C5 FOREST MANAGEMENT PLAN 2006–2026

# APPENDIX 6C. HYDROLOGICAL EFFECTS OF THE PREFERRED FOREST MANAGEMENT SCENARIO IN THE C5 FOREST MANAGEMENT UNIT

**Hydrological Effects of the Preferred Forest Management Scenario In the C5 Forest Management Unit**

Report Prepared for:
Alberta Sustainable Resource Development
Edmonton, Alberta

Prepared by:
Watertight Solutions Ltd.
Edmonton, Alberta

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**Executive Summary**

Sustainable Resources Development (SRD) developed a management plan titled "The Preferred Forest Management Scenario in the C5 Forest Management Unit" (Preferred C5 Scenario) in the Southern East-Slopes of Alberta. Because water resources and values could be affected by the proposed forest harvesting SRD contracted Watertight Solutions Ltd to evaluate the potential hydrologic effects of the Preferred C5 Scenario.

The hydrologic effects of forest harvesting in the C5 FMU were simulated using two models: ECA-Alberta (Silins, 2000) and WRENSS-Eca-Ab (Swanson, 2000). ECA-Ab was used to simulate the hydrologic effects of the proposed harvesting plan in terms of %ECA , simulated changes in annual yield (mm and %), and the timing of hydrologic recovery. The more detailed WRENSS-EcaAb (WRENSS) was used to evaluate the hydrologic effects of forest harvesting in 7 small sub-basins within the Crowsnest River Watershed near the towns of Blairmore and Colman. The effects of harvesting in these watersheds were evaluated in terms of simulated increases in annual yield (mm, %), maximum daily peak flow, % ECA and hydrologic recovery.

The two models used are similar in many aspects. ECA-AB was developed based on the logic and structure of WRENSS, to produce a version that was simple and easier to apply. Both models predict changes in water yield and %ECA based on long-term average climatic data, long-term average streamflow, forest growth and watershed conditions. WRENSS has the added option of providing estimates of changes in maximum daily peak flows based on locally available streamflow data. ECA-AB simulations were simulated for 135 years; WRENSS simulations were ran for 101-134 years.

Simulations of water yield increases by both models showed nil to small increases in annual water yield. This was the case for the large watershed simulations done with ECA-AB and simulations for the 7 small sub-basins simulated by WRENS-Eca-Ab. The low response of annual water yield to forest harvesting was attributed to the very high precipitation and runoff in most of the C5 FMU. The addition of an extra 1- 11 mm of extra water generated by harvesting to annual water yields of 300-600 mm produced small percent increases in annual water yield. Increases in annual water were not significantly different from the long term mean annual flows for these watersheds (i.e. increases did not exceed upper 95% confidence limit for mean flow). Simulated increases in maximum daily flows for the 7 small watersheds indicated a small to nil response the proposed harvesting in the C5 Preferred Scenario. The differences in peak flow increases among recurrence intervals of 2-100 years were small.

The levels of %ECA in the watersheds were different for the two models because of differences in the level and timing of harvesting and methods of calculation. Maximum ECA on the large watersheds varied from 0.2% to 10%, while values for the small watersheds varied from 29% to 50%. Harvesting on the smaller basins was smaller and more concentrated spatially.

Hydrologic recovery was defined as the years needed for water yield increases to be equal or less than 1%. Hydrologic recovery in both the small and big watersheds was variable being a function of the rate and timing of harvesting. Values ranged from short periods (< 10 years) to long periods (> 50 years). Recovery in some watersheds with low response levels was maintained for long periods because of repeated low levels of harvesting. Water yield increases in more than

half of the watersheds was less than 1% which was interpreted as a nil response to forest harvesting.

The results from ECA-AB and WRENSS indicate that simulated increases in annual yield, ECA, and peak flows based on the proposed harvesting plan were not significant, and well below the detection limit using standard hydrometric techniques. As a result, the simulated increases in annual water yield and maximum daily flows should not be a threat to aquatic habitats or fauna.

Specific changes in water yields are listed below for each model.

Hydrologic changes simulated by ECA-AB were:

- Increases in water yield and %ECA varied between watersheds
- Maximum simulated yield increase was 13.8% (7.3mm) in the Beaver Creek watershed (all others were <4%).
- Maximum predicted increases in ECA ranged from 0.2% (Pincher Creek) to 10% (Dutch/Highwood River).
- Hydrologic recovery from ranged from 0 years (10 of 19 watersheds),3-17 years (5 watersheds) to 38 – 64 (4 watersheds).

The more detailed, WRENSS model evaluated the hydrologic effects of forest harvesting in 7, smaller sub-basins within the Crowsnest River watershed. These watersheds were evaluated in terms of predicted increases in annual yield (mm and %), peak flows, timing of hydrologic recovery, and impacts on stream bank stability, erosion potential, and the expected impacts on fish and fish habitat associated with the proposed harvesting plan.

Predicted changes in annual yield, ECA (%), and peak flows were based on the area harvested within each of the watersheds, rate of forest growth, and long-term average climatic conditions. WRENSS simulations were projected for 101-134 years, and were based on average precipitation and flow conditions. The results indicated that projected yield increases were very low for all 7 sub-basins within the Crowsnest River watershed.

Hydrologic changes simulated by WRENSS were:

- Maximum annual yield increases were proportionally very low, ranging from 0.6% (Crowsnest Creek) to 3.5% (Pelletier Creek)
- Maximum yield increases for 4 of the 7 watersheds occurred during the first 20 years of harvesting (2006-2026)
- Changes in peak flows were also very small, ranging from 0.1%, (Crowsnest Creek) to 3.6% (Pelletier Creek) for the 2-yr return interval storm and 0.2% (Crowsnest Creek) to 4.4% (Pelletier Creek) for the 100-yr return interval storm.
- Equivalent clear-cut area (ECA) values for these watersheds ranged from 30.6% (Allison Creek) to 50.6% (Crowsnest Creek).
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The impacts of forest harvesting on water quality are most associated with the effects of soil disturbance and exposure, erosion and sediment deposition caused by log skidding and road construction than changes in water yield or peak flows. Increased water yield and peak flows could add or enhance the effects of surface disturbances to water quality. Observations in the literature suggest that a 50% increase in bankfull discharge has the potential to change stream morphology and in turn aquatic habitats. Paired basin studies report such changes can occur when 40% to 50% of forest cover in a watershed is removed in a short time period. Changes in aquatic habitats are slow to develop and more likely to occur with the permanent removal of forest cover in a watershed. It is doubtful that such changes would occur as the result of forest management, where forest cover is retained over the long run. However, a limit of some kind is probably warranted to minimize the potential for less dramatic effects of forest cover removal on peak flows.

The protection and maintenance of water quality is best protected by focusing on the design and construction of road-stream crossings, prompt revegetation and erosion control of disturbed sites and stream crossings, monitoring of water quality at disturbed sites or watersheds and periodic inspections to determine effectiveness of management practices.

In conclusion it was recommended that work be undertaken to develop guidelines to minimize potentially adverse effects of water yield and peak flow increases. Such information is needed by government and forest industry by the requirements in the current forest management planning manual, which specifies the prediction of water yield increases in detailed forest management plans. Guidelines should be based on regional climatic and hydrologic differences within the Province (e.g. foothills versus boreal). Guidelines or limits would be scaled to reflect regional (e.g. forest management units) annual water yield and peak flows with respect to local variability, as currently defined by available hydro-meteorological data. Such guidelines to be designed to recognize existing methods used to estimate/simulate hydrologic changes. It is anticipated that any guidelines developed will be modified as better information and methods evolve. Special attention should be given to testing ECA or other similar measures as a parameter that can be used to monitor potential impacts, and in reporting/assessments in detailed forest management plans.

## DISCLAIMER

The assessment of hydrological impacts of harvesting presented in this report reflects the output from hydrologic simulation models and does not necessarily reflect actual impacts that may be observed. Ultimately, the reliability of estimates produced using these and other similar models depends on the availability of representative climatic/hydrometric data, and regional forest growth characteristics of Alberta provincial average growth and yield data, and harvesting plans. In this context, the authors have evaluated the hydrometric data used in this analysis and consider these data to be a reliable reflection of hydrologic conditions for the analysis. Limitations or errors due to deviation in actual forest growth rates from provincial average growth rates or limitations imposed by spatial/temporal scale of analysis are outside the author's control. In particular, the spatial distribution of harvested blocks, as well as the presence of additional disturbances (fire, insects, etc.) will also affect water yields.

Furthermore, it is re-emphasized that the ECA-AB and WRENSS models project average annual water yield changes over time based on un-routed flow (generated runoff), assuming average climatic/hydrologic conditions in the region and the rate of stand regeneration. Therefore, changes in annual water yield due to disturbance will vary from simulations based on the actual variability in climate and the degree of departure from average climatic conditions.

Watertight Solutions Ltd.
R.L. Rothwell RPF 150

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**Hydrologic Effects of the Preferred Forest Management Scenario In the C5 Forest Management Unit**

# Introduction

The objective of this report was to assess the effects of "The Preferred Forest Management Scenario in the C5 Forest Management Unit" (Preferred C5 Scenario) on annual water yield, Equivalent Clear-Cut Area (ECA %), changes in peak flows, the timing of hydrologic recovery (time required for yield increases to approach zero (<1%)), and the possible impacts of projected yield increases and peak flows on water quality, fish and fish habitat.

# Background

Sustainable Resource Development (SRD) has developed a forest management plan for the C5 Forest Management Unit (C5 FMU) in the Southern East-Slopes of Alberta. Because it is well documented that forest harvesting can affect water yield and peak flows, SRD contracted Watertight Solutions Ltd. to evaluate the potential effects of forest harvesting in the C5 FMU.

Two hydrologic models common to Alberta were used to evaluate the hydrologic effects of forest cover removal in C5 FMU. Models are a practical methodology because they can provide quick and effective assessments. Direct measurement of the effects of forest harvesting on water is not feasible because of the extensive nature of forest harvesting, long duration of hydrologic changes and costs involved. Models are useful because they can identify potential problems before they occur.

Both models provide estimates of changes in annual water yield, hydrologic recovery and ECA (%), and the WRENSS model (Swanson, 2000), which is more detailed and provides estimates of peak flow changes in addition to changes in annual yield and ECA (%). For both models, changes in annual water yield are based on the area harvested in a watershed, rate of forest growth and water balance calculations of generated runoff.

Water yield is the total volume of water flowing from a watershed in a specified time period. Annual water yield can be expressed for 12 months or for the open-water season (March-October). In Alberta, most hydrometric stations are only monitored for the open water season because of the difficulties and cost in monitoring winter flows. Streamflow during the winter months usually accounts for less than 10% of total annual flow.

Generated runoff is a water balance calculation of runoff which is the difference between long term average precipitation and evaporative losses in a watershed, and is not routed to the stream channel. In more simple terms it is the water that is generated on the land surface that is available for runoff following the removal of forest cover. Generated runoff is expressed in units of depth on the land surface (mm) and not as a flow in the stream channel in units of $m^3$/sec.

Hydrologic recovery is the time required for increases in water yield to disappear with the growth of forest regeneration. Increases in water yield decline as evapotranspiration[1] losses

[1] Evapotranspiration refers to the total evaporative loss of water in an ecosystem, which includes evaporation from open water surfaces, soil, from the foliage of vegetation and terrestrial surfaces (interception) and the water used by plants (transpiration).

increase with forest regeneration in harvest blocks. Hydrologic recovery is expressed in years. In this report hydrologic recovery is assumed to occur when simulated increases in water yield are ≤ 1%.

Equivalent Area Clearcut (ECA) is a measure or index of hydrologic recovery. It is a measure of the disturbed area (i.e. harvest blocks) in a watershed that is in a condition to contribute extra water to streamflow. ECA is at a maximum at the time of harvest and then decreases with the re-establishment and growth of trees. The physical model supporting ECA is that vegetation removal changes water yield in rough proportion to the leaf surface area or basal area removed from a site (Ager and Clifton 2005). ECA is defined as the area harvested times a reduction factor that describes the recovery of evapotranspiration losses. ECA is usually expressed in hectares of harvested area and as a percent of the harvested area. ECA can also be expressed as a percent of watershed area, which is hydrologically more informative.

To identify potential changes in water yield and peak flows with implications for fisheries, hydrologic assessments should be done for watersheds of a size that are sensitive to flow change. This kind of information can be obtained by simulating water yield and peak flow increases in small representative watersheds (50-100 $km^2$) for harvest levels ranging from moderate to maximum.

## Harvest Scenario

The harvest plan for simulation prepared by SRD is titled "The Preferred Forest Management Scenario in the C5 Forest Management Unit" (Preferred C5 Scenario)" (Figure 1). Harvest levels were determined by a series of iterations using harvest scheduling models and followed up by in depth assessments in the office and harvest block layout in the field.

The hydrologic effects of the harvesting to be simulated include historic harvesting (1970-2005) and the harvesting proposed in the Preferred C5 Scenario (2006-2100). Simulations were run for 130-135 years to capture the combined (cumulative) effects of historic harvesting and the proposed future harvesting.

Harvesting in the Preferred C5 Scenario is planned to occur in two phases, 2006-2026 and in the following 100 years (2026-2105). Harvesting planning for phase 1 is completed and ready for implementation pending final approval. Harvest plans for phase 2 are conceptual with the areas for harvest identified primarily by harvest schedule models.

The hydrologic effects of harvesting in 19 large watersheds (150-1000 $km^2$) in the C5 FMU will be done using the ECA_Alberta (ECA-AB) model. A second set of simulations will be done with WRENSS-EcaAb (WRENSS) model for 7 small sub-basins (9-56 $km^2$) where harvesting is more concentrated in time and space which makes the potential for hydrologic change greater.

Maps used in timber supply analyses identified 3 additional small watersheds (Carbondale –Lynx Creek, Crowsnest North York and York Creek), which were consolidated into the larger Carbondale and Crowsnest River watersheds for the ECA-AB and WRENSS simulations.

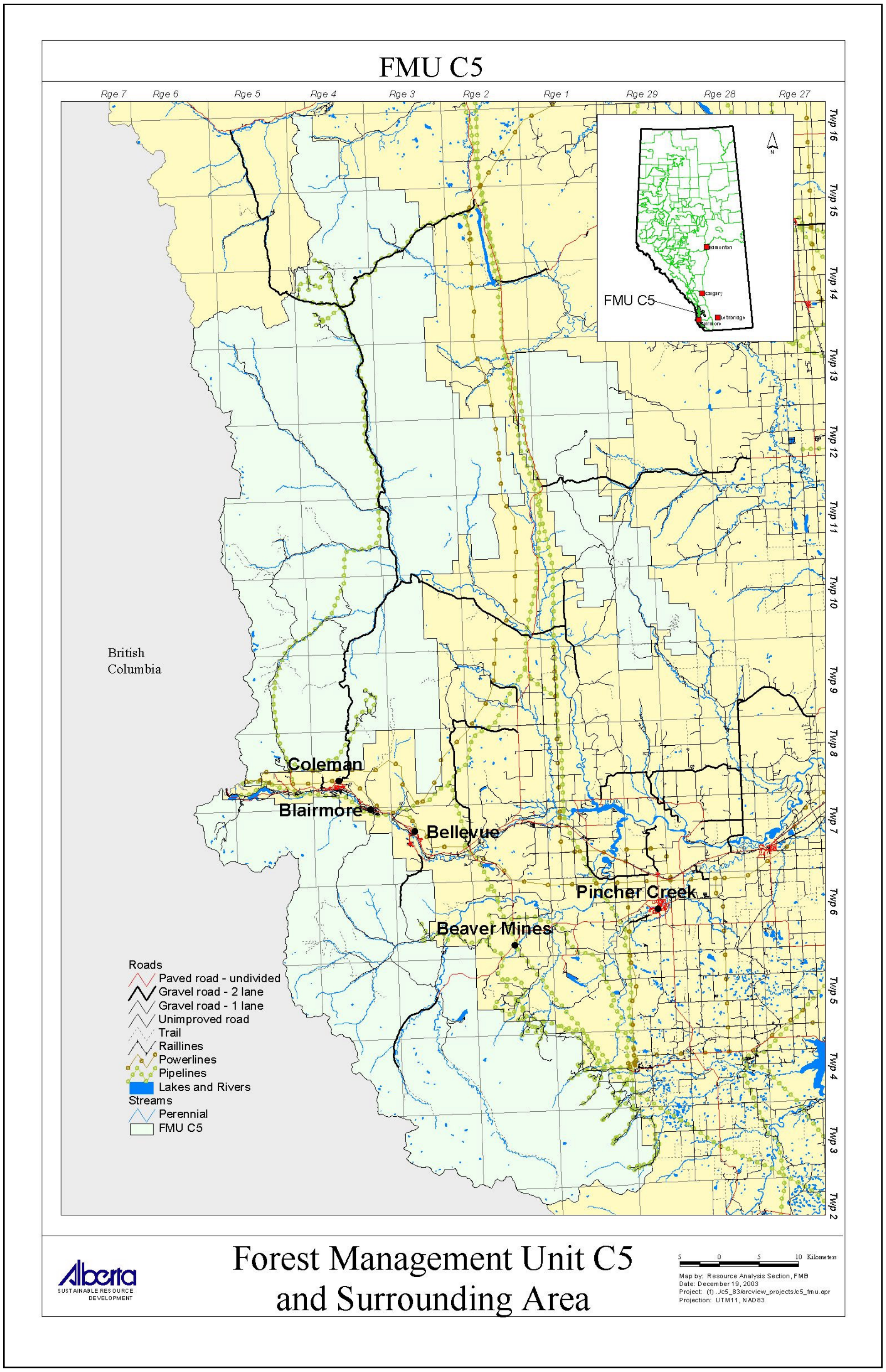


**Figure 1 Location of C5 forest management unit (courtesy of Forestry Corp).**

# Methods

This hydrologic analysis consisted of two components. First, the ECA-AB model was applied to each of the 19 large watersheds (Figure 2) within the C5 Forest Management Unit (FMU). Second, the WRENSS model was applied to 7 smaller sub-basins located within the Crowsnest River Watershed (Figure 3).

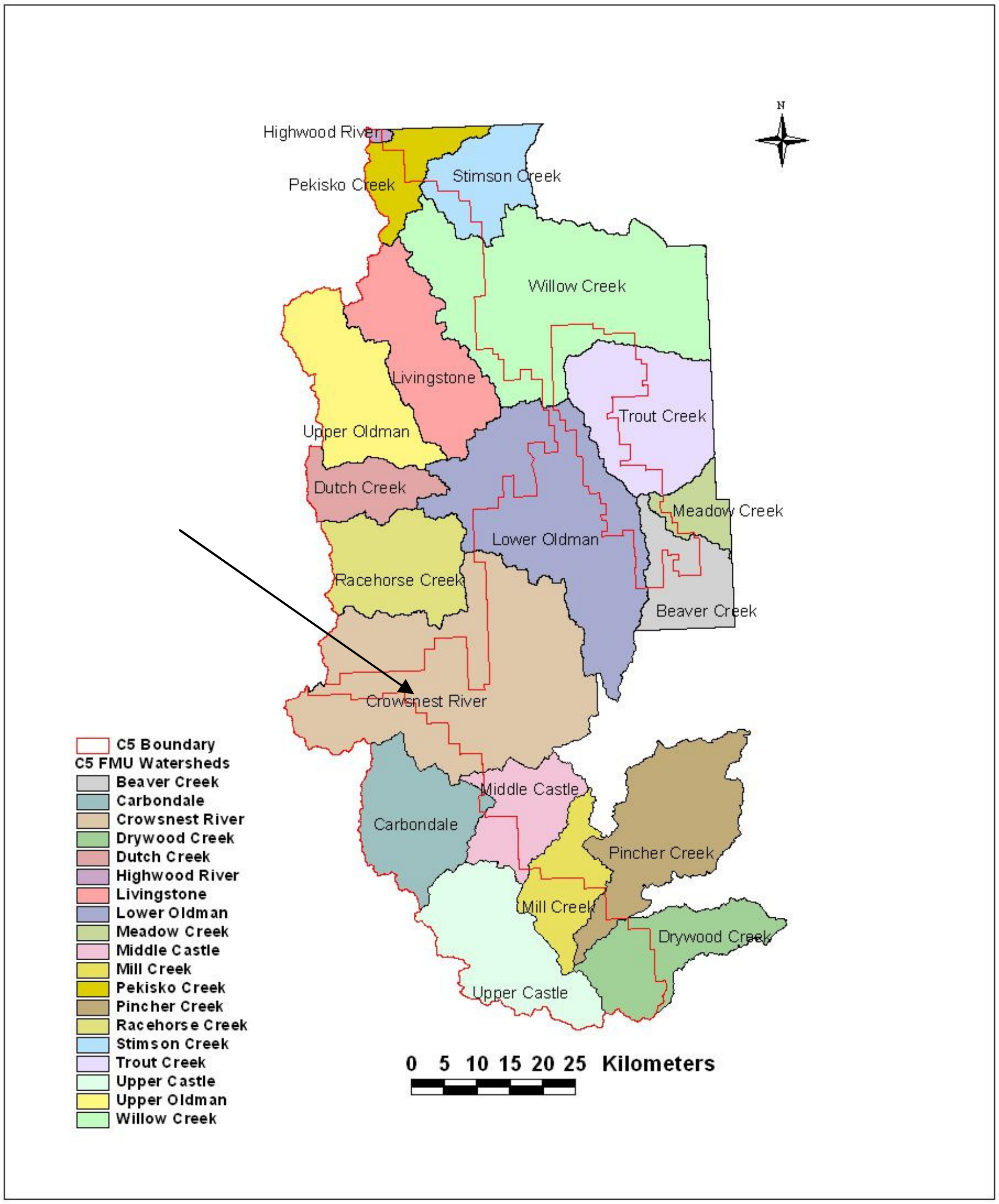


**Figure 2 Map of the C5 Forest Management Unit (FMU) and the 19 watersheds lying either partially of wholly within the C5 boundary. Arrow shows general location of 7 small sub-basins. Maps used in timber supply analyses identified 3 additional small watersheds (Carbondale –Lynx Creek, Crowsnest North York and York Creek), which were consolidated into the larger Carbondale and Crowsnest River watersheds.**

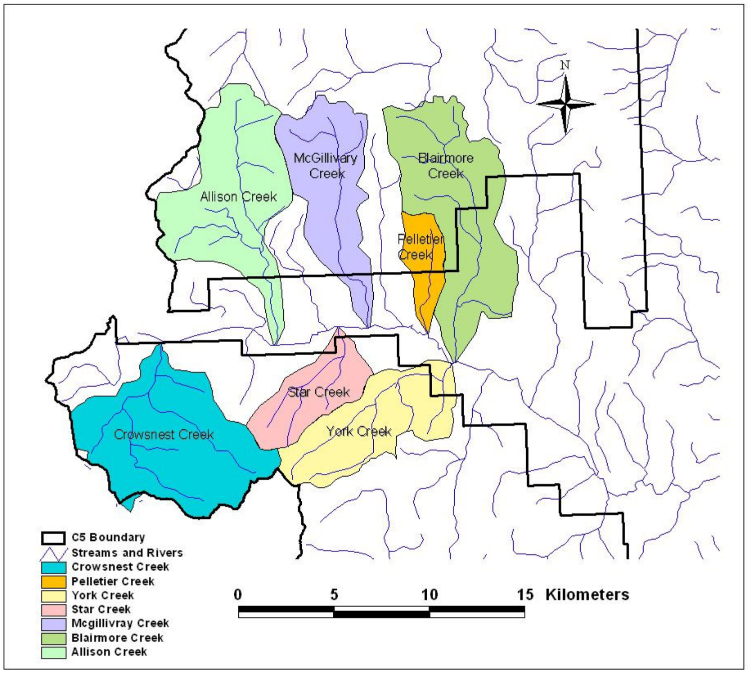


**Figure 3 Map of the Crowsnest Region of the C5 Forest Management Unit showing the 7 sub-basins evaluated using the WRENSS model**

The hydrologic analysis contained in this report was a collaborative effort between the Forestry Corp. and Watertight Solutions Ltd. All model input data relating to the proposed harvesting plan (including year of harvest, block size (ha), species, site quality, etc) as outlined in Appendices 3 and 4 were provided to Watertight Solutions Ltd., by The Forestry Corp. The hydrometric and climatic inputs data were obtained by Watertight Solutions Ltd. from Water Survey of Canada (streamflow), Environment Canada (precipitation), and the Alberta Land and Forest Service (precipitation) and was summarized by Watertight.

# ECA-AB

## Hydrologic Input Data

Although precipitation data were generally available for most of the FMU, not all watersheds had active or historic hydrometric stations to characterize the long-term average annual water yield. As a result, representative stations from similar, adjacent watersheds were used to characterize the streamflow of those watersheds with missing records. The selection of representative streams was based on 3 characteristics, 1) Streams were located relatively close (geographically), 2) The gauged streams were from watersheds that were similar in size and topography, and 3) The gauged streams have a long enough record (> 10 years) to characterize the range of natural variability.

The hydrologic effects of the Preferred C5 Scenario were evaluated for each of the 19 large watersheds using the ECA-AB model (Forestry Corp Run90022 TSA) . The effects were simulated for 135 years, (1970-2100), and included up to 35 years (1970-2005) of historic harvesting as well as 100 years (2006-2100) of proposed harvesting. This enabled the effects of past disturbances on water yield to be combined with proposed future harvesting (i.e. the cumulative effect of both past and proposed future forest harvesting disturbances on water yield).

### Model Parameters

The ECA-AB model uses two approaches to estimate the rate of hydrologic recovery. The first is based on the rate of basal area growth. The second is based on the rate of annual volume growth. Both approaches utilize the Alberta provincial average growth/yield data for unmanaged (fire origin) stands. The volume growth function generally simulates a more rapid hydrologic recovery than the basal area function and does not require the user to specify an age at full hydrologic utilization for each species. With this option, hydrologic recovery is predicted based on the close relationship between volume growth and stand level leaf area index (LAI)[2] (Long and Smith, 1992; and Kollenberg and O'Hara, 1999).

Recent work by Brabender and Silins (2004), has confirmed that there is a strong relationship between annual volume growth and LAI for lodgepole pine in Alberta). As a result, this analysis used the rate of annual volume growth to estimate hydrologic recovery which is assumed to occur at the time (age) of maximum stand LAI for any given species. Research by Lieffers *et al* (2002) shows similar relationships for aspen, where maximum LAI occurs from 15-25 years depending upon site conditions. Values for white spruce are not documented but are expected to exceed 40 years.

### Model Output, Interpretation and Statistical Analysis

The model was run on an annual time-step to provide estimates of area harvested (ha and %), yield increases (mm and %), and ECA (ha and %) on an annual basis. The results were also summarized by decade (10-yr maximums and 10-year average values) in order to illustrate or show trends in the data. Confidence intervals (95%) and standard deviations were used to test if simulated water yield increases were significantly different ($\alpha$=0.05) from long-term average annual water yields for watersheds in the Preferred C5 Scenario.

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[2] LAI or leaf area index is an estimate of the total leaf area ($m^2$) or evaporative surface in a forest stand for water lost by transpiration to the atmosphere.

## WRENSS

The hydrologic effects of the Preferred C5 Scenario on the 7 small watersheds were simulated using the WRENSS model (Swanson, 2000). The watersheds range in size from 9.4-56.5 $km^2$ and are located in the Crowsnest Pass Region of the C5 Forest Management Unit (Figure 3). WRENSS was used as it provides estimates of changes in peak flows as well as annual water yield, which provides an opportunity to assess potential impacts on stream channel morphology and aquatic habitat. Watertight Solutions used the spatial harvest data (Run 90022 TSA) provided by The Forestry Corp to run the model and interpret the results.

### Hydrologic Input Data

Although precipitation data was generally available for most of the Crowsnest River watershed not all sub-basins within the watershed had active or historic climatic records. As a result, long-term average annual precipitation data from the town of Coleman (central to all 7 sub-basins) was used as the model input. Similarly, not all sub-basins within the Crowsnest River watershed had active or historic streamflow records. As a result, long-term average annual water yield for the Crowsnest River at Frank was used as the input for the model.

The hydrologic effects of the proposed harvesting plan were evaluated for each of the 7 small sub-basins within the watershed using the WRENSS model. The effects were simulated for 101-134 years, based on the supplied harvesting scenario.

### Model Parameters

ECA-AB is based and developed from WRENSS, which means data requirements, output and internal logic of the two models are similar. The major difference between the two models is that WRENSS stratifies watersheds by aspect to reflect potential differences in evapotranspiration, and includes the effects of snow redistribution in harvest blocks on water yield increases. The absence of a geo-spatial analysis for aspect of forest stands in ECA-AB makes it easier to use. Simulated water yield increases in ECA-AB however are ~ 5% greater than those in WRENSS.

Hydrologic recovery in WRENSS is based on the recovery of basal area, a more conservative estimator, which is considered by some to be more inclusive in that in considers both leaf area and root occupancy of a site. Growth estimates in both models are based on provincial growth and yield information (i.e. Phase III inventory data). The use of other sources of growth and yield data is possible in WRENSS. Experience to date with other growth and yield data shows small differences in model output, suggesting small differences from provincial growth and yield information, or low sensitivity in the model.

Hydrologic recovery is most easily inferred from ECA. There are two different estimates of ECA are available in WRENSS. The first is the traditional approach, where $ECA_{BA}$ is based on the recovery of basal area with the establishment of forest regeneration (ratio of current basal area to maximum possible for a site, Eq.1). The second is based on the recovery of simulated water yield increases to pre-harvest or undisturbed conditions (Eq.2). Hydrologic recovery based on maximum water yield increase can be shorter by half the number of years obtained with basal area. It should be noted that hydrologic recovery based on $ECA_Q$ includes both recovery of basal area and the effects of snow redistribution in harvest blocks(i.e. snow scour/sublimation). $ECA_Q$ based on water yield is considered a more direct and realistic estimate of hydrologic recovery.

Eq.1 $$ECA_{BA} = \frac{BA_{current}}{Max\ BA} \times Harvest\ Area$$

Max BA = maximum basal area possible for a given site
$BA_{current}$= basal area for year –n of a specified time series

Eq.2 $$ECA_Q = \frac{\Delta Yield_{current}}{\Delta Yield_{\max Q}} \times Harvested\ \ Area$$

$\Delta Yield_{maxQ}$ = maximum water yield increases in a give time series
$\Delta Yield_{current}$ = water yield increase for year- n in a given time series

Another major difference between ECA-AB and WRENSS is estimation of increases in peak flows (maximum daily and instantaneous). Peak flow estimates in WRENSS are based on locally available maximum flow data (Water Survey of Canada 2003) for provincial forest management units. Estimates of peak flows before and after harvesting with increases in $m^3$/sec and area-mm for recurrence intervals of 2, 5, 20, 50 and 100 years are provided.

# ECA-AB Results

## ECA-AB Precipitation Inputs

The C5 FMU is characterized by diverse precipitation regimes. Generally, the south westernmost portion of the FMU receives the greatest annual precipitation with values in excess of 1150 mm/year (Figure 4  Table 1). These annual values decrease substantially as you move north and eastward across the FMU. The Porcupine Hills region encompassing the Lower Oldman, Beaver, Meadow, Trout, and Willow Creek watersheds have the lowest average annual precipitation values (450-500 mm/year).

Watershed average annual precipitation values for the FMU ranged from 474 mm/year in the Meadow Creek Watershed, to 923 mm/year in the Carbondale and the Upper Castle Watersheds (Table 1).

## ECA Alberta Streamflow Inputs

Due to vast differences in topography, geology, and climatic regimes across the C5 FMU, the average annual water yield regimes vary considerably between watersheds (Figure 5). However, the distribution and magnitude of average annual water yield follows very closely with that of annual precipitation. The largest annual flows are found in the southwestern portion of the FMU where annual precipitation is highest. Average yields in this area of the FMU approach 700 mm/year. As with precipitation, the lowest average annual water yield is in the Porcupine Hills (31-75 mm/year).

Watershed average annual water yield values for the FMU ranged from 31 mm/year in the Beaver Creek Watershed, to 680 mm/year in the Upper Castle Watersheds (Table 2).

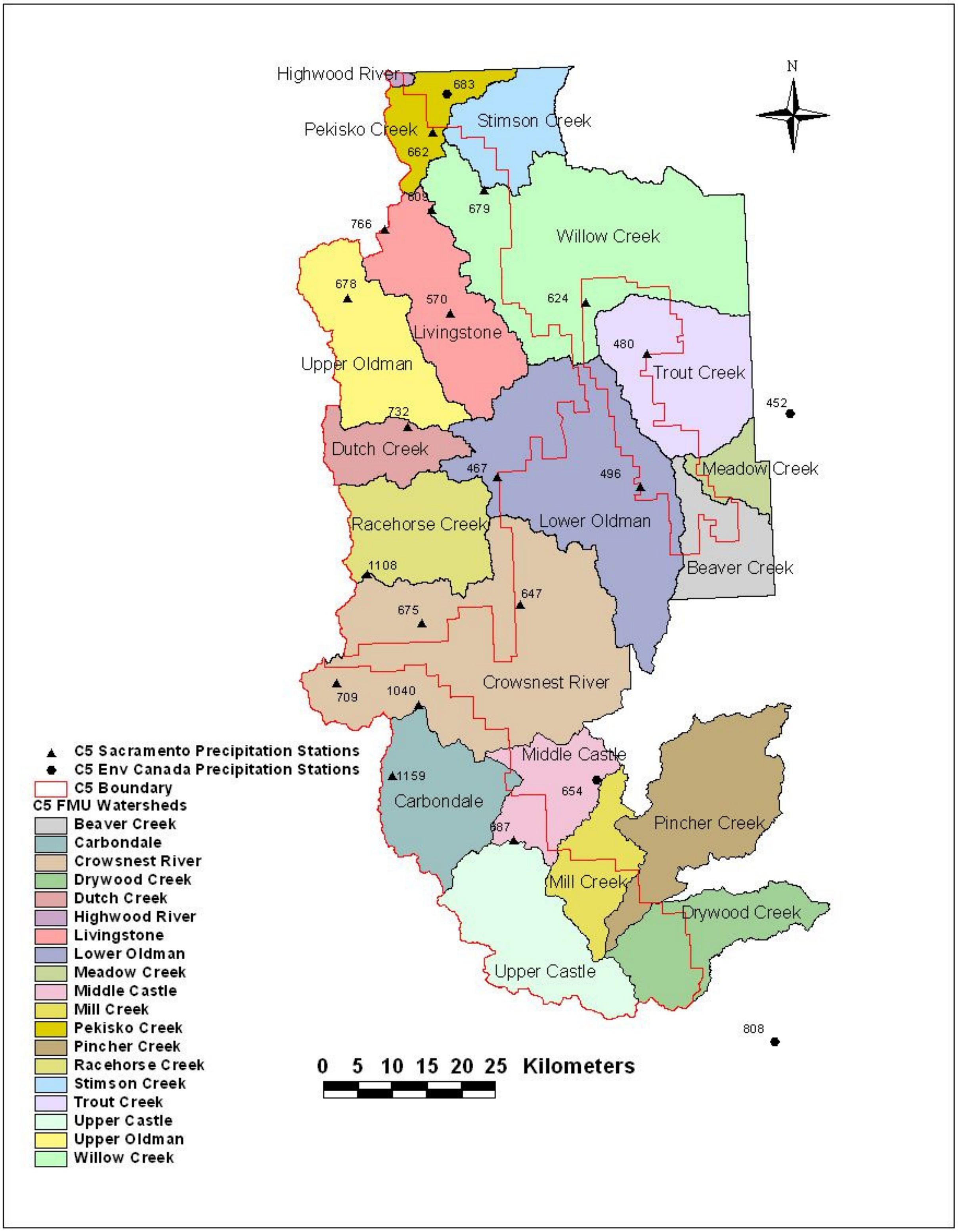



**Figure 4 Map of the C5 FMU showing the distribution of precipitation gauges used as inputs to the ECA-AB model**

## Table 1 C5 Watershed average annual precipitation inputs for the ECA-AB model

| Watershed | Station Name | Annual Precipitation (mm) | LFS_ID/Env. Can | Years of Data | Years | Elevation (m) | Years in operation |
|---|---|---|---|---|---|---|---|
| **Beaver Creek** | WEST PORCUPINE | 496 | E01 | 16 | 1986-2002 | 1448 | 43 |
| | **Basin Average** | **496** | | | | | |
| **Carbondale** | CASTLE RS | 687 | A01 | 17 | 1986-2002 | 1387 | 43 |
| | GOAT CREEK | 1159 | A11 | 16 | 1986-2002 | 1859 | 32 |
| | **Basin Average** | **923** | | | | | |
| **Crowsnest River** | ALLISON PASS | 1108 | B12 | 17 | 1986-2002 | 1981 | 42 |
| | COW CREEK | 647 | B08 | 16 | 1986-2002 | 1433 | 37 |
| | CROWSNEST CREE | 709 | B10 | 17 | 1986-2002 | 1463 | 42 |
| | SASKATOON MTN | 675 | B06 | 17 | 1986-2002 | 1768 | 42 |
| | YORK CREEK | 1040 | B03 | 17 | 1986-2002 | 1539 | 42 |
| | **Basin Average** | **858** | | | | | |
| **Drywood Creek** | CASTLE RS | 687 | A01 | 17 | 1986-2002 | 1387 | 43 |
| | WATERTON RIVER | 808 | Env. Can | | | 1281 | |
| | **Basin Average** | **748** | | | | | |
| **Dutch Creek** | ALLISON PASS | 1108 | B12 | 17 | 1986-2002 | 1981 | 42 |
| | SUGARLOAF S.E. | 732 | C07 | 17 | 1986-2002 | 1875 | 33 |
| | LIVINGSTONE GA | 467 | C13 | 17 | 1986-2002 | 1417 | 42 |
| | **Basin Average** | **600** | | | | | |
| **Highwood River** | PEKISKO | 683 | Env. Can | | | 1439 | |
| | PEKISKO | 662 | D04 | 17 | 1986-2002 | 1539 | 39 |
| | **Basin Average** | **673** | | | | | |
| **Livingstone** | COAT CREEK | 570 | C14 | 17 | 1986-2002 | 1646 | 41 |
| | LIVINGSTONE GA | 467 | C13 | 17 | 1986-2002 | 1417 | 42 |
| | HAILSTONE BUTT | 609 | D02 | 17 | 1986-2002 | 2362 | 34 |
| | WILKINSON SUMM | 766 | G07 | 17 | 1986-2002 | 1981 | 29 |
| | **Basin Average** | **688** | | | | | |
| **Lower Oldman** | COAT CREEK | 570 | C14 | 17 | 1986-2002 | 1646 | 41 |
| | LIVINGSTONE GA | 467 | C13 | 17 | 1986-2002 | 1417 | 42 |
| | SUGARLOAF S.E. | 732 | C07 | 17 | 1986-2002 | 1875 | 33 |
| | WEST PORCUPINE | 496 | E01 | 16 | 1986-2002 | 1448 | 43 |
| | **Basin Average** | **614** | | | | | |
| **Meadow Creek** | WEST PORCUPINE | 496 | E01 | 16 | 1986-2002 | 1448 | 43 |
| | CLARESHOLM MEA | 452 | Env. Can | | | 1052 | |
| | **Basin Average** | **474** | | | | | |
| **Middle Castle** | CASTLE RS | 687 | A01 | 17 | 1986-2002 | 1387 | 43 |
| | BEAVER MINES | 654 | Env. Can | | | 1286 | |
| | **Basin Average** | **671** | | | | | |
| **Mill Creek** | CASTLE RS | 687 | A01 | 17 | 1986-2002 | 1387 | 43 |
| | BEAVER MINES | 654 | Env. Can | | | 1286 | |
| | **Basin Average** | **671** | | | | | |
| **Pekisko Creek** | PEKISKO | 683 | Env. Can | | | 1439 | |
| | PEKISKO | 662 | D04 | 17 | 1986-2002 | 1539 | 39 |
| | **Basin Average** | **673** | | | | | |
| **Pincher Creek** | CASTLE RS | 687 | A01 | 17 | 1986-2002 | 1387 | 43 |
| | BEAVER MINES | 654 | Env. Can | | | 1286 | |
| | **Basin Average** | **671** | | | | | |
| **Racehorse Creek** | LIVINGSTONE GA | 467 | C13 | 17 | 1986-2002 | 1417 | 42 |
| | SUGARLOAF S.E. | 732 | C07 | 17 | 1986-2002 | 1875 | 33 |
| | ALLISON PASS | 1108 | B12 | 17 | 1986-2002 | 1981 | 42 |
| | **Basin Average** | **920** | | | | | |
| **Stimson Creek** | WILLOW CREEK R | 679 | D01 | 17 | 1986-2002 | 1494 | 39 |
| | **Basin Average** | **679** | | | | | |
| **Trout Creek** | EAST PORCUPINE | 480 | F01 | 16 | 1986-2002 | 1372 | 41 |
| | **Basin Average** | **480** | | | | | |
| **Upper Castle** | CASTLE RS | 687 | A01 | 17 | 1986-2002 | 1387 | 43 |
| | GOAT CREEK | 1159 | A11 | 16 | 1986-2002 | 1859 | 32 |
| | **Basin Average** | **923** | | | | | |
| **Upper Oldman** | COAT CREEK | 570 | C14 | 17 | 1986-2002 | 1646 | 41 |
| | SUGARLOAF S.E. | 732 | C07 | 17 | 1986-2002 | 1875 | 33 |
| | OYSTER CREEK | 678 | C10 | 17 | 1986-2002 | 1829 | 41 |
| | **Basin Average** | **660** | | | | | |
| **Willow Creek** | WILLOW CREEK R | 679 | D01 | 17 | 1986-2002 | 1494 | 39 |
| | HAPPY VALLEY | 624 | F02 | 16 | 1986-2002 | 1402 | 30 |
| | **Basin Average** | **652** | | | | | |

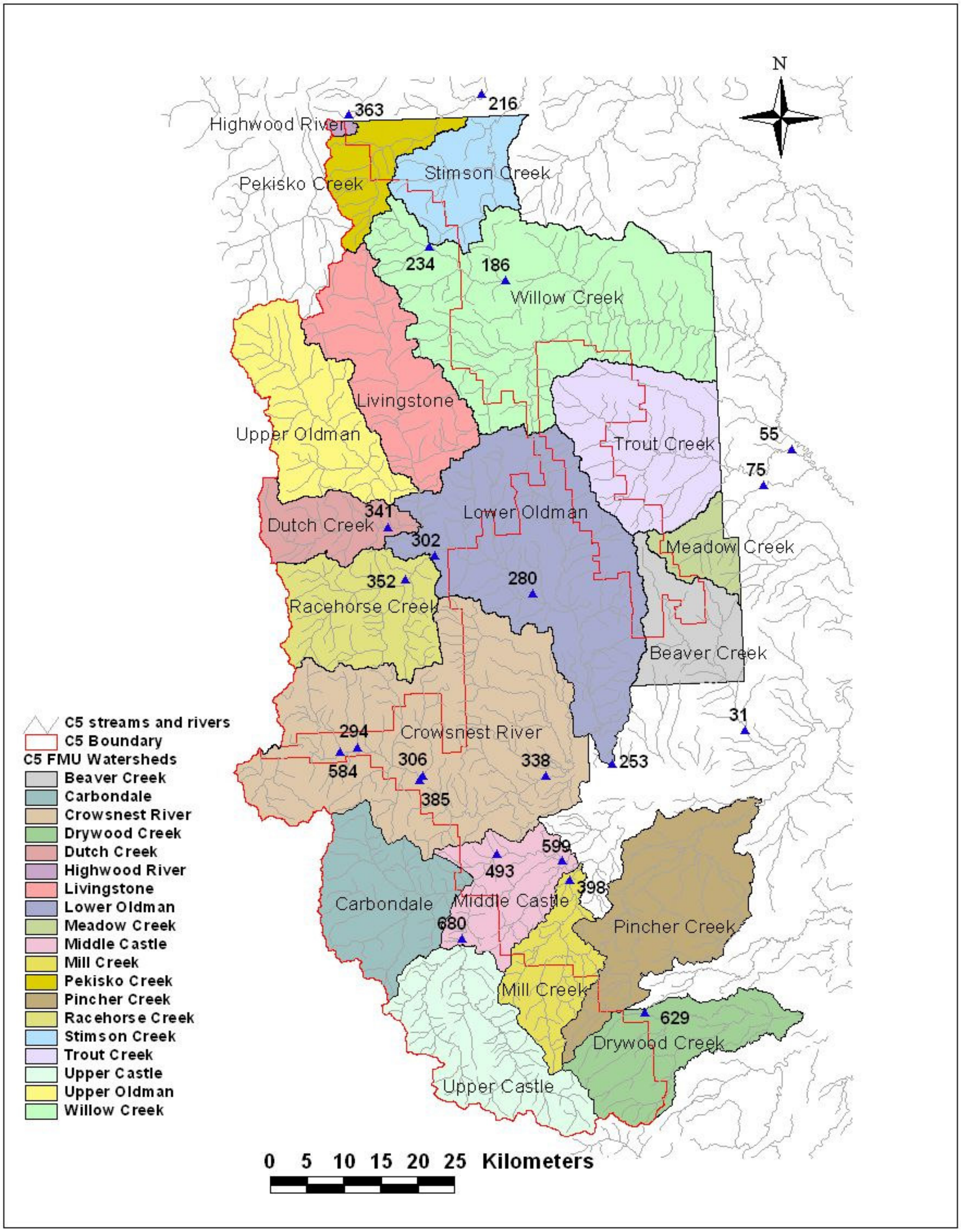



**Figure 5 Map of the C5 FMU showing the distribution of streamflow monitoring sites used as inputs in the ECA-AB model**

## Table 2   C5 Watershed average annual water yield inputs for the ECA-AB model

| Watershed | Sation Number | Station Name | Watershed Area(km2) | Annual Yield(mm) | PERIOD |
|---|---|---|---|---|---|
| **Beaver Creek** | 05AB013 | BEAVER CREEK NEAR BROCKET | 255.81 | 31 | 1913-1986 |
| | 05AB006 | MEADOW CREEK AT HART'S RANCH | 101.69 | 75 | 1908-1923 |
| | | | **Basin Average** | **53** | |
| **Carbondale** | 05AA015 | CASTLE RIVER AT MCDONALD'S RANCH | 759.46 | 493 | 1916-1945 |
| | 05AA022 | CASTLE RIVER NEAR BEAVER MINES | 820.55 | 599 | 1945-2003 |
| | | | **Basin Average** | **546** | |
| **Crowsnest River** | 05AA013 | MCGILLIVRAY CREEK NEAR COLEMAN | 32.46 | 294 | 1921-2003 |
| | 05AA009 | CROWSNEST RIVER NEAR COLEMAN | 162.21 | 584 | 1910-1916 |
| | 05AA030 | GOLD CREEK NEAR FRANK | 63.32 | 306 | 1975-2003 |
| | 05AA008 | CROWSNEST RIVER AT FRANK | 403.02 | 385 | 1910-2003 |
| | 05AA002 | CROWSNEST RIVER NEAR LUNDBRECK | 675.50 | 338 | 1908-1931 |
| | | | **Basin Average** | **381** | |
| **Drywood Creek** | 05AD016 | DRYWOOD CREEK NEAR TWIN BUTTE | 30.56 | 629 | 1935-1986 |
| | | | **Basin Average** | **629** | |
| **Dutch Creek** | 05AA026 | DUTCH CREEK NEAR THE MOUTH | 142.58 | 341 | 1966-1995 |
| | | | **Basin Average** | **341** | |
| **Highwood River** | 05BL019 | HIGHWOOD RIVER AT DIEBEL'S RANCH | 773.64 | 363 | 1950-2003 |
| | | | **Basin Average** | **363** | |
| **Livingstone** | 05AA021 | OLDMAN RIVER AT THE GAP | 1205.29 | 302 | 1944-1949 |
| | 05AA026 | DUTCH CREEK NEAR THE MOUTH | 142.58 | 341 | 1966-1995 |
| | | | **Basin Average** | **322** | |
| **Lower Oldman** | 05AA023 | OLDMAN RIVER WALDRON'S CORNER | 1445.93 | 280 | 1949-2003 |
| | 05AA021 | OLDMAN RIVER AT THE GAP | 1205.29 | 302 | 1944-1949 |
| | 05AA001 | OLDMAN RIVER NEAR COWLEY | 1938.00 | 253 | 1908-1949 |
| | | | **Basin Average** | **278** | |
| **Meadow Creek** | 05AB006 | MEADOW CREEK AT HART'S RANCH | 101.69 | 75 | 1908-1923 |
| | | | **Basin Average** | **75** | |
| **Middle Castle** | 05AA015 | CASTLE RIVER AT MCDONALD'S RANCH | 759.46 | 493 | 1916-1945 |
| | | | **Basin Average** | **493** | |
| **Mill Creek** | 05AA011 | MILL CREEK NEAR THE MOUTH | 178.91 | 398 | 1910-1986 |
| | 05AA028 | CASTLE RIVER AT RANGER STATION | 375.25 | 680 | 1967-2003 |
| | | | **Basin Average** | **539** | |
| **Pekisko Creek** | 05BL006 | PEKISKO CREEK AT PEKISKO | 202.78 | 216 | 1912-1931 |
| | 05BL019 | HIGHWOOD RIVER AT DIEBEL'S RANCH | 773.64 | 363 | 1950-2003 |
| | | | **Basin Average** | **290** | |
| **Pincher Creek** | 05AD016 | DRYWOOD CREEK NEAR TWIN BUTTE | 30.56 | 629 | 1935-1986 |
| | | | **Basin Average** | **629** | |
| **Racehorse Creek** | 05AA027 | RACEHORSE CREEK NEAR THE MOUTH | 217.65 | 352 | 1966-2003 |
| | | | **Basin Average** | **352** | |
| **Stimson Creek** | 05BL006 | PEKISKO CREEK AT PEKISKO | 202.78 | 216 | 1912-1931 |
| | 05AB040 | WILLOW CREEK AT SECONDARY 532 | 65.32 | 234 | 1996-2003 |
| | | | **Basin Average** | **225** | |
| **Trout Creek** | 05AB028 | WILLOW CREEK ABOVE CHAIN LAKES | 161.68 | 186 | 1965-1995 |
| | 05AB005 | TROUT CREEK NEAR GRANUM | 440.83 | 55 | 1908-2003 |
| | | | **Basin Average** | **121** | |
| **Upper Castle** | 05AA028 | CASTLE RIVER AT RANGER STATION | 375.25 | 680 | 1967-2003 |
| | | | **Basin Average** | **680** | |
| **Upper Oldman** | 05AA021 | OLDMAN RIVER AT THE GAP | 1205.29 | 302 | 1944-1949 |
| | 05AA026 | DUTCH CREEK NEAR THE MOUTH | 142.58 | 341 | 1966-1995 |
| | | | **Basin Average** | **322** | |
| **Willow Creek** | 05AB040 | WILLOW CREEK AT SECONDARY 532 | 65.32 | 234 | 1996-2003 |
| | 05AB028 | WILLOW CREEK ABOVE CHAIN LAKES | 161.68 | 186 | 1965-1995 |
| | | | **Basin Average** | **210** | |

## ECA Alberta Simulations

The watersheds within the C5 FMU range in size from 7.2 km$^2$ to 1023 km$^2$ with an average of approximately 350km$^2$ (Table 3). Five of the 19 watersheds lie entirely within the C5 boundary and 10 watersheds have less than half of their area within the FMU. Historic harvesting was present in 13 watersheds (prior to 2006), and ranged from 0.1% (Willow Creek) to 23.2% (Dutch Creek) of the total watershed area within the FMU harvested. Proposed harvesting within the next 20 years (phase 1 2006-2026) ranged from 0% (Drywood, Highwood, Meadow, Pekisko, and Pincher, and Upper Castle Creek watersheds) to 12.1% in the Racehorse Creek watershed. By the end of the planning horizon (phase 2 2105), the proposed watershed areas harvested in the 19 C5 watersheds ranged from 0.5% (Pincher Creek) to 55.2% (Dutch Creek) (Table 3).

**Table 3 Historic and proposed harvesting (% of total watershed area) within each of the 19 C5 watersheds**

| Watersheds | Total Area ha | Area in C5 | % in C5 | Area of Watershed Harvested % | | | |
|---|---|---|---|---|---|---|---|
| | | | | Prior to 2006 | Historic and Proposed at 2026 | New Harvesting 2006-2026 | Total at 2105 |
| Beaver Creek | 20108 | 6446 | 32 | 3.7% | 4.2% | 0.4% | 19.4% |
| Carbondale Ck | 30934 | 29397 | 95 | 6.5% | 11.9% | 5.4% | 31.0% |
| Crowsnest River | 102286 | 41075 | 40 | 1.9% | 6.5% | 4.6% | 15.5% |
| Drywood Creek | 28473 | 13021 | 46 | 0.0% | 0.0% | 0.0% | 2.2% |
| Dutch Creek | 15551 | 15551 | 100 | 23.2% | 31.3% | 8.1% | 55.2% |
| Highwood River | 721 | 454 | 63 | 0.0% | 0.0% | 0.0% | 12.9% |
| Livingstone | 35890 | 35890 | 100 | 5.4% | 16.5% | 11.1% | 24.0% |
| Lower Oldman | 77674 | 30226 | 39 | 1.5% | 3.4% | 1.8% | 10.7% |
| Meadow Creek | 9166 | 1167 | 13 | 0.0% | 0.0% | 0.0% | 2.5% |
| Middle Castle | 21120 | 6129 | 29 | 3.7% | 8.8% | 5.0% | 17.8% |
| Mill Creek | 19038 | 10538 | 55 | 2.3% | 5.1% | 2.8% | 16.2% |
| Pekisko Creek | 14448 | 7883 | 55 | 0.0% | 0.0% | 0.0% | 7.3% |
| Pincher Creek | 43440 | 3011 | 7 | 0.0% | 0.0% | 0.0% | 0.5% |
| Racehorse Creek | 30584 | 30584 | 100 | 14.0% | 26.0% | 12.1% | 47.0% |
| Stimson Creek | 20701 | 3576 | 17 | 0.0% | 0.7% | 0.7% | 6.0% |
| Trout Creek | 40385 | 16701 | 41 | 1.1% | 5.6% | 4.5% | 17.9% |
| Upper Castle | 37166 | 37166 | 100 | 4.5% | 4.5% | 0.0% | 31.0% |
| Upper Oldman | 34376 | 34376 | 100 | 8.7% | 17.0% | 8.3% | 33.2% |
| Willow Creek | 90903 | 26310 | 29 | 0.1% | 3.2% | 3.1% | 7.6% |

Simulated maximum increases in water yield for all except one watershed were very low with values ranging from 1-4% in 10 watersheds, and less than 1% in 8 watersheds (Table 4). These values in practical terms are close to zero indicating an almost nil response to harvesting. The primary reason for these low responses is that these watersheds are located in a high precipitation and runoff zone. Annual runoff in the region averages from 31-680 mm/year (Table 2). The addition of an extra 1-9 mm of extra water to these streams is relatively small.

The only exception to the above was Beaver Creek where the simulated water yield increase was 13.8% (11.1 mm) (Table 4, Figure 6). The larger increase was largely due to low level of water yield from this watershed, which is more of a prairie than forest environment. The long term average water yield for Beaver Creek is 31 mm/year. Annual precipitation at Beaver Creek is 496 mm compared to values of 600-923 mm in many of the other watersheds in the C5 FMU (Table 1).

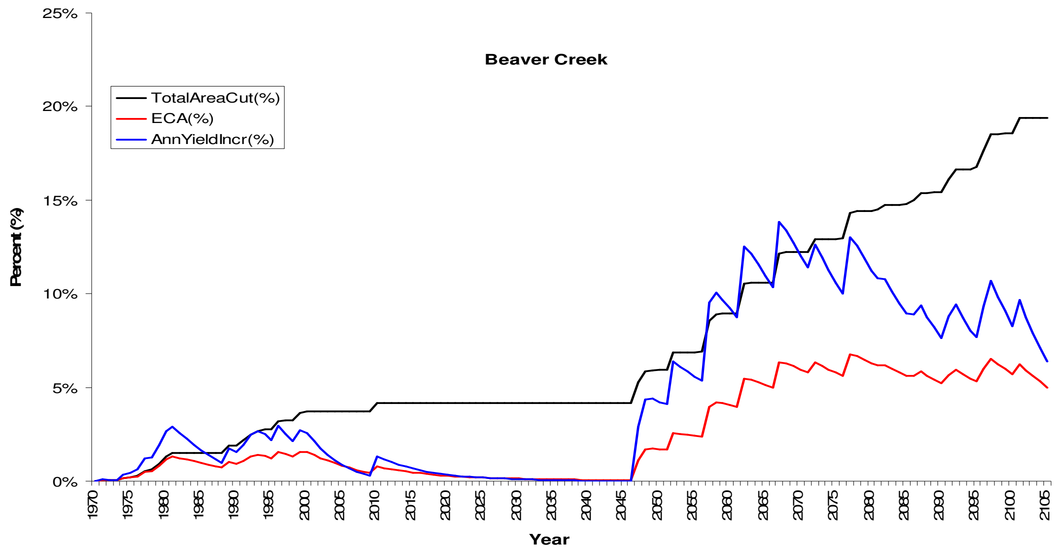
The levels of disturbance in the 19 watersheds in terms of %ECA was small, because of the low amount of harvesting in the watersheds and long intervals of 20-40 years between phase 1 and 2 harvesting (2006-2026 and 2026-2105) which favored hydrologic recovery. Maximum values of %ECA occurred during periods of concentrated harvesting. Maximum annual %ECA ranged from 0.2% to 10.0% (Pincher Creek and Dutch/Highwood River watersheds respectively) (Table 4).

**Table 4** Simulated Annual Yield and ECA outputs for the 19 C5 Watersheds sorted maximum to minimum for percent increases and yield increases (mm).

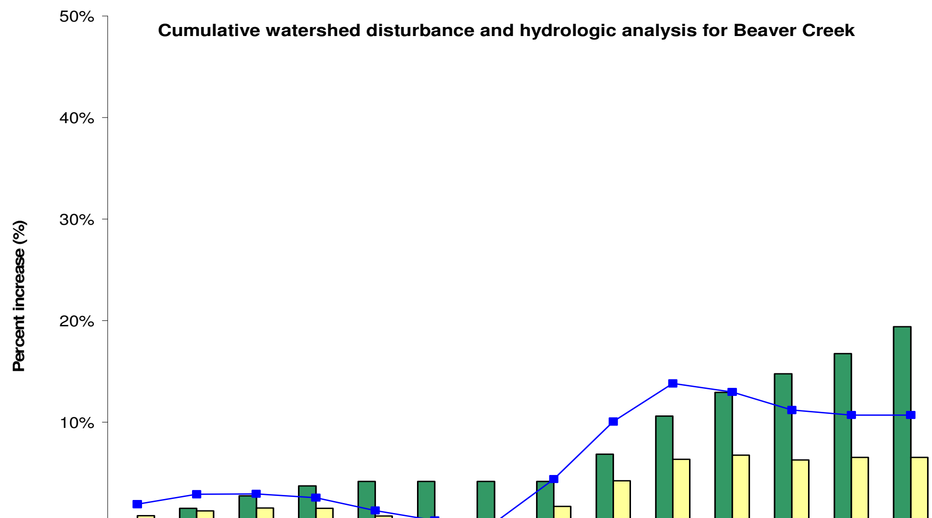
| Watershed | Max ECA(%) | Max yield Increase(%) | Watershed | Max ECA(%) | Max yield increase(mm) |
|---|---|---|---|---|---|
| Beaver Creek | 6.8% | 13.8% | Racehorse Creek | 8.1% | 11.1 |
| Trout Creek | 5.3% | 3.9% | Highwood River | 10.0% | 9.0 |
| Racehorse Creek | 8.1% | 3.2% | Beaver Creek | 6.8% | 7.3 |
| Highwood River | 10.0% | 2.5% | Livingstone | 7.5% | 6.6 |
| Meadow Creek | 1.7% | 2.2% | Dutch Creek | 10.0% | 6.4 |
| Livingstone | 7.5% | 2.0% | Upper Oldman | 7.1% | 5.7 |
| Dutch Creek | 10.0% | 1.9% | Carbondale | 6.5% | 5.4 |
| Upper Oldman | 7.1% | 1.8% | Trout Creek | 5.3% | 4.7 |
| Pekisko Creek | 4.0% | 1.4% | Crowsnest River | 3.4% | 4.3 |
| Crowsnest River | 3.4% | 1.1% | Pekisko Creek | 4.0% | 4.2 |
| Carbondale | 6.5% | 1.0% | Upper Castle | 6.2% | 3.7 |
| Stimson Creek | 1.7% | 0.9% | Stimson Creek | 1.7% | 2.1 |
| Willow Creek | 1.8% | 0.9% | Lower Oldman | 2.4% | 2.0 |
| Lower Oldman | 2.4% | 0.7% | Willow Creek | 1.8% | 1.8 |
| Upper Castle | 6.2% | 0.5% | Meadow Creek | 1.7% | 1.7 |
| Middle Castle | 2.7% | 0.3% | Middle Castle | 2.7% | 1.3 |
| Mill Creek | 3.8% | 0.2% | Mill Creek | 3.8% | 1.2 |
| Drywood Creek | 1.2% | 0.1% | Drywood Creek | 1.2% | 0.4 |
| Pincher Creek | 0.2% | 0.004% | Pincher Creek | 0.2% | 0.02 |

The order of simulated increases (i.e. maximum to minimum) based on extra mm of flow and percentages are not in full agreement (Table 4) because of differences in average annual yields between watersheds. This is not uncommon when comparing relative (%) and absolute (mm) increases. Examination of the results however shows similar a grouping between watersheds with large and small increases in annual yield. In hydrologic terms the use of mm of extra flow is more correct, but percentages are commonly used as they are more easily interpreted and understood by most people.

**A**




**B**




| | 1975 | 1985 | 1995 | 2005 | 2015 | 2025 | 2035 | 2045 | 2055 | 2065 | 2075 | 2085 | 2095 | 2105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumulative area cut (%) | 0.19% | 1.52% | 2.76% | 3.73% | 4.16% | 4.16% | 4.16% | 4.16% | 6.87% | 10.61% | 12.93% | 14.78% | 16.76% | 19.41% |
| 10-yr Max ECA (%) | 0.81% | 1.29% | 1.55% | 1.53% | 0.78% | 0.28% | 0.12% | 1.72% | 4.23% | 6.34% | 6.76% | 6.27% | 6.53% | 6.53% |
| 10-yr Max Yield Increase (%) | 1.92% | 2.90% | 2.95% | 2.57% | 1.31% | 0.32% | 0.10% | 4.39% | 10.07% | 13.81% | 12.99% | 11.20% | 10.71% | 10.71% |

**Figure 6 ECA-AB output for Beaver Creek. Graph A illustrates simulated increases in annual water yield, total area harvested and %ECA in the watershed. Water yield increases for historic harvesting was less than 5%. Harvesting in phase 1 of the Preferred C5 Scenario (2006 – 2026) was small producing a water yield increase of ~3%. A maximum increase in simulated water yield of 13.8% occurred in phase 2 around 2065. Frequent harvest entries starting at 2045 produce a "stepped" pattern for increases in water yield and % ECA. Increases in water yield decline after 2065. %ECA from 2065 remains relatively constant because of repeated harvest entries which slowed hydrologic recovery.**

**Graph B shows decadal averages for area cut, simulated water yield increases and % ECA. The 10-year averages reduce year to year variability and show water yield on averaged 10%-14% for the period 2065-2085. %ECA for the same period averaged ~ 6.5%. (See Appendix 1 for results on other watersheds)**

The simulation results in Table 5 are expressed in 10-year averages to provide an expression of the medium to long term effects of harvesting on water yield. Maximum increases usually occur in the first to second year after harvesting and do not give an indication of the persistence or duration of impacts for the medium and long term.

The 10-year averages show low to nil levels for %ECA (disturbance) and water yield increases for all watersheds except Beaver Creek (Appendix 1). %ECA in the majority of watersheds varied from less than 1% up to 6%. 10-year averages for water yield increases ranged from 0% to 2%. Again the low response in these values is a reflection of the low level of harvesting and timing of harvesting in the watersheds in a region of high precipitation and runoff.

Responses in Beaver Creek were larger. The simulated water yield increase of 13.8% was more noticed in the 10-year averages. The maximum increase in water yield occurred in the second phase of the proposed harvesting (2026-2100) where 10-year averages ranged from 4.4% in 2045 to maximums of 13.8% -12.99 in 2065-2075 and declined afterwards to 10.7% in 2105. The use of 10-year averages in Beaver Creek shows that the simulated increase in water yield was sustained by frequent harvesting in the watershed (Watershed Summary Beaver Creek Figure 1). In contrast the effects of earlier harvesting in Beaver Creek (1975-2005) disappeared by 2025.

**Table 5 Simulated 10-year average yield and ECA Outputs for the 19 C5 Watersheds sorted maximum to minimum for 10-year averages of maximum %ECA, % yield increase and yield increase in mm.** `

| Watershed | Max 10-yr avg ECA Increase(%) | Watershed | Max 10-yr avg Yield Increase(%) | Watershed | Max 10-yr avg Yield Increase(mm) |
|---|---|---|---|---|---|
| Highwood River | 8.0% | Beaver Creek | 11.7% | Racehorse Creek | 8.6 |
| Dutch Creek | 7.6% | Trout Creek | 3.1% | Beaver Creek | 6.2 |
| Livingstone | 6.7% | Racehorse Creek | 2.4% | Highwood River | 5.8 |
| Racehorse Creek | 6.4% | Livingstone | 1.7% | Livingstone | 5.5 |
| Upper Oldman | 6.2% | Highwood River | 1.6% | Upper Oldman | 4.8 |
| Beaver Creek | 6.1% | Meadow Creek | 1.5% | Dutch Creek | 4.6 |
| Carbondale | 5.5% | Upper Oldman | 1.5% | Carbondale | 4.5 |
| Upper Castle | 5.4% | Dutch Creek | 1.3% | Trout Creek | 3.8 |
| Trout Creek | 4.4% | Carbondale | 0.8% | Crowsnest River | 2.9 |
| Mill Creek | 3.4% | Crowsnest River | 0.8% | Upper Castle | 2.8 |
| Crowsnest River | 2.8% | Pekisko Creek | 0.8% | Pekisko Creek | 2.2 |
| Middle Castle | 2.5% | Willow Creek | 0.6% | Lower Oldman | 1.7 |
| Pekisko Creek | 2.3% | Stimson Creek | 0.6% | Stimson Creek | 1.4 |
| Lower Oldman | 2.3% | Lower Oldman | 0.6% | Willow Creek | 1.4 |
| Willow Creek | 1.4% | Upper Castle | 0.4% | Meadow Creek | 1.1 |
| Stimson Creek | 1.4% | Middle Castle | 0.2% | Middle Castle | 1.0 |
| Meadow Creek | 1.4% | Mill Creek | 0.2% | Mill Creek | 1.0 |
| Drywood Creek | 1.1% | Drywood Creek | 0.0% | Drywood Creek | 0.3 |
| Pincher Creek | 0.2% | Pincher Creek | 0.003% | Pincher Creek | 0.02 |

The time for hydrologic recovery among the 19 watersheds was highly variable (Table 6). Simulated increases in water yield for 10 of the watersheds was less 1%, which by the definition of hydrologic recovery used in this report means a nil response to forest harvesting. Another two watersheds were marginal with simulated increases slightly greater than 1%. Recovery under these conditions was 2-3 years. In the remaining 7 watersheds where simulated water yield increases were
greater than 1.5%, recovery occurred in 7 to 74 years. The time to recovery in these watersheds varied with the frequency of harvesting. The long delay in reaching hydrologic recovery in 5-6 watersheds was caused by frequent low levels of harvesting late in the simulation runs.

**Table 6 Hydrologic recovery for watersheds was defined to occur when simulated water yield was less than 1%. Recovery was measured from year of peak yield(s) to time of recovery. Watersheds with simulated increases < 1% are marked as nil. Estimates with a "+" indicate that a longer simulation period was needed.**

| Watershed | Hydrologic Recovery years |
|---|---|
| Beaver Creek | 9, 38+ |
| Carbondale | Nil |
| Crowsnest River | Nil |
| Drywood Creek | Nil |
| Dutch Creek | 17 |
| Highwood River | 8 |
| Livingstone | 15 |
| Lower Oldman | Nil |
| Meadow Creek | 43+ |
| Middle Castle | Nil |
| Mill Creek | Nil |
| Pekisko Creek | 3 |
| Pincher Creek | Nil |
| Racehorse Creek | 8+ |
| Stimson Creek | Nil |
| Trout Creek | 64 |
| Upper Castle | Nil |
| Upper Oldman | 47 |
| Willow Creek | Nil |

A more complete description of the ECA-AB model results, including the timing of (year/decade) maximum annual and 10-year average %ECA as well as simulated yield increases (% and mm) for each watershed is provided in Appendix 1 ECA Alberta Individual Watershed Summaries.

## ECA-AB Statistical Analysis

The hydrologic effect of the Preferred C5 Scenario was evaluated in terms of simulated increases in annual water yield for the three watersheds with the largest simulated yield increases (Beaver Creek 13.8%, Racehorse Creek 3.2%, and Trout Creek 3.9%).The upper 95% confidence limit was used to determine if simulated increases in annual water yield were significantly greater ($\alpha$=0.05) than the long-term average water yield for a watershed (i.e. base yield).

Figure 7 shows the history of annual water yields for Beaver Creek near Brocket (1921-2003). The long term average annual water yield was used as a reference to test for a significant increase in water yield. The average water yield for Beaver Creek is 31mm /year, and the variability of annual yield is large with values ranging from 4mm to 116 mm. A maximum simulated increase of 13.8% for Beaver Creek was not large enough to make post harvest annual yield (31*1.138 = 35 mm) significantly different ($\alpha$=0.05) from the long-term average annual yield. An increase equal to or greater than 29% (40 mm) was required to significantly exceed the long term average annual water yield for Beaver Creek.

Figure 8 shows the annual water yields for Racehorse Creek near its mouth (1966-2003). The average annual yield for this watershed is 352 mm/year, with annual values ranging from 150 mm to 636 mm. A maximum simulated increase of 3.2% (7 mm) for Racehorse was not large enough to make post harvest annual yield (352 *1.032 = 363) significantly different ($\alpha$=0.05) from the long term average annual yield. An increase equal to or greater than 11% (yield =391 mm) was required to significantly exceed the long term average annual water yield for Racehorse Creek..

Figure 9 shows the annual water yields for Trout Creek near Granum (1908-2003). The average annual water yield for this watershed is 55 mm/year, with values ranging from 6mm to 196 mm. A maximum simulated increase in annual yield of 3.9% (9 mm)for Trout Creek was not large enough to make post harvest annual yield (55*1.039=57mm) significantly different ($\alpha$=0.05) from the long-term average annual yield. An increase equal to or greater than 29% (55*1.29=71mm) was required to significantly exceed the long term average annual water yield for Trout Creek.

The simulated increases for all watersheds were also less than the informal "15%" rule often cited as a limit on increases in water yields. Adoption of a limit for increased water flows is a difficult task because of the high variability of annual and peak flows, and the absence of definitive data that links the effects of changes in flows to downstream flooding and changes in aquatic habitats. The "15%" rule was initially suggested (*by J. Taggert, Alberta Environment)* as the amount of water yield increase that could "be added to a unit hydrograph[3] (*for a watershed)* without an undue increase in peak flow" (Swanson 2002).

[3] A unit hydrograph is defined as, the discharge hydrograph of one inch of surface runoff distributed uniformly over the entire basin for a given time. In simple terms it represents the average hydrograph response for a watershed in response to a storm of given time (2-hour storm, 4 hour storm). The flow coordinates (y-axis) are normalized (unitized) such that they vary linearly with the volume of precipitation in a storm (e.g. if y inches of rainfall generates 1 inch of runoff, 2y precipitation generates 1 inches of runoff).

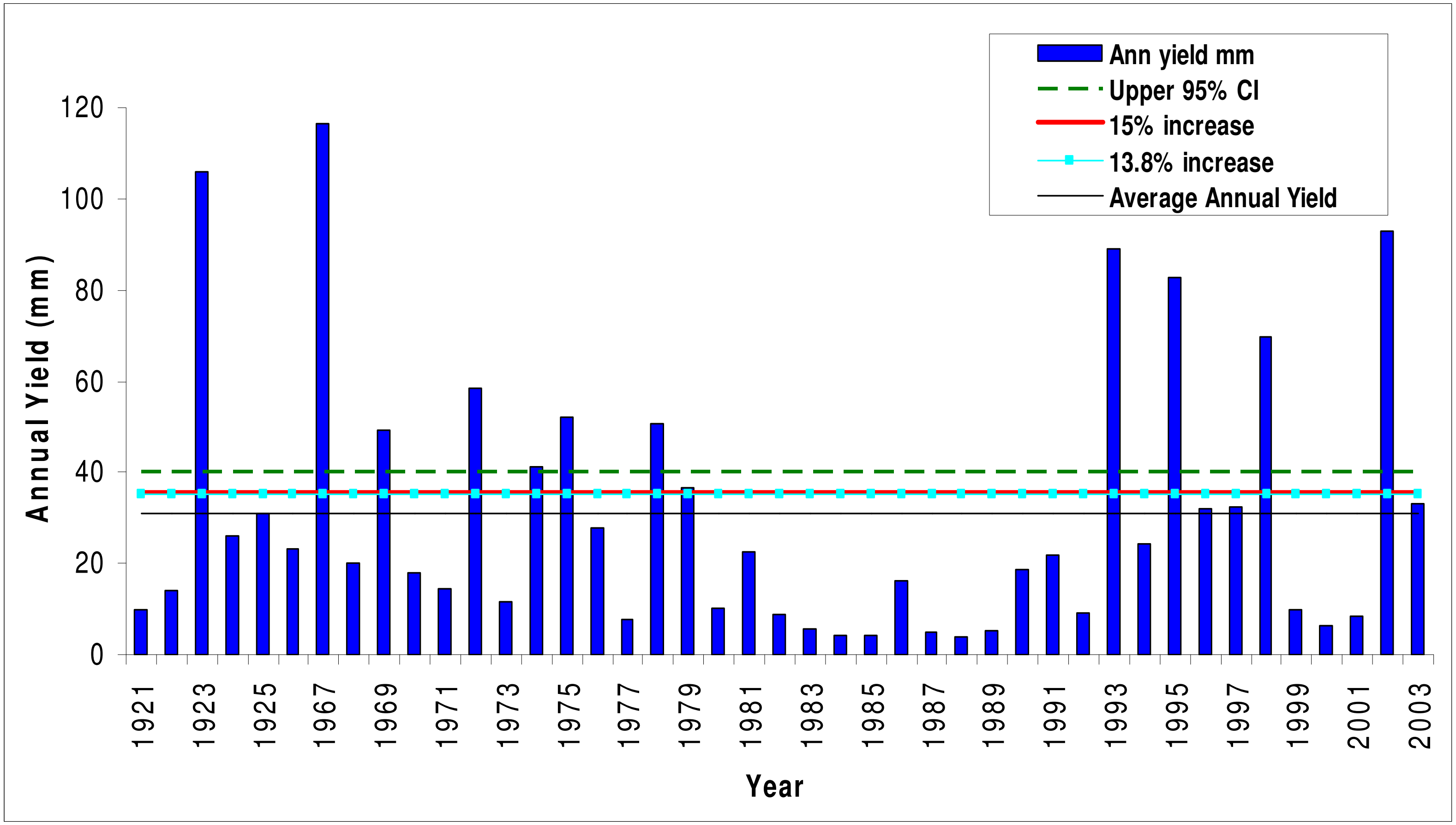



**Figure 7 Annual water yield for Beaver Creek near Brocket (1921-2003), average annual water yield, ECA-AB simulated increase in annual water yield with respect to an "informal "15%" rule and upper 95% confidence interval. Simulated 13.8% increase in water yield was less than "15%", and not significantly different from the average annual yield.**

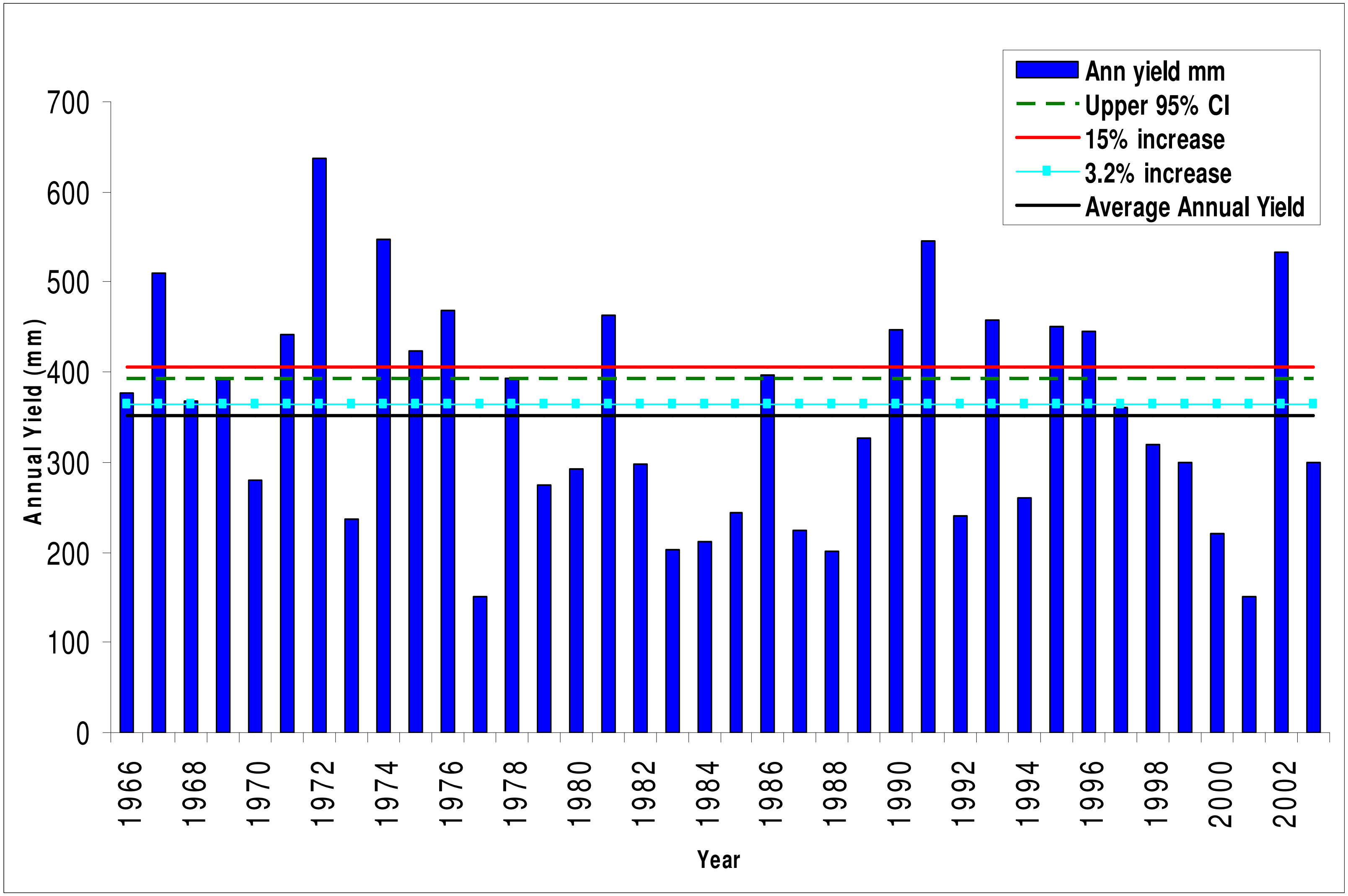



**Figure 8 Annual water yield, and average annual water yield (1966-2003) for Racehorse Creek near the mouth. ECA-AB simulated water yield increase, with respect to an informal "15%" rule and upper 95% confidence interval. Simulated 3.2% increase in water yield was less than "15%" and not significantly different from average annual yield.**

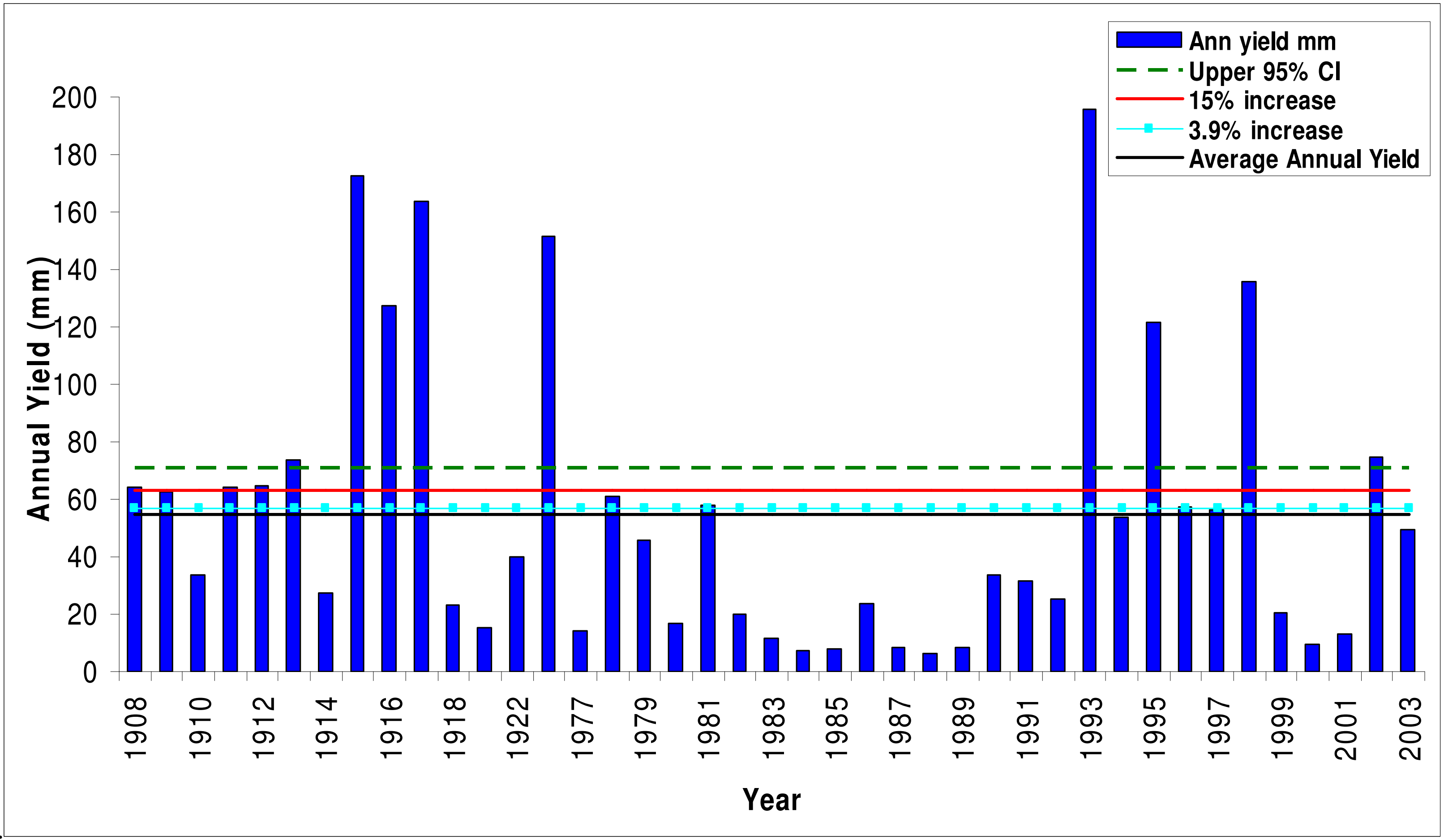



**Figure 9 Annual water yield and average annual water yield (1908-2003) for Trout Creek near Granum. ECA-AB simulated water yield increase, with respect to an informal "15%" rule and upper 95% confidence interval. Simulated 3.9% increase in water yield was less than "15%" and not significantly different from average annual yield.**

## ECA-AB Summary

The results from this analysis indicate that projected yield increases were very low, with absolute values ranging from less than 1 mm to a maximum of 11 mm. Percentages increases showed a similar trend with values of less than 1% up to 13.8%. It's likely that the small increases (<1%) in generated runoff will be retained as soil moisture or go to groundwater and not to the stream channel. However, if all extra water were routed to the stream channel, the increase in yields for all nineteen watersheds would not be significant and likely undetectable using standard hydrometric techniques.

The reasons for such small simulated increases were the low levels of historic and proposed harvesting in the watersheds and the high rates of annual runoff for the watersheds. The scheduling of low harvest levels in lower runoff watersheds and higher harvest levels in high runoff watershed further contributed to low responses. The addition of an extra 1 – 11 mm to annual flows of 400-680 mm makes for a small relative change in flow (i.e. percent change) In addition, the combination of limited entries for harvesting in the Preferred C5 Scenario and low harvest levels throughout the FMU allowed full hydrologic recovery in many of the watersheds.

A comparison of simulated water yield increases for historic (before 2006) and proposed harvesting (2006-2026 and 2026-2105) showed very small differences. Simulated water yield increases for historic harvesting in all watersheds were < 1%. Increases for the Preferred C5 Scenario were less than 2% in 13 watersheds, 2% to 4% in 5 watersheds and 13.8% in one watershed. The maximum increase was in Beaver Creek which also has the lowest water annual yield ($\Delta Q/\bar{x}$ x 100 = 11.1/31 x 100 = 13.8%). It should noted, that in low runoff regions, increases in water yield expressed as a percents will usually be greater than the same increases in a higher runoff region.

The statistical analysis for differences between simulated increases in water yield and the long term average water yield were variable among the watersheds tested. For example, in Beaver Creek and Trout Creek a 29% or greater increase (≥) in water yield was required to significantly ($\alpha$ = 0.5) exceed the long-term average yield. In contrast an increase of only ≥11% is required to exceed the long-term water yield in Racehorse Creek. These differences between watersheds are caused by the magnitude and variability of water yields among watersheds, and the expression of increases as percents.

In conclusion, the simulated increases in annual water yield for all watersheds were small, not significantly different from long term average flows, and would be extremely difficult to detect by normal hydrometric methods.

# WRENSS Results

## WRENSS Simulations

This section describes the results of the hydrologic analysis of 7 small sub-basins located in the Crowsnest Pass region of the C5 Forest Management Unit (Figure 3). The reason for this analysis was that the impacts of forest harvesting on water yield and peak flows are usually more noticeable in small watersheds where harvesting is more concentrated spatially and temporally. The hydrologic effects of the Preferred C5 Scenario on these watersheds were simulated using the WRENSS hydrologic model (Swanson, 2000)(Figure 10).

The sub-basins ranged in size from 9.4 km$^2$ (Pelletier Creek) to 56.1 km$^2$ (Allison Creek) with an average of approximately 36.5 km$^2$ (Table 7). Watersheds in the ECA-AB analysis averaged 350 km$^2$ in size. The percent area harvested in the watersheds over 130 years ranged from 16.5% (Crowsnest Creek) to 52.6% (McGillivary Creek).

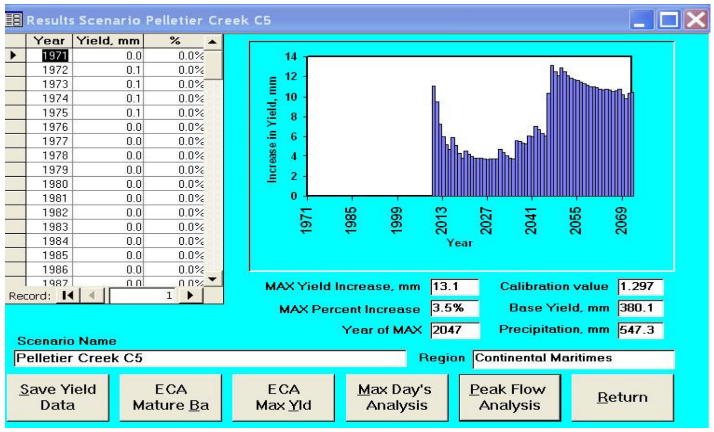
**Table 7 WRENSS output summary table for the seven sub-basins within the Crowsnest River watershed**

| | | | Maximum Increase in Annual Water Yield | | % Increases in Maximum Daily Flow for Recurrence Intervals years | | | | | | Maximum ECA (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Watershed** | **Area (km$^2$)** | **Area Cut (%)** | **%** | **mm** | **2** | **5** | **10** | **20** | **50** | **100** | |
| Star Creek | 18.8 | 52.5 | 2.2 | 8.2 | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 | 2.6 | 33.9 |
| Allison Creek | 56.1 | 37.7 | 2.6 | 9.8 | 2.3 | 2.4 | 2.5 | 2.6 | 2.7 | 2.7 | 30.6 |
| Pelletier Creek | 9.4 | 39.7 | 3.5 | 13.1 | 3.6 | 3.9 | 4.0 | 4.2 | 4.3 | 4.4 | 40.1 |
| York Creek | 32.3 | 39.4 | 1.6 | 6.0 | 1.4 | 1.5 | 1.6 | 1.7 | 1.7 | 1.7 | 31.8 |
| Crowsnest Creek | 54.5 | 16.5 | 0.6 | 2.5 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | 50.6 |
| Blairmore Creek | 51.1 | 41.4 | 3.0 | 11.5 | 3.1 | 3.3 | 3.4 | 3.5 | 3.7 | 3.7 | 38.9 |
| McGillivray | 33.5 | 52.6 | 3.2 | 12.0 | 2.3 | 2.5 | 2.6 | 2.7 | 2.8 | 2.9 | 29.9 |

The average annual water yield (i.e. baseline yield) for these watersheds in Crowsnest area is very high (225-629 mm/year), therefore the simulated percent increases in annual water yields were proportionally low. The maximum simulated water yield increases ranged from 0.6% (Crowsnest Creek) to 3.5% (Pelletier Creek), which generated an extra 2.5 to 13.1 mm/ year (Table 7.Figure 10). Simulated increases in four of the 7 watersheds occurred in phase 1 (2006-2026) of the Preferred C5 Scenario. Increases in the other three sub-basins occurred in phase 2 (2026-2105). Again the magnitude of increases was small for all watersheds.

Simulated changes in maximum daily flows were also low ranging from 0.1% (Crowsnest Creek) to 3.6% (Pelletier Creek) for the 2-yr recurrence interval storm and 0.2% (Crowsnest Creek) to 4.4% (Pelletier Creek) for the 100-yr storm flows. Increases of these magnitudes are difficult if not impossible to detect by direct measurement.

A

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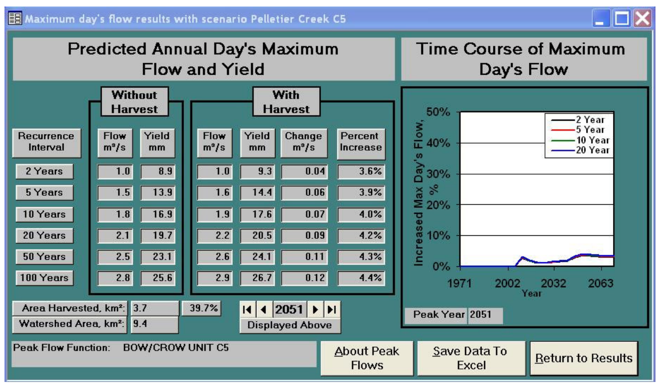


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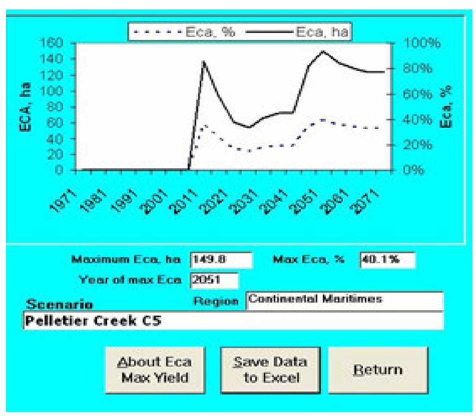


**Figure 10 WRENSS output for Pelletier Creek.**

**A Pelletier Creek had the greatest simulated increase in annual water yield. Watershed area is 9.4 km$^2$. Total area harvested in the watershed was 373 ha or 39.7%. Simulation was done in 1-year time steps for 101 years. Streamflow for the Crowsnest River at Frank was used as a base yield to calculate percent change in annual water yield. Precipitation input data was the long tem average for the town of Colman. An extra 13.1 mm of water was generated by the harvesting which was a 3.5% increase in annual water yield.**

**B Increases in maximum daily flows for Pelletier Creek ranged from 3.6% to 4.4% for recurrence interval events of 2 years to 100 years. Pre-harvest maximum daily flows varied from 1.0 m$^3$ to 2.8 m$^3$/sec compared to 1.04 m$^3$/sec to 2.9 m$^3$/sec after harvesting. The small differences in peak flows between without harvest and with harvest indicate a low to nil response to forest cover removal.**

**C %ECA based on water yield recovery. Maximum values correspond to period of harvesting. Decreasing values represent periods of hydrologic recovery with establishment and growth of forest regeneration.**

. The small differences in simulated increases among recurrence intervals suggested the Preferred C5 Scenario will have a small effect on maximum daily flows. Percent increases for the 2-10 year events are usually greater than those for the 20-100 year events. Larger increases in maximum daily flows would be expected in situations where the area harvested was greater and more concentrated in time.

Maximum $\%ECA_Q$ in the 7 sub-basins ranged from 30% (Allison Creek) to 60% (Pelletier Creek). The differences and variability in %ECA within and between these watersheds was determined by the extent and rate of harvesting (Appendix 2). In most of the watersheds there were multiple peaks in ECA associated with periods of harvesting. In some watersheds, especially those with small increases in water yield, ECA following harvesting declined rapidly to almost full hydrologic recovery in less than 5 years. (e.g. Crowsnest Creek page xx). In other watersheds ECA was sustained at levels of 10%-20% by frequent small harvests at short time intervals (e.g. Allison Creek page 71, York Creek page 79).

%ECA percentage in these simulations was based on the recovery of simulated water yield (Eq.2). ECA expressed this way is considered more correct hydrologically because it is a direct measure of how fast simulated increases in water yield change following harvesting. Further, ECA based on recovery of water yield is about one-half of that estimated with basal area. Maximum $\%ECA_Q$ in McGillivary Creek (**Error! Reference source not found.**) was 29% compared to 60% obtained with $ECA_{BA}$. Hydrologic recovery can also be sooner with $\%ECA_{Q.}$ Recovery in McGillivary Creek (time when $\%\Delta Q \leq 1\%$) was 7 years earlier (10% in 2109) than the $ECA_{BA}$ estimate (25% in 2115).

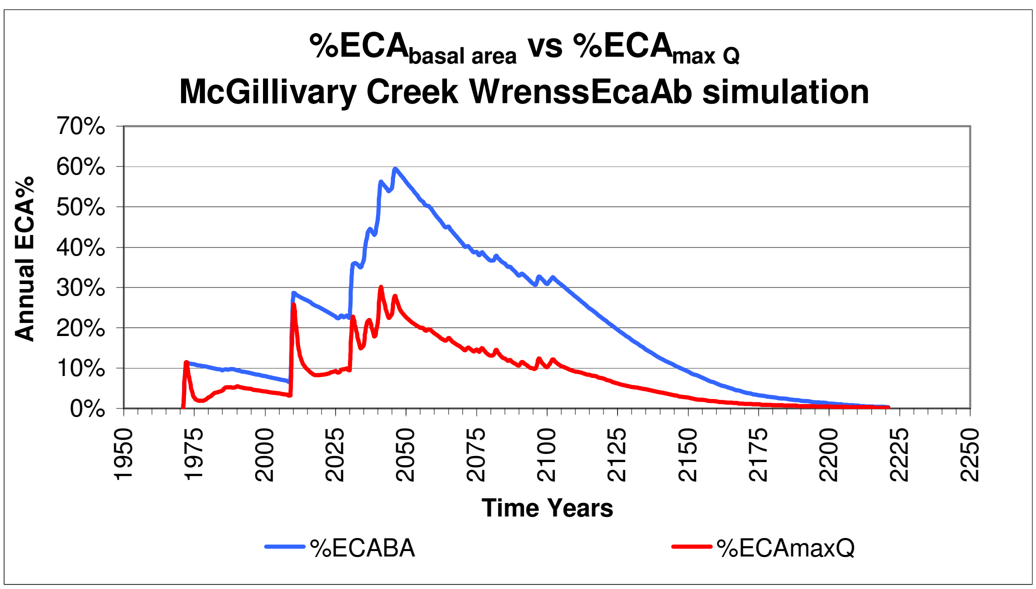


**Figure 11 % ECA for McGillivary Creek based on basal area and maximum increase in water yield. Maximum ECA based on recovery of water yield was 29% compared to 60% based on basal area.**

Hydrologic recovery in the 7 sub-basins was variable with values ranging from 6 to 71 years Table 8). The long time for recovery in some sub-basins may seem a surprise, given the small simulated water yield increases. Hydrologic recovery in these sub-basins was delayed by frequent harvesting following peak increases in water yield. In these simulations the delay in

most cases was not significant because increases in water yield were low and very close of recovery. However in other situations where increases are larger, frequent harvesting will delay recovery and maintain yield increases as an elevated level.

It is hypothesized by the authors that multiple harvests in watersheds should be spatially limited to produce “acceptable” water yield increases, and spaced time-wise to allow for significant hydrologic recovery. Acceptable increases in annual water yield would fall within the range of natural variability as defined by recurrence intervals equal to or less than 5 years. Based on an analysis of flows in the Grande Cache-Grande Prairie region (Watertight Solutions Ltd unpublished reports) this would keep increased annual water yields and peak flow within 15%-20% of “average conditions”. The time to hydrologic recovery would be used to decide the time for additional harvests in a watershed. Hydrologic recovery could be defined by the occurrence of maximum leaf area by the dominant harvested forest cover type in a watershed, or by an assumed increase in water yield (e.g. ≤ 5% or mm of extra water with respect to regional long term flows).

**Table 8 Hydrologic recovery for WRENSS simulations of 7 small sub-basins in the C5 FMU. Hydrologic recovery estimated as difference between time maximum increases in water yield and time when increase in water yield ≤1%. Blank entries were watersheds where simulated water yield increases were less than 1% (i.e. a nil response to harvesting).**

| Watershed | Hydrologic recovery years |
|---|---|
| Star Creek | 44 |
| Allison Creek | 6, 40 |
| Pelletier Creek | 50 |
| York Creek | 33 |
| Crowsnest Creek | |
| Blairmore Creek | 17 |
| McGillivery Creek | 71 |

## WRENSS Statistical Analysis

The hydrologic effects of the Preferred C5 Scenario were evaluated for the sub-basin with the largest simulated yield increase (Pelletier Creek). The upper 95% confidence intervals were used to determine if the simulated increases in annual water yield was significantly different ($\alpha$=0.05) from the long-term average water yield (i.e. base yield).

Annual water yield for the Crowsnest River near Frank (1910-2003) was used as a representative base yield for all seven sub-basins. The average annual flow for this watershed is 385 mm/year, with values ranging from 172 mm/year to 635 mm/year.

The simulated maximum increase in annual water yield for Pelletier Creek of 3.5% (385*1.035 = 398 mm) was not large enough to make a post harvest annual water yield significantly different from the long term average water yield of the Crowsnest River. This was also the case for the other 6 sub-basins. An increase equal to or greater than 6.6% (385*1.066 =

410) was required to significantly exceed the long term average water yield of Crowsnest River (Figure 12). Please see Appendix 2 (WRENSS Individual Sub-basin Summaries) for a more complete description of the WRENSS model results, including the timing (year) of maximum %ECA, simulated yield increases (% and mm) and increases in maximum daily flows for each sub-basin.

## WRENSS Summary

The results of this analysis indicated that simulated increases in water yield were very low, ranging for most watershed from less than 1% to 3.5% (2.5-13 mm). It was anticipated that the effects of forest harvesting on these small sub-basins would be greater than for the large watersheds analyzed with ECA-AB. Previous experience has found that simulated water yield increases on small to medium watersheds (50-100 $km^2$) or less are often greater than for the same amount of harvesting on a large watershed (>100$km^2$).

The low response in water yield from harvesting on both large and small watersheds is attributed to the very high precipitation and runoff in most of the C5 FMU. Annual precipitation and runoff for the majority of watersheds ranges from 600-923 mm and 210-680 mm respectively. The addition of an extra 1-13 mm of water to water yields of these magnitudes is a small relative change. These increases are so small that it would be difficult to impossible to detect them by normal hydrometric methods.

Simulated increases in maximum daily flows following harvesting were also small with values ranging from less than 1% to 4%, with little difference between recurrence intervals of 2 years to 100 years. The low response to peak flows is attributed to the low levels harvesting. Previous experience from the literature and other WRENSS simulations by Watertight Solutions shows that increases in peak flows decrease with increasing recurrence intervals. Larger percent increases are expected for the 2-10 year events than for the 20-100 year events. In these simulations there was little difference in peak flows among the different recurrence intervals, which suggests a nil effect on peak flows.

Likely reasons for such small predicted changes in annual yields and maximum daily flows are due to a combination of factors including fairly low harvest levels in low runoff watersheds, and higher harvest levels in high runoff watersheds. The effect of which is a smaller percentage change in simulated yield and peak flow increases. In addition, the fairly low level and dispersed harvesting pattern throughout the FMU allowed significant hydrologic recovery of harvest blocks.

Hydrologic recovery in this set of simulations was variable largely depending upon the scheduling and rate of harvesting in the watersheds. Many of the watersheds were close to or at hydrologic recovery before and after the proposed harvesting. Some watersheds varied in and out of hydrologic recovery (i.e. varied above and below the limit of ≤1%) throughout the simulation. Recovery in other watersheds took considerable time, being sustained by frequent harvesting that held water yield increases above the 1% level.

In conclusion, analysis show that the simulated maximum increases in annual yield and maximum daily flows for the Preferred C5 Scenario were low and should fall with the range of natural variability and in practical terms are not detectable by direct measurement using standard hydrometric techniques.

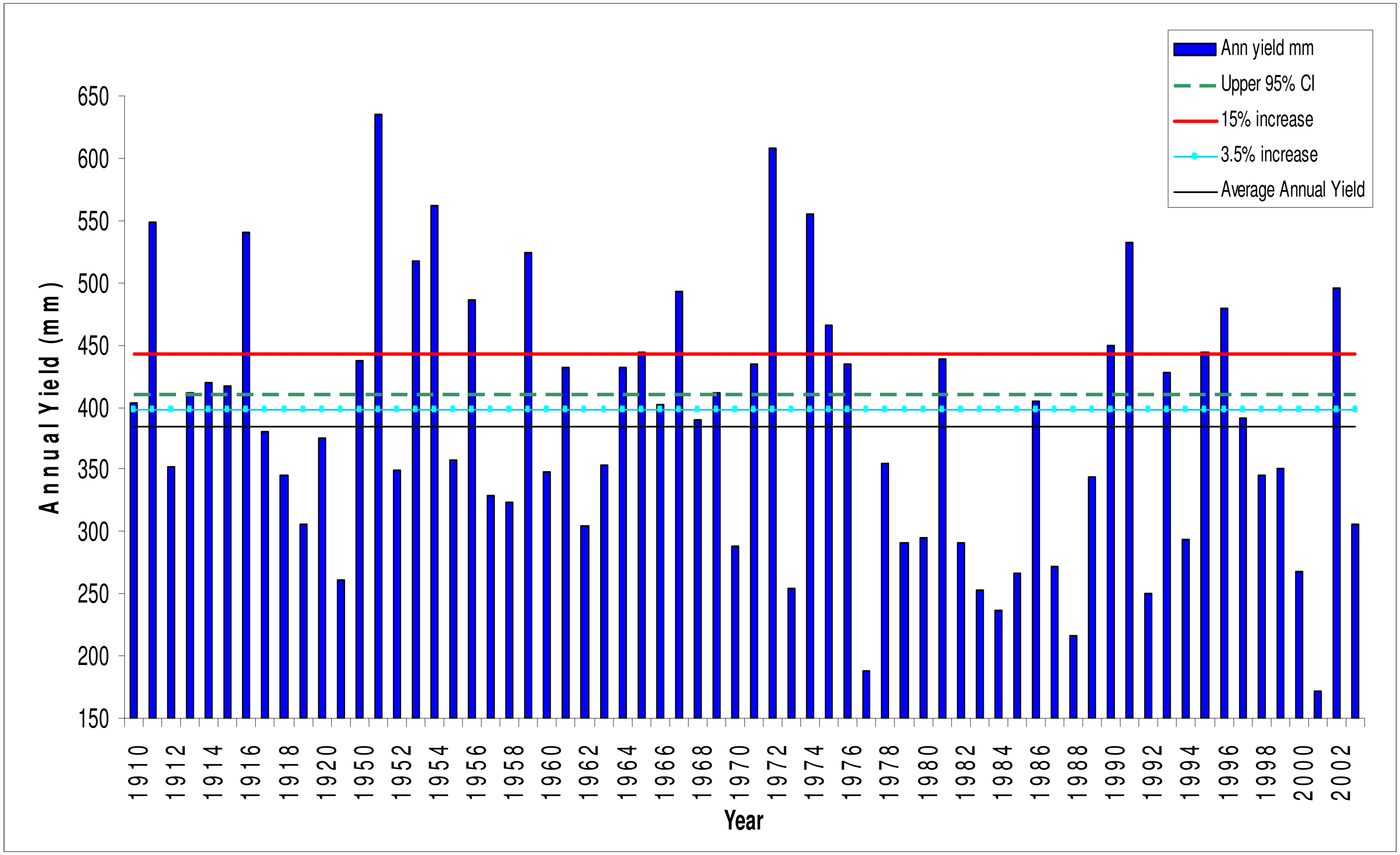


**Figure 12 Annual water yield, average annual water yield (1910-2003) for the Crowsnest River near Frank.. Simulated 3.5% increase in water yield was less than "15%" and not significantly different from average annual yield.**

# Discussion

## Water Simulations

Simulated increases in maximum annual water yield obtained with ECA-AB and WRENSS were similar. Both models indicated low to nil percent increases in annual water yield in response to harvesting proposed in the Preferred C5 Scenario. This was anticipated for the ECA-AB simulations because harvesting in large watersheds is often dispersed spatially and temporally resulting in small to medium relative changes in water yield.

Simulated increases in maximum annual water yield with ECA-AB ranged from 0.9% 3.9%, with the exception of Beaver Creek with an increase of 13.8%. These simulated increases were not significantly different from the long term average water yields for these watersheds. The average size for watersheds in the ECA-AB simulations was 350 $km^2$ and the average percent area harvested in the watersheds was 19% with minimum and maximum values of 0.5% and 55%.

Greater responses were expected with the WRENSS simulations because harvesting in small watersheds (average size 36 $km^2$) where the removal of forest cover is usually greater in relative terms and more concentrated spatially and temporally. The average area harvested in the watersheds was ~40% with minimum and maximum values of 16.5% and 52.6%. However, simulated increases obtained with WRENSS were also small, ranging from 0.6% to 3.5%. These increases with WRENSS were not significantly different from the long term average water yield used in the simulations.

These low responses for both ECA-AB and WRENSS were attributed to a combination of low and dispersed levels of harvesting and high annual water yield in most watersheds. The average areas harvested for all watersheds in the ECA-AB simulations prior to 2006, during 2006 to 2026 and afterwards in 2046 to 2062 were respectively 4%, 7.6% and 3.6%.

The addition of an extra 1-11 mm to high annual water yields of 225-680 mm in large and small watersheds in these simulations made small relative and absolute changes in water yield. The only exception was Beaver Creek. (7.3 mm), which is located on the east boundary of the C5 FMU and is, characterized more by prairie than forest cover. Average water yield for Beaver Creek is 31 mm which resulted in an increase of 13.8% (7.3 mm/31) that was higher than the other watersheds, but was still within the limits of natural variability (i.e. less than the upper 95% confidence limit) of the long term annual water yield. The temporal distribution of harvesting in the WRENSS simulations (i.e. small watersheds) was similar to those in the ECA-AB simulations.

Larger simulated increases (≥ 20%) in water yield in these watersheds could occur if the areas harvested were greater and/or more concentrated in time. Experimental watershed studies using the paired basin approach[4] indicate that 15%-20% of forest cover must be removed before

[4] A paired basin study consists of a control and treatment basin which ideally should be similar in terrain, forest cover and climate. The flows of both watersheds are monitored for a period of time (5-10 years) until the flow for the treatment watershed can be predicted with a high level of confidence from the flow of the control basin. ($Q_{TRT} = a + bQ_{CTRL}$ with $R^2 > 90\%$). At this point a forest removal treatment is applied to the treatment basin. The change is

water yield increases can be detected. These results are useful but cannot be easily extrapolated to commercial forest harvesting, because the majority of these studies were conducted on small watersheds (2-7 $km^2$) where 100% of forest cover was removed in a short period of time (i.e. 1-2 seasons) to test for maximum effect on streamflow.

Commercial harvesting usually removes forest cover in larger watersheds in a series of harvests spaced over a number of years. This often produces watersheds with a mix of newly harvested areas, harvested areas in some stage of hydrologic recovery and uncut areas. This varied landscape tends to reduce the effects of forest harvesting on water yield and peak flows in comparison to increases reported in paired basin studies (i.e. small watersheds). Simulated increases in water yield in this report were within the range found in watershed studies in snow dominated regions (Table 9).

Average water yield increase in the Hinton-Edson area based on a comparison of 9 harvested and 9 unharvested watersheds was 52% during the snow melt runoff and 27% for the full flow season (i.e. May-September) (Swanson and Hillman 1977). The average watershed size for the harvested basins was 54%. Harvesting generated an extra 42 mm in the harvested watersheds, or an extra 84 mm directly from cut-blocks and cleared areas (Table 9) that were 20-1400 ha in size (Swanson *et al* 1986).

**Table 9 Comparison of simulated water yield increases in Preferred C5 Scenario (WRENSS) to results from experimental watershed studies (adapted from Swanson *et al* 1986).**

| Watershed | Area (ha) | Annual Precipitation mm | Annual Water Yield mm | %Area Cut ha | Increase in Yield | |
|---|---|---|---|---|---|---|
| | | | | | Total mm | Harvested Areas mm |
| Cabin Creek Ab | 212 | 840 | 310 | 21 | 17 | 79 |
| Hinton Ab | 1497 | 513 | 147 | 50 | 42 | 84 |
| Wagon Wheel Gap Colorado | 81 | 536 | 157 | 100 | 25 | 25 |
| Fool Creek Colorado | 289 | 762 | 283 | 40 | 74 | 185 |
| Preferred C5 Scenario | 404 | 547 | 380 | 40 | 2.5-13.1 | 15-33 |

Percent area cut and simulated water yield for Preferred C5 Scenario are averages for all 7 basins analyzed.

Harvesting 21% of Cabin Creek in the Kananaskis Valley increased water yield by 6% or an extra 17 mm (Swanson *et al* 1986). The may seem small, but it is reasonably high when compared to the area actually harvested (44.9 ha). Extra water generated directly from the cut-blocks was 79 mm, which is very similar to that observed for the Hinton-Edson region. Extra water generated for harvest blocks in the WRENSS simulations was lower averaging 22 mm with minimum and maximum values of 15mm and 33mm. These values are similar to water yield increases at Wagon Wheel Gap in the Colorado Rocky Mountains as discussed by Swanson *et al* (1986).

The magnitude of water yield increases generated by forest harvesting is a function of the extent of harvesting and timing of sequential harvests in a watershed. Experience in

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flow in the post treatment period is predicted as the difference between observed post treatment flow minus the predicted flow for the treatment basin estimated from the control basin ( $\Delta Q = Q_{AFTER} - Q_{BEFORE} = Q_{AFTER} - (a + bQ_{CTRL})$

conducting hydrologic assessments with WRENSS (Watertight Solutions Ltd unpublished reports) indicates that simulated water yield increases for first harvest entries into watersheds are usually less than 15%-20%, where the percent of harvesting in watersheds ranged from 10% to 35%.

Water yield increases can be expected to be greater with multiple entries into a watershed. The magnitude of such increases will depend upon the frequency of entries. If entries are too frequent, there is no opportunity for hydrologic recovery and water yield increases will become additive and increase with each successive harvest. Multiple entries will produce a pattern of "stepped" increases with each annual cut that usually level out to a constant level and then decline with a reduction or cessation in harvesting (Figures 6A, 10). Experience with WRENSS simulations (Watertight Solutions Ltd unpublished reports) for multiple entries into watersheds produced simulated water yield increases of 8%-26% where harvesting in watersheds varied from 60%-91% over a 100-150 year time period.

Over the long run this will be a normal pattern for harvesting in watersheds. The net result on water is that multiple harvest entries into a watershed make a permanent and variable change in water yield. The magnitude and duration of such changes is dependent on the extent and timing of harvesting. In both the ECA-AB and WRENSS simulations for the C5 Preferred Scenario the small increases in simulated water yield (1%-3%) were sustained for long periods of time by frequent harvesting.

Simulated increases in maximum daily flows (WRENSS) were also small with values ranging from less than 1% to 4%. The explanation for this is again the high rates of flows from these watersheds and relatively small volumes of extra water produced by forest harvesting.
This was illustrated by the small differences in flow events for recurrence intervals of 2 – 100 years. Normally larger percent increases are expected for the 2-10 years events and smaller increases for the 20-100 years.

The reason for this is that the maximum volume of extra water contributed to storm events because of forest cover removal is a function of the daily maximum rate of evapotranspiration for a watershed. This is a relatively constant for a given forest harvesting scenario, which becomes less important when expressed as a percent of increasing maximum flow events (i.e. recurrence intervals). These low responses suggest that harvesting in the Preferred C5 Scenario will have a small effect on maximum daily flows.

The level of disturbance in the watersheds expressed by %ECA was different between the two simulation models. Maximum %ECA for ECA-AB ranged from 0.2% to 10%, while that for WRENSS ranged from 29% to 50%. A direct comparison of the two methods is not provided in this report. The differences in the area and timing of harvesting among the 19 large watersheds and the 7 small sub-basins selected for simulation and differences in how ECA was calculated in the two models prevents a valid comparison.

Estimates from ECA-AB were based on the recovery of annual growth increment and not basal area which is the traditional approach to calculating %ECA. Current annual growth increment was used because it is strongly correlated with maximum leaf area (Brabender 2005), which is assumed to approximate hydrologic recovery (i.e. full recovery of evapotranspiration losses). The reduction factor to estimate ECA is a ratio of current growth to the maximum growth at time of maximum leaf area multiplied times the harvested area.

%ECA in WRENSS was calculated as a function of how fast simulated increases water yield change with the recovery of evapotranspiration (i.e. growth of forest regeneration). It is different from the traditional approach that uses basal area to estimate recovery. The reduction factor used in WRENSS is the ratio of current yield increase to maximum yield increase multiplied by area harvested. ECA based on maximum water yield reaches hydrologic recovery in about half the time and area as calculated with basal area (Swanson 2005). However, basal area is still inherent in the $ECA_Q$ estimates because it is used in WRENSS to calculate changes in water yield (i.e. evapotranspiration) with the removal of forest cover and the growth of regeneration.

Hydrologic recovery in both sets of simulations was highly varied. Estimates provided with both models ranged from short periods (< 10 years) to long periods (> 50 years). In the ECA-AB simulations more than half of the watersheds had simulated water yield increases less than 1%, which can be interpreted as a nil response. Harvesting in the WRENSS simulations were on smaller watersheds where the harvesting tended to be more concentrated in time giving slightly pronounced but still small increases in yield.

Using recovery of water yield to 1% or less is a very conservative estimate for hydrologic recovery. Both models are not highly precise in their estimates of water yield increases. Hydrologic recovery most likely occurs sooner than that indicated by recovery to 1% or less. The use of the time to maximum leaf surface area may be a much better estimate of hydrologic recovery. However, there are others who contend that recovery of basal area is a better index of hydrologic recovery as it includes both the time for leaf area recovery and full site occupancy (i.e. root development). A compromise between these two views, protection of aquatic ecosystems and the economics of forest management is needed.

The results of these simulations for the Preferred C5 Scenario illustrate that low levels of harvesting dispersed over time in areas of high runoff in large and small watersheds produced a small effect on water yield and peak flows. These results should not be extrapolated outside of the C5 FMU. They should not be used to identify limits or guidelines to manage water yield and peak flow increases. The results in this report are a single sample of a high precipitation and runoff region. Several simulations that cover a range of harvesting scenarios (e.g. low to high levels of harvesting) in different forest regions (e.g. southern and northern foothills and boreal forests) and climatic zones are required to develop limits and guidelines.

There is a need for guidelines to manage the effects of forest harvesting on water flows. The objectives of such guidelines will vary with different climatic regions and local needs in the province. In regions such as Southern Alberta where water is in short supply for downstream users, objectives might be to maintain or increase water yield. In areas where water yield is not a large issue or where important fish habitat exists, objectives could be to minimize increases in water yield and peak flows.

Forest management practices to maintain and enhance water yield should be based on harvesting systems designed to increase snow accumulation and reduce the rate of snow disappearance (melt and sublimation) thereby making more water available for flow. Extensive research literature on this subject exists dating from the early 1960's in the United States and Western Canada. Few applications of the knowledge exist except for of harvesting in municipal watersheds where a net gain in water was captured in or diverted to reservoirs. The greatest benefit of these programs will be local with less value to downstream users. To be effective such programs would require a large area that could be managed for a single resource to the partial or complete exclusion of other resource users.

Forest management practices to minimize water yield increases and impacts on aquatic ecosystems would be to disperse harvesting in time and space, where time was provided between harvests to allow significant hydrologic recovery. The simulation results in this report are a good example of this, but are not that representative of harvest planning followed by forest companies. Harvest scheduling by forest companies usually will involve frequent harvest entries into watersheds. Management strategies and guidelines to minimize the cumulative effects of multiple harvest entries should address the total area harvested in a watershed, frequency of harvesting or rate of hydrologic recovery, and acceptable limits for water yield and peak flow increases. Developing such guidelines is not an easy task given the availability of hydrologic data for small to medium sized watersheds and imperfect understanding of the response of aquatic ecosystems to increased flows.

It was hypothesized by the authors that multiple harvests in watersheds should be spatially limited to produce "acceptable" water yield increases, and spaced time-wise to allow for significant hydrologic recovery. Acceptable increases in annual water yield would fall within the range of natural variability as defined by recurrence intervals equal to or less than 5 years. Based on an analysis of flows in the Grande Cache-Grande Prairie region (Watertight Solutions Ltd unpublished reports) this would keep increased annual water yields and peak flow within 15%-20% of "average conditions". The time to hydrologic recovery would be used to decide the time for additional harvests in a watershed. Hydrologic recovery could be defined by the occurrence of maximum leaf area by the dominant harvested forest cover type in a watershed, or by an assumed increase in water yield (e.g. $\leq$ 5% or mm of extra water with respect to regional long term flows).

%ECA appears to be a useful parameter to assess the potential effects of forest harvesting on water and other resources (e.g. aquatic habitat). It is easy to calculate and if effective would not require hydrologic simulations which can be expensive. However, there are no scientifically well defined values or procedures to set ECA limits or to link ECA to increases in water yield and peak flows. Values in the literature are variable, subjective estimates. Further work, analyses and decisions on how ECA is calculated and used are needed. Links of this nature are necessary to make ECA a valid measure of disturbance acceptable to forest managers, biologists and the public. Also the focus of looking at short and long term changes in water should be considered as was done in this report (e.g. maximum changes and decadal averages).

Of the methods used to calculate ECA in this report, the one based on the recovery of water yield appears most appropriate. It is a direct measure of water yield, whereas basal area and current annual increment are not. Adjustments within ECA-AB or WRENSS are possible to make them complement each other. Another advantage of WRENSS is the simulation of changes in peak flows which are relevant to assessing potential changes to aquatic habitat than just changes in water yield.

Another modification to consider for ECA estimates is to express them as a percent of watershed area instead of disturbed area (e.g. harvested area). Most applications reported in the literature are based on the recovery of the disturbed areas and are not watershed based estimates. ECA expressed as a percent of watershed area should be more useful with respect to water yield and peak flow increases which are watershed based parameters. ECA expressed this way is an index of disturbance and recovery for the watershed as a whole and not just the harvested areas.

## Reliability of Results

Initial testing of the WRENSS methodology for application in Alberta was compared against the results from major experimental watershed studies in North America (personal communication R. H. Swanson). WRENSS estimates compared favorably to water yield increases reported in the scientific literature. Water yield changes were on average within 10% of results from paired basins studies (personal communication R. H. Swanson).

However, the reliability of any model is determined in large part by the availability and quality of data available. Both of the models used in this report are simple with modest data requirements and were developed as tools for forest managers. The primary output for both models is simulated increases in annual water yield. ECA-AB is a simplified version of WRENSS where the requirement for aspect of forest stands, and the effect of snow redistribution within harvest blocks on water yield was removed A single paired comparison between the two models (Watertight Solutions unpublished report), shows simulated water yield increases in ECA-AB average about 5% greater than those in WRENSS.

Data quality is probably the most limiting factor on the reliability of estimates from these two models. One of the basic premises for both models is that by using long term average precipitation and streamflow the year to year variation in both are minimized such that changes in water yield are represented by reduction in evapotranspiration with forest harvesting. (i.e. $\Delta Q = \Delta ET$ where changes in annual storage ~ zero).

Unfortunately these data are not always available. Precipitation can be found for most watersheds, either onsite or at nearby stations. A minimum record of 10 years or more for all 12 months of the year is preferred. In many situations data is available for the spring to fall period with winter missing. This usually is not that limiting as estimates can be made on a regional basis from stations with 12 months of record.

Obtaining representative streamflow data to be used as a base flow is often a problem. A majority of the available flow data in Alberta and elsewhere in Canada is for large watersheds (> 100 $km^2$) and not small to medium sized watersheds where the effects of forest harvesting are most likely to be noticed. What is important about this is that simulated water yield increases outputted as millimeters by both models are expressed as percents of the long term base flow. Greater confidence in percent increases would be enhanced if a larger data base for smaller sized watersheds was available.

Forest cover data is usually provided by forest companies and is of good quality. The primary parameters used include: areas harvested, year of harvest, aspect of forest stands, forest species harvested and to be regenerated and growth and yield data at the stand level, which includes basal area, tree height and current annual increment (Appendices 3 and 4). The growth data are used to estimate yield increases, effects of snow redistribution and the rate of evapotranspiration recovery. This information is important, but not as critical as the precipitation and streamflow data in simulating water yield increases. Results could be improved, especially for hydrologic recovery, if growth was better described in the first 20 years of stand establishment when trees are young and growing rapidly (i.e. non-mertchantable trees < diameter breast height ).

The results from both models are still considered to be reasonable even with these data problems. It should be remembered that the WRENSS methodology was developed to provide managers with a tool to assess the potential for change in water yield and not to provide a highly precise prediction. Few models that describe or simulate natural process are capable of doing this. The advantage of both of the models is that data is usually available and they are easy to use. The results from the WRENSS methodology should be interpreted as estimates of relative change and described or thought of in terms of small, medium, and large increases, with small to medium as acceptable and large as questionable or unacceptable.

## Potential Impacts – Aquatic Habitat and Water Quality

### Aquatic Habitat

The small effects of forest harvesting on water yield and peak flow in the C5 Preferred Scenario indicate a low impact on aquatic habitat in the forest management unit. Simulated increases in annual water yield in the large watersheds ranged from almost zero to 4%. Simulation results were similar in the small 7 basins. Simulated increases for maximum daily flows in the small watersheds were also low ranging from 1-4% among recurrence intervals of 2-100 years. All of these increases were well within the range of natural variability of flows for watersheds examined.

A greater extent and concentration of harvesting in the C5 FMU would be necessary before increases in water yield and peak flows alone could cause permanent and significant changes to aquatic habitats. Increased water yield and peak flow have the potential to change aquatic habitat by changing stream channel morphology, which includes the size and shape of a stream channel and the nature of its streambed material. Changes in the morphology of stream channels can have direct effects on the aquatic habitat, animals and plants found in a stream or water body.

Increased flows and peaks that persist over a long period of time, have more energy to erode streambeds and banks and to transport and deposit material in stream channels that can change the nature of a stream. Verry (2004) in a retrospective study of the effects land conversion from forest to agriculture in the Midwestern United States cited increased bank full discharge[5] as a cause for the straightening of stream channels and changes in aquatic habitats. These changes were cumulative in nature and slow to evolve over 60-100 years.

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[5] Baneful discharge is the flow that will fill the channel to the tops of its stream banks. Hydrologically a flood occurs when the bankfull discharge is exceeded. A rule of thumb used by hydrologists is the recurrence interval for

Peak flows are usually considered to be more important or indicative of the potential to affect stream channel morphology and aquatic habitats than water yield, which is a more integrative parameter. Peak flows and channel characteristics (e.g. depth, width, and stream substrate) determine how much flow can be carried in a channel without flooding and damage. Sterling (1988) observed at Tri-Creeks Experimental watershed that flow events with a frequency of 10-years had the potential to impact fish populations.

Guillemette *et al* (2005) in a recent paper and others suggest that a 50% increase in bankfull discharge with a recurrence interval of 5-years can significantly affect aquatic ecosystems and stream morphology. Guillemette *et al* (2005) reviewed paired basin studies from around the world and observed that such flows occurred when 40%-50% of the basins were harvested.

A recent study of the natural variability of water flows in the Grande Prairie-Grande Cache Region (Watertight Solutions 2005) found that the recurrence intervals for 15%-25% increases in mean annual water yield and peak flows averaged 3-5 years. Natural variability was defined as the long term mean ± 2 standard deviations. A range of possible increases to mean water yield and peak flows and their recurrence intervals were identified and assessed by systematically reducing the range of natural variability for 19 watersheds in the region.

**Water Quality**

The impacts of forest harvesting on water quality are most associated with the effects of soil disturbance and exposure, erosion and sediment deposition caused by log skidding and road construction than changes in water yield of peak flows. The removal or disturbance of riparian vegetation will also have significant effects on water quality. Increased water yield and peak flows could add or enhance the effects of surface disturbances to water quality. For example increased flows could contribute to increase suspended sediment loads by the entrainment of logging debris during high flows that disturb streambeds by scouring.

Increased peak flows could affect water quality by increasing sediment loads through scouring of streambeds and stream banks. As mentioned earlier, observations by Verry (2005), Guillemette et al (2005) and others suggest that a 50% increase in bankfull discharge has the potential to change stream morphology. Verry noted that increases to bankfull discharge associated with conversion of forest to agriculture in the Midwestern United States reduced the sinuosity and aquatic habitat of streams. Such changes occurred over a 60-100 year period.

It is doubtful that such changes would occur as the result of forest management, where forest cover is retained over the long run. However, a limit of some kind is probably warranted to minimize the potential for less dramatic effects of forest cover removal on peak flows. Limits or guidelines should be based on some measure or index of “natural” variability of flows for forest regions in the province (e.g. southern and northern foothills, and boreal regions).

The protection and maintenance of water quality is best protected by focusing on the design and construction of road-stream crossings, prompt revegetation and erosion control of

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the bankfull discharge is 2 years. This is not a fast and true rule however, as reports of 5-10 up to 100 years exist are reported in the literature.

disturbed sites and stream crossings, monitoring of water quality at disturbed sites or watersheds and periodic inspections to determine effectiveness of management practices.

## Summary and Conclusions

Sustainable Resources Development (SRD) developed a management plan titled "The Preferred Forest Management Scenario in the C5 Forest Management Unit (Preferred C5 Scenario)" in the Southern East-Slopes of Alberta. Because water resources and values can be affected by the proposed forest harvesting SRD contracted Watertight Solutions Ltd to evaluate the potential hydrologic effects of the Preferred C5 Scenario.

The hydrologic effects of forest harvesting in the C5 FMU were simulated using two models: ECA-AB (Silins, 2000) and WRENSS-Eca-Ab (Swanson, 2000). ECA-Ab was used to simulate the hydrologic effects of the proposed harvesting plan in terms of %ECA, simulated changes in annual yield (mm and %), and the timing of hydrologic recovery. The more detailed WRENS-EcaAb was used to evaluate the hydrologic effects of forest harvesting in 7 small sub-basins within the Crowsnest River Watershed near the towns of Blairmore and Colman. The effects of harvesting in these watersheds were evaluated in terms of simulated increases in annual yield (mm, %), maximum daily peak flow, % ECA and hydrologic recovery.

The two models used are similar in many aspects. ECA-AB was developed based on the logic and structure of WRENSS, to produce a version that was simple and easier to apply. Both models predict changes in water yield and %ECA based on long-term average climatic data, long-term average streamflow, forest growth and watershed conditions. WRENSS has the added option of providing estimates of changes in maximum daily peak flows based on locally available streamflow data. ECA-AB simulations were simulated for 135 years; WRENSS simulations were ran for 101-134 years.

Simulations of water yield increases by both models showed nil to small increases in annual water yield. This was the case for the large watershed simulations done with ECA-AB and simulations for the 7 small sub-basins simulated by WRENS-Eca-Ab. The low response of annual water yield to forest harvesting was attributed to the very high precipitation and runoff in most of the C5 FMU. The addition of an extra 1- 11 mm of extra water generated by harvesting to annual water yields of 300-600 mm produced small percent increases in annual water yield. Increases in annual water were not significantly different from the long term mean annual flows for these watersheds (i.e. increases did not exceed upper 95% confidence limit for mean flow). Simulated increases in maximum daily flows for the 7 small watersheds were also very small, which indicated a low response to the C5 Preferred Scenario. The differences in peak flow increases among recurrence intervals of 2-100 years were small.

The levels of %ECA in the watersheds were different for the two models because of differences in the level and timing of harvesting and methods of calculation. Maximum ECA on the large watersheds varied from 0.2% to 10%, while values for the small watersheds varied from 29% to 50%. Harvesting on the smaller basins was smaller and more concentrated spatially and temporally.

Hydrologic recovery was defined as the years needed for water yield increases to be equal or less than 1%. Hydrologic recovery in both the small and big watersheds was variable being a function of the rate and timing of harvesting. Values ranged from short periods (< 10 years) to long periods (> 50 years). Recovery in some watersheds with low response levels was maintained for long periods because of repeated low level of harvesting. Water yield increases in more than half of the watersheds was less than 1% which was interpreted as a nil response to forest harvesting.

The results from ECA-AB and WRENSS indicate that simulated increases in annual yield, ECA, and peak flows based on the proposed harvesting plan are likely not significant, and well below the detection limit using standard hydrometric techniques. As a result, the simulated increases in annual water yield and maximum daily flows should not be a significant threat to aquatic habitats or fauna.

Specific changes in water yields are listed below for each model.

Hydrologic changes simulated by ECA-AB were:

- Increases in water yield and %ECA varied between watersheds
- Maximum simulated yield increase was 13.8% (7.3mm) in the Beaver Creek watershed (all others were <4%).
- Maximum predicted increases in ECA ranged from 0.2% (Pincher Creek) to 10% (Dutch/Highwood River).
- Hydrologic recovery from ranged from 0 years (10 of 19 watersheds),3-17 years (5 watersheds) to 38 – 64 (4 watersheds).

The more detailed, WRENSS model evaluated the hydrologic effects of forest harvesting 7 smaller sub-basins in the Crowsnest River watershed. These watersheds were evaluated in terms of predicted increases in annual yield (mm and %), peak flows, timing of hydrologic recovery, and impacts on stream bank stability, erosion potential, and the expected impacts on fish and fish habitat associated with the proposed harvesting plan.

Simulated changes in annual yield, ECA (%), and peak flows were based on the area harvested within each of the watersheds, rate of forest growth, and long-term average climatic conditions. WRENSS simulations were projected for 101-134 years, and were based on based on average precipitation and flow conditions. The results indicated that projected yield increases were low in all 7 sub-basins within the Crowsnest River watershed.

Hydrologic changes simulated by WRENSS were:

- Maximum annual yield increases were proportionally very low, ranging from 0.6% (Crowsnest Creek) to 3.5% (Pelletier Creek)
- Maximum yield increases for 4 of the 7 watersheds occurred during the first 20 years of harvesting (2006-2026)
- Changes in peak flows were also very small, ranging from 0.1%, (Crowsnest Creek) to 3.6% (Pelletier Creek) for the 2-yr return interval storm and 0.2% (Crowsnest Creek) to 4.4% (Pelletier Creek) for the 100-yr return interval storm.
- Equivalent clear-cut area (ECA) values for these watersheds ranged from 30.6% (Allison Creek) to 50.6% (Crowsnest Creek).

The impacts of forest harvesting on water quality are most associated with the effects of soil disturbance and exposure, erosion and sediment deposition caused by log skidding and road construction than changes in water yield or peak flows. Increased water yield and peak flows could add or enhance the effects of surface disturbances to water quality. Observations in the literature suggest that a 50% increase in bankfull discharge has the potential to change stream morphology and in turn aquatic habitats. Paired basin studies report such changes can occur when 40% to 50% of forest cover is removed in a short time period of time. Changes in aquatic habitats are slow to develop and more likely to occur with the permanent removal of forest cover in a watershed. It is doubtful that such changes would occur as the result of forest management, where forest cover is retained over the long run. However, a limit of some kind is probably warranted to minimize the potential for less dramatic effects of forest cover removal on peak flows.

The protection and maintenance of water quality is best protected by focusing on the design and construction of road-stream crossings, prompt revegetation and erosion control of disturbed sites and stream crossings, monitoring of water quality at disturbed sites or watersheds and periodic inspections to determine effectiveness of management practices.

In conclusion it is recommended that work be undertaken to develop guidelines to minimize potentially adverse effects of water yield and peak flow increases. Such information is needed by government and forest industry by the requirements in the current forest management planning manual, which specifies the prediction of water yield increases in detailed forest management plans. Guidelines should be based on regional climatic and hydrologic differences within the Province (e.g. foothills versus boreal). Guidelines or limits would be scaled to reflect regional (e.g. forest management units) annual water yield and peak flows with respect to local variability, as currently defined by available hydro-meteorological data. Such guidelines to be designed to recognize existing methods used to estimate/simulate hydrologic changes. It is anticipated that any guidelines developed with be modified as better information and methods evolve. Special attention should be given to testing ECA or other similar measures as a parameter that can be used to monitor potential impacts and in reporting/assessments in detailed forest management plans.

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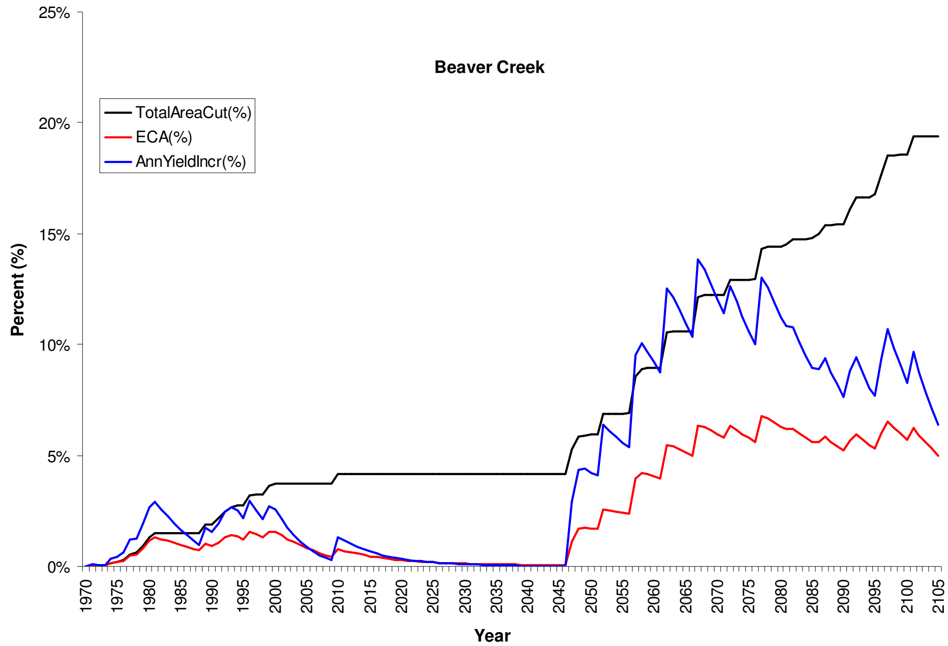
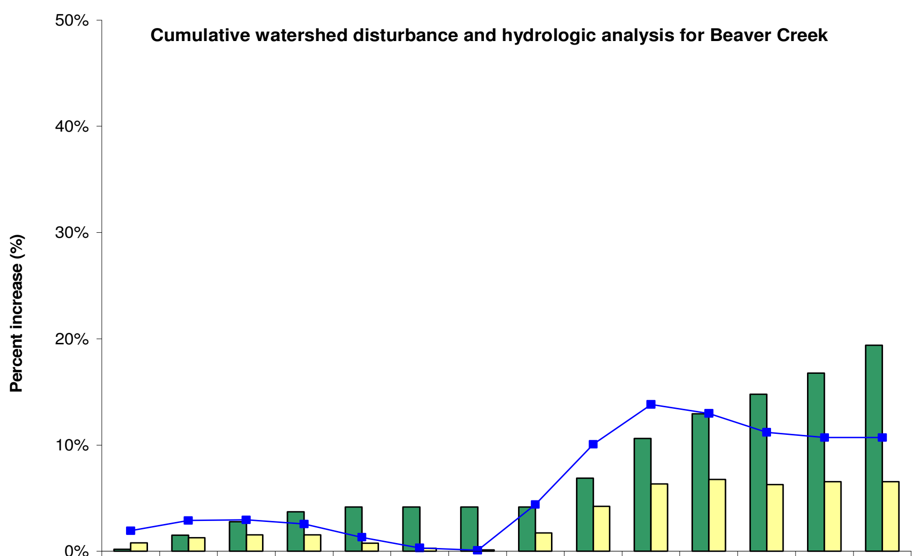
# Appendix 1 ECA Alberta Individual Watershed Summaries

# Beaver Creek

| Beaver Creek | | Year/Decade |
|---|---|---|
| Area harvested prior to 2006 (historic harvesting) (%) | 3.73% | |
| Cumulative area harvested (historic and proposed ending in fall 2026) (%) | 4.16% | |
| New area proposed for harvest 20 years ( 2006-2026) (%) | 0.43% | |
| Total area harvested at the end of the 100 year planning horizon (2105) (%) | 19.41% | |
| Max 10-yr avg ECA increase | 6.15% | 2090-2100 |
| Max 10-yr avg yield increase% | 11.73% | 2070-2080 |
| Max 10-yr avg yield increase (mm) | 6.22 | 2070-2080 |
| Max ECA (%) | 6.76% | 2087 |
| Max yield increase (%) | 13.81% | 2067 |
| Max yield increase (mm) | 7.3 | 2067 |



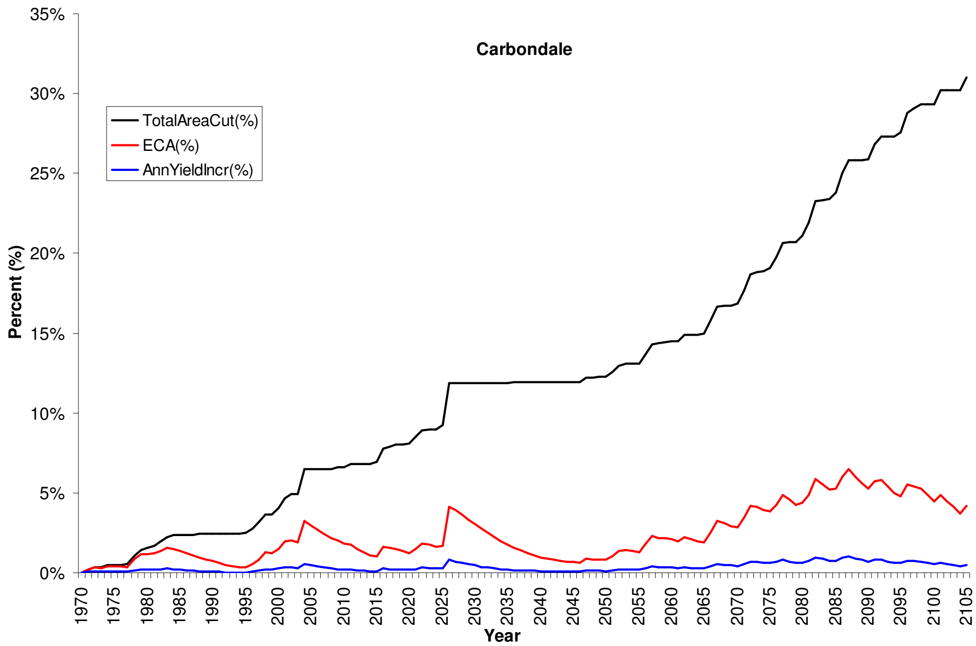



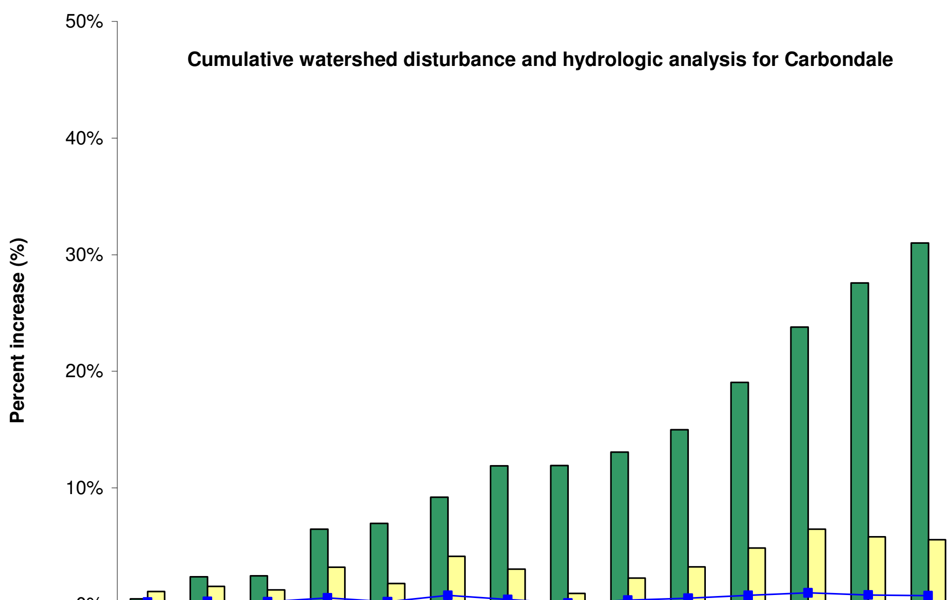

| | 1975 | 1985 | 1995 | 2005 | 2015 | 2025 | 2035 | 2045 | 2055 | 2065 | 2075 | 2085 | 2095 | 2105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumulative area cut (%) | 0.19% | 1.52% | 2.76% | 3.73% | 4.16% | 4.16% | 4.16% | 4.16% | 6.87% | 10.61% | 12.93% | 14.78% | 16.76% | 19.41% |
| 10-yr Max ECA (%) | 0.81% | 1.29% | 1.55% | 1.53% | 0.78% | 0.28% | 0.12% | 1.72% | 4.23% | 6.34% | 6.76% | 6.27% | 6.53% | 6.53% |
| 10-yr Max Yield Increase (%) | 1.92% | 2.90% | 2.95% | 2.57% | 1.31% | 0.32% | 0.10% | 4.39% | 10.07% | 13.81% | 12.99% | 11.20% | 10.71% | 10.71% |

Decade

# Carbondale River

| Carbondale | | Year/Decade |
|---|---|---|
| Area harvested prior to 2006 (historic harvesting) (%) | 6.45% | |
| Cumulative area harvested (historic and proposed ending in fall 2026) (%) | 11.88% | |
| New area proposed for harvest 20 years ( 2006-2026) (%) | 5.43% | |
| Total area harvested at the end of the 100 year planning horizon (2105) (%) | 31.02% | |
| Max 10-yr avg ECA increase | 5.51% | 2095-2105 |
| Max 10-yr avg yield increase% | 0.82% | 2040-2050 |
| Max 10-yr avg yield increase (mm) | 4.50 | 2040-2050 |
| Max ECA (%) | 6.46% | 2047 |
| Max yield increase (%) | 0.99% | 2047 |
| Max yield increase (mm) | 5.4 | 2047 |



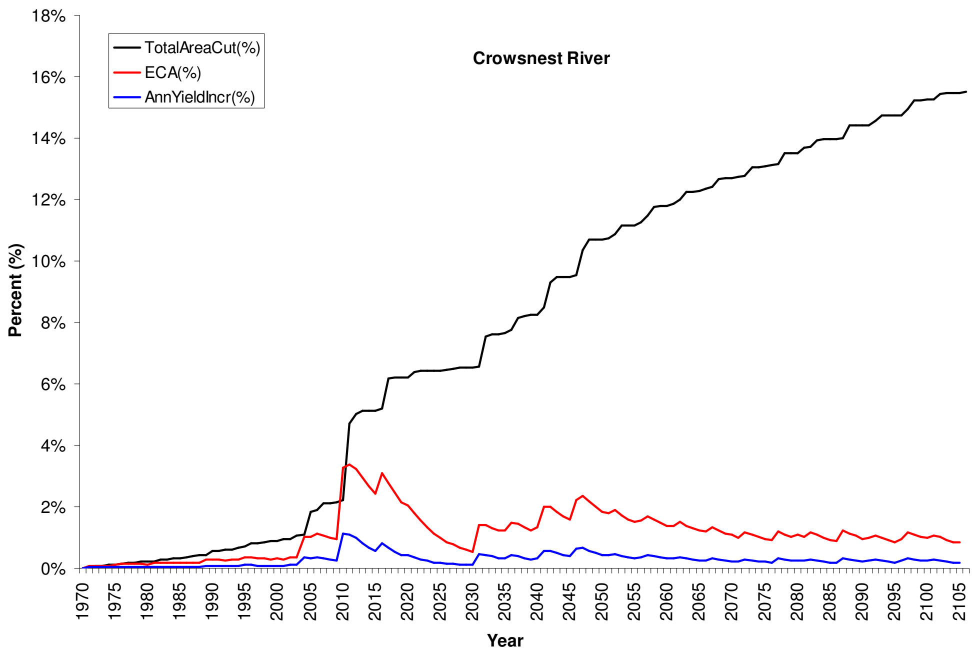



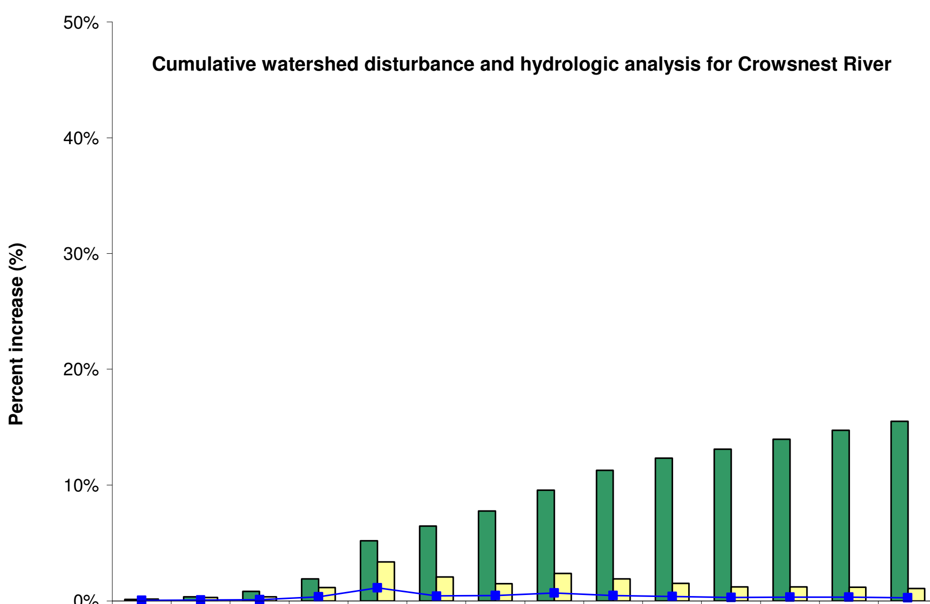

| | 1975 | 1985 | 1995 | 2005 | 2015 | 2025 | 2035 | 2045 | 2055 | 2065 | 2075 | 2085 | 2095 | 2105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumulative area cut (%) | 0.47% | 2.37% | 2.47% | 6.45% | 6.94% | 9.21% | 11.89 | 11.93 | 13.07 | 15.00 | 19.06 | 23.80 | 27.57 | 31.02 |
| 10-yr Max ECA (%) | 1.12% | 1.54% | 1.25% | 3.20% | 1.79% | 4.14% | 3.04% | 0.95% | 2.26% | 3.22% | 4.84% | 6.46% | 5.81% | 5.56% |
| 10-yr Max Yield Increase (%) | 0.20% | 0.25% | 0.23% | 0.56% | 0.24% | 0.79% | 0.44% | 0.12% | 0.38% | 0.54% | 0.78% | 0.99% | 0.81% | 0.76% |

Decade

# Crowsnest River

| Crowsnest River | | Year/Decade |
|---|---|---|
| Area harvested prior to 2006 (historic harvesting) (%) | 1.89% | |
| Cumulative area harvested (historic and proposed ending in fall 2026) (%) | 6.48% | |
| New area proposed for harvest 20 years ( 2006-2026) (%) | 4.59% | |
| Total area harvested at the end of the 100 year planning horizon (2105) (%) | 15.52% | |
| Max 10-yr avg ECA increase | 2.83% | 2010-2020 |
| Max 10-yr avg yield increase% | 0.76% | 2010-2020 |
| Max 10-yr avg yield increase (mm) | 2.91 | 2010-2020 |
| Max ECA (%) | 3.37% | 2021 |
| Max yield increase (%) | 1.12% | 2008 |
| Max yield increase (mm) | 4.3 | 2008 |



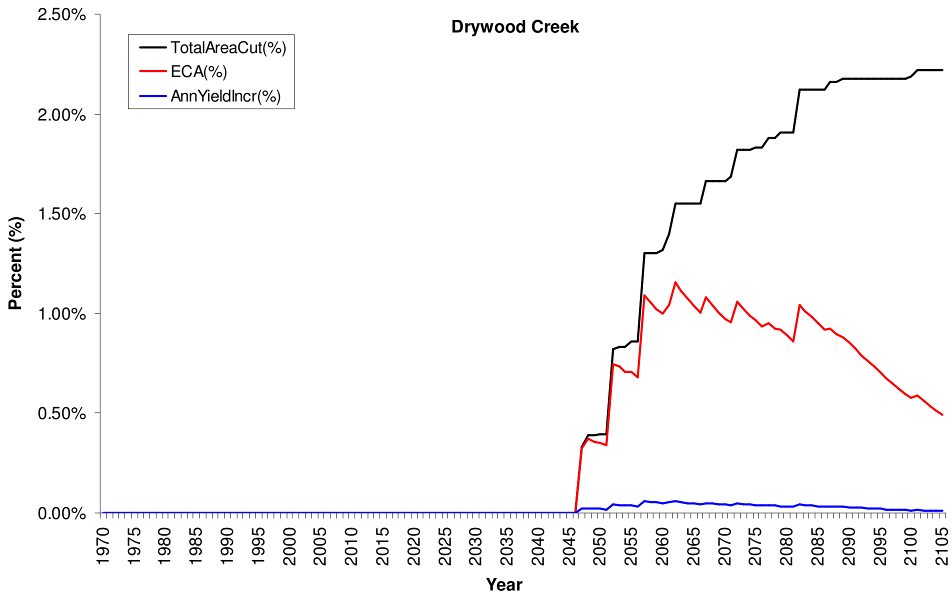




| | 1975 | 1985 | 1995 | 2005 | 2015 | 2025 | 2035 | 2045 | 2055 | 2065 | 2075 | 2085 | 2095 | 2105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumulative area cut (%) | 0.14% | 0.34% | 0.81% | 1.89% | 5.18% | 6.47% | 7.75% | 9.56% | 11.26 | 12.33 | 13.11 | 13.96 | 14.73 | 15.52 |
| 10-yr Max ECA (%) | 0.14% | 0.29% | 0.36% | 1.14% | 3.37% | 2.05% | 1.47% | 2.35% | 1.88% | 1.50% | 1.19% | 1.22% | 1.17% | 1.06% |
| 10-yr Max Yield Increase (%) | 0.05% | 0.08% | 0.10% | 0.36% | 1.12% | 0.42% | 0.45% | 0.67% | 0.46% | 0.37% | 0.30% | 0.32% | 0.32% | 0.27% |

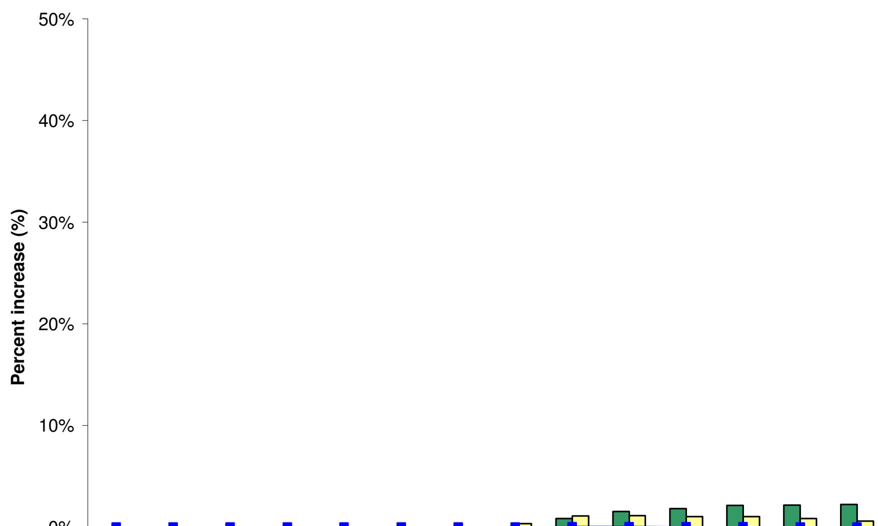
Decade

# Drywood Creek

| Drywood Creek | | Year/Decade |
|---|---|---|
| Area harvested prior to 2006 (historic harvesting) (%) | 0.00% | |
| Cumulative area harvested (historic and proposed ending in fall 2026) (%) | 0.00% | |
| New area proposed for harvest 20 years ( 2006-2026) (%) | 0.00% | |
| Total area harvested at the end of the 100 year planning horizon (2105) (%) | 2.22% | |
| Max 10-yr avg ECA increase | 1.06% | 2070-2080 |
| Max 10-yr avg yield increase% | 0.05% | 2060-2070 |
| Max 10-yr avg yield increase (mm) | 0.31 | 2060-2070 |
| Max ECA (%) | 1.15% | 2067 |
| Max yield increase (%) | 0.06% | 2067 |
| Max yield increase (mm) | 0.4 | 2067 |




**Cumulative watershed disturbance and hydrologic analysis for Drywood Creek**

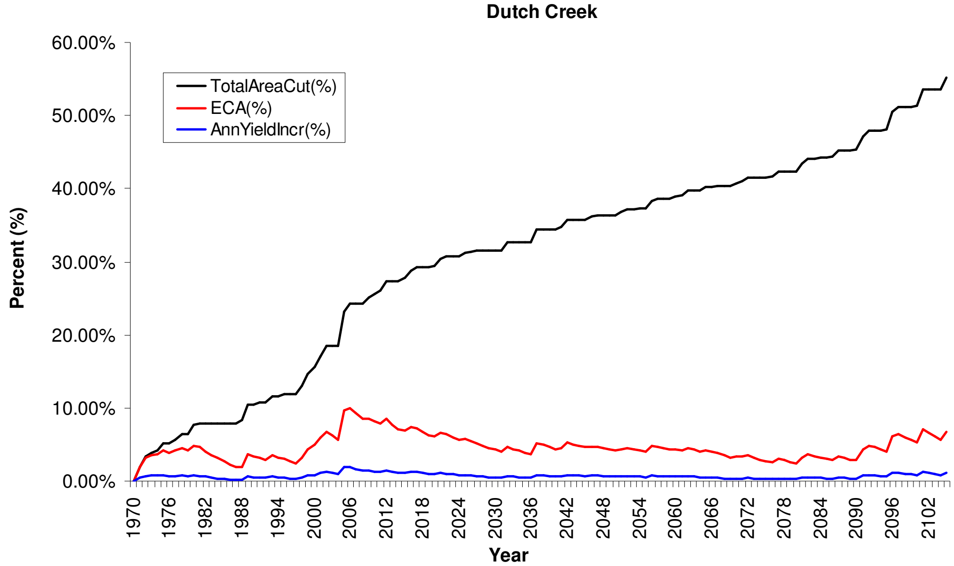



| | 1975 | 1985 | 1995 | 2005 | 2015 | 2025 | 2035 | 2045 | 2055 | 2065 | 2075 | 2085 | 2095 | 2105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumulative area cut (%) | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.86% | 1.55% | 1.83% | 2.12% | 2.17% | 2.22% |
| 10-yr Max ECA (%) | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.37% | 1.09% | 1.15% | 1.06% | 1.04% | 0.85% | 0.59% |
| 10-yr Max Yield Increase (%) | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.02% | 0.06% | 0.06% | 0.05% | 0.04% | 0.03% | 0.01% |

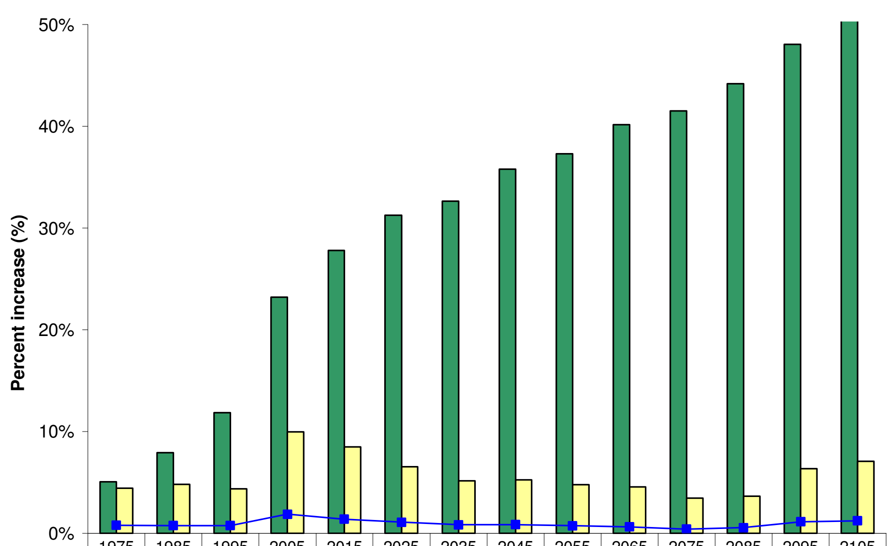
**Decade**

# Dutch Creek

| Dutch Creek | | Year/Decade |
|---|---|---|
| **Area harvested prior to 2006 (historic harvesting) (%)** | 23.22% | |
| **Cumulative area harvested (historic and proposed ending in fall 2026) (%)** | 31.32% | |
| **New area proposed for harvest 20 years ( 2006-2026) (%)** | 8.10% | |
| **Total area harvested at the end of the 100 year planning horizon (2105) (%)** | 55.24% | |
| **Max 10-yr avg ECA increase** | 7.57% | 2000-2010 |
| **Max 10-yr avg yield increase%** | 1.35% | 2000-2010 |
| **Max 10-yr avg yield increase (mm)** | 4.60 | 2000-2010 |
| **Max ECA (%)** | 9.99% | 2006 |
| **Max yield increase (%)** | 1.88% | 2006 |
| **Max yield increase (mm)** | 6.4 | 2006 |



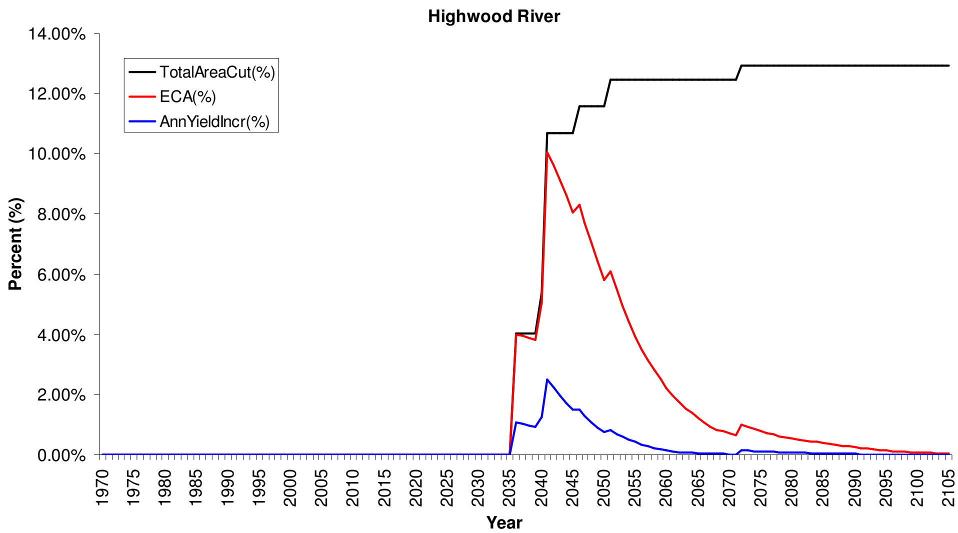

**Cumulative watershed disturbance and hydrologic analysis for Dutch Creek**



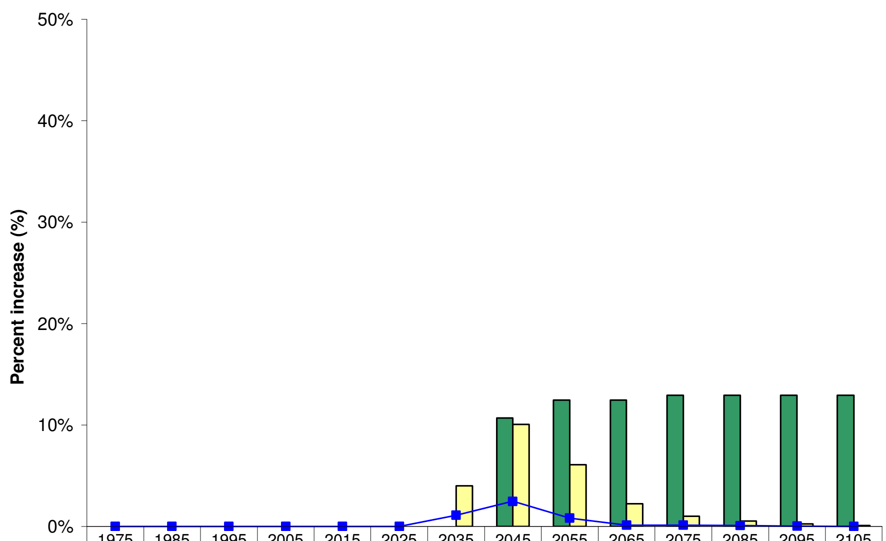

| | 1975 | 1985 | 1995 | 2005 | 2015 | 2025 | 2035 | 2045 | 2055 | 2065 | 2075 | 2085 | 2095 | 2105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumulative area cut (%) | 5.1% | 7.9% | 11.9% | 23.2% | 27.8% | 31.3% | 32.6% | 35.8% | 37.3% | 40.1% | 41.5% | 44.2% | 48.0% | 55.2% |
| 10-yr Max ECA (%) | 4.4% | 4.8% | 4.4% | 10.0% | 8.5% | 6.6% | 5.2% | 5.3% | 4.8% | 4.6% | 3.5% | 3.7% | 6.4% | 7.1% |
| 10-yr Max Yield Increase (%) | 0.8% | 0.8% | 0.8% | 1.9% | 1.4% | 1.1% | 0.8% | 0.9% | 0.7% | 0.6% | 0.4% | 0.5% | 1.1% | 1.2% |

# Highwood River

| Highwood River | | |
|---|---|---|
| | | Year/Decade |
| Area harvested prior to 2006 (historic harvesting) (%) | 0.00% | |
| Cumulative area harvested (historic and proposed ending in fall 2026) (%) | 0.00% | |
| New area proposed for harvest 20 years ( 2006-2026) (%) | 0.00% | |
| Total area harvested at the end of the 100 year planning horizon (2105) (%) | 12.93% | |
| Max 10-yr avg ECA increase | 8.00% | 2080-2090 |
| Max 10-yr avg yield increase% | 1.59% | 2080-2090 |
| Max 10-yr avg yield increase (mm) | 5.77 | 2080-2090 |
| Max ECA (%) | 10.04% | 2087 |
| Max yield increase (%) | 2.48% | 2082 |
| Max yield increase (mm) | 9.0 | 2082 |




Cumulative watershed disturbance and hydrologic analysis for Highwood River

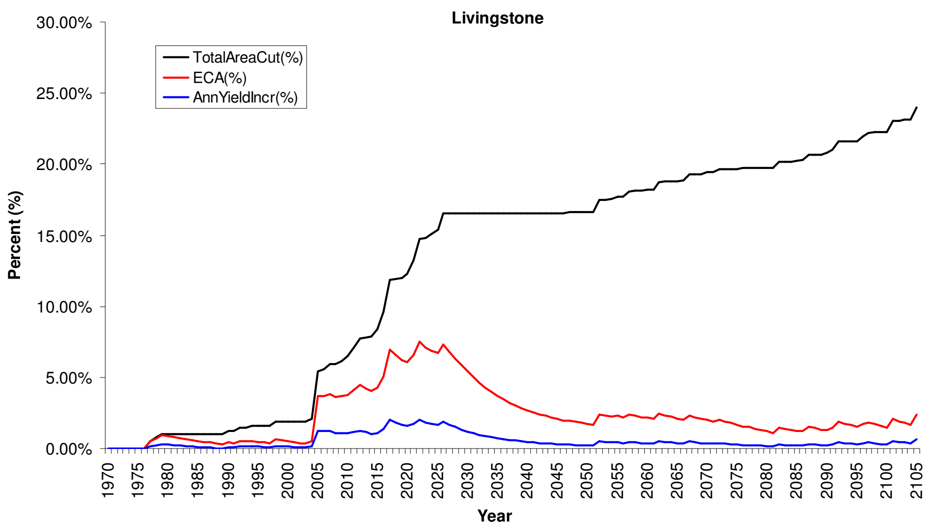



| | 1975 | 1985 | 1995 | 2005 | 2015 | 2025 | 2035 | 2045 | 2055 | 2065 | 2075 | 2085 | 2095 | 2105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumulative area cut (%) | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 10.68% | 12.47% | 12.47% | 12.93% | 12.93% | 12.93% | 12.93% |
| 10-yr Max ECA (%) | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 3.99% | 10.04% | 6.09% | 2.22% | 1.01% | 0.52% | 0.25% | 0.08% |
| 10-yr Max Yield Increase (%) | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 1.09% | 2.48% | 0.83% | 0.13% | 0.13% | 0.07% | 0.02% | 0.00% |

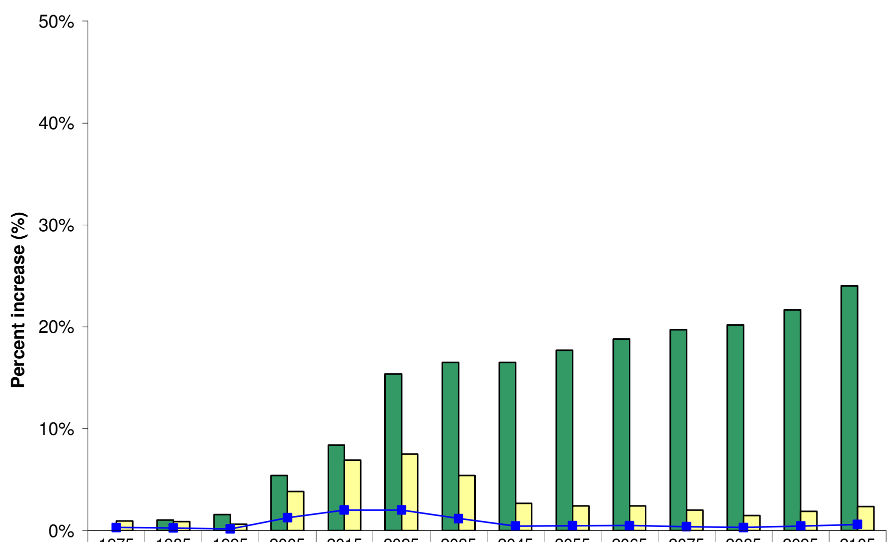
Decade

## Livingstone River

| Livingstone | | Year/Decade |
|---|---|---|
| **Area harvested prior to 2006 (historic harvesting) (%)** | 5.41% | |
| **Cumulative area harvested (historic and proposed ending in fall 2026) (%)** | 16.52% | |
| **New area proposed for harvest 20 years ( 2006-2026) (%)** | 11.11% | |
| **Total area harvested at the end of the 100 year planning horizon (2105) (%)** | 24.03% | |
| **Max 10-yr avg ECA increase** | 6.72% | 2020-2030 |
| **Max 10-yr avg yield increase%** | 1.69% | 2020-2030 |
| **Max 10-yr avg yield increase (mm)** | 5.45 | 2020-2030 |
| **Max ECA (%)** | 7.53% | 2032 |
| **Max yield increase (%)** | 2.04% | 2017 |
| **Max yield increase (mm)** | 6.6 | 2017 |



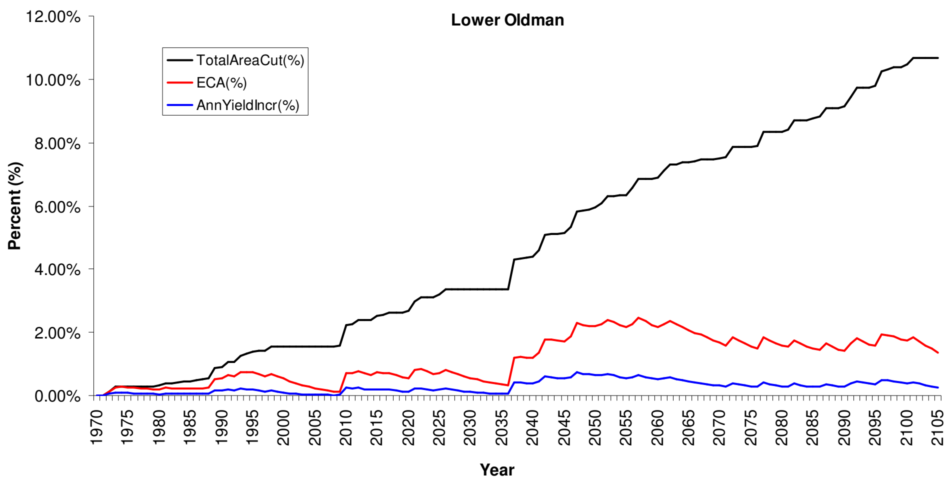

**Cumulative watershed disturbance and hydrologic analysis for Livingstone**



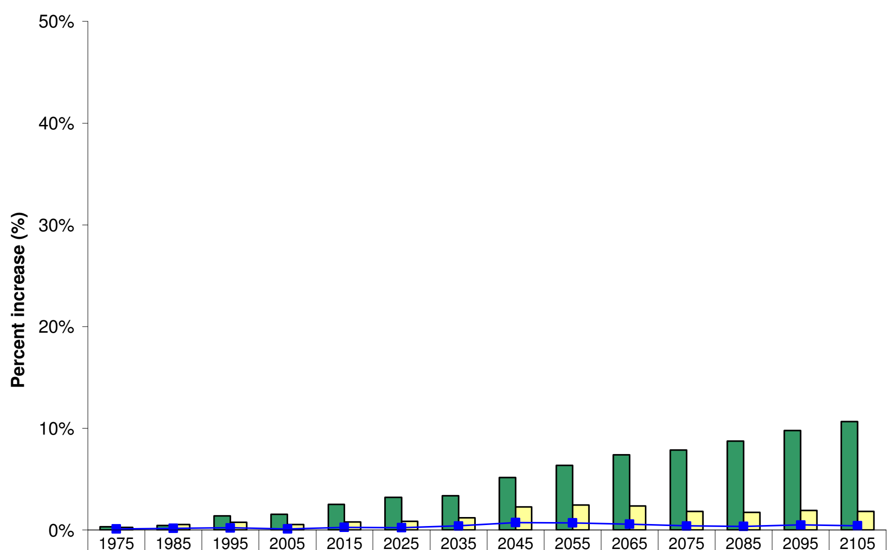

| | 1975 | 1985 | 1995 | 2005 | 2015 | 2025 | 2035 | 2045 | 2055 | 2065 | 2075 | 2085 | 2095 | 2105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumulative area cut (%) | 0.00% | 1.04% | 1.57% | 5.41% | 8.41% | 15.37% | 16.52% | 16.52% | 17.71% | 18.81% | 19.69% | 20.21% | 21.65% | 24.03% |
| 10-yr Max ECA (%) | 0.95% | 0.89% | 0.62% | 3.83% | 6.93% | 7.53% | 5.42% | 2.67% | 2.41% | 2.43% | 2.03% | 1.48% | 1.89% | 2.39% |
| 10-yr Max Yield Increase (%) | 0.30% | 0.26% | 0.16% | 1.26% | 2.00% | 2.04% | 1.19% | 0.47% | 0.47% | 0.50% | 0.39% | 0.31% | 0.45% | 0.61% |

# Lower Oldman River

| Lower Oldman | | Year/Decade |
|---|---|---|
| Area harvested prior to 2006 (historic harvesting) (%) | 1.55% | |
| Cumulative area harvested (historic and proposed ending in fall 2026) (%) | 3.36% | |
| New area proposed for harvest 20 years ( 2006-2026) (%) | 1.81% | |
| Total area harvested at the end of the 100 year planning horizon (2105) (%) | 10.68% | |
| Max 10-yr avg ECA increase | 2.29% | 2080-2090 |
| Max 10-yr avg yield increase% | 0.61% | 2080-2090 |
| Max 10-yr avg yield increase (mm) | 1.71 | 2080-2090 |
| Max ECA (%) | 2.45% | 2087 |
| Max yield increase (%) | 0.73% | 2082 |
| Max yield increase (mm) | 2.0 | 2082 |




Cumulative watershed disturbance and hydrologic analysis for Lower Oldman

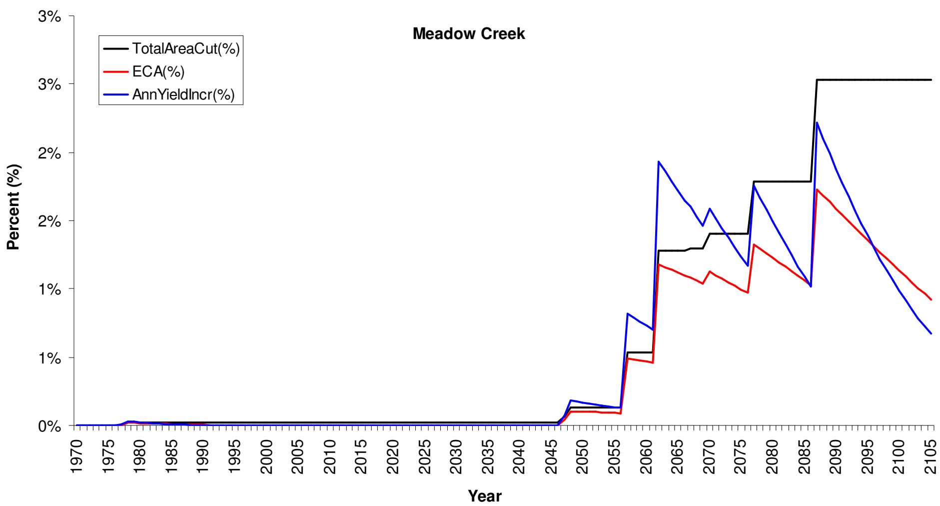



| | 1975 | 1985 | 1995 | 2005 | 2015 | 2025 | 2035 | 2045 | 2055 | 2065 | 2075 | 2085 | 2095 | 2105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumulative area cut (%) | 0.30% | 0.45% | 1.39% | 1.55% | 2.51% | 3.20% | 3.37% | 5.15% | 6.35% | 7.37% | 7.87% | 8.75% | 9.79% | 10.68% |
| 10-yr Max ECA (%) | 0.28% | 0.53% | 0.76% | 0.54% | 0.78% | 0.84% | 1.21% | 2.28% | 2.45% | 2.35% | 1.84% | 1.74% | 1.94% | 1.83% |
| 10-yr Max Yield Increase (%) | 0.10% | 0.17% | 0.22% | 0.10% | 0.24% | 0.23% | 0.41% | 0.73% | 0.69% | 0.57% | 0.41% | 0.37% | 0.49% | 0.42% |

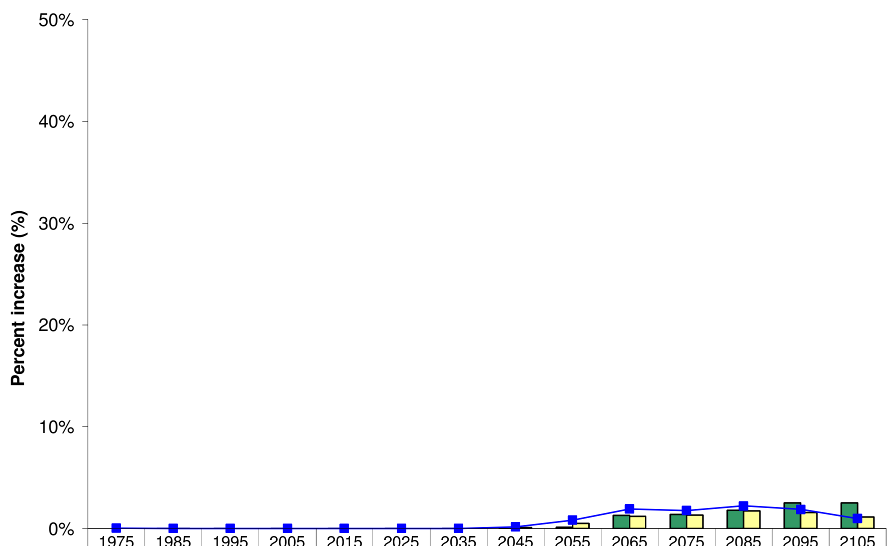
Decade

# Meadow Creek

| Meadow Creek | | Year/Decade |
|---|---|---|
| Area harvested prior to 2006 (historic harvesting) (%) | 0.02% | |
| Cumulative area harvested (historic and proposed ending in fall 2026) (%) | 0.02% | |
| New area propopsed for harvest 20 years ( 2006-2026) (%) | 0.00% | |
| Total area harvested at the end of the 100 year planning horizon (2105) (%) | 2.53% | |
| Max 10-yr avg ECA increase | 1.38% | 2060-2070 |
| Max 10-yr avg yield increase% | 1.51% | 2060-2070 |
| Max 10-yr avg yield increase (mm) | 1.13 | 2060-2070 |
| Max ECA (%) | 1.73% | 2067 |
| Max yield increase (%) | 2.22% | 2067 |
| Max yield increase (mm) | 1.7 | 2067 |




Cumulative watershed disturbance and hydrologic analysis for Meadow Creek

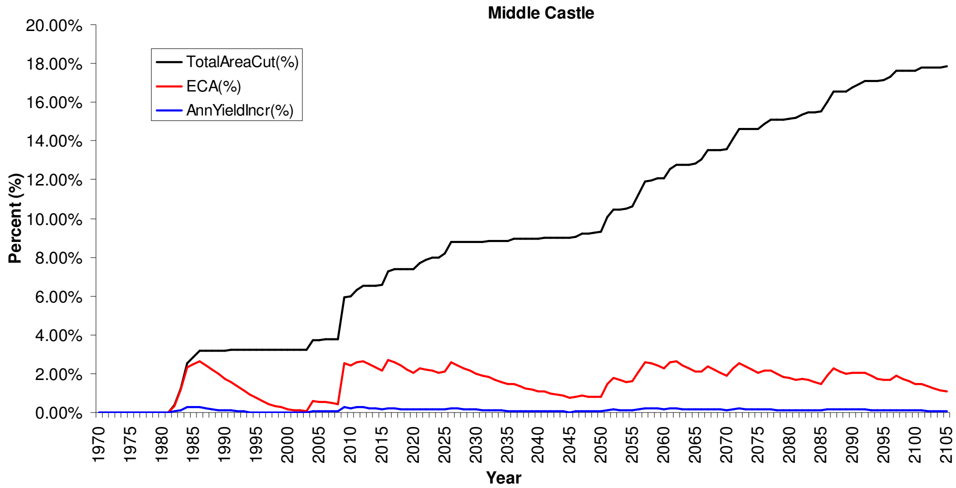



| | 1975 | 1985 | 1995 | 2005 | 2015 | 2025 | 2035 | 2045 | 2055 | 2065 | 2075 | 2085 | 2095 | 2105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumulative area cut (%) | 0.00% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% | 0.02% | 0.13% | 1.28% | 1.40% | 1.78% | 2.53% | 2.53% |
| 10-yr Max ECA (%) | 0.02% | 0.02% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.11% | 0.49% | 1.18% | 1.32% | 1.73% | 1.59% | 1.13% |
| 10-yr Max Yield Increase (%) | 0.03% | 0.02% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.18% | 0.82% | 1.93% | 1.76% | 2.22% | 1.88% | 0.98% |

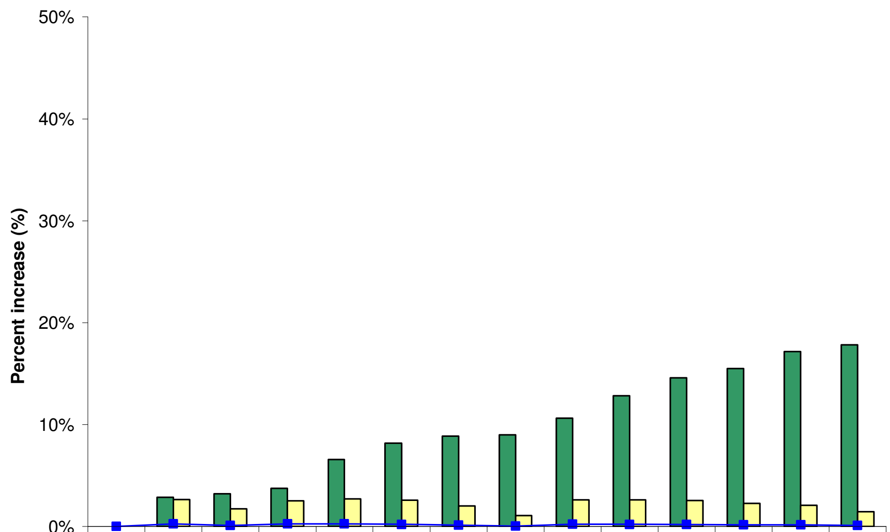
Decade

## Middle Castle

| Middle Castle | | Year/Decade |
|---|---|---|
| Area harvested prior to 2006 (historic harvesting) (%) | 3.74% | |
| Cumulative area harvested (historic and proposed ending in fall 2026) (%) | 8.79% | |
| New area proposed for harvest 20 years ( 2006-2026) (%) | 5.05% | |
| Total area harvested at the end of the 100 year planning horizon (2105) (%) | 17.84% | |
| Max 10-yr avg ECA increase | 2.45% | 2040-2050 |
| Max 10-yr avg yield increase% | 0.21% | 2040-2050 |
| Max 10-yr avg yield increase (mm) | 1.04 | 2040-2050 |
| Max ECA (%) | 2.70% | 2041 |
| Max yield increase (%) | 0.27% | 2041 |
| Max yield increase (mm) | 1.3 | 2041 |




Cumulative watershed disturbance and hydrologic analysis for Meadow Creek

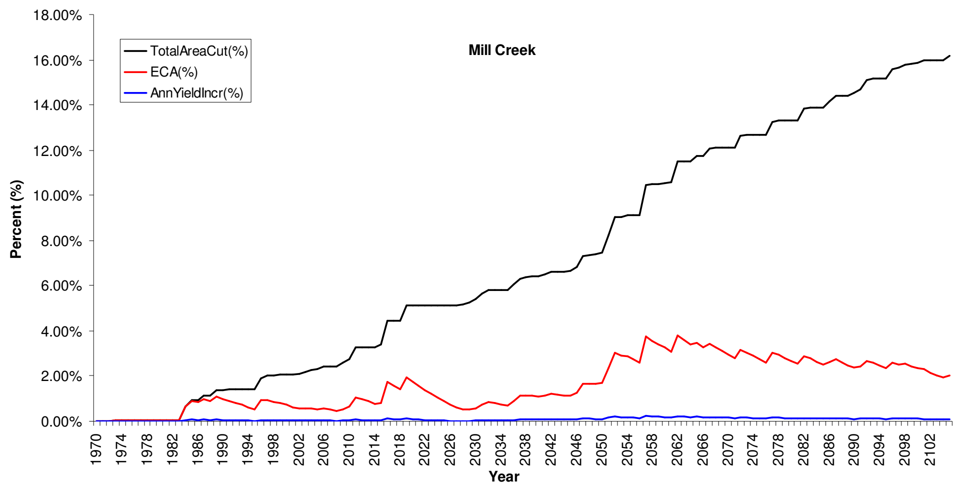



| | 1975 | 1985 | 1995 | 2005 | 2015 | 2025 | 2035 | 2045 | 2055 | 2065 | 2075 | 2085 | 2095 | 2105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumulative area cut (%) | 0.00% | 2.85% | 3.21% | 3.74% | 6.57% | 8.18% | 8.87% | 9.00% | 10.65% | 12.84% | 14.60% | 15.50% | 17.16% | 17.84% |
| 10-yr Max ECA (%) | 0.00% | 2.64% | 1.74% | 2.51% | 2.70% | 2.56% | 2.01% | 1.08% | 2.60% | 2.62% | 2.55% | 2.26% | 2.07% | 1.46% |
| 10-yr Max Yield Increase (%) | 0.00% | 0.25% | 0.10% | 0.27% | 0.25% | 0.21% | 0.14% | 0.05% | 0.23% | 0.20% | 0.20% | 0.18% | 0.14% | 0.09% |

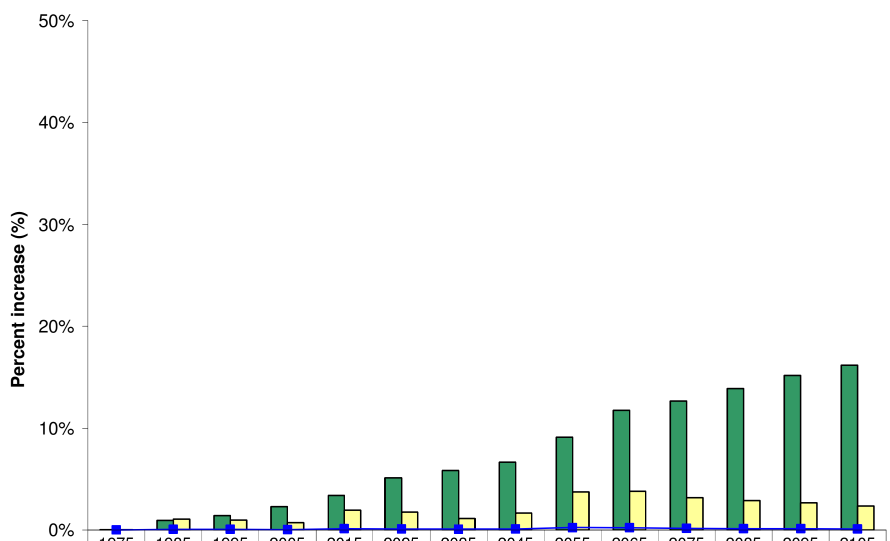
Decade

# Mill Creek

| Mill Creek | | Year/Decade |
|---|---|---|
| Area harvested prior to 2006 (historic harvesting) (%) | 2.29% | |
| Cumulative area harvested (historic and proposed ending in fall 2026) (%) | 5.12% | |
| New area proposed for harvest 20 years ( 2006-2026) (%) | 2.83% | |
| Total area harvested at the end of the 100 year planning horizon (2105) (%) | 16.19% | |
| Max 10-yr avg ECA increase | 3.36% | 2020-2030 |
| Max 10-yr avg yield increase% | 0.18% | 2020-2030 |
| Max 10-yr avg yield increase (mm) | 0.95 | 2020-2030 |
| Max ECA (%) | 3.79% | 2021 |
| Max yield increase (%) | 0.22% | 2021 |
| Max yield increase (mm) | 1.2 | 2021 |




**Cumulative watershed disturbance and hydrologic analysis for Mill Creek**

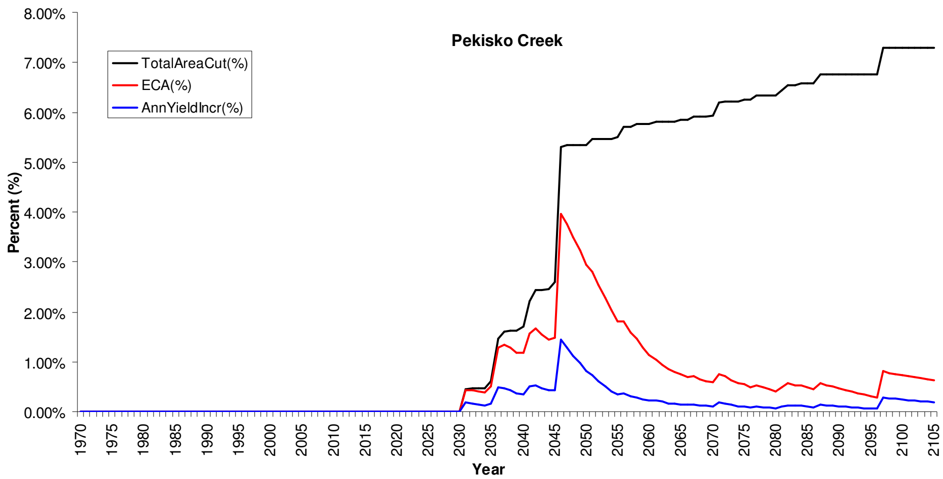



| | 1975 | 1985 | 1995 | 2005 | 2015 | 2025 | 2035 | 2045 | 2055 | 2065 | 2075 | 2085 | 2095 | 2105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumulative area cut (%) | 0.03% | 0.93% | 1.39% | 2.29% | 3.37% | 5.12% | 5.82% | 6.67% | 9.13% | 11.74% | 12.67% | 13.88% | 15.18% | 16.19% |
| 10-yr Max ECA (%) | 0.03% | 1.07% | 0.99% | 0.71% | 1.93% | 1.75% | 1.14% | 1.67% | 3.74% | 3.79% | 3.16% | 2.88% | 2.67% | 2.33% |
| 10-yr Max Yield Increase (%) | 0.00% | 0.06% | 0.05% | 0.03% | 0.11% | 0.09% | 0.07% | 0.10% | 0.22% | 0.21% | 0.16% | 0.14% | 0.12% | 0.10% |

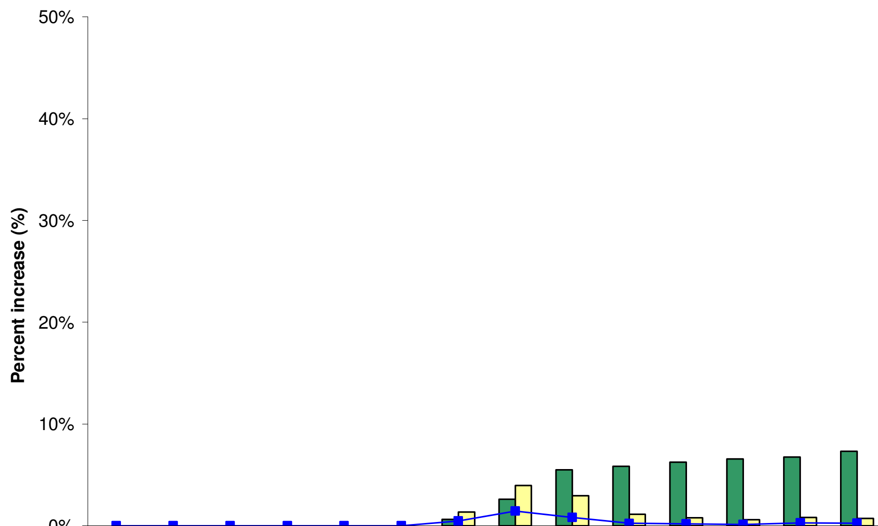
**Decade**

# Pekisko Creek

| Pekisko Creek | | Year/Decade |
|---|---|---|
| Area harvested prior to 2006 (historic harvesting) (%) | 0.00% | |
| Cumulative area harvested (historic and proposed ending in fall 2026) (%) | 0.00% | |
| New area proposed for harvest 20 years ( 2006-2026) (%) | 0.00% | |
| Total area harvested at the end of the 100 year planning horizon (2105) (%) | 7.29% | |
| Max 10-yr avg ECA increase | 2.33% | 2080-2090 |
| Max 10-yr avg yield increase% | 0.75% | 2080-2090 |
| Max 10-yr avg yield increase (mm) | 2.18 | 2080-2090 |
| Max ECA (%) | 3.95% | 2027 |
| Max yield increase (%) | 1.44% | 2026 |
| Max yield increase (mm) | 4.2 | 2026 |




Cumulative watershed disturbance and hydrologic analysis for Pekisko Creek

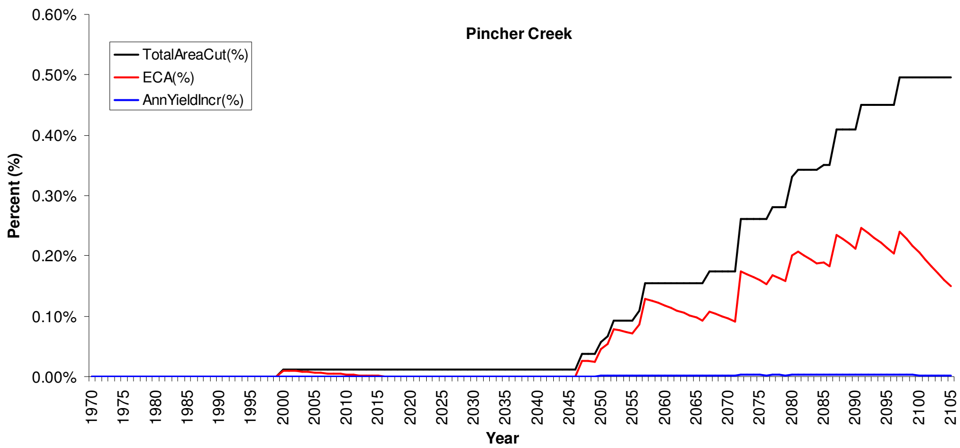



| | 1975 | 1985 | 1995 | 2005 | 2015 | 2025 | 2035 | 2045 | 2055 | 2065 | 2075 | 2085 | 2095 | 2105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumulative area cut (%) | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.62% | 2.61% | 5.49% | 5.85% | 6.25% | 6.58% | 6.75% | 7.29% |
| 10-yr Max ECA (%) | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 1.35% | 3.95% | 2.95% | 1.14% | 0.76% | 0.58% | 0.80% | 0.73% |
| 10-yr Max Yield Increase (%) | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.48% | 1.44% | 0.82% | 0.22% | 0.18% | 0.14% | 0.28% | 0.24% |

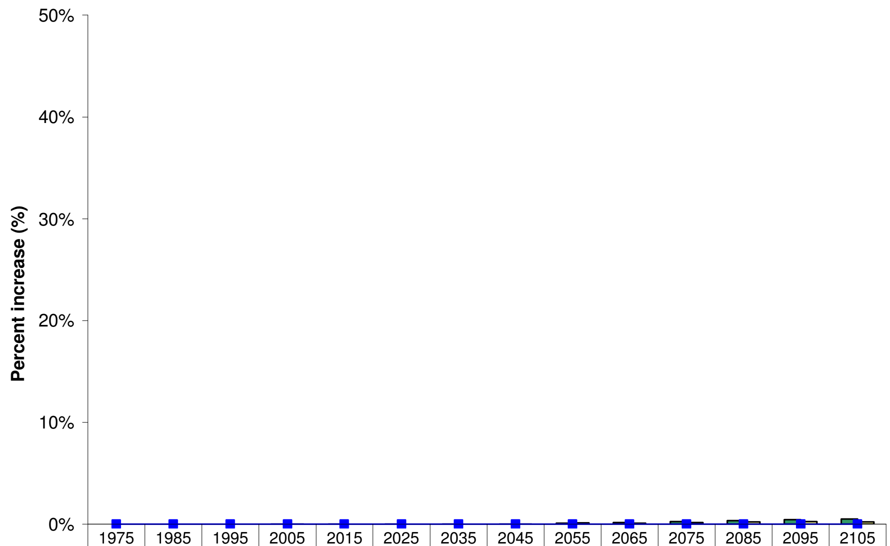
Decade

## Pincher Creek

| Pincher Creek | | |
|---|---|---|
| | | Year/Decade |
| Area harvested prior to 2006 (historic harvesting) (%) | 0.01% | |
| Cumulative area harvested (historic and proposed ending in fall 2026) (%) | 0.01% | |
| New area proposed for harvest 20 years ( 2006-2026) (%) | 0.00% | |
| Total area harvested at the end of the 100 year planning horizon (2105) (%) | 0.50% | |
| Max 10-yr avg ECA increase | 0.22% | 2070-2080 |
| Max 10-yr avg yield increase% | 0.003% | 2070-2080 |
| Max 10-yr avg yield increase (mm) | 0.019 | 2070-2080 |
| Max ECA (%) | 0.25% | 2072 |
| Max yield increase (%) | 0.004% | 2072 |
| Max yield increase (mm) | 0.02 | 2072 |




Cumulative watershed disturbance and hydrologic analysis for Pincher Creek

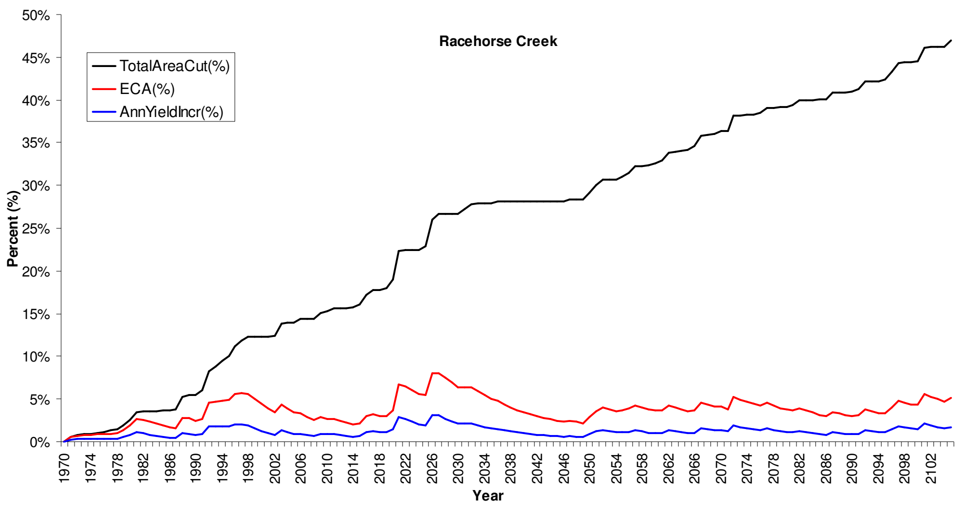



| | 1975 | 1985 | 1995 | 2005 | 2015 | 2025 | 2035 | 2045 | 2055 | 2065 | 2075 | 2085 | 2095 | 2105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumulative area cut (%) | 0.00% | 0.00% | 0.00% | 0.01% | 0.01% | 0.01% | 0.01% | 0.01% | 0.09% | 0.16% | 0.26% | 0.35% | 0.45% | 0.50% |
| 10-yr Max ECA (%) | 0.00% | 0.00% | 0.00% | 0.01% | 0.00% | 0.00% | 0.00% | 0.03% | 0.13% | 0.12% | 0.17% | 0.24% | 0.25% | 0.21% |
| 10-yr Max Yield Increase (%) | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |

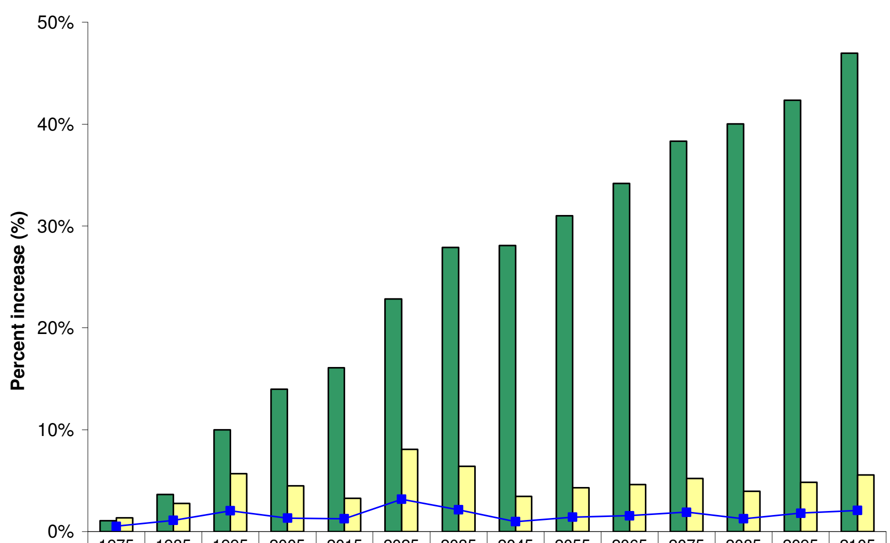
Decade

# Racehorse Creek

| Racehorse Creek | | Year/Decade |
|---|---|---|
| **Area harvested prior to 2006 (historic harvesting) (%)** | 13.97% | |
| **Cumulative area harvested (historic and proposed ending in fall 2026) (%)** | 26.02% | |
| **New area proposed for harvest 20 years ( 2006-2026) (%)** | 12.06% | |
| **Total area harvested at the end of the 100 year planning horizon (2105) (%)** | 46.96% | |
| **Max 10-yr avg ECA increase** | 6.43% | 2030-2040 |
| **Max 10-yr avg yield increase%** | 2.44% | 2030-2040 |
| **Max 10-yr avg yield increase (mm)** | 8.60 | 2030-2040 |
| **Max ECA (%)** | 8.07% | 2032 |
| **Max yield increase (%)** | 3.16% | 2032 |
| **Max yield increase (mm)** | 11.1 | 2032 |




**Cumulative watershed disturbance and hydrologic analysis for Racehorse Creek**

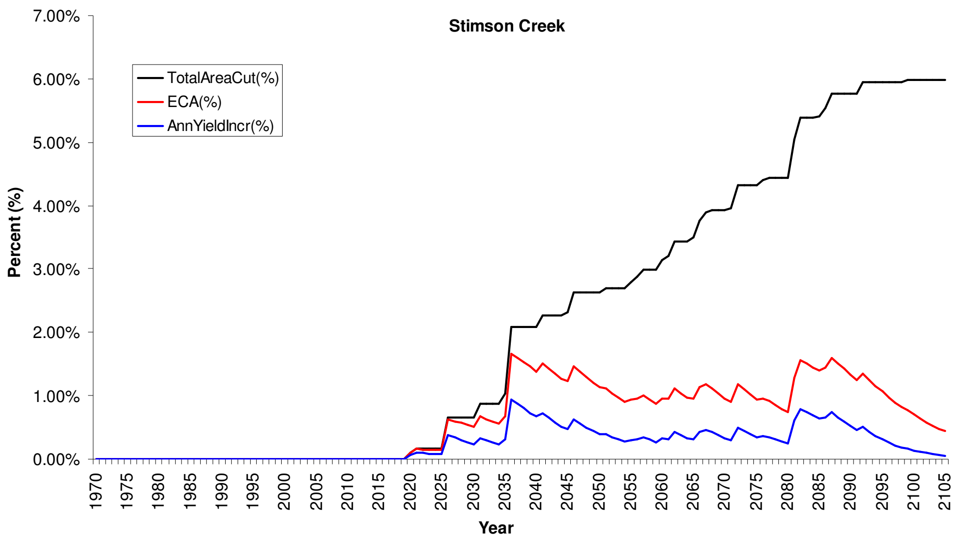



| | 1975 | 1985 | 1995 | 2005 | 2015 | 2025 | 2035 | 2045 | 2055 | 2065 | 2075 | 2085 | 2095 | 2105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumulative area cut (%) | 1.05% | 3.65% | 10.00% | 13.97% | 16.07% | 22.83% | 27.89% | 28.08% | 31.00% | 34.19% | 38.33% | 40.01% | 42.36% | 46.96% |
| 10-yr Max ECA (%) | 1.35% | 2.75% | 5.67% | 4.48% | 3.28% | 8.07% | 6.42% | 3.45% | 4.29% | 4.60% | 5.21% | 3.94% | 4.83% | 5.56% |
| 10-yr Max Yield Increase (%) | 0.51% | 1.09% | 2.03% | 1.31% | 1.26% | 3.16% | 2.13% | 0.97% | 1.39% | 1.55% | 1.89% | 1.25% | 1.80% | 2.07% |

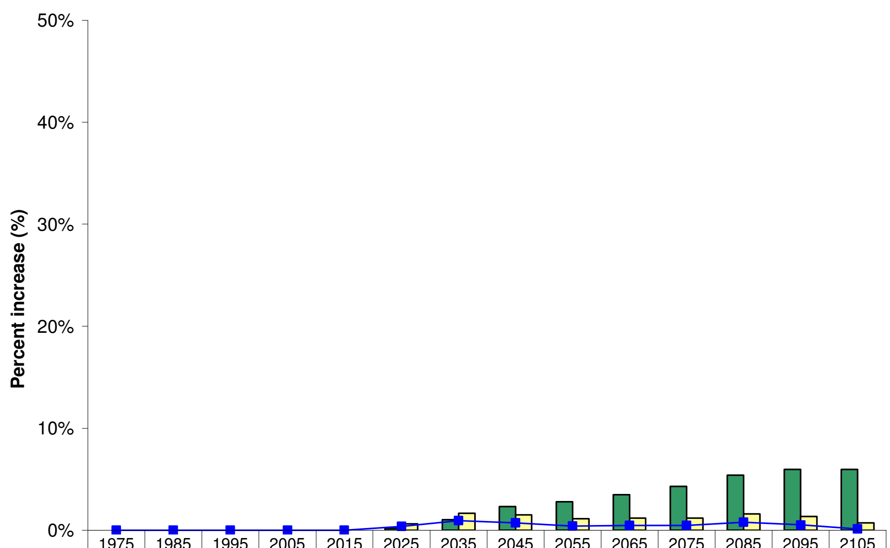
**Decade**

## Stimson Creek

| Stimson Creek | | Year/Decade |
|---|---|---|
| Area harvested prior to 2006 (historic harvesting) (%) | 0.00% | |
| Cumulative area harvested (historic and proposed ending in fall 2026) (%) | 0.66% | |
| New area proposed for harvest 20 years ( 2006-2026) (%) | 0.66% | |
| Total area harvested at the end of the 100 year planning horizon (2105) (%) | 5.98% | |
| Max 10-yr avg ECA increase | 1.39% | 2080-2090 |
| Max 10-yr avg yield increase% | 0.64% | 2080-2090 |
| Max 10-yr avg yield increase (mm) | 1.43 | 2080-2090 |
| Max ECA (%) | 1.66% | 2082 |
| Max yield increase (%) | 0.94% | 2077 |
| Max yield increase (mm) | 2.1 | 2077 |




Cumulative watershed disturbance and hydrologic analysis for Stimson Creek

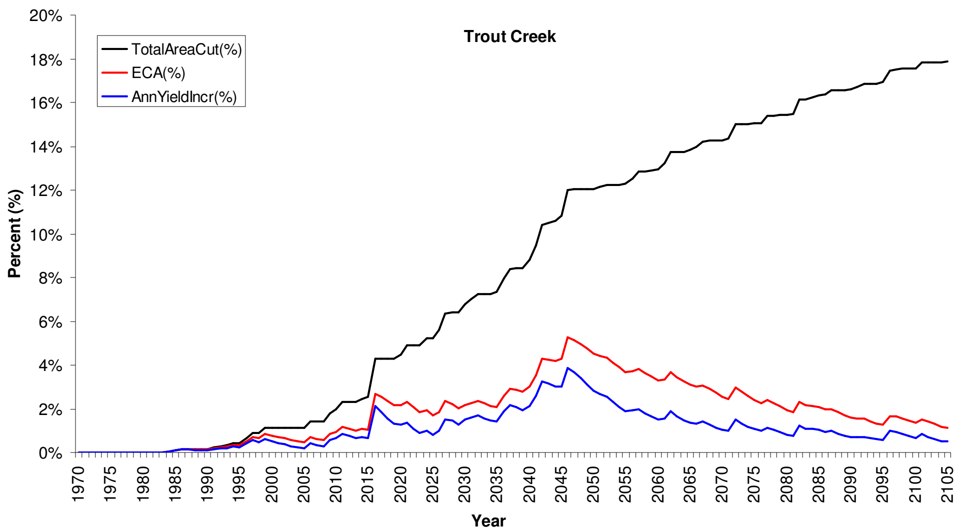



| | 1975 | 1985 | 1995 | 2005 | 2015 | 2025 | 2035 | 2045 | 2055 | 2065 | 2075 | 2085 | 2095 | 2105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumulative area cut (%) | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.16% | 1.03% | 2.31% | 2.79% | 3.49% | 4.31% | 5.40% | 5.96% | 5.98% |
| 10-yr Max ECA (%) | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.62% | 1.66% | 1.50% | 1.13% | 1.19% | 1.18% | 1.59% | 1.35% | 0.70% |
| 10-yr Max Yield Increase (%) | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.38% | 0.94% | 0.72% | 0.40% | 0.46% | 0.49% | 0.79% | 0.52% | 0.14% |

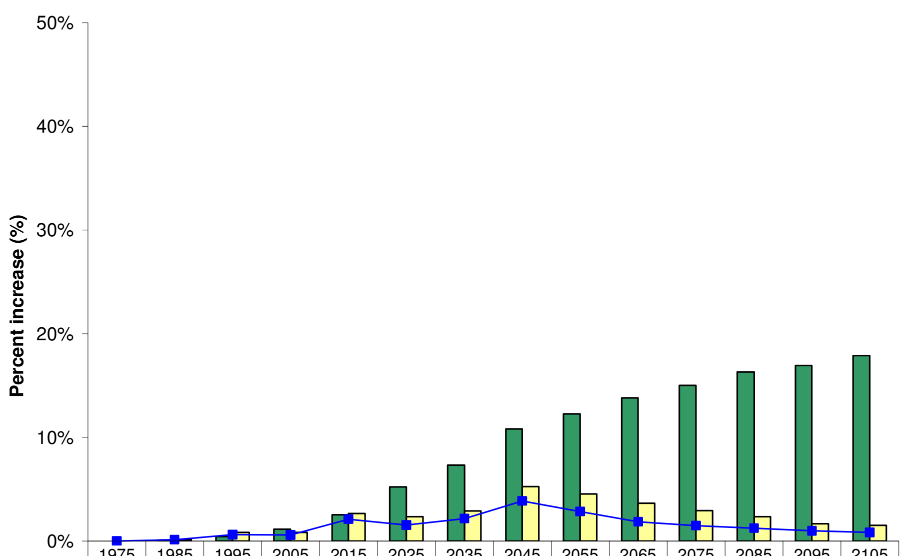
Decade

# Trout Creek

| Trout Creek | | Year/Decade |
|---|---|---|
| Area harvested prior to 2006 (historic harvesting) (%) | 1.12% | |
| Cumulative area harvested (historic and proposed ending in fall 2026) (%) | 5.60% | |
| New area proposed for harvest 20 years ( 2006-2026) (%) | 4.48% | |
| Total area harvested at the end of the 100 year planning horizon (2105) (%) | 17.89% | |
| Max 10-yr avg ECA increase | 4.37% | 2040-2050 |
| Max 10-yr avg yield increase% | 3.11% | 2040-2050 |
| Max 10-yr avg yield increase (mm) | 3.77 | 2040-2050 |
| Max ECA (%) | 5.27% | 2042 |
| Max yield increase (%) | 3.87% | 2026 |
| Max yield increase (mm) | 4.7 | 2026 |




Cumulative watershed disturbance and hydrologic analysis for Trout Creek

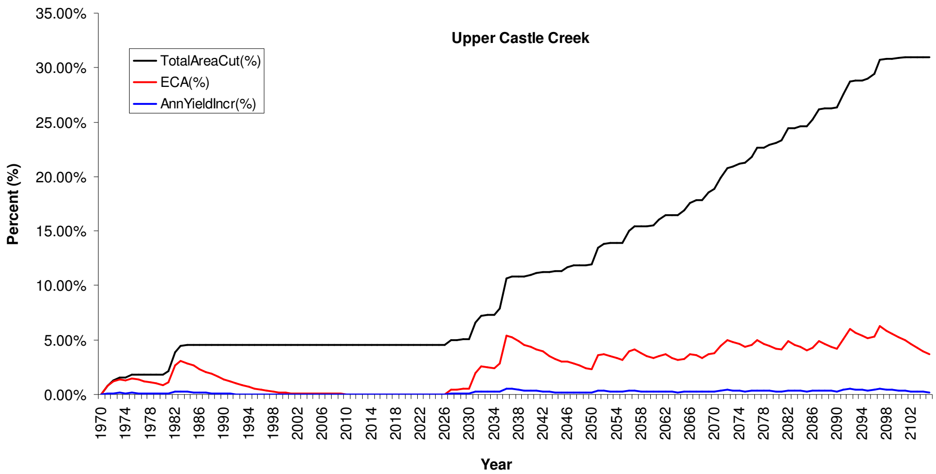



| | 1975 | 1985 | 1995 | 2005 | 2015 | 2025 | 2035 | 2045 | 2055 | 2065 | 2075 | 2085 | 2095 | 2105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumulative area cut (%) | 0.00% | 0.10% | 0.43% | 1.12% | 2.55% | 5.22% | 7.33% | 10.82% | 12.27% | 13.83% | 15.04% | 16.32% | 16.92% | 17.89% |
| 10-yr Max ECA (%) | 0.00% | 0.15% | 0.84% | 0.85% | 2.66% | 2.35% | 2.91% | 5.27% | 4.54% | 3.66% | 2.94% | 2.33% | 1.66% | 1.51% |
| 10-yr Max Yield Increase (%) | 0.00% | 0.14% | 0.61% | 0.57% | 2.11% | 1.52% | 2.16% | 3.87% | 2.84% | 1.86% | 1.49% | 1.24% | 0.97% | 0.83% |

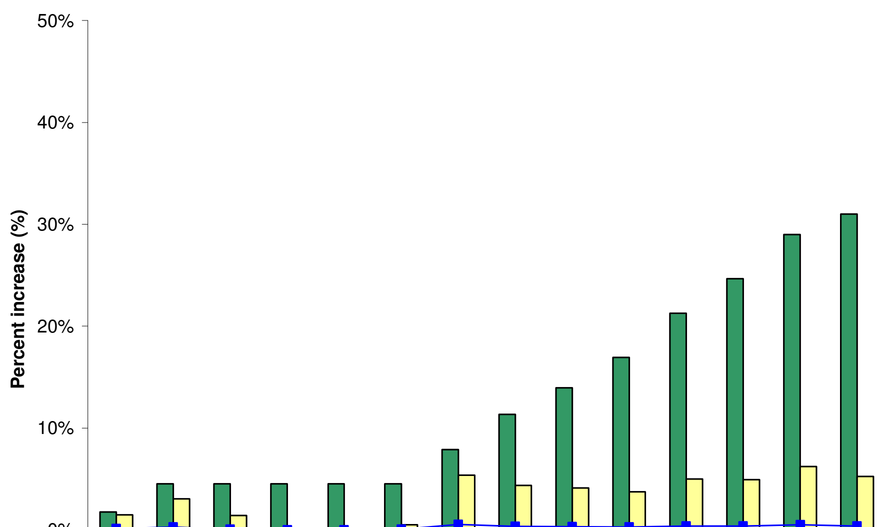
Decade

# Upper Castle River

| Upper Castle | | Year/Decade |
|---|---|---|
| Area harvested prior to 2006 (historic harvesting) (%) | 4.52% | |
| Cumulative area harvested (historic and proposed ending in fall 2026) (%) | 4.52% | |
| New area proposed for harvest 20 years ( 2006-2026) (%) | 0.00% | |
| Total area harvested at the end of the 100 year planning horizon (2105) (%) | 30.99% | |
| Max 10-yr avg ECA increase | 5.44% | 2070-2080 |
| Max 10-yr avg yield increase% | 0.42% | 2070-2080 |
| Max 10-yr avg yield increase (mm) | 2.84 | 2070-2080 |
| Max ECA (%) | 6.23% | 2072 |
| Max yield increase (%) | 0.54% | 2072 |
| Max yield increase (mm) | 3.7 | 2072 |




Cumulative watershed disturbance and hydrologic analysis for Upper Castle

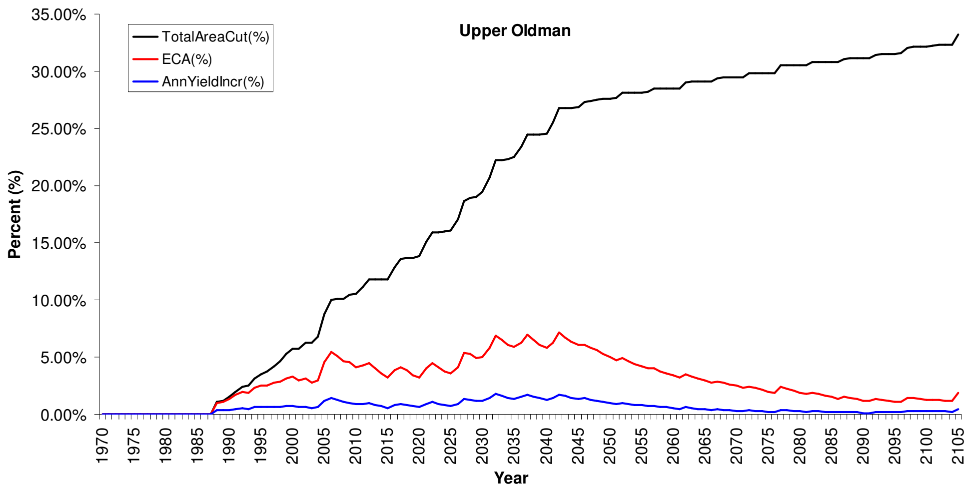



| | 1975 | 1985 | 1995 | 2005 | 2015 | 2025 | 2035 | 2045 | 2055 | 2065 | 2075 | 2085 | 2095 | 2105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumulative area cut (%) | 1.77% | 4.52% | 4.52% | 4.52% | 4.52% | 4.52% | 7.87% | 11.34% | 13.94% | 16.93% | 21.27% | 24.66% | 28.98% | 30.99% |
| 10-yr Max ECA (%) | 1.45% | 3.05% | 1.39% | 0.15% | 0.04% | 0.50% | 5.36% | 4.36% | 4.10% | 3.72% | 5.00% | 4.93% | 6.23% | 5.25% |
| 10-yr Max Yield Increase (%) | 0.14% | 0.28% | 0.06% | 0.00% | 0.00% | 0.05% | 0.54% | 0.34% | 0.32% | 0.26% | 0.39% | 0.38% | 0.49% | 0.36% |

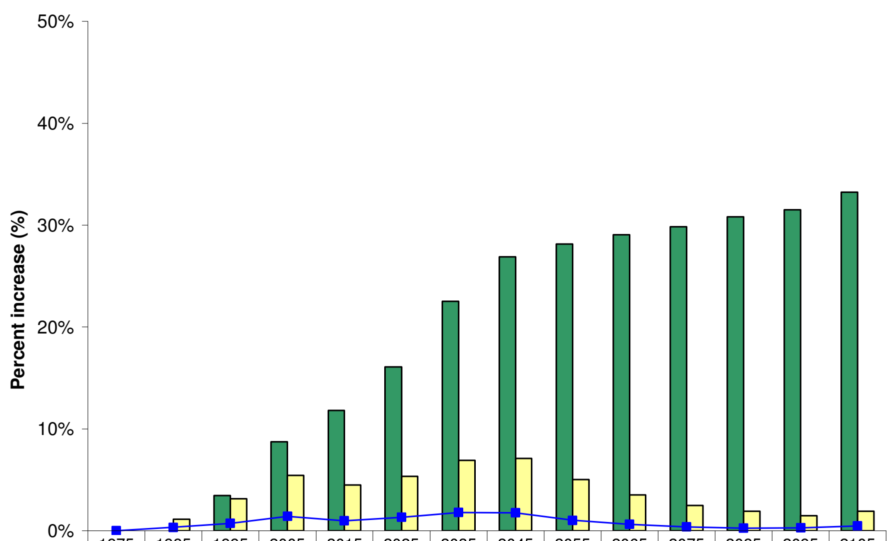
Decade

# Upper Oldman River

| Upper Oldman | | Year/Decade |
|---|---|---|
| Area harvested prior to 2006 (historic harvesting) (%) | 8.72% | |
| Cumulative area harvested (historic and proposed ending in fall 2026) (%) | 17.03% | |
| New area proposed for harvest 20 years ( 2006-2026) (%) | 8.32% | |
| Total area harvested at the end of the 100 year planning horizon (2105) (%) | 33.24% | |
| Max 10-yr avg ECA increase | 6.20% | 2040-2050 |
| Max 10-yr avg yield increase% | 1.50% | 2030-2040 |
| Max 10-yr avg yield increase (mm) | 4.81 | 2030-2040 |
| Max ECA (%) | 7.11% | 2037 |
| Max yield increase (%) | 1.78% | 2037 |
| Max yield increase (mm) | 5.7 | 2037 |




Cumulative watershed disturbance and hydrologic analysis for Upper Oldman

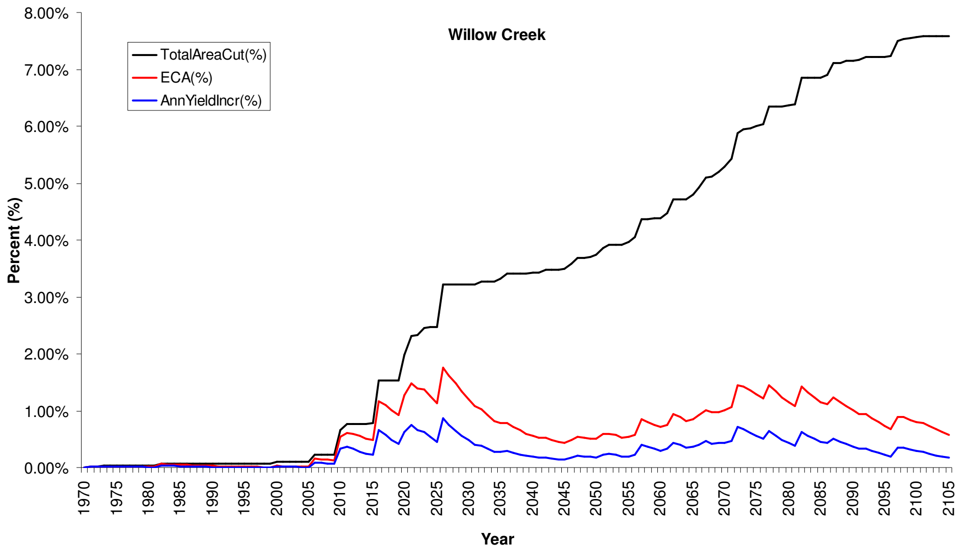



| | 1975 | 1985 | 1995 | 2005 | 2015 | 2025 | 2035 | 2045 | 2055 | 2065 | 2075 | 2085 | 2095 | 2105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumulative area cut (%) | 0.00% | 0.00% | 3.46% | 8.72% | 11.82% | 16.07% | 22.53% | 26.88% | 28.16% | 29.07% | 29.82% | 30.83% | 31.50% | 33.24% |
| 10-yr Max ECA (%) | 0.00% | 1.10% | 3.14% | 5.45% | 4.48% | 5.34% | 6.92% | 7.11% | 5.02% | 3.52% | 2.47% | 1.92% | 1.47% | 1.91% |
| 10-yr Max Yield Increase (%) | 0.00% | 0.33% | 0.71% | 1.40% | 0.98% | 1.31% | 1.78% | 1.74% | 1.02% | 0.61% | 0.38% | 0.26% | 0.29% | 0.48% |

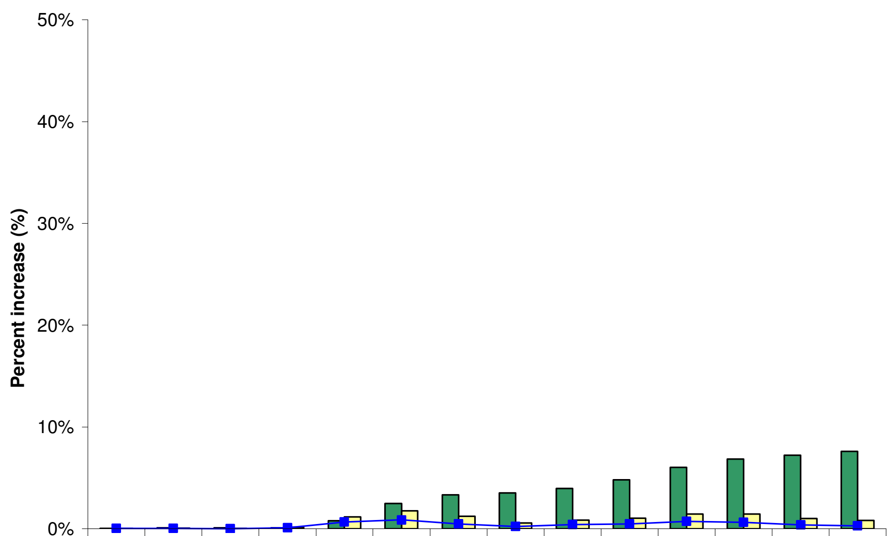
Decade

# Willow Creek

| Willow Creek | | Year/Decade |
|---|---|---|
| Area harvested prior to 2006 (historic harvesting) (%) | 0.10% | |
| Cumulative area harvested (historic and proposed ending in fall 2026) (%) | 3.23% | |
| New area proposed for harvest 20 years ( 2006-2026) (%) | 3.13% | |
| Total area harvested at the end of the 100 year planning horizon (2105) (%) | 7.59% | |
| Max 10-yr avg ECA increase | 1.41% | 2080-2090 |
| Max 10-yr avg yield increase% | 0.65% | 2080-2090 |
| Max 10-yr avg yield increase (mm) | 1.36 | 2080-2090 |
| Max ECA (%) | 1.75% | 2087 |
| Max yield increase (%) | 0.86% | 2087 |
| Max yield increase (mm) | 1.8 | 2087 |




Cumulative watershed disturbance and hydrologic analysis for Willow Creek

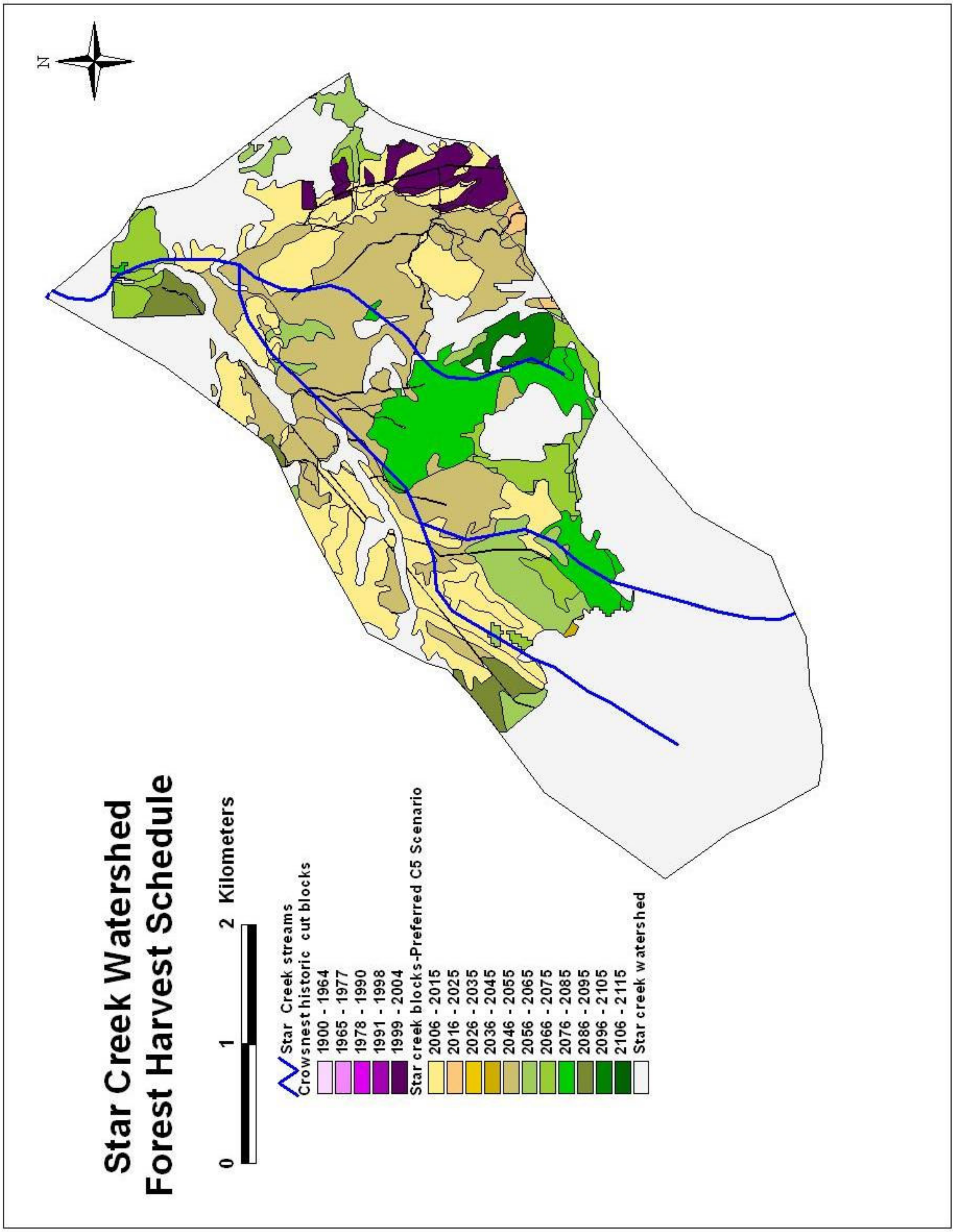



| | 1975 | 1985 | 1995 | 2005 | 2015 | 2025 | 2035 | 2045 | 2055 | 2065 | 2075 | 2085 | 2095 | 2105 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cumulative area cut (%) | 0.03% | 0.07% | 0.07% | 0.10% | 0.78% | 2.46% | 3.33% | 3.50% | 3.96% | 4.81% | 6.01% | 6.86% | 7.22% | 7.59% |
| 10-yr Max ECA (%) | 0.03% | 0.06% | 0.03% | 0.15% | 1.16% | 1.75% | 1.21% | 0.55% | 0.85% | 1.01% | 1.44% | 1.43% | 1.00% | 0.80% |
| 10-yr Max Yield Increase (%) | 0.02% | 0.04% | 0.01% | 0.09% | 0.66% | 0.86% | 0.48% | 0.21% | 0.40% | 0.46% | 0.71% | 0.63% | 0.36% | 0.29% |

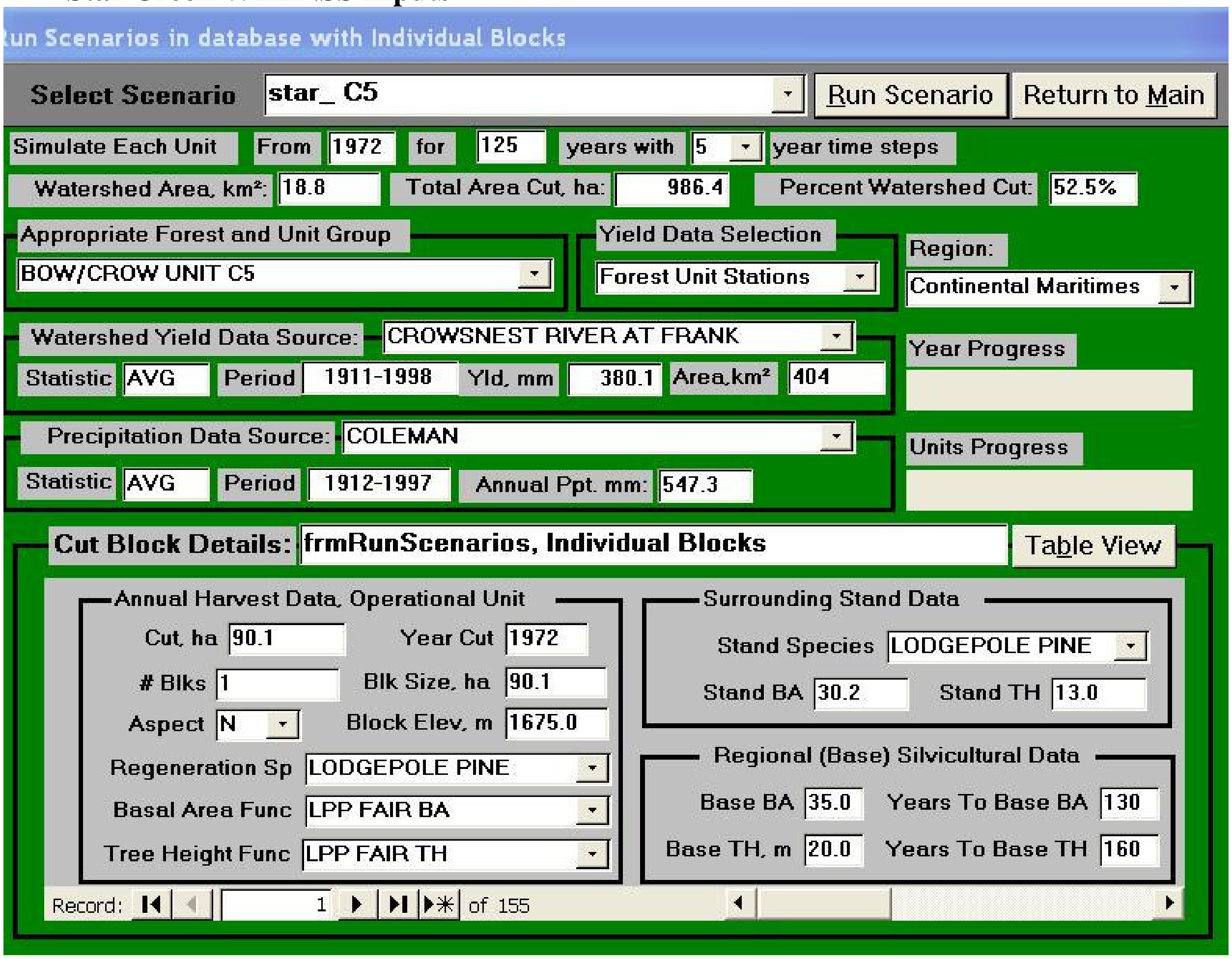
Decade

# Appendix 2 WRENSS Individual Sub-Basin Summaries

**Star Creek Map**

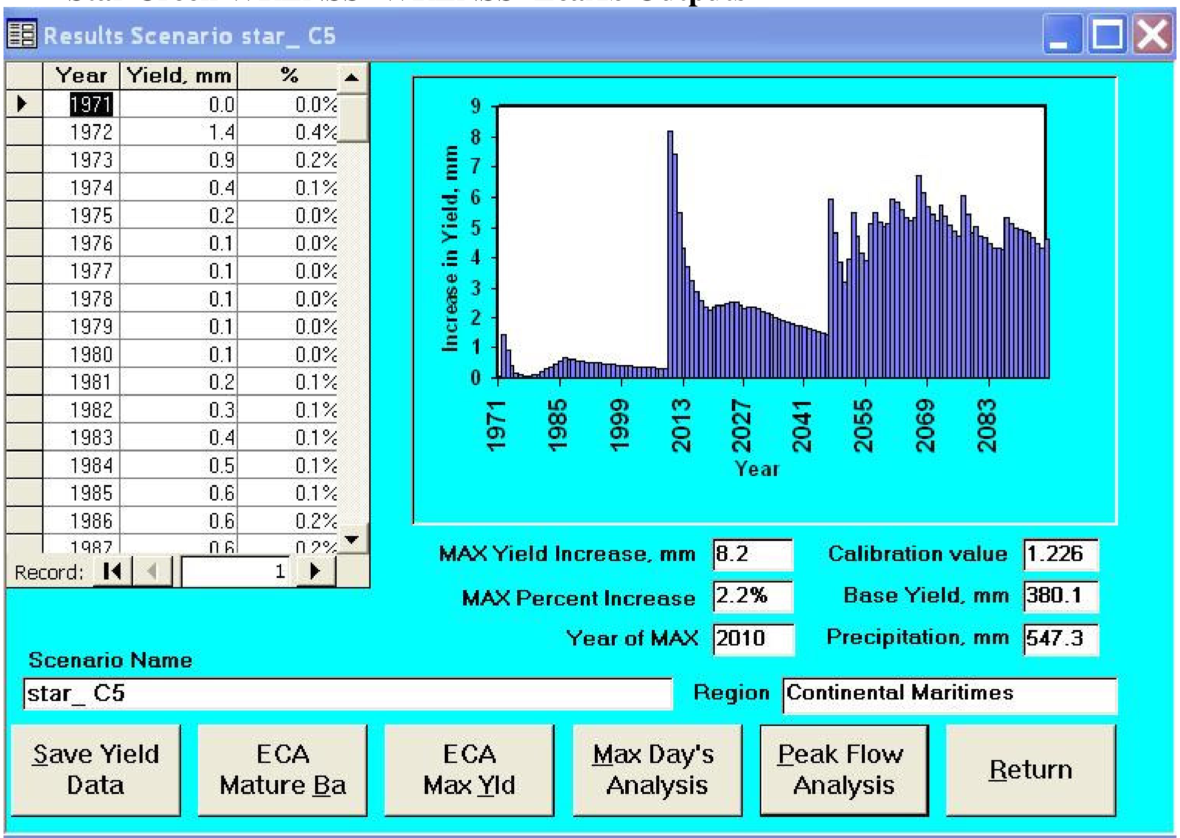


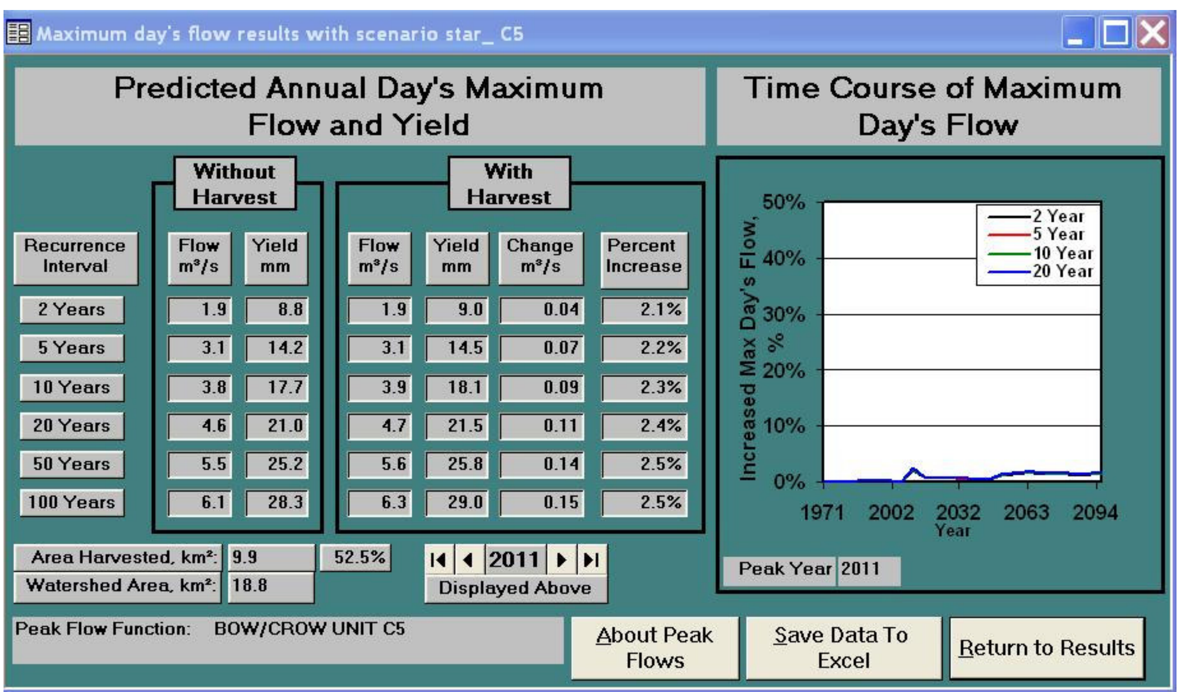
**Star Creek WRENSS Inputs**



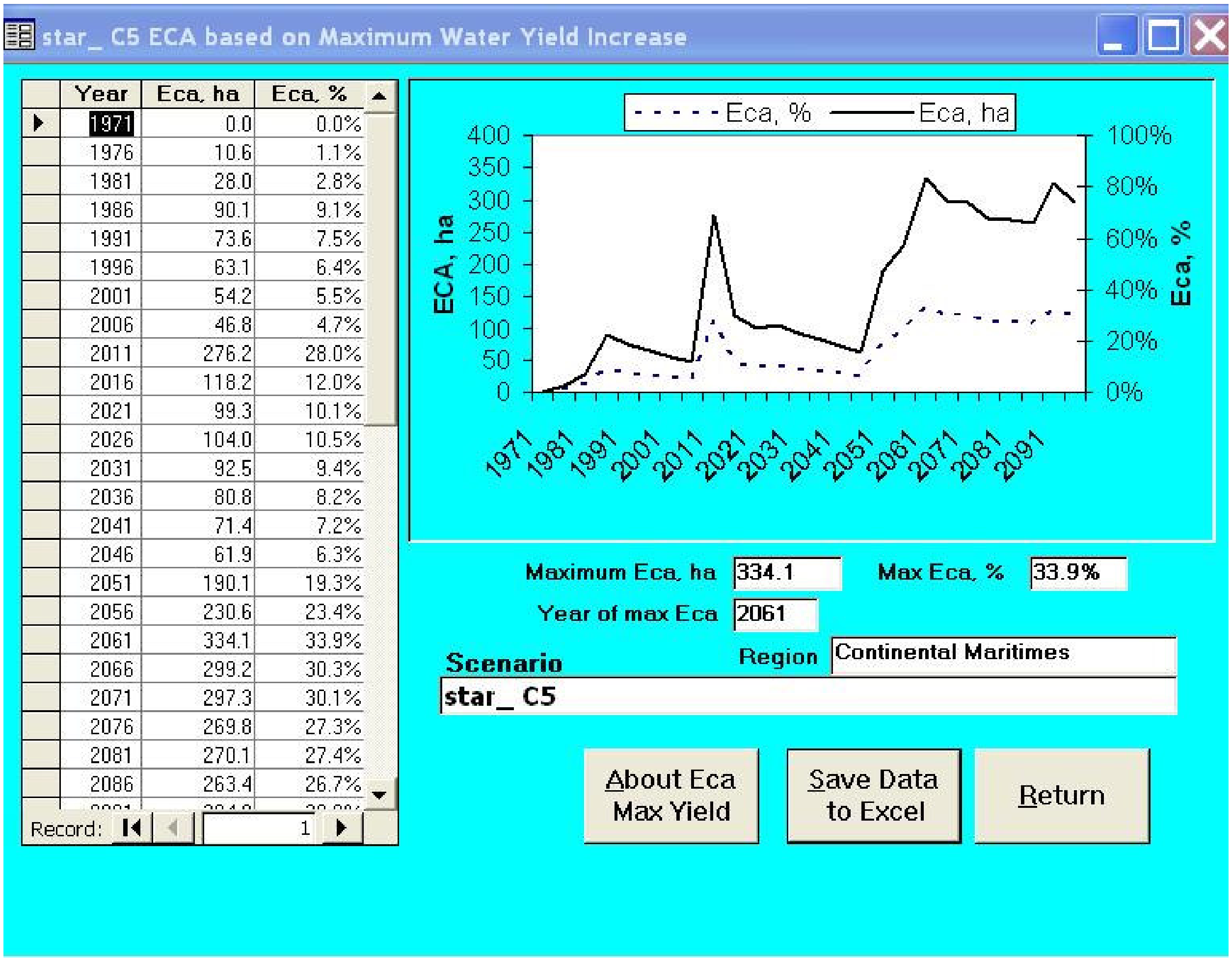

- 52.5% of the watershed harvested over 125 years
- Annual precipitation 547.3mm/year
- Annual water yield 380.1mm/year

**Star Creek WRENSS- WRENSS- EcaAb Outputs**



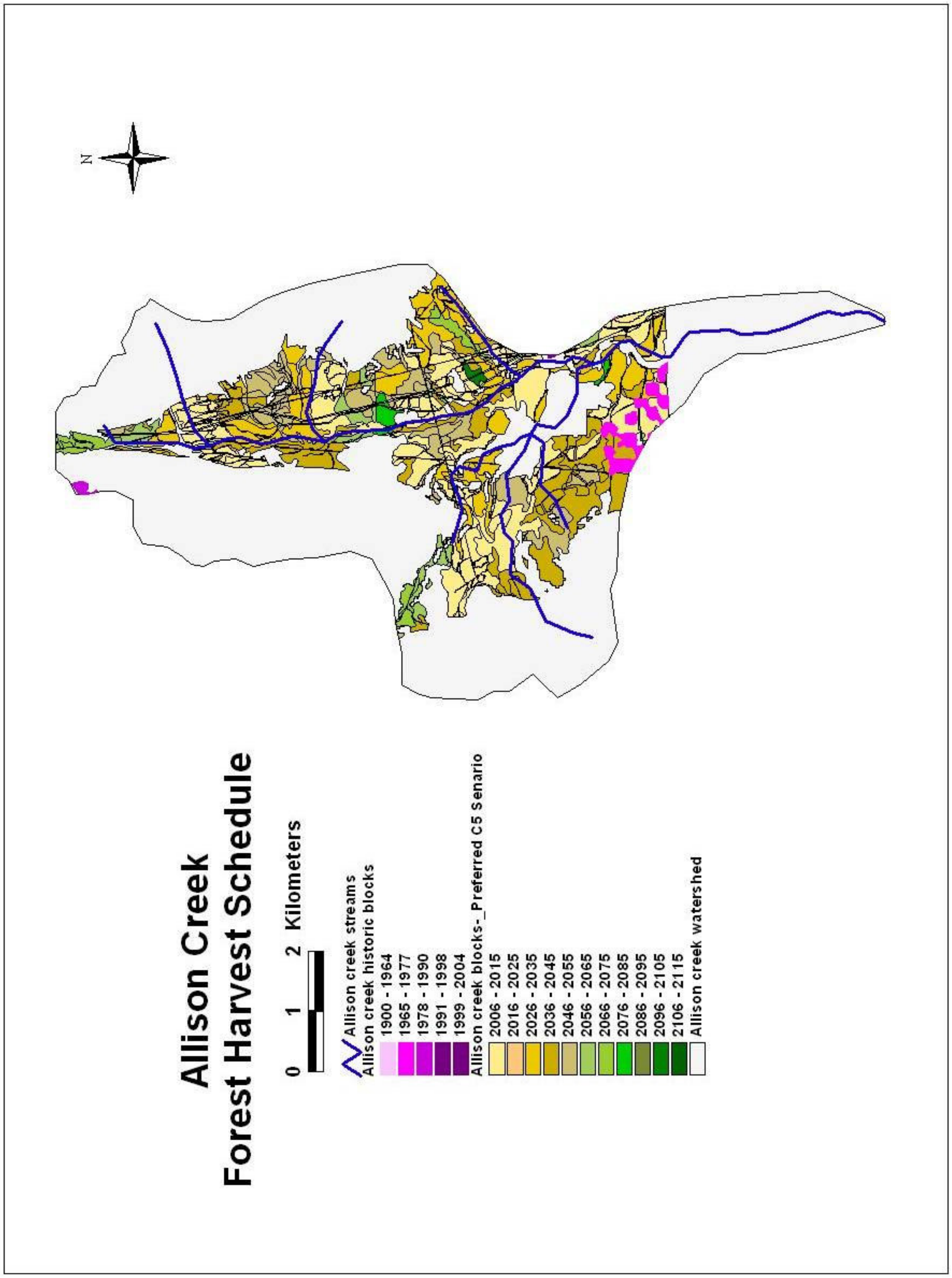




- Simulated maximum yield increase low 2.2% (9.8mm) (an extra 9.8 mm of flow)
- Simulated peak flow increases low 2.1% (2-yr return) and 2.5% (100-yr return)

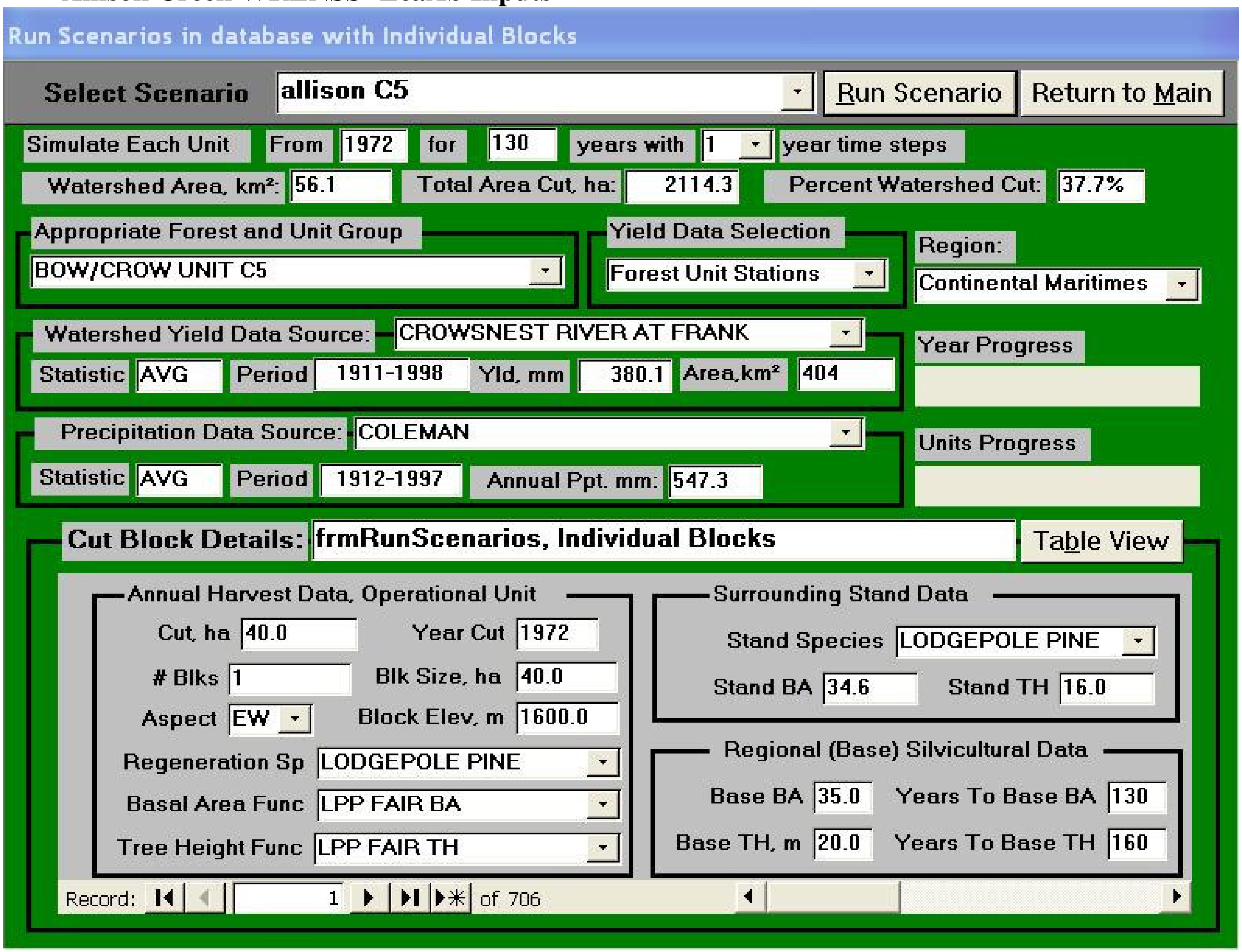



- Maximum ECA is 33.9% occurring at year 2061.

**Allison Creek Map**

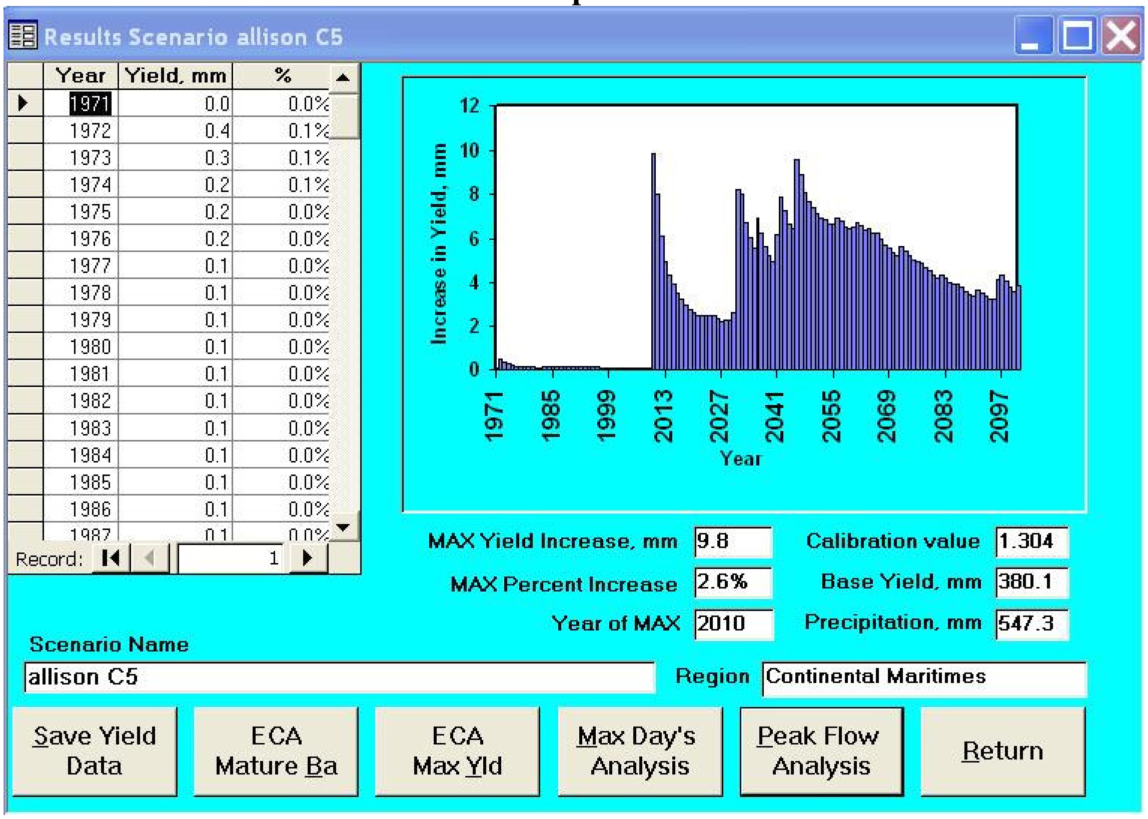


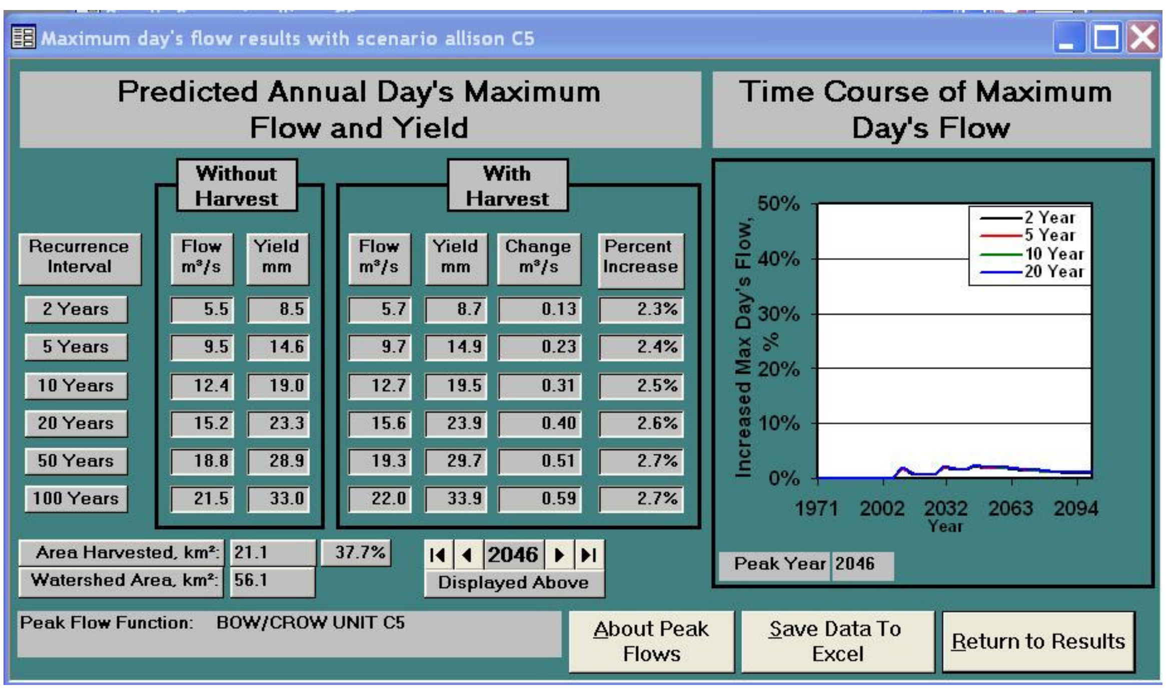
**Allison Creek WRENSS- EcaAb Inputs**



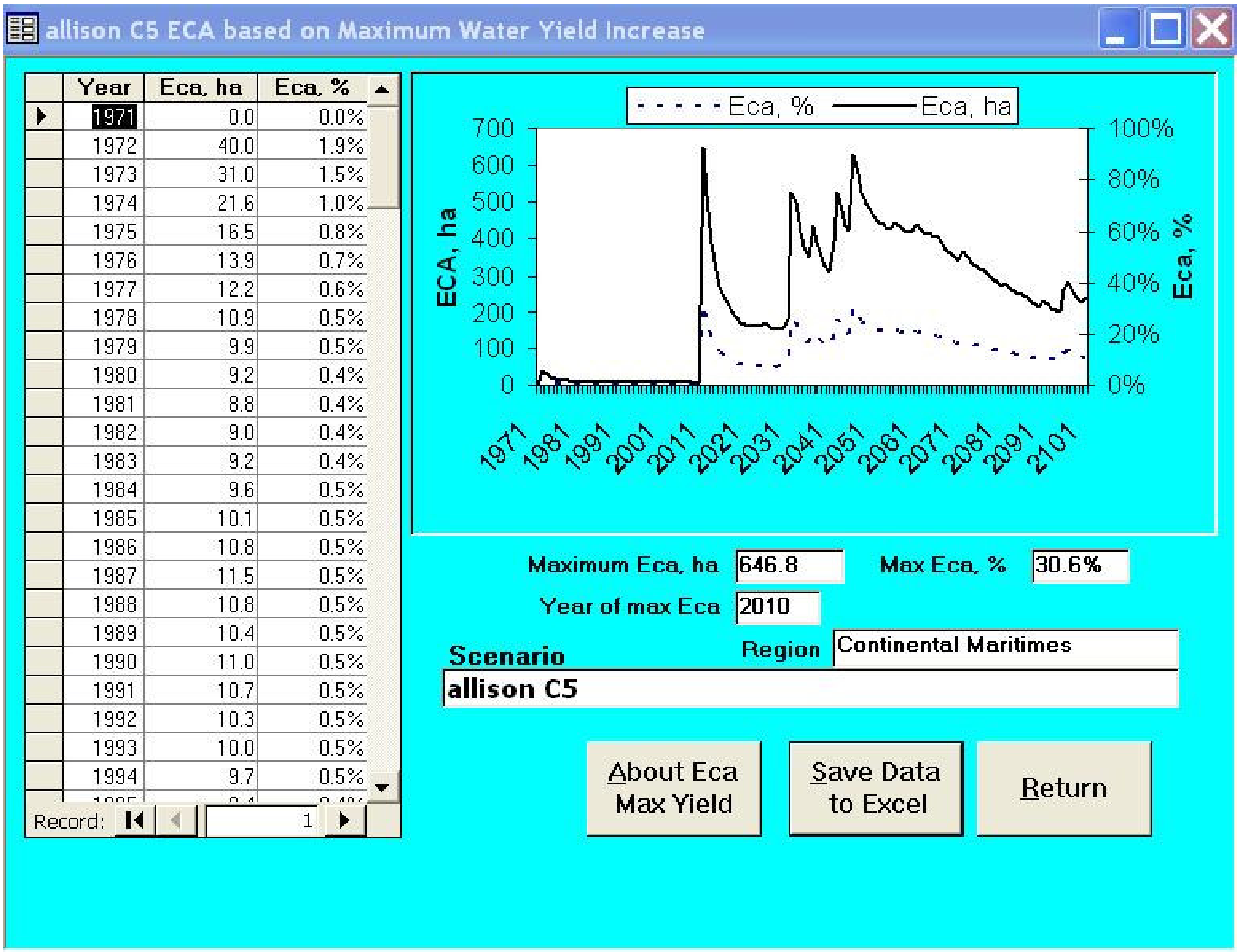

- 37.7% of the watershed harvested over 130 years
- Annual precipitation 547.3mm/year
- Annual water yield 380.1mm/year

**Allison Creek WRENSS- EcaAb Outputs**



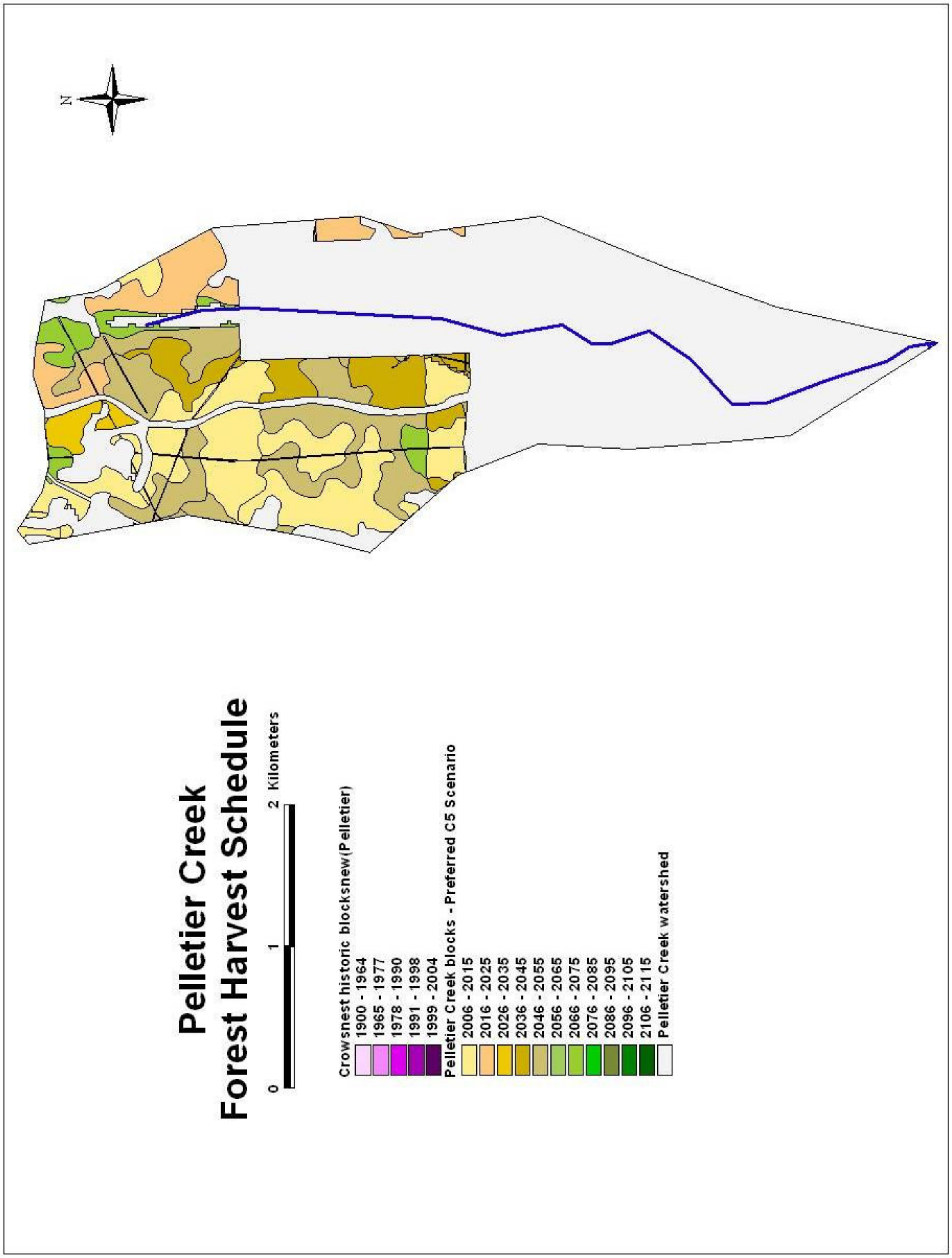




- Simulated maximum yield increase low 2.6% (9.8mm)
- Simulated peak flow increases low 2.3% (2-yr return) and 2.7% (100-yr return)

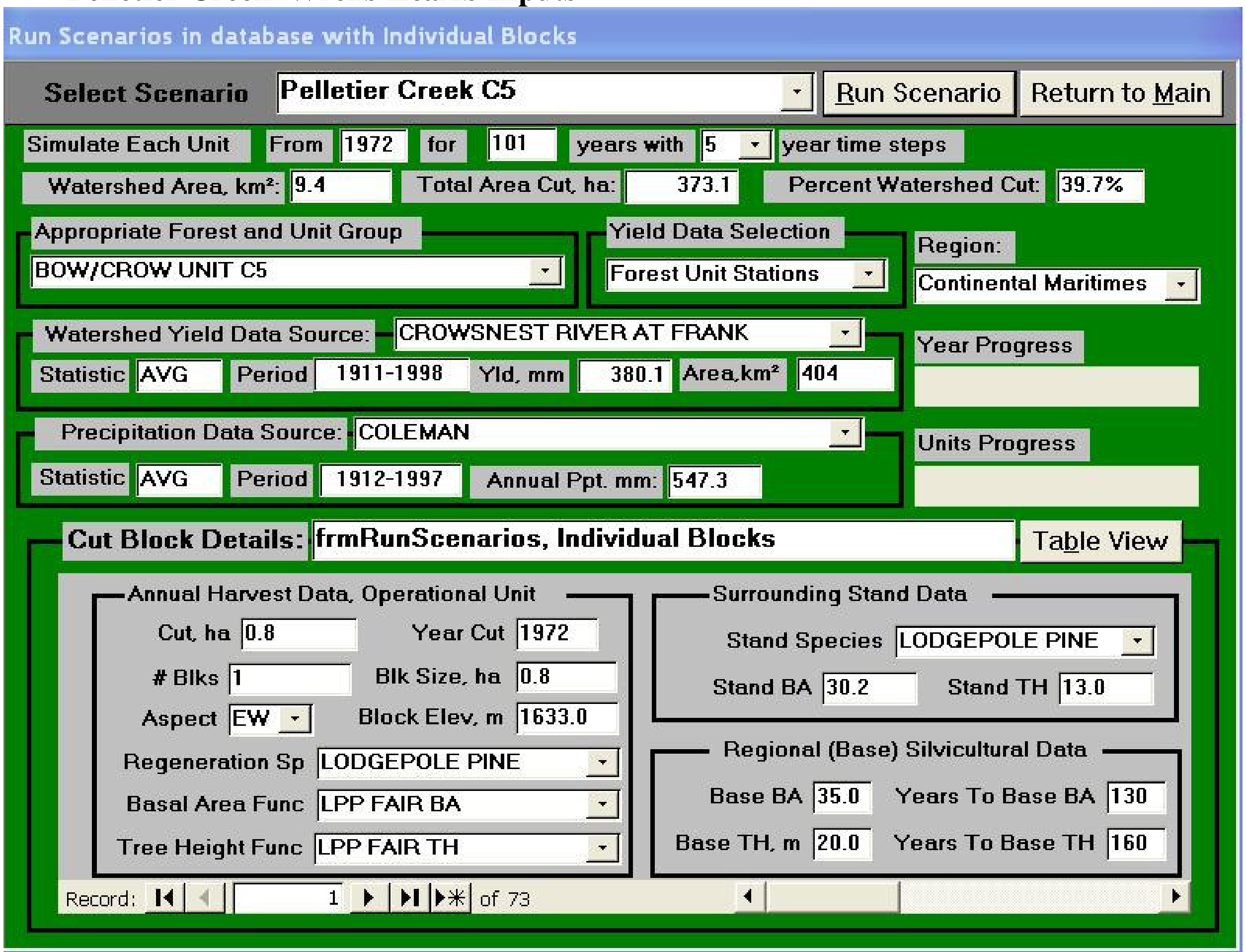



- Maximum ECA is 30.6% occurring at year 2010.

**Pelletier Creek Map**

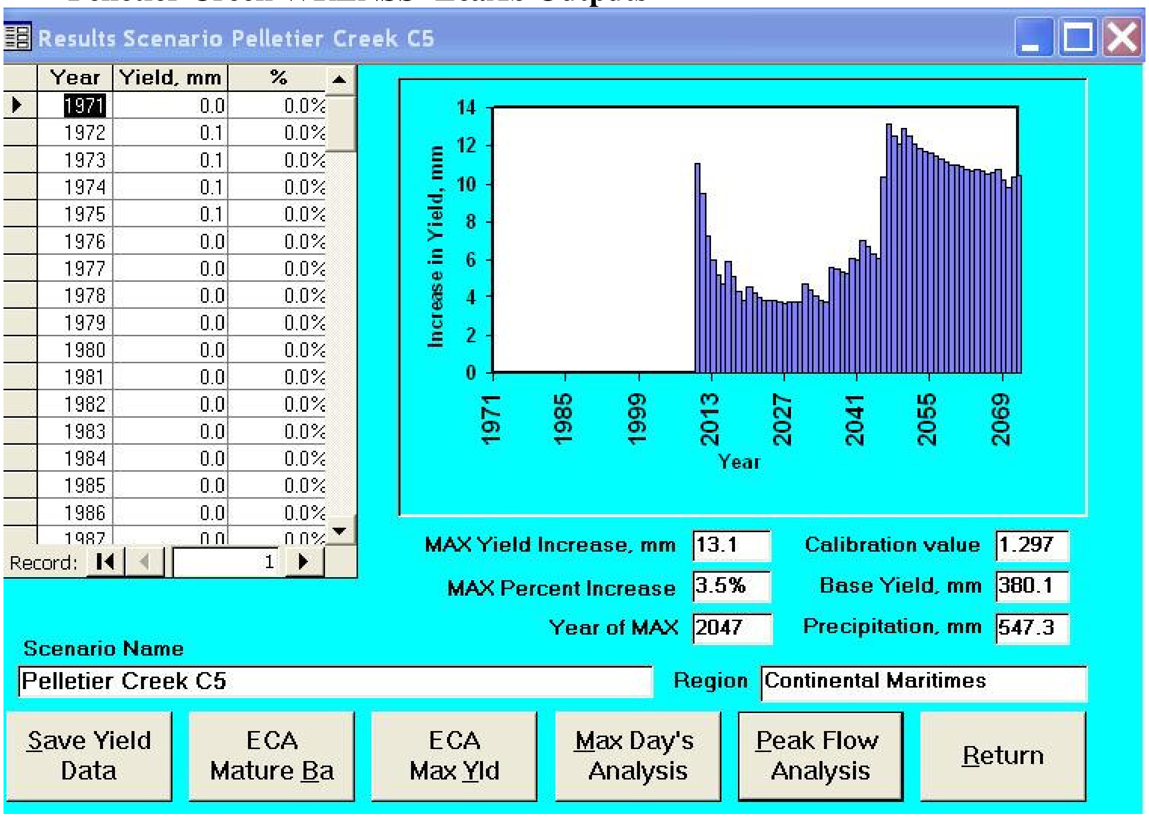


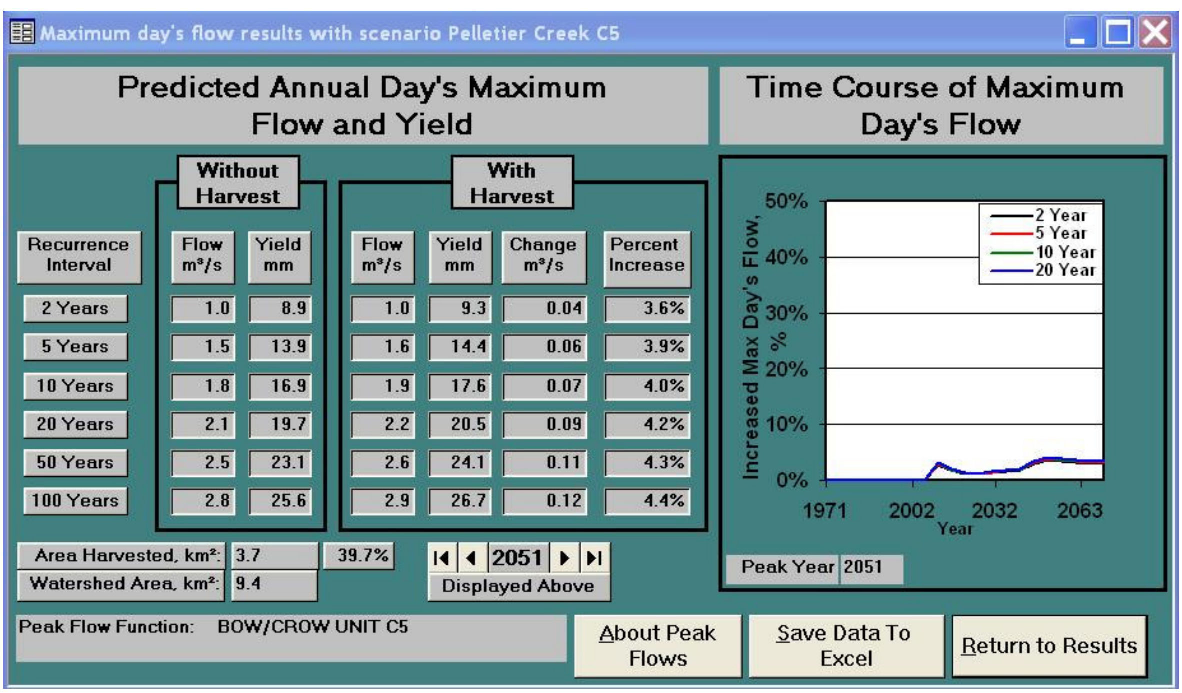
**Pelletier Creek Wrens-EcaAb Inputs**




- 39.7% of the watershed harvested over 101 years
- Annual precipitation 547.3mm/year
- Annual water yield 380.1mm/year

**Pelletier Creek WRENSS- EcaAb Outputs**



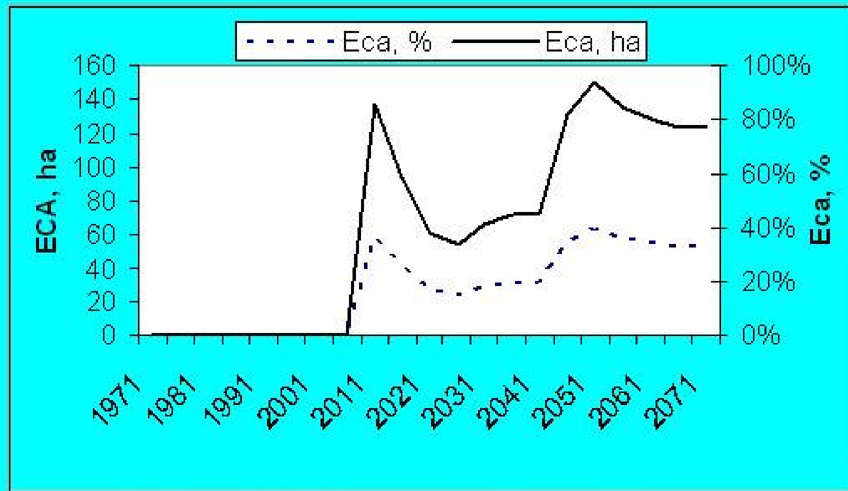




- Simulated maximum yield increase is low 3.5% (13.1mm)
- Simulated peak flow increases are low 3.6% (2-yr return) and 4.4% (100-yr return)

Pelletier Creek C5 ECA based on Maximum Water Yield Increase

| Year | Eca, ha | Eca, % |
|---|---|---|
| 1971 | 0.0 | 0.0% |
| 1976 | 0.8 | 0.2% |
| 1981 | 0.5 | 0.1% |
| 1986 | 0.3 | 0.1% |
| 1991 | 0.2 | 0.1% |
| 1996 | 0.2 | 0.1% |
| 2001 | 0.2 | 0.1% |
| 2006 | 0.2 | 0.0% |
| 2011 | 137.3 | 36.8% |
| 2016 | 93.8 | 25.1% |
| 2021 | 61.6 | 16.5% |
| 2026 | 54.1 | 14.5% |
| 2031 | 66.6 | 17.8% |
| 2036 | 72.5 | 19.4% |
| 2041 | 71.8 | 19.3% |
| 2046 | 131.5 | 35.2% |
| 2051 | 149.8 | 40.1% |
| 2056 | 135.3 | 36.3% |
| 2061 | 128.8 | 34.5% |
| 2066 | 123.6 | 33.1% |
| 2071 | 124.6 | 33.4% |
| * | 0.0 | 0.0% |

Record: 1




Maximum Eca, ha: 149.8 Max Eca, %: 40.1%

Year of max Eca: 2051

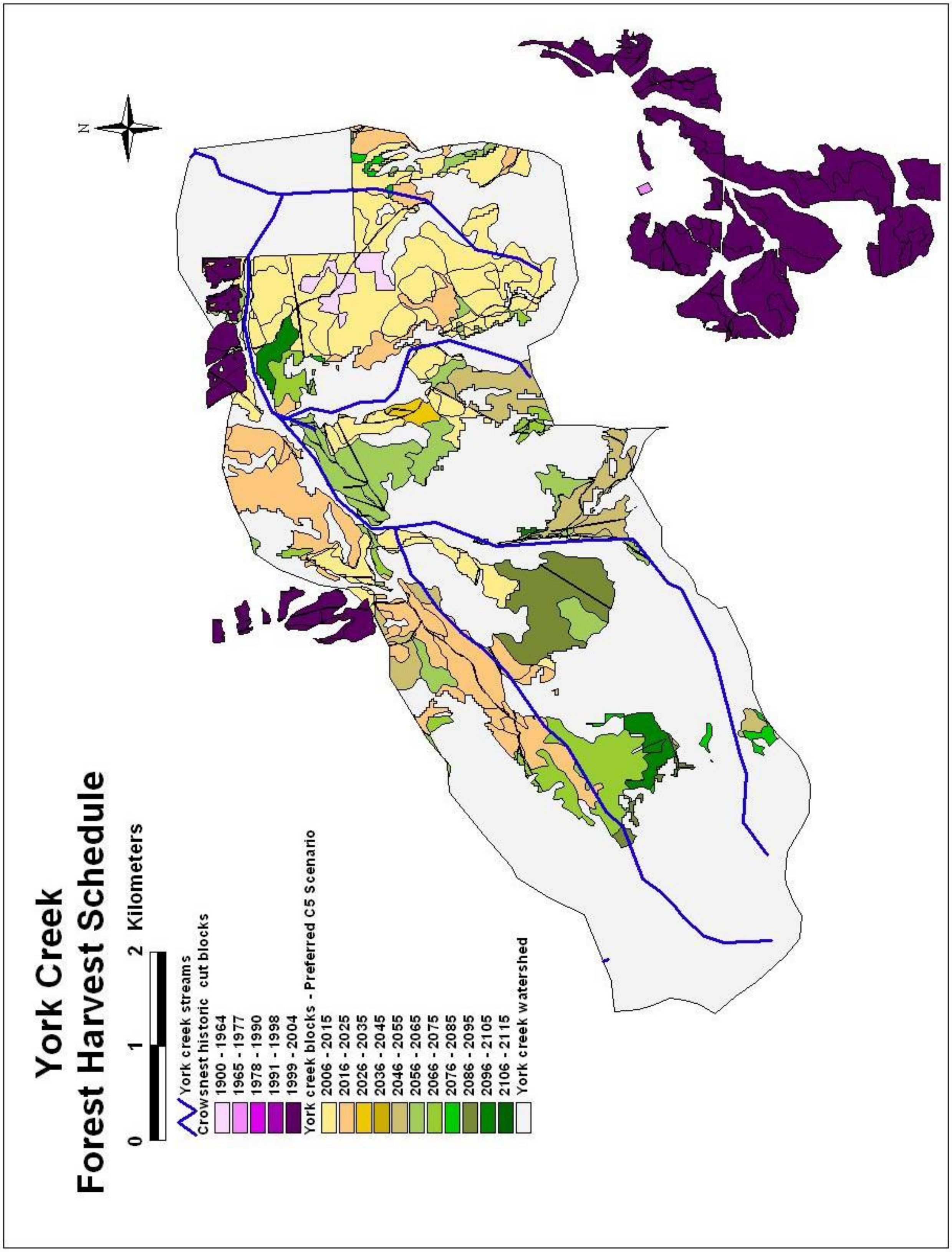
Scenario: Pelletier Creek C5

Region: Continental Maritimes

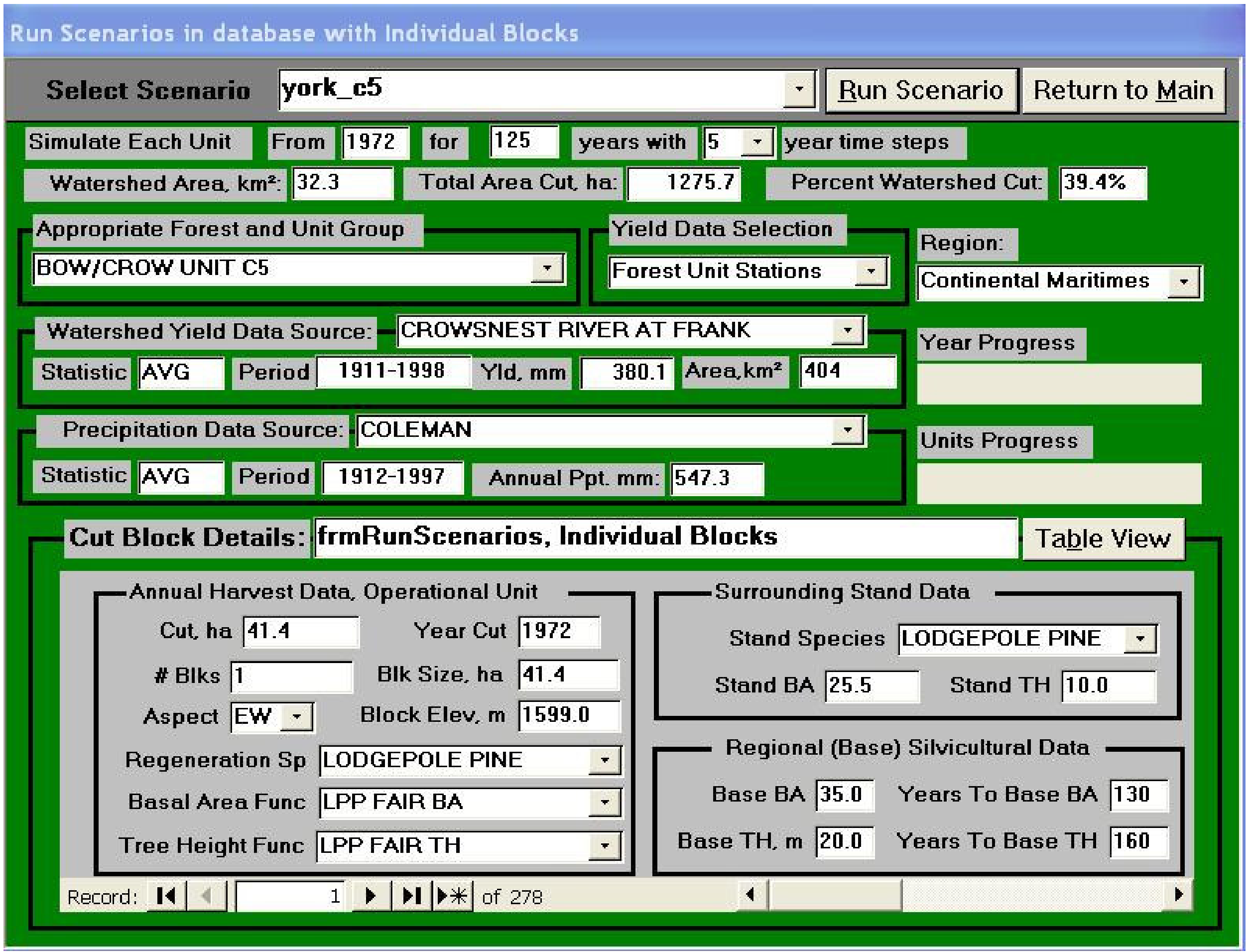
About Eca Max Yield | Save Data to Excel | Return

- Maximum ECA is 40.1 % occurring at year 2051.

**York Creek Map**

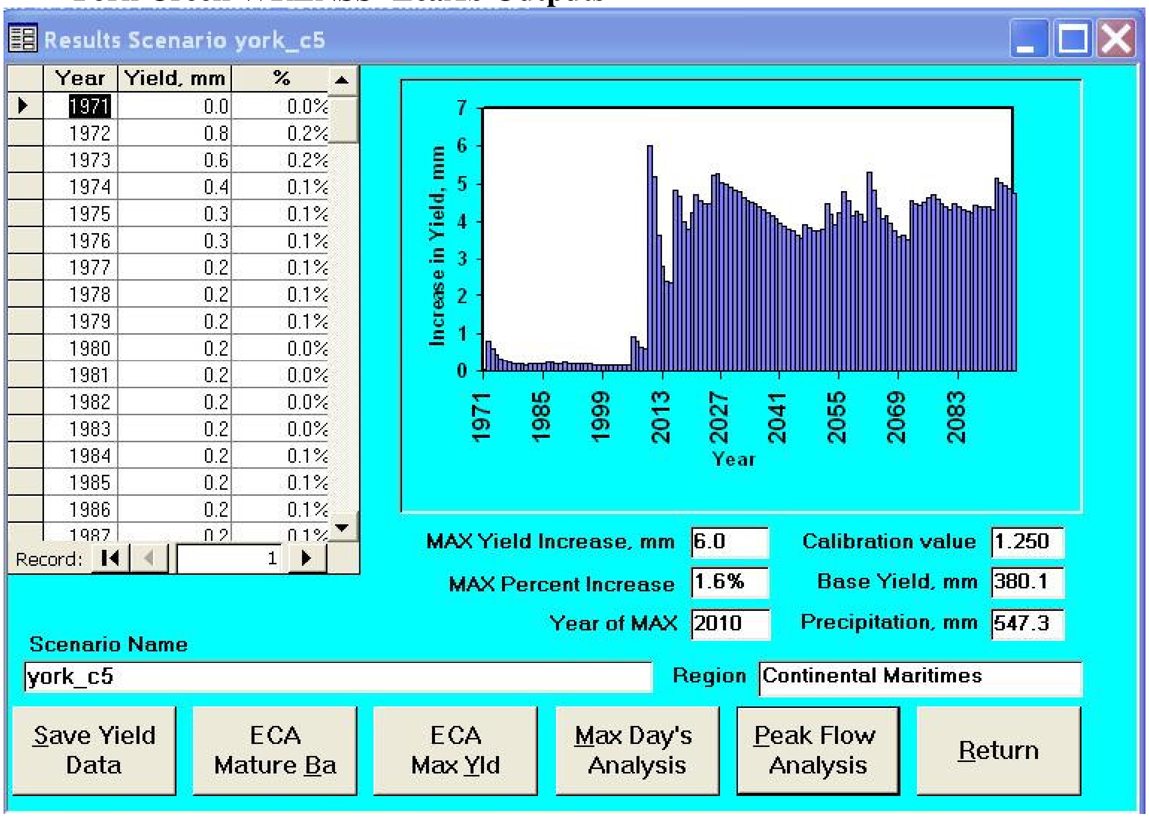


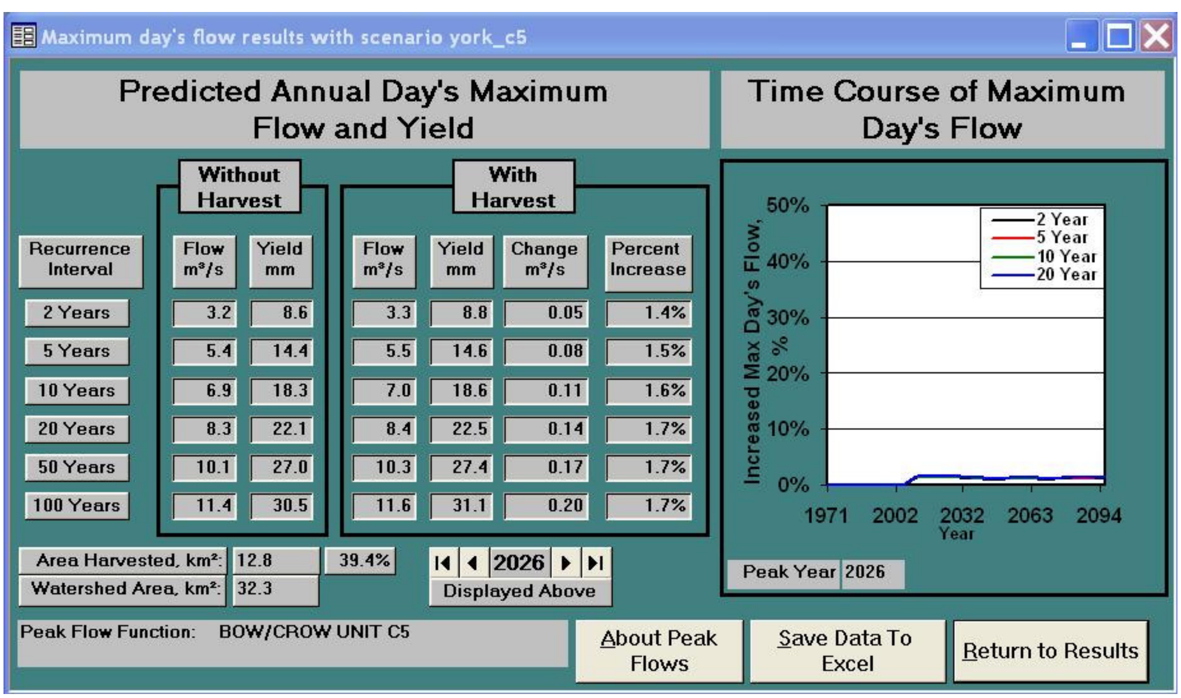
**York Creek WRENSS- EcaAb Inputs**




- 39.4% of the watershed harvested over 125 years
- Annual precipitation 547.3mm/year
- Annual water yield 380.1mm/year

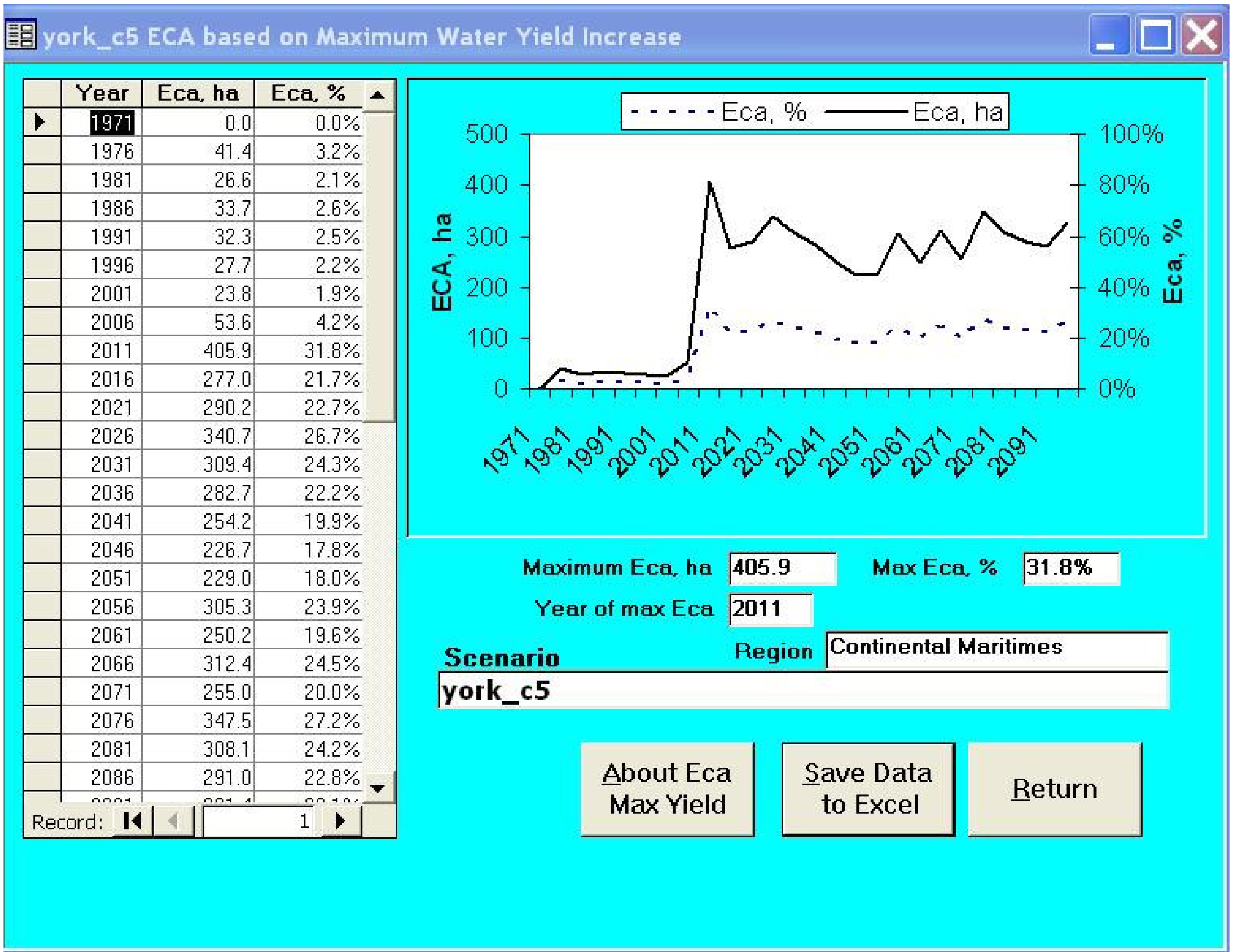
## York Creek WRENSS- EcaAb Outputs



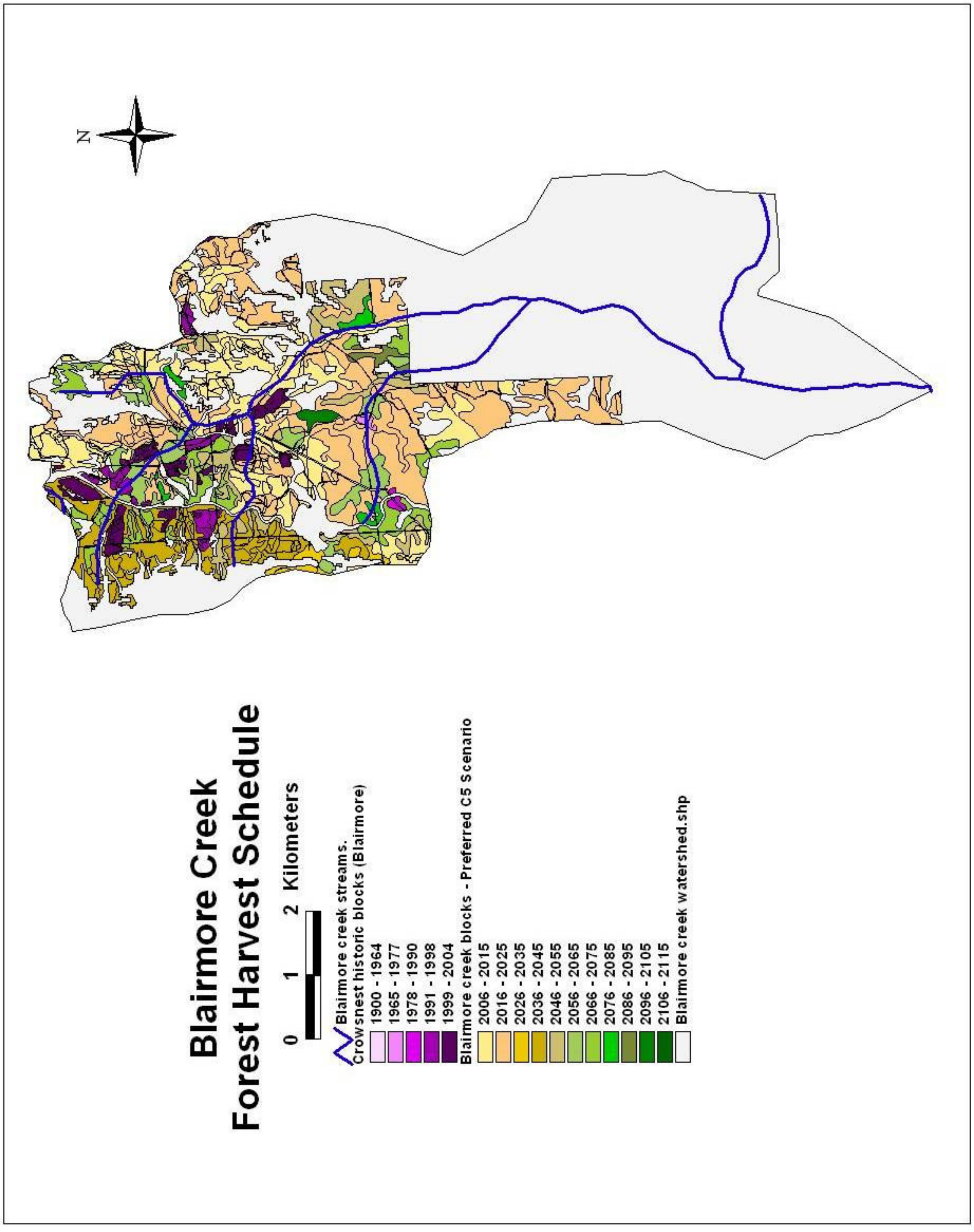

- Simulated maximum yield increase is low 1.6% (6 mm)

- Simulated peak flow increases are low 1.4% (2-yr return) and 1.7% (100-yr return)

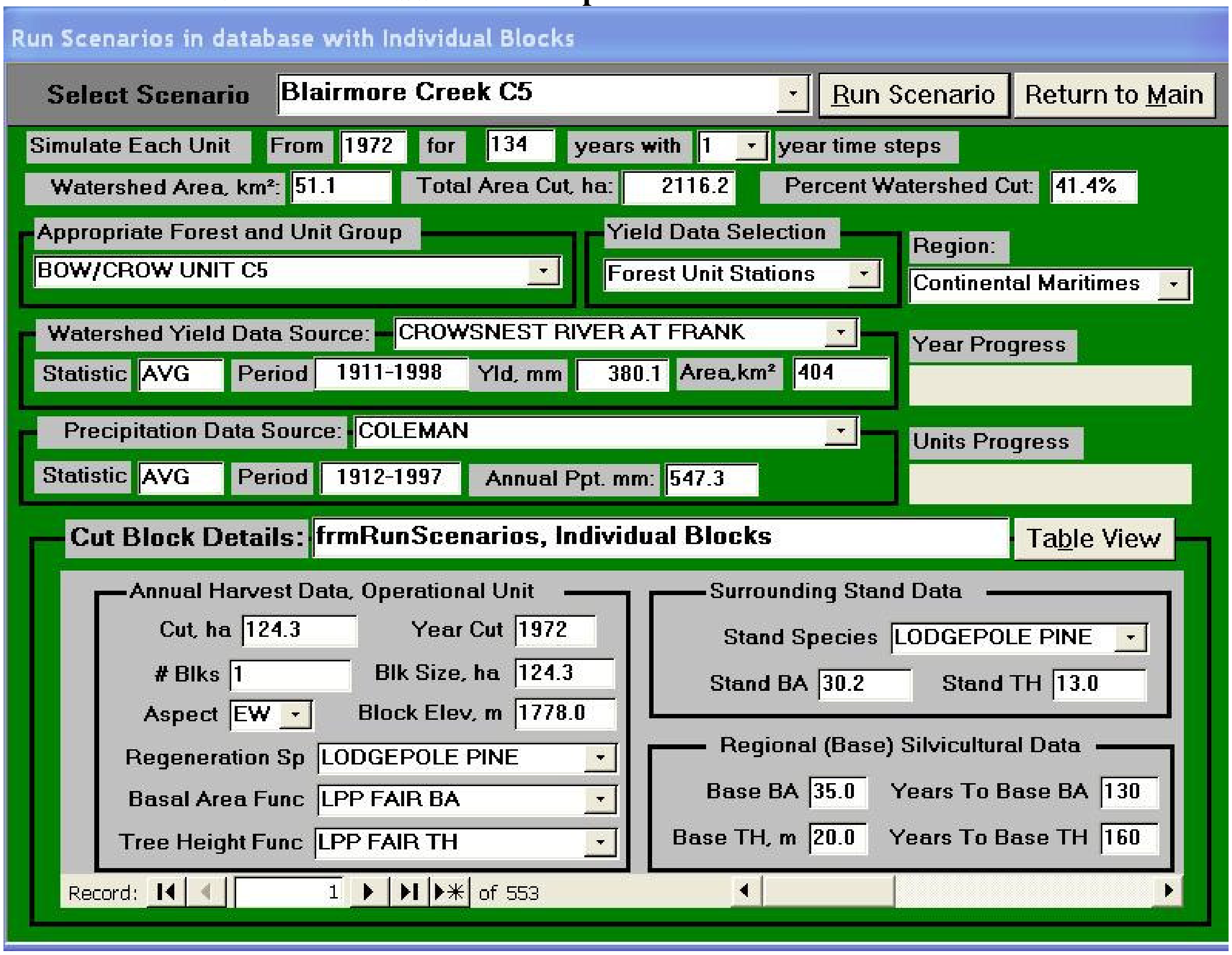



- Maximum ECA is 31.8% occurring at year 2011.

**Blairmore Creek Map**

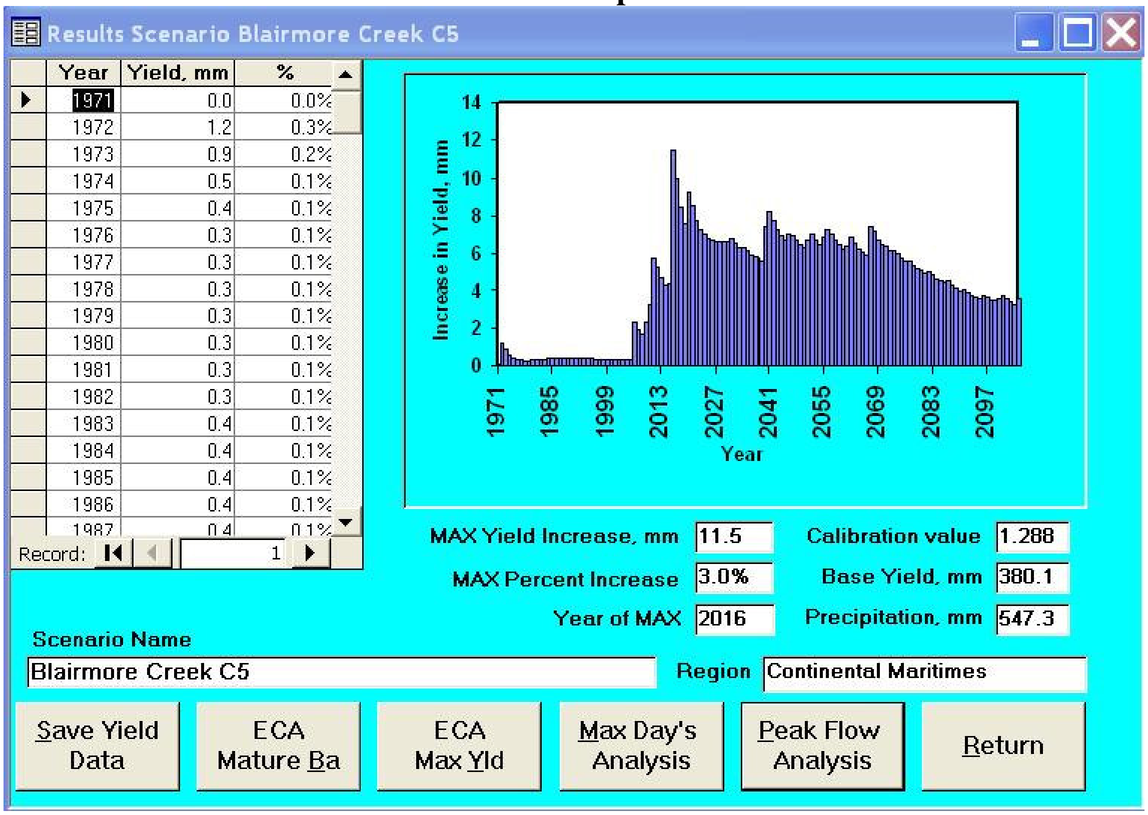


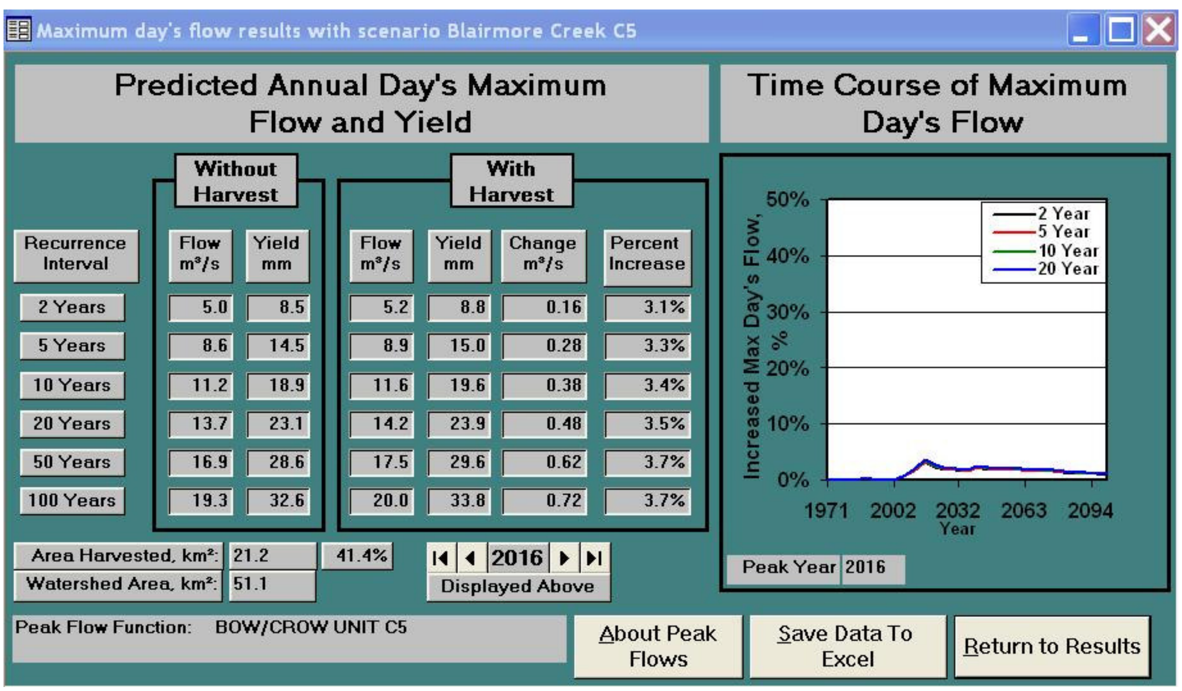
**Blairmore Creek WRENSS- EcaAb Inputs**



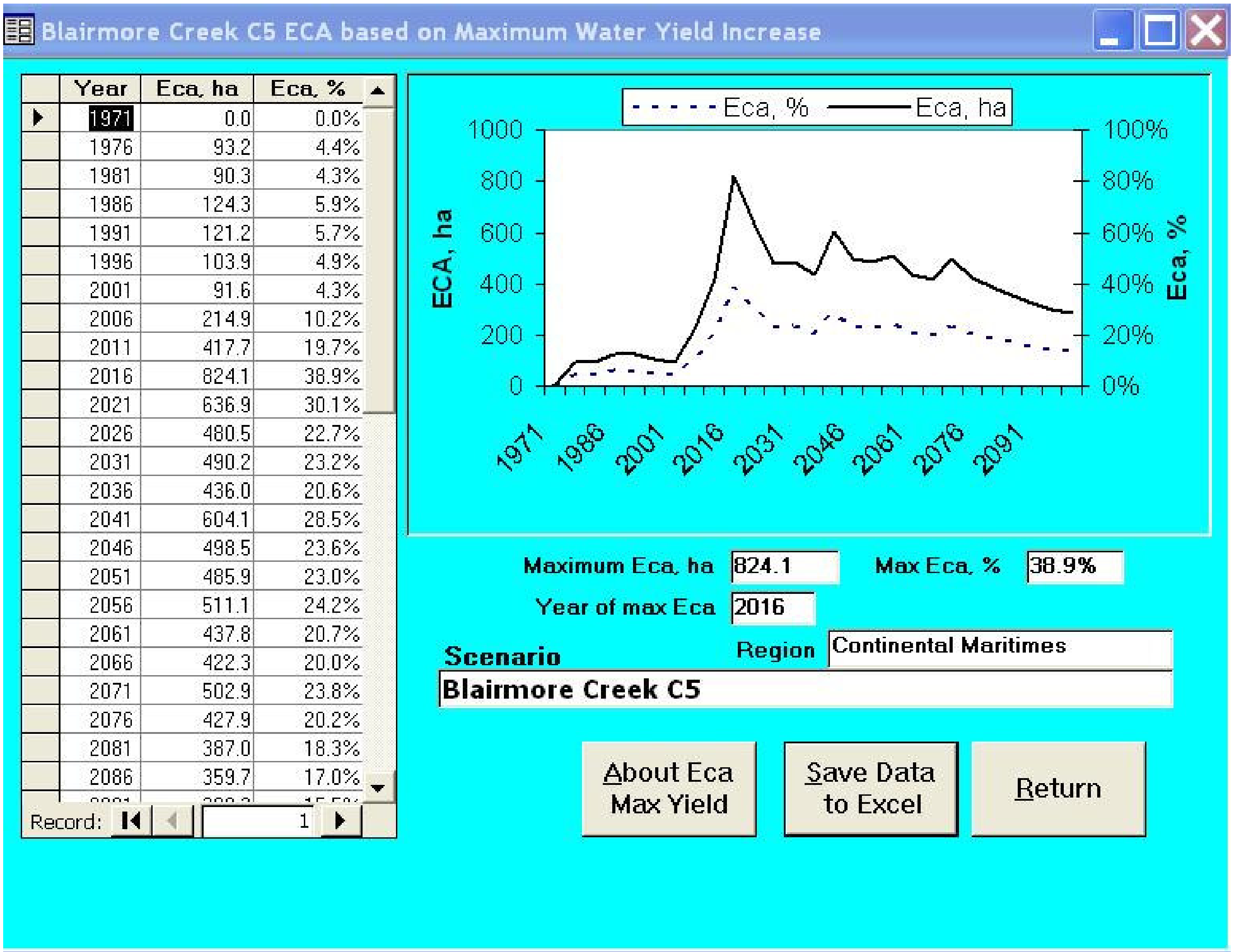

- 41.4% of the watershed harvested over 134 years
- Annual precipitation 547.3mm/year
- Annual water yield 380.1mm/year

**Blairmore Creek WRENSS- EcaAb Outputs**



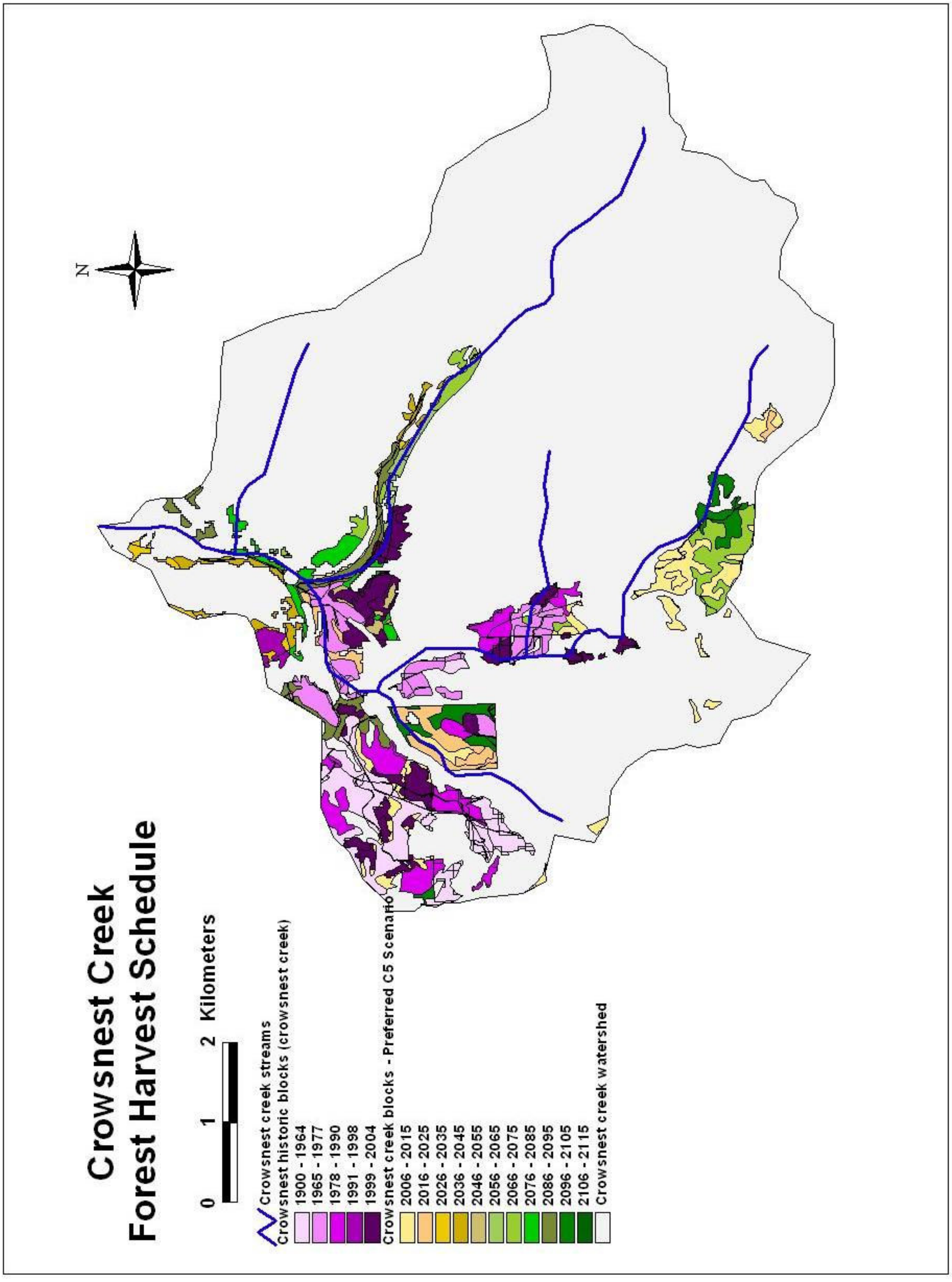




- Simulated maximum yield increase is low 3.0% (11.5 mm)
- Simulated peak flow increases are low 3.1% (2-yr return) and 3.7% (100-yr return)

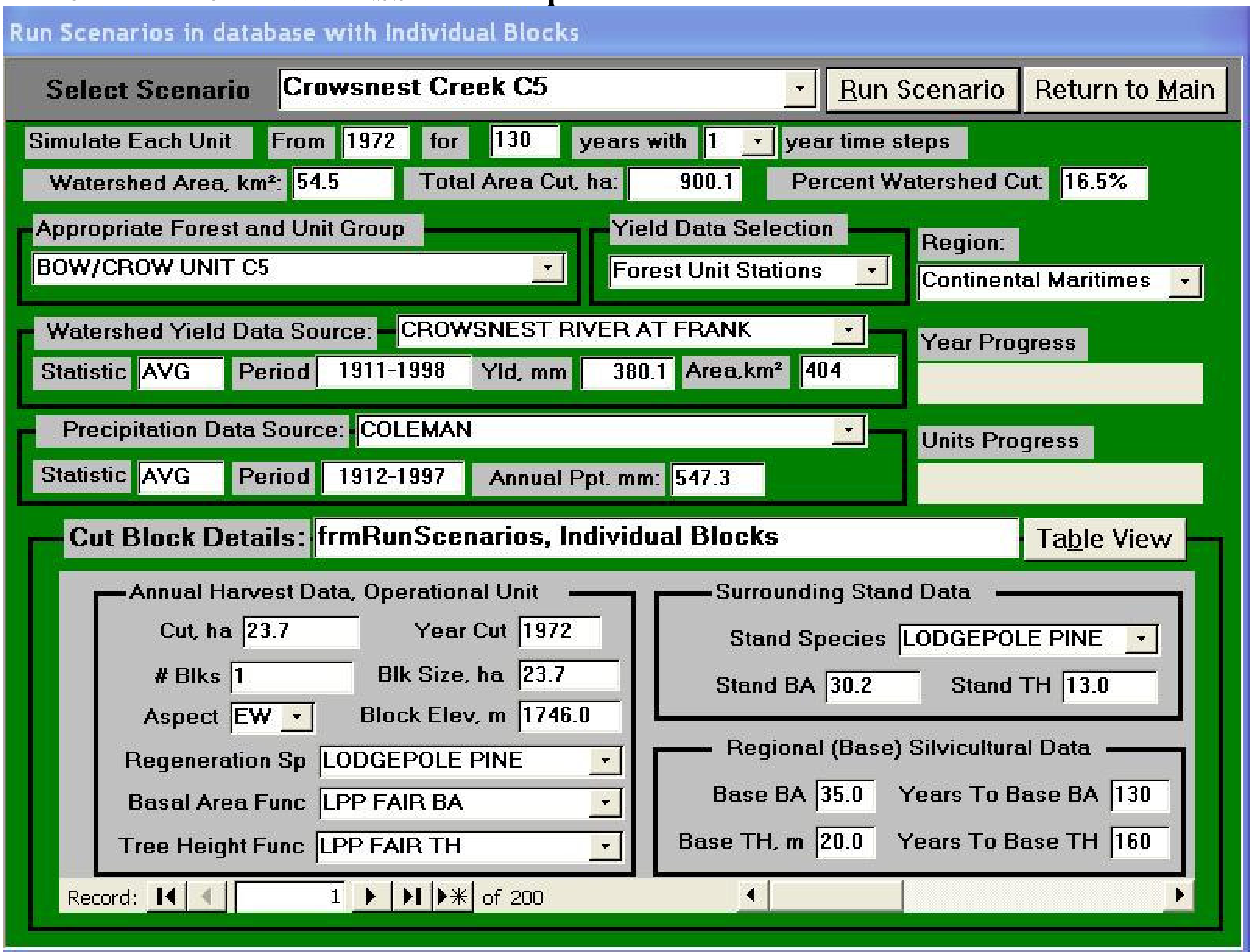



- Maximum ECA is 38.9% occurring at year 2016.

**Crowsnest Creek Map**

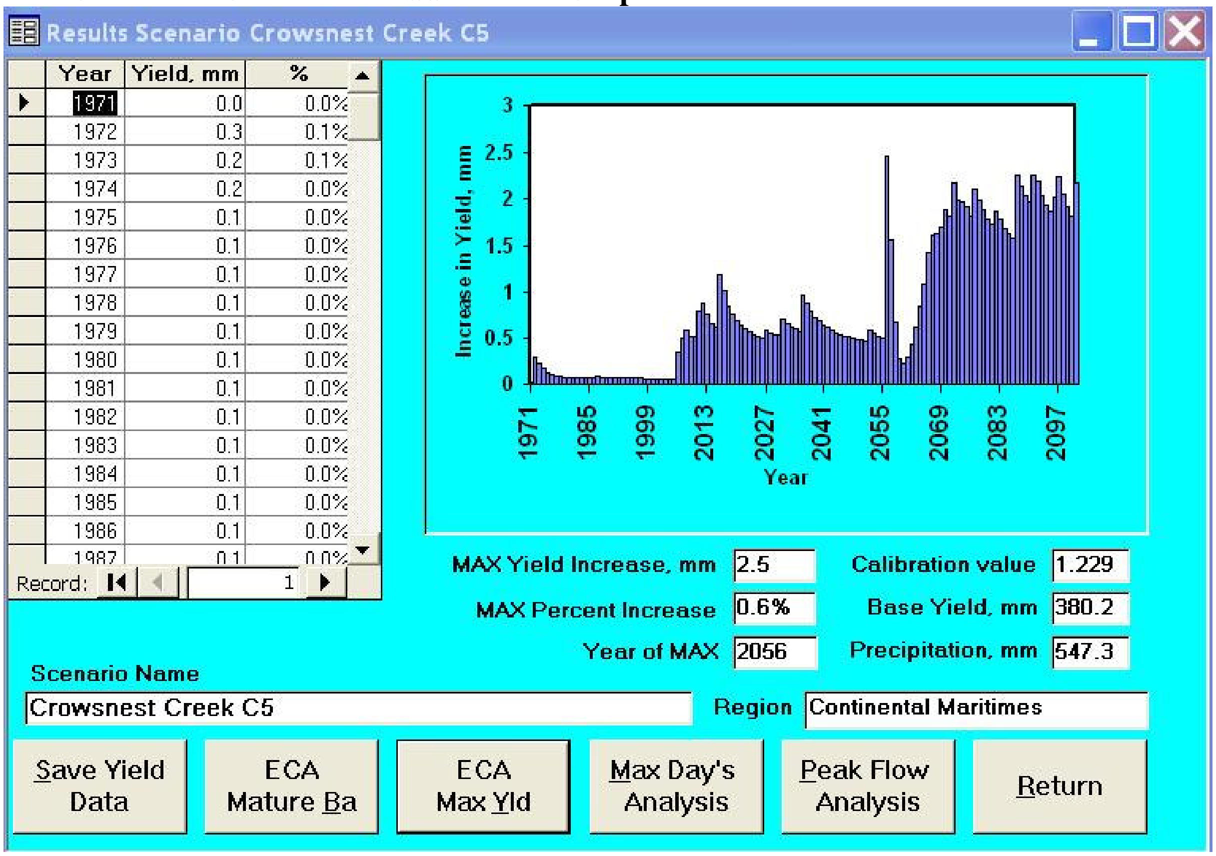


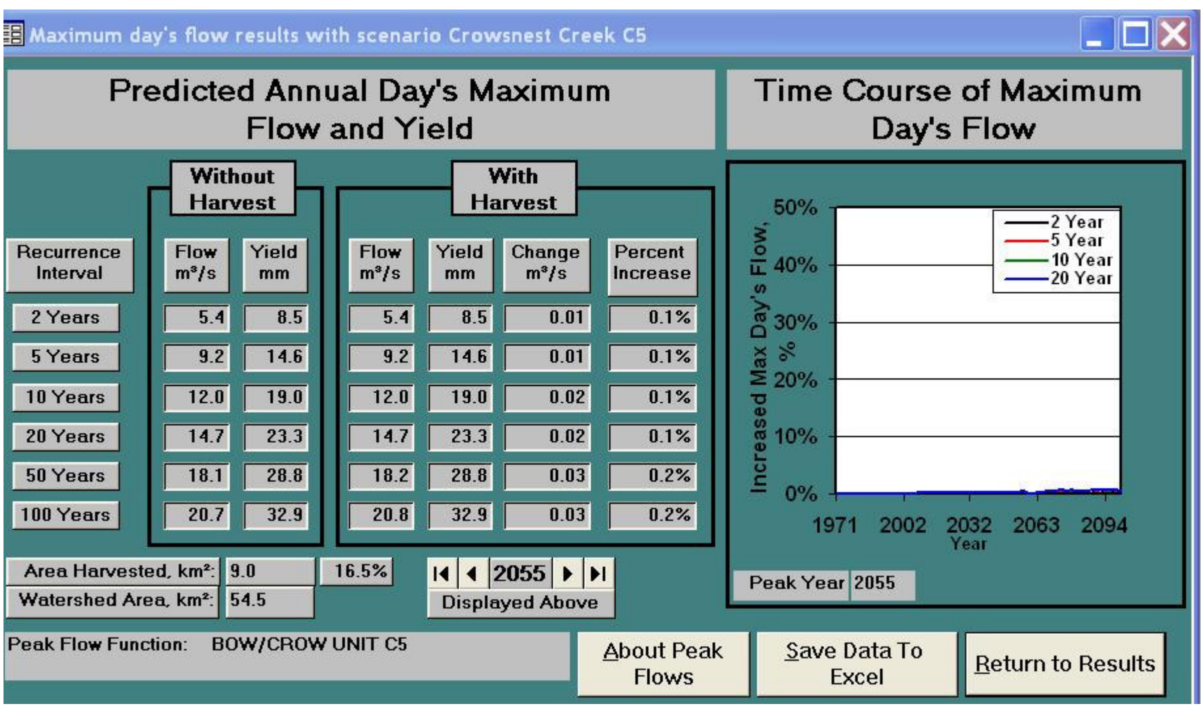
**Crowsnest Creek WRENSS- EcaAb Inputs**



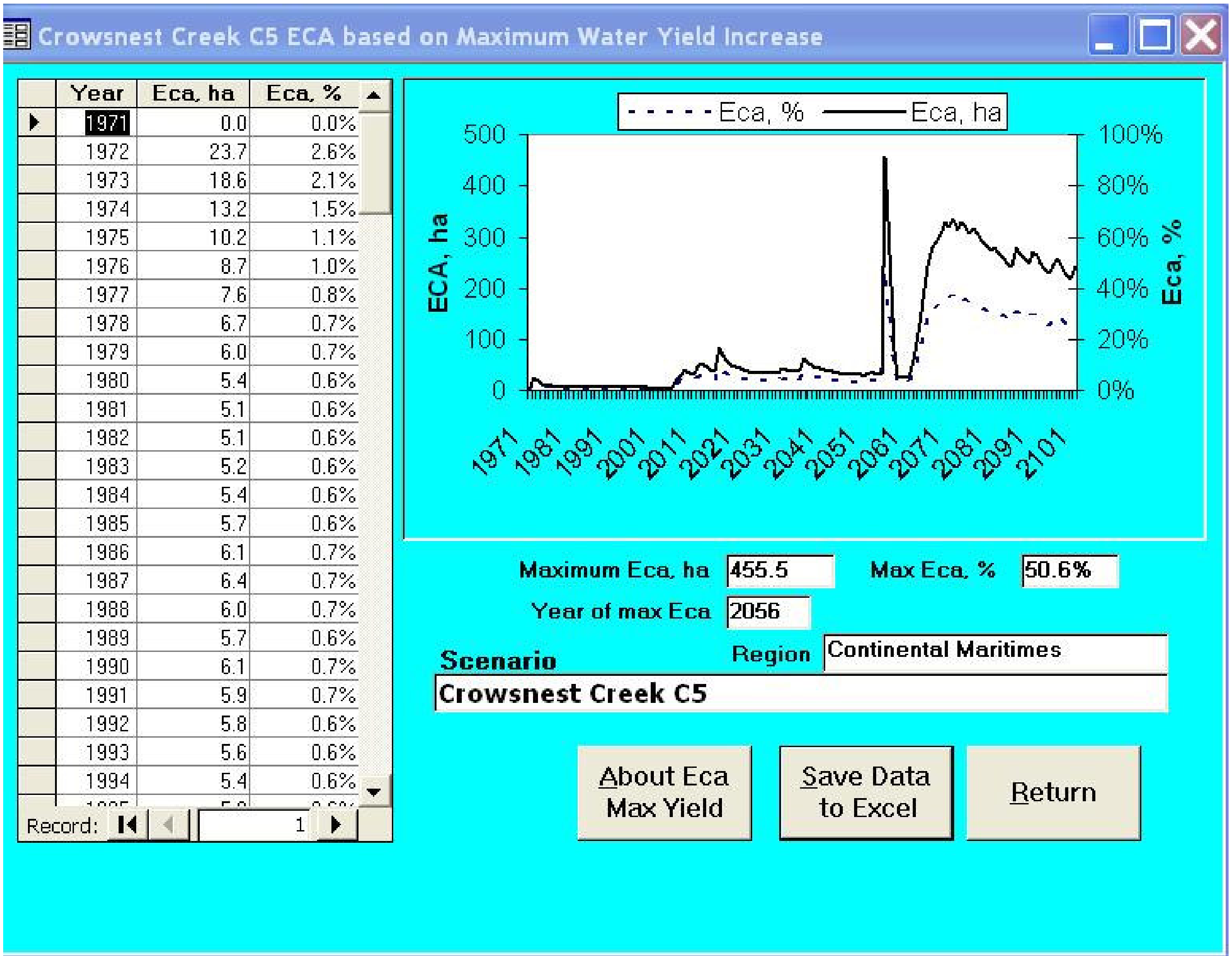

- 16.5% of the watershed harvested over 130 years
- Annual precipitation 547.3mm/year
- Annual water yield 380.1mm/year

**Crowsnest Creek WRENSS- EcaAb Outputs**



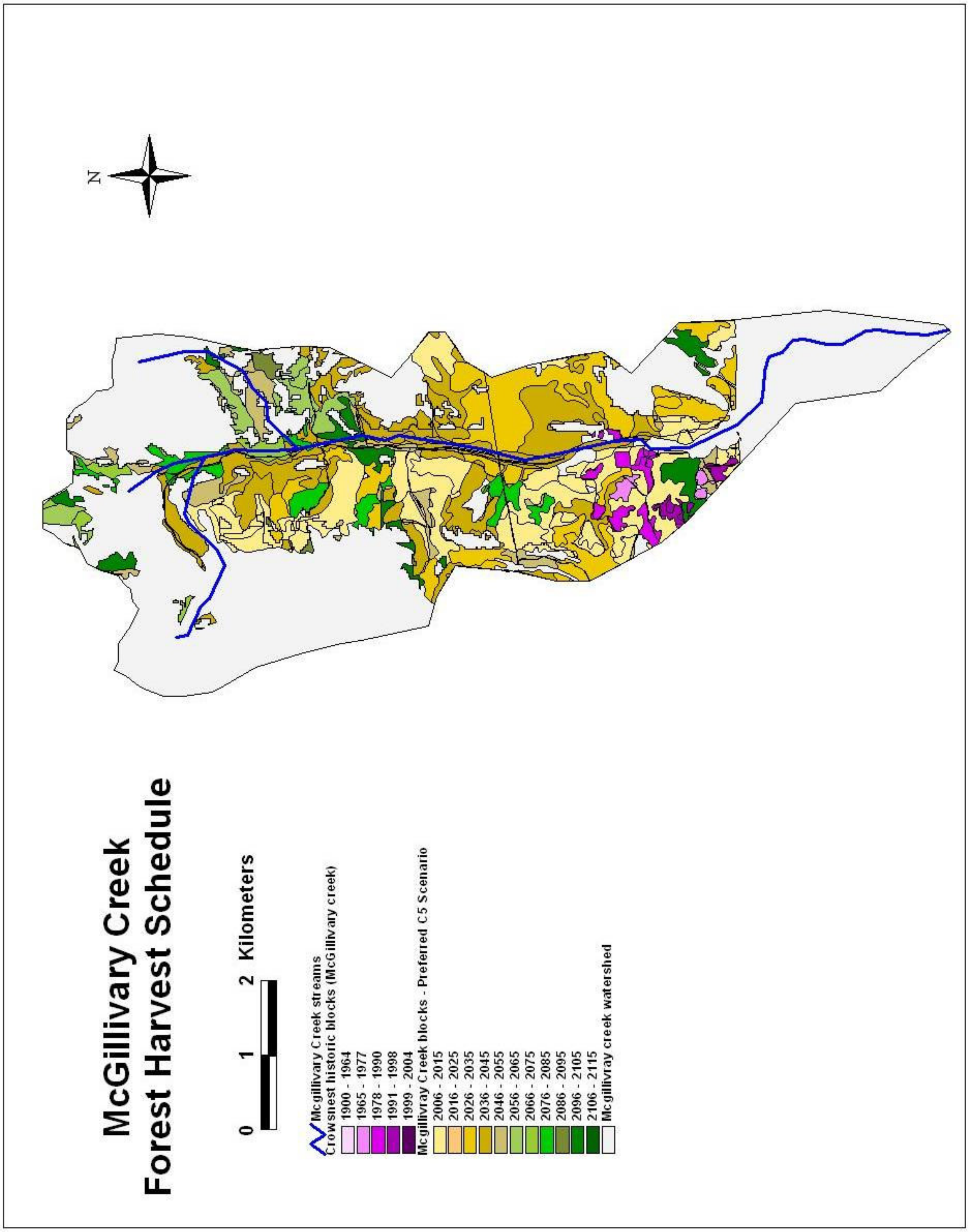

- Simulated maximum yield increase is low 0.6% (2.5 mm)
- Simulated peak flow increases are low 0.1% (2-yr return) and 0.2% (100-yr return)



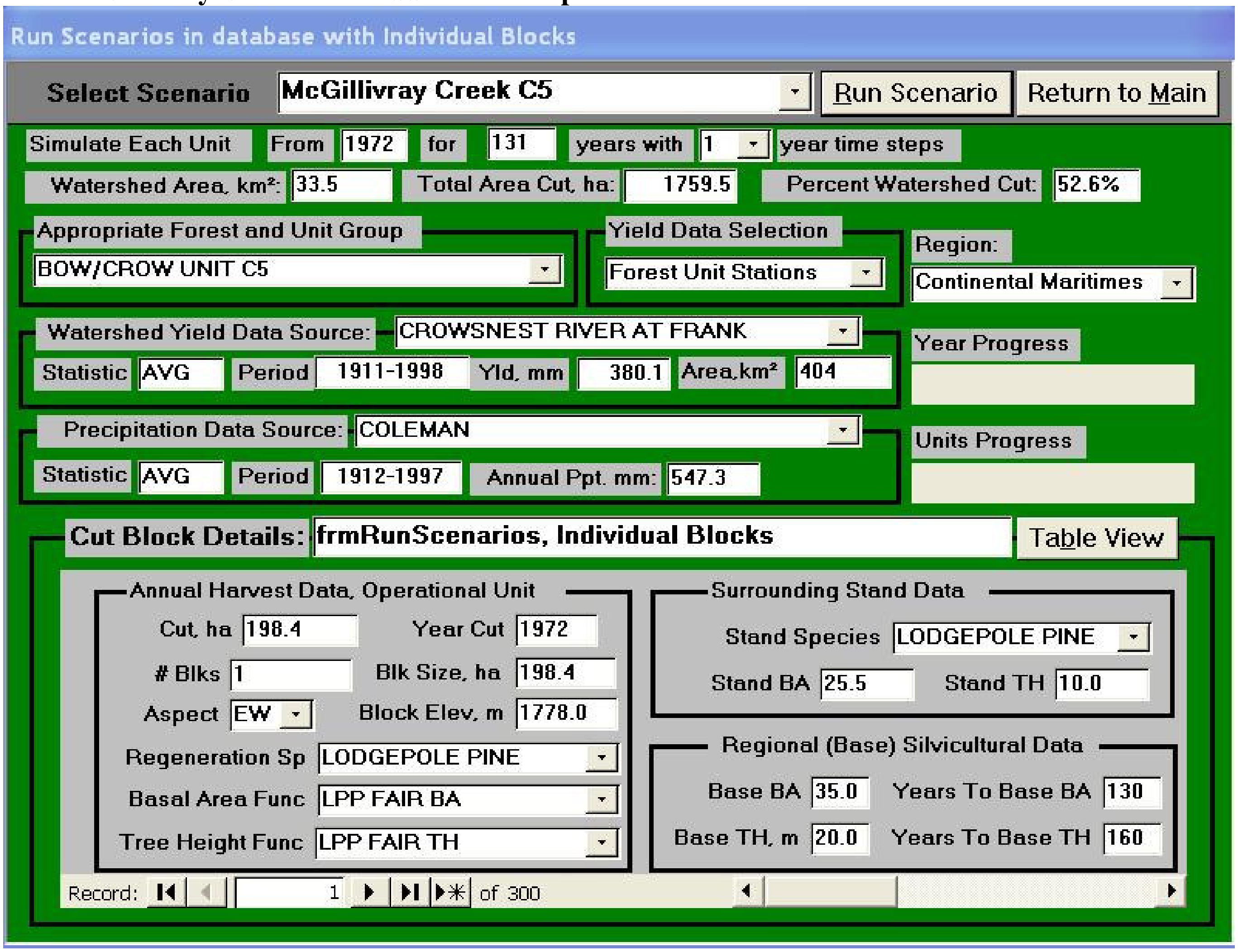

| Year | Eca, ha | Eca, % |
|---|---|---|
| 1971 | 0.0 | 0.0% |
| 1972 | 23.7 | 2.6% |
| 1973 | 18.6 | 2.1% |
| 1974 | 13.2 | 1.5% |
| 1975 | 10.2 | 1.1% |
| 1976 | 8.7 | 1.0% |
| 1977 | 7.6 | 0.8% |
| 1978 | 6.7 | 0.7% |
| 1979 | 6.0 | 0.7% |
| 1980 | 5.4 | 0.6% |
| 1981 | 5.1 | 0.6% |
| 1982 | 5.1 | 0.6% |
| 1983 | 5.2 | 0.6% |
| 1984 | 5.4 | 0.6% |
| 1985 | 5.7 | 0.6% |
| 1986 | 6.1 | 0.7% |
| 1987 | 6.4 | 0.7% |
| 1988 | 6.0 | 0.7% |
| 1989 | 5.7 | 0.6% |
| 1990 | 6.1 | 0.7% |
| 1991 | 5.9 | 0.7% |
| 1992 | 5.8 | 0.6% |
| 1993 | 5.6 | 0.6% |
| 1994 | 5.4 | 0.6% |

- Maximum ECA is 50.6% occurring at year 2056.

**McGillivray Creek Map**

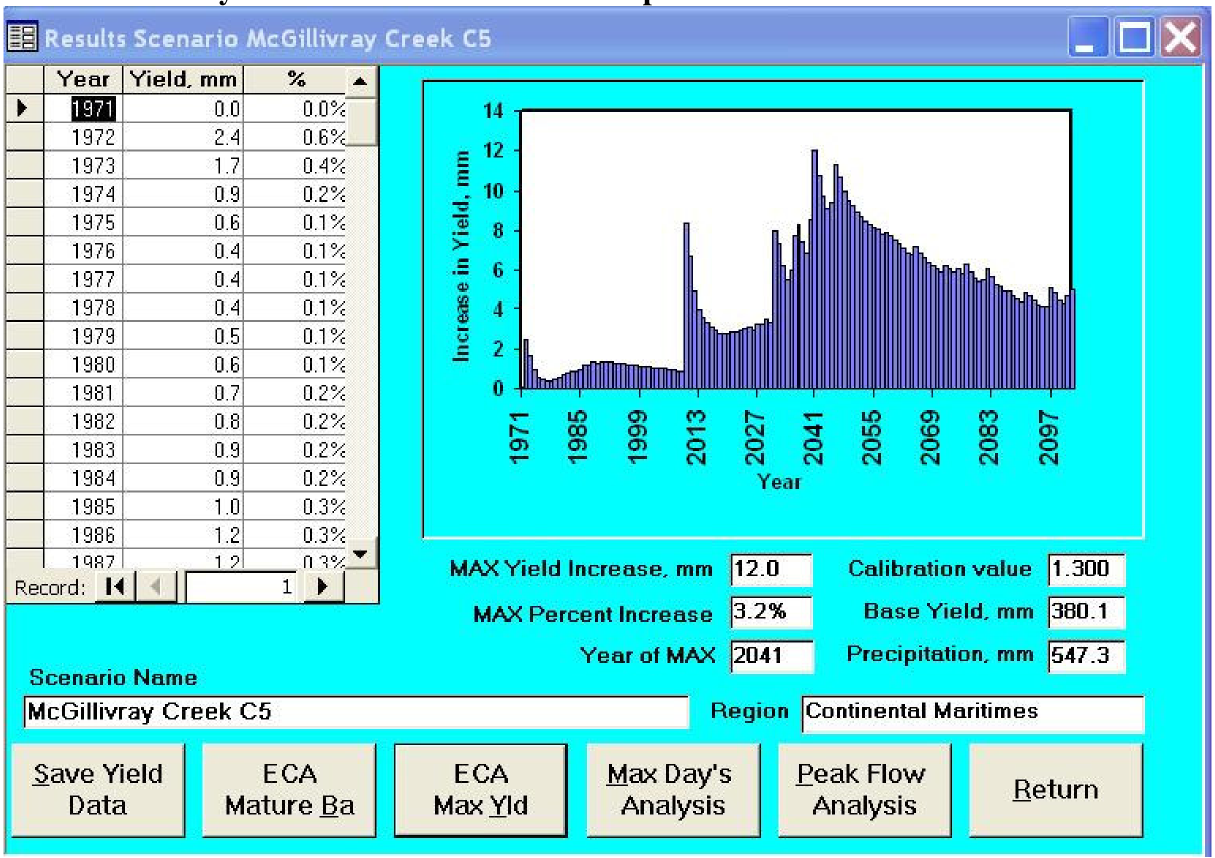


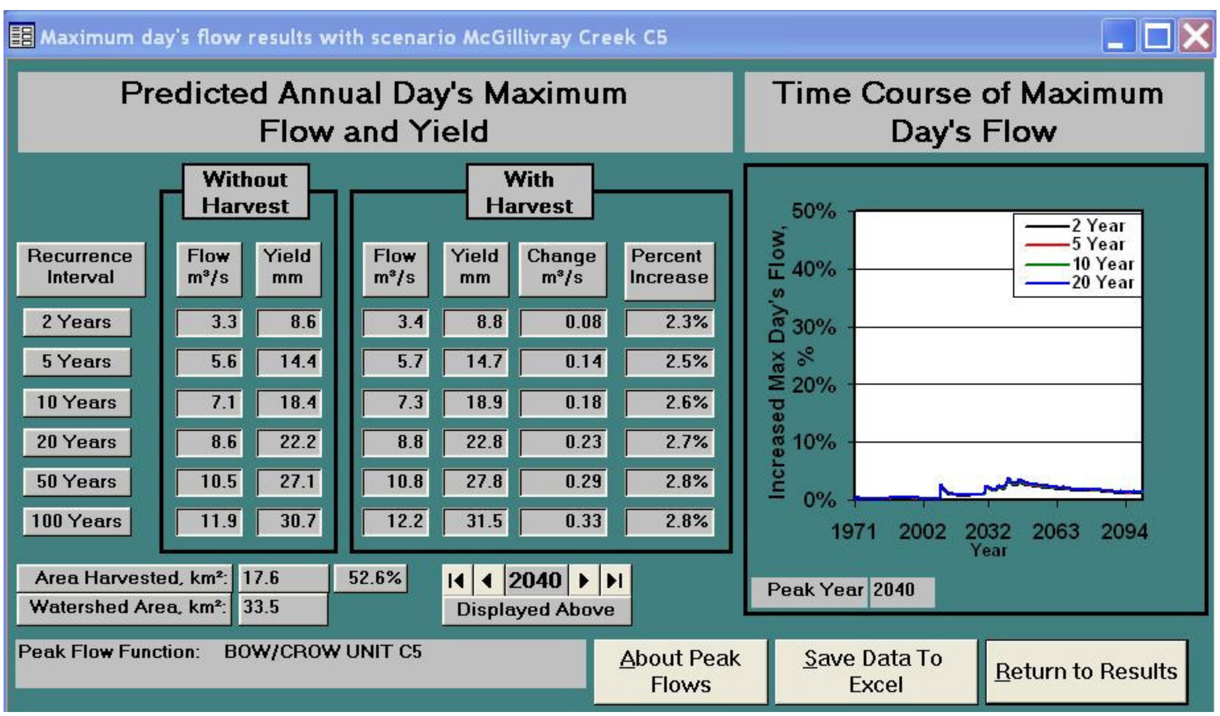
**McGillivray Creek WRENSS- EcaAb Inputs**



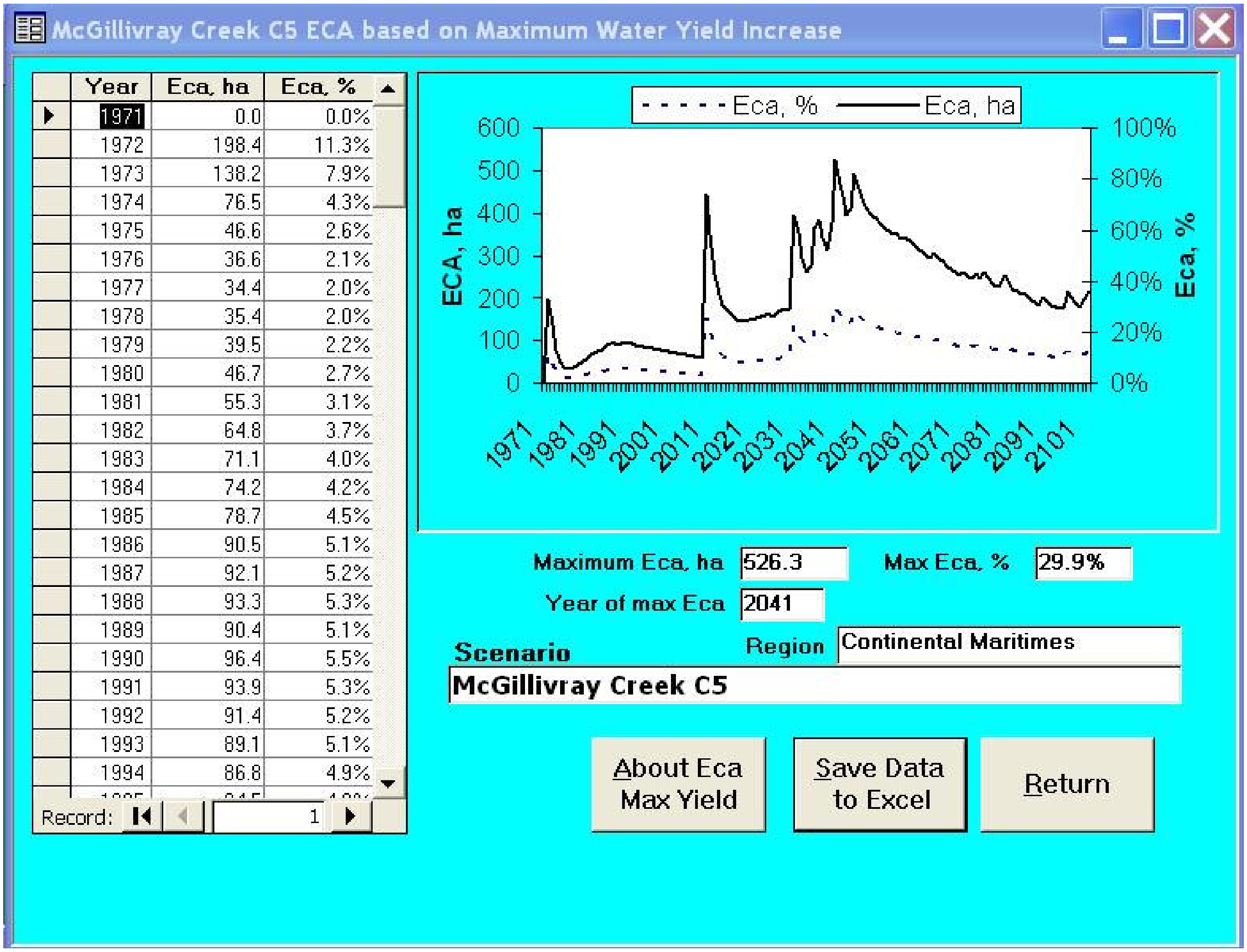

- 52.6% of the watershed harvested over 131 years
- Annual precipitation 547.3mm/year
- Annual water yield 380.1mm/year

**McGillivray Creek WRENSS- EcaAb Outputs**




- Simulated maximum yield increase is low 3.2% (12 mm)
- Simulated peak flow increases are low 2.3% (2-yr return) and 2.8% (100-year return)




- Maximum ECA is 29.9% occurring at year 2041.

# Appendix 3 ECA-AB Procedure/Data Requirements

The hydrologic effects of forest harvesting will be simulated by Forestry Corp. using the ECA-AB hydrologic model (Silins, 2000). The ECA model provides an estimate of changes in average annual water yield based on the area harvested in a watershed, the rate of forest growth and water balance calculations of generated runoff (determined from long-term monthly precipitation and annual water yield).

ECA refers to “equivalent clearcut area” which describes the current “effective” area that an old or recovering disturbance (e.g. clearcuts, burns, insect defoliation or extensive disease mortality) represents in terms of hydrologic effects. The concept can also be used to express the partial state of recovery from disturbance of individual forest stands, or the cumulative effects of multiple disturbances across large landscapes (net effect of multiple disturbances at different stages of ecological recovery) over long periods of time. In addition to an estimate of ECA or the partial state of hydrologic recovery of individual disturbances or entire watersheds, the technique can also be used to predict changes in annual water yield relative to baseline annual water yields. The main application of the model is to evaluate the effect of disturbances on streamflow in a watershed, and to project the cumulative effect (net combined effect) of both past and proposed forest harvesting and/or natural disturbance on streamflow.

ECA procedures were originally developed in the early 1970’s in Idaho by hydrologists with the USDA Forest Service (Silvey et al., 1973). Initially, the ECA model was conceived as a means of estimating the hydrologic impact of additional forest harvesting in watersheds where previous harvesting or other land disturbances had already occurred. The objective was not to produce a detailed, highly accurate simulation of streamflow, but rather a projection of streamflow changes over time assuming average climatic conditions in the region.

The physical model supporting ECA is that vegetation removal changes water yield in rough proportion to the leaf surface area or basal area removed from a site (Ager and Clifton 2005). ECA is defined as the area harvested times a reduction factor that describes the recovery of evapotranspiration losses. ECA is expressed in hectares of harvested (disturbed area) or as a percent of the harvested area. ECA can also be expressed as a percent of watershed area, which in may be more informative from a planning perspective.

Overall, the ECA-AB model provides a relatively simple framework for evaluation of hydrologic effects of forest harvesting with more modest input data requirements. However, the accuracy of model outputs depend primarily on accurate information on hydrologic recovery of forest stands after disturbance, and the availability of representative regional streamflow and precipitation data.

**Data Requirements**

| | |
|---|---|
| Current and Regenerating Species | Any Phase III species code is acceptable but all simulations are based on provincial average yield classes for unmanaged stands (0/0 utilization standard) for pine, white spruce, black spruce, and deciduous species |
| Block Area | Area of harvested unit in hectares |
| Year of Harvest | The year the unit was cut in yyyy format |
| Site Quality | Site quality code corresponding to average site index described in provincial yield tables. Acceptable codes are g (good), m (medium), and f (fair). |
| Watershed Area | The total size of the unit in hectares (watershed, FMU, or FMA) |
| Average Annual water yield | Expressed in area mm |
| Average Annual Precipitation | Expressed in area mm |

# Appendix 4 WRENSS Procedure/Data Requirements

The WRENSS procedure (**W**ater **R**esource **E**valuation for **N**on-Point **S**ilvicultural **S**ources, WrnsSdr Version 2000) (Swanson, 2000) was initially developed by the U.S. Forest Service and the U.S. Environmental Protection Agency (EPA 1980), and later adapted for use in Canada. WRENSS-MF uses long term monthly precipitation, annual flow data from representative watersheds, GIS-generated harvest data, watershed characteristics, and growth functions to estimate changes in annual water yield and changes in peak flow for the 2, 10 20, 50 and 100 year recurrence intervals.

Changes in water yield are caused by the removal of tree cover (i.e. vegetation), which reduces evapotranspiration and makes more water available for flow. The WRENSS Procedure estimates changes in flow by taking the difference between annual water balances for pre-harvest and post-harvest conditions. The change in flow is an estimate of the change in evapotranspiration (ET), which is expressed as:

$$\Delta Q = Q_{post\ harvest} - Q_{pre\ harvest}$$

$$(P_{post} - ET_{post}) - (P_{pre} - ET_{pre}) = ET_{post} - ET_{pre} = \Delta\ ET$$

$$\Delta Q = \Delta ET.$$

Long-term averages of pre and post precipitation are assumed to be equal, which makes them the equal and causes them to cancel out in the calculation. It is also assumed that watershed storage changes over the long term approach zero.

Flow estimates in WRENSS are based on water balance calculations of generated runoff (GRO), which is excess water produced on cut blocks following harvesting. GRO becomes true runoff (i.e. routed flow) when it reaches the stream channel. GRO is strongly affected by watershed storage and in the short term (e.g. 1-2 years) may not be equal to actual flow ($Q_A$). However in the long term (e.g. 10+ years) GRO approaches actual flow as annual change in watershed storage approaches zero ($\Delta S$~0). GRO is defined as:

$$Q_{GRO} = \text{Input} - \text{Losses} = P - ET \pm \Delta S$$

Where:

$P$ = precipitation
$ET$ = evapotranspiration losses
$\Delta S$ = change in watershed storage.
$Q$ = annual or seasonal flow

WRENSS also provides estimates of changes in maximum flows for return periods of 2, 5, 10, 20, 50 and 100 years. Peak flow changes assessed in WRENSS are based on regression analyses that predict peak flow as a function of watershed size. It predicts maximum daily flow as a function of mean daily flow for the period of March-September. Maximum daily flows are estimated for undisturbed and disturbed conditions for a given return period event. The difference between these two flows is then added to the maximum flow estimated as a function of watershed area. In some situations the difference between maximum and mean daily flow will be constrained if it exceeds the maximum daily change in evapotranspiration calculated by WRENSS (i.e. daily flow of 3.91 cubic meters/second).

### Data Requirements

| GIS-generated data | Purpose in WRENSS |
|---|---|
| SCENARIO | Title of scenario being tested. |
| AREA CUT | Area of harvested unit in hectares |
| NUMBLOCKS | Number of blocks comprising the harvested unit. This field and the BLKSIZE field allow the grouping of several blocks of similar size, species, aspect and year of harvest into one area. The Total area of all of these similar blocks goes into AREACUT field, and either the number of blocks comprising that area go into this field or the average size of the individual block goes into the BLKSIZE field. |
| BLKSIZE | The size of individual blocks in hectares |
| BLK YRCUT | The year the block or group of blocks was cut in yyyy format. |
| BLK ELEV | The average elevation of the block or group of blocks in meters. Used in WRENSS-MF to adjust precipitation data from a different elevation to that the cut blocks being analyzed. |
| BLK ASPECT | The average aspect of the block as N, S, or EW. Aspect is used in conjunction with precipitation to estimate potential evapotranspiration. Maximum potential ET on south aspects and minimum on north aspects. |
| BLK REGEN | The species that the block is to be regenerated on a block. Lodgepole Pine, White Spruce or Deciduous are the only appropriate choices. |
| BUF SPECIES | The species of the surround stand, again LPP or WS or Deciduous are the only appropriate choices. Used to estimate species harvested on existing cut blocks. |
| BUF BA | The basal of the surrounding stand in $m^2$/ha. Used to estimate basal on existing cut blocks. |
| LUT BASEBA | The anticipated basal area of regeneration on the site at maturity, or the number of years in the rotation. Represents maximum basal area in ratio to adjust ET upwards or downwards. |
| LUT BAYEAR | The anticipated number of years to reach the basal area at maturity or the number of years in the rotation. |
| IN BAFUNCT | The name of the basal area growth functions for regeneration in the unit. This is assigned during operation of WRENSS-MF. |
| BUF HT | The height of the surrounding stand in meters. Used to estimate redistribution effects of snow movement in cut blocks and surrounding stands. |
| LUT BASETH | The anticipated height of the regeneration on the site at maturity or at the end of the rotation. |
| LUT THYEAR | The anticipated number of years to reach the height of maturity, of the number of years in the rotation. |
| IN THFUNCT | The name of the height growth functions for regeneration in the unit. This is assigned during operation of WRENSS-MF. |
| IN RECORD | Block ID. This may be changed to a 15 character wide field if necessary to identify your blocks. This is not used in WRENSS-MF runs. |