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Russell Creek: Summary of Research and Implications for Professional Practice

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INTRODUCTION

Watershed management is based on the application of models to predict the probable outcome of hypothetical management scenarios. There is enormous variability in the type and complexity of models that are used. In research, the preference is for process-based distributed hydrologic simulation models such as "Distributed Hydrology-Soil-Vegetation Model" (DHSVM, Wigmosta *et al*., 1994), while the professional community in BC bases much decision making for forested watersheds on the application of the Coastal and Interior Watershed Assessment Procedures (CWAP and IWAP, BC Ministry of Forests, 2001). Despite their obvious differences, these two types of model share a common problem: both must be based on a complete and accurate understanding of the dominant hydrological processes that govern the response of the watershed for which a decision is needed. Without that understanding, most models are based on the wrong theories, and as a result, management decisions based on application of those models may fail to produce the desired results.

Research at Russell Creek has been under way for 15 years. Russell Creek is a 31 km^2 sub-basin of the Tsitika River watershed on northeastern Vancouver Island (Figure 1), with active ongoing forest management and a logging history dating back to the early 1980s. The Tsitika River drains an area of 370 km^2 into Robson Bight in the Strait of Georgia. Access to the watershed is gained via the Island Highway about half way between Sayward and Woss.

Primarily a sediment budget research project, we are currently in a phase of the research that has led us to instrument the watershed intensively in an effort to develop a hydrological simulation model that accurately represents the variability among the dominant processes. Our long term objective is to develop an integrated, process-based model that can be used to investigate the effects of forest harvesting and roads on rain-on-snow (ROS) and sediment production processes. Funded by the Forest Science Program (FSP), the Tsitika

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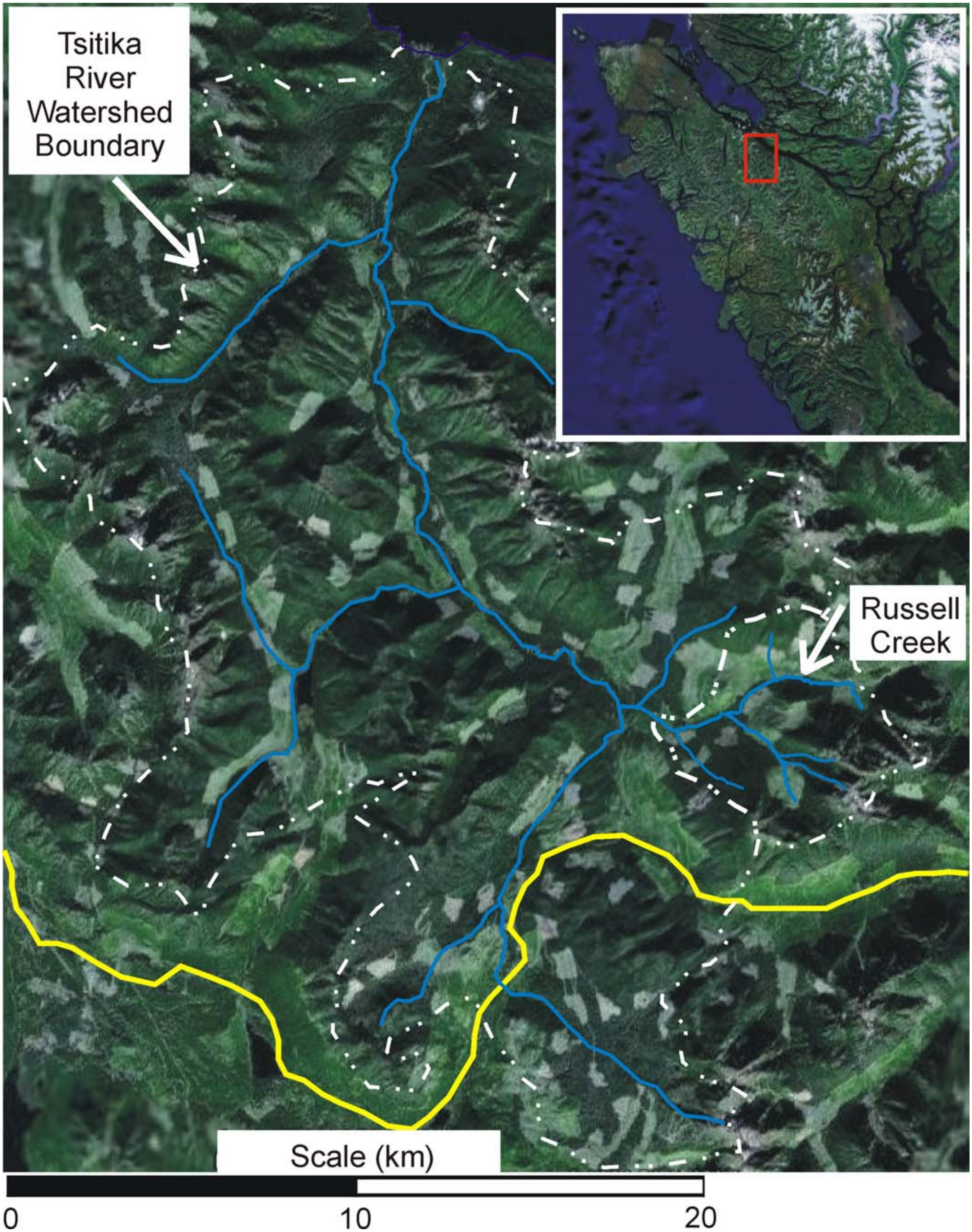

Figure 1. The Tsitika River Watershed showing Russell Creek ssub-basin and location on NE Vancouver Island. The yellow line is the Island Highway.

River Sediment Budget Project (of which Russell Creek is the currently active phase) is applied research in that its primary aim is to produce a model that is operationally focused at the watershed scale, but conceptually accurate and based on commonly available data. We have identified several areas where theoretical understanding of the dominant processes is inadequate, and are conducting field studies to fill in these knowledge gaps.

Along the way we have learned a lot about how coastal watersheds behave, and these findings can be translated into information leading to better-informed decision making for management of coastal watersheds. We have passed on much of this information in existing publications and at conferences in Canada and the USA. Our findings can be broken down into three categories: sediment production and transport (sediment budget), water quantity processes, and technical and innovative methods.

1. SEDIMENT BUDGET COMPONENT

Every project has to start somewhere – in early November 1991, Rob Hudson worked with Water Survey of Canada (WSC) to install streamflow and turbidity instrumentation at three sites in the Tsitika River watershed. One of those sites was dubbed by WSC as "Russell Creek near the Mouth." Each site had the WSC standard of the day for continuous water level measurement: a nitrogen-bubbling site feed, measured by a mercury manometer and recorded by pen on a clock-driven chart. The turbidity was measured by D&A Instruments' OBS-3 probes and recorded by the old low-resolution Unidata PDL loggers, and the sampling was done by ISCO 3700 automatic samplers. Hudson went back later that same month and installed a tipping bucket rain gauge near the site. Thus began Russell Creek; a sediment budget project based on one stream gauge and one tipping bucket rain gauge.

In 1994, our team consisted of Rob Hudson and various technical assistants. We began to build a network of nested stream gauge sites to facilitate the sediment budget work. We built five mainstem sites to measure streamflow and turbidity/suspended sediment, and three meteorological sites measuring total precipitation, rainfall, temperature, solar radiation, humidity, and wind. In 1997, we took over operation of the main stream gauge at Russell Creek (which became known as "Russell Main") as well as the Catherine Creek gauge. John Fraser joined the team as the principal technician.

We then created a secondary network of sites at the sediment source scale within Russell Creek watershed to measure sediment production from a variety of natural and man-made sources. At that time the secondary sites were all monitored and sampled manually. Working with MSc student Ryan Hanson, we succeeded in sampling a series of storms in the fall of 1998 that resulted in a sediment budget model where inputs and outputs agreed to within 10% (Hudson, 2001b).

Since then we have continued to monitor and sample and to take advantage of prevailing conditions to learn what we can about the effects of roads on sediment production and transport processes, the effectiveness of road deactivation, and the relative importance of roads in relation to other sediment sources.

Results:

- Our sediment source inventory for Russell Creek included about 150 significant sources: 47 stream crossings, more than 30 gullies, and 70 slope failures (Hudson, 2001b).
    - o The most significant sources are landslides on the sidewalls of incised stream reaches, which generally supply up to 60% of the sediment produced during storms in Russell Creek watershed.
    - o About 40% of the sediment production from landslides is derived from two features in Stephanie Creek; both are unlogged.
    - o Gullies supply about 25% of the sediment; about 60% of that comes from one large feature, also in Stephanie Creek and also unlogged.
- The detailed sediment budget work in Russell Creek was done at a time when the road network was not in active use. Sediment delivered to streams at road crossings under conditions of non-use varied from 0 to 12% of the total sediment production for storms ranging in size from 20 to 80 mm (Hudson, 2003).
- Factors controlling sediment production:
    - o Lithology and connectivity:
        - ♦ Sediment production on basaltic lithology is six times that of granitic lithology.
        - ♦ There is a similar ratio for terrain directly connected to a stream network as opposed to terrain disconnected by a valley flat (Hudson, 2001c, Hudson and Tolland, 2003).
    - o Road construction and use: the effect is variable depending on the density of new road, the lithology of terrain where roads are constructed, and the magnitude of the event responsible for sediment production.
        - ♦ We have documented up to a 100-fold increase in sediment yield for small events with peak flows less than 10 m^3/s, a 10-fold increase for events with peak flow between 10 and 20 m^3/s (return interval between 0.5 and 1.0 years), and no change for larger events.
        - ♦ Sediment production and transport events involving road sediment effects tend to be dominated by fines. The fines greatly augment yield for smaller events which are dominated by fines naturally. Large events tend to be increasingly dominated by transport of sand which tends to overwhelm the excess fines produced by roads.
        - ♦ This information was derived from results obtained in the fall of 2004 following an accelerated rate of timber harvest in anticipation of tenure change (Hudson, 2006).

2. WATER QUANTITY MODELING COMPONENT

Russell Creek is a typical coastal watershed: it is wet and ROS-dominated, with shallow soils and steep topography. This is arguably one of the least understood types of watershed. ROS processes are driven by parameters that are highly variable spatially and difficult to measure under wet freeze-thaw conditions. Our studies have shown that the combination of high precipitation, steep slopes and shallow soils results in the dominance of preferential flow processes over matrix flow under Darcy's law, as the primary process governing storm runoff. Similarly, at Carnation Creek, Beckers and Alila (2004) had to include subroutines to simulate vertical and lateral preferential flow in a distributed model in order to simulate measured hydrograph responses. The current challenge facing us at Russell Creek is to extend that work to a ROS environment. This involves modeling the different process groups at scales that represent the variability of the processes, using elements of a size such that their interaction will accurately represent the watershed scale process. We are currently involved in building and testing distributed networks within the watershed and its sub-catchments to provide input to process-based studies that will eventually be integrated into the distributed model.

The Team:

To accomplish this challenging task we have adopted a team approach. The senior members, Drs. Rob Hudson, Younes Alila and Markus Weiler, have broad and complementary skills in field data collection and analysis, model development, and process-based field studies. We have three PhD students and one post-doc, each studying different aspects of the problem described above. Axel Anderson joined the group in 2003 and has focused on a detailed study of preferential flow paths. In May 2005, Dr. Markus Hrachowitz came onboard from Austria for a two-year post-doctoral position to investigate the variability of the precipitation regime and to design a supplementary network to measure meteorological parameters at an appropriate spatial resolution. More recently, Bill Floyd has undertaken a study to investigate interactions between the precipitation regime and forest canopies, and Rabin Bhattarai has undertaken a model development study to integrate and upscale the various process-based studies. John Fraser continues to contribute technical expertise to the project and is responsible for primary network operation and sediment budget data collection.

Results:

- **Preferential flow network** is a term commonly used in the literature to define a connected group of individual preferential flow features. We have documented that individual preferential features can have a finite capacity to carry flow, but when one feature has reached its capacity, another feature can join the network and carry additional flow. This means that, at least for our study site, these networks may be considered to have an almost infinite capacity to transport subsurface water (Anderson and Weiler, 2005).
  - o Subsurface flow rates: The rate of water movement through the preferential flow network is in the order of 10^{-3} m/s, compared with the 10^{-6} m/s rate typical of matrix flow under Darcy's Law.
  - o During most storms, about 80% of hillslope water is derived from preferential flow. We expect that the contributions of preferential flow will vary with storm size, but more analysis is still required.
- **Runoff response**: this is defined as the rate at which a land segment delivers water into stream channels. Our groundwater data show that hollows stay saturated most of the time, the ridge-top wells rarely show a saturated zone, and the wells on the hillslopes show a transient response pattern. Areas with fast runoff response would include hollows, riparian zones and ridge tops where high water tables or shallow soils might produce overland flow, and areas dominated by preferential flow. Areas with slow runoff response include areas of groundwater recharge. On a hillslope the runoff response would generally increase down-slope.
- **Effects of roads on peak streamflow**: Given the above, we expect the effect of roads on peak flows to be small compared with a watershed where subsurface flow is dominated by matrix flow. Where preferential flow is dominant, conversion of subsurface flow to ditch flow has little effect on peak flow because there is not a large difference between the subsurface and surface flow velocities (Beckers and Alila, 2004).
- **Effects of forest harvesting on peak streamflow**: If runoff response were uniform there would be a direct relationship between the proportion of area logged and the change in peak flow. In a watershed where runoff response is mixed (such as Russell Creek), the effect of harvesting depends entirely on where you log. We would expect a greater change in peak flow and timing of the peak if we harvested areas with high runoff response. Conversely, harvesting areas of slow runoff response may increase groundwater recharge, low flow, or soil storage, but may not affect peak flow as much.

3. TECHNICAL DEVELOPMENTS

We are still using some of the original instrumentation that we started with in 1991, but technically we have come a long way since then in developing methods better suited to harsh conditions. During the course of this work we have tested state-of-the art, off-the-shelf technology and developed several alternative methods and technologies:

- The original **OBS-3 turbidity probes** are still in use at Russell Main and elsewhere, as are the original ISCO samplers. We began using this technology when it was still in its infancy and found it necessary to develop methods and protocols for handling the probes and for interpreting the data (Hudson, 2001a).
- We no longer use the old WSC system to measure water level. Primarily we use **submersible transducers** to measure stage at mainstem sites, and **capacitive probes** at many of the smaller sites where we monitor streamflow.
  - o Due to the active nature of stream channels and the relatively high frequency of "channel forming" events, we have found that a heavily armoured submersible transducer provides the most effective high-resolution solution to continuous monitoring of stage for situations where we really want the high flow data no matter what. A future publication will describe this technology.

  - o Smaller streams have been temporarily gauged (for two to three seasons) using weirs constructed from plywood and UV-resistant plastic. To gauge many streams while keeping costs to a minimum, we have used stand-alone "Odyssey" capacitive water depth probes combined with small dedicated data loggers.

- **Salt dilution gauging**: we developed an operational method to measure streamflow in steep turbulent channels where traditional current metering cannot be applied accurately (Hudson and Fraser, 2005).

- **Total precipitation gauging**: We wrestled with the operation of standpipe gauges for a long time. Eventually we developed an alternative method of operating standpipe type gauges – the "displacement type" gauge, a high-resolution and virtually maintenance-free solution to a traditionally high-maintenance and not-very-accurate-or-reliable-but-essential measurement (Hrachowitz et al., 2005).

- **Natural tracers**: in addition to applied tracers we started an experiment that uses natural ions as tracers to determine the sources of stream water during storms. These techniques are well established in the literature and combining them with our intensive hydrometric measurements will help us to determine the types of runoff response found at Russell Creek.

4. CONCLUSION

Russell Creek, with its mixed terrain, ROS-dominated precipitation regime, and steep, active riffle-pool channel, is a typical coastal watershed. Our ongoing research is aimed at answering questions that have remained unanswered after decades of coastal watershed research. Along the way we have gained valuable insight into the inner workings of this watershed, and we will continue to pass on those insights to the benefit of professional watershed management in BC.

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