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October 24, 2010

To: Bob Cusimano, Manager, EAP Westside Operations Section

Through: Karol Erickson, Supervisor, EAP Modeling & Information Support Unit

From: Paul Pickett, Environmental Engineer, Modeling & Information Support Unit

Subject: Flow Indicator Methodology

Introduction

As part of my water resource modeling tasks, you had requested my support for the development of an environmental indicator for low stream flow conditions. This indicator would be used for multiple purposes, including:

- The Governor's Government Monitoring and Performance (GMAP) initiative
- The Salmon Recovery Office's State of Salmon (SOS) in Watersheds reports
- The Puget Sound Partnership's Dashboard of Indicators

In the past an indicator had been used based on flows above a critical low flow, defined as the 20^{th} percentile low flow at each stream flow monitoring station being assessed. Discussions between the Environmental Assessment Program (EAP), the Water Resources Program, and agency management led to a decision to explore an alternative low flow indicator. I worked with the technical workgroup you convened to define that new indicator.

Based on those discussions, the workgroup determined that an indicator based on a critical low flow was not desirable, because it only provided information about the status of a stream for that particular year as driven by weather conditions. An indicator based on regulatory minimum instream flows had similar problems. In addition, the basis and purpose of those regulatory flows were inconsistent, having been derived from a variety of methodologies with different objectives, and designed for a specific regulatory use rather than as an indicator.

Another challenge was whether an environmental indicator, which would tell you the status of environmental conditions regardless of their causes, could also be used as a program performance measure, which would tell you the effectiveness of a specific policy or program. The workgroup's recommendation was to develop an environmental indicator and to recognize that a performance measure would have to be derived through a more detailed analysis.

Finally, an outcome of the discussions was to develop an environmental indicator based on an analysis of trends, rather than the status of a certain year. This indicator would evaluate if and how flow conditions were changing, rather than their status at a fixed point in time. However, changes in the trend can be evaluated as additional years are added, and conditions in any given year can be compared to the trend.

Methodology

The workgroup evaluated a number of options, and after a certain amount of "trial and error" arrived at the decision to use a trend in the annual minimum 30-day average flow during the summer season (June through October). This metric focuses on key fisheries habitat needs, while still allowing some data smoothing that avoids the dominance of data extrema. Also, use of the annual 30-day minimum flow is likely to avoid any problems with autocorrelation of values, i.e. the flow for each year is likely independent of flows for previous and following years.

The period selected for evaluating trends was Water Year (WY) 1975 (October 1974 - September 1975) through the current year of evaluation. This year was chosen for several reasons:

- A common baseline was desired for all the stream flow records, so trends could be compared without the complications of different periods of climate conditions.
- A longer data set is more likely to show significance.
- Most major hydroelectric projects had been completed by this year, ending a 25-year "era of the big dam". To go back earlier would begin to mix regulated and unregulated streamflows in many stream flow data sets, complicating the trend analysis.
- An analysis of climactic variability suggested that a long data set was desirable to avoid trends caused by an unbalanced mix of cool and warm phases of the Pacific Decadal Oscillation. For example, beginning a trend in the mid-1980's would result the early half of the data starting in a warm phase and the end of the data set falling in a cool phase, potentially creating a trend related mostly to this climatic oscillation. Starting in the mid-1970s or earlier helps to balance cool and warm phases across the data set.

Ultimately, the goal is to develop indicators for rivers and streams statewide. A logical organization of these indicators is the Salmon Recovery Regions. Since these regions do not include every Water Resource Inventory Area (WRIA), these regions were modified by assigning non-salmon recovery WRIAs to the region to which they are tributary. Those modified regions are listed in Table 1 and shown in Figure 1.

As a “pilot” for this methodology, this indicator was developed just for the Puget Sound region. This matched the most pressing needs for the three purposes described above. In the future the indicator can be applied to the other regions for use in GMAP and SOS reports.

Table 1. List of Salmon Recovery Regions used for flow indicator analysis.

Salmon Region	Code	WRIAs
Puget Sound	PS	1-18
Washington Coast	WC	19-24
Lower Columbia River	LCR	24-29
Middle Columbia River	MCR	30-31, 36-43
Snake River	SR	32-35
Upper Columbia River	UCR	44-51
Northeast Washington	NEW	52-62

For the Puget Sound regions, thirteen stream gages were selected for use in developing indicators (Table 2), based on these criteria:

- Gages used by the University of Washington’s Climate Impacts Group for modeling future hydrologic scenarios.
- Gages used by Ecology in the past for the previous indicator.
- Gages that are low in the basin, where they are most affected by human activities and where flows most affect salmon.
- Gages with records covering all or most of the years from 1975 to 2009.

Table 2. Flow monitoring stations selected for indicator analysis - Puget Sound

USGS Station No.	Station Name	WRIA
12119000	Cedar River at Renton	8
12079000	Deschutes River near Rainier	13
12048000	Dungeness River near Sequim	18
12045500	Elwha River at McDonald Bridge near Port Angeles	18
12113000	Green River near Auburn	9
12121600	Issaquah Creek near Mouth near Issaquah	8
12167000	North Fork Stillaguamish River near Arlington	5
12089500	Nisqually River at McKenna	11
12213100	Nooksack River at Ferndale	1
12101500	Puyallup River at Puyallup	10
12200500	Skagit River near Mount Vernon	3
12061500	Skokomish River near Potlatch	16
12150800	Snohomish River near Monroe	7

For each of these stations flow data time series were developed for October 1, 1974 through September 30, 2009. A rolling 30-day average was calculated from the data. Then for each year, the minimum 30-day average was selected from July 1 through October 31 (June through October flows). These series of annual minimum 30-day flows were then evaluated for trends. All of the stations had 35 years represented, except for the Deschutes River (31 years) and the Nisqually River (33 years).

Two methods were used to evaluate trends (Helsel and Hirsch, 1991):

- The Mann-Kendall nonparametric trend test. This method has been used by the U.S. Geological Survey in national studies (Lins and Slack, 1999). Nonparametric tests are robust with non-normal distributions.
- A parametric linear regression trend test. All linear trends were also tested for normality, independence, and constant variance (homoscedasticity) of residuals.

For characterization of the trends, the slope of the linear trend was evaluated to determine if flows were decreasing or increasing, and the two-tail p-value of the test examined to determine significance. The strongest significance from either test was used for the characterization. The slope and significance were described as follows:

- Strong increasing (positive slope, $p < 0.1$)
- Weak increasing (positive slope, $p < 0.5$)
- No trend ($p \geq 0.5$)
- Weak decreasing (negative slope, $p < 0.5$)
- Strong decreasing (negative slope, $p < 0.1$)

Typically much lower p-values are selected to determine significance in hypothesis testing. However, for the purpose of an indicator, a p-value of less than 0.5 suggests that “more likely than not” a trend is significant, which is useful in this context.

One advantage of this approach to a simple status indicator is that the results can be reported for each river or rolled together into one test. For the GMAP, for example, the metric chosen was “the percent of 13 Puget Sound rivers and creeks that are stable or improving”. The key message communicated by this metric is that if low flows in a river are declining, that is “bad”, while if flows are increasing or at least stable, that is “good”. The target is 100% of streams with stable or increasing flows.

Presentation of Results

Trends were analyzed beginning in WY 1975 and ending in WY 1998. The analysis was repeated for subsequent years through WY 2009 (Figure 2). This analysis shows if trends are shifting over the last 12 years. WY 1998 was chosen as the first ending year because in that year both the salmon recovery and watershed planning laws were passed. As can be seen in Table 3, seven out of thirteen Puget Sound rivers (54%) were increasing or stable, while the other five were weakly or strongly decreasing.

Table 3. Trend analysis results for annual minimum 30-day average flow for 13 Puget Sound rivers and creeks from WY 1975 through the WY shown.

Station Name	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Cedar River	**WI**	**WI**	**SI**	**SI**	**SI**	**WI**	**WI**	**WI**	**WI**	**WI**	**SI**	**SI**
Deschutes River	**WD**	**WD**	**WD**	**WD**	**SD**	**SD**	**SD**	**SD**	**SD**	**SD**	**SD**	**SD**
Dungeness River	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**
Elwha River	**WD**	**NT**	**NT**	**NT**	**WD**	**WD**	**NT**	**NT**	**WD**	**WD**	**NT**	**WD**
Green River	**WD**	**WD**	**WD**	**WD**	**WD**	**WD**	**WD**	**WD**	**WD**	**WD**	**WD**	**WD**
Issaquah Creek	**SD**	**SD**	**SD**	**SD**	**SD**	**SD**	**SD**	**SD**	**SD**	**SD**	**SD**	**SD**
NF Stillaguamish R	**SD**	**SD**	**SD**	**SD**	**SD**	**SD**	**SD**	**SD**	**SD**	**SD**	**SD**	**SD**
Nisqually River	**WI**	**SI**	**WI**	**WI**	**WI**	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**
Nooksack River	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**
Puyallup River	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**	**WI**	**NT**	**NT**	**NT**	**NT**	**NT**
Skagit River	**NT**	**WI**	**WI**	**WI**	**NT**	**NT**	**WI**	**WI**	**NT**	**NT**	**NT**	**NT**
Skokomish River	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**	**NT**	**WI**	**NT**
Snohomish River	**WD**	**WD**	**WD**	**WD**	**WD**	**WD**	**WD**	**WD**	**SD**	**SD**	**WD**	**WD**

SI = strongly increasing; **WI** = weakly increasing; **NT** = no trend; **WD** = weakly decreasing; **SD** = strongly decreasing

A number of graphical methods were explored for presenting this indicator. Figures 2 and 3 show the indicator for WY 1975 through 2009. Figure 2 was provided as the GMAP Puget Sound indicator (see Attachment 1), and shows the five categories of the indicator with the names of the rivers falling into each category. Figure 3 shows the WY 1975-2009 trend with each river shown separately. The bar shows the slope of the trend – positive for increasing flows and negative for decreasing, and the label indicates the river name and the significance of the trend.

For Figures 4 and 5 the trend was calculated for 12 different periods beginning with WY 1975-1998 and adding a year to the trend until 2009 is reached. Figure 4 shows for each period the simple metric of the percent of rivers with stable or increasing low flows. Figure 5 shows the same periods but breaks the metric out into three categories of increasing (weak or strong trend), stable (no significant trend), and decreasing (weak or strong trend).

The different graphical presentations are provided to show how the indicator could be presented for different purposes and audiences.

Future Work

Puget Sound represents one of seven regions which will each have indicators developed. Gages for indicator development were identified for the other 6 regions. Attachment 2 shows recommended gages for each region. These stations were selected using the same criteria used for selecting the Puget Sound rivers in Table 2 above.

The Columbia, Snake, and Pend Oreille Rivers were not included because the majority of their watershed where most of the flow originates is outside the state. Gages for the tributaries of these rivers were chosen from the most downstream gage that was most relevant for basin management. Although much of the Spokane River watershed is in Idaho, and the gage at Long Lake Dam is farther downstream, the three gages selected best represent the conditions in the watershed in Washington.

There are more long-term real-time USGS gages inside Puget Sound (119) than there are in the other six salmon recovery regions (111). Limiting the gages to those lowest in the basin reduces that number of streams that can be used for indicators. It may be worth considering adding more gages to better represent subwatersheds in the regions outside Puget Sound, similar to the approach used in the Spokane River basin.

Now that the method has been developed and spreadsheets set up for the analysis, other staff can complete the calculation of indicators for the other 5 regions. Attachment 3 provides instructions for use of the spreadsheet for calculating a trend for another time series of flow data.

References

Helsel, D.R. and R.M. Hirsch, 1991. Techniques of Water-Resources Investigations Book 4, Chapter A3. U.S. Geological Survey, Reston, VA.
http://pubs.usgs.gov/twri/twri4a3/html/pdf_new.html

Lins, H. F. and J.R. Slack, 1999. Streamflow Trends in the United States. Geophysical Research Letters, Vol. 26, No. 2, Pages 227-230, January 15, 1999. American Geophysical Union.

Figures

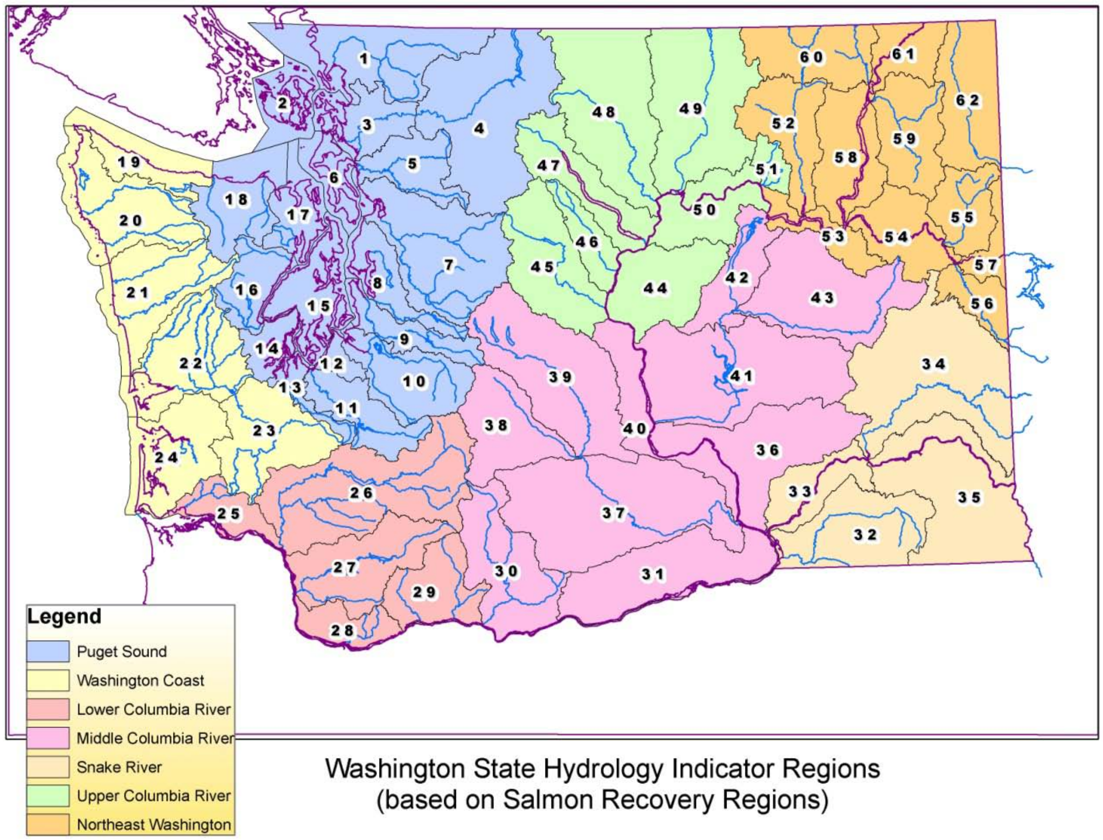

Figure 1. Modified salmon recovery regions used for regional flow indicator analysis (shown with WRIA numbers).

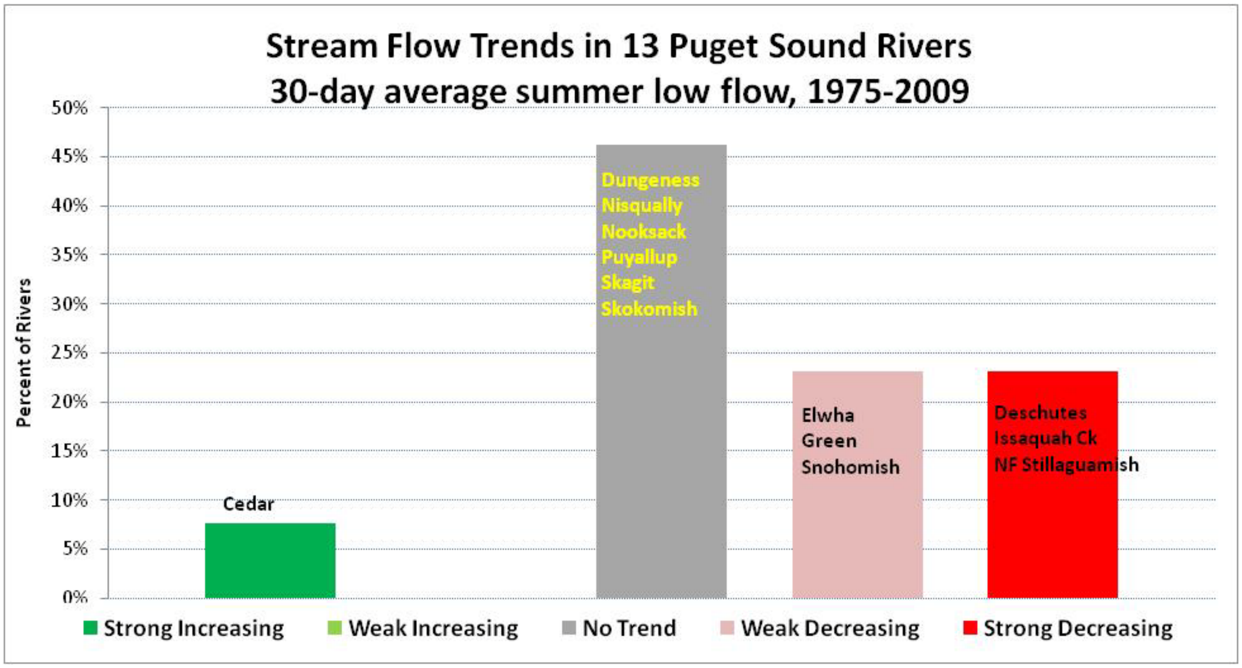

Figure 2. Flow indicator showing trend for 1975-2009, with 5 trend categories and river names.

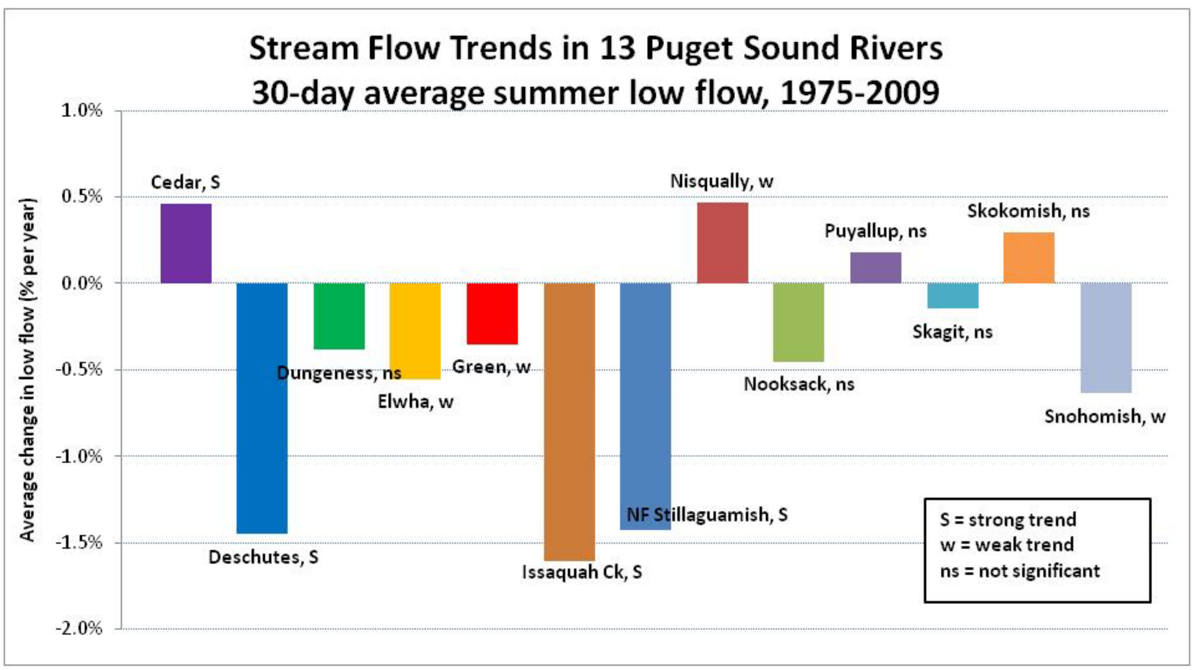

Figure 3. Flow indicator showing trend for 1975-2009, with each river, its trend slope, and its significance level.

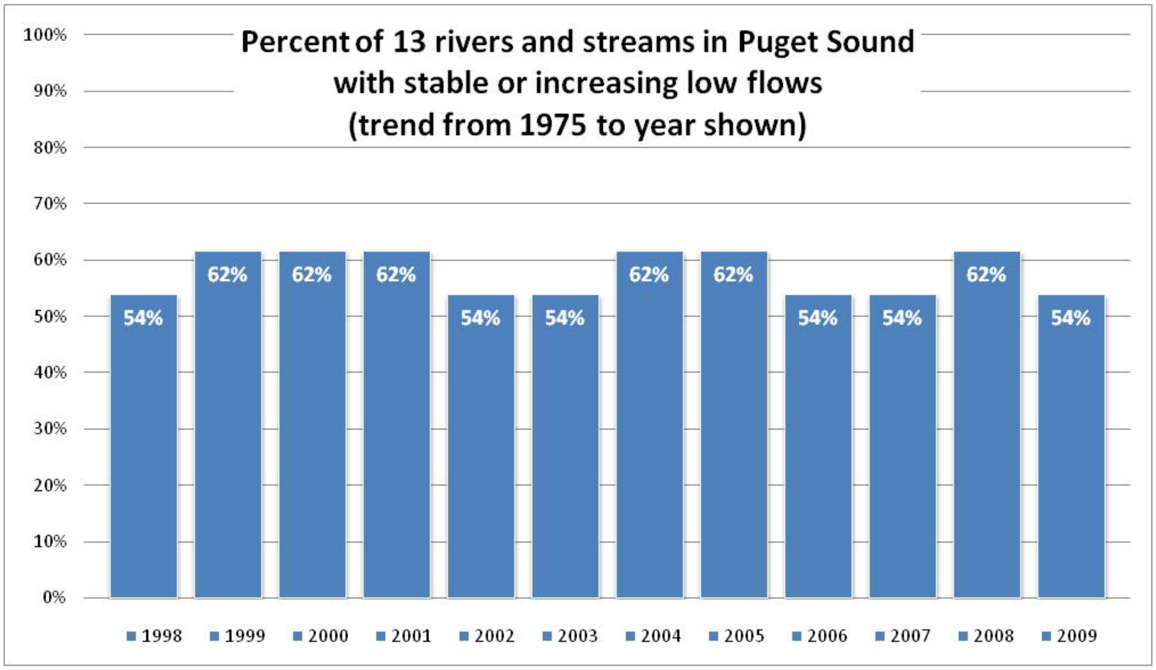

Figure 4. Combined flow indicator showing trend changes over 12 different end years.

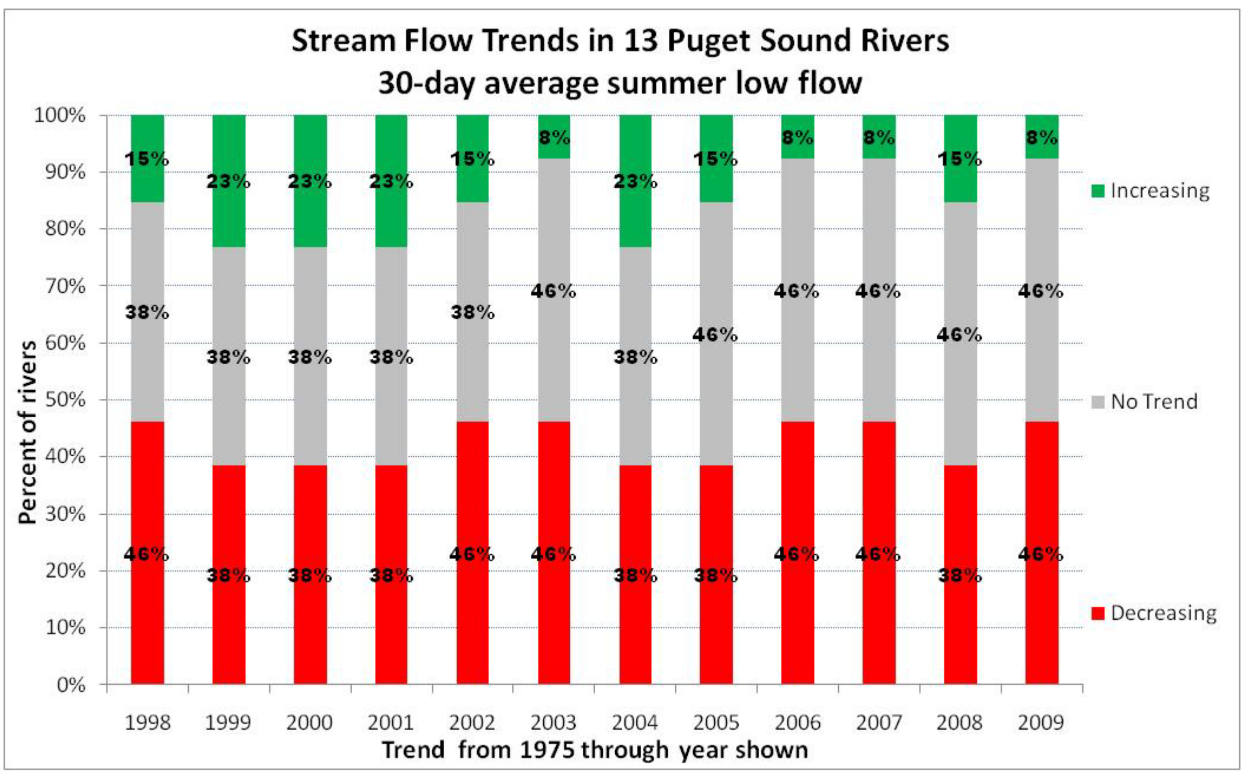

Figure 5. Flow indicator showing trend changes over 12 different end years, split out by trend direction.

Attachment 1

3.6 - In-stream flows **Major Puget Sound rivers and streams with summer flows that are increasing, decreasing, or stable.**

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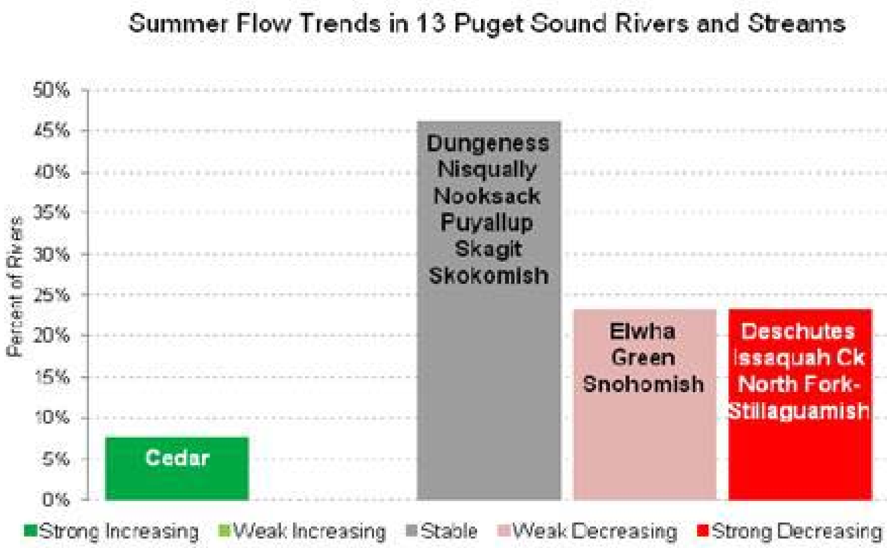

Drill Down Measures

3.6.a - Permit-exempt wells
3.6.b - Basins with instream flow rules

Summary Analysis

- Of the 13 Puget Sound rivers and streams:
  - One shows summer flows that are strongly increasing.
  - Six show stable, or no trend, toward increasing or decreasing.
  - Six are weak or strongly decreasing in summer flows.
- The target is for all thirteen major rivers and streams to either have no trend or increasing 30-day average summer low flows.
  - Increasing and stable flows in rivers and streams during the summer months are important for fish migration and life, for people, and to help maintain the ecology of Puget Sound.
- These thirteen major rivers and streams represent the drainaige of about 68% of Puget Sound's watershed area.
- In 2009:
  - Strong increasing trends were monitored in the Cedar River. Since 2006, the City of Seattle is implementing an Habitat Conservation Plan to protect flows.
  - Strong decreasing trends were monitored in the Deschutes and North Fork Stillaguamish Rivers, and Issaquah Creek. These rivers and stream are in areas of high population growth where watershed planning was either ended or did not include stream flow/water quantity issues.
  - Weak decreasing trends were monitored in the Elwha, Green, and Snohomish Rivers.
- Since 1998 (the year the salmon recovery and watershed planning laws were passed):
  - The Deschutes River has shifted from

Data Notes

Data Source:	U.S. Geological Survey NWIS; data current as of August 2010.
Measure Definition:	The percent of 13 long-term flow gages for rivers and streams in Puget Sound whose trends in annual 30-day average summer low flows were either increasing (weak or strong), no trend, or decreasing (weak or strong). The trend data is from 1975 through 2009.
Target Rationale:	Target: 100% of streams showing stable or increasing flow trends. The summer (June through October) lowest 30-day average flow is a statistical measure of low flow that has been linked to salmon habitat needs.

Link to Agency Strategic Plan:	This measure supports Ecology's strategic priorities to protect and restore Puget Sound and Facing Climate Change.
Relevance:	Stable or improving low flows show that salmon habitat and other instream uses are being protected.
Notes: (Optional)	The year 1975 was chosen to begin the trend because: most major dam construction was complete by that date; this longer time series is more likely to show statistical significance; and the longer time frame minimizes the effect of inter-annual and inter-decadal climate variation. A linear regression provides the most sensitive measure of trend, but the Mann-Kendall non-parametric test has been used by USGS in previous studies. Both trend methods are used. If either test shows significance with probability < 0.5 the trend is considered weakly significant (more likely than not the trend exists), and if probability < 0.1 the trend is considered strongly significant (90% chance the trend exists).

Also Available

Action Plan:	Yes
Extended Analysis:	Yes

a weakly decreasing low summer flow to strongly decreasing low summer flow.

- The Nisqually River has shifted from an increasing trend changing to no trend.

Action Plan

Title	Who	Due Date	Status	Status Date
ForumDate : 2010-10-15 (1)				
Review Flow Data Trends.	Paul Pickett and Brad Caldwell	9/1/2011	In Progress	9/2/2010

Add a new item

Extended Analysis

- Challenges:
  - Long-term commitment and a well-funded program are needed to see improvements in trends.
  - Decreasing trends need to have a technical analysis to identify causes and target effective management approaches.

Attachment 2

List of proposed USGS stations for flow indicator trend analysis.

USGS	Station Name	Region[1]	WRIA	UW[2]	ECY[3]
12119000	Cedar River at Renton, WA	PS	9		y
12079000	Deschutes River near Rainier, WA	PS	13		y
12048000	Dungeness River near Sequim, WA	PS	18		y
12045500	Elwha River at McDonald Bridge near Port Angeles	PS	18	y	y
12113000	Green River near Auburn	PS	9	y	y
12121600	Issaquah Creek near Mouth near Issaquah, WA	PS	8		y
12167000	North Fork Stillaguamish River near Arlington	PS	5	y	
12089500	Nisqually River at McKenna, WA	PS	11		y
12213100	Nooksack River at Ferndale	PS	1	y	y
12101500	Puyallup River at Puyallup, WA	PS	10		y
12200500	Skagit River near Mount Vernon	PS	3,4	y	y
12061500	Skokomish River near Potlatch	PS	16	y	y
12150800	Snohomish River near Monroe	PS	7	y	y
12120000	Mercer Creek near Bellevue, WA	PS	8		
12010000	Naselle River near Naselle, WA	WC	24		y
12013500	Willapa River near Willapa, WA	WC	24		y
12031000	Chehalis River at Porter, WA	WC	22	y	y
12035000	Satsop River near Satsop, WA	WC	22	y	y
12037400	Wynoochee River Above Black Creek Nr Montesano, WA	WC	22		y
12039500	Quinault River at Quinault Lake	WC	21	y	
12040500	Queets River near Clearwater, WA	WC	21	y	y
12041200	Hoh River at U.S. Highway 101 near Forks, WA	WC	20	y	y
14243000	Cowlitz River at Castle Rock, WA	LCR	26	y	y
14220500	Lewis River at Ariel, WA	LCR	27	y	
14222500	East Fork Lewis River near Heisson, WA	LCR	27		y
14123500	White Salmon River near Underwood, WA	LCR	29		y
12472600	Crab Creek near Beverly	MCR	41	y	
14113000	Klickitat River near Pitt, WA	MCR	30	y	y
12510500	Yakima River at Kiona, WA	MCR	37,38,39	y	y
13351000	Palouse River at Hooper, WA	SR	34	y	y
13344500	Tucannon River near Starbuck, WA	SR	35	y	y
14018500	Walla Walla River near Touchet, WA	SR	32		y
12452800	Entiat River near Ardenvoir, WA	UCR	59	y	y
12449950	Methow River near Pateros, WA	UCR	56	y	y
12447200	Okanogan River at Malott, WA	UCR	60	y	y
12462500	Wenatchee River at Monitor, WA	UCR	55	y	y
12452500	Chelan River at Chelan Dam	UCR	57	y	
12409000	Colville River at Kettle Falls, WA	NEW	46	y	y
12424000	Hangman Creek at Spokane, WA	NEW	48	y	y
12404500	Kettle River near Laurier, WA	NEW	49	y	y
12431000	Little Spokane River at Dartford, WA	NEW	45	y	y
12422500	Spokane River at Spokane, WA	NEW	47	y	y

[1]PS = Puget Sound; WC = Washington Coast; LCR = Lower Columbia River; MCR = Middle Columbia River; SR = Snake River; NEW = Northeast Washington; UCR = Upper Columbia River
[2]Stations included in the University of Washington Climate Impacts Group climate change scenario modeling
[3]Stations included in previous Department of Ecology flow indicators.

Attachment 3

Instructions for setting up a spreadsheet to calculate trends

I. Copy a spreadsheet tab and name it for the gage to be used for a new analysis.
   A. Change the gage name and the gage number in the upper left hand corner
   B. Update the hyperlink in the gage number to the webpage for NWIS flow data at that station.

II. Copy in the flow data beginning on October 1, 1974.
   A. Check that the time series is complete or that missing data are inserted as blanks.
   B. Check that the 30-day average formulas are pointing to the correct cells and are pasted in for the entire time series. The 30-day average begins on October 30th and is hindcasting.
   C. Check that all years being analyzed are listed in Column F
   D. Check that all formulas for the annual minimum 30-day average are pointing to the correct cells for the given year (July 1 through October 31.

III. Calculate the Mann-Kendall trend analysis
   A. Examine the matrix for the Mann-Kendall. The upper left hand value compares the first year to the second year and enters a “+1” if the second year is larger than the first, “-1” if the second year is less than the first, and “0” if they are the same.
   B. Values in each column proceed with comparing subsequent years to year indicated at the top of the column. Check that the formulas are pointing to the correct years.
   C. Two macros have been provided to allow easy refilling of the matrix if values need to be changed.
      1. One copies the formula you have highlighted to the next cell diagonal to the right and down.
      2. The other copies the highlighted formula at the top of the column to the rest of the column’s cells.
      3. Pay close attention to which values are “anchored” with a “$”. They may need to be changed before using the macro.
         a. When copying diagonally, anchor the columns but not the rows of both cell addresses.
         b. When copying down the column, and anchor the row and column of the upper value, but neither row nor column of the lower value.
   D. Make sure all the years with data are included in the matrix, and all the years without data are blank.
   E. Check the formulas on the left and make sure they are pointing to the entire matrix where appropriate.

F. When all the formulas are present and pointing to the correct location, the trend statistics are calculated automatically.

IV. Calculate the linear regression trend.

A. Under the “Data” tab, click on “Data Analysis”, highlight “Regression”, and click “OK”

1. “Input Y Range” should be the annual low flows
2. “Input X Range” should be the years next to the annual low flows
3. Click on “Output Range” and point to the cell with the text “SUMMARY OUTPUT”
4. Click checks into “Residuals”, “Residual Plots”, “Standardized Residuals”, and “Normal Probability Plots”
5. Click “OK”, accept overwriting existing data.
6. Two new plots will appear. You can delete the new plots because the existing plots are formatted and point to the new data.
7. Check the existing graphs to make sure they are pointing to the correct data, especially if you have added a new year of data.

V. Compare the Mann-Kendall results to the Linear Regression

A. The “P-value” for the X variable gives the significance of the slope for the linear regression. This value needs to be doubled to get a 2-tail significance that can be compared to the M-K results.

B. The summary tab of the spreadsheet is set up to automatically update when the calculations are done.

C. If the spreadsheet is modified for a new set of stream gages, the summary tab and the gage-specific tabs will need to updated as well