11 July 2003

Documentation for DELTA-Q Program

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Purpose and origin of the program

This program is designed to calculate the cumulative changes in flow on a watershed scale from areas subjected to the combination of forest harvest and roads. The change in flow due to the removal of forest cover by fires also can be calculated, but data limitations means that the fire-induced changes in flow only consider the change in forest cover, and not the possible effects of a change in runoff processes. Flows are defined in terms of their percentile on a flow duration curve, and the user selects the flows that they are most interested in (e.g., high flows, low flows, or the median annual flow). In this program high flows are represented by the 99th percentile (i.e., the flow that is only exceeded 1% of the time), median flows are the 50th percentile, and low flows are represented by the 1st percentile (i.e., the flow that is exceeded 99% of the time). The default values and values in the database are based on daily rather than instantaneous flows.

The program allows users to estimate the change in flow in either absolute terms (cubic feet per second per square mile, or cfs mi^{-2}) or percentage terms. The user must select or provide these values for the area that they are modeling. To facilitate this process, the program provides a database of the absolute and percent changes in flow from 26 paired-catchment experiments (Austin, 1999). Because the Delta-Q program has no means for estimating the baseline flow conditions in the watershed(s) being simulated, the percent changes in flows are relative to the flows measured in each of the control watersheds, not the watershed(s) being simulated. Hence calculations of percent change are likely to be less reliable than calculations of the absolute changes, as the actual percent change in the simulated watershed will depend in part on the magnitude of the runoff in the watershed(s) being simulated. In some cases the percent change may have limited physical meaning, such as when the base flow for comparison is very small (i.e., a large increase in a small number is still a small number).

Selection and origin of the changes in flow. The program allows users to input their own values for changes in a given flow percentile or they can use the default values. The default values represent the median change determined from an analysis of selected flow percentiles for 26 paired-catchment experiments using flow duration curves (Austin, 1999). The change in flow for each paired watershed study was determined by first calculating the change in flows between the calibration and treatment periods for the control watershed. The pre-treatment flows on the treated watershed were then adjusted according to the observed change in flow on the control watershed. The difference between the adjusted flows for the calibration period and the measured flows for the treatment period on the treated watershed was assumed to represent the treatment effect (typically road building and forest harvest) (Austin, 1999). To minimize the effect of year-to-year variability, the changes in flow were calculated for the first three years after treatment. The resulting values are presumed to represent the change in flows in the first year after harvest or fires, as the hydrologic recovery in the first three years after an activity should be relatively small. The rate of hydrologic recovery was determined for each paired-watershed study by calculating the changes in flow after treatment for up to five successive two-year periods, depending on the number of years of post-treatment flow data.

The observed changes in flow unavoidably include the effects of roads and skid trails as well as forest harvest. In some cases roads were constructed prior to forest harvest, but a review of studies from 135 treated catchments found only one study with a statistically significant change in flow due to roads and landings (Harr et al., 1975). In that study 12% of the watershed area was in roads and landings, which is a much higher percentage than would be expected under current management guidelines and best management practices. A recent review of hydrograph changes in 10 paired-catchment studies suggested that roads were an important cause of the observed increases in flow for large events (Jones, 2000), but the effect of roads could not be independently identified.

The program allows the user to view the results from each paired-catchment study, and then enter a change in flow according to the study(ies) that best represent their watershed. For reference, the median absolute and percent changes in the 99th flow percentile are 0.19 cfs mi^{-2} and 12%, respectively. For the 50^{th} percentile, the median and absolute and percent changes in flow are 0.02 cfs mi^{-2} and 22%, and for the 1^{st} percentile the median absolute and percent changes in flow are 0.005 cfs mi^{-2} and 59%, respectively. Note the percent change at lower flows is much larger than the percent change at higher flows, but the absolute changes are much greater for the higher flow percentiles (i.e., nearly all of the additional water comes during periods of higher flows). Because some streams dried up or were not monitored during winter low flows, the median change in flow for the 50^{th} percentile is based on 26 studies, and the median change for the 1^{st} percentile is based on only 18 studies (Austin, 1999). The absolute values can be converted to L^3 s^{-1} ha^{-2} by multiplying by 0.109, and to m^3 s^{-1} km^{-2} by multiplying by 0.0109.

It should be noted that approximately half of the 26 basins had at least 85% of the vegetation removed, while 12 basins had less than 85% of the vegetation removed. While the change in flow due to forest harvest should increase as a greater percent of the forest cover is removed, simple regression analysis for the study watersheds showed that percent area cut explained less than 20% of the observed changes in absolute flows for the 50^{th} and 99^{th} percentiles, and 38% of the variability in the 1^{st} percentile. This indicates that site conditions are a very important control on the magnitude of the observed changes in flow. We've explicitly chosen to present the original values in the database rather than linearly adjusting the observed changes in flow on partially-cut basins to 100% removal of the forest cover. However, the user may choose to adjust the values in the database according to the percent harvested, and the database contains the necessary information to do so.

Selection of the time period for hydrologic recovery. The successive analysis of the flow duration curves showed that hydrologic recovery is much more rapid for low flows than for high flows. Conceptually, it seems that relatively little regrowth is needed for summer evapotranspiration to "use" up the water saved by the removal of forest vegetation, and by 10 years after harvest there typically is no statistically significant increase in low or median flows. In contrast, the recovery in high flows is much slower, implying a slower recovery of the processes that control the change in high flows. Depending on the location, these processes could include the change in rainfall interception rates during larger storm events, the change in peak snowmelt rates, and the change in runoff due to roads or soil compaction.

The program assumes a linear decline in the change in flows until complete hydrologic recovery. The suggested default values for hydrologic recovery are one-third to one-half the rotation age for the 99^{th} percentile, no more than one-quarter of the rotation age for median flows, and a maximum of 10 years for the 1^{st} percentile flow. Again, the user can modify the rates of hydrologic recovery if the default values are not believed to be representative of the watershed(s) being modeled.

<u>Effects of fires and roads on flow percentiles as compared to forest harvest.</u> For the purpose of this program, the change in flow due to forest harvest is presumed to be the same as the change in flow due to the removal of the forest vegetation by burning. This assumption is unlikely to be valid when the runoff processes have been substantially altered by a fire-induced water repellent layer (e.g., DeBano, 1981, 2000) or the soil sealing that can occur after burning the surface organic layer (Ramos et al., 2000). In such cases burning may induce a much larger increase in peak flows than would result from forest harvest, but the paucity of post-fire runoff data and the high variability between sites (see review in Robichaud et al., 2000) precluded us from suggesting default values for the changes in flow from severely-burned areas. The difference in the change in runoff between forest harvest and severely-burned areas probably will be greatest for rain-dominated areas and areas burned at high severity.

Similarly, the program does not allow the user to independently calculate the hydrologic effect of roads. Roads clearly affect the amount and timing of runoff at the local scale through a variety of processes. For example, site-scale studies have measured the changes in runoff on road surfaces (e.g., Reid and Dunne, 1984; Ziegler and Giambelluca, 1997), and recent modeling studies have estimated the effects of roads on runoff for steep, humid areas in the Pacific Northwest (La Marche and Lettenmaier, 2001; Wigmosta and Perkins, 2001). However, paired-catchment studies generally have not been able to detect the effect of roads on runoff independent of the effects of forest harvest (e.g., Ziemer, 1981; King and Tennyson, 1984; Jones, 2000). This does not mean that roads do not affect runoff, but simply that the effect of roads was not detectable at the catchment scale due to the errors in measuring discharge, the variability between treated and control catchments, and the typically short duration of the monitoring periods prior to and after road construction.

An explicit accounting of the changes in flow due to roads is not incorporated into this program because of the limited amount of measured data, the difficulty in extrapolating from these studies to other areas, and the high uncertainty with respect to the values that should be used to represent the changes in flows due to roads. As more data become available the effects of fires and roads on runoff may be more explicitly incorporated into the Delta-Q program. Similarly, the effects of other changes in land use, such as urbanization, might be incorporated into later versions of the Delta-Q program.

Other considerations in the use of the Delta-Q model. Delta-Q does not explicitly consider how the location of a given activity or the local site conditions affect the estimated changes in flow. While site conditions and location relative to a stream channel can alter the magnitude and timing of a change in flow due to forest harvest, the paucity of data and the difficulty of quantifying the different controlling factors means that - at least at this stage - the program uses a lumped approach to calculate the changes in flow due to forest management. If this is a concern, the user could define additional activity layers and assign different values to different locations.

The program also does not consider the effect of flow routing on the calculated changes in flow. To do so would require extensive data on channel hydraulics and a much higher temporal resolution of the underlying flow data. Other models are available to calculate the changes in flow on a spatially-explicit basis and route these through the stream network to the location of concern (e.g., Wigmosta and Perkins, 2001). While it may be desirable to use such models to more accurately predict the likely changes in flow from management activities, the goal of the DELTA-Q program is to provide land managers with a GIS-based tool that can quickly estimate the approximate magnitude of the changes in different flow percentiles that might have occurred in a given watershed, and to calculate the changes in flow that might result from one or more proposed actions. More detailed modeling might then be conducted on the watersheds where a change in flow is identified as a primary concern. The lack of any explicit routing component implies that the Delta-Q program is most applicable to watersheds where the time period for flow routing is substantially less than one day.

By judiciously selecting values for the absolute or percent change in flow and the time to hydrologic recovery, the model should be applicable to a relatively wide range of forest conditions and geographic areas. However, in many areas there is a paucity of paired-watershed or other data, and in these cases the model predictions will have a higher degree of uncertainty. The model was designed to be used on the planning watershed scale (e.g., 5-50 mi^2), but it could provide a rough guide to the magnitude of hydrologic change on watersheds where the routing of flow is substantially shorter than one day. In one case (H.J. Andrews 1) we did calculate the changes in flow for both hourly and daily flows, and the two sets of values were within 20% in all cases (Austin, 1999).

We have not attempted to estimate the changes in flow for more extreme events because of the rapid decline in sample size with increasing recurrence interval. This means that the estimated changes in flow from extreme events are progressively less reliable with increasing recurrence interval. Both hydrologic theory and field studies indicate that forest management causes a progressively smaller **percent** change with increasing flow magnitudes (i.e., forest management should have a smaller relative effect on the 99.9^{th} percentile of flow than the 99^{th} percentile), and this trend is strongly supported by our analysis of flow duration curves. At the other end of the flow duration curve, the **absolute** changes in flow should become progressively smaller at progressively lower flows (i.e., forest management should result in a smaller absolute effect on the 0.1 percentile flow than the 1.0 percentile flow). It is more difficult to predict how forest harvest will affect absolute flows with increasing flow magnitude, or how forest harvest will affect the percent change in flow at progressively smaller flows. In all cases the user must consider whether the calculated change in flows is significant from a hydrologic or water resources perspective.

The model also can evaluate the changes in flow that would result from different scenarios of future activities. This is best accomplished by creating coverages with polygons of the proposed treatments. As with the other activity layers, each treatment polygon must be assigned a year for that activity. Change in flow values are assigned to each type of activity in the same manner as for past activities. By using the accumulation table, the effects of the proposed activities can be added to the effects of past activities to obtain a total change for the time period of interest.

Algorithm

The calculations are based on the area affected, the number of years since the altering activity, the number of years until full hydrologic recovery, and the change in runoff. Change in runoff can be calculated as a percent change (equation 1) or an absolute change (equation 2).

$$D(Q) = \sum_{i=1}^{m} \left[1 - \frac{x(i)}{n} \right] * \frac{A(i)}{AWS} * d(q) \qquad (1)$$

$$D(Q) = \sum_{i=1}^{m} \left[1 - \frac{x(i)}{n} \right] * A(i) * d(q) \qquad (2)$$

where:

D(Q) = total change in flow in the watershed being modeled;

d(q) = change in runoff in absolute (cfs mi^{-2}) or percentage terms for each activity type. To calculate percentages, the user must input the change in flow in percent.

i = polygon identification number;

m = total number of affected polygons;

x (i) = years since activity in area ***i***;

n = number of years to full hydrologic recovery;

A (i) = area (m^2) of activity;

AWS = area of watershed (m^2).

Delta-Q

Instructions for Use:

Double Click on the Delta-Q desktop icon, Delta-Q.exe in Windows Explorer or start\programs\Delta-Q. Click on the opening splash screen to start.

DELTA-Q

Instructions for Use:

To access the Delta-Q module, click on the "Delta-Q" button from the Cumulative Effects model opening screen. After clicking "Continue" on the opening screen, successive forms appear to guide the user through data identification and data entry.

The user can repeat Delta-Q with different activity polygon coverages (e.g., forest harvest, fires, or other land uses) and put the results in the same table in order to sum the effects from all activities (step 12).

1. Select the data directory. Click on this button to open a window that enables the user to choose the drive and directory with spatial data. Use the drop-down box to select a drive and double click on directories to produce the sub-directory tree. Select a directory and click OK. This will close the window and return the user to the initial menu.

2. Select a coverage from the list that appears in the next box. The data coverage must contain: (1) areas of forest management treatments, activities, or fires; (2) a numeric field with the year of the treatment or activity; and (3) a field detailing the type of activity. By selecting a data coverage, the list of fields in the coverage will appear in the next box.

3. Click on the next box to select a field containing the year of the activity. The data contained in the selected field must be in numeric format and contain a four digit year (e.g. 2004).

4. Choose watershed(s). Click on the button to reveal a window containing three boxes.
a) The top left box lists the coverages in the data directory. Click on a watershed coverage.
b) The lower left box displays the fields available in the selected coverage. Click on a field that contains the names identifying individual watersheds.
c) The long box on the right lists the watersheds named in the coverage. Choose the watershed for analysis. If no watershed is selected, Delta-Q will run using all watersheds in the coverage and list the results for each watershed.

Once the activity and watershed coverages are chosen, the program will create a new temporary coverage by clipping the activity coverage to the spatial extent of the watershed. Be patient, as this may take a few minutes depending on the size of your coverage. This ensures that the original coverages are unchanged. The new coverage will be deleted when CEMod ends.

5. Choose the level of flow to calculate. Within the database, the low, median, and high flow options are defined as the 1st, 50th, or 99th percentiles, respectively. "Other" can be used to designate a different flow percentile, but no default or literature values are provided.

6. Choose whether the change in flow values are to be calculated in absolute (cfs mi^{-2}) or percent terms. Choosing one of these options will show the "Choose Activity Field"

window. This window lists the fields in the selected activity coverage. The user can choose which field contains information about the type of activity (e.g., fire severity or type of silvicultural activities). Select a field and click on "OK" to show the "Assign change..." window.

The "Assign change..." window has two columns that need to be filled for each activity field. The first column is for flow change values and the second column is for the number of years to hydrologic recovery. Click the row next to each activity type to add a value or click ‘enter' to move to the next row. Click "OK" when finished. If no values are entered the program assumes that the activity has no effect on runoff.

A note at the bottom of the table informs the user of the median values from 26 paired watershed studies for the chosen flow percentile. Under the "View results..." button, the user can review the flow changes, key site characteristics, and published references for each of the 26 paired-watershed studies.

Note that the percent values are relative to the controls to the paired watershed data, as the Delta-Q module has no means of estimating the baseline flow conditions in the watershed being simulated. To calculate a percent change for your watershed you need to calculate the absolute change and then relate this to the measured or estimated flows on your watershed.

Click on the Continue button to progress to the second input menu.

7. Enter a four-digit year to begin the analysis. The end year is optional. If the user does not enter an ending year, the beginning year is automatically entered and the flow change is calculated for one year only.

8. Enter a name for the table of results. The table will be reused, in that results from subsequent runs of the program will be appended until the user enters a different table name.

9. Enter a name for the table of accumulated effects. This table will sum the effects of all coverages for each year.

10. Click on "Calculate" when all data values are entered. This may take a while!

11. Click on the display results button when the calculations are finished. The table shows the name of the watershed, the years modeled, area of activity in square miles, change in flow, and the units for this run (either cfs mi^{-2} or percent). The table is exported to the designated file "*table*".txt.

The user can run Delta-Q on several data layers and save all the results to the same table or to different tables depending on the selected table name(s). If Delta-Q is run on several layers for the same years, watersheds, and units, the results can be accumulated to account for overlapping activities.

12. After running DELTA-Q on more than one data layer, the results for the watershed can be accumulated from the results table window and will be displayed in the "Cumulative Effects" window. This table can be exported to text format using the "Export Table" button.

All tables are in ArcInfo format. Tables can be exported to comma-delimited text files from the CEMod startup and cumulative results windows.

Spatial Data Requirements for the Change in Flow Module

Notes:

All coverages must be in same projection with units in meters.

All coverages must be in the same workspace.

User must have write access to the workspace containing the coverages. Delta-Q has a utility that will copy coverages between workspaces.

Required coverages:

1. An ArcInfo coverage of forest management activity, fire areas, or other land uses.
   a) This coverage must have ArcInfo polygon topology.
   b) The activity coverage must contain a numeric item that details year of activity in 4 digit (YYYY) format. Polygons without a year are ignored in the calculations.
   c) The activity coverage must contain a field to designate the activity type(s) in character format (e.g., type of harvest or fire intensity). This prompts the user to input the change in flow for each activity type. Areas without an activity type are ignored in the calculations.
2. An ArcInfo coverage of watersheds is needed to select the area of interest.
   a) This coverage must have ArcInfo polygon topology.
   b) The user will be asked to select the character field with the names needed to choose a watershed.

Program Side Effects

The program creates 2 coverages that are overwritten each time the program runs:

- *Tmp_ws* is the chosen watershed polygon;
- *Tmp_act* is the activity areas intersected with *tmp_ws*.

The program creates a series of tables, including calcyyyy.tmp, flowyyyy.tmp, and the specified results tables in ArcInfo format.

These coverages and tables are deleted when the program is closed. If you want to use them in ArcInfo use the copy or export utilities to copy them to different filenames before quitting the program.

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