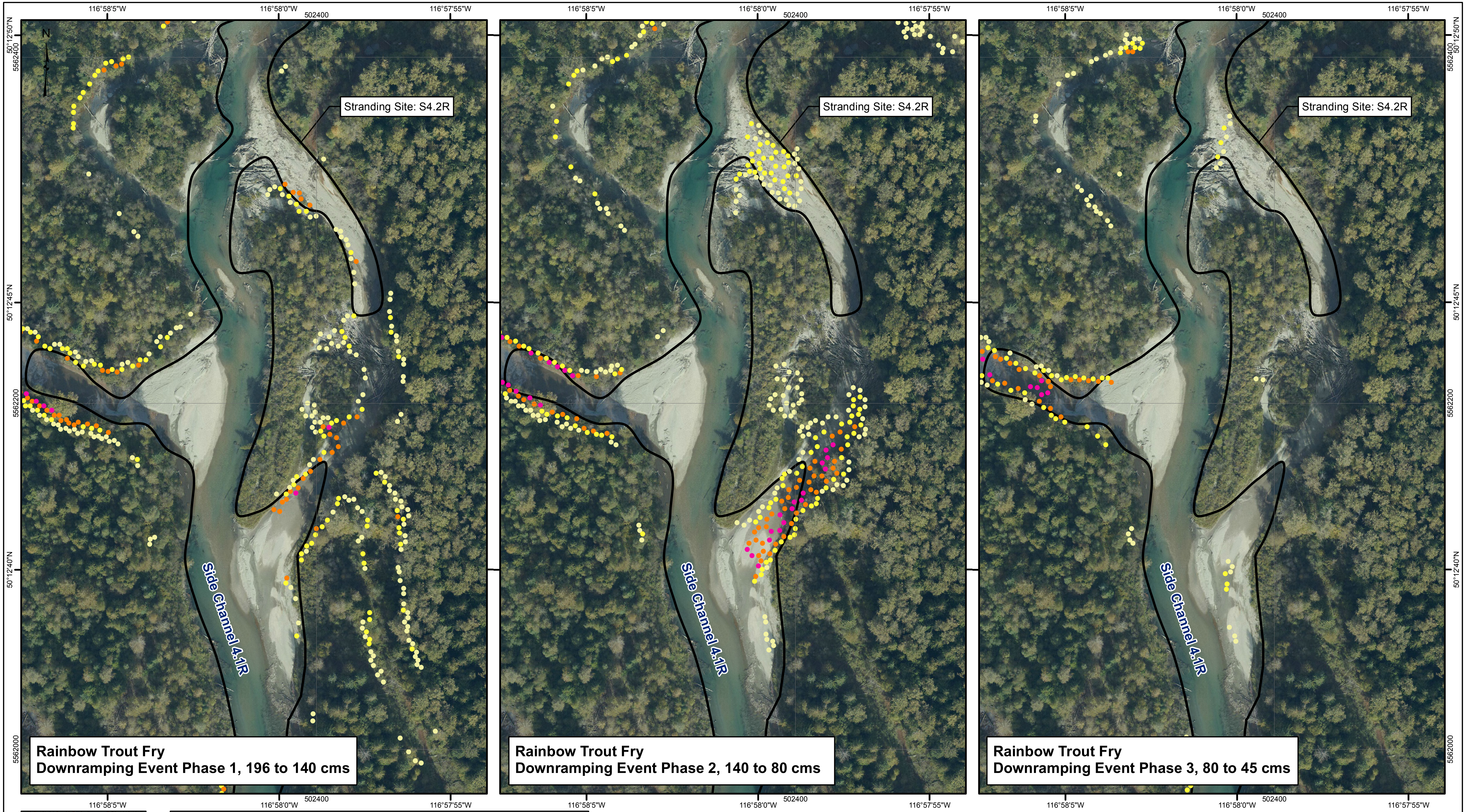
Scale 1:2,000

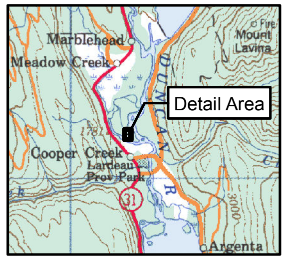
0 50 100 Metres

0 100 200 400 Feet

Coordinate System: UTM Zone 11 Metres, NAD 83

DSGN	MSN	nhc	BC hydro	
IND CHKD			Downramping Depth Changes	
DFTG	MSN		DDMMON#3 - Lower Duncan River Hydraulic Model	
DFTG CHKD	MSG			
INSPD				
REV				
ACPT		DATE 25 JUN 2013	DWG NO. CAD Mapsheet 1 of 2	Fig 27





Legend

Change in Depth (m)

- -0.54 - -0.50
- -0.49 - -0.40
- -0.39 - -0.30
- -0.29 - -0.20
- -0.19 - -0.10
- -0.09 - 0.00

DDMMON16 Stranding Sites - Non-Index

Oct 2012 orthophotography supplied by BC Hydro.

Scale 1:2,000

0 50 100 Metres

0 100 200 400 Feet

Coordinate System: UTM Zone 11 Metres, NAD 83

DSGN	MSN
IND CHKD	
DFTG	MSN
DFTG CHKD	MSG
INSPD	
REV	
ACPT	

nhc

BC hydro

Downramping Depth Changes

DDMMON#3 -
Lower Duncan River Hydraulic Model

DATE 25 JUN 2013

DWG NO. CAD

Mapsheet 1 of 2

Fig 28

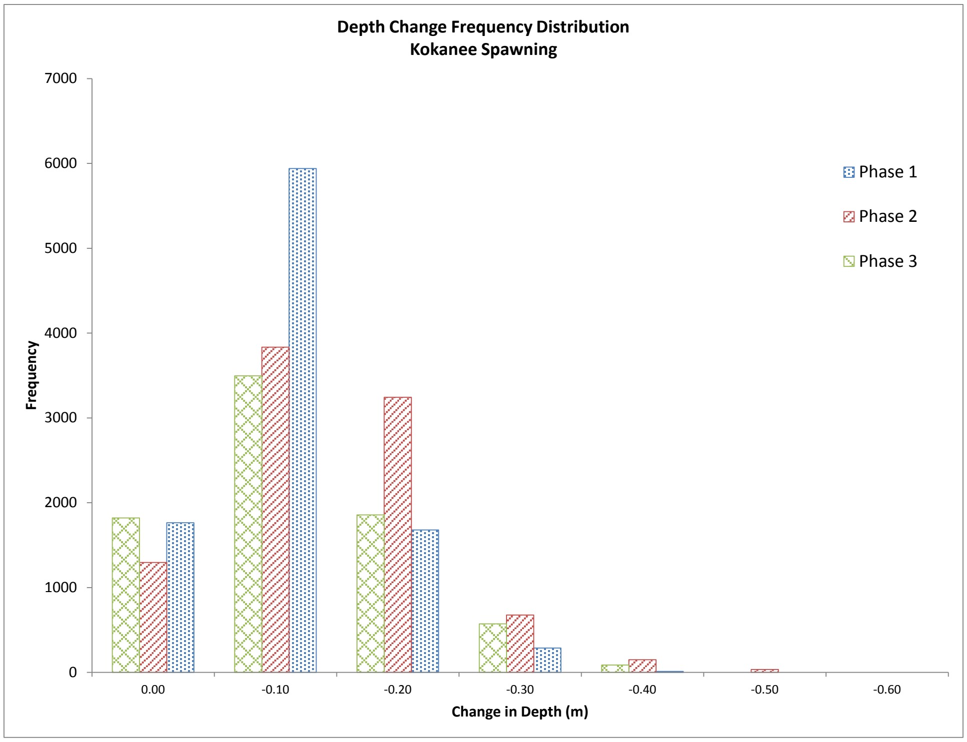


Figure 29. Frequency distribution of water depth change for kokanee spawning habitat.

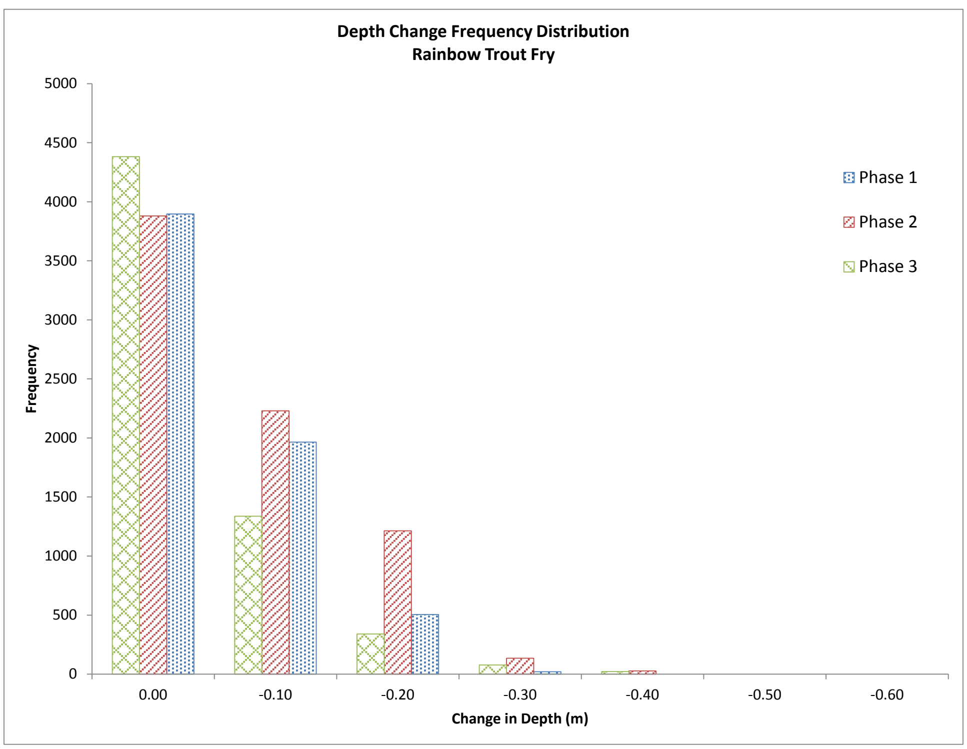


Figure 30. Frequency distribution of change in depth for rainbow trout fry rearing habitat.

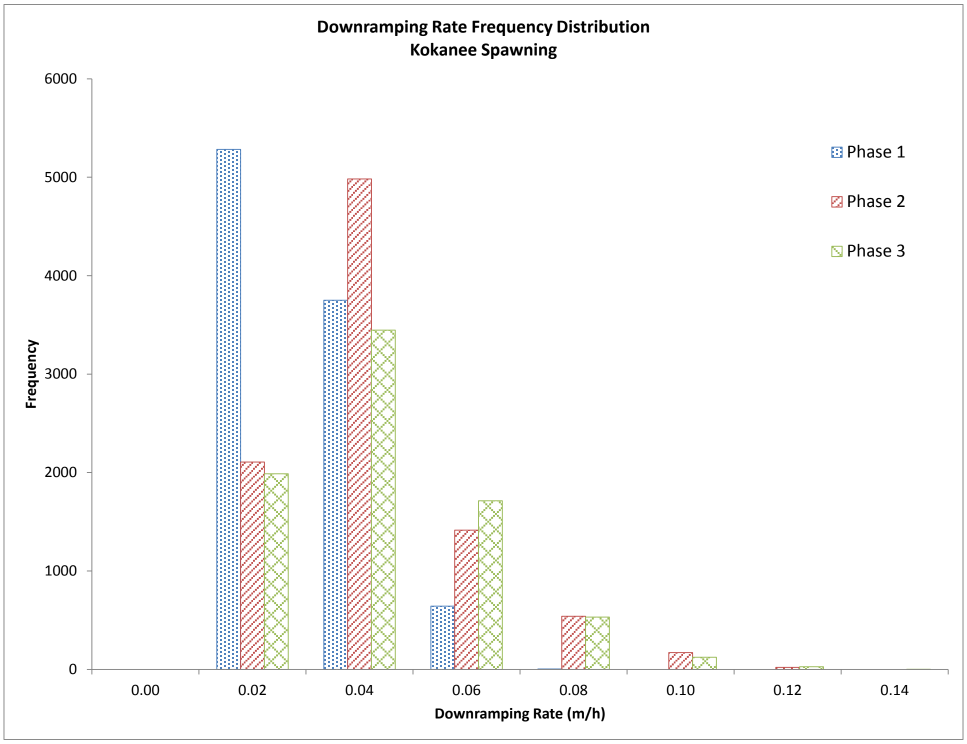


Figure 31. Frequency distribution of downramping rate for kokanee spawning habitat.

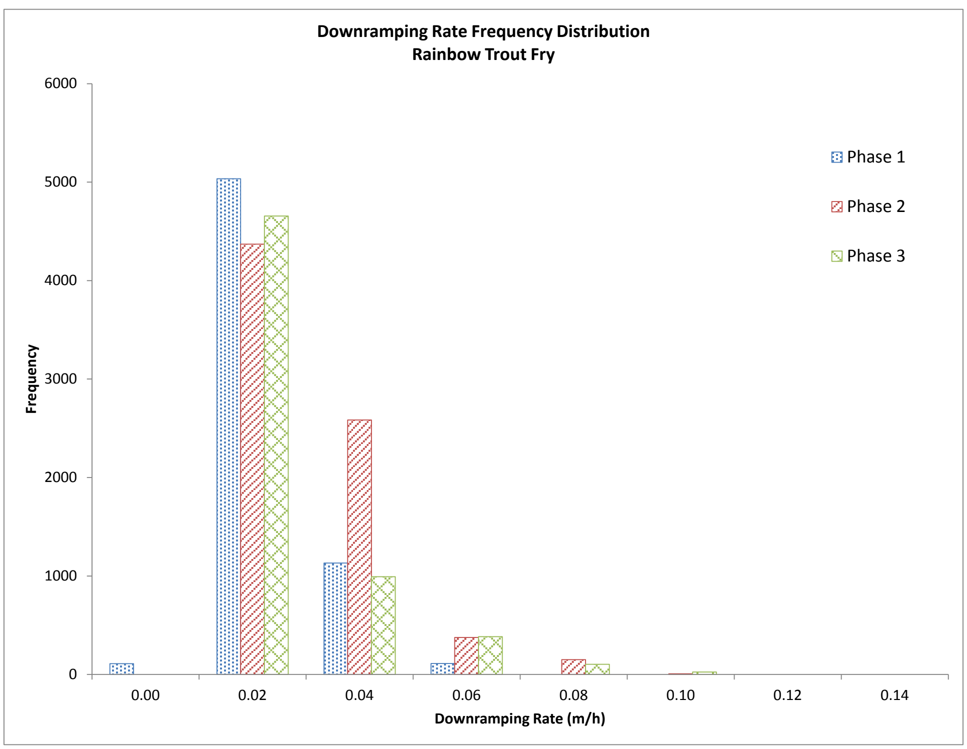


Figure 32. Frequency distribution of downramping rate for rainbow trout fry rearing habitat.

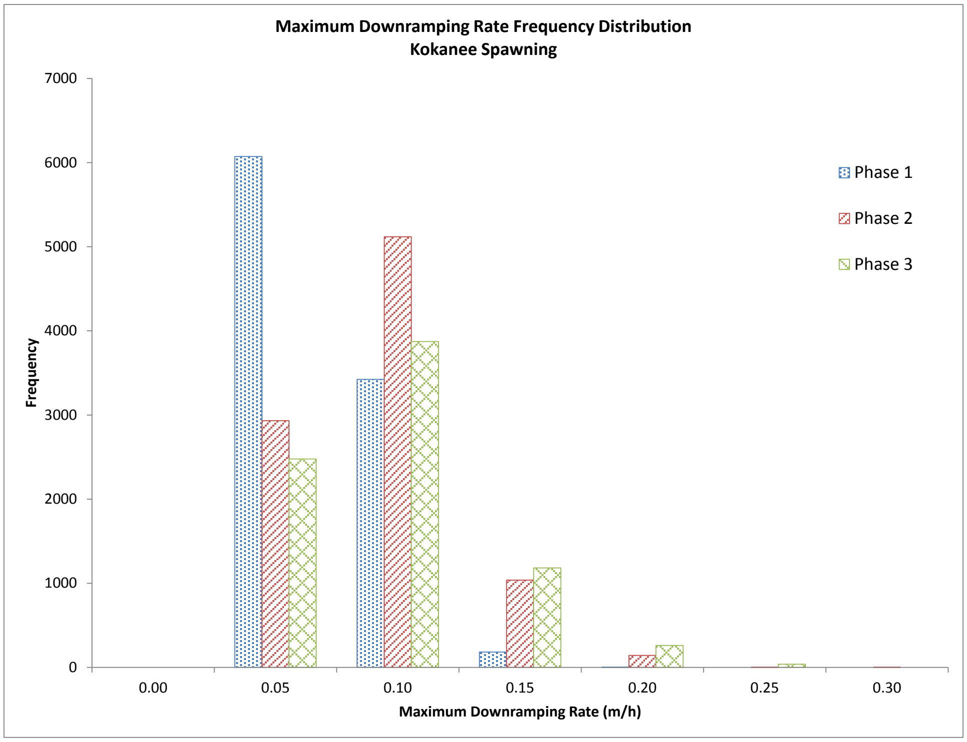


Figure 33. Frequency distribution of maximum downramping rate for kokanee spawning habitat.

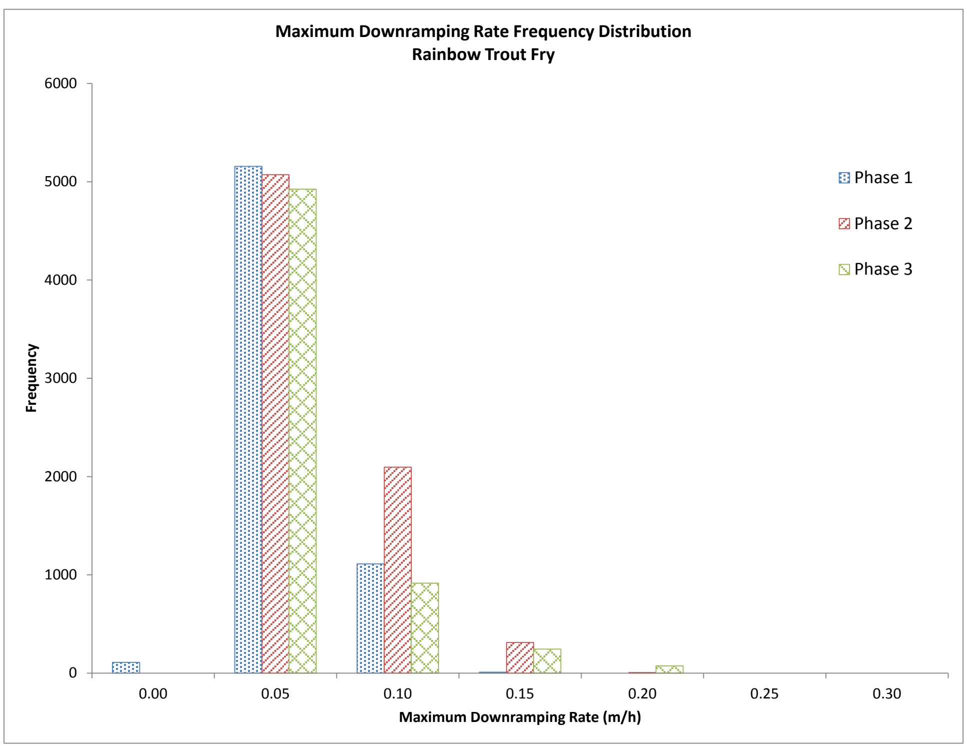


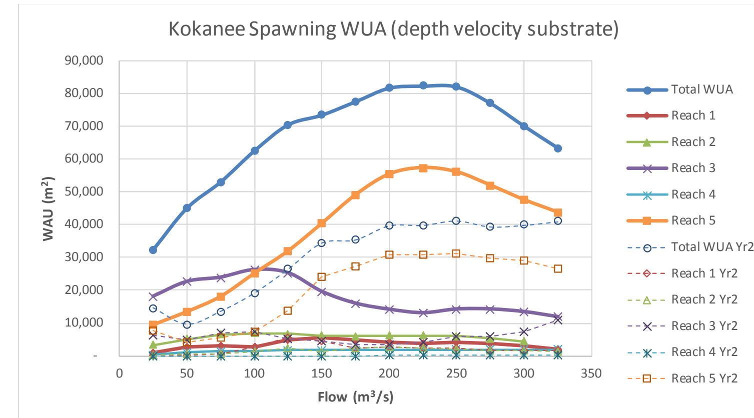
Figure 34. Frequency distribution of maximum downramping rate for rainbow trout fry rearing habitat.

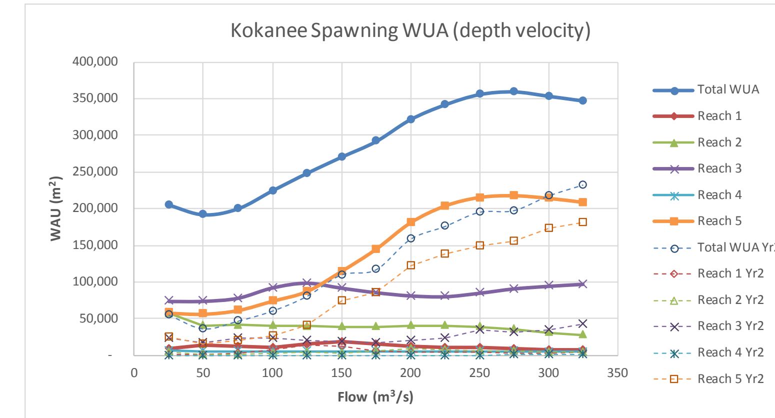
Appendix A Weighted Usable Area Estimates

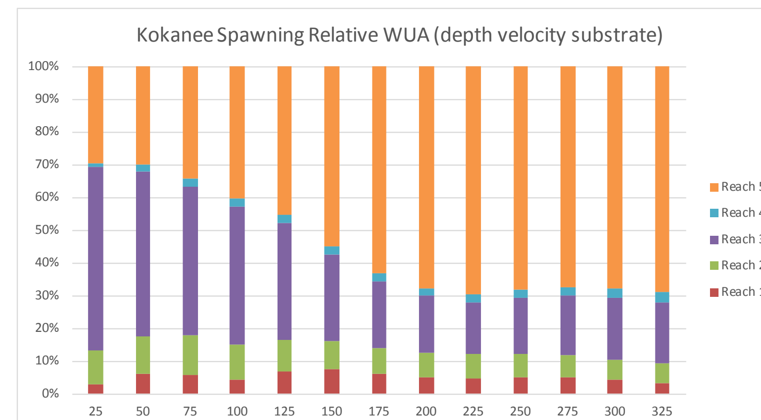
Total WUA (m^2)		Kokanee Spawning WUA (depth velocity substrate)						Kokanee Spawning WUA (depth velocity)					
Total Flow	**Wetted Area**	**Total WUA**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**	**Total WUA**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**
25	1,190,089	32,222	973	3,340	18,052	339	9,518	205,319	9,612	57,420	73,921	6,355	58,011
50	1,286,918	44,970	2,779	5,169	22,557	952	13,513	192,106	14,537	40,825	74,117	5,993	56,634
75	1,363,921	52,983	3,100	6,471	23,855	1,416	18,142	200,196	13,024	41,361	78,313	5,871	61,626
100	1,463,382	62,513	2,610	6,907	26,181	1,630	25,186	224,763	11,197	41,102	92,472	5,702	74,290
125	1,544,330	70,505	4,938	6,663	25,217	1,688	31,999	248,532	16,160	40,166	98,965	5,755	87,486
150	1,666,154	73,476	5,593	6,195	19,537	1,753	40,398	270,595	18,488	39,400	92,175	5,760	114,773
175	1,758,582	77,575	4,800	6,001	15,938	1,731	49,104	291,867	15,796	39,490	85,988	5,776	144,817
200	1,867,616	81,746	4,168	6,194	14,091	1,870	55,423	321,778	12,692	40,650	81,595	5,988	180,853
225	1,962,823	82,369	3,860	6,217	13,031	1,875	57,386	341,911	10,886	40,989	80,410	5,860	203,766
250	2,062,781	82,116	4,029	5,964	14,160	1,866	56,097	355,975	10,219	39,553	85,181	5,626	215,397
275	2,144,173	77,114	3,841	5,212	14,177	1,859	52,027	359,716	9,590	35,718	91,173	5,436	217,799
300	2,222,183	70,108	2,953	4,363	13,361	1,824	47,607	353,832	8,471	31,204	94,685	5,204	214,267
325	2,323,577	63,418	2,092	3,784	11,822	1,923	43,795	347,397	7,594	28,305	97,443	5,186	208,871

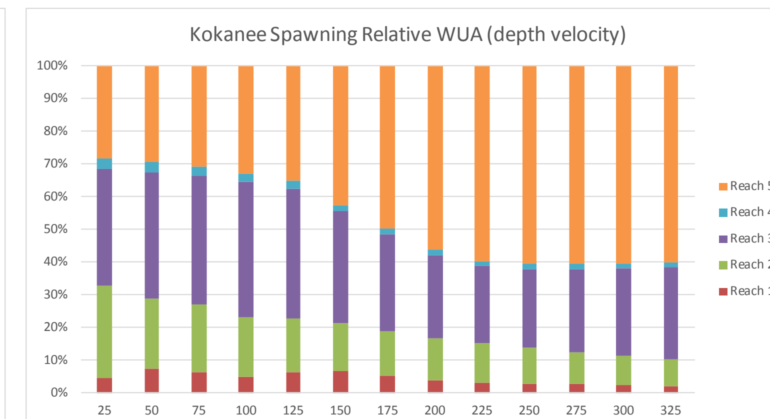
Relative WUA ($WUA\ m^2$ / $Total\ WUA\ m^2$)		Kokanee Spawning WUA / Total WUA (depth velocity substrate)						Kokanee Spawning WUA / Total WUA (depth velocity)					
Total Flow	**Wetted Area**	**Total WUA**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**	**Total WUA**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**
25	1,190,089	32,222	3%	10%	56%	1%	30%	205,319	5%	28%	36%	3%	28%
50	1,286,918	44,970	6%	11%	50%	2%	30%	192,106	8%	21%	39%	3%	29%
75	1,363,921	52,983	6%	12%	45%	3%	34%	200,196	7%	21%	39%	3%	31%
100	1,463,382	62,513	4%	11%	42%	3%	40%	224,763	5%	18%	41%	3%	33%
125	1,544,330	70,505	7%	9%	36%	2%	45%	248,532	7%	16%	40%	2%	35%
150	1,666,154	73,476	8%	8%	27%	2%	55%	270,595	7%	15%	34%	2%	42%
175	1,758,582	77,575	6%	8%	21%	2%	63%	291,867	5%	14%	29%	2%	50%
200	1,867,616	81,746	5%	8%	17%	2%	68%	321,778	4%	13%	25%	2%	56%
225	1,962,823	82,369	5%	8%	16%	2%	70%	341,911	3%	12%	24%	2%	60%
250	2,062,781	82,116	5%	7%	17%	2%	68%	355,975	3%	11%	24%	2%	61%
275	2,144,173	77,114	5%	7%	18%	2%	67%	359,716	3%	10%	25%	2%	61%
300	2,222,183	70,108	4%	6%	19%	3%	68%	353,832	2%	9%	27%	1%	61%
325	2,323,577	63,418	3%	6%	19%	3%	69%	347,397	2%	8%	28%	1%	60%

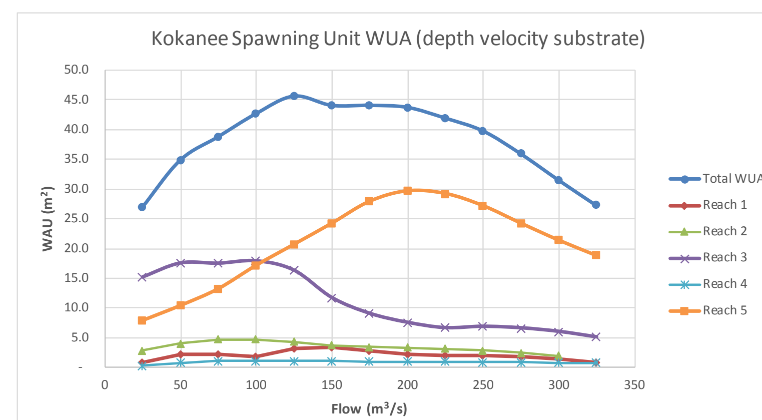
Unit WUA ($WUA\ m^2$ / $Area \times 10^3\ m^2$)		Kokanee Spawning WUA / Wetted Area (depth velocity substrate)						Kokanee Spawning WUA / Wetted Area (depth velocity)					
Total Flow	**Wetted Area**	**Total WUA**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**	**Total WUA**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**
25	1,190,089	27.1	0.8	2.8	15.2	0.3	8.0	172.5	8.1	48.2	62.1	5.3	48.7
50	1,286,918	34.9	2.2	4.0	17.5	0.7	10.5	149.3	11.3	31.7	57.6	4.7	44.0
75	1,363,921	38.8	2.3	4.7	17.5	1.0	13.3	146.8	9.5	30.3	57.4	4.3	45.2
100	1,463,382	42.7	1.8	4.7	17.9	1.1	17.2	153.6	7.7	28.1	63.2	3.9	50.8
125	1,544,330	45.7	3.2	4.3	16.3	1.1	20.7	160.9	10.5	26.0	64.1	3.7	56.6
150	1,666,154	44.1	3.4	3.7	11.7	1.1	24.2	162.4	11.1	23.6	55.3	3.5	68.9
175	1,758,582	44.1	2.7	3.4	9.1	1.0	27.9	166.0	9.0	22.5	48.9	3.3	82.3
200	1,867,616	43.8	2.2	3.3	7.5	1.0	29.7	172.3	6.8	21.8	43.7	3.2	96.8
225	1,962,823	42.0	2.0	3.2	6.6	1.0	29.2	174.2	5.5	20.9	41.0	3.0	103.8
250	2,062,781	39.8	2.0	2.9	6.9	0.9	27.2	172.6	5.0	19.2	41.3	2.7	104.4
275	2,144,173	36.0	1.8	2.4	6.6	0.9	24.3	167.8	4.5	16.7	42.5	2.5	101.6
300	2,222,183	31.5	1.3	2.0	6.0	0.8	21.4	159.2	3.8	14.0	42.6	2.3	96.4
325	2,323,577	27.3	0.9	1.6	5.1	0.8	18.8	149.5	3.3	12.2	41.9	2.2	89.9

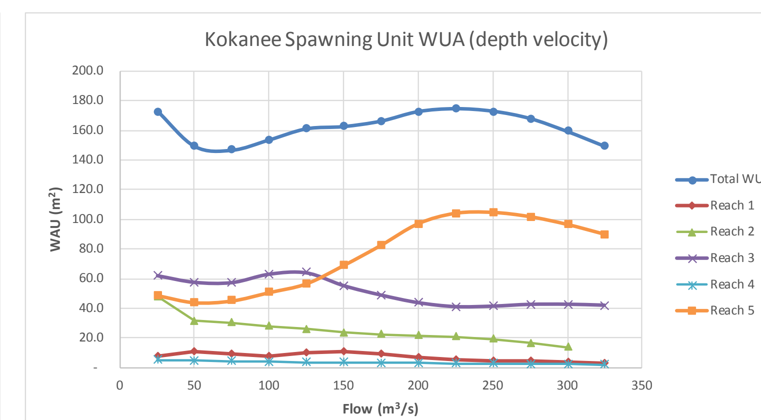




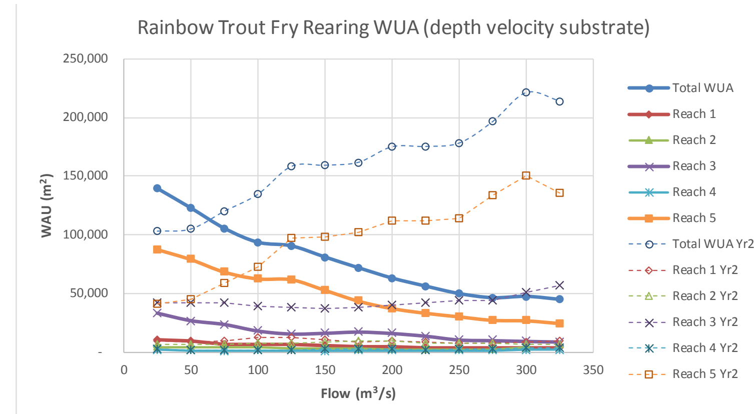


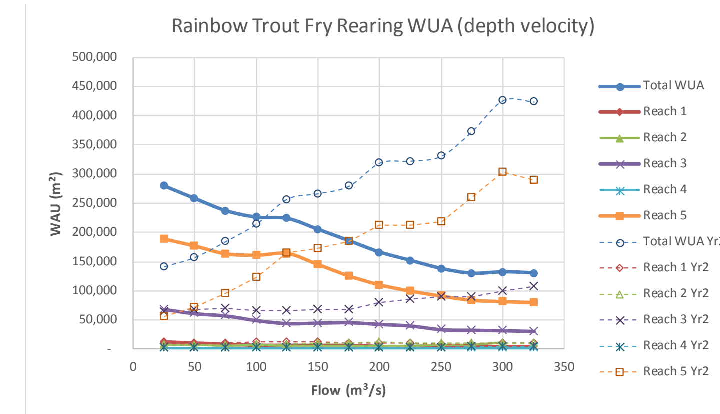




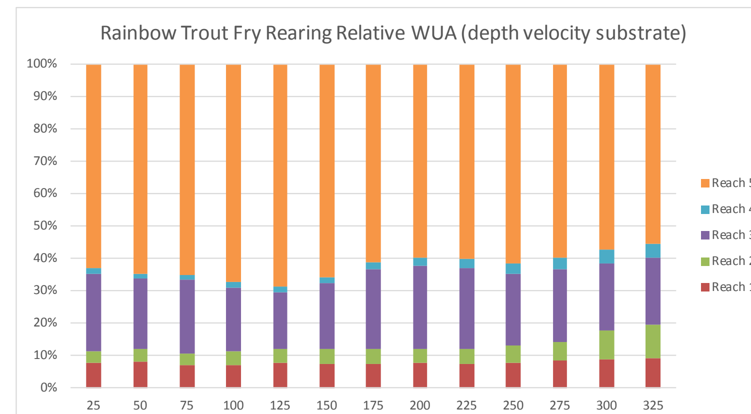


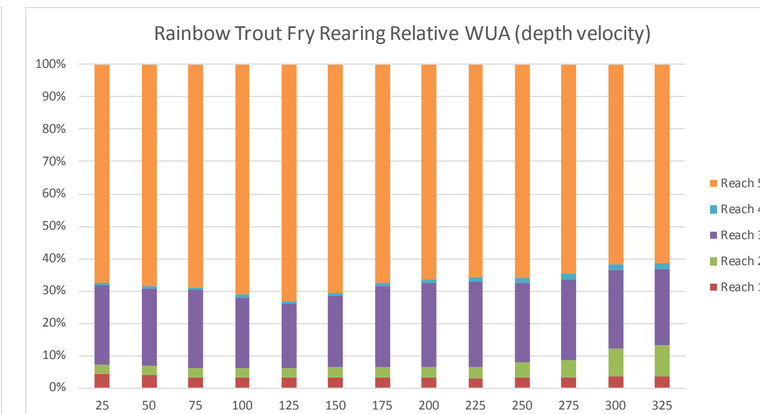
Total WUA (m^2)		Rainbow Trout Fry WUA (depth velocity substrate)						Rainbow Trout Fry WUA (depth velocity)					
Total Flow	**Wetted Area**	**Total WUA**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**	**Total WUA**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**
25	1,190,089	139,168	10,978	4,773	33,230	2,356	87,831	279,138	11,862	7,693	68,806	2,702	188,075
50	1,286,918	122,560	9,967	4,544	27,021	1,699	79,329	257,434	10,545	7,253	61,434	2,100	176,102
75	1,363,921	105,239	7,352	3,956	23,856	1,445	68,629	236,670	7,836	6,637	57,488	1,847	162,862
100	1,463,382	93,387	6,616	4,020	18,404	1,457	62,890	225,636	6,997	6,720	49,396	1,959	160,564
125	1,544,330	90,320	6,863	3,885	15,918	1,455	62,199	223,337	7,252	6,494	44,187	1,991	163,412
150	1,666,154	80,842	6,082	3,666	16,538	1,408	53,149	204,585	6,546	6,522	45,102	1,951	144,464
175	1,758,582	71,691	5,343	3,373	17,536	1,529	43,910	185,112	5,814	6,284	45,773	2,126	125,115
200	1,867,616	62,953	4,761	2,728	16,346	1,469	37,649	165,559	5,174	5,604	42,834	2,084	109,862
225	1,962,823	56,119	4,148	2,571	14,119	1,625	33,656	151,421	4,482	5,338	40,017	2,231	99,351
250	2,062,781	49,776	3,838	2,701	10,958	1,656	30,622	137,551	4,213	6,704	33,548	2,279	90,807
275	2,144,173	46,250	3,871	2,676	10,417	1,655	27,630	129,530	4,188	6,815	32,565	2,240	83,721
300	2,222,183	47,378	4,129	4,284	9,796	1,957	27,212	132,060	4,626	11,589	31,770	2,529	81,547
325	2,323,577	44,838	4,111	4,600	9,269	1,946	24,912	130,205	4,538	12,668	30,566	2,550	79,883





Relative WUA (WUA m^2 / Total WUA m^2)		Rainbow Trout Fry WUA / Total WUA (depth velocity substrate)						Rainbow Trout Fry WUA / Total WUA (depth velocity)					
Total Flow	**Wetted Area**	**Total WUA**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**	**Total WUA**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**
25	1,190,089	139,168	8%	3%	24%	2%	63%	279,138	4%	3%	25%	1%	67%
50	1,286,918	122,560	8%	4%	22%	1%	65%	257,434	4%	3%	24%	1%	68%
75	1,363,921	105,239	7%	4%	23%	1%	65%	236,670	3%	3%	24%	1%	69%
100	1,463,382	93,387	7%	4%	20%	2%	67%	225,636	3%	3%	22%	1%	71%
125	1,544,330	90,320	8%	4%	18%	2%	69%	223,337	3%	3%	20%	1%	73%
150	1,666,154	80,842	8%	5%	20%	2%	66%	204,585	3%	3%	22%	1%	71%
175	1,758,582	71,691	7%	5%	24%	2%	61%	185,112	3%	3%	25%	1%	68%
200	1,867,616	62,953	8%	4%	26%	2%	60%	165,559	3%	3%	26%	1%	66%
225	1,962,823	56,119	7%	5%	25%	3%	60%	151,421	3%	4%	26%	1%	66%
250	2,062,781	49,776	8%	5%	22%	3%	62%	137,551	3%	5%	24%	2%	66%
275	2,144,173	46,250	8%	6%	23%	4%	60%	129,530	3%	5%	25%	2%	65%
300	2,222,183	47,378	9%	9%	21%	4%	57%	132,060	4%	9%	24%	2%	62%
325	2,323,577	44,838	9%	10%	21%	4%	56%	130,205	3%	10%	23%	2%	61%





Unit WUA (WUA m^2 / Area x 10^3 m^2)		Rainbow Trout Fry WUA / Wetted Area (depth velocity substrate)						Rainbow Trout Fry WUA / Wetted Area (depth velocity)					
Total Flow	**Wetted Area**	**Total WUA**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**	**Total WUA**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Reach 5**
25	1,190,089	116.9	9.2	4.0	27.9	2.0	73.8	234.6	10.0	6.5	57.8	2.3	158.0
50	1,286,918	95.2	7.7	3.5	21.0	1.3	61.6	200.0	8.2	5.6	47.7	1.6	136.8
75	1,363,921	77.2	5.4	2.9	17.5	1.1	50.3	173.5	5.7	4.9	42.1	1.4	119.4
100	1,463,382	63.8	4.5	2.7	12.6	1.0	43.0	154.2	4.8	4.6	33.8	1.3	109.7
125	1,544,330	58.5	4.4	2.5	10.3	0.9	40.3	144.6	4.7	4.2	28.6	1.3	105.8
150	1,666,154	48.5	3.7	2.2	9.9	0.8	31.9	122.8	3.9	3.9	27.1	1.2	86.7
175	1,758,582	40.8	3.0	1.9	10.0	0.9	25.0	105.3	3.3	3.6	26.0	1.2	71.1
200	1,867,616	33.7	2.5	1.5	8.8	0.8	20.2	88.6	2.8	3.0	22.9	1.1	58.8
225	1,962,823	28.6	2.1	1.3	7.2	0.8	17.1	77.1	2.3	2.7	20.4	1.1	50.6
250	2,062,781	24.1	1.9	1.3	5.3	0.8	14.8	66.7	2.0	3.2	16.3	1.1	44.0
275	2,144,173	21.6	1.8	1.2	4.9	0.8	12.9	60.4	2.0	3.2	15.2	1.0	39.0
300	2,222,183	21.3	1.9	1.9	4.4	0.9	12.2	59.4	2.1	5.2	14.3	1.1	36.7
325	2,323,577	19.3	1.8	2.0	4.0	0.8	10.7	56.0	2.0	5.5	13.2	1.1	34.4