Duncan Dam Water Use Plan

Monitoring Program Terms of Reference

- **DDMMON#9 Lower Duncan River Mosquito Monitoring and Management Plan Development**

May 13, 2013

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9.1 MONITORING PROGRAM RATIONALE

9.1.1 Background

Mosquitoes are common to the interior of BC. In some years particular species of mosquitoes can be a considerable nuisance to humans and livestock, in that their main food source are the blood of humans and animals. With the potential arrival of West Nile virus (WNv) in BC, there is now heightened public awareness of mosquitoes generally. Of the 50 species of mosquitoes found in BC, only some show a preference for human blood meals and/or are potential carriers of West Nile virus[1]. The two species that are most likely to be carriers of the virus, Culex tarsalis and Culex pipiens, are not considered to be ‘nuisance’ species.

Larvae of Culex tarslais and Culex pipiens are commonly prevalent in man-made environments such as ditches and drains. The virus is maintained in bird reservoirs and mosquitoes that bite both birds and humans are required to amplify transmission. Certain groups are more prone to contracting the disease, such as elderly people with compromised immune systems. The virus is most commonly detected in humans late in the mosquito season as adult Culex mosquitoes seek indoor overwintering sites between August and October. The role of potential nuisance bridge vectors (epizootic), such as Aedes vexans, in the spread of the virus is not believed to be significant in other Canadian provinces, such as Ontario (Dr. Fiona Hunter, Brock University, pers. comm.)

Construction on the Duncan Dam began in 1965 and the facility became operational in 1967. The 40 m high earth-fill dam acts as a storage reservoir for a drainage basin of some 2,400 km2 and receives the largest inflows in May and June from snowmelt. Inflow from precipitation is generally heaviest during the July to October (or later) period. The dam is operated under the terms of the Columbia River Treaty whereby full pool is ideally achieved in July. The Duncan Reservoir is 45 km long and holds 1,727 million m3 of storage with an average drawdown of 30m. Because of the restrictions of the treaty it is unusual for large volumes of water to be discharged from the dam between May and early- to mid-July. Thus, there is some uncertainty if discharges from the dam have very much, if any, impact on the major mosquito-hatching season that occurs commonly in this area, and across wetlands at similar latitudes of most of North America, between May and June. The unregulated Lardeau River upstream of the dam, combined with the Meadow Creek discharges, causes considerable flooding of low-lying grassland in the Meadow Creek area at this time. One fecund and extremely aggressive ‘nuisance’ species, Aedes vexans, is ideally adapted to this habitat and Meadow Creek and the surrounding areas are well known as a major source of larval infestation of this genus in the spring (DGRA – 1999).

The Upper Duncan River floodplain at its confluence with Duncan Reservoir and the Lower Duncan River at its confluence with Kootenay Lake are two known sources of *Aedes* mosquito production. There are also significant opportunities for production in the Lower Duncan River floodplain adjacent to Meadow Creek, Hamill Creek and Cooper Creek tributaries. Kootenay Lake levels generally reach a peak in mid-June and then

[1] In 2003, the Interior Health Authority initiated a corvid (crow and raven) and mosquito surveillance program to test for West Nile virus (WNv) within their jurisdiction (Revelstoke/Electoral Area B Mosquito Control Program handout). Although the virus has yet to be detected in BC, it was detected in Alberta and Washington in 2005 and surveillance for the virus in BC continues.

drops down to a plateau by the beginning of September. The initial drop can be quite sudden and leave large areas of shallow water exposed to warm summer temperatures, often leading to a major mosquito outbreak in the Lower Duncan River area. Similarly for the Lower Duncan River floodplain, where dam discharges or natural flow recessions can lead to untimely occurrences of optimal mosquito habitat conditions.

The Duncan Dam Water Use Plan (WUP) consultative process was initiated in 2001 with the objective of gaining stakeholder consensus on the operation of the Duncan Dam for a set period following the conclusion of the WUP process. To do so, several operating alternatives were evaluated against performance measures representing stakeholder interests. These performance measures integrated assumptions and knowledge of processes governing a particular interest into their interaction with operations of river and reservoir levels. The Duncan Dam WUP Consultative Committee (CC) was particularly interested in the effect operations had on nuisance mosquito production in the Lower Duncan River floodplain[2].

A study of the influence of the Duncan Dam on mosquito production of the Lower Duncan Floodplain was carried out in 2002 (Acroloxus Wetlands Consultancy (AWC), 2002) to establish the potential causes behind the reported extension in the duration of the mosquito-hatching season in the area. The study focused on the potential influence of the Duncan Dam and how operations might influence mosquito-breeding opportunities. The study linked flooding regime, vegetation type and the potential breeding grounds of different mosquito species. The vegetation was classified and mapped over the Lower Duncan floodplain and adult and larval mosquitoes were sampled in a number of study areas with different vegetation types and at a range of different proximities from the Duncan Dam. The study focused its study sites in marshes, swamps and fens in the Lower Duncan River floodplain because it was anticipated that these might provide habitat for second-generation hatches and they could be affected by Lower Duncan River flows.

The study resulted in the following key conclusions:

- Larvae Monitoring: The larvae found in the study sites were mainly of the *Culex, Culiseta* and *Anopholes* genera, however the adult mosquitoes recorded were predominantly of the *Aedes* variety. This could be explained by several factors:
    - that *Aedes* species are known to be strong flyers and may have migrated considerable distances from their breeding grounds,
    - that the study period for the report was too short to detect *Aedes* larvae,
    - that the mosquito abatement program had already treated potential breeding sites, and, most importantly,
    - that suitable habitats for *Aedes* breeding sites along the river banks and stream-lake interfaces (identified by integrating published information with maps of the Lower Duncan floodplain) were not properly sampled for the 2002 study which concentrated instead on swamps and marshy areas.
- Operations Analysis: The first and most significant hatch of *Aedes* mosquitoes was found to occur during late May and early June when discharges from the Duncan Dam are usually negligible. However, once full pool is reached in July, high volume dam discharges may lead to flooding in some areas due to a combination of factors that affect groundwater, overbank flow and cause back flooding in the Meadow

[2] During the Water Use Planning process, mosquito issues above Duncan Dam (e.g. the Upper Duncan River floodplain) were not considered due to the lack of human use in the area, and the belief that the distance between areas of potential mosquito production and areas of human habitation were too large to be of impact.

Creek area. An important finding of the study was that if above average dam discharges do occur June to August, the river water can spill over as surface flooding into the adjacent ponds and marshes. This can cause backfilling in Meadow Creek and side channels and lead to increased groundwater levels, which can lead to inundation of low lying areas such as those classified as Low Bench. In 2002, such an exceptional event did occur in which the Duncan flow peaked at approximately 500 m^3/sec in mid-June, which caused Meadow Creek to backfill just as flood levels were receding from the Lardeau freshet. High dam discharges may also have caused re-flooding of Low Bench areas around the head of Kootenay Lake

- Hatching Behaviour: Renewed flooding stimulates more eggs to hatch on each new flood but is unlikely to produce the high densities of larvae found in the first hatch unless new areas are flooded that were not inundated earlier in the year. Reflooding in any one year can have a delayed effect on mosquito populations by providing new opportunities for egg laying, which may lead to increased larval production in future high-flood years. The 2002 study did not persist long enough to test this hypothesis.

The Mosquito Nuisance Performance Measure (PM) was designed according to the study findings, using the following parameters to determine the amount of productive mosquito habitat in the Lower Duncan floodplain:

- Timing: the PM reports the area of flooded mosquito habitat between 1 July to 31 August – the period of known mosquito productivity and flow management requirements;
- Area: Areas identified in the AWC (2002) study were integrated into the hydraulic model prepared for the DDM WUP (Klohn Crippen 2003) to develop a relationship between river flow and mosquito habitat flooding;
- Hatching: the model assumed that mosquito habitats initially flooded 1 July to 31 August would be 100% productive and that those habitats would be 50% productive during the second flooding over this period, and only 5% productive in third and consecutive flooding events (i.e. that the productivity of mosquito habitats seen within each year diminish with increased flooding).

The total area flooded was calculated each year over the model period. In general, the results of the performance measure tracked closely with the flood-risk PM, demonstrating that mosquito habitat flooding is reduced when general flooding is managed effectively.

Since the conclusion of the AWC (2002) study, several study improvements have been identified toward refining the Mosquito Nuisance PM and the mosquito management program on the Lower Duncan River:

- Species-specific research - to determine the precise requirements, distribution and habitat use of a particular species life cycle needs to be investigated over an extended period of time. Predator-prey relationships also commonly operate on alternating interannual cycles (this will not be part of the scope of this study).
- Hydrologic analysis: hydrologic and typographic questions, such as the effect of river flows and dam discharges on groundwater levels in different marshes, are complex and require extensive investigation over a longer review period to resolve.
- Soil effects: The saturation level of the soil may be particularly important and high groundwater levels caused by flooding in the previous year might be significant.
- Kootenay Lake effects: Backflooding and dewatering of the Lower Duncan River at the confluence with Kootenay Lake caused by surcharge and drawdown respectively may also be a contributing factor to mosquito production.

- Environmental effects: Stochastic events, such as storms or major downpours and temperature changes might complicate interpretation of results and the abatement program must be considered in the study of natural mosquito populations in this area.
- Abatement program effectiveness: there are unknown interactions between mosquito production through hydrologic events and control through the abatement program that need ongoing study to refine control techniques effectively and efficiently.

An additional DDM WUP monitoring study being conducted outside of these study terms will provide a detailed hydraulic model for the Lower Duncan River floodplain (DDMMON#3 – Lower Duncan River Hydraulic Model Development). Mosquito production areas defined and typed by vegetation in AWC (2002) can be integrated into the model to get a definitive relationship between mosquito habitat and river flow.

To substantiate the conclusions drawn from the AWC 2002 study it was recommended that:

1. Data gaps should be addressed in a long term study program to improve understanding of mosquito production in the Lower Duncan River floodplain and to develop a management plan with specific recommendations for operations of the Duncan Dam and the ongoing abatement programme in the first year.
2. After the first year continue to update the management plan annually based on ongoing activities in the watershed.

Completing this study will result in partial fulfillment of requirements ordered by British Columbia's comptroller of Water Rights, specifically clause 6(e) of BC Hydro's Duncan Dam Conditional Water License 27027.

9.1.2 Management Questions

This monitoring program is designed to address the following management questions as they pertain to mosquito production in the Duncan Floodplain area.

1. How may the volume of discharges from the Duncan Dam affect production of *Aedes* mosquitoes through inundation of Low Bench areas in the Lower Duncan and Lardeau floodplains from May to September?
2. Do groundwater variations in different areas at different dam discharges relate to flooding regimes, vegetation types and mosquito production?
3. How widely do adult mosquitoes disperse from their breeding grounds and how significant is the Duncan Dam in creating adult mosquito nuisance to residents of the Lower Duncan Floodplain? Can we better predict the potential nuisance mosquito production associated with vegetation types?
4. Is the current Performance Measure effective at predicting the potential production of late outbreaks of nuisance mosquitoes related to Duncan Dam operations?
5. Can we more accurately predict when outbreaks of nuisance mosquitoes are most likely to occur given particular environmental and climatic conditions?
6. What can the current mosquito abatement program (managed by the RDCK) do to improve its effectiveness based on the information collected in this program
7. Is the operation of the Duncan Dam linked to production of high competence West Nile virus vector mosquitoes?

9.1.3 Management Hypothesis

Two primary hypotheses will be tested in this monitoring program.

H01: Nuisance mosquito productivity is correlated to environmental and stochastic factors, such as precipitation and temperature, and to the frequency and amplitude of flooding.

This hypothesis will be refuted where theorized correlations cannot be statistically validated.

H02: Existing nuisance and West Nile virus mosquito management programs on the Lower Duncan River can be improved through increased understanding of drivers to mosquito productivity.

This hypothesis will be refuted where no reduction in monitored levels of mosquito production are documented following the implementation of management initiatives recommended in this monitoring program on an annual basis. This assessment will consider other environmental factors, including local natural inflows, temperature and previous outbreaks, that may influence current results.

9.1.4 Key Water Use Decision Affected

The results from this monitoring program will be used to refine the design of the Mosquito Nuisance Performance Measure used during the Duncan Dam Water Use Plan (DDM WUP) process to assess the impacts of operations on mosquito production. During the review period, these results will be applied where applicable to the improvement of the mosquito abatement program managed by the Regional District of the Central Kootenay area. At the conclusion of the DDM WUP review period, this refined performance measure may be applied in decision processes towards mitigating operations that potentially exacerbate mosquito nuisance in the Lower Duncan River and Lardeau River floodplains, or, where applicable, information will be provided to Fortis BC for consideration in their operations of Kootenay Lake.

9.2 MONITORING PROGRAM PROPOSAL

9.2.1 Objectives and Scope

The three objectives of this monitoring program are:

- To refine the mosquito nuisance performance measure originally designed for the DDM WUP by improving the resolution of the flow-habitat flooding relationship and increasing the understanding of mosquito production drivers and migration in the lower Duncan River floodplain;
- To provide meaningful recommendations towards improving the effectiveness of the current mosquito abatement program; and
- To provide meaningful recommendations towards identifying and addressing the potential threat of West Nile virus.

In general, the objective of this monitoring program will be to determine whether there are water management strategies and operating alternatives that could be implemented to minimize potential impacts on nuisance and West Nile vector mosquito production in the Duncan floodplain.

9.2.1.1 Study Area

The study area consists of the Lower Duncan River floodplain from the Duncan Dam to the Kootenay Lake confluence and all portions of tributaries between that are influenced hydrologically by Duncan Dam operations (Figure 9-1). Vegetation classifications summarized in AWC (2002) will provide the basis for future assessments, and will be transferred to any updated orthophotos available at the time of survey. The hydraulic modeling conducted during the WUP (Klohn Crippen 2003) will be updated in a separate study over the review period and will be integrated into the flow-habitat relationships integral to the Mosquito Nuisance PM. Study areas above the Duncan Dam will be investigated briefly in this study but is not considered the focus area of study.

Sites will be identified by using existing classification of vegetation types from the 2002 study as a proxy for distribution of different species of mosquitoes (Table 9-1). The 2002 study showed that wetland vegetation classifications appeared to be closely matched to flooding regimes and specific mosquito production, probably because shade provision of different plants affects water temperature, which is known to be a significant factor in the choice of egg-laying locations by the females of different mosquito species. The Low Bench areas were relatively easily defined from 1:20,000 orthophotos at the time. Any recent orthophoto images or new Digital Elevation Model (DEM) data will be used to help refine the existing delineation of the Low Bench areas and to ensure all areas in the Lardeau floodplain that might be inundated by back flooding of Meadow Creek are included in the study. As indicated in the tasks below, all study sites will be selected in coordination with staff from the Lower Duncan River mosquito abatement program.

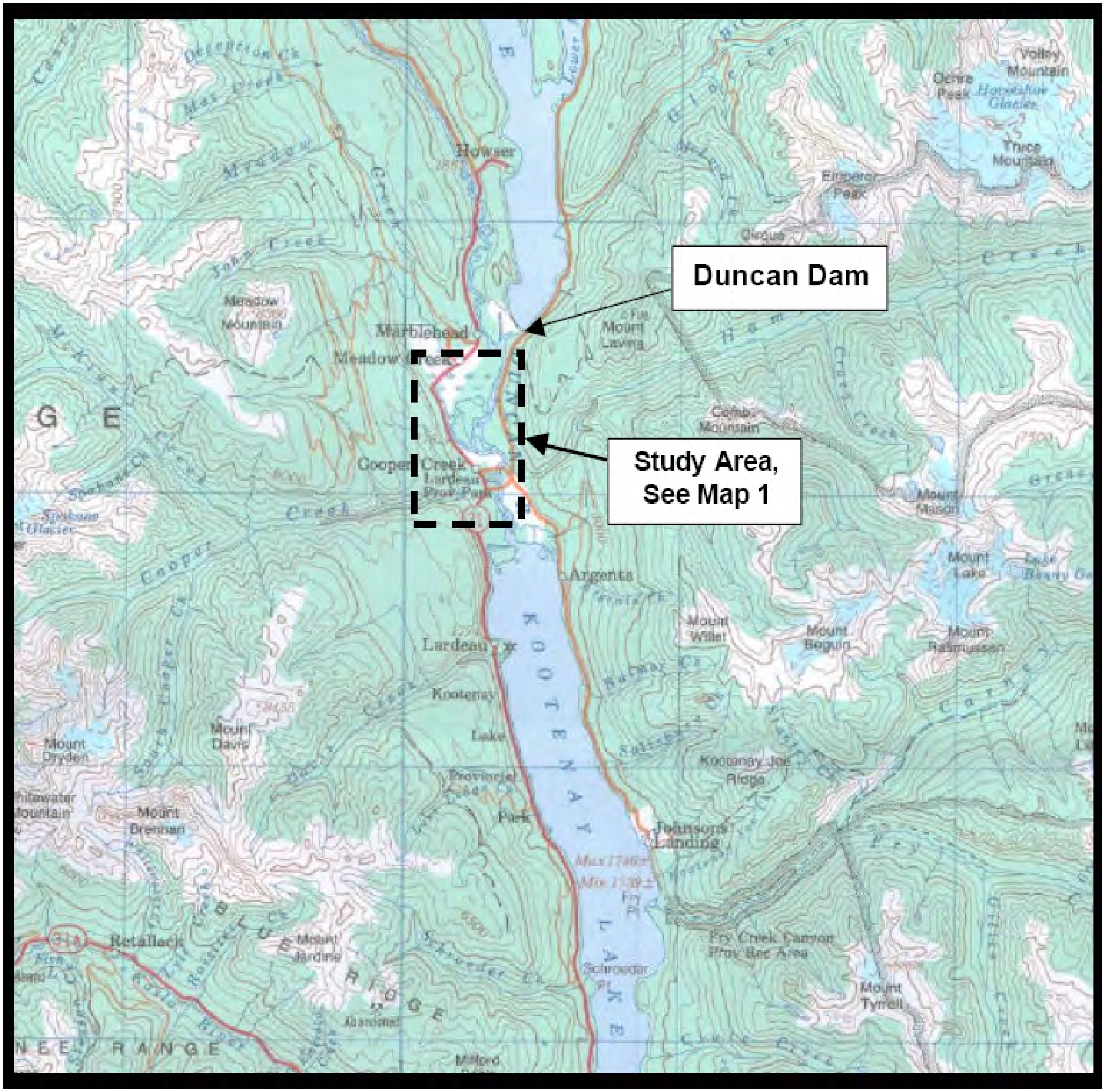

Figure Error! No text of specified style in document.**-1: Map of the Kootenay region showing location of Duncan Dam and boundaries of the 2002 AWC study area.**

Table Error! No text of specified style in document.**-1: The projected breeding habitats of mosquito species found in the Lower Duncan Floodplain (based on field data and Belton 1983). See Table 3-4 in AWC 2002**

Vegetation Classification Code	A1a	A1b	A1c	A1d	A1e	A1x	A2	A3	B1	B2	B4	B5	C1	E1	E2	E3	E4	E5	E6
Mosquito Species Sample Sites >	JS/BS	OC	LD		MC	CX			BS		LR								
Aedes campestris																			X
Aedes canadensis									X		X			X	X	X	X	X	
Aedes cinereus			X						X		X			X	X	X	X	X	
*Aedes communis**		X												X	X			X	
Aedes euedes											X								
Aedes excrucians	X		X											X					X
Aedes increpitus											X			X					X
*Aedes intrudens**		X																	X
Aedes pullatus																	X		
Aedes sierrensis						X					X				X			X	
*Aedes sticticus**						X								X	X			X	
Aedes vexans														X					X
* Black-legged *Aedes* Group		X				X								X	X			X	X
Anopheles earlei	X																		X
Anopheles punctipennis or freeborni			X																
Culiseta alaskaensis	X	X	X	X	X				X										
Culiseta impatiens			X																
Culiseta incidens	X								X										
Culiseta inornata	X	X	X		X				X		X				X		X	X	
Culiseta minnesotae	X			X			X												
Culex tarsalis		X	X																X
Culex territans	X	X	X	X	X				X	X		X							
Mansonia perturbans							X												

9.2.1.2 Study Duration

Due to implementation logistics, this study program is proposed to start in Year 2 of the review period, and will wrap up in Year 11. All study timing referenced in the tasks below are stated in terms of their implementation within the review period. The schedule is appended below (Table **Error! No text of specified style in document.**-2).

Low Bench surveys will be carried out in Years 2 and 3 of the review period, followed by a reduced survey every second year after that. The number of survey periods, and the frequency of larval surveillance may be changed to accommodate study requirements to answer management questions. At the end of each study year, the consulting biologist will recommend either a reduction or increase in effort dictated by the status of the study, the time remaining in the study program, and the data quality retained to date. BC Hydro will consider recommendations from the Mosquito Advisory Committee and the consulting biologist when assessing the amount of effort required to answer the management questions. All field work will be undertaken between May and September, with timing and/or environmental circumstances to remain consistent across the review period. A mosquito management plan that considers the current mosquito abatement program, Duncan Dam operations and the trends observed in mosquito production will be produced after studies in Years 2, 7 and 11.

9.2.1.3 Timing of Surveys

Field surveys will be carried out monthly and/or in coordination with both extreme water level changes between May and September and ongoing mosquito abatement program activities. To this end, survey program biologists will be required to communicate regularly with plant operators and abatement program staff to forecast water levels and map out abatement program treatment sites respectively. Operations staff will be asked to give advanced warning of upcoming events so that the surveys can be undertaken at these key times when there is most likely to be extensive flooding of low lying areas.

Larval Surveillance in the Low Bench Duncan Dam area and in residential areas within 10 miles of the Duncan Dam will be conducted 4 times on a monthly basis between May and September in Years 2 and 3.[3] In Years 5, 7, 9 and 11 the surveys will be reduced to twice a year and should take only 12 days in total to complete for a team of four.

9.2.2 Approach

The approach for this study program is divided into five tasks:

1. Refine existing vegetation mapping from updated orthophoto mapping for the lower Duncan River floodplain Data for this task is being provided in a separate monitoring study (DDMMON#8 – Lower Duncan River Riparian Cottonwood and Wildlife Use Monitoring).
2. Conduct surveys of Low Bench areas in the Duncan floodplain to determine the extent and production of mosquito breeding grounds (where females lay eggs, larvae and pupae develop and adults emerge), particularly those of *Aedes vexans* and *Aedes sticticus* - potential high competence WNv vectors at different times of the year. Water levels and water temperature are to be monitored at survey sites throughout the survey period.
3. A portion of sampling sites will be designated as residential. Data from these sites will be reflective of the conditions around local residences.
4. From the surveys conducted in the floodplain, prepare and update an integrated pest management (IPM) plan to improve the current mosquito abatement program in the lower Duncan River floodplain, the areas within 10 miles of the Duncan Dam, including the areas above the Duncan Dam, and to address potential WNv risk. The plan may also provide recommendations for future Duncan Dam operations that might mitigate impacts on mosquito production, and will be developed in year 2, and updated in years 7 and 11.
5. Investigate the relationship between open channel water elevation to vegetation type and mosquito breeding grounds at different dam discharges and produce an improved flow and flooding regime model through water level monitoring at sampling sites and analysis of local hydrology, dam discharges and reservoir levels throughout the program. The hydraulic model will be developed in a separate monitoring program (DDMMON#3 – Lower Duncan River Hydraulic Model Development),

A significant component of this monitoring program will be the coordination of field and analytical work with the ongoing Lower Duncan River floodplain mosquito abatement program. Coordination will include:

a) Local involvement: to ensure that quick responses to monitoring requirements is provided in this program and that local expertise is included, it is strongly recommended that the consultant team include resources from the Lardeau/Meadow Creek areas. The Lower Duncan River Mosquito Advisory

[3] As above, frequency of larval surveillance, or number of survey periods may be changed to accommodate study requirements to answer management questions.

Committee[4] has offered to identify potential resources – contact Richard Brenton (rbrenton69@gmail.com). Members of the advisory committee will also be included in program quality assurance, conducting field and report reviews.

b) Mosquito abatement program coordination: field sampling timing and site locations need to be coordinated with abatement staff to ensure that results are not confounded by abatement activities and are considerate of local ecologic knowledge.

9.2.3 Methods

9.2.3.1 Vegetation Mapping Updates

In Year 2 of the review period, the consultant for this project will conduct a search of new relevant information that has become available since previously studied by AWC (2002). These sources will include new vegetation classification data from DDMMON#8 – Duncan River Watershed Riparian and Cottonwood Monitoring, and DEM elevation data of the area or hydrologic information relating groundwater to different flooding regimes from DDMMON#3 – Lower Duncan River Hydraulic Model Development. Existing maps will be refined through GIS software: Vegetation polygons will be described by area, elevation, vegetation type, and mosquito species using the area. A summary of changes between the two vegetation mapping exercises will be provided.

9.2.3.2 Low Bench Surveys Below the Duncan Dam

The Low Bench surveys should be undertaken on the ground by freshwater entomologists with extensive experience in mosquito ecology, monitoring and surveillance, in particular of known vectors of West Nile virus. Field technicians should assist the biologists who are familiar with the use of GPS technology and mosquito sampling protocols. Field technicians will have local knowledge of the area; the field technician will be given training, as required. Data collected will be collated by a GIS software technician and formatted into a transferable database.

Prior to any field sampling, the lead entomologist will coordinate their work with the ongoing abatement program as indicated below to ensure minimal interference.

Larval Mosquito Sampling Techniques

Larval sampling sites will be chosen in consultation with abatement staff within each Low Bench area to allow a statistically robust analysis of the results over the review period. Larval sampling will be initiated once the floodplain is inundated by spring freshet (varies from year to year) and will continue once per month for four months Intensive surveys will be conducted in Years 2 and 3. In Years 5 and 7 the intensity of sampling will be reduced from 4 times to two times. Then in years 9 and 11, sampling will be conducted once[5]. As above, timing of sampling will be selected in coordination with abatement staff, and will consider requirements to assess influences of Duncan Dam operations on mosquito production.

At each surface water site, larval and pupal mosquitoes will be sampled using a standard 500 ml long handled dip sampler (Service 1976), following the standard larval sampling procedure described in the Municipal Mosquito Control Guidelines (Ellis 2004).

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[4] The advisory committee was struck by the Central Kootenay Regional District (RDCK) to advise on the abatement program and liaise with BC Hydro on mosquito issues in the Lower Duncan River floodplain.

[5] As above, frequency of larval surveillance, or number of survey periods may be changed to accommodate study requirements to answer management questions.

Ten consecutive dip samples will be taken at each sampling station and numbers of aquatic stages recorded cumulatively.

Physical information recorded on GPS handheld units at each surface water site will include habitat type, temperature, water level, water clarity, presence of fish, and vegetation cover. All pupae and instars of larval mosquitoes collected will be saved. Depending upon the number of specimens collected, samples will be placed either in small clear plastic vials (<50) or, for larger samples (>50), in Ziploc® bags. Samples will be kept in a cooler for transportation. All 3rd and 4th instar larvae will be preserved in 75% Ethanol. Earlier instars will be kept and reared to later instars for identification to species. Pupae will be similarly kept and reared to adults. Samples with more than 100 larvae will be sub-sampled, and a minimum of 100 larvae will be randomly identified. These results will be used to determine the species breakdown of the entire sample.

Earlier instars will be kept in large containers and reared to later instars that can subsequently be preserved for identification. Pupae will be similarly kept in containers and reared to adults. Wherever possible, larvae will be identified to species, or at least to genera.

Adult Mosquito Sampling Techniques

Adult mosquitoes will be sampled using one of three methods: light traps, gravid traps or emergent traps; the choice of trapping mechanism depends on a number of factors including the site characteristics, accessibility, cost, staffing and availability of materials. Appropriate adult traps will be placed at sampling locations determined by field investigations and specific factors related to the nature of the breeding grounds and the behaviour of particular mosquito species. Adult trapping will begin with the larval surveillance and be conducted at monthly intervals to coincide with the larval sampling to monitor high competence WNv species. Different species of mosquitoes have different life cycle patterns: for example most *Aedes* species over winter as eggs and have single generations, whereas *Culex* species over winter as adults and go through many generations each year. Adult sampling techniques and timing will depend on the species that are found in the study area and will be prescribed accordingly once the earlier phases of the program are complete and in order to meet the objectives of the study.

The three available methods are:

- *Light Traps*: These traps catch primarily females searching for a blood meal but they also catch adult males. CDC light traps baited with dry ice (CO_2) will be set between 6:00 and 8:00 pm and collected the next morning between 7:00 and 9:00 am. Light traps are used to trap adult female mosquitoes that are searching for a blood meal. CDC light traps are an effective tool in monitoring the types of species, and relative number of adult mosquitoes present in the area.
- *Gravid Traps*: These traps attract gravid females searching for egg laying sites. CDC Gravid traps will be set using hay infusions prepared 7 days in advance and will be set between 6:00 and 8:00 pm and collected the next morning between 8:00 and 10:00 am. Gravid traps are used to trap female mosquitoes, which have had a blood meal and are seeking a site for egg laying.
- *Emergence Traps*: These traps catch adults as they emerge from their pupal skin. Emergence traps will be set for periods of between 1 and 2 weeks, depending on the availability of field crews to check the catches. Emergent traps are set where eggs have already been laid, and are used to trap the larvae as they emerge as adults from the pupae stage.

In all cases adults will be frozen after collection and identified to species and sex. It is customary to set more than one style of trap at each sampling location and for pairs of traps to be used at each site.

9.2.3.3 Survey of the Residential Areas Within 10 miles of Duncan Dam

This study will be undertaken at the selected residential sites representing Meadow Creek, Cooper Creek, and Hamill Creek , and will aim to locate major sources of mosquito production, such as standing surface waters, to measure the abundance of adult mosquitoes in residential areas. The timing of this survey will be coordinated in tandem with the low bench survey. Similar methods will be used for sampling the larval and adult populations as for the low bench surveys in order to provide enough data to establish both levels of nuisance and potential high risk WNv vector spots – see below. As with the low bench surveys, both timing and sites for sampling will be reviewed with abatement staff.

9.2.3.4 Prepare an Integrated Pest Management Plan

An integrated pest management plan (PMP) will be prepared in the first year of this program (“year 2” of the WUP review period) using the results of the surveys carried out in the surveys above to assist the abatement program and to address the potential threat of West Nile virus in the area. The plan will include four elements: evaluation, strategic planning, implementation and effectiveness. The PMP will be submitted to the RDCK for review and comment prior to finalization. The plan will be re-evaluated in years 7 and 11 of the review period to incorporate new data and to assess results from the previous year. A formal review of the current mosquito abatement program and the operational aspects of the current WUP will be conducted with the Lower Duncan River Mosquito Advisory Committee and abatement program staff in years 2, 7 and 11 of the review period to ensure the PMP is effective and applicable.

9.2.3.5 Creating a Flow and Flooding Regime Model and Refining the Mosquito Performance Measure

In order to be able to investigate potential links between mosquito production and seasonal flooding regimes, dam discharge data needs to be collated for the duration of the study. It will also be necessary to obtain data on river flows and water levels. This data would be obtained partly from the study sites and also from BC Hydro operations staff and processed by data technicians to calculate mean levels and flows for different time periods as required.

AWC (2002) recognized that the consideration of operational changes to mitigate the mosquito nuisance would depend on predictive capabilities but that these might be confounded by stochastic events, such as heavy precipitation or atypical air temperatures. The flow level previously recommended was the best estimation from the current data and existing hydrological models available at the time, but it was recognized that the resolution of the measure would need to be closely monitored over a period of years and adjustments might have to be made to improve performance[6]. A more sensitive PM was suggested by AWC (2002) that might link the areas of different vegetation types to different elevations and take into account the effect of the periodicity, amplitude and extent of flooding events on mosquito hatching. However, due to insufficient data, this could not be achieved without further study. Studies initiated in the

[6] The lower Duncan River channel morphology is constantly changing which in turn can influence discharge at which flooding may occur in traditional mosquito breeding areas.

DDM WUP monitoring program include the development of a hydraulic model of the lower Duncan River floodplain, which will analyze to provide the relationship between inflow events and habitat flooding (see DDMMON#3 – Lower Duncan River Hydraulic Model Development TOR). Historic climatic data will be collated from BC Hydro and Environment Canada and any other available local sources for this purpose.

Water levels will be monitored at each site throughout the study using 6 remote water level sensors. Six temperature loggers will also be installed between sample sites.

9.2.4 Data Analysis

The analysis will provide insight into the breeding locations of *Aedes* species in Low Bench areas and better target the potential influence of operations of the Duncan Dam on nuisance mosquito production. With nuisance mosquito species in particular, there is potential for high variation in numbers of different species from season to season and from one year to the next. There are also confounding factors in the study areas, such as the use of larvicides in abatement programs being conducted in the study area that may vary from one year to the next depending on the amount and type of product used and when and where it is applied. In the first year of study (year 2 of the review period), the analysis will be largely confined to presentation of maps and charts which provide the most valuable indication of where the key problem areas exist, when the levels of mosquito nuisance are liable to be most annoying to residents in different areas and how operations may be affecting production in key breeding areas. With information gathered from annual monitoring the scope for more detailed statistical analysis increases.

1. At the end of year 2 of the review period, spatial analysis of mosquito breeding sites in the Low Bench areas will produce maps showing larval and adult densities of different species of mosquito collected at different stages of the breeding season. Mapping will be updated in Years 3, 5, 7, 9 and 11 of the review period for the low bench sites. Mapping will include annotations of study sites, temperature and water level monitoring locations, as well as areas under mosquito control.
2. Daily mean water temperatures for each location will be calculated from average hourly temperature measured by data loggers at each vegetation type in Year 2 and 3 of the review period. Water depth measurements taken at each location will be plotted alongside mean water temperature and larval and adult species composition and abundance represented as pie charts for each sampling date.
3. A risk analysis of potential threat posed by the arrival of West Nile virus will be conducted if suitable WNv vectors are identified in the residential study. This analysis will identify priority locations where pre-emptive controls may be required. An integrated mosquito management plan will be devised which considers short and long-term options for mitigation of the threat from high risk WNv vector sites in the most cost-effective and environmentally conscious way.
4. The hydraulic model being prepared under DDMMON#3 will be integrated with the spatial analysis conducted in (1) above to develop a relationship between instream flow and mosquito production potential for the floodplain. A performance measure tool will be developed that will further integrate temperature, timing and flood frequency with production potential over time to help evaluate operational and mitigative alternatives to manage mosquito production in the Duncan/Lardeau floodplain.

5. Over the ten year monitoring period, data will be collected to allow detailed statistical analysis that will aim to uncover correlations between management operations, environmental variables and mosquito production, and recommend revised PMs for the WUP review period.

9.2.5 Interpretation of Monitoring Program Results and Reporting

At the end of Year 2 of the review period, an Interim Report will provide all the detailed analysis from the studies carried out in the first year of this program. This report will give detailed consideration to the natural factors (e.g. temperature and natural water level changes) that affect mosquito distribution and production and will consider the relationship between Low Bench areas and flooding regimes particularly in relation to discharges from the Duncan Dam. It will also assess the importance and specific impacts of management operations such as control of water levels and flows on mosquito production and offer recommendations for how operations may be tailored to reduce potential mosquito nuisance. At the end of each of years 3, 5, 7 and 9 of the review period, an update report will be produced. At the end of the review period (year 11), a Final Report will be produced analyzing long-term trends. All final interpretations from this monitoring program will be done in consideration of input from the Lower Duncan River Mosquito Advisory Committee (on behalf of the Central Kootenay Regional District) and mosquito abatement program staff.

9.2.6 Schedule

All tasks will be carried out first in year 2 of the review period. In general, the 11-year program is to proceed as follows after year 2:

- Low bench surveys will be repeated in Years 3, 5, 7, 9 and 11 of the review period
- An update of the mosquito integrated pest management plan will be prepared in Years 7 and 11 of the review period; and
- Reporting and performance measure developments will be updated in Years 3, 5, 7, 9 and 11 of the review period.

Specifically, each task is to be carried out as outlined in the following table[7]

Table Error! No text of specified style in document.**-2: Proposed schedule for task completion for DDMMON#9**

Task	YR1 2008	YR2 2009	YR3 2010	YR4 2011	YR5 2012	YR6 2013	YR7 2014	YR8 2015	YR9 2016	YR10 2017	YR11 2018
Contract Award and Initiation		01-Feb									
Information Review and Vegetation Mapping Updates		X	X		X		X		X		X
Equipment Installation for Review period		X									
Low Bench Surveys - number of surveys		4	4		2		2		1		1
Residential Area Surveys		4	4		2		2		1		1
Prepare and Review Integrated Pest Management Plan		X					X				X
Develop Flow Regime Model and Performance Measures		X	X		X		X		X		X
Draft Reporting		30-Nov	30-Nov		31-Oct		31-Oct		31-Oct		30-Nov
Final Reporting		31-Dec	31-Dec		30-Nov		30-Nov		30-Nov		31-Dec

[7] As above, frequency of larval surveillance, or number of survey periods may be changed to accommodate study requirements to answer management questions.

9.2.7 Budget

Total Revised Program Cost: $608,264.00.

9.3 REFERENCES

Acroloxus Wetlands Consultancy (2002) The influence of the Duncan Dam on the Mosquito Populations of the Lower Duncan Floodplain. Prepared on behalf of the Duncan Water Use Plan Consultative Committee.

Belton P (1983) The Mosquitoes of British Columbia. BC Provincial Museum, Handbook No 41.1-189.

Klohn Crippen (2003) Duncan Dam Water Use Plan River Engineering: Lower Duncan and Lardeau River and Meadow Creek. Final engineering report prepared for Duncan Dam Water Use Plan project, BC Hydro, Burnaby, BC.

Hunter F (2005) Department of Biological Sciences. Brock University

Ellis R (2004) Municipal Mosquito Control Guidelines. Health Canada Bureau of Infectious Diseases. 54pp.

Service (1976) Mosquito Ecology and Field Sampling Methods. Applied Science Publishers Ltd, London, UK.