Final Report
Hydrologic Effects Forest Harvesting
Sundance Forest Industries Forest Management Area

Report Prepared for:
Sundance Forest Industries
Edson, Alberta

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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 WRENSS and other hydrological models depends on the availability of representative climatic/hydrometric data, and regional forest growth and yield data, and harvesting plans. In this context, Watertight Solutions has evaluated the hydrometric data used in this analysis and considers 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 WRENSS model projects 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.

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Table of Contents

List of Tables

List of Figures

Executive Summary

The effects of a forest harvesting plan on annual water yield, maximum daily flows and hydrologic recovery were assessed for Sundance Forest Industries (SFI) using the WRENSS model. The proposed harvest was for a 20 year period (200702026) in SFI's forest management area (FMA) located south of the town of Edson, Alberta.

The FMA exists as two separate blocks, with one located in the Pembina River and Brazeau River watersheds and the other in the McLeod River watershed immediately south of the town of Edson. Harvesting is planned for the period 2007-2026, with most occurring in the southern block of the FMA. Forest cover in these watersheds includes pure to mixed stands of aspen (*Populus tremuloides*), white spruce (*Picea glauca*) and lodgepole pine (*Pinus contorta*) and poorly drained wetlands with black spruce (*Picea mariana*).

Twenty-four sub-watersheds were selected in this area for simulations. These watersheds ranged in size from 10 to 103 km^2 (Table 1 Figure 4). Four sub-watersheds selected for simulations in the northern block ranged in size from 25 to 252 km^2. Harvest levels ranged from < 1% to 47 % of watershed areas for both blocks.

Results of the assessment were as follows.

Water Yield

- Simulated increases in annual water yield of 11.1%- 17.8% were significantly greater than representative flows on 10 of 24 watersheds. Most of these watersheds were located in the Low Elevation South Block of the FMA where water yield was lowest.
- These increases may exceed the upper limits of natural variability for water yield for the region based on experience elsewhere. An analysis of flow variability for the region is be needed to confirm this observation.
- These increases in water yield were attributed to high levels of harvesting which removed 30% - 47% of forest cover in the watersheds.
- On the remaining 14 watersheds water yields were not significantly different from representative flows with simulated increases ranging from <1% – 8.5%. Forest cover removal in these watersheds varied from <1% - 29%.
- Low responses in water yield in watersheds with harvest levels of 20%-29% were the result of a mix of historical harvesting prior to the proposed harvest for 2006-2026. Hydrologic recovery of historical blocks was advanced which moderated water yield increases.

Hydrologic Recovery

- Hydrologic recovery, the time for water yield increases to disappear or approach "pre-harvest levels", was assumed to occur when increases in water yield were ≤ 5%.
- Hydrologic recovery, averaged 14 years for all watersheds, with minimum and maximum values of 0- 41 years.
- Hydrologic recovery for watersheds with significant increases in water yield averaged 23 years, with minimum and maximum values of 16 and 41.
- Hydrologic recovery in watersheds with no significant increase in water yield averaged 4 years, with minimum and maximum values of 0 and 15.

- Watersheds with zero years for recovery occurred in watersheds with harvesting < 10% of watershed area, or where increases in water yield were ≤ 5%.

% Watershed ECA

- Watershed Equivalent Clearcut Area (ECA) was based on the return of increased water yield to "pre-harvest" conditions.
- %ECA for watersheds with significant increases in water yield averaged 23% with minimum and maximum values of 16% and 31%.
- %ECA for watersheds with no significant change in water yield averaged 11% with minimum and maximum values of 1% and 26%.

Peak Flows

- The largest simulated increases in maximum daily flows for the 2-year and 5-year events occurred in watersheds with high levels of harvesting (41%-47%).
- Increases for the 2-year and 5 year events varied from 8.3%-11.1% and 8.3% - 11.5% respectively.
- Increases in watersheds with less harvesting (1.3%-21.7%) for the 2-year and 5-year events ranged from <1% - 4.7%.
- Increases in peak flows showed a decreasing trend with an increase in recurrence intervals. The trend varied from strong for watersheds with high levels of harvesting to weak or nonexistent for watersheds with less harvesting.
- Increases for maximum flows were judged to fall within the range of natural variability

In conclusion the simulated increases in water yield and peak flows for the proposed harvesting by SDI are considered small to moderate in magnitude and duration. The high levels of harvesting in watersheds with maximum increases were moderated by the existence of historical harvesting. Based on current knowledge and experience no adverse impacts on water quality and aquatic habitat are expected, contingent upon the application of existing ground rules.

Increases in water yield and peak flows can be managed by rescheduling and reducing in the level of harvesting. This is not necessary for the current plan, but future harvesting should include considerations for hydrologic recovery to minimize the potential for cumulative impact on water yield and peak flows. Frequent entries into a watershed will sustain water yield increases and delay hydrologic recovery.

The current plan also includes strategies to minimize the impacts and spread of anticipated mountain pine infestations by harvesting a large component of mature pine stands in watersheds. The simulated changes in water yield and peaks for this plan are modest when compared to potential impacts if stands are attacked and destroyed by mountain pine beetles (Love 1955; Troendle and Nankervis 2000; Uunil et al 2006; Forest Practices Board 2007).

Final Report
Hydrologic Effects of Forest Harvesting In Sundance Forest Industries Forest Management Area

Introduction

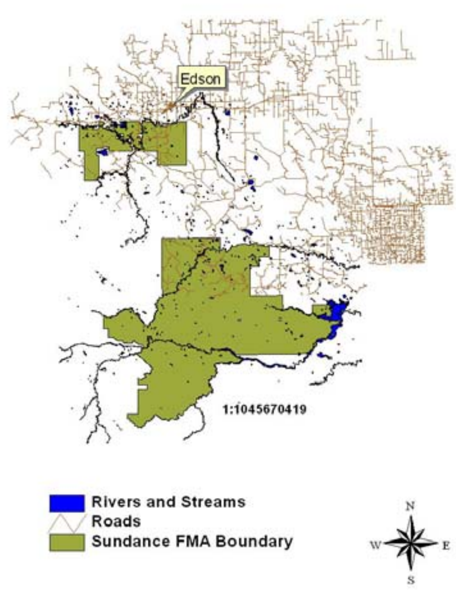
The objective of this report was to assess the hydrologic effects forest harvesting in Sundance Forest Industries (SFI) forest management area. This report addresses the effects of forest harvesting on water yield, maximum daily flow and hydrologic recovery.

SFI's forest management area (FMA) is located south of the town of Edson (Figure 1). The FMA exists as two separate blocks, with one located in the Pembina River and Brazeau River watersheds and the other in the McLeod River watershed immediately south of the town of Edson. Harvesting is planned for the period 2007-2027, with most occurring in the southern block of the FMA. Forest cover in these watersheds includes pure to mixed stands of aspen (*Populus tremuloides*), white spruce (*Picea glauca*) and lodgepole pine (*Pinus contorta*) and poorly drained wetlands with black spruce (*Picea mariana*).

Hydrologic assessment of harvesting was done as follows:

1. Prepare a hydrologic land-base for the FMA
2. Identify 3rd order basins and consolidate into watersheds 50-100 km^2 in size
3. Assemble and prepare harvest schedule data for analysis
4. Assemble hydro-meteorological data for the region
5. Run hydrologic simulations (WRENSS) of proposed harvesting
6. Analyze and report results.

Figure 1 Sundance forest management area is located south of Edson



Methods

Hydrologic Land Base

A hydrologic land-base defines the number and extent of watersheds within a FMA. Hydrologic assessments are ideally done on a watershed basis, which includes all of the historical and proposed forest harvesting (i.e. disturbances) that can affect water flows. This is not always possible as FMA boundaries are seldom watershed based.

The hydrologic land-base prepared for SFI was done by identifying 3rd order basins in the region (Figure 2), which were consolidated into larger basins of 50-100 km^2 (Figure 3) which were used for simulations (Figure 4). Attempts were made to limit watershed sizes to < 100 km^2 which is a scale commonly used in forest planning. Furthermore, the effects of forest harvesting on water flows becomes small or obscured on large watersheds (> 200-300 km^2) because the extent on harvesting in relative terms is less and the mix of newly harvested sites, unharvested sites and regenerated sites moderates flow responses.

Harvest Data

Harvest data and scheduling used in these assessments was prepared by The Forestry Corp. Primary data included were: harvest block area, year of cut, harvest block aspect, species to be harvested, and species to be regenerated and site quality (Appendix 1).

Most of the proposed harvesting is located in southern block of the FMA. Twenty-four sub-watersheds were selected in this area for simulations. These watersheds ranged in size from 10 to 103 km^2 (Table 1 Figure 4). Four sub-watersheds selected for simulations in the northern block ranged in size from 25 to 252 km^2. Harvest levels ranged from < 1% to 47 % of watershed areas for both blocks.

Hydro-Meteorological Data

Streamflow and precipitation data were downloaded from web sites of the Meteorological Service of Canada and Water Survey of Canada. Precipitation data were obtained from "2002 CDCD WEST CD" (Environment Canada 2002) for Western Canada. Streamflow data were obtained from HYDAT–CD ROM (Environment Canada 2003) which contains flow data for all of Canada. Most of the precipitation and hydrometric stations for forested regions in Alberta obtained from these sources are provided in WRENSS model as "look up tables" that allow specific stations to be input into the program.

Streamflow data for the Embarras River, Rat Creek and Brown Creek rivers were used in hydrologic simulations (Table 2) as representative watersheds. These were three hydrometric stations in the region with long term data. These watersheds are large compared to those selected for hydrologic assessment (218-648 km^2 vs 10-252 km^2). The ideal would be to select watersheds similar in size, vegetation and topography to those for assessment.

Figure 2 Third order watersheds defined for the regions south of Edson. These sub-watersheds were used as a base to define a hydrologic land-base for the SFI's FMA and to select watersheds for simulation.

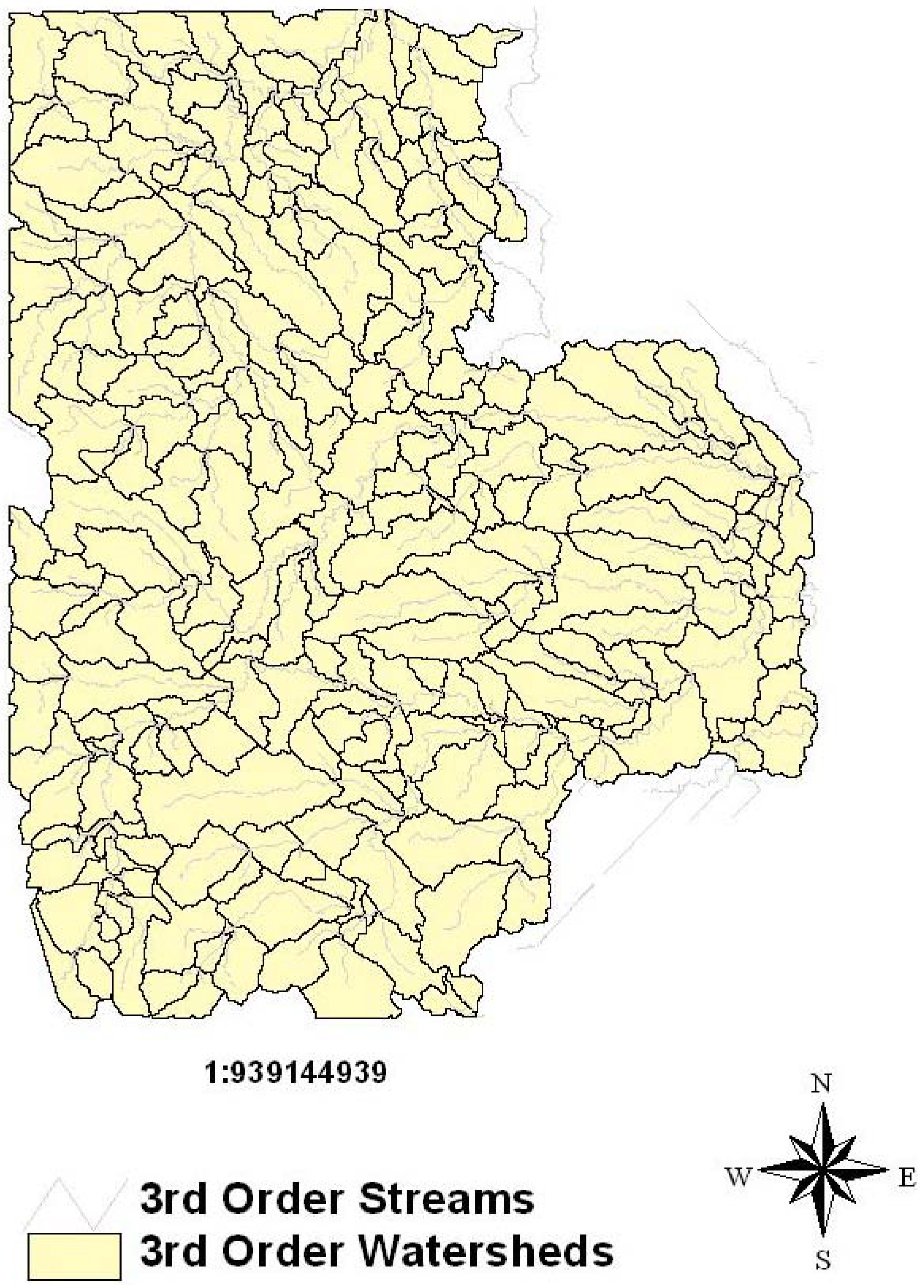
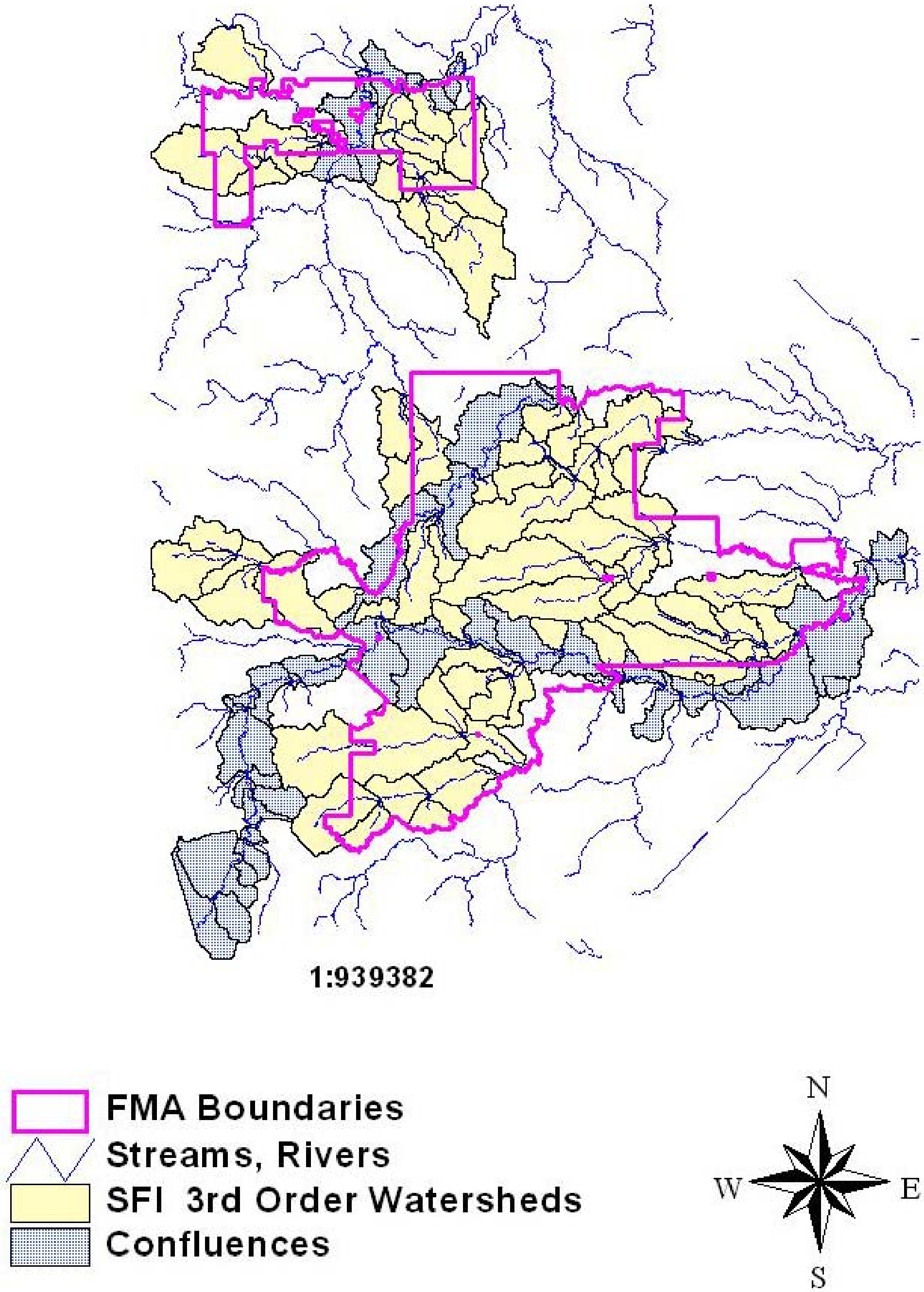


Figure 3 SFI's hydrologic land base was formed by consolidation of smaller 3rd order sub-watersheds. These watersheds ranged in size from 6 – 121 km^2 (Table 1). No watersheds in the confluence zones were identified because they were usually small (< 3rd order) and not easily identified.



+Figure 4 Selection of watersheds for simulation was based on watershed size (≤ 100 km2) and regions where harvesting was concentrated on the FMA.

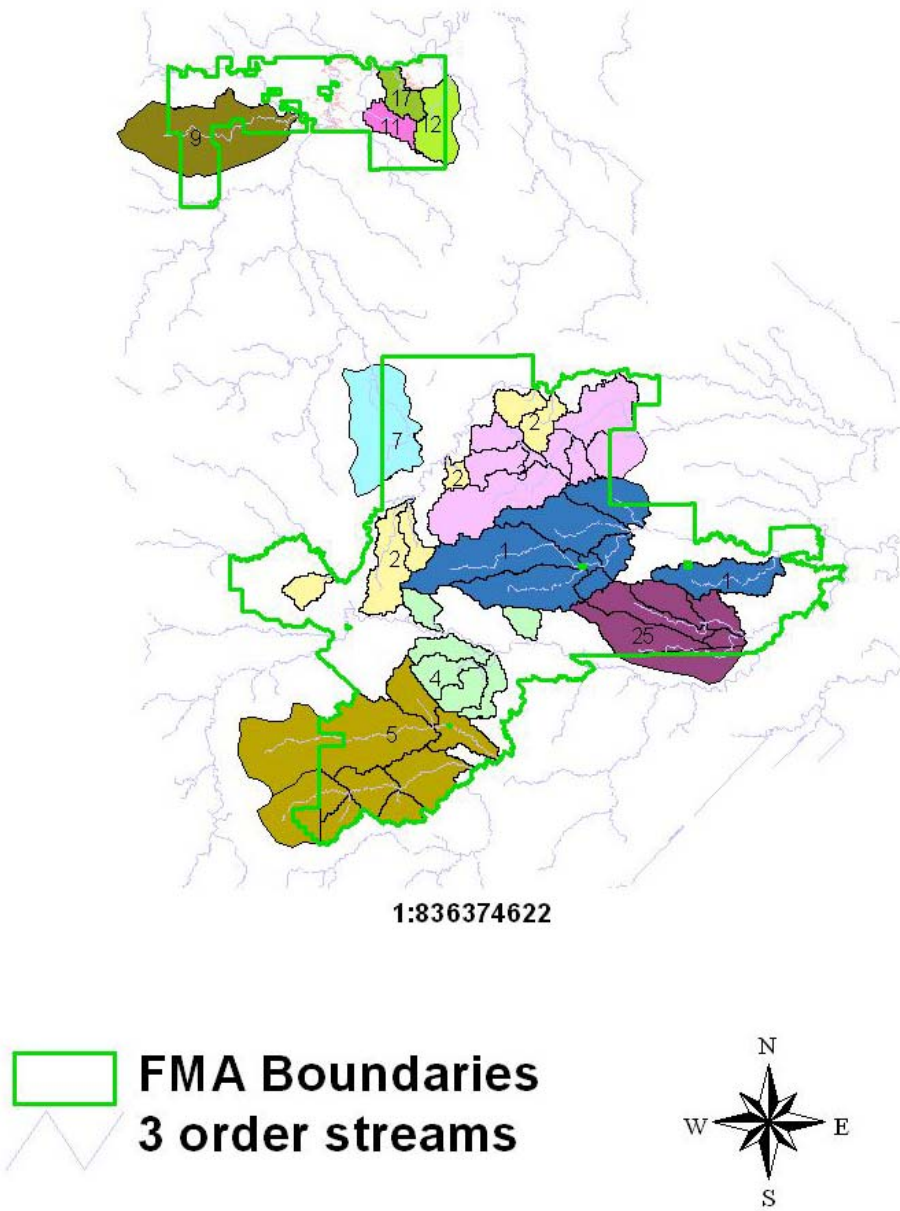


Table 1 Harvest levels in watersheds selected for harvesting.

Watershed Number	Area km^2	Hectares Harvested	% Watershed Harvested
North Block			
1100	251.6	1134	4.5
1200	48.4	465	9.6
1700	24.6	859	35
9000	83.3	263	3.2
South Block –High Elevation			
4001	95.6	3154	33
4002	24.9	725	29.1
5001	87.8	69	0.8
5002	190.9	499	2.6
South Block – Low Elevation436			
1001	69.6	3310	47.6
1002	57.5	1233	21.5
1003	102.8	4843	47.1
1004	67.3	2777	41.3
1005	45.4	1005	22.2
2001	54.3	1807	33.3
2002	21.2	672	31.7
2003	24.3	720	29.6
2004	10.1	436	43
2501	48.1	1648	34.3
2502	81.2	1395	17.2
3001	54.1	2111	39
3002	94.3	3899	41.4
3003	14.7	407	27.7
7001	35.6	44	1.3
7002	63.8	1524	23.9

The selection of representative watersheds for the simulations is important as their long term average water yield (area-mm) is used to calculate percent increases in water yield. Most of the available hydrometric data is for large watersheds, whose water yields are usually smaller than those of tributary sub-watersheds ($\leq$ 100 km^2) which are normally candidates for simulations. When this occurs the most likely outcome is that simulated changes in water yield are likely to overestimated.

The Sundance FMA was divided into three water yield zones based on available data (Figure 5). The Embarras River was used as a base yield for watersheds in the north block of the FMA. The southern block was divided into two zones with Brown Creek as a base flow in the higher elevation zone and Rat Creek for the lower elevation zone to the east (Figure 5). Higher percentage flow increases can usually be expected in areas with lower water yield compared to areas of higher water yield. The lower water yield boundary in each zone was used to calculate percentage increases.

Table 2 Hydrometric stations used in WRENSS simulations

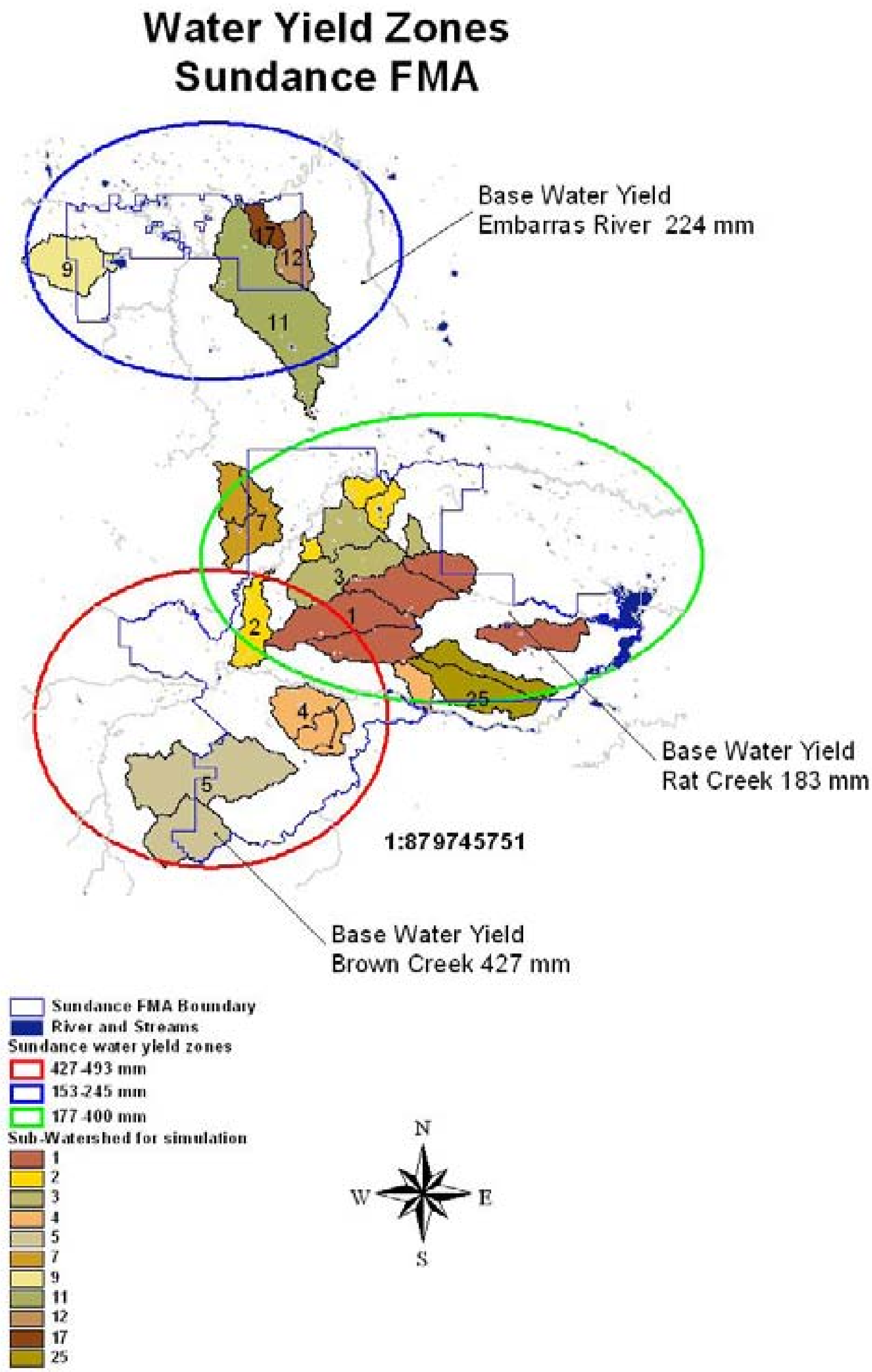
Watershed	Area km^2	Years of Record	Annual Water Yield mm		
			Avg	Max	Min
Embarras River	647.7	19	223.7	330.5	95.0
Rat Creek	606	31	183.7	363.2	76.5
Brown Creek	218.0	29	426.7	763.8	149.0

Annual and monthly precipitation records are required for WRENSS. Data of this nature are difficult to find in forested regions. Data from the Edson and the Nordegg Ranger Station were used in the simulations (Table 3).

Table 3 Annual precipitation at Edson and Nordegg Ranger Station

Station	Years Record	Annual	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sept	Oct	Nov	Dec
Edson	10	532.1	27.5	24.8	18.5	26.7	63.1	67.1	112.3	72.3	47.8	31.7	19.0	21.3
Nordegg R.S.		585.5	27.8	16.0	27.0	34.8	70.5	99.8	101.4	78.7	59.4	28.0	20.8	21.5

Figure 5 Water yield zones were constructed to account for differences in flow in the FMA. The lower boundary in each zone was used to calculate percent increases in water yield.



Hydrologic Simulations

WRENSS

Simulations were done using WRENSS (Water Resource Evaluation for Non-Point Silvicultural Sources) which was developed by the U.S. Forest Service and the U. S. Environmental Protection Agency (EPA 1980). WRENSS was designed to be used as an operational tool for forest planning. It is relatively simple in concept and has modest data requirements. It is not a "high end" research model designed to simulate daily flows (i.e. routed runoff).

Swanson (2000, 2005) prepared a computer version of the procedure (WRENSS) for Alberta conditions and modified it by linking climate and flow databases to the program. Outputs from WRENSS include:

- Increase in annual water yield
- Hydrologic recovery
- Equivalent clear-cut area
- Increases in maximum annual daily flows and maximum annual instantaneous flows for 2, 5, 10, 20 50 and 100 year recurrence intervals

Estimated changes in annual water yield are based on seasonal water balance calculations of generated runoff (GRO), which is water that will eventually become runoff but has not reached the stream channel. Increases in water yield (ΔQ) are a change in evapotranspiration (ΔET) resulting from the removal of forest cover. Increases in water yield are obtained by taking the difference between harvested and unharvested conditions.

Increases in water yield in WRENSS are expressed as area-millimeters (area-mm) and percentages. Area – mm is the volume of increased flow (or reduced ET) expressed as a uniform depth over a watershed. Increases in water yield are expressed as percents of the mean annual water yield (i.e. base yield in WRENSS) for the watershed being analyzed or a nearby representative watershed, which is of similar size, forest cover and climate (i.e. precipitation).

Increases in water yield should be considered as relative changes (e.g. small, medium, and large). Few if any models are capable of providing exact, absolute changes. Furthermore, annual water yields are highly variable among watersheds and hydrologic regions. For example, annual yields in some years in boreal forest watersheds can be 0-100 mm, while in the Rocky Mountains water yields can be 400-800 mm. An increase of 40 mm in a Rocky Mountain watershed would be a small percentage compared to a similar increase in a boreal forest watershed. Percentages must be carefully interpreted.

Hydrologic recovery is an estimate of the time required for increased water yield to disappear as trees grow back on harvest blocks to full occupancy of the site or a condition similar to pre-harvest conditions. WRENSS uses basal area as a surrogate for leaf surface area. Hydrologic recovery is assumed to occur with the time of maximum leaf area or the recovery of evapotranspiration to pre-harvest levels. Stand basal area is used as a surrogate for leaf surface area in WRENSS. This provides a very conservative estimate of hydrologic recovery as the time for basal area to return to a "mature stand level can be very long (e.g. 80-100 years).

Leaf surface area and by association hydrologic recovery is thought to occur earlier than the time to maximum basal area. Brabender (2005) reports maximum LAI for lodgepole pine around 25 years and a strong relationship between maximum LAI and periodic annual increment (PAI). Silins (2000) utilized these relationships to estimate ECA and hydrologic recovery in a modified version of WRENSS (i.e. ECA-Alberta). Based on the above, hydrologic recovery in this assessment was assumed to occur when simulated increases in water yield were ≤ 5%. This approach gives estimates comparable to the values reported in the literature (Brabender 2005, Lieffers et al 2002).

Equivalent Area Clearcut (ECA) is an 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 regeneration of harvest blocks. 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 in this assessment as the area (hectares) harvested times a reduction factor that describes the recovery of evapotranspiration losses. ECA estimates in WRENSS are provided in terms of basal area recovery and recovery of water yield. ECA_Q based on water yield recovery was used in this assessment. It is considered a more direct and realistic estimate of hydrologic recovery. ECA_Q is expressed in hectares of “harvested area” and as a percent of the watershed area.

WRENSS also estimates increases in maximum daily and instantaneous flows due to harvesting for return periods of 2, 5, 10, 20, 50 and 100-year events. WRENSS uses watershed area to estimate peak flows ($Q_{peak\text{-}area}$) for all return periods in the unharvested condition. The difference between the mean March to September streamflow in the unharvested and harvested condition is used to estimate the change in peak flow ($Q_{peak\ mean\ flow}$) caused by harvesting for each return period. The difference in $Q_{peak\ mean\ flow}$ between the harvested and unharvested conditions is added to $Q_{peak\text{-}area}$ to obtain the maximum flow for a given return period. (A more detailed description of WRENSS in provided in Appendix 1).

Simulations

Hydrologic simulations were done for 100 years (2006-2106) for each watershed with a 1 year time step. Percent increases in water yield were determined using the Embarras River, Rat Creek and Brown Creek as representative watersheds (i.e. base yield). The hydrologic region used was the New England/Boreal. Peak flows equations were for the Edson region. Specific data requirements for WRENSS simulations are shown in Appendix 2. Watersheds selected for simulations and the extent of harvesting and basin order are described in Table 1

Statistical Assessments

Increases in water yield were assessed by comparing increased water yields to those of nearby representative watersheds. Annual water yield increases were compared to the long term mean annual/seasonal flows of representative with watersheds 10 years or more of flow record. If a simulated increase in water yield exceeded the upper 95% confidence limit for the mean annual flow of its representative watershed it was considered a significant increase in water yield.

Statistically the ideal situation for evaluating water yield increases would be to have long term streamflow record for the watershed being assessed. This seldom occurs, other than on experimental watersheds. The approach adopted in WRENSS is based on the assumption that nearby watersheds of similar size, forest cover, topography and climatic regimens represent a reasonable benchmark upon which managers can evaluate potential changes in water yield.

The Embaras River, Rat Creek and Brown Creek were used as representative watersheds in the these simulations. Confidence limits for mean water yield were calculated as: $0 \pm (t)\ (s_0)$ where $0 =$ mean water yield**,** t = t value and s_0 = standard error of the mean = $\sqrt{(s^2/n)}$.

Confidence limits for each watershed were:

Embarras River ---- 224 mm ± (2.093 * 12.417) = 25.988 mm ---- (25.988/224)*100 = 11.6%
Upper 95% confidence limit = 224 + 25.998 = 249.98 mm

Rat Creek ---- 183 mm ± (2.457 * 9.804) = 24.088 mm ---- (24.088/183)*100 = 13.16%
Upper 95% confidence limit = 183 + 24.088 = 207.08 mm

Brown Creek ---- 427 mm ± (2.462 * 17.735) = 43.663 mm ---- (43.663/)*100 = 10.2%
Upper 95% confidence limit = 427+ 43.663 = 470.66 mm

Simulated water yield increases greater than 11.6%, 13.16% and 10.2% were considered significant increase in comparisons made with Embarras River and Rat Creek and Brown Creek respectively. Significant increases in water yield were assumed to contribute to higher seasonal flows in affected watersheds.

Results

Water Yield

The largest simulated increases in annual water yield were in the Low Elevation - South Block. Increases ranged from 13.9% to 17.8% in watersheds where the percent area harvested varied from 39% to 47% (Table 4). Volumetric increases were an extra 20 to 33 mm of water. All of these increases were significant with respect to the representative watershed (Rat Creek). Increases in the remaining 5 watersheds were not significant, ranging from < 1% to 8.5%. The extra water generated in these watersheds was 1- 16 mm.

Simulated water yield increases in the North Block of the FMA ranged from a significant increase of 12.2% in watershed 1700 to no significant changes in the remaining watersheds (1.2-3.4%). Extra water generated by harvesting ranged from a high of 27 mm to lows of 3-8 mm.

Simulated water yield increases in the High Elevation – South Block were not significant. Percent increases ranged from 0.6 – 5.2%. Extra water generated by harvesting varied from 1- 22 mm.

Hydrologic Recovery and % ECA

Hydrologic recovery for all watersheds averaged 14 years with maximum and minimum values of 0 and 41 years (Table 4). Zero values were in watersheds with low to nil harvesting and very low increases in annual water yield. The maximum time for recovery was in watershed 1001 where the increase in water yield and percent harvesting was 17.8% and 47.6% respectively.

Maximum % Watershed ECA, a measure of disturbance or recovery of evapotranspiration, varied from lows of 1%-5% for watersheds with little harvesting to highs of 27%-31% for watersheds with large water yield increases and harvest levels > 40%.

Peak Flows

The largest increases in simulated maximum daily flows occurred in the Low Elevation South Block where harvesting was greatest and more frequent (Table 5). Increases for the 2-yr to 5-yr recurrence interval events[1] varied from 8.6% to 11.1% and 8.5% to 11.5% in watersheds 2004, 1003 and 3002. The percent area harvested in these watersheds varied from 41% to 47%. Low increases ranged from 0.2% to 4.7% with harvest levels of 1.3% to 21.7%.

Simulated increases in peak flows for most of the watersheds showed a weak decreasing trend with an increase in recurrence intervals. The reason for this is the volume of extra water generated by forest cover removal in a watershed is relatively constant volume. Increases for the 2-year events varied from <1% - 11.1% compared to <1% - 7.6% for the 100 year events. The low response of peak flows was in large part a reflection of small increases in annual water yield.

[1] Recurrence interval is the average period of time expected to elapse between successive occurrence of events of given size or larger. For example an event with a recurrence interval of 2-years can be expected to be equaled or exceeded once every 2 years, or to occur 50 times in 100 years

Table 4 Simulated increases in annual water yield, % maximum watershed ECA and hydrologic recovery in SDI's forest management area. Watersheds in each block are sorted by maximum to minimum % increase in water yield. Medium and low disturbances represented by yellow and blue shading respectively. Asterisks indicate significant increase in water yield with respect to representative watersheds.

Watershed Number	Area km^2	% Watershed Harvested	Yield Increase mm	% Increase Yield	Maximum % Watershed ECA	Hydrologic Recovery years
North Block						
1700	24.6	35	27.2	12.2*	19	17
9000	83.3	3.2	2.7	1.2	5	0
1100	251.6	4.5	3.8	1.7	26	0
1200	48.4	9.6	7.6	3.4	2	0
High Elevation South Block						
4001	95.6	33	21.8	5.1	16	0
4002	24.9	29.1	22.2	5.2	14	0
5001	87.8	0.8	0.9	0.2	1	0
5002	190.9	2.6	2.6	0.6	1.8	0
Low Elevation South Block						
1001	69.6	47.6	32.7	17.8*	29	41
1003	102.8	47.1	31	16.9*	27	34
1004	67.3	41.3	30	16.4*	24	36
2004	10.1	43	29.1	15.9*	31	23
3002	94.3	41.4	27	14.7*	23	29
3001	54.1	39	25.5	13.9*	24	20
2001	54.3	33.3	22.7	12.4	22	21
2002	21.2	31.7	21.7	11.8	19	16
2003	24.3	29.6	20.9	11.4	20	16
2501	48.1	34.3	20.4	11.1	16	31
7001	35.6	1.3	1.1	0.6	1	0
2502	81.2	17.2	11.5	6.3	8	5
1002	57.5	21.5	13	7.1	11	9
1005	45.4	22.2	13.9	7.6	12	13
3003	14.7	27.7	14.2	7.7	13	12
7002	63.8	23.9	15.7	8.5	15	15

Table 5 Simulated Increases in maximum daily flows generated by forest harvesting in SDI's forest management area. Medium (5% - 15%) and low increases (<5%) are shown yellow and blue shading respectively.

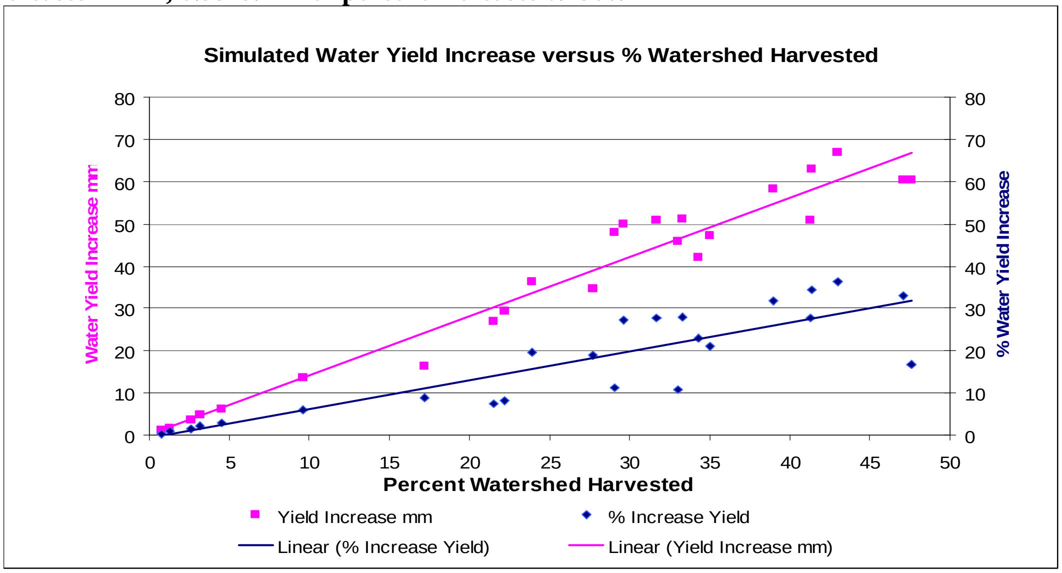
Watershed	Area km^2	% Watershed Harvested	Recurrence Interval – Years						Maximum % Watershed ECA	% Increase Water Yield
			2	5	10	20	50	100		
North Block of FMA										
1700	24.6	35	8.3	8.4	8.4	7.2	5.7	4.9	19	12.2
1200	48.4	9.6	2.6	2.6	2.6	2.1	1.7	1.5	5	3.4
1100	251.6	4.5	1.3	1.3	1.3	1.2	1.1	1.0	26	1.7
9000	83.3	3.2	0.9	0.9	0.9	0.7	0.6	0.5	2	1.2
South Block – High Elevation										
4001	95.6	33	7.8	8.7	8.4	6.4	4.9	4.1	16	5.1
4002	24.9	29.1	6.2	6.9	6.5	5	3.9	3.3	14	5.2
5002	190.9	2.6	1.0	1.2	0.8	0.6	0.5	0.4	1	0.6
5001	87.8	0.8	0.1	0.1	0.1	0.1	0.1	0.1	18	0.2
South Block – Low Elevation										
2004	10.1	43	11.1	11.5	9.7	7.7	6.1	5.2	29	15.9
1003	102.8	47.1	9.6	9.5	9.5	9.4	8.7	7.6	27	16.9
3002	94.3	41.4	8.6	8.5	8.5	8.4	7.6	6.6	24	14.7
2002	21.2	31.7	8.5	8.7	8.0	6.4	5.1	4.4	31	11.8
3001	54.1	39	8.3	8.3	8.3	8.3	7.1	6.1	23	13.9
2003	24.3	29.6	7.7	7.9	7.6	6.1	4.8	4.2	24	11.4
2501	48.1	34.3	7.2	7.2	7.2	7.2	5.9	5.1	22	11.5
1004	67.3	41.3	6.8	6.8	6.8	6.8	6.8	6.8	19	16.4
2001	54.3	33.3	6.7	6.8	6.8	6.8	6.0	5.2	20	12.4
1005	45.4	22.2	5.3	5.4	5.4	4.6	3.7	3.2	16	7.6
1002	57.5	21.5	4.7	4.7	4.7	4.7	3.9	3.4	1	7.1
3003	14.7	27.7	4.4	4.5	4.5	4.6	4.1	3.6	8	7.7
7002	63.8	23.9	4.4	4.4	4.4	4.4	4.4	3.8	11	8.5
2502	81.2	17.2	4.4	4.4	4.4	3.8	3.1	2.7	12	6.3
1001	69.6	47.6	4.0	4.0	4.0	4.0	4.0	4.0	13	17.8
7001	35.6	1.3	0.2	0.2	0.2	0.2	0.2	0.2	15	0.6

Discussion

Water Yield Increases

Increases in water yield are determined primarily by the extent and frequency of harvesting and watershed size. Harvesting that exceeds 30% - 40% or more of a watershed can be expected to increase water yield above “acceptable levels” (Figure 6). Large increases in water yield and peak flows can also be expected when harvesting is concentrated in a short period of time (<5 years) or sustained for long periods (Figures 7, 8). This was the case for 10 of the 24 watersheds assessed in this report where harvesting varied from 29.7%-47%.

Figure 6 Simulated water yield increases in versus percent of watershed harvested. R^2 for increases in mm, 0.9519. R^2 for percent increases 0.7566.



Experience in other regions of Alberta (Watertight Solutions 2005) suggests increases greater than 20%-25% exceed the natural variability[2] of flows with recurrence intervals less than 5 years. Flow events of these magnitudes and frequencies are considered sensitive to disturbance because of the smaller size and greater frequency. Percent increases in smaller flows are often bigger than for larger and less frequent events. Furthermore, the greater frequency of occurrence of small events (i.e. recurrence intervals < 5 years) may have greater cumulative effects in terms of energy to shape and change stream channel morphology (and aquatic habitat) may be greater in the long term than single large events.

The interaction of watershed size and area harvested will also influence water yield responses. Small watersheds usually show larger responses in water yield than larger watershed with a similar level of harvesting. For example, harvesting 1649 ha in watershed 2501(48 km^2) produced a maximum water yield increase of 11.1%, while harvesting 1396 ha in watershed 2502 (81 km^2) increased water yield by 6.6%. The lower response in 2502 is attributed to its greater size and less disturbance (maximum % ECA 14% vs 30%). Larger watersheds will often have a mix of newly harvested areas, old harvest areas and uncut areas that moderate water yield increases.

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[2] Natural variability is defined as long term mean annual flow ±2 standard deviations.

Figure 7 Simulated increases in annual water yield for watershed 2501, Sundance Industries FMA. Watershed size 49.1 km^2, % harvested 34.3%, max water yield increase 11.1%, max%ECA 16%, hydrologic recovery 31 years. Arrow indicates time of hydrologic recovery (ΔQ ~ 5%).

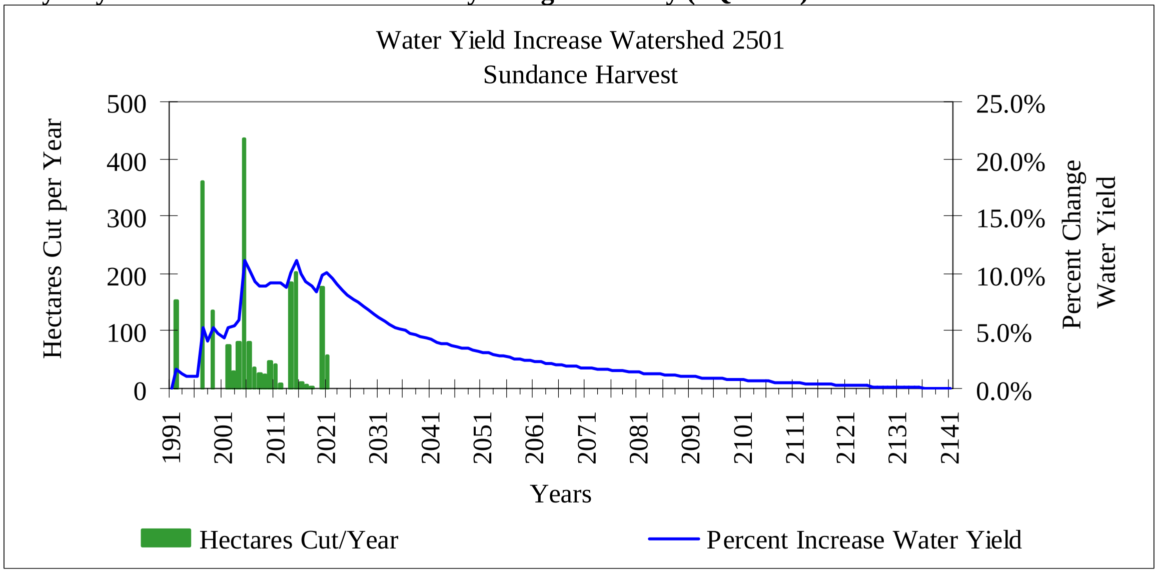
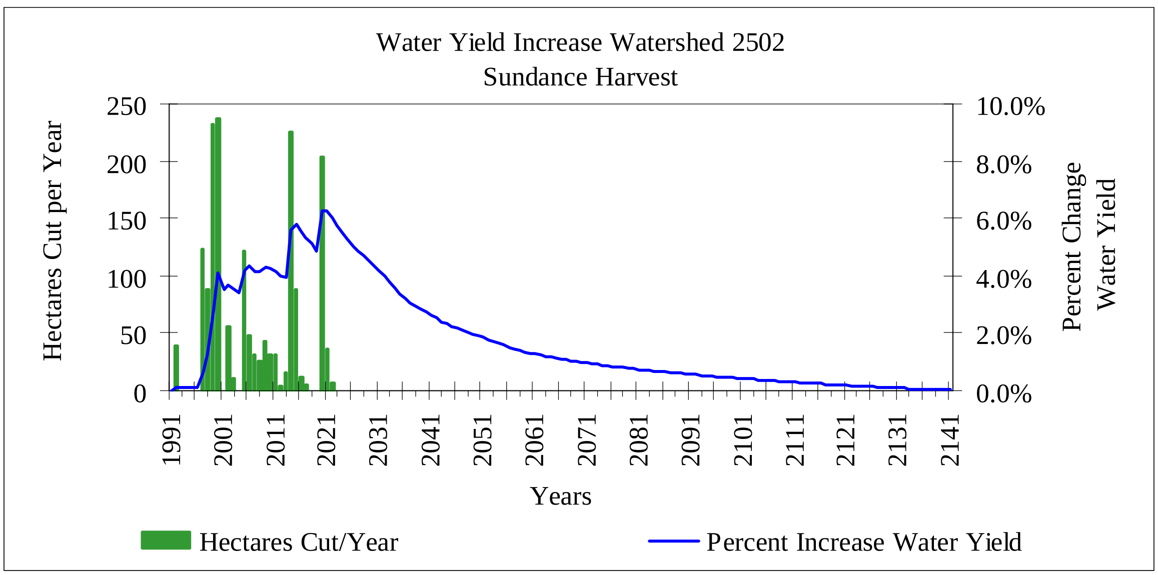


Figure 8 Simulated increases in annual water yield for watershed 2502, Sundance Industries FMA. Watershed size 81.2 km^2, % harvested 17.2%, max water yield increase 6.3%, max% ECA 8%, hydrologic recovery 5 years. Arrow indicates time of hydrologic recovery (ΔQ ~ 5%).



It should be noted that flow responses in WRENSS simulations are strongly affected by the choice of representative watersheds used as a base to calculate percent increase. The Embarras River, Rat Creek and Brown Creek were representative watersheds in these simulations. These watersheds are bigger in area than the most of the watersheds assessed. Water yields from smaller watersheds are often greater than those of larger watersheds because the volume of flow is expressed on an areal basis. The significance of this is that the water yield increases from these simulations could be "over estimates". Because of this it is best when interpreting these results to consider changes in flow in relative terms (low, med, high or acceptable unacceptable) and not as absolute numerical values.

Another point to consider is that watersheds or regions characterized by low annual flows will usually produce higher percentage increases in flow than those with high annual flow. This is evident for the south block-low elevation where Rat Creek with an annual flow of 183 mm was used compared to 224 and 427 for the Embarras River and Brown Creek. Ideally representative watersheds should be of similar size, topography vegetation and climate. This is often not possible. An effort was made to account for this by stratifying flows within the FMA, but there is no substitute for good data. Access to flow data for small to medium sized watersheds would make simulations more reliable.

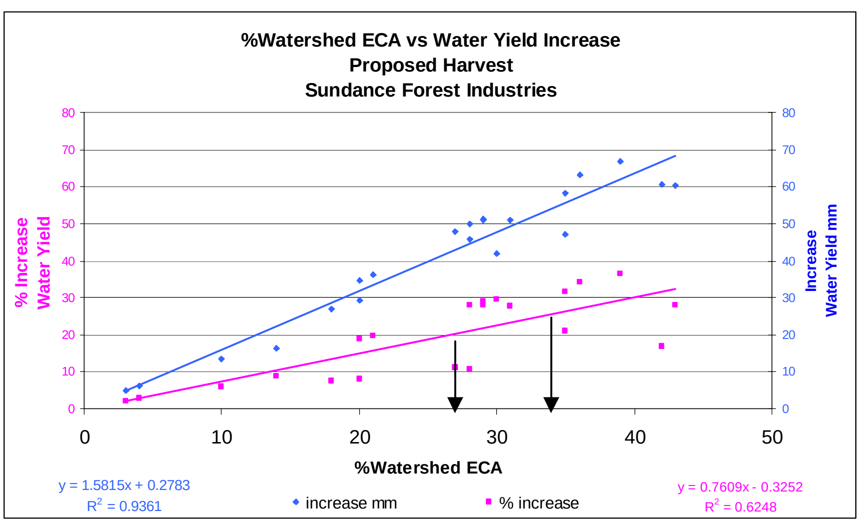
Hydrologic Recovery and %ECA

Hydrologic recovery is primarily controlled by the magnitude of water yield increases or the area and frequency of harvesting in a watershed (Figures 7, 8). Recovery will usually be shortest for a single harvest in a watershed followed by a period of no harvesting. Sustained or frequent harvesting will prolong the time for hydrologic recovery, with water yield elevated for long periods of time.

Hydrologic recovery in the watersheds averaged 14 years with minimum and maximum values of 0 and 41 years. These results appear to be reasonable but should also be used in relative terms (short, medium, long) and not as absolutes because of the uncertainty of methods and data used to estimate recovery.

Percent ECA may be a better metric than hydrologic recovery for planning purposes as it is based on sampled growth and yield data or simulated output supported by such data. However to be a useful tool ECA values should be based or referenced to "acceptable" levels of change for water yields and peak flows. Figure 9 illustrates how %ECA and water yield increases can be compared and used for planning purposes. For example, if water yield increases of 20-25% were considered "acceptable" %ECA levels of 27-37% could be used as targets/limits for watershed disturbance.

Figure 9 Regression of water yield increases on %Watershed ECA for harvest proposed by Sundance Forest Industries.

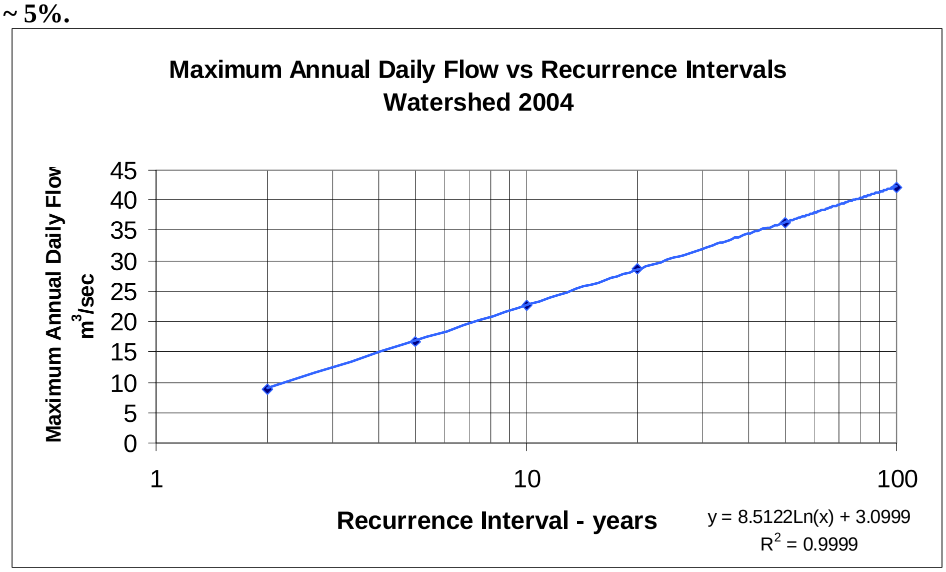


Peak Flows

Increases in peak flows following forest harvesting are also determined by the extent and frequency of forest harvesting and the climate and hydrology of a watershed. Increases in the magnitude and frequency of 2-5 year recurrence interval peaks are of concern. Recent literature suggests that sustained increases of ≥ 50% in bankfull discharge[3], which is defined equivalent to the 1.5-2 year recurrence interval events, can contribute to permanent changes in stream channel morphology and aquatic habitat (Guillemette et al 2005; Verry 2004). Such changes are slow to develop and are usually expressed by widening, deepening and loss of sinuosity in stream channels along with attendant changes in aquatic habitat. Such changes are slow to develop, possibly taking 60-100 years to become noticeable.

The largest increase in simulated maximum annual daily flow in these simulations was 11.1% (8.9 m^3/sec to 9.88 m^3/sec) for the 2 year event in watershed 2004. The change in frequency for the "new" 2-year event was 5% (Figure 10). What this means is that prior to harvesting a flow of 9.88 m^3/sec could be expected to occur 45 times per 100 years. After harvesting, as the new 2-year event, it can be expected to occur 50 times per 100 years. This assumes that the variability and distribution of the population has not changed.

Figure 10 Maximum annual daily flow versus recurrence intervals Watershed 2004. 2-year event = 8.9 m^3/sec was increased by 11.1% to 9.88 m^3/sec. Recurrence interval prior of harvesting for a flow of 9.8 m^3/sec was 2.22 years, which means such a flow can be expected ~ 45 time/100 years. Following harvesting as the new 2-year event it can be expected to occur ~ 50 times/100 years. Its frequency of occurrence has increased by 0.50 – 0.45 = 0.05 ~ 5%.



The increases in magnitude shown for these simulations fall short of the 50% threshold level suggested in the literature (Guillemette et al 2005; Verry 2004). Based on experience elsewhere in the province, the larger increases will likely exceed the range of natural variability of peak flows for the region. An analysis of annual maximum daily flows in the Grande Prairie region indicated increases ≥ 12%-23% could exceed the "natural variability" of 2-4 year events (Watertight Solutions 2005).

[3] Bankfull discharge is the flow that completely fills a stream channel to the tops of its banks. The recurrence interval of bankfull discharge is assumed to be 1.5-2 years.

Summary and Conclusions

Hydrologic assessment of a proposed harvest plan by Sundance Forest Industries indicated the following:

Water Yield

- Simulated increases in annual water yield of 11.1%- 17.8% were significantly greater than representative flows on 10 of 24 watersheds. Most of these watersheds were located in the Low Elevation South Block of the FMA where water yield was lowest.
- These increases may exceed the upper limits of natural variability for water yield for the region based on experience elsewhere. An analysis of flow variability for the region is be needed to confirm this observation.
- These increases in water yield were attributed to high levels of harvesting which removed 30% - 47% of forest cover in the watersheds.
- On the remaining 14 watersheds water yields were not significantly different from representative flows with simulated increases ranging from <1% – 8.5%. Forest cover removal in these watersheds varied from <1% - 29%.
- Low responses in water yield in watersheds with harvest levels of 20%-29% were the result of a mix of historical harvesting prior to the proposed harvest for 2006-2026. Hydrologic recovery of historical blocks was advanced which moderated water yield increases.

Hydrologic Recovery

- Hydrologic recovery, the time for water yield increases to disappear or approach "pre-harvest levels", was assumed to occur when increases in water yield were ≤ 5%.
- Hydrologic recovery, averaged 14 years for all watersheds, with minimum and maximum values of 0- 41 years.
- Hydrologic recovery for watersheds with significant increases in water yield averaged 23 years, with minimum and maximum values of 16 and 41.
- Hydrologic recovery in watersheds with no significant increase in water yield averaged 4 years, with minimum and maximum values of 0 and 15.
- Watersheds with zero years for recovery occurred in watersheds with harvesting < 10% of watershed area, or where increases in water yield were ≤ 5%.

% Watershed ECA

- Watershed Equivalent Clearcut Area (ECA) was based on the return of increased water yield to "pre-harvest" conditions.
- %ECA for watersheds with significant increases in water yield averaged 23% with minimum and maximum values of 16% and 31%.
- %ECA for watersheds with no significant change in water yield averaged 11% with minimum and maximum values of 1% and 26%.

Peak Flows

- The largest simulated increases in maximum daily flows for the 2-year and 5-year events occurred in watersheds with high levels of harvesting (41%-47%).
- Increases for the 2-year and 5 year events varied from 8.3%-11.1% and 8.3% - 11.5% respectively.
- Increases in watersheds with less harvesting (1.3%-21.7%) for the 2-year and 5-year events ranged from <1% - 4.7%.
- Increases in peak flows showed a decreasing trend with an increase in recurrence intervals. The trend varied from strong for watersheds with high levels of harvesting to weak or nonexistent for watersheds with less harvesting.
- Increases for maximum flows were judged to fall within the range of natural variability

In conclusion the simulated increases in water yield and peak flows for the proposed harvesting by SDI are considered small to moderate in magnitude and duration. The high levels of harvesting in watersheds with maximum increases were moderated by the existence of historical harvesting. Based on current knowledge and experience no adverse impacts on water quality and aquatic habitat are expected, contingent upon the application of existing ground rules.

Increases in water yield and peak flows can be managed by rescheduling and reducing in the level of harvesting. This is not necessary for the current plan, but future harvesting should include considerations for hydrologic recovery to minimize the potential for cumulative impact on water yield and peak flows. Frequent entries into a watershed will sustain water yield increases and delay hydrologic recovery.

The current plan also includes strategies to minimize the impacts and spread of anticipated mountain pine infestations by harvesting a large component of mature pine stands in watersheds. The simulated changes in water yield and peaks for this plan are modest when compared to potential impacts if stands are attacked and destroyed by mountain pine beetles (Love 1955; Troendle and Nankervis 2000; Uunil et al 2006; Forest Practices Board 2007).

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Appendix 1 WRENSS

WRENSS

WRENSS (Water Resource Evaluation for Non-Point Silvicultural Sources) was developed by the U.S. Forest Service and the U. S. Environmental Protection Agency (EPA 1980). WRENSS was designed to be used as an operational tool for forest planning. It is relatively simple in concept and has modest data requirements. It is not a "high end" research model designed to simulate daily flows (i.e. routed runoff).

Swanson (1997) prepared a computer version of the procedure (WRENSS) for Alberta conditions and modified it by linking climate and flow databases to the program. WRENSS 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. Swanson also included methods for estimating changes in peak flows for 2, 10, 20, 50 and 100 year recurrence intervals. Estimates of watershed disturbance in terms of equivalent clear-cut area (ECA) (Ager A. A. and C. Clifton. 2005) based on recovery of basal area or water yield increases are included in WRENSS. Version 3.0 of WrnsEcaAb (Swanson 2000) was used in this assessment.

Estimated changes in annual water yield are based on seasonal water balance calculations of generated runoff (GRO), which is water that will eventually become runoff but has not reached the stream channel. Increases in water yield (ΔQ) are a change in evapotranspiration (ΔET) resulting from the removal of forest cover. Increases in water yield are obtained by taking the difference in GRO before and after harvesting.

Eq.1 $GRO = Input – Losses = P – ET \pm \Delta S$

P = precipitation

ET = evapotranspiration losses

ΔS = change in watershed storage.

Eq.2 $\Delta Q \sim \Delta ET = (P_{after\ harvest} – GRO_{after}) – (P_{before\ harvest} - GRO_{before})$, where precipitation before and after harvest is assumed to be the same.

GRO is strongly affected by watershed storage and in the short term may not equal actual flow (Q_A). Over the long-term however GRO = Q_A as average annual change in watershed storage approaches zero ($\Delta S \sim 0$). Long term precipitation and streamflow data are essential for the application of WRENSS.

Increases in water yield in WRENSS are expressed as area-millimeters (area-mm) and percentages. Area – mm is the volume of increased flow (or reduced ET) expressed as a uniform depth over a watershed. Increases in water yield are expressed as percents of the mean annual water yield (base yield in WRENSS) for the watershed being analyzed or a nearby representative watershed, which is of similar size, forest cover and climate (i.e. precipitation).

Percent increases should be considered as relative changes (e.g. small, medium, and large). Few if any models are capable of providing exact, absolute outputs. Furthermore, annual water yields are highly variable among watersheds and hydrologic regions. For example, annual yields in some years in boreal forest watersheds can be 0-100 mm, while in the Rocky Mountains water yields can be 400-800 mm. An increase of 40 mm in a Rocky Mountain watershed would be a small percentage compared to a similar increase in a boreal forest watershed. Percentages must be carefully interpreted.

Water responses provided by WRENSS are cumulative in that they can show both water yield increases and the rate of hydrologic recovery, which is the time for evapotranspiration and water flows to return to pre-harvest levels. Hydrologic recovery in WRENSS is estimated in two ways. The first is the traditional approach based on the recovery of basal area to pre-harvest conditions with the establishment of forest regeneration. Recovery occurs when current basal area equals maximum basal area for a given site. The second is based on the recovery of simulated water yield increases to pre-harvest or undisturbed conditions ($\Delta Q \sim 0$). Hydrologic recovery based on water yield was defined as the time required for the maximum increases in annual flow (or peak flows) to decrease to levels equal to or less than 1%. The time required for hydrologic recovery is a function of the amount and frequency of harvesting in a watershed, and the occurrence and rate of growth of forest regeneration.

Equivalent Area Clearcut (ECA) is an 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 establishment and growth of regeneration. 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 estimates in WRENSS are provided in terms of basal area recovery (Eq.3) and recovery of water yield (Eq.4). ECA is expressed in hectares of harvested area and as a percent of the harvested area. %ECA in this assessment was reported as a percent of watershed area, which is hydrologically more informative.

Eq.3 $$ECA_{BA} = \frac{BA_{current}}{Max\ BA} \times Harvest\ Area$$

Max BA = maximum basal area possible for a given site

$BA_{current}$= basal area for year –n of a specified time series

Eq.4 $$ECA_{Q} = \frac{\Delta Yield_{current}}{\Delta Yield_{\max Q}} \times Harvested\quad Area$$

$\Delta Yield_{maxQ}$ = maximum water yield increases in a given time series

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

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). Hydrologic recovery based on maximum water yield increase can be shorter by half the number of years obtained with basal area. ECA_Q is considered a more direct and realistic estimate of hydrologic recovery, and was used in this report.

WRENSS also estimates increases in maximum daily and instantaneous flows due to harvesting for return periods of 2, 5, 10, 20, 50 and 100-year events. WRENSS uses watershed area to estimate peak flows ($Q_{peak\text{-}area}$) for all return periods in the unharvested condition. The difference between the mean March to September streamflow in the unharvested and harvested condition is used to estimate the change in peak flow ($Q_{peak\ mean\ flow}$) caused by harvesting for each return period. The difference in $Q_{peak\ mean\ flow}$ between the harvested and unharvested conditions is added to $Q_{peak\text{-}area}$ to obtain the maximum flow for a given return period.

In WRENSS the maximum change in peak flow attributable to the effects of forest harvesting is constrained by the maximum reduction in daily evapotranspiration rate (i.e. the volume of extra water made available by harvesting), estimated by WRENSS for a completely undisturbed watershed.
In some situations (e.g. high precipitation) the change in peak flow can exceed the daily maximum evapotranspiration rate. When this occurs it is area weighted with respect to the amount of disturbance in the watershed. For example, if the maximum evapotranspiration was 5.0 mm/day and 47% of the watershed was undisturbed, it would be reduced to 2.65 mm/day (e.g. 5.0 mm/day*(1-0.47) = 2.65 mm/day or 4.13 m^3/sec). The adjusted value would then be added to the estimated peak flow (i.e. $Q_{peak\text{-}area}$).

This constraint is built into the WRENSS program. The assumption inherent in this constraint is that the increase in peak flow generated by harvesting “alone” is controlled by the maximum reduction in daily potential evapotranspiration. Under these conditions the increase in maximum daily flows attributable to harvesting can be similar for a range of return periods, and persist for sustained periods until evapotranspiration recovers with regrowth of harvested areas. When this occurs, a plot of peak flow increases will appear to be flat or truncated.

WRENSS simulations can be based on average, maximum or minimum precipitation conditions. For average conditions, estimated changes in flow are what can be expected in an “average” year. WRENSS cannot provide an estimate of the effects of climatic variation on water yield and peak flows. Simulations for maximum or minimum conditions can provide an estimate of the effects of climatic extremes. In years of high precipitation flow changes would be larger and in years of low precipitation smaller. Precipitation inputs are constant for the length of a simulation and conditions being simulated.

WRENSS does not estimate flow for ungauged basins and does not produce routed stream flow (i.e. it does not indicate how much water will flow on a given day). It also does not carry over surpluses or deficits from one year to the next. The reliability of results from WRENSS can only be as good as the precipitation and flow data used. If precipitation data is representative, accurate and of sufficient duration, then WRENSS will provide an estimate of average annual water yield that is generally within 10% of measured water yield (Swanson 2000). However, it is important to remember that most precipitation data is usually under estimated.

Appendix 2 Data requirements for WRENSS Simulations

To run a WRENSS simulation two files are required. The first is a “control” file containing information describing a watershed and the streamflow data and precipitation data to be used in the simulation (Table 1). The second is a unit file containing information for each harvest clock to be harvested in the watershed (Table 2)

Table 1 – Watershed data for WRENSS simulations (Control File)

Field name	Type	Size	Dec	Description
SCENARIO	C	100		Joint identifier to link this table with the harvested blocks in tbl_Units. This name must be the same as the one used for all of the harvested blocks in any given scenario, usually a watershed.
AREA_ CUT	N	20	5	Total area of the scenario or watershed in km^2.
WS_STATION	C	100		The name or identifier of a stream gauging station in the Foothills Model Forest Area. Can be supplied at run time.
WS_YIELD	N	20	5	Supplied by link to WS_STATION at run time.
WS_STAT	C	6		Unless specified as Max or Min, defaults to Avg at run time.
WS_PERIOD	C	9		Supplied by link to WS_STATION at run time.
WS_REGION	C	100		The name of the type of analysis used in peak flow determinations, Instantaneous Max or Daily Max. Can be supplied at run time.
REGION	C	5		WRENSS regions CM or RM only. Can be supplied at run time.
WX_SOURCE	C	100		The name or identifier of a weather station in the Foothills Model Forest Area. Can be supplied at run time.
WX_STAT	C	6		Unless specified as Max or Min, defaults to Avg at run time.
WX_PERIOD	C	9		Supplied by link to WX_STATION at run time.
ANNUAL_PPT	N	20	5	Supplied by link to WX_STATION at run time.
BASE_YEAR	N	6	0	Default of 1-year prior to earliest year in the BLK_YRCUT field in tbl_Units is supplied by WrnsSdr at run time. Any year earlier than the first year cut can be supplied by the user.
START_YEAR	N	6	0	Default of 1-year prior to earliest year in the BLK_YRCUT field in tbl_Units is supplied by WrnsSdr at run time. Any year earlier than the first year cut can be supplied by the user.
END_YEAR	N	6	0	Default of 100-years after the START_YEAR is supplied by WrnsSdr at run time. This default of 100 years can be changed in the WrnsSdr Global Options form. Any year later than the first year cut can be supplied by the user.
RECORDNO	N	10	0	The user should not enter any information into this field. It is used internally within WrnsSdr.

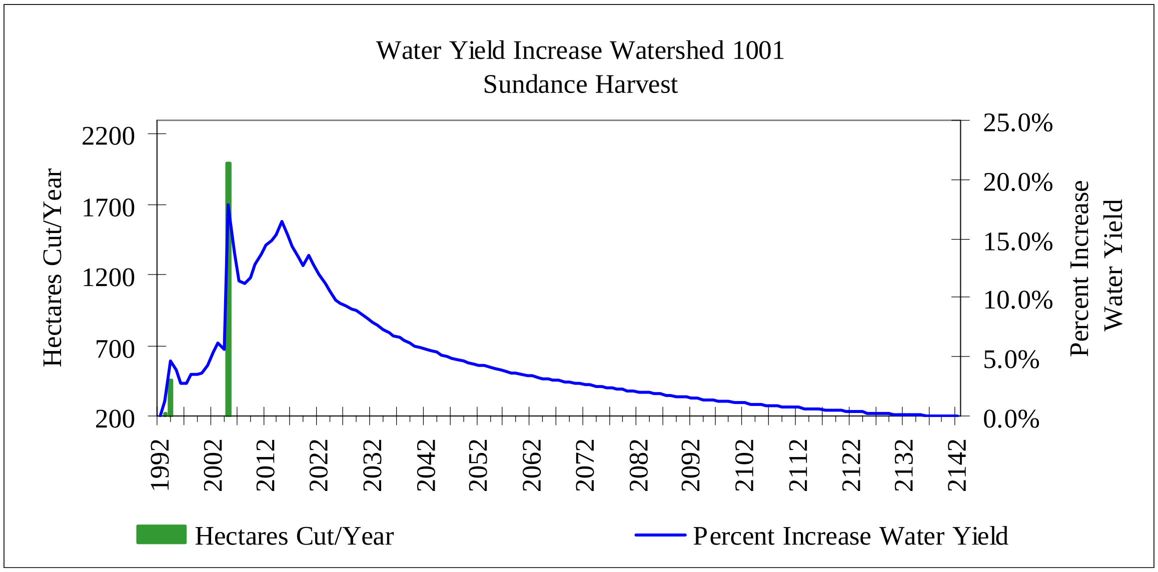
Table 2 – Harvest data for WRENSS simulations (Unit file)

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 WRNSSDR-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 function for regeneration in the unit. This is assigned during operation of WRNSSDR-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 function for regeneration in the unit. This is assigned during operation of WRNSSDR-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 WRNSSDR-MF runs.

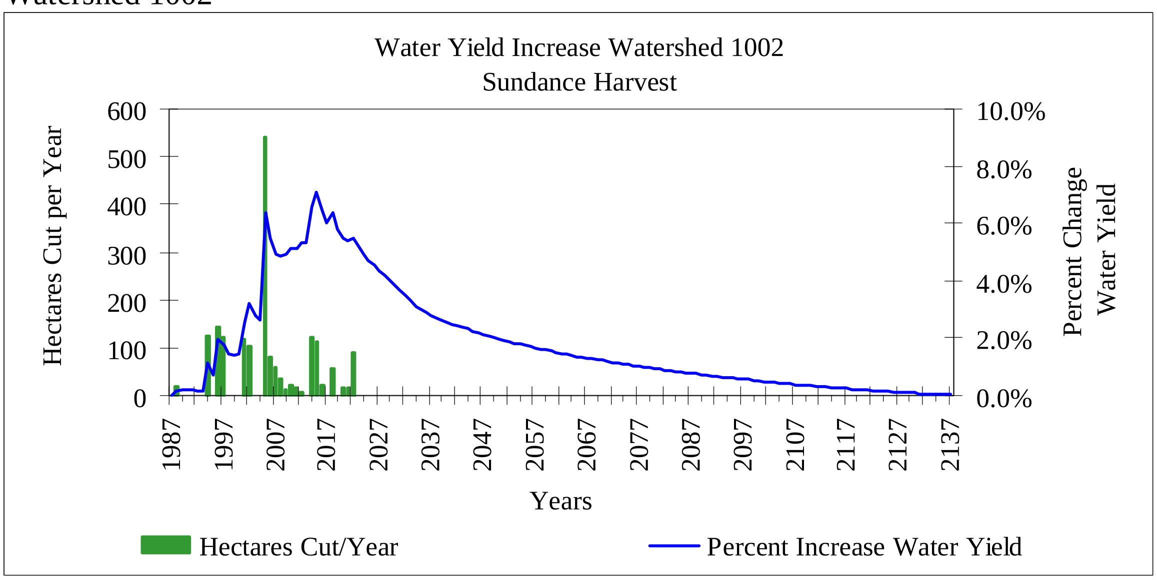
Appendix 3 WRENSS Water Yield Responses to Harvesting

The content of this appendix includes plots of annual water yield increases and hectares harvested per year for each watershed simulated.

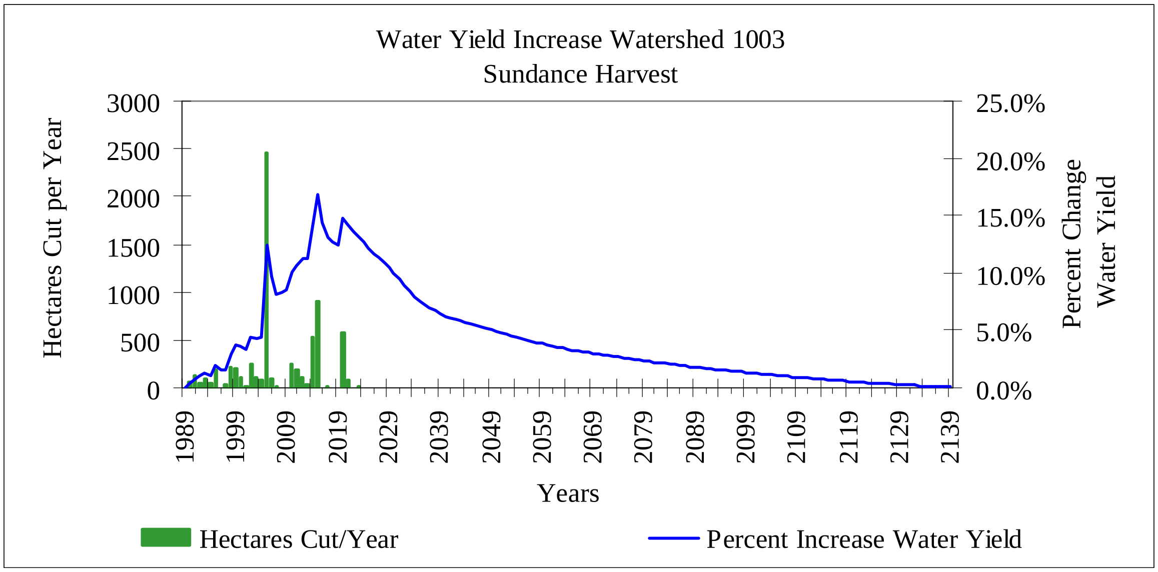
Watershed 1001



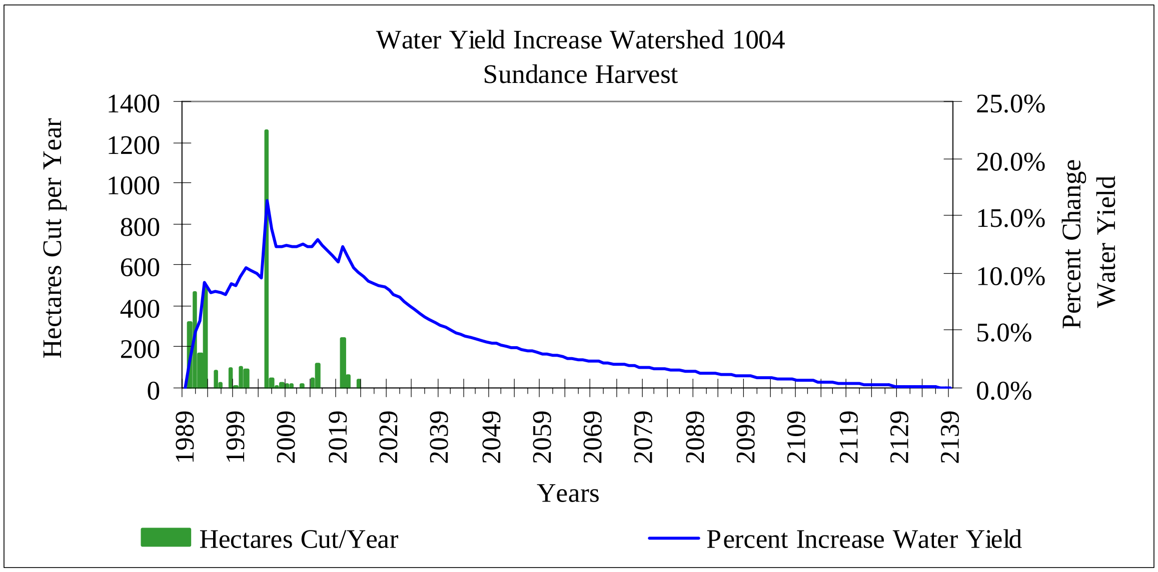
Watershed 1002



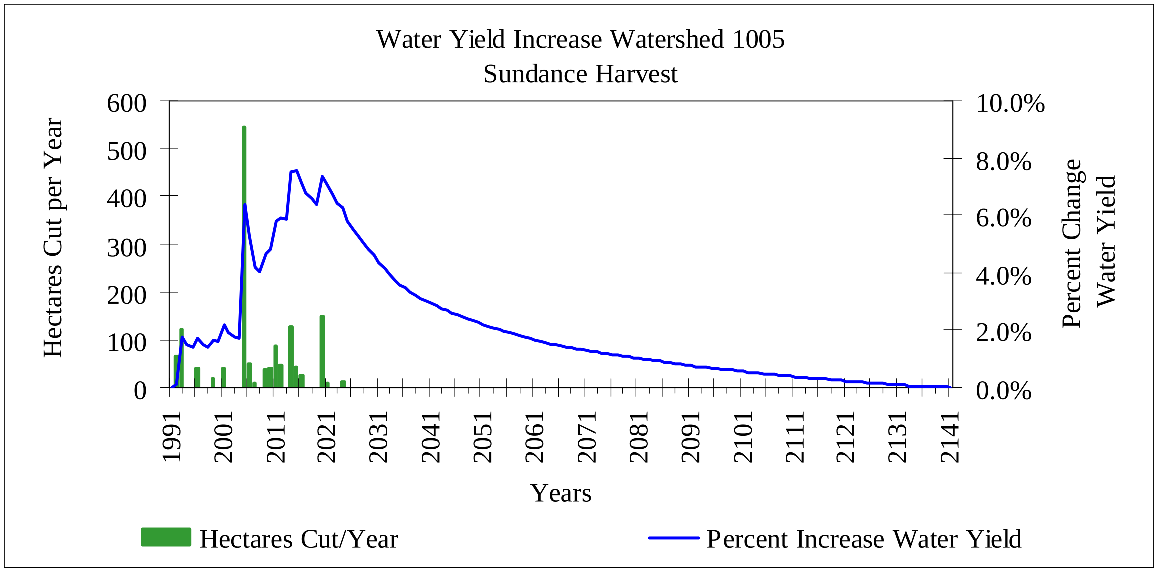
Watershed 1003



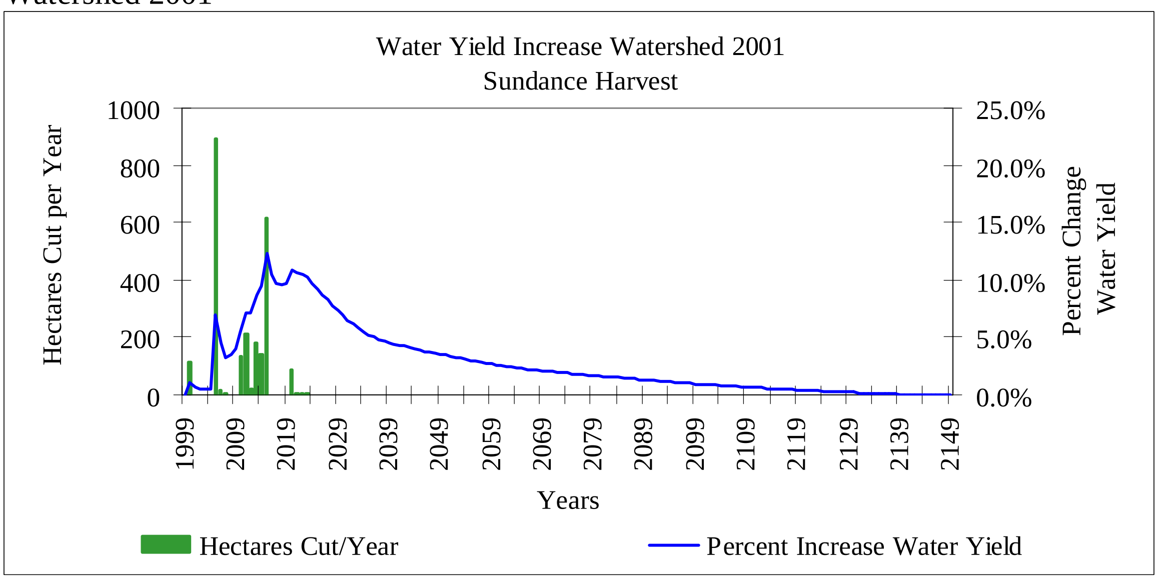
Watershed 1004



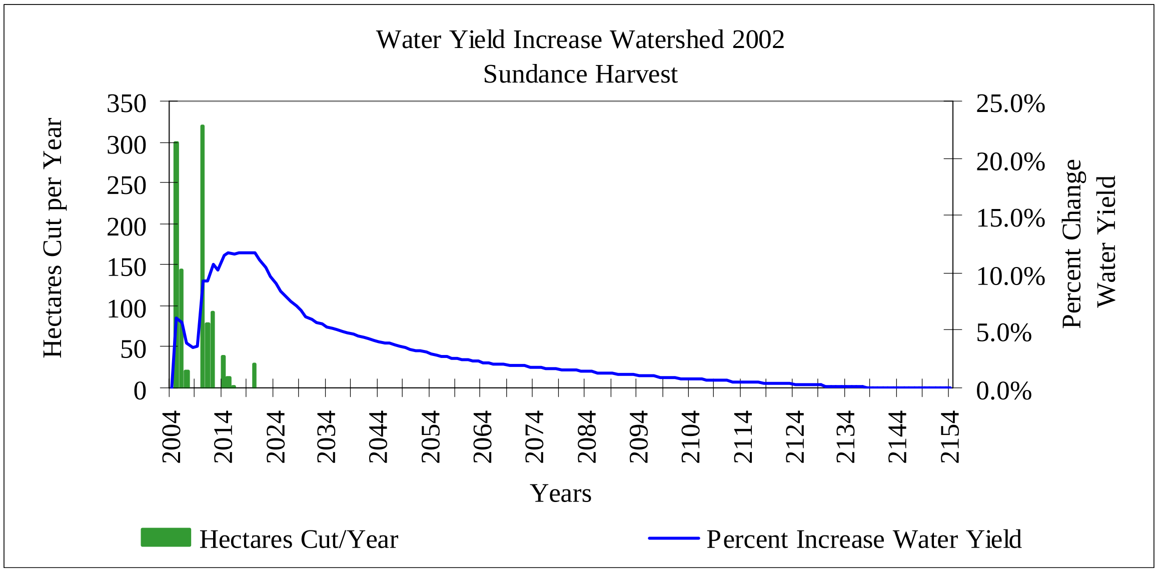
Watershed 1005



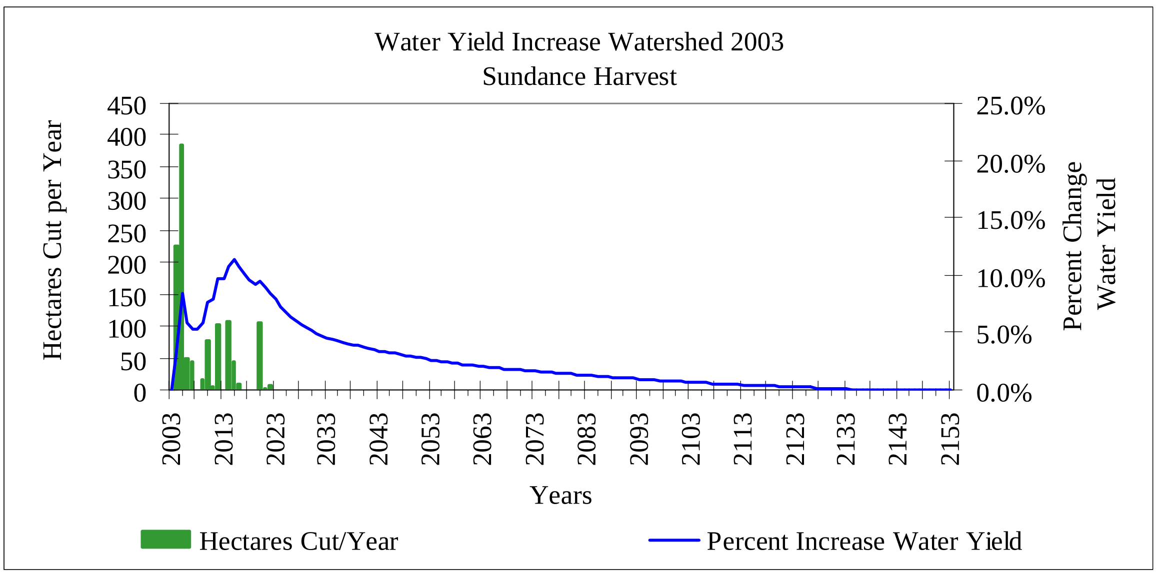
Watershed 2001



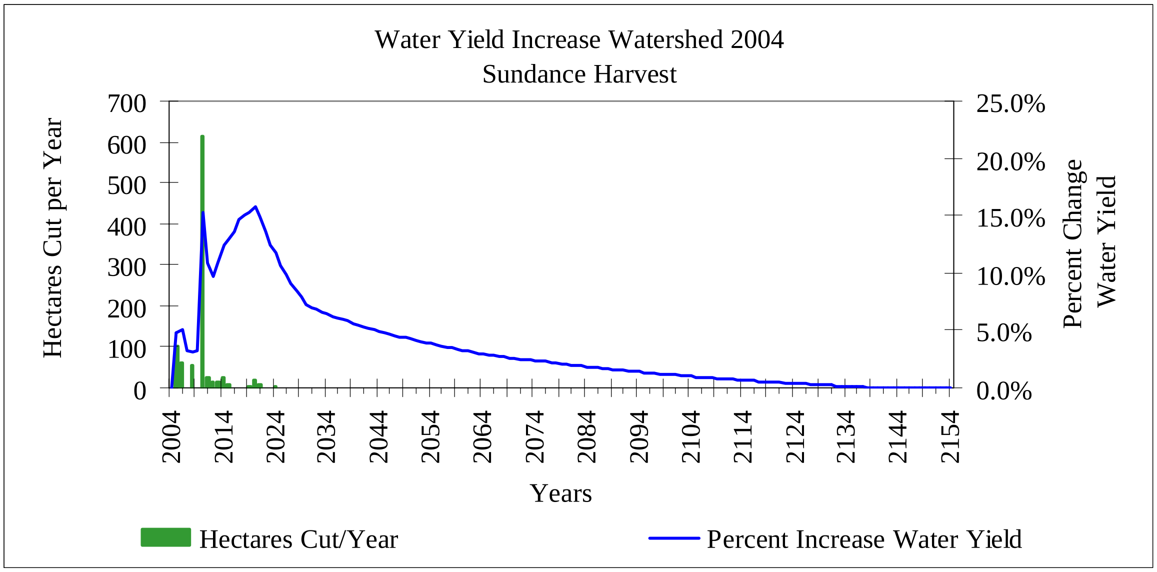
Watershed 2002



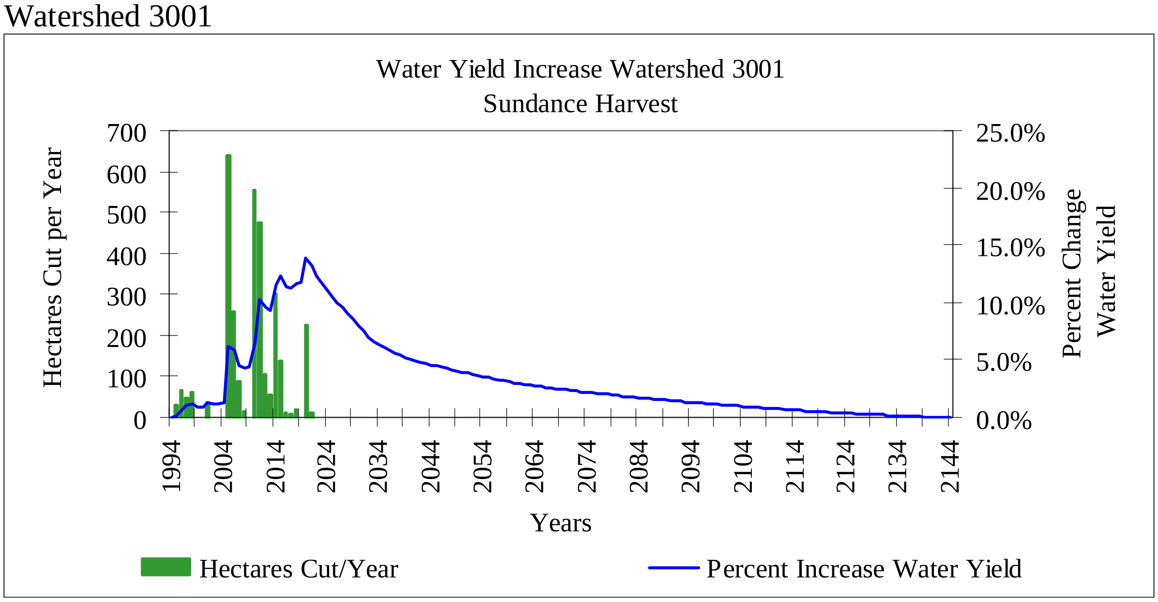
Watershed 2003



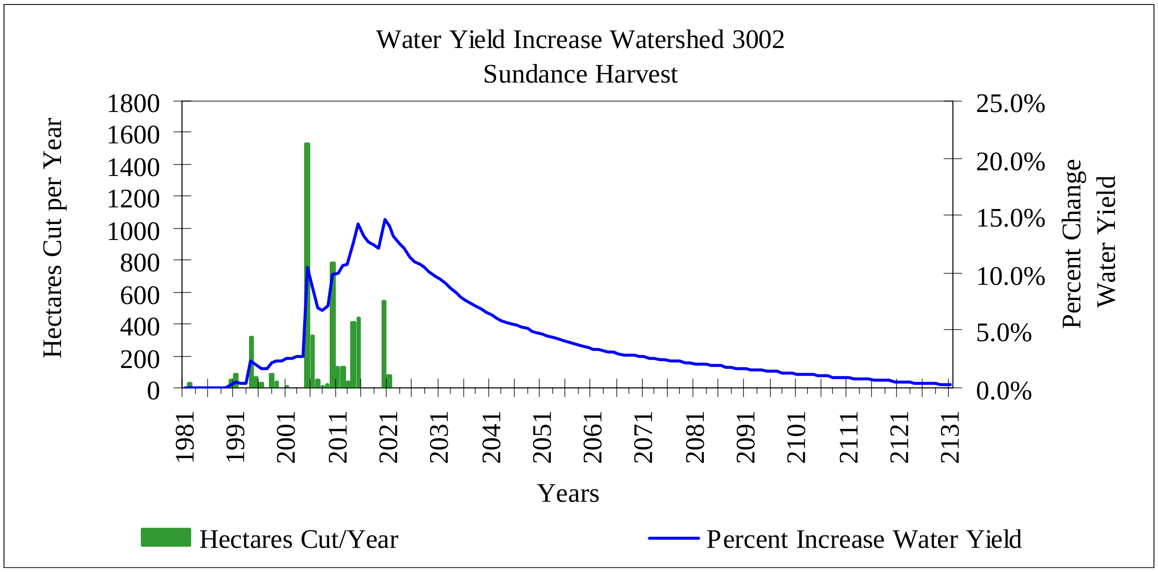
Watershed 2004



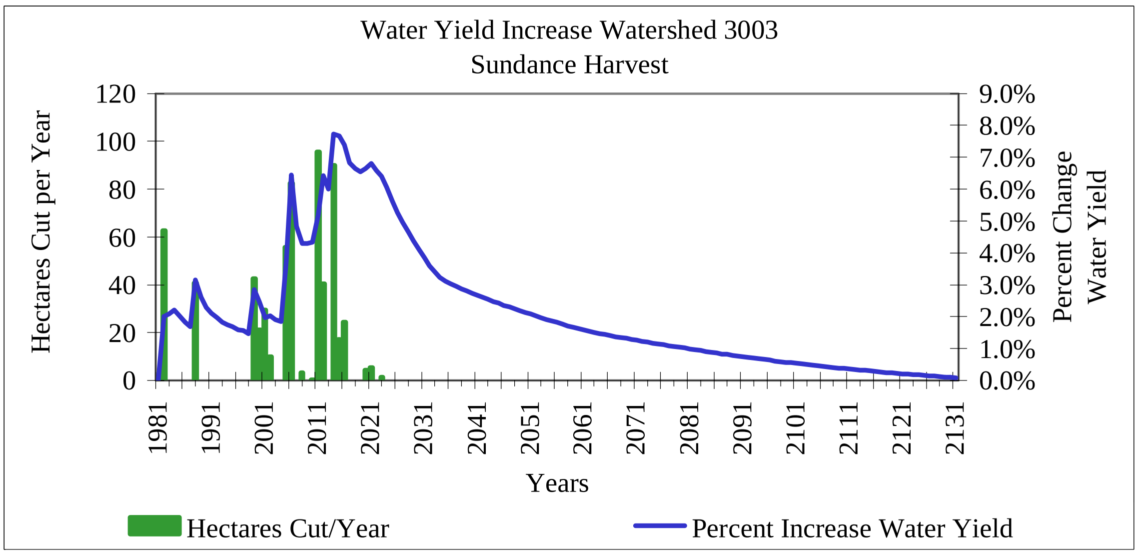
Watershed 3001



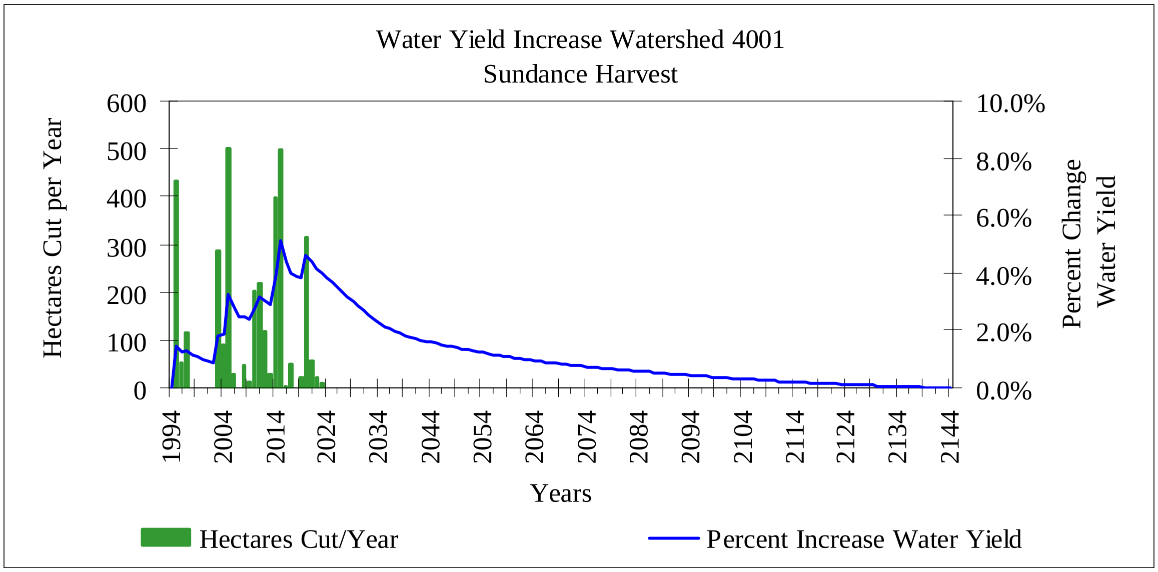
Watershed 3002



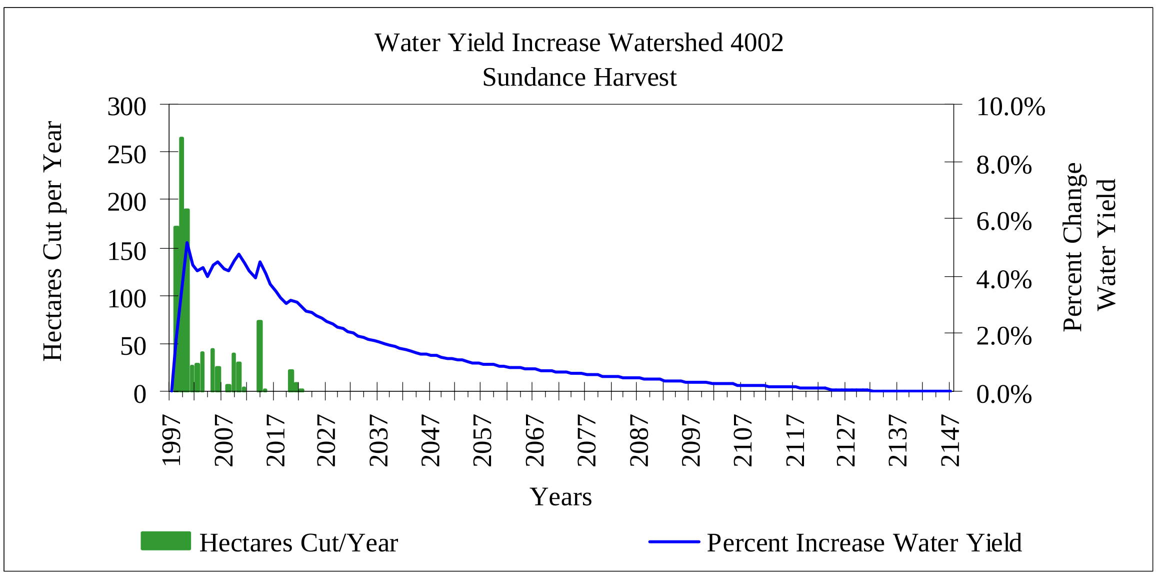
Watershed 3003



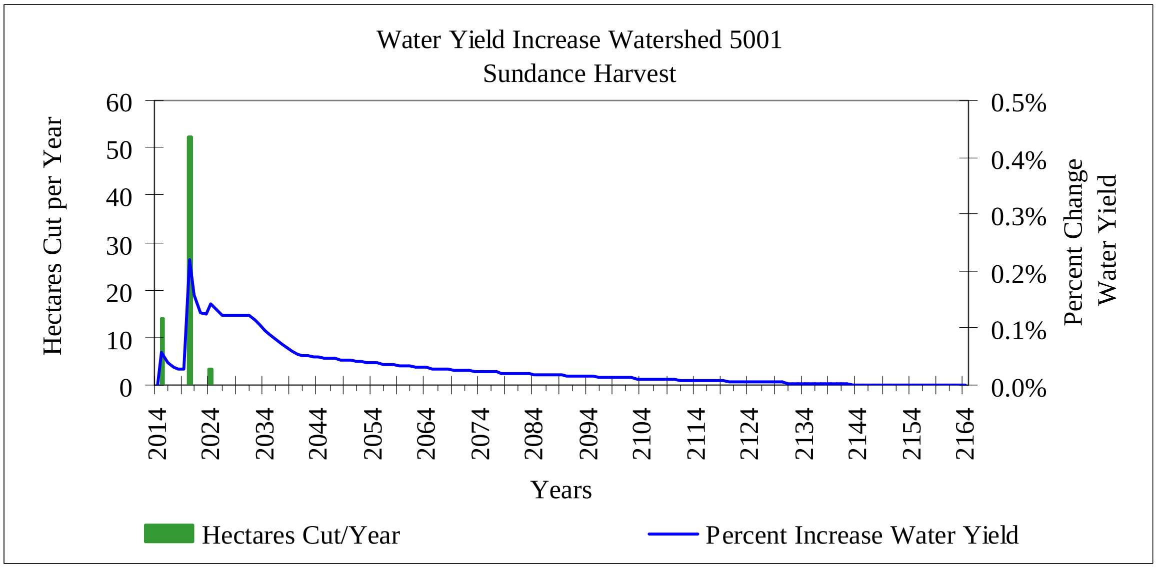
Watershed 4001



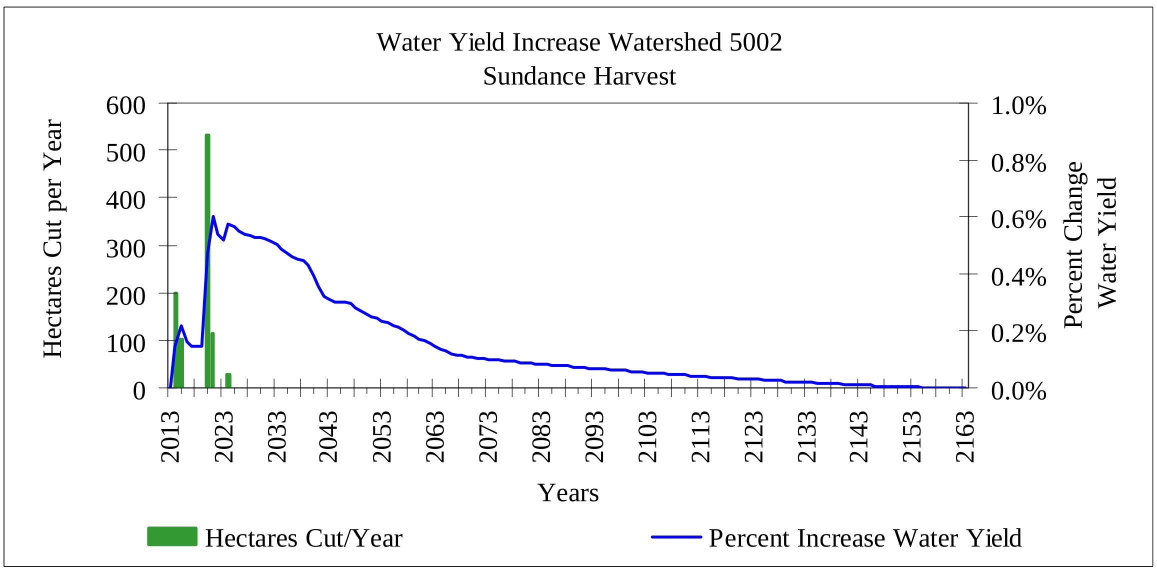
Watershed 4002



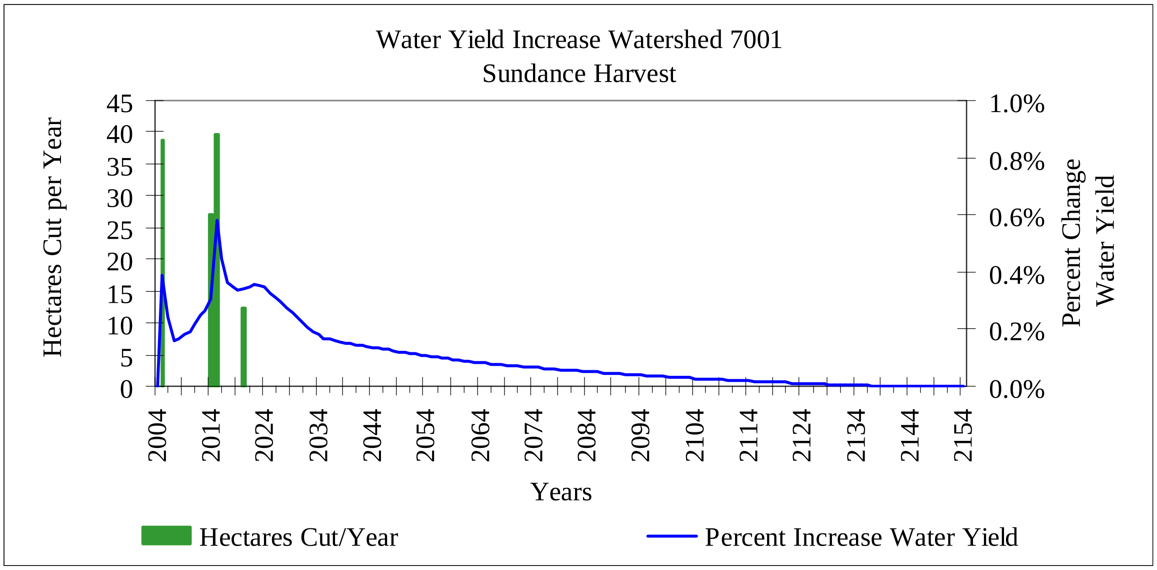
Watershed 5001



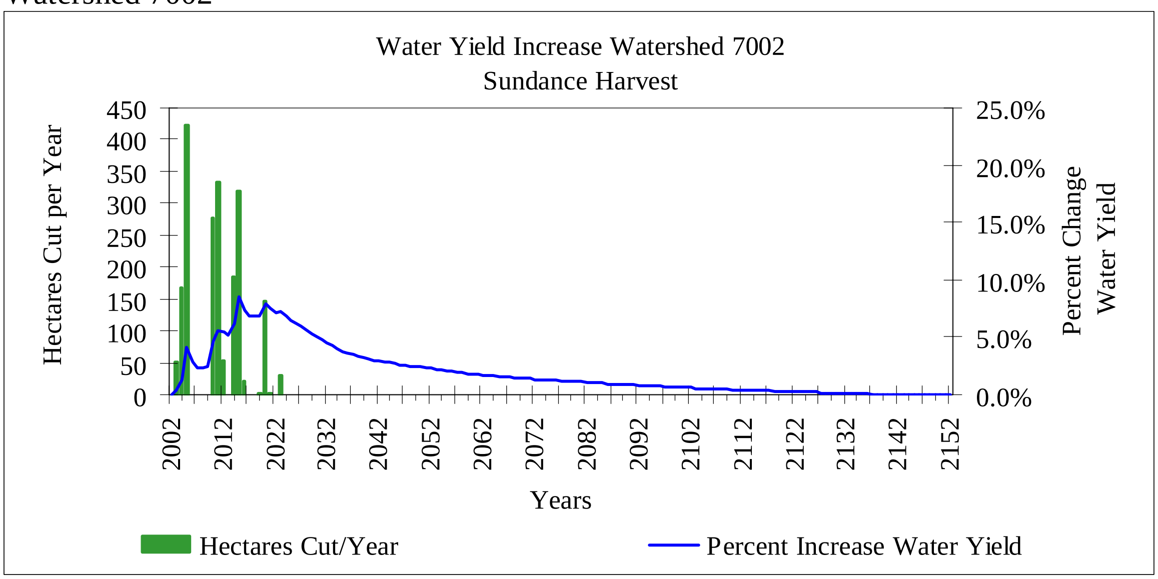
Watershed 5002



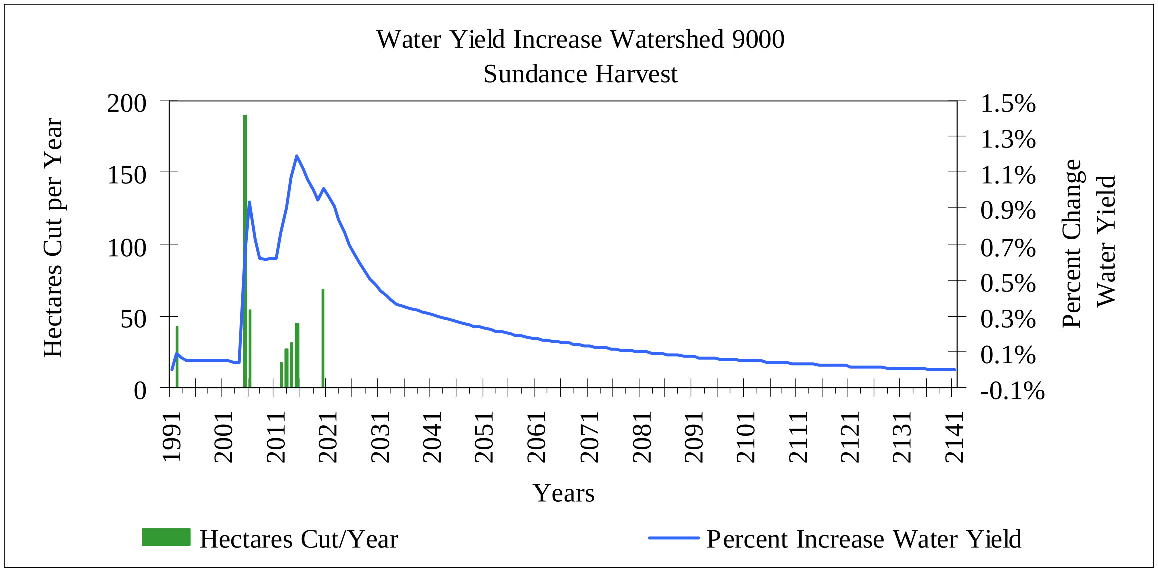
Watershed 7001



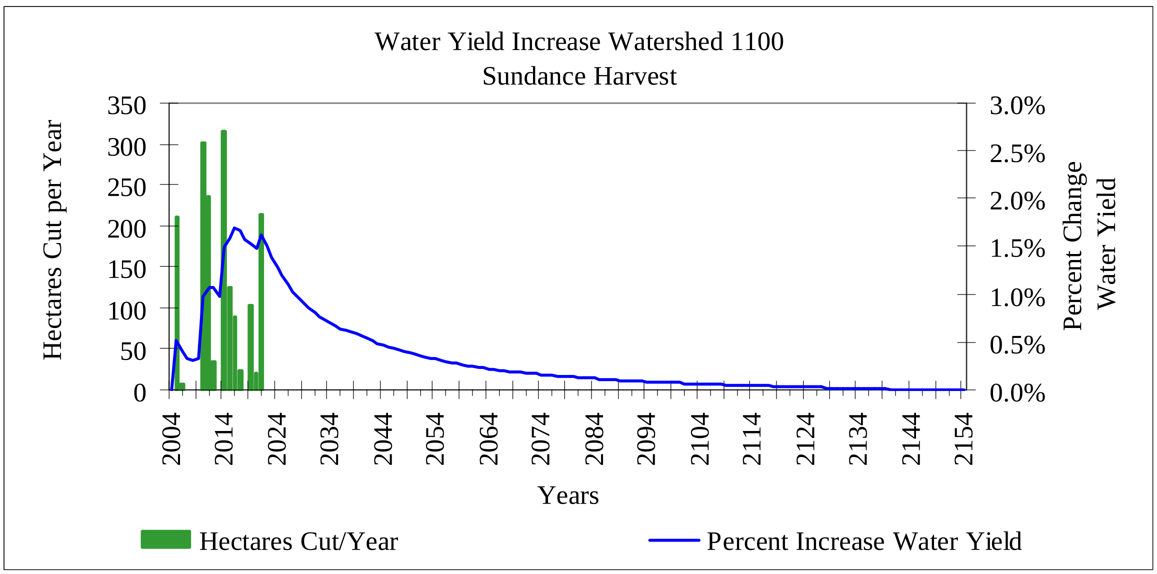
Watershed 7002



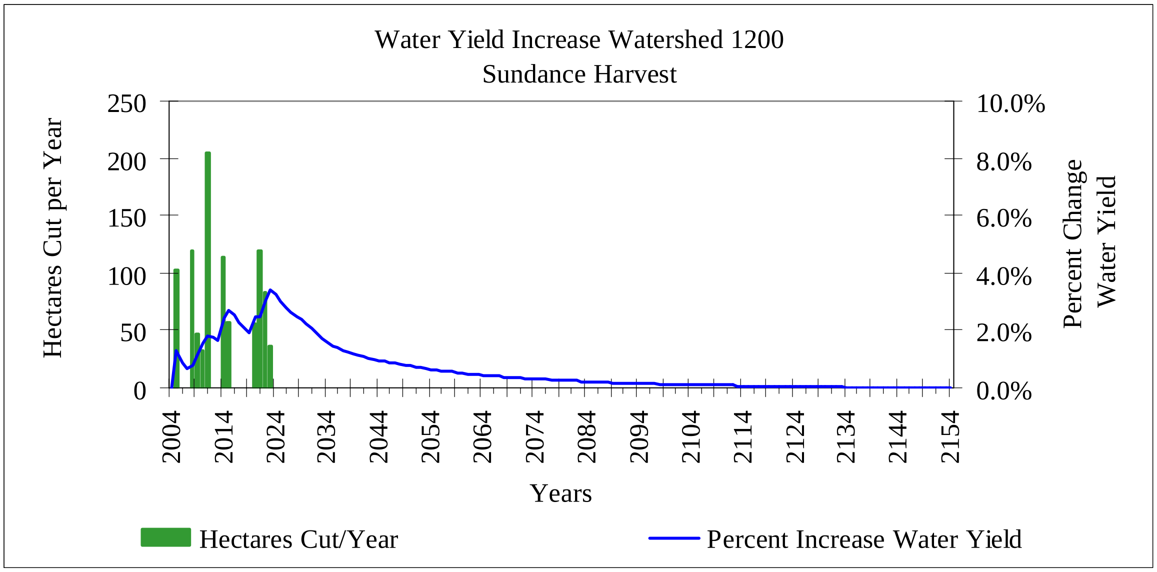
Watershed 9000



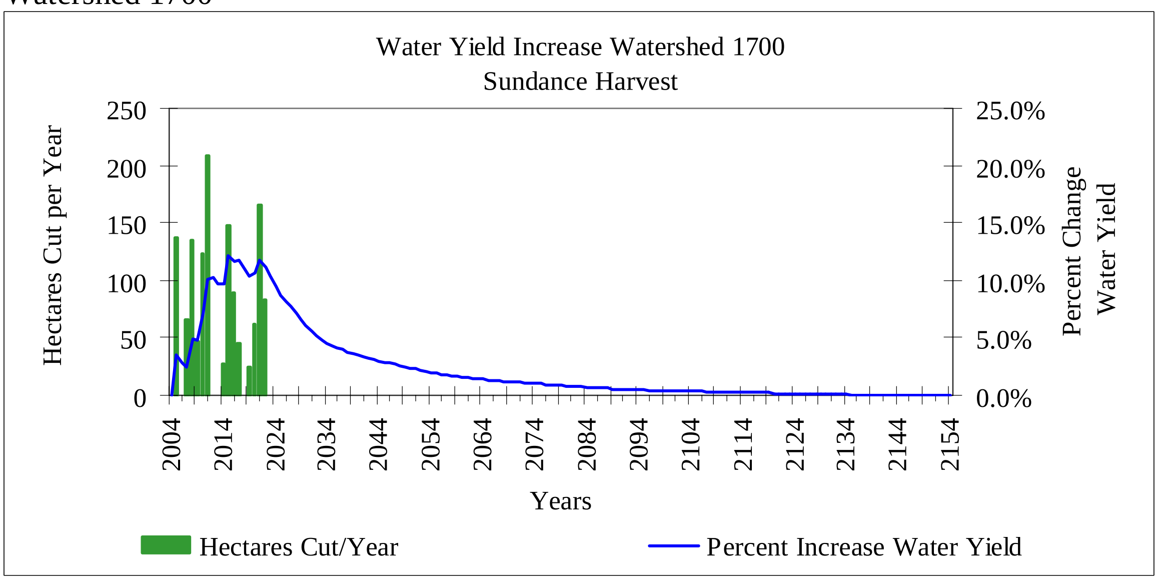
Watershed 1100



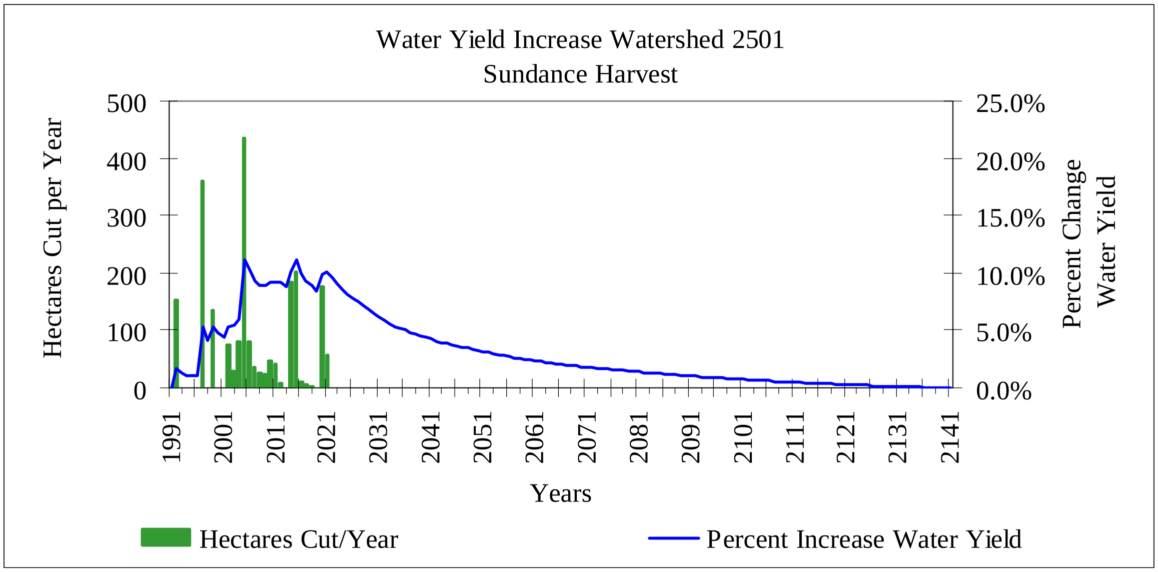
Watershed 1200



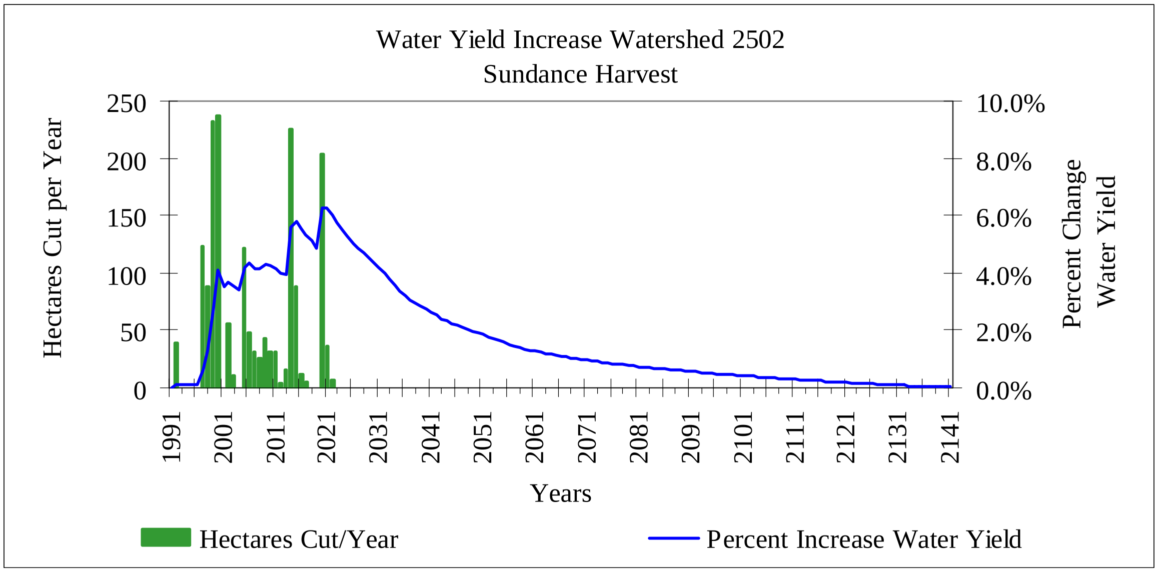
Watershed 1700



Watershed 2501



Watershed 2502



Appendix 4 WRENSS Inputs and Outputs

Contents of this appendix includes

1. Inputs for scenario
2. Maximum water yield increases
3. %ECA for disturbed areas based on water yield "recovery"[1]
4. %ECA for disturbed areas based on basal area "recovery"[1]
5. Predicted annual daily maximum flows with and without harvesting

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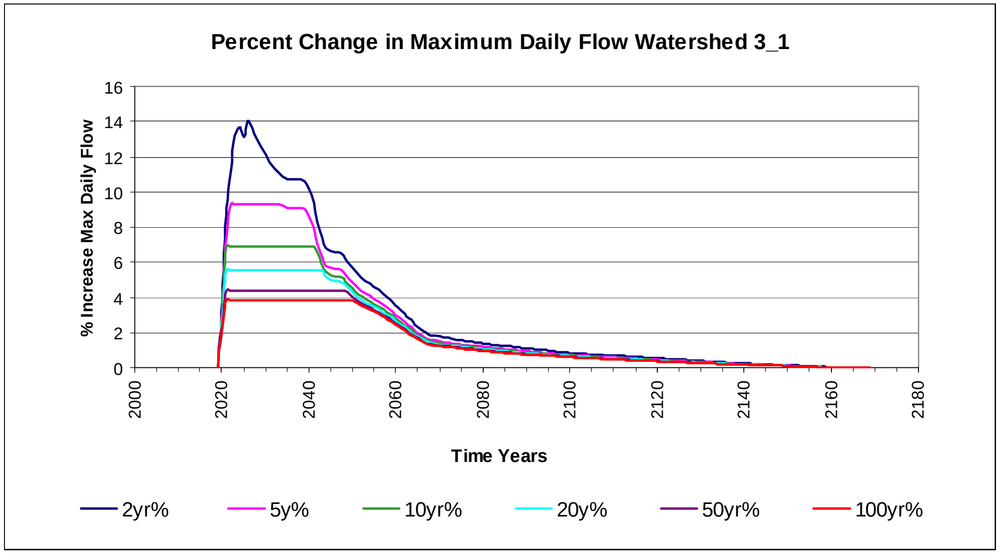
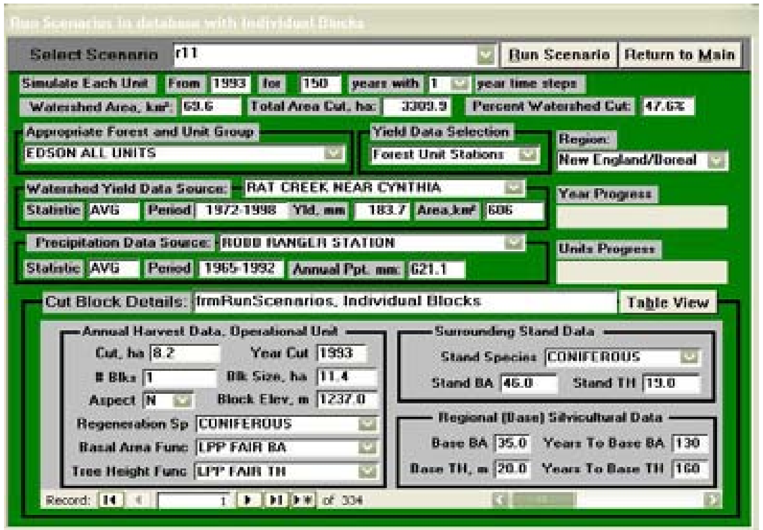
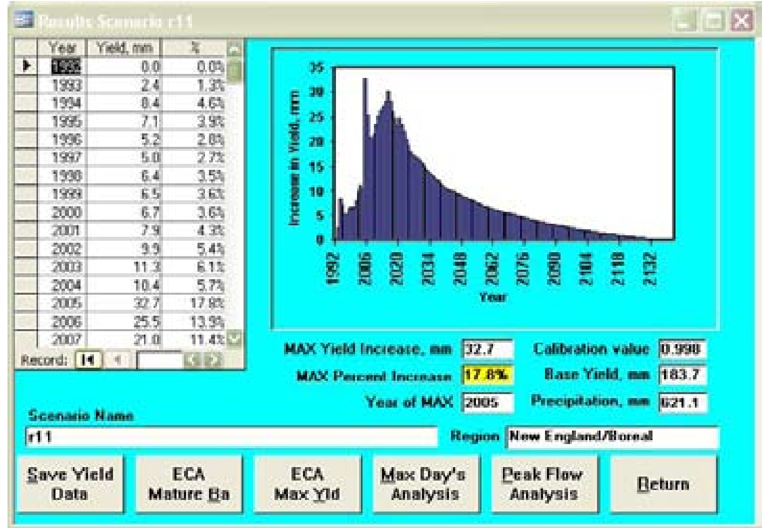
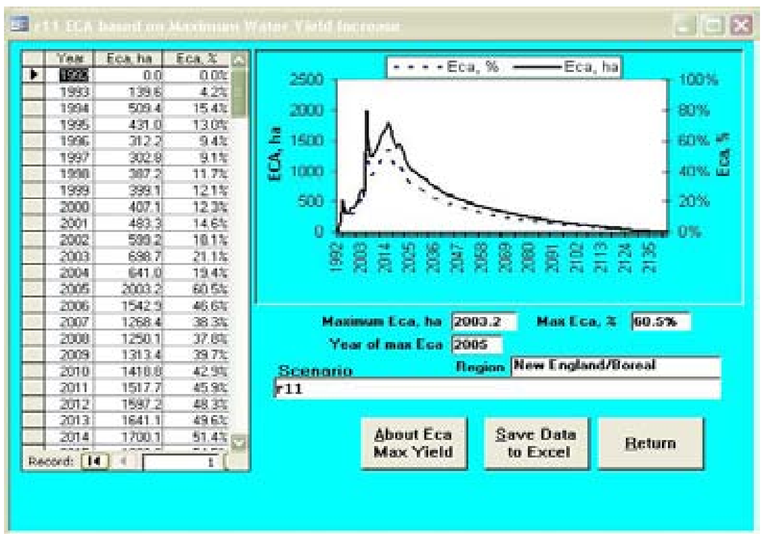
1. %Watershed ECA is obtained by dividing ECA in hectares by watershed area in hectares. Values for ECA in text are expressed on a watershed basis. The shape and timing for curves will be the same for disturbed area and watershed area, but magnitudes will be different (i.e. less for watershed because of its greater area).
2. Peak flow changes are estimates of the contribution of forest harvesting to peak flows, which cannot exceed the maximum daily evapotranspiration (ET) rate calculated by WRENSS. When this occurs (i.e. $Q_{peak} > ET_{daily\ max}$) peak flows are constrained by an area-weighted reduction in maximum daily ET for a watershed. In other words, the extra water generated by harvesting that contributes to increased peak flows becomes constant for a given period of time until evapotranspiration rates have recovered where a reduction in flows can occur. The figure below illustrates how this constraint the magnitude of changes in peak flows. Peak flow changes on watersheds can remain elevated (i.e. constrained) for periods of 5-30 years depending on the extent of harvesting

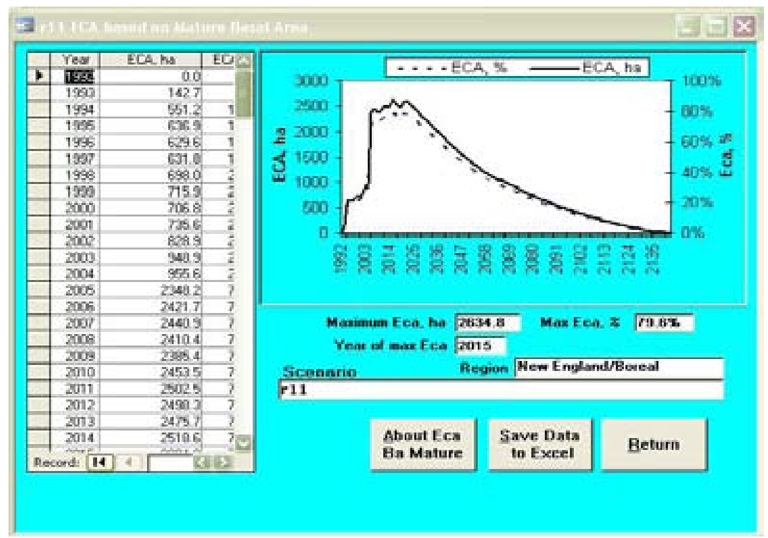


Watershed 1001









Watershed 1001..continued

Maximum day's flow results with scenario r11

Predicted Annual Day's Maximum Flow and Yield

Recurrence Interval	Without Harvest Flow m³/s	Without Harvest Yield mm	With Harvest Flow m³/s	With Harvest Yield mm	Change m³/s	Percent Increase
2 Years	6.0	7.5	6.3	7.8	0.24	4.0%
5 Years	11.0	13.6	11.4	14.2	0.44	4.0%
10 Years	14.6	18.2	15.2	18.9	0.59	4.0%
20 Years	18.2	22.6	18.9	23.5	0.73	4.0%
50 Years	22.7	28.2	23.7	29.4	0.91	4.0%
100 Years	26.2	32.5	27.2	33.8	1.04	4.0%

Area Harvested, km²: 33.1 47.6%

Watershed Area, km²: 69.6

2004 Displayed Above

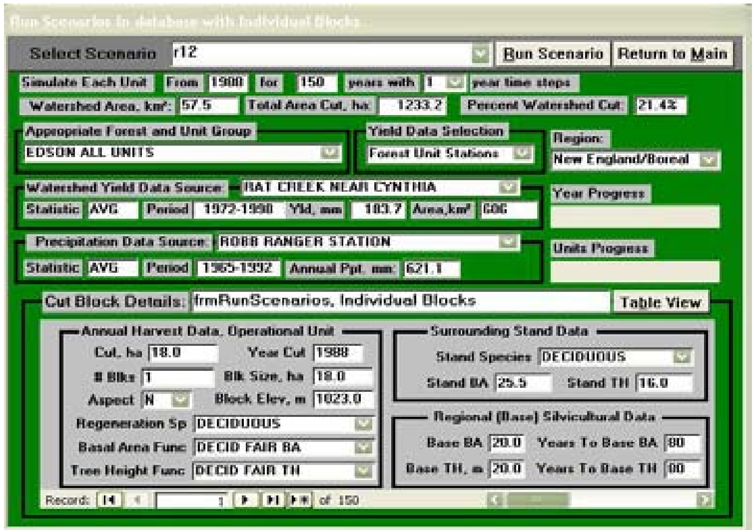
Peak Flow Function: EDSON ALL UNITS

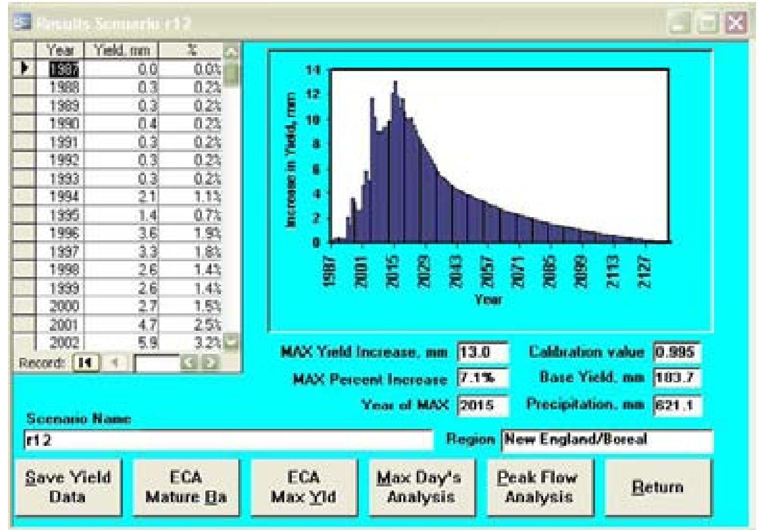
Time Course of Maximum Day's Flow

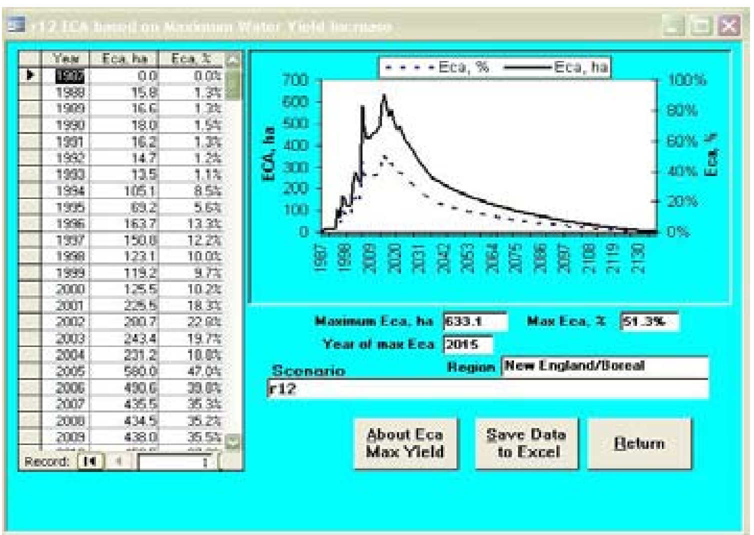
Peak Year 2004

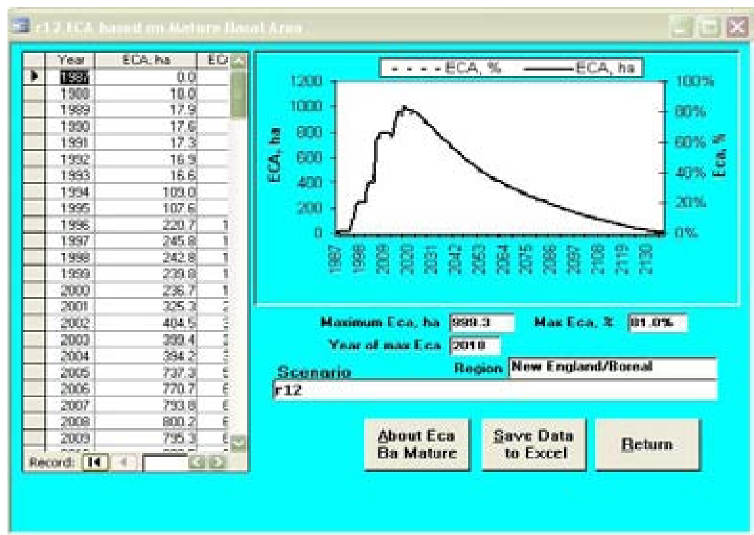
About Peak Flows | Save Data To Excel | Return to Results

Watershed 1002

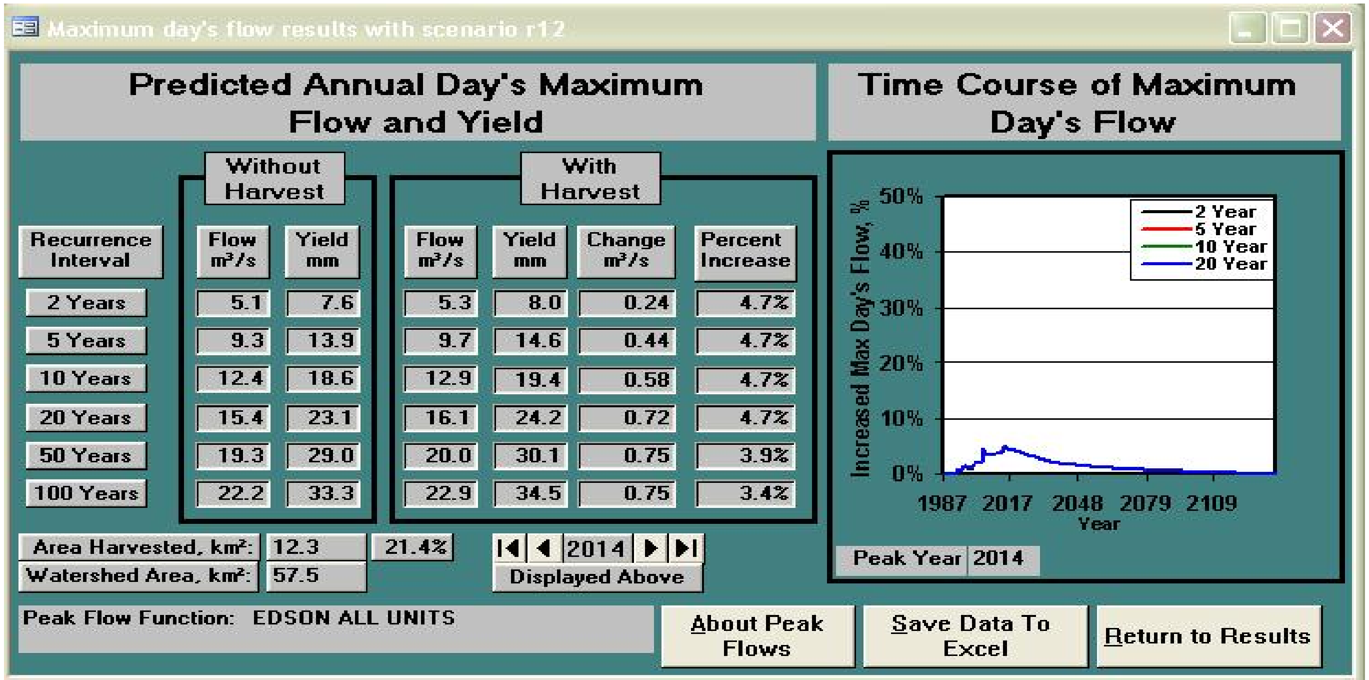








Watershed 1002…continued



Maximum day's flow results with scenario r12

Predicted Annual Day's Maximum Flow and Yield

Recurrence Interval	Without Harvest Flow m³/s	Without Harvest Yield mm	With Harvest Flow m³/s	With Harvest Yield mm	Change m³/s	Percent Increase
2 Years	5.1	7.6	5.3	8.0	0.24	4.7%
5 Years	9.3	13.9	9.7	14.6	0.44	4.7%
10 Years	12.4	18.6	12.9	19.4	0.58	4.7%
20 Years	15.4	23.1	16.1	24.2	0.72	4.7%
50 Years	19.3	29.0	20.0	30.1	0.75	3.9%
100 Years	22.2	33.3	22.9	34.5	0.75	3.4%

Area Harvested, km²: 12.3 21.4%

Watershed Area, km²: 57.5

2014 Displayed Above

Peak Flow Function: EDSON ALL UNITS

Time Course of Maximum Day's Flow

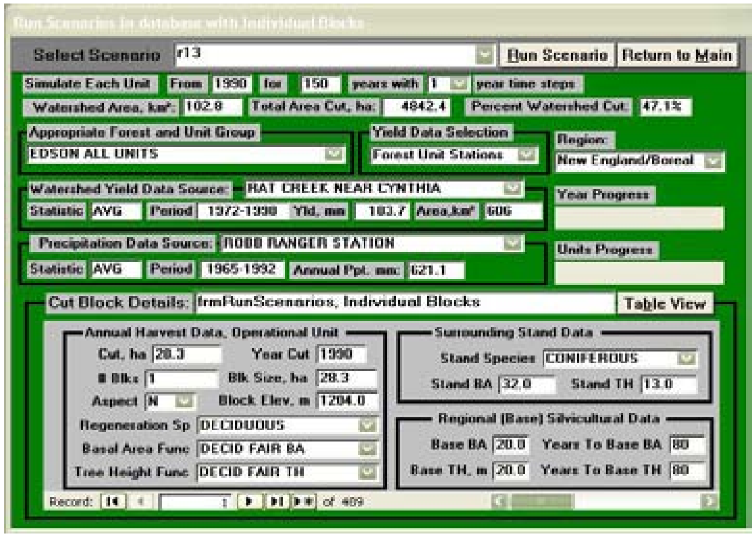
Peak Year 2014

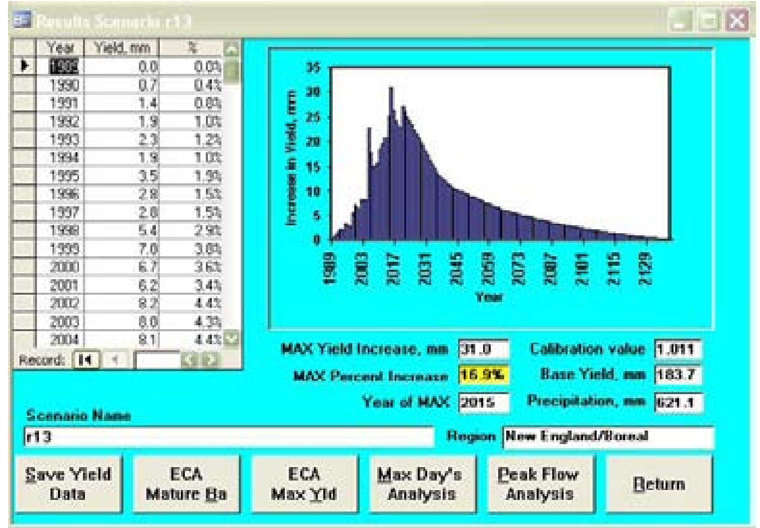
About Peak Flows

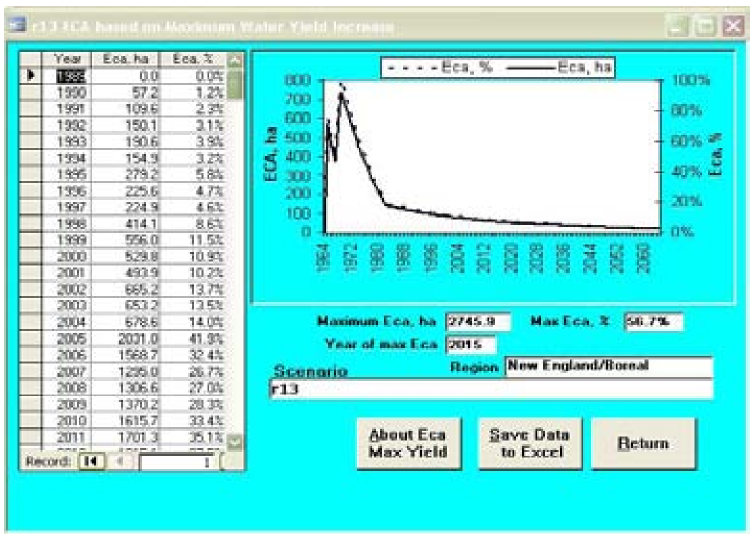
Save Data To Excel

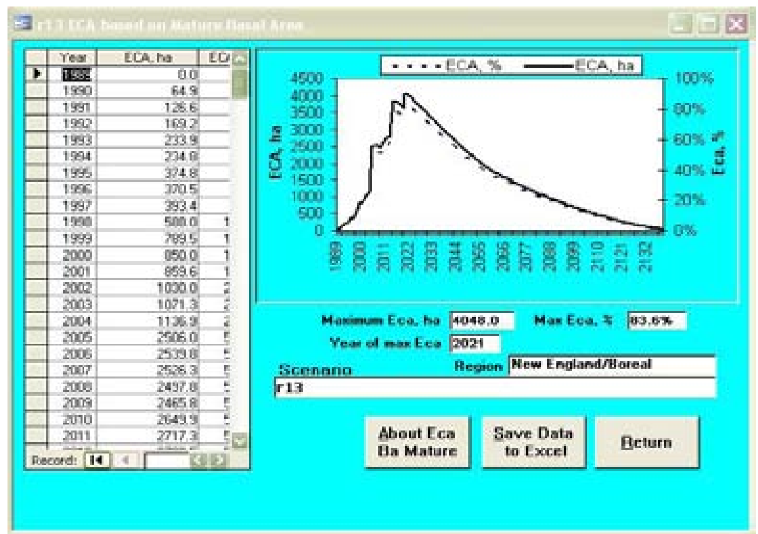
Return to Results

Watershed 1003

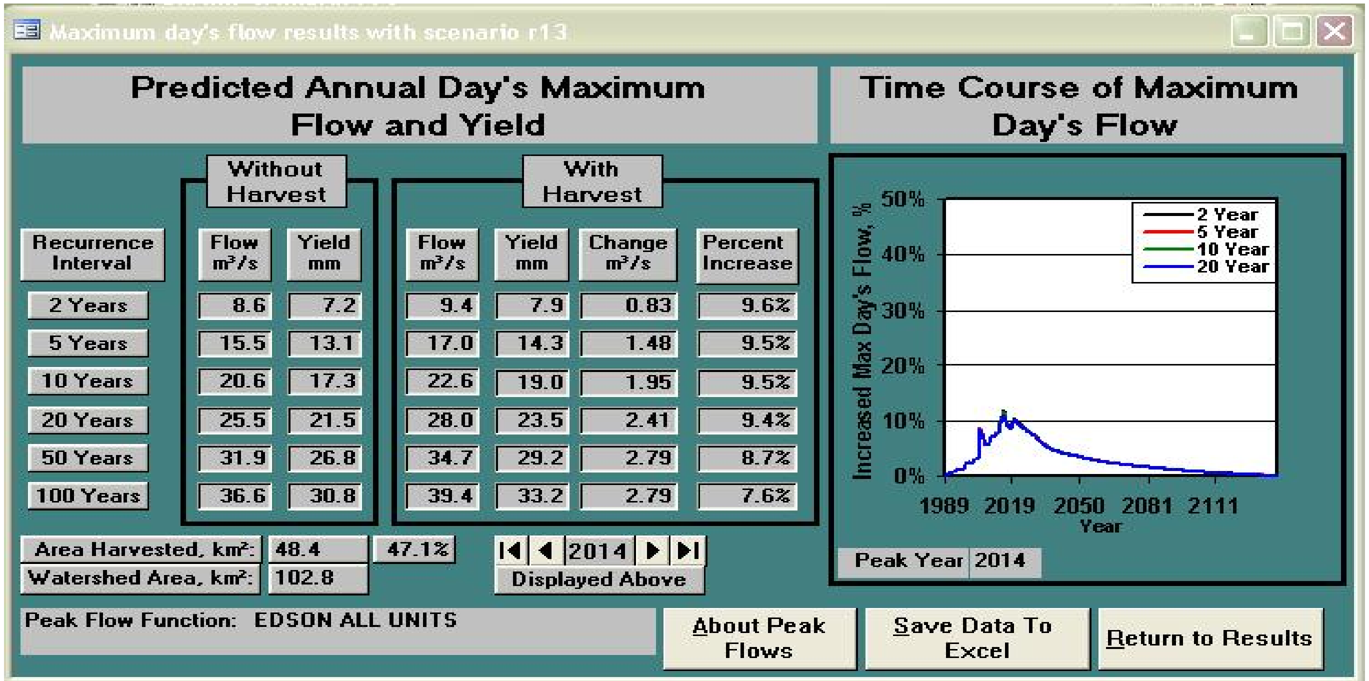








Watershed 1003…continued



Maximum day's flow results with scenario r13

Predicted Annual Day's Maximum Flow and Yield

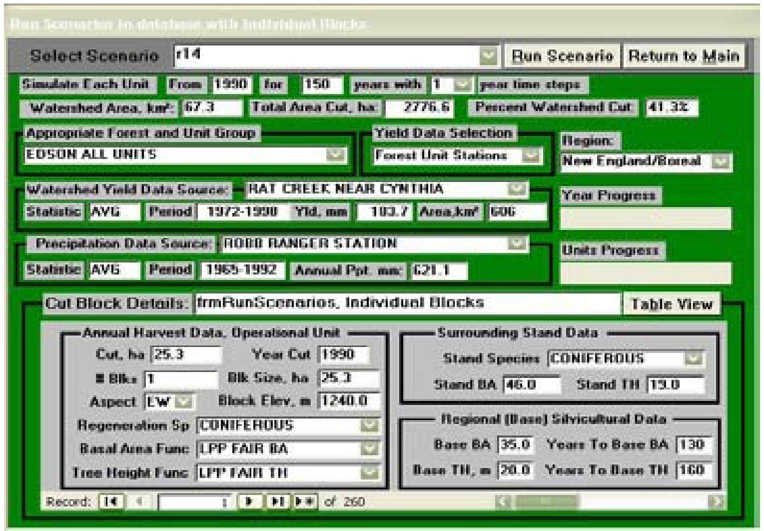
Recurrence Interval	Without Harvest: Flow m³/s	Without Harvest: Yield mm	With Harvest: Flow m³/s	With Harvest: Yield mm	With Harvest: Change m³/s	With Harvest: Percent Increase
2 Years	8.6	7.2	9.4	7.9	0.83	9.6%
5 Years	15.5	13.1	17.0	14.3	1.48	9.5%
10 Years	20.6	17.3	22.6	19.0	1.95	9.5%
20 Years	25.5	21.5	28.0	23.5	2.41	9.4%
50 Years	31.9	26.8	34.7	29.2	2.79	8.7%
100 Years	36.6	30.8	39.4	33.2	2.79	7.6%

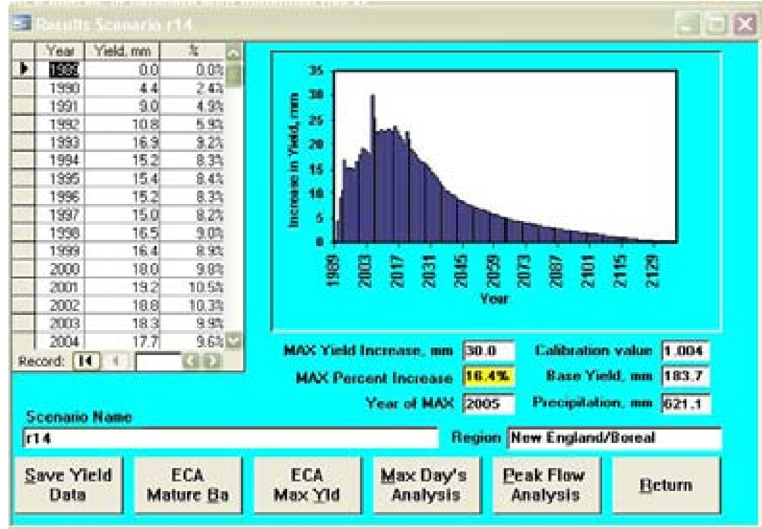
Area Harvested, km²: 48.4 47.1%
Watershed Area, km²: 102.8

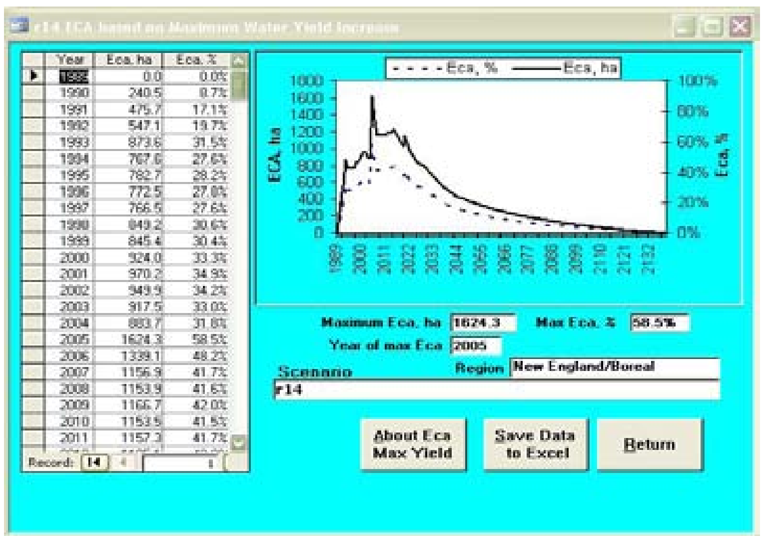
2014 Displayed Above

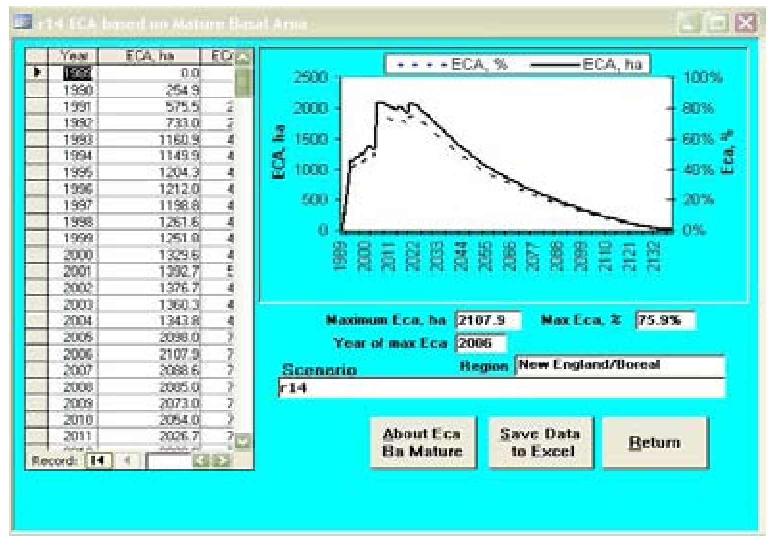
Peak Flow Function: EDSON ALL UNITS

Watershed 1004

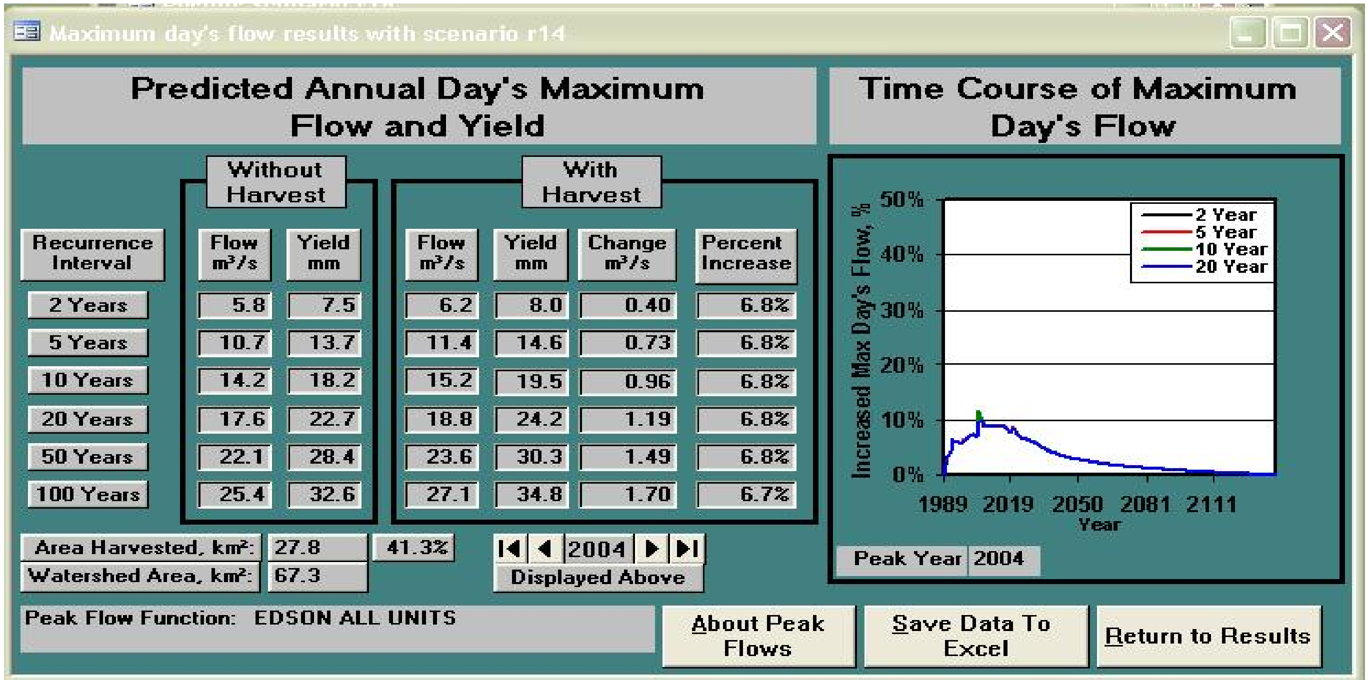








Watershed 1004…continued



Maximum day's flow results with scenario r14

Predicted Annual Day's Maximum Flow and Yield

Recurrence Interval	Without Harvest: Flow m³/s	Without Harvest: Yield mm	With Harvest: Flow m³/s	With Harvest: Yield mm	With Harvest: Change m³/s	With Harvest: Percent Increase
2 Years	5.8	7.5	6.2	8.0	0.40	6.8%
5 Years	10.7	13.7	11.4	14.6	0.73	6.8%
10 Years	14.2	18.2	15.2	19.5	0.96	6.8%
20 Years	17.6	22.7	18.8	24.2	1.19	6.8%
50 Years	22.1	28.4	23.6	30.3	1.49	6.8%
100 Years	25.4	32.6	27.1	34.8	1.70	6.7%

Area Harvested, km²: 27.8 41.3%

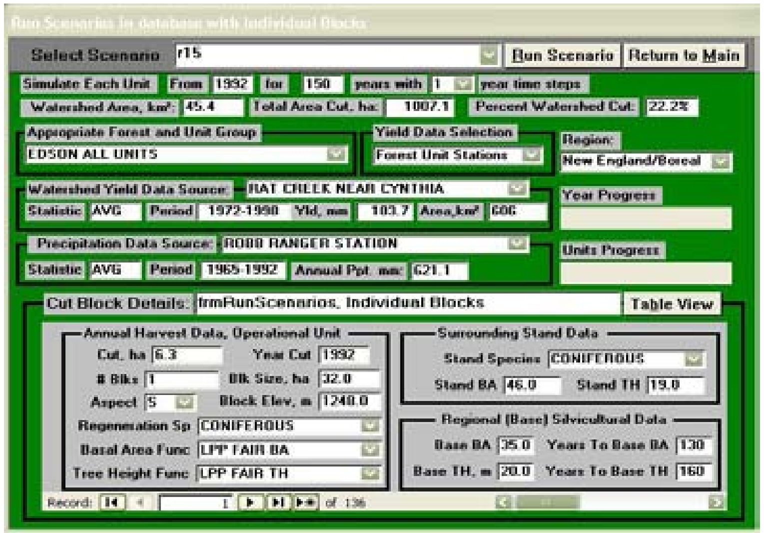
Watershed Area, km²: 67.3

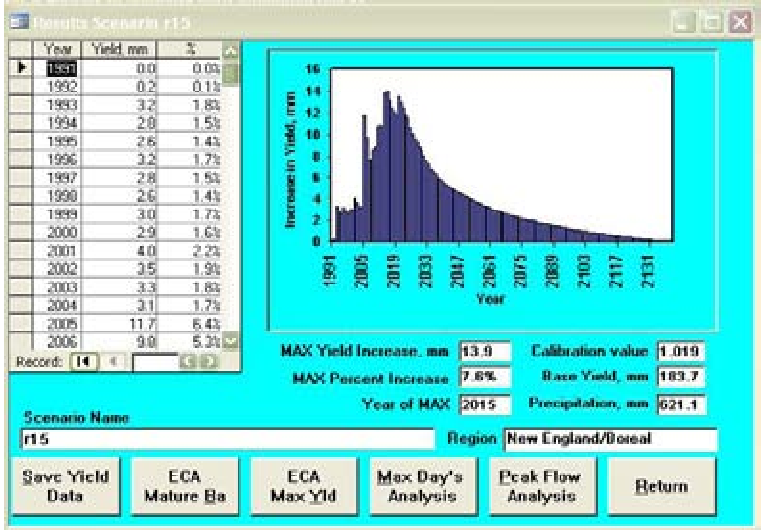
2004 Displayed Above

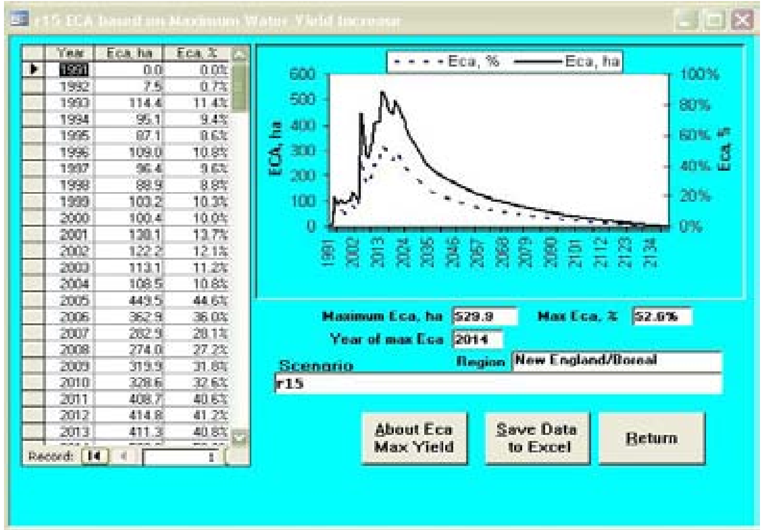
Peak Flow Function: EDSON ALL UNITS

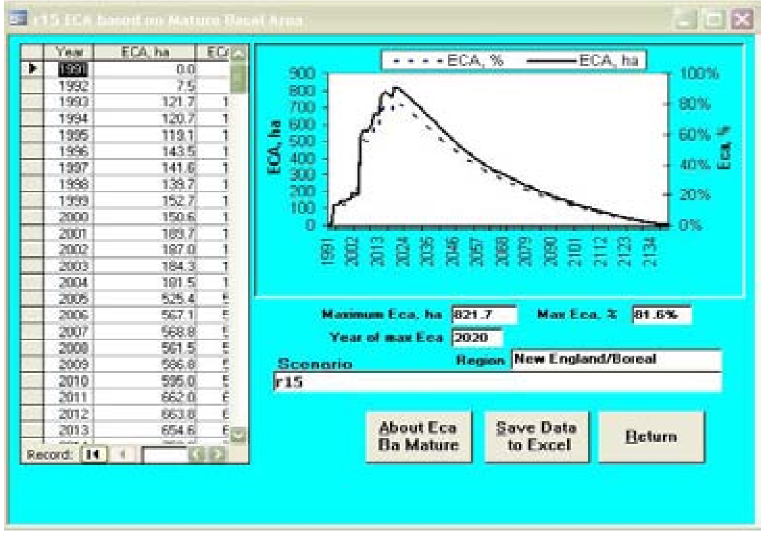
About Peak Flows | Save Data To Excel | Return to Results

Watershed 1005









Watershed 1005…continued

Maximum day's flow results with scenario r15

Predicted Annual Day's Maximum Flow and Yield

Recurrence Interval	Without Harvest: Flow m³/s	Without Harvest: Yield mm	With Harvest: Flow m³/s	With Harvest: Yield mm	With Harvest: Change m³/s	With Harvest: Percent Increase
2 Years	4.1	7.8	4.3	8.2	0.22	5.3%
5 Years	7.5	14.3	7.9	15.1	0.40	5.4%
10 Years	10.0	19.1	10.6	20.1	0.54	5.4%
20 Years	12.5	23.8	13.1	24.9	0.58	4.6%
50 Years	15.7	29.9	16.3	31.0	0.58	3.7%
100 Years	18.1	34.4	18.7	35.5	0.58	3.2%

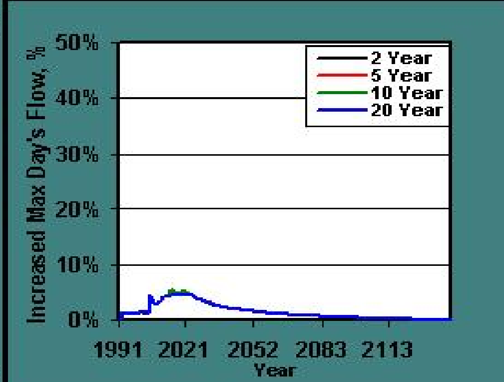
Area Harvested, km²: 10.1 22.2%

Watershed Area, km²: 45.4

2014 Displayed Above

Peak Flow Function: EDSON ALL UNITS

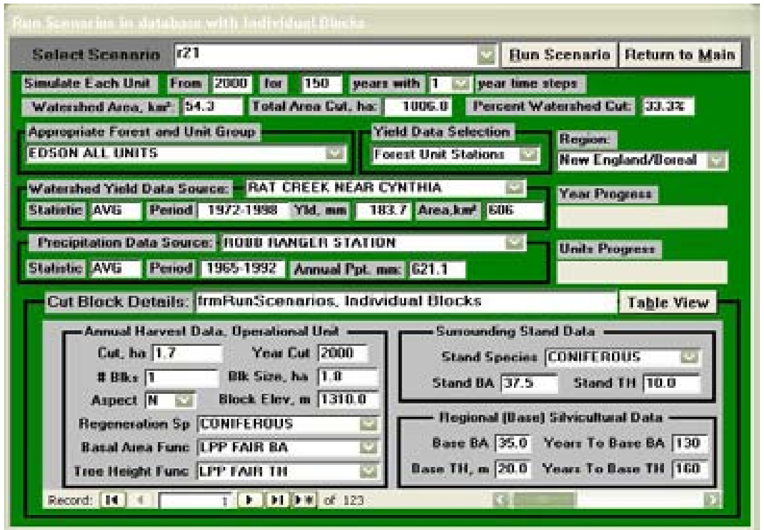
Time Course of Maximum Day's Flow

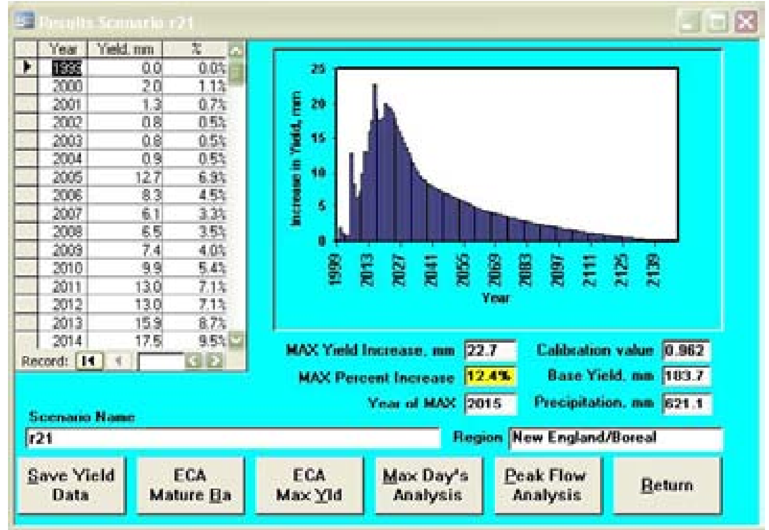


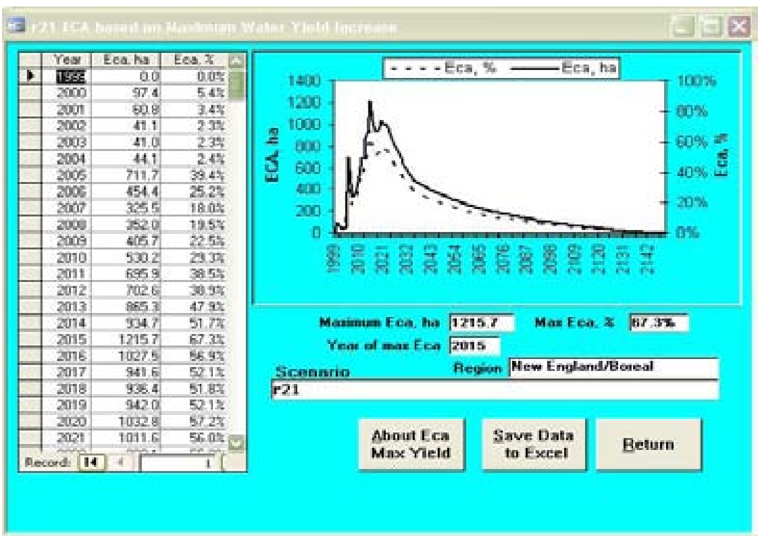
Peak Year 2014

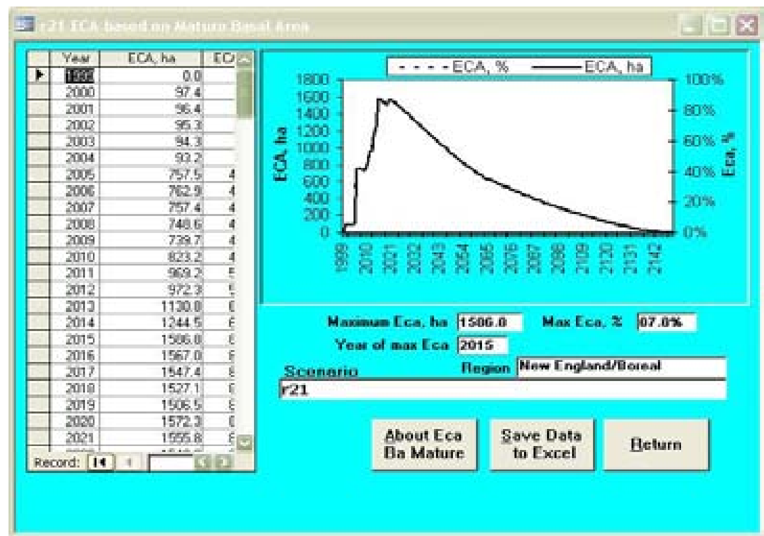
About Peak Flows | Save Data To Excel | Return to Results

Watershed 2001

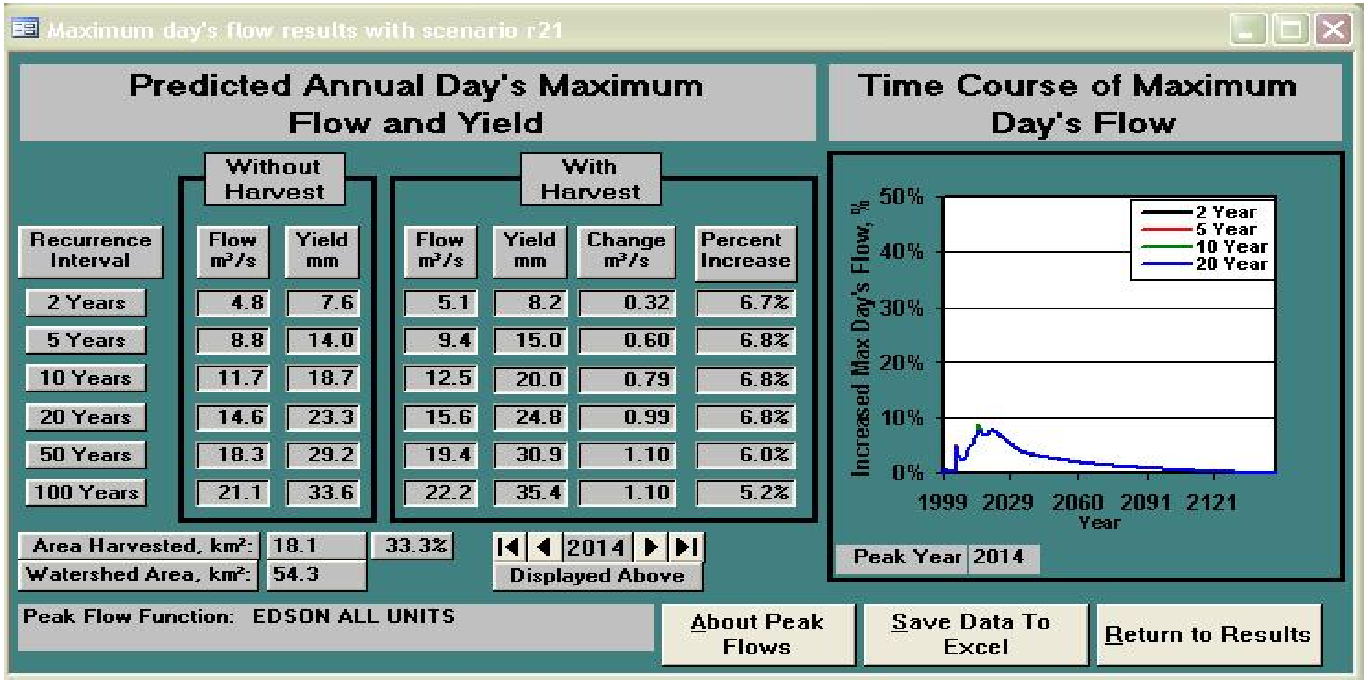






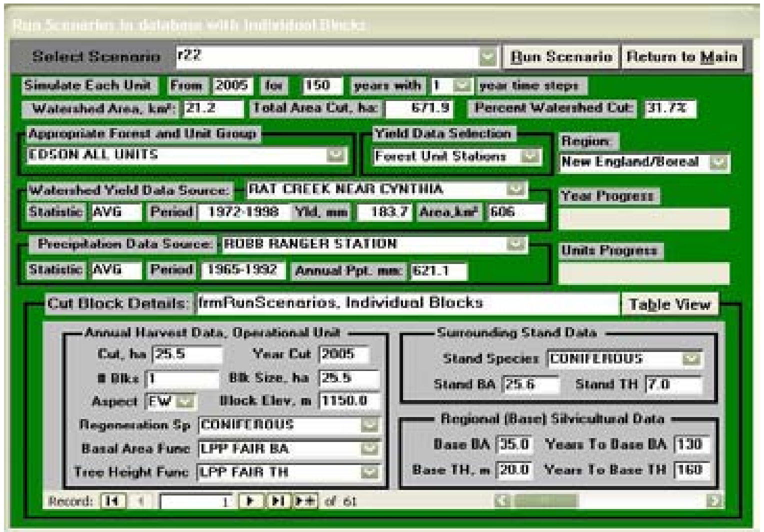


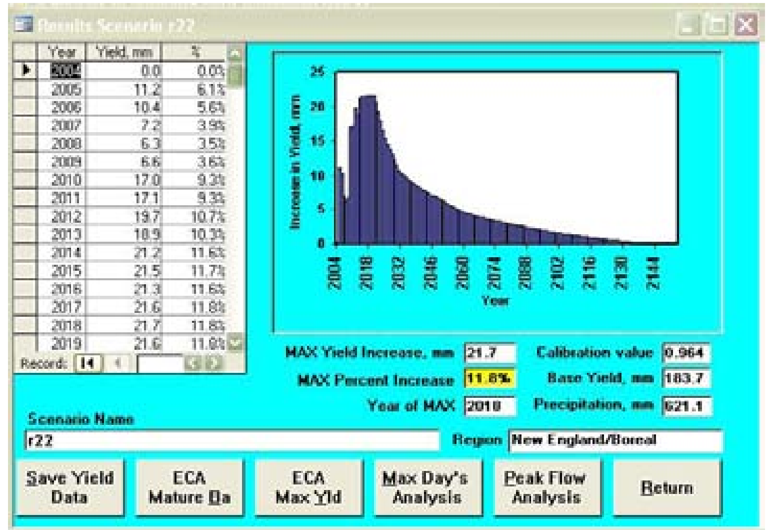
Watershed 2001…continued

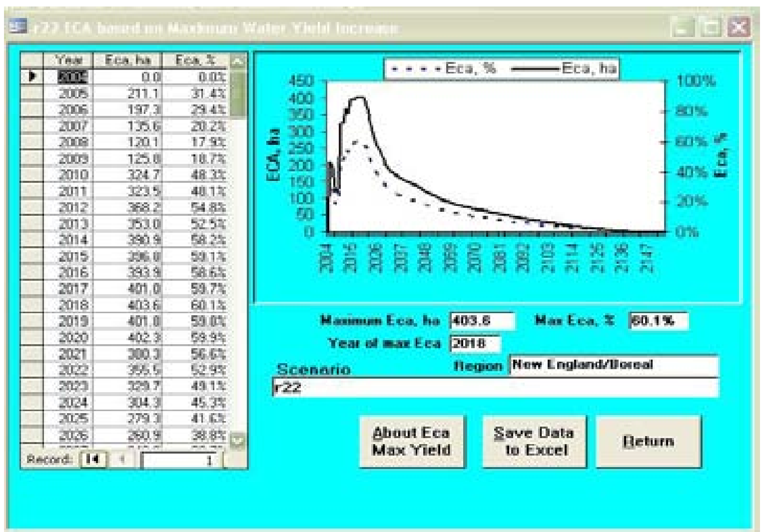


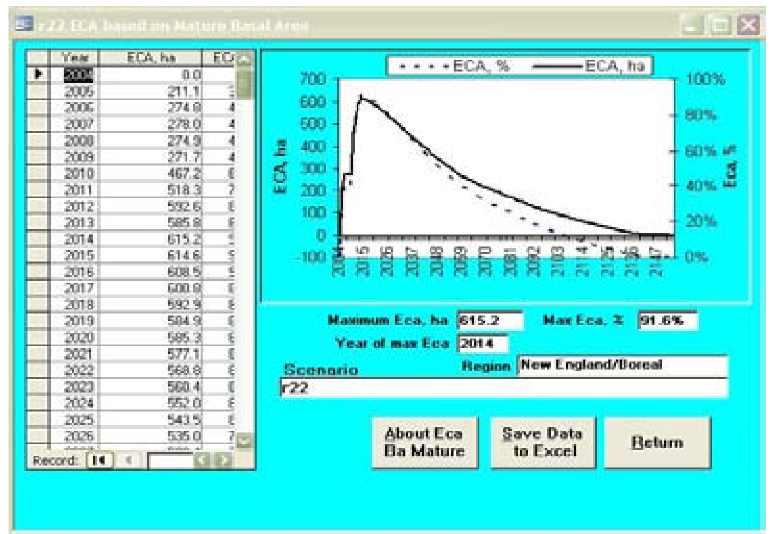
Recurrence Interval	Without Harvest Flow m³/s	Without Harvest Yield mm	With Harvest Flow m³/s	With Harvest Yield mm	Change m³/s	Percent Increase
2 Years	4.8	7.6	5.1	8.2	0.32	6.7%
5 Years	8.8	14.0	9.4	15.0	0.60	6.8%
10 Years	11.7	18.7	12.5	20.0	0.79	6.8%
20 Years	14.6	23.3	15.6	24.8	0.99	6.8%
50 Years	18.3	29.2	19.4	30.9	1.10	6.0%
100 Years	21.1	33.6	22.2	35.4	1.10	5.2%

Watershed 2002

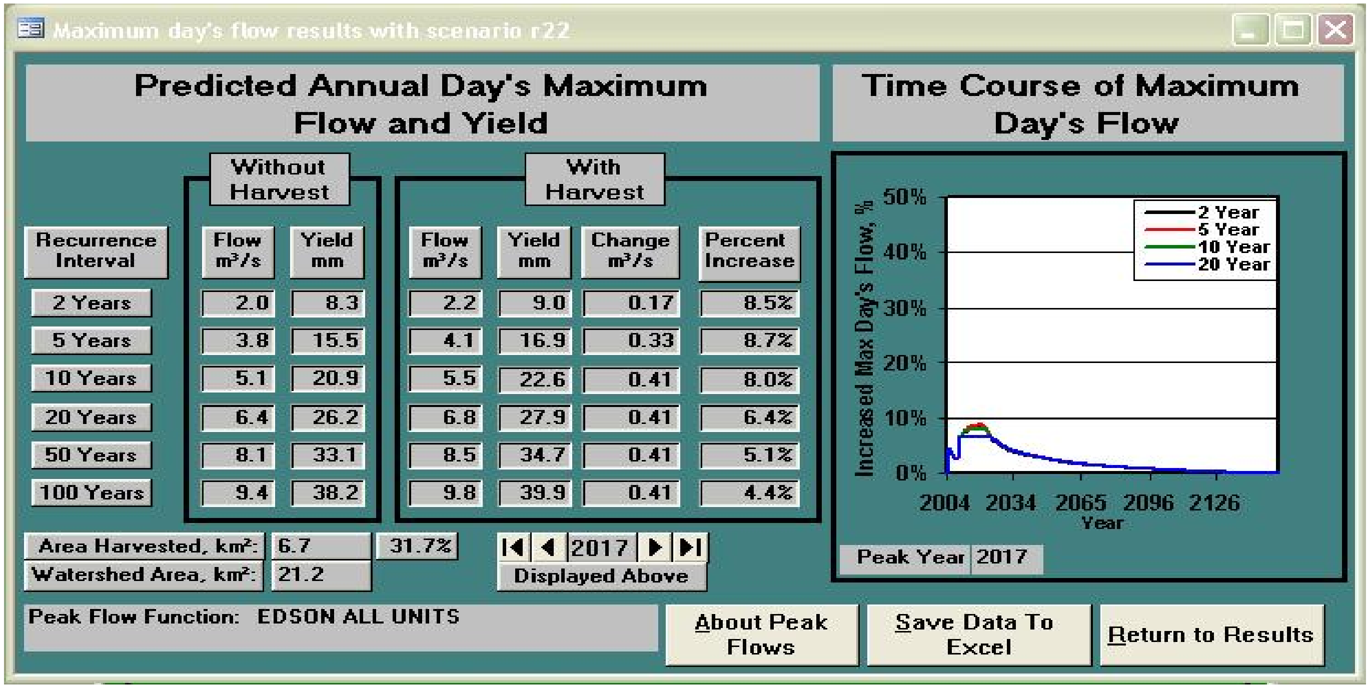








Watershed 2002…continued

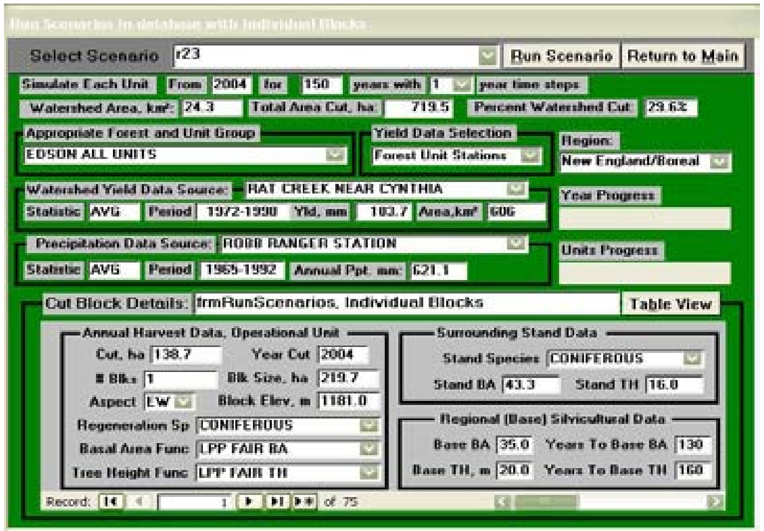


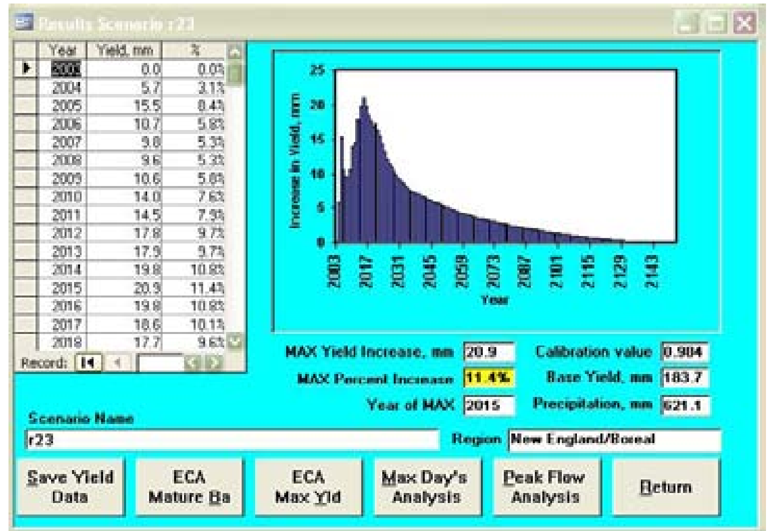
Maximum day's flow results with scenario r22

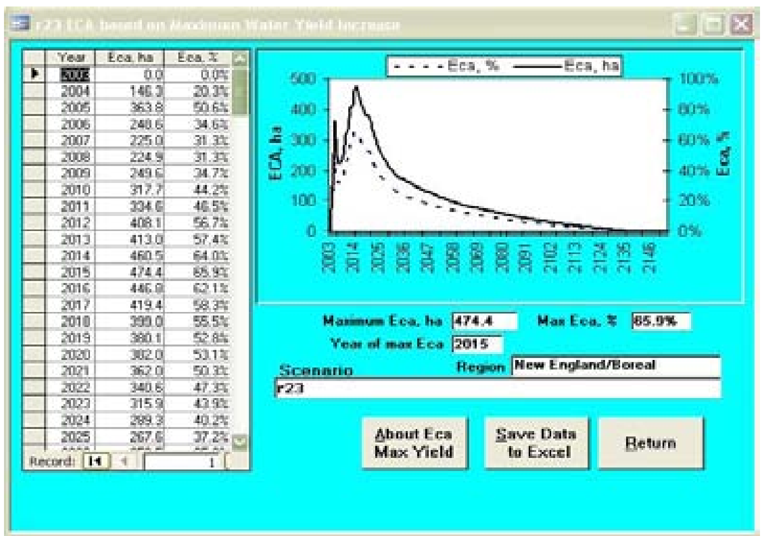
Predicted Annual Day's Maximum Flow and Yield	Without Harvest		With Harvest			
Recurrence Interval	Flow m³/s	Yield mm	Flow m³/s	Yield mm	Change m³/s	Percent Increase
2 Years	2.0	8.3	2.2	9.0	0.17	8.5%
5 Years	3.8	15.5	4.1	16.9	0.33	8.7%
10 Years	5.1	20.9	5.5	22.6	0.41	8.0%
20 Years	6.4	26.2	6.8	27.9	0.41	6.4%
50 Years	8.1	33.1	8.5	34.7	0.41	5.1%
100 Years	9.4	38.2	9.8	39.9	0.41	4.4%

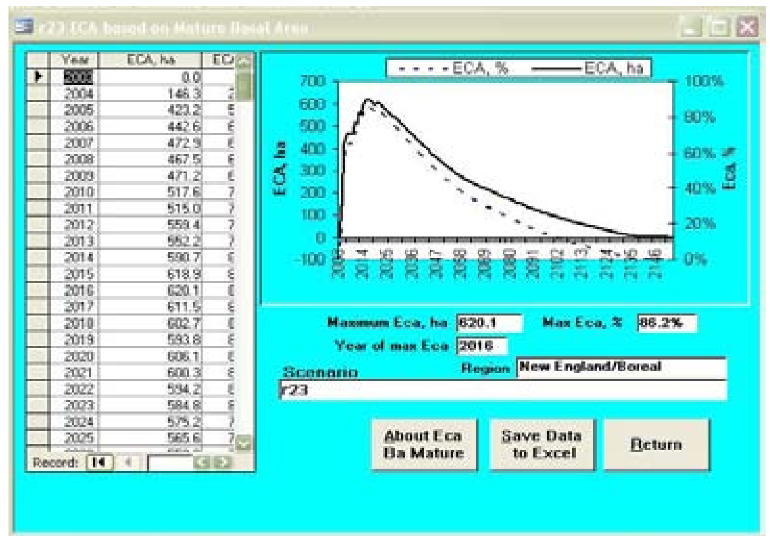
Area Harvested, km²: 6.7 31.7%
Watershed Area, km²: 21.2
2017 Displayed Above
Peak Flow Function: EDSON ALL UNITS

Watershed 2003

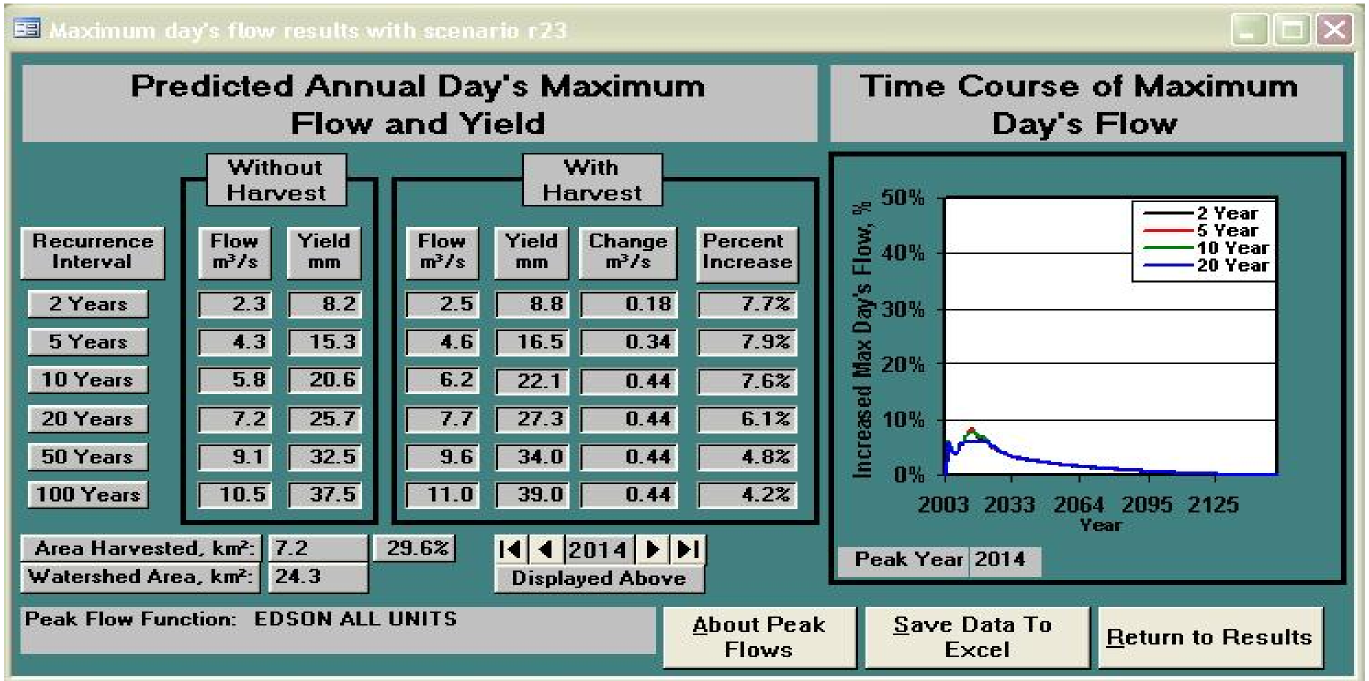






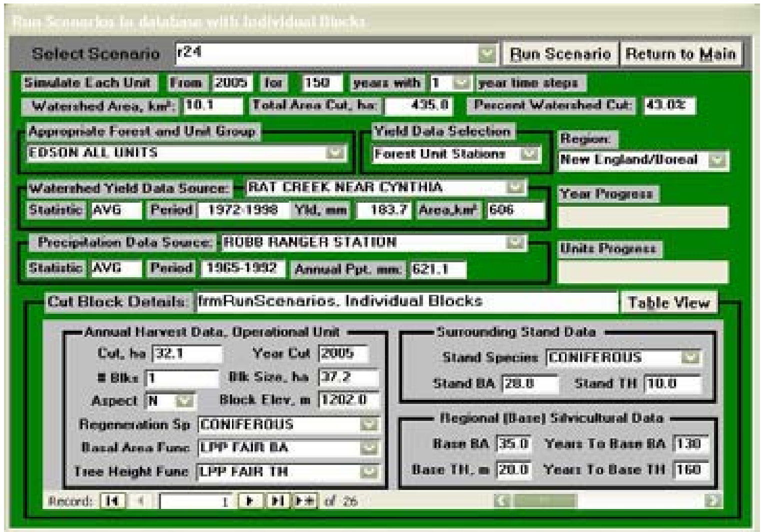


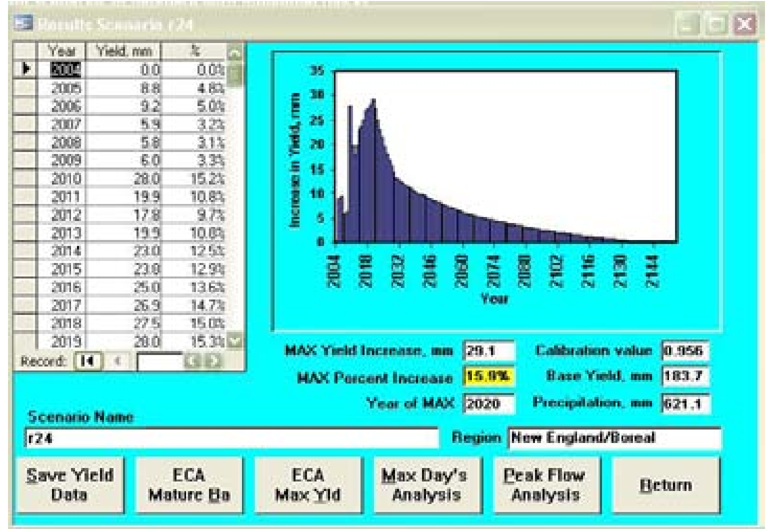
Watershed 2003…continued

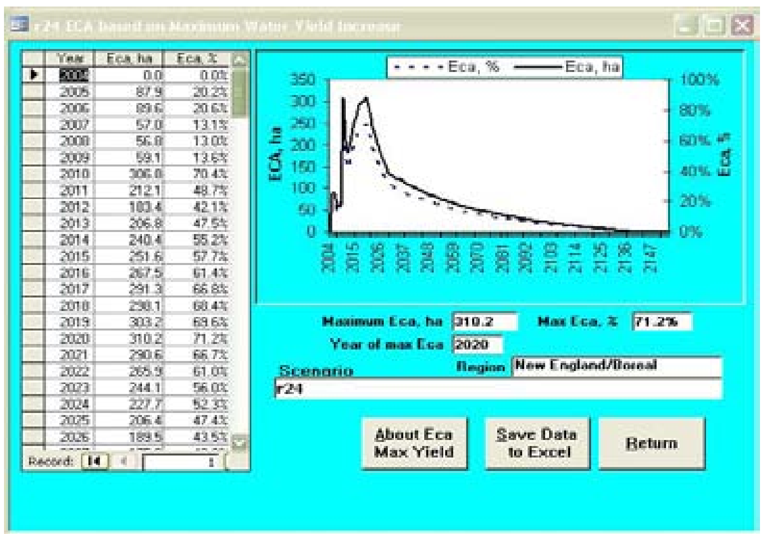


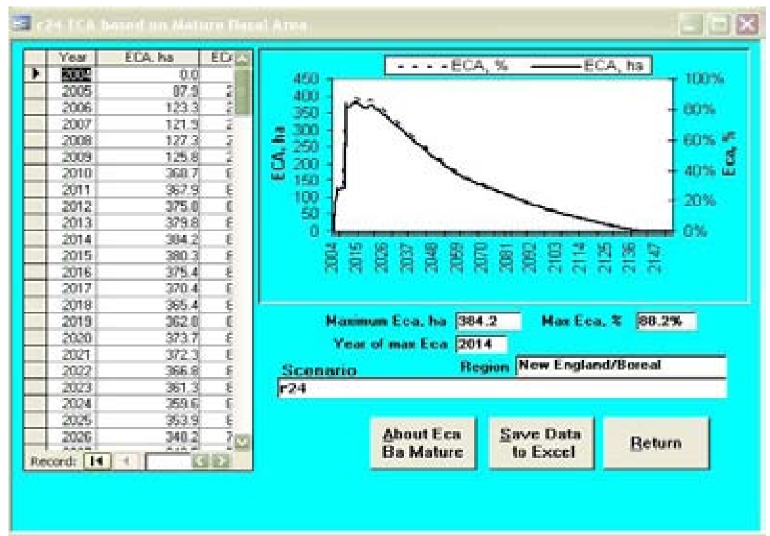
	Without Harvest		With Harvest			
Recurrence Interval	Flow m³/s	Yield mm	Flow m³/s	Yield mm	Change m³/s	Percent Increase
2 Years	2.3	8.2	2.5	8.8	0.18	7.7%
5 Years	4.3	15.3	4.6	16.5	0.34	7.9%
10 Years	5.8	20.6	6.2	22.1	0.44	7.6%
20 Years	7.2	25.7	7.7	27.3	0.44	6.1%
50 Years	9.1	32.5	9.6	34.0	0.44	4.8%
100 Years	10.5	37.5	11.0	39.0	0.44	4.2%

Watershed 2004

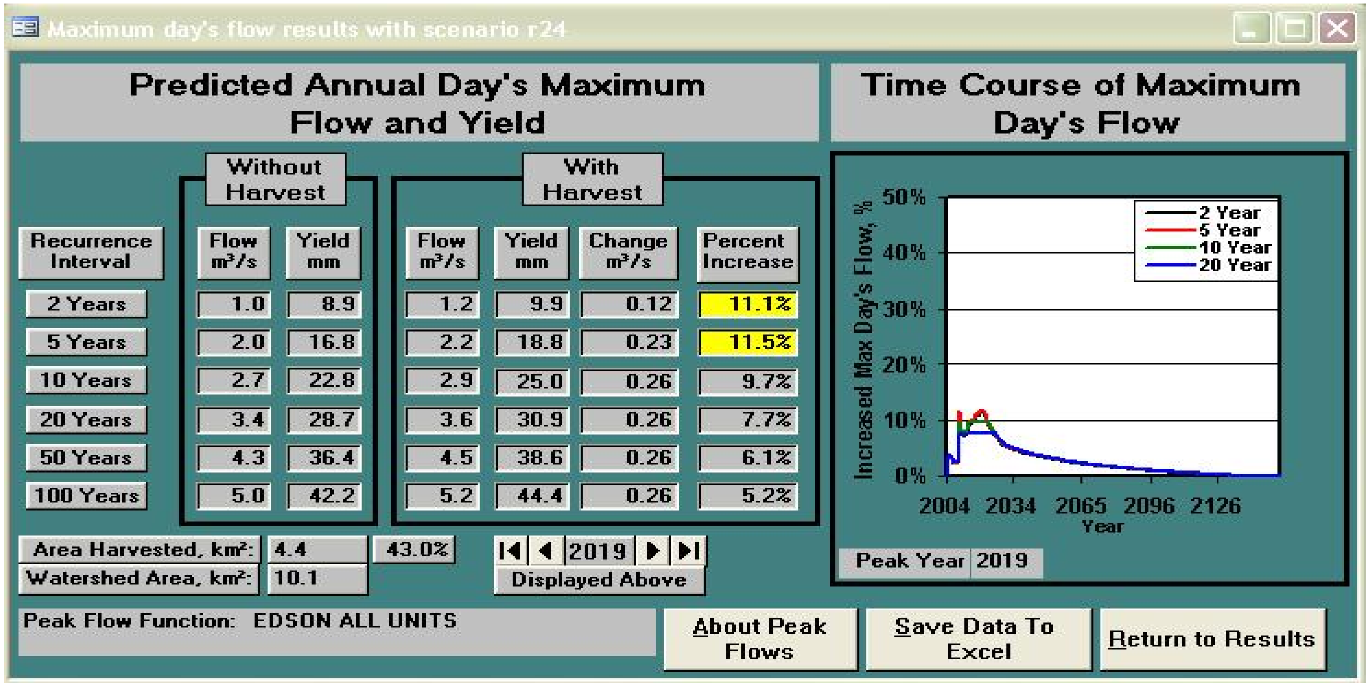






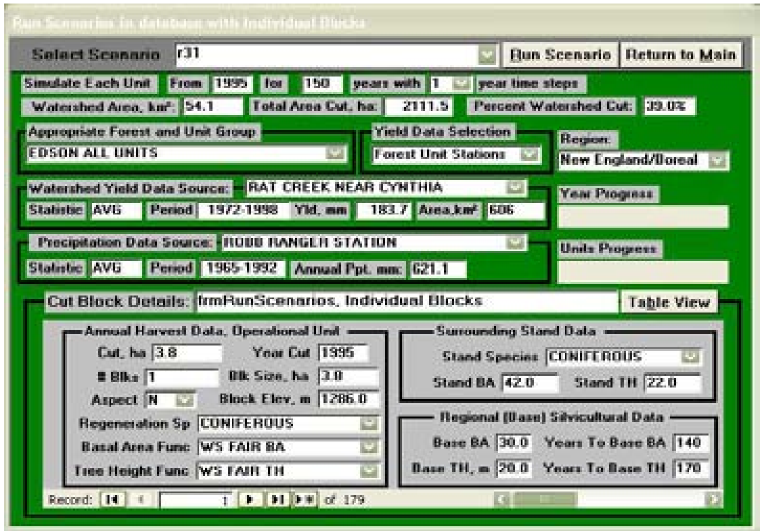


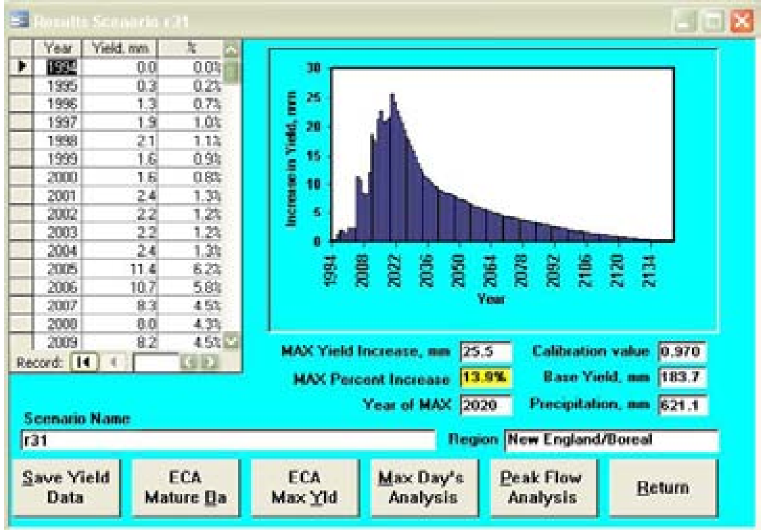
Watershed 2004…continued

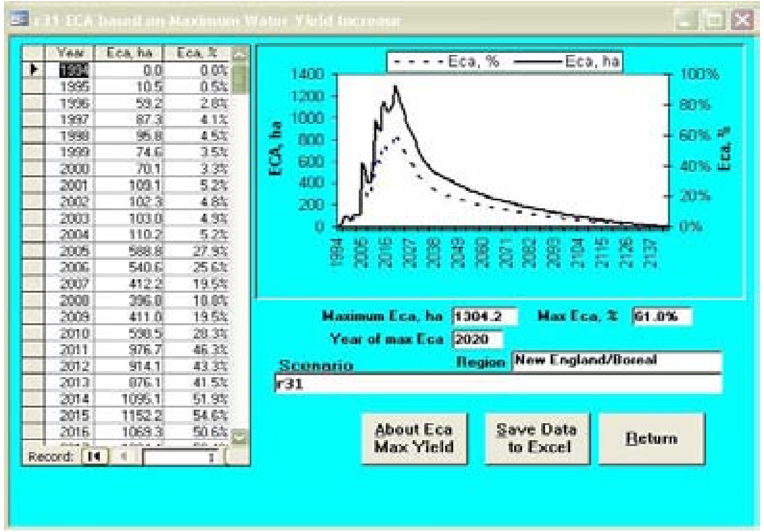


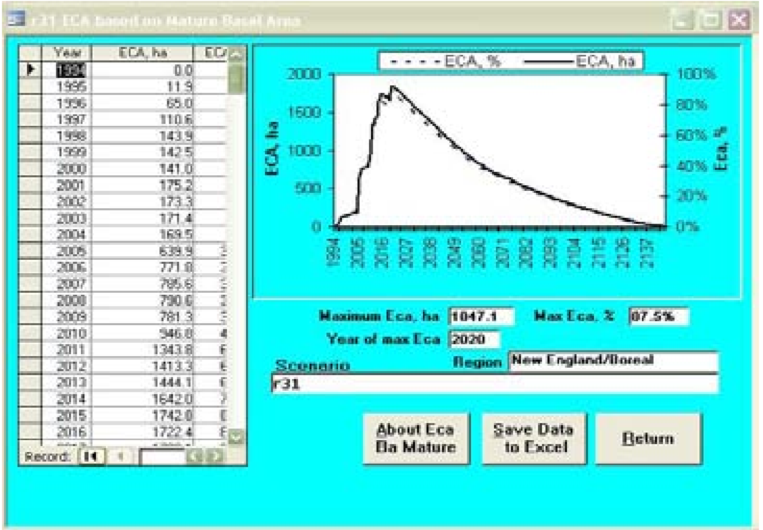
Recurrence Interval	Without Harvest Flow m³/s	Without Harvest Yield mm	With Harvest Flow m³/s	With Harvest Yield mm	Change m³/s	Percent Increase
2 Years	1.0	8.9	1.2	9.9	0.12	11.1%
5 Years	2.0	16.8	2.2	18.8	0.23	11.5%
10 Years	2.7	22.8	2.9	25.0	0.26	9.7%
20 Years	3.4	28.7	3.6	30.9	0.26	7.7%
50 Years	4.3	36.4	4.5	38.6	0.26	6.1%
100 Years	5.0	42.2	5.2	44.4	0.26	5.2%

Watershed 3001

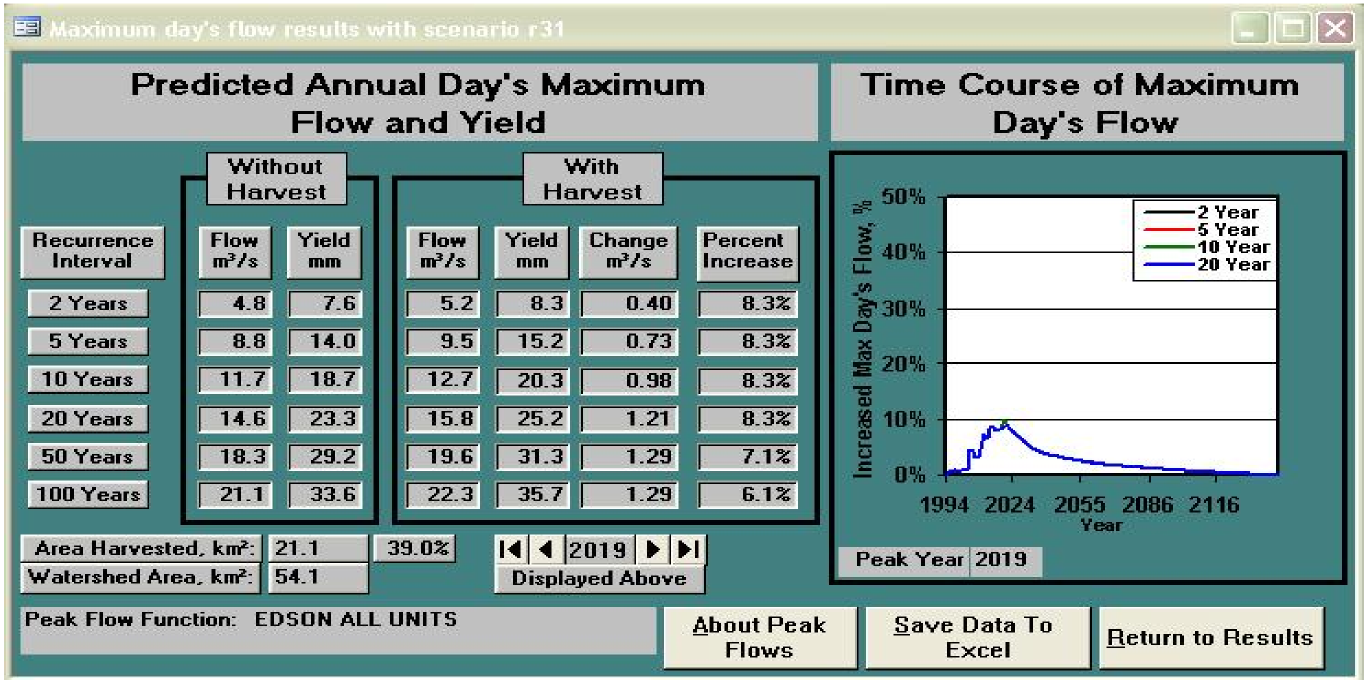








Watershed 3001…continued



Maximum day's flow results with scenario r31

Predicted Annual Day's Maximum Flow and Yield

Recurrence Interval	Without Harvest Flow m³/s	Without Harvest Yield mm	With Harvest Flow m³/s	With Harvest Yield mm	Change m³/s	Percent Increase
2 Years	4.8	7.6	5.2	8.3	0.40	8.3%
5 Years	8.8	14.0	9.5	15.2	0.73	8.3%
10 Years	11.7	18.7	12.7	20.3	0.98	8.3%
20 Years	14.6	23.3	15.8	25.2	1.21	8.3%
50 Years	18.3	29.2	19.6	31.3	1.29	7.1%
100 Years	21.1	33.6	22.3	35.7	1.29	6.1%

Area Harvested, km²: 21.1 39.0%

Watershed Area, km²: 54.1

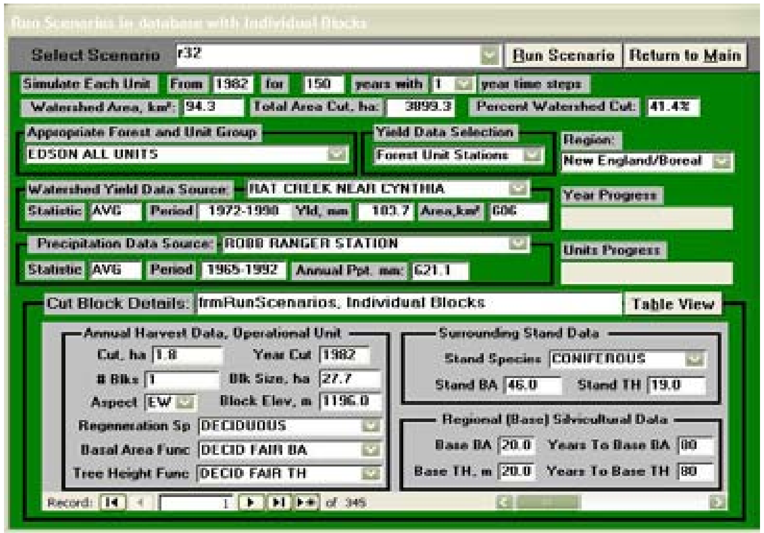
2019 Displayed Above

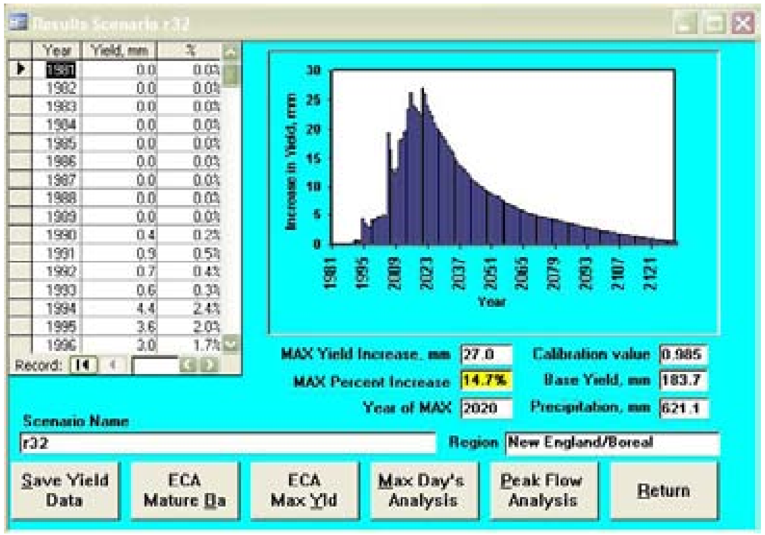
Peak Flow Function: EDSON ALL UNITS

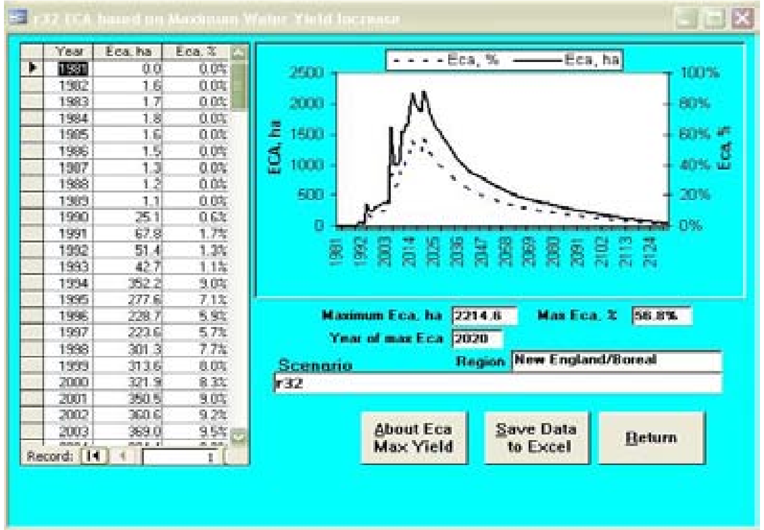
About Peak Flows | Save Data To Excel | Return to Results

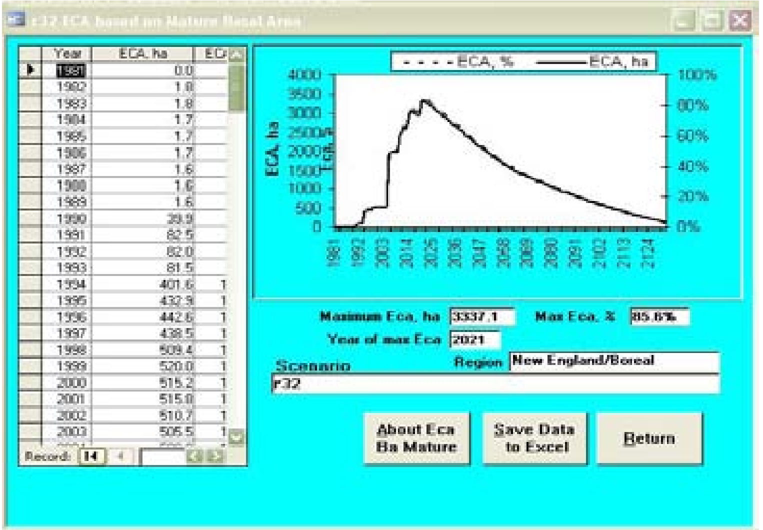
Time Course of Maximum Day's Flow

Watershed 3002

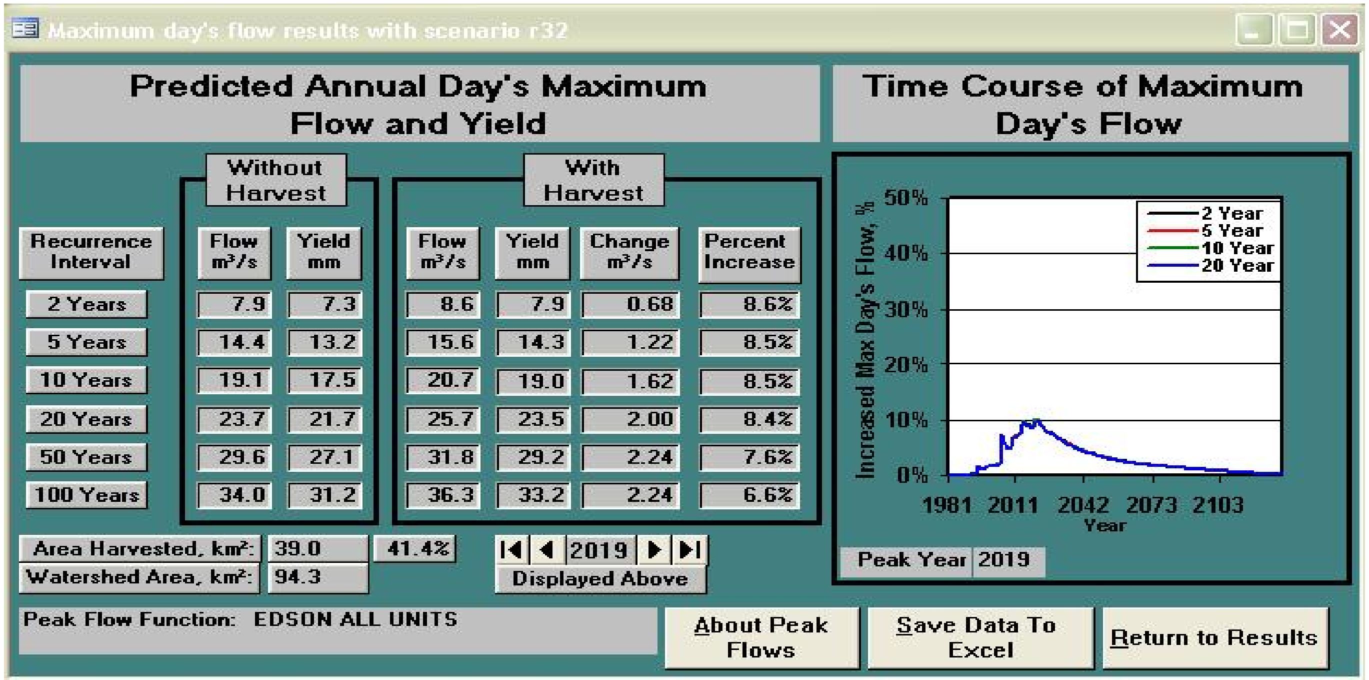






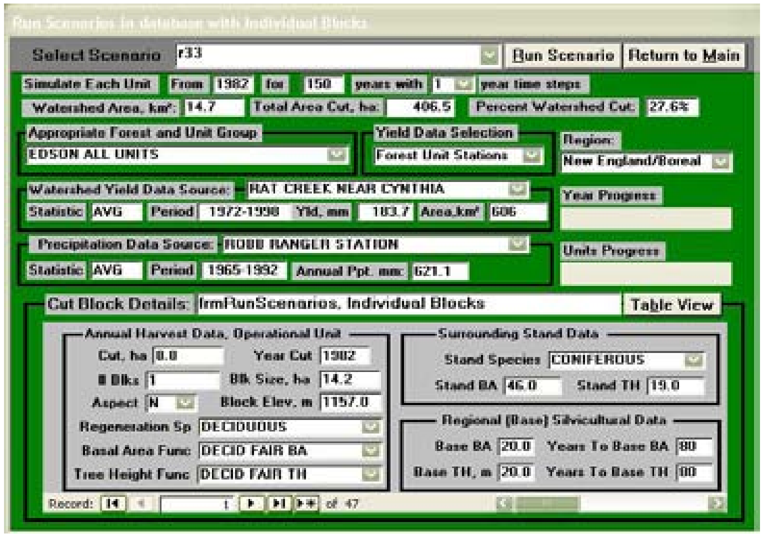


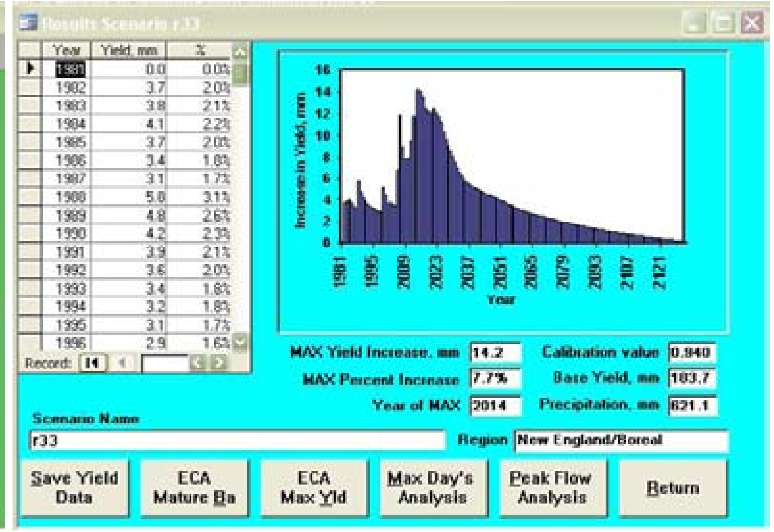
Watershed 3002…continued

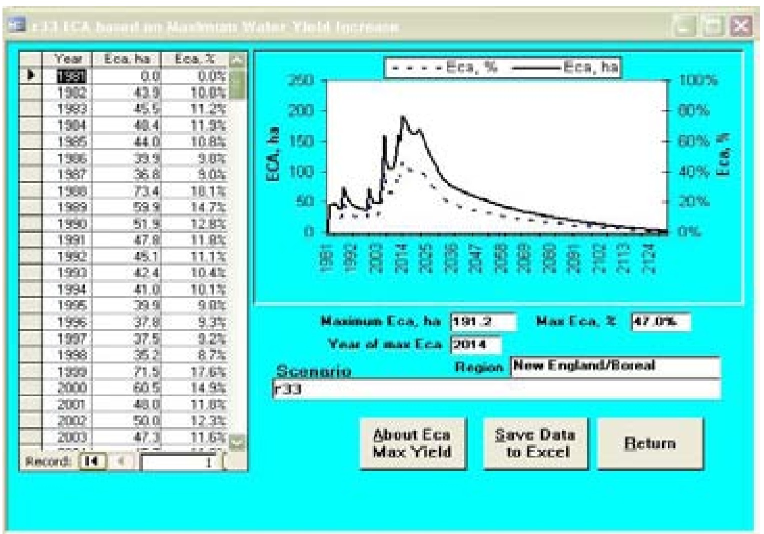


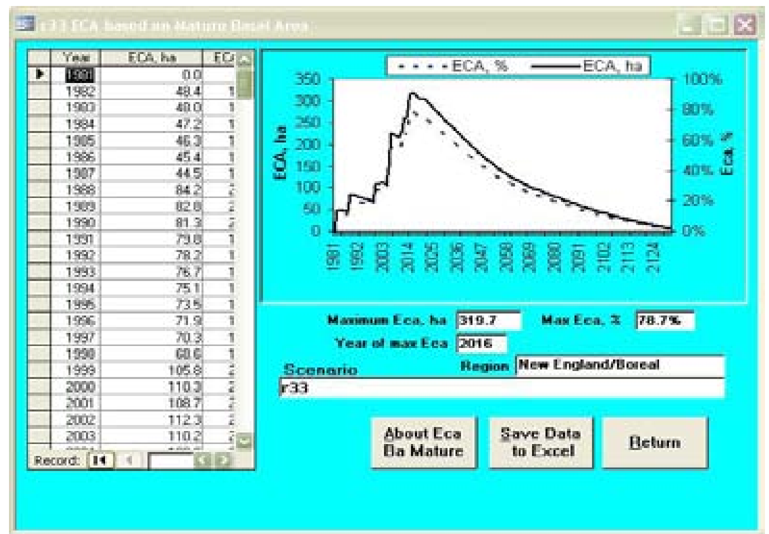
Recurrence Interval	Without Harvest Flow m³/s	Without Harvest Yield mm	With Harvest Flow m³/s	With Harvest Yield mm	Change m³/s	Percent Increase
2 Years	7.9	7.3	8.6	7.9	0.68	8.6%
5 Years	14.4	13.2	15.6	14.3	1.22	8.5%
10 Years	19.1	17.5	20.7	19.0	1.62	8.5%
20 Years	23.7	21.7	25.7	23.5	2.00	8.4%
50 Years	29.6	27.1	31.8	29.2	2.24	7.6%
100 Years	34.0	31.2	36.3	33.2	2.24	6.6%

Watershed 3003

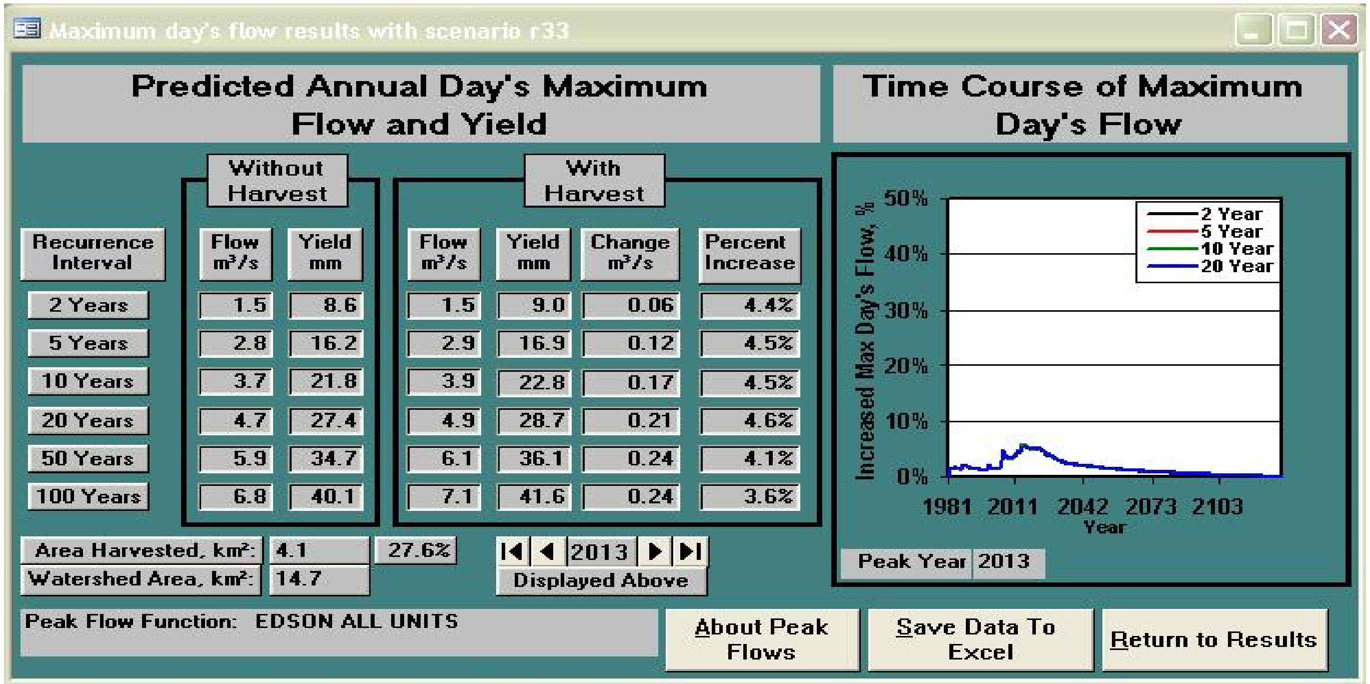








Watershed 3003..continued


Maximum day's flow results with scenario r33

Predicted Annual Day's Maximum Flow and Yield

Recurrence Interval	Without Harvest Flow m³/s	Without Harvest Yield mm	With Harvest Flow m³/s	With Harvest Yield mm	Change m³/s	Percent Increase
2 Years	1.5	8.6	1.5	9.0	0.06	4.4%
5 Years	2.8	16.2	2.9	16.9	0.12	4.5%
10 Years	3.7	21.8	3.9	22.8	0.17	4.5%
20 Years	4.7	27.4	4.9	28.7	0.21	4.6%
50 Years	5.9	34.7	6.1	36.1	0.24	4.1%
100 Years	6.8	40.1	7.1	41.6	0.24	3.6%

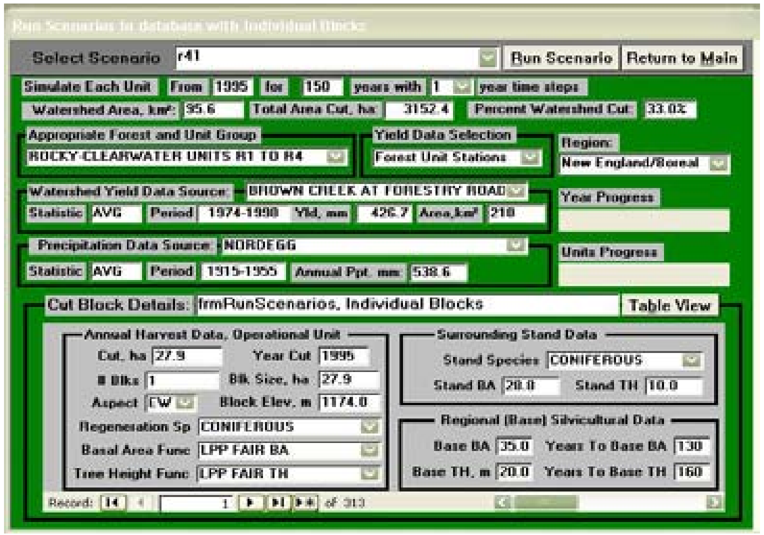
Area Harvested, km²: 4.1 27.6%

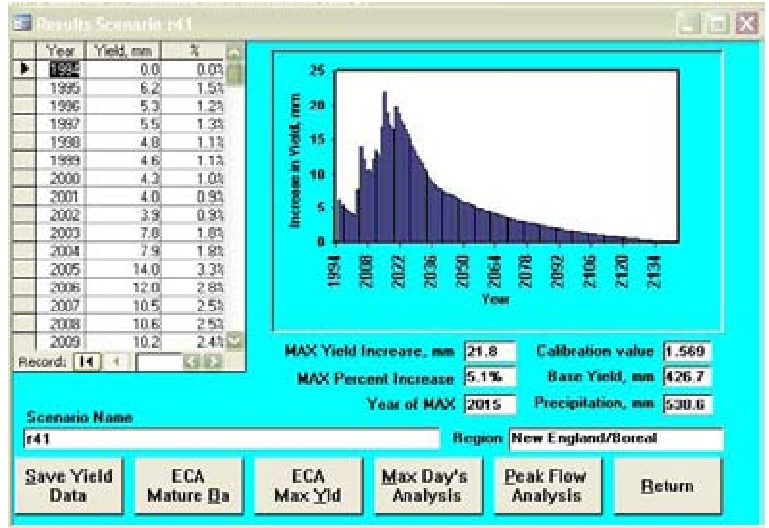
Watershed Area, km²: 14.7

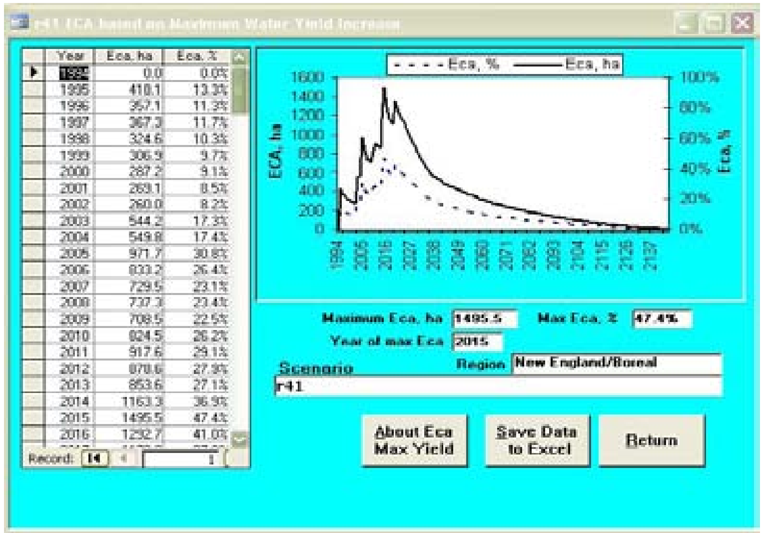
2013 Displayed Above

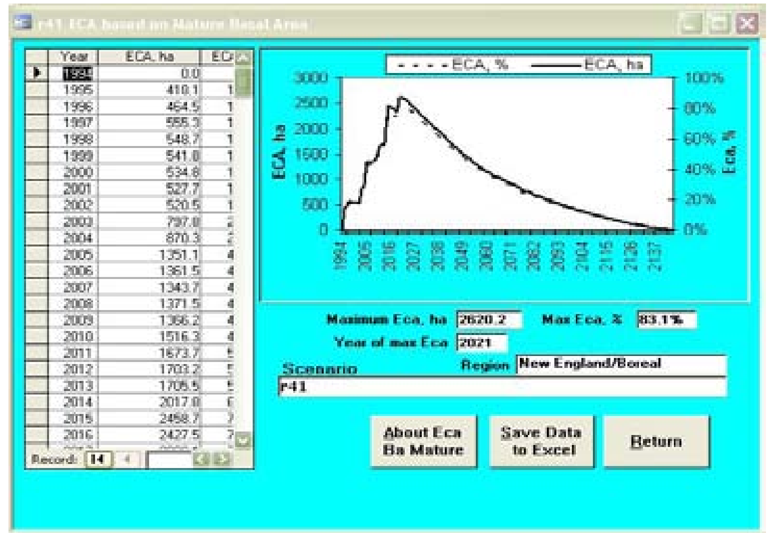
Peak Flow Function: EDSON ALL UNITS

Watershed 4001









Watershed 4001…continued

Maximum day's flow results with scenario r41

Predicted Annual Day's Maximum Flow and Yield

Recurrence Interval	Without Harvest: Flow m³/s	Without Harvest: Yield mm	With Harvest: Flow m³/s	With Harvest: Yield mm	Change m³/s	Percent Increase
2 Years	7.2	6.5	7.8	7.0	0.56	7.8%
5 Years	15.7	14.1	17.0	15.4	1.37	8.7%
10 Years	22.4	20.2	24.3	21.9	1.87	8.4%
20 Years	29.3	26.4	31.1	28.1	1.87	6.4%
50 Years	38.5	34.8	40.4	36.5	1.87	4.9%
100 Years	45.5	41.1	47.4	42.8	1.87	4.1%

Area Harvested, km²: 31.5 33.0%

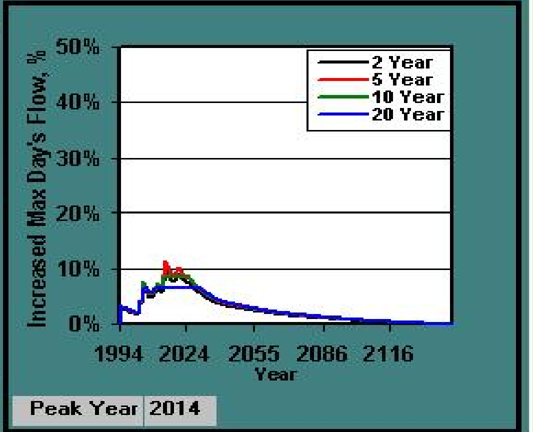
Watershed Area, km²: 95.6

2014 Displayed Above

Peak Flow Function: ROCKY-CLEARWATER UNITS R1 TO R4

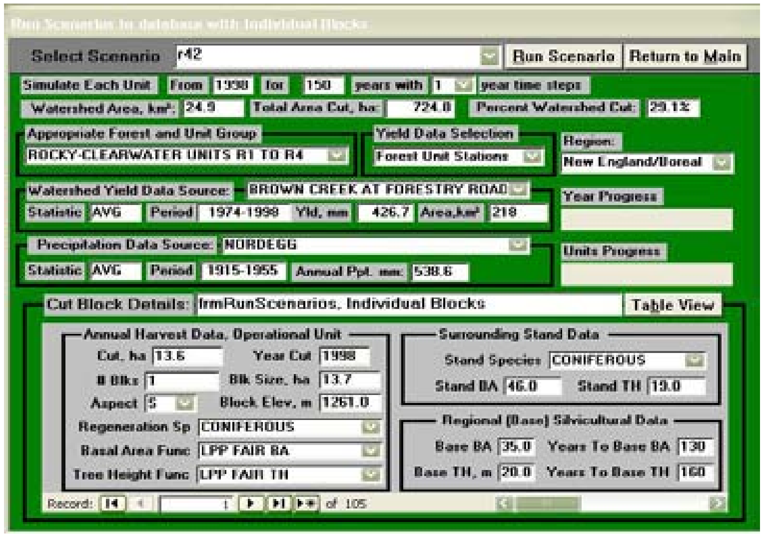
About Peak Flows | Save Data To Excel | Return to Results

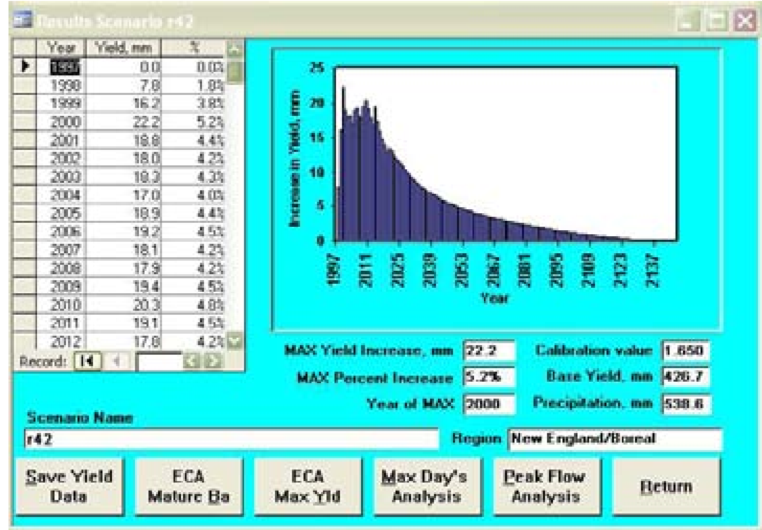
Time Course of Maximum Day's Flow

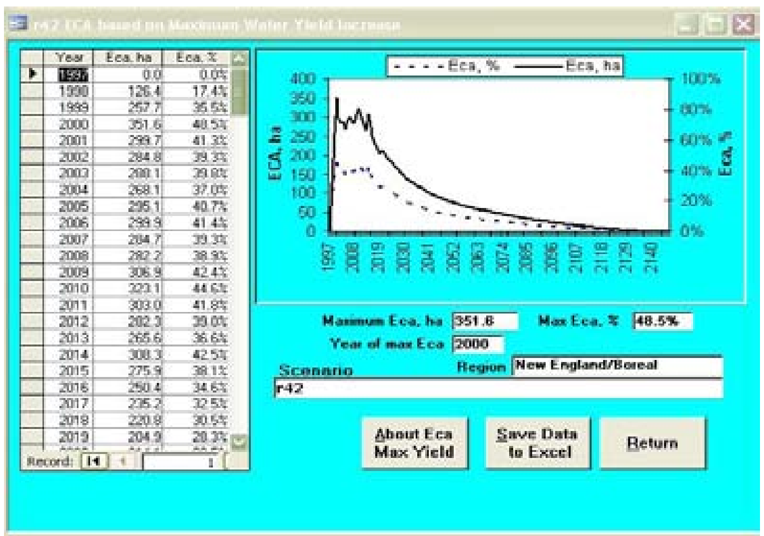


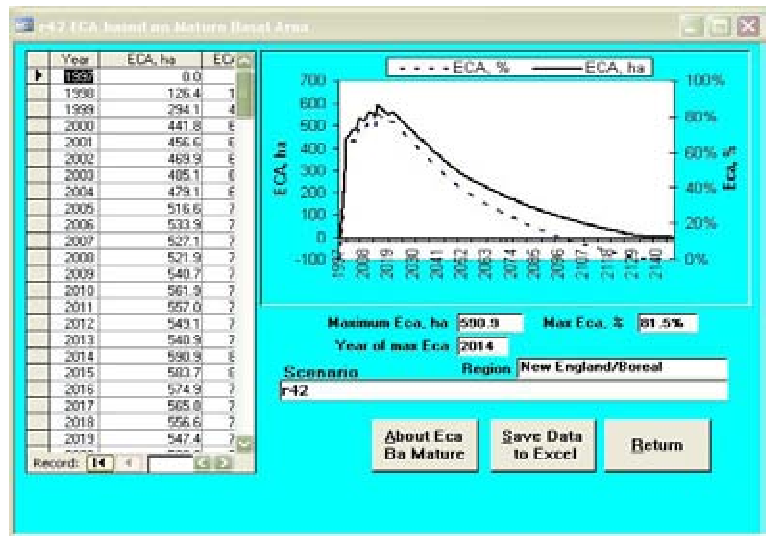
Peak Year 2014

Watershed 4002

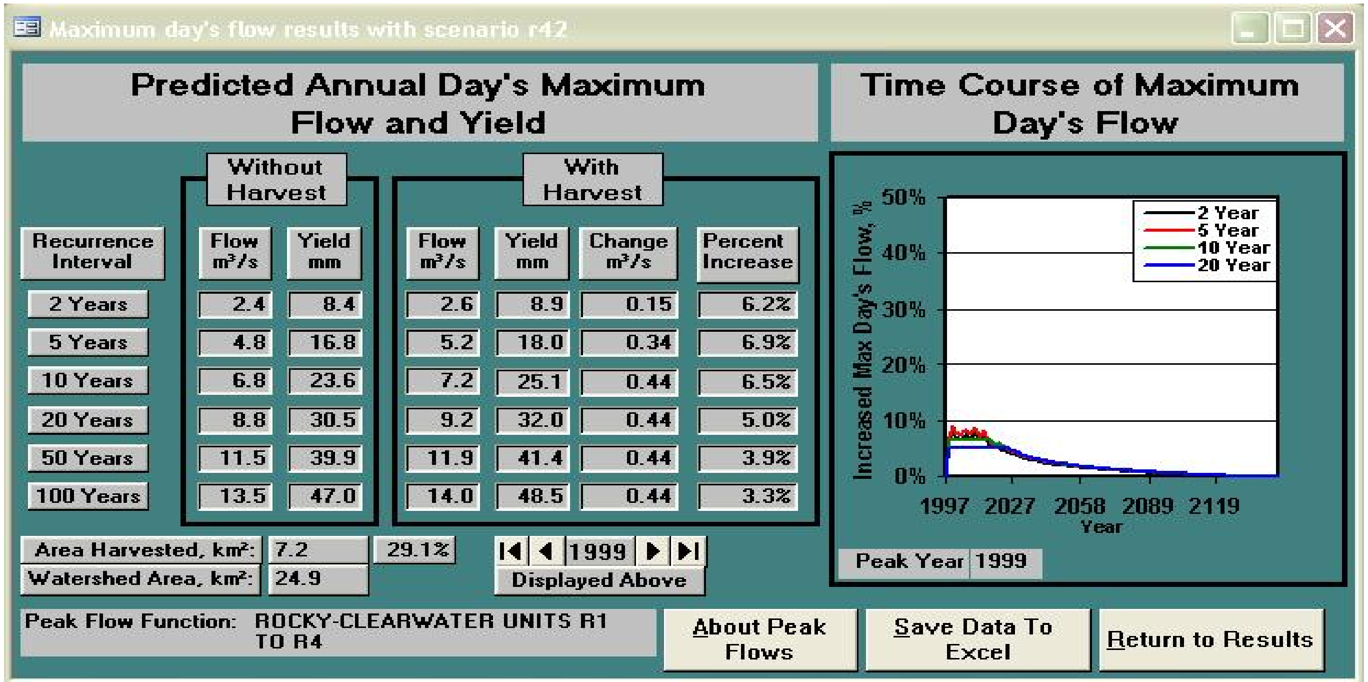






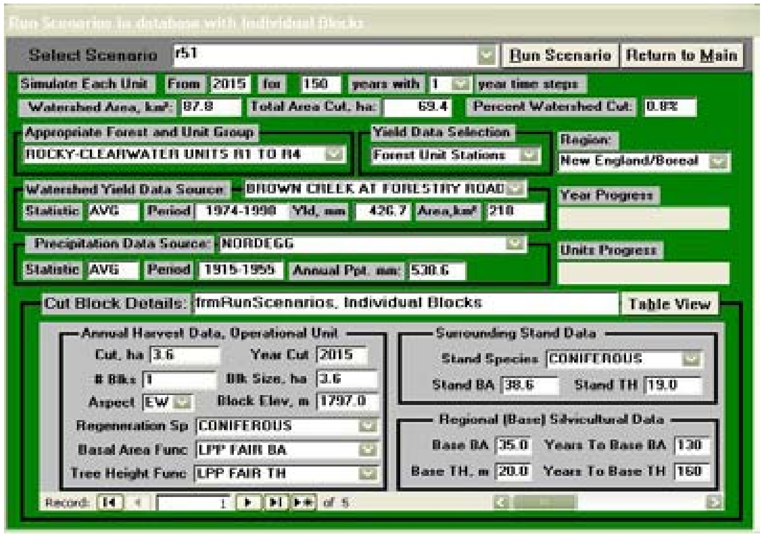


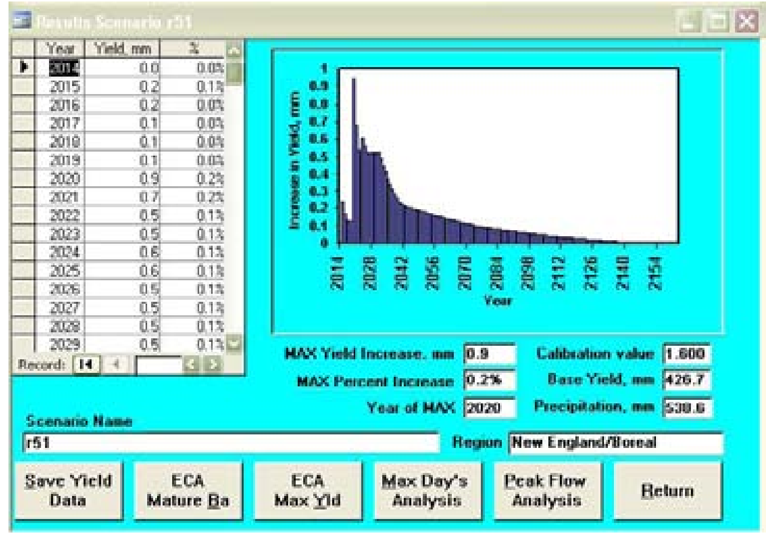
Watershed 4002…continued

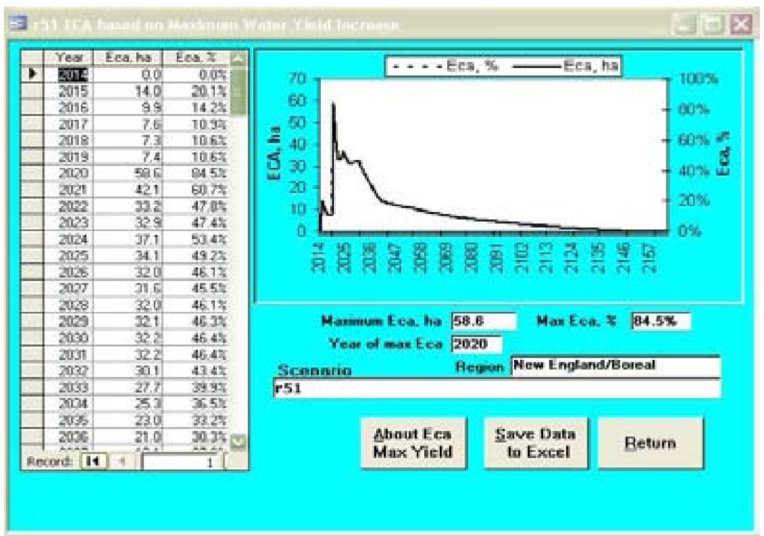


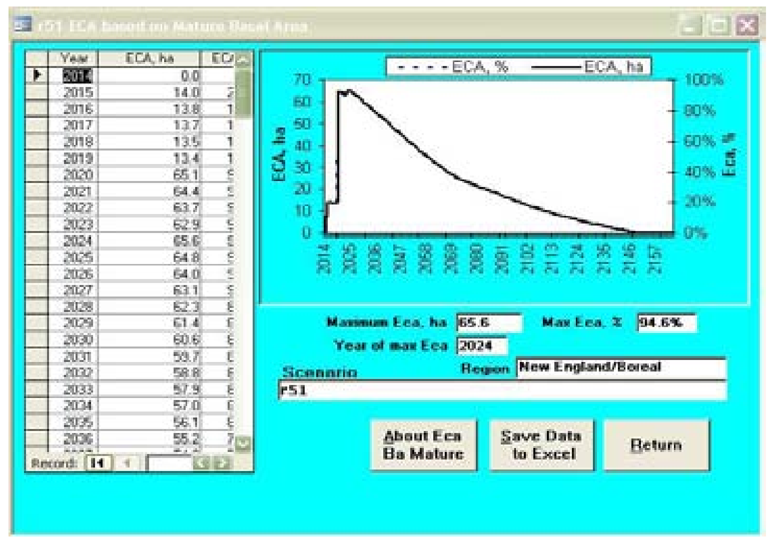
Recurrence Interval	Without Harvest Flow m³/s	Without Harvest Yield mm	With Harvest Flow m³/s	With Harvest Yield mm	Change m³/s	Percent Increase
2 Years	2.4	8.4	2.6	8.9	0.15	6.2%
5 Years	4.8	16.8	5.2	18.0	0.34	6.9%
10 Years	6.8	23.6	7.2	25.1	0.44	6.5%
20 Years	8.8	30.5	9.2	32.0	0.44	5.0%
50 Years	11.5	39.9	11.9	41.4	0.44	3.9%
100 Years	13.5	47.0	14.0	48.5	0.44	3.3%

Watershed 5001

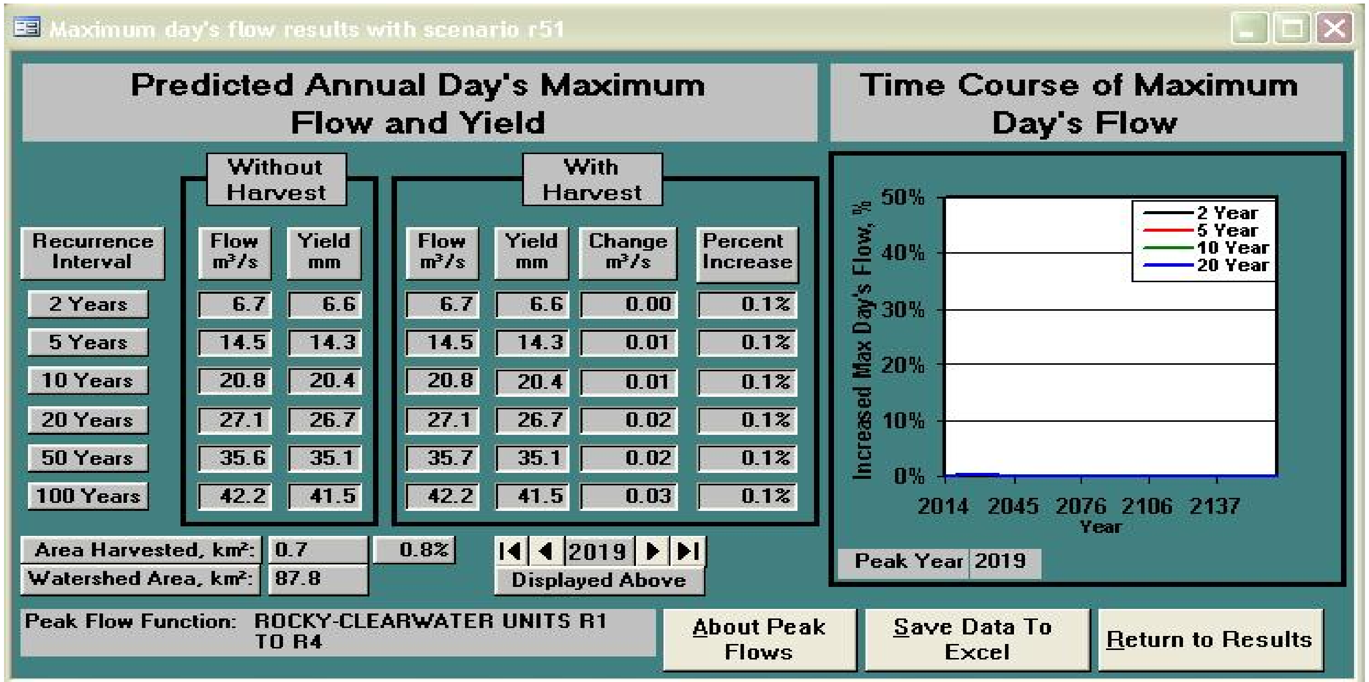








Watershed 5001…continued



Maximum day's flow results with scenario r51

Predicted Annual Day's Maximum Flow and Yield

Recurrence Interval	Without Harvest Flow m³/s	Without Harvest Yield mm	With Harvest Flow m³/s	With Harvest Yield mm	Change m³/s	Percent Increase
2 Years	6.7	6.6	6.7	6.6	0.00	0.1%
5 Years	14.5	14.3	14.5	14.3	0.01	0.1%
10 Years	20.8	20.4	20.8	20.4	0.01	0.1%
20 Years	27.1	26.7	27.1	26.7	0.02	0.1%
50 Years	35.6	35.1	35.7	35.1	0.02	0.1%
100 Years	42.2	41.5	42.2	41.5	0.03	0.1%

Area Harvested, km²: 0.7 0.8%

Watershed Area, km²: 87.8

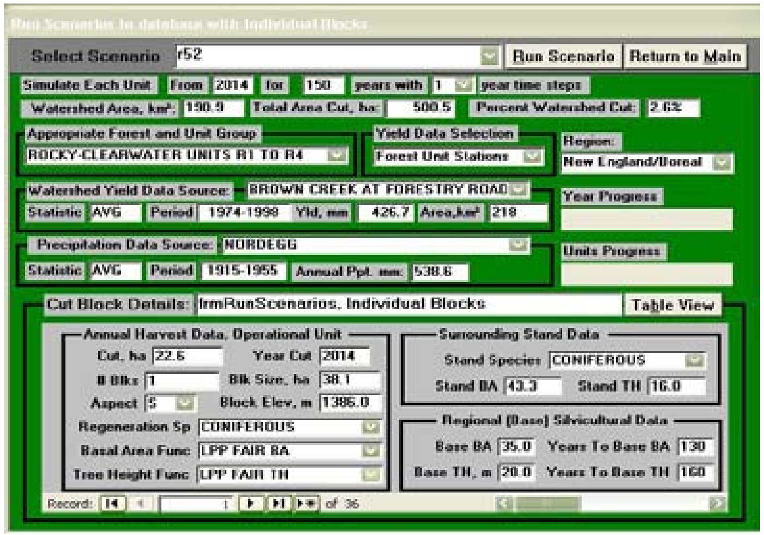
2019 Displayed Above

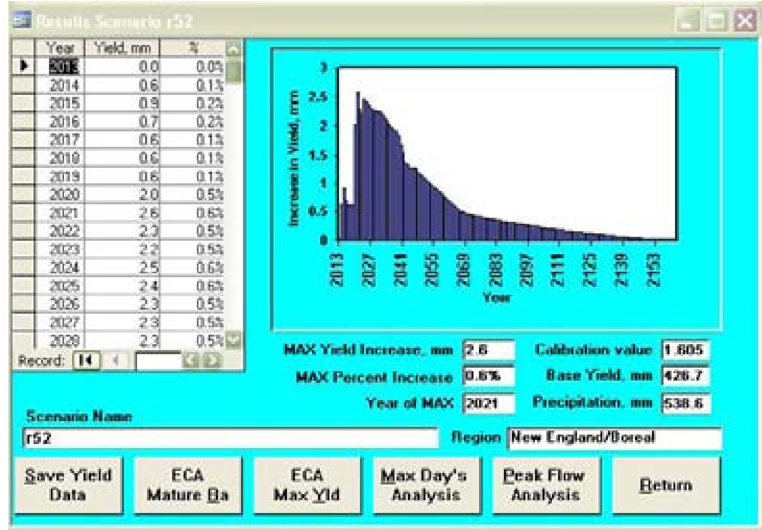
Peak Flow Function: ROCKY-CLEARWATER UNITS R1 TO R4

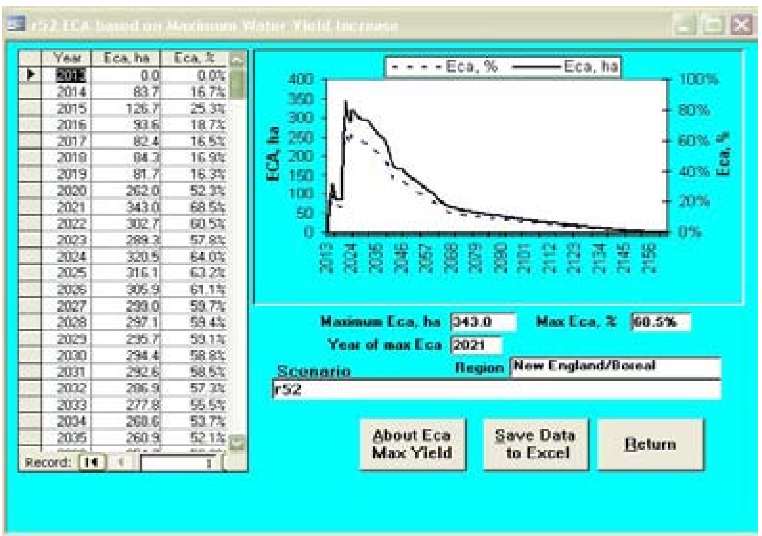
About Peak Flows | Save Data To Excel | Return to Results

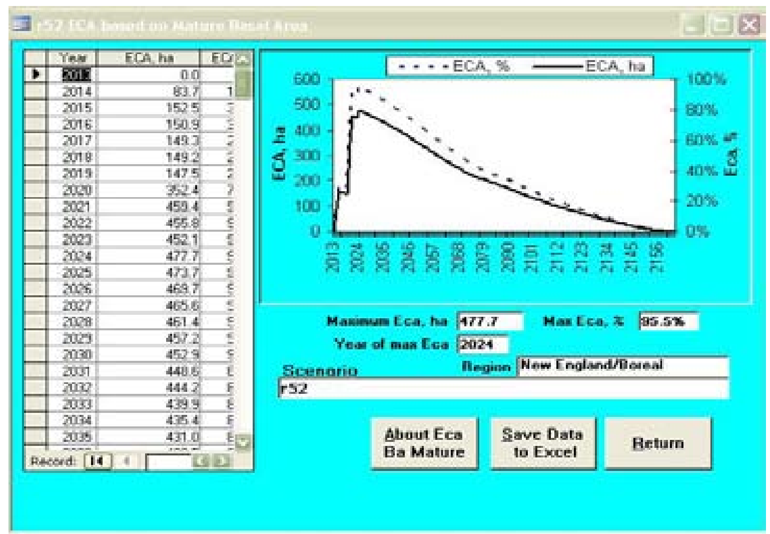
Time Course of Maximum Day's Flow

Watershed 5002

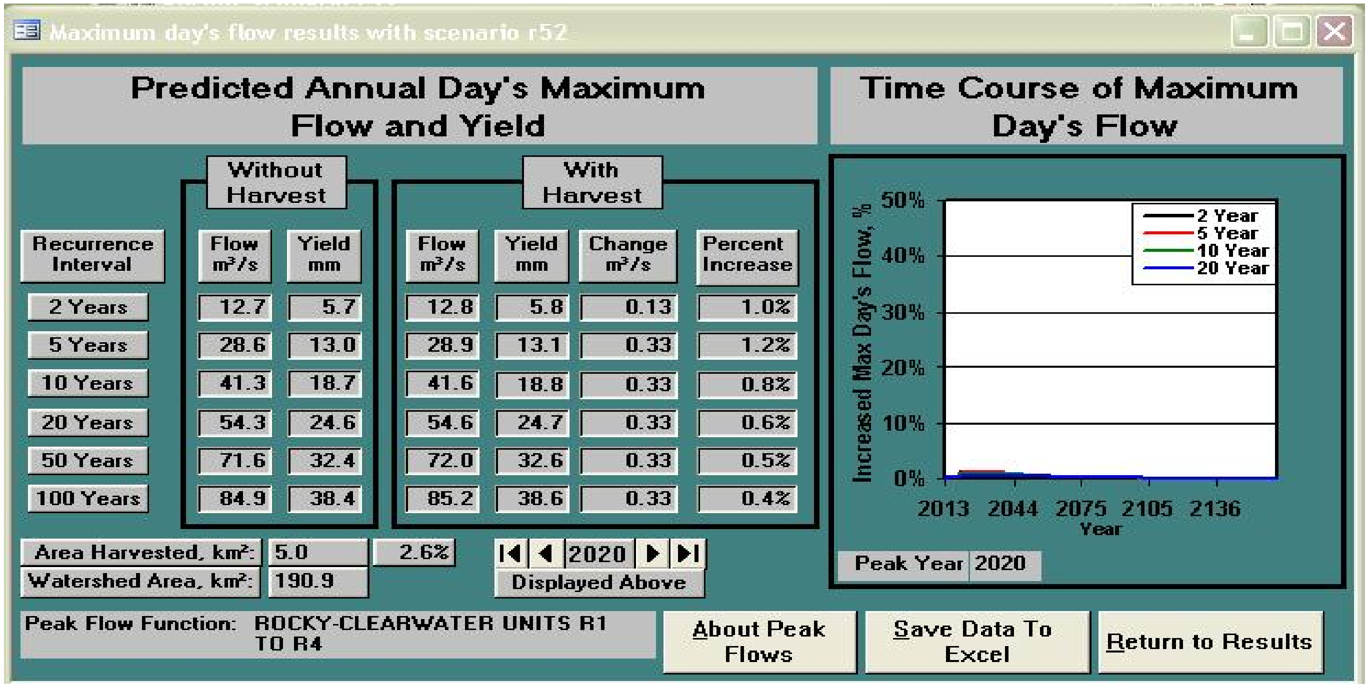








Watershed 5002…continued



Maximum day's flow results with scenario r52

Predicted Annual Day's Maximum Flow and Yield

Recurrence Interval	Without Harvest: Flow m³/s	Without Harvest: Yield mm	With Harvest: Flow m³/s	With Harvest: Yield mm	With Harvest: Change m³/s	With Harvest: Percent Increase
2 Years	12.7	5.7	12.8	5.8	0.13	1.0%
5 Years	28.6	13.0	28.9	13.1	0.33	1.2%
10 Years	41.3	18.7	41.6	18.8	0.33	0.8%
20 Years	54.3	24.6	54.6	24.7	0.33	0.6%
50 Years	71.6	32.4	72.0	32.6	0.33	0.5%
100 Years	84.9	38.4	85.2	38.6	0.33	0.4%

Area Harvested, km²: 5.0 | 2.6%

Watershed Area, km²: 190.9

2020 Displayed Above

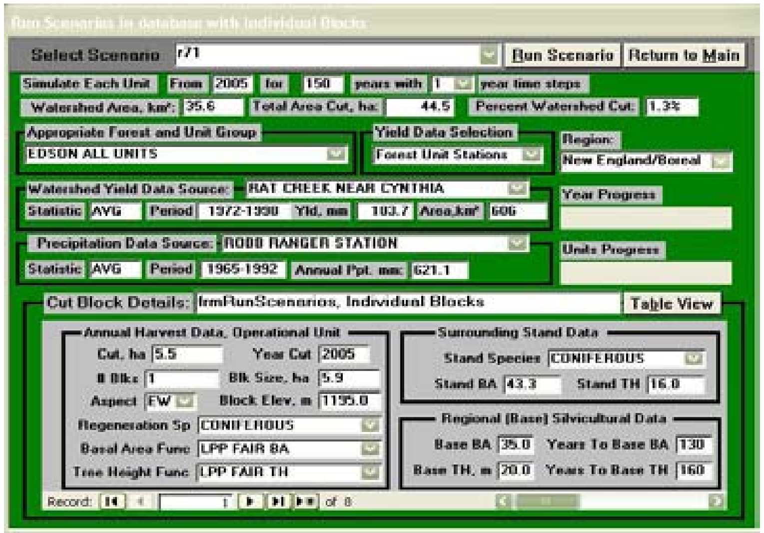
Peak Flow Function: ROCKY-CLEARWATER UNITS R1 TO R4

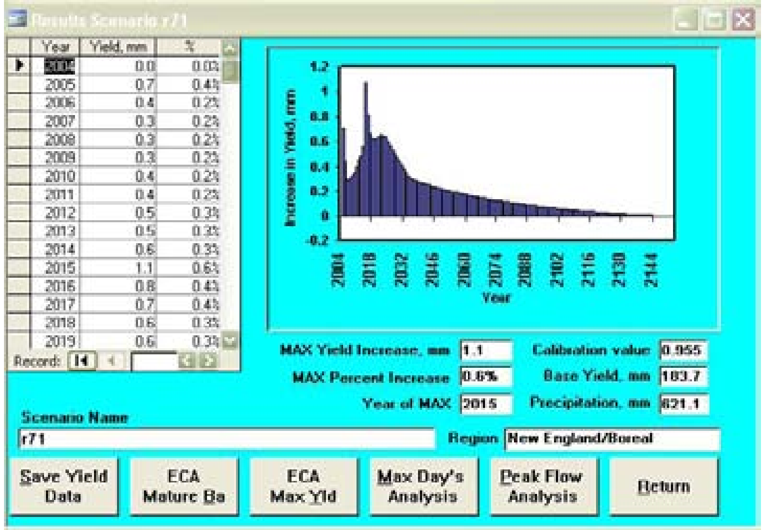
About Peak Flows | Save Data To Excel | Return to Results

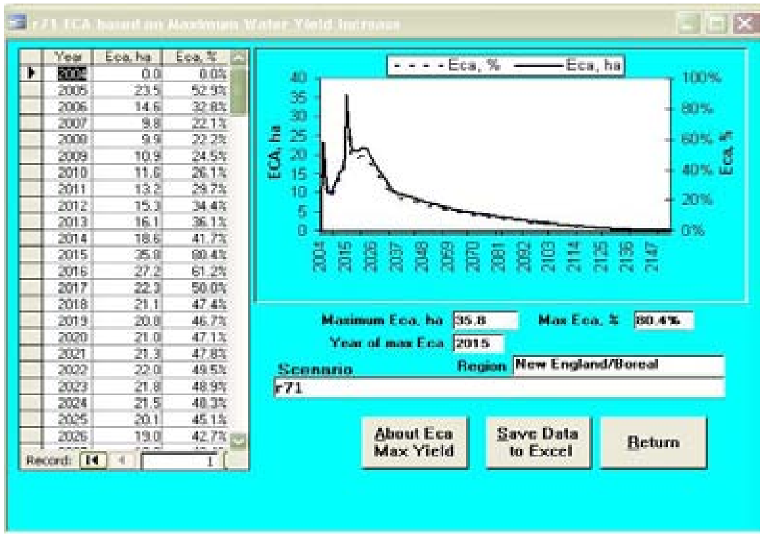
Time Course of Maximum Day's Flow

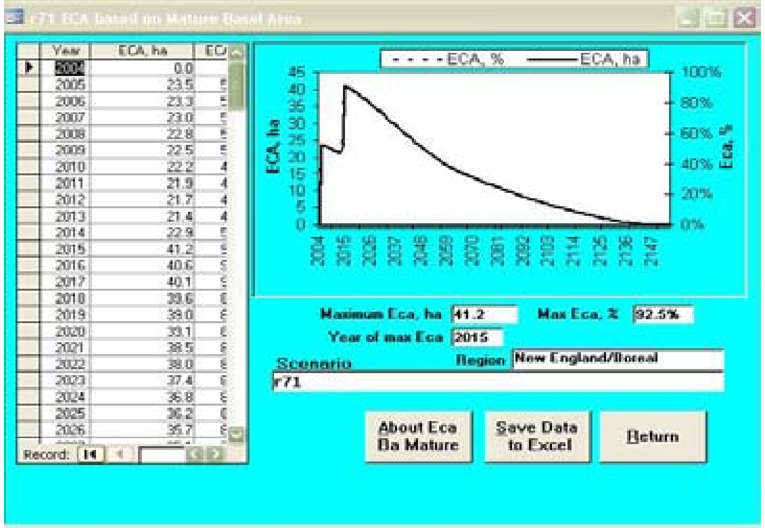
Peak Year 2020

Watershed 7001

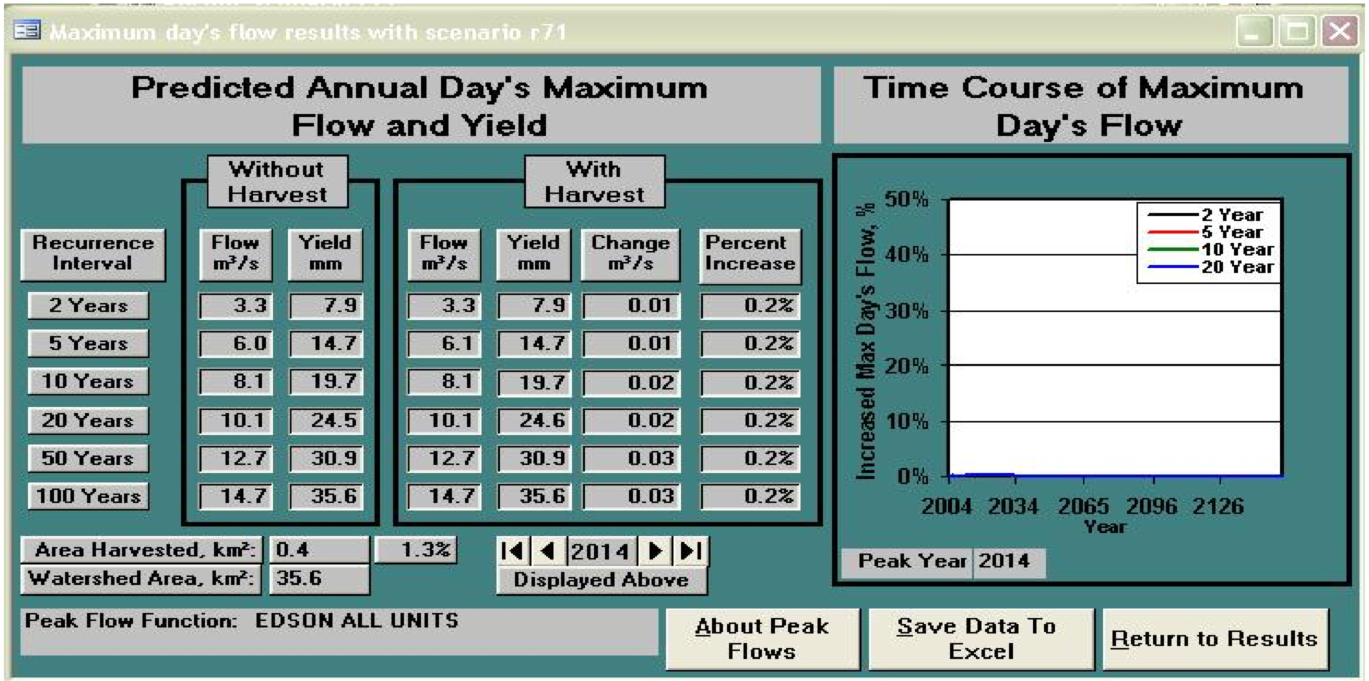








Watershed 7001…continued



Maximum day's flow results with scenario r71

Predicted Annual Day's Maximum Flow and Yield

Recurrence Interval	Without Harvest: Flow m^3/s	Without Harvest: Yield mm	With Harvest: Flow m^3/s	With Harvest: Yield mm	With Harvest: Change m^3/s	With Harvest: Percent Increase
2 Years	3.3	7.9	3.3	7.9	0.01	0.2%
5 Years	6.0	14.7	6.1	14.7	0.01	0.2%
10 Years	8.1	19.7	8.1	19.7	0.02	0.2%
20 Years	10.1	24.5	10.1	24.6	0.02	0.2%
50 Years	12.7	30.9	12.7	30.9	0.03	0.2%
100 Years	14.7	35.6	14.7	35.6	0.03	0.2%

Area Harvested, km^2: 0.4 1.3%
Watershed Area, km^2: 35.6

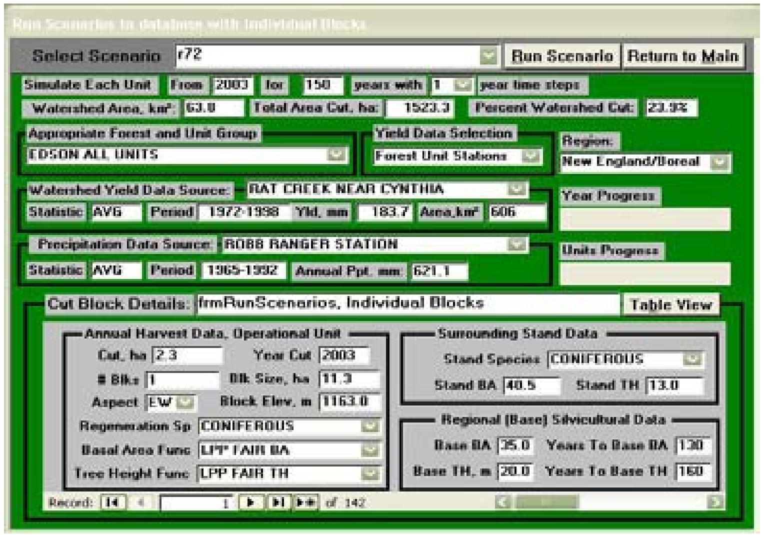
2014
Displayed Above

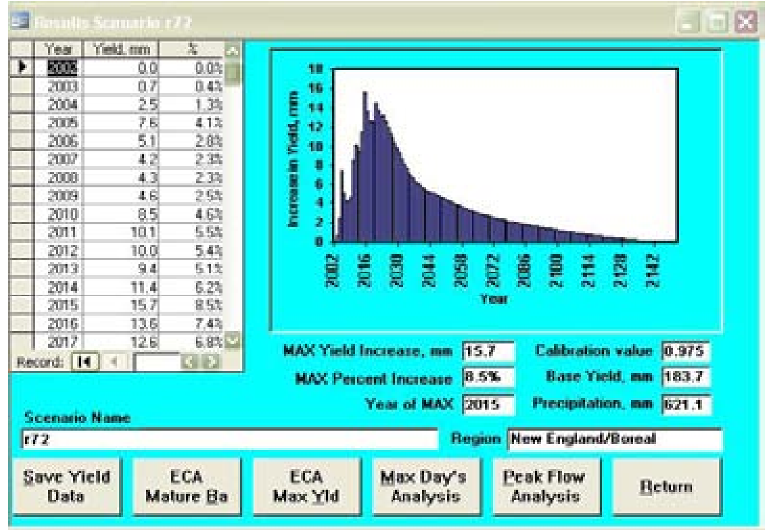
Peak Flow Function: EDSON ALL UNITS

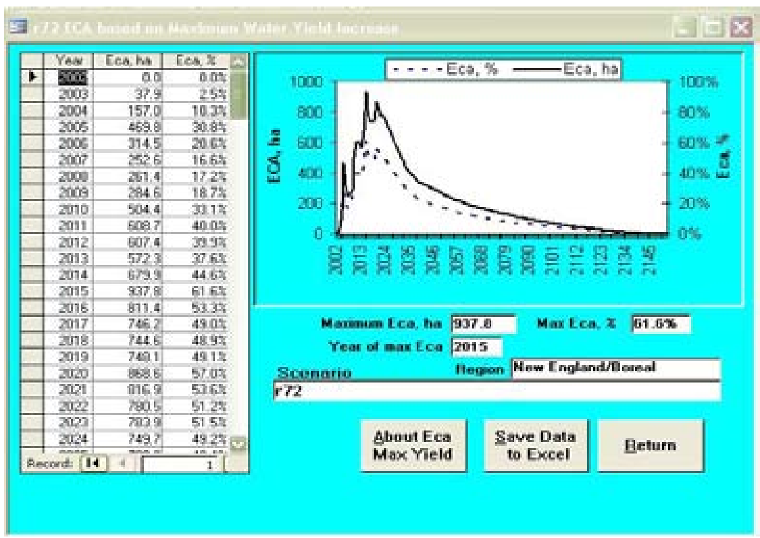
About Peak Flows
Save Data To Excel
Return to Results

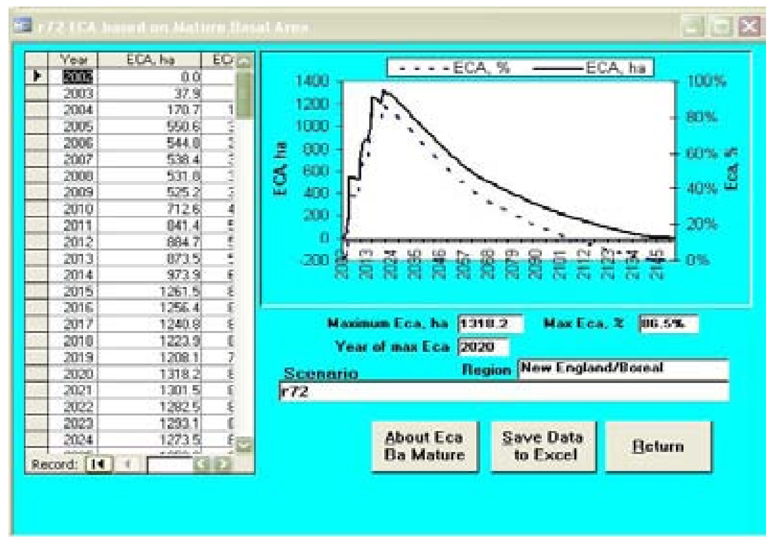
Time Course of Maximum Day's Flow

Watershed 7002

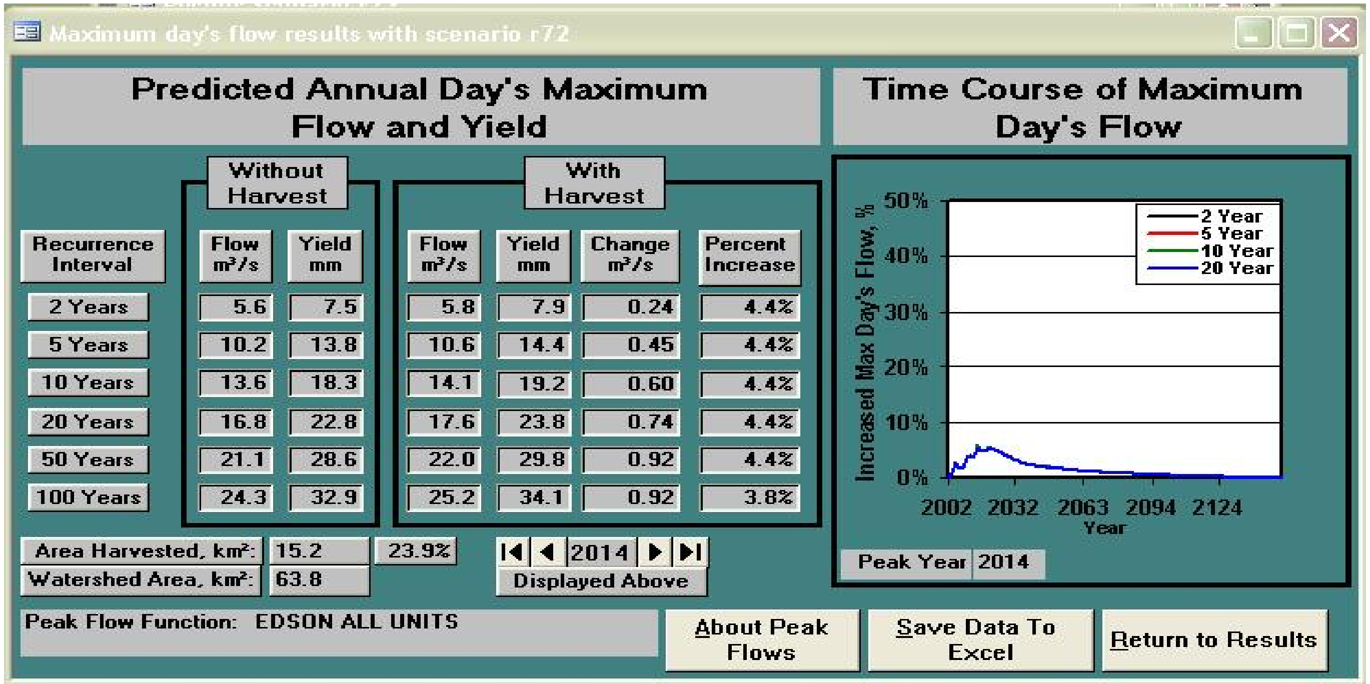




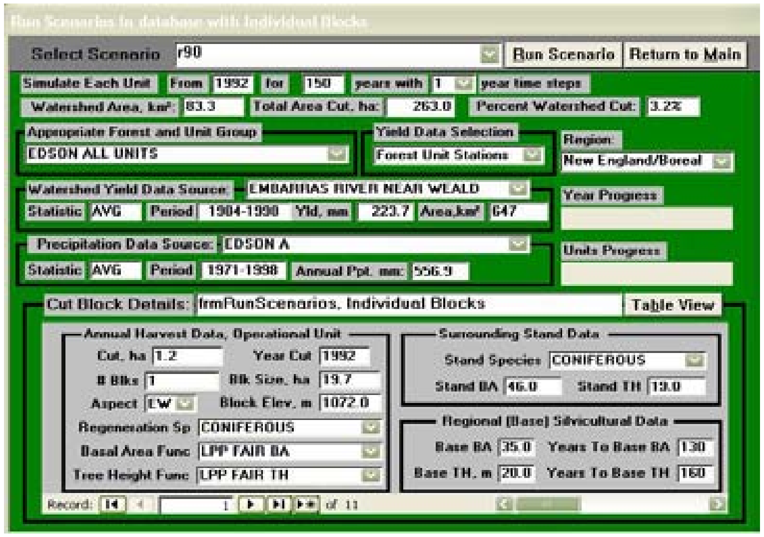


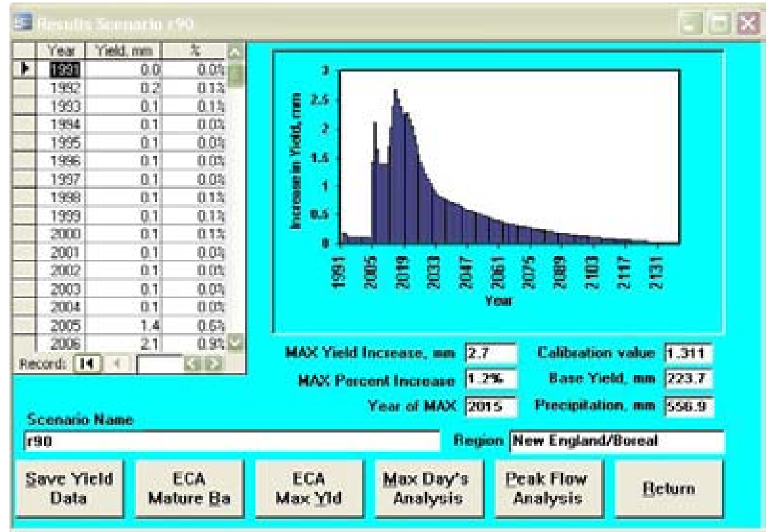


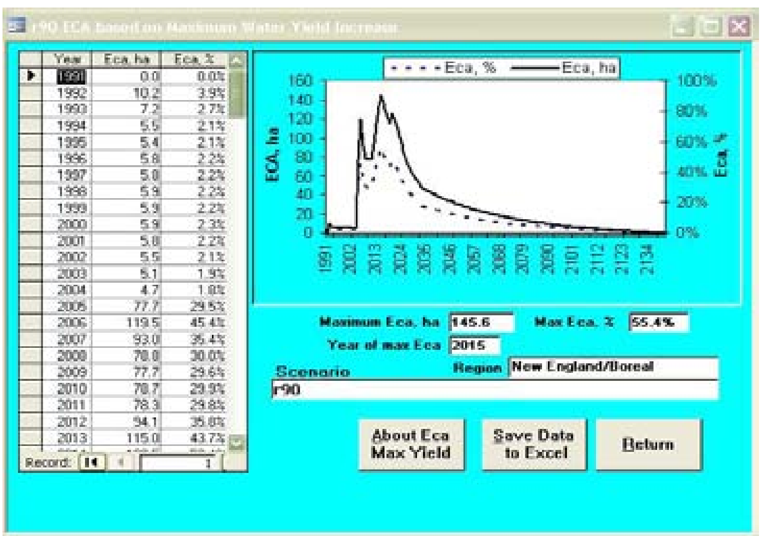
Watershed 7002…continued

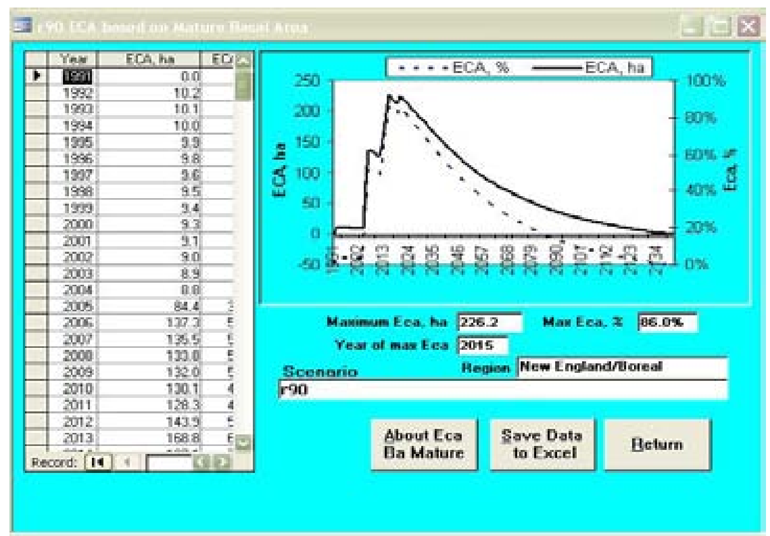


Watershed 9000

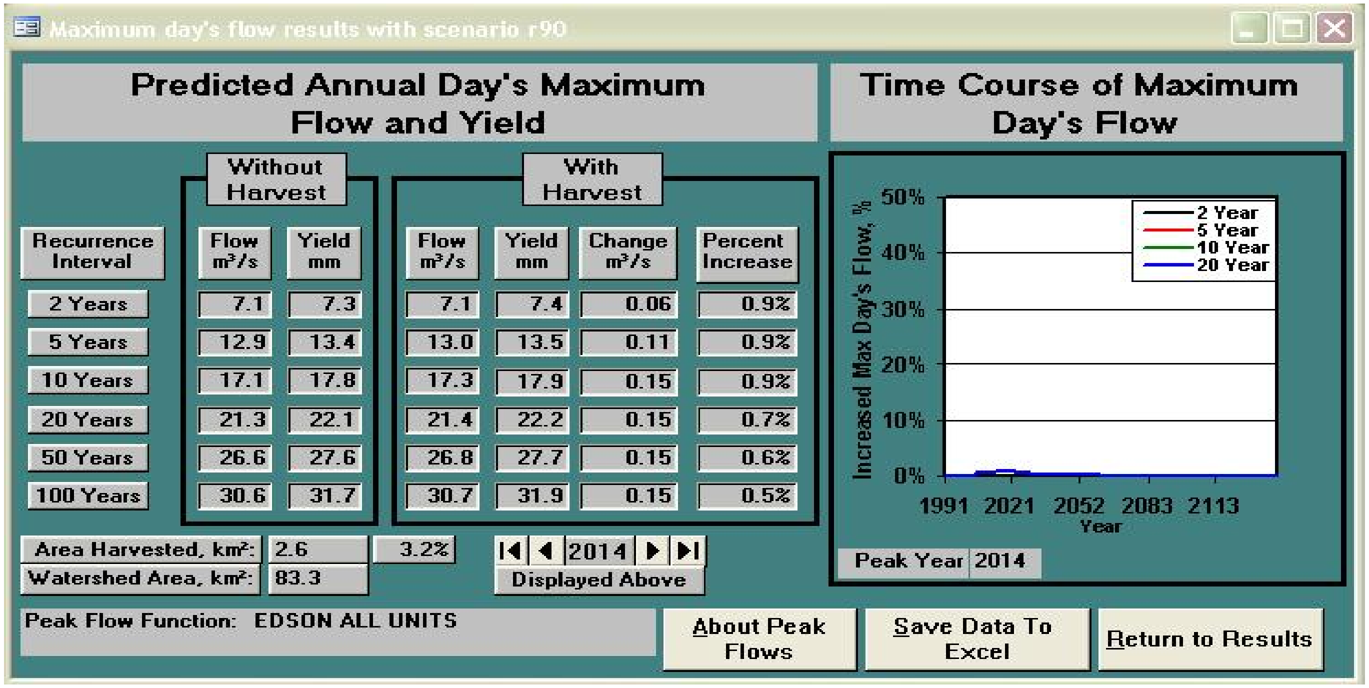






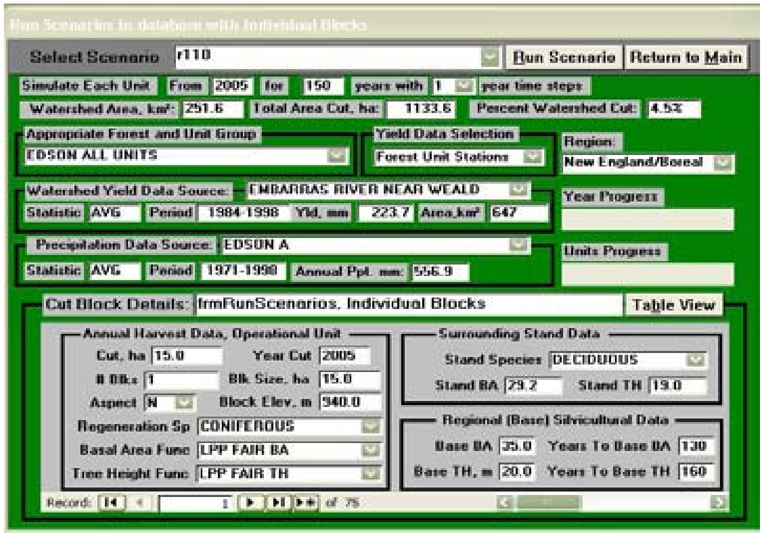


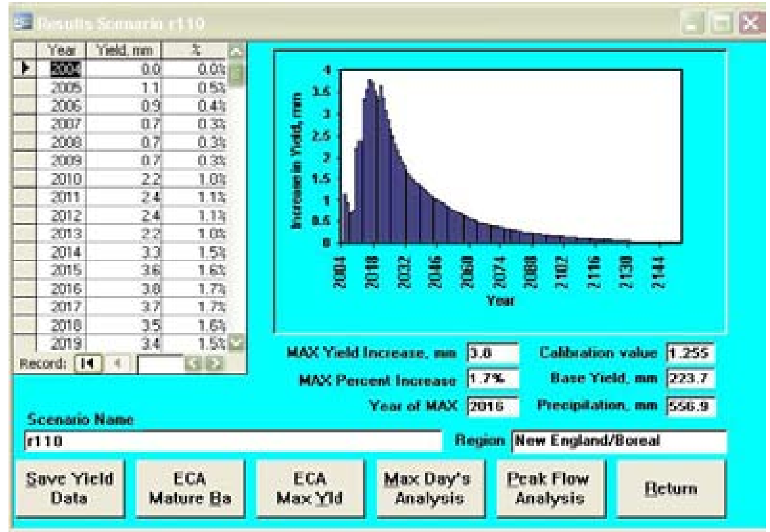
Watershed 9000…continued

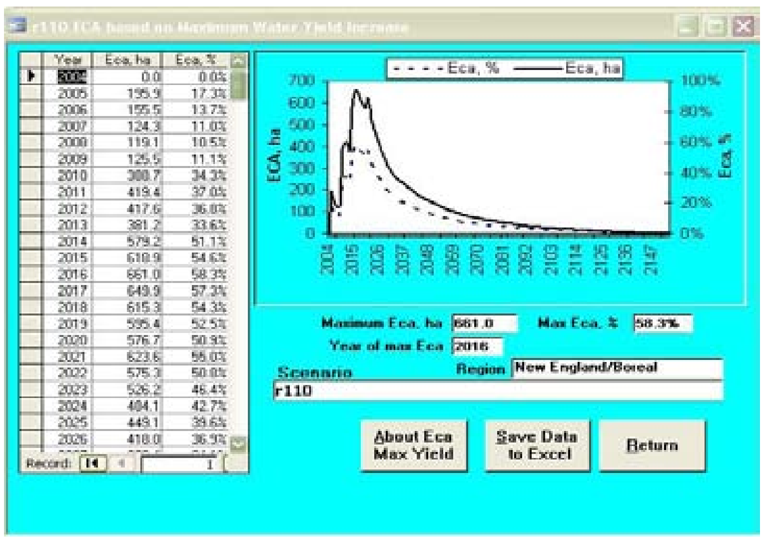


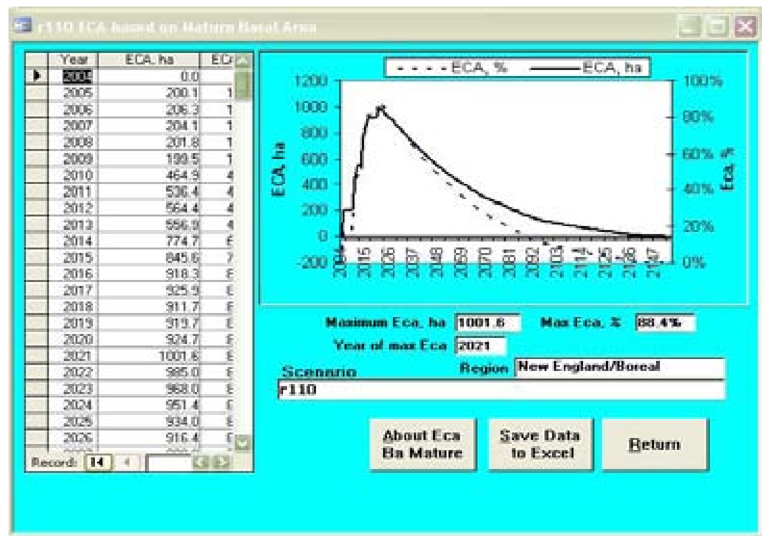
Recurrence Interval	Without Harvest Flow m^3/s	Without Harvest Yield mm	With Harvest Flow m^3/s	With Harvest Yield mm	Change m^3/s	Percent Increase
2 Years	7.1	7.3	7.1	7.4	0.06	0.9%
5 Years	12.9	13.4	13.0	13.5	0.11	0.9%
10 Years	17.1	17.8	17.3	17.9	0.15	0.9%
20 Years	21.3	22.1	21.4	22.2	0.15	0.7%
50 Years	26.6	27.6	26.8	27.7	0.15	0.6%
100 Years	30.6	31.7	30.7	31.9	0.15	0.5%

Watershed 1100









Watershed 1100…continued

Maximum day's flow results with scenario r110

Predicted Annual Day's Maximum Flow and Yield

	Without Harvest		With Harvest			
Recurrence Interval	Flow m³/s	Yield mm	Flow m³/s	Yield mm	Change m³/s	Percent Increase
2 Years	19.4	6.7	19.6	6.7	0.25	1.3%
5 Years	34.5	11.9	35.0	12.0	0.44	1.3%
10 Years	45.4	15.6	45.9	15.8	0.57	1.3%
20 Years	55.9	19.2	56.6	19.4	0.69	1.2%
50 Years	69.4	23.8	70.2	24.1	0.76	1.1%
100 Years	79.4	27.3	80.2	27.5	0.76	1.0%

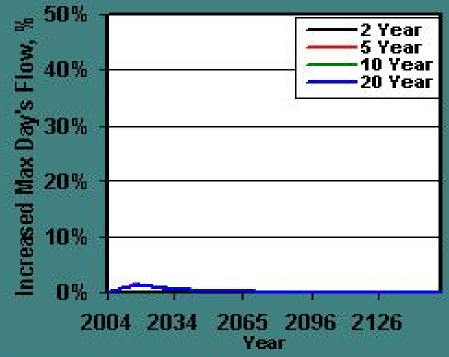
Area Harvested, km²: 11.3 4.5%

Watershed Area, km²: 251.6

2015 Displayed Above

Peak Flow Function: EDSON ALL UNITS

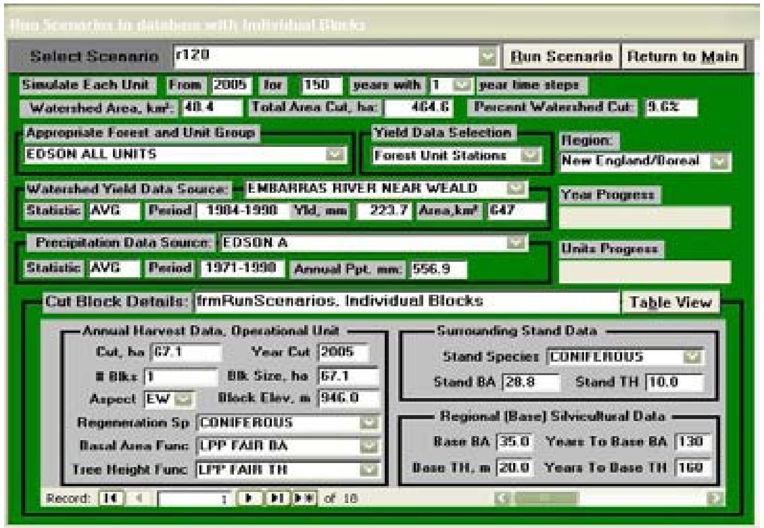
Time Course of Maximum Day's Flow

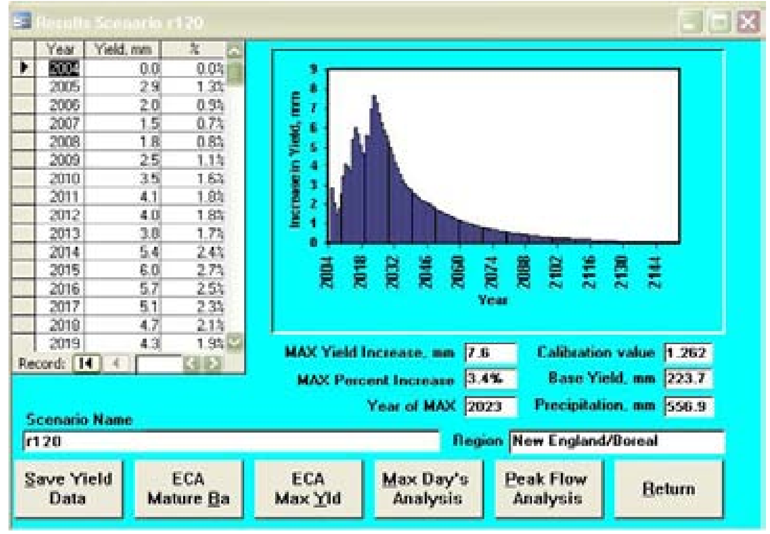


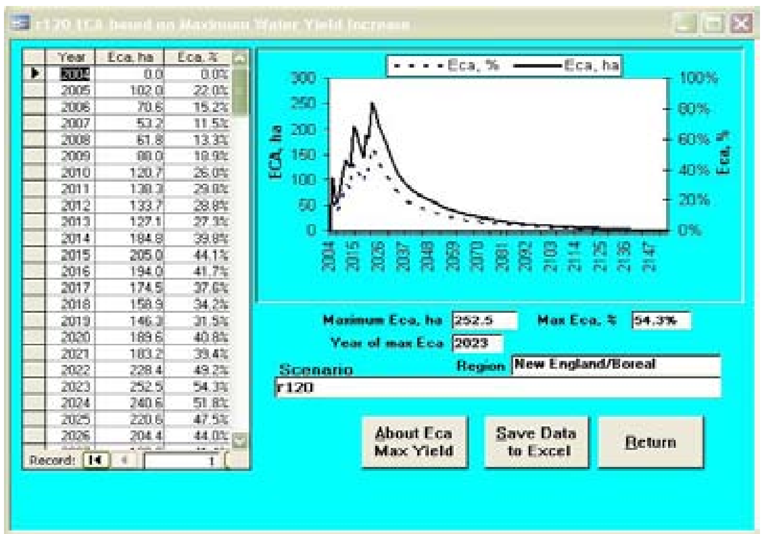
Peak Year 2015

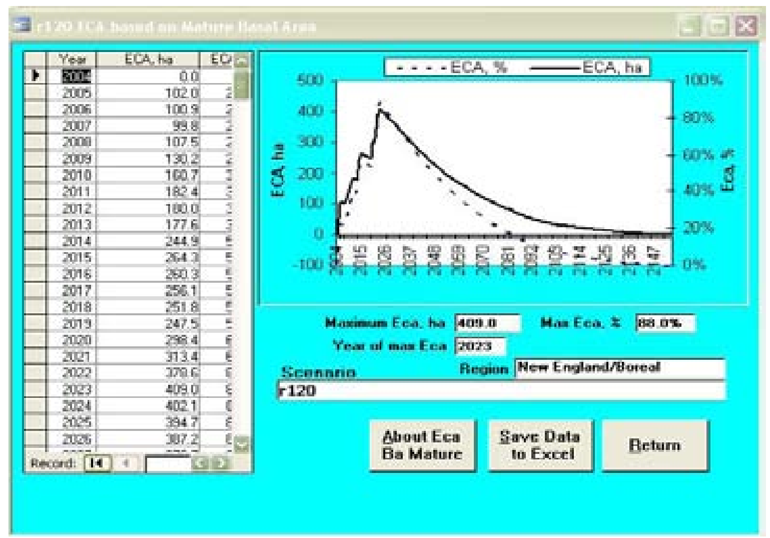
About Peak Flows | Save Data To Excel | Return to Results

Watershed 1200

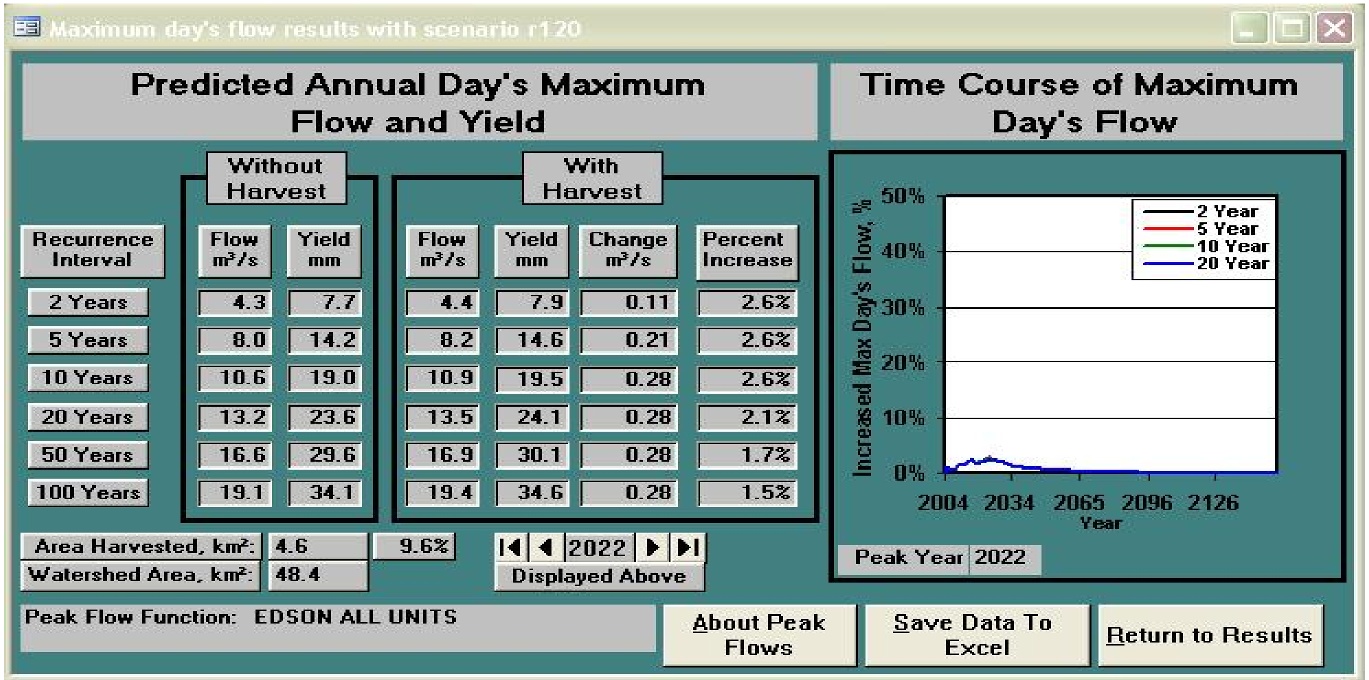




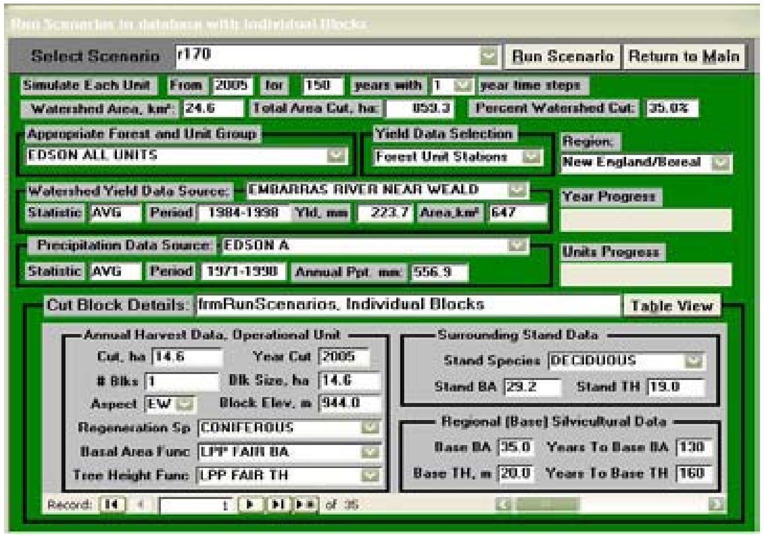


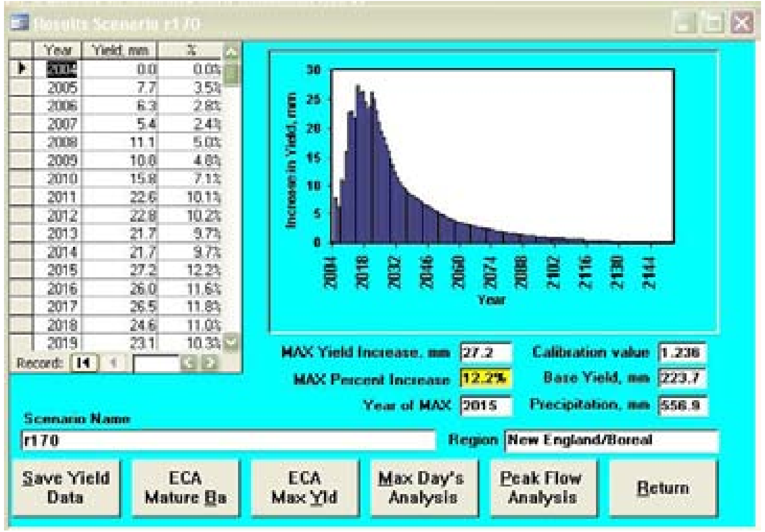


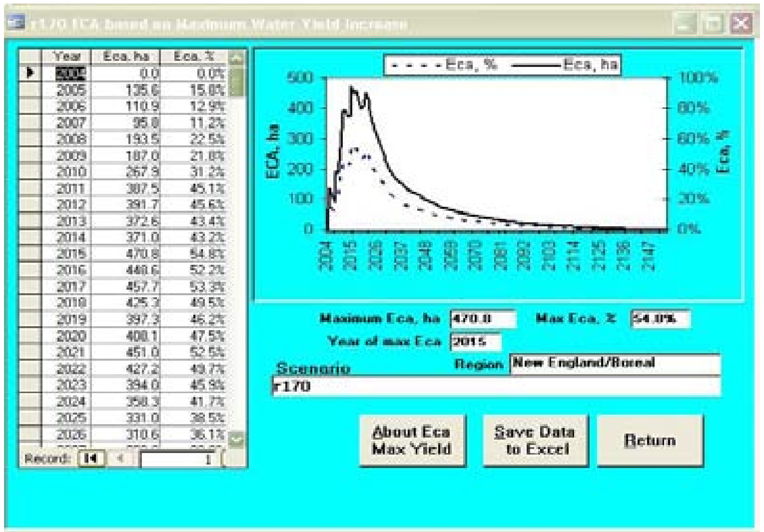
Watershed 1200…continued

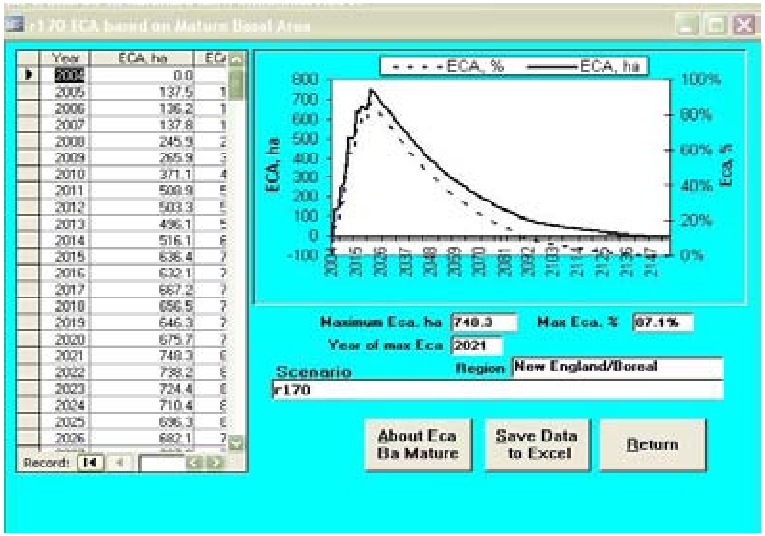


Watershed 1700

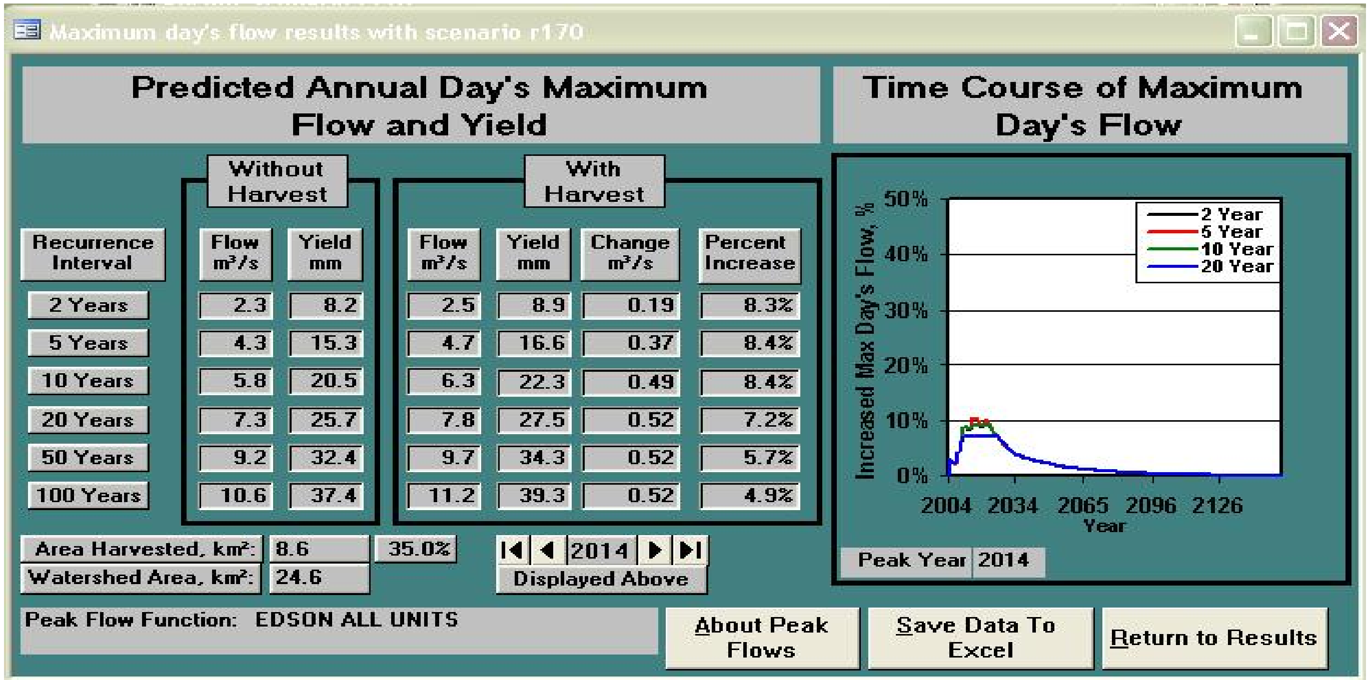








Watershed 1700…continued



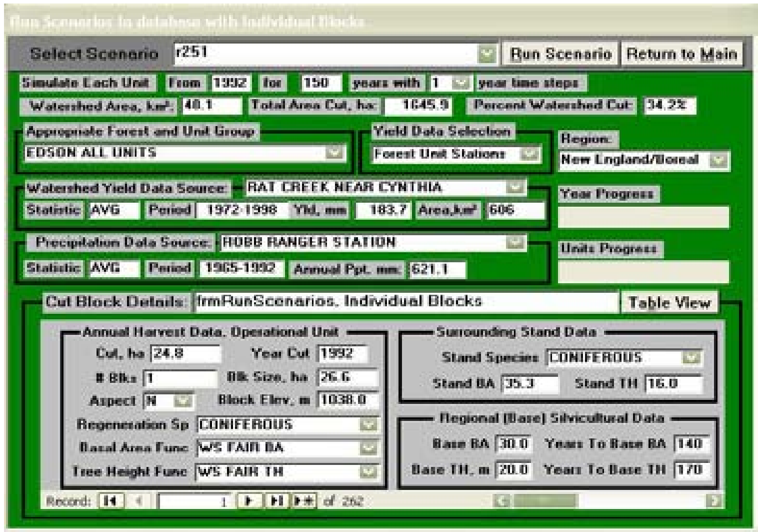
Maximum day's flow results with scenario r170

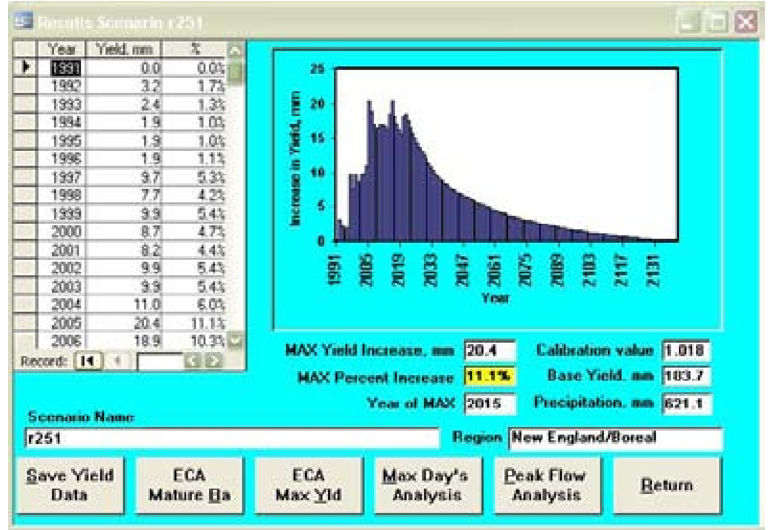
Predicted Annual Day's Maximum Flow and Yield

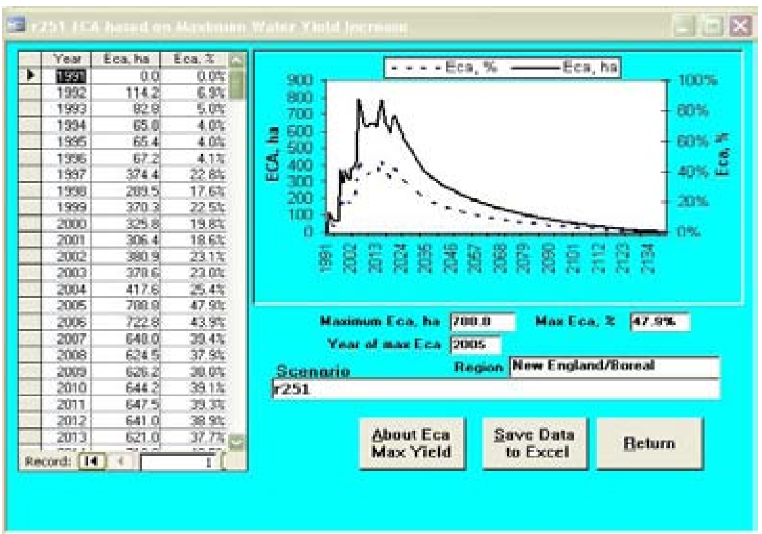
Recurrence Interval	Without Harvest Flow m³/s	Without Harvest Yield mm	With Harvest Flow m³/s	With Harvest Yield mm	Change m³/s	Percent Increase
2 Years	2.3	8.2	2.5	8.9	0.19	8.3%
5 Years	4.3	15.3	4.7	16.6	0.37	8.4%
10 Years	5.8	20.5	6.3	22.3	0.49	8.4%
20 Years	7.3	25.7	7.8	27.5	0.52	7.2%
50 Years	9.2	32.4	9.7	34.3	0.52	5.7%
100 Years	10.6	37.4	11.2	39.3	0.52	4.9%

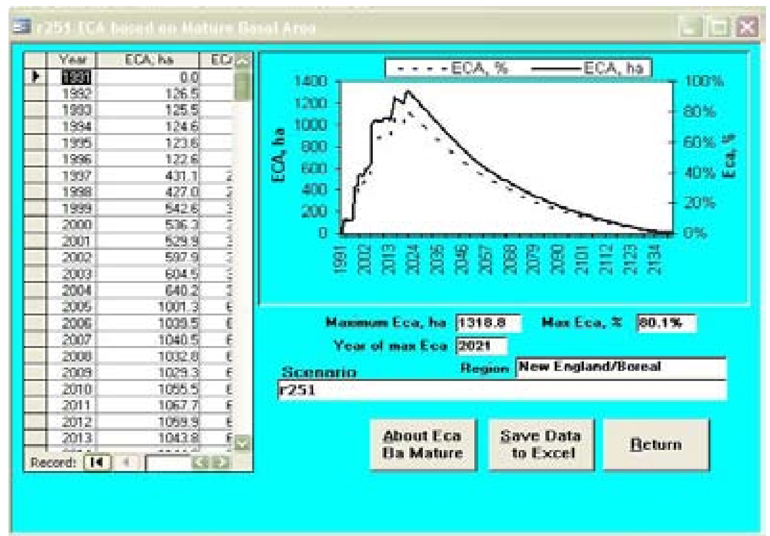
Area Harvested, km²: 8.6 35.0%
Watershed Area, km²: 24.6
2014 Displayed Above
Peak Flow Function: EDSON ALL UNITS

Watershed 2501

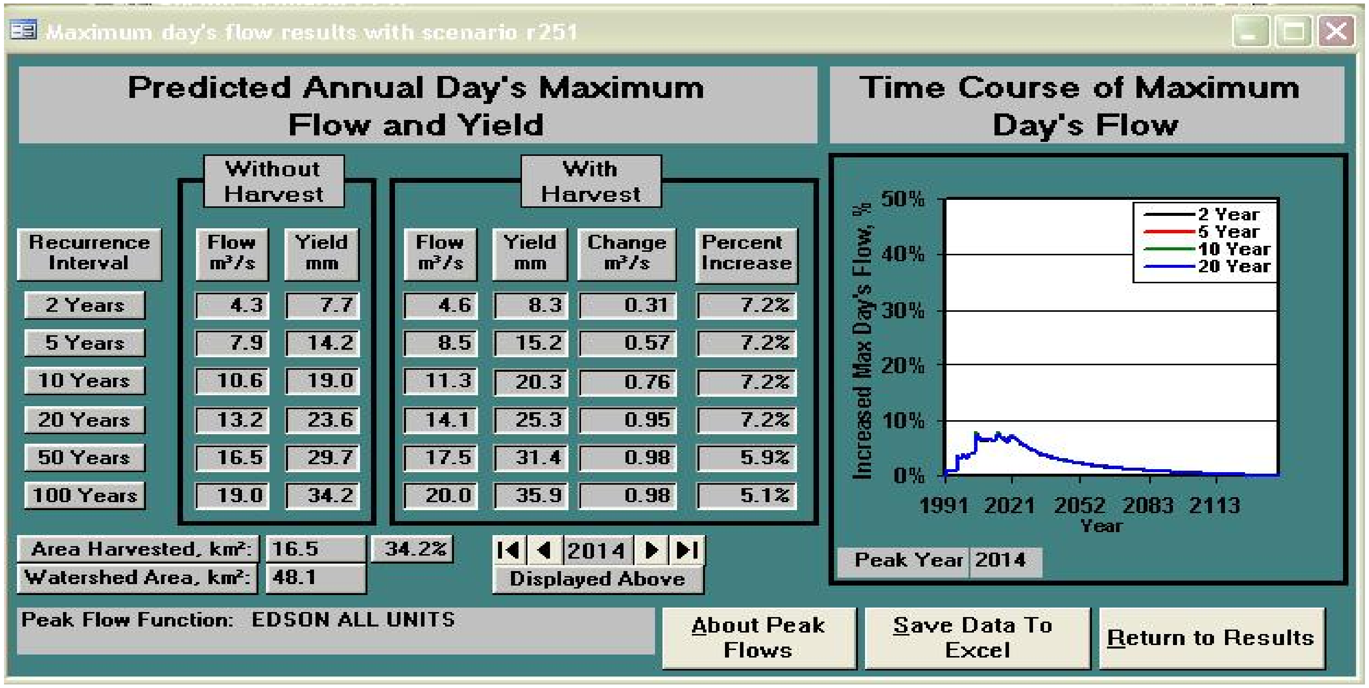




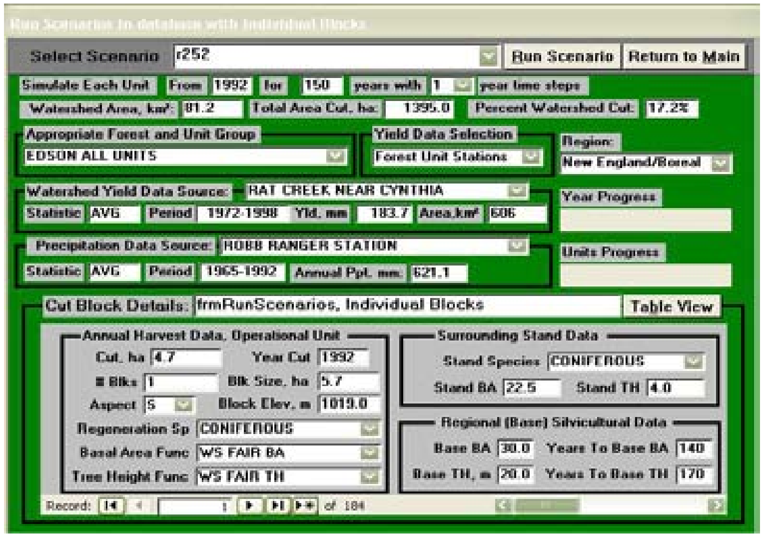


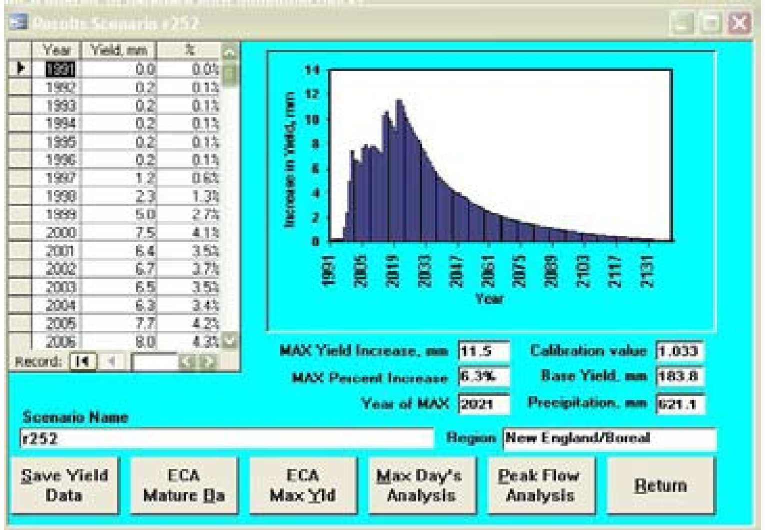


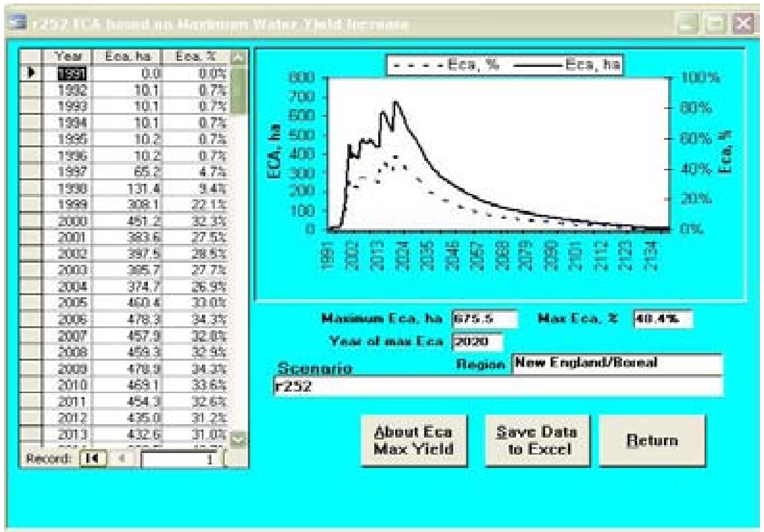
Watershed 2501…continued

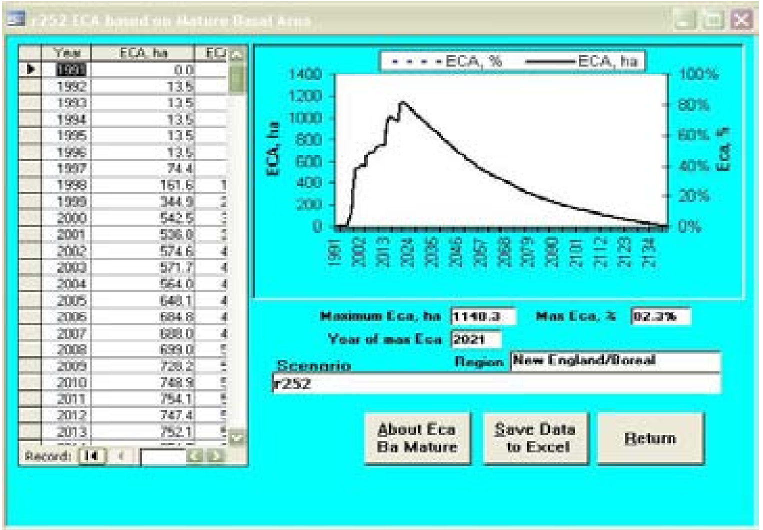


Watershed 2502

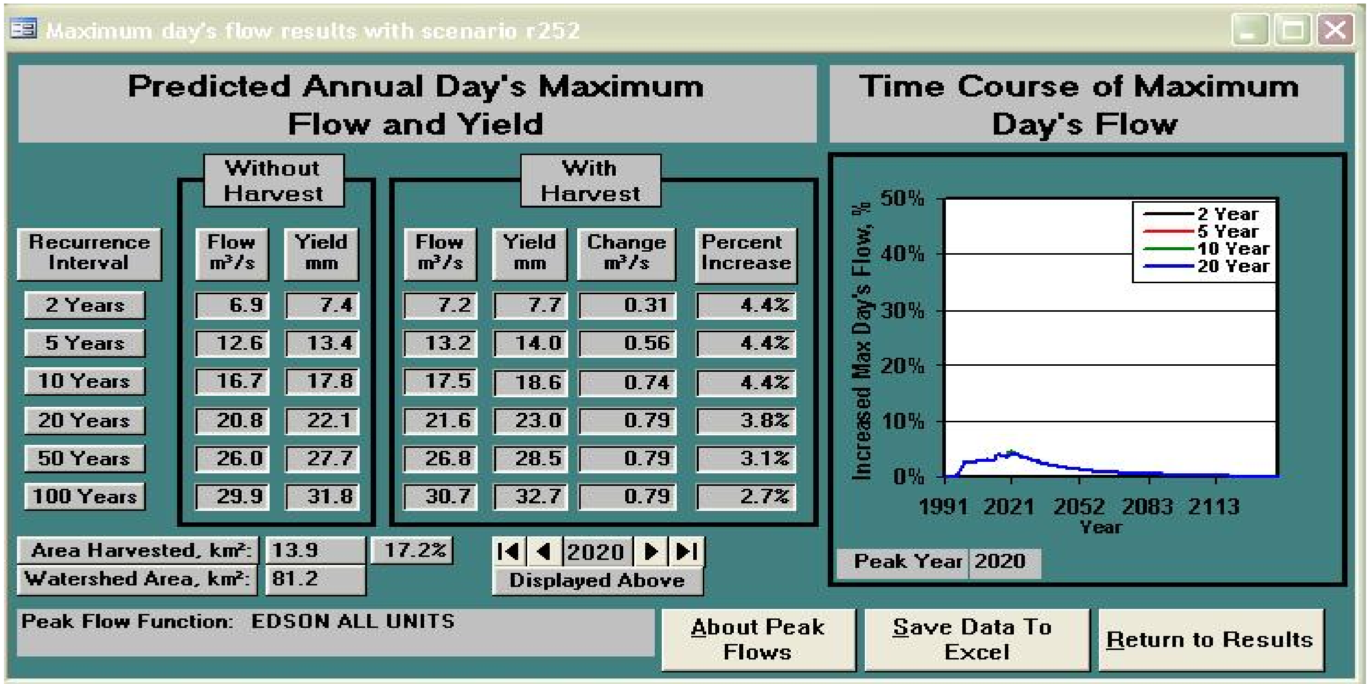








Watershed 2502…continued



Maximum day's flow results with scenario r252

Predicted Annual Day's Maximum Flow and Yield

Recurrence Interval	Without Harvest Flow m³/s	Without Harvest Yield mm	With Harvest Flow m³/s	With Harvest Yield mm	Change m³/s	Percent Increase
2 Years	6.9	7.4	7.2	7.7	0.31	4.4%
5 Years	12.6	13.4	13.2	14.0	0.56	4.4%
10 Years	16.7	17.8	17.5	18.6	0.74	4.4%
20 Years	20.8	22.1	21.6	23.0	0.79	3.8%
50 Years	26.0	27.7	26.8	28.5	0.79	3.1%
100 Years	29.9	31.8	30.7	32.7	0.79	2.7%

Area Harvested, km²: 13.9 17.2%

Watershed Area, km²: 81.2

2020 Displayed Above

Peak Flow Function: EDSON ALL UNITS